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AN ASSESSMENT OF ECOLOGICAL AND SOCIO-ECONOMIC VULNERABILITY OF COASTAL FISHING COMMUNITIES TO CLIMATE VARIABILITY: A STUDY OF LOWER TANA DELTA AND UNGWANA BAY, KENYA

BY

MUMINI NDENGE DZOGA

THESIS

Submitted in fulfilment of the requirements for the Degree of

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GEOGRAPHY AND ENVIRONMENTAL STUDIES

at the

UNIVERSITY OF THE WITWATERSRAND

LEAD SUPERVISOR: PROF. DANNY SIMATELE

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Ethics Clearance Number: H16/10/24

October, 2018

PhD Geography and Environmental Studies

DECLARATION-1 PLAGIARISM

I, Mumini Ndenge Dzoga, declare that this thesis (data, diagrams, graphs, tables and any other information) is my own original work, except to the extent that has been acknowledged.

This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then: their words have been paraphrased and the general information attributed to them has been referenced. Where their exact words have been used, then their writings have been placed in italics and inside quotation marks, and then referenced.

The thesis is being submitted for the award of the Degree of Doctor of Philosophy (PhD) to the Faculty of Science at the University of the Witwatersrand in Johannesburg, South Africa. It has not previously been submitted for examination or award of degree to any other institution of learning.

DECLARATION-2 PUBLICATION

I, Mumini Ndenge Dzoga, declare that I personally undertook all the data collection, analysis, development and writing of the manuscripts and articles mentioned below. I wish to commend my co-authors for providing useful advice and comments, as well as editing the manuscripts. Sections of this work have been published or submitted as manuscripts for publication to the following peer reviewed journals:

1. Dzoga, M., Simatele, D., Munga, C. (2018). Application of the DPSIR Model to Coastal and Marine Fisheries Management in Kenya. *Journal of Environmental Management*, 13. **(Under review)**

2. Dzoga, M., Simatele, D., Munga, C. (2018). Assessment of Ecological Vulnerability to Climate Variability on Coastal Fishing Communities: A study of Ungwana Bay and Tana Estuary, Kenya. *Ocean & Coastal Management*, 8. **(Published)**

3. Dzoga, M., Simatele, D., Munga, C., Gamoyo, M. (2018). Impact of Selected Environmental Variables on the Distribution, Composition and Abundance of Fin Fish in Ungwana Bay and Lower Tana Delta, Kenya. *Journal of Environmental Management*, 12. **(Under review)**

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Signature:  Mumini Ndenge Dzoga Date: 1st October, 2018

As the candidate's supervisor, I certify the above statement and approve this thesis for submission. I certify that the above statement is correct.

Lead supervisor

Signature:  Prof. Mulala Danny Simatele Date: 1st October, 2018

Co-supervisor

Signature:  Dr. Cosmas Munga Date: 1st October, 2018

DEDICATION

To

My father and my late mother

and

My wife Rukia, and my 3 daughters: Warda, Zubeda and Rahma

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EXECUTIVE SUMMARY

This study assessed the ecological and socio-economic vulnerability of coastal fishing communities to climate variability in Ungwana Bay and the Lower Tana Delta, north coast Kenya. This was achieved through: determination of artisanal catch composition, distribution and catch rates in relation to climate variability; identification and characterization of existing sources of livelihood for fishing communities in terms of natural resource dependency and sustainability of technology used in resource exploitation; evaluation of the ecological and socio-economic vulnerability of the fishing communities to climate variability and; evaluation of the effectiveness of the existing coastal and marine governance structures for the management of fisheries resources.

The study methodology adopted 3 approaches. The first approach was the application of ecological (fisheries resources) sensitivity assessment for climate vulnerability measurement adopted from Metcalf et al. (2014). This approach determined the ecological vulnerability index (exposure and sensitivity of fisheries) to climate variability which then was used together with fishing communities adaptation index to measure the overall vulnerability level of the fishing communities by applying the IPCC vulnerability measurement model $VI = (E + S) - AC$. Where: VI = Vulnerability index, E = Exposure, S = Sensitivity, AC = Adaptation capacity. In this study, however, significant anthropogenic factors that affect fin fish abundance, composition and distribution in the study area were incorporated to establish the total sensitivity index for the fin fish resources.

The second approach involved the shore-based catch assessment where fin fish species identification was conducted from artisanal landings along the shoreline. Apart from species identification, critical information was also captured such as weight, individual fish total length (TL, cm), fishing crafts and gears used, time taken (hr) for fishing and crew number. The data was useful in determining catch composition and distribution using non-Metric Multidimensional Scale (nMDS) technique, abundance and fishing effort using Microsoft Excel and STATISTICA statistical software v7. Analysis of Similarity (ANOSIM) was used to test for significant differences where clear separation of catch samples existed. Where significant composition existed, SIMPER analysis was used to determine which fin fish taxon/taxa contributed to the dissimilarity.

The third approach included collecting long term data of terrestrial temperature and rainfall from the Kenya Department of Meteorology; long term data on sea surface temperature (SST), rainfall as well as sea surface chlorophyll (SSC) from Moderate Resolution Imaging Spectroradiometer (MODIS) and Global Historical Climatology Network (GHCN-Monthly); and long term data on artisanal fin fish landings from the Kenya Fisheries Service (KeFS). In addition, the socio-economic survey was also conducted among the artisanal fishing communities. A total of 379 semi-structured questionnaires were used to collect data from the selected fishing areas of Ngomeni (206), Kipini (144) and Ozi (29). Respondents were identified by purposive and simple random method and then engaged on a one to one interview. Mean and trends of the rainfall, terrestrial temperature, sea surface temperature as well as sea surface chlorophyll were computed using Microsoft Excel and MATLAB Software. Frequencies of socio-economic variables were coded and

entered into SPSS software where respective variables were analyzed descriptively using actual values and relative percentages and then graphically represented. Chi-Square (χ^2) test was used to determine whether there was a significant association in natural resource dependence among the artisanal fishing communities livelihood, and whether there was a significant association in factors resulting in the dependence of the natural resources (fisheries, terrestrial forests, mangroves and land).

Ngomeni and Ozi artisanal fishing communities indicated high vulnerability to climate variability levels of 0.9 and 0.8, respectively. Impact of environmental variables was observed with most abundant fin fish families where significant and positive correlations were determined on Carcharhinidae, Lutjanidae, and Serranidae with SST (P = 0.001; r = 0.9726; P = 0.001, r = 0.8921; P = 0.001 r = 0.8804) and sea surface chlorophyll (P = 0.001; r = 0.9191; P = 0.001, r = 0.7904; P = 0.001 r = 0.7880), respectively. Trends in terrestrial temperature showed strong and positive correlation with time (R^2 = 0.7588). Distinct catch composition was observed across habitats (marine, estuarine and riverine) (R = 0.27, P = 0.001) as well as across fishing zones with seasons (Ngomeni, Kipini and Ozi) (R = 0.332, P = 0.001). Small scale coastal fishing communities livelihood showed significant association with natural resources dependence (P = 0.001, χ^2 = 494.153a). Key factors that resulted to the high dependence on natural resources for livelihood were population pressure, low level of education and lack of employment (χ^2 = 24.273[a]; P = 0.004), (χ^2 = 46.319[a]; P = 0.001), and (χ^2 = 17.863[a]; P = 0.037), respectively.

The study found out that both fisheries resources as well as the fishing communities were vulnerable to climate variability. Therefore, there is need for identification and protection of the breeding habitats and refuge for fish species; and the need to strengthen existing control measures for fisheries resources and promoting environmentally friendly fishing methods thus lowering anthropogenic destruction of habitats and enhancing breeding areas. Further, empowerment of the artisanal fishing communities is critical to enable investment in alternative sources of livelihood. The empowerment may be in form of provision of affordable loans at minimal interest by the respective county governments of Kilifi and Tana River as well as creating awareness among the fishing communities on relevance of education and opportunities to pursue education. Finally, the county governments need to improve the existing education and health facilities to reduce distance covered in accessing services. The available education and health facilities may be inadequate considering the vast geographical area and the increase of human population.

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CHAPTER 1

FRAME OF REFERENCE

1.1. Background of the study

Climate variability patterns have changed in the last few decades characterized by irregular frequencies and intensity of heat waves, temperatures, and rainfall (IPCC, 1996; IPCC, 2007b). These unprecedented changes are further projected to continue for the coming decades in the 21st Century resulting in more impacts in climatic systems (IPCC, 2007a). Climate change phenomenon and impacts in coastal regions are well documented (Cahoon & Hansel, 2002; Epstein and Mills, 2006; Cruz et al., 2007). Vulnerability of the coastal regions to climate variability is mostly associated with natural hazards encompassing the rise of the sea level, chronic coastal erosions, coastal floods, and storm surges (Gornitz & Kanciruk, 1989; New Jersey Department of Environmental Protection, Office of Coastal Management, 2011; Mahapatra et al., 2013). Coastal communities and ecosystems have therefore, become susceptible to the compounding effects of climate variability (Palmer et al., 2011).

The coastal ecosystems support numerous socio-economic activities (Metcalf et al., 2015). Through their services such as provision of serene environment, they have attracted both local and international tourists thus supporting and making the tourism economy the largest business globally with a 10% of Gross Domestic Product (GDP) worldwide (Honey & Krantz, 2007). The tourism economy ranges from small scale businesses that deal with artifacts, massage, collection and selling of shells to large business industries such as

cottages and beach hotels which offer accomodation and conference facilities (Ibid). As a consequence of their proximity to the oceans, the coastal ecosystems have good climatic conditions that favor agricultural economy (Waite et al., 2014). They also provide raw materials for charcoal making, constructions, and medicine for the coastal communities, and have cultural values in terms of shrines and ritual sites (Pendleton et al., 2014).

The fisheries sector, in particular, is an important economic sector that is sustained by ecological systems in the coastal regions globally (Abila, 2010). The coastal ecosystems provide conducive environment for spawning and habitats for the fish species (Geere, 2014). In this way, they are crucial fishing grounds enabling fisheries exploitation for commercial and subsistence purposes. Globally, the fisheries sector supports the livelihood of about 660-820 million of people (FAO, 2012). It also sustains international trade worth US$ 14 Billion (Abila, 2010).

The coastal ecosystems have experienced continuous influx of people in pursuance of their services due to their potential support of the socio-economic activities stated above. This has resulted in the increase of population in these regions (Palmer et al., 2011). Because of the population growth in the coastal regions, the socio-economic services which depend directly or indirectly on the natural resources have exerted pressure on the coastal ecological systems (Ibid). As the socio-economic demands for the ecological services increase, the capacity of the ecosystems to support these demands remain relatively constant (UNEP, 2015). This provides an additional stress to the coastal ecological systems. Consequently, these systems are vulnerable to both climate variability and socio-economic

pressure. On the other hand, the degradation of ecological systems threatens the sustainability of the socio-economic activities.

In comparison with the other economic activities at the coast, the fisheries sector is the most impacted by climate change and variability through the increase in temperature and the irregular frequencies and intensity of rainfall (Perry et al., 2009). The increase in temperature has resulted in the degradation of fisheries habitats such as coral reefs due to coral bleaching (Cinner et al., 2011). The temperature increase and irregular rainfall variability interfere with the spawning of fish species, their ability to reach maturity, and their optimal survival limits (Overland et al., 2010). Consequently, both the fin fish and shell fish species might respond to the changing climate variability conditions by migrating to favorable environs, or may die at larval stage leading to low species composition, low recruitment, limited distribution, and low catches (Metcalf et al., 2015). Fish stock reduction triggers social conflicts based on the competition for fishing grounds and the ownership of fisheries resources (Munga et al., 2014). There is need, therefore, for a vulnerability assessment of the coastal regions to climate variability so as to enhance proper management structures for sustainable use of natural resources (Palmer et al., 2011).

Several studies have been conducted to measure different elements of vulnerability of fisheries to climate variability. Some studies targeted spatial vulnerability of fisheries (Das et al., 2014), while others focussed on coral reef-based capture fisheries vulnerability (Cinner et al., 2011). Most importantly, studies have now integrated the aspect of ecology

and socio-economic vulnerability to fishing communities explaining the inter linkages of these aspects though in different approaches (Islam et al., 2014; Cinner et al., 2013; Metcalf et al., 2015) . The results are critical in understanding the management of fisheries resources and the adaptation of fishing communities to climate variability, thereby, sustaining coastal ecosystems and socio-economic activities.

In Kenya, the fisheries sector is supplied by inland and, coastal and marine fisheries production. The inland fisheries is mainly from lakes, rivers, and aquaculture production. Despite the extensive coastline of approximately 640 km (Government of Kenya, 2014), coastal and marine fisheries production is low with about 2-6% compared to the inland fisheries which generate 94-98% of the total national fish production (FAO, 2007). The fisheries sector contributes 0.5% of Gross Domestic Product (GDP) to the national economy, and has employed at least 80, 000 people (Government of Kenya, 2008). Kenya has an Exclusive Economic Zone (EEZ) of 200 nautical miles (230, 000 km^2) of marine fisheries exploitation (Ibid). However, most of marine fishing is conducted within the shallow continental zone by artisanal fisheries (UNEP, 2006; Cinner et al., 2011). As reported by the Government of Kenya (2014), the Marine Artisanal Fisheries Frame Survey documented the use of low level fishing technology.

The Kenyan coastal ecosystems are already under pressure from the socio-economic dependency for tourism, sport-fishing, cottages, beach hotels, agriculture, artisanal and industrial fisheries, and cultural services (Kitheka, 2002; Munga et al., 2014). The sustainability of these socio-economic activities relies on the sustainability of the coastal

ecosystems. Current changes of climate variability as well as projected climate change may negatively affect and increase the vulnerability of the Kenyan coastal ecosystems. This will in turn affect the socio-economic activities especially for the fishing communities due to the associated reduction in fish stocks. Currently, the Kenyan coastal and marine fisheries production is generally low at an average annual production of around 8, 000 metric tons, however with a potential production of 130, 000 metric tons (Government of Kenya, 2014). Most of the artisanal fishing communities are unable to access offshore resources due to the use of low level fishing technology (Ibid). With these challenges, therefore, the fishing communities would be highly impacted both economically and socially. Taking this into consideration, the Kenyan fishing communities need a vulnerability assessment in ecological and socio-economic dimensions. This would help in proper planning for adaptation to the impacts due to climate variability, management of natural resources, and sustainable livelihood support.

1.2. Thematic consideration

This study adopts the marine ecological vulnerability assessment of climate variability method presented by Pecl (2014), adapted and modified by Metcalf et al. (2015). The method is applicable in case studies assessment due to lack of capacity to detect and predict responses of fish species on a wide range. The approach focuses on fish species composition, distribution, and phenology in Australia (Pecl, 2014). It noted that climate variability has the potential to destruct spawning, recruitment, and maturity of fish species (Pecl, 2014). Consequently, fish species would migrate to favourable environment or die at

young stage thus reducing the fish stock in a particular region (Pecl, 2014). Fish stock reduction means economic and social constraints to the coastal fishing communities (Metcalf et al., 2015).

Many of the coastal communities in Kenya rely on coastal and marine fisheries as their core source of livelihood (Government of Kenya, 2014). On the other hand, the coastal and marine fisheries depend on stable climate of less variability (Overland et al., 2010). Therefore, increase in climate variability will have an impact on ecological systems and the socio-economic activities of the coastal communities. The Kenyan coastal ecosystems are extremely vulnerable to climate variability (Government of Kenya, 2010). Awuor et al. (2008) warned of the submergence of 17% of the land surface of Mombasa City with a rise of 0.03m of the sea level. The north coast region is currently eperiencing high frequencies of temperature and rainfall (Ibid). All these variations in climate elements are expected to increase the vulnerability of the coastal communities as well as the associated ecosystems.

The coastal ecological vulnerability assessment in Kenya was previously conducted in an international assessment study comprising four other countries including Tanzania, Madagascar, Mauritius, and Seychelles (Cinner et al., 2011, 2013). The study focused on coral reef-based fisheries capture vulnerability to climate variability of the coastal communities. It revealed high rate of coral reef bleaching on large scales as a result of temperature anomalies. This had a direct impact to reduced marine production and ultimately affects the livelihood of coastal fishing communities (Cinner et al., 2011, 2013). Based on the wide scope coverage of the study, however, the focus was more general and

limited to a few selected indicators of exposure, sensitivity, and adaptive capacity (Cinner et al., 2011, 2013).

There was need, therefore, to broaden the scope of indicators to have a wide coverage but in a case study view. It was critical to conduct specific case studies assessment, and to focus on the catch composition, distribution and quantity vulnerability of the fishing communities in general to climate variability. The focus also aimed at performing an in-depth analysis of the social and economic susceptibility of the fishing communities. Case studies give robust information relevant to the communities which can be easily assimilated in the management and sustainable use of fisheries resources as an adaptation effort. In view of the above observation, this study attempted to assess the ecological sensitivity of the lower Tana Delta and Ungwana Bay to irregular climate variability and the resultant impact on the coastal fishing communities. The study investigated how climate variability affects the abundance of fish stock and how these affected the livelihood options available to coastal living communities in Tana River County in a case study approach.

1.3. Research questions

1. Are the existing coastal and marine governance structures effective in the management of the resources?
2. What is the level of ecological and socio-economic vulnerability of fishing communities to climate variability?

3. How is the catch composition, distribution and quantity in relation to climate variability?
4. How are the other sources of livelihood and characteristics of fishing communities in regard to natural resource dependency, and nature of technology deployed for resource exploitation?

1.4. Aim and objectives of the study

The aim of this study was to assess the ecological and socio-economic vulnerability of fishing communities in lower Tana Delta and Ungwana Bay in north coast Kenya to climate variability. Specific objectives of this study were:

1. to evaluate the effectiveness of the existing governance structures for coastal and marine resources and recommend sustainable management approach;
2. to evaluate the ecological and socio-economic vulnerability of the fishing communities to climate variability;
3. to determine catch composition, distribution and quantity in relation to climate variability;
4. to identify and characterize other sources of livelihood of fishing communities in terms of natural resource dependency and sustainability of technology used in resource exploitation;

1.5. Scope of the study

The study was conducted in the lower Tana Delta and Ungwana Bay region of the north coast Kenya. It solely targeted the coastal fishing communities of the region with special interest on artisanal fisheries exploitation and alternative sources of livelihood. The artisanal fisheries that were studied included fresh water and estuarine finfish exploited in the lower Tana and Ungwana Bay. The lower Tana Delta comprised of Ozi and Kipini BMU fishing areas while Ungwana Bay included the expansive waters between Ras Shaka to the north of the bay to Ras Ngomeni to the south.

1.6. Justification and significance of the study

Climate change is a reality that is experienced globally. Temperature has increased especially during the last three decades (1983-2012), a period which is considered as the warmest since the last 1400 years in the northen hemisphere (IPCC, 2014). The average temperature has increased from 1880 to 2012 by 0.85 ºC, while the mean sea level has risen by 0.19 m from 1901 to 2010 (IPCC, 2014). These changes have an impact on livelihoods of particularly the artisanal fishing communities. This is because the economy and livelihoods of especially the local fishing communities is intertwined within the ecosystems where the ecosystem services and products are influenced by climate variability (Badjeck et al., 2010). The artisanal fisheries of Ungwana Bay and the Lower Tana Delta in north coast Kenya experiences similar climatic changes thus subjected to vulnerability conditions. The fisheries resources in this area are the primary source of livelihood to the artisanal fishing communities as well as the coastal communities at large.

The fisheries resources also provide the country with foreign income from exports. Therefore, this study investigated the level of vulnerability of fisheries resources as well as the fishing communities to climate variability in the area.

The study has established high vulnerability level of fishing communities to climate variability, particularly Ngomeni and Ozi fishing communities. In addition, the study area experience increasing terrestrial temperatures as well as reduced rainfall frequencies. Sea Surface Temperature (SST) and Sea Surface Chlorophyll (SSC) have been observed to be the key environmental elements that affect the abundance, composition and distribution of fin fish resources. Additional pressure on the fisheries resources is associated with high dependency of natural resources by the fishing communities as well as increased population status. Review of coastal and marine resource management structures indicated ineffective performance thus resulting to overlap of duties, therefore, degradation of the resources.

Consequently, the study has described ecological and anthropogenic measures necessary to sustain fisheries as a way to adapt to the prevailing climatic conditions. It has also described management frameworks to be adopted for future research in order to improve the overall management of fisheries resources in the area. Furthermore, this study has described key social factors of the artisanal fishing communities that need to be strengthened for better adaptation to climate variability by the communities. Thus the adoption and implementation of proposed recommendations would help in sustainable

use and conservation of the resources as well as providing effective framework for understanding and managing coastal and marine fisheries in Kenya.

1.7. Methodological approach

This study was conducted in the lower Tana Delta and the adjacent Ungwana Bay in Kenya (Figure 1.1). The study of this nature may be based on cultural ecology or natural and physical ecological approaches. In the former approach, much emphasis of the study is anchored on theoretical foundation supported by existing literature. In the later approach, the study is based on empirical approaches that may have been applied already and are currently modified as per the study or the methods are currently investigated. Therefore, this study was based on natural and physical sciences anchored in existing empirical methodologies that were modified based on availability of data.

This study was conducted by adopting three main approaches which included ecological sensitivity assessment on vulnerability measurement of marine socio-ecological systems to climate variability, shore based catch assessment and socio-economic survey.

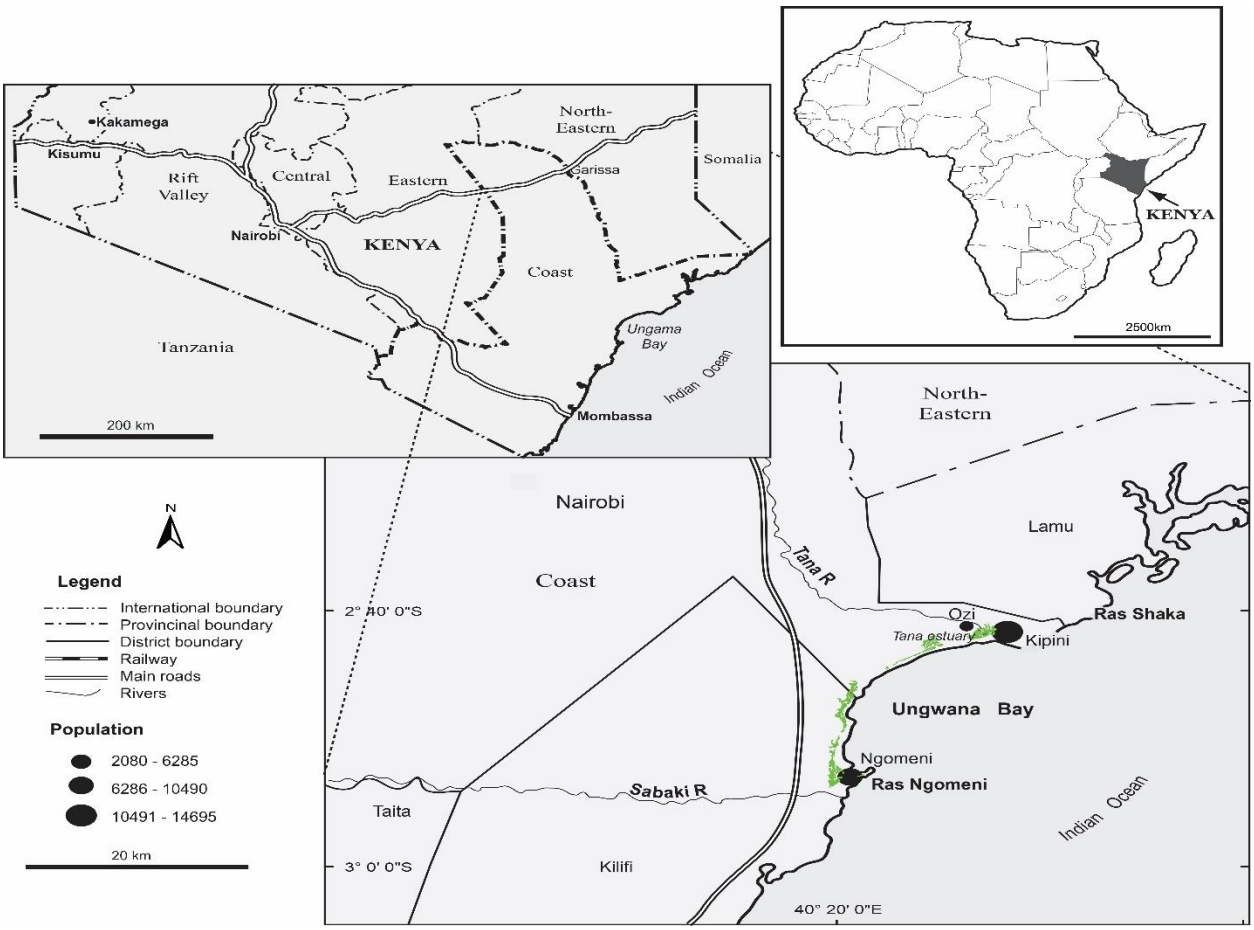


Figure 1.1. Map showing the fishing areas of Ngomeni, Kipini, and Ozi in Ungwana Bay and Lower Tana Delta, north coast, Kenya (Source, author)

The method of ecological sensitivity assessment was adopted from Metcalf *et al.* (2015) in vulnerability measurement of marine socio-ecological systems. It relies on fish species biological information existing in literature to evaluate species' sensitivity to environmental variables and establish the ecological sensitivity index. The method focuses on 3 elements: Ecological Sensitivity, Exposure and Adaptation. The study adopted the criteria of Welch et al. (2014) in identifying important ecological and economic fin fish species in Ungwana Bay and Lower Tana Delta (see Appendix 3). Then the biological profile of the identified species was assessed from a set of environmental variables developed by

Pecl et al. (2014) in a scale of 1-3 to determine their ecological sensitivity index (see Appendix 4). Then the exposure indicators were measured from the available long term data (1983-2015) of temperature and rainfall and their projections on the study site. The biological profiles of the identified species were then assessed from the exposure indicators using a set of criteria developed by Welch et al. (2014) to determine the overall exposure index (see Appendix 5). Adaptation indicators employed icluded the household size, education level, employment, disease status, access to health services, access to potable water, and other sources of livelihood. The indicators were measured using a scale of 1-3 to determine the overall adaptation index (see Appendix 4). All the indicators were normalized by the following formula before being aggregated into their respective index:

$$X_{ij} = \frac{Xi - MinXij}{MaxXij - MinXij} \dots\dots\dots\dots\dots i$$

Where:

X_{ij} is the normalized value of ij data set for a specific indicator,

Xi is the actual value to be normalized,

X_{Max} and X_{Min} are the maximum and minimum values of the indicator.

$$y_{ij} = \frac{MaxXij - Xi}{MaxXij - MinXij} \dots\dots\dots\dots\dots ii$$

Where:

Yij is the normalized value of ij data set for a specific indicator,

Xi is the normalized actual value ,

X_{Max} and X_{Min} are the maximum and minimum values of the indicator.

