The Impact of Water Hyacinth (*Eichhornia Crassipes*) on the Productivity, Profitability and Species Composition of the Lake Victoria fishery, Kenya

by

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DECLARATION BY THE STUDENT

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This thesis is dedicated to my entire family, including my wife Flora, and the children; Arnold, Linda, Loy and Lameck for their continued support and encouragement during my study.

ACRONYMS AND ABBREVIATIONS

WH	Water Hyacinth
LVEMP	Lake Victoria Environmental Management Project
U.S.	United States
KARI	Kenya Agricultural Research Institute
KMFRI	Kenya Marine and Fisheries Research Institute
R & D	Research and Development
ISNAR	International Service for National Agricultural Research
GOK	Government of Kenya
PFA	Production Function Analysis
USDA	United States Department of Agriculture
UK	United Kingdom
L	Lake
GDP	Gross Domestic Product
EU	European Union
Km	Kilometre
Kg	Kilogram
Unpubl.	Unpublished
n.d.	Not dated
GIS	Geographic Information System
Ha	Hectare
BOD	Biological Oxygen Demand
$	US dollar
CBA	Cost Benefit Analysis
M	Metre
Mt	Mountain
C	Centigrade
O.	*Oreochromis*
MSY	Maximum Sustainable Yield
VAR	Vector Auto Regression
ECM	Error Correction Model

R.	*Rastrineobola.*
CPUE	Catch Per Unit Effort
CBS	Central Bureau of Statistics
UNEP	United Nation Environmental Programme
CPI	Consumer Price Index
FCA	Fish Catch Assessment
DF	Dickey and Fuller
ADF	Augmented Dickey and Fuller
PP	Phillips and Perron
Mm	Milimetre
WTP	Willingness To Pay
IRF	Impulse Response Function
spp	Species
%	Percentage
Ksh	Kenya Shilling
Ln	Natural Logarithm
NS	Not Significant
WHI	Water hyacinth Intensity
P	Probability
Std	Standard deviation
R^2	Coefficient of determination
T	Student’s t-value
d.v.	Dummy Variable
DW	Durbin Watson

ABSTRACT

One of the sectors gravely hampered by water hyacinth (WH) on L. Victoria (Kenya) is the fishery sector. This has prompted the need to develop an approach for modeling impacts of WH on fish production. The main objective of this study was assessing the impact of (WH) on production and fish species composition on the L.Victoria fishery (Kenya). It was postulated that WH infestation has led to reduced fish catch, net benefits and change in fish species composition.

Cost benefit analysis (CBA) provided information on the net benefits of fishing with and without WH, while Production functions (PF) were used to establish determinants of fish production using cross sectional data. Error Correction Models (ECM) used beach sample times series data (1990-2000) to assess the effect of WH, climate and fish prices on the major L. Victoria fisheries, while Vector Auto regression (VAR) models were used to measure the effects of fish price and WH intensity on fish species composition of L. Victoria (1986-2000).

The results showed that WH intensity was highest between 1996-1999 and increased fishing costs by 35% and decreased net income by 52%. The PFs identified fishing crew, boat size and WH as having significant effects on fish catch and income. Both the PF and ECM results indicated that WH had a negative and positive effect on the Tilapiines and mixed fish respectively. In the short run ECM results indicated that both rainfall and price had less significant effect on catch per unit effort (CPUE) in all fisheries. However, in the long run price had significant impacts in most of the fisheries as compared to the rainfall factor. Trends in the fish species composition indicated an increase in the mixed

Tilapiines and *Protopterus* while there was a decline in the *R. argentea* and *Mormyrus*. The impulse response analysis indicated that a 10% shock in WH led to a decline of fish catch for *R. argentea* (1.5%) and an increase in *Protopterus* (8%), Mixed Tilapiines (10%) and Haplochromis (2%). Generally, the prices moved in the same direction with the catch and then changed to opposite direction as from the third year. Since the benefits of WH are realized on the non-commercial fish species but little or negative on the three major commercial species, there is need to develop a suitable surveillance and control system for WH in order to keep this weed below economic injury levels.

