IMPACTS OF CLIMATE CHANGE AND VARIABILITY ON COASTAL AND MANGROVES DEPENDENT FISH

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EXTENDED ABSTRACT

Climate change will affect fishery resources and challenge policy makers to develop sustainable exploitation strategies. However, the information on the impacts of climate change and variability on fishery resources is still fragmentary. The present study gives an overview of literature on the impact of climate change and variability on marine environment and fish populations with a focus on the processes that govern the response of fish to marine environment and climate change. The research was conducted partly in field to assess the impacts of current climatic conditions on marine environment fish composition and recruitment patterns of mullet in mangrove ecosystem. The field work was conducted in two sites i.e. non estuarine mangroves and estuarine mangroves areas. In the laboratory the effect of projected future elevated CO_2 and temperature on hatching, survival and morphology of marine fish, sillago (*Sillago japonica*) was examined.

The first study aimed at describing site and seasonal variations in fish species in Mbegani non-estuarine mangrove (MnEM) and Ruvu estuarine mangrove (REM) sites in Bagamoyo. Variation in fish species, selected environmental parameters (i.e. dissolved oxygen, salinity, water temperature, water pH) and meteorological parameters i.e. rainfall and atmospheric temperature) were examined between the sites. Seine nets, fyke nets and gill nets were used to collect fish samples from upper, middle and lower parts of the mangrove study sites. At each sampling station, sample collection was conducted for two consecutive days per month. Analysis of data revealed that total fish catch; species number and diversity index varied greatly among stations within site. This was caused by environmental parameters which in turn were affected by rainfall and atmospheric temperature. Species specificity to habitat could also be a factor contributing to the observed variation. Fish abundance showed no significant difference ($p > 0.05$) between

seasons and sites regardless of the influence of Ruvu River which flows throughout the year. Multivariate analysis revealed significant ($p < 0.05$) separations in fish community composition among stations in two study sites. However, no clear demarcation of fish communities was observed in lower station at REM site and upper and lower stations in MnEM site. It is suggested that environmental variables such as DO, salinity and pH were the main determinant factors of community composition in Bagamoyo mangrove ecosystems.

The second study examined effect of meteorological factors on recruitment patterns i.e. annual distribution patterns and size structure of mullet of two mullet species in REM and MnEM sites in Bagamoyo mangroves ecosystem. The fish samples were collected during low tide using beach seine of 20 m long, 2 m wide with a stretched mesh size of 1.6 cm towed over an area of 100 m^2. Mullet species, counts and length were collected in two consecutive days each month from January to December of 2012. The abundance of *Mugil cephalus* and *Valamugil buchanani* varied significantly ($p < 0.05$) between sites and seasons. The mullet collected on mangroves were all juveniles and were positively correlated ($p < 0.05$) with rainfall and dissolved oxygen (DO). The atmospheric temperature had significantly ($p < 0.05$) effect on environmental parameters i.e. DO, salinity, temperature and pH which in turn affected mullet recruitment patterns. Habitat characteristics such as muddy substrate and presence of macroalgae also contributed to the distribution pattern of mullets.

The third study examined effects of elevated carbon dioxide (CO_2) and temperature on survival and morphology of Japanese whiting, *Sillago japonica*. The study was conducted at Ocean acidification laboratory at the Institute for East China Sea Research (ECSER), Nagasaki University, Japan. The study examined hatching success, survival and

morphology of the larvae of *Sillago japonica*. There were four treatments namely; (i) control (C), seawater pCO_2 382µatm, temperature 27 °C; (ii) high CO_2 (HC), 915µatm, 27 °C; (iii) high temperature (HT), 385 µatm, 31 ^{o}C; and (iv) high CO_2+high temperature (HCT), 932µatm, 31 ^{o}C. The experiment was repeated four times. Ten fertilized eggs of were incubated in each treatment for 24hrs and their hatching success determined. Fifty (50) hatched larvae were observed until the completion of yolk sac absorptions on the third day post hatching to determine effect of elevated CO_2 and temperature on survival and morphology of sillago larvae. Temperature appeared to have exerted a stronger influence on hatching success and larval survival. The hatching success and larvae survival 3 days post hatching were both significantly ($p > 0.05$) depressed in HT (52.5 ± 1.25%, 23.8 ± 4.38%) and HCT (51.3 ± 3.13%, 20.0 ± 0.63%) treatments than in Control (C) (98.1 ± 0.94%, 74.4±2.03%) and HC (95.0±2.5%, 49.7±3.44%) treatments respectively. In contrast, CO_2 was the predominant factor responsible for morphological abnormality: percentage morphological abnormality was significantly (p>0.05) higher in HC (15.8±2.72%) and HCT (41.0±10.86%) treatments than in C (0.4±0.65%) and HT (2.4±2.40%) treatments. Most individuals in HC and HCT treatments had body axis either curved or bent, with aberrant swimming behavior. These results suggest that projected future elevated CO_2 and temperature will have significant negative impacts on hatching success, larval survival and morphology of *S. japonica*, which might have serious ramifications for recruitment of the species.

DECLARATION

I, GLORIA KAVIA YONA, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

____________________ __________________

GLORIA KAVIA YONA Date

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DEDICATION

To my husband Gerald Msovela and Sons, Humphrey and Ray

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Paper 2.

Yona, G. Madalla, N., Bwathondi, P., Lamtane, H., Mwandya, AW. Mayer, I. (2017). The effect of meteorological factors on recruitment patterns of two mullet species in Bagamoyo mangroves ecosystem, Tanzania. *African Journal of Tropical Hydrobiology and Fisheries*. 15: 15-26.

Paper 3.

Yona G, Madalla N, Mwandya A, Ishimatsu A, Bwathondi P. (2016). Effects of elevated carbon dioxide and temperature on survival and morphology of Japanese whiting (*Sillago japonica). International Journal of Fisheries and Aquatic Studies*, 4(1): 341-244.

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LIST OF ABBREVIATIONS AND SYMBOLS

%	Percentage
<	Smaller than
>	Greater than
^0C	Degree Centigrade or Celsius
ANOVA	Analysis of Variance
DIC	Dissolved Inorganic Carbon
FAO	Food and Agriculture Organization of the United Nations
GLM	General Linear Model
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilogram
MnEM	Mbegani non Estuarine Mangroves
P –value	Probability value
PSU	Practical Salinity Unity
R^2	Coefficient of determination
REM	Ruvu Estuarine Mangroves
Cm	centimeter
NS	Non significant
pCO_2	Partial pressure CO_2
SST	Sea Surface Temperature
M	meter
SPSS	Statistical Package for social Science
SUA	Sokoine University of Agriculture
TAFIRI	Tanzania Fisheries Research Institute

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Climate Change

Climate change according to Intergovernmental Panel on Climate Change (IPCC) refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer (IPCC, 2007). Climate change is attributed directly or indirectly to human activity that alters the composition of the global atmosphere in addition to natural climate variability, observed over comparable time period. Several climate changes have been observed at continental, regional and ocean basin scales.

This include chances in global temperatures, ice/glacier melting, precipitation amounts, ocean salinity and wind patterns and aspects of extreme weather including droughts, heavy precipitation and the intensity of tropical cyclones. Observations show that Earth's climate has been warming due to anthropogenic activities in particular the burning of fossil fuels (coal, oil and gas) and large scale deforestation which cause emissions to the atmosphere of large amount of green house gases of which the most important is carbon dioxide (CO_2) (NASA, 2016).

The atmospheric carbon dioxide (CO_2) concentration has been relatively stable between 180 and 280 parts per million (ppm) for approximately 650 000 years before the industrial period (Siegenthaler *et al.,* 2005). Currently, the CO_2 concentration in the atmosphere ranges from 400 ppm as a result of burning fossil fuels and land use changes (Dlugokencky, 2016). The CO_2 concentration that had been increasing at a rate of 1% per year during the 20th century is now increasing to approximately at 3% per year (IPCC, 2007b).

The global average temperature has risen for 0.74^{o}C during the past 100 years (1906-2005). The warming for the next 20 years is projected to be about 0.2^{o}C per decade (United Nations Framework Convention on Climate Change (UNFCCC), 2011). Continued greenhouse gas emissions at or above current rates would cause further global warming and induce many changes in the global climate system. However, global-warming antagonists say that "the surface temperatures in the most popular data sets are skewed by what is called the urban heat island effect, whereby buildings, pavement, and other heat-retaining or heat-reflecting artifact located near monitoring stations inflated temperature values" (Ritter, 2012).

1.2 Ocean Acidification

About 48% of the anthropogenic CO_2 in the atmosphere produced during the past 200 years has been absorbed by the world's oceans (Sabine *et al.*, 2004) making them potential sink for the CO_2. The dissolved CO_2 forms carbonic acid, which readily dissociates into bicarbonate (HCO_3^-), carbonate (CO_3^{2-}) and hydrogen (H^+). Thus addition of anthropogenic CO_2 absorbed in ocean waters results in the increase production of H^+ which consequently lowers the pH and hence increased acidity (Caldeira and Wickett, 2003). Acidity is a measure of the concentration of H^+ ions and is reported in pH units, where $pH = -\log_{10}(H^+)$. A pH decrease of 1 unit means a 10-fold increase in the concentration of H^+, or acidity. This reaction ($CO_2 + H_2O \leftrightarrow H_2CO3 \leftrightarrow HCO_3^- + H^+ \leftrightarrow CO_3^{2-} + 2H^+$) is referred to as the carbonate buffering system and through this process ocean pH has remained between 8.0 and 8.3 units for the last 25 million years, despite periods of high atmospheric CO_2 concentrations (Widdicombe and Spencer, 2008). Predictions show that before the industrial period began, ocean surface water pH had fallen slightly by approximately 0.1 pH units, indicating about 29% increase in the concentration of H^+ ions compared to pre-industrial times. The ocean pH is expected to drop more by 0.3 to 0.5 pH units (Mora *et al.*, 2013). A decrease in pH by as much as 0.45 units or an equivalent of 185% increase in H^+ concentration over the 21st century is predicted for the Arctic surface waters (Steinacher *et al.*, 2009). These changes are predicted to continue rapidly as the oceans take up more anthropogenic CO_2 from the atmosphere. The global average CO_2 concentration in the atmosphere is projected to reach 1000 ppm by 2100 (SRES A1FI Scenario) (IPCC, 2007b).

The degree of change to ocean chemistry, including ocean pH, will depend on the mitigation and emissions pathways (Anderson and Bows, 2011) that the society takes (Turley, 2008). The increase in anthropogenic CO_2 concentration has been observed and quantified in several parts of the world's oceans. For instances increase of ocean anthropogenic CO_2 has already been observed in the Indian Ocean from 1978-1995 (Peng *et al.*, 1998), the Pacific Ocean from 1973-1996 (Peng *et al.*, 2003), in the Southern Ocean's Antarctic Bottom Water from 1968-1996 (McNeil *et al.*, 2001), and in bottom waters along the Indian-Atlantic boundary (Lo Monaco *et al.*, 2005). The increase in the partial pressure of CO_2 (pCO_2) in the Nordic seas from 1981-2003 has been attributed to the flow of Atlantic water from the south laden with high concentrations of anthropogenic pCO_2 and the inflow of low pCO_2 Polar water, which enhances local uptake of atmospheric CO_2 in the Nordic Seas (Olsen *et al.*, 2006).

1.2 Global Warming and its Effect on the Ocean

Global warming due to climate change in recent decades is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global sea level (Bates *et al.*, 2008). The average sea surface temperature (SST) has increased by approximately 0.7°C from pre-industrial to current situation (IPCC, 2007b). The average global SST is projected to rise by between 2.5 and 4.7°C by year 2100 when compared to industrial level, depending on the magnitude of future CO_2 emissions (IPCC, 2007b; Royal Society, 2010). It is expected that the global warming will occur most significantly in the upper 500–800 m of the Ocean (Bernal, 1993). Climate-change models predict that tropical SST will increase by up to 3°C in this century (Ganachaud *et al.*, 2011). Increasing temperature trends in Dar es Salaam Tanzania are detectable in a number of temperature indices with the most significant (at the 90% confidence level) for increasing (approximately 1^{o}C) both minimum and maximum daily temperatures (Tadross and Johnston, 2012). Also it is projected that the atmospheric temperature rise ranged from 1.0 to 1.5 for B1 scenario and 1.5 to 2.0 for A2 scenario in Dar es Salaam (Tadross and Johnston, 2012). The mean temperature anomalies in Dar es Salaam, trend shows that mean monthly temperature is increasing (Figure 1).

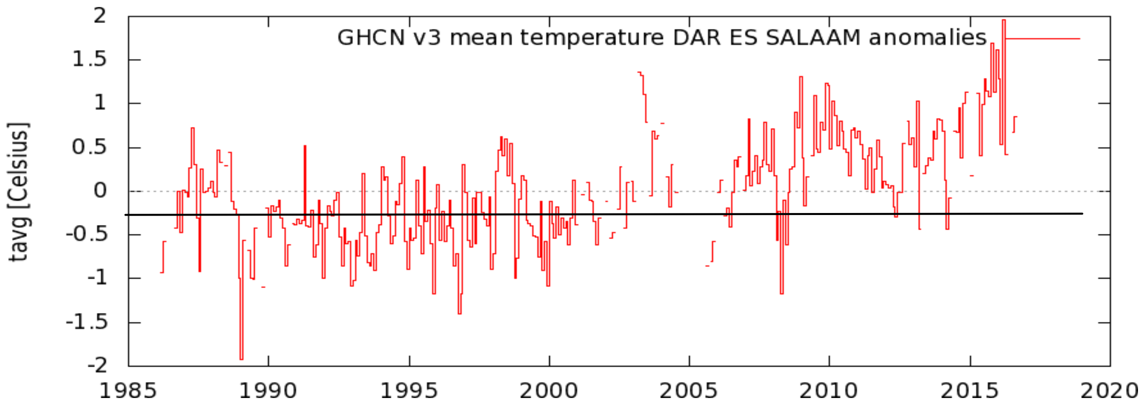

Figure 1: The mean temperature anomalies in Dar es Salaam for 1986 to 2016.
(Source: satellite data extracted from, www.climexp.knmi.nl)

Global average annual precipitation through the end of the 21st century is expected to increase although changes in the amount and intensity of precipitation will vary significantly by region (IPCC, 2013). This will be particularly pronounced in tropical and high-latitude regions, which are also expected to experience overall increases in precipitation (IPCC, 2013). Precipitation is important because its type, amount, frequency, duration and intensity affects other hydrologic processes like the amount and timing of freshwater inflow into coastal regions including mangroves area and estuarine, which in turn affects the incidence and severity of hypoxic events (Hauri *et al.*, 2009). In Dar es salaam Tanzania, the annual timescale from 1980 to 2010 there were also significant detectable trends in total rainfall decline , as well as the reduction in number of consecutive wet days, days > 10 mm rainfall and days > 20 mm rainfall (Tadross and Johnston, 2012). The monthly rainfall anomalies in Dar es Salaam trend shows that the amount of rainfall is decreasing (Figure 2).