The specific formulae was applied based on the (↑) and (↓) functional vulerability relationship with the indicators (see Table 3.2).

The final climate vulnerability index was calculated using the IPCC (2007) formular as follows:

$$VI = (E + S) - AC \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots iii$$

Where:

VI = Vulnerability index;

E = Exposure;

S = Sensitivity;

AC = Adaptation capacity.

Shore-based catch assessment was conducted to collect fisheries data to determine catch composition, species richness, and fishing effort (catch rate, number and types of fishing gears and crafts) in relation to marine, estuarine and riverine habitats in Ngomeni, Kipini and Ozi fishing zones of Ungwana Bay and the Lower Tana Delta, Kenya. The data was concurrently collected in 8 days of every month from January to December 2017 in the 3 fishing areas. During the sampling days, all species of fish landings were separated before the total weight (kg) and individual total length (TL, cm) were measured. Fish species were identified using the FAO Species Identification Guide for marine resources in Kenya (FAO, 2012). A weighing balance was used to measure the total weight by species while a fish measuring board with a fixed meter tape was used to measure the total length for each individual fish. For large catches, the total weight was first measured, and then a homogenous sub-sample was randomly taken from the catch where different fish species

were separated before weighing and individual fish total length measured. For small catches, similar procedure was followed without sub-sampling. Recorded additional data included time taken for fishing (hr), type of fishing craft, craft crew size and the type of fishing gear used. Non-Metric Multidimensional Scaling (nMDS) technique was used to determine whether distinct seasonal catch composition existed across habitat types, and also across fishing zones. 1-way ANOSIM was used to test significant difference in the seasonal catch composition across habitats and across the fishing zones. In both cases, 1-way SIMPER analysis was performed to identify which fish species contributed to dissimilarity. Seasonal catch rate (kg/fisher.hr^{-1}) was calculated for each fishing zone. In each zone, the total weight for each month was divided by the total number of crew (w/f), and then divided by the total number of fishing hours of the same month (w/f:hr). The seasonal average catch rates were then computed for each zone. Differences between seasons and across fishing zones in catch rates were determined using 2-way ANOVA test. Homoscedascity of variances was tested using the Levene's test at $p > 0.05$. Pair-wise comparison was conducted using post hoc (Tukey HSD) test. These tests were conducted using STATISTICA statistical software v.7. Microsoft Excel was used to determine the mean length of the most abundant and common species in each fishing zone with craft-gear combination. The differences in species length between the different craft-gear combinations were conducted using the non-parametric Kruskal-Wallis test. Rarefaction curves were used to determine species diversity across fishing zones with habitat and craft-gear combination. Craft and gear frequencies as well as the frequencies of the most 5 abundant species in each fishing zone were also determined by Microsoft Excel.

The socio-economic survey was carried out to collect data on artisanal fishing communities addressing their annual income from fisheries resources, other sources of livelihood, dependence on natural resources and social factors. Semi structured interview with questionnaires were used to collect data (see Appendix 2). Respondents were engaged on one to one interview during the data collection. The total sample size for the study was determined by the infinite Cochran (1977) formular. This is because the overall population of the entire region was more than 50, 000 fishing families (households) (Government of Kenya, 2009). Any population above 50, 000 is considered infinite. Therefore, the sample size for infinite population was computed using the Cochran's infinite formular whereby:

$$n_0 = \frac{z^2 pq}{e^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Where:

n_0 = sample size,

z = is the selected critical value of desired level of confidence,

p = is the estimated proportion of an attribute that is present in the population,

q = 1-p,

e = is the desired level of precision

In social sciences, 95% level of confidence is an acceptable accuracy level and a precision value of 15% and below is acceptable level of variability in sample size determination.

Therefore, level of confidence was set to be 95% hence z = 1.96, desired precision was set to be ±5% hence e = 0.05, infinite population is normally set to be 50% hence p = 0.5, q = 1−0.5= 0.5

Sample size $n_0 = \frac{(1.96^2)(0.5)(0.5)}{(0.05)^2} = 384.16 \approx 384$

When excluding other parts of the region, the specific population size for the study area was 27, 020 people which comprised of Ngomeni, Kipini and Ozi only. Therefore, Cochran (1977) suggested a correction formular to correct the sample size calculated by infinite formular when specific population size is known. Thus the sample size in equation (i) was corrected by Cochran's correction formula (1977) as follows:

$$n = \frac{n_0}{1+\frac{(n_0-1)}{N}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Where:

n = new sample size to be determined,

n_0 = sample size derived from eq...(i),

N = actual population size of the subjects

$$n = \frac{384}{1+\frac{(384-1)}{27020}} = 378.6 \approx 379$$

Specific sample size in each study area was determined by the following formular:

$w = \frac{n}{N}$ ……(iii)

Where: w = weight,

n = Population for each stratum

N = Total population for the three strata

W × total sample size……(iv)

Where: w = weight

Thus the sample size for Ngomeni, Kipini and Ozi were determined as follows:

Ngomeni = $\frac{10241}{27020} \times 379 = 143.6 \approx 144$

Kipini = $\frac{14695}{27020} \times 379 = 206.1 \approx 206$

Ozi = $\frac{2084}{27020} \times 379 = 29.2 \approx 29$

Purposive sampling was used to identify fishing communities, and then simple random sampling was used to select the respondents. The respondents were identified through a simple random process which was conducted through the help of chief administrators and village elders in the respective areas. All the names of household heads of fishing communities were assigned numbers and then a table of random number generator was

used to produce the numbers to be included in the sample size. The corresponding household names on the random numbers generated were then identified and engaged in the semi-structured interview.

1.8. Structure of the study

This thesis is developed on publications. The **first chapter** describes the general introduction of the study, thematic consideration, research questions, aim of the study, scope of the study, justification and significance of the study and finally the structure of the study. **Chapter two** provides a critical review of literature illustrating the application of coastal and marine management models, particularly the Driver-Pressure-State-Impact-Response (DPSIR) model in the assessment and management of coastal and marine fisheries. **Chapter three** presents the first methodological approach of the study. It empirically examines the ecological and socio-economic vulnerability of artisanal fishing communities to climate variability in the study area. It provides recommendation measures to sustain fisheries resources and to enhance adaptation measures for the artisanal fishing communities. The **fourth chapter** examines the impact of long term climatic data of sea surface temperature, sea surface chlorophyll and rainfall on the distribution, composition and abundance of fin fishes in Ungwana Bay and the Lower Tana Delta in Kenya. **Chapter five** presents the second methodological approach of this study. It provides characterization of artisanal fisheries based on composition, abundance, and catch rates, boat and gear types as well as fish species length in Ngomeni, Kipini and Ozi. The third methodological approach of this study is presented in **chapter six**. The chapter

provides socio-economic characteristics of artisanal fishing communities and climate variability characteristics of Ungwana Bay and the Lower Tana Delta. It shows the social factors resulting in dependence on natural resources and coping measures adopted by the communities. **Chapter seven** presents a synthesis and conclusion of the study as well as providing recommendation measures.

CHAPTER 2

LITERATURE REVIEW:
"Application of the DPSIR Model to Coastal and Marine Fisheries Management in Kenya"[1]

Abstract

Natural resource management frameworks are important in generating information that inform the development of appropriate policies and regulations for effective management and utilization of different aspects of ecosystems. The Driving force-Pressure-State-Impact and Response (DPSIR) model is one of such frameworks which has been widely applied globally in assessing, addressing and communicating environmental problems. This model provides a nexus between the cause of environmental problems and the resultant pressures, associated impacts as well as responses needed to countercheck the environmental issues and challenges. This paper is a review of the existing information on studies of a similar nature in Kenya that applied the DPSIR model in assessing the coastal and marine fisheries management issues as well as studies with different methodological approaches that focused on these resources. In this paper, the use of DPSIR model has been extensively reviewed on its application to understand a number of environmental challenges; however, the application of the model was limited to terrestrial ecosystems in most of the studies in Kenya. This therefore, has created a deficiency in understanding the potential of DPSIR model in the effective management of coastal and marine resources, particularly in the context of sub-Saharan Africa and taking Kenya as a case study.

***Key words**: DPSIR model, Coastal and marine fisheries, Management model, Kenya*

[1]Dzoga, M., Simatele, D., Munga, C. (2018). Application of the DPSIR Model to Coastal and Marine Fisheries Management in Kenya. Journal of Environmental Management, 13. (Under review)

2.1. Introduction

Since inception, the Driver-Pressure-State-Impact-Response (DPSIR) model has attracted varied responses. The model was developed in the 1990s as a tool for environmental assessment and to demonstrate the relationship between environment and human systems in the form of cause and associated consequences (Kristensen, 2004; Carr et al., 2007; Mimidis et al., 2017). In the mid-1990s, the model was adopted by the European Environment Agency (EEA) which then became widely recognized among researchers and policy makers (Carr et al., 2007; Svarstad et al., 2007). Mattas et al. (2014) consider the DPSIR model an appropriate and simple tool to address the main environmental problems and, thus strengthens decision making process in policy and the regulatory enforcement. As a tool for environmental management, the DPSIR model is often, applied by natural scientists and has proved to be useful in identifying drivers of environmental degradation and the associated policy response (Lan et al., 2014).

Despite its value and potential for environmental assessment and management, the DPSIR model has been criticized for several weaknesses (Svarstad, 2007; Carr et al., 2007). The model defies flexibility and assumes a unidirectional functioning of established indicators (Carr et al., 2007). Flexibility is viewed in the perspective of possible responses in between two elements of the model such as drivers and pressure. For example, if pressure on natural resources is extremely high as a result of intense human driving forces, then responses may be initiated at the pressure level to minimize the intensity of the driving forces. Contrary to this perspective, the responses in the DPSIR model are generated at the

end of the cycle. Therefore, even though the model illustrates the cause-effect relationship, Svarstad (2007) is of the view that the model has failed to establish the same relationship between the elements. This limitation is acknowledged by Stavros et al. (2016) in their work which noted that some pressure results into instant impact while some impact requires immediate response. In such cases therefore, the model tends to be rigid, thus, has been described as a means of disseminating information rather than an analytical tool (Carr et al., 2007).

Nevertheless, the critics agree that the DPSIR model is a tool for conveying environmental information. This is particularly important for decision makers in enforcing environmental regulations. Based on the information generated through various studies, specific natural resource regulations are recommended especially those involving public participation in controling environmental issues such water pollution (Islam et al., 2012; Mattas et al., 2014). After reviewing two decades of lessons learned from the use of DPSIR model, Patricio et al. (2016) suggested that the model is indeed important as a unifying tool in assessing linkages in human presures with coastal and marine ecosystems. In this regard, the DPSIR model is best placed at identifying important drivers, pressure and the state of tropical artisanal coastal and marine fisheries resources such as that of the Kenyan context. Despite the long term existence of the DPSIR model, there is generally less observed application of the model in the assessment of coastal and marine resources (Patricio et al., 2016). This is particularly the case with the Kenyan scenerio where this model has not been applied in most environment-related studies.

Coastal and marine fisheries resources in Kenya experience a myriad of management challenges. This is because of high dependence level by the artisanal fishing communities on fisheries resources as well as inability of the communities to access offshore resources due to lack of appropriate fishing technology (Government of Kenya, 2014). A good example is the Malindi-Ungwana Bay bottom trawl prawn fishery in north coast Kenya which has for over four decades resulted in degradation of bottom habitats as well as decreased target and bycatch species (Munga et al., 2012; Munga et al., 2014). High fishing pressure has also been reported for inshore artisanal fisheries along the entire Kenya coast due to the ever increasing fishing effort (Government of Kenya 2014, 2016) with resultant reduced catches and degradation of habitats such as corals and mangroves (Fondo et al., 2014). In addition, the effects of climate change may further impact the artisanal coastal and marine fisheries resources. Consequently, proper assessment of these resources using appropriate tools is required to ensure sustainable management.

This paper therefore, presents a critical review of literature to illustrate the application of DPSIR model in the assessment of coastal and marine fisheries management in Kenya. The overall objective is to analyze the application of the different elements of the DPSIR model within the Kenyan context and establish the extent to which it can be used as a tool for the effective management of coastal and marine resources. In addition, this review intends to identify existing gaps with the objective of recommending better approaches for management of coastal and marine fisheries resources in Kenya and the Western Indian Ocean (WIO) region at large.

2.2. Methods

This paper is based on information compiled through a rapid appraisal and critical review of literature ranging from published journal articles, electronic books, and reports on the potential of DPSIR model in management of natural resources particularly coastal and marine fisheries. The process involved a thorough desktop search from Google Scholar using key searching words such as DPSIR, DPS, PSR, natural resource management framework, fisheries management framework, coastal, and marine fisheries. The initial search involved global perspective of the model application, then narrowed down to coastal and marine fisheries publications. Due to limited literature on the application of DPSIR model in the management of coastal and marine fisheries in Kenya, a general review was conducted on the available studies with different methodological approaches on the state of fisheries along the Kenyan coast with an objective of identifying the Drivers-Pressure-State-Impact-Response within the DPSIR framework. The resultant sources of literature were selected and carefully analyzed to include peer reviewed articles, authenticated reports and electronic books suitable for this study. All relevant and used literature sources were acknowledged and appropriately cited. In total, 34 literature sources were reviewed for this study, and out of which 16 had a global perspective while 18 were appropriate for the Kenyan scenerio.

2.3. The DPSIR model and coastal and marine fisheries management

The DPSIR model is commonly known as a tool for assessing the causal links on environmental problems structured into five main elements namely: Driver, Pressure,

State, Impact and Respone (see Figure 2.1) (Kristensen, 2004). In general, drivers comprise the needs of a society to be satisfied which trigger activities to meet them (Kristensen, 2004; Patricio et al., 2016). These activities are termed as pressure symbolizing the force exerted on natural resources. Kristensen, (2004) further described the change of quality of the natural resources due to exerted pressure as the state of the resources. The impact is the resultant effect of the quality of the natural resources on socio-economic life of humanity. Ultimately, measures developed to control these effects are known as responses.

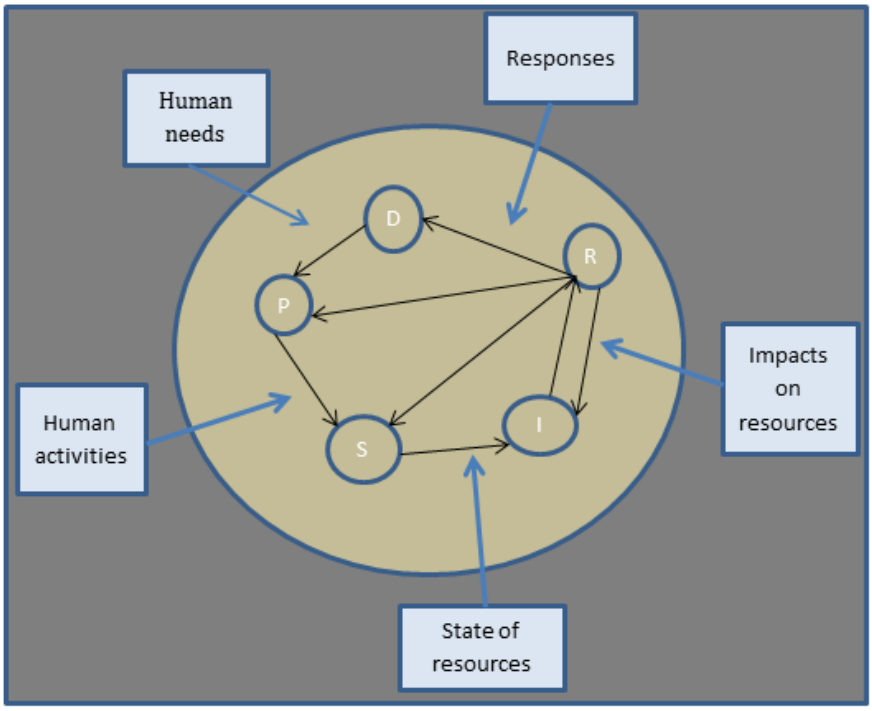


Figure 2. 1 DPSIR assessment model (modified from Kristensen, 2004)

Though the model appears simple in application, studies have increasingly interpreted these elements differently thus, creating a sense of confusion at decision making level (Svarstad et al., 2007; Oesterwind et al., 2016). Consequently, Oesterwind et al. (2016)

suggested a common understanding and interpretation of the five elements in coastal and marine studies. The authors defined Drivers as a cause of a phenomenon instead of a societal need, Pressure as human activities or natural processes affecting ecosystem, State as the actual condition of the ecosystem, Impact as the resultant effects of ecosystem change on human and natural resources, and Responses as all actions undertaken to control the perceived effects. Lewison et al. (2016) reviewed literature in order to demonstrate the application of DPSIR in formulating empirical research of coastal systems. The study illustrated that DPSIR can be quantitatively applied in conducting assessments of coastal systems. As a result, it proposed a quantitative way of applying DPSIR for coastal studies.

Coastal and marine resources are complex in interaction especially those in developing tropical countries. Thus, there is a need for a common framework that can integrate the complexity for easier and sustainable management of natural resources (Ojeda-Martı´nez et al., 2008). For over two decades, researchers have made efforts to develop such frameworks without success (Patricio et al., 2016). For example, the Ecosystem Approach to Fisheries Management (EAFM) framework was developed to ensure a holistic view of the ecosystem where human actors are an integral part in its development and application, thereby ensuring that human needs are achieved while maintaining the health of natural resources (Gracia et al., 2003). However, Cowan et al. (2012) notes that the EAFM has neither succeeded nor failed in ensuring a holistic management of coastal and marine ecosystems thereby requiring the development of a model that would contribute to the effective and sustainable management of the associated resources. USAID (2013) suggested

the DPSIR model as a framework for reporting the state of coastal and marine resources. Recent studies have noticed the need of the DPSIR model as a tool of communicating and managing coastal and marine ecosystems (Patricio et al., 2016; Oesterwind et al., 2016; Lewison et al., 2016). Therefore, the DPSIR model is currently commonly recomended in the management of coastal and marine systems following a common interpretation and understanding of the elements as well as the methodological approach.

2.4. Contextualising DPSIR model on coastal and marine fisheries management in Kenya

While DPSIR model has gained much recognition globally, there are still very limited studies that have adopted this approach in Kenya. Wangai et al. (2017) applied the DPSIR model in identifying and qualifying indicators for the nexus between cultural ecosystem services and human wellbeing. However, the focus of the study was entirely based on establishing how human actors influence environmental change and how institutional frameworks and processes are structured to respond to these changes. Mangi et al. (2007) on the other hand applied the DPSIR model to understand the challenges of reef fisheries management in Kenya. This study recommended appropriate indicators that are useful in assessing reef fisheries and therefore their management (see Table 2.1). In view of this, the current paper relies on the stated indicators and, to some extent, it includes other indicators that fit in the definition of DPSIR elements so as to broaden the understanding of environmental problems and the resultant consequences of coastal and marine fisheries management along the Kenyan coast.

Table 2. 1. DPSIR indicators of reef fisheries management along the Kenyan coast (Mangi et al., 2007)

Drivers	Pressures	State	Impact	Responses
Population	Increase of number of fishers	Fish abundance	Decrease in fish catch	Legislations
Unemployment	Over-exploitation	Live coral cover	Destruction of livelihoods	Planning regulations
Cultural tradition	Destructive fishing gears	Sea urchins population	Conflicts increase	
Poverty		Change due to climate variability		

Marine and coastal fisheries in Kenya are well studied (Munga et al., 2014; Okemwa et al., 2015; Osuka et al., 2016). However, none of these studies adopted the DPSIR model approach to articulate coastal and marine fisheries management issues within the 5 elements of the framework. As a result, there is vague description of the underlying driving forces that could trigger the ecological problems experienced. The methodological approaches of coastal and marine studies focussed mostly on quantifying and describing various aspects of fisheries resources including abundance, species distribution and composition (McClanahan et al., 1999; Munga et al., 2012; Okemwa et al., 2015). Despite their significant contribution in identifying challenges and issues of fisheries resources, these studies have minimal understanding of the associated driving factors. This is where the DPSIR model provides a unifying platform by describing and quantifying the driving factors as the first step for comprehending the issues of coastal and marine resources as well as their management. In this review, therefore, the model was applied to draw rational approach to the identification of driving factors in the isolated studies with different

methodological approaches to enhance coherence on management of coastal and marine reasources in Kenya. Obura (2001) characterized the coastal and marine resources of Kenya and noted that human population growth is a significant factor that increased the demand for fisheries resources. The coastal population grows at a rate of 3.7% annually exerting high pressure on the fisheries resources (Obura, 2001). In a different approach, Kitheka (2002) described high dependence on natural resources as an important factor that increases the demand on fisheries resources as well. The fishing areas of Ngomeni and Kipini in north coast Kenya have depicted high dependency level by the local communities on the artisanal fisheries resources at 90% and 70%, respectively (Kitheka, 2002). Population increase as well as high dependence level on the coastal and marine fisheries constitute the main driving factors for fisheries resources in Kenyan. These two indicators, however, were not captured by Mangi et al. (2007) in the definition of driver indicators but they illustrate the driving force exerted on coastal and marine fisheries in Kenya. By applying the DPSIR approach, this review has highlighted these indicators as the main driving factors for coastal and marine fisheries in Kenya that need to be linked all through the model so as to generate approriate information for appropriate responses.

The second component of the DPSIR model measures the pressure exerted by driving factors. This is critical for providing benchmarks upon which decisions are based. Studies have adequately explained the element of presure on coastal and marine fisheries resources in Kenya (Fondo et al., 2014; Aloo et al., 2014). Fondo et al. (2014), for example, documented cases of overexploitation of coastal and marine fisheries in Kenya. Reef fisheries in Kenya have a standard yield of between 2 and 4 tons $km^{-2}yr^{-1}$ (Fondo et al.,

2014). However, the extraction of these resources along the Kenya coast lies between the unsustainable annual yield of 5.07 and 12.9 tons km^{-2} with a mean of 8.8 tons $km^{-2}yr^{-1}$ thus exceeding the threshold limits (Fondo et al., 2014). Samoilys et al. (2017) confirmed this issue of overexploitation by acknowledging high productivity of reef fisheries that exceeds the recommended range. Further, the use of destructive fishing gears in artisanal fishery has amplified the pressure exerted on these resources. The use of prohibited fishing gears such as beach seines and monofilament nets has resulted in landing of large quantities of immature and small-sized individuals in this fishery (Fondo et al., 2014; Munga et al., 2014; Osuka et al., 2016). Reverting to the DPSIR model, a clear link between the drivers and pressures of coastal and marine fisheries in Kenya is well established. For instance, the increase of human population in the coastal region has resulted to a higher demand for fisheries resources and therefore, has significantly contributed to the overexploitation of the fisheries resources. This link between the two elements generate the required information useful for the management of the resources.

Referring to the general definition of the State element in the DPSIR model, this review defines the state of fisheries as the actual quantification and characteristics in various habitats or threshold limit of exploitation. These quantifications and thresholds of fisheries resources provide the baseline information where the extent of impacts on the resources can be measured by the model. With this perspective, therefore, the overall annual production of coastal and marine fisheries in Kenya is estimated to be less than 10 000 tons (Ruwa, 2006). Aloo et al. (2014) confirmed this by providing the actual value of coastal and marine production of 8000 tons annually. These studies, however, estimated the

quantification values mainly for awareness purpose thus failed to describe the level of impacts of fisheries. The DPSIR model harmonizes this by providing a common platform where the baseline information of coastal and marine fisheries may be used to assess the extent of impacts associated within a particular study.

The inshore estimated total production of coastal and marine fisheries is 20000 tons yr^{-1} (Oduor, 1984). Current annual production reveals impacts on the resources. The current inshore production estimates of the resources is 8000 tons yr^{-1} (Ruwa, 2006; Aloo et al., 2014). Studies have qualitatively confirmed the decline of coastal and marine resources in various parts of the Kenya coast. For example, Fondo et al. (2014) showed the decline in reef fisheries catch of 1998 in the southern coast of Kenya while Osuka et al. (2016) indicated the decline of the same resources within the same period in north coast of Kenya. Habitat degradation such as loss of mangroove cover, sea grass and corals were viewed as an impact on fisheries production (Fondo et al., 2014). Due to limited information on the quality of resources in the past, it is difficult to assess their degradation condition presently. In spite of the limited information on the status of habitats, this is a critical indicator that needs to be included among the impact indicators as it addresses changes of ecosystems. Observed conflicts between the artisanal fishery and the semi-industrial bottom trawl prawn fishery signified more impacts on fisheries. Munga et al. (2014) recorded that similarity in catch composition between the two groups could be the root cause of the conflicts. The DPSIR model bridges the gap on the existing piecemeal studies that focused on coastal and marine fisheries in Kenya by addressing their outcome appropriately within the 5 main elements thus able to comprehend the issues of the

resources management in totality. Therefore, the impacts of coastal and marine fisheries in Kenya include the decline in abundance, habitat degradation, and conflicts among the fishers in the artisanal fishery and between other stakeholders in the fishing sector.

Kenya has several regulative and legislative measures to manage the coastal and marine fisheries which are described as good instruments in providing sustainable fisheries management (Hoof & Steins, 2017). These include: The Fisheries Act of 1991, The Wildlife (Conservation and Management) Act of 2002, Kenya Forest Act, The Maritime Zones Act, Environmental Management Act of 1999, Local Authority and Planning Act, Water Act, Maritime Authority Act and Kenya Ports Authority Act (Japp, 2011).

The Acts are supported by various institutions responsible for enforcing and implementing coastal and marine fisheries regulations. These institutions have sectoral functioning for the regulative responsibilities. For instance, the Ministry of Agriculture, Livestock and Fisheries through the State Department for Fisheries, is responsible for fisheries policy implementation in Kenya (Hoof and Steins, 2017). However, there are other institutions which are important in managing and implementing coastal and marine fisheries resources and policies. These include The Kenya Wildlife Service (KWS), The Kenya Forests Service (KFS), and The National Environmental Management Authority (NEMA). Their mandate and responsibility in the management of coastal and marine resources as stipulated in the Acts often overlap and clash. In mangrove forests management, for example, KWS has strictly forbade the extraction of the resources in reserve areas, however, sustainable use of the resources in the reserve areas is allowed by KFS (Alemayehu, 2017). Further

conflicts in institutional mandates have been demonstrated by Alemayehu (2017). These include the challenge to protect the coastal riparian zones (30 meters from the high water mark). Intense tourism development activities are undertaken in the riparian zones thus affecting fisheries resources. This is mostly attributed to lack of sectoral coordination in resources management. While KWS is responsible to protect the riparian zones, The Local Authority and Planning is responsible for authorising such development. This has encouraged exploitation of the riparian zones thus affecting fisheries resources. Furthermore, the Beach Management Units (BMUs) have experienced challenges in implementation and monitoring of artisanal fisheries (Hoof and Steins, 2017). The BMUs operate on voluntary basis which makes them detached from the local and national government in fisheries management which is mostly attributed to lack of financial support (Hoof and Steins, 2017).