The CBA, PF, ECM and VAR models were recommended for impact assessments of WH on fish productivity, net benefits and fish species composition. The choice of each will depend on the objectives of the study and data availability.

Key Words. Water hyacinth, Impact, PF, ECM, VAR, IRF

CHAPTER 1

INTRODUCTION AND BACKGROUND INFORMATION

1.1 Introduction

This chapter gives an overview of the Kenyan fishery sector with particular emphasis on the L. Victoria fisheries, specific and information on the water hyacinth incidence within the African continent and in particular East Africa. The aim is to develop a clear understanding of the fishery sector in Kenya, identify the importance of the L. Victoria fishery in the overall fishery sector in Kenya, and assess potential loss/benefits that could be caused by water hyacinth. This chapter is important as it gives background information that is necessary in comprehending the modeling that is to be undertaken in discerning the impact of water hyacinth on the fish catch/value that ensue in the subsequent chapters.

1.2 The Kenya Fishery and its Evolution

Commercial fishing is said to have started in Kenya in the early 20th century when gill nets of European origin were imported into the lake Victoria and rapidly expanded to replace indigenous fishing methods. This was the time when the Uganda railway line reached Kisumu town on L.Victoria giving a boost to the fishing activity through export facilitation (Garrod 1961).

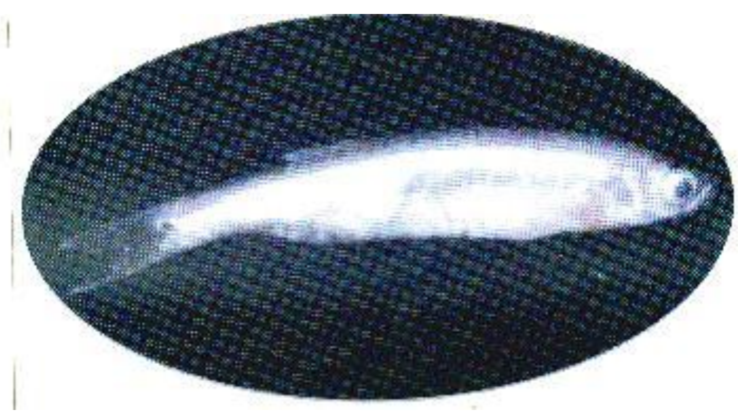
The Kenya Fishery sector has experienced dramatic changes since the 1950's. Prior to this, fishery activities were more or else traditional with fishermen using traditional fishing methods and targeting the local market. The canoes were sailed and manually operated. No outboard engines were used before 1980. The most important fish species were the Tilapiines, Haplochromines, *Protopterus* and C*larias*, which were sold locally to a limited number of women, fish mongers (Abila and Jansen 1997).

The fishery changed greatly from the 1980's with the introduction of two commercial fisheries mainly *Lates niloticus* and *O. niloticus* in the 1950's. The Lake Victoria fisheries experienced a big transformation and saw the fishery become a vibrant commercial sector targeting not only the local but also the export market mainly for *Lates niloticus*. The market for the fish industry was provided by the establishment of commercial centers necessitated by improved transport (railway line) and roads with the fish consumers migrating to the new urban centres after the Second World War (Garrod 1961). Nile perch expanded from an annual production of 1000 tons in 1981 to123,000 tons in 1991 on the Kenyan side of the lake (Abila and Jansen 1997). Presently, the dominant fish species in the lake consist of the *Lates niloticus*, *R. argentea* and the Tilapiines (Jansen 1997, Jansen *et al* 1999, Bokea and Ikiara) (Plate1.1).

However, by the beginning of the 1990's the fishery sector experienced another landmark in the lake Victoria fisheries with the infestation of water hyacinth. It has been reported by both scientists and fishermen that certain fish species, which had been a delicacy for the local communities, had reappeared and this was attributed to the presence of water hyacinth (Njiru *et al* 2000). According to reports (Carvine 1997), water hyacinth has affected the species balance/composition in terms of fish catch and prices, hence the

Lates niloticus

Oreochromis spp.



