THE INFLUENCE OF SALTWORKS' WASTE-BRINE ON DISTRIBUTION OF MANGROVE CRABS (DECAPODA, PORTUNIDAE) WITHIN THE GONGONI-KURAWA INTERTIDAL AREA, KENYA

BY

SONIA KABIBI MUMBA

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DECLARATION

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Ms. Sonia Kabibi Mumba

Reg.No.NRM/PGF/03/13

Signature Date

This thesis has been submitted with our approval as University supervisors.

Prof. Julius O. Manyala, Ph.D.

Department of Fisheries and Aquatic Sciences,

University of Eldoret,

Signature Date

Prof. James Njiru, Ph.D.

Kenya Marine and Fisheries Research Institute

Mombasa

Signature Date

DEDICATION

To my parents, thank you for the investment you bestowed in me. To my brothers and sisters and my husband who always expected the best from me. They have expected nothing but achievement in life. Thank you all for the confidence you have ever had in me.

ABSTRACT

Evaporation is one of the oldest methods employed in sea salt production, a process that involves pumping seas water into a series of ponds where solar evaporation concentrates it into brine, and precipitates the salt; which is then harvested manually. Lack of baseline information on the effect of the discharged brine at the Gongoni-Kurawa region caused the need to determine its impact on the marine ecosystem. The objectives of this study were to compare the productivity of the coastal water, identify the effect of brine on mangrove crab species diversity and distribution and to determine the impact of the physic-chemical parameters and productivity on distribution and diversity of the mangrove crabs. The impact of the discharged hyper-saline waste-brine waters on mangrove crabs along the intertidal habitats bordering two of the biggest salt works; Krystalline and Kurawa salt industries was investigated in this study. Sampling was done during both spring and neap season using $1m^2$ quadrats, to crabs collected from the quadrats used to estimate the densities. A total of 34 mangrove crab species were recorded, with abundances significantly higher ($p>0.05$) within the inlets' habitats as compared to the outlets (discharge-point) habitats. Six species *Macrophthalmus grandidieri*, *Uca chlorophthalmus*, *Terebralia palustris*, *Macrophthalmus latreillei*, *Uca tetragonon* and *Amaea acuminata* were most dominant and occurred in all of the transect samples. Higher species diversity and evenness were recorded in inlet habitats at Kurawa compared to the outlets. The inlet habitats reported higher Maximum Shannon-Wiener diversity, whereas outlets recorded lower diversity, with Marereni recording considerably lower H_{max}, at 0.95. Species distribution showed a significant reduction of the genera *Uca* and *M. grandidieri* ($p<0.05$) at Marereni outlet habitats, but an increase in *U. vocans* at the inlet habitats. Large numbers of small sized species were recorded at the outlet compared to the inlet at both Kurawa and Marereni. Similarly, there was a higher abundance of *genera Uca*, *M. ovalina*, *M. grandidieri*, *M. latreillei*, *Amaea acuminata* and *Cerithidea decollata* ($p<0.05$) during the spring tide period while the abundances of *U. vocans* dropped during the same period. The higher densities of *M. ovalina* and *Uca inversa* were mainly associated with spring tides. PCA showed dominance of *M. grandidieri* (PC-1 score = 0.9129) at the inlet and outlet of the Kurawa site during both spring and neap tide, thereby accounting for most of the inertia. CCA showed that there was a strong positive loading of Chlorophyll-*a* on the abundance of *M. ovalina* at the Kurawa inlet habitats during the spring tide, but negative loading of salinity, pH and total phosphorus on *Pseudograpus elongatus* and *T. palustris* at Kurawa outlet habitats during neap tide. This asymmetric distribution between inlets and outlets was explained by significant variations in salinity as well as site specific salinity gradients at the two study sites; Marereni and Kurawa in north coast, Kenya. Suggestions for improving salt production and quality while minimizing adverse environmental effects through frequent monitoring of the water quality parameters and the mangrove crabs before and after brine discharged were recommended.

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ABBREVIATIONS

ANOVA	Analysis of Variance
CCA	Canonical Correspondence Analysis
EDTA	Ethylene-diamine-tetra-acetic acid
EIA	Environmental Impact Assessment
EMCA	Environmental Management and Coordination Act
EMP	Environmental Management Plan
ESP	Economic Stimulus Program
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GOK	Government of Kenya
KBS	Kenya Bureau of Statistics
KCDP	Kenya Coastal Development Project
KMFRI	Kenya Marine and Fisheries Research Institute
KNCHR	Kenya National Commission on Human Rights
LDCs	Lease Developed Countries
MSF	Multi Stage Flash
NaCL	Sodium Chloride
NEMA	National Environmental Management Authority
NET	National Environment Tribunal
P&DEC	Provincial and District Environmental Committees
PC	Principal Component
PCA	Principal Component Analysis
RO	Reserve Osmosis

SQT	Sediment Quality Triad
TDS	Total Dissolved Solids
TUM	Technical University of Mombasa
UNEP	United Nation Environmental Program
USGS	United States of America Geological Survey
WCS	Wildlife Conservation Society
WNO	World Nature Organization

DEFINITION OF TERMS

Conservation – means protection, preservation, management or restoration of wildlife and of natural resources such as forests water.

Crystallization - is a phase change in which a crystalline product is obtained from a solution.

Brine - means a solution having a dissolved solids concentration greater than that of sea water (35,000 milligrams per litre)

Inter-tidal - is also known as the foreshore and seashore and sometimes referred to as the littoral zone, is the area that is above water at low tide and under water at high tide (tidal range area)

Salinity - is the measure of all the salts dissolved in water

Salt marshes - is an area of coastal grassland that is regularly flooded by seawater

Saline water - is salty water, classified by the dissolved solids concentration in water

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

Common salt, or sodium chloride, is the chemical compound NaCl and occurs naturally in many parts of the world as the mineral halite and as mixed evaporates in salt lakes (Eugster & Hardie, 1978). Seawater presents one of the best sources of this natural nutrient, which contains an average of 2.6% NaCl by weight (Fofonoff, 1985). However, the seawater also contains other dissolved solids, with salt representing ≈77% of the Total Dissolved Solids (TDS).

According to Korovessis and Lekkas (2000), evaporation is one of the oldest methods employed in sea salt production. Majority of the industries for salt extraction are concentrated in tropical warm-climates where the weather permits solar evaporation during most months of the year. The process involves pumping seas water into a series of ponds where solar evaporation concentrates it into brine, and precipitates the salt; which is then harvested manually or mechanically. Over 30% of the global salt (sodium chloride) production estimated at 200 million mt per year is produced from solar salt works (Davis, 2000). During the process, all the impurities comprising about 23% of the TDS are drained-off and discharged into the intertidal environments prior to the harvesting of the salt. To minimize contamination of seawater intake into the solar salt works with the discharged the toxic waste brine, the industries employ separate inlets and outlets, ranging from a few hundred meters to several kilometres.

However, despite the numerous salt manufacturing industries as well as desalination plants scattered around the world, very few studies have been conducted on the impacts of the hyper-saline waste brine discharge on the environment (Tularam & Ilahee 2007; Latteman & Höpner 2008). Consequently, the natural chemical impurities continue to be discharged back to many intertidal marine environments. These highly concentrated/hypersaline waste brines are loaded with potent toxic remains of the evaporation process and present a huge threat to both flora and fauna of the intertidal environment, especially the mangrove and fisheries resources which are the mainstay of majority of the coastal rural populace of many of the Least Developed Countries (LDCs) in the tropics (Kumar & Khan, 2013).

Anthropogenic activities have been highlighted as the primary disturbances causing the recent changes in marine biological diversity in many coastal and sub-tidal areas globally (Skinner, 2008), and salt farming being one of them. Globally, the effects of the hyper-saline waste-brine disposal have been documented in some studies such as impacts on salinity (Tularam & Ilahee, 2007; Haurwitz *et al.*, 2008), pH (Skinner, 2008), fish fauna (Einav & Lokiec, 2003), local marine biota (Von Medeazza, 2005), sea grass meadows (Gacia *et al.*, 2007) as well as on the physico-chemical properties of the receiving waters (Ruso, 2007).

The additional and significant environmental issue associated with the waste brine is its high concentration of salts and residual chemicals including the chemicals employed during the ‘cleaning’ of the harvested salt. According to Roberts *et al.* (2010), majority of the solar salt work industries usually discharge the waste brine with little or no treatment; often back into the source mangrove habitats along the coast, thereby impacting negatively on the environment and the associated flora and fauna. Numerous studies have been conducted on the solar salt works (Swami *et al.*, 2000) but most have concentrated on the chemistry and techniques of the processes, with most of the quantitative research focusing on a priori modelling of the potential impacts of brine discharge. However, these predictions have rarely been tested after solar salt industries are constructed and neither do the industries or authorities conduct any environmental audits during the operation phase of the solar salt works.

Coastal intertidal and mangrove habitats are home to many benthic macro-invertebrates which inhabit the upper sediment environments (Ngo-Massou *et al.*, 2014). These organisms are >0.5 mm in size and range from sedentary and resident organisms, to highly migratory species (Teal, 1958). They inhabit all types of intertidal environments and majority of the sedentary fauna spend part or most of their life-cycle attached to submerged rocks, logs or vegetation (Ngo-Massou *et al.*, 2012). The migratory fauna, including some species such as the mangrove crabs dig burrows within the marine environments, but often have limited-distance migrations. Consequently, these benthic macro-invertebrates are impacted by the physical, chemical, and biological conditions of the environments due to their limited ability to escape pollution (Ngo-Massou *et al.*, 2012), and therefore, present very good indicators of the quality of the aquatic environments (Rader & Reed, (2005). Furthermore, the benthic macro-invertebrates exhibit stress related to the effects of both short and long term pollution events, and they may also show the cumulative impacts of pollution.

Some of the benthic invertebrates exhibit little tolerance to any kind pollution and, are relatively easy to sample and identify as they are visible (Wilhm & Dorris, 1966). The basic principle behind the use of benthic macro-invertebrates as environmental indicators is that they exhibit varying levels of pollution tolerance from one species to the next (Ngo-Massou *et al.*, 2014). Therefore, if an intertidal habitat is densely inhabited by pollution-tolerant macro-invertebrates, while pollution-sensitive organisms are absent; it is sensible to conclude that the site is mostly likely experiencing a pollution problem (Lancellotti & Vasquez, 2000). Coastal intertidal marshes and mangroves often exhibit a limited number of macro invertebrate species due to a number of environmental stressors such as salinity, water-logging, temperature, and exposure, augmented by rapid changes in environmental conditions (Teal, 1958; Gordon *et al.*, 2013; Mokhtari *et al.*, 2015).

Over the last few decades, biological diversity has received increased interest but according to Ellingsen (2002), very few studies have focused on mangrove and intertidal habitats and hence knowledge of coastal and marine biodiversity lags behind that of terrestrial systems. Notwithstanding, the fact that the world oceans cover ≈70% of the earth, creating rich coastal soft-sediment habitats in majority of the intertidal areas calls for immediate research focus on the coastal and marine habitats (Snelgrove, 1998). Despite being at the receiving end of the wider-basin ecosystems receiving numerous pollutants from the water-sheds, these marine habitats support a diverse array of macro-benthic communities which play important roles in ecosystem processes such as recycling nutrients, secondary production, detoxification, dispersion and burial of pollutants, and secondary production. Additionally, many macro-invertebrates comprise valuable seafood for man and also provide prey for a variety of teleost fishes and birds Thrush & Dayton 2002).

1.2 Problem Statement

Waste-brine discharge is one of the most significant environmental issues associated with solar sea salt production due to the presence of highly potent salt concentration and residual chemicals, including chemicals used during the ‘cleaning’ of the salt after harvesting. In many salt industries, and especially within the Developing and Least Developing Countries (LDCs), majority of salt industries discharge the untreated waste-brine back into the mangrove habitats along the coast with little regard to the likely impacts of these toxic concentrates on the environment and the associated flora and fauna. In Kenya, along the Gongoni-Kurawa coastal stretch north of Malindi, the operations of the numerous salt works are no different, and the impacts of the discharges on the marine environment, although little documented, cannot be understated. Apart from environmental impacts there are numerous conflicts between the salt industries and the local communities, who have highlighted the issues such as the salination of underground freshwater, mortality of both juvenile fish and adult fish species and crustaceans during weeks when the salt works discharge their brine, and when the mangroves habitats get flooded with the waste brine. Furthermore, the occurrence of soft-shelled (moulted like individuals) in majority of the exploited mangrove crabs and shrimps in these inshore habitats and creek fisheries is a common phenomenon calling for rapid assessment of the impacts of these industries not only on the intertidal biota, but to the entire marine ecosystem. Despite these noted impacts of the disposed waste-brine on the environment and on some select fauna, studies on both the short-term and long-term impacts of the disposed brine on the small-scale inshore fisheries as well as the other fisheries associated with the mangrove ecosystems, creeks, bays and river mouths are however, clearly lacking. This may partly be attributed to the fact that majority of the affected small-scale fisher-folks often migrate to utilize the alternative fisheries of the inlet reservoirs of the salt works where species such as penaeid shrimps (*Penaeus* spp), and other marine fish species thrive. However, the compromise might not compensate for loss of some fisheries such as oysters (*Crassostrea* spp) and crabs (Portunidae) which prefer the mangrove habitats for both the juveniles and adult stages.

Mangrove areas form important nursery and feeding grounds for many offshore marine fish species as well as habitats for a variety of terrestrial birds which depend on the abundance of the marine flora and fauna in these habitats. Consequently, any impacts on the mangrove ecosystems and coastal habitats go beyond localized species depletions, to wide ecosystem impacts on the associated flora and fauna of inshore environments, as well as both the small-scale inshore- and offshore- industrial fisheries which are closely linked to the habitats, including the bottom trawl shrimp fisheries of the adjacent Malindi-Ungwana Bay. Therefore, the little benefits derived by the locals from employment in the salt works and the scanty fisheries within the inlet reservoirs, cannot compensate for the likely wider impacts of the waste-brine discharge into the intertidal ecosystems. Evidently, the lack of baseline studies and documented information on the impacts of these salt works remains the biggest hindrance to the design of environmentally sound and sustainable salt works management systems, as well as establishment of key environmental audit guidelines for these expansive industries. The few studies conducted within the salt works only assessed the socio-economic impacts of the salt works on the local communities (Ochiewo, 2004). Therefore, a comprehensive assessment of the salt works in relation to impacts on the mangrove ecosystems and the associated flora and fauna, as well as to the overall impacts on the environment, is long overdue. In such studies, special attention must be focus on the disposal of the hyper-saline waste-brine which is often laden with heavy metal concentrates and chemicals, in an effort to spearhead an integrated sustainable development plan for salt mining along the Gongoni-Kurawa coast in Malindi. This will benefit both the local and national economies while preserving ecological integrity of these important ecosystems. Therefore, the present study aimed to assess the impacts of the hypersaline waste-brine discharge on the environment using mangrove crabs as the key macro-invertebrates indicators.