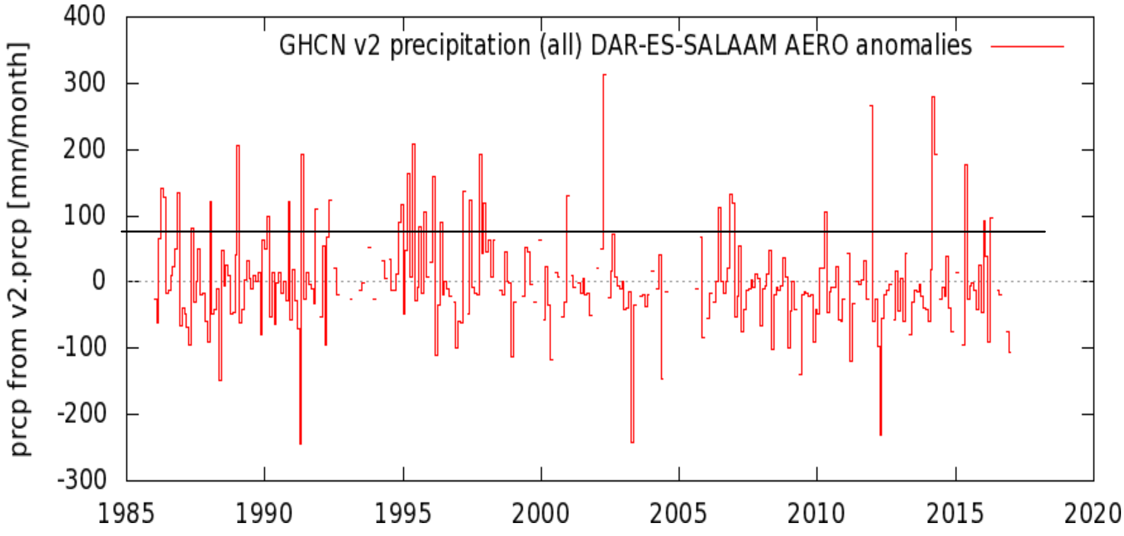

Figure 2: The mean precipitation anomalies in Dar es Salaam for 1986 to 2016 (Source: satellite data extracted from, www.climexp.knmi.nl)

Impacts of climate change exacerbate pressure on fisheries systems which already experiencing other stresses such as over fishing, loss of habitat, pollution and disturbance (Brander, 2006). In particular, small-scale fishing communities in developing countries, which constitute 90% fishery-dependent people (FAO, 2012), will face complex and localized impacts, as predicted by the IPCC with high confidence (IPCC, 2007a). These impacts can range from changes in ecosystems and fish stocks (IPCC, 2007a; Drinkwater *et al.*, 2010). Marine fish will be affected by the impacts of climate change mainly through two aspects, namely the (i) natural habitats modification and food supply (ii) changes in marine water chemistry. They provide critical ecosystem services (feeding, breeding and protection from predators) and play other vital socioeconomic and environmental functions to mankind (Spalding *et al.,* 2010). The complex structure of mangroves such as prop root and high natural food productivity are favourable environment for survival of juvenile fish (Rypel *et al.,* 2007). Mangrove ecosystems contain complex creek systems that provide protection to fish during low tide when the rest of mangrove ecosystems are exposed (Rehage and Loftus, 2007). Mangroves play an important role in reducing impacts of elevated carbon dioxide (CO_2) in the atmosphere (Alongi, 2014). The critical importance of mangroves in mitigating the effects of climate change is increasingly being recognized (Donato *et al.,* 2011).

However, these habitats are experiencing a global decline due to both human and climate induced perturbations. For instance, over 50% of the world's mangroves has been lost over the past decades (FAO, 2007), and the diversity of mangrove forests are declining rapidly (Duke *et al.,* 2007). Due to the importance of mangrove ecosystem to fish and other marine organisms, the continued degradation, loss and fragmentation of any of these habitats may pose a threat to the recruitment, persistence and sustainability of marine fish populations (Pihl *et al.,* 2005) thereby negatively impacting the socio-economic benefits of coastal communities dependent on them. Because rates of environmental change are exceptional in many instances, the impacts on marine organisms and ecosystems are likely also to be unprecedented. The growth and success of an individual species in a changing ocean depends on many environmental factors (Hauri *et al.,* 2009). The primary producers such as phytoplankton which form base of aquatic food chain are decreasing due to increase in water temperature thus reducing food availability along the food chain. The reduction of phytoplankton has been reported in higher latitudes (Gregg *et al.,* 2003) and

Pacific and Indian oceans (Polovina *et al.,* 2008). Nevertheless, temperature is an important trigger of life cycle of many marine organisms and often plays a critical role in synchronization of feeding, growth and reproduction (Creary, 2013). Whenever, these processes are not synchronized timing between occurrences of fish larvae and their prey is mismatched thus affect the survival of recruits.

The SST is predicted to stimulate migration of marine organisms based on their temperature tolerance, with heat-tolerant species expanding their range northward and those less tolerant species retreating (Creary, 2013). This change in ocean dynamics will have a deleterious effect on species that are unable to migrate and could lead to their demise. According to the IPCC AR4, about 20-30% of fish species assessed so far are at increased risk of extinction if average SST exceeds 1.5 to 2.5°C (IPCC, 2007b). If reaches 3.5°C, could be significant extinctions ranged from 40 to 70% of species assessed around the globe may occur (IPCC, 2007b). Fishes have evolved physiologically to live within a specific range of environmental variation, and existence outside that range can be stressful or fatal (Barton *et al.,* 2002). Tropical fishes are predicted to be sensitive to global warming because many appear to have a narrow thermal tolerance range (Wright *et al.,* 2009). Low dissolved oxygen (DO), or hypoxia, is another threat to marine and estuarine ecosystems worldwide. DO is inversely related to temperature, thus the predicted future increase in temperature may lead to reductions in aerobic scope (Portner *et al.,* 2002; Nilsson *et al.,* 2009). Offshore severe hypoxia less than 2 mg l^{-1} can cause mortality (Hauri *et al.,* 2009).

Sub-optimal environmental conditions can decrease foraging, fecundity, alter metamorphosis, and disrupt endocrine homeostasis and migratory behavior (Portner *et al.,* 2001). Also affects critical swimming speeds (Johansen and Jones, 2011), somatic growth

(Munday *et al.,* 2008), and reproductive output (Donelson *et al.,* 2010; Yona *et al.,* 2016), adult mortality, dispersal and connectivity (Houde, 1989). Nevertheless, increased temperature showed to favour growth rates and shorten pelagic larval duration (Takahashi *et al.,* 2012). Tropical ectothermic species may be especially vulnerable to rising temperatures because many have a narrower thermal tolerance range than equivalent temperate species (Sunday *et al.,* 2011) and tend to live closer to their thermal optimum; therefore, even relatively small increases in temperature could lead to declines in individual performance (Stillman, 2003).

Several efforts have been made to recognize the association between marine physical changes in ocean environment and biological processes which affect fish stock (Byrne *et al.,* 2002). Understanding the environmentally dependent productivity of fish stocks is necessary for the efficient utilization of marine fish resources (Pécuchet *et al.,* 2014). Meteorological parameters such as rainfall and atmospheric temperature are highly correlated with marine environmental variables (Lagade *et al.,* 2011). These are associated with marine fish recruitment variability (Heath, 2007). However, determination of effects of climate variability on fish ecosystem is complex due to its effect on multitude of environmental factors that in turn affect different levels of biological processes (Harley *et al.,* 2006). Slight changes in key environmental variables such as temperature, salinity and dissolved Oxygen (DO) can severely modify the abundance, distribution, and availability of fish populations (Olsen *et al.,* 2011; Asha *et al.,* 2015). Mullets, for example, are widely spread coastal pelagic fish occurring in the mangroves and estuaries of tropics and sub tropics. They are commercially important fish throughout the world, supporting many coastal communities' fisheries and aquaculture activities (Pillay and Kutty, 2005). They are also important forage fishes representing significant food source for upper-level piscivores (Mwandya *et al.,* 2010).

1.3 Problem Statement and Study Justification

Studies on climatic factors i.e. elevated atmospheric temperature and CO_2 which affect marine and mangroves are increasingly gaining attention. The impacts of climate change and variability in Tanzania have been mostly documented in terrestrial habitats with little attention on important marine habitats such as coral reefs, mangroves and seagrass beds. However, there is limited information linking the effect of climate change and variability on mangrove dependent fish in Tanzania.

Potential impacts of meteorological variables such as rainfall and temperature on recruitment patterns of mangroves dependent fish species have been neglected so far. Climate change has direct impact on precipitation amount, patterns and distribution which in turn influence river flow rate. Available evidence demonstrated that river flow is a critical factor in maintaining nutrient and detrital input to estuaries and mangroves, as well as preventing the development of hypersaline conditions within these systems. In addition, the nutrients support growth of micro and macro algae which are essential food for mullet and other organisms. It is reasonable to expect that on-going climatic changes may also affect a number of mangroves dependent fish species such as mullet. They are the most important animal protein sources and used aquaculture in many regions of the world. The impacts of rise in sea surface temperature (SST) and sea level have been noted in Tanzania marine waters. It was projected that the atmospheric temperature at Bagamoyo will increase by 0.85 – 1.65^0C, and the long rains occurred between March to May will decrease significantly in 2020-2040 (Besa, 2013). There is limited information on effects of meteorological parameters such as rainfall and temperature to both environmental variables, mullet abundance and how they affect mullet recruitment on mangroves ecosystem.

Furthermore, the future projected elevated CO_2 and SST has been reported elsewhere to have detrimental effect on shellfish and juvenile fish. However, little is known on their effects on hatching, survival and morphology of fish larvae with yolk sac. Since this is a very crucial stage of fish development as it is related to predator escape and resistance to starvation. Understanding of this ability can help to provide information for an ecological understanding of marine fish-larvae and help to predict the future population.

Changing fish distributions and abundances will undoubtedly affect fishing communities whose livelihood depends on these resources. Coastal-based harvesters may be impacted negatively or positively by changes in fish stocks due to climate change. These impacts can affect the range of the whole ecosystems and fish stocks (IPCC, 2007a; Drinkwater *et al.,* 2010). A detailed study on how the meteorological parameters (rainfall and temperature) and environment variables (dissolved oxygen (DO), salinity, temperature and pH) affects fish assemblages and recruitment patterns in mangroves ecosystem can provide important insights to address future impacts of Tanzanian marine fish population status and for monitoring purposes.

1.4 Study Aim and Objectives

1.4.1 Main objective

The aim of this study was to evaluate effect of climate change and variability on coastal and mangrove dependent fish. To achieve this aim, specific objectives were:

1.4.2 Specific objectives

i. To examine fish assemblages in mangrove ecosystems under prevailing climatic condition in Bagamoyo, Tanzania.

ii. The assess effect of meteorological factors on recruitment patterns of two mullet species in Bagamoyo mangroves ecosystem, Tanzania.

iii. To assess effects of elevated carbon dioxide and temperature on survival and morphology of Japanese whiting *Sillago japonica* larvae.

1.5 Thesis Structure

The thesis comprises five chapters which are briefly described as follows. Chapter one is introductory part which gives the background information of climate change and variability as well as ocean chemistry particularly ocean acidification. Impacts of climate change and variability especially elevated CO_2 and temperature on marine fish survival, migration, growth and abundance.

Chapter two investigated effects of meteorological and environmental variables on fish assemblages under non estuarine Mbegani mangroves (MnEM) site and Ruvu estuarine mangroves (REM) ecosystem in Bagamoyo District. It also examined the impacts of meteorological parameters on marine environment.

Chapter three examined the effects of climate variability on recruitment patterns of fish in Bagamoyo mangroves using *Mugil cephalus* and *Valamugil buchanani* as a case study. The study explores distribution pattern and size structure of the mullets in Ruvu estuarine mangroves and Mbegani non-estuarine mangroves ecosystem in relation to environmental conditions and meteorological parameters.

Chapter four assessed effect of elevated CO_2 and temperature on hatching, survival and morphology of *Sillago japonica* larvae.

Chapter five is concluding chapter, where it summarizes major findings practical implications as well as recommendations for further research, conservation, and fisheries management.

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CHAPTER TWO

FISH ASSEMBLAGES IN MANGROVE ECOSYSTEMS UNDER PREVAILING CLIMATIC CONDITION IN BAGAMOYO, TANZANIA

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FISH ASSEMBLAGES IN MANGROVE ECOSYSTEMS UNDER PREVAILING CLIMATIC CONDITION IN BAGAMOYO, TANZANIA

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ABSTRACT

Mangroves ecosystem play crucial role to fisheries by providing nursery, feeding and refuge areas for many fish species including commercial valuable species. This study aimed at determining variations in fish composition between sites and seasons in Mbegani non-estuarine mangrove (MnEM) and Ruvu estuarine mangrove (REM) in Bagamoyo. The study also examined the relationship between fish species composition with environmental parameters (dissolved oxygen, salinity, water temperature, water pH) and meteorological parameters (rainfall and atmospheric temperature) in MnEM and REM sites in Bagamoyo. Fish samples were collected by using seine nets, fyke nets and gill nets from three sampling stations namely; upper, middle and lower parts at each site. At each sampling station, sample collection was conducted for two consecutive days per month. The results revealed that total fish catch and species number varied greatly among stations within each site. This was suggested to be caused by variations in environmental parameters which were influenced by rainfall and atmospheric temperature. Species specific to habitat could also be among the factors contributing to the variation. Fish abundance showed no significant different ($p > 0.05$) between seasons regardless of the influence of river Ruvu. Multivariate analysis revealed significant separations in fish community composition influenced by environmental DO, salinity, temperature and pH as well as muddy and macrophyte habitat. However, there was no clear demarcation of fish communities in lower station at REM site with upper and lower stations in MnEM site, due to similarity of environmental variable. Additionally, rainfall and temperature showed significant influence on environmental variables and therefore affected fish community composition indirectly. The protection of mangrove ecosystems should be considered in the management of fishery resources, especially regarding their key role providing nursery areas, feeding and breeding ground for many commercially and ecologically fish species.

Keywords: Fish assemblages, Mangrove Ecosystems, Prevailing Climatic Condition

1. Introduction

Mangroves ecosystems provide essential goods and services to coastal communities including shoreline protection, water quality purification and provision of fishery and forest products (Alongi, 2002; Spalding *et al.,* 2010). Mangroves ecosystems play crucial roles to fisheries resources by provision of nursery, feeding and refuge areas for many fish species and crustaceans (Lugendo, 2007; Nagelkerken *et al.*, 2008) as well as providing breeding areas for some fish species (Lagade *et al.*, 2011). Mangroves have several attributes which make them an important fish habitat. These include the abundance of food resources in a form of detritus and others which are important to fish larvae, juveniles and adults (Verweij *et al.,* 2006; Rypel *et al.,* 2007). In addition, the complex structural features of mangroves, especially their prop-root system, sheltered areas and shallow water favour juvenile fish by providing them protection from predators (Verweij *et al.,* 2006; Rypel *et al.,* 2007). Mangrove ecosystems contain complex creek systems that connect the seaward edge of the embayment, estuaries or lagoons with interior landwards side of the mangrove forest. The presence of mangrove creeks provides protection to fish during low tide when the rest of mangrove ecosystems are exposed (Rehage and Loftus, 2007). The critical importance of mangroves in mitigating the effects of climate change is increasingly being recognized (Donato *et al.*, 2011). Mangroves play an important role as a carbon sink (sequestration), reducing the impacts of elevated carbon dioxide (CO_2) in the atmosphere (Alongi, 2014).

The natural environments including mangrove ecosystems and salt marshes have been undergoing extraordinary change due to global warming (Fischlin *et al.,* 2007). The climate variability at the sea directly influences marine environmental variables which in turn determine the distribution, migration and abundance of fish and other aquatic organisms (Chiba *et al.*, 2006). It is also reported that climate variability has direct effect on mangroves dependent fish distribution and abundance (Alongi, 2002; Gilman *et al.*, 2007). The increase of few degrees in atmospheric temperature will raise the water temperature and cause major hydrologic changes affecting the physical and chemical properties of water. The rise in seawater temperature has effects on early life development of marine fishes (McLeod *et al.,* 2013; Yona *et al.*, 2016). The rise is also associated with lower dissolved oxygen concentrations (DO), which can negatively impact fishery resources (Fick *et al.*, 2005). The atmospheric temperature changes also modify precipitation patterns (IPPC, 2007b). These changes may affect distribution and survival of marine fish in various ways (Cahill *et al.*, 2012). Changes in precipitation affects river discharge rates (Pejman *et al.*, 2009) which in turn alters salinity, hence strong influence on structure and composition of fish communities (Barletta *et al.*, 2005; Lugendo, 2007). Several studies have shown that the changes of marine environmental factors such as DO levels, water temperatures and pH may affect fish community structure (Roessing *et al.*, 2005; Aschan *et al.*, 2013). Overall, the deleterious impact of both anthropogenic and climate change on mangrove ecosystems are severely impacting coastal communities which rely heavily on the services provided by mangroves.

The importance of mangroves to fish communities in Tanzanian coast has been well studied (Lugendo, 2007; Mwandya *et al.*, 2009, Kimerei *et al.*, 2011). Among key variables reported structuring fish assemblages includes habitat characteristics in mangroves area like bottom substrate, water quality parameters (Lugendo, 2007; Mwandya *et al.*, 2009) and the biotic factors like predation and food availability (Mwandya *et al.*, 2009). The knowledge of fish community structure and species composition has been used for long term comparisons of changes in biological communities for management purposes and conservation (Adite *et al.*, 2013) as well as to assess environmental qualities (Rosenberg, *et al.*, 2004; Selleslagh and Amara, 2008). Therefore, the purpose of this study was to assess the effects of prevailing climatic condition on fish assemblage in mangroves at Bagamoyo District, Tanzania. Specifically, the present study was undertaken: (1) to determine variation of fish composition between sites and seasons in a non-estuarine mangrove (MnEM) and an estuarine mangrove (REM) sites in Bagamoyo, (2) to examine the relationship between the fish composition with environmental parameters (DO, salinity, water temperature and water pH) and meteorological parameters (rainfall and atmospheric temperature) in MnEM and REM sites in Bagamoyo.

