MS Thesis

Environment and Natural Resources

Optimal Management Policy for the Kenyan Marine Artisanal Fishery

Author
Simon Wahome Warui

Supervisor

Professor Ragnar Arnasson

Faculty of Economics

Graduating October 2014

HÁSKÓLI ÍSLANDS

Optimal Management Policy for the Kenyan Marine Artisanal Fishery

Author: Simon Wahome Warui

Final thesis for MS-degree in Environment and Natural Resources

Supervisor: Professor Ragnar Arnasson

Faculty of Economics

School of Social Sciences, University of Iceland
Graduation October 2014

Optimal Management Policy for the Kenyan Artisanal Marine Fishery

This is a 60 credit thesis to obtain a MS degree at the Faculty of Economics, School of Social Sciences, University of Iceland.

Printed by: Háskólaprent
Reykjavik, Iceland, 2014

Preface

This thesis was financed by the United Nation University-Fisheries Training Programme (UNU-FTP) of Iceland, from August 2012 to October 2014. The Government of Kenya through the Ministry of Agriculture, Livestock and Fisheries, under State Department of Fisheries, supported the study.

I wish to thank Dr. Tumi Tomasson, the UNU-FTP Director, who has, actually been a "father" to me in Iceland, and his office fraternity, my family. They have been a strong support and encouragement during the study. The help I received from Professor Ragnar Arnasson has been many fold. Apart from critically reviewing each paper, he has introduced me to a number of concepts and practices on Bioeconomic and Fisheries' Management. He was central in the support of this thesis, especially in his vast abilities in numerical programming, without which nothing seemed to work.

I thank the Principal Secretary, Professor Michemi Ntiba, Ministry of Agriculture, Livestock and Fisheries, for not only nominating me to this course but, his motivation and encouragement to further my studies. I am proud of him and his vision on the Kenya's fisheries.

I am grateful for the patience of my family for allowing me to be away from them for two years. I owe them my love.

Abstract

An marine artisanal fishery under open-access regime was feared to be overexploited and unsustainable to declining catch per unit effort and increased fishing effort. A bioeconomic model on the fishery was developed based on Gompertz-Fox surplus production model (Fox, 1970) to analyse the fishery. The objective was to determine the optimal utilization policy and its benefits and the path and appropriate management system to drive the fishery to the optimality. The analysis indicated the fishery exploitation was lower than maximum sustainable yield (MSY) level and thus sustainable though at sub-optimum. The optimum sustainable policy was at maximum economic yield (MEY) level, which was lower than the MSY. The current fishing effort was causing dissipation of the fisheries rent. The fishery can generate over 30% more profit than currently is, by reducing the current effort by 36%. An optimum dynamic adjustment path for the fishery to the long run sustainable fishery was developed that was more efficient with high present value of profits. Its implementation was considered drastic to the fishing community and fishery-linked industries that are likely not able to adjust quickly to the change. A moderate path considered more acceptable but with 8.6% loss in PV. A property right management system was recommended, with allocation of quota to the fishermen through the existing community-based fisheries management system for its administration.

Table of contents

List of figures

List of tables

Chapter 1. Introduction

Human dependence on marine life in Kenya is significant, both in terms of the nutritional value provided by fish and other seafood to the population and in terms of the level of economic security the fishing industry provides for the coastal communities. According to Ochiewo (2008) the inshore small-scale artisanal fishery is the most dominant of the marine fisheries activities. It contributes over 80% of the fish yield from marine waters, with the difference accounted to the commercial trawlers. With its contribution of only 6% (8,865 tonnes) of the 154,000 tonnes of national fish production in 2012, it provided a per capita of 3.0 kg supply of animal protein to the 3 million coastal population, generating US$ 13.9 million in revenue, and providing direct employment to 13,700 fishermen (State Department of Fisheries (FD), 2012). Thus, assuming a mean household size of 5.5 (Ministry of Planning and National Development 2006), the marine artisanal fishery supported the livelihood of over 75,000 fishermen household members exhibiting the highest national poverty level of 64% (Hoorweg, 2009).

The fishery direct linkage to gear and boat making and repair industry, fish processing, ice making and transportation sector gives yet to be quantified multiplier effect to the national economy (FD, 2012). The inshore fish stocks offer further tangible benefits to society, through revenues earned from sport-fishing tourism, as well as providing useful ecosystem services (Stakstad, 2006).

Although there are licensed industrial Distant Water Fishing Vessels (DWFV) operating in the Kenya's Exclusive Economic Zone (EEZ), these have insignificant economic linkages to the Kenya economy except in the annual fishing access permit charges of US$ 50,000 per vessel. These vessels land their catch in offshore Indian Ocean Islands, with the catch credited to the flag State of the fishing vessel, which are not Kenyan.

1.1 State of the artisanal fishery

Despite its importance to national food security and economy, there is evidence that the marine artisanal fishery is economically declining and faces the threat of stock collapse with negative community and economic implications (FD, (2012); Trott, (2009)). This is suggested by the rapid increase of the fishing effort by 220% from 1,230 boats 2000 to 3,947 boats in 2012, with the Catch per Unit Effort (CPUE) showing a general decline trend, dropping by 42% from 0.020 tonnes/boat-day to 0.012 tonnes/boat-day during the same period (FD, 2000, 2001,2003..., 2012).

The mangroves and the coastal wetland lagoons, and the fringing coral reefs ecosystems, support the fishery. According to McClanahan, (2013) the coral reefs, which extends nearly the entire Kenya coastline, is the most important ecosystem toward fishery support. Nevertheless, it is under threat of unsustainable levels of fishing and the impacts of global climate change. The high fishing pressure is affecting the corals in two ways; (i) by affecting the ecosystem balance by removing high population of herbivorous fish that feed on algae (using traps and spear-guns) and are key to the recovery of the corals that have "bleached" as a result of warming surface waters, and (ii), physical destruction of the coral reef by deployment and use of some types of fishing gears and equipment like ring nets and reef seines).

There is a direct relationship between the health status of the corals (McClanahan, 1994), and the fish communities' assemblage. High fish population densities are associated with healthy coral reefs when compared to the degraded zones. So, it could be correct as McClanahan, (2013) puts it that "as the coral die off, the artisanal valuable fish stocks also disappear". Although no scientific stock assessment study has been done, the declining CPUE is a strong indication of declining fish stocks in the artisanal fishing grounds within the reefs.

In the study done in the Kenya's South Coast reefs, (Mangi & Roberts, 2007) attributed the declining fish catch from coral reefs to environmental degradation and increased fishing effort. Although no data was provided in support to enable verification, they suggested that possibly the Maximum Sustainable Yield (MSY) of many fish species was already exceeded. Despite this, studies elsewhere support their finding that habitat destruction (Wood et al, 2000) and fishery overcapitalization (FAO, 1999) can cause fish catch reduction. Pacific Southwest Research Station (PSW), (1995); (Barber, R. T. & Chavez, F.P., 1983) included reduced recruitment as a possible cause too. However, excessive harvest is widely accepted as the major contributor (Roughgarden, J., & Smith, F., 1996).

1.2 The paradox of poor fishery economics and social welfare

Kenya's marine artisanal fishery management is operated under a loosely regulated open-access regime. Both, the management system's economic efficiency and its management tools for environmental conservation are doubted by the local environmental organizations (Trott, 2009); The East African Wild Life Society, 2014) as well as Kenya Association of Sea Anglers (Ndurya, M. (2010, April 12).

Though the fishery is as old as the country's recorded history, the beneficiary community has been poor for a very long time. Although the fisheries has generated an estimated annual revenue of US$ 7.6 million for the last seventeen years, apparently it does not seem to improve the welfare of the target community (FD, 2000, 2001,2003..., 2012).

Many suggestions have been advanced to explain the poverty among fishermen. But to highlight some possible causes from Bene, (2003), they are: (i) resource overexploitation which leads to low fish productivity and low per capita income; (ii) lack of alternative income outside the fishery by virtue of remote locations of rural fishing. While both could contribute to poverty, we regard them as a consequence of a more fundamental cause, namely the common property, open-access arrangement of the fishery. Based on the Hardin (1968) on "tragedy of the commons" and Gordon, (1954) "common property nature of the fisheries", the logical explanation of the observed poverty in the fishery is straightforward. The open-access nature of the fishery allowed more and more people to enter the artisanal fishing sector, leading to economic (and possibly biological) overexploitation of the resources- thus the Malthusian dimension of the poverty, dissipation of the fisheries economic rents, and finally impoverishment of the fishing community. Basically, under the common property arrangement, the fishery is doomed to excessive fishing effort, overexploited fish stocks low economic productivity and low income to fishers. Thus, to improve the biological state and economics of the fishery, a more appropriate fisheries management system has to be imposed. .

1.3 Current management measures

Recognising the stock could be in the decline, the Fisheries Department, Kenya, has initiated the development of management plans for the commercially important fish species. The Prawn Management Plan, 2011 is operational, with its management objective being Maximum Sustainable Yield. The development of Lobster and Small Pelagic management plans is on-going, both adopting the Ecosystem Approach to Fisheries (EAF) management principles which is being tried in the South West Indian Ocean (SWIO) coastal and island States under the auspices of the Food and Agriculture Organization of the United Nations (FAO).

We concur with Larkin (1977), *"An Epitaph for the Concept of Maximum Sustained Yield"* opinion that determining the MSY is merely a step toward establishing the optimum yield of a fishery, and therefore a natural component of all fisheries management plans. The fundamental questions, as raised by Gulland (1969), are: Will the use of traditional MSY strategy in the exploitation of the artisanal marine fisheries of Kenya result in a sustainable yield? Should the attainment of the MSY yield be the objective of management? Are there more workable management strategies? According to Larkin, (1977), the use MSY involves greater fishery instability as well as less economic benefits than say the MEY (maximum economic yield).

To avoid the problems associated with the MSY, Doubleday, (1976) suggests that any management policy should **not** to go for MSY as a management objective, but rather for a lower level of exploitation (and larger stocks) that involves less instability and biological risks as well as offering higher net economic returns on a sustainable basis. In the face of limited biological and economic knowledge, Walters C. J, (1976), considers a much more sophisticated technique for optimization and adaptive control in the fisheries management.

For these reasons, it seems clear that the Prawn Fishery management Plan already in place as well as the on-going development of the Lobster and Small Pelagic Management Plans are based on the wrong management objective and, therefore, can at best be sub-optimal. An optimal management policy that considers the advice given above, and which is the guiding principle of this paper, is needed.

1.4 Threats and possible fisheries collapse

According to Sethi, (2003), fisheries collapse is an increasingly common phenomenon worldwide, even in managed fisheries, if the management practices are sub-optimal and unsustainable and the management of the stock is subject to serious governance deficits. Roughgaden,J & Smith, F, (1996), give a case study of cod fishery off the Newfoundland, which in 1973 was placed under a careful Total Allowable Catch (TAC) regime by the Canadian Department of Fisheries and Ocean. Yet the fishery collapsed between 1991-93, even with very high fishers' compliance. They explained the cause as being the setting of too low management target stock biomass incapable of providing adequate natural insurance under environmentally variable conditions and a fairly constant harvest regime. This led to cod harvest exceeding biological production and the stock was driven towards extinction.

Given these experiences, there is a real possibly that the Kenya Fisheries Management plans, by adopting the MSY target, are targeting dangerously low stock biomass level. The consequences might not be different from the Newfoundland cod fishery, if a similar environmental variability occurs in the marine artisanal fishery.

Other instances of large profitable fisheries complete collapse are the Californian sardine fishery in the 1950s, the Atlanto-Scandian herring fishery in the late 1960s, and the Peruvian anchovy fishery in 1972. The example above and the case study of the Newfoundland cod fishery are a warning signal to Kenya’s marine artisanal fishery that unless optimally managed, they are neither exempted nor immune to such phenomena.

1.5 Fisheries Optimality

An “optimum sustainable yield” (OSY) by itself is not a technical reference point (Wallace, 1975), but a state that may result after satisfying criteria on economic, social and biological values while effectively ensuring that the fishery remains within a safe and productive limits. It is not limited to maximizing net profits or sustainable yield only (FAO, 1995). The OSY is the target of an optimally managed fishery. It is the main purpose of this essay to estimate and clearly define the OSY as a fishery management objective of the Kenya’s marine artisanal fishery.

More precisely, the objective of this study is to: (i) determine the optimal utilization policy for the artisanal fishery; (ii) assess the potential benefits (iii) determine the optimal adjustment path, and; (iv) determine an appropriate management regime that can achieve these aims.

1.6 Significance of the study

The findings of this study will fill an existing gap of empirical studies on sustainable use of artisanal marine fishery resources in Kenya. The information generated is expected to assist policy makers in making informed decisions about the management of the fishery. The results of the study can be extended to similar situations in the South West Indian Ocean (SWIO) region as well as fisheries in fresh water bodies.

The organization of this paper is a follows: Chapter 2 covers background information on the fishery giving a general definition and characteristics of the Kenya marine artisanal fishery, the study area and fishing grounds, fishing effort and catch trend and socio-economics of the fishermen. Chapter 3 defines and derives the model used in examining the fishery. It includes the biological, the harvesting and the economic functions of the model. It gives the data sources required for the estimation of the biological, harvesting and economic parameters and concludes with the details of the parameter estimation process. Chapter 4 deals with the fishery sustainability, optimal equilibrium and the maximization of present value (PV) of harvesting paths. Chapter 5 discusses the results and the implementation of the optimum policy. Chapter 6 concludes by highlighting the major finding of the study and provides policy recommendations.

Chapter 2. Background Information

2.1 Marine Fisheries of Kenya

The Kenya marine fishery is estimated to have a potential of 150,000 – 300,000 tonnes consisting of many species. The fishery is segmented into: deep-sea fishery operated by Distant Water Fishing Nations (DWFN), and fisheries within the territorial water band of 12 nautical mile (nm) from shore (primarily within coral reefs which line the coastline) operated by artisanal fishers. While the Distant Water Fishing fleets are active throughout the year, the operations of the artisanal fishers are influenced by the weather pattern. During the periods of September to March, the influence of the Northeast monsoon winds (Kazi kazi) calms the sea and fishing activities and fish landings are normally high. In April to August, the fish landings decrease due to the stormy Southeast monsoon winds (Kusi) rendering the seas unfavourable for small fishing crafts.

2.2 Artisanal Fisheries

2.2.1 Definition and characteristics

Artisanal fisheries are generally identified with low levels of technology often accompanied with low levels of organization and industrialization. It can equally be defined as a traditional fisheries involving fishing households, using relatively small amount of capital and energy, relatively small vessels (if any), and making short fishing trips close to shore, mainly for local consumption, and possibly for export (Charles, 2001; FAO, 2005).

Artisanal fishing boats operating in Kenya marine waters are fairly homogenous. All are less than 11m in length and operate from the shore to the outer edges of the fringing reef along the coastline. Most are dugout canoes with or without outriggers and usually powered by sail while the larger boats are planked (Coppola, 1982) and some motorized. The use of small boats and low technological investment per fisher categorizes the fishery as small-scale and/or artisanal (FAO, 2005). According to a recent count, the fishery consists of 3,947 boats of which about 10% are motorized and 13,706 fishermen (FD, 2012). Only two boats are larger than 10m and of intermediate technical complexity and licensed for prawn trawling in Ungwana Bay, and its catch counted as industrial fishery.

In addition to the artisanal fishing vessels, considerable artisanal fishing takes place without the help of vessels, employing a range of low technology fishing methods. These include beach seines, fishing by hook and line from shore, fish traps and weirs (large and small), and manual harvesting of seaweed, bivalves, crabs, etc. in coastal zones.

An Act of Parliament, CAP 378 of the Fisheries Acts, guides artisanal fishing operations. Major tenets of the Act are to control slot sizes, fishing seasons and areas, gear types and fish hygiene. The mandate to enforce the Act is bestowed upon the Department of Fisheries of Kenya.

2.2.2 The study Area

The marine artisanal fishing grounds were mapped by R/V Dr. Fridtjof Nansen cruise research vessel undertaking acoustic surveys in depths between 10 -700m. Demersal and pelagic fish densities and potential yields at each depths zone were assessed. The area up to depth of 400m and covering a total area of 20,511km2 was reported as potential fishing grounds for the artisanal fishery (table 1). This study was conducted between December 1980 and December 1982 (Iversen, S.A. & Myklevoll, S.1984).

Table 1. Distribution and respective surface area of fishing ground offshore the administrative areas along the Kenyan coast up to depths of 200m.

Depth Ranges (m)	Areas (km^2)				Total (Km^2)
	Lamu (Lamu & Tana River)	Malindi (Malindi & Kilifi)	Mombasa	Kwale	
0 - 100	2,107	2,306	167	529	5,109
100 - 200	4,714	2,659	229	703	8,305

Source: (Carrara, G. & R.S. Coppola. 1985)

The defined fishing zones are; Lamu= from Somali border to 2°22'S; Ungwana Bay = 2°22'S to 3°20'S: Malindi and Mombasa (Mid-coast) = 3°20'S to 4°30'S; Kwale (South Coast)= 4°30'S to Tanzanian border. (Figure1). As the table shows, Lamu has the largest area either within the depths up to 100m or 200m, followed by Kilifi, Kwale and Mombasa in that order.