1.3 Justification

The mangrove ecosystems along the Kenya coast and the associated floral and faunal resources are important sources of livelihoods for coastal communities. Based on the fisheries records; over 20,000 persons in Magarini sub-county highly depend on the ocean and its resources. The fishermen, fisher traders and fish dealers are organised into beach management unit, whose aim is to bring on-board all stakeholders with interest(s) in fisheries resource management. However, entry of the salt works within the Gongoni-Kurawa coastal stretch, one of the richest mangrove ecosystems along the coast has elicited mixed feelings of both benefits (from employment) and loss (from impacted fisheries, groundwater freshwater sources). The situation is augmented by the lack of studies on each of the key issues associated with the salt works, and especially the impacts of the disposed hyper-saline waste-brine on the mangroves ecosystems, fisheries, and general species biodiversity. Therefore, the present study aimed to assess the impacts of the hypersaline waste-brine discharge on the environment using mangrove crabs as the key macro-invertebrates indicators, they can sensitive creatures and therefore can show scientists when an ecosystem is degraded.

Further, the study also sought to compare the variations in the water quality status at both the inlet and outlet habitats of the salt works, assess the potential impacts of both the pumping of water from the creeks and the discharge of waste-brine into the outlet habitats. The overall goal was to support environmental monitoring to safeguard the livelihoods of the numerous fisher-folks who are dependent on the mangrove ecosystems and associated resources for livelihood.

1.4 Objectives

1.4.1 Overall objective

The overall objective of this study was to assess the influence of solar salt works' hypersaline waste-brine on distribution of mangrove crabs (Decapoda, Portunidae) along the Gongoni-Kurawa intertidal areas, north coast Kenya.

1.4.2 Specific objectives

The specific objectives of this study were to:-

i) Compare the productivity of the coastal waters (both at the inlet and outlet habitats) in relation to Chlorophyll *a* and nutrients along the Gongoni-Kurawa coastal stretch, north coast Kenya,

ii) Assess the effect of hyper-saline waste-brine discharge on mangrove crab species′ diversity and distribution along the Gongoni-Kurawa coastal stretch, north coast Kenya,

iii) Determine the impact of the physico-chemical parameters and productivity on distribution and diversity of the mangrove crab species along the Gongoni-Kurawa coastal stretch, north coast Kenya.

1.4.3 Hypothesis

This study tested for the following research hypotheses:

H_{01}: There is no difference on the productivity and nutrients of the coastal waters; at the inlet and outlet habitats, of salt farms,

H_{02}: Discharge of hyper-saline waste-brine into the marine environment does not have any effect on the mangrove crab species′ diversity and distribution along the Gongoni-Kurawa coastal stretch, north coast Kenya,

H_{03}: The physico-chemical parameters and productivity influence the distribution and abundance of the mangrove crab species along the Gongoni-Kurawa coastal stretch, north coast Kenya.

CHAPER TWO

LITRETURE REVIEW

2.1 History of Salt Production

The demand for common salt, or sodium chloride globally stood at 327 million mt in 2015, representing close to double the global seafood production from both capture and culture fisheries which was estimated as 167 million mt in 2014 (Korovessis & Lekkas, 2000). The huge consumption of salt presents a very rich industry despite the low prices of this commodity and was globally valued at US$ 13.4 billion in 2015. The traditional method of solar evaporation has remained the most dominant method of producing salt, accounting for 38% of the total salt produced globally (Korovessis & Lekkas, 2000). It is also the most economical method of salt mining, and especially in areas with favourable hot climate conditions, which occurs in majority of the tropics and sub-tropics, and especially in Africa, Middle East, and the Asia-Pacific regions with many of the Least Developed Country (LDCs), (Culligan *et al.*, 2012). It is predicted that salt production growth is fastest in these regions, and therefore, solar evaporation will account for an increasing share of the global salt production in future. However, it is predicted that rock salt and brine production would continue to increase in 2015/2016 although their respective rates of growth still lag that of solar salt evaporation (Culligan *et al.*, 2012).

Production data from Warren (2016) shows that the United States was the world's leading salt producing nation until 2005, when China took the lead to become the top salt producing country in the world. The total salt production in the United States decreased by 6% in 2010, recording ≈43 million mt compared with the production in 2009. Based on the (USGS) data for 2010 (Warren, 2016), about 28 companies operated an estimated 60 salt production plants in 16 states of the United States. According to the British Geological Survey (BGS) data for 2012 (Brown *et al.*, 2014) on the salt producers in the world for countries with available statistics, China was still ranked first in position, having produced 62,158,000 mt, followed by United States 40,200,000 mt, then India ranked the third (24,500,000 mt). Kenya on the other hand was ranked 78, with a production of 24,000 mt, contributes 0.01% of the world production.

Africa produces around 5 million mt of the 181.5 million mt sea salt produced globally. The salt production techniques used in many Sub-Saharan African countries are predictable and in some areas very simple (Venkatesh & Rizwan, 2013). There are two major government owned sea salt operations in Eritrea, on the Red Sea coast and several privately-owned small and medium sized operations. In Ethiopia on the other hand, a group of small producers are established around Afdera and Dobi in the Afar region which supplies the entire country. Mozambique and Angola's production is slowly gaining momentum whereas in Kenya and Tanzania, sea salt and brine-salt are widely produced. Generally, every country has own unique system of salt production, distribution and consumption.

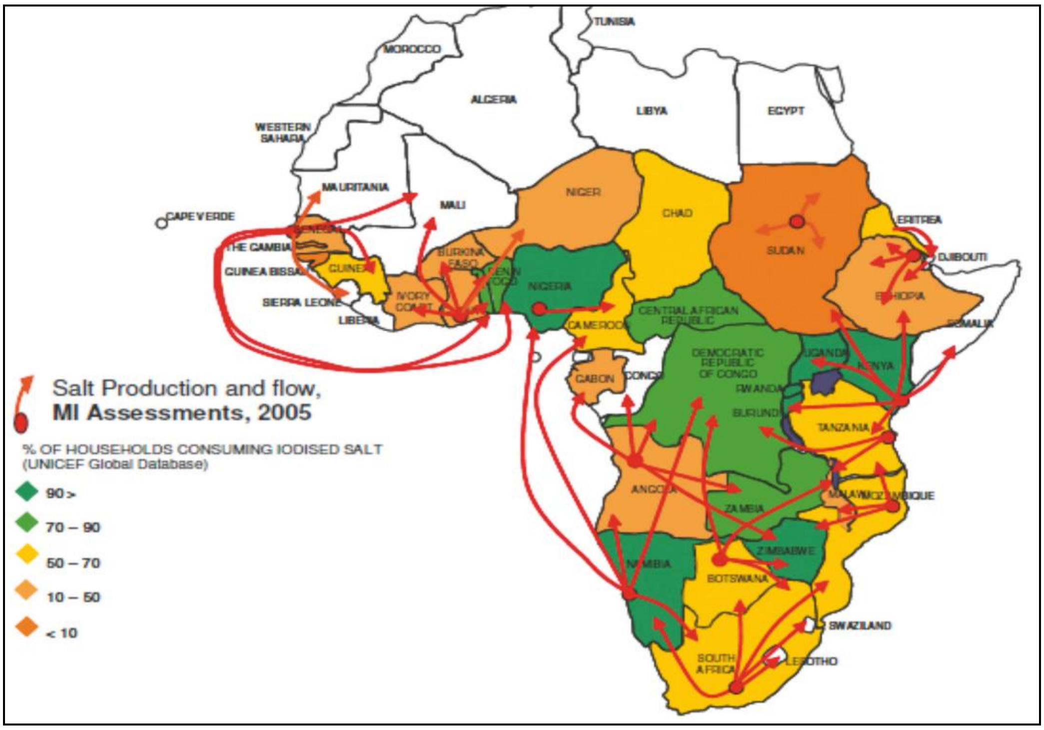


Figure 0.1: Salt production, flow and percentage of households consuming iodised salt. (UNICEF Global Database, 2005)

According to Venkatesh and Rizwan (2013), Angola, Botswana, Ethiopia, Ghana, Mozambique, Namibia, Senegal, South Africa, Sudan, and Tanzania comprise the ten (10) key salt producing countries in sub-Saharan Africa. However, BGS data for 2012 (Brown *et al.*, 2014) ranked Kenya at position 17 among the salt producing countries in Africa; Egypt (2,883,577 mt), Tunisia (1,131,200 mt) and Namibia (738,000 mt) being the first leading African countries. The salt produced in these countries has a wide reach and potential to make the greatest impact on iodized salt coverage in the region.

There are three (3) groups of salt consumers; the chemical industry being the largest using about 60% of the total production, converting the sea salt mainly into chlorine, caustic soda and soda ash needed for petroleum refining, organic synthesis and glass production (Sedivy, 2008). Domestic consumption presents the second largest user of salt, utilizing ≈30%. Common salt as NaCl is important for supporting the physiological functions in man, as well as for managing the eating habits. The salt is available from thousands of sources in hundreds of qualities as table, cooking and salt for food production. Lastly about 10% (Sedivy, 2008) of salt is needed for road de-icing, water treatment, production of cooling brines and many other, smaller applications especially in the developed countries.

2.2 Salt Production along the Kenya Coast

Salt farming along the Kenya coast dates back to the late 1920's when the first entrants, Mombasa Salt Works established its first ponds in the Gongoni areas of north-coast Kenya (Kenya National Commission on Human Rights, 2006). The location of solar salt works is controlled by the rainfall regime and the occurrence of suitable impermeable soils (Jhala, 2006). These conditions occur from Ngomeni northwards to the Lamu area. Extensive salt works have been established at the Gongoni-Fundisa area and Kurawa. Since then several other farms have been established including Krysalline, Kurawa, Malindi, Kensalt and KEMU (Okoth, 2012). The total area dedicated to salt production is over 5,000 hectares that yield an average of over ≈170,000 mt of salt annually, but the local communities appear to have benefited very little from the salt works and the wider environmental impacts are not fully understood (Okoth, 2012). The coastal stretch still has a huge/massive potential for expansion of salt farming in the region.

The method of salt production employed by all the companies within the Gongoni-Kurawa area has not changed much since inception of the solar salt production farms in the 1920's (KNCHR, 2006). The method of salt production utilised by the five established companies is very much the same throughout the area. Seawater is introduced into the ponds which are run in series. Slight variations may occur in the method of filling the ponds which utilize tidal energy (Ahmed *et al.,* 2003; Morillo *et al.,* 2014). In the first pond, undesirable salts of low solubility are removed and the water then flows into concentration, evaporation and crystallization ponds. Crystallized salt is gathered from the ponds manually by excavation, washed and transported to the refining industries in Mombasa, while the waste-brine is discharged into man-made canals that empty into the nearby intertidal areas and creeks. There salt companies operating in the Gongoni-Kurawa coast north of Malindi, and the estimated acreage, year of venture, location size of labour are shown in Table 2.1.

Table 0.1: Salt companies operating in the Gongoni-Kurawa coast north of Malindi town (Source Okoth, 2010)

Name	**Location**	**Year started**	**Area (Ha)**	**Labour force (#persons)**
Krystalline Salt Limited	Marereni	1985	-	170.0
KENSALT Limited	Gongoni	1974	2,264.9	400.0
Malindi Salt Works	Malindi	1984	665.0	140.0
Kurawa Industries Limited	Kurawa	1976	595.2	-
KEMU Salt Packers Prod. Ltd.	Marereni	1997	3,835.0	200.0

2.3 Global Solar Salt Production Systems

According to Sedivy (2008), sea water contains ≈30.1 kg NaCl m^{-3} and 998.64 kg of water per cubic meter. Consequently, ≈89.9% of this water must be evaporated before the first crystals of NaCl can start to form. A further ≈6.2% of the water must evaporated before the brine becomes concentrated enough for evaporation to slow down considerably, leaving ≈4.0% of waste-brine, whose further evaporation would contaminate the salt and lower the quality of the salt. Therefore, this 4.0% of waste-brine must be discarded by discharging into the intertidal areas before the crystallized salt is dug up.

The salt works operations may be continuous or seasonal depending on the duration of operation (Davis, 2000). In the continuous operation, a salinity gradient is maintained throughout the serial ponds, and this system produces salt continuously throughout the year. In the seasonal type, a salinity gradient is also maintained to produce salt only during the summer.

Generally, the salt works are designed to consist of a sequence of shallow ponds through which seawater flows and evaporates in stages, keeping the salinity of each pond within a narrow range. Shortly before water reaches saturation with sodium chloride, the brine repeatedly flows into crystallizer ponds (crystallizers), where evaporation continues and the liquid above the salt is occasionally removed until 5-20 cm of salt is deposited on the pond bottoms. According to Davis (2000), the deposited salt is harvested, washed and stored for a period of time to decrease contaminants before sending to market. In well-functioning and properly managed solar salt-works, the processes produce salt of upto 99.7% purity on a dry basis. Raventós *et al.*, (2006) has documented three systems of evaporating the sea water namely; single, double and multi-pond systems. Three stages in the production process; reservoirs, condensers and crystallizers constitute the basic steps towards improving the salt manufacturing technology.

2.4 Brine Disposal Method

The waste-brine discharge from salt manufacturing companies contains a high percentage of salts and dissolved minerals (Culligan *et al.,* 2012). Pe´rez-Gonza´lez *et al.* (2015) notes that the characteristics of the waste fluid depend on the quality of the feed water, the pre-treatment method which often employs added chemicals, and the cleaning procedures used. The essential concentrations are found to be double or higher than that in in-coming seawater. In de-salination plants, about 55% of brine is generated from the seawater (Meneses *et al.*, 2010).

Most of the waste-brine disposal in the salt manufacturing companies along the coast has been through direct discharge to the sea. There are two types of brine discharge methods applied in a desalination plant; through a water channel and a pipeline (Culligan *et al.,* 2012). The brine might be excluded directly either into the ocean or combined with other discharges. Particular factors play significant roles in the discharge plume and the diffusion into the seawater, which include; (i) direction of the wind and speed, which affect the dilution of the highly concentrated column into seawater in a given distance, (ii) wave height and speed, which aids in the variation of seawater properties and may have significant effects on the ambient environment and, lastly (iii) bathymetry and the mean and average tidal ranges.

2.5 Environmental Impacts of Brine

The environmental impacts of waste brine discharge on the environment range from direct impacts on physico-chemical parameters to wide spread impacts on both flora and fauna, as we well as impacts on the wider ecosystem. These impacts are outlined below.

2.5.1 Impact on marine ecosystem

It has been shown that (Svensson, 2005; and Culligan *et al.*, 2012) that waste-brine disposal poses a major environmental impact on the ocean, especially the disturbance of both flora and fauna at the area of the outlet due to higher salinity levels and the chemical constitution of the waste-water. The immediate impacts that of salt production processes, are associated with the marine structures constructions, mainly at the water intake site and the outlet, often in relation to clearing of mangroves and the construction of water feeder canals. During operation, the waste-brine, which is denser than the receiving sea waters, creates plume at the outlet, inhibits free water mixing and consequently sinks to the bottom. According to Hogan (2008), Dawoud, (2012) and Gordon *et al.* (2013), the immediate impacts associated with the processes that come with brine discharge include:

i) Impacts on the water quality and on the benthic organisms present in the receiving water body, due to digging up of trenches and placement of new infrastructures;

ii) Impacts on navigation and fishing, and this is because of the presence of new infrastructures;

iii) Impacts on the coastal dynamics of beaches by the presence of structures in the active beach profile zone, which may affect long shore and cross-shore sediment transport.