Despite demonstrating good institutional and regulative structures, responses to the management of coastal and marine resources is still a challenge in Kenya. This is attributable to overlapping and clashes in mandates by various institutional structures responsible for the management of resources. Consequently, these responses are characterized by lack of commitment in implementation and enforcement (Ruwa, 2006; Hoof & Steins, 2017). In addition, the fisheries policies were developed with no consideration of economic, social, biological, and environmental sustainability; thus encouraging conflicts among and between fishing communities (Ruwa, 2006). It is important to note that the ineffectiveness of coastal and marine responses could be as a result of information generated from non-uniform study methods thus failed to link all

aspects of the ecosystem. The effective identification of coastal and marine fisheries issues as well as their management can be achieved by adopting the DPSIR model approach. In this review, the DPSIR model has contextualized the coastal and marine fisheries issues into the 5 elements thus providing a common platform to make rational responses (see Table 2.2).

Table 2. 2. Coastal and marine fisheries challenges in Kenya using DPSIR model approach

Drivers	Pressure	State	Impacts	Responses
Extreme levels of natural resource dependency	Over exploitation of fisheries	Annual fisheries production of less than 10 000 tons	Fluctuation of fisheries abundance	Policies developed without socio-economic, environmental, and biological consideration
Increase of coastal population?	Use of destructive gears	Annual production treshold of 2-4 tons $km^{-2}yr^{-1}$ of reef fisheries	Habitat degradation	Lack of monitoring and control
	Increase of fishing effort		Conflicts among fishers	Poor enforcement and implementation

Summary and conclusion

The coastal and marine fisheries in Kenya have been well studied. However, these studies focused on abundance, species composition and distribution as well as gear type interactions. The interaction between resource users and the biological resources remain understudied. As a result, policies and regulations were developed based on information

generated majorly from a single component of an ecosystem. Consequently, the overall management of fisheries resources seem to have been compromized.

DPSIR model clearly provides a unifying platform where every component in an ecosystem is taken into consideration. The main gap to effective fisheries management in Kenya is lack of identification and analysis of core drivers of coastal and marine fisheries issues. This review has clearly illustrated this gap which needs to be addressed in future studies. In addition to the indicators by Mangi et al. (2007), this review has also identified the need to include natural resource dependance level and habitat degradation as important indicators when conducting a DPSIR analysis in fisheries reources. Future studies of coastal and marine fisheries to include DPSIR methodological approach in order to develop and enforce policies and regulations that are inclusive of all aspects of the system. (Government of Kenya, 2016).

CHAPTER 3

Assessment of ecological vulnerability to climate variability of coastal fishing communities: A study of Ungwana Bay and Tana Estuary, Kenya[2]

Abstract

Fisheries resources are important in supporting the livelihood of many coastal communities especially in the developing tropical countries. Fisheries resources however, continue to face unprecedented pressure from the impacts of climate change, and this presents both ecological and socio-economic challenges to the dependent communities. This paper assessed the ecological vulnerability to climate variability of artisanal fishing communities in Ungwana Bay and the Lower Tana Delta in Kenya, using selected fin fish species. A combination of approaches was adopted and used to identify and determine exposure, sensitivity, and adaptation indicators. These included a critical review of existing literature, socio-economic survey, and computation of temperature and rainfall variation using long term data from 1983 to 2015. The method of Equal Weights (EW) was applied to all indicators after normalization. The data was normalized in a scale of 0 to 1, where 0 indicated low vulnerability level and 1 high vulnerability. By using composite index, the selected Ngomeni and Ozi fishing communities within the larger Ungwana Bay and Lower Tana Delta indicated high levels of vulnerability of 0.9 and 0.8 respectively. Due to high vulnerability level and poor adaptation capacity by the local fishing communities in the selected study sites, we recommend government and non-governmental agencies to reinforce community based

[2] Dzoga, M., Simatele, D., Munga, C. (2018). Assessment of ecological vulnerability to climate variability on coastal fishing communities: A study of Ungwana Bay and Tana Estuary, Kenya. Ocean and Coastal Management, 14. (The paper has been revised the second time by the journal and is currently under review)

organizations (CBOs) activities on ecological conservation and social network creation to promote short and long term adaptation measures.

Keywords: *Small scale fisheries, Climate change, Susceptibility, Ungwana Bay, Lower Tana Estuary, Kenya*

3.1. Introduction

Coastal and marine ecosystems are sensitive to climate variability even with minimal degree of fluctuation (Pallewatta, 2010). In addition to climate variability, these ecosystems experience over-exploitation as a result of increasing human population demands (Palmer et al., 2014). Therefore, climate variability as well as human pressure threaten the sustainability of fisheries resources (Brander, 2010). Globally, temperature has significantly changed and has increased[3] over the last three decades (IPCC, 2014; Rahmstorf et al., 2017). Climate variability has been described as unequivocal thus, causing implication on the long term condition of fisheries resources (IPCC, 2007; Caputi et al., 2015). Severe variations of climatic elements may result in reduced abundance as a result of death and migration of some fish species (Welch et al., 2014). The compounding effects of climate variability and anthropogenic pressure may cause high rate of degradation of coastal and marine ecosystems and result in reduced or lost ecosystem services (Palmer et al., 2014).

Degraded ecosystems such as those of coastal and marine have high potential to affect the social and economic wellbeing of the dependent fishing communities (Pallewatta, 2010). These effects are associated with reduced fish catches which then affect the social and political life of the communities (Nayak et al., 2014; Bhatta et al., 2016). For example, Bhatta et al. (2016) observed that changes in wetland ecosystem in Maguri-Motapung, India resulted to essential reduction of fish stocks. Likewise, the source of poverty among small scale fisheries in Brazil and India has been linked to ecological changes (Nayak et al., 2014).

[3] The average global temperature on Earth has increased by about 0.8° Celsius (1.4° Fahrenheit) since 1880. It is argued that two-thirds of the warming has occurred since 1975, at a rate of roughly 0.15-0.20°C per decade (IPCC, 2014).

Studies have made significant effort in addressing the socio-economic wellbeing of fishing communities in terms of their vulnerability to climate variability (Cinner et al., 2011; Islam et al., 2014; Metcalf et al., 2015). Cinner et al. (2011) conducted a regional study which examined vulnerability of coastal communities to the impacts of climate change on coral reef fisheries. Existence of different levels of vulnerability to coral reef fisheries was observed in different countries studied where Kenya showed the highest level of vulnerability compared to Tanzania, Seychelles, Mauritius and Madagascar (Cinner et al., 2011). Metcalf et al. (2015) also examined the vulnerability of marine socio-ecological systems as a precussor for adaptation strategies. It was noted that vulnerability assessment assists communities to realise their strengths and weaknesses thus ensuring appropriate assimilation of adaptation measures. Understanding the level of vulnerability in a community is necessary to identify and develop appropriate interventions and acceptable coping measures that would contribute to sustainable use of fisheries resources (Julia et al., 2009).

The Ungwana Bay and Lower Tana Delta in north coast Kenya are important fishing areas sustaining the artisanal (small scale as well as traditional fisheries) fishing communities (Munga et al., 2014a). The bay is considered as one of the richest in fisheries resources along the Kenyan coast (Government of Kenya, 2015). However, pressure on the fisheries resources along the bay has been high as a result of shrimp bottom trawling activity since the last four decades (Fulanda *et al.,* 2011; Munga *et al.,* 2012). Fin fish bycatch ranged between 432.0t in 2001 to 603.2t in 2004 (Munga et al., 2012). This triggered conflicts between the shrimp bottom trawling and the artisanal fishing activities over the fisheries resources (Munga et al., 2014a). Climate

variability in the bay has become an additional threat to fisheries resources (Munga et al., 2014b). Deenapanray and Tan, (2011), projected an increase in temperature of 3.3 °C and 21% decrease in rainfall by 2050 in the region.

This study therefore, assesses the vulnerability of the fishing communities to climate variability using selected fin fish species in Ungwana Bay and the Lower Tana Delta, north coast Kenya. On one hand, the fin fish species were used to establish the level of exposure and sensitivity of the ecosystems, and on the other hand, the fishing communities were used to determine their adaptation capacity.

3.2. Materials and Methods

This study focused on three fishing communities namely; Ngomeni, Kipini, and Ozi located within the Ungwana Bay and Lower Tana Delta of north coast Kenya (Fig. 3.1). Ngomeni and Kipini communities are dominant for estuarine and marine fisheries while Ozi is dominant for riverine fisheries (Abila, 2010). The dependance of marine fisheries among the artisanal fishing communities is estimated to be 90% and 70% in Ngomeni and Kipini respectively (Kitheka, 2002). The ecosystem of the study area is enriched with nutrients from upstream supplied by River Tana and River Sabaki thus supporting the diversity of fisheries resources. We used a set of methods that are commonly applied in ecological vulnerability assessment of fishing communities according to Cinner et al. (2011) and Metcalf et al. (2015).

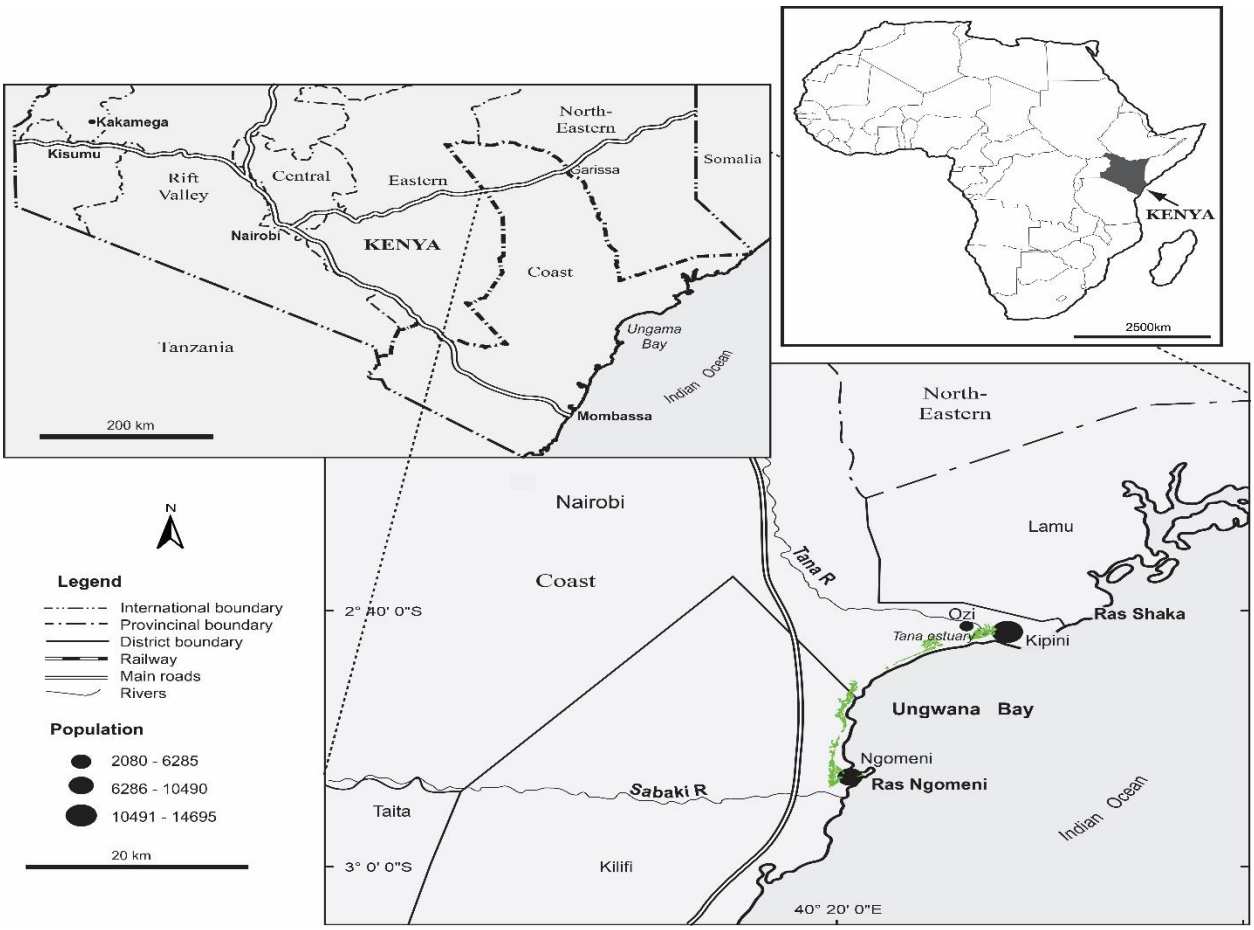


Figure 3. 1 Map showing fishing communities (Ngomeni, Kipini, and Ozi) in Ungwana Bay and Lower Tana Delta, north coast, Kenya (Source, author)

Firstly, we adpoted the method of ecological sensitivity assessment used by Metcalf et al. (2015) in vulnerability measurement of marine socio-ecological systems. The method relies on fish species biological information existing in literature to evaluate species' sensitivity to environmental variables and establish the ecological sensitivity index. We used the available literature to identify key commercially important fin fish species as well as developing their biological profiles describing the species' life history, habitat usage, and levels of environmental tolerance conditions (WWF, 2014). The species' biological profile was then assessed from a set of environmental indicators developed by Pecl et al. (2014) to determine their sensitivity level

using a scale of 1-3, where 1 indicated low and 3 high sensitivity (Table 3.1). Five demersal fin fish species were identified from the study area which met the desired criteria and these were: blackspotted rubberlip (*Plectorhinchus gaterinus*), pinkear emperor (*Lethrinus lentjan*), dory snapper (*Lutjanus fulviflamma*), marbled parrotfish (*Leptoscarus vaigiensis*), and shoemaker spinefoot (*Siganus sutor*) (WWF, 2014). We perceived fishing demand, fishing pressure, and human population as important factors contributing to sensitivity of fin fish resources. These parameters were therefore included in determination of ecological sensitivity index in the study area.

Secondly, we identified temperature, rainfall and perception of the fishing communities on the impact of climate variability on fin fish production as exposure indicators based on the available data and applicable to the study area. Data on the perception of fishing communities was collected through socio-economic survey (method described in the next paragraph). A scale of 1 – low, 2 – medium, and 3 – high was used to measure the perception of the fishing communities on the impact of climate variability in fin fish production for the last 10 years. Two sets of temperature data were analysed. Terrestrial Temperature (TT) for the riverine study site (Ozi), and Sea Surface Temperature (SST) for the estuarine and marine study sites (Kipini and Ngomeni). The SST was derived from National Oceanic and Atmospheric Administration (NOOA) for a 30 year period (1983-2015), while TT as well as rainfall data were obtained from the Kenya Meteorological Department, Malindi Station for the same period. The mean increase of SST, TT, and rainfall were computed and compared against maximum and minimum threshold values (projected maximum and minimum of temperature and rainfall in the area) to estimate the exposure level (Deenapanray & Tan, 2011). Fritzsche et al. (2014) indicated the

need to introduce threshold values to capture realistic condition of vulnerability of an index particularly for data with minimal or no difference in values. Threshold values are the maximum and minimum range of an indicator and are derived from experts or published literature (Fritzsche et al., 2014).

Lastly, the socio-economic survey was carried out to collect data on artisanal fishing communities addressing the level of fish demand, fishing pressure, climate change impacts on fish production, human population as well as adaptation factors. We defined adaptation capacity as the ability of the fishing communities to cope with the dynamics of fisheries resources due to climate variability impacts. Therefore, we developed and collected data for a set of seven adapatation indicators to assess the strength of the communities to respond to the above condition. The adaptation indicators included household size, education, employment, disease status, access to health services, access to potable water, and alternative sources of livelihood. All the indicators were measured in a scale of 1 – 3 (1 – low, 2 – medium, and 3 – high).

The sample size for the study was determined by the infinite Cochran (1977) formula. This is because the overall population of the entire region was more than 50,000 fishing communities (Government of Kenya, 2009). Any population above 50,000 is considered infinite. Therefore, the sample size for infinite population was computed using the Cochran's infinite formula whereby:

$$n_0 = \frac{z^2 pq}{e^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (i)$$

Where:

n_0 = sample size,

z = is the selected critical value of desired level of confidence,

p = is the estimated proportion of an attribute that is present in the population,

q = 1-p,

e = is the desired level of precision

In social sciences, 95% level of confidence is an acceptable accuracy level and a precision value of 15% and below is acceptable level of variability in sample size determination.

Therefore, level of confidence was set to be 95% hence z = 1.96, desired precision was set to be ±5% hence e = 0.05, infinite population is normally set to be 50% hence p = 0.5, q = 1− 0.5= 0.5

Sample size $n_0 = \frac{(1.96^2)(0.5)(0.5)}{(0.05)^2} = 384.16 \approx 384$

When excluding other parts of the region, the specific population size for the study area was 27,020 people which comprised of Ngomeni, Kipini and Ozi only. Therefore, Cochran (1977) suggested a correction formula for the sample size calculated by infinite formula when specific population size is known. Thus the sample size in equation (i) was corrected by Cochran's correction formula (1977) as follows:

$$n = \frac{n_0}{1+\frac{(n_0-1)}{N}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (ii)$$

Where:

n = new sample size to be determined,

n_0 = sample size derived from eq...(i),

N = actual population size of the subjects

$$n = \frac{384}{1+\frac{(384-1)}{27020}} = 378.6 \approx 379$$

Specific sample size in each study area was determined by the following formula:

$$w = (\frac{n}{N} \times sample\ size \quad \text{.....(iii)}$$

Where: *w* = weight,

n = Population for each stratum

N = Total population for the three strata

Thus the sample size for Ngomeni, Kipini and Ozi were determined as follows:

Ngomeni = $\frac{10241}{27020} \times 379 = 143.6 \approx 144$

Kipini = $\frac{14695}{27020} \times 379 = 206.1 \approx 206$

Ozi = $\frac{2084}{27020} \times 379 = 29.2 \approx 29$

Semi structured interviews with questionnaires were used to collect data. Respondents were engaged on one to one interview during the data collection. Purposive sampling was used to identify fishing communities, and then simple random sampling was used to select the respondents. The respondents were identified through a simple random process which was conducted through the help of chief administrators and village elders in the respective areas. All the names of household heads of fishing communities were assigned numbers and then a table of random number generator was used to produce the numbers to be included in the sample size. The corresponding household names on the random numbers generated were then identified and engaged in the semi-structured interviews.

Table 3. 1. Definition of sensitivity indicators and criteria for measuring fin fish species'sensitivity to climate variability in Ungwana Bay and Lower Tana Delta, Kenya (Adopted from Pecl et al., 2014). Scale of measurement ranges from 1 to 3, where 1-indicates low, 2-medium, and 3-high sensitivity level to climate variability.

Sensitivity indicators		High sensitivity (3)	Medium (2)	Low sensitivity (1)
Abundance	Fecundity (egg production)	< 100 eggs per year	100-20, 000 eggs/year	>20, 000 eggs/year Low sensitivity (3)
	Successive recruitment events sustaining the fish abundance	Highly episodic	Occasional & variable	Consistent every 1-2 years
	Age at maturity	>10 years	2 - 10 years	<2 years
	General *versus* specialist habitat	Reliance on both habitat and prey	Reliance on either habitat and prey	Reliance on neither habitat and prey
Distribution	Capacity of larval duration - hatching to settlement	<2 weeks or no larval stage	2-8 weeks	>2 months
	Physiological tolerance-latitudinal coverage of adult species as an indicator for environmental tolerance	$<10^0$ latitude	10 – 20^0 latitude	$>20^0$ latitude
Phenology	Environmental variable as a phenological cue for breeding – cues include salinity, temperature, currents and freshwater flows	Strong correlation of spawning to environmental variable	Weak correlation of spawning to environmental variable	No apparent correlation of spawning to environmental variable
	Migration (seasonal or spawning)	Migration is common for the whole population	Migration is common for some of the population	No migration

3.2.1. Normalization of Indicators

Different scales of units were used in measuring sub-indices of sensitivity, exposure, and adaptation capacity. These sub-indices were then normalized into a common scale ranging from 0 to 1. Where 0 indicates low level of vulnerability while 1 shows critical level. The method of Equal Weights (EW) was applied to all indicators. This method is simple and has been recommended and used in several studies (Fritzsche et al., 2014; Žurovec et al., 2017). Based on the functional relationship of indicators with vulnerability (See Table 3.2), formulae (i) and (ii) were used to normalize the indicators with (↑) and (↓) functional vulerability relationship accordingly (see Fritzsche et al., 2014; Žurovec et al., 2017). The overall average of exposure, sensitivity, and adaptation index was then computed from their respective sub-indices with Microsoft Excel.

$$X_{ij} = \frac{Xi - MinXij}{MaxXij - MinXij} \dots\dots\dots\dots\dots i$$

Where:
X_{ij} is the normalized value of ij data set for a specific indicator,
Xi is the actual value to be normalized,
X_{Max} and X_{Min} are the maximum and minimum values of the indicator.

$$y_{ij} = \frac{MaxXij - Xi}{MaxXij - MinXij} \dots\dots\dots\dots\dots ii$$

Where:
Yij is the normalized value of ij data set for a specific indicator,
Xi is the normalized actual value ,
X_{Max} and X_{Min} are the maximum and minimum values of the indicator.

Table 3. 2. Definition of functional relationship of indicators with vulnerability used for normalization of data. (↑) – Positive, (↓) – Negative relationship with vulnerability

	Sub indicators	Vulnerability functional relationship with the indicator
Exposure Indicator	Temperature	(↑) - The higher the indicator the higher the vulnerability (Žurovec et al., 2017)
	Rainfall	(↑) - The higher the indicator the higher the vulnerability (Žurovec et al., 2017)
	Climate impact on fin fish production	(↑) - The higher the indicator the higher the vulnerability (This study)
Sensitivity indicator	Abundance	(↓) - The higher the indicator, the lower the vulnerability (Pecl et al., 2014)
	Distribution	(↑) - The higher the indicator the higher the vulnerability (Pecl et al., 2014)
	Phenology	(↑) - The higher the indicator the higher the vulnerability (Pecl et al., 2014)
	Fin fish demand	(↑) - The higher the indicator the higher the vulnerability (This study)
	Fishing pressure	(↑) - The higher the indicator the higher the vulnerability (This study)
	Human population	(↑) - The higher the indicator the higher the vulnerability (Žurovec et al., 2017)
Adaptation capacity indicator	Household size	(↑) - The higher the indicator the higher the vulnerability (This study)
	Education	(↓) - The higher the indicator, the lower the vulnerability (Žurovec et al., 2017)
	Employment	(↓) - The higher the indicator, the lower the vulnerability (Žurovec et al., 2017)
	Disease status	(↑) - The higher the indicator the higher the vulnerability (This study)
	Access to health services	(↓) - The higher the indicator, the lower the vulnerability (This study)
	Access to water services	(↓) - The higher the indicator, the lower the vulnerability (This study)
	Alternative sources of livelihoods	(↓) - The higher the indicator, the lower the vulnerability (This study)

3.2.2. Framework of vulnerability analysis

We applied the IPCC (2007) model of vulnerability assessment to calculate the final vulnerability level (see Figure 3.2). The indicators were aggregated using the formula below:

$$VI = (E + S) - AC \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots iii$$

Where:
VI = Vulnerability index;
E = Exposure;
S = Sensitivity;
AC = Adaptation capacity.

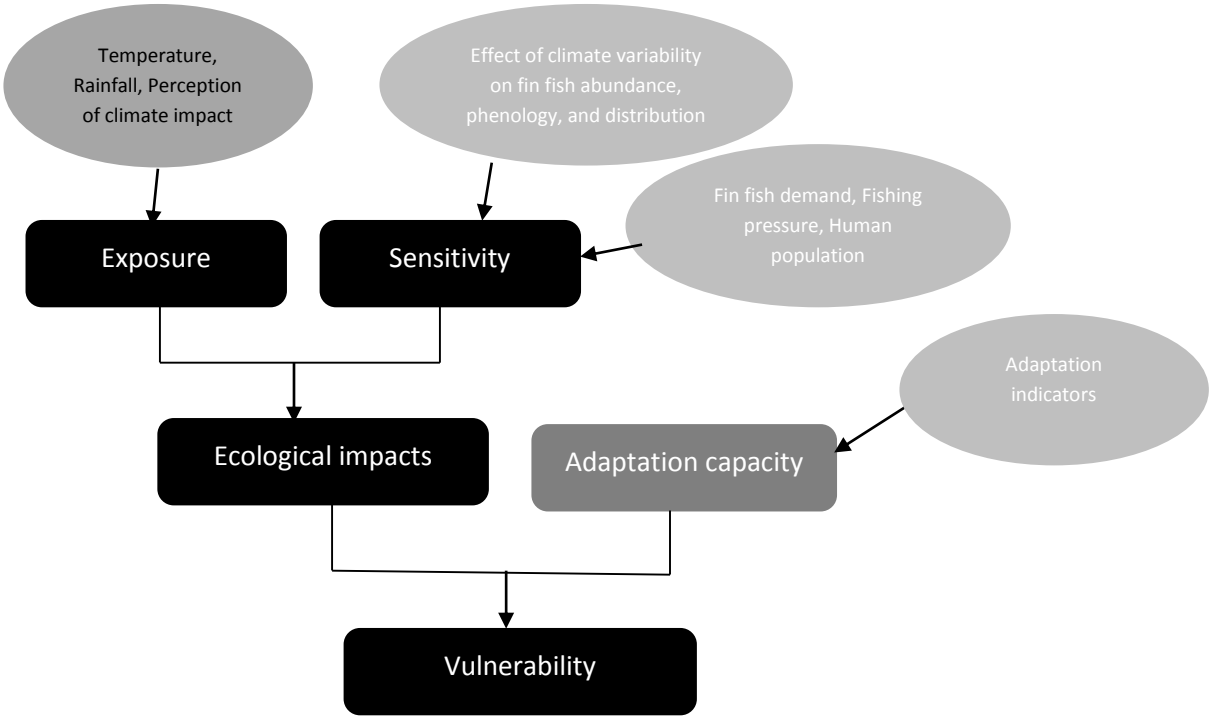


Figure 3. 2 Framework of vulnerability measurement (Adopted from IPCC, 2007).