2. Material and Methods

2.1. Study area

The study was conducted in Mbegani which is a non-estuarine mangrove (MNEM) and Ruvu which is an estuarine mangrove area (REM) sites in the Bagamoyo District (6°26′ S, 38°54′ E). Bagamoyo lies 75 km north of Dar-es-Salaam on the coast of Indian Ocean (Fig.1). The climate of Bagamoyo District is influenced by two major monsoon winds, namely, the Northeast (NE) and Southeast (SE) monsoons. The NE monsoon (October to March) is characterized by high air temperature, low wind speeds and consequently calmer sea. In contrast, during the SE monsoons (April to September), the air temperature is low, the sky is cloudy, the wind is stronger and the sea is rough. These two monsoon winds bring two pronounced rainy seasons, long rainfall period from March to May and short rainfall period from October to December while the rest of the time is dry (Francis *et al.,* 2000). The annual rainfall ranges from 750 to 1500 mm (Richmond, 2002). Nevertheless, currently the rainfall pattern and amount of rainfall in Bagamoyo District and surrounding areas has changed presumably due to the impacts of climate change and climate variability (Mahenge *et al.*, 2011; Mahenge and Katikiro, 2013). The annual seawater temperature and salinity is normally in the range of 20 - 30^{0}C and 35 – 36 psu respectively throughout the year (Richmond, 2002). The salinity in estuarine and non-estuarine mangrove habitats normally ranges from 5 to 36 psu depending on freshwater input and tidal patterns (Lugendo, 2007; Mwandya *et al.,* 2009).

In case of 2012, the year of sampling, the drought period was prolonged. Therefore, two main seasons were identified, a wet season (March through May) which received more than average (46.5mm) rain per month and dry season (remaining months) which received less than average rain per month (Table 1).

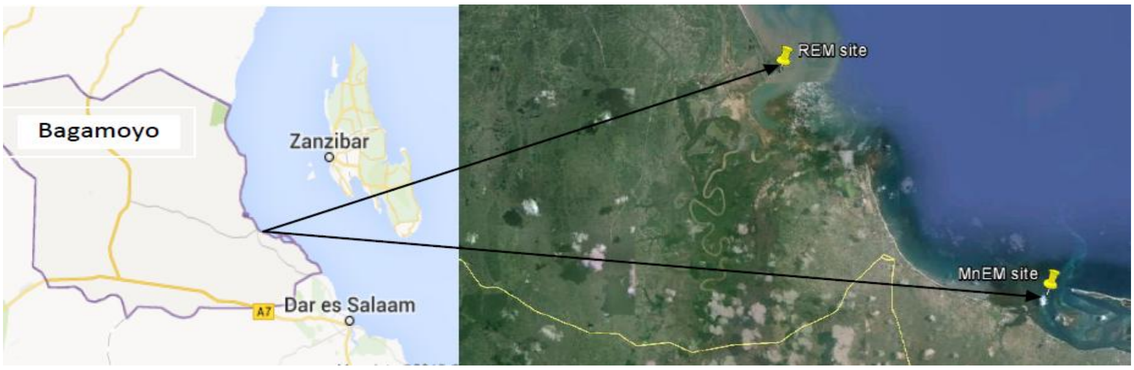

Figure 1: Location of study sites, Bagamoyo District, Tanzania. Source: Google map

Table 1: The meteorological parameters the rainfall and temperature distribution in Bagamoyo district recorded in 2012 (n=12)

Variables	Rainfall (mm)	Temperature (^oC)
Mean	46.5	31.7
Maximum	135	35
Minimum	1.1	29.9
Standard deviation (SD)	43.5	1.5

(Source: Tanzania Meteorological Agency (TMA) Dar es Salaam, 2012)

The mangrove forest in the Mbegani non-estuarine mangrove (MnEM) is lined with a large tidal creek which never dries, even during low spring tide. The creek ends into a landward stream (Nyanza River) which is a source of freshwater into the mangrove forest during the rainy season. The most dominant mangrove species at the seaward side of the forest is *Sonneratia alba* (Kimerei *et al.*, 2011), while the upstream margins of Nyanza creek is dominated by *Avicennia marina* and *Xylocarpus granatum* (Mwandya *et al.*, 2010). In the Ruvu estuarine mangrove area (REM) *S. alba* forms pure stands on the seaward side of the river mouth while *Heritiera littoralis* is a riverside mangrove species that grows only in habitats with low salinity and found on the upper part of the river (Semesi *et al.*, 2001).

2.2. Sampling and data collection

Fish samples were collected monthly from January to December, 2012 (except July) from both the MnEM and REM sites. At each site, three sampling stations were established which represented an upper part i.e. upper Mbegani (UM) and upper Ruvu (UR) (away from the sea), middle i.e. middle Mbegani (MM) and middle Ruvu (MR), and lower part i.e. lower Mbegani (LM) and lower Ruvu (LR) (close to the sea) respectively. The selected stations at both mangrove sites differed in their physico-chemical characteristics (Table 2), bottom substrate and water depth (Table 3).

Table 2: Environmental characteristic (Mean value ±SD) of different mangrove habitat, depth and distance from the sea

Environmental variables	Site					
	REM			MnEM		
	UR	MR	LR	UM	MM	LM
Dissolved Oxygen (DO)	4.4±0.6	4.5±0.7	4.9±0.5	4.8±0.4	4.3±0.6	5.0±0.5
Temperature	29.9±0.5	30.2±1.2	30.3±4.6	30.7±0.9	29.8±1.0	30.7±0.9
Salinity	21.0±4.9	24.2±4.1	29.4±4.8	29.7±5.4	29.1±5.4	30.2±5.3
pH	7.9±0.1	7.9±0.1	8.1±0.1	8.0±0.1	8.0±0.1	8.1±0.1

REM = Ruvu estuarine Mangroves, MnEM = Mbegani non Estuarine Mangroves, UR = Upper Ruvu, MR = Middle Ruvu, LR = Lower Ruvu, UM = Upper Mbegani, MM = Middle Mbegani, LM = Lower Mbegani

Table 3: Bottom substrate (Mean value ±SD) of different mangrove habitat, depth and distance from the sea

Bottom substrate	Site					
	REM			MnEM		
	UR	MR	LR	UM	MM	LM
Mud (%)	60	65	35	45	60	5
Sand (%)	35	25	40	35	25	25
Coralline (%)	0	0	5	15	0	45
Seagrass (%)	5	10	20	5	15	25
Maximum depth (m) at high tide	0.6m	0.9m	1.1m	0.4m	0.7m	1.2m

REM = Ruvu estuarine Mangroves, MnEM = Mbegani non Estuarine Mangroves, UR = Upper Ruvu, MR = Middle Ruvu, LR = Lower Ruvu, UM = Upper Mbegani, MM = Middle Mbegani, LM = Lower Mbegani

Water quality parameters, including dissolved oxygen (DO), salinity, temperature and pH were measured prior to fish sampling at each station by using YSI 6600 V2-4 water-quality multi-probe (YSI, Yellow Springs, Ohio, USA). The atmospheric (Atm) temperature and rainfall parameters data for Bagamoyo during 2012 were obtained from Tanzania Meteorological Agency (TMA), Dar es Salaam. At each sampling station, sample collection was conducted for two consecutive days per month.

2.3. Description on fish sampling

Fish samples were collected during both low and high tide using gillnets, fyke nets and seine nets. The three different fishing gears were used in order to obtain an accurate estimation of the fish composition at each site. Seine net with a dimension of 20 m length, 2 m height, and 1.6 cm mesh size was deployed immediately adjacent to the mangrove forest. At each station, two hauls were performed in quick succession with a sampled area of $100m^2$. Two monofilament gillnets (100 m length, 4 m height) consisting of 4 nets of different mesh sizes (1, 1.5, 2.5 and 4 cm) were set perpendicular to the mangroves at the REM site and across the deepest part of the creek at the MnEM site. Floaters and sinkers were attached to the upper and lower parts of gill net respectively to ensure that the net remained stretched from the bottom upwards. Two fixed fyke nets were set at the mouth of tributaries entering the river Ruvu from the mangroves, and on small creek outlets from mangroves at daytime slack high water. The fyke net consisted of two wings (10m length × 2m width, 1.8 cm stretched mesh size) and a fyke net body (two circular stainless steel hoops; total length: 4.5 m; 1.8 cm stretched meshed size) connected by an inlet funnel. The fish were collected from the fyke net body during ebb tide. The fish catch from each station were humanely killed by a blow to the head and placed in a labelled plastic bag and kept on ice before being transported to the laboratory. In the laboratory fish were sorted, identified and counted. Specimens were identified to the lowest possible taxonomic level by the aid of identification books (Bianchi, 1985).

2.4. Statistical data analysis

The variations in fish catch, species number and marine environmental parameters (DO, salinity, temperature and pH) among stations were tested using one-way ANOVA, whereas between seasons and sites variations were tested using t-test. Before analysis data were first tested for homogeneity of variance using Levene's test. Multiple comparisons were performed using Tukey's test for data that showed homogeneity of variance and when equal variance were not assumed even after transformation (Square root or log (X+1) the Gomes-Howell test was used. Gomes-Howell post hoc test was used following the Kruskal-Wallis test because it is more powerful and specifically designed for lack of homogeneity of variance (Field, 2000).

The similarity on fish species compositions were assessed using non-metric multidimensional scaling (nMDS) (PRIMER package; Clarke and Warwick, 1994). The original data containing the total individual fish number both sites and all species were

$Log_{10}(X+1)$ transformed to generate the Bray-Curtis similarity matrix. The data were Log(X+1) transformed to reduce weight influence of most dominant species.

To examine the relationship between fish catch and species number with environmental variables (i.e. DO, salinity, temperature and pH) between sites, two sets of Pearson bilateral correlation were performed. The Linear regression analyses of environmental and meteorological parameters were performed based on partial correlations procedure computed to show the association of the separate independent variables with dependent variable, while controlling for the effects of one or more additional variables. These analyses were performed using SPSS for windows (Field, 2000). Significance level of 0.05 was used in all tests.

3. Results

3.1. Marine environmental variables

Water salinity showed significant difference (t-test, df= 64, p = 0.001) between sites, whereas water temperature, DO and water pH showed no significant difference (t-test, p > 0.05) between REM and MnEM sites. The DO, salinity and pH showed significant (t-test, df= 64, p = 0.000 for all variables) variations between seasons, while water temperature showed no significant (t-test, df= 64, p = 0.05) variation between season. The DO was high during wet season while the salinity and pH decreased during wet season. The averages of measured environmental parameters i.e. DO, salinity, water temperature and water pH is shown in Table 4.

Table 4: One way ANOVA multiple comparisons (Gomes-Howel) of environmental variable among station in each sites

Stations	Sites			
	REM		MnEM	
	Mean catch	Total Species	Mean catch	Total Species
U	82±21**	17±3*	146±32NS	33±6*
M	42±22**	11±5*	77±27**	11±1**
L	345±123**	41±7**	204±56NS	41±5*

REM = Ruvu estuary Mangroves; MnEM = Mbegani non Estuarine Mangroves. Different letter along the column in each site shows significant different at $p<0.05$

3.2. Variations in fish catch and species number between sites

In total, 9941 individual fish were collected and identified to species and genera level. They were found to belong to 85 species from at least 42 families (appendix 1). The total fish catch and species number showed significant difference among stations in each site. However, they showed no significant difference between sites and seasons. In both sites, lower stations had significantly higher mean fish catch and species number compared to the other stations (Table 5). However, UM and LM stations in MnEM site showed no significant difference in mean fish catch (Table 5).

Table 5: One way ANOVA multiple comparisons (Gomes-Howel) of average fish catch and total species of the fish collected at REM and MnEM site

	REM Site		MnEM Site	
Stations	**Mean catch**	**Total Species**	**Mean catch**	**Total Species**
U	82±21**	17±3*	146±32NS	33±6*
M	42±22**	11±5*	77±27**	11±1**
L	345±123**	41±7**	204±56NS	41±5*

** Significant at 0.01 levels; * Significant at 0.05 levels; NS correlation is not significant at 0.05 levels along the column. REM = Ruvu estuarine Mangroves, MnEM = Mbegani non Estuarine Mangroves, U = Upper; M = Middle and L = Lower, Data are combined samples from gillnet, seine and fyke net

The fish species dominated were *Apogon* spp, *Ambassis gymnocephalus, Mugil cephalus, Lutjanus fulviflamma, Hemiraphus far, Gerres filamentosus, Gerres oyena, Valamugil buchanani, Monodactylus argenteus, Leiognathus equulus* in UM and LM stations of MnEM site were similar in LR station in REM site (Table 6).

Table 6: Dominant Mangrove fish species in percentage contribution of total catch found in LR station in REM site, in UM and LM and stations in MnEM site

Dominant species	LR station	UM station	LM station
Apogon spp	8.82	11.19	6.46
A. gymnocephalus	8.29	8.77	6.45
M. cephalus	7.07	5.46	6.48
L. fulviflamma	6.78	6.18	4.62
H. far	5.99	5.12	3.34
G. filamentosus	5.04	2.16	5.49
G. oyena	4.89	5.51	6.10
Valamugil spp	4.98	1.48	2.89
M. argenteus	4.88	1.06	4.96
L. equulus	4.86	4.43	3.38

REM = Ruvu estuarine Mangroves, MnEM = Mbegani non Estuarine Mangroves, LR = Lower Ruvu, UM = Upper Mbegani, LM = Lower Mbegani

In general there was greater overall distribution in fish species between mangrove sites however 17 species showed site specific occurrence. Nine (9) species appeared only in REM site and eight (8) species appeared only in MnEM site (Appendix 1). The UR, MR and MM stations were dominated with different fish species (Table 7).

Table 7: Dominant Mangrove fish species in percentage contribution of total catch found in Bagamoyo mangrove ecosystem, REM and MnEM site and stations

Fish Species in mangrove	Percentage contribution to total catch
Ambassis gymnocephalus	10.84
Apogon spp.	10.79
Gerres oyena	6.98
Mugil cephalus	6.35
G. filamentosus	6.07
Arothrons spp.	5.45
Lutjanus fulviflamma	3.81
Hemiramphus far	3.61
Monodactylus argenteus	3.12
Valamugil spp.	2.94
Leiognathus equulus	2.83
Dominant Fish Species in UR station in REM site	**Percentage contribution to total catch**
A. gymnocephalus	13.51
Apogon spp.	11.80
G. oyena	10.54
G. filamentosus	9.21
Scomberoides commersonnianus	6.79
Dominant Fish Species in MR station in REM site	**Percentage contribution to total catch**
Arius spp.	35.07
Sillago macullatus	10.33
A. gymnocephalus	6.60
Hilsa kelee	5.35
Apogon spp.	5.22
Dominant Fish Species in MM station in MnEM site	**Percentage contribution to total catch**
Arothrons spp.	49.47
A. gymnocephalus	12.40
Apogon spp.	6.85
G. filamentosus	5.79

REM = Ruvu estuarine Mangroves, MnEM = Mbegani non Estuarine Mangroves, UR = Upper Ruvu, MR = Middle Ruvu, MM= Middle Mbegani

3.3. Community structure

The non-metric multidimensional (nMDS) ordination scaling plots showed similar patterns based on fish species similarity. Four groups were illustrated separately, groups one and two consisted of mainly fish samples collected in UR and MR stations in REM site and the third group consisted of mainly fish samples collected in MM station in MnEM site. The fourth group consisted of fish sampled at LR station in REM site, UM and LM stations in MnEM site (Figure 2).