Other impacts associated with the digging-up process itself include: a) occupation and physical destruction of benthic ecosystems located in the dredging area; b) increased suspended solids in the waters; c) turbidity and reduction in the percentage of light penetration through the water column and consequently; and d) the processes impact the benthic primary producers.

Studies have shown that the concentrations of suspended solid higher than 20 mg L^{-1} cause adverse initial disturbance and also affect the growth of the seabed flora (Dawoud, 2012), leading to re-suspension of sediments, nutrients or pollutants into the water column. The settling of the suspended solids buries the benthic organisms; and since the particles are transported by the water currents the effect on the benthic organisms is felt even far away from the dredging area. Other impacts are connected with the open water intakes include negative impacts on habitats that are found around the intake area due to extraction of large quantities of water, trapping of larger organisms on screen mesh during water intake, physical damage and disorientation (Hogan, 2008). Based on these negative impacts conflicts between the salt companies and the local communities have been on the rise on local fisheries (Gordon *et al.*, 2013).

Under a study area in north coast Kenya, artisanal fishermen and the community in Kurawa-Gongoni coast have reported decline in fish production due to fish kills at the outlets of the salt works, causing migration of fish to deeper waters in response brine discharge, (Gordon *et al.*, 2013). The survey reported that Ngomeni was a thriving fish harbour for years before entry of the salt companies, and the associated activities which diverted rivers by building dykes, destroyed almost all the rich fishing grounds. Consequently, as more and more salt works are constructed, increasing impact of the waste-brine disposal are being felt by the local communities who are dependent on the mangrove and coastal habitats for sources of livelihood as documented by Gordon *et al.* (2013).

2.5.1 Water quality

The direct discharge of waste-brine into the environment and estuary without prior treatment greatly impact the physico-chemical parameters of the receiving waters with resultant increase in sea salinity (Von Medeazza, 2005); thus impacting negatively on marine life such as juvenile fishes, fish eggs and mangrove sprouts. Parry (1960) documented that raising the salinity level up to 50 ppt could probably have a serious impact on the fish size and on their survival rate. According to Skinner (2008), brine disposal causes eutrophication, due to the high levels of phosphorus in the brine effluent and also alters the water quality parameters that are essential for the development, growth and survival of the marine organisms. The pH-range of marine environments also changes due to the brine discharge although this may be negligible compared to other impacts on the physico-chemical parameters.

Discharge of waste-brine causes thermal pollution due to increased temperatures of the receiving sea waters, which changes to ≈40^0Cnear the area of the waste-brine disposal (Danoun, 2007). Some studies (Abdul-Wahab, 2007; Roberts *et al.*, 2010) have been carried out to determine how the distribution and natural balance of marine flora and fauna respond to alteration in temperature. The distribution and extent of the temperature alteration was found to depend on the location of the waste-brine discharge.

Brine discharge also affects the dissolved oxygen (DO) levels of the receiving waters (California Coastal Commission, 2004; Haurwitz *et al.*, 2008). Since DO levels are inversely proportional to salinity levels, increasing salinity results in decreased oxygen levels resulting in hypoxia caused mortality. Further, Increasing temperature of the receiving waters also result in decreased dissolved oxygen with resultant decline in both faunal and floral biomass

2.5.2 Fauna and flora

Changes in salinity have been found to influence reproduction in marine organisms as well as the developmental stages and growth rate (Neuparth *et al.*, 2002). For example, increased salinity has been found to significantly disrupt transmission of larvae during the most delicate life stages. Although many marine species can withstand salinity fluctuations, they may not survive sudden changes in salinity associated with the brine disposal (Haurwitz *et al.*, 2008). According to several studies (Meneses *et al.*, 2010; Culligan *et al.*, 2012; Gordon *et al*., 2013; Venkatesh & Yusufali, 2013), benthic environments may tolerate salinity increases of about 1ppt but the actual impact of brine may be a function of the particular ecosystem in the disposal area. The denser waste-brine causes plumes which extend further along the seafloor than at the surface (Gacia *et al*., 2007; Al-Barwani, & Purnama, 2008). The behaviour of the waster-brine plume is of biological importance and potentially contributes to greater exposure of benthic organisms to brine discharges than pelagic and planktonic organisms. For example, brine discharges to sea grass meadows show more intensive water quality shifts when pore-waters are analysed, rather than overlying waters (Gacia *et al.*, 2007) and hence organisms inhabiting depressions in hard and soft substrata are differentially exposed. For sea-grass exposed to vertically stratified salinities under laboratory conditions showed significant effects to survival regardless of exposure method (Sanchez-Lizaso *et al.*, 2008). Majority of the studies have focused on quantifying the impact of brine on physico-chemical as well as biological characteristics of the marine environment (Ahmed & Anwar, 2012).

According to King and Brown of 2010, mangroves inhabit inter-tidal habitats along estuaries, rivers, bays and islands growing as groups in sheltered areas where fine sediments accumulate, and where they are inundated by seawater during the daily tidal cycle. In Africa the mangroves are very diverse morphologically and in flora and fauna. A total of 17 mangrove species are found in Africa with eight species uniquely in west and central Africa while nine species are unique to eastern African costs. Mangrove species in Eastern Africa include *Avicennia marina*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Heritiera littoralis*, *Lumnitzera racemosa*, *Rhizophora mucronata*, *Sonneratia alba* and *Xylocarpus granatum*. Faunal composition is also very diverse with and includes mammals, molluscs, crustaceans, fish, wildlife, reptiles and a variety of aquatic and semi aquatic birds (King & Brown, 2010).

Despite the importance of these mangrove ecosystems, they have been subjected to enormous pressures and threats within the past decades with great losses due to numerous factors including urbanisation, infrastructural development, quarrying, salt and sand extraction; pollution from industries; absence of appropriate legislation (Ajonina *et al.,* 2005), proliferation of invasive species and climate-change effects accentuated by population growth (Ajonina *et al.,* 2005).

Mangrove species are known to be obligate halophytes, growing in habitats with medium salinities of <25 ppt (Bulow & Ferdinand, 2013). Waste brine discharge is known to result in increased salinity but the ability for the mangrove to counteract this osmotic potential for water uptake becomes increasingly difficult (Lovelock *et al*., 2006). Under chronic salinity stress, many mangrove species suffer leaf mortality accompanied by a notable decrease in leaf production rate, which in most cases can lead to the tree's death (Bulow & Ferdinand, 2013). The success of mangrove seedlings is also influenced by certain salinity ratios which vary from one species to the next.

Crabs are the most abundant macro-invertebrates in mangrove ecosystems with an estimated 275 species inhabiting these intertidal habitats. The genus *Uca,* or fiddler crabs present the most abundant group with densities of up to 70 crabsm^{-2}, and are particularly important to the functioning of the mangrove ecosystems. During burrowing, crabs improve the infiltration of ground water, water from high tides and freshwater runoff (Bulow & Ferdinand, 2013) which helped in flushing out excess salt that also reduces the soil salinity. The burrows also oxygenate the sediment by creating air spaces in otherwise oxygen-deprived sediments. Crab holes also provide refugia for many organisms, including fish, molluscs and worms. Furthermore, many crabs feed on large amounts of fallen mangrove leaves and propagules while other species eat algae and detritus. Therefore, the presence of crabs in these ecosystems has been shown to improve the growth of mangrove and salt marsh plants, and also increase the biomass and diversity of other organisms (Katrina & Chin, 2006).

In addition, the burrowing activity alters the topography and micro-hydrology, while functioning as a system of channels that carry water, dissolved nutrients and oxygen to the anaerobic soils around mangrove roots at the same time (Bulow & Ferdinand, 2013). This bio-perturbation process increases the reactive anaerobic area of the mangrove soils, thereby helping to facilitate the decomposition and mineralization of nutrients to improve mangrove viability. The absence of crabs, and therefore their burrows, could result in plant nutrient deficiencies and unfavourable soil conditions that would reduce mangrove primary production and damage the overall ecosystem.

Increase of salinity levels caused by waste-brine discharge are among the main factors influencing reproduction, dispersal and recruitment of organisms in marine, coastal and estuarine habitats (Ruso. *et al*, 2007).

According to Wolchok (2006) who studied salt works in Pemba, the effect of waste-brine on crabs is diverse, but fish populations declined due to development of salt farms. In some cases, fish landings may increase due to additional catches of fish in the reservoirs, but more often decline because certain species of fish living in estuarine environments are poisoned by increased salinity from the salt works. Studies by Wolchok (2006) have shown that fish populations are much lower near salt farms, and these changes in the fish nurseries and habitats in the mangroves linked to the destruction of mangroves.

2.5.3 Impact of waste-brine discharge on artisanal fisheries

Salt production in Kenya is conducted in large-scale intertidal farms along the Gongoni-Marereni coast off the Malindi-Ungwana Bay (Gordon *et al.,* 2013). The clearing of extensive mangroves forests and other terrestrial vegetation for excavation of the crystallization reservoirs is known to impact negatively on the key species such as the mangrove mud crab and the associated fishery due to habitat loss (Gordon *et al.,* 2013). The crabs depend on the mangroves for critical habitats during their life cycle since as adults they feed on benthic invertebrates living in the mangroves. Consequently, lower crab catches have been reported in areas impacted by heavy harvesting of mangroves (Government of Kenya, 2012).

2.6 Treatment and Management of the Waste-Brine

A serious limitation in the salt farming producing concentrated solutions, is the lack of adequate methods of waste brine disposal such that the brine does not re-enter and contaminate the raw water inlet system (Buckley *et al.,* 1987). Globally, waste-brine management is a challenge in the absence of regulations guiding the physico-chemical parameters of brine effluents from desalination plants (Palomar & Losada, 2011).

The impacts of a salt works waste-brine discharge on the marine environment depend on the physical and chemical properties of the desalination plant reject streams, and the susceptibility of coastal ecosystems to these discharges depending on their hydrographical and biological features. Therefore, a good knowledge of both the effluent properties and the receiving environments is required in order to evaluate the potential impacts of salt production on the marine environment.

In Kenya, different management measures have been considered for exploiting the marine resources (Fondo, 2004). The Agenda 21 of the Kenya constitution requires integration of economic, social and environmental factors of development in decision making at the policy, planning and management levels; so as to influence the actions of governments, industry and individuals towards efficient and sustainable development (Gordon *et al.*, 2013). This can be achieved by promoting income-generating activities such environmentally sound mining to protect the livelihoods of local communities and native people. To ensure sound environmental consideration in the economic growth and development in Kenya, the government enacted the Environmental Management and Coordination Act, 2013 (EMCA). The Act created several institutions to play different roles towards good management and governance of the environment i.e. {National Environment Tribunal, Provincial and District Environmental Committees, and National Environmental Management Authority (NEMA)}. Section 58 of EMCA, requires that Environmental Impact Assessment (EIA) to be conducted in accordance with the regulations and guidelines before the initiation of the development projects. This by extension ensures that Section 67 of the Constitution of Kenya grants a right to clean and safe environment to all.

FAO Code for Responsible Fisheries, Article 6.5 (1995), advocates for a precautionary approach to management of fisheries resource. This provision allows for giving priority to conservation measures where scientific data is not available or sufficient to make an informed decision arising from utilizing a fisheries resource. Whereas the EMCA (2013) provides for the drafting and implementation of an Environmental Management Plan prior to starting operations of a high impact project like salt works, this act came into force later on hence this provision didn't help at the time. However, given their implementation of an Environmental Management Plan (EMP) following the said regulation, the reporting from the salt farms along the Kenyan Coast cannot be relied upon to give negative effects on the environment if any, since that would jeopardize their credibility and operating license. There are several environmental-related grievances especially from the communities; (human health, agriculture, fresh water and fish production) directly attributable to the establishment and operation of salt works in Gongoni, Marereni and Kurawa areas within the greater Magarini division (Gordon *et al*., 2013).

CHAPER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was conducted at two areas in Gongoni-Kurawa area, north coast of Kenya (Fig. 3.1) adjacent to the salt works namely: Marereni and Kurawa which are home to some of the biggest salt works along this coast. Marereni is an area that is populated with people and whose geographical coordinates are 2° 52' 9", 40° 8' 44", whereas Kurawa is a semi-populated area with coordinates of 2°41'41.28"S and 40°9'35.58"E.

Each area was characterized by wide-ranging saltpan fringed by mixed mangroves forests on their seaward margins. The study areas chosen were commonly used for fishing activities during high tides. In each location constant discharging of the waste-brine from the salt work companies had caused the formation of recognizable streams of devoid mangroves. The critical habitat along the Gongoni-Kurawa is the mangrove forests.

The climate and the weather systems on the Kenyan coast are dominated by the scale pressure systems of the Western Indian Ocean and the two distinct monsoon seasons; the dry northeast monsoon- from October to March, and the wet southeast monsoon- from April to September (McClanahan, 1988).

Two study stations inlet and outlets were investigated at each area to account for water quality and the mangrove crab species distribution.

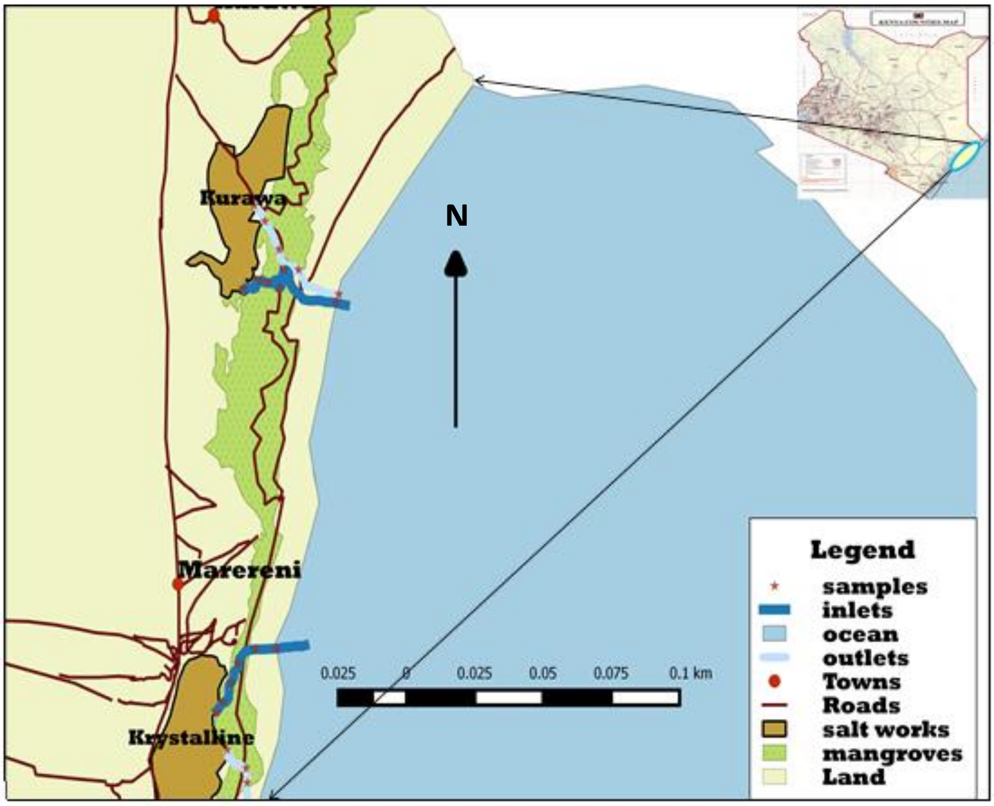


Figure 0.1: Map showing the sites for data collection, Marereni and Kurawa along the Malindi-Ungwana Bay, in North coast Kenya.