3.3. Results

3.3.1. Exposure indicators

Take note of the definition of the index values in normalization of indicators above, where 0 implies low level of vulnerability and 1 high level of vulnerability. This interpretation is used across all the results presented.

Overall average exposure index for Ozi, Ngomeni, and Kipini, was 0.70, 0.63, and 0.33, respectively (Table 3.3). The high vulnerability exposure in Ozi and Ngomeni was due to high exposure of the impact of climate variability in fin fish production of 1.00 and 0.88 for the two sites accordingly. Temperature recorded minimal vulnerability levels across all the study sites of 0.00 in Ngomeni, 0.00 in Kipini, and 0.12 in Ozi. Unlike temperature, rainfall recorded high vulnerability levels of 1 across all the study sites (see Table 3.3).

Table 3. 3. Normalised values for exposure, sensitivity, and adaptation capacity indicators in Ungwana Bay and Lower Tana Delta, Kenya. Index measurement scale range from 0 to 1, where 0 - low vulnerability while 1 - critical level.

Indicators		Sub-indices	Ngomeni	Kipini	Ozi
Exposure		Temperature	0.00	0.00	0.12
		Rainfall	1.00	1.00	1.00
		Impact of climate on fin fish production for the last 10 years	0.88	0.00	1.00
		Average	**0.63**	**0.33**	**0.70**
Sensitivity	Abundance	*Plectorhinchus gaterinus*	0.75	0.75	0.75
		Lethrinus lentjan	0.63	0.63	0.63
		Lutjanus fulviflamma	0.25	0.25	0.25
		Leptoscarus vaigiensis	0.25	0.25	0.25
		Siganus sutor	0.25	0.25	0.25
	Distribution	*Plectorhinchus gaterinus*	0.25	0.25	0.25
		Lethrinus lentjan	0.75	0.75	0.75
		Lutjanus fulviflamma	0.75	0.75	0.75
		Leptoscarus vaigiensis	0.25	0.25	0.25
		Siganus sutor	0.75	0.75	0.75
	Phenology	*Plectorhinchus gaterinus*	0.50	0.50	0.50
		Lethrinus lentjan	0.50	0.50	0.50
		Lutjanus fulviflamma	0.50	0.50	0.50
		Leptoscarus vaigiensis	0.50	0.50	0.50
		Siganus sutor	0.50	0.50	0.50
	Fin fish demand	Socio-economic survey	0.29	0.00	1.00
	Fishing pressure	Socio-economic survey	0.37	0.00	1.00
	Human population	Kenya National Bureau of Statistics, (1999)	0.65	1.00	0.00
		Average	**0.57**	**0.55**	**0.60**
Adaptation capacity		Household Size	1.00	0.00	0.86
		Education	0.00	1.00	0.30
		Employment	0.00	0.14	1.00
		Health status	0.00	1.00	0.13
		Access to health services	0.43	1.00	0.00
		Access to potable water	0.41	1.00	0.00
		Alternative source of livelihoods	0.00	0.08	1.00
		Average	**0.26**	**0.60**	**0.47**

3.3.2. Sensitivity indicators

Overall average sensitivity index was slightly high in all the study sites with the highest value of 0.60 in Ozi, followed by 0.57 in Ngomeni, and 0.55 in Kipini (Table 3.3). Fin fish demand as well as fishing pressure contributed to high vulnerability level of 1 in sensitivity indicator in Ozi, while population pressure contributed to high vulnerability of 1 in sensitivty indicator in Ngomeni and Kipini (Table 3.3). The selected marine fin fish species recorded similar sensitivity levels of abundance, distribution and phenology indices in all the study sites (Table 3.3). However, analysis of individual species' sensitivity to climate variability revealed variations where *Lethrinus lentjan* showed high vulnerability level of 0.63. *Plectorhinchus gaterinus, Lutjanus fulviflamma and Siganus sutor* showed moderate vulnerability (0.50 all cases), while *Leptoscarus vaigiensis* indicated low vulnerability (0.33) (Table 3.4).

Table 3. 4. Sensitivity of selected fin fish species to climate variability in Ungwana Bay and Lower Tana Delta, Kenya. Index measurement scale range from 0 to 1, where 0 - low vulnerability while 1 - critical level.

Fin fish species	Abundance	Distribution	Phenology	Average sensitivity level
Plectorhinchus gaterinus	0.75	0.25	0.50	0.50
Lethrinus lentjan	0.63	0.75	0.50	0.63
Lutjanus fulviflamma	0.25	0.75	0.50	0.50
Leptoscarus vaigiensis	0.25	0.25	0.50	0.33
Siganus sutor	0.25	0.75	0.50	0.50

3.3.3. Adaptation capacity indicators

In adaptation capacity index Kipini, Ozi and Ngomeni depicted an overall index value of 0.60, 0.47 and 0.26 respectively (Table 3.3). The high vulnerability in adaptation capacity in

Kipini was as a result of poor education, health status, access to health services, and access to potable water which all depicted an index value of 1 (Table 3.3). On the other hand, the low vulnerability in adaptation capacity in Ngomeni was as a result of better education, employment, health status, and availability of alternative sources of livelihood which all recorded an index value of 0.00 (Table 3.3).

3.3.4. Vulnerability of Fishing Communities in Comparison with Exposure and Sensitivity for the Selected Fin fish Species

In the Ungwana Bay and Lower Tana Delta, Ngomeni and Ozi fishing communities showed high levels of vulnerability of 0.94 and 0.83 respectively. Kipini fishing communities indicated relative low level of vulnerability of 0.26 (Figure 3.3). The exposure of climate variability to fin fish resources was also high in Ozi (0.70) and Ngomeni (0.63) compared to Kipini (0.33) while sensitivity of the species to climate variability was high across all the sites (Figure 3.4). The sensitivty index for Ozi, Ngomeni and Kipini was 0.60, 0.57, and 0.55, respectively (Figure 3.4).

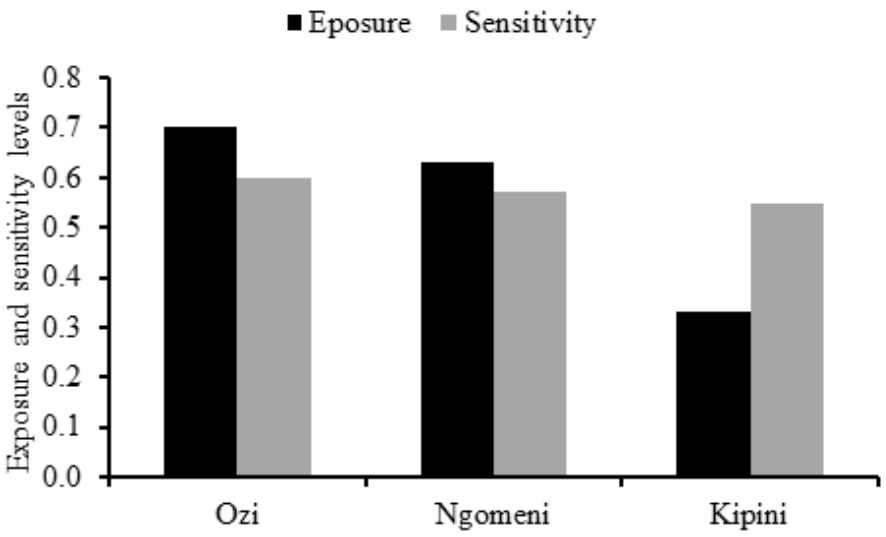


Figure 3. 3 Comparison of exposure and sensitivity levels of the selected marine fin fish species among the fishing communities in Ungwana Bay and Lower Tana Delta, Kenya

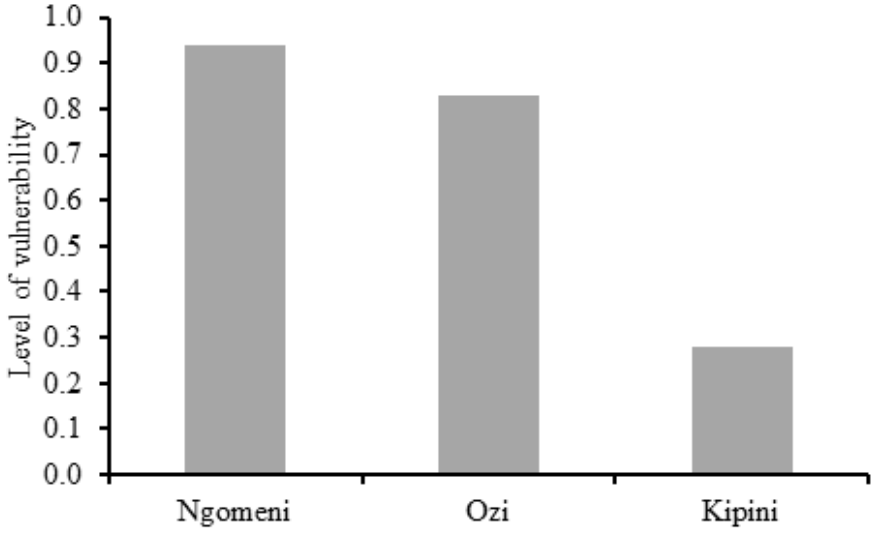


Figure 3. 4 Comparison of vulnerability of fishing communities in Ungwana Bay and Lower Tana Delta, Kenya

3.4. Discussion

Sustainable sources of livelihood for artisanal fishers largely depend on the sustainability of ecosystem services including provisioning for fisheries resources. Thus understanding the ecosystem vulnerability to climate change is critical for ensuring food security to communities who primarily depend on natural resources, particularly the coastal and marine resources. We present an assessment that helps to understand the vulnerability status of the fishing communities based on their ecological vulnerabilty.

Fisheries resources tolerate specific environmental conditions suitable to their biological functioning (Welch et al., 2014). Climate variability affect these environmental conditions thereby threatening fisheries resources globally (Chowdhury et al., 2010). Reduction of rainfall frequencies is a key threat to fisheries resources in Ungwana Bay and the Lower Tana Delta. These areas are continuously supplied by freshwater from River Tana and Sabaki which form an important estuarine ecosystem that support fisheries productivity. In line with the rainfall variability observation made in this study, Deenapanray and Tana (2011) projected a 25% reduction of rainfall in Malindi-north coast of Kenya within which the study area is located by 2050. This may intensify water supply reduction from the rivers thus resulting in the decrease in estuarine coverage, low nutrient supply and change in environmental conditions hence affecting fisheries production (Kibria et al., 2017). Ngomeni and Ozi are particularly at a high threat in fisheries production compared to Kipini. This may be attributable to their locations, Ngomeni is purely marine environment and Ozi a riverine environment. Kipini is both estuarine and marine environment thus

providing a wide spatial adaptation to fin fish species against climate variability. Generally, the tropical regions are characterized by reduction of rainfall which may reduce water availability in fisheries habitats and cause changes in environmental conditions as well as loss of fisheries resources. (Kibria et al., 2017).

In most cases, fisheries (ecological) sensitivity is assessed using environmental indicators for selected specific species (Pecl et al., 2014). However, ecosystem functioning is affected by both natural and anthropogenic factors. Thus, apart from biological sensitivity of fisheries, Mecalf et al. (2014) noted there is need to capture important socio-economic factors that directly affect fisheries resources for sensitivity assessment. In this regard, the sensitivity of the selected fin fish species (biological) across the study sites indicated similar levels. This is because the Ungwana Bay and Lower Tana Delta experience the same climatic conditions. However, the overall sensitivity level was highly influenced by differences in anthropogenic pressure exerted on fisheries resources at Ngomeni, Kipini, and Ozi. Ozi experiences high demand for fisheries resources, therefore, exerting high fishing presure on the resources. On the other hand, Ngomeni and Kipini experience the challenge of population increase thereby escalating the demand for fisheries resources with time. In a study for measuring the vulnerability of marine socio-ecological systems, Metcalf et al. (2015) found similar results in Australia where the level of vulnerability was partly influenced by high dependency of humans on natural resources in Bowen community. Therefore, these socio-economic factors may aggravate sensitivity threat to fisheries resources in the long run. Overall, fisheries sensitivity level is relatively high in the study area.

Kipini fishing community is highly vulnerable to adaptation capacity compared to Ngomeni and Ozi. Education, health status, health services and portable water accessibility are the main factors that contributed to vulnerability in adaptation capacity in Kipini. Kipini is characterized by the presence of both local and foreign migrant artisanal fishers (Munga et al., 2012). These migrant artisanal fishers, sail from Tanzania to Kenya seasonally depending on fish availability. With the migratory pattern life, the foreign fishing communities in Kipini may experience challenges in pursuing education and health services adequately. The presence of foreign fishing communities together with the local fishing communities has resulted in the increase of population in Kipini thus exerting pressure on education and health facilities available. On the other hand, Ngomeni and Ozi are mostly composed of local resident fishing communities thus having better access to education and health services. Education and health services are the most important adaptation factors that contributed to low vulnerability in Ngomeni and Ozi. Wamsler et al. (2012) confirmed this in their work which demonstrated that education plays an important role to enhance adaptation capacity to climate change among poor communities. In addition to education and heath services, Ngomeni is also characterized by accessibility to alternative livelihoods and potable water. Though Ngomeni and Kipini indicated good adaptation capacity, this study generalized most of the adaptation indicators. For example, employment status were not determined to differentiate among permanent, casual, and contract basis. Permanent employment present better adaptation capacity to climate variability than casual and contract employment types. This is due to the constant income earning among the permanent employed group which enable them to plan in advance for

appropriate coping action as opposed to causal and contract employed groups. Generally, the vulnerability of coastal and marine artisanal fishing communities is highly associated with low level of adapation capacity in developing countries (Islam et al., 2014; Adelekan and Fregene, 2015). Education and employment capacity, for example, were among the significant adaptation factors that resulted in high vulnerability of coastal artisanal fishing communities in Bangladesh (Islam et al., 2014).

Despite indicating good adaptation capacity, Ngomeni and Ozi fishing communities are still highly vulnerable to climate variability. Fishing activity is the core source of livelihood to the communities. However, the fisheries resources showed high exposure levels of vulnerability especially in Ngomeni and Ozi. Futher to this, these resources also showed high sensitivity level of vulnerability across all the study sites. Therefore, marginal variations of natural and anthropogenic factors may impact fisheries resources and eventualy affect the fishing communities. Since the fishing communities primarily depend on these resources for their livelihood, their vulnerability to climate variability will remain to be high.

Conclusion

The Ungwana Bay and Lower Tana Delta ecosystem experience two significant threats. On one hand, there is high exposure to climate variability (Cinner *et al*., 2011) and on the other hand, there is increased anthropogenic pressure to fisheries resources. These have direct effect to the fisheries resources in the study area. The artisanal fishing communities are

therefore directly vulnerable to these conditions. Among the effects on artisanal fishing communities may include reduction in catches therefore resulting in low economic returns and food insecurity. Further, most of the artisanal fishing communities are characterized by low adaptation capacity to climate variability.

Consequently, there is need for appropriate intervention measures to cope with these conditions. Breeding habitats and refuge for fish species should be identified and protected. These include the coral and mangrove environments which absorb carbon and enhance conducive micro-environment for fisheries resources thus reducing ecological sensitivity. Anthropogenic ecological sensitivity can be reduced by strengthening existing control measures for fisheries resources and promoting environment friendly fishing methods. The existing control measures include fishing zones delienated by the Government of Kenya on fishing grounds to protect the artisanal fishers, and measures to reduce bycatch. Fishing activities for artisanal fishers are conducted between 0-5nm while for the bottom trawlers is conducted between 5-200nm (Munga *et al.,* 2012). However, these measures are not fully implemented (Munga *et al.,* 2014).

There is also need to empower the local community to invest in alternative sources of livelihood. This may be achieved through provision of affordable loans at minimal interest by the government. Empowerment can also be in a form of providing awareness to the fishing communities on the relevance of education and available opportunities to pursue education. The availble educational and health facilities may be inadequate considering the vast geographical area and the increase of human population. Thus improvement of the

existing facilities would help to reduce the distance covered on accessing such services. We therefore recommend government and non-governmental agencies to reinforce community based organisation activities especially on ecological conservation, and promoting education through provision of scholarships to the fishing communities.

CHAPTER 4

Impact of Selected Environmental Variables on the Distribution, Composition and Abundance of Fin Fish in Ungwana Bay and Lower Tana Delta, Kenya[4]

Abstract

Understanding effects of environmental variables on fisheries resources is useful for sustainable management of the resources. This paper discusses the impact of sea surface temperature (SST), rainfall and sea surface chlorophyll (SSC) on fin fish distribution, composition and abundance in Ungwana Bay and the lower Tana Delta in Kenya. During North East Monsoon (NEM) season, the SST was observed to be high while SSC and rainfall were low. In South East Monsoon (SEM) season, the reverse observation was made. The annual pattern of SST and SSC indicated insignificant increasing trend. However, significant and positive correlations were identified between Carcharhinidae, Lutjanidae, and Serranidae with SST (P = 0.001, r = 0.9726; P = 0.001, r = 0.8921; P = 0.001 r = 0.8804) and sea surface chlorophyll (P = 0.001, r = 0.9191; P = 0.001, r = 0.7904; P = 0.001 r = 0.7880), respectively. Trends in rainfall indicate negative correlations with fin fish family. Between 2002 and 2015, the annual mean SST and rainfall in the study area was 27.15 ± 0.055 °C and 86.23 ± 4.17 mm, respectively. The fin fish annual mean landing during the same period was 2,194.8 ± 310.9 metric tonnes. There was also significant composition in fin fish landings by area and habitat combination (R = 0.938, P = 0.001). SST and SSC are, therefore, the important environmental variables affecting the distribution, composition, and abundance of fin fish in Ungwana Bay

[4] Dzoga, M., Simatele, D., Munga, C., Gamoyo, M. (2018). Impact of Selected Environmental Variables on the Distribution, Composition and Abundance of Fin Fish in Ungwana Bay and Lower Tana Delta, Kenya. Journal of Environmental Management, 12. (Under review)

and the Lower Tana Delta, Kenya. This study highlights the possibility of compound effects of the environmental variables and non-climatic factors such as fishing effort on fisheries resources thus the need to control and regulate the non-climatic factors for sustainable use and management of fisheries in the study area.

Key Words: *Environmental variability, Coastal and marine ecosystems, Artisanal fisheries, Ungwana Bay, Lower Tana Delta, Kenya*

4.1. Introduction

Like other aquatic organisms, distribution, composition and abundance of fin fish in coastal and marine ecosystems can be influenced by environmental factors (Rivera, 2013; Chul Jun et al., 2016). Studies have extensively demonstrated that the alteration of temperature, rainfall, and other environmental elements such as nutrients, sea surface chlorophyll (SSC), salinity, depth, and turbidity influence fisheries productivity (Bruno et al., 2013; Pecl et al., 2014; Franco etal., 2016). The alteration of these environmental variables can interfere with the biological functioning of fish as well as levels of catches (Welch et al., 2014). Notably, temperature and rainfall may be the key climatic elements that influence the magnitude of other environmental elements in the coastal and marine ecosystems resulting to different habitat conditions supporting specific fish species (Dineshbabu et al., 2016). Fluctuations of sea surface temperature (SST), SSC and rainfall influence seasonal fish composition, distribution, and abundance (Rivera, 2013) and therefore this explains the importance of weather conditions as drivers of fin fish availability in the coastal and marine ecosystems.

Long term fisheries catch data is important in the determination of trends and catch composition. However, most developing tropical coastal and marine artisanal fisheries are characterized by short term fisheries data which cannot exhaustively explain the trends and catch composition (Penas, 2007). Effective and sustainable policies for fisheries resource management can therefore, be derived from the long term fisheries catch data (Penas, 2007; Erisman et al., 2010). In general, enforcement of policies may either support

climate change coping strategies for resource users or destroy them if poorly developed and implemented (Simatele, 2010). Thus, long term environmental data for SST, SSC, and rainfall can provide clear patterns of climate variability with an impact on fisheries resources dynamics over time and space. This information can facilitate the adoption of appropriate, effective and sustainable intervention and mitigation measures to ensure fisheries resources are sustainably exploited.

The Ungwana Bay and Tana Estuary, Kenya are important ecosystems that support a diversity of fisheries resources (Abila, 2010). The fisheries resources are exploited both for subsistence (artisanal fisheries) as well as for commercial (semi-industrial fishery) targeting both domestic and international markets (Kimani et al., 2012; Munga et al., 2014). In terms of livelihood dependency in the area, an estimated 90% of the local population rely on fishing activities (Kitheka, 2002). Noticing the significance of the Lower Tana Delta to the local economy as well as national, it is therefore essential to assess the status of the fisheries resources using long term SST, SSC and rainfall data with an aim of providing reliable information useful for management actions and formulation of policies for the fisheries resources of the bay.

Substantial concerns on the well-being of Ungwana Bay and Tana Estuary ecosystems have been addressed by several studies. For example, specific studies have focused on sustaining fisheries in the bay through examining the impacts of semi-industrial bottom shrimp trawling on the artisanal fishery (Fulanda et al., 2011; Munga et al., 2014). Other studies have determined the economic value and spatial distribution of the bottom trawl shrimp

fishery (Abila, 2010; Kimani et al., 2012). A study conducted by Munga et al. (2012) between 2001 and 2006 confirmed declining total shrimp and artisanal fin fish landings in the bay. The study also confirmed that shrimp and fish landings declined due to variation in trawling activities and artisanal fishing effort before the government imposed a ban on bottom shrimp trawling in the bay between 2006 and 2011. Further, these authors noted that the important factor for the declining fisheries landings in the bay could have been attributed to impacts of the 1997-1998 *El-Nino* phenomenon. In addition to the impacts of overfishing, and the challenge on impacts due to changing climate and variability, long term trends in artisanal landings as well as SST, SSC and rainfall are important in shedding more light on the status of the fisheries resources in the area. This paper therefore, assesses the status of fin fishes using long term SST, SSC and rainfall data on catch abundance, composition, and distribution and provides management recommendations for the bay's fisheries resources.

4.2. Materials and methods

4.2.1. The study area

The Ungwana Bay area covers a shoreline stretch of about 200 km extending from Ras Ngomeni to Ras Shaka (Kitheka, 2002; Kimani et al., 2012; Fig. 4.1). It lies within the latitudes 2º 30'S and 3º 30'S and longitudes 40º 00'E and 41º 00'E (Munga et al., 2014). River Tana is the largest river basin in Kenya that drains its waters into the bay (Bouillon et al., 2009). This forms a relatively extensive estuarine ecosystem known as the Tana

Estuary. The ecosystem in the area include mangrove forests, sandy shores, tidal flats, islets, and patchy reefs (Munga et al., 2014). The Ungwana Bay and Tana Estuary, both support diversity of fisheries resources as well as subsistence and commercial fishing economies, particularly the bottom shrimp trawl fishery (Abila R. , 2010). The region experiences two distinct seasons, the South East Monsoon (SEM) from April to September dominated by cool temperature and rough sea, and the North East Monsoon (NEM) from October to March with warm and calm sea. The artisanal fishery and semi-industrial shrimp trawl fishery activities are highest in the NEM and SEM seasons, respectively (McClanahan, 1988; Munga et al., 2012).

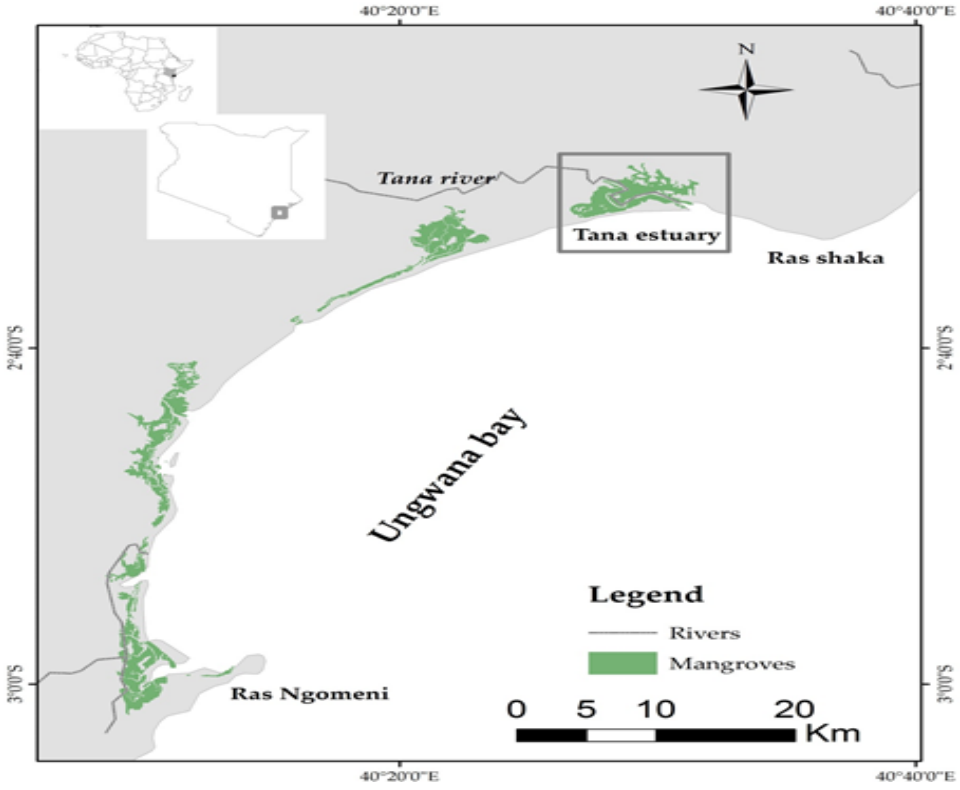


Figure 4. 1. Map showing the **s**tudy area of Ungwana Bay and Lower Tana Delta and Estuary, north coast, Kenya (Source, author)

4.2.2. Data collection

Mean monthly Sea Surface Temperature (SST, °C) and sea surface chlorophyll (SSC, $mg.m^{-3}$) satellite data were obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) at spatial resolution of 4 km spanning from 2002 to 2016. Rainfall data for Malindi region was obtained from Global Historical Climatology Network (GHCN-Monthly) database spanning the same period. Fin fish landings data by weight (metric tonnes, MT) for the same period was obtained from the Kenya Fisheries Service (KeFS). Artisanal landings data is usually recorded from the daily landings by trained fisheries assistants and beach management units officials as part of their responsibilities in co-management of the fisheries resources with the national and county governments. The compiled artisanal landings data in form of taxa landed and weight is submitted to KeFS on monthly basis for compilation of fish statistics for management and development purposes.