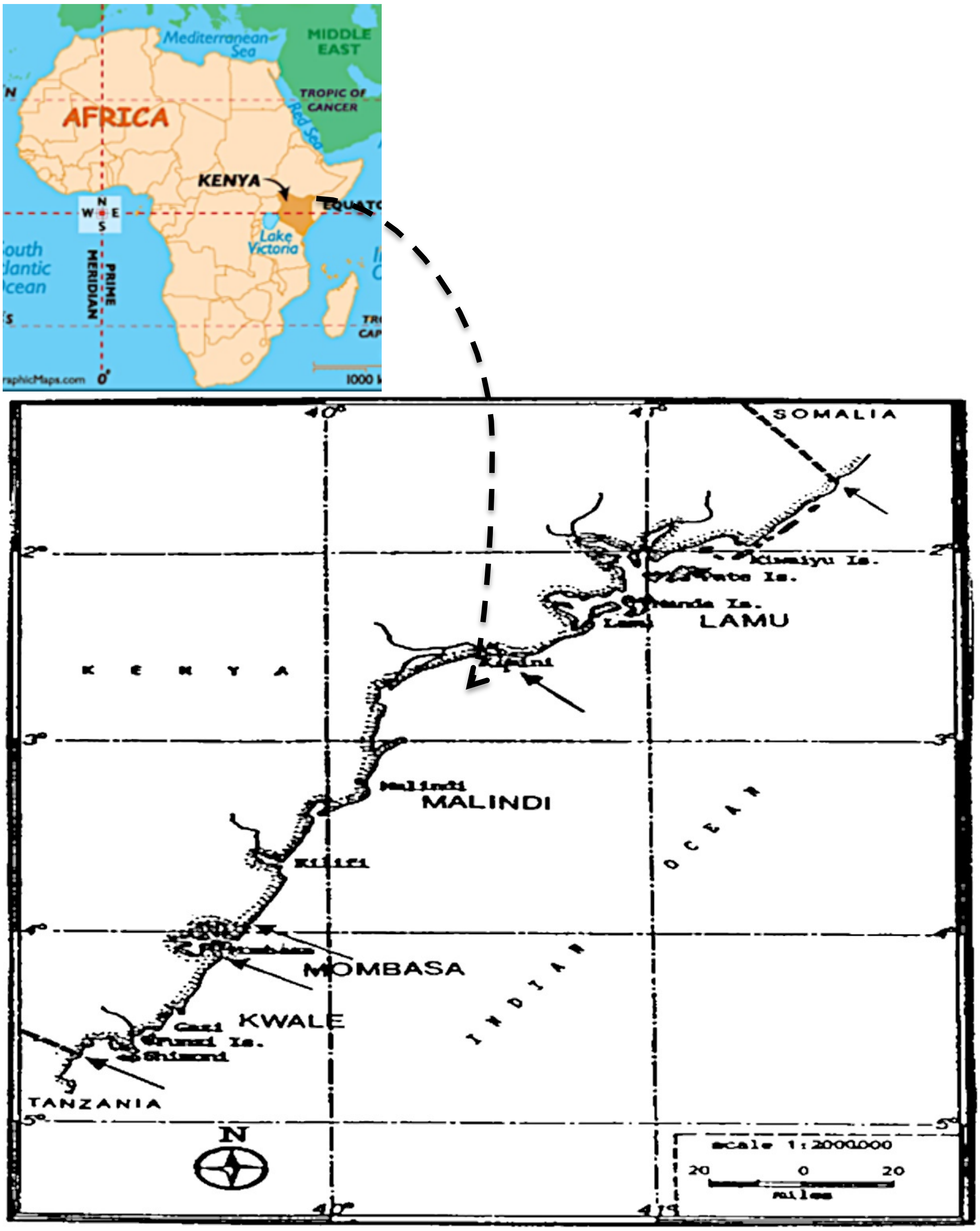


Figure 1. Map of study area showing Lamu (Lamu & Tana River), Malindi (Malindi &Kilifi), Mombasa and Kwale fishing grounds extending from Kenya-Somalia border to the Northeast up to Kenya –Tanzania border to the Southwest. Source: (Coppola, 1982)

2.2.3 Fishing grounds and their productivity

The estimated potential sustainable demersal yield was estimated at 4,088 tonnes (excluding swimming crabs and non-commercial fish) and about 10,000 tonnes for the small pelagic (mainly scads and mackerels) over the total 0 to 400 m depth region of 20,500 km2 (FAO/IOP, 1978; Iversen & Myklevoll, 1984). The highest abundance, although mainly of fish having low commercial value, was observed in depths of 10 - 50 m. The potential yield for the area beyond the coral reefs was estimated at about 5,000 - 7,500 tonnes. However, the available technology limits most of the fishermen to depths up to 100m covering only one quarter (5,109 km2) of the potential artisanal fishing grounds. With these qualifications, it is clear that sustainable harvest from fishing grounds accessible to the artisanal fleet is substantially less than for the whole area surveyed by the Frithjof Nansen survey.

Since 1984 no similarly comprehensive survey has been done. However, average fish catch from 2008 – 2012 indicate a general decline in fish catch from all fishing grounds by some 13% compared to 1984 catches. The five-year period 2008-2012 yielded an aggregate fish catch of 8,580 tonnes and standard deviation of ± 375. Except for Malindi (currently Kilifi county) which showed an increase by 20% above the 1984 catches, all the other fishing grounds suffered a decline: Mombasa -51%; Kwale -12%, and; Lamu -7%. However, Lamu and Kwale still maintained their lead in high fish catches as was in 1984 (see table 2 and further details in Appendix 2).

Table 2. Comparison of the fish catches of 1984 and a mean of five years from 2008 – 2012 with administration areas re-organized to match scenario in 1984 along the Kenyan coast waters up to depths of 100m.

Counties (reorganized as 1984)	Catches (1984)	5 years mean (2008 - 2012)	% change
Lamu (Lamu & Tana River)	2,868	2,681	-7
Malindi (Malindi & Kilifi)	1,854	2,216	20
Mombasa	2,141	1,057	-51
Kwale	2,997	2,626	-12
Total	9,860	8,580	-13

Source. Carrara & Coppola, (1985); FD, (2008; 2009;2010; 2011; & 2012).

Carrara and Coppola (1985) calculated fishing grounds productivity (tonnes/km2) by dividing the catches for 1984 (table 2) by the areas of the fishing grounds to a depth up to of 100 m (table 1) as shown in table 3 below. The relatively low values for Lamu and Malindi are at least partly due their respective much wider continental shelf values used in the calculation. Using the same procedure on the calculated five-years' mean (2008-2012) in table 2, the artisanal fishing ground lost their productivity by about 13% within a period of 30 years.

Table 3. Comparing changes in productivity in coastal waters fishing grounds up to depths of 100m over a period of 30 year from 1984 and 2012.

Calculated based on:	Lamu (Lamu & Tana River)	Malindi (Malindi & Kilifi)	Mombasa	Kwale	Combined
1984 catches	1.36	0.8	12.83	5.67	1.93
Mean (2008-12) catches	1.27	0.96	6.33	4.96	1.68
% change	-6.62	20	-50.66	-12.52	-12.95

Source: Carrara & Coppola, (1985); FD, (2008; 2009;2010; 2011; & 2012)

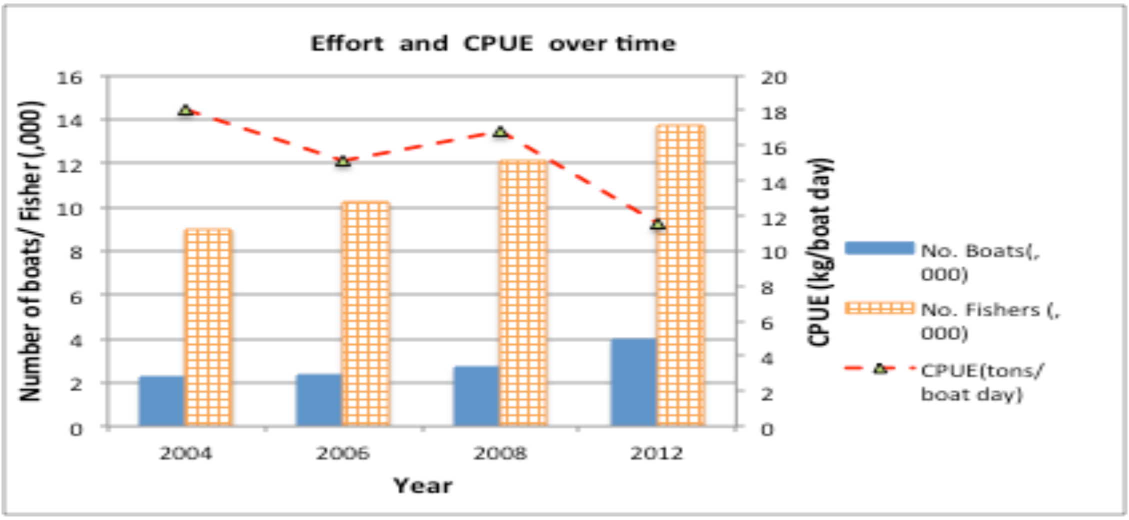
Except for Malindi (currently Kilifi county), which improved its productivity by 20%, all other grounds were negatively affected. Mombasa was worst affected with over -50% change, followed by Kwale (-12.5%) and Lamu (-6.6%). Basically the artisanal fishing grounds are on a downward trend losing their fish productivity by 0.3%/year, on average. (Table 3).

2.2.4 Fishing gears, effort and CPUE over time

The fishing gear applied include gill nets, long line, beach seines, prawn seines, reef seines, cast nets, hand lines, monofilament, trawl nets, scoop nets, ring nets, trammel nets, trolling lines, spear guns/harpoons and trap/baskets. The total number of fishing gear was estimated in four Fisheries Frame Surveys of 2004, 2006, 2008 and 2012. This showed a mean of 31,882, a maximum of 37,240, a minimum of 25,373 and a standard deviation of 4,378. The most common gear used in number was long-line (11,154) followed by gill nets (5,354), hand-lines (5,260), traps/basket (4,787) and monofilament

1,666. All other 10 gears summed to 3,661 (>3%) of the total number (Appendix 2). Most of these fishing gear for instance the beach seine, reef seine, monofilament net, trawl nets and ring net have low selectivity and scoop up many species and sizes of fish. Note that some of the gears do not require a boat to operate like the spear gun and basket trap (Samoilys, M.A., Maina G et al. 2011).

The number of artisanal fishermen increased by 52% from 9,017 in 2004 to 13,706 in 2012, while the number of boats increased by 77% from 2,233 to 3,945 during the same period. The trend of change in the number of fishermen and boats and the corresponding catch per unit effort (CPUE) is illustrated in Figure 2 below.



Source: FD.(2004; 2006; 2008; 2012).

Figure 2. Showing changes in number of fishing boats and fishers over a period of eight year (2004 - 2012) established through Fisheries Frame Surveys and the corresponding CPUE during the same period.

The declining CPUE (dashed line), indicates declining stocks. For instance CPUE declined from 18kg/boat-day in 2004 to 12 kg/ boat-day in 2012 - a decline of 36% within a period of eight years (Figure 2). At the same time, fishing effort as measured by the number of boats and fishermen increased drastically.

2.2.5 Fish catch trends and major fish species

Fish catches and CPUE exhibit a downward trend from 1996 to 2000. Thereafter, fish catch has generally increased until 2012 but with a declining CPUE. Fish harvest increased by 86% from 4,763 tonnes in 2000 to 8,947 tonnes in 2011 while CPUE declined by 42%, from 0.020 tonnes/boat-day to 0.012tonnes/ boat-day in 2012 (Figure 3). This increase in fish catch but decline in CPUE is explained by a huge increase in fishing effort measured as fishing boats during the same period (Figure 2). The decline in CPUE is an indication of a declining fish stock on the artisanal marine fishing grounds.

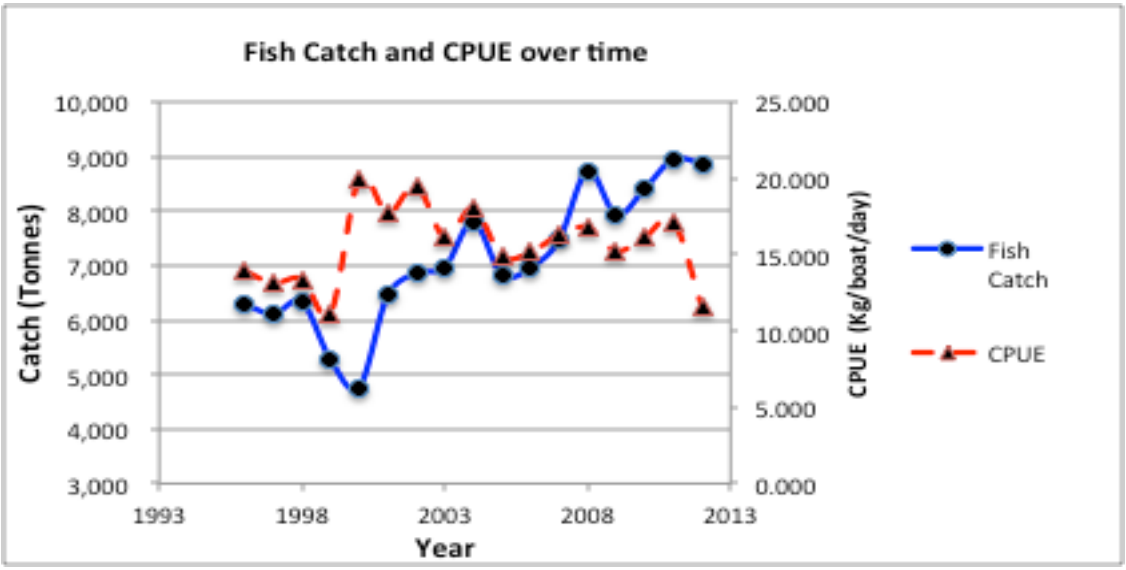


Figure 3. Fish aggregate catches in tonnes and CPUE in tonnes/boat-day from 1996 -2012 with fish landing showing a general increase and CPUE declining over time.

Demersal finfish were about 65.6% of the marine artisanal fisheries during 2008 – 2012. When crustaceans (4.5%) and molluscs (4.6%), which characteristically are demersal, are included, the demersal fishery contributes an average of 74.6% of the aggregated fish catch weight during 2008-12. Pelagic species, mainly scads and mackerels, contributed an average of 25.4% to the total artisanal catch (table 4).

Table 4. Mean percentage of each fish category contribution to the total fish catches indicating also the maximum, minimum and Standard Deviation of the mean taken from year 2008 – 2012.

Category	% Contribution			SD (±tonnes)
	Mean	Max	Min	
Demersal finfish	65.57	60.7	53.47	170
Pelagic	18.7	20.96	26.17	52
Shark, Ray & Sardine	6.67	7.59	8.67	57
Crustaceans	4.51	5.47	5.88	43
Mollusks	4.55	5.29	5.82	37
Total	100	100	100	

There are over 33 fish species of commercial importance in the artisanal fishing ground of Kenya. However, 15 species dominate the fisheries with a total catch about 64.9% of the landings (Appendix 4).

Vessel and fisher density and yield/boat/year vary from one fishing ground to the other. Lamu and Kwale are the most attractive fishing grounds due to the high yield potential while Malindi was the least. Mombasa and Kwale have the highest fishermen density due to their small size fishing grounds and high fish stock density per unit area (table 5; Appendix 2).

Table 5. Effort density on boats and fisher in various fishing grounds and the respective potential yield/ boat/year based on effort data of 2012

Fishing ground	Fish density (ton/ km2)	Effort density		Yield (ton/year/boat)
		Km2/boat	Fishers/ km2	
Lamu	1.27	2.00	1.80	2.50
Malindi	0.96	1.80	2.00	1.70
Mombasa	6.33	0.30	8.70	2.00
Kwale	4.96	0.50	7.30	2.50

Source: Carrara & Coppola. (1985); FD. (2008; 2009;2010; 2011; 2012)

Based on the calculated decline in fish density by 13% from (1.93tonnes/km^2 in 1984 to 1.68tonnes/km^2 in 2012), the fishing grounds offered each boat the possibility to catch an average of 2.2 tonnes/year compared to 2.51 tonnes/year in 1984. The density decline also indicates that the commercial fish stocks biomass possibly had declined from the estimated 14,000 tonnes (1984) to some 12,000 tonnes (2012).

Chapter 3. Fisheries and the Bioeconomic model

Numerical fisheries models are necessary for fisheries administrators to predict the evolution of resource abundance and assess the impact of different policies. Biomass evolution predictions are necessary for management measures to be taken in time (Garcia and Le Reste, 1981). Detailed population dynamics models require biological data on fish growth, mortalities, age class structure and recruitment. Where these data are not available, simple biological models like surplus production models utilizing only catch and effort data over a number of years often suffice for biomass evolution prediction (Sparre and Venema, 1992). Adding to this data on prices and costs allow the construction of simple bio-economic models (World Bank and FAO Sunken billions 2009). This is the approach adopted in this study.

3.1 The General Model

The general fisheries model employed here consists of three key functional relationships:

1. Biomass growth

$$\dot{x} = G(x) - y$$

where $G(x)$ is the natural biomass growth as a function of biomass, *x.* The variable y is the yield or harvest from fishing and $\dot{x} = \frac{\partial x}{\partial t}$ represents the instantaneous change in biomass.

2. Harvest function

$$y = Y(e, x)$$

where harvest, y, is a function of fishing effort, e, and biomass *x*.

3. Profit function

$$\pi = p \cdot Y(e, x) - C(y, e) - fk$$

where *p* denotes the unit price of catch, fk is the fixed cost while *C*(*y*,*e*) represent the harvesting (variable) costs that depends naturally on fishing effort. It also depends on harvest because often the crew is remunerated by a share in the catch and, besides, there are usually landing costs and other handling costs associated with the volume of harvest.The expression, $p \cdot Y(e,x)$, of course represents revenues for the fishing activity.

3.2 Specific functional forms

3.2.1 Biomass Growth

The specific biomass growth function for the Kenya artisanal fishery stock was assumed to follow the Gompertz-Fox surplus production model which may be written as:

$$G(x) = r \cdot x \cdot \ln\left(\frac{K}{x}\right)$$

where, as before, x is the population biomass, r is an infinite growth rate and K is the carrying capacity or the virgin biomass.