3.2 Sampling and Data Collection

3.2.1 Physico-chemical parameters

Two sampling sites were selected for this study; Marereni and Kurawa salt farms, with ten (10) sub-stations on each site, based on the flow and concentration of the brine along the water channels towards the ocean. Five stations; St. 1_I to St 5_I (I= Inlet) located at the inlet, and St. 1_O to St. 5_O (O=Outlet) located at the outlet where the waste-brine is discharged into the mangrove ecosystems, and an average of each per site found in both the inlet and the outlet.

Water samples were collected from both the inlet and outlets using clean clear plastic 250 ml-bottles, which were kept at a low temperature in a cooler box and taken to Pwani University for analysis. At the laboratory salinity was measured using a hand-held/portable Brix refractometer REF107 0-90 % Brix model, where two drops of the water sample was dropped at the surface of its prism to be measured. The corresponding scale of light and dark boundary was then read, which the brix of measured water sample was observed under the light. The water samples were also measured for pH at the Pwani biological laboratory using a digital pH meter (pH211-microprocessor pH meter from Hanna instrument).The electrode tip of the pH-meter was submerged into the sample and stirred briefly and stable readings were taken. For the analysis of nutrients, the water samples were then filtered using a millipore filtering system and analyzed for total phosphorous and nitrate by adopting standard procedure of Goldman and Jacobs (1961) as outlined below.

For the total phosphorous analysis (Goldman & Jacobs, 1961), a preliminary sample treatment was done where 0.05 ml (1 drop) phenolphthalein indicator was added to 100 ml sample. For the samples that turned pink, a strong acid solution was added drop-wise to discharge the color. There after 4.0 ml molybdate reagent I and 0.5 ml (10 drops) stannous chloride reagent I was added and thoroughly mixed after each addition. Rate of color development and intensity of color depended on temperature of the final solution.

A standard curve of absorbance for phosphate concentration versus known phosphate concentrations was then prepared, where six standard phosphorus concentrations and distilled water blank were treated with the same digestion procedures as the samples. The 6 values were used to plot absorbance versus phosphate concentration to give a straight line passing through the origin. A total of 6 dilutions of the 5.0 mg/l Phosphate standard were prepared to result to final concentrations which included the final concentrations (0.1 mg/l, 0.2 mg/l, 0.4 mg/l, 0.6 mg/l, 0.8 mg/l and 1.0 mg/l), the volumes of the standards and the final volumes in the flask. The absorbances were recorded and the curve plotted. After 10 min, using the same specific interval for all determinations, colour photometrically at 690 nm was measured and compare with a calibration curve, using distilled water blank. Lastly, using the formula below the Total phosphorous was calculated and recorded.

$$\boldsymbol{Mg\frac{P}{L} = mgP(in\ approx\ 104.5\ ml\ final\ volume) * \frac{1000}{ml}sample}$$

Where:

Mg P/L = Total phosphorous

The method employed for the nitrate analysis was the ultraviolet spectrophotometry screening method (Goldman & Jacobs, 1961). Each water sample (50 ml) was filtered and mixed thoroughly with 1 ml of HCL solution. A standard curve was then prepared where NO_3^- calibration standards that ranged from 0 to 7 mg NO_3^--n/l were diluted to 50 ml of the volumes of intermediate nitrate solution: 0, 2.00, 4.00, 7.00 and 35.0 ml. NO_3^- standards were also treated in same manner as the samples. Using the spectrophotometry measurement, the absorbances were read against redistilled water set at zero absorbance using a wavelength of 220 nm to obtain NO_3^- reading; and a wavelength of 275 nm to determine interference due to dissolved organic matter. For the samples and standards, the absorbance reading at 275 nm was subtracted two times from the reading at 220 nm to obtain absorbance due to NO_3^- and the results recorded.

Analysis of chlorophyll-*a* was conducted at the laboratories in the University of Eldoret using standard methods (American Public Health Association [APHA], 1998). The water sample of 100 ml was filtered using a filtration unit and the residue placed in a stoppered test-tube containing 100ml of a pure (100%) methanol. The content was then put in a water bath until the pigment was completely extracted. The solution was then transferred to a centrifuge for 15min at 3500 revolution per minute (rpm). The super-natant solution was considered for determination of optical density in a spectrophotometer. The super-natant solution so obtained was transferred to a 1cm cuvette of the spectrophotometer for the determination of chlolophyll-*a* at a wave length of 665nm. There after the chlorophyll-a content was calculated using the formula below and the data obtained recorded.

$$\mathbf{Chlorophyll} - \boldsymbol{a} = \mathbf{11.85}\boldsymbol{E}\mathbf{655}$$

Where:

E **=** wave length

3.3.2 Crabs

Assessments were conducted for a total of five months in the two sampling stations: Marereni and Kurawa. At the stations, crab samples were collected at both neap and spring low tide. Crab sampling was done using a (1m x 1m) wooden quadrat at each site (outlet and inlet area) at the littoral zones.

Plate 0.1: Quadrat set at the sampling site (Source, Author, 2014)

In order to give a representative data 10 replicate sampling locations were randomly chosen at a distance of 0-10m horizontally along the water channels that flows into the ocean and then 0-10m vertically to identify the species type, density, richness and diversity. The crab samples were hand-picked while some were scoped. The crabs were washed through a sieve, sorted and identified to species level according to Richmond, (2011) in situ and others packed in zipped paper bags and labelled depending on the site collected; and preserved in iced cooler box and taken to the Pwani University laboratory where they were identified according to Richmond (2011). At the Pwani University laboratory the crabs were removed and counted and the number recorded based on the species type. The crab size was also determined by measuring the carapace length using a vainer calliper to the nearest 0.1centimetres. Only the record of the four most abundant crab species in both the sites was used to determine the size frequency distribution of the crabs.

3.4 Data Analysis

Data analysis was carried out based on the random sample collected during the study. Means, Standard Errors and tables were used for descriptive statistics. General Liner Model (GLM) was used to test for difference in the environmental factors between stations and tide levels. Data analysis was based on species level in order to provide greater resolution of selectivity and potential overlap among sites. Logistic regression was used to estimate coefficients (parameter estimates), standard error of the coefficients, z-values and p-values. These sets of parameter estimates, gave non-parallel lines for the response values. Principal Component Analysis (PCA) was used as a tool in exploratory data analysis to explain the association and groupings between the crab species and the sampling stations. Canonical Correspondence Analysis (CCA) was used to show the relationship between crab abundance and the environmental factors. It was applied to determine the environmental factors influencing the distribution of the portunid species in the Marereni-Kurawa intertidal ecosystems between site and station. The taxa richness (for higher classification level), Shannon-Wiener diversity index and dominance index $\boldsymbol{Nin\,f} = \frac{\mathbf{1}}{\mathbf{max}}\{\boldsymbol{P_i}\}$, were used in order to reduce the multivariate (multi-taxa) complexity of the data into a single (or small number of indices) that were evaluated for each sample.

Size distribution by species was established from the sampled catch using standard length measurements. Macro invertebrates species composition data was used to determine species abundance between the two sampling station; of Kurawa and Marereni.

3.4.1 Diversity Indices

This study's Shannon-Wiener diversity index, dominance index and maximum diversity and were statistically analysed by using the univariate technique of Analysis of Variance (ANOVA) using the Microsoft Excel.

3.4.1.1 Shannon-Wiener diversity index (H')

This measured the diversity of taxa in categorical data by treating taxa as symbols and their relative population sizes as the probability. This index took into account the number of taxa and their evenness. The index increased either by having additional unique taxa, or by having greater taxa evenness.

Shannon-Wiener diversity index was calculated using the following formula:

$$\boldsymbol{H} = -\sum_{\boldsymbol{i}=\boldsymbol{1}}^{\boldsymbol{s}} -(\boldsymbol{P_i} * \mathbf{ln}\, \boldsymbol{P_i})$$

Where:

H = the Shannon diversity index

$\mathbf{P}_{\boldsymbol{i}}$ = fraction of the entire population made up of species i

S = numbers of species encountered

∑ = sum from species 1 to species S

High values of H represented more diverse communities. A community with only one species would have an H value of 0 because P_i would equal 1 and be multiplied by ln P_i which would equal zero. If the species were evenly distributed then the H value would be high. So the H value allowed us to know not only the number of species but how the abundance of the species is distributed among all the species in the community.

3.4.1.2 Dominance index (Nin f)

Dominance reflected the distribution of traits in a community, which in turn affects the strength and sign of both intraspecific and interspecific interactions (Hillebrand *et al*., 2008). Dominance index is a quantitative estimate of biological variability that was used to compare taxa communities by expressing how individuals were distributed among the different taxa, taking larger values when no taxa dominate the total abundance. Higher values of the index indicated low dominance, while lower values indicated high dominance.

This index is calculated by the following formula:

$$\boldsymbol{Nin\ f} = \frac{\mathbf{1}}{\mathbf{max}}\ \{\boldsymbol{P_i}\}$$

Where:

Nin f (D) = Dominance index

P_i = fraction of the entire population made up of species *i*

3.4.1.3 Species Evenness

Species evenness was used to show how close in number each species in the environment is. Higher values of the index indicated high evenness, while lower values indicated high evenness.

This index is calculated by the following formula:

$$\boldsymbol{J'} = \frac{\boldsymbol{H'}}{\boldsymbol{H'}\mathbf{max}}$$

Where:

H' = the number derived from the Shannon diversity index

***H'*$_{max}$** = the maximum possible value of H (if every species was equally likely)

J' is constrained between 0 and 1. The less variation in communities between the species (and the precence of a dominant species), the lower the *J'* is and vice versa.

3.4.1.4 Logistic Regression

Logistic regression showed the estimated coefficients (parameter estimates), standard error of the coefficients, z-values and p-values. The odds ratio and a 95% confidence interval for the odds ratio were also shown. The coefficient associated with a predictor was the estimated change in the logit with a one unit change in the predictor, assuming that all other factors and covariates were the same. This was statistically analysed using the Microsoft Excel. The negative the value the lower the number of species community it is by the same number and vice versa.

CHAPTER FOUR

RESULTS

4.1 Physico-Chemical Parameters

4.1.1 Salinity

Kurawa was observed to have high levels of salinity at the outlets as compared to Marereni outlets and lower levels of salinity observed at the Marereni inlet as at Kurawa inlet (Table 4.1). The salinity at Kurawa-outlet were highest 50.25 ± 6.92 (ppt) during spring tide, but slightly higher than those observed during neap tides 49.67 ± 6.78 ppt. The lowest salinity values were recorded in Marereni-inlet 22.62 ± 4.40 ppt during the neap tide. There was a general drift of salinity being low at the inlets and high at the outlets for both Kurawa and Marereni. Based on the GLM-ANOVA test, there was a significant different between the sites (F = 4.77, p <0.0005) and station (F = 21.51, p<0.0005).

4.1.2 Variation in pH

The pH observed ranged from 7.92 to 8.42. Highest pH values were recorded at Marereni inlet 7.73 ± 0.05 during spring while the lowest pH values were recorded at Kurawa outlet 7.56 ± 0.07 during neap as shown in the table below (Table 4.1). Higher value at Marereni inlet dropped towards the outlet during spring tide. On the contrary, pH increased towards the outlet at Kurawa during the neap tide. While Marereni recorded a decline of pH towards the outlets, the decline in the spring tide was greater compared to the neap tide. General the pH observed during the period was decreasing towards the outlets. GLM-ANOVA showed no significant differences of the pH between the sites (F: 1.64, $p = 0.20$), station ($F = 0.33$, $p > 0.0005$) and tide ($F = 0.41$, $p > 0.0005$).

4.1.3 Changes in Chlorophyll-a

Concentration of Log chlorophyll–*a* was generally higher during the neap tide with an exception in Kurawa-inlet, where high concentration was found during the spring tide (-1.44 ± 0.19) as during the neap tide (-1.47 ± 0.13). The inlets generally recorded high concentrations compared to the outlets during both tides. Fluctuation of the same was found to be higher during the neap compared to during the spring tide. However there was no significant difference in Chlorophyll-*a* at the sites ($F = 1.76$, $p > 0.0005$), stations ($F = 3.15$, $p > 0.0005$) and at the two tide levels ($F = 0.84$, $p > 0.0005$).

Kurawa-outlet had the least chlorophyll-*a* concentration (-1.81 ± 0.08) was relatively similar to that observed at Marereni outlet (-1.80 ± 0.15) during spring, as shown in table 4.1.

Table 0.1: General Linear Model (GLM) Analysis of the water quality parameters at the sites, stations and during the tide cycles

Site	Station	Tide	Log Phosphorous (*ml*)		pH		Log Chlorophyll-a (*ml*)		Salinity(*ppt*)		Log Nitrates (*ml*)	
Kurawa	Inlet	Neap	-1.20 ±0.09		7.60 ± 0.15		-1.47 ± 0.13		27.71 ± 3.84		0.64 ± 0.05	
Kurawa	Inlet	Spring	-1.33 ±0.04		7.63 ± 0.06		-1.44 ± 0.19		31.56 ± 2.24		0.94 ± 0.15	
Kurawa	Outlet	Neap	-1.18 ±0.07		7.66 ± 0.06		-1.65 ± 0.12		50.25 ± 6.92		0.75 ± 0.08	
Kurawa	Outlet	Spring	-1.38 ±0.06		7.56 ± 0.07		-1.81 ± 0.08		49.67 ± 6.78		1.09 ± 0.11	
Marereni	Inlet	Neap	-1.32 ±0.09		7.71 ± 0.06		-1.64 ± 0.26		22.62 ± 4.40		0.60 ± 0.10	
Marereni	Inlet	Spring	-1.37 ±0.06		7.73 ± 0.05		-1.77 ± 0.12		25.83 ± 1.97		0.99 ± 0.15	
Marereni	Outlet	Neap	-1.36 ±0.08		7.69 ± 0.08		-1.69 ± 0.14		40.31 ± 5.64		0.64 ± 0.06	
Marereni	Outlet	Spring	-1.43 ±0.04		7.63 ± 0.06		-1.80 ± 0.15		39.00 ± 5.86		0.88 ± 0.16	
			F-statistic	**p-value**	**F-statistic**	**p-value**	**F-statistic**	**p-value**	**F-statistic**	**p-value**	**F-statistic**	**p-value**
Site			4.16	0.044*	1.64	0.20	1.76	0.19	4.77	0.03*	0.98	0.33
Station			0.29	0.595	0.33	0.57	3.15	0.08	21.51	<0.0005*	0.34	0.56
Tide			5.45	0.022*	0.41	0.52	0.84	0.36	0.07	0.80	15.90	<0.0005*

NB: * indicate where significant difference was observed.