4.2.3. Data analyses and statistical tests

Data on SST, SSC and rainfall were averaged on monthly and annual basis using MATLAB software. The data was then used to calculate monthly climatology in form of trends (2004 – 2015) and seasonality as well as trend analysis (2004 – 2015), and seasonality of fin fish abundance using the same software. The software was also used to determine the relationship of oceanic variables with fin fish abundance. The relationship between SST, SSC, and rainfall with fin fish composition was evaluated based on a simple linear regression model ($Y = a + bX$), where Y is the dependent variable (fin fish composition) and X is the independent variables (SST, SSC, rainfall). Line ab is the intercept of Y when X =

0. Microsoft Excel was used to calculate the relative abundance of fin fish by taxa and identified the 5 most abundant fin fish taxa. Fin fish taxa composition was analysed using the multivariate non-Metric Multidimensional Scaling (nMDS) technique and identified whether distinct composition in fin fish landings existed between fishing areas with habitat type combination. Distinct fin fish composition was tested for significant differences by 1-way Analysis of Similarity (ANOSIM) and differences confirmed by pair-wise comparison tests. Where significant differences existed, 1-way SIMPER analysis was performed to identify which fin fish taxon/taxa contributed to the dissimilarity among samples. All the multivariate tests were performed using Bray Curtis similarity matrix in PRIMER v6 statistical software.

4.3. Results

4.3.1. Seasonality of sea surface temperature, sea surface chlorophyll, rainfall and fin fish landings

During the North East Monsoon (NEM) season (December to March), SSC concentration was relatively low about 0.5 mg/m^3, while SST was observed to be around 27°C increasing to 29°C in April during the inter-monsoon season (Fig. 4.2). During the South East Monsoon (SEM) season (June to September), there was an increase in SSC concentration to a maximum of 2 mg/m^3 in July to August. During this period, SST was observed to decrease to a minimum of 25°C. Rainfall was higher in SEM than in NEM season. During this season, rainfall intensified from March to a maximum of 8 mm/month towards the end of SEM season. The seasonal pattern of fin fish landing showed that maximum catch, ranges from

21 to 24 MT and occurred from October to May with a peak in December with minimum fish landings during the SEM season (June to July).

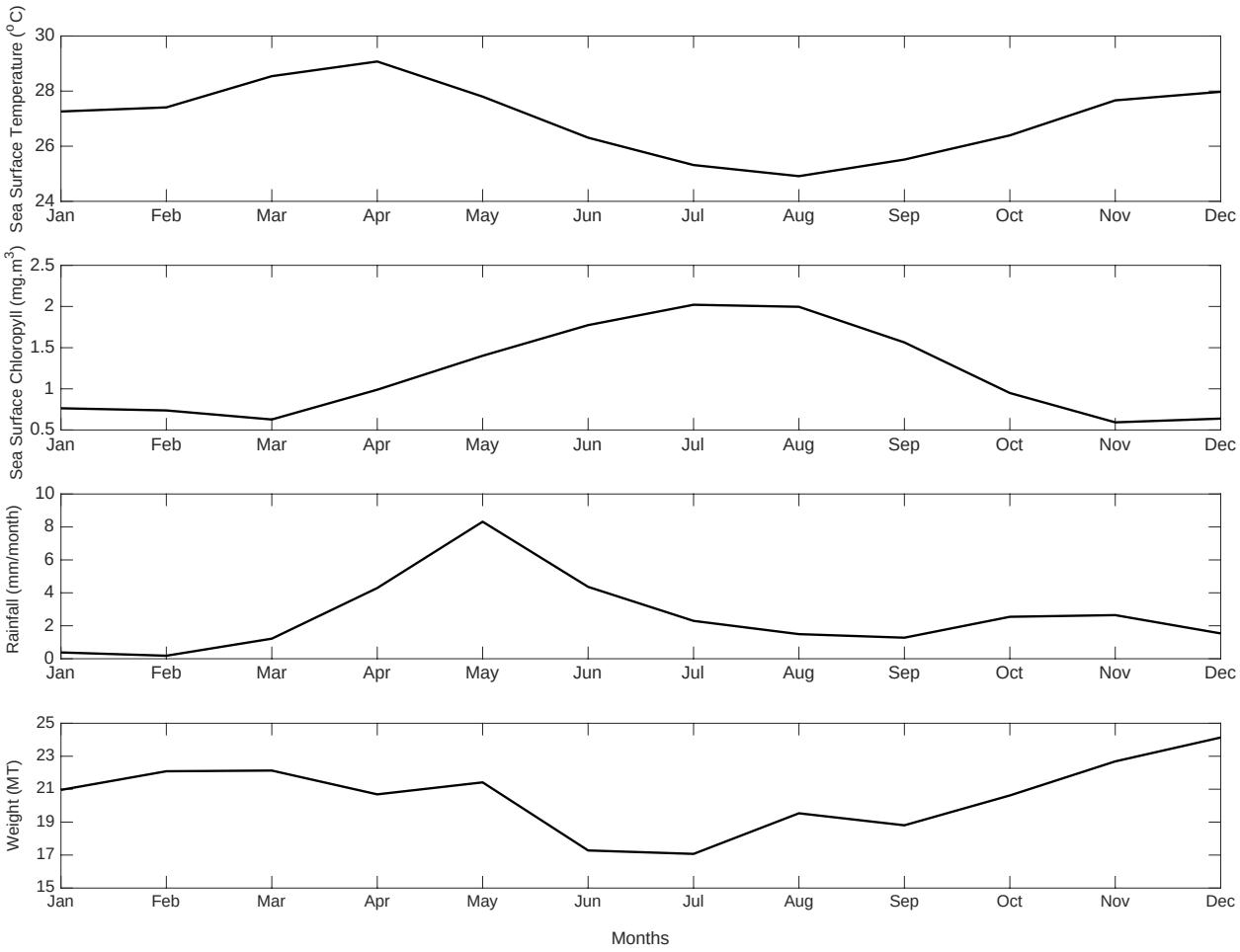


Figure 4. 2 Monthly average of Sea Surface Temperature, Sea Surface Chlorophyll, rainfall averaged within the Bay region and fin fish landings in the Lower Tana Delta and Ungwana Bay north coast Kenya (Source, author)

4.3.2. Annual trends of sea surface temperature, sea surface chlorophyll, rainfall, and fin fish abundance

The mean annual SST and SSC showed an inter-annual variability with an increasing trend in SST (P = 0.819, r = 0.0739) and a decreasing trend of SSC (P = 0.278, r = -0.3412) though

not significant in both cases. Maximum SST was observed in 2011 while maximum SSC occurred in 2008 (Figure 4.3). Rainfall showed marginal increasing trend with major peak recorded in 2006 and a minor peak in 2014 (Figure 4.3). Fin fish abundance recorded an increasing trend from 2004 to 2015 (Figure 4.3).

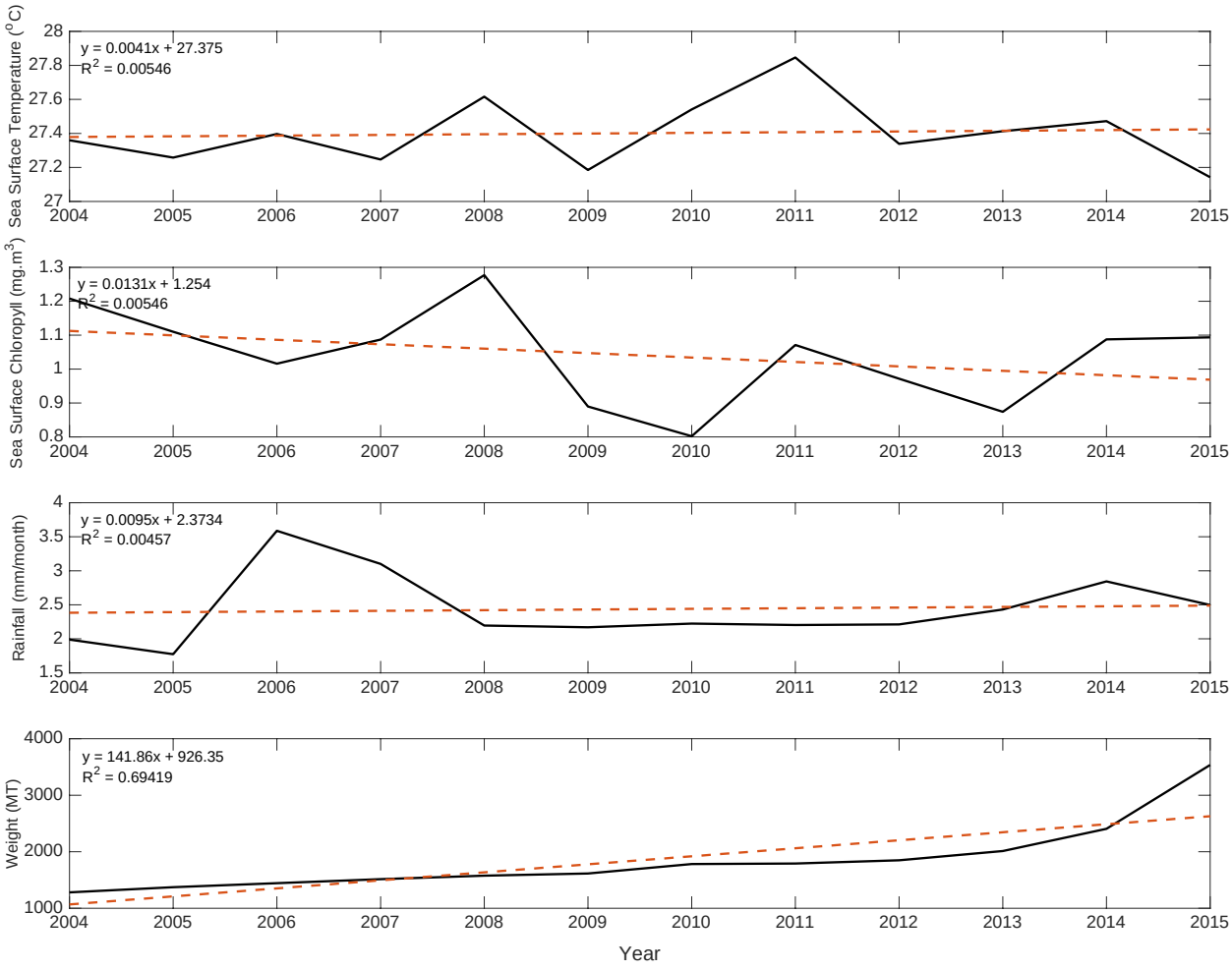


Figure 4. 3 Annual trends of sea surface temperature, sea surface chlorophyll, rainfall and fin fish abundance in the Lower Tana Estuary and Ungwana Bay, Kenya (Source, author)

4.3.3. Annual trends of the most abundant fin fish taxa and relationship with sea surface temperature, sea surface chlorophyll and rainfall

During the study period, the most abundant fin fish taxa recorded were Lutjanidae (11.6%), Carcharhinidae (9.2%), Serranidae (8.7%), Claridae (8.1%), and Scombridae (7.0%) (Figure 4). The least abundant fish taxa were Haemulidae (1.0%), Black skin (0.8%), Pouter (0.7%), Streaker (0.6%), and Mullidae (0.5%) (Figure 4.4). During the period of investigation (between 2004 and 2012), the total annual landings of the most abundant taxa generally showed an increasing trend (Figure 4.5). This was however, not the case with the family Claridae that showed decreasing total annual landings for the last two years of investigation (2011 and 2012). Annual total landings for the family Serranidae did not show much variation with only discernible increased landings recorded for the last three years. For the individual trend in the families Carcharhinidae, Lutjanidae, and Scombridae, marginal variations in annual landings during the study period were evident. Most of the fin fish families showed significant and positive correlation between SST and SSC except for Claridae which indicated a negative correlation with both climate variables. Rainfall depicted a negative correlation with most of the fin fish families (Figure 4.6).

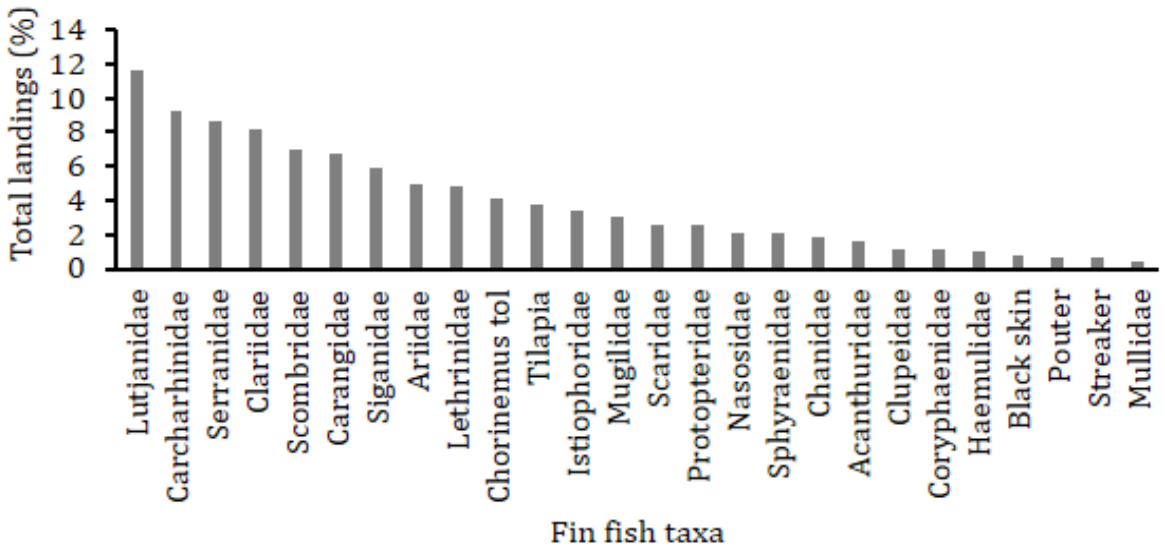


Figure 4. 4 Total landings by major fin fish taxa for the last 11 years (between 2004 and 2015) in the Lower Tana Delta and Ungwana Bay, north coast Kenya.

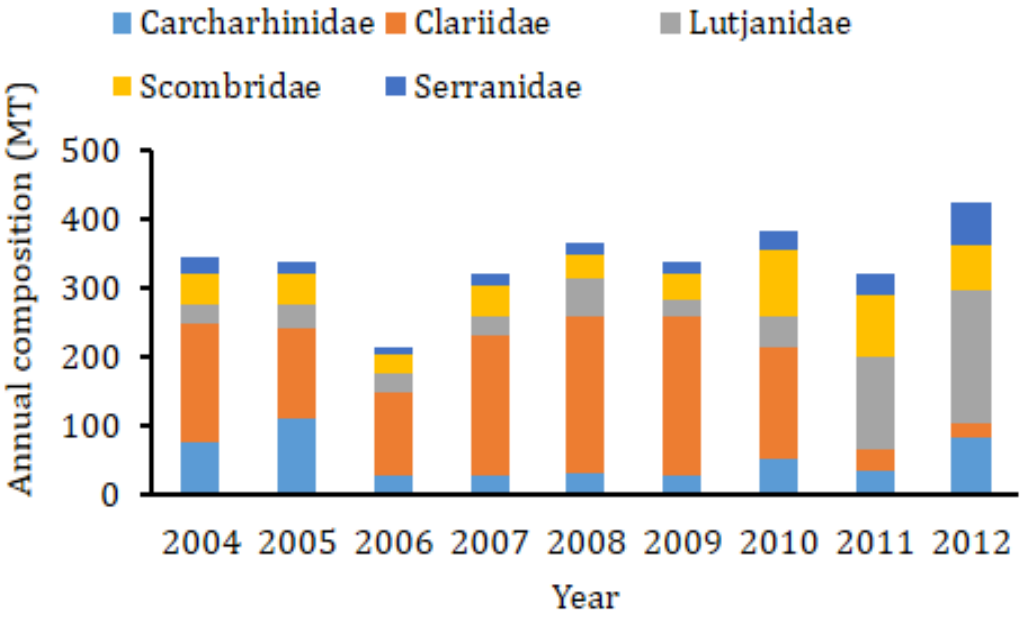


Figure 4. 5 Annual composition (MT) of the most abundant fin fish taxa between 2004 and 2012 in the Lower Tana Estuary and Ungwana Bay, Kenya

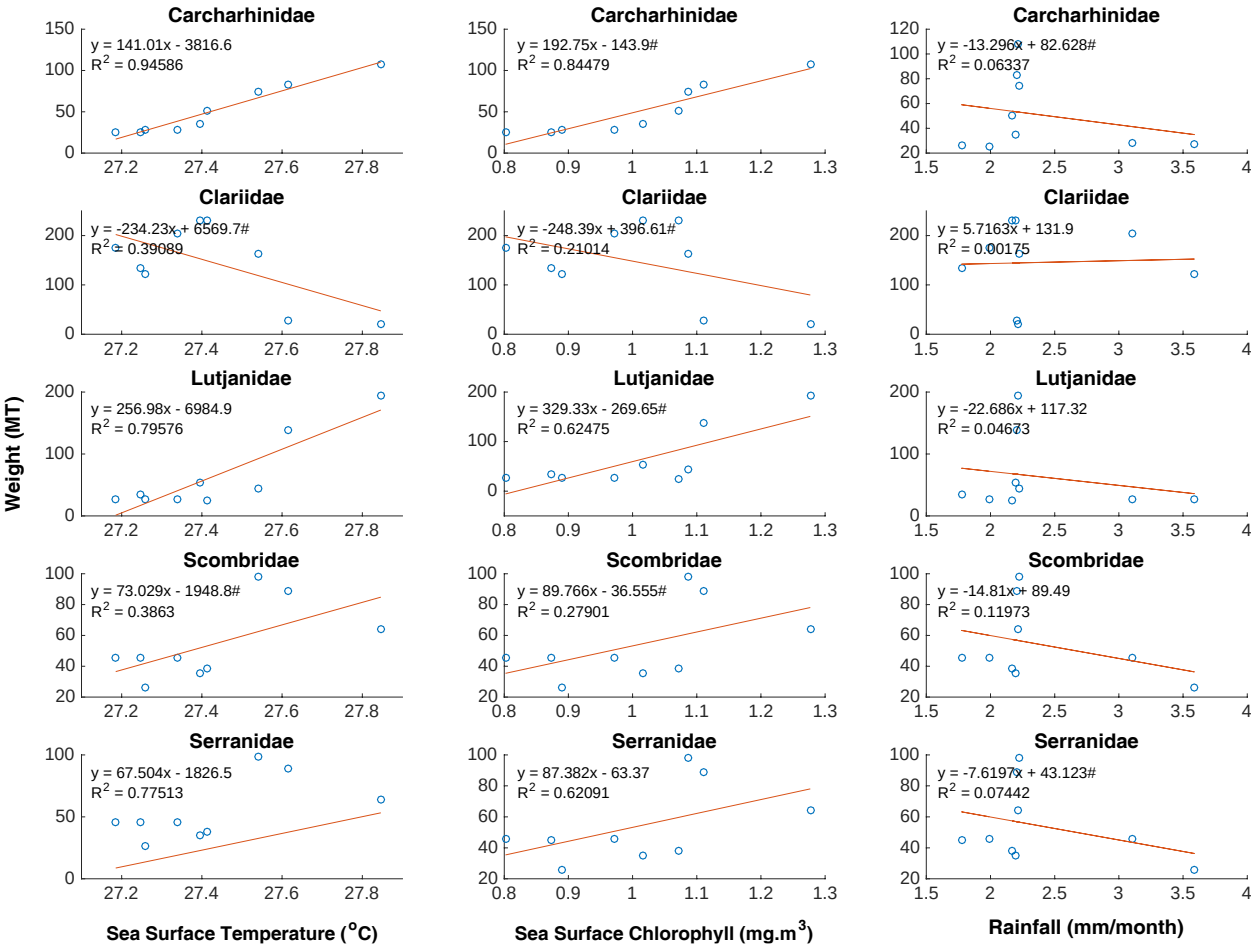


Figure 4. 6 Relationship between Fin Fish Family, Sea Surface Temperature, Sea Surface Chlorophyll and rainfall in the Lower Tana Delta and Ungwana Bay, Kenya

4.3.4. Composition of fin fish landings by fishing area with habitat combination

The non-Metric Multidimensional Scaling (nMDS) plots showed distinct separation of fin fish landings across fishing areas with habitat combination (Figure 4.7). The samples of Tana Estuary with freshwater combination were much dissimilar from those samples from Ungwana Bay with both demersal and pelagic combination, and from Tana Estuary with pelagic combination. One–way ANOSIM test indicated a significant distinct composition in

fin fish landings (R = 0.938, *P* = 0.001). Results of pair–wise comparison tests confirmed there was indeed significant differences across all fishing areas with habitat combinations (*P* < 0.05 in all cases). One–way SIMPER results confirmed that the differences in composition of demersal fin fish in Ungwana Bay and Tana Estuary was attributed to more abundant fish family Ariidae in the Tana Estuary (24.7%) compared to 4.97% in Ungwana Bay. The dissimilarity was also attributed to more abundant mixed demersal fishes (31.2%) and more abundant mixed pelagic fishes (29.9%) in Tana Estuary and Ungwana Bay.



Figure 4. 7 nMDS plots showing distinct composition in fin fish landings by fishing area with habitat combination based on standardised annual total of fin fish landings

4.4. Discussion

This study assessed the status of fin fish on abundance, distribution, and composition in relation to selected environmental variables of SST, SSC and rainfall. The Tana Estuary and

Ungwana Bay ecosystem is affected by the monsoon seasons with decreased SST observed during the SEM season and increased SSC concentrations and rainfall during the same season. There is an observed increase in SST and reduced concentrations of SSC and rainfall during the NEM season. The SST and SSC trends observed in this study agree with those recorded by Diankha *et al.* (2013) confirming that high SST corresponds to low SSC and vice versa. Similarly, McClanahan (1998) also confirmed low SST during the SEM season and high SST during the NEM season. Seasonal fin fish landings were higher during NEM than in SEM season with a peak in the month of December. SSC is an important indicator of nutrients rich waters for marine organisms and therefore, an indicator of fish abundance (Kumar *et al.,* 2015). However, despite high SSC associated with the SEM season, there was a corresponding observed low abundance of fin fish in the area. Instead high fish abundance was observed to correspond with the low SSC during the NEM season. This means, the fin fish abundance could also be affected by non-climatic factors other than the seasons such as the fishing effort. For example, the artisanal fishing activities are normally high in NEM season due to favourable fishing conditions characterized by warm waters and low wind frequencies and the level of fishing activities are usually reduced during the SEM season due to reversed sea conditions.

Environmental factors have been documented to influence the abundance, distribution, and composition of fishes (Bruno et al., 2013; Pecl et al., 2014; Franco et al., 2016). The Ungwana Bay and Lower Tana Delta fin fish abundance, composition and distribution to some extent are affected by the SST and SSC. This effect was observed to be more pronounced among the selected fin fish families of Carcharhinidae, Lutjanidae, and

Serranidae and less pronounced among the family Scombridae. To some extent, rainfall showed a negative relationship with the family Claridae. SST and SSC, therefore, influence the abundance of fin fishes thus accounting for different levels of composition and distribution depending on fin fish taxon. Input of fresh water and sediments from the Tana and Sabaki rivers draining into the bay may also have contributed to the fin fish variation, although this was not investigated in this study. It is important to note, however, interaction between environment and biology is complex due to other underlying factors such as non-linear and non-climatic dynamics (Nagelkerken & Munday, 2016). This is depicted in the annual trends of environmental factors and fin fish abundance. Despite the increasing trend of SST and decreasing trend of SSC between 2004 and 2015, the fin fish abundance showed an increasing trend over the same period. Therefore, besides SST and SSC trends, the general upward trend in fin fish abundance could also have been the result of non-climatic influences such as fishing effort.

Except the family Claridae, there was an observed increasing trend in annual landings of the most abundant fin fish families. Claridae is fundamentally estuarine with its production dependent significantly on conditions of the estuarine habitat. Reduction in abundance of Claridae may be characterised by the negative change of the estuarine ecosystem due to the increase of SST. The estuarine ecosystem change could also have been triggered by human activities such as agriculture and mangrove deforestation as pointed out by Terer et al. (2004), that 80% of the local community in the lower Tana Estuary noticed the reduction in size of the Tana River.

Fin fish landings have shown distinct spatial composition by fishing areas with habitat combination. A distinct catch composition between freshwater habitats (lower Tana Delta) and marine habitats in this study identified as Ungwana Bay demersal and pelagic, and Tana Estuary demersal and pelagic was observed. For the marine habitats, further distinct composition is evident between Ungwana Bay and Tana Estuary. With the case of freshwater and marine habitats, the distinct catch composition was due to variances in environmental habitat conditions. Salinity level in the estuarine environments decreases with distance upstream while chlorophyll concentration is highly found on surface and deeper waters (Gameiro et al., 2004; Syukri, 2009). In this regard, the marine habitat is characterised by high level of salinity together with high chlorophyll concentration due to greater depths while the Lower Tana Delta is associated with reduced salinity levels with high chlorophyill concentration due to presence of shallow waters.

With the case of marine habitats (demersal and pelagic of Ungwana Bay and Tana Estuary), the distinct composition in fin fish landings could be attributed to variation in depth of the coastal continental shelf thus the variation in temperature (Jiménez, 2001). The relatively shallow and extensive continental shelf of Ungwana Bay and Tana Estuary covers 2.8 km with a mean depth of 12 m from the river mouth. The depth increases offshore to a sudden mean depth of 100 m at 12.9 km (Kitheka, 2002). Gebrekiros, (2016) noted that distinct fish composition assemblages are determined by the differences in bathymetric and habitat scale, environmental filtering, and anthropogenic effects. Thus the Tana Estuary is composed of pelagic and demersal marine fin fishes that tolerate lower water depth with

warm temperature compared to those of Ungwana Bay in deep waters with low temperature.

It is important to note that the fin fish catch composition was mainly made up of mixed demersal and mixed pelagic. These were unidentified fin fish taxa which made up higher percentage composition. Since catch composition was distinct with habitat type, the observed fluctuations of SST and SSC may have caused the differences. Pecl et al. (2014) noted any variations in climatic elements have the potential to change the composition, abundance, and distribution of fishes. Therefore SST and SSC to some extent accounted for the uncertainities and variation in fin fish composition in the identified habitats.

Conclusion

SST and SSC are the potential environmental elements influencing the abundance, composition, and distribution of fin fishes in the Lower Tana Estuary and Ungwana Bay. In addition to this, the fin fishes are also affected by non-climatic factors such as fishing effort among other human interventions although not investigated in this study. Distinct habitat conditions favour specific type of fin fishes. Change in habitat condition is triggered by both climatic and non-climatic factors. The Lower Tana Estuary and Ungwana Bay fin fish catches indicate an increasing trend irrespective of the prevailing climatic conditions. It is important, therefore, to ensure the sustainability of the fishing activities, ecosystems, and associated human interventions. For this reason, there is need for awareness creation among the artisanal fishers on the likelihood impact of SST and SSC on fisheries resources.