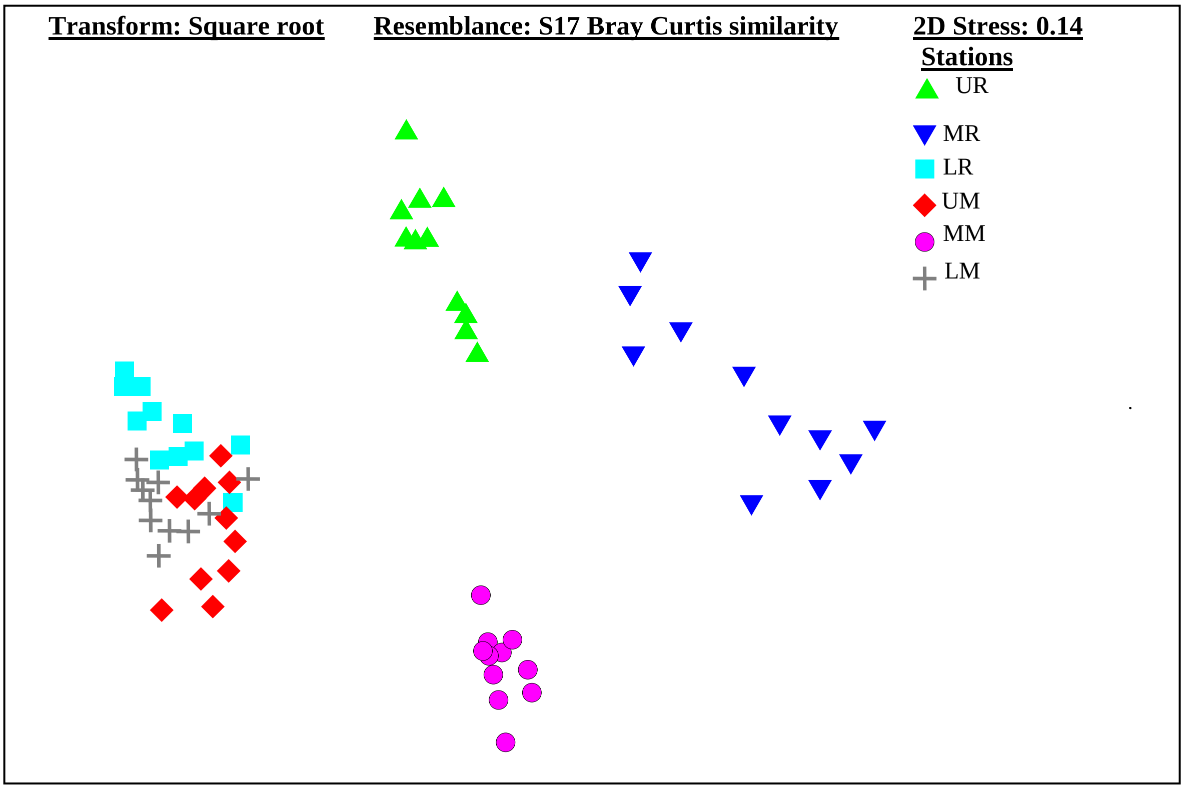

Figure 2: Non-Metric multi-dimensional scaling (nMDS) ordinations of fish assemblage structure separated in different stations according to fish species. The plot based on Bray-Curtis similarities index using Log(X+1) transformed data for fish catch UR = Upper Ruvu, MR = Middle Ruvu, LR = Lower Ruvu, UM = Upper Mbegani, MM = Middle Mbegani, LM = Lower Mbegani

3.4. Correlation between fish catch, marine environmental and meteorological variables

The Pearson bilateral showed significant positive correlation (Pearson two-tailed, $p < 0.05$) between DO and pH with total fish catch and total species number. However, salinity and water temperature did not show significant (Pearson two-tailed, $p > 0.05$)

correlation with fish catch but significant (Pearson two-tailed, $p < 0.05$) correlation with total species (Table 8).

Table 8: Pearson Bilateral Correlations between marine environmental and meteorological variables and fish variables at mangrove ecosystem in Bagamoyo

Variables	Fish Catch	Total species	Rainfall	Atm Temp
Dissolved Oxygen	0.488**	0.462**	0.601**	0.276*
Salinity	0.330	0.236*	0.588**	0.480**
Water Temperature	0.175	0.336**	0.104	0.597**
pH	0.306**	0.397**	0.405**	0.427**

** Correlation is significant at 0.01 levels (2 tailed); * Correlation is significant at 0.05 levels (2 tailed). Atm = Atmospheric, Temp = Temperature

3.5. Relationship between environmental and meteorological parameters

Multiple linear regression analysis revealed significant ($R^2 = 0.57$, $p = 0.000$; $R^2 = 0.55$, $p = 0.000$) relationship between rainfall and atmospheric temperature with environment variables. The coefficient of regression for rainfall showed significant positive ($p = 0.000$, $p = 0.028$) relationship with DO and water temperature respectively and significant negative ($p = 0.029$) relationship with salinity. The coefficient of regression for atmospheric temperature showed only significant positive ($p = 0.000$) relationship with water temperature. Surprisingly, neither rainfall nor atmospheric temperature showed significant relationship with water pH. Multiple linear regression analysis showed that neither rainfall nor atmospheric temperature had significant ($R^2 = 0.052$, $p = 0.341$; $R^2 = 0.092$, $p = 0.111$) relationship with fish catch and species number respectively.

4. Discussion

The present study provides the information about fish composition in relation to environmental and meteorological parameters in Mbegani non-estuarine (MnEM) and Ruvu estuarine mangrove (REM) sites at Bagamoyo District Both sites support many fish species, but dominated by few species, which is a general characteristic of mangroves ecosystem (Tzeng and Wang 1992, Lugendo, 2007; Mwandya *et al.*, 2009). The dominant species included *Ambassis gymnocephalus*, *Apogon* spp., *Gerres oyena*, *G. filamentosus*, *Mugil cephalus*, *Arothron* spp., *Lutjanus fulviflamma*, *Hemiramphus far*, *Monodactylus* *argenteus, Valamugil* spp. and *Leiognathus equulus*. These species were also reported in mangroves ecosystem of Chwaka bay, Zanzibar (Lugendo *et al.,* 2007), Tudor creek in Kenya (Little *et al.,* 1988). The higher number of fish species could be attributed by a combination of factors provided by mangroves such as food availability, presence of suitable refuge sites and optimal growing conditions (2001; Verweij *et al.,* 2006; Rypel *et al.,* 2007).

In the present study lower stations, close to the sea had more fish catch compared to other stations in both sites. This could suggest that the fish species inhabiting mangroves originated from the sea. It is known that most of mangrove dependent fish spawn offshore and then fish larvae are transported to mangroves area by ocean currents and diffusion caused by tidal currents (Tzeng and Wang 1992). However, our results are contrary to what was reported by Mwandya *et al.* (2009) on similar study conducted in MnEM site which showed higher fish density and species number at the upper and intermediate stations compared to lower station. The observed differences could be due to rise in marine water temperature. For instance, during 2005 at MnEM site water temperature ranged from 29.0^{o}C to 32.7^{o}C (Mwandya *et al.,* 2007) and during this study, the water temperature ranged between 29.9 ^{o}C to 35.0^{o}C, thus an increase of 0.9 - 2.3^{o}C. In another study, Richmond (2002) reported lower temperature in Bagamoyo ranged from 20^{o}C to 30^{o}C, which is lower than 5 - 9.9^{o}C compared to that recorded in this study. Temperature is recognized as a key regulator in marine life through its control of metabolism, and its influence on development and ontogenetic plasticity in fish larvae (Dionisio *et al.,* 2012; Pankhurst and Munday, 2011). High temperature affects eggs hatching and survival of young marine fish (McLeod *et al.,* 2013; Gagliano *et al.,* 2007; Kearney *et al.,* 2009; Yona *et al.,* 2016). The change in meteorological variables at Bagamoyo coastal waters was not only limited to temperature but was also noticeable in rainfall. During the present study there was prolonged drought and the annual rainfall was 558.3 mm which was lower than what was reported in previous years. For example Richmond (2002) reported that average annual rainfall ranged from 700 mm to 1500 mm in Bagamoyo coastal area. The little amount of rainfall and changes of rainfall patterns were also reported by FEWS NETS, (2012) that the northern coastal area of Tanzania including Bagamoyo District will likely receive little rainfall below the average. This was also reported by Mahenge *et al.,* (2011) and Mahenge and Katikiro, (2013) that currently the rainfall pattern and amount of rainfall in Bagamoyo District and surrounding areas has changed presumably due to the impacts of climate change and seasonal variability. The meteorological variation could affect the distribution and amount of fish as well as species number in the surveyed area.

Such variations in atmospheric temperature and rainfall are closely linked with marine environment variables. For instance, rainfall had significant positive correlated with DO and negatively correlation with salinity and water pH. Likewise, the atmospheric temperature was positively correlated with water temperature. These changes of marine environmental parameters have greater influence in total fish catch and species number. Environmental variables were also reported elsewhere as the primary determinant of fish distribution and diversity in mangrove habitats (Tzeng and Wang 1992; Barletta *et al.,* 2005; Roessing *et al.,* 2005; Lugendo, 2007; Mwandya *et al.,* 2010; Aschan *et al.,* 2013). It has also been reported that rainfall/freshwater runoff is a critical factor in maintaining nutrient and detritus input to mangroves and estuaries, as well as preventing the development of hypersaline conditions within these systems (Salen-Picard *et al.,* 2002; Meynecke *et al.,* 2006). The nutrients favor phytoplankton growth and hence increase DO in water through photosynthesis process (Robin, *et al.,* 2011) which support marine life. However, multiple linear regressions showed neither rainfall nor atmospheric temperature to have relationship with fish variables. This could be due to the fact that rainfall was far below the average value in that area to influence the fish variables. Nevertheless, atmospheric temperature was also reported elsewhere to have no measurable influence on tropical fish catch (Smith, 1990, Meynecke *et al.,* 2006). This could be attributed to the narrow range of temperature in tropics throughout the year to show a significant relationship.

Additionally, the nMDS fish grouping in lower Ruvu (LR) station in Ruvu estuarine mangroves (REM) site showed no significant demarcation of fish grouping in upper Mbegani (UM) and lower Mbegani (LM) stations at Mbegani non Estuarine mangroves (MnEM) site. This grouping suggests to be influenced by environmental DO, salinity, temperature and pH as well as muddy and macrophyte habitat. This was also reported elsewhere that environmental parameters and habitat characteristics were the main factors for structuring and diversity of fish assemblages in mangroves (Lugendo *et al.,* 2006; Mwandya *et al.*, 2009; Kantoussan, *et al.*, 2012).

5. Conclusion and recommendation

The current weather conditions i.e. rainfall and atmospheric temperature did not show any direct effect on fish assemblages in mangroves ecosystem. However, is current weather condition showed directly corrected with environmental variable such as DO; salinity, water temperature and pH. Rainfall was positively correlated with DO but negatively correlated with salinity and pH. Atmospheric temperature was positively correlated with water temperature, salinity and pH but negatively correlated with DO. Fish assemblages were rather influenced by the environmental parameters and habitat characteristics.

It is recommended that other stressors such as environmental pollution, overfishing, deforestation and uses of illegal fishing gears which exacerbate impact of climate change should be controlled.

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Appendix 1: Mangrove fish families/species total catch and percentage contribution found in Bagamoyo mangrove forest

Family	Species	REM SITE		MnEM Site	
		Catch	%contribution	catch	%contribution
ACANTHURIDAE	*Acanthurus bleekeri*	18	0.34	67	1.42
	Acanthurus dusumieri	43	0.82	76	1.61
AMBASSIDAE	*Ambassis gymnocephalus*	644	12.34	424	8.98
APOGONIDAE	*Apogon spp.*	580	11.11	483	10.23
ARIIDAE	*Arius spp.*	96	1.84	00	0.00
ATHERINIDAE	*Atherion africanus*	00	0.00	9	0.19
	Hypoatherina temminckii	00	0.00	88	1.86
BELONIDAE	*Strongylura leiura*	12	0.23	11	0.23
BOTHIDAE	*Bothus pantherinus*	25	0.48	39	0.83
CARANGIDAE	*Caranx papuensis*	77	1.48	5	0.11
	Caranx sexfasciatus	41	0.79	18	0.38
	Gnathanodon speciosus	69	1.32	11	0.23
	Scomberoides commersonnianus	74	1.42	00	0.00
	Trachinotus spp.	103	1.97	11	0.23
CHANIDAE	*Chanos chanos*	17	0.33	14	0.30
CLUPEIDAE	*Amblygaster leiogaster*	8	0.15	44	0.93
	A. sirm	19	0.36	16	0.34
	Dussumieria acuta	00	0.00	6	0.13
	Herklotsichthys punctatus	00	0.00	5	0.11
	H. quadrimaculatus	23	0.44	19	0.40
	Hilsa kelee	38	0.73	10	0.21
	Pellona ditchella	46	0.88	23	0.49
	Sardinella albella	16	0.31	23	0.49
	S. melanura	31	0.59	38	0.80
	S. gibbosa	24	0.46	9	0.19
	Spratelloides gracilis	00	0.00	76	1.61
CYNOGLOSSIDAE	*Paraplagusia bilineata*	33	0.63	17	0.36
DREPANIDAE	*Drepane punctata*	19	0.36	00	0.00
ELOPIDAE	*Elops machnata*	23	0.44	9	0.19
ENGRAULIDAE	*Stolephorus heterolobus*	31	0.59	49	1.04
	S. punctifer	24	0.46	44	0.93
	Thryssa baelama	24	0.46	39	0.83
	T. setirostris	14	0.27	53	1.12
	T. vitrirostris	32	0.61	47	1.00
GERREIDAE	*Gerres oyena*	334	6.40	354	7.50
	Gerres filamentosus	295	5.65	303	6.42
GOBIIDAE	*Glossogobius spp.*	56	1.07	26	0.55
	Amblygobius spp.	72	1.38	15	0.32
HAEMULIDAE	*Pomadasys commersonnii*	48	0.92	37	0.78
	Plectorhinchus spp.	23	0.44	7	0.15
HEMIRAMPHIDAE	*Hemiramphus far*	230	4.41	126	2.67
HOLOCENTRIDAE	*Myripristis randalli*	13	0.25	18	0.38
	Neoniphon argenteus	14	0.27	34	0.72

Family	Species	REM SITE Catch	%contribution	MnEM Site catch	%contribution
LABRIDAE	*Hologymnosus anulatus*	00	0.00	36	0.76
	Cheilio inermis	10	0.19	6	0.13
	Thalassoma fuscum	00	0.00	8	0.17
LEIOGNATHIDAE	*Gazza minuta*	50	0.96	34	0.72
	Leiognathus equulus	163	3.12	116	2.46
	L. fasciatus	21	0.40	20	0.42
	L. elongates	16	0.31	9	0.19
	Secutor insidiator	31	0.59	31	0.66
LETHRINIDAE	*Lethrinus spp.*	7	0.13	9	0.19
LUTJANIDAE	*Lutjanus fulviflamma*	215	4.12	160	3.39
	L. argentimaculatus	47	0.90	31	0.66
	Lutjanus spp.	19	0.36	47	1.00
MEGALOPIDAE	*Megalops cyprinoides*	9	0.17	00	0.00
MONODACTYLIDAE	*Monodactylus argenteus*	160	3.07	147	3.11
MUGULIDAE	*Mugil cephalus*	368	7.05	258	5.46
	Valamugil spp.	183	3.51	107	2.27
MULLIDAE	*Paraupeneus spp.*	13	0.25	49	1.04
	Upeneus spp.	20	0.38	42	0.89
NEMIPTERIDAE	*Scolopsis vosmeri*	3	0.06	50	1.06
	Nemipterus japonicus	6	0.11	3	0.06
PLATACIDAE	*Platax orbicularis*	30	0.57	31	0.66
POMACANTHIDAE	*Pomacanthus spp.*	6	0.11	22	0.47
RANCHYNTRIDAE	*Ranchycentron canadum*	10	0.19	13	0.28
SCARIDAE	*Scarus ghobban*	16	0.31	79	1.67
SCIAENIDAE	*Umbrina spp.*	47	0.90	10	0.21
	Johnieops spp.	25	0.48	00	0.00
SCOMBRIDAE	*Auxis thazard*	21	0.40	00	0.00
SERRANIDAE	*Epinephelu species*	28	0.54	18	0.38
	Epinephelus malabaricus	38	0.73	7	0.15
	Promicrops lanceolatus	28	0.54	12	0.25
SIGANIDAE	*Siganus spp.*	48	0.92	10	0.21
SILLAGINIDAE	*Sillago sihama*	34	0.65	14	0.30
	S. maculate	20	0.38	00	0.00
SPARIDAE	*Acanthopagrus spp.*	51	0.98	00	0.00
	Rhabdosargus sarba	3	0.06	00	0.00
SPHYRAENIDAE	*Sphyraena barracuda*	00	0.00	40	0.85
SYNODONTIDAE	*Saurida gracillis*	7	0.13	21	0.44
	S. tumbil	4	0.08	17	0.36
TERAPONIDAE	*Terapon spp.*	26	0.50	56	1.19
	Pelates quadrillineatus	22	0.42	6	0.13
TETRAODONTIDAE	*Arothron spp.*	68	1.30	469	9.93
UNKNOWN	*unidentified spp.*	57	1.09	31	0.66
Total individual	**9941**		**5219**		**4722**
Total species	**84**		**77**		**76**
Total family	**42**		**40**		**37**

CHAPTER THREE

THE EFFECT OF METEOROLOGICAL FACTORS ON RECRUITMENT PATTERNS OF TWO MULLET SPECIES IN BAGAMOYO MANGROVES ECOSYSTEM, TANZANIA

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The Effect of Meteorological factors on Recruitment Patterns of two mullet species in Bagamoyo Mangroves Ecosystem, Tanzania.