Rastroneobola argentea

Plate 1. 1: Three major fish species landed on L.Victoria (Kenya)

profitability of the fishery sector. Among the species, which were reported to have reappeared, were *Clarias and Protopterus.*

The Kenyan fishery handles an average of 175,410 tons of fish annually since 1986 with the current weight being 206,441 tons in the year 2000 (Table 1.1 and Figure 1.1). This production has increased to 212,948 tons in 2001 (GOK *2002a).* These consist of the fresh water fish derived from the various lakes (Victoria, Turkana, Baringo, Naivasha, Jipe, and river dams and fish farms), marine fish and crustaceans. Lake Victoria accounts for the bulk of this production averaging 91.6% of the total weight and an average of 85.6% of the total value annually. There was a notable decline in the percentage contribution of fish emanating from L.Victoria between the period 1995-1999 which apparently coincided with the time when the lake was heavily infested with water hyacinth implying that it may have had a significant impact to the quantity of fish landed. The percent contribution of L. Victoria to the National fish production dropped from 95.4% in 1994 to 91.5% in 1999. Over more or else the same period there is an apparent trend of the percentage contribution by the value superseding that of the total weight, as it is evident from Figure 1.1. This could be linked to increased prices of the fish products caused by the reduced quantity supplied. However, from 1997 to 2000 there was a ban/restriction on fish products from L. Victoria imposed by European Union, which is the biggest market for fish from East Africa due to the fear of contamination of fish with *Salmonella* and *Vibrio cholerae* and *Vibrio parahaemoliticus* (Henson *et al* 2000).

Table 1. 1 Contribution of Lake Victoria (Kenya) to the annual National Fish Production in 1986-2000*.

Year	National Production		L.Victoria Production		% of L.Victoria to the National total**	
	Tons	Kshs ('000')	Tons	Kshs ('000')	% Tons	% Value
1986	119,798	360,060	103163	237,340	86.1	65.9
1987	133,065	527,480	113552	317,020	85.3	60.1
1988	138,133	648,220	125,071	493,020	90.5	76.1
1989	146,401	819,160	135,429	647,060	92.5	79.1
1990	201,778	1,810,640	185,101	1,547,420	91.7	85.5
1991	198,562	1,812,520	186,366	1,586,620	93.9	87.5
1992	163,251	3,442,980	151,216	3,144,300	92.6	91.3
1993	183,193	3,765,680	174,829	3,482,790	95.4	92.5
1994	202,965	3,971,920	193,652	3,637,600	95.4	91.6
1995	193,848	5,204,260	181,888	4,678,140	93.8	89.9
1996	180,984	6,587,080	166,460	6,129,840	92.0	93.1
1997	168,062	4,635,340	151,293	4,152,000	90.0	89.6
1998	176,003	6,699,280	158,876	6,268,700	90.3	93.6
1999	218,659	7,660,557	200,153	7,194,940	91.5	93.9
2000	206,441	7,891,610	192,738	7,468,960	93.4	94.6
Mean	**175,410**		**161,319**		**91.6**	**85.6**

Source:
* Statistical Abstracts, Republic of Kenya. Various Issues.
**Authors own computation