This may lower anthropogenic destruction of habitats such as mangrove and seagrass ecosystems thus enhancing breeding areas and fish habitats. Local measures should be enforced to limit agricultural encroachment along the estuary, control mangrove deforestation used for charcoal making, and promoting environmental friendly fishing techniques.

CHAPTER 5

Characterisation of artisanal catches in selected fishing zones of Ungwana Bay and Lower Tana Delta, Kenya[5]

Abstract

Shore-based assessment of fisheries resources in Ngomeni, Kipini and Ozi fishing zones of the Malindi-Ungwana Bay and Lower Tana Delta, north coast Kenya was conducted from January to December, 2017 to establish catch composition, species richness, and fishing effort (catch rate, number and types of fishing gears and crafts) in relation to marine, estuarine and riverine habitats. Distinct catch composition (R = 0.27, P = 0.001) was observed across the three habitats. Spatially and seasonally, the catch composition significantly differed across the three fishing zones, and between the north east and south east monsoon seasons (R = 0.332, P = 0.001). Chirocentrus dorab was the most abundant fish species in Ngomeni further south of the bay while Arius africanus and Clarias gariepinus were the most abundant species in Kipini further north, and Ozi upstream, respectively. Gillnets with dhow (mashua) and fibreglass boats in Ngomeni (marine) as well as canoe-basket traps in Ozi (riverine) landed significantly larger Scomberomorus commerson and Arius africanus (Kruskal Wallis test: Df = 2; F = 197.141; p = 0.0001; Df = 2, F = 490, p = 0.001), respectively. Species diversity by zone with habitat and fishing craft combination showed higher diversity for Ngomeni in the marine habitat with mashua fishing crafts than in Kipini for the same habitat with fishing craft combination. The lowest species diversity was associated with the riverine habitat in Ozi with

[5] Dzoga, M., Simatele, D., Munga, C. (2018). Characterization of artisanal catches in selected fishing zones of Ungwana Bay and Lower Tana Delta, Kenya. 14. (In submission)

canoes. Significant catch rates (Df = 2, F = 10.43, p = 0.001; Df = 1, F = 5.897, p = 0.021) were observed in the 3 fishing zones and during the North East Monsoon (NEM) and the South East Monsoon (SEM), respectively. Canoes were the most common fishing crafts especially in Ngomeni with a composition of 37.1%, Ozi (97.5%) as well as mashua crafts in Kipini with a composition of 44.5%. The monofilament nets were common in Ngomeni (34.0%), more basket traps for Ozi with a composition of 63.6%, and more handlines (28.8) for Kipini fishing zone. The 3 main fishing zones of Ungwana Bay and the Lower Tana Delta are distinct in catch characteristics. This distinctness is attributed to the differences in habitat types and fishing methods. Ngomeni is characterized by better fishing crafts of mashua and fibreglass boats compared to Kipini and Ozi fishing zones.

***Key words**: Artisanal fisheries, Characterization of catches, Ungwana Bay, Lower Tana Delta, Kenya*

5.1. Introduction

The value of fisheries resources to humanity has been extensively studied in various scopes of socio-economic systems (Cinner, et al., 2011; FAO, 2012; Metcalf, et al., 2015). Nonetheless, fisheries resources still receive special attention globally. This is due to the constant changes associated with the coastal and marine socio-ecological systems (Fuller et al., 2017). Consequently, fisheries systems need to be regularly assessed to understand current status. It is from this perspective that artisanal fisheries especially in the tropics have been variously characterized.

Rondeau et al. (2016), identified and characterized the important sites for fish and invertebrates of coastal waters with the aim of conserving and managing endangered species. Surís-Regueiro and Santiago (2014) described the relationship of coastal and marine fisheries dependency on employment by characterizing income and employment from fisheries dependency. Some studies have acknowledged the challenge on enhancing artisanal fisheries management due to its open access nature (González-Álvarez et al., 2016). Other studies have narrowed focus and characterized catch by different gears in different sites to determine fishing effort for fisheries management (Laurence et al., 2015; Munga et al., 2014).

Despite the significance of coastal and marine fisheries in supporting commercial and subsitence fishery sub-sectors in the Malindi-Ungwana Bay and Lower Tana Delta in north coast Kenya, the main fishing zones have not been conclusively studied, and more studies

have concentrated on fisheries resources of the estuary and marine environments negleting riverine habitat (Abila, 2010; Munga, et al., 2012; Munga, et al., 2014). However, these studies have described the impact of semi-industrial bottom trawl over the artisanal fishery and the resultant conflict arising from targeting the same species and accessing the same fishing grounds. Importantly, the studies demonstrated the effectiveness of government regulations that were imposed on bottom trawl prawn fishery which had negatively impacted the fishery with reduced catches.

The Ungwana Bay ecosystem can be categorized into marine, estuarine and riverine habitats covering the three main fishing zones of Ngomeni to the south of the bay, Kipini and Ozi further north of bay. Therefore, this paper characterizes the artisanal catches in the three main fishing zones in reference to the identified existing habitats. Comparisons are made on seasonal and spatial (habitats) catch composition (species and sizes), and fishing effort (catch rates, number of fishing crafts and gears).

5.2. Material and methods

5.2.1. Study area

This study was conducted in the Malindi-Ungwana Bay and lower Tana Delta in north coast Kenya covering the fishing zones of Ngomeni, Kipini and Ozi (Fig. 5.1). Ngomeni and Kipini are located within the Ungwana Bay while Ozi is located in the Lower Tana Delta along the River Tana. All the 3 fishing zones experience two seasons annually; the North East

Monsoon (SEM) from October to March and the South East Monsoon (SEM) from April to September (McClanahan, 1988). The Ungwana Bay and Lower Tana Delta ecosystem is one of the richest ecosystems along the Kenya coast which support fisheries resources as well as socio-economic activities for the artisanal fishing communities (Abila, 2010).

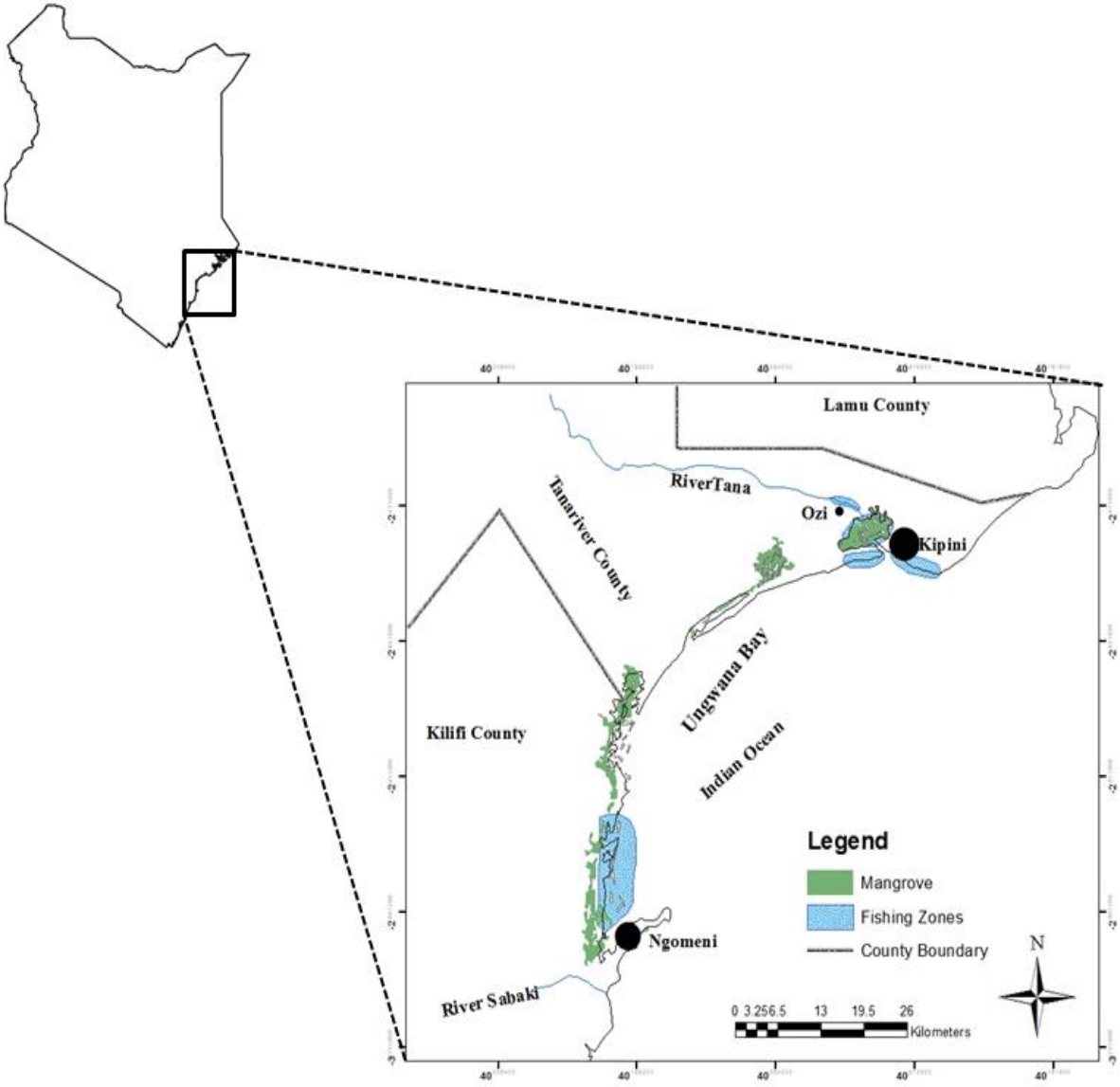


Figure 5. 1. Map showing the fishing zones of Ngomeni, Kipini and Ozi in Ungwana Bay and Lower Tana Delta, Kenya (Source, author)

5.2.2. Data collection

Concurrent shore-based catch assessment surveys were carried out for 8 days of every month from January to December 2017 in Ngomeni, Kipini and Ozi fishing zones. During the sampling days, all species of fish landings were separated before the total weight (kg) and individual total length (TL, cm) were measured. Fish species were identified using the FAO Species Identification Guide for marine resources in Kenya (FAO, 2012). A weighing balance was used to measure the total weight by species while a fish measuring board with a fixed meter tape was used to measure the total length for each individual fish. For large catches, the total weight was first measured, and then a homogenous sub-sample was randomly taken from the catch where different fish species were separated before weighing and individual fish total length measured. For small catches, similar procedure was followed without sub-sampling. Recorded additional data included time taken for fishing (hr), type of fishing craft, craft crew size and the type of fishing gear used.

5.2.3. Data analyses

Non-Metric Multidimensional Scaling (nMDS) technique was used to determine whether there exists distinct seasonal catch composition across habitat types, and also across fishing zones. 1-way ANOSIM was used to test significant difference in the seasonal catch composition across habitats and across the fishing zones. In both cases, 1-way SIMPER analysis was performed to identify which fish species contributed to the dissimilarity. Seasonal catch rate (kg/fisher.hr^{-1}) was calculated for each fishing zone. In each zone, the total weight for each month was divided by the total number of crew (w/f), and then

divided by the total number of fishing hours of the same month (w/f:hr). The seasonal average catch rates were then computed for each zone. Differences between seasons and across fishing zones in catch rates were determined using 2-way ANOVA test. Since data was non-parametric, transformed data log (X+1) was used for the 2-way ANOVA parametric test and homoscedascity of variances was tested using the Levene's test at $p > 0.05$. Pair-wise comparison was conducted using post hoc (Tukey HSD) test. These tests were conducted using STATISTICA statistical software v.7. Microsoft Excel was used to determine the mean length of the most abundant and common species in each fishing zone with craft-gear combination. The differences in species length between the different craft-gear combinations were conducted using the non-parametric Kruskal-Wallis test. Rarefaction curves were used to determine species diversity across fishing zones with habitat and craft-gear combination. Craft and gear frequencies as well as the frequencies of the most 5 abundant species in each fishing zone were also determined by Microsoft Excel.

5.3. Results

5.3.1. Composition of fin fish species in Ungwana Bay and Lower Tana Delta

During the study period, a total of 191 fin fish species were identified which comprised of 104 species in north east monsoon (NEM) season and 87 species in south east monsoon (SEM) season. The largest fin fish sample of 33,370.6 kg was recorded for Kipini fishing zone followed by Ngomeni with a total of 29,879.3 kg and Ozi with a total of 2, 179.3kg. An overall total number of 19, 943 individuals were sampled in the entire Ungwana Bay and Lower Tana Delta.

Non-Metric Multidimensional (nMDS) plots showed distinct separation of samples across habitat types (Figure 5.2). 1-way ANOSIM indicated a significant difference in sample composition across the habitat types ($R = 0.27$; $P = 0.001$). Results of pair-wise comparison tests confirmed significant differences in the composition of samples across all habitat types ($P < 0.05$ in all cases). A distinct fin fish composition was also observed across the fishing zones with season combination (Figure 5.3). Similarly, 1-way ANOSIM indicated a significant difference in sample composition across fishing zones with season combination ($R = 0.332$; $P = 0.001$). Results of pair-wise comparison tests confirmed significant differences in the composition of samples across all fishing zones with season combination ($P < 0.05$ in all cases) except Ozi which indicated no seasonal significant difference ($R = 0.003$; $P = 0.421$). Results of SIMPER analysis showed that while *Arius africanus, Otolithes ruber and Pelona ditchela* contributed most to the dissimilarity in the estuarine habitat, *Chirocentrus dorab, Pristipomoides filamentosus, Scomberomorus commerson and Pristipomoides sieboldii* contributed most of the dissimilarity in the marine habitat of Kipini and Ngomeni fishing zones (Table 5.1).

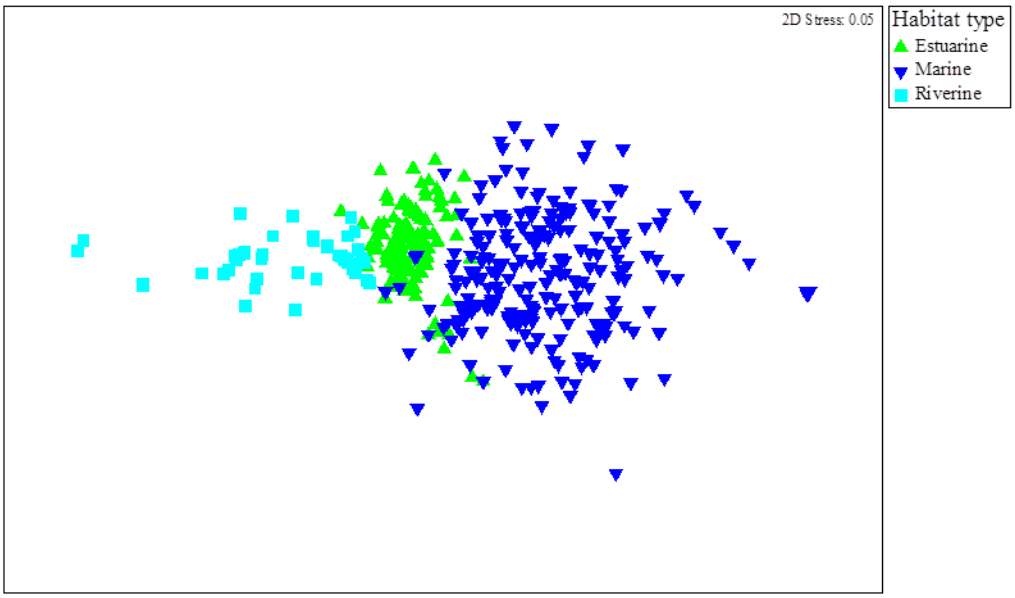


Figure 5. 2 Non-metric MDS plots showing the composition of catches by habitat types in Ungwana Bay and Lower Tana Delta, Kenya based on species abundance from shore-based catch assessments

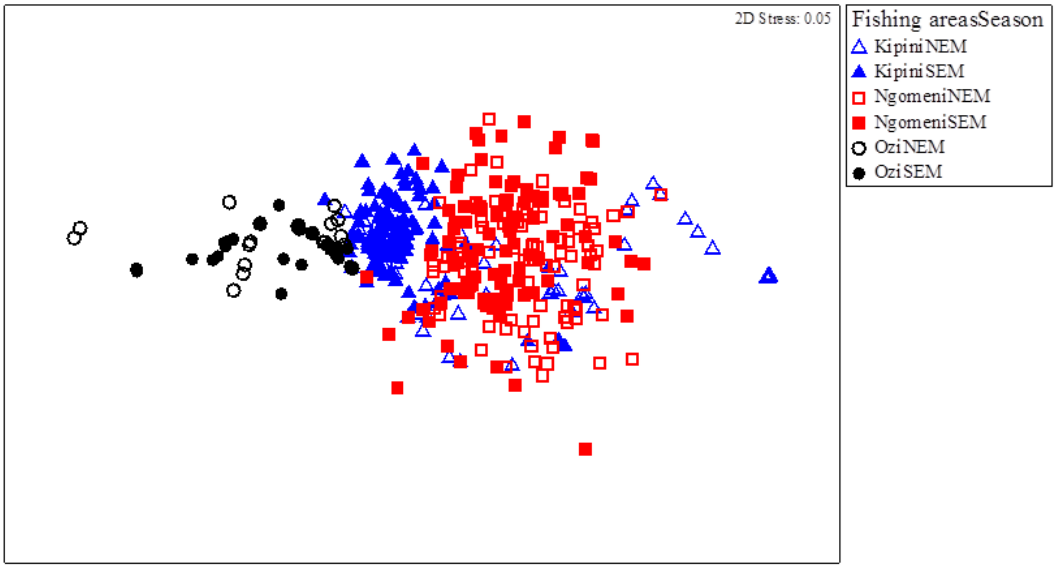


Figure 5. 3 Non-metric nMDS plots showing the composition of catches by fishing zone with season combination in Ungwana Bay and Lower Tana Delta, Kenya based on species abundance from shore-based catch assessments

Table 5. 1. One-way SIMPER Analysis: Species contributing to the dissimilarity in terms of abundance (%) between habitat types (estuarine *versus* marine) with an average dissimilarity of 97.8%.

	Estuarine habitat	**Marine habitat**		
Species	Average abundance (%)	Average abundance (%)	Average dissimilarity	Contribution (%)
Arius africanus	**40.17**	1.01	19.90	20.35
Otolithes ruber	**17.38**	1.18	8.71	8.91
Pelona ditchela	**14.78**	0.33	7.48	7.64
Chirocentrus dorab	0.00	**14.00**	7.00	7.16
Pristipomoides filamentosus	0.00	**13.75**	6.88	7.03
Scomberomorus commerson	0.03	**11.73**	5.87	6.00
Pristipomoides sieboldii	0.00	**10.02**	5.01	5.12

5.3.2. Species richness and abundance

Based on fishing zone, habitat and fishing craft types, rarefaction curves indicated that Ngomeni-marine-*mashua* category recorded the highest expected number of species, followed by Ngomeni-marine-canoe while Kipini-estuarine-outrigger canoe, and Ozi-riverine-canoe categories recorded the lowest expected number of species (Figure 5.4). Based on the types of fishing gears used, the rarefaction curves showed that monofilament net caught the highest number of species, then followed by gillnet, seine net, handline, basket trap, longline and speargun (Figure 5.5).

For Ngomeni fishing zone, the 5 most abundant fin fish species sampled were *Chirocentrus dorab*, *Scomberomorus commerson*, *Thunnus albacares*, *Euthynnus affins* and *Rastrelliger kanagurta* (Table 5.2). For Kipini the 5 most abundant species were *Arius africanus*,

Otolithes ruber, *Pelona ditchela*, *Argyrops spinifer* and *Pristipomoides filamentosus* (Table 5.2). *Clarias gariepinus*, *Arius africanus*, *Plotosus limbatus*, *Oreochromis niloticus* and *Protopterus annectens* were the 5 most abundant fin fish species sampled in Ozi (Table 5.2).

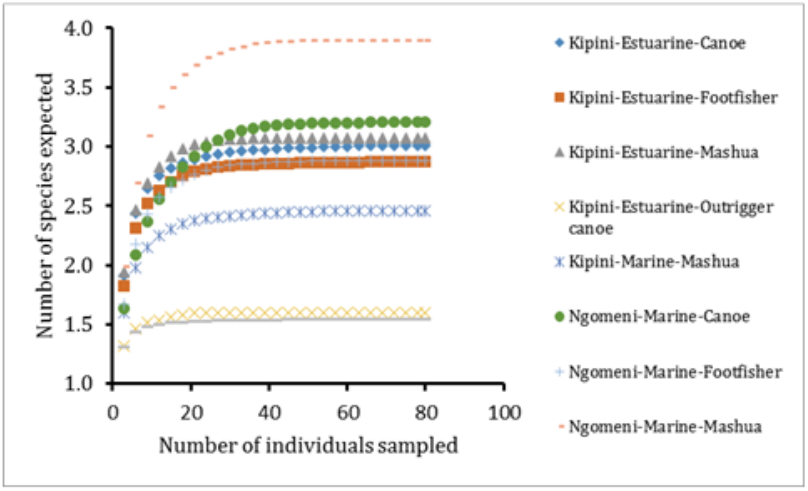


Figure 5. 4 Rarefaction curves showing the expected total number of species caught with increase in sample size for the different fishing zones with habitat and fishing craft combination in Ungwana Bay and Lower Tana Delta, Kenya

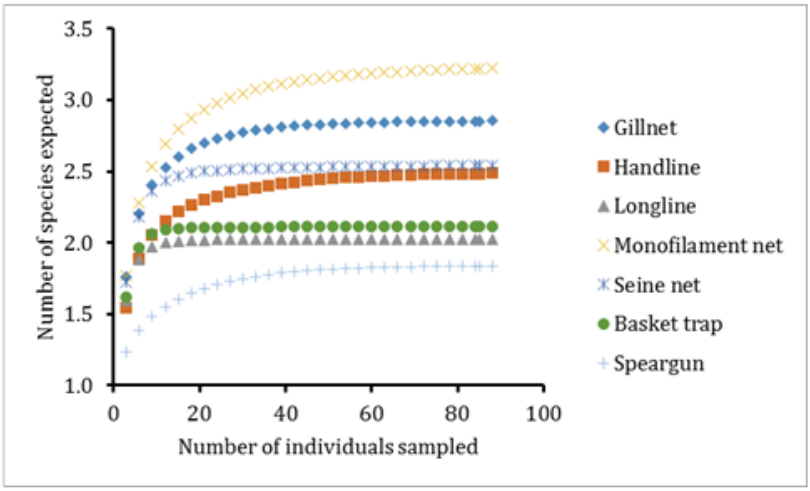


Figure 5. 5 Rarefaction curves showing the total expected number of species caught with increase in sample size for the different types of fishing gears in Ungwana Bay and Lower Tana Delta, Kenya

Table 5. 2. Five most abundant fin fish species by fishing zone in Ungwana Bay and Lower Tana Delta, Kenya

Ngomeni	**Number of individuals sampled**	**(%)**
Chirocentrus dorab	1560	31.2
Scomberomorus commerson	644	12.9
Thunnus albacares	228	4.6
Euthynnus affinis	185	3.7
Rastrelliger kanagurta	180	3.6
Kipini		
Arius africanus	2396	26.6
Otolithes ruber	1426	15.8
Pelona ditchela	1261	14
Argyrops spinifer	583	6.5
Pristipomoides filamentosus	566	6.3
Ozi		
Clarias gariepinus	2672	44.9
Arius africanus	1829	30.8
Plotosus limbatus	748	12.6
Oreochromis niloticus	522	8.8
Protopterus annectens	158	2.7

5.3.3. Artisanal fishing gears and crafts

Comparisons on the types of artisanal fishing gears used in the study area showed that basket traps (63.6%) were most common in Ozi fishing zone, handlines (28.8%) in Kipini, and monofilament nets (34%) in Ngomeni (Table 5.3). Fishing craft types comparisons indicated that canoes were most common in Ozi (97.5%) with foot fishers making a composition of 2.5%. The canoes also were most common in Ngomeni (37.1%) closely followed by the use of *mashua* crafts (32.6%) and then use of fibreglass crafts and foot fishers at 26.4 and 3.9%, respectively. The *mashua* crafts were most common in Kipini (44.5%) followed by foot fishers (28.5%) and canoes (27.0%).

Table 5. 3. Composition of artisanal fishing gear types sampled in Ungwana Bay and Lower Tana Delta, Kenya

Types of gear	Kipini	(Freq %)	Ngomeni	(Freq %)	Ozi	(Freq %)
Basket traps	1	0.2	0	0.0	180	**63.6**
Gillnets	174	27.4	144	27.0	34	12.0
Handlines	183	**28.8**	174	32.5	1	0.4
Longlines	51	8.0	11	2.1	19	6.7
Monofilament nets	159	25.0	182	**34.0**	0	0
Ring nets	0	0.0	3	0.7	0	0
Scoop nets	0	0.0	1	0.2	0	0
Seine nets	68	10.6	1	0.2	40	14.1
Skin diving	0	0	1	0.2	0	0
Spearguns	0	0	18	3.1	9	3.2

5.3.4. Fishing effort and species sizes

Over the study period, the mean catch rate (kg/fisher.hr^{-1}) in the Ungwana Bay and Lower Tana Delta was higher during the North East Monsoon (NEM) than the South East Monsoon (SEM) season in Ngomeni and Kipini fishing zones (Figure 5.6). The Ozi fishing zone showed marginal differences of catch rate between the seasons (Figure 5.6). Ngomeni fishing zone recorded the highest catch rate followed by Kipini and Ozi respectively (Figure 5.6). The 2-way ANOVA test indicated significant difference of catch rate across fishing zones (Df = 2, F = 10.43, p = 0.001) and between the seasons (Df = 1, F = 5.897, p = 0.021). Post hoc pair-wise comparison (Tukey HSD) test confirmed that the catch rates were significantly different between Ngomeni and Ozi as well as Kipini and Ozi (p < 0.05 both cases). The seasonal catch rate was significantly higher in NEM than SEM season for Ngomeni (p < 0.05) but not for Kipini and Ozi (p > 0.05 both cases).