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Abstract
We studied the annual distribution patterns and size structure of mullet fish in Ruvu Estuarine Mangrove (REM) and Mbegani non Estuarine Mangroves (MnEM) areas of Bagamoyo Tanzania in relation to meteorological parameters. Mullets were collected during low tide using beach seine of 20 m long, 2 m wide with a stretched mesh size of 1.6 cm towed over an area of about 100 m^2. Two mullet species, *Mugil cephalus* and *Valamugil buchanani* were found in study area varied significantly in terms of abundance between sites and between seasons. The *M. Cephalus* abundance was signicantly higher in REM site than in MnEM sites (Kruskal Wallis, $p < 0.024$). The abundance of *M. cephalus* and *V. buchanani* were significantly higher during rainy season than dry season ((Kruskal-Wallis, $p < 0.020$; $p < 0.001$) respectively. The mullet collected on mangroves area were all juveniles and were positively correlated (($p < 0.05$) with rainfall and dissolved oxygen. However, they were indirectly correlated (($p < 0.05$) with atmospheric temperature which significantly affects other environmental parameters and in turn affect mullet recruitment patterns. Understanding the relationships among meteorological factors, environmental parameters and mullet recruitment patterns can be useful for forecasting future success of fishery and mariculture progress in Tanzania.

Keywords: Climate variability, Mangroves ecosystems, Mullet fish, Recruitments patterns

Introduction

Mullets are widely spread coastal pelagic fish occurring in the mangroves and estuaries areas of tropics and sub tropics. They are commercially important fish throughout the world, supporting many coastal communities both from capture fisheries and aquaculture industries (Pillay and Kutty, 2005). Mullets are the most important forage fishes representing significant food source for upper-level piscivores

(Mwandya *et al.,* 2010). They are catadromous fish and therefore recruit in lagoons, coastal waters, mangroves and estuarine areas following a period of offshore spawning (Ditty and Shaw, 1996). The mullet can reach a maximum standard length (SL) of 120 cm, with a maximum weight of 8 kg. The length at first maturity is 36 cm SL (Froese, *et al.,* 2014)

Recruitment is an important component of population dynamics and plays an essential role in the abundance of organism because the survival of juveniles influences adult population (Aburto-Oropeza, *et al.,* 2007). Understanding and predicting recruitment pattern of fish larvae is considered as stepping-stone for appropriate and effective fisheries management (Svendsen *et al.,* 2007; Botsford *et al.,* 2009) and biodiversity conservation (Jones *et al.,* 2007; Almany *et al.,* 2009). The recruitment variability in life history of pelagic fish, especially those with short life spans and plankton feeders, makes their populations sensitive to climate fluctuations (Aburto-Oropeza, *et al.,* 2007). Recruitment variability plays a principal role in determining patterns of population density and community structure (Svensson *et al.,* 2006).

Meteorological parameters such as rainfall and atmospheric temperature are highly correlated with marine environmental variables (Meynecke *et al.,* 2006; Lagade *et al.,* 2011). These are associated with marine fish recruitment variability (MacKenzie and Koster 2004), distribution and abundance of fish (Weijerman *et al.,* 2005; Heath, 2007).

Several efforts have been made to recognize the association between physical changes in ocean environment and biological processes which affect fish stock (Byrne *et al.,* 2002). However, the association has been difficult to understand as large numbers of environmental variables which have been tested for correlation with recruitment resulted into highly spurious correlation (Mwandya *et al*., 2009). The impacts of rise in sea surface temperature (SST) and sea level have been noted in Tanzania marine waters. It was projected that the atmospheric temperature at Bagamoyo will increase by 0.85 – 1.65^{0}C, and the long rains occurred between March to May will decrease significantly in 2020-2040 (Besa, 2013).

Currently, little is known on how meteorological parameters affect mullet abundance on mangrove habitat areas as rainfall lowers marine salinity. In addition, runoff water brings nutrients to the mangroves area which in turn favours growth of micro and macro algae which are essential food for mullet and other organisms. Also through photosynthesis, dissolved oxygen (DO) in mangrove environments increases which is important in supporting marine life. Therefore, it is important to evaluate the effects of meteorological parameters to both mullet abundance and environmental variables, and how they affect mullet recruitment.

The current study examines distribution pattern and size structure of mullets in Ruvu estuarine and Mbegani non-estuarine mangroves ecosystems in relation to environmental conditions and meteorological parameters.

Material and Methods

Study Area

The study was conducted at two mangrove systems of Bagamoyo District, namely Ruvu which is an estuarine Mangroves area (REM) (6^{o}22'S, 38^{o}51'E) and Mbegani which is non Estuarine Mangroves (MnEM) (6^{o}27'S, 38^{o}58'E) sites (Figure 1). The Ruvu estuary is strongly influenced by the marine environment up to 23 km inland.

The salinity fluctuates through the tidal cycle and seasons. The highest salinity is during the spring high tide, during the low rain season. The estuary substrate varies from sand to mud. Agricultural activities along Ruvu lower Ruvu basin influences Ruvu water quality (Ngowe and Machiwa, 2004) like increases of nutrients level resulted from runoff from nearby farms.

Bagamoyo District usually experiences two rainy seasons, namely heavy and long rains that occur from March to May and short and light rains from October to December. The rest of the months are dry. The entire study area is influenced by a strong semidiurnal tidal rhythm where the mean tidal range is approximately 3.5 m. During this study (2012) there was no rainfall recorded from October to December and therefore the dry season was prolonged.

Prior to the establishment of permanent sampling stations, determination of coverage of the major bottom substrate types (seagrass, macroalgae, sand and/or mud) was done using a square frame of 1 m^2 that was randomly placed on each site (n = 50). The water depth during high and low tides were recorded and thereafter the seining areas were established (Table 1).

Table 1: Habitat characteristics of the study sites within mangroves area.

Variables	MnEM Site	REM Sites
Depth at high tide	1.2m	1.3m
Depth at low tide	0.6m	0.7m
% Seagrass cover	20	25
% Macroalgae	20	35
% Sand and shells	50	10
% Mud	10	30

(Data are average values from 50 quadrate replicates conducted in each site i.e. MnEM and REM)

REM = Ruvu Estuarine Mangrove, MnEM = Mbegani non Estuarine Mangrove

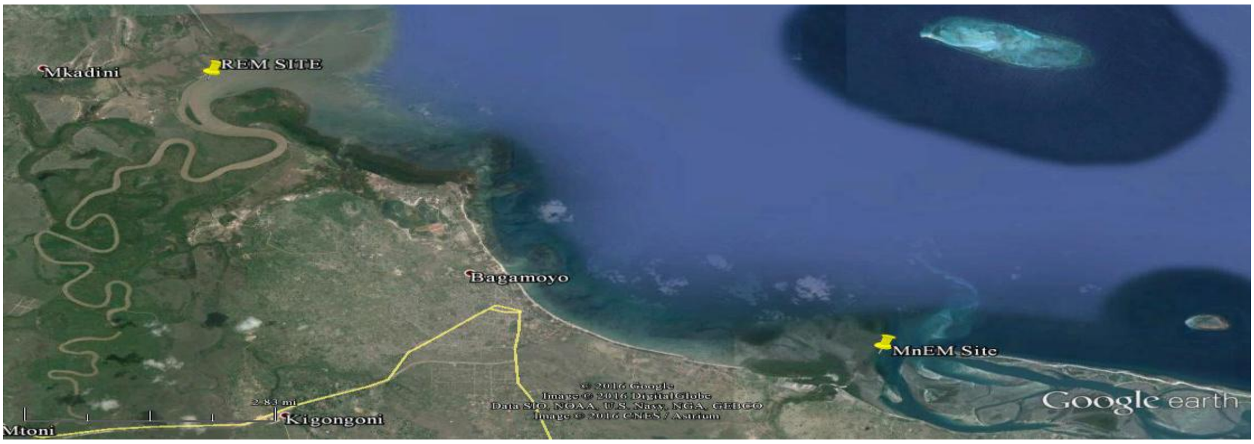

Figure 1: Mbegani non estuarine and Ruvu estuarine mangroves area, Bagamoyo

Sampling Procedure

Mullet fish were caught using a beach seine of 20 m long, 2 m wide with a stretched mesh size of 1.6 cm. The beach seine was towed during the low tide over an area of about 100 m^2 in each haul. This was done each month from January to December 2012 (except July).

Two replicate hauls were taken at every site during each sampling trip. To minimize the effect of consecutive sampling, the second haul was taken 10 minutes after the first haul. The catches of each haul were placed in separate labeled plastic bags and transported in an ice-box to the laboratory for identification. The mullets were distinguished from each species according to morphological identification as described by Bianchi, (1985). *Mugil cephalus* (Stripped mullet) juveniles were characterized by olive-green dorsally, sides silvery shading to white ventrally; lateral stripes sometimes distinctive and pectoral fins short when folded forward does not reach eye. *Valamugil buchanani* (Blue tailed mullet) were characterized by greenish dorsally, flanks and abdomen silvery, small gold patch on upper operculum, caudal fin bright blue, pectoral fins yellow with dark blue spot dorsally. The caught fish were counted and standard length (SL) of each individual for each species was measured using measuring board to the nearest 0.1cm. The fish were further divided into size class intervals of 2 cm and grouped for each site i.e. REM and MnEM to assess spatial distribution patterns in size frequency. Fish abundance was calculated by taking average number of fish harvested divided by a total seined area.

Water quality variables which included dissolved oxygen (DO), salinity, water temperature and pH were measured prior to fish sampling at each sampling station by using YSI 6600 V2-4 water-quality multi-probe (YSI, Yellow Springs, Ohio, USA). The monthly atmospheric (Atm) temperatures and rainfall data for Bagamoyo during 2012 were obtained from Tanzania Meteorological Agency (TMA), Dar es Salaam. At each sampling site, samples were collected for two consecutive days per month.

Data Analysis

The variations in number of individuals and abundance of two Mullet species between sites and seasons (rainy/wet and dry) were analyzed by using T-test. The differences in DO, salinity, temperature and pH between sites and seasons were also analyzed by using T-test. Prior to each analysis, Levene's (1960) test was applied to check for homogeneity of variances. When the assumptions were not met even after transformed into $\ln\log_{10}$ or square root were analyzed using non parametric test i.e. Mann-Whitney and Kruskal Wallis test. The relationships between *M. cephalus, V. buchanani*, environmental variables and meteorological data were analyzed using Principal Component Analysis (PCA) using MiniTab 15.03 program.

Environmental variables

Dissolved Oxygen (DO) and salinity varied between sites and seasons. The DO was higher at Ruvu Estuarine Mangrove (REM) site compared to Mbegani non Estuarine Mangrove (MnEM) site whereby salinity was higher at MnEM site. The DO and salinity showed significant difference between sites (t-test; df = 20, $p = 0.030$) and (t-test; df = 20, $p = 0.02$) respectively (Table 2). In terms of seasons, DO was higher during wet period whereas salinity and pH were higher during dry season.

DO, salinity and pH showed significant differences (t-test; df = 20, $p = 0.001$; df = 20, $p = 0.003$ and df = 20, $p = 0.000$) between wet and dry period respectively (Table 2).

Seasonality within sites showed the same trend that DO was higher during wet period whereas salinity and pH were higher during dry season for REM and MnEM sites. The DO, salinity and pH showed significant differences (t-test; df = 10, $p < 0.001$) for each tested parameters and for both sites.

Temperature was relatively stable across sites and seasons, with slightly higher by seasons (Table 2).

Table 2: The means (± Standard deviation, SD), minimum and maximum values of environmental variables (n = 11) between sites and seasons

Parameters	Sites							Seasons						
	REM			MnEM				REM			MnEM			
	Mean	Min	Max	Mean	Min	Max	*p*-value	Mean	Min	Max	Mean	Min	Max	*p*-value
DO (mg/l)	5.08 (0.35)	3.8	5.8	4.7 (0.37)	3.8	5.7	0.030	4.72 (0.30)	3.8	5.5	5.36 (0.18)	4.2	5.8	0.000
Salinity (psu)	27.95 (5.02)	13.9	33.5	32.66 (3.43)	19.6	36.1	0.020	32.49 (2.85)	20.3	36.1	24.48 (3.6)	13.9	24.3	0.000
Temp (°C)	30.42 (1.21)	28.2	31.8	30.79 (0.80)	28.5	32.1	NS	30.52 (1.14)	28.2	32.1	30.83 (0.60)	29	31.7	NS
pH	8.09 (0.13)	7.65	8.3	8.12 (0.14)	7.83	8.37	NS	8.17 (0.10)	7.75	8.37	7.95 (0.07)	7.65	8.08	0.000

REM = Ruvu estuarine Mangrove, MnEM = Mbegani non Estuarine Mangrove, Max = Maximum, Min = Minimum, DO = Dissolved Oxygen, Temp = Temperature

Species Occurrence and Distribution Patterns in the Study Area

A total of 494 individuals of *M. cephalus* and 226 of *V. buchanani* were collected in the study areas.

The abundance *M. cephalus* was significantly (Mann-Whitney U, $p < 0.009$) higher than that of *V. buchanani* at REM and MnEM sites. The results showed that abundance of *M. cephalus* was significantly higher (Kruskal Wallis, DF = 1, $p < 0.024$) in REM site which has relative higher percentage of macrophytes and muddy sediment than in MnEM sites whereas *V. buchanani* showed no significant difference (Kruskal Wallis, DF = 1, $p > 0.847$) in abundance between REM and MnEM sites.

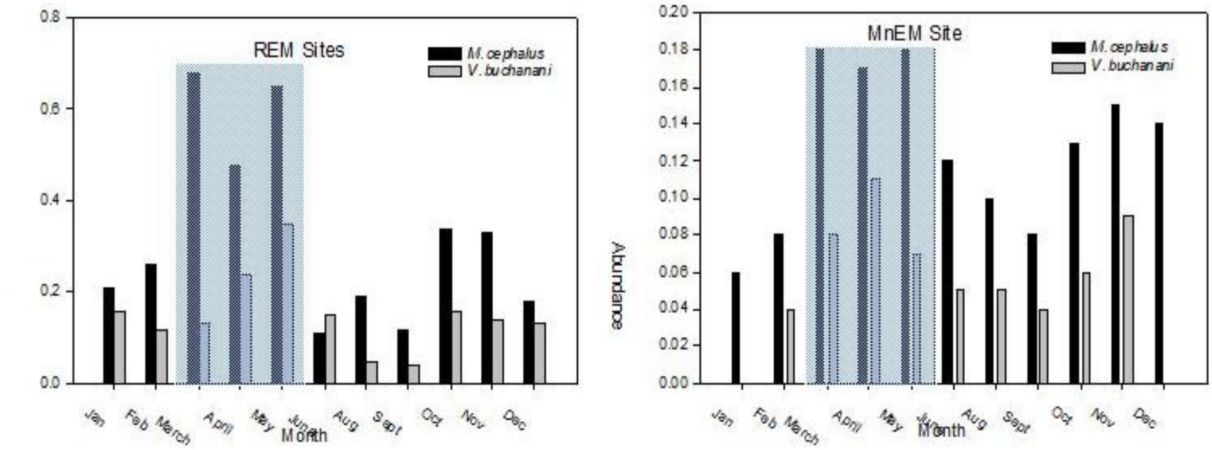

Figure 2: Seasonal abundance of *M. cephalus* and *V. buchanani* in the study areas.

The abundance of *M. cephalus* and *V. buchanani* were significantly higher (Kruskal-Wallis, df= 1, $p < 0.020$; df=1, $p < 0.001$) respectively during wet season than dry season (Figure 2). Both *M. cephalus and V. buchanani* occurred throughout the year with high peaks at the start and end of wet season for both sites.

Size Class Distribution

The size of *M. cephalus* found in REM and MnEM sites ranged from 0.1 to12 cm SL and while *V. buchanani* range from 2.1 to 12 cm SL with mean length size of 4.9 cm and 4.8 cm SL respectively. These size ranges include all juveniles (Bianchi, 1985). In general, the frequency percent contribution in class size was dominated by 4.1-6.0 cm. SL size class for both sites in both species *M. cephalus* and *V. buchanani* (Figure 3).

Correlation between mullets Abundance, Environmental and Meteorological Parameters

The first three axes of a PCA of environmental and meteorological factors contributed to a significant part (82.7%) of the total variance (Table 3). The first three Eigenvalues PC1 = 3.0, PC2 = 2.4 and PC3 = 1.2 in PCA indicating the high proportional of variation in *M. cephalus and V. buchanani* data could be explained by hypothetical axes.