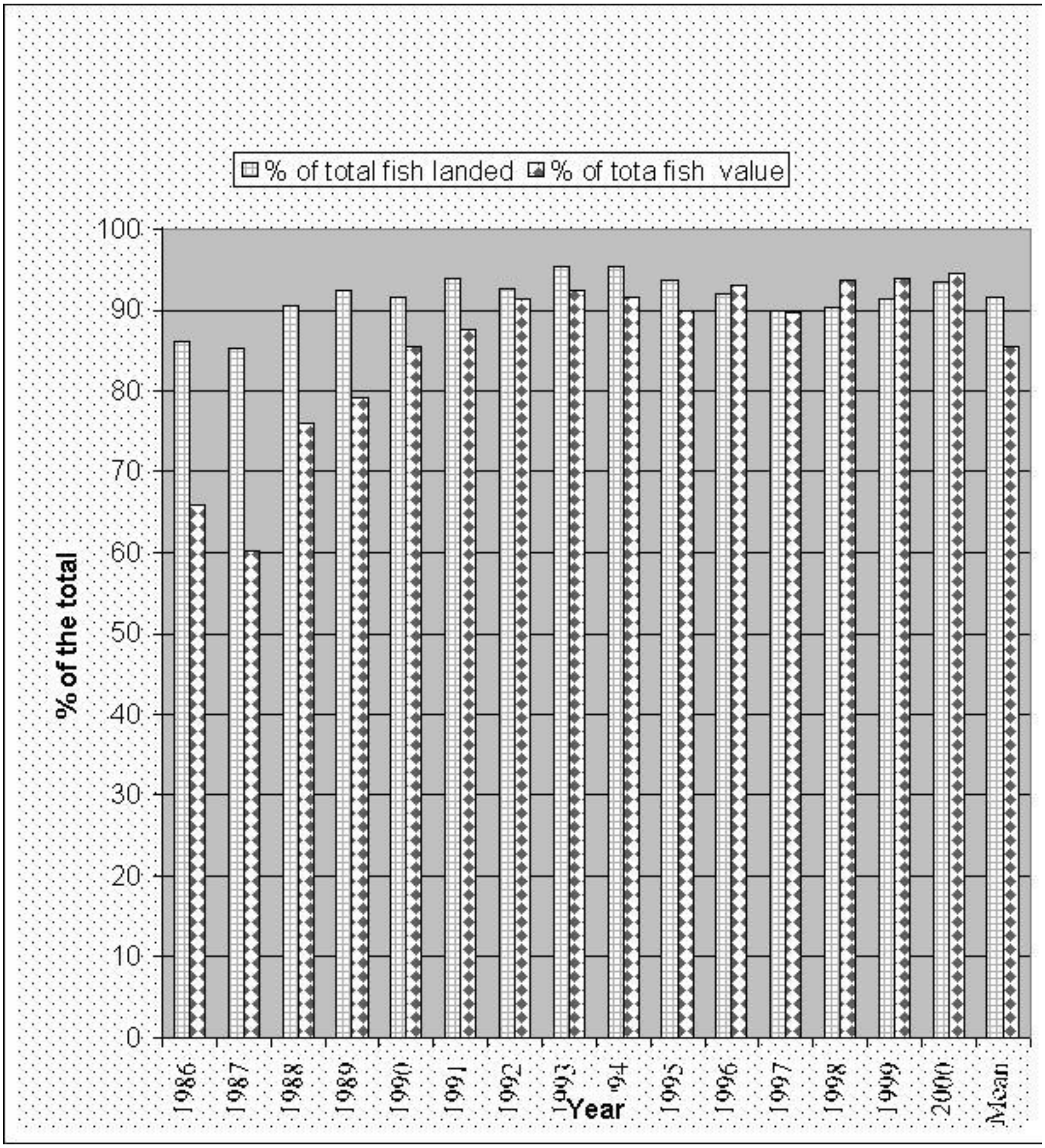


Figure 1. 1 L.Victoria (Kenya) Fish Contribution (%) to the National Totals by Tonnage and Value, 1986-2000

From 1996 to the year 2000, the fishing industry has recorded constant contribution of approximately 0.3% to the Gross domestic Product (GDP), although the sector recorded negative or low growth rate from 1998 to 2000 as compared to 2.3% in 1997 (GOK 2001b). From the above observations there is a clear indication that water hyacinth and to some extent the EU ban[1] may have had profound effect on the L. Victoria fishery in terms of quantity landed, prices and fish diversity. Kenya Economic surveys have also identified these two main factors as having impacted on the quantity of fish landed and their prices (GOK 1996-2001a). To date there has been no systematic quantification and proof of these effects as alluded to by biologists, ecologists or economists. With this in mind this study undertakes to provide scientific information that may help assess the impact of water hyacinth in the lake Victoria fisheries.

1.3 Lake Victoria