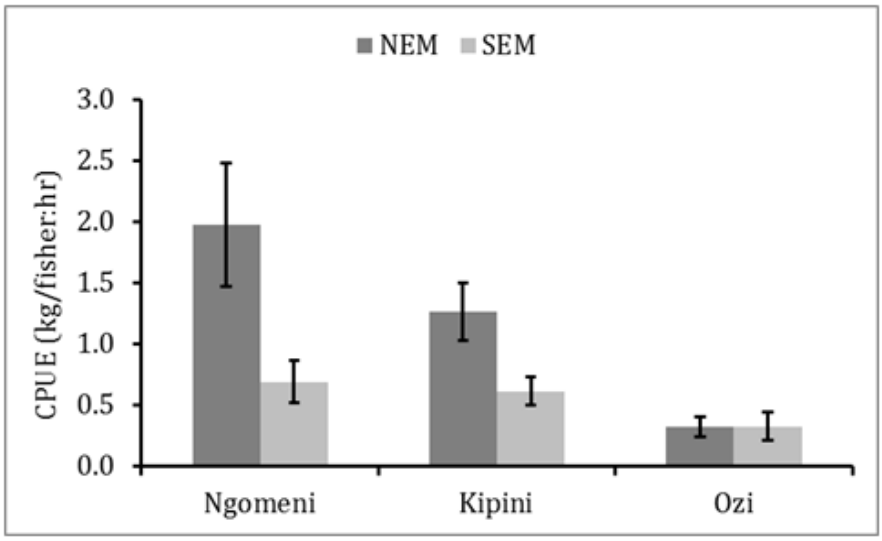


Figure 5. 6 Seasonal catch rate by fishing zone for the Ungwana Bay and Lower Tana Delta artisanal fishery, Kenya

Based on species caught with craft-gear combination, *Scomberomorus commerson* was the most abundant in Ngomeni. *Arius africanus* and *Otolithes ruber* were the most abundant in Kipini; *Arius africanus* was also the most abundant in Ozi (Figure 5.7). In Ngomeni, the gillnet used with fibreglass and *mashua* landed significantly larger individuals than those landed by monofilament with canoes (Kruskal Wallis test: Df = 2; F = 197.141; p = 0.0001). Pair-wise comparison test confirmed significant difference between *mashua*-gillnet with canoe-monofilament, and between fibreglass-gillnet with canoe-monofilament ($p < 0.005$ both cases). All the craft-gear combination used in Kipini landed significant larger species of *Arius africanus* and *Otolithes ruber* (Kurskal Wallis test: Df = 6, F = 327, p = 0.001) except footfisher-monofilament ($p < 0.05$). In Ozi fishing zone, the canoe-basket trap landed significant larger species of *Arius africanus* than canoe-gillnet and canoe-seine net (Kruskal Wallis test: Df = 2, F = 490, p = 0.001). The pair-wise comparison test confirmed significant

difference between canoe-basket trap with canoe-gillnet, and canoe-basket trap with canoe-seine net (p = < 0.05 both cases).

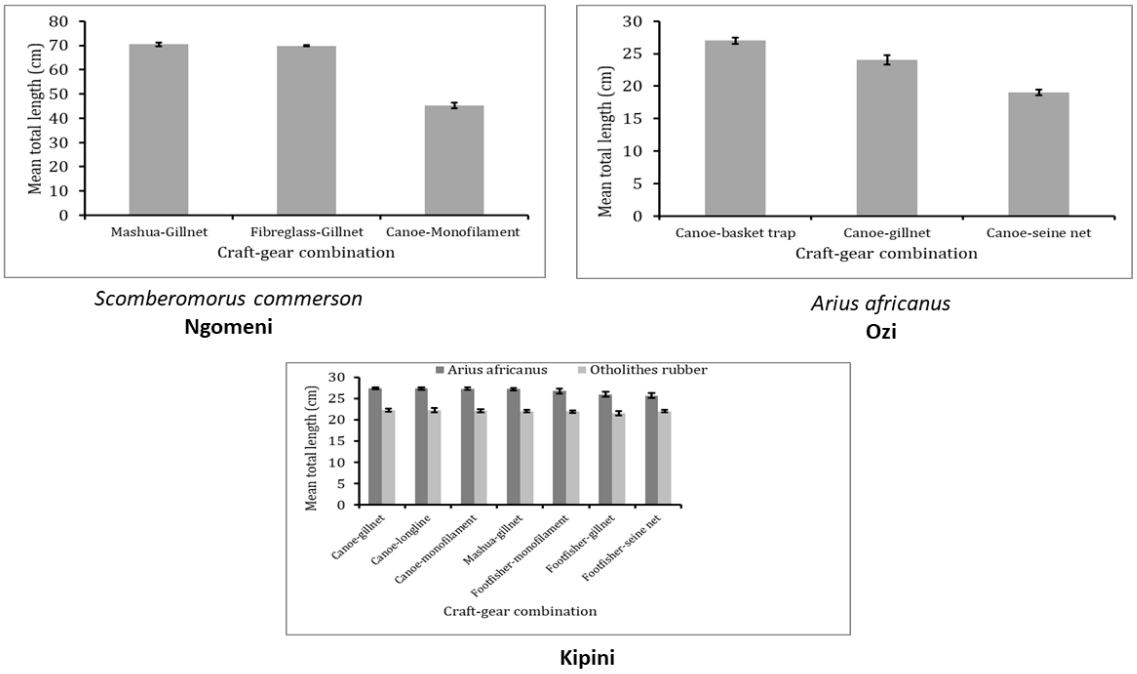


Figure 5. 7 Mean total length of the most abundant and common fin fish species across zones with craft-gear combination in Ungwana Bay and Lower Tana Delta, Kenya

5.4. Discussion

Fisheries resources of the Ungwana Bay and Lower Tana Delta of north coast Kenya are generally confined to marine, estuarine and riverine habitats. Ngomeni, Kipini and Ozi fishing zones show distinct fisheries composition. This is attributed to differences in habitat types in the 3 main fishing zones. Ngomeni is exclusively marine habitat while Ozi is entirely riverine habitat. Kipini is composed of both estuarine and marine habitats. Though not investigated in this study, the differences in environmental elements (nutrients, temperature, depths and turbidity) in different habitat types are the key factors

contributing to the distinct catch composition across habitat types and fishing zones (Winemiller and Leslile, 1992; Munga et al., 2013). For example, Winemiller and Leslie, (1992) observed that the differences in environmental variables (depth, water type, substrate type and turbidity) in habitats determined the distinct assemblage of fish resources in tropical freshwater and marine ecotone. Munga et al. (2013) also made similar observations where the differences of depth, turbidity and season in Malindi-Ungwana Bay, Kenya were the main environmental factors that caused the distinct composition of panaeid shrimp species. Therefore, the variations of environmental elements in the 3 habitats could be the key factors for distinct catches experienced by the artisanal fisheries in Ngomeni, Kipini and Ozi.

In this study, marine habitat is rich in species diversity compared to estuarine and riverine habitats. High species richness is associated with *mashua* boats in Ngomeni fishing zone. The *mashua* boats are characterized by outboard engines and sails thus able to exploit fisheries resources over long period and accessing deep offshore waters resulting in high species diversity landings (Munga et al., 2014). However, estuarine habitats are generally known to be characterized by high species diversity than the marine and riverine habitats. Murase et al. (2014) for instance, observed high species diversity in estuarine habitat (53.6%) than marine habitat (46.4%) in the gulf of Nicoya, Pacific coast of Costa Rica. In this study, therefore, the richness of species diversity in marine habitat may be attributed to the differences of fishing effort in the 3 fishing zones. Ngomeni fishing zone (marine habitat) indicated the highest catch rate compared to Kipini and Ozi fishing zones. Apart from habitats and crafts, high species richness was also associated with gillnets. The

gillnets are commonly used with *mashua* boats thus landing the highest species diversity (Munga et al., 2014). In this study, however, the commonly used gears observed were monofilament net, handlines and basket trap for Ngomeni, Kipini and Ozi respectively.

Ngomeni, Kipini and Ozi are characterized by different catch rates. Their differences may be associated with the fishing methods particularly the use of crafts in fisheries exploitation. Ngomeni has considerable good fishing crafts such as *mashua* and fibreglass boats which have the capacity of accessing deep waters for longer period. Similarly, Kipini is also characterized by the usage of *mashua* boats but not the fiberglass boats. Both *mashua* and fibreglass boats are not commonly used in Ozi. The seasonal catch rate was high during North East Monsoon (NEM) than the South East Monsoon (SEM). Mwangudza et al. (2017) also observed high fisheries catch rates in the NEM season in Ungwna Bay, Kenya. The differences of weather conditions between NEM and SEM could be the key factors for the differences in catch rates between the seasons (Munga et al., 2014). The NEM season is characterized with warm temperature and calm waters while the SEM season is associated with cool temperatures and rough waters (McClanahan, 1998).

In Ngomeni, the most abundant species landed with craft-gear combination was *Scomberomorus commerson*. The largest species were landed by *mashua*-gillnets confirming observation made by Munga et al. (2014). This was associated by the offshore accessibility of *mashua* boats fixed with large mesh size gillnets which enabled the catch of large species (Munga et al., 2014). Like other tropical estuarine habitats, Kipini is characterized by multi-gear and multi-species fishery. *Arius africanus* and *Otolithes ruber* were the most abundant

and common species in Kipini caught by 7 different craft-gear combinations. Siddique et al. (2013) confirmed the multi-gear and multi-species catch in estuarine habitat of Meghna River, Bangladesh. *Arius africanus* was also the most abundant species in Ozi fishing zone. Canoe-basket trap landed the largest species of *Arius africanus* in the zone. Ozi fishing zone borders the Kipini estuarine habitat thus partly characterized by brackish waters which support some of marine-estuarine species such as the *Arius africanus*.

Conclusion

Ngomeni, Kipini and Ozi fishing zones in Ungwana Bay and the Lower Tana Delta have distinct catch composition attributed to the existence of marine, estuarine and riverine habitats. The fishing zones are also characterized by different catch rates mostly associated with differences in fishing methods. Marine habitats are rich in species diversity with large sized individuals compared to estuarine and riverine habitats. Whereas *mashua*-gillnets and canoe-basket traps land the largest size of the most abundant species in Ngomeni and Ozi respectively, multi-craft and gear combination lands the largest species in Kipini. Since marine habitat was associated with large sized species, the artisanal fishers need appropriate fishing crafts such as *mashua* and fibreglass boats to exploit the deep offshore marine fisheries. Therefore, we recommend possesion of such fishing technology among the artisanal fishing communities that will enable them to exploit more of marine resources than the estuarine and riverine resources.

CHAPTER 6:

Climate variability and small-scale fisheries in Kenya: Characterization of current socio-economic conditions of artisanal fishing communities in Ungwana Bay and the Lower Tana Delta[6]

Abstract

Small-scale coastal fishing communities in the tropics have varied responses to climate variability constraints. These responses are often part of the different ways in which communities build adaptive capacity and resilience against internal and external stresses in their bid to reduce the impacts of prevailing and projected weather conditions. It is widely accepted that small-scale coastal fishing communities depend on fisheries resources for their livelihood. If these resources are increasingly becoming scarce as a result of climate variability pressure, a natural question to ask revolves around the ability of these fishing communities to employ alternative livelihood strategies. Drawing from a recent cross-sectional field study conducted in Ungwana Bay and the Lower Tana Delta, north coast of Kenya coupled with analysis of long term terrestrial temperature and rainfall data, this paper describes the climate variability and the socio-economic status of the small-scale or artisanal fishing communities and how these communities are adapting to existing challenges. Trend in terrestrial temperature indicated a strong and positive correlation over time for the region (R2 = 0.7588). Small scale coastal fishing communities livelihood showed significant association with natural resource dependence (P = 0.001, χ^2 = 494.153a). Furthermore, empirical evidence indicated that while fishing is an important source of livelihood in

[6] Dzoga, M., Simatele, D., Munga, C. (2018). Climate variability and small-scale fisheries in Kenya: Characterization of current socio-economic conditions of artisanal fishing communities in Ungwana Bay and the Lower Tana Delta. 12. (In submission)

Ngomeni and Kipini, the Ozi fishing community has expanded its sources of livelihood to include crop production. Population pressure, low level of education, and unemployment have been identified as key socio-economic factors leading to the heavy dependence on natural resources for livelihood support (χ^2= 24.273a, P = 0.004; χ^2 = 46.319a, P = 0.001 and χ^2 = 17.863a; P = 0.037, respectively). It is recommended in this paper that the provision of both civic and formal education may play an important role in equipping fishing communities with knowledge for embracing and adopting alternative livelihood strategies and income generation opportunities. These strategies would also contribute to less pressure on the fisheries resources for sustainable livelihood.

Key words: *Climate variability, Small scale fisheries, Artisanal fishing communities, socio-economic characteristics, Ungwana Bay, Kenya*

6.1. Introduction

Natural and human environments are at high risk from climatic variability (McMichael *et al.,* 2003). To a high degree, climate variability impacts have been manifested through degradation of natural environments which then affect the human environment through direct or indirect impacts, respectively (Scott *et al.,* 1990; Cahoon and Hansel, 2002). The direct impacts encompass a range of natural hazards and extreme events such as increased soil salinity, drought and flooding while indirect impacts are manifested through deterioration in the social-economic elements (Cruz, *et al.,* 2007; Epstein and Mills, 2006; McMichael *et al.,* 2003). Human livelihoods are intertwined with climatic conditions (Trenberth *et al.,* 2000). It has been argued that variations in temperature and rainfall affect human livelihoods especially for those communities whose livelihood systems are rainfall and ecosystem dependent (Badjeck *et al.,* 2010). Simatele *et al.* (2012) have observed that variations in weather conditions tend to compromise the ability of the poor people to secure sustainable livelihoods due to the fact that they lack the necessary asset portfolios to deploy and adapt to climate variability.

Globally, artisanal or small-scale coastal fishing communities predominantly depend on fisheries resources for their livelihood and largely rely on low-productive traditional fishing methods thus coined as *"poorest of the poor"* (Allison and Ellis, 2001). Degradation of natural resources due to climate variability results in decline in catches. Mustapha *et al.* (2013) noted that climatic extremes may compel abandonment of artisanal fisheries. Badjeck *et al.* (2010) further argues for the need to understand the implications of climate variability on fishing communities in order to identify the entry point for policy

implementation and decision making, foster livelihood diversification of grassroot communities, and strengthen institutions mandated with facilitating the adaptive capacity and resilience of vulnerable fishing communities.

The Ungwana Bay and Lower Tana Delta region in north coast Kenya experiences condusive oceanographic conditions characterized by the South East Monsoon (SEM) and North East Monsoon (NEM) seasons prevailing from April to September, and October to March, respectively. These seasons favor a number of livelihood activities such as fishing (Munga *et al.,* 2014). The Ungwana Bay area, in particular, is widely known for its high biodiversity especially in fisheries and birds (Abila, 2010; Munga et al., 2014). To a large extent, the area is known as home for artisanal fishing communities (Government of Kenya, 2015). However, projections on climate variability in the entire region of north coast Kenya within which the study area is located, estimated an increase in temperature by 0.3 °C, as well as a decrease in rainfall by 25% by 2050 (Deenapanray and Tan, 2011). These climate projections have a potential to significantly and negatively affect the livelihood status of the many poor coastal communities as a result of the change in ecosystem services. In view of these observations, this paper characterizes and discusses the current climatic variability and socio-economic status of the artisanal fishing communities and how these communities are adapting to these challenges.

6.2. Materials and methods

Data was collected using a cross-sectional socio-economic survey in three study sites namely: Ngomeni, Kipini, and Ozi typical of coastal fishing communities (Figure 6.1).

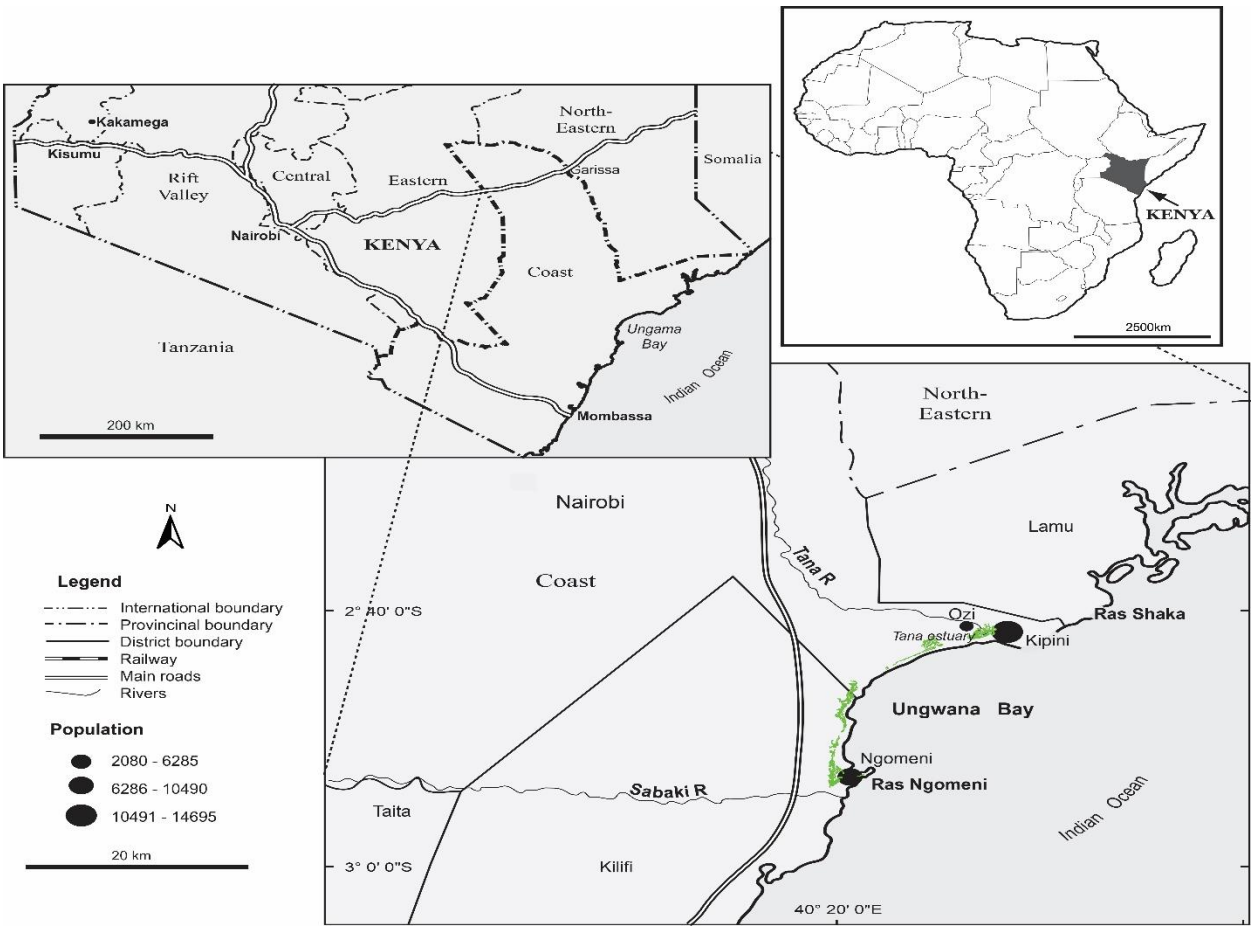


Figure 6. 1 Map showing the study sites of Ngomeni, Kipini, and Ozi in Ungwana Bay and Lower Tana Delta, north coast, Kenya (Source, author)

In order to draw a representative sample size of the study, the Cochran's (1977) formula was employed:

$$n_0 = \frac{z^2 pq}{e^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Where:

n_0 = sample size,

z = is the selected critical value of desired level of confidence,

p = is the estimated proportion of an attribute that is present in the population,

q = 1-p,

e = is the desired level of precision

$$n = \frac{n_0}{1+\frac{(n_0-1)}{N}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Where:

n = new sample size to be determined,

n_0 = sample size derived from eq...(i),

N = actual population size of the subjects

The weight for each study site was determined by the following formula (iii) based on the total population of each area.

$w = n/N$……..(iii)

Where: w = weight,

n = Population for each stratum

N = Total population for the three strata

The total population of Ngomeni, Kipini and Ozi was 10,241, 14,695 and 2,084 (Government of Kenya, 2009), respectively. A representative sample of 144, 206 and 29 individuals from Ngomeni, Kipini and Ozi were selected through a simple random process. Therefore, an overall total of 379 heads of fishing families were interviewed during the study period.

6.2.1. Data collection

Long term rainfall and terrestrial temperature data for the three study sites was obtained from the Kenya Meteorological Department, (i.e. Msabaha - Malindi station) spanning a period from 1999 to 2016. Semi-structured interviews using questionnaires were used for data collection. The questionnaires were administered through one on one interview of the respondents addressing their annual income from fishing activities, other sources of livelihood, natural resource dependence, and social factors. The respondents were selected through a simple random process which was conducted through the help of the respective area government administration officers and village elders. All the names of household heads of the fishing communities were assigned numbers and then a table of random numbers was generated and produced the order of sampling procedure and the sample size. The corresponding household names on the random numbers generated were then identified before engaged in the semi-structured interviews.

6.2.3. Data analysis

Mean and trends of rainfall and terrestrial temperature were computed using Microsoft Excel. Socio-economic variables were coded and entered into SPSS software where respective variables were analyzed descriptively using actual values and relative percentages and then graphically represented. Chi-Square (χ^2) test was used to determine whether there was a significant association in natural resource dependence among the artisanal fishing communities livelihood, and whether there was a significant association in

factors resulting in the dependence on the natural resources (fisheries, terrestrial forests, mangroves and land).

6.3. Results

6.3.1. Rainfall and temperature variability

Based on the 1999-2016 rainfall and terrestrial temperature data, the Ungwana Bay and Lower Tana Delta in north coast Kenya recorded a mean rainfall of 85.11 ± 4.36 mm and terrestrial mean temperature of 30.55 ± 0.08 °C. During the same period, rainfall showed a decreasing trend while terrestrial temperature indicated an increasing trend (Figure 6.2). The rainfall trend showed weak and inverse relationship (R^2 = 0.178) with time while the trend in terrestrial temperature indicated a strong and positive correlation (R^2 = 0.7588) with time (Figure 6.2).

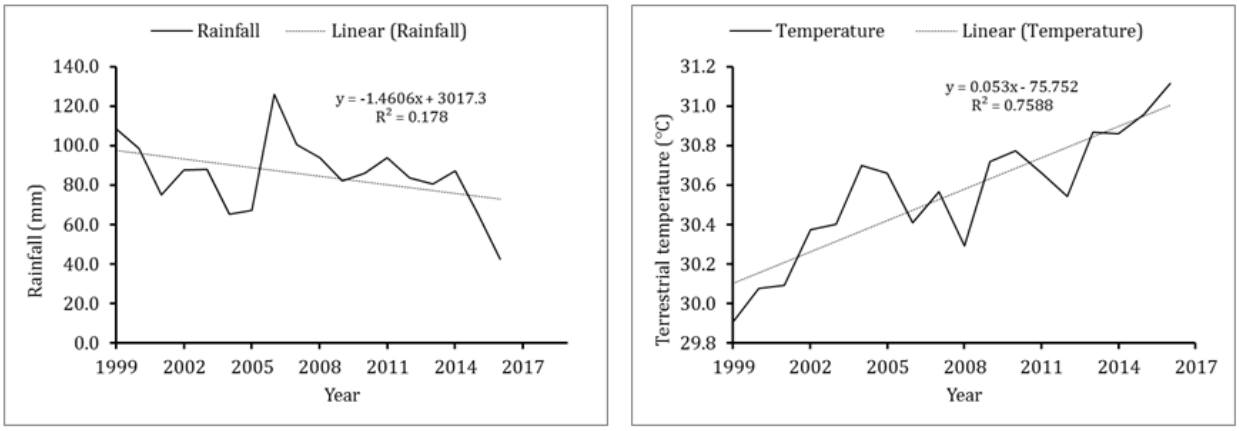


Figure 6. 2 Mean annual trends of rainfall and terrestrial temperature between 1999 and 2016 in Ungwana Bay and Lower Tana Delta, in north coast Kenya (Data source: Kenya Meteorological Department, Malindi Station)

6.3.2. Socio-economic attributes of small-scale fishing communities

A total of 379 individuals were interviewed during the study period. The monthly average income on fisheries livelihood among the fishing communities in the three study sites varied. Ngomeni showed relatively high monthly average income per person ($ 52 ± 4) followed by Kipini at $ 33 ± 2 and Ozi at $ 24 ± 3 (Figure 6.3). The artisanal fishing communities of Ngomeni, Kipini and Ozi revealed high levels of unemployment of 88.2%, 88.3%, and 93.1% respectively (Figure 6.4). Majority of the respondents attained elementary level of education where Ngomeni comprised of 54.9%, Kipini (49.5%), and Ozi with 53.6% (Figure 6.5). Across all the study sites, perception on population growth status showed that the population has been increasing with time (Figure 6.6).

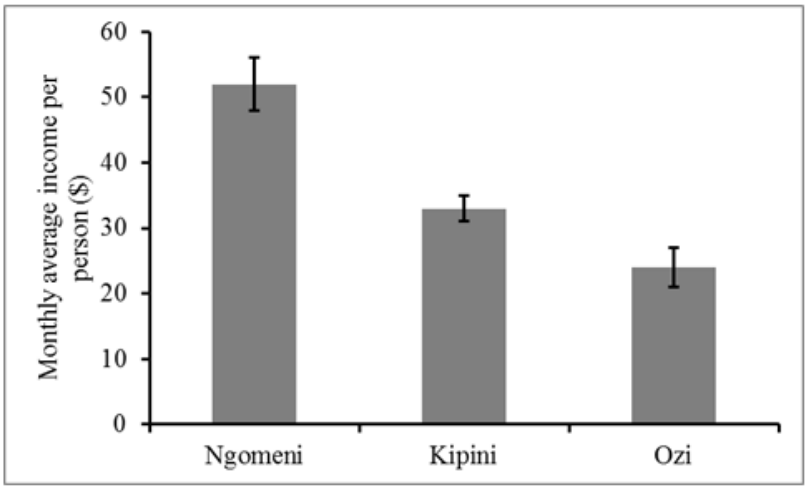


Figure 6. 3 Annual average income per person of artisanal fishing communities in Ungwana Bay and Lower Tana Delta, Kenya (1 US$ = 101 Ksh)

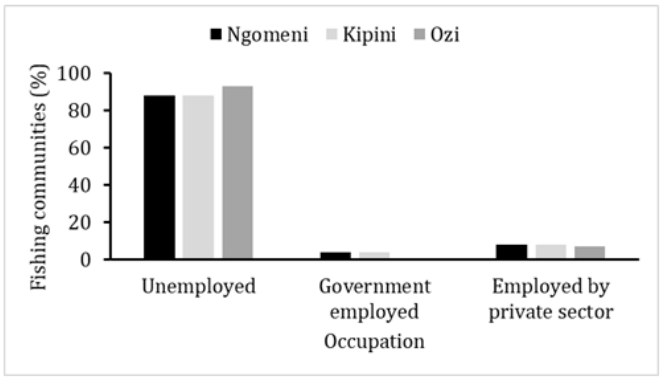


Figure 6. 4 Employment status of respondents by study sites in Ungwana Bay and Lower Tana Delta, Kenya

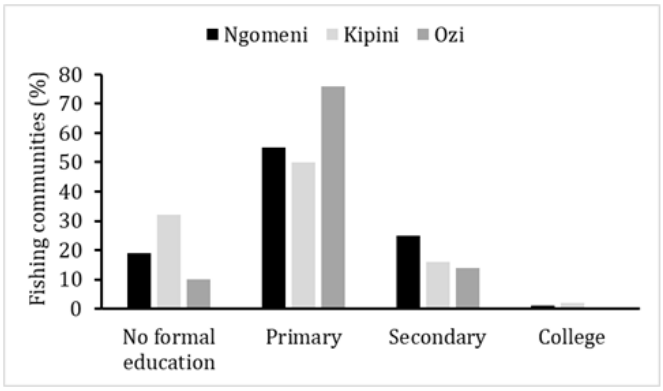


Figure 6. 5 Education status of respondents by study sites in Ungwana Bay and Lower Tana Delta, Kenya

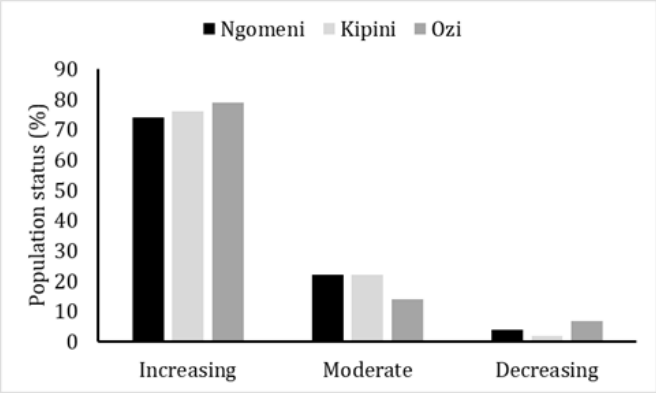


Figure 6. 6 Perception on population growth based on outcome of the respondents by study sites in Ungwana Bay and Lower Tana Delta, Kenya

6.3.3. Dependence on natural resources by small-scale fishing communities

High dependence of natural resources among the small-scale (artisanal) fishing communities was observed across all the study sites (Table 6.1). Livelihood of the small-scale fishing communities showed significant association with the dependence on natural resources ($P = 0.001$, $\chi^2 = 494.153a$).

Table 6. 1. Dependence level (%) on natural resources by small-scale fishing communities in Ungwana Bay and Lower Tana Delta, Kenya

Study Sites	Natural resources	Formal employment
Ngomeni	100	0
Kipini	99	1
Ozi	100	0

6.3.4. Status of sources of livelihood and factors resulting in dependence on natural resources for livelihood support

Fishing activity forms a core source of livelihood for artisanal fishing communities in Ngomeni with 74.3% and in Kipini with 57.8%. However, crop farming (48.3%) have been slightly more practiced than fishing (44. 8%) in Ozi (Table 6.2). Results of Chi-Square test indicated significant association between natural resource dependence with population growth (χ^2 = 24.273[a]; *P* = 0.004), with education (χ^2 = 46.319[a]; *P* = 0.001), and with employment (χ^2 = 17.863[a]; *P* = 0.037).

Table 6. 2. Composition (%) of sources of livelihood for fishing communities in Ungwana Bay and Lower Tana Delta, Kenya

Study Area	Fishing	Crop farming	Livestock keeping	Charcoal producers	Formal Employed	Fish traders	Food vendors	Shell collectors	Hoteliers	Others
Ngomeni	74.3	6.9	2.1	4.9	3.5	0.7	2.1	0.7	1.4	3.5
Kipini	57.8	18.9	8.7	2.4	2.9	7.3	1.0	0.0	1.0	0.0
Ozi	44.8	48.3	3.4	0.0	0.0	3.4	0.0	0.0	0.0	0.0

6.4. Discussion

The Ungwana Bay and Lower Tana Delta region in north coast Kenya is characterized by increasing variability of rainfall and terrestrial temperature. Though weak correlation was observed on rainfall over time, the decreasing rainfall trend in the study area has also been reported in several studies (Deenapanray and Tan, 2011; Langat *et al.,* 2017). Langat *et al.* (2017) in their study of rainfall variability in the Tana River Basin noted that while rainfall is characterized by increasing trends in the upstream (high lands), the downstream

(coastal lands) is characterized by decreasing trends. Thus, the Tana River flow is highly influenced by the amount of rainfall upstream. Furthermore, Langat *et al.* (2017) also noted that the Tana Delta receives a mean annual rainfall of 79.57 mm against a mean annual of 85.11 ± 4.36 mm recorded in this study. In addition, Deenapanray and Tan (2011) projected a decrease of the rainfall in the region by 25% in 2050. Notably, terrestrial temperature according to this study has shown increasing trend as well as strong and positive correlation over time. Likewise, projections have estimated an increase in temperature in the region by 0.3 °C in 2050 (Deenapanray and Tan, 2011). Therefore, rainfall and temperature variability in the study area is apparent with already observed implications to the small-scale fishing communities as found out in this study.

The small-scale fishing communities in Ungwana Bay and Lower Tana Delta, north coast Kenya are similar to the rest of tropical coastal artisanal communities globally characterized by low mean annual income, high level of unemployment, and low level of education. Similarly, Perret (2010) observed that majority (54%) of the small-scale fishing communities in Singkaraka Lake, Indonesia had attained elementary education while Paudel *et al.* (2016) showed that 69% of the artisanal fishing communities in Nepal were illiterate. Attainment of basic education limits accessibility to decent employment opportunities due to low level of skills. Higher education on the other hand is important for skilled labour and productive workforce thus enhance high standard of living (International Labour Organization, 2011). Comparable to the relatively low monthly average income per person of the small-scale fishing communities in Ngomeni ($ 52 ± 4), Kipini ($ 33 ±2), and Ozi ($ 24 ± 3), most of the artisanal fishing communities in Nepal were

reported to have a slightly high monthly average income of $ 60.2 ± 2.6 from fisheries (Paudel *et al.,* 2016). The overall population trend of the artisanal fishing communities in Ungwana Bay and Lower Tana Delta has been increasing. Secours Islamique France (SIF) (2013) confirmed the Tana Delta region has experienced population growth that has turned more land into settlement schemes and farming.

While the small-scale fishing communities are still dependent on fisheries resources despite the prevailing climatic challenges globally (Paudel *et al.,* 2016; Perret, 2010), these fishing communities have also been engaging in other sources of livelihood especially for Ozi community where crop farming seems to be slighlty more important than fishing. This may be attributed to the general observation of core livelihood activities in the Tana Delta region which is characterized by farming and pastoralism (Secours Islamique France, 2013). Other livelihood such as fishing, hunting and honey gathering are considered less important in the region (Secours Islamique France, 2013). On the other hand, crop farming is less important for Ngomeni and Kipini communities. Ngomeni and Kipini are adjacent to the Indian Ocean thus rely mostly on fisheries resources for livelihood. However, the current fisheries dependency level for Ngomeni (74%) and Kipini (58%) is lower compared to the dependency level reported by Kitheka, (2002) in Ngomeni and Kipini (90%, 70%) respectively. This may be due to climate variability challenges experienced and possible expansion of livelihood sources.

Demographic factors such as population growth have been observed to accelerate environmental degradation due to high dependency on natural resources (Harte, 2007). In

this study, population growth, unemployment and low level of education are the factors that cause high dependency on natural resources among the artisanal fishing communities. Lack of employment, population growth and low level of education compel communities to rely on natural resources thus resulting to resources deterioration (Hammad & Tumeizi, 2010). Paudel *et al.* (2016) confirmed this in their study where the artisanal fishing communities in Nepal recommended better education and alternative occupations to conserve their ecological resources of Ganges River dolphin. Thus poor education and lack of employment may force fishing communities to exert pressure on natural resources.

Conclusion

The Ungwana Bay and Lower Tana Delta ecosystem is exposed to increasing terrestrial temperature and decreasing rainfall over time. The ecosystem is also an important source of livelihoods to the local communities with an increasing population growth. Majority of the artisanal fishing communities are poorly educated and unemployed with resultant high dependence pressure on the available natural resources. The climatic variability coupled with anthropogenic pressure may impact the fisheries resources and in turn affect the fishing communities. The artisanal fishing communities need to expand their sources of livelihood to include other feasible activities such as crop farming especially for Ngomeni and Kipini communities. Therefore, there is need for community sensitization on climate variability impacts, provision of education and improved crop production to balance between sustainable resource use and environmental management.

CHAPTER 7

GENERAL CONCLUSION AND RECOMMENDATIONS

7.1: Synthesis and general conclusion

Climate change is unequivocal (IPCC, 2001, 2007). Global and regional projections of climate variability signify more impacts especially to ecosystems and their associated livelihood support (IPCC, 2001; Deenapanray and Tan, 2011). Globally, the artisanal fishing communities depict total reliance on fisheries resources for their livelihood (Allison and Ellis, 2001). Therefore, with the current and projected trends of climate change, these communities as well as their ecological resources may be susceptible to the changing conditions. As a result, this study was conducted to assess the ecological and socio-economic vulnerability of fishing communities to climate variability in Ungwana Bay and the Lower Tana in Kenya.

Fisheries resources as well as the artisanal fishing communities of Ungwana Bay and the Lower Tana Delta were observed to be vulnerable to climate variability in this study. Though the trends in sea surface temperature are not significant, the terrestrial temperature trends showed strong and positive correlation in increase with time while the terrestrial rainfall trends indicated weak and inverse relationship with time. Sea surface temperature and sea surface chlorophyll are the key environmental variables affecting fisheries resources in the study area. Therefore, the vulnerability of fisheries resources on climate variability is manifested through reduction in abundance as well as distribution and composition of resources among the artisanal fishing communities. In addition to the

environmental factors, the fisheries resources may also be affected by non-climatic factors such as fishing activities and other extractive uses. Thus the climatic variability as well as non-climatic factors exert pressure on the fisheries resources hence amplifying their vulnerability.

The artisanal fishing communities were also vulnerable to climate variability. This was partly due to their primary dependence on the fisheries resources for their livelihood and also the low level of adaptation capacity. Majority of the communities are either illiterate or have attained elementary level of education. This limited their skills in securing formal employment opportunities thus turned to dependence on natural resources for their livelihood. In addition, their population was perceived to be increasing thus exerting additional pressure on the natural resources and therefore intensified their general vulnerability.

With this perspective, the coastal and marine resources need better management strategies. However, the management of coastal and marine resources is still a challenge in Kenya. This study found that the management challenges may be as a result of lack of a unifying model where different aspects of coastal and marine resource issues can be comprehended. Most of the coastal and marine research studies in Kenya are based on different methodological approaches which focused on specific aspect of the entire ecosystem. This limited an understanding of some important aspects of the ecosystem such as driving factors resulting in pressure on resources. Nonetheless, management regulations of the coastal and marine resources were drawn from those studies. As a result, the coastal

and marine management structures may not be effective for proper monitoring and enforcement of appropriate measures to protect and conserve these resources in Kenya.

In summary, the approach of this study was anchored in five main research papers. These papers strategically addressed the issue of ecological vulnerability of artisanal fishing communities due to climate variability, depicted the climatic variability conditions, characterized the artisanal fisheries as well as the artisanal fishing communities in natural resource dependence, and finally addressed the issue of coastal and marine resource management in the Ungwana Bay and the Lower Tana Delta in Kenya.

7.2: Description of knowledge generated

The review of coastal and marine resource management structures indicated ineffective performance of the structures thus resulting to overlap of duties and degradation of resources. Lack of a unifying framework for conducting coastal and marine resource research, has resulted to inconsistency recommendations that lacked holistic approach in management. Therefore, the DPSIR model provide a better unifying framework that ensures inclusiveness of all aspects of the coastal and marine ecosystem studies hence generation of better recommendations on the management of resources.

This study has established high vulnerability level of fishing communities to climate variability, particularly Ngomeni and Ozi fishing communities. In addition, the study area experience increasing terrestrial temperatures as well as reduced rainfall frequencies. Sea Surface Temperature (SST) and Sea Surface Chlorophyll (SSC) have been observed to be the

key environmental elements that affect the abundance, composition and distribution of fin fish resources. Additionally, different types of habitats determine specific fin fish species composition, abundance and distribution. Catch differences in Ngomeni, Kipini and Ozi is associated with different of the fishing technology. Ngomeni has better fishing technology compared to Kipini and Ozi thus resulted to high catch rates. Further pressure on the fisheries resources is associated with high dependency of natural resources by the fishing communities as well as increased population status.

7.3: Recommendations

For sustainability of natural resources particularly fisheries resources, there is need for identification and protection of the breeding habitats and refuge for fish species. These include the coral and mangrove ecosystems which absorb carbon and enhance conducive micro-environments for fisheries resources. There is also the need to strengthen the existing management measures for fisheries resources and promoting environment friendly fishing methods thus lowering the anthropogenic destruction of habitats and enhancing breeding areas. Local measures should be enforced to limit encroachment along the estuary and control mangrove cutting and other extractive uses. This will result in vulnerability reduction on fisheries resources.

For the artisanal fishing communities, there is need for adaptation improvement measures which include empowerment of the local community to invest in other sources of livelihood in addition to fishing and crop production. This may be achieved through provisioning of

affordable loans at minimal interest by Kilifi and Tanariver County Governments. Empowerment can also be in the form of providing awareness to the fishing communities on the relevance of education and available opportunities to pursue education. The government needs to improve the existing education and health facilities to reduce the distance covered in accessing such services. The available educational and health facilities may be inadequate considering the vast geographical area and the increase of human population.

For the management of coastal and marine fisheries, there is need to adopt the Driver-Pressure-State-Impact-Response (DPSIR) model in conducting studies. The model provides a unifying platform where all aspects of coastal and marine resources can be comprehended. It provides a framework where rational management strategies can be developed and implemented. Therefore, future coastal and marine studies may need to adopt this approach so as to develop appropriate managerial strategies.

Further research is needed to broaden the socio-economic indicators on climate change vulnerability assessment. Most of the socio-economic indicators were generalised in this study. For example, employment indicator can be further categorised into permanet, contract and casual employment. Permanet employment provide better adaptation than contract and casual employment. Therefore, future studies need to be more specific in categorization of indicators for effective vulnerability assessment.

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APPENDICES

Appendix 1: Structured questionnaire

This questionnaire will be administered by research assistants to fishermen in semi structured interviews form

A. Socio-economic indicators

Human assets indicators

1. Household member (who?) (including absent members who contribute to the household)	***2. Gender*** (male -1, female -2	***3. Age*** (years) {1-for(0-17), 2-for(18-35), 3-for(36-50), 4-for(51-80)}	**4. Marital status** (married – 1, unmarried– 2, others ……..3	**5. Education level** (no education-0, primary-1, secondary-2, higher secondary or technical-3, bachelor-4, master-5)	***6. Technical skills*** (0-masonary, 1-hair dressing, 2-welding, 3-carpenter, 4-mechanics, 5-others)	**7. Employment status** (1-unemployed, 2-government employed, 3-employed by private sector)	**7. Health condition**	
							Disease status (0-not suffering for any disease, 1-suffering from a particular disease	***Disease effects*** (0-complete hinders me from working, 1-hindered me from working for a particular period, 3-does not hinder me from working
Household members								
……..of HH								
……..of HH								
……..of HH								
……..of HH								

HH size								

B Natural assets indicators

Types of natural resources	**Please tick the natural resource useful to your livelihoods**	**Level of dependency** (1-low, 2-medium, 3-high)	**Importance on livelihoods** (1-low, 2-medium, 3-high)	**Rate their productivity in the last 10 years** (1-low, 2-medium, 3-high)	**Rate their current productivity** (1-low, 2-medium, 3-high)	**Success on management structures to recover the resources** (1-low, 2-medium, 3-high)	**How has the management structures helped you in terms of livelihoods conditions** (1-dedreased, 2-moderate, 3-increased, 4-no change
1 Fisheries							
2 Mangroves							
3 seagrass							
4 Land							
5 Ocean waters							
6 River waters							
7 coastal forests							

F Physical assets indicators

1 Where is your place of residence……..

2 What is your status of residence **Tenant** ( ) **Lease** ( ) **Own house** ( )

3 What is the nature of your house **Permanent** ( ) **Semi-permanent** ( ) **Temporary** ( )

4 Do you own any of the following?

Assets	**1-Yes**	**2-No**	**Fisheries assets**	**1-Yes**	**2-No**
Truck/car			Net		
TV			Freezer		
Phone			Boat		
Bicycle			Drier		
Cart			Handline		
Sanitary toilets			Hooks		

G Social assets indicators

1. Do you have access to the following facilities in your area:
   a) Health facilities 1-Yes, 2-No ( )
   b) Tap water 1-Yes, 2-No ( )
   c) Household Electricity 1-Yes, 2-No ( )
2. What type of water do you take **Tap water** ( ) **River water** ( ) **Bore hole water** ( )

Please name the association membership that you are affiliated

Associations	**How beneficial are they to you (1-low, 2-medium, 3-high)**
1……..	
2……..	
3 ……..	
4 ……..	

LIVELIHOOD CHARACTERISTICS

1. What is the main income generating activity of your family?
   a) Fishing

b) Government officer
c) Charcoal making
d) Fish trading
e) Crop farming
f) Livestock farming
g) Boat/net repairing
h) Shell collecting
i) Working in beach hotel facilities
j) others, _____

2. What are other income generating activities are you relying on? Please use the table below to answer this question

Livelihoods categories	**Please tick the one applicable to you**	**Estimate of income per year** (KSh)	**Which gender performs the following duties in your family** (1-male, 2-female)	**Rate the level of dependency** (1-low, 2-medium, 3-higjh)	**How was your livelihoods status in the past 10 year** (1-large, 2-medium, 3-small)	**How is your current livelihoods status** (1-large, 2-medium, 3-small)
1 fishing						
2 crop farming						
3 livestock farming						
4 charcoal making						
5 sea weed farming						
6 fish trading						
7 boat/net repairing						
8 food vending						
9 shell						

collecting						
10. working in hotel facility						
10 others (specify)						

3. What is source of energy used for cooking?
   a) Fuel wood
   b) Kerosene
   c) Gas
   d) Electricity
   e) Others,_____

E What tools do you use in conducting the following activities? (Applicable to the person)

Fishing	**Crop farming**	Livestock farming	Charcoal production	Sea weed farming
1	1	1	1	1
2	2	2	2	2
3	3	3	3	3
4	4	4	4	4
5	5	5	5	5

For the tools you have listed, how can you rate their production capacity? 1-low ( ) 2-medium ( ) 3-high ( )

Which tools do you consider destructive in your opinion to the ecosystems below?

Fisheries	**Wetlands**	Mangroves	Corals	Seagrass
1	1	1	1	1
2	2	2	2	2
3	3	3	3	3
4	4	4	4	4
5	5	5	5	5

DPSIR INDICATORS

Driver indicators

1. How is the current population status compared to the **population** 10 years ago
   1-Decreasing, 2-Moderate, 3-Increasing ( )
2. What is the output intensity for the following economic activities in this area:
   a) Fisheries 1-Low, 2-Moderate, 3-High ( )
   b) Tourism 1-Low, 2-Moderate, 3-High ( )
   c) Agriculture 1-Low, 2-Moderate, 3-High ( )
   d) Charcoal making 1-Low, 2-Moderate, 3-High ( )

Pressure indicators

1. How is the rate of land conversion to the following activities:
   a) Hotel facilities 1-Low, 2-Moderate, 3-High ( )
   b) Agricultural cultivation 1-Low, 2-Moderate, 3-High ( )
2. What is the rate of pollution on the natural resources as a result of the following economic activities:
   a) Tourism 1-Low, 2-Moderate, 3-High ( )
   b) Agriculture 1-Low, 2-Moderate, 3-High ( )
3. What is the current demand for the following economic products
   a) Fisheries
      i. Fishes 1-Low, 2-Moderate, 3-High ( )
      ii. Shells 1-Low, 2-Moderate, 3-High ( )
      iii. Sea weeds 1-Low, 2-Moderate, 3-High ( )
      iv. Mangroves trees 1-Low, 2-Moderate, 3-High ( )
   b) Agriculture
      i. Cultivated crops 1-Low, 2-Moderate, 3-High ( )
      ii. Livestock products 1-Low, 2-Moderate, 3-High ( )
   c) Tourism

i. Accommodation services 1-Low, 2-Moderate, 3-High ( )
ii. Conferences services 1-Low, 2-Moderate, 3-High ( )

State indicators

1. What is the current damage status on the following ecosystems:
   a) Mangroves 1-Low, 2-Moderate, 3-High ( )
   b) Coral reef 1-Low, 2-Moderate, 3-High ( )
   c) Seagrass 1-Low, 2-Moderate, 3-High ( )
   d) Land 1-Low, 2-Moderate, 3-High ( )
2. How is the productivity rate for the following livelihoods:
   a) Fish stock 1-Low, 2-Moderate, 3-High ( )
   b) Shells 1-Low, 2-Moderate, 3-High ( )
   c) Agricultural crops 1-Low, 2-Moderate, 3-High ( )
   d) Livestock 1-Low, 2-Moderate, 3-High ( )
   e) Charcoal 1-Low, 2-Moderate, 3-High ( )

Impact indicators

1. How can you say about the current income you obtain from the economic activities:
   f) Fish stock 1-Reduced, 2-Moderate, 3-Increased ( )
   g) Shells 1-Reduced, 2-Moderate, 3-Increased ( )
   h) Agricultural crops 1-Reduced, 2-Moderate, 3-Increase ( )
   i) Livestock 1-Reduced, 2-Moderate, 3-Increased ( )
   j) Charcoal 1-Reduced, 2-Moderate, 3-Increased ( )
2. What is the level of disease emergence due to pollution
   1-Low, 2-Medium, 3-High ( )
3. Are there social conflicts as a result of fishing grounds ownership? 1-Yes, 2-No ( )
4. If yes, what is the intensity on the conflicts? 1-Low, 2-Moderate, 3-High ( )

Response indicators

Please name the governance structures that are used to monitor natural resource exploitation	**For how long have they been in operation** (1-last 5 years, 2-last 10 years, 3-last 15 years, 4- over 15 years	**Please rate them in terms of their success on improving natural resource management** (1-low, 2-medium, 3-hig)	**Please rate them in terms of their success on improving your livelihoods** (1-low, 2-medium, 3-hig)
1……..			
2……..			
3……			
4……..			
5……..			
6……			
7……..			

Please tick the reasons that have caused the reduction and degradation of livelihoods and its associated natural resources below

Causes of reduction and degradation of livelihoods resources	**Magnitude of causes**		
	Low	Medium	High
The decrease of water quality and quantity of the lake and its surrounding			
The use of fishing gear with small net size			
The use of fertilizers and poisonous materials from industries			
Lack of socialization of rules/regulation to fishing community			

Lack of coordination between government and fishing community			
Weak law enforcement			

Appendix 2: Landing based and boat activity fishery survey tool

Name of fisher (optional):			Date:
Resident Village:		County:	
Boat type:	Propulsion:		Boat length:
No. of fishers:	Gear type:	Time out:	Time in:
Fishing ground:	Landing site:	No. of nets:	Total length:
Total catch (kg):	BAC (Days):		Mesh sizes:
Species name	Total No.	Total Weight (kg)	Price/kg

Appendix 3: Criteria for assessing level of importance of fish species

Ecological and socio-economic attributes	Importance level		
Name of fish species (.....)	High (3)	Medium (2)	Low (1)
Ecological importance - Considers trophical level of interaction			
Socio-cultural importance - Species historically targeted due to popularity significance usage in a society)			
Economic importance – monetary value in terms of most commercial targeted species			

Appendix 4: Criteria for assessing level of sensitivity of fish species to climate change

Sensitivity characteristics			Biological Sensitivity of fish to climate change		
			High sensitivity (3)	Medium (2)	Low sensitivity (1)
Sensitivity indicators	Abundance	Fecundity (egg production)	< 100 eggs per year	100-20, 000 eggs/year	Low sensitivity (3)
		Recruitment Period (successive recruitment events sustaining the fish abundance)	Highly episodic	Occasional & variable	Consistent every 1-2 yrs
		Age at maturity	>10 years	2 - 10 year	<2 years
		General Vs specialist habitat	Reliance on both habitat and prey	Reliance on either habitat and prey	Reliance on neither habitat and prey
	Distribution	Capacity of larval dispersal/duration - hatching to settlement	<2 weeks or no larval stage	2-8 weeks	>2 months
		Physiological tolerance-latitudinal coverage of adult	$<10^0$ latitude	$10 – 20^0$ latitude	$>20^0$ latitude

		species as a proxy for Environmental Tolerance			
	Phenology	Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents and freshwater flows	Strong correlation of spawning to environmental variable	Weak correlation of spawning to environmental variable	No apparent correlation of spawning to environmental variable
		Environmental variable as a phenological cue for settlement or metamorphosis	Strong correlation to environmental variable	Weak correlation to environmental variable	No apparent correlation to environmental variable
		Temporal mismatches of life cycle events – duration of spawning, breeding or moulting season	Brief duration; <2 months	Wide duration; 2 – 4 months	Continuous duration; >4 months
		Migration (seasonal or spawning)	Migration is common for the whole population	Migration is common for some of the population	No migration

Appendix 5: Criteria for assessing impact of fish species exposure to climate change

Projections		Low = 1	Medium = 2	High = 3
Exposure indicators	Altered SST (x-y)	Adult spends <50% of time in surface (<25 m) waters	Adult spends 50-80% of time in surface (<25 m) waters	Adult spends 80-100% of time in surface (<25 m) waters
	Rainfall alterations (x-y)	Spends no time in estuarine or freshwater habitats during any life history phase	Spends <50% of time in estuarine or freshwater habitats; no critical (larvae, juvenile, spawning) life history phase in these habitats	Spends >50% of time or has critical (larvae, juvenile, spawning) part of life cycle in estuarine or freshwater habitats
	Habitat changes (loss of productivity, structure or function)	Species with wide habitat preferences	Species dependent on pelagic or mangrove/estuarine habitats	Species dependent on seagrass or coral reef habitats
	Altered river flow/nutrient supply	Spends no time in estuarine or freshwater habitats during any life history phase	Spends <50% of time in estuarine or freshwater habitats; no critical (larvae, juvenile, spawning) life history phase in these habitats	Spends >50% of time or has critical (larvae, juvenile, spawning) part of life cycle in estuarine or freshwater habitats
	Altered wind velocity and ocean currents	Live young/egg bearers or no dependence on large-scale wind/current for larval dispersal/settlement	Proximate dispersal/settlement of young not entirely dependent on large-scale wind/current dispersal	Dispersal/settlement of young 100% dependent on large-scale wind/currents