By adding harvest to the equation, we obtain the effect of fishing on population dynamics:

$$\frac{\partial x}{\partial t} = r \cdot x \cdot \ln\left(\frac{K}{x}\right) - y \tag{1}$$

where y is the harvest and $\ln$ is the natural logarithm of a number and $\partial x / \partial t \equiv \dot{x}$. We may write Equation (1) more simply as:

$$\dot{x} = \alpha \cdot x - \beta \cdot x \cdot \ln(x) - y \tag{2}$$

The change in biomass in discrete time will be approximated by the following equation:

$$x(t+1) - x(t) = \alpha \cdot x(t) - \beta \cdot x(t) \cdot \ln(x) - y(t) \tag{3}$$

where the biomass at time $t+1$, $x(t+1)$, minus the biomass at time t, $x(t)$, is equal to the biomass growth less harvest, $y(t)$ at time t.

The equilibrium (or sustainable) state of the biomass, defined by $\dot{x} = 0$, can therefore be represented by the expression:

$$x(t+1) - x(t) = \alpha \cdot x(t) - \beta \cdot x(t) \cdot \ln(x) - y(t) = 0 \tag{4}$$

3.2.2 Harvest Function

The harvests from the fishery are based on a generalized Schaefer harvest equation:

$$y = q \cdot e \cdot x^{\delta} \tag{5}$$

where q is the catchability coefficient measuring the schooling behaviour of the artisanal fish stock. According to Clark, C. W (2005 p.226) there are three types of fish schooling behaviour or concentration profile. Sedentary (demersal) species have Type I category with $\delta > 1$; Diffusive species like Tuna have Type II $\delta = 1$, and; aggregative pelagic fish like Anchoveta have Type III with $0 \le \delta < 1$. About 75% of the Kenya marine artisanal fisheries are demersal while the rest are pelagic. A common value of $\delta = 1$ was chosen to represent the aggregate fish stock comprising demersal and pelagic.

3.2.3 The cost function

The cost function is specified as:

$$TC = C(y,e) = (a \cdot p \cdot y) + (b \cdot e) + fk \tag{6}$$

where TC is the total cost, a, is a measure of the crew share of the revenues, p is the price of landings and b is the marginal cost of effort.

3.2.4 Profits function

The profits from the fishery are defined as the total revenues $(R = p \cdot y)$ less total costs (TC) defined above. We, therefore obtain the profit function as:

$$\pi = p \cdot (1-a) \cdot y - b \cdot e - fk$$

or by substituting in for y .

$$\pi = p \cdot (1-a) \cdot q \cdot e \cdot x^{\delta} - b \cdot e - fk \tag{7}$$

It is important to note that this profit function is linear in fishing effort.

3.2.5 Equilibrium relationships

On the basis of the above stock biomass growth (Equation (4)) functional specifications, equilibrium harvest and fishing effort as a function of biomass are given below:

$$y = \alpha \cdot x - \beta \cdot x \cdot \ln(x) \tag{8}$$

$$e = \frac{\alpha}{q} - \frac{\beta \cdot \ln(x)}{q} \tag{9}$$

The equilibrium profit function as a function of biomass can then be written as:

$$\pi = p\cdot(1-a)\cdot y - fk - b\cdot e = p\cdot(1-a)\cdot(\alpha\cdot x - \beta\cdot x\cdot\ln(x)) - fk - b\cdot\left(\frac{\alpha}{q}-\frac{\beta\cdot\ln(x)}{q}\right). \quad (10)$$

The MSY effort level was estimated using th eequation derived equilibrium equation below

$\alpha\cdot x - \beta\cdot x\cdot\ln(x) = q\cdot e\cdot x$ ie $(G(x) = y(e,x)$

Equilibrium effort is given by

$$e = \frac{\alpha - \beta\cdot\ln(x)}{q}$$

Max yield at MSY is given by

$$\frac{2y}{2x} = \alpha - \beta\cdot\ln(x) - \beta = 0$$

Solving for MSY biomass x_{MSY}

$$\Rightarrow \ln(x) = \frac{\alpha-\beta}{\beta}$$

$$x = \exp\left(\frac{\alpha-\beta}{\beta}\right)$$

$$E_{MSY} = \frac{\alpha - \beta\cdot(\alpha-\beta)/\beta}{q}$$

$$\Rightarrow E_{MSY} = \frac{\beta}{q} \quad (11)$$

The bionomic equilibrium (BE) is derived from the condition that $\dot{x} = 0$, (Clark, C.W, 2005) and where,

$$\pi = R - TC = 0$$

In other words, where total revenues and costs are equal. Using Equation (7) above, this may be written as:

$$\pi = p\cdot(1-a)\cdot q\cdot e\cdot x^{\delta} - b\cdot e - fk = 0$$

Substituting in for e in this equation yields an expression for the bionomic equilibrium biomass as:

$$p\cdot(1-a)\cdot(\alpha\cdot x - \beta\cdot x\cdot\ln(x)) - b\cdot\left(\frac{\alpha}{q}-\frac{\beta\cdot\ln(x)}{q}\right) - fk = 0 \quad (12)$$

This equation can be solved numerically. Once X_{BE} has been found from Equation (12), it becomes possible to find the corresponding effort level and harvest from the equilibrium function.

The profit maximizing biomass (X_{MEY}) static reference point may be obtained by the maximizing the profit function in equation (10) with respect to biomass i.e.

$$\max_{x} \quad p \cdot (1-a) \cdot (\alpha \cdot x - \beta \cdot x \cdot \ln(x)) - b \cdot \left(\frac{\alpha}{q} - \frac{\beta \cdot \ln(x)}{q} \right) - fk = 0 \tag{13}$$

This solution to this maximization problem will in general have to be found by numerical means.

3.3 Equilibrium

Equilibrium in the fishery is defined by $\dot{x} = 0$. It immediately follows that

$$G(x) = Y(e,x),$$

which implicitly defines the equilibrium biomass as

$$x = \Psi(e),$$

and subsequently the equilibrium harvest as

$$y = Y(e, \Psi(e)) \equiv \Omega(e).$$

A slight complication arises as the equilibrium biomass, $x = \Psi(e)$, may exhibit more than one solution for biomass for any level of effort. Normally, only one of these solutions makes sense so this does not cause significant problems. This potential complication will be ignored in what follows.

Equilibrium profits are obviously

$$\pi = p \cdot Y(e,x) - C(Y(e,x),e) = p \cdot \Omega(e) - C(\Omega(e),e) \tag{14}$$

So we see that for each level of fishing effort that is chosen there will be a corresponding equilibrium biomass, harvest and profits. This raises the question of the optimal or profit maximizing level of fishing effort. This can be found by maximizing profits in Equation(14) above yielding the condition:

$$p \cdot \Omega_e(e^*) - C_y(\Omega_e(e^*), e^*) - C_e(\Omega_e(e^*), e^*) = 0 ,$$

provided *e**>0.

Solving this equation for the optimal effort, *e** also yields the optimal biomass, harvest and profits as:

$$x^* = \Psi(e^*) \tag{15}$$

$$y^* = \Omega(e^*) \tag{16}$$

$$\pi^* = p \cdot \Omega(e^*) - C(\Omega(e^*), e^*) \tag{17}$$

Our optimization problem of interest seeks to

$$\max_{e} \quad p \cdot Y(e,x) - C(Y(e,x),e) \tag{18}$$

subject to (s.t)

$$G(x) - Y(e,x) = 0$$

$$e \geq 0$$
$$x \geq 0$$

To determine the values for e that maximizes π, and the existence constraint of initial condition x_0, the *Lagrangian* expression below for the problem was formed, which introduced the shadow price of the fish stock (biomass) denoted by $\lambda > 0$

$$L = p \cdot Y(e,x) - C(Y(e,x), e + \lambda \cdot (G(x) - Y(e,x))$$

The necessary conditions to solve the optimal level of $e(t)$, $x(t)$, and $\lambda(t)$ along an approach path and the steady-state bioeconomic optimum e^*, x^* and λ^* are

(1) $\dot{L}_e = \mathrm{e}^{-r \cdot t} \cdot (p \cdot Y_e - C_e - \lambda \cdot Y_e) = 0 \qquad (e > 0)$

(2) $\dot{L}_x = e^{-r \cdot t} \cdot (p \cdot Y_x + \lambda \cdot (G_x(x) - Y_x)) = 0 \qquad (x > 0)$

(3) $\dot{L}_\lambda = G(x) - Y(e,x) = 0$

Condition (1) to (2) and (3) are central in determining the optimum time paths for λ, e and x. Condition (1) provides that maximizing instantaneous profits is not optimal and should be modified by shadow values of biomasses. The fishing effort in the fishery should be expanded only until the marginal profits equal the marginal value of the biomass extracted by the effort measured by $\lambda \cdot Y_e$. Condition (2) gives the equations of motion for the shadow value of the biomasses along the optimum utilization path (Ragnar,2000).

The *fundamental equation of renewable natural resour*ces needed to solve for the two equilibrium values for fishing effort e and biomass, x was derived at by combining condition (1) and (2) above as follows;

$$p \cdot Y_x + \left(p - \frac{C_e}{Y_e} \right) \cdot (G_x(x) - Y_x) = 0$$

$$\Rightarrow \; G_x(x) - Y_x + \frac{p \cdot Y_x \cdot Y_e}{p \cdot Y_e - C_e} = 0$$

$$\Rightarrow \; G_x(x) + \frac{p \cdot Y_x \cdot Y_e - p \cdot Y_e \cdot Y_x + Y_x \cdot C_e}{p \cdot Y_e - C_e} = 0$$ which gives

$$G_x(x) + \frac{Y_x \cdot C_e}{p \cdot Y_e - C_e} = 0$$ which was rewritten as

$$G_x(x) + \frac{Y_x(e,x) \cdot C_e(Y(e,x),e}{\pi_e(e,x)} = 0$$

where $G(x)$ is the marginal net growth rate, and $\frac{Y_x(e,x) \cdot C_e(Y(e,x),e}{\pi_e(e,x)}$ is the marginal stock effect (MSE).The sum of the two terms in the left hand side (LHS) is interpreted as the *resource's rate of return.*

Thus, a more traditional representation of a static optimal equilibrium (Clark & Munro ,1975; Arnason 2000) is:

$$G_x(x^*) + \frac{Y_x(e,x) \cdot C_e(Y(e,x),e}{(p - C_y(Y(e,x),e) \cdot Y_e(e,x) - C_e(Y(e,x),e)} = 0$$

$$G(x) = Y(e,x)$$

Substituting the specific functions discussed (Equations (2), (5), (6) and (7) above, we get

$$\alpha - \beta \cdot \ln(x) - \beta + \frac{((b + fk) \cdot q \cdot (\alpha / q - \beta \cdot \ln(x) / q)}{(p \cdot (1 - a) \cdot q \cdot x) - (b + fk)} = 0 \qquad (19)$$

$$\alpha \cdot x - \beta \cdot x \cdot \ln(x) - q \cdot e \cdot x^{\delta} = 0$$

Which obviously implicitly define e^* and x^*

3.4 Dynamics

Though static reference points are useful, their static nature diminishes their utility as fisheries management tools. This is especially true since it is unlikely that any fishery is in equilibrium at any given time (Seijo et al. 1998). Dynamic representations which consider changes in biomass, effort, costs and benefits (profits) over time are much more realistic.

3.4.1 Dynamic optimal equilibrium

The dynamic profit maximization problem is to find the time path for the fishing effort that maximizes present value of profits from the fishery (Arnason, 2000) by solving for:

$$\max_{e} \quad \int_{0}^{\infty} (p \cdot Y(e,x) - C(Y(e,x),e)) \cdot e^{-r \cdot t}\, \partial t \tag{20}$$

subject to $\dot{x} = G(x) - Y(e,x)$

$x \geq 0,$

By combining biomass growth, harvest and profit functions, optimal equilibrium reference points for a given rate of discounting, r were developed to simulate the optimal discounted fishery over time. The dynamic optimal equilibrium expression was similarly derived at as for the static case (Equation (19)), but in the dynamic case the maximization equiulibrium solution (Arnason, 2000, Clark and Munro 1975), is found to be:

$$G_x(x^*) + \frac{Y_X(e,x) \cdot C_e(Y(e,x),e}{(p - C_y(Y(e,x),e) \cdot Y_e(e,x) - C_e(Y(e,x),e)} = r \tag{21}$$

$G(x) = Y(e,x)$,

where r denotes the rate of discounting. This obviously produces a different equilibrium solution for *e** and *x** than Equation (19) above. More specifically, in that it would cause the resource's rate of return equal to the rate of discount, r .

Assuming the functional forms above (Equations (2), (5), (6) and (7), these equations are:

$$\alpha - \beta \cdot \ln(x) - \beta + \frac{((b + fk) \cdot q \cdot (\alpha / q - \beta \cdot \ln(x) / q)}{(p \cdot (1 - a) \cdot q \cdot x) - (b + fk)} = r \tag{22}$$

$$\alpha \cdot x - \beta \cdot x \cdot \ln(x) - q \cdot e \cdot x^{\delta} = 0$$

3.4.2 Optimal dynamic adjustment path

Now, with the optimum effort, e^* and corresponding biomass , x^* , harvest , y^* and the current fishery status known, an adjustment approach path to take the fishery to the sustainable long run situation was developed starting from period of the optimum policy implementation, $t1$. According to Clark, (1985) the present value of a future flow of benefits is the amount of benefits at year t that is equally desirable to the future flow of benefits. Thus, the maximization problem was to maximize present value for all future net benefits for every period time, t from time $t1$ onwards. The procedure was subject to stock biomass, $x(t)$ at each period t, which is the resources available for exploitaion, the harvest, $y(t)$ and the effort, $e(t)$ that affects the amount of resources available for the next period. The maximization problem not only depends on the level of harvest at time t but also on the resources left for future exploitation. The fishing effort was chosen as the control variable for the procedure. Since the fishery generates, on a consistent manner, full operations data annually, discrete profit maximization procedure was used, and the maximization problem expressed as

$$\max_{e} \sum_{t=0}^{\infty} (p \cdot Y(e(t), x(t)) - C(e(t))) \cdot \frac{1}{(1+r)^t} \tag{23}$$

subject to $x(t+1) = x(t) + G(x(t)) - Y(e(t), x(t))$

And, thus, at every period t, the present value of profits $\pi(t)$, can be expressed as:

$$PV_{\pi} = \frac{R(t) - TC(t)}{(1+r)^t} = \frac{\pi(t)}{(1+r)^t} \tag{24}$$

where $R(t)$ are revenues, $TC(t)$ the total costs at time t. The PV is dependent on the rate of discounting, r. A high rate of discounting will lead to lower present value, while a low rate of discounting leads to higher values for net benefits in the future (Seijo et al., 1998). The PV of a flow of profits over a time interval $[0, T]$, NPV_{π}, is obtained as:

$$NPV_{\pi} = \sum_{t=0}^{T} \frac{\pi(t)}{(1+r)^t} \tag{25}$$

3.5 Data Sources

To apply the model the following parameter were to be estimated: (i) for the biological function, alpha(α) and beta (β); (ii) for harvest function catchability coefficient(q), schooling parameter(δ), and; (iii) profit function marginal cost of effort(b), revenue sharing (labour) cost(a), landing price(p), and fixed costs(fk) . The model includes a number of variables but it can be transformed in various ways.

3.5.1 Officially available data

The available data was on aggregate fishing effort (number of boats), fish catch and revenues, which were obtained from the State Department of Fisheries, Kenya. The information was extracted from the department records on "Annual statistical bulletins" and "Marine Waters Fisheries Frame Surveys". With the total catch and total revenue, it was possible to calculate average ex-vessel fish price. Data on fishing investment and operation costs and gear deployment time was not available from the government agencies.

3.5.2 Independent Field Surveys

A field survey was conducted in the Archipelago Islands of Faza and Kizingitini in Lamu County between June and first week of September 2013. This was to obtain data on average fish landing by boat-gear type in weight and species and variation between vessels. Observation on fish sales was made to verify average unit fish prices. Interviews were conducted on fishermen to establish the investment and operation costs associated with the fisheries. The principal objectives were: (i) to fill in the gaps in data on gear application time, investment and operation costs, and average catch/boat-type (ii) provide a check on the reliability of the data that exist on fish prices and fish species composition (iii) to develop, within a fairly short time period, an understanding of the fishing industry.

A total of 360 boats were sampled as they made their landings (Faza 103; Kizingitini 257). A catalogue on boat-gear types was developed, with corresponding investment cost and propulsion system (appendix 8), average number of hours of gear deployment/day, average number of active days/week, weight of fish caught and ex-vessel prices, fuel consumption/fishing trip, and revenue sharing method. The data generated by the study were to be used in estimating actual fishing effort (e), unit fishing effort cost (c) parameters on fixed cost (fk), fishing-trip cost (b), labour cost (a) and for calculation of the profit (π).

3.5.2.1 Gear deployment time

The boats length was between 4.0m and 11.7m, with a mean of 7.6m. Five type of fishing boat were identified namely: *Mashua (MS), Dau (DA), Foot Fisher (FF) and Mtumbwi (MT)*. *Mtumbwi* are dung out canoe made from tree trunk and about 4 m length. *Hori* is a canoe made of planks. It can be fitted with outrigger and small sail and propelled using oar. When fitted with a sail it is called *ngalawa* (*Foot Fisher*). It is sometime difficult to distinguish Hori from *dau.* However *dau* are wider inside, have a flat bottom, are longer, and have a curved silhouette. *Foot Fisher* are not made in Kenya, but come from Pemba, Tanzania. *Mashua* are larger in size fishing vessel mainly used for out-of- reef fishing. They are made from plank wood and have sails. Each boat type detailed specifications are given in Appendix 9.

Each category would be either motorized or non-motorized, except the *Mtumbwi* which were all non-motorized due to their relatively small size. The total motorized and non-motorized boats constituted 6.4% and 93.6% of the sampled boats. The observed boats categories and gear deployment time is as in table 6 below.