Table 3: Eigenvalues and percentage of variation of first four principal factors

Variables	PC1	PC2	PC3	PC4
Eigen-value	3.0	2.4	1.2	0.5
Total (%)	37.8	29.9	15.0	6.7
Cumulative %	37.8	67.7	82.7	89.3

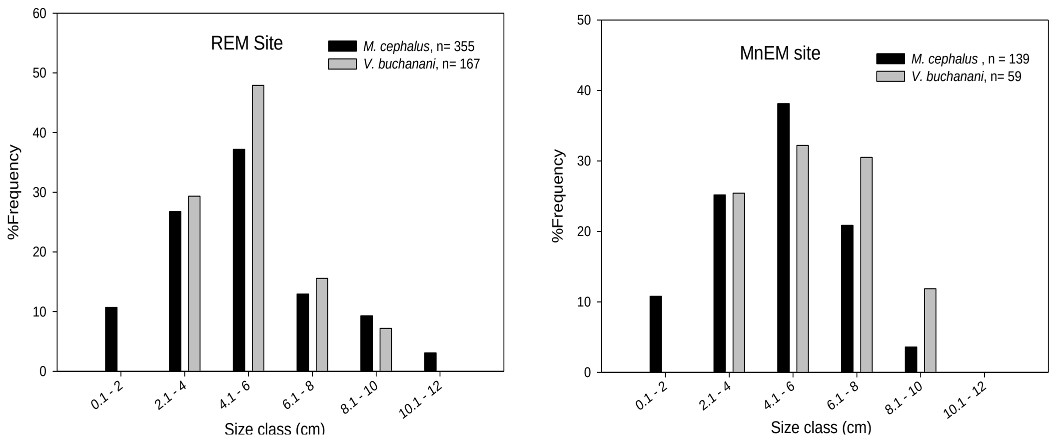

Figure 3: Frequency Percentage distribution of *M. cephalus* and *V. buchanani* in class size in each site

The first axis was negatively correlated with *M. cephalus*, *V. buchanani*, rainfall and DO whereas was positively correlated with atmospheric temperature, salinity, environmental temperature and pH. Second axis was positively correlated to all tested parameters while the third axis was negatively correlated with *M. cephalus*, *V. buchanani*, salinity but pH was positively correlated to rainfall, atmospheric temperature, DO and environmental temperature (Table 4).

Table 4: The correlation between variables and principle factors

Variable	PC1	PC2	PC3	PC4
M. cephalus	-0.231	0.512	-0.271	0.301
V. buchanani	-0.263	0.491	-0255	0.363
Rainfall (mm)	-0.456	0.107	0.335	-0.139
Atm temp (^{o}C)	0.339	0.258	0.512	0.212
DO (mg/l)	-0.411	0.242	0.036	-0.723
Salinity (psu)	0.471	0.235	-0.262	-0.322
Env temp (^{o}C)	0.122	0.390	0.605	-0.020
pH	0.385	0.390	-0.225	-0.293

PC= Principle component, Atm= Atmospheric, Env= environment, DO = Dissolved Oxygen

PCA graph showed clear the association between mullet species with environmental and meteorological variables. *M. cephalus* and *V. buchanani* abundance was positively correlated with rainfall and DO whereas other environmental variables salinity, environmental temperature, pH and atmospheric temperature were negatively correlated (Figure 4).

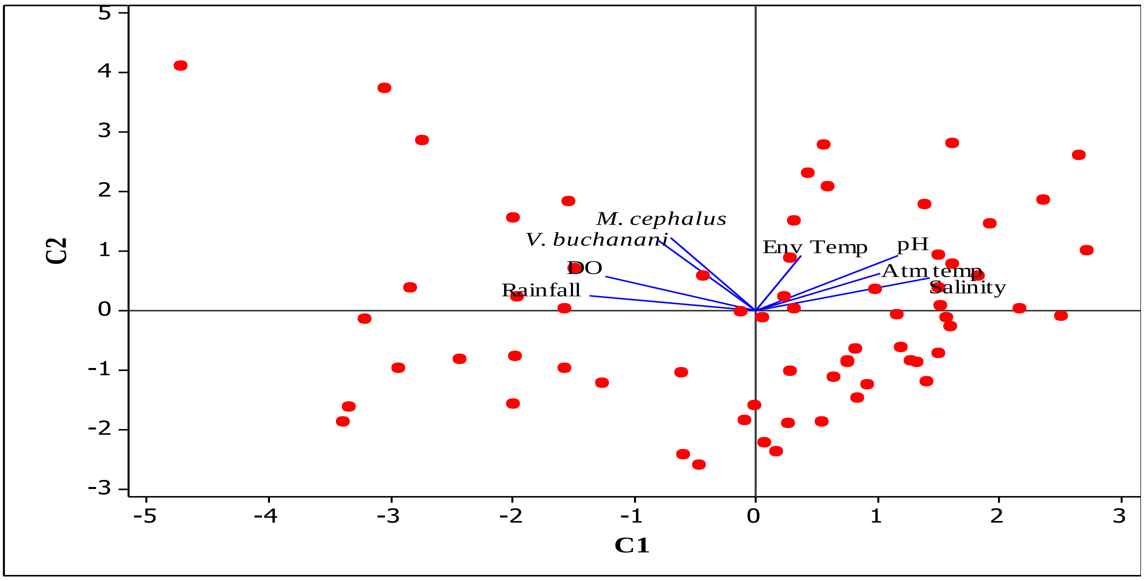

Figure 4: Principal Component Analysis graph showing correlation between striped mullet abundance and environmental and meteorological variable. Atm= Atmospheric, Env= environment, DO = Dissolved Oxygen

Discussion

Our results indicated that estuarine mangrove (REM) site had higher mullet abundance compared to non estuarine mangrove (MnEM) site. Environmental factors like low salinity which is well tolerated and favoured by mullet juveniles (Wenner and Beatty, 1993) and therefore acts as a barrier to large predators. Habitat characteristics like muddy substrate and macrophytes are favourable habitats for mullets, which is relative high in REM than MnEM site. These explain why mullets are more in REM than MnEM sites. Macrophytes reported to attract fishes by provision of food and shelter (Lugendo et al., 2007; Gullstro¨m et al., 2008). Also high abundance of mullet in REM site could be due to the influence of Ruvu River which dilute salt concentration of marine water and bring in nutrients which favour live-feed growth for mullet. The high abundance of *M. cephalus* than *V. buchanani* in Bagamoyo mangrove area could be linked with migration patterns of those species during spawning and fry settling time. In addition, it may be as results of reduced environmental quality of the spawning grounds of the two species hence favouring the more adapted species i.e. *M. cephalus*. The low salinity and high pH in REM compared to MnEM sites favour growth of most fish species especially the juveniles hence the abundance of the mullets at the REM. Therefore increased rainfall will favour the recruitment of these species.

Results from current study revealed that mullet enter non estuarine and estuarine mangroves throughout the year, with intensive recruitment into the surveyed sites during the wet season. This is reflected by a significant positively relationship between mullet catch, DO and rainfall in the study area (Figure 4). The observed results are in line with other studies that showed high fish abundance during rainfall has been recorded at lower Caete estuary in Northern Brazilian coast (Barletta *et al.*, 2003). However, spawning and recruitment peaks may be initiated by environmental cues (Redding and Patiño, 1993). The variation in recruitment pattern within a year could probably be due to variation in the timing of favorable conditions that enhance survival. Such conditions may include environmental factors such as DO for supporting life, hydrographic mechanism which facilitates larval transportation to mangroves nursery grounds Other factors include meteorological factors such as rainfall which enhances primary production (Muller-Karger *et al*., 1989) as well as increased water turbidity which provides camouflage from predation (Mwandya *et al.*, 2009).

The atmospheric temperature did not show any significant link with mullet recruitment, although it showed significant association with environmental parameters such as water temperature, salinity and pH and therefore indirectly affecting mullet recruitment. A similar finding was reported in tropical Australia of having no significant association between water temperature and fish catch (Meynecke *et al.,* 2006). It is well known that global warming/temperature are closely associated with rainfall amount and distribution patterns (Marvel and Bonfils, 2013; DOE/Lawrence Livermore National Laboratory, 2013) leading to biological response of fish species (Meynecke *et al.,* 2006). When the environment is not favourable, fish larvae could actively avoid the nursery place or indirectly by increased mortality rate and hence no recruitment (Robins *et al.,* 2005) or changes fish assemblage (Whitfield, 2005), shifting of nursery habitat due to high temperature as reported in Australia (Meynecke *et al.,* 2006). Similarly, elsewhere, temperature has been reported to have an influence on Sprat, *Sprattus sprattus* recruitment (Mollman *et al.,* 2008), Mackerel, *Scomber scombrus* (ICES, 2007) Sole, *Solea solea* (Darnaude *et al.,* 2004); spawning in Atlantic cod, *Gadus morhua* (Heath, 2007).

Precipitation in Tanzania and its natural variability are distributed differentially in the different regions of the country and seasons or the year. The complex rainfall patterns have been reflected in the FEWS NETS (2012) forecast models of precipitation change, showing the annual rainfall for the northern coastal plain in Tanzania, including Bagamoyo to be below the average value. Results suggested that rainfall plays an important role on modifies DO and salinity in mangroves ecosystem which has an impact recruitment patterns of mullet. These findings are in agreement with modeling experiments which showed fisheries recruitments to have direct links with meteorological forces (Meynecke *et al.,* 2006; Ottersen *et al.,* 2010). The water runoff from rainfall lowers marine salinity and brought nutrients to the mangroves area which favours growth of micro and macroalga essential food for mullet and other organisms. Also through photosynthesis DO in mangrove environments increases which support marine life.

Conclusion and Recommendations

Understanding the complex effects of meteorological parameters on mullet is of vital importance for the sustainability of coastal fisheries. In addition, the study has demonstrated the importance of mangroves ecosystem as an important area in which *M. cephalus* and *V. buchanani* recruit and hence require protection from habitat degradation. Further, this recruitment is influenced by a combination of environmental and meteorological parameters.

Therefore, information on recruitment patterns of juvenile mullets as related to meteorological and environmental parameters is crucial for effective fisheries management. In addition, it is important information to aquaculture managers to inform decision on where to put mullet farms, as the farm should be near to seed source for easy collection and stocking.

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CHAPTER FOUR

EFFECTS OF ELEVATED CARBON DIOXIDE AND TEMPERATURE ON SURVIVAL AND MORPHOLOGY OF JAPANESE WHITING *SILLAGO JAPONICA*

Yona G, Madalla N, Mwandya A, Ishimatsu A, Bwathondi P

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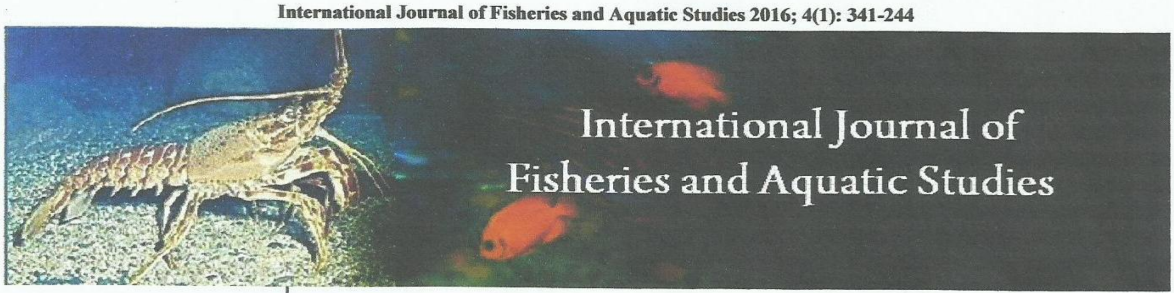

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Effects of elevated carbon dioxide and temperature on survival and morphology of Japanese whiting *Sillago japonica*

Yona G, Madalla N, Mwandya A, Ishimatsu A, Bwathondi P

Abstract
This study examined hatching success, survival and morphology of the larvae of *Sillago japonica* under four treatments: (i) control (C), seawater pCO_2 382μatm, temperature 27 °C; (ii) high CO_2 (HC), 915μatm, 27 °C; (iii) high temperature (HT), 385 μatm, 31 °C; and (iv) high CO_2+high temperature (HCT), 932μatm, 31 °C. For each experiment 4 replicates were conducted and the experiments were repeated 4 times. Ten fertilized eggs were incubated in each treatment for 24hrs, the hatching success were calculated. Fifty (50) hatched larvae were observed until the completion of yolk sac absorptions on 3 days post hatching, to observe survival and morphology of fish larvae. Temperature appeared to have exerted a stronger influence on hatching success and larval survival. The hatching success and larvae survived 3 days post hatching were both significantly (p>0.05) depressed in HT (52.5±1.25%, 23.8±4.38%) and HCT (51.3±3.13%, 20.0±0.63%) treatments than in C (98.1±0.94%, 74.4±2.03%) and HC (95.0±2.5%, 49.7±3.44%) treatments respectively. In contrast, CO_2 was the predominant factor responsible for morphological abnormality: percentage morphological abnormality was significantly (p>0.05) higher in HC (15.8±2.72%) and HCT (41.0±10.86%) treatments than in C (0.4±0.65%) and HT (2.4±2.40%) treatments. Most individuals in HC and HCT treatments had body axis either curved or bent, with aberrant swimming behavior. These results indicate that projected future ocean environments will have significant negative impacts on hatching success, and larval survival and morphology of *S. japonica*, which might have serious ramifications for recruitment of the species.
Keywords: Elevated Carbon dioxide, marine fish larvae, *Sillago japonica*, survival and morphology, temperature

1. Introduction
The anthropogenic activities like burning of fossil fuel are increasing atmospheric carbon dioxide (CO_2) concentration which is causing global warming and ocean acidification (Feely *et al.*, 2004 [1]; Orr *et al.*, 2005) [2]. The atmospheric carbon dioxide concentration that had been increasing at a rate of 1% per year during the 20th century is now increasing to approximately 3% per year (IPCC, 2007) [3]. The CO_2 concentration in the atmosphere is projected to reach 1000ppm by 2100 (SRES A1FI Scenario) and (IPCC, 2007) [3] while recent global mean CO_2 concentration is approximately to 390ppm (Conway and Tans, 2011) [4]. About one-third of the anthropogenic CO_2 produced in the past 200 years has been taken up by the oceans (Sabine *et al.*, 2004) [5] which alter ocean chemistry through acidification process. Modeling studies suggest that by 2100 surface ocean pH will decline by 0.3-0.41 units compared to current levels (Caldiera and Wickett, 2005 [6]. Doney *et al.*, 2009) [7]. The impacts of ocean acidification on invertebrate development have been broadly studied (Doney *et al.* 2009 [7]. Byrne, 2011 [8]. Dupont *et al.*, 2010 [9], Hendriks *et al.*, 2010 [10]; Kroeker *et al.*, 2010 [11]. Fabry *et al.*, 2008) [12]. Research suggested that ocean acidification affects the physiological processes of marine organisms (Pörtner, 2008) [13] and consequently, their ecological functions and interactions with other organisms (Widdicombe and Spicer, 2008) [14]. Comparatively few studies have investigated the effects of climate change on coral fish (Munday *et al.*, 2008[15]; Roesig *et al.*, 2004) [16]. The declining pH was reported to affect coral fish behavior

(Dixson *et al*, 2010 [17]; Munday *et al.*, 2010 [18]; Simposon *et al.*, 2011 [19]; Ferrari *et al.*, 2012 [20]; Domenici *et al.*, 2012) [21], reduce hatching success or survival of finfish (Baumann *et al.*, 2011 [22]; Chamber *et al.*, 2014) [23] and deform fish larvae (Baumann *et al.*, 2011 [22]).
Global warming and ocean acidification are recognized as global problems (Doney *et al.*, 2009) [7]. The global warming caused by additional CO_2 lead into an increase in mean sea-surface temperatures (SST) between 1.1 and 6.4 °C by 2100 with the best estimates ranging between 2 and 4.5 °C (IPCC, 2007) [3]. The increase in SST projected to occur will cause thermal stress to wider range of marine organism, in which most of them are already confined to their temperature tolerances or exceeded their limit (Hoffman and Todgham, 2010) [24]. Some studies on invertebrate showed that ocean warming has an effect on embryo development and caused embryo mortality as well as skeletal dissolution for juvenile invertebrate (Byrne 2011 [8]; Negri *et al*,. 2007 [25], Whalan *et al.*, 2008) [26] Early findings reported that marine invertebrate larvae normally require a narrower temperature range for development compared to adults (Foster, 1971) [27]. High temperature under culture condition was reported to cause fish larvae morphology deformity for instance *Solea senegalensis* (Dionisio *et al.*, 2012) [28] *Pseudopleuronectes herzensteini* (Aritaki and Seikai, 2004) [29] halibut (Lewis-McCrea *et al.*, 2004) [30] gilthead seabream (Georgakopoulou *et al.*, 2010) [31], European seabass (Koumoundouros *et al.*, 2001) [32] and wolfish (Pavlov and Moksness, 1996) [33]. Additionally, temperature was demonstrated to influence marine larval dispersal distance, with the implications for the understanding and effective management of marine populations, connectivity and ecosystem (O'Connor *et al.*, 2007) [34]
Very few studies have shown that future increases in CO_2 and SST will have synergistic effect in feeding behavior of coral fish (Nowicki *et al.*, 2012) [35]. However, currently there is a limited evidence to support hypothesis that elevated CO_2 and temperature affect hatching, survival and morphology of marine fish larvae with yolk sac. The fish larva with yolk sac is a very crucial stage of fish development as related to predator escape, prey searching and resistance to starvation. Therefore understanding of these ability can help to provide information not only for an ecological understanding of marine fish-larvae, but also for conducting intensive larval rearing on a large scale and help to predict the future population.
Therefore, this study examined the effect of elevated CO_2 and temperature on survival and morphology of *Sillago japonica* yolk sac larvae. *S. japonica* was selected for the present study because they can hatch and reared easily under captivity; it is one of representative of coastal fish and is used for aquaculture.