4.1.4 Nitrates

Nitrate concentrations were high during spring as compared to the neap tide as shown in Table 4.1 above. Kurawa outlet had the highest nitrate concentration (1.09 ± 0.11) mg/l during spring tide and lowest in Marereni inlet (0.60 ± 0.10) mg/l during neap tide. GLM ANOVA test showed that there was a significant difference ($F = 15.90, p<0.0005$) on the nitrates between the tides. Nitrates concentrations were generally higher at the outlets in all sites as compared to the inlets, though no significant difference was observed ($F = 0.34, p > 0.56$).

4.1.5 Total Phosphorous

The Total Phosphorous (TP) concentration in the water was high during neap than spring tide in all sites, with values ranging from -1.18 ± 0.07 miligrams per litre (mg/l) in Kurawa outlet to -1.43 ± 0.04 miligrams per litre (mg/l) in Marereni outlet as shown in Table 2. Kurawa outlet had the highest T.P concentration of -1.18 ± 0.07 mg/l during neap, while Marereni outlet had the lowest concentration -1.43 ± 0.04 mg/l during spring tide. Generally Kurawa had higher TP concentration compared to Marereni in all tidal levels with a significant difference between the site ($F= 4.16, p < 0.0005$). Tides were shown to have a significant effect on the total phosphates concentration according to the GLM ANOVA test, in that the concentration of phosphates was significantly different between the two tidal regimes ($F = 5.45, p < 0.0005$), i.e. between neap and spring tides. The different stations did not register any significant total phosphates concentrations ($F = 0.29, p > 0.0005$) as shown in the table above. (Table 4.1)

4.2 Taxonomy of Mangrove Crabs

A total number of 34 crab species of 17 families were captured at Marereni and Kurawa (Table 4.2). A total of 10 specific species were present at both the inlet and outlet both in Kurawa and Marereni. Marereni and Kurawa inlets with 24 species recorded the highest while Kurawa-outlet with 19 species recorded the least. Marereni-outlet recorded 21 species. Species from family Littorinidae, Macrophthalmidae, Mactridae, Ellobiidae and Grapsidae were only recorded in Marereni.

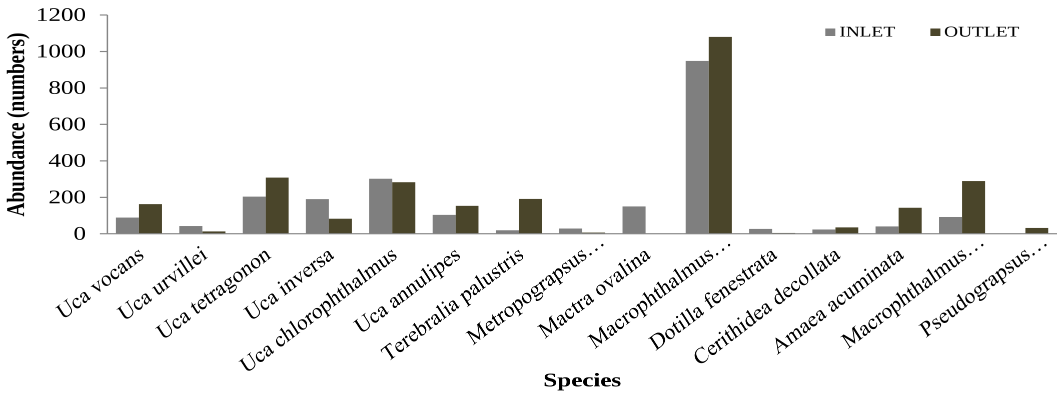
Table 0.2: Families and macro-invertebrate species obtained at Marereni and Kuruwa area (Inlet and Outlet) during the study period with + showing presence

Family	**Species**	**Marereni**		**Kurawa**	
		Inlet	**Outlet**	**Inlet**	**Outlet**
-	*Alpheus* sp	+		+	+
Epitoniidae	*Amaea acuminata*	+	+	+	+
Cerithiidae	*Rhinoclavissinensis*			+	+
	Cerithedea decollata		+		
-	*Diola lauta*	+		+	
Diogenidae	*Clibanarius virescens*			+	+
	Diogenes avarus		+		
Dotillidae	*Dotilla fenestrate*	+	+	+	+
Grapsidae	*Metopograpsus messor*		+	+	+
	Llyograpsus paludicola	+	+		
Lucinidae	*Anodontia edentula*	+			
Gecarcinidae	*Cardisoma carnifex*	+			+
Potamididae	*Terebralia palustris*	+	+	+	+
	Cerithidea decollata	+		+	
Sesarmidae	*Sesarmops impressus*		+	+	+
	Chiromantes eulimene	+	+	+	+
	Neosarmatium meinerti	+	+	+	
Littorinidae	*Littoraria scabra*	+	+		
	Littoraria undulate	+	+		
	Littoraria glabrata			+	
Macrophthalmidae	*Macrophthalmus latreillei*	+		+	
	Macrophthalmus grandidieri	+	+	+	+
Mactridae	*Mactra ovalina*		+	+	
Ellobiidae	*Melampus sp*	+		+	
Varunidae	*Pseudograpsus elongate*	+	+		+
Portunidae	*Scylla serrate*	+	+	+	+
Ocypodidae	*Uca annulipes*	+	+		+
	Uca chlorophthalmus	+	+	+	+
	Ocypode ceratophthalmus			+	
	Uca inversa	+	+	+	+
	Uca tetragonon	+	+	+	+
	Uca urvillei	+	+	+	+
	Uca vocans	+	+	+	+

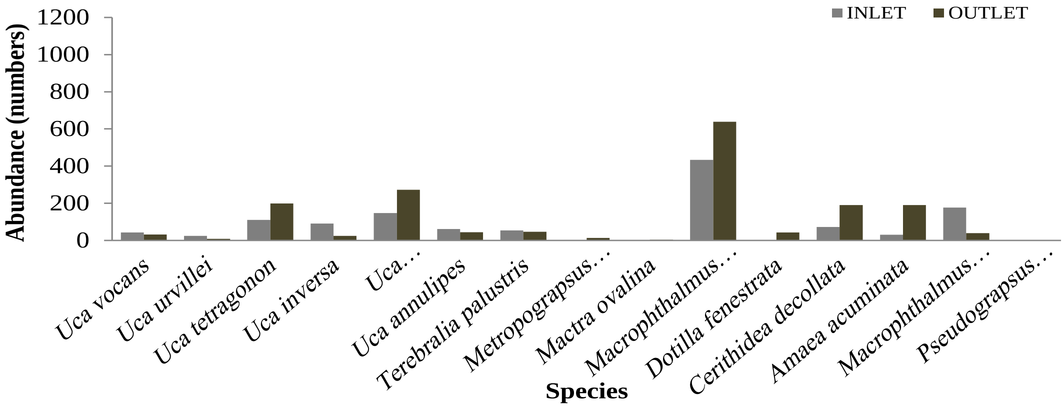
4.2.1 Species abundance

A total of fifteen most dominant crab species was captured at the two sampling sites Fig.4.1. Nine species were observed in Kurawa compared to five at Marereni.

At Kurawa *Macrophthalmus grandidieri* with 1 080 number of crabs was the most dominant while *Pseudograpsus elongates and Matra ovalina* had no representation at inlet and outlet respectively (Fig. 4.1a). At Marereni, *M grandidieri, Pseudograpsus elongates and Matra ovalina* with 639, 1and 2 crabs was the highest and the lowest respectively (Fig. 4.1b).



(a)



(b)

Figure 0.1:Dominant crab species at Kurawa (a) and Marereni (b) inlet and outlet sampled between February and July 2015.

4.2.2 Size–frequency distribution

Generally *M. grandidieri*, *U. tetragonon* and *U. chlorophthalmus* recorded the largest number in samples in every station as *M. latreillei* recorded the least count. Large numbers of small sized species were observed at all outlets of each sites as compared to the inlets.

In Kurawa inlet most recorded crabs were under the class interval 1-1.5 (cm); *M. grandidieri* 423, *U. chlorophthalmus* 100 and *M. tetragonon* 70 number of species, while *U. tetragonon* recorded the least number under the class intervals 0-0.5 and 2.0-2.5 cm (Fig. 4.2).

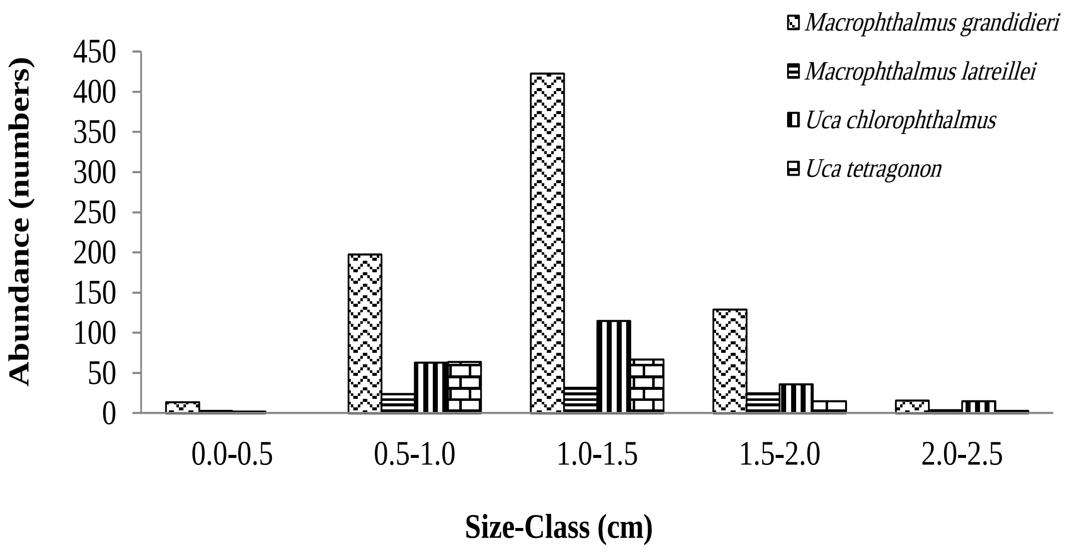


Figure 0.2:The size distribution in centimetres of the four most captured crab species in Kurawa inlet during the study period.

At Kurawa outlet most of the crabs recorded were under the class interval 0.5-1.0 and 1.0-1.5 (cm). The crab *M. grandidieri* recorded the largest number 424 and 115 in the two class intervals respectively (Fig. 4.3).The lowest number of all species was recorded under the class interval 3.0-3.5 cm and above; which constituted only 0.5% in the frequency distribution.

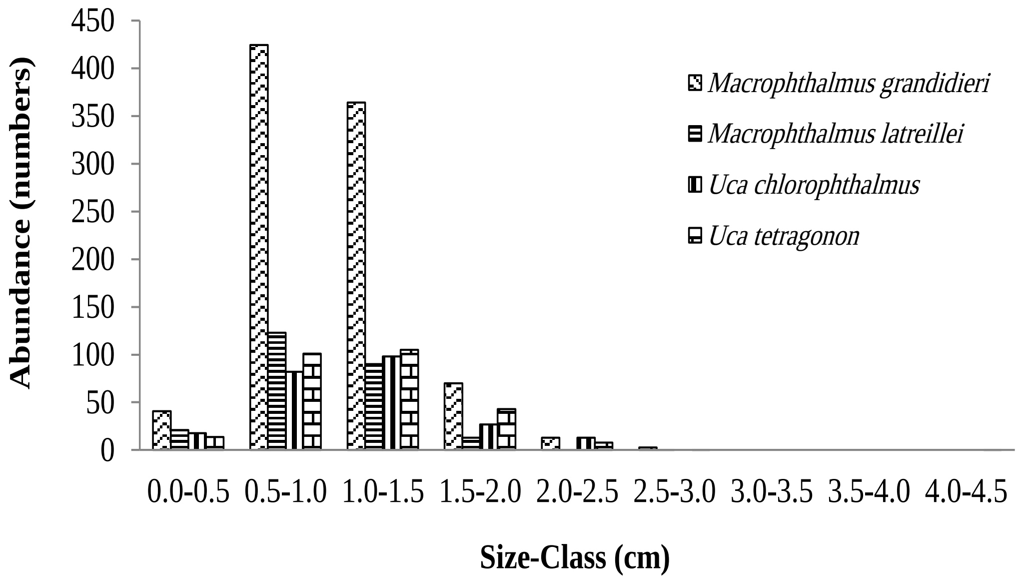


Figure 0.3:The size distribution in centimetres of the four most captured crabs species in Kurawa outlet during the study period.

At Marereni inlet, most crabs were caught under the class interval 0-2.5 (cm) with *M. grandidieri* crab specie having the highest record; 433. Very few numbers of specie *U. chlorophthamus* about 1% were recorded under class intervals above 0-2.5cm (Fig. 4.4).

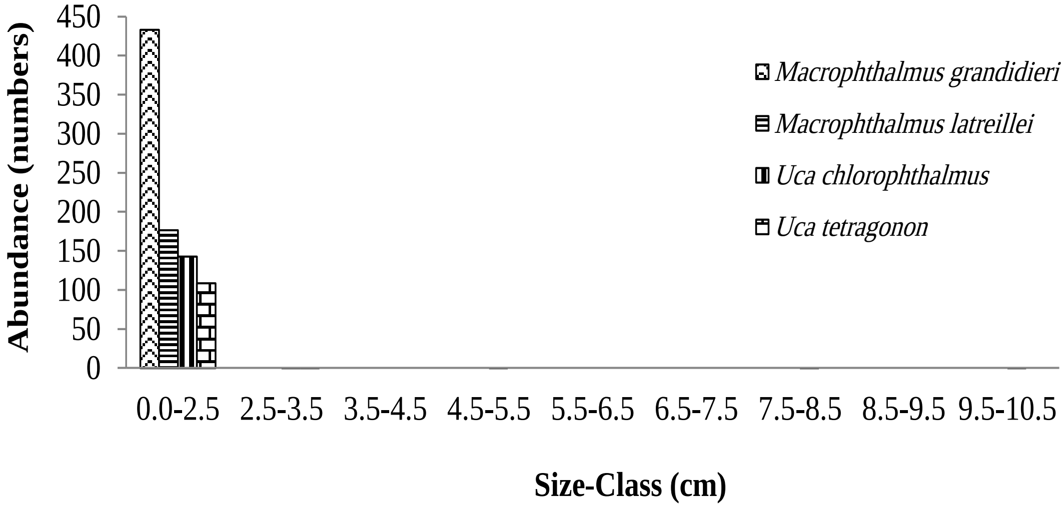


Figure 0.4:The size distribution in centimetres of the four most captured macro invertebrate species in Marereni inlet during the study period.

In Marereni outlet, largest number of crabs were caught in the class interval 1.0-1.5 cm consisting of 315 *M. grandidieri* , 135 *U. chlorophthalmus* and 95 *U. tetragonon* (Fig. 4.5). A total of 13 crabs was caught under class interval of 0-0.5 cm while 3 crabs, two *M. grandidieri* and single *Uca chlorophthalmus* were recorded under the class interval of 2.0-2.5 cm.