Table 6. Boat type and category and respective gear deployment time for the marine artisanal fishery, Kenya observed between June and September 2013

Boat type		Propulsion		Gear deployment time/day (hrs)			No. fishing day/week			Hrs/ week	Boat - days
Name (code)	Total	With engine	No engine	Min	Max	Mean	Min	Max	Mean		
Mashua (MS)	214	5	209	8	24	16.9	3	7	5.4	91.8	199
Dau (DA)	7	5	2	13.6	18.1	15.4	4	6	4.4	67.7	147
Foot fisher (FF)	36	9	27	15.2	21	18.9	3	7	5.1	95.8	207
Hori (HR)	3	4	58	7.8	20	15.4	3	7	5.4	83.2	180
Mtumbwi (MT)	40	0	42	13	19.92	18.1	4	7	6	109	236
Average						16.6			5.4		194

All boats have, on average 11.5 hours/day and 20.6 hours/day, and 3.4 days/week and 6.8 days/week as minimum and maximum gear deployment time respectively. The mean was 16.6 hours/day and 5.4 days/week.

3.5.2.2 Catch by boats and gear type

Seven types of fishing gears were identified to be in use by all fishing boats. The mots commonly used gears was seine net (33.1%) followed by beach-seine (29.7%). The others are gill net (16.9%), monofilament (8.1), hand-line (5.8%), reef seine (5%) and traps (1.4%) in that order. The use of seine net was associated with all boats. However, gill net was mostly identified with *Mashua* due to their comparative large sizes, which accommodate more crews needed to operate the gill net. Monofilament gear is popular to *Hori* boat owners for the gear is light and convenience to the boat small size.

A total of 5,760 kg was landed by the sampled boat and each landings was associated with the boat type, category and with the fishing gear used *Mashua* are the most important fishing boat (85%) while *Foot fishers* and *Dau* are the least important (table 7).

Table 7. Fish catch in weight and percentage by boat type for the marine artisanal fishery, Kenya observed in the period of June - September 2013.

Boat type	Total catch (kg)	% contribution
Mashua (MS)	4895	8.5
Hori (HR)	530	9.2
Mtumbwi (MT)	260	4.5
Dau (DA)	45	0.8
Foot fisher (FF)	31	0.5
Total	5760	

The motorized boat landed about 6% and the non-motorize about 93% 0f the observed catch. This was attributed to the low number of the boats with engine as compared to non-motorized. The two boat categories have a comparatively similar mean catch and with equally low minimum catch (table 8).

Table 8. Fish catch in weight and percentage by boat propulsion system for the marine artisanal fishery, Kenya observed in the period of June – September 2013

	Boat with engine	Boat with no engine
Min	2	0.3
Mean	15.7	16.3
Total	356.7	5403.3
%	6.2	93.8

This was an indication that there was no advantage of a motorized boat over the non-motorized and all boats are homogenous in their fishing effectiveness. This would explain why fishermen are slow in adopting mechanized boats, rather they use paddles and wind sails for propulsion.

Beach seine and the gill nets are most important fishing gear contributing in both contribution of to total catch and in their mean catch. Traps and hand line are the least important using the same criteria (table 9).

Table 9. Fish catch in weight and percentage by boat propulsion system for the marine artisanal fishery, Kenya in the period of June – Sept. 2013.

Gear type	Total catch (kg)	Minimum catch (kg)	Maximum catch (kg)	Mean catch (kg)
Beach Seine (BS)	4189.1	4	587	94.3
Reef Seine (RS)	51.5	2	20	6.1
Gill Net (GN)	839.3	0.3	105	33.1
Seine Net (SN)	203.1	0.3	68	4.1
Traps (TR)	67.7	15	57	32.6
Hand line (HL)	82.1	1.1	24	9.4
Monofilament (MF)	327.2	5	70	27
Total	5760			

Beach seine contributed 73% of the total catch followed by gill net (15%) with traps and hand-line being with 1% each. With a total catch of 5760kg made by 360 boats, the mean catch per boat was 16kg/boat-trip. On the criteria of importance based on the global average catch /boat-trip, monofilament nets and traps become too as important gear as their daily catch is approximately double the daily average.

3.5.2.3 Fish prices

A random observation of 664 fish sales weighing a total of 4792kg and which was constituted of 32 fish species was made as the boat lands at the beaches. The number of fish in each sale sample was counted and their weight and price noted. Sales of the same fish species were grouped together, and their number, weight, mean price and total revenue tallied together. All sales were later aggregated to get total number, weight and revenues during the study period. The total revenue was divided by total weight to get the mean ex-vessel fish price. The detailed weight and average price and total revenues are shown in Appendix 7. The minimum price for all fish species was Ksh70 (US$0.8) and the maximum was Ksh 830 (US$9.54) for Lobsters (*Panalirus spp*). The mean ex-vessel price was calculated by dividing the total revenues by the total weight sold. The fish species with total weight and revenues ≥ than 1.0% were identified and their contribution to the fishery examined. These were the first 17 fish species listed in the appendix.

These species contributed to over 95% in total catch and in revenues with a mean ex-vessel price of Ksh 121/kg (US$1.39/kg at Foreign Exchange rate Ksh87/US$ of 2013). The price degraded to Ksh 120 (US$1.38) when all the 32 species were considered. Three fish species namely *Hemiramphus spp, Panulirus spp* and *Lutjunus bohar were* identified as of major economic significant with each contributing to more than 10% of the reveunues, with the later two attracting premium prices.

3.5.3 Biological Data

To apply the model, data on aggregate fish catch and fishing effort (number of boats) from 1977 to 2012 was used. The data was collated from the State Department of Fisheries as Annual Statistical Bulletins. Data generated from field survey on gear application time was used together with Fisheries Frame survey data to calculate standard total fishing effort in boat-days/year. The aggregate fish catch and total effort/year (Appendix 6) was used in the calculation of catch per unit effort $(CPUE)$ and thereafter in the estimation of the parameters α, β in equation (18) which implicitly define the biological parameters MSY, $XMAX$, r and K.

3.5.4 Effort Data

The effort data was obtained from the State Department of Fisheries Annual Statistical Bulletins from 1996 to 2012. The data was corroborated by more detailed data from Marine Fisheries Frame Surveys reports of 2006, 2008, 2010 and 2012. The frame survey reports provided data on fishing boats categories into motorized, wind powered and paddled boats as well as various varieties of fishing gears, their sizes and quantities registered in each study year. This boats categorization provided the number of motorized boats per year, which was important in the calculation of the fuel cost of fishing trip. The information provided on effort was in number of registered boats and in motorized or non-motorized category (table 10).

Table 10. Fishing effort in number of boats and mode of propulsion for the Kenya marine artisanal fishery from 1996 to 2012.

Year	Non-motorized boats	Motorized boats	Total boats	Year	Non-motorized boats	Motorized boats	Total boats
1996	2,215	123	2,338	2005	2,185	183	2,368
1997	2,276	124	2,400	2006	2,137	231	2,368
1998	2,314	126	2,440	2007	2,093	275	2,368
1999	2,313	127	2,440	2008	2,368	319	2,687
2000	1,102	129	1,231	2009	2,355	332	2,687
2001	1,751	130	1,881	2010	2,342	345	2,687
2002	1,681	132	1,813	2011	2,330	357	2,687
2003	2,099	134	2,233	2012	2,720	370	3947
2004	2,098	135	2,233				

Source:FD,(1996, 1997, 1998, 1999......& 2012)

The field survey established that the average boat fishing trip takes 16.59 hours/day and is actively fishing for 5.39 days/week. The gear application time was calculated as a product of fishing trip time/day, number of active days/week and the number of weeks/year, which gave an average of 193.84 boat days/year, as shown:

Total effort= (Fishing trip time (hour)/24) No. of active days/week* 52 weeks/year *total number of boats*

3.5.5 Economic Data

The economic data on marginal fishing costs were obtained through interviews held with 30 fishing boats' captains in the fishing villages of Faza and Kizingitini, in Lamu County. The cost of boat (Appendix 9) was verified with the boat-gear costs catalogue developed by CORDIO East Africa LTD in partnership with fishermen from Kwale County. Cost adjustment was made appropriately and where necessary to conform to market prices of gears and equivalent new boats. The data provided on investment cost of a non-motorized boat-gear combination was US$1454 and for motorized category as US$ 4710. Non-motorized boats account to about 90% of the total fishing boats while the motorized about 10%. The calculated average was about US$1712. Other information provided was on fuel consumption given as 15 litre/trip, annual boat docking charge of US$10.8, annual boat and crew registration and license at US$1.4 each, crew revenue sharing ratio of 50:50 after trip cost deduction and boat repair and maintenance at 5% of boat-gear cost.

The historical information on fuel cost was obtained from World Bank Webpage (World Bank Indicators- Kenya-Transport, 2013). Boat fuel consumption information generated through interviews was counterchecked with regional engine suppliers, Mombasa and compared with equivalents boats from Kilifi County fishermen.

Revenue and profits was developed from data obtained from the Catch–Effort Assessment survey. The average catch/boat (weight) per trip was 16kg and average unit prices for all fish species caught was US$ 1.38/kg, and which was used in this study.

3.6 Estimation of Parameters

3.6.1 Biological Parameters

The α and β in the Gompertz-Fox (G-F) surplus production model was estimated with the help of regression methods. The q parameter was calculated based on the generalized harvest equation $y = q \cdot e \cdot x^{\delta}$, giving $q = \frac{y}{e \cdot x^{\delta}}$. By using aggregate harvest, effort and biomass data q value for each year from 1997 to 2012 was calculated, that gave an average value of $q = 0.0002$. In the regression process, the coefficient C (q) was restricted to the calculated average value while the values of A and B was estimated.

The estimation equation was derived from the Gompertz-Fox equation as follows

(i) $\dot{x} = \alpha \cdot x - \beta \cdot x \cdot \ln(x) - y$

The assumed harvesting function is

(ii) $y = q \cdot e \cdot x$,

Therefore:

$$x = \frac{y}{q \cdot e} .$$

The continuous time in the G-F function was approximated by

(iii) $\dot{x} = x(t+1) - x(t)$

Given all this, equation (i) can be rewritten as

$$\frac{y(t+1)}{q \cdot e(t+1)} - \frac{y(t)}{q \cdot e(t)} = \alpha \cdot \frac{y(t)}{q \cdot e(t)} - \beta \cdot \frac{y(t)}{q \cdot e(t)} \cdot \ln\left(\frac{y(t)}{q \cdot e(t)}\right) - y$$

By multiplying both sides of the equation by q we get

(iv) $\frac{y(t+1)}{e(t+1)} - \frac{y(t)}{e(t)} = \alpha \cdot \frac{y(t)}{e(t)} - \beta \cdot \frac{y(t)}{e(t)} \cdot \ln\left(\frac{y(t)}{q \cdot e(t)}\right) - y \cdot q$

Note that $\frac{y}{e} = CPUE$.

By dividing both sides of the Equation (iv) above by the CPUE, which is equivalent to multiplying by $\frac{e_{(t)}}{y_{(t)}}$ we get

$$\frac{CPUE_{(t+1)}}{CPUE_{(t)}} - 1 = \alpha - \beta \cdot \ln\left(\frac{CPUE_{(t)}}{q}\right) - q \cdot e_{(t)}$$

Which is the same as

$$\frac{CPUE_{(t+1)}}{CPUE_{(t)}} - 1 = \alpha + \beta \cdot \ln(q) - \beta \cdot \ln(CPUE_{(t)}) - q \cdot e_{(t)}$$

This is our estimation equation, which we write more conveniently as

$$\frac{CPUE_{(t+1)}}{CPUE_{(t)}} - 1 = A + B \cdot \ln(CPUE_{(t)}) + C \cdot e_{(t)} \quad (26)$$

where

$$A = \alpha + \beta \cdot \ln(q),$$
$$B = -\beta$$
$$C = -q$$

Obviously, from estimates of the parameters A, B and C, q and β can be obtained directly. The parameter α can be obtained as $\alpha = A + B \cdot \ln(-C)$.

Now, the variables in Equation ((26) only depend on catch and effort on which we have data and have calculated the CPUE and the lnCPUE (Appendix 10).

The dependent variable ($CPUE_{(t+1)} / CPUE_{(t)} - 1$) was regressed against the explanatory variables $\ln(CPUE)$ and effort (boats). A total of 26 observations were analysed. The coefficient of determination (best-fit regression line) (R^2) was 0.1814 indicating 82% of the residues were unaccounted for. ANOVA test value $p = 0.059$ $(p > 0.05)$ indicated there was statistically no relationship between effort applied and the fish catch landed. Durbin–Watson test for residuals coefficient value of 1.8496 showed there was no serial autocorrelation and thusthe data was independent. The skewness and excess kurtosis coefficient of 3.6690 and 16.4244 respectively indicated lack of normal distribution of the residue. The parameter estimates are summarized in Table 11.

Table 11. Regression Analysis outputs on A and B estimates and diagnostic checks while restricting catchability coefficient (q) at 0.0002.

Coefficient	Value	SE
A	1.518	0.2939
B	-0.92494	0.02831
C	-0.002	0

It is typical for this kind of an approach to get a low R^2 value and lack of normality of the residues. It is likely that errors in the variables are a source of some statistical problem: This can be corrected by the use of instrumental variable techniques or 2SLS. That, however is not very feasible because of lack of instruments.

From the estimated equation (26) $A = \alpha + \beta \cdot \ln(q)$, which gave a value of $A = 9.3958929$. Coefficient $B = \beta = -0.92494$ and $C = q = -0.002$. On the basis of these parameters, the key fishery characteristics were calculated as shown in table 12 below.

Table 12. Key characteristic of the Kenya marine artisanal fishery and their estimating equations.

Coefficient	Symbol	Estimating equation	Value
Xmax (tonnes)	K	$K = \exp\left(\frac{\alpha}{\beta}\right)$	25,806.5
XMSY (tonnes)	X_{MSY}	$X_{MSY} = \exp\left(\frac{\alpha - \beta}{\beta}\right)$	9,493.7
MSY (tonnes)	MSY	$MSY = -\left(\frac{1}{\beta}\right) \cdot \exp(\alpha - 1)$	8,781.1
Effort at MSY (boats)	E_{MSY}	$E_{MSY} = \frac{\beta}{q}$	4624.7

3.6.2 Fishing cost

The total fishing costs (TC) are defined as the sum of the fixed cost((fk) and variable costs. Fixed costs are those incurred independent of the fishing activity and include (i) capital cost comprising of depreciation of vessel and equipment (ii) average annual docking and fishing boat/gear registration charges, and (iii) average annual boat/gear maintenance fees. Variable costs are those that are associated with the actual fishing activity. They can be split into (i) variable costs related to fishing effort, and (ii) variable costs dependent on landed fish value, like the labour cost, marketing and administration charges. The cost function could be estimated directly using the following equation;

$$C(y,e) = a \cdot y + b \cdot e + fk$$

This requires accurate time series data on $C(y,e)$, and harvest (y), and effort (e) and through a regression procedure the constant a, b and fk would be estimated. Due to lack of this information we used a constructed cost function as detailed below;

3.6.2.1 Fixed costs

To vet the average fixed cost, the investment of boat-gear combination was estimated first. The information to get these costs was provided through interviews with boat captains and verified with boat-gear catalogue developed by CORDIO East Africa Limited. About 90% of all the boats are non-motorized and the average boat-gear combination cost of Kshs108039 (US$1,454 at an average exchange rate of Kshs 74.30/ US$, of the Central Bank of Kenya rate between 1996 -2012). The rest 10% had an outboard engine and an average boat-gear combination cost of Ksh300,000 (US$4,037). Thus, the average cost of any boat-gear combination was US$ 1,712. The depreciation costs and boat repairs and maintenance was calculated at 5% of the investment costs, which gave US$85.6/year for each expense. The annual docking charges cost was obtained from the boat captains and verified with Kenya Ports Authority (KPA) webpage, which is fixed at US$10.77/year. The annual boat registration fee and fisherman license has been constant since 1996 – 2012 at US$1.35/year. According to SDoF, (2004; 2006; 2008; and 2012) and the field survey information, each fishing boat has an average of 4 crews. The boat charge, thus, was US$1.35 and for the crews US$5.40/year. The total fixed cost for a single boat thus, was US$188, while the total cost for the fleet depends on the number of vessels. The summary is as in table 13 below

Table 13. Average annual fixed cost in US$ per fishing boat for Kenya artisanal marine fishery

Item	Unit cost (kshs)	Unit cost (US$)	Note
90% Non motorized boats	108,032	1,454	90% of total
10% Motorized	349,953	4,710	10% of total
Average cost(All boats)	127,202	1,712	Average
Depreciation cost	6,360	85.6	5.0% of capital cost
Repair & maintenance	6,360	85.6	5.0% of capital cost
Docking charges	800	10.8	Mean Forex Kshs 74.30/US
Boat annual registration fee	100	1.4	Mean Forex Kshs 74.30/US$
Crews annual license	401	5.4	Average of 4 crews/boat
Total	13,222	188.8	Unit fixed cost

3.6.2.2 Variable costs

To estimate the variable costs related to fishing effort, we included the fuel cost for the motorized boats, the cost of food and provisions for 5 crew/boat/ fishing trip. The fuel cost was based on an average of 15-litres/trip as provided by boats captain through interview and multiplied by the 193.84 boat day/year to get 2907.6 litres/boat/year. The value was multiplied by the average fuel cost of US$ 0.94/litre as calculated from 1996 – 2012 data obtained from World Bank database (World Bank Indicators-Kenya-Transportation), times the total number of motorized boats/year. Then the total fuel cost was distributed to all fishing boats to get an average fuel cost/boat.

$$Fuel\ cost = \frac{15litre * 193.84boat\ days * US\$0.94/litre * No. motorized\ boat}{Total\ No. of\ boats}$$

The procedure was repeated for all years from 1996-2012 and an average value of US$240/boat/year was obtained (Appendix 8)

Food and other crew provisions were estimated at Ksh50/crew/trip (US$ 0.67) for four crews/boat for 193.84 boat-days per year. This is on the basis of information provided by fishermen through interviews. This amounted to US$519/boat/year. The marketing and Beach Management Unit (BMU) administration charges are fixed at US$ 0.07/kg of fish landed. From the information generated from the Catch–Effort Assessment survey conducted in June-September, 2013, the average daily (trip) catch per boat was 16kg. This translated to US$ 1.12/day each for municipal and BMU (table 14). Annual variable cost was calculated on the assumption that each boat has a unit effort of 193.84 boat-days per year.