2. Material and methods

2.1 Experimental animal and Egg Collection

Naturally `fertilized eggs of *S. japonica*) were obtained from Nagasaki Prefecture Fisheries Research (NPFR) around 08.30 am in the morning. Eggs were collected in 500ml beaker which was covered with plastic paper. The Nagasaki Prefecture Fisheries Research (NPFR) is about 100m from ECSER Institute, 32 °48'39"N, 129 °46'20"E), Nagasaki, Japan where research was conducted. The brood stock were reared under 3000L round plastic tank under ambient temperature (27.5 °C) and pCO2 (392 µatm) with continuous flow of sand filtered seawater. The Broodstock were fed twice a day 09h00 and 16h00 artificial feed according to their nutritional requirement. Sillago spawned around 12pm midnight. The eggs were examined under microscope and unfertilized eggs were removed.

2.2 Experimental setup

Four (4) different treatment levels in four replicates were used in this study. (i) Control (C) i.e. temp = 27 °C; pCO_2 = 380 µatm (ii) Elevated CO_2 (HC) i.e. 27 °C; pCO_2 = 1000 µatm (iii) Elevated temperature (HT) i.e. temp = 31 °C; p CO_2 380 µatm (iv) Combination of elevated temperature and CO_2 (HCT) i.e. temp = 31 °C; pCO_2 = 1000 µatm. The experiment was repeated four during the month of July, 2013.

2.3 Sea water manipulation

Natural seawater was sand filtered before being pumped into 4 header plastic containers of capacity of 15liters. Pure CO_2 was bubbled into each tank in order to get the desired pH and pCO_2 for control 380ppm which was the current situation and 1000ppm according to year 2100 prediction by A1FI scenario (IPCC, 2001) [36]. The flow rate of 10L/minute CO_2 free air was used to obtain current situation and air: CO_2 was at a ratio of 10L/minute:6.20cc/minute respectively was used for to obtain the future pCO_2 and pH. The CO_2 blended gas was prepared with a gas blender (Kofloc, GB-2C, Japan). The electric heaters were used to adjust temperature of sea water, raised to 27 and 30.5 °C for current and future situation respectively. These temperatures correspond to current day July average SST at East China Sea and 3 °C increase beyond the July average SST.
The water pH and temperature of treatment tanks was monitored daily using digital probes and maintained at a desired level throughout the experimental time. Temperatures were measured using digital probe thermometer. The pH was measured using National Bureau of Standard (NBS) scale. Salinity was measured before the start of experiment by using portable refractometer (Atago, 100-S, Japan). Before starting the experiment the water sample was taken to estimate total alkalinity (AT) by using total alkalinity titrator (Kimoto, ATT-05, Japan) in duplicate. These data were used to determine partial pressure of CO_2 (pCO_2) in each treatment by using CO2Calc 1.2.0 (Robbins, 2010) [37], with dissociation constants K1 and K2 from Mehrbach *et al.*, (1973) [38] refit by Dickson and Millero, (1987) [39]. Dissolve Oxygen (DO) concentration during the experiment was measured daily in each container using portable DO meter (Eyela, NCB-1200, Japan).

Table 1: The experimental seawater quality (mean ± SD). The Dissolved Oxygen (DO), Temperature, PH and Total Alkalinity (TA) were measured but pCO_2 was calculated by using CO2calc 1.2.0

Treatments	Sea water parameters				
	DO (mg/l)	Temp °C	pH(NBS)	TA (µmol/kg SW)	pCO_2 (µatm)
C	6.65±0.24	26.8±0.25	8.17±0.01	2184.0±79.0	391.0±8.01
HC	6.55±0.16	27.0±0.32	7.85±0.01	2159.0±82.0	939.0±19.0
HT	6.36±0.11	30.8±0.32	8.16±0.01	2043.1±23.0	396.0±9.02
HCT	6.46±0.09	30.6±0.65	7.85±0.01	2144.0±28.0	947.0±18.0

2.4 Data Collection and Analysis

2.4.1 Hatching Percentage (HP)

Ten fertilized eggs were randomly assigned in 4 replicates in 500mls containers with a lid on it for each treatment to examine hatching percentage (HP) after 24 hour incubation. During incubation time the treated water was exchanged at a rate of 0.34ml/minutes. The fish larvae hatched were counted from each container then averaged percentage were calculated separately for each treatment

2.4.2 Larval survival and Morphology deformities

Fifty fertilized eggs were randomly assigned in 1000mls containers in 4 replicates for each treatment. Then 20 fish larvae were retained in each container with a lid on it to observe larval survival, morphology deformities with water exchanged at a rate of 2ml/minute. These parameters were examined at day three after incubation when the digestive system is completely developed and egg yolk is almost completely absorbed (Oozeki, *et al.*, 1992) [40]. Fish larvae survived to day 3 in each container were counted and then used to compute mean percentage of survival for each treatment. The fish larvae were also observed, their morphological deformities from each container were recorded then percent of deformities was calculated for each container and then the mean percentage was calculated for each treatment.

2.5 Data analysis

Two-way ANOVA was used to compare effect of experimental time and treatments to assess the consistency of the results. The effect of treatments on hatching (HP), survival (SV) and Morphology deformity (MD) were analyzed by using one-way ANOVA followed by post hoc Games Howells multiple comparison test to observe the differences between treatments. Before analysis data were first tested for homogeneity of variance using Levene's test. If data did not show homogeneity of variance even after transformation into square root or log (X+1) then Games Howells multiple comparison test was used.

3. Results

3.1 Hatching percentage (n=40)

Results revealed that temperature has significant effect on hatching success of sillago fish. Each experiment showed consistently significant ($p<0.001$) decrease in hatching success at elevated temperature. The HT and HCT had significantly ($p<0.001$) lower hatching success for experiments 1, 2, 3 and 4. The control (c) and high CO_2 treatments showed no significant difference ($p>0.05$), for exp 1, 2, 3 and 4 treatments in hatching success. Likewise, the HT and HCT showed no significant effect ($p>0.05$) for all experiments in hatching success (Figure 1).

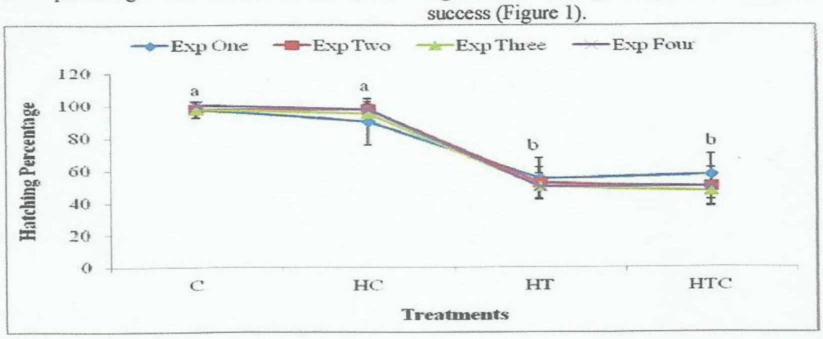

Fig 1: The average Hatching Percentage of *Sillago* eggs (n=10) at different treatment observed 24h after incubation for Each for experiments conducted at different time. Different letter on the error bar shows significant different at $p<0.05$.

Survival at day 3 (n=20)

The results revealed that elevated CO_2 and temperature (HC, HT and HCT) had significant ($p<0.05$) effect on survival of Sillago fish larvae (Figure 2). In all experiments, the control showed significant higher ($p<0.01$) larvae survival, three days post hatch followed by HC in all treatments. While treatments HT and HCT showed significant lowest (($p<0.01$) survival in three days post hatch whereby HT and HCT showed no significant different ($p>0.05$).

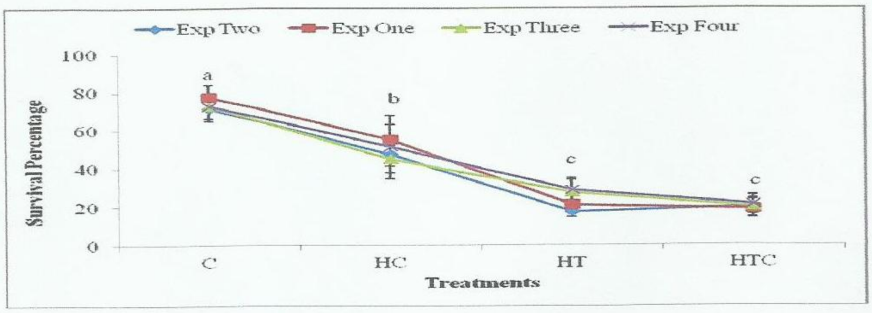

Fig 2: The average survival percentage (SV) of sillago at different treatment observed 3 days post hatch. n=20 for each treatment. Different letter on the error bar shows significant different at $p<0.05$.

Morphology deformity percentage as per number of survivors

Figures 3 and 4 showed that elevated CO_2 and temperature have great impact on sillago larvae morphology deformity (MD). In all experiments, HCT showed significant ($p<0.05$) synergistic effect of elevated CO_2 with temperature on impacts of morphology deformities of sillago fish larvae. The HC and HT showed significant ($p<0.05$) of sillago fish larvae however, the HC and HT showed no significant ($p>0.05$) difference on fish larvae morphology deformity. The control had significant ($p<0.05$) the lowest number of fish larvae with morphology deformity compared to other treatments (Figure 3).

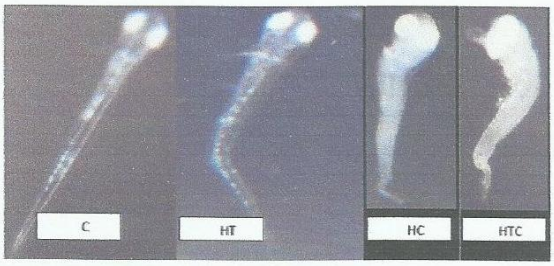

Fig 3: Effect of elevated CO_2 and temperature to early life stage of *Sillago japonica* survived 3 days post hatch

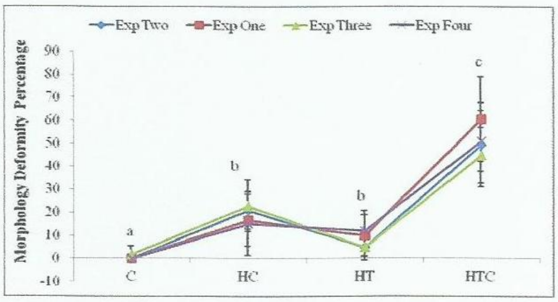

Fig 4: The average morphology deformity Percentage of sillago fish larvae survived 3 days post hatch at different treatment. Different letter on the error bar shows significant different at $p < 0.05$.

4. Discussion

The present study unambiguously revealed that the future projected elevated by both CO_2 and temperature of the oceans may affect hatching, survival and morphology of marine fish larvae. Regardless of marine fish being known to have well developed acid-base regulatory system, still they are susceptible to elevated CO_2 which leads to ocean acidification (Munday *et al*., 2010 [18]; Baumann *et al*., 2011 [22]; Ishimatsu *et al*., 2008 [41]; Frommel *et al*., 2011 [42]; Esbaugh *et al*., 2012[43]; Bignami *et al*., 2013 [44]; Enzor *et al*., 2013 [45]; Hurst *et al*., 2013) [46]. Temperature is known as a main physical regulatory in marine life to have a noticeable power on metabolism and implications in development as well as induces ontogenetic plasticity in fish larvae (Dionisio *et al*., 2012 [28]; Pankhurst and Munday, 2011) [47]. The hatching percentage of sillago eggs were unaffected by elevated CO_2 when exposed to approximately 942 µatm CO_2 resulting into 7.85 pH during the present study. This could be due to short time of exposure to elevated CO_2 to make a significant changes as it took less than 24hrs to hatch also it could suggests that sillago eggs are resistant to elevated CO_2. Similar findings were reported elsewhere when eggs exposed to projected future elevated CO_2 (Munday *et al*., 2009 [48]; Franke and Clemmesen, 2011) [49]. However, findings from temperate Atlantic fish *Menidia beryllina* showed a considerable mortality of eggs when exposed to elevated CO_2 (Baumann *et al*., 2011) [22] Also it was reported that the vulnerability of early developmental stage of fish like eggs, sperms, larvae and juveniles to elevated CO_2 levels is higher than for adults (Kikkawa *et al*., 2003 [50]; Ishimatsu *et al*., 2004) [51]. The elevated temperature 31 °C has exerted stronger influence on hatching success in sillago fish. Failure of sillago eggs to hatch at elevated temperatures in all four successive experiments suggests that the elevated temperature is outside the tolerance limit for development of sillago eggs. It has also been reported that the hatching rate of sillago eggs has a tendency to decrease at temperatures over 28 °C (Hotta *et al*., 2001) [52]. It has also been reported that egg is the most sensitive life stages of fish species as small increases in temperature can severely increase egg mortality (Gagliano *et al*. 2007) [53]. These findings agree with the long time laboratory findings in sole fish egg mortality occurred as the temperature increases (Irvin, 1974 [54]; Pepnin, 1991) [55] and common carp (Richter *et al*., 1987) [56]. The same trend showed in the currently research that small increase in temperature increased mortality of northern rock sole larvae *Lepidopsetta polyxystra* (Laurel and Blood, 2011) [57] and common carp (El-Hakim and El-Gamal, 2009) [58]. Similar to this, temperature is known as the main environmental factor affecting development of fish eggs as well as certain morphological features and hatching rate (Nwosu and Holzlohnev, 2000 [59]; Bagenal and Braun, 1978) [60]. At temperature of 27 °C the hatching percentages of sillago fish was higher compared to future elevated temperature of 31 °C. It is being proposed that 27 °C is the optimum temperature for hatching of sillago eggs. This temperature corresponds to the environmental temperature during the period of natural reproduction. Therefore, the elevated temperature has greater implications for the future sillago stock abundance as fish hatching success predicts the next generation.

Our results also showed that elevated temperature exerts a stronger influence of survival of sillago fish larvae than CO_2 alone. This could be due to high metabolic rate beyond the tolerance limit of sillago fish larvae. The metabolic rate which is the fundamental measure of physiological activities mediates most of biotic effects of warming (Herbing and Boutilier, 1996 [61]; McLeod *et al*., 2013) [62]. The similar findings were reported on *Amphiprion percula*, coral fish larvae that high temperature reduces their survival (McLeod *et al*., 2013) [62] and cardinal fish species (Munday *et al*., 2009) [48]. All organisms are known to have lethal limits to their temperature range and within that range organisms have optimal temperature for development of physiological activities (Hokanson, 1977 [63]; Rombough, 1997) [64]. The elevated CO_2 and reduced pH alone also showed impacts on survival of sillago fish larvae. This was also reported to exert severe effect on survival of silver sea bream *Pagrus major* eggs and larvae (Ishimatsu *et al*., 2004) [51]. This suggested that the acid-base regulatory system was not well developed at this young stage and thus compromising their physiological compensatory mechanisms. Also their small size could be increasing cost of homeostasis hence more vulnerable to environmental elevated CO_2 predicted to occur in near future (Brauner, 2009 [65]; Melzner *et al*., 2009) [66]. However, contrary to what was reported that the elevated CO_2 had no effect of on growth and survival of juveniles of common coral reef fish, the spiny damselfish *Acanthochromis polyacanthus* (Munday *et al.*, 2011) [67] that was consistent with some cold water fish showed to tolerate elevated CO_2 levels above those predicted to occur in the shallow ocean due to increasing anthropogenic CO_2 emissions (Kikkawa *et al.*, 2003[50]; Ishimatsu *et al.*, 2004 [51]). This showed that the ability of fish to tolerate low pH due to elevated CO_2 is species specific.

The synergistic interactions between temperature and CO_2 consequently have great implications on survival of unfed sillago larvae and therefore ecological implication to marine fish abundance and distribution. The findings showed that in marine organisms, low pH is thought to enhance ion regulatory costs and thus baseline energy demand whereas elevated temperature increases baseline metabolic rate (Kreiss *et al.*, 2015)[68]. This synergistic interaction effect was reported to increase mortality of *Ostorhinchus doederleini* which suggested that the physiological condition of individuals was severely compromised at elevated CO_2 and temperature was sufficient to cause increased mortality (Munday *et al.*, 2009)[48]. Such differences suggest that the composition of marine fish communities may shift due to changes in relative rates of mortality among species in global warming world. Sillago fish feeds in low food chain and therefore reduction of their number will have an impact on their predators' abundance and distribution as well as changes in eating habits.

From the findings, it can be revealed that elevated CO_2 was the predominant factor responsible for morphological deformity of sillago fish larvae. This suggests that early life stages can be negatively impacted by elevated CO_2, but how does the elevated CO_2 affect fish morphology is currently unknown. Recent findings reported that elevated CO_2 caused considerable higher percentage of malformations in newly hatched temperate Atlantic fish *Menidia beryllina* larvae (Baumann *et al.*, 2011) [22]. It was proposed that, sensitivity to elevated CO_2 at the earliest life stages could concomitantly reflect poor development of acid-base regulation and cardio-respiratory control mechanisms. These mechanisms are possibly linked to increased gill function and muscle activity due to swimming activity (Perry and Gilmour, 2006) [72] as well as tissue damage and necrosis in fish larvae (Frommel *et al.*, 2011) [42]. Likewise, such mechanism could also be due to high metabolic cost incurred to maintain physiological activities at elevated CO_2 and ultimately reduces temperature energy available for tissue synthesis (Ishimatsu *et al.*, 2004 [51]; Kurihara *et al.*, 2008 [69]; Shirayama, 2002 [70]) and therefore affect energy requirements for activity among ontogenetic stages (Baumann *et al.*, 2011) [22]. HT which also showed significant sillago larvae morphology deformity, was also similar to those reported in *Solea senegalensis* (Dionisio *et al.*, 2012) [28], *Pseudopleuronectes herzensteini* (Aritaki and Seikai, 2004) [29], halibut (Lewis-McCrea *et al.*, 2004) [30], gilthead seabream (Georgakopoulou *et al.*, 2010) [31], European seabass (Koumoundouros *et al.*, 2001) [32] and wolfish (Pavlov and Moksness, 1996) [33]. It was also suggested that the skeleton deformity at high temperature could be due to effect of stress caused by altered developmental timing (Das *et al.*, 2006) [71].

5. Conclusion

This study highlights the potential effects of future elevated CO_2 and temperature on hatching, survival and morphology of unfed sillago fish larvae. Elevated temperature showed high impacts on hatching and survival of sillago fish larvae, nevertheless to some extent it showed an effect on morphology deformity. While the elevated CO_2 exerted strong effect on fish larvae morphology deformity, however, the additive effect of elevated temperature worsen the situation. The synergetic impacts of elevated CO_2 and temperature have great impacts on the early life and reproductive stages will have consequences on aquatic ecology. Most individuals in HC and HCT treatments had body axis either curved or bent, with aberrant swimming. These results indicate that projected future ocean environments will have significant negative impacts on hatching success, and larval survival and morphology of *S. japonica*, which might have serious ramifications for recruitment of the species. Comparative studies on other teleost and elasmobranch species are critically needed and such effort can eventually help fisheries managers and policy-makers take proactive measures targeting most vulnerable species.

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reef fish, the spiny damselfish *Acanthochromis polyacanthus* (Munday *et al.*, 2011) [67] that was consistent with some cold water fish showed to tolerate elevated CO_2 levels above those predicted to occur in the shallow ocean due to increasing anthropogenic CO_2 emissions (Kikkawa *et al.*, 2003[50]; Ishimatsu *et al.*, 2004 [51]). This showed that the ability of fish to tolerate low pH due to elevated CO_2 is species specific.

The synergistic interactions between temperature and CO_2 consequently have great implications on survival of unfed sillago larvae and therefore ecological implication to marine fish abundance and distribution. The findings showed that in marine organisms, low pH is thought to enhance ion regulatory costs and thus baseline energy demand whereas elevated temperature increases baseline metabolic rate (Kreiss *et al.*, 2015)[68]. This synergistic interaction effect was reported to increase mortality of *Ostorhinchus doederleini* which suggested that the physiological condition of individuals was severely compromised at elevated CO_2 and temperature was sufficient to cause increased mortality (Munday *et al.*, 2009)[48]. Such differences suggest that the composition of marine fish communities may shift due to changes in relative rates of mortality among species in global warming world. Sillago fish feeds in low food chain and therefore reduction of their number will have an impact on their predators' abundance and distribution as well as changes in eating habits. From the findings, it can be revealed that elevated CO_2 was the predominant factor responsible for morphological deformity of sillago fish larvae. This suggests that early life stages can be negatively impacted by elevated CO_2, but how does the elevated CO_2 affect fish morphology is currently unknown. Recent findings reported that elevated CO_2 caused considerable higher percentage of malformations in newly hatched temperate Atlantic fish *Menidia beryllina* larvae (Baumann *et al.*, 2011) [22]. It was proposed that, sensitivity to elevated CO_2 at the earliest life stages could concomitantly reflect poor development of acid-base regulation and cardio-respiratory control mechanisms. These mechanisms are possibly linked to increased gill function and muscle activity due to swimming activity (Perry and Gilmour, 2006) [72] as well as tissue damage and necrosis in fish larvae (Frommel *et al.*, 2011) [42]. Likewise, such mechanism could also be due to high metabolic cost incurred to maintain physiological activities at elevated CO_2 and ultimately reduces temperature energy available for tissue synthesis (Ishimatsu *et al.*, 2004 [51]; Kurihara *et al.*, 2008 [69]; Shirayama, 2002 [70]) and therefore affect energy requirements for activity among ontogenetic stages (Baumann *et al.*, 2011) [22]. HT which also showed significant sillago larvae morphology deformity, was also similar to those reported in *Solea senegalensis* (Dionisio *et al.*, 2012) [28], *Pseudopleuronectes herzensteini* (Aritaki and Seikai, 2004) [29], halibut (Lewis-McCrea *et al.*, 2004) [30], gilthead seabream (Georgakopoulou *et al.*, 2010) [31], European seabass (Koumoundouros *et al.*, 2001) [32] and wolfish (Pavlov and Moksness, 1996) [33]. It was also suggested that the skeleton deformity at high temperature could be due to effect of stress caused by altered developmental timing (Das *et al.*, 2006) [71].

5. Conclusion

This study highlights the potential effects of future elevated CO_2 and temperature on hatching, survival and morphology of unfed sillago fish larvae. Elevated temperature showed high impacts on hatching and survival of sillago fish larvae, nevertheless to some extent it showed an effect on morphology deformity. While the elevated CO_2 exerted strong effect on fish larvae morphology deformity, however, the additive effect of elevated temperature worsen the situation. The synergetic impacts of elevated CO_2 and temperature have great impacts on the early life and reproductive stages will have consequences on aquatic ecology. Most individuals in HC and HCT treatments had body axis either curved or bent, with aberrant swimming. These results indicate that projected future ocean environments will have significant negative impacts on hatching success, and larval survival and morphology of *S. japonica*, which might have serious ramifications for recruitment of the species. Comparative studies on other teleost and elasmobranch species are critically needed and such effort can eventually help fisheries managers and policy-makers take proactive measures targeting most vulnerable species.

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CHAPTER FIVE

5.0 INSIGHT ACROSS EMPIRICAL CHAPTERS, CONCLUSION AND RECOMMENDATIONS

5.1 Insight Across Empirical Chapters

This thesis assessed the impacts of climate change and variability on coastal and mangroves dependent fish. Climate change is already happening and it is predicted that further climate change will occur irrespective of cuts in greenhouse gas emissions (IPCC, 2007). Without adaptation, the impacts of climate change are making and will make multiple effects to fish and fish communities which in turn will have great impacts particularly to small-scale fishing communities in developing countries, which constitute about 90% of fishery-dependent people (FAO, 2012).

Mangroves are known as potential nursery, feeding and breeding grounds for ecological and commercial fish species and crustaceans (Nagelkerken *et al.,* 2008, Lagade *et al.*, 2011) which contribute to local abundance of fish population. Mangroves play an important role in carbon sequestration, reducing the impacts of elevated carbon dioxide (CO_2) in the atmosphere (Bouillon *et al.,* 2008; Alongi, 2014). The critical importance of mangroves in mitigating the effects of climate change is increasingly being recognized (Donato *et al.,* 2011). However, there is paucity in information on how the prevailing condition and changes of marine environment affects fish assemblages and mullets fish recruitment in mangrove ecosystem (**Chapters 2 and 3)**.

Mullet fish are widely spread coastal pelagic fish occurring in mangroves and estuarine. They are commercial important food fish around the world, harvested from wild environment or supplied as farmed fish. Mullet are ecological important link in the energy flow within mangrove and estuarine communities (Bester, 2004). Mullet fish recruits on mangrove area (**chapter 3)**.

The anthropogenic activities are increasing atmospheric carbon dioxide (CO_2) concentration causing global warming and ocean acidification (Orr *et al.*, 2005). Several modeling studies suggest that by 2100 surface ocean pH will decline by 0.3-0.41 units compared to current levels (Caldiera and Wickett, 2005; Doney *et al.,* 2009) and sea surface temperature (SST) will rise by between 2 and 4.5 °C (IPCC, 2007). The impacts of ocean acidification on invertebrate development have been broadly studied (Doney *et al.* 2009; Kroeker *et al*., 2010). It affects physiological processes of marine organisms (Pörtner, 2008) and therefore, their ecological functions and interactions with other organisms (Widdicombe and Spicer, 2008). Ocean acidification is reported to affect behavior coral fish (Simposon *et al*., 2011; Ferrari *et al*., 2012) reduce hatching success and/or survival of finfish (Baumann *et al*., 2011; Chamber *et al.,* 2014) and cause deformation in fish larvae (Baumann *et al*., 2011). In marine environment the ocean acidification and SST have synergistic impacts on marine organisms. Nevertheless, information on how elevated CO_2 and temperature affect hatching and survival of coastal fish larvae was scanty. Thus *S. japonica* larvae were chosen for the present study due to its importance in fisheries and aquaculture. Being a forage fish, it also it plays importance ecological role as source of feed in aquatic feed chain **(Chapter 4**) The knowledge gathered in this thesis is of paramount importance towards sound management and conservation of marine resources.

The research used both field work and laboratory studies. The studies in **chapters 2 and 3** examined fish assemblages in mangrove ecosystems under prevailing climatic conditions and explore the effect of meteorological parameters on mullet fish recruitment patterns in estuarine and non estuarine Mangroves ecosystem respectively, Bagamoyo District, Tanzania. In **chapter 2**, three sampling stations were established, upper, middle, and lower stations of the mangrove. The selection was based on their physico-chemical characteristics, bottom substrate and water depth. Different fishing gears were used in order to obtain an accurate estimation of the fish composition at estuarine and non estuarine in Bagamoyo Mangroves ecosystem. In **Chapter 3,** samples were collected from two sites using seine net of 20 m lenght, 2 m wide and streched meshed size of 1.6 cm towed during the low tide over an area of about 100 m^2 in each haul. Sampling was done in two consecutive days each month from January to December (**Chapters 2 and 3)**. The laboratory work, examined the predicted elevated CO_2 and temperature on hatching and survival of *S. japonica* yolk sac larvae **(Chapter 4)**.

5.1.1 Fish Assemblage and recruitment Bagamoyo mangrove ecosystem

In order to assess fish assemblaged and recruitment, fish catch and species number were assessed were assessed in two sites (REM and MnEM) and three stations (lower, middle and upper) in each site. Also the seasonal variation between sites as well as seasons (wet and dry) were also assessed. Findings revealed that the fish catch and species number were not significantly different between sites and seasons (**chapter 2).** This indicates that MnEM and REM ecosystems play a significant role as nursery and feeding grounds (Kimerei *et al*., 2011). The seasonal variation in fish catch and species number are common in mangroves (Kathiresan and Bingham, 2001), for instance, mullet catch showed variation between wet and dry seasons (**chapter 3).** Nevertheless, there are some evidences that seasonal variations are not always statistically significant (Hindell and Jenkins, 2004) (**chapter 2)**. The *M. Cephalus* and *V. Buchanani* species of mullet fish were all juvenile ranging from 0.1-12 cm standard length (**Chapter 3)**. Juvenile fish use mangroves ecosystems as nursery, feeding and refuge areas against predators (Nagelkerken *et al.*, 2008, Kimerei *et al.*, 2011). The lower station (RL) on REM site showed high fish catch compared to other stations (UR and MR) and those species were similar to species found in upper (UM) and lower (LM) stations of MnEM site (**chapter 2)**. There are reasons to believe that environmental variables such as DO, salinity, temperature and pH are the main determinant of assemblage structure within mangrove ecosystem (Mwandya *et al.*, 2009).

5.1.2 Meteorological factors on recruitment patterns of two mullet species

The meteorological parameters (atmospheric temperature and rainfall) are directly linked with marine environment (dissolved oxygen, salinity, water temperature and pH) (**Chapters 2 and 3).** Suprisingly, none of the meteorological parameters showed direct association with fish catch and species number (**Chapter 2),** although, rainfall showed direct influence on mullet abundance (**Chapter 3)** similar findings by Evance *et al.* (1997) and Galindo-Beat *et al.* (2000). Atmospheric temperature showed indirect association with fish catch through the environment **(Chapters 2 and 3)**. However, the near future 2020-2040 predicted rise in atmospheric temperature will act as marine "*ghost*" which will have great consequences on marine ecostystem and coastal communities if precautions will not be taken.

5.1.3 Elevated CO_2 and temperature on hatching and survival of fish larvae

In Chapter 4, elevated temperature showed impacts on hatching and survival of fish larvae and to some extent resulted on morphological deformity. On other hand, elevated CO_2 exerted strong effect on fish larvae deformities and the additive effect of elevated temperature to elevated CO_2 worsen the situation. The synergistic impacts of elevated CO_2 and temperature have significant impact on early life and reproductive stages of *S.*

japonica and consequently the whole aquatic ecology (**Chapter 4)**. Furthermore rise in seawater temperature is reported to affect early life development of marine fish (**Chapter 4)** (Yona *et al.*, 2016), fish distribution and migration (Perry *et al.*, 2005; Menzel *et al.*, 2006). The rise atmospheric temperature is also associated with lower dissolved oxygen concentrations (DO) (**Chapters 2 and 3),** which in turn affect recruitment patterns of mullet fish (**Chapter 3).** The rise in environmental temperature value could be proxy of processes capable of enhancing pre-recruitment mortality rate, directly in offshore transport obstructing migration and or indirectly enhances poor food availability induced by increase in temperature.

5.2 Conclusions

Coastal and mangroves dependent fish are significantly affected by climate change and variability. Furthermore, meteorological factors have significantly impacts on marine environment and consequently influence marine fish abundance and distribution. More specific it can be conclude that:

i. The prevailing climatic conditions i.e. rainfall and atmospheric temperature did not show any direct effect on fish assemblages in mangroves ecosystem. They however, directly influenced environmental factors such as DO; salinity, water temperature and pH. Rainfall was positively correlated with DO but negatively correlated with salinity and pH. Atmospheric temperature was positively correlated with water temperature, salinity and pH but negatively correlated with DO. Fish assemblages were rather influenced by the environmental parameters and habitat characteristics.

ii. Rainfall had direct influence on recruitment of the two mullet species i.e. Mugil. *cephalus* and *Valamugil buchanani* in mangroves ecosystem. Even though recruitment of the two species occurred throughout the year, with its peak during rainy season (March through May).

iii. Elevated CO_2 and temperature has resulted in low hatching success, low larval survival and high morphological deformities in Japanese whiting *Sillago japonica*. Furthermore, combination of elevated CO_2 and temperature has shown larger effect due to synergetic effects during early life and reproductive stages. This potentially may have serious consequences on recruitment of *S. japonica*.

5.3 Recommendations

i. Apart from impacts of climate change on fisheries resources in mangrove ecosystem, other stressors such as environmental pollution, overfishing, deforestation and uses of illegal fishing gears should be controlled. Policies on management of mangrove ecosystems, fisheries and environment should be reinforced in order to have sustainable exploitation of fishery resources.

ii. Sustainable utilization of mangrove resources should be promoted among local communities along the coast. Furthermore alternative livelihood activities including mariculture and bee keeping should be emphasized to minimize unsustainable exploitation of mangroves resources.

iii. Comparative studies of future projected elevated CO_2 and temperature should be undertaken to elucidate their impacts on other vulnerable marine fish of economic importance.

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