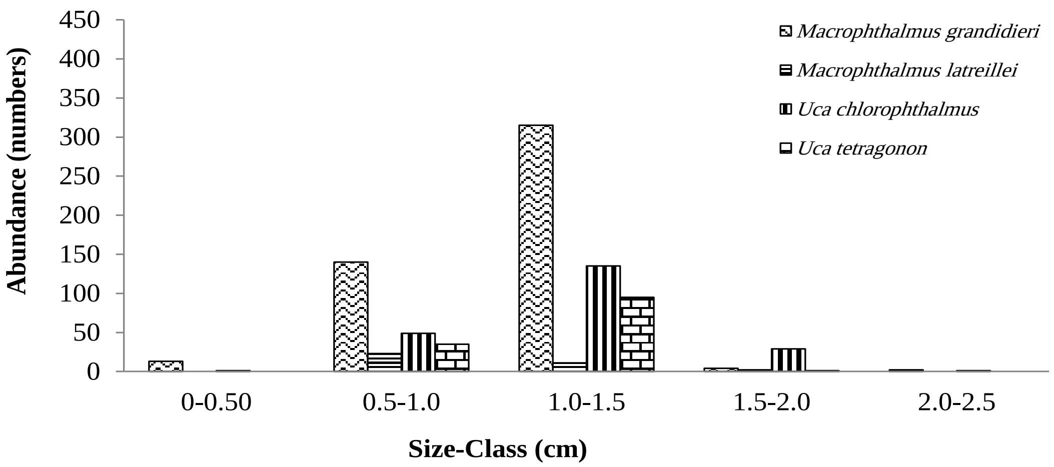


Figure 0.5:The size distribution in centimetres of the four most captured macro invertebrate species in Marereni outlet during the study period.

4.2.3 Diversity Index

The Shannon Wieners diversity index calculated for the 16 most abundant and diverse species was higher at the Marereni outlet (Table 4.3). The evenness of the crabs found in Marereni outlet was higher than the other. Maximum Diversity (H_{max}) was higher at Kurawa than in Marereni (Table 4.3).

Table 0.3:Response information used in the nominal logistic regression based on the 16 most abundant crab specie samples in the Kurawa-Marereni area of Malindi.

Diversity Index	**Kurawa**		**Marereni**	
	Inlet	**Outlet**	**Inlet**	**Outlet**
Shannon-Wiener	0.8912	0.8462	0.9785	1.0262
Maximum Diversity	1.1461	1.1461	1.0414	0.9542
Evenness	0.7776	0.7383	0.9396	1.0754

4.3 Logistic Regression

A total of 34 crab species were identified and enumerated in the Kurawa-Marereni area of Malindi but only 16 species with a total count of more than 200 were used in the logistic regression analysis. The most abundant species was *M. grandidieri* followed by *U. chlorophthalmus, T. palustris, U. tetragonon* and *A. acuminata.* The predictors of the species abundance were found to be the site (with two levels; Kurawa and Marereni), station (with two levels; inlet and outlet) and the tides (Neap and spring).

The first set of estimated logits, labelled Logit(1), are the parameter estimates of the change in logits of *U. urvillei* relative to the reference species (*U. vocans*). The p-values of <0.0005 for site, indicate that there is sufficient evidence that a change in site from inlet to outlet affected the occurrence of *U. urvillei* as compared to *U. vocans*. The negative coefficient (-3.61) for site indicates there tend to be less *U. urvillei* at the outlet as compared to the inlet. The estimated odds ratio of 0.03 implies that the odds of occurrence of *U. urvillei* at the outlet, is only 3% as compared to the inlet when station and tides are held constant (Table 4.4).

The p-value for station (<0.0005) indicate that there is sufficient evidence to conclude that a change in station from Kurawa to Marereni affected the occurrence of *U. urvillei* as compared to *U. vocans.* The positive coefficient (1.20) for station indicates there tend to be more *U. urvillei* at Marereni as compared to Kurawa.

The estimated odds ratio of 3.3 implies that the odds of occurrence of *U. urvillei* at Marereni is about 3 times higher than Kurawa when site and tide are held constant.

The p-value for tides (0.263) indicates that there is insufficient evidence to conclude that a change in tide cycle from neap to spring affected the occurrence of *U. urvillei* as compared to *U. vocans.* The positive coefficient (0.18288) for tides indicates there tend to be more *U. urvillei* at spring tides as compared to neap tides. The estimated odds ratio of 1.2 implies that the odd of occurrence of *U. urvillei* at spring tides is almost equal neap tides when site and station are held constant.

All the species showed evidence of differences from *U. vocans* between site, station and tide cycle except *D. fenestrata* between tide cycles. The odds ratio against *U. vocans* was highest for *S. impressus* between sites (480), *M. ovalina* between tide cycles (172) and *D. fenestrata* between stations (44).

Table 0.4:Nominal logistic regression results showing the probability and odds ratio of different crab species with *U. vocans* as the reference even.

Predictor	Coef	SE Coef	Z	p-value	Odds Ratio	95% CI	
						Lower	Upper
Logit 1: (*U. urvillei/U. vocans*)							
Constant	-0.96219	0.07530	-12.78	<0.0005			
Outlet	-3.60498	0.21146	-17.05	<0.0005	0.03	0.02	0.04
Marereni	1.20202	0.13566	8.86	<0.0005	3.33	2.55	4.34
Spring	0.18288	0.16333	1.12	0.263	1.20	0.87	1.65
Logit 2: (*U. tetragonon/U. vocans*)							
Constant	0.41962	0.04533	9.26	<0.0005			
Outlet	-0.26164	0.05027	-5.20	<0.0005	0.77	0.70	0.85
Marereni	1.59419	0.07726	20.63	<0.0005	4.92	4.23	5.73
Spring	1.62580	0.06452	25.20	<0.0005	5.08	4.48	5.77
Logit 3: (*U. inversa/U. vocans*)							
Constant	-0.00679	0.05124	-0.13	0.895			
Outlet	-2.13681	0.06255	-34.16	<0.0005	0.12	0.10	0.13
Marereni	1.30951	0.08532	15.35	<0.0005	3.70	3.13	4.38
Spring	2.47296	0.07161	34.53	<0.0005	11.86	10.30	13.64
Logit 4: (*U. chlorophthalmus/U. vocans*)							
Constant	0.54079	0.04381	12.34	<0.0005			
Outlet	-0.31533	0.04833	-6.53	<0.0005	0.73	0.66	0.80
Marereni	1.66802	0.07584	21.99	<0.0005	5.30	4.57	6.15
Spring	2.18751	0.06294	34.76	<0.0005	8.91	7.88	10.08
Logit 5: (*U. annulipes/U. vocans*)							
Constant	0.40732	0.04919	8.28	<0.0005			
Outlet	-0.78605	0.05810	-13.53	<0.0005	0.46	0.41	0.51
Marereni	0.85807	0.08903	9.64	<0.0005	2.36	1.98	2.81
Spring	-0.62971	0.09882	-6.37	<0.0005	0.53	0.44	0.65
Logit 6: (*T. palustris/U. vocans*)							
Constant	0.60076	0.04608	13.04	<0.0005			
Outlet	0.63521	0.05091	12.48	<0.0005	1.89	1.71	2.09
Marereni	1.26588	0.07690	16.46	<0.0005	3.55	3.05	4.12
Spring	-0.59512	0.07213	-8.25	<0.0005	0.55	0.48	0.64
Logit 7: (*S. impressus/U. vocans*)							
Constant	-7.99744	0.35593	-22.47	<0.0005			
Outlet	3.71150	0.29465	12.60	<0.0005	40.92	22.97	72.89
Marereni	6.17567	0.21990	28.08	<0.0005	480.91	312.52	740.01
Spring	-2.53461	0.29751	-8.52	<0.0005	0.08	0.04	0.14
Logit 8: (*P. elongatus/U. vocans*)							
Constant	-2.17558	0.12415	-17.52	<0.0005			
Outlet	2.14976	0.12776	16.83	<0.0005	8.58	6.68	11.02
Marereni	-0.43898	0.14061	-3.12	0.002	0.64	0.49	0.85
Spring	-9998.80	4746.06	-2.11	0.035	0.00	0.00	0.00

Table 4.4: (Continued.) Nominal logistic regression results showing the probability and odds ratio of different crab species with *U. vocans* as the reference even.

Predictor	Coef	SE Coef	Z	p-value	Odds Ratio	95% CI Lower	95% CI Upper
Logit 9: (*M. messor/U. vocans*)							
Constant	-1.25172	0.08442	-14.83	<0.0005			
Outlet	-2.24273	0.15176	-14.78	<0.0005	0.11	0.08	0.14
Marereni	0.43433	0.18813	2.31	0.021	1.54	1.07	2.23
Spring	-0.61441	0.25115	-2.45	0.014	0.54	0.33	0.88
Logit 10: (*M. ovalina/U. vocans*)							
Constant	-1.19818	0.08268	-14.49	<0.0005			
Outlet	-4.97077	0.12078	-41.16	<0.0005	0.01	0.01	0.01
Marereni	-1.45208	0.13482	-10.77	<0.0005	0.23	0.18	0.30
Spring	5.14769	0.09633	53.44	<0.0005	172.03	142.44	207.78
Logit 11: (*M. latreillei/U. vocans*)							
Constant	0.79768	0.04384	18.20	<0.0005			
Outlet	-0.64202	0.04943	-12.99	<0.0005	0.53	0.48	0.58
Marereni	1.84998	0.07665	24.14	<0.0005	6.36	5.47	7.39
Spring	1.06248	0.06534	16.26	<0.0005	2.89	2.55	3.29
Logit12:(*M. grandidieri/U. vocans*)							
Constant	2.64972	0.03905	67.85	<0.0005			
Outlet	-0.60249	0.04413	-13.65	<0.0005	0.55	0.50	0.60
Marereni	1.32654	0.07333	18.09	<0.0005	3.77	3.26	4.35
Spring	1.78184	0.06025	29.57	<0.0005	5.94	5.28	6.69
Logit 13: (*D. fenestrata/U. vocans*)							
Constant	-3.71402	0.12394	-29.97	<0.0005			
Outlet	1.60102	0.11487	13.94	<0.0005	4.96	3.96	6.21
Marereni	3.77995	0.10328	36.60	<0.0005	43.81	35.78	53.64
Spring	-0.02540	0.10810	-0.23	0.814	0.97	0.79	1.20
Logit 14: (*C. decollata/U. vocans*)							
Constant	-0.55714	0.05011	-11.12	<0.0005			
Outlet	-0.74764	0.05259	-14.22	<0.0005	0.47	0.43	0.52
Marereni	3.05420	0.07859	38.86	<0.0005	21.20	18.18	24.74
Spring	2.18144	0.06663	32.74	<0.0005	8.86	7.77	10.09
Logit 15: (*A. acuminata/U. vocans*)							
Constant	-0.95301	0.05728	-16.64	<0.0005			
Outlet	1.39259	0.06063	22.97	<0.0005	4.03	3.57	4.53
Marereni	2.15333	0.07692	27.99	<0.0005	8.61	7.41	10.02
Spring	1.07519	0.06568	16.37	<0.0005	2.93	2.58	3.33

The Log-Likelihood from the maximum likelihood iterations with G-statistic (the test statistic for testing the null hypothesis that all the coefficients associated with predictors equal 0 versus them not all being zero) was 48.4 with a p-value of <0.0005, indicating that at $\alpha = 0.05$, there is sufficient evidence for at least one coefficient being different from 0 (Table 6).

Pearson and deviance goodness-of-fit tests gave p-values 0.730 and 0.640 respectively, indicating that there is evidence to suggest the model fits the data. If the p-value is less than selected α-level, the test would indicate that the model does not fit the data.

Table 0.5:The Log-Likelihood and Goodness of Fit test for the nominal logistic regression model of the crab species.

Log-Likelihood = -201176.098
Test that all slopes are zero: G = 48399.994
DF = 45
p-value = <0.0005

Goodness of Fit Test:

Method	**Chi-Square**	**DF**	**p-value**
Pearson	5.97083E+14	270	0.730
Deviance	1.84772E+05	270	0.640

4.4 Crab abundance by site

The first Principal Component Analysis (PCA), component-1 showed a strong correlation of *M. grandidieri* to Kurawa inlet and outlet during both spring and neap tide (U-Lambda = 0.92), *M. ovalina* to Kurawa inlet during spring tide (U-Lambda = 0.08) and *T. palustris* to Kurawa outlet during neap tide (U-Lambda = 0.15), thereby accounting for most of the inertia (Fig. 4.6). Component-2 accounted for most of the variations of *M. ovalina* at the inlet in Kurawa during spring tides as opposed to *T. palustris* at the outlet in Kurawa during neap tides.

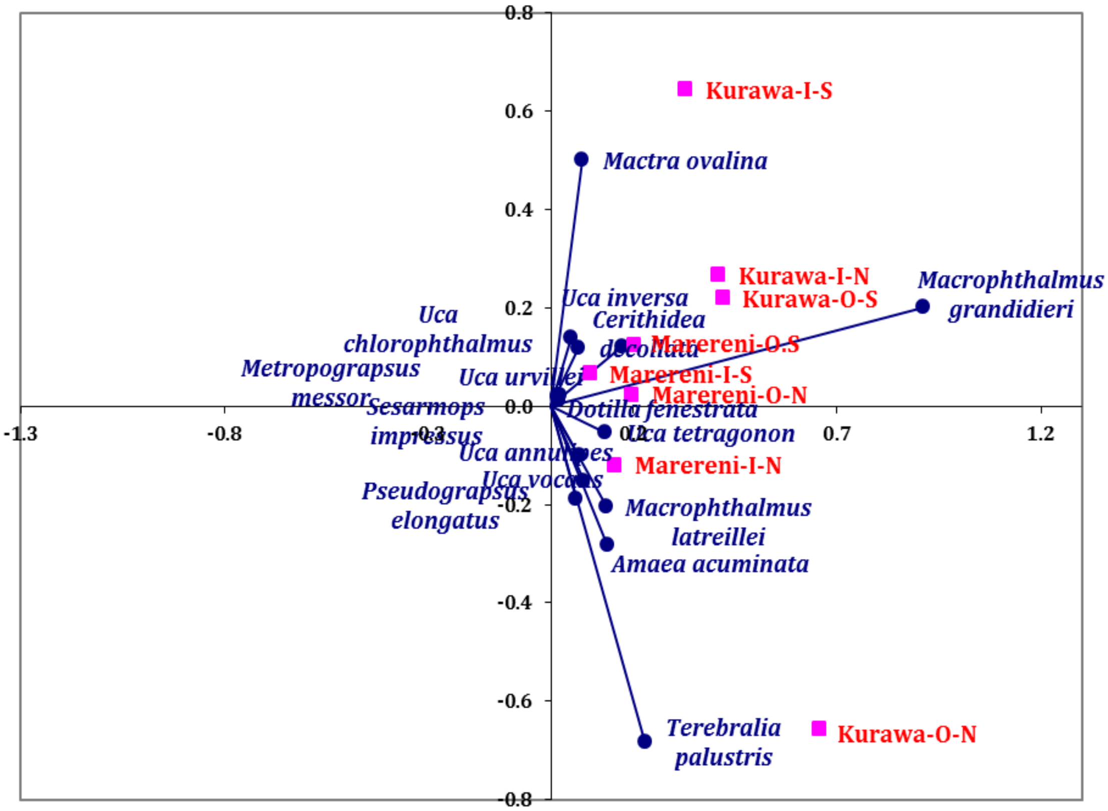


Figure 0.6:Relationship between crabs abundance and site, station and tides in Kurawa-Marereni area observed during the study period.