Table 14. Estimated average daily and annual variable cost in US$ per fishing boat for Kenya artisanal marine fishery.

Item	Unit cost (US$)	Cost/trip (US$)	Annual cost (US$)	Note
Fuel	0.94/litre	1.24	240	1.32 litre/trip at US$0.94/litre for 193.84 boat days/year
Food & Supply	0.67/crew	2.68	519	US$0.67/crew (Ksh 50)/ for 4 crews/trip for 193.84 boat days
Marketing	0.07/kg	1.12	217	US$0.07/kg of fish landed. Av catch/trip was 16kg
BMU	0.07/kg	1.12	217	US$0.07/kg of fish landed. Av catch/trip was 16kg
Total		6.16	1,193	

3.6.2.3 Economic parameters

Labour cost was calculated on a 50:50 sharing ratio on the market value of the landed fish after deduction of variable costs from each fishing trip. The unit price of the fish was an average of the ex-vessel fish prices for 2007-2012, which gave US$ 1.38/kg or US$1,380/tonne. Thus, the observed daily average catch of 16kg had a landing value of US$22.08. The labour cost was calculated by first deducting the variable cost of US$6.16 from the revenue, and then balance was divided by two i.e.

$$\frac{DR - DVc}{2} = \frac{22.08 - 6.16}{2} = 7.96 \text{ /boat trip}$$

where DR, is the daily revenue and DVc, is daily variable cost.

The daily labour cost was about 40% of the total daily revenue i.e. $labour = 0.4(p \cdot y)$. The crew wage was validated on the basis of the catch and marketing data from 1996 to 2012 and on year after year actual ex-vessel price with an average US$1,041/tonnes. This gave daily revenue of US$16.2 and crew wage of US$5.0, which was approximately 30% of the revenue $(0.3(p \cdot y))$. This value was considered more reliable as it was an average of several years' actual values. The marginal cost of effort (b) was estimated by dividing the sum of the variable cost per trip by the number of days per trip. In this case the number of days per trip was one, and thus

$$b = \frac{Vc / trip}{No.day / trip} = \frac{6.16}{1 day} = 6.16$$

The economic parameters are summarized in table 15.

Table 15. Estimated average value of the economic parameters for Kenya artisanal marine fishery.

Parameters	Symbol	Value (US$)	Note
Price (US$/tonne)	p	1,380	Based on average unit price of fish landed in 2007 -2012
Labour as share of revenue	a	0.3	Value given in interview with fishermen
Marginal cost/effort	b	6.16	Estimated cost/trip
Discounting rate	d	0.085	Central Bank of Kenya rate in 2012

Based on the fixed, variable and economic parameters, the cost function of a single boat was given as:

$$C(y,e) = a \cdot (p \cdot y) + (b \cdot e) + fk$$

Where p, is the unit price of fish in US$/tonne and y, is the yield in tonnes and fk is the unit fixed cost. The cost function for the whole fleet was the summation over all the boats. Since the boats were considered homogeneous, the cost function becomes:

$$C = N \cdot c = a \cdot p \cdot N \cdot y + (b \cdot N \cdot e) + N \cdot fk = a \cdot p \cdot Y + b \cdot E + FK$$

where; C is the total cost for the fleet, N the total number of boats, c the cost function of a single boat, Y the aggregate harvest by the fleet, E the effort of the fleet, and FK is the fleet fixed cost.

Profits function for a single boat can be expressed as

$$\pi = p \cdot (1 - 0.3y) - (b \cdot e + fk)$$

On plugging into the equation the parameter already calculated the expression becomes:

$$\pi = 1380(0.7y) - (6.16(193.84) + 320)$$

where y is the total fish landed by a boat in a year.

And the total profit function for the fleet was expressed as:

$$\pi = 1380(0.7Y) - (6.16(E) + FK$$

Chapter 4. Numerical Analysis and Outputs

The previously developed bioeconomic model for the Kenya marine artisanal fishery was used to identify optimal fisheries policies. An optimal profit maximizing sustainable policy was developed and compared with the current state of the artisanal fishery. Then economically efficient adjustment paths of the fishery from its current state to an optimal one were determined. Two adjustment paths were considered. The first is a path involved the complete withdrawal of all effort from the fishery to enable the fish stock to rebuild as fast as possible to the long run optimal level and thereafter gradually increase the effort to the optimal. The approach is more efficient but socially more disruptive to a fishing community with poor labour mobility and intangible alternative employment.

The second adjustment path, referred to as the moderate path, involves gradual reduction of fishing effort over a period of five-years until the optimal sustainable state of the fishery is attained and maintained thereafter. The second approach is more socially acceptable as it allows the fishery participants more time to adjust and the forward and backward linkages to develop possibly mitigating the adjustment costs to the changes.

4.1 Optimal sustainable fisheries

The social purpose of the fishing is to maximize the net value of production thus maximizing its contribution to GDP and general social welfare. The best fisheries management is the one that induces the fishing industry to produce the maximum sustainable net output. A fishery is regarded as sustainable when the revenue and biomass under consideration would converge to a positive equilibrium in the long run, if the effort were kept constant at the corresponding level. The socially optimal level of the fishery occurs when the fishing effort, profits and consequently the contribution of the fisheries to the GDP is maximized.

In this case, Kenya marine artisanal fishery is represented by sustainable fisheries curves (Figure 4) that are based on Gompertz-Fox surplus production model. The curves show the revenue, biomass and costs as a function of fishing effort. The lower part represents the biomass in a downward direction and describes what happens to a sustainable biomass as effort is increased. The upper part describes the revenue and costs of the fishery with changing effort level. Since effort, E is non-decreasing function of biomass, x (i.e. greater stock abundance results/ implies more intensive fishing) and of fish price, p, it implies that the boat owner employs the maximum effort if marginal revenues exceed costs and uses zero effort otherwise. The biomass is reduced as effort is increased until at effort level $E(t) > E_{MSY}$ and the stock becomes less than the maximum sustainable yield and becomes biologically overfished. At effort $E(t) = E_{\infty}$ (BE) all economic rent is completely dissipated and the resource becomes economically overexploited. The stock continue to gradually decline as $E(t) \rightarrow E_{MAX}$ but survives total collapse but at significantly low biomass level.

The revenue initially increases with increase in effort but at a decreasing rate as biomass is reduced up to a certain level when the sustainable revenues are maximized at MEY. When fishing effort is increased beyond this point the sustainable revenue declines up to a certain level of effort (BE) where costs and total revenue are the same and profits are zero. At this point, the most inefficient vessels exit the fishery but the marginal vessel (i.e. the least efficient still fishing) operates at break-even effort, while the most efficient operate profitably even at that level.

The socially optimal level of the fishery occurs at fishing effort level $E_{MEY} = 2445$ fishing boats approximately, and profits are $US\$3.804$ million. The effort that maximizes the profit is less than the E_{MSY}, which is 4625 boats yielding profits of $US\$2.087$ million. The optimal sustainable biomass $X_{MEY} = 15210$ tonnes, and is comparatively higher than $X_{MSY} = 9494$ tonnes, and correspondingly more biologically conservative. The fishery depicted a bionomic equilibrium (BE) point at which level of fishing effort, $E_{BE} = 5931$ boats and the fishing cost equals to revenue

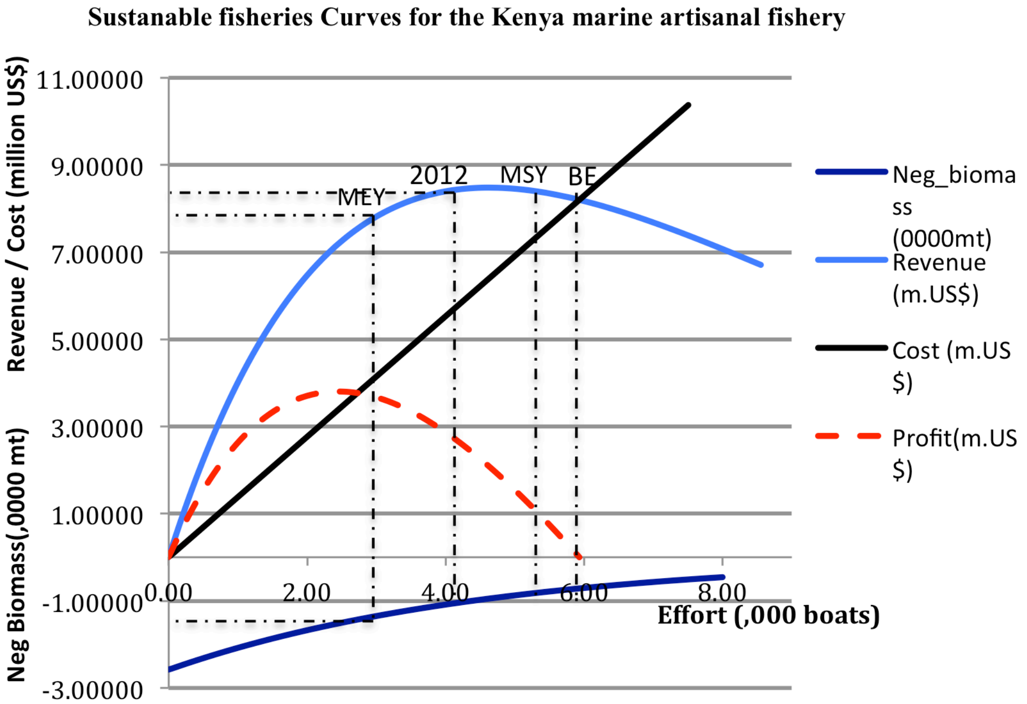


Figure 4. Static sustainable fisheries curves for the Kenya marine artisanal fishery defining its BE, MSY, MEY reference points and the current fishery status (2012) based on Gompertz-Fox surplus production model

The current effort is 1502 boats (61.4%) above the optimal (E_{MEY}) effort, and consequently the biomass and revenues are sub-optimal. On the basis of the static sustainable fisheries model, the current fishing efforts should be reduced from 3947 to 2445 boats (Figure 4).

Although the current (2012) effort is above the optimal level, it is lower than the effort at maximum sustainable yield (E_{MSY}) as well as, of course, the bionomic equilibrium by 678 and 1984 fishing boats respectively. The corresponding (2012) biomass and profits at 10,992tonnes and $US\$2.924$ million are correspondingly higher than those at E_{MSY} of 9,494 tonnes and $US\$2.087$ million respectively (table 16). Statistical comparisons at different reference points are as summarized in table 16.

Table 16. Static reference points BE, MSY and MEY and the 2012 fisheries status and corresponding statistical properties on biomass, effort, harvest and profits for Kenya marine artisanal fishery

Outputs	Statistics					Comment
	Current (2012)	BE	MSY	MEY	Difference (MEY vs MEY)	
Biomass (mt)	10,992	7,158	9,494	15,210	4,218	Less than MEY level
Effort (No. boats)	3,947	5,931	4,625	2,445	1,502	Above MEY level
Harvest(mt)	8,677	8,490	8,781	7,438	1,240	Less than the current level
Profit m.US$)	2.9239	0	2.0872	3.8037	0.88	Less than MEY level

4.2 Optimal dynamic equilibrium

In order to develop the “best” harvest policy that maximizes the present value of net benefits as discussed earlier, our infinite-horizon problems are whether a unique optimal (equilibrium) biomass, $x = x^*$ exists (and hence $e = e^*$). The fundamental Equation (6) or, equivalently Equation (7) was used to numerically find x^* (and hence e^*) that maximizes profit, π^* Once x^* is determined, its corresponding e^* and π^* are also known from Equations (18) and (19).

From the analysis (Appendix 11) there exists an optimal equilibrium biomass level $x = x^*$, which is a function of the discount rate and of the other biological and economic parameters of the maximization problem. The solution was identified with two levels of biomass $x(t) = x^*$ and their corresponding effort $e(t) = e^*$ that generated the highest net benefits $\pi(t) = \pi^*$. These are: (i) at $x =$ 15202 tonnes and corresponding $e = 2447$ boats at profits of $US\$3.8037$ million at $d = 0$, and (ii) at $x = 14915$ tonnes and effort of 2535 boats and profits of $US\$3.8001$ million, at $d = 0.05$.

The optimal effort at zero discounting was lower than at 0.05. However, the corresponding x^* and, π^* at $d = 0$ was higher than those at $d = 0.05$. The optimal equilibrium effort at $d = 0.05$ was higher than optimal effort $E_{MEY} = 2445$ boats, determined under static sustainable fisheries (table 15). However, the difference of two boats between the optimal equilibrium effort at $d = 0$ and that predicted by the sustainable fisheries model was considered insignificant.

Although maximization of sustainable economic yield, or rent are higher at $d = 0$, it is particularly an extreme proposal based on the supposition that the society is, and should be, willing to make arbitrary current sacrifices to benefit future generation. This is a "most conservative" management policy that may not be the realistic and acceptable. On the contrary, in an open access fishery, the rate of discounting is set at infinity and the value of the future revenues set to zero. This is the "least conservative" policy that leads to dissipation of economic rent. The optimal solution is between these extremes, and thus diminishing the optimality of the solution at $d = 0$.

Thus, $e^* = 2535$ boats was used as the optimal control effort and $x^* = 14915$ tonnes as the optimal equilibrium biomass for the time path present value maximization approaches.

4.3 Present Value Maximization Paths

With the biomass $x^* = 14915$ tonnes as our solution to the profit maximization problem, and while our initial biomass $x_0 \neq x^*$, and effort $e_0 \neq e^*$, our dynamic problem was which approach will be optimal from x_0 to x^* and corresponding e_0 to e^*. The maximization solution was to find the optimal path from the current $x = x(t) = 10992$ tonnes to $x^* = 14915$ tonnes and $e = e(t) = 3947$ boats to $e^* = 2535$ boats at $d = 0.05$.

The optimal harvest policy for a linear profit function is to utilize the harvest rate $y^*(t)$ that drives the biomass level $x = x(t)$ towards x^* as rapidly as possible (Clark, C.W, 2005). Denoting $y_{\max}$ as the maximum feasible harvest rate, the harvesting option are:

$$y^*(t) = \begin{cases} y_{\max} & \text{whenever } x > x^* \\ G(x^*) & \text{whenever } x = x^* \\ 0 & \text{whenever } x < x^* \end{cases}$$

Conrad, (2010) refers this approach path as *"most rapid approach path"* (MRAP). Since our $x_0 = x(t) < x^* = 14915$ tonnes at $d = 0.05$, the approach is to close the fishery ($y^* = 0$) until x has increased to x^*. Since harvest, y is a function of the fishing effort through the general harvest relation $y = q \cdot e \cdot x$, it is obviously possible to achieve the harvest objective by the use of the fishing effort as the control. The initial fishing effort $e = e(t) = 3947$ boats was reduced to $e = 0$ boats during the first control year using the MRAP herein referred as "dynamic adjustment path. The effort was incrementally adjusted upward in subsequent control years until optimal effort was attained on the fourth year.

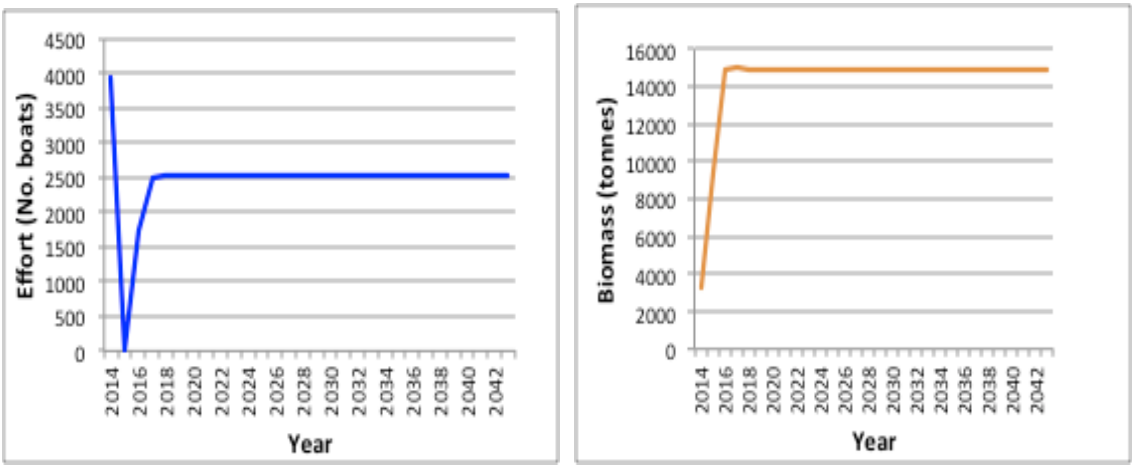
However, this simple control policy of closing down of a fishery completely or rapid removal of effort or harvest seems to be an extreme action due to its accompanying social-economic problems to a vulnerable community and the forward and backward linkage like fish processing, transport, ice-making and boats and gear making industries that may not be able to adjust quickly to such drastic change. An moderate approach path was used as an alternative path where excess fishing effort was reduced gradually and equally within a five-year period until the optimal effort was attained and maintained thereafter. The dynamic and moderate paths trajectories on actual effort, real biomass, harvest and profits were analyzed and PV compared on a finite horizon of 30 years.

4.3.1 Optimal Dynamic adjustment paths

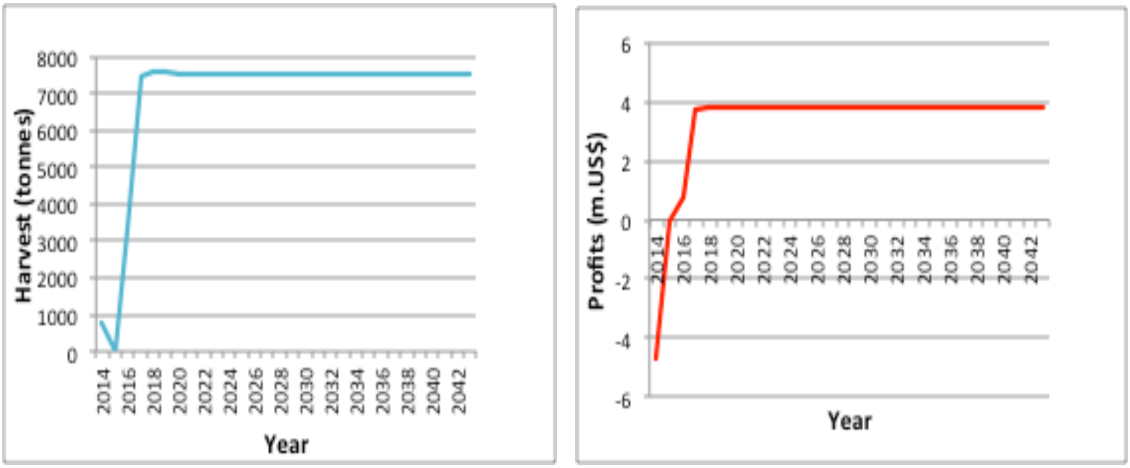
The analysis assumed the 2014 fishing effort to be the same as that of 2012, which was 3947 boats and started fishery control 2015. The initial biomass (x_0) was assumed to be 10,992 tonnes. The analysis indicates that current (2014) fishing effort should substantially be reduced by the most rapid approach. This will lead to rapid rebuilding of the fish stock biomass and generate substantial profits. If a 5% discount rate is assumed, the profits maximizing policy for the artisanal fishery was to set the fishing effort to 2535 boats. This was done in four steps within four control years. The first step the fishery was closed and the effort was reduced to zero and no fish harvest ($y^*(t_0) = 0$). Steps 2 to 4 involved increase of effort up to the optimal long run sustainable fishery. A total of 1750 boats were introduced in second year, 760 in third and 25 in the fourth.

Thus, the total effort during the first four control years was; 0, 1750, 2510 and 2535 boats in the first, second, third and fourth year respectively. The long run equilibrium biomass, harvest and profits are attained in the sixth year of management when the effort was set at optimal in the fourth year. The optimal fishing policy founded in the PV of profit maximization path is shown in Figure 6(i), (ii), (iii), and (iv), and detailed numerical outcomes in Appendix 12.

This policy resulted in an equilibrium rather than "pulse fishing", where the stock is fished heavily and then allowed to build again.



(i) Effort **(ii) Biomass**



(iii) Harvest **(iv) Profits**

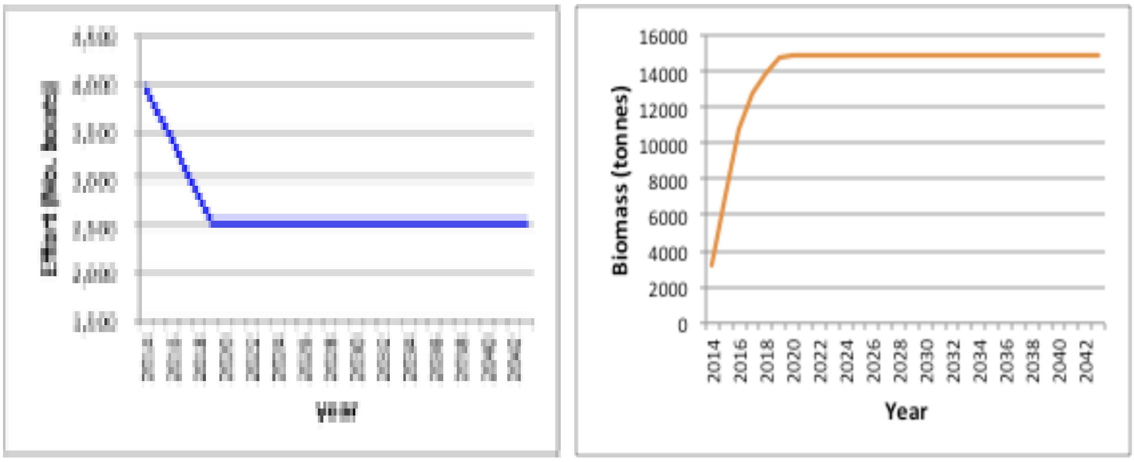
Figure 5. Showing (i) fishing effort (ii) biomass response, (iii) harvest status, and (iv) profits trajectories during the PV maximizing path for the Kenya marine artisanal fishery, at 5% rate of discounting.

During the second year of management, the harvests will be lower than optimal and some profits losses will occur in the first and second year due to fixed costs. Through this effort adjustment the fishery profits will be increased by 30% from US$2.923/year in 2012 to a sustainable US$ 3.80/year from the sixth year. The total present value (PV) discounted at 0.05 over a 30-year horizon was US$68.7million.

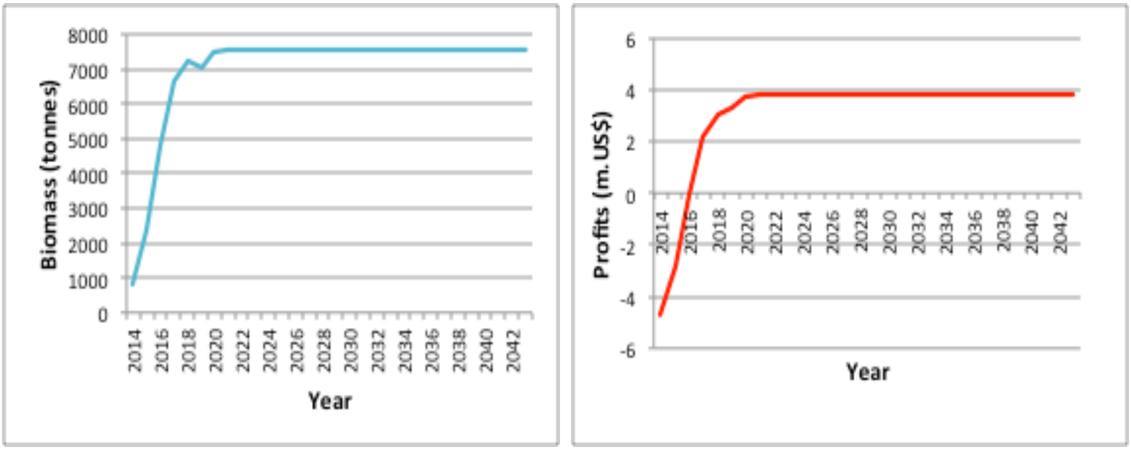
4.3.2 Moderate adjustment paths

A moderate dynamic path for the artisanal fishery is to reduce the fishing effort from the current (2014) level gradually and constantly down to the optimal long run equilibrium of the fishery. In this approach the current fishing effort of 3947 boats was reduced to 2535 boats. The excess effort of 1412 boats above the optimal was reduced in five steps, each covering one control year and targeting reduction of 282 boats in each year. The effort was reduced from the current 3947 to 3665 boats in the first year and to 3382, 3100, 2817 and finally the optimal 2535 in the second, third fourth and fifth year respectively. The objective of gradual reduction of the fishing effort towards the long run level was to rebuild the fish stock biomass from the assumed 1000 tonnes to the optimal long run profits maximizing biomass of 14917 tonnes, which also ensures the sustainability of the artisanal fishery. The outcome of this policy is illustrated in the moderate path shown in figure 7(i), (ii), (iii) and (iv), and detailed numerical outcomes are shown in Appendix 13.

The fish stock biomass increased gradually along the path toward the long run optimal equilibrium. Under this policy the harvest is also gradually reduced from 2012 of 8676 tonnes to 7563tonnes at long run equilibrium due the downward adjustment of fishing effort. The long run biomass, harvest and profits equilibrium was attained in the eighth year of fishery management. This fishery recovery policy can equally be expected to improve the economic benefits from the fishery. The profits will increase from the 2012 value of US$2.923 million/year to long-term sustainable benefits of US$ 3.80 million/year at equilibrium. The total PV in the finite horizon of 30 years is expected to be US$62.9 million.



(i) Effort **(ii) Biomass**



(iii) Harvest **(iv) Profits**

Figure 6. Showing (i) fishing effort trajectory under moderate adjustment path with (ii) biomass response, (iii) harvest status, and (iv) profits during the PV maximizing path for the Kenya marine artisanal fishery, at 5% rate of discounting.

The fish stock biomass increased gradually along the path toward the long run optimal equilibrium. Under this policy the harvest is also gradually reduced from 2012 of 8676 tonnes to 7563tonnes at long run equilibrium due the downward adjustment of fishing effort. The long run biomass, harvest and profits equilibrium was attained in the eighth year of fishery control. This fishery recovery policy can equally be expected to improve the economic benefits from the fishery. The profits will increase from the 2012 value of US$2.923 million/year to long-term sustainable benefits of US$ 3.80 million/year at equilibrium. The total PV in the finite horizon of 30 years is expected to be US$62.9 million.

The dynamic path took seven control years to drive the fishery’s biomass, harvest and profits to the long run optimal equilibrium when the effort was set at optimal in the fourth year, and nine years for the moderate when effort was gradually reduced to optimal within five years. Observation was made that dynamic adjustment path had a higher PV as compared to moderate at $d = 0.05$. It thus, implies dynamic path is more optimal than the moderate at the same rate of discounting. However, the moderate path seems more realistic and acceptable than the dynamic path.

Chapter 5. Discussion

5.1 Results overview and the optimum fishery policy

The artisanal fishery model detailed earlier predicts that harvest of the fishery at MSY equals the stock maximum growth, $Y_{MSY} = \max G(x)$. This implies that any larger harvest than Y_{MSY} rate would cause biological overexploitation ultimately leading to depletion of the fish stock. At biomass level, $X_{MSY} = 9494$ tonnes the productivity of the fishery is maximized. According to results (table 15 and appendix 10), exploitation of the fishery at the optimum effort level $E_{MSY} = 2535$ boats at 5% rate of discounting generated 82% more net benefits at a sustained stock biomass that was 57% greater than those at MSY level, and at an effort only 55% of the MSY. These net benefits and biomass at MEY were 30% and 36% respectively greater than those of the 2012 (current) fisheries, and was generated at an effort just 64% of the current. From an economic point of view, neither is harvesting at MSY effort, $E_{MSY} = 4625$ boats nor at the current effort level $E(t) = 3947$ boats imply efficiency to maximize net benefits. The two states are neither also the best conservation management policies. Maximum resource benefits and best conservation management policy were at the MEY effort level.

Going by the model prediction and the results of this study, the current fishing effort and stock biomass of the marine artisanal fishery, Kenya is at a sustainable level. This is contrary to the general perception it is overexploited. The decline in fish stock from its original level of abundance may give the thought that the resource is overexploited-while not. The fishing effort $E(t)$ was 15% lower than the E_{MSY}, biomass $X(t)$ was 16% higher than X_{MSY}, harvest, $Y(t)$ precariously 1.2% less than Y_{MSY}, and profits was 40% higher than π_{MSY}. However, from our last paragraph, our analysis showed that the current unmanaged artisanal fishery is economically inefficient. It employs too much effort, and being an open-access system, has the potential to overexploit the fish stocks and reduce the overall sustainable harvest, draining away potential economic benefits obtainable through the fishery. In 2012 the model predicted US$ 0.88 million of economic rents were from the fishery.

The fishery can generate considerable fisheries rents. This should not be mistaken that the fishery's management system is efficient. It should be understood that this is unmanaged competitive fishery in its early development phase. As the fishery matures, effort increase and stock decline, the fishery would become severely sub-optimal. As the fishery is still profitable and some existing vessels are making profits, motivation exists for the entry of new or improved vessel, resulting to an increased effort.

The fishery is likely to shift its status to the bionomic equilibrium (BE) at effort level $E = E_\infty = 5931$ boats where the total revenue, TR equals total cost TC and where profits are zero. The fishery status was 67% toward reaching this inefficient state. Both theory and the experience from numerous real fisheries have established that the open-access fishery practices ultimately lead the fishery to that state. It would be the least desirable state to the fishermen as they would only break-even their costs. Fishing effort greater than at BE level, ($E > E_\infty$) would lead some fishermen to lose money and be forced to withdraw from the fishery. Neither the fishermen nor the society at large would enjoy the benefits that could accrue if the fishery were under proper management.

If effort can be somehow be reduced, clearly higher economic rents can be generated from the fishery. This is particularly evident since the current fishing effort of 3947 boats exceeds the optimum MEY effort, $e^* = 2535$. A reduction of this effort would have a double effect of increasing revenues and decreasing fishing costs. In any case, the excess expenditure of effort characteristic of the open-access fishery results in economic inefficiency. The model shows that maximum sustainable benefits from of the fishery is achieved by reducing the current harvests to the optimal sustainable yield (OSY) level of 7438 tonnes, which is 14%, lower than the current by reducing the effort level to 2535 boats which was 36% lower than the current effort. As earlier mentioned the stock biomass and profits are enhanced by 36% and 30% respectively over the current. The higher fish stock biomass can greatly reduce the fish search and harvesting cost, while the profits, if properly used, go a long way towards permanently improving the economic and social situation of the fishing community.

To move from the current artisanal fishery exploitation level to the long run optimal takes time. Initially, in order to rebuild the stock biomass, harvest rates will have to be reduced. Dynamic adjustment paths, which maximize the present value of economic benefits over time, involve quite drastic reduction of effort and harvests during the first year of control. However, as demonstrated above, it is possible to define more moderate adjustment paths, which maintain a fairly high catch level every year while attaining the long run OSY within a reasonable time (eight years) and without much loss in the present value of economic benefits (8.6)%). Such paths may well be socially more acceptable and, therefore, feasible.

5.2 Fisheries Management system and policy implementation

It is important to recall that the calculation of optimum effort in number of boats was done based on an average catch of 16kg/boat/day for a possible maximum 193.84 fishing days in a year (i.e. 3.1tonnes/year/boat). Thus, optimum policy implementation objective was to ensure that the optimum MEY harvest, $Y_{MEY} = 7869$ tonnes, which generates maximum net benefits, was not exceeded.

5.2.1 Biological management system

The implementation of this policy will be done in an environment where other management instruments are in existence. For instance, there are established marine protected areas (MPA) like Kiunga marine park in the north, specifically for Lobsters' protection, Watamu Marine Park in Malindi and Kizite Marine park in the south under the management of Kenya Wildlife Services. Ungwana Bay fishing grounds, near Malindi, disproportionately populated by juvenile prawn during the April to August period is annually closed for shallow prawn trawling during this season to allow them to mature. Some fishing gears like ring nets were banned due in 2011 due to the alleged non-selectivity to targeted fish and their destructive nature to the environment during their operation in the reefs. Use of gill nets with mesh size less than 2.5 inches are prohibited to allow the fast-growing young fish to mature for recruitment into the fishery. These measures are a direct biological management system enforced through the Act of Parliament CAP 378 of the Fisheries Act, 1991.The objective is to increase stock growth, enhance biomass, and consequently, increase the fish yield. Though these measures are still relevant in the fishery's management, they seem neither effective in controlling fishing effort nor maximizing the economic benefits from the fishery. The optimum policy considers the existence of these measures and complements rather than contradicts them.

5.2.2 Economic fisheries management system

The implementation of the policy in controlling the number of fishing boats also intends to include the restriction on the Total Allowance Catch (TAC) that was calculated as optimal harvest. In essence the policy may end imposing control on economic inputs of the fishery. Controlling the number of boats would just be restricting one component of the effort. Fishermen are potentially capable adjusting and countering this measure through other components of the effort like changing to to bigger boats, increase the number of fishing days, use of improved fish finding capability, and increasing the ratio effective fishing time to total operating time by use of high speed strong engines to reach the fishing grounds. Application of these counter measures in the adjustment path essentially increases the effective effort and the fishing cost. When these measures are likely to increase the stock biomass, the adjustment costs will counter the optimal policy objective to maximize net present value of the economic benefits over time from the fishery.

5.2.3 Property right management system

In implementing this optimal policy, the number of boats will be used completely in a different form rather than effort management. Towards solving the open-access problem of ever increasing effort by competing fishers, it is important to give economic incentives to the fishermen by allocating a share of the TAC. Thus, the effort in number of boats initially was used as a management measure to reduce the harvest level to the optimal. Reduction of a single boat will be equated to reduction of 16kg. Accordingly, the reduction of the excess 1412 boats within the first five years of the moderate adjustment path will essentially reduce the current yearly harvest level by about 809 tonnes. For fairness and equity, each remaining boat will be allocated an yearly quota of 3.1 tonnes. At the long run fishery equilibrium it is expected that the optimal TAC of 7869 tonnes be allocated to "equivalent" 2535 boats. Ultimately, it is the fisherman who is to decide the most efficient effort to harvest his quota with.

By the requirement of the fisheries law in Kenya, all artisanal fishing boats operate under the local Community-based fisheries management arrangements called Beach Management Unit (BMU). There are about 130 such units along the Kenya coastline. Each unit is associated with a particular geographical area and a community. Each BMU should reduce its number of boats by about 36% to meet the total target. Priority should target boat owners with more than one fishing boat. To reduce the policy administration and management costs, the fishing share will be allocated to BMU who will distribute them as quotas to remaining boat owners. It will be the BMU's responsibility also to enforce the management rules and collect quota catch data. A proportion of the quota will be transferable to other fishermen to ensure full utilization of all the TAC and induce trade of quota among fishermen. The allocation will be made in five-year periods through tradable access permits by fisheries authorities to provide share security. The fisheries' agency will still need to monitor the BMU to see that they do not exceed their allocated shares. This approach will make the fishermen find it to their advantage to adjust the fishing effort to the socially optimal level.

5.3 Benefits from the policy implementation

We assume that the model we used to construct the moderate adjustment path is true. On successful implementation of the policy created through the model simulation, we will get social-economic benefits and resource sustainability. The impact of the optimum sustainable yield (OSY) and the corresponding moderate adjustment paths with maximizing the present value of profits of the marine artisanal fishery can be described as follows:

(i) Economic benefit

By reducing the fishing effort by about one third (36%) we will gain US$1.95 million annually. This policy is not only targeting improving the profits of the fishery to US$3.8 million but also create a long-run net present value of US$62.9 million. The excess profit will go a long way towards improving the fishing community social and economic welfare. The government stand to generate extra revenue by granting 2535 fishing access licenses as "Tradable Permits" which are expected to attract premium price in contrast to the current annual fee of US$1.4. A robust fishery is expected to encourage private companies to invest in fish processing and value addition enterprises. These will create employment opportunities to some of the boat owners and crews that will be laid off through the boats reduction process. Thus, economically there may be no net loss to the community and to the fishing industry.

(ii) Control of fishery overexploitation

A fishery is not sustainable if the total catch exceeds the harvest at MSY level. As earlier stated, the current (2012) catch was only 1.2% less the harvest at MSY. This implies that the fishery can enter into overexploitation phase with just a slight increase in effort. The implementation of OSY of this policy places the fish harvest safely at 10.4% lower than the MSY level, controlling, overfishing and making the fishery sustainable in the long run.

5.4 Limitation of the study

(i) The model built for this study used the aggregate catch and effort data. Fishing effort was considered as the main factor influencing the artisan fishery. Other determinants of fish catch such as environmental degradation of fishing grounds especially the coral reef and annual changes in weather were excluded. It is necessary to study other factors influencing the catch and later extend and refine this model by more reliable data.

(ii) The data used in the model can cause data error. The assumed data and parameters might reflect a false result creating concern for the reliability and accuracy of the data. For future study, the emphasis should be given to get the real data in a standard way.

(iii) The benefits and finding of the study are not static forever. As the artisanal fishery is conducted in fragile coral reefs’ environment, the biological and ecological conditions have the possibility of changing. In such eventualities, the outcome of the study will not be reliable, and this would be the uncertainty of the policy.

(iv) The fishing profits generated, and the fishing effort levels depend to a large extent on the price of fish and the cost of fishing, which were assumed to be constant over time in the study. Any change, increase or decrease in prices would substantially increase or reduce the value of the estimated profits. In the future, study that will produce accurate and variable fish prices and effort costs will be helpful.

Chapter 6: Conclusion and Recommendations

The general perception that the fishery is overexploited is incorrect. The fishery was still sustainable and making profits. The harvest, effort was lower and biomass higher than those at MSY level.

The artisanal fishery has the potential to accrue over 80% more net profits than its current status, if optimally managed. However, t risks in rapidly becoming overexploited and unsustainable if the current effort level is increased. The current (2012) harvest was precariously 1.2% less the MSY level. The current fishery status was sub-optimum.

The open–access fishing regime practiced in the fishery was the source of the fishery problems. The system motivates fishermen to expand the fishing capacity to be competitive, thus driving the effort to unsustainable level, causing depletion of the resources and making it unprofitable

A management system that gives economic incentive to the fishermen can drive the fishery to a socially optimum level that generates maximum sustainable net benefits for improvement of social and economic welfare of the fishing community.

The fishing effort should be reduced by 36% to 2,535 boats to harvest a TAC of 7,869 tonnes through individual quota (IQ) arrangements. This should involve the fishermen in decision-making and engage the fishery's stakeholders for it acceptance.

The boat owners and crews that are laid off the fishing should be given diversification of skills to make them more suitable for the non-fishing sector. The county government should work out plans on how best they can utilize the usable laid-off boats, especially in water transport of people and good, ecotourism and cleaning of beaches, which are under respective county's governments jurisdictions.

References

Arnasson, R.(2000). Economic Instruments to achieve Ecosystem Objectives in Fisheries Management. *ICES journal of Marine Science*.

Barber, R. T. and Chavez, F.P. (1983). Biological consequences of El Nino,Science, 222: 1203-1210.

Bene, C. (2003). When Fishery Rhymes with Poverty: A first Step Beyond the Old Paradigm on Poverty in Small-Scale Fisheries. *World Development, 31*(No. 6), 949-2003.

Birkett, L. (1978).Western Indian Ocean Fishery Resources Survey. Report on the cruises of R/V Professor Mesyatsev, December 1975 - June 1976/July 1977. Tech. Rep. Indian Ocean Programme., (21): 97 p.

Carrara, G. and R.S. Coppola. (1985). Results of the first year of implementation of the Kenyan catch assessment survey. RAF/79/065/WP/18/85/E: 85 p.

Charles, A. T. (2001). Sustainable Fishery Systems. *Fish and Aquatic Resources Series* (Series 5).

Clark, C.W. and Munro, G.R. (1975). Economies of fishing and modern capital theory: a simplified approach. *Journal of Environmental Economics and Management, Vol. 2*, 92 -106.

Clark, C.W. (1985a). *Bioeconomic Modelling and Fisheries Management*. p.46. New York: Willey Interscience.

Collin, C.W. (2005). *Mathematical Bioeconomics. Optimal Management of Renewable Resources*. Pure and Applied Mathematics. A Willey-Interscience Series of Texts, Monographs, and Tracts. Second Edition.

Coppola, R. (1982). *Aerial frame survey along the coast of Kenya.* artisanal sector, Kenya Marine and Fisheries Research Institute, Project UNDP/FAO, Mombasa, Kenya.

Doubleday, W. (1976). Environmental fluctuatios and fisheries management. *ICNAF Sel*(Pap. 1), 141-50.

FAO/IOP. (1979). Report of the Workshop on the fishery resources of the Western Indian Ocean South of the Equator. Mahe, Seychelles, 23 October - 4 November 1978. Dev. Rep. Indian Ocean Programme. (45): 102 p.

FAO. (1995). Reference points for fisheries management. (J. a. Caddy, Ed.) FAO Fisheries Technical Paper, 347.

FAO. (1999). Managing Fishing Capacity*:* Selected Papers on Underlying Concepts and Issues*.* Food and Agriculture Organization of the United Nations, FAO Fisheries Depart. Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. (2005). Small-Scale and artisanal fisheries. *Fisheries and Aquaculture topics*. (J. Johnson, Ed.).

Fisheries Department (FD). (1997). Annual Statistical Bulletin. Ministry of Agriculture and Rural Development.

FD. (2000). Annual Statistical Bulletin for 1998 to 2000. Ministry of Agriculture and Rural Development.

FD. (2001). Fisheries Annual Statistical Bulletin. Ministry of Agriculture and Rural Development.

FD. (2002). Fisheries Annual Statistical Bulletin. Ministry of Livestock and Fisheries Development.

FD. (2003). Fisheries Annual Statistical Bulletin. Ministry of Livestock and Fisheries Development.

FD. (2004). Report on the Marine Waters Frame Survey. Ministry of Livestock and Fisheries Development.

FD. (2004). Fisheries Annual Statistical Bulletin. Ministry of Livestock and Fisheries Development.

FD. (2005). Fisheries Annual Statistical Bulletin. Ministry of Livestock and Fisheries Development.

FD. (2006). Marine Waters Frame Survey 2006 Report. Ministry of Livestock and Fisheries Development.

FD. (2006). Fisheries Annual Statistical Bulletin. Ministry of Livestock and Fisheries Development.

FD. (2007). Fisheries Annual Statistical Bulletin. Ministry of Fisheries Development.

FD. (2008). Marine Waters Fisheries Frame Survey 2008 Report. Ministry of Fisheries Development.

FD. (2008). Fisheries Annual Statistical Bulletin. Ministry of Fisheries Development.

FD. (2009). Fisheries Annual Statistical Bulletin. Ministry of Fisheries Development.

FD. (2010). Fisheries Annual Statistical Bulletin. Ministry of Fisheries Development.

FD. (2011). Fisheries Annual Statistical Bulletin. Ministry of Fisheries Development

FD. (2012). Marine Waters Fisheries Frame Survey 2012 Report. Ministry of Fisheries Development.

Fox, W.W. (1970). An exponential surplus–yield model for optimizing exploited fish populations. Transactions of the American Fisheries Society 99 (1) : 80-88.

Garcia, S. and L. Le Reste. (1981). Life Cycles Dynamics, Exploitation and Management of Coastal Penaeid Shrimp Stocks. *FAO Fishery Technical Paper 203* FAO, Rome.

Gordon, H. (1954). The Economic Theory of a Common Property Resources: The Fishery. *The Journal of Political Economy, 62*(No. 2).

Gulland, J. A. (1969). Manual Of Methods For Stock Assessment, Part 1. Fish Population Analysis- Fao Manuals in Fisheries Scvience, No. 4.

Hardin, G. (1968). The Tragedy of the Commons. *Science, 162*(No. 3859), 1243-1248.

Hoorweg, J. W. (2009). *Artisanal Fishers on the Kenya Coast.*

Iversen, S.A., and Myklevoll, S. (1984). *The Proceedings of the Norad-Kenya Seminar to Review the Marine Fish Stocks and Fisheries in Kenya.* Kenya Marine and Fisheries Marine Institute. Bergen, Norway: Agency of international Development Institute of Marine Research.

Larkin, P. A. (1977, January). An Epitaph for the Concept of Maximum Sustainable Yield. *Transactions of the American Fisheries Society, 106* (Number 1).

Mangi, S. C. and C. M. Roberts. (2007). Factors influencing fish catch levels on Kenya's coral reefs. Fisheries Management and Ecology 14:245-253.

McClanahan, T.R. (1994). Kenya coral reef lagoon fish: effects of fishing, substrate complexity, and sea urchins. The Wildlife Conservation Society. Coral Reef Conservation Project. Springer-Verlag.

McClanahan, T.R. (2013, April 22). Helping Coral Survive a Changing Climate. Wildlife Conservation Society. *Kenya's Waters*. Retrieved May20, 2014, from http://www.wcs.org/where-we-work/oceans/west-indian-ocean/kenya.aspx

Ministry of Planning and National Development (MoPND). (2006). *Kenya Integrated Household Budget Survey(Kihbs).* Basic Report.

Ndurya, M. (2010, April 12). Fishermen divided over adoption of ring net. *Daily Nation, Kenya*.

Ochiewo, J. (2008). Socio-economic aspects of the Kenyan Marine Fisheries. *Magazine of Department of Fisheries of Kenya*.

Pacific Southwest Research Station (PSW). (1995). Ecology and Conservation of Marbled Murrelet. United States Department of Agriculture, Forest Service. Albany, California: Pacific Southwest Research Station.

Roughgaden, J., andf Smith, F., (1996). Why fisheries collapse and what to do about it. *Natl. Acad. Sci. USA, 93*(Ecology), 5078-5083.

Samoilys, M.A., Maina G.W and Osuka K. (2011). Artisanal fishing gears of Kenyan Coast. Mombasa: CORDIO/USAID.

Seijo J.C., Defeo, O., and Salas, S. (1998). Fisheries Bioeconomics. Theory, Modelling and Management. Rome: FAO;1998. Fisheries Technical Paper 368 (108 pp.)

Sethi, G. C. (2003). Fisheries Management Under Multiple Uncertainty.

Sparre, P. and S.C. Venema. (1992). Introduction to Tropical Fish Stock Assessment I, *FAO Fisheries Technical Paper 306.1, Rev.1*. FAO, Rome.

Stakstad, E. (2006). Global Loss of Biodiversity Harming Ocean Bounty. News of the Week, 314(Science), 745.

State Department of Fisheries (SDoF). (2012). Fisheries Annual Statistical Bulletin. Ministry of Agriculture, Livestock and Fisheries.

The World Bank and FAO. (2009). The sunken Billion. The Economic Justification for Fisheries Reform.

The East African Wild Life Society. (2014). Ringnet fishery: means of livelihood or scourge of the sea. Retrieved January 2014, from THE EAST AFRICAN WILD LIFE SOCIETY: *wildlife.org/aboutus/129-ringnet-fishery-means-livelihood-or-scourge-of-the-sea*

Trott, S. (2009). Sustainable Fisheries Programme, Watamu. *Watamu Marine Association*.

Wallace, D. (1975). Optimal sustanable yield as a concept in fisheries management. *American Fisheries Society*(9), 5-8.

Walters, C. J. (1975). Optimal harvest Strategies for Salmon in Relation to Environmental Variability and Uncertain Production Parameters. *Journal of the Fisheries Research Board of Canada, 32*, 1777-1784.

Walters, C. J. (1976). Adaptive control of fishing systems. *Journal of Fisheries REsources Board, Canada, 33*, 145-159.

Wood, S. Sebastian, K and Scherr, S. J. (2000). Pilot Analysis of Global Ecosystems. World Resources Institute, Agroecosystems. Washingto, DC: International Food Policy Research Institute and World Resources Institute.

World Bank. (2013). World Bank Indicators-Kenya-Transportation. *http://www.tradingeconomics.com/kenya/pump-price-for-gasoline-us-dollar-per-liter-wb-data.html.* Download 3 November 2013.

VNIRO. (1978). Western Indian Ocean Fisheries Resources Survey. FAO/UNDP/USSR-Cooperative Project. Dev. Rep. Indian Ocean Programme., (46): 130 p.

Appendices

Appendix 1. Comparison of the fish catches of 1984 and those from 2008 – 2012 giving the mean, minimum, maximum and Standard Deviation (SD) of the four re-organized administrative areas along the Kenyan coast up to depths of 200m.

Old Adm. Area (1984)	Fish Catch (1984)	Districts after 1984	Catch Weights by District (tonnes)					Mean	Min	Max	SD
			2008	2009	2010	2011	2012				
Lamu	2,868	Lamu	2,195	2092	2,271	2,396	2,279	2681	2,232	3,185	372
		Tana River	144	140	358	789	743				
Malindi	1,854	Malindi	1,509	1134	1,679	-	-	2,216	1,747	2,408	247
		Kilifi	899	613	511	2,331	2,403				
Mombasa	2,141	Mombasa	927	1041	1,135	1,116	1066	1,057	927	1,135	73
Kwale	2,997	Kwale	3,082	2907	2,452	2,314	2,373	2626	2,314	3,082	309
Total	9,860		8,756	7927	8,406	8,946	8,865	8,580	7,927	8,946	375

Source: (Carrara, G. and R.S. Coppola. 1985; FD. 2008; 2009; 2010; 2011; 2012)

Appendix 2. Types of gears and respective quantities deployed for the harvesting of marine artisanal fish of Kenya as established by Fisheries Frame survey of 2004, 2006, 2008 and 2012.

	2004		2006		2008		2012		
Gear type	Total	%	Total	%	Total	%	Total	%	Average
Gill net	7374	21.67	5916	19.15	3956	15.59	4168	11.19	16.9
Long line	10908	32.06	8224	26.63	9009	35.51	16476	44.24	34.61
Beach seine	274	0.81	560	1.81	139	0.55	217	0.58	0.94
Prawn seine	226	0.66	264	0.85	545	2.15	730	1.96	1.41
Reef seine	158	0.46	146	0.47	146	0.58	63	0.17	0.42
Cast net	520	1.53	812	2.63	499	1.97	408	1.1	1.8
Hand line	5682	16.7	6540	21.17	4132	16.29	4686	12.58	16.69
Monofilament	902	2.65	1050	3.4	1472	5.8	3239	8.7	5.14
Trawl nets	21	0.06	20	0.06	28	0.11	3	0.01	0.06
Scoop net	562	1.65	764	2.47	596	2.35	652	1.75	2.06
Ring net	1	0	11	0.04	15	0.06	22	0.06	0.04
Trammel net	28	0.08	23	0.07	35	0.14	48	0.13	0.11
Trolling line	608	1.79	708	2.29	625	2.46	741	1.99	2.13
Spear gun	447	1.31	624	2.02	1007	3.97	1349	3.62	2.73
Trap/basket	6318	18.57	5224	16.91	3169	12.49	4438	11.92	14.97
TOTAL	34029		30886		25373		37240		

Source: (FD. 2004; 2006; 2008; 2012)

Appendix 3. Distribution of boats and fishermen in various fishing grounds according to Marine Frame Surveys of 2004, 2006, 2008 and 2012.

Boundary/Administrative changes			Marine Fisheries Frame Surveys							
			2004		2006		2008		2012	
District in 1984	Between 1984-2010	Counties from 2010	No. Boats	No. fishers	No. Boats	No. fishers	No. Boats	No. fishers	No. Boats	No. fishers
Lamu	Lamu	Lamu	395	2,134	347	1,978	429	2,255	756	3,064
	Tana River	Tana River	49	247	56	475	80	588	314	643
Malindi	Malindi	Kilifi	447	1,778	434	2,022	515	2,669	699	2,830
	Kilifi		253	1,104	350	1,344	380	1,912	583	1883
Mombasa	Mombasa	Mombasa	292	957	455	1,349	434	1,390	542	1,449
Kwale	Kwale	Kwale	797	2,797	726	3,086	849	3,263	1,053	3,837
		TOTAL	2,233	9,017	2,368	10,254	2,687	12,077	3,945	13,706

Appendix 4. Fish species of commercial importance that contribute at least 2% of the total weight. Mean contribution was calculated from 2008 – 2012 fish catch data in the marine artisanal fisheries, Kenya.

Category	Type of fish	Mean (tonnes)	Maxi. (tonnes)	Min. (tonnes)	% contribution to annual production			SD
					Mean	Maxi	Min	
Demersal								
1	Rabbit fish	562	791	412	6.9	8.8	5.9	18.9
2	Scavenger	540	683	431	6.6	7.6	6.2	13.2
3	Parrot fish	284	432	193	4.6	6	3	15.3
4	Snapper	375	538	217	3.5	4.8	2.8	10.8
	Sub-total				21.6	27.2	17.9	
Pelagic								
5	Barracuda	283	327	246	3.5	3.7	3.5	4.5
6	Little Mackerels	273	419	145	3.3	4.7	2.1	12.5
7	Bonitos/ tuna	245	320	180	3	3.6	2.6	7.8
8	Mullets	243	292	201	3	3.3	2.9	5.9
9	Cavalla jacks	210	283	157	2.6	3.2	2.3	5.9
10	Sharks & Rays	246	373	165	3	4.2	2.4	10
11	Sardines	186	224	130	2.3	2.5	1.9	4.4
	Sub-total				20.7	25.2	17.7	
Crustacean								
12	Prawn	259	408	153	3.2	4.6	2.2	11.1
13	Crabs	160	235	110	2	2.6	1.6	6.1
	Sub-total				5.2	7.2	3.8	
Mollusc								
14	Octopus	311	419	187	3.8	4.7	2.7	12.5
15	Squids	156	191	134	1.9	2.1	1.9	2.9
	Sub-total				5.7	6.8	4.6	
	TOTAL	4,334	5,935	3,061				
TOTAL		8,187	8,947	6,959	53.2	66.4	44	

Appendix 5. Data entry sheet for catch and effort survey detailing on the type and scope of the field data collection.

<table>
<tr><td colspan="5">Catch &Effort Assessment Survey on Marine Artisanal Fishery, Kenya, in June -Sept 2013</td></tr>
<tr><td colspan="5">Form No……………………………….</td></tr>
<tr><td colspan="4">Name of Data Collector</td><td>Phone
No………………………..</td></tr>
<tr><td colspan="2">County/District:</td><td colspan="2">Landing site:</td><td>Date: / /</td></tr>
<tr><td colspan="2">Boat Type:</td><td colspan="2">Boat length:</td><td>Propulsion mode:</td></tr>
<tr><td colspan="2">Area fished:</td><td colspan="2">No of fishers / Crew:</td><td>No of gears:</td></tr>
<tr><td colspan="2" rowspan="2">Main Gear Type Code:</td><td colspan="2">Mesh / hook size</td><td rowspan="2">Time Out:</td></tr>
<tr><td colspan="2">Small: Large:</td></tr>
<tr><td colspan="2" rowspan="2">Total weight of catch (kg):</td><td colspan="2">Value of catch:</td><td>Time In:</td></tr>
<tr><td colspan="3">No of days fished in last 7 days:</td></tr>
<tr><td>1</td><td>Family / Species</td><td>Total No</td><td>TW (kg)</td><td>Price/kg</td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td></td><td></td><td></td><td></td></tr>
<tr><td>7</td><td></td><td></td><td></td><td></td></tr>
<tr><td>10</td><td></td><td></td><td></td><td></td></tr>
<tr><td>13</td><td></td><td></td><td></td><td></td></tr>
<tr><td>14</td><td></td><td></td><td></td><td></td></tr>
<tr><td>15</td><td></td><td></td><td></td><td></td></tr>
<tr><td>16</td><td></td><td></td><td></td><td></td></tr>
<tr><td>17</td><td></td><td></td><td></td><td></td></tr>
<tr><td>18</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="4"></td></tr>
</table>

Appendix 6. Time series aggregate catch and effort data used in biological parameter estimation

Year	Catch (tonnes)	No. boats
1977	4046	3585
1978	4634	3585
1979	4070	3585
1980	5336	3585
1981	5967	3585
1982	7116	3585
1983	5000	3585
1984	10688	1828
1990	9972	1828
1993	4336	1900
1996	6296	2338
1997	6106	2400
1998	6332	2440
1999	5271	2440
2000	4763	1231
2001	6451	1881
2002	6860	1813
2003	6968	2233
2004	7805	2233
2005	6823	2368
2006	6959	2368
2007	7467	2368
2008	8736	2687
2009	7926	2687
2010	8406	2687
2011	8947	2687
2012	8865	3947

Source: SDOF, Kenya

Appendix 7. Average ex-vessel fish price in Kenya shilling per kilogram for the marine artisanal fishery, Kenya observed in June to September 2013.

	Scientific name	No. fish	Wt. (kg)	% to total wt.	Price (Ksh/ kg)	Revenue (Ksh)	% to total Rev.
1	*Hemiramphus spp*	5017	1203.3	25.1	85	102,281	17.784
2	*Panulirus spp*	830	113.5	2.4	830	94,164	16.373
3	*Lutjanus bohar*	830	113.5	2.4	680	77,146	13.414
4	*Leptoscarus vaigiensis*	5492	660.5	13.8	70	46,234	8.039
5	*Siganus spp*	3665	482.6	10.1	80	38,606	6.713
6	*Scylla serrata*	187	128.1	2.7	280	35,868	6.237
7	*Caranx melampygus*	198	258.5	5.4	120	31,020	5.394
8	*Sphyraena jello*	182	234.5	4.9	95	22,278	3.874
9	*Mugil cephalus*	602	294.2	6.1	70	20,594	3.581
10	*Lethrinus spp*	1391	217.5	4.5	80	17,400	3.025
11	*Platax spp*	1202	187.9	3.9	80	15,034	2.614
12	*Plicofollis dussumieri*	304	179.5	3.7	80	14,360	2.497
13	*Pomacanthus imperator*	193	120.5	2.5	80	9,636	1.676
14	*Plectorhynchus spp*	418	101.5	2.1	89	9,034	1.571
15	*Istiophorus platypterus*	438	98.9	2.1	80	7,910	1.375
16	*Gerres oyena*	356	98.2	2.0	78	7,660	1.332
17	*Cheilio inermis*	675	97.5	2.0	70	6,822	1.186
18	*Naso brevirostris*	65	53.0	1.1	80	4,240	0.737
19	*Epinephelus spp*	31	22.7	0.3	100	2,265	0.394
20	*Dascyllus aruanus*	32	9.0	6.0	242	2,178	0.379
21	*Acanthurus leucosternon*	72	22.0	0.5	80	1,760	0.306
22	*Abudefduf sporoides*	51	15.0	0.3	110	1,650	0.287
23	*Plotosus lineatus*	3	15.0	0.3	108	1,613	0.280
24	*Monodactylus argenteus*	22	15.0	0.3	80	1,200	0.209
25	*Bothus patherinus*	36	14.5	0.3	80	1,160	0.202
26	*Tylosurus crocodilus crocodilus*	26	11.5	0.2	75	863	0.150
27	*Kyphosus cinerascens*	12	6.0	0.1	120	720	0.125
28	*Pomadasys maculatum*	12	8.0	0.2	80	640	0.111
29	*Carcharhinus melanopterus*	5	5.0	0.1	80	400	0.070
30	*Leiognathus equula*	49	4.5	0.1	75	338	0.059
31	*Mulloides vanicolensis*	6	0.3	0.0	75	23	0.004
32	*Chano chanos*	6	0.3	0.0	75	19	0.003
	Total	22408	4792			575,112	

Appendix 8. Annual fuel cost calculated on an average fuel consumption/boat/year of 15litres/ boat fishing trip and at US$ 0.94/litre from 1996-2012.

Year	Unit fuel consumption/yr (litres)	Total No. boats	No. Motorized boats	Fuel cost/litre (US$)	Total Fuel cost-motorized (US$)	Av. Fuel cost/boat(All boats) (US$)
1996	2907.6	2,338	123	0.9	335,785	144
1997	2907.6	2,400	124	0.9	340,087	142
1998	2907.6	2,440	126	0.9	344,389	141
1999	2907.6	2,440	127	0.9	348,691	143
2000	2907.6	1,231	129	0.9	352,992	287
2001	2907.6	1,881	130	0.9	357,294	190
2002	2907.6	1,813	132	0.9	361,596	199
2003	2907.6	2,233	134	0.9	365,898	164
2004	2907.6	2,233	135	0.9	369,898	166
2005	2907.6	2,368	183	0.9	501,417	212
2006	2907.6	2,368	231	0.9	632,937	267
2007	2907.6	2,368	275	0.9	753,496	318
2008	2907.6	2,687	319	0.9	874,055	325
2009	2907.6	2,687	332	0.9	908,990	338
2010	2907.6	2,687	345	0.9	943,925	351
2011	2907.6	2,687	357	0.9	978,860	364
2012	2907.6	3,090	370	0.9	1,013,795	328
					Average	240

Appendix 9. Different boat types, specifications and costs for marine artisanal fishery Kenya estimated in June –September 2013.

Boat type	Length	Material	Propulsion	Centre pole (for sail)	Steering	Rudder fixture	Crew	Price (Ksh)
Mashua	10m	Plank	Sail	Permanent	Rudder with stick	Removable	4 to 6	350,000
Dau	5 m	Plank	Sail	Removable	Rudder with stick	Permanent	2 to 3	127,096
Foot Fisher	5 - 6 m	Dug-out	Sail	Permanent	Rudder with stick	Removable	4	203,354
Hori	3 m	Plank	Sail	Removable	Rudder with shoulder rope	Removable	2 to 3	66,090
Mtumbwi	3 m	Dug-Out	Paddles/Pole (few sail)	No	Paddles/pole	N/A	1 to 2	35,587

Boat description: Hoporweg. et al. (2009).

Price benchmarking: Obura. et al (2002.)

Appendix 10. Time series aggregate catch and effort data, as well as calculated CPUE and ln(CPUE) used in biological parameter estimation.

Year	Catch	Boats	CPUE	lnCPUE
1977	4046	3585	1.13	0.12
1978	4634	3585	1.29	0.26
1979	4070	3585	1.14	0.13
1980	5336	3585	1.49	0.4
1981	5967	3585	1.66	0.51
1982	7116	3585	1.98	0.69
1983	5000	3585	1.39	0.33
1984	10688	1828	5.85	1.77
1990	9972	1828	5.46	1.7
1993	4336	1900	2.28	0.83
1996	6296	2338	2.69	0.99
1997	6106	2400	2.54	0.93
1998	6332	2440	2.6	0.95
1999	5271	2440	2.16	0.77
2000	4763	1231	3.87	1.35
2001	6451	1881	3.43	1.23
2002	6860	1813	3.78	1.33
2003	6968	2233	3.12	1.14
2004	7805	2233	3.5	1.25
2005	6823	2368	2.88	1.06
2006	6959	2368	2.94	1.08
2007	7467	2368	3.15	1.15
2008	8736	2687	3.25	1.18
2009	7926	2687	2.95	1.08
2010	8406	2687	3.13	1.14
2011	8947	2687	3.33	1.2
2012	8865	3947	2.25	0.81

Appendix 11. Optimal Equilibrium matrix calculating the optimal effort, E^* and the corresponding optimal biomass, X^* and profits, π^* for the Kenya Marine artisanal fishery.

x	Gx	e	Ce	Yx	p*Ye-Ce	MSE	rrr	roi 1	Difference	Profit (mUS$)
1	8.47095	46979.46	1382.854	9.395893	-1382.661	-9.39721	-0.92625	0.05	-0.97625	-64.9567
1277	1.85535	13901.46	1382.854	2.780292	-1136.09	-3.38419	-1.52883	0.05	-1.57883	-15.7933
2554	1.21459	10697.67	1382.854	2.139535	-889.518	-3.32614	-2.11155	0.05	-2.16155	-9.5158
3830	0.83968	8823.12	1382.854	1.764625	-642.947	-3.79537	-2.95568	0.05	-3.00568	-5.6728
5106	0.57366	7492.98	1382.854	1.498597	-396.375	-5.22823	-4.65457	0.05	-4.70457	-2.97
6382	0.3673	6461.19	1382.854	1.292238	-149.804	-11.92879	-11.5615	0.05	-11.6115	-0.9679
7659	0.19869	5618.13	1382.854	1.123626	96.768	16.05711	16.2558	0.05	16.2058	0.5437
8935	0.05612	4905.32	1382.854	0.981063	343.339	3.95139	4.00751	0.05	3.95751	1.6842
10211	-0.06737	4287.84	1382.854	0.857568	589.911	2.01029	1.94292	0.05	1.89292	2.5294
11487	-0.1763	3743.18	1382.854	0.748635	836.482	1.23763	1.06132	0.05	1.01132	3.1311
12764	-0.27375	3255.96	1382.854	0.651191	1083.054	0.83145	0.5577	0.05	0.5077	3.5264
14876	**-0.41542**	**2547.58**	**1382.854**	**0.509515**	**1491.227**	**0.47249**	**0.05706**	**0.05**	**0.00706**	**3.799**
15164	**-0.43317**	**2458.87**	**1382.854**	**0.491774**	**1546.888**	**0.43963**	**0.00646**	**0.05**	**-0.04354**	**3.8036**
16441	-0.50791	2085.16	1382.854	0.417032	1793.46	0.32155	-0.18635	0.05	-0.23635	3.7397
17717	-0.57706	1739.41	1382.854	0.347881	2040.031	0.23581	-0.34124	0.05	-0.39124	3.5484
18993	-0.6414	1417.71	1382.854	0.283543	2286.603	0.17148	-0.46992	0.05	-0.51992	3.2417
20269	-0.70155	1116.95	1382.854	0.22339	2533.174	0.12195	-0.5796	0.05	-0.6296	2.8294
21546	-0.75803	834.56	1382.854	0.166911	2779.746	0.08303	-0.67499	0.05	-0.72499	2.3199
22822	-0.81126	568.42	1382.854	0.113684	3026.317	0.05195	-0.75931	0.05	-0.80931	1.7202
25526	-0.91483	50.54	1382.854	0.010108	3548.769	0.00394	-0.91089	0.05	-0.96089	0.1794

Appendix 12. Detailed outcomes using dynamic adjustment path for the PV profits maximization for the Kenya marine artisanal fishery in a finite horizon of 30 years at 0.05 discounting rate.

sn	Year	Biomass (tonnes)	Growth (tonnes)	Actual Fishing effort (boats)	Actual Harvest (tonnes)	Real Biomass (tonnes)	Revenues (m.US$)	Costs (m.US$)	Profits (m.US$)	PV of profits (m.US$)
1	2014	1000	3006.63	3947	789.4	3217.23	0.76	5.46	-4.7	-4.7
2	2015	3217.23	6195.82	0	0	9413.05	0	0	0	0
3	2016	9413.05	8780.76	1750	3294.57	14899.24	3.18	2.42	0.76	0.69
4	2017	14899.24	7570.06	2510	7479.42	14989.89	7.23	3.47	3.75	3.24
5	2018	14989.89	7532.02	2535	7599.87	14922.04	7.34	3.51	3.84	3.16
6	2019	14922.04	7560.55	2535	7565.47	14917.11	7.31	3.51	3.8	2.98
7	2020	14917.11	7562.61	2535	7562.97	14916.74	7.31	3.51	3.8	2.84
8	2021	14916.74	7562.76	2535	7562.79	14916.71	7.31	3.51	3.8	2.7
9	2022	14916.71	7562.77	2535	7562.77	14916.71	7.31	3.51	3.8	2.57
10	2023	14916.71	7562.77	2535	7562.77	14916.71	7.31	3.51	3.8	2.45
11	2024	14916.71	7562.77	2535	7562.77	14916.71	7.31	3.51	3.8	2.33
12	2025	14916.71	7562.77	2535	7562.77	14916.71	7.31	3.51	3.8	2.22
27	2040	14916.71	7562.77	2535	7562.77	14916.71	7.31	3.51	3.8	1.07
28	2041	14916.71	7562.77	2535	7562.77	14916.71	7.31	3.51	3.8	1.02
30	2043	14916.71	7562.77	2535	7562.77	14916.71	7.31	3.51	3.8	0.92
									PV=	51.2
									PV after that=	17.6
									Total PV=	**68.7**

Appendix 13: Detailed outcomes using moderate adjustment path for the PV profits maximization for the Kenya marine artisanal fishery in a finite horizon of 30 years at 0.05 discounting rate.

sn	Year	Biomass (tonnes)	Growth (tonnes)	Actual Fishing effort (boats)	Actual harvest (tonnes)	Real Biomass (tonnes)	Revenues (m.US$)	Costs (m.US$)	Profits (m.US$)	PV of profits (m.US$)
1	2014	1000	3006.63	3,947	789	3217.23	0.76	5.46	-4.7	-4.7
2	2015	3217.23	6195.82	3,665	2358	7055.08	2.28	5.07	-2.79	-2.66
3	2016	7055.08	8462.81	3,382	4772	10745.55	4.61	4.68	-0.07	-0.06
4	2017	10745.55	8707.89	3,100	6662	12791.63	6.44	4.29	2.15	1.86
5	2018	12791.63	8303.75	2,817	7208	13887.55	6.96	3.9	3.07	2.52
6	2019	13887.55	7959.28	2,535	7041	14805.84	6.8	3.51	3.3	2.58
7	2020	14805.84	7608.73	2,535	7507	14908.01	7.25	3.51	3.75	2.8
8	2021	14908.01	7566.41	2,535	7558	14916.05	7.3	3.51	3.8	2.7
9	2022	14916.05	7563.05	2,535	7562	14916.66	7.31	3.51	3.8	2.57
10	2023	14916.66	7562.79	2,535	7563	14916.71	7.31	3.51	3.8	2.45
11	2024	14916.71	7562.77	2,535	7563	14916.71	7.31	3.51	3.8	2.33
12	2025	14916.71	7562.77	2,535	7563	14916.71	7.31	3.51	3.8	2.22
27	2040	14916.71	7562.77	2,535	7563	14916.71	7.31	3.51	3.8	1.07
28	2041	14916.71	7562.77	2,535	7563	14916.71	7.31	3.51	3.8	1.02
29	2042	14916.71	7562.77	2,535	7563	14916.71	7.31	3.51	3.8	0.97
30	2043	14916.71	7562.77	2,535	7563	14916.71	7.31	3.51	3.8	0.92
									PV=	45.29
									PVafter that=	17.59
									Total PV=	**62.87**