4.5 Crab Abundance and Environmental Factors

Canonical Correspondence Analysis (CCA) showed that on the first Principal Component, there was a strong positive loading of Chlorophyll-*a* (primary productivity) on the abundance of *M. ovalina* at Kurawa inlet during the spring tide, but negative loading of salinity, pH and total phosphorus on *P. elongatus* and *T. palustris* at Kurawa outlet and Marereni inlet during neap tide (Fig. 4.7). On the second Principal Component, there was a generally no substantial loading of all environmental variables (chlorophyll-*a*, pH, salinity and total phosphorus) on the abundance of *M. ovalina* at Kurawa inlet during spring tide and *T. palustris* and *P. elongatus* at Kurawa outlet during the neap tide.

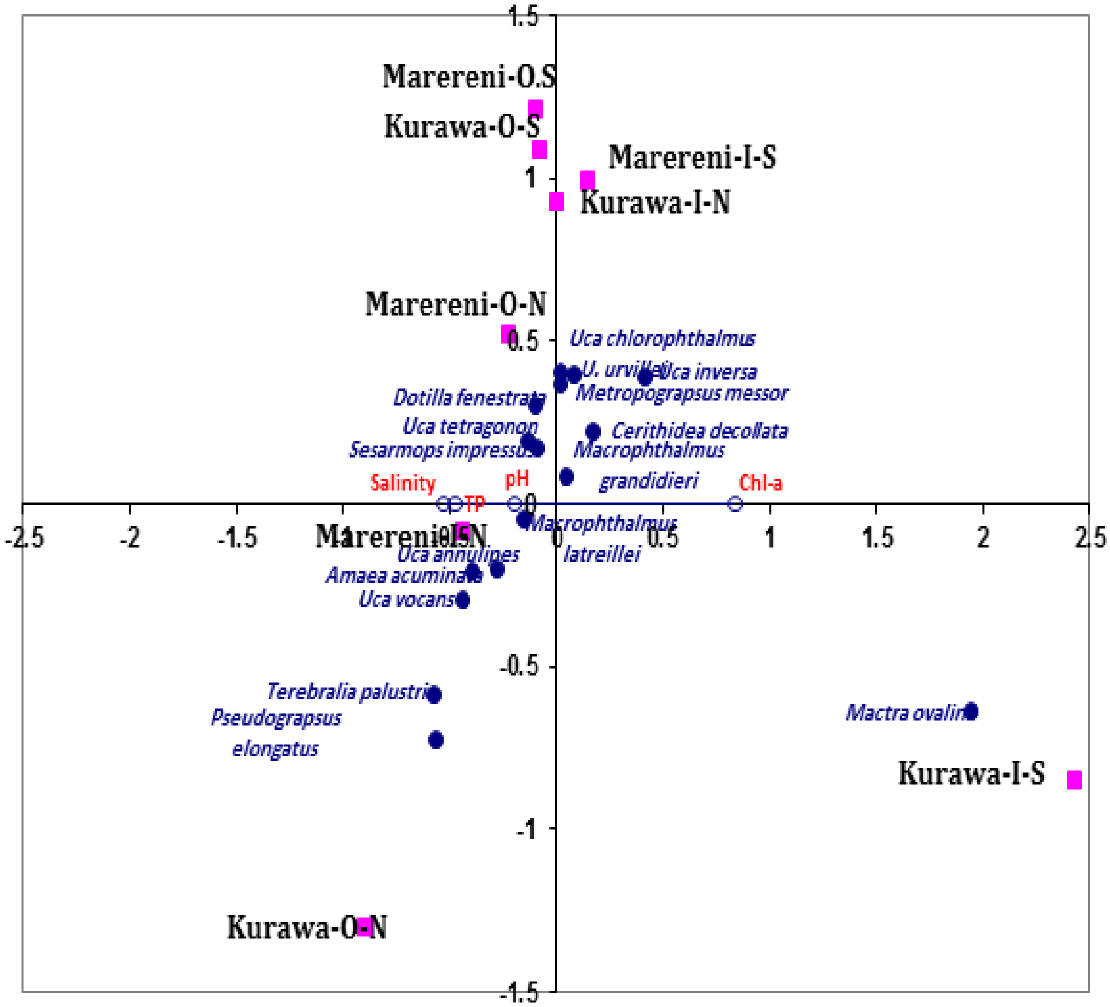


Figure 0.7: Relationship between crabs abundance and the environmental factors at different site, station and tides in Kurawa-Marereni area observed during the study period.

CHAPTER FIVE

DISCUSSION

5.1 Water Quality and Intertidal zone Productivity

5.1.1 Effect of change in Salinity levels on the water quality parameters

The mean salinity levels that were along Kurawa – Marereni areas where the hyper-saline solution from the salt industries was discharged to the open waters were twice at the outlets as compared to the inlets, where the water from the ocean is pumped into the ponds at both sampling sites. This is due to the brine discharge from the salt industries which is usually hyper-saline and could probably increase the salinity levels at the outlets. On the other hand, very low level of salinity at the inlets (Marereni) could be due to occasional rainfalls that could cause decrease of salinity levels. Oceans that receive rain tend to have lower salinity levels near the surface where the water is more diluted. This observation was similar to that of Toole *et al.,* 2010. This effect is intensified by the lower density of normal seawater, which stays at the surface while the more dense salt-rich water; brine sinks. The salinity of the ocean varies from place to place especially at the surface. Much of the ocean has salinity between 34ppt and 36ppt, but there are places that tend to be higher or lower. According to Tularam and Ilahee (2007) reverse osmosis processes do not impact much on the alteration of temperature; brine discharges from such process increase the salinity by twice that of the seawater. The direct discharge of waste-brine into the environment and estuary without prior treatment; has shown to greatly impact the physico-chemical parameters of the receiving waters with resultant increase in sea salinity. This condition will have a direct negative impact on the marine life such as fish eggs and mangrove sprouts, causing the mature fish to migrate to deeper water to avoid the toxic and corrosive nature of the brine. This was similar to what Von Medeazza of 2005 also observed.

The ocean productivity conditions of Kurawa and Marereni area seemed to be affected. This was revealed by low concentration of chlorophyll-*a* levels at the outlets as compared to the inlet stations though statistically there was no sufficient evidence to show that change in station brought about difference in their concentrations. The observed changes may still be attributed to changes in water quality parameters caused by environmental degradation by discharged brine waste from the salt industry, which altered the water quality parameters thus affecting the normal functionality of the marine ecosystem. This probably led to decline of green aquatic matter in the sea water (producers) that are depended upon by other aquatic organism such as fish, birds, worms and crabs for food. Waste-brine disposal poses a major environmental impact on the ocean, especially the disturbance of both flora and fauna at the area of the outlet due to higher salinity levels and the chemical constitution of the waste-water. In addition, waste brine reddish in color increases the water turbidity thus affects the water quality conditions hence disrupts the photosynthesis process due to less sunlight penetration. This information agrees with that which of found by other scientists, (Svensson, 2005; Zou *et al.*, 2008; Culligan *et al.*, 2012). Higher salt concentration also leads to the extinction of plankton species.

Waste brine discharge did not show any clear effects on water pH levels but a general decrease towards the outlets was observed. The levels ranged from 7.55 to 7.74, though during the spring tide the pH levels were low at the outlets. This slight change at the different stations still could be due to the anthropogenic activity from the near-by salt farm which discharge high levels of salinity that affects the pH levels of the ocean. The observation in this study agrees with that of (Zou *et al.*, 2008) who documented that as the pH levels in the oceans decreases, the oceans become more acidic. This could have significant impacts on life in the sea. Therefore a slight decrease of the pH value can cause ocean acidification increase adding up to the climate change issue that is currently trending in the word that has a great negative effect on the aquatic life. In addition, such changes on water quality play a significant role in the growth and size of aquatic life and the marine species disturbance, which all depend on the well stable environment; an observation that was also made by Danoun of 2007. Therefore based on the results the study discovered that there was difference on the productivity of the coastal waters at the inlet and outlet habitats along the Gongoni-Kurawa coastal stretch in Kenya; hence rejected the second null hypothesis.

5.2 Crab species

5.2.1 Distribution and diversity

This study provided a starting point for the abundance, distribution and diversity of benthic macro-fauna of mangroves in Gongoni-Kurawa area within the salt work region. The distribution of crabs showed relationships to salinity and degree of tidal inundation.The dominant species such as *M. grandidieri*, *M. ovalina*, *U. chlorophathalmus*, *T. palustris* and *P.elongatus* shifted throughout the study period. These observed differences among the crabs may have been related to changes in water quality which affect the environment causing change. The effect of the brine waste discharge in water quality of the water channels in Kurawa and Marereni were also evident in the crab communities, which exhibited reduced/increased species numbers and individuals per species per site based on the logistic regression test done. Such species can therefore be used as indicators of salt intrusion since they can tolerate the hyper-saline water. This is in line with Danoun (2007), who reported that changes in the salinity can play two opposite roles on the marine organisms' existence; it can be of benefit for some of these organisms such as shellfish and at the same time can have an adverse impact on other species. Decrease in the abundance of majority of crabs in this study associated with tides at different stations showed indeed how the brine discharge seasonally alters the abundance of the crabs, since salinity levels change with tidal flows. This was similar to that was also observed by (Savenije, 2006).

Literature (Cohen, 2010; Hossain *et al.,* 2015), documents that increase in salinity at the coastal areas is viewed as the major factor limiting species distributions as these vary significantly in relation to the level of salinity. This research was similar to what was observed in this study, since large numbers of small sized species (*M. grandidideri, M. latreillei, U. chlorophthalmus* and *U. Tetragonon*) were reordered at the outlets where constant waste brine is being discharged back to the open waters as compared to the inlets. An observation that could have been caused by the presence of brine having affecting their propagation activities due to its salt concentration nature and toxicity hence interfering with their development and growth rate. In addition the ability of crabs to tolerate stress; through the development of their physiological mechanisms that is isosmotic intracellular volume regulation, could have enabled them to cope with the changes (increase) of the environmental salinity at the outlet. In addition, Romano and

Zeng of 2012 agrees to this study by stating that intertidal marsh crabs being osmoregulators are able to control their internal osmotic concentration to maintain levels that may be different from the external environment. They do this by being less permeable to water and salt, and by having controls, their regulatory organs naturally include gills and renal organs which can concentrate and excrete salt, similar to Freire, Onken and McNamara of 2008. These finding were also well explained by Conde *et al.*, (2000); although crabs recognitions or adjustments to polluted areas seemed to be high, some differences in size have been seen among populations at different water salinities levels. Zimmerman *et al.*, 2002 also affirmed with this studies as he documented that crabs found in hyper-saline lagoons under research appear to mature at a smaller size than those in fresher riverine areas.

Changes in water salinity concentrations have an influence in the population density of the crabs, causing higher population growth rate. According to Von Medeazza of 2005, the change of the salinity levels caused by brine waste discharge, has been found to be associated with reduction in the density of less tolerant species and increase in the density of more tolerant species. This was similar to what was found out in this study. According to Orr *et., al* 2005; Doney *et., al* 2012, marine animals inclusive of the crabs are adapted to keep their body salts at a constant level, so that they don’t interfere with the metabolism within cells, but significant changes in salinity can cause problems for some and also can negatively affect their growth and reproduction, and ultimately, their survival; which was same with what was found in this study, thus recording different numbers of species at the outlets compared to the inlets. This explains how some of the crabs in this study were able to cope with large salinity fluctuations (the euryhaline species)while others tolerated a narrow range of salinities, hence conquering with the fact that brine constitutes a hyper-saline layer that sinks towards the seabed and due to its greater density imposes great impact on the benthos.

Diversity values in the study area ranged from 0.738-1.146, values that according to Wilhm and Dorris (1966) where: (values less than 1.0 for diversity index (*H*) in the waters indicated heavy pollution in aquatic environment while values between 1.0 and 3.0 indicated moderate; and values exceeding 3.0 indicated non-polluted water), suggested that the mangroves ecosystem under which the crabs were examined in this study were heavily polluted and the crab community was under stress due to either natural or anthropogenic factors. This explains perhaps the effect of the present brine discharged from the salt industries along the water channels that affects the crabs' diversity. Low value of the diversity index is generally interpreted as characteristic of a less assorted population in terms of species as compared to a high value which describes high variety of species in a population. The low value also described a polluted condition in this case, a poor water quality state over time, where depending on the species few (more) tolerant genera dominate the community. Higher values were recorded in normal sea waters (inlets) where few or more specie dominate depending of the tolerant ability.

Maximum diversity recorded in this study at the inlets might be due to more favorable environmental factors, such as low salinity which play a vital role in faunal distribution, observations that agreed to El wahab and Hamada, 2012; and Kumar & Khan of 2013. The Shannon Wiener's diversity index for the crab species captured in this study was higher in Marereni outlet 1.026 than Marereni inlet 0.979, a case that was different in Kurawa. The diversity value in Kurawa was high in the inlet 0.891 as compared to the outlet 0.846. There was no major difference in terms of species diversity between the two stations (Kurawa outlet/Kurawa inlet). This explains that there are more varied species in Marereni outlet compared to the inlet which could be probably due to the presence of waste brine discharged from the salt industry, thus bringing about the existence of species that can only tolerate high levels of salinity compared to those at the inlet station. A different scenario was observed in Kurawa. Research by Ruso *et al.*, 2007; Cooley and Heberger, 2013 state the effects of brine on estuarine system having high levels of dissolved solids which allow the formation of a density gradient, especially in low energy systems such as bayous; oil and chlorides are incorporated into sediments near brine discharges. This condition severely depressed the abundance and richness of benthic in-fauna. Observation that affirms to that of this study. Bryant of 1990 found a different scenario to this study as he documented that the ranges of crab species diversity were greater in Oklahoma streams than in salt creeks.

Lastly the strong correlation of *M. grandidieri* to Kurawa inlet and outlet during spring and neap tides, *M. ovalina* to Kurawa inlet during spring tide and *T. palusris* to Kurawa outlet during neap tide; shows how extensive brine discharge has the potential to heavily affect local crabs. Generally, salinity of the water changes constantly over the tidal cycle, but addition of brine discharge from the nearby Gongoni- Marereni salt industries, caused the crabs to respond quickly, metabolically to survive to the drastic changes in salinity. Therefore, the above mentioned crab species seems to be among the few special euryhaline species that were able to tolerate wide ranges of salinities just as oysters and blue crabs in that *M. ovalina* for instance could be only associated with Kurawa inlet during spring tide as *T. palustris* to Kurawa outlet during neap tide. Therefore this study was able to reject the second hypothesis; discharge of hyper-saline waste brine into the marine environment does not have any effect on the mangrove crab species diversity and distribution along the Gongoni-Kurawa coastal stretch in Kenya.

5.2.2 Crabs and the environmental factors

Physico-chemical parameters such as salinity, pH, chlorophyll-*a*, and total phosphorus and nitrates directly influenced the composition and abundance of crabs. High salinity, low pH, and low chlorophyll-a negatively influenced the species distribution and abundance in Kurawa and Marereni outlets as they recorded low species composition as compared to the inlets which had low salinity levels, high nutrients and high chlorophyll-*a* levels resulting in high species richness. The PCA analysis confirmed the changes in crabs' distribution at the different station since there was a strong relationship (Figure. 4.6) of *M. ovalina* to Kurawa inlet during spring tide and *T. palustris* to Kurawa outlet during neap tide. This shows that *sp M. ovalina* can be related to an environment that is less saline content and productive becoming one of the stenohaline species which can tolerate narrow band of salinity, as *T. palustris* can withstand harsh saline condition. Since salt concentration in water (composed mainly of salts such as sodium, potassium, carbonates, sulfates) and amount of salts in animals (crabs) body is very important in aquatic life; it should be naturally balanced. Therefore, unlike *M. ovalina*, *T. palustris* may have been able to withstand the salinity variation by adjusting their tissues' aminoacids concentration adapting it to the concentration of the water. Finding that concur with those of Jenkins *et al.*, 2012. In addition, osmoregulation being an essential physiological process for the majority aquatic crustaceans may have enabled the *T. palustris* among other species to cope with the discrepancies between the ion concentrations within their bodies and the aquatic environment that they inhabited. This observation were again similar to those of Romano and Zeng, 2012. Therefore, these changes of species distribution, abundance and richness were probably due to variation in the tolerance level of environmental changes due to brine waste discharge observed in the affected areas; outlets. This is supported by Griffith *et al.*, (2005); Miri and Chouikhi, 2005) and Ngodhe *et al.*, (2012) who concluded that the distribution of aquatic macro invertebrates' occurrence is set by physical and chemical tolerance of the individual macro invertebrates to an array of environmental factors.

In this study, CCA further confirmed the change of species dominance and richness with the change of water quality parameters in different water bodies. Component 1 and 2 were adequate to describe the environmental factors (water quality parameters) that affected the water bodies under study. For instance, chlorophyll-*a* (primary productivity) had a strong positive influence in Kurawa inlet during both neap and spring tide (where abundant *Mactra ovalina* was observed) and Marereni inlet during spring with component 1. This was negative with respect to Kurawa and Marereni outlets during both spring and neap tides.

Negative loading of salinity, pH and nutrients were observed at the outlets of both sites on *P*. *elongatus* and *T. palustris* at Kurawa outlet and Marereni inlet during tide (Figure 4.7). This analysis still confirms the impact water quality parameters have on macro invertebrate communities, and therefore when negatively influence will affect the composition and distribution of marine organisms in the ecosystem. Kumar and Khan 2013 explains the components of the environment which might be important in determining the distribution of crabs; substratum, food, salinity, exposure or tides and other animals and therefore change in these factors affect the crabs distribution either negatively or positively. Information that affirms to the observations found under this study. In addition, water quality and benthos characteristics have been investigated in coastal ecosystems around the world (Swami *et al.*, 2000; Kumar & Khan, 2013), and indicated that the health of benthic communities is related to water quality conditions in fringing communities, such as mangroves. Therefore environmental conditions like salinity, oxygen, temperature and nutrients have an influence the composition and distribution of biota.

Literature (Dunbar *et al*., 2003; Hashim & Hajjaj, 2005; Gacia *et al*., 2007; Al-Barwani, & Purnama, (2008) have documented a few crab species and macro-benthos as indicator of pollution and hyper-salinity associated with salt works discharge. For instance, Polycheates to increased nitrates and phosphates from domestic outfalls (Bellan, 1967). Filter feeding oysters and mussels, were used as indicators of lipid-soluble pollutants in the marine environments (Al-Madfa *et al.,* 1998) and hermit crabs are documented to be common in tropical intertidal areas and occupy the empty shells of marine gastropods (Dunbar, Coates and Kay, 2003). In this study crabs such as *U. inversa, U. urvillei, T. palustris, M. grandidieri* and *P. elongatus* can be used as indicators of high saline solution, as they were highly associated with high salinity levels both in abundance and existence at the outlets during the neap tide as compared to the other crab. *Mactra ovalina*, *M. grandidieri* and *Uca. tetragonon* on the other hand can be used as indicator of low saline water since they were found in inlets during spring and neap tides respectively. Therefore the study was able to find out that physic-chemical parameters and water productivity influence the distribution and abundance of the mangroves crab species along Gondoni-Kurawa coastal stretch, Northern part of Kenya.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Based on the objectives, results from this study and available literature, it is concluded that:

i) The hyper-saline waste-brine discharge affects the mangrove crab species in several ways:

   a) Crab diversity was higher in the inlet (less unpolluted) as compared to the outlet (more polluted) site.

   b) Few numbers of small-sized crab species; *M. grandidieri*, *U. chlorophthalmus*, *U. tetragonon* and *M. latreillei*, was found at the outlets compared to those observed at the inlets indicting effect of brine on their growth.

   c) Brine discharge seasonally alters the abundance of crabs. There was increase in abundance of crab species; *U. urvillei*, *U. tetragonon*, *U. chlorophthalmus*, *U. inversa*, *M. grandidieri*, *M. latreillei*, *M. ovaina*, *A. acuminata* and *C. decollata* compared to *U. vocans* during spring tide as compared to neap due to their physiological adaptation to high salinity levels.

ii) The productivity of the coastal waters along the Gongoni-Kurawa coastal stretch is characterized by:

a) pH has low loading on the abundance and distribution of crabs in Kurawa and Marereni in both inlets and outlets, during the different tidal cycles.

b) Chlorophyll-*a* was observed to be higher at the inlets compared to the outlet, but there was no significant difference between the sites and the tides

c) The concentrations of total phosphates were higher at the outlets though there was no significant different between the sites and tide.

d) Tides had a significant effect on the nitrates concentration with a clear difference between nitrates in the different tides.

iii) Salt work discharge was found to be associated with changes in physico-chemical parameters and productivity which impact on the abundance of mangrove crab species along the Gongoni-Kurawa coastal stretch, north coast Kenya in several ways:

a) There was a strong correlation of *M. grandidieri* to Kurawa inlet and outlet during spring and neap tide, *M. ovalina* to Kurawa inlet during spring tide and *T. palustris* to Kurawa outlet during neap tide.

b) There was a strong positive loading of chlorophyll-*a* on the abundance of *M. ovalina* at Kurawa inlet during the spring tide but negative loading of salinity, pH and total phosphorus on *P. elongates* and *T. palustris* at Kurawa outlet and Marereni inlet during neap.

It can therefore be concluded that variation in species diversity, dominance and richness were as a result of spatio-temporal change of water quality parameters sampled.

6.2 Recommendations

The following recommendations are made, based on the objectives, results and conclusion of the study:

i) Monitoring of the water quality parameters along such affected areas; salinity, chlorophyll-*a*, and nutrients should be done frequently along mangrove ecosystems along Kurawa-Marereni area and other areas where salt industries are found. This should include assessment of the influences on the spatiotemporal distribution and abundance of mangrove crabs before and after the brine discharge.

ii) Monitor the status/ conditions of the crabs in that region. [Example; the [Before-After Control-Impact] Monitoring]. This information will be helpful to advice the salt works managers of what levels of the brine discharge is affecting the aquatic resources specially the crabs and to what extent.

iii) Because discharges can be designed to result in rapid initial dilution around the discharge, we recommend that they be regulated by a mixing zone approach wherein the water quality regulations are met at the mixing zone boundary. The mixing zone should encompass the near field processes, defined as those influenced hydro dynamically by the discharge itself. These processes typically occur within a few tens of meters from the discharge, therefore we conservatively recommend that the mixing zone extend 100 m from the discharge structure.

This information that will assist the salt works farms to understand the influence the amount of waste brine they discharge affect the mangrove crabs and to what extent. This information will assist the fisheries managers to come up with guidelines that will not only assist on the proper management of the natural marine resources but also advise the salt work personal as the production of salt is done; though to generate the county's national income, but also to maintain an environmental sound marine ecosystem for the next generation.

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APPENDICES

Appendix I: Pollutants (Brine) draining to the mangroves from salt pond areas in Gongoni- Kurawa Salt farm (Source, Author, 2014)

Appendix II : Summary of the some crab species description recorded in the study

Name	Description		
	Body	***Habitat***	***Distribution***
Dotilla fenestrata	Carapace: width 10mm, length 7mm. Carapace globose with dorsal pattern of grooves; pereopod 5 with transparent patch on merus.	Burrows in the littoral fringe of sheltered semi-exposed sand beaches.	West Indian Ocean
Terebralia palustris	Thick, Heavy, conical shell with long pointed spire, up to 12cm. Whorls with strong axial ribs crossed by deeply incised spiral grooves. Colour dark brown.	Upper eulittoral mud or in mangrove swamps.	Indo-Pacific
Cerithidea decollata	Thick strong elongated shells up to 3 cm, with five whorls and about 20 axial ribs. Colour grey brown	Trunks of mangrove trees	West Indian Ocean
Sesarmops impressus	Carapace: width 29mm, length 25mm. Maximum width of carapace towards rear; lateral borders with two teeth. Chela covered in fine granules but without spines or tubercles	Mangroves	West Indian Ocean, Red Sea to W Pacific Ocean.
Neosarmatium meinerti	Common in high shore mangroves. Carapace: width 50mm, length 45mm. carapace front with small tooth on inner margin of eye socket and with pronounced second tooth on outer border.	Burrows in mud in the upper zone of mangrove forests.	West Indian Ocean, Red Sea to W Pacific Ocean.
Macrophthalmus latreillei	Carapace: width 60mm, length 40mm. Carapace broadly rectangular heavily granulates, with four lateral teeth, the last of which is very small. Inner surface of dactyls very hair.	Lower eulittoral	West Indian Ocean, Red Sea to W Pacific Ocean
Macrophthalmus grandidieri	Carapace: width 25 mm, length 12mm. Carapace rectangular, much wider than long, with three lateral spines, the second being the longest. Light brown to dark blue, underneath and chelae lighter.	Eulittoral of muddy sand beaches, in mangroves	West Indian Ocean

Appendix III : Pictures of the mostly recorded benthic macro invertebrate

Macrophathalmus grandidieri(www.google.com)

Macrophathalmus latreillei (www.google.com)

Terebralia palustris (photo)

Mactra ovalina (www.google.com)

Cerithidea decollate (www.google.com)

Sesaemops impressus (www.google.com)

Dotilla fenestrate (www.google.com)

Neosarmatium meinerti (www.google.com)

Uca annulipes (www.google.com)

Uca chlorophthalmus (www.google.com)

U. vocan (photo)

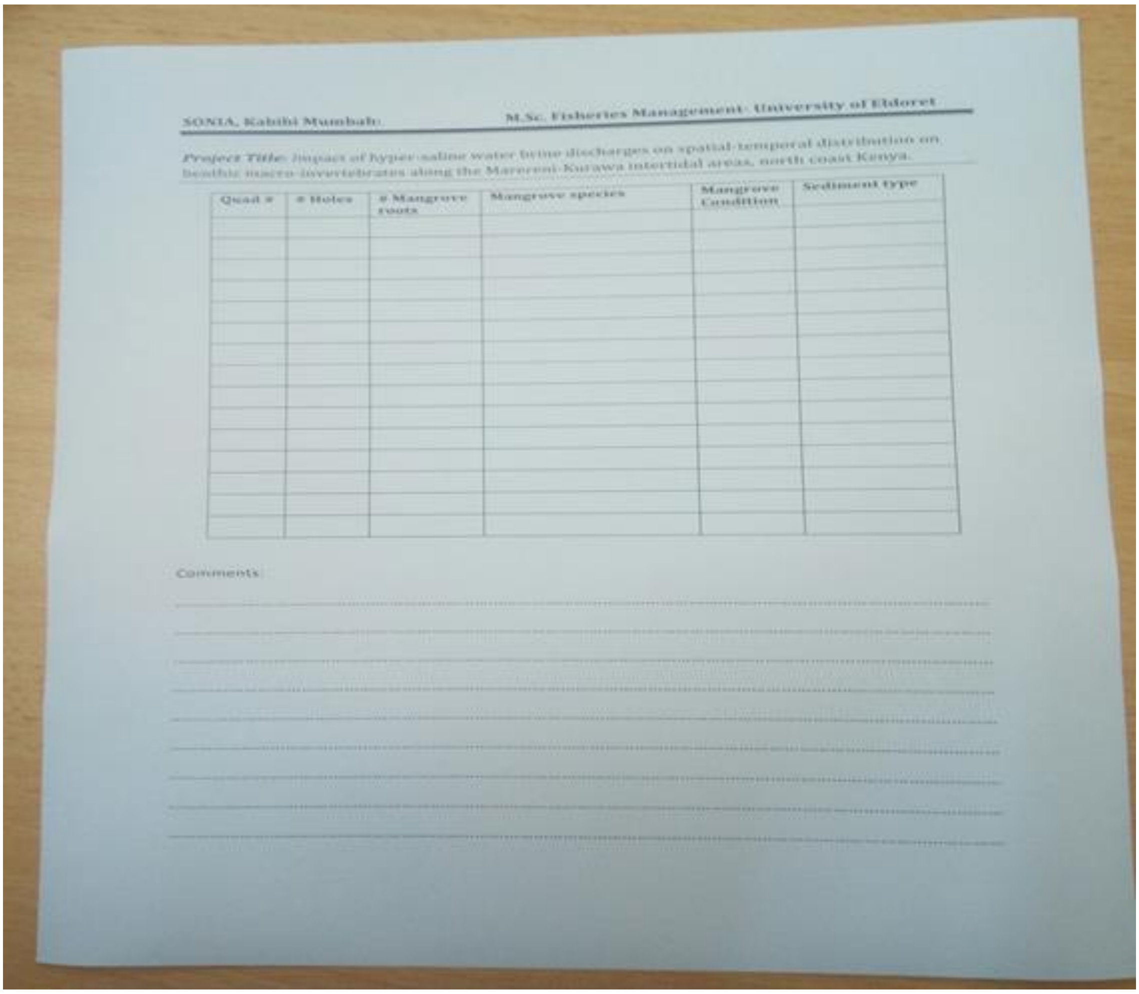
Appendix IV : Response information used in the nominal logistic regression based on the 16 most abundant crab species samples in the Kurawa-Marereni area of Malindi.

Value	**Count**
Uca vocans	2798
Uca urvillei	388
Uca tetragonon	6814
Uca inversa	2723
Uca chlorophthalmus	9914
Uca annulipes	2656
Terebralia palustris	9382
Sesarmops impressus	750
Pseudograpsus elongatus	1808
Metropograpsus messor	275
Mactra ovalina	4544
Macrophthalmus latreillei	7075
Macrophthalmus grandidieri	50793
Dotilla fenestrate	1009
Cerithidea decollate	4997
Amaea acuminate	6522
Total	**112448**

Appendix V : Factor information used in the nominal logistic regression based on station, site and tide effects on the abundant crab species samples in the Kurawa-Marereni area of Malindi

Factor	Levels	Values	
Station	2	Inlet	Outlet
Site	2	Kurawa	Marereni
Tides	2	Neap	Spring

Appendix VI : Data sheet used for crabs data collection at the site



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Quad #	# Holes	# Mangrove roots	Mangrove species	Mangrove Condition	Sediment type

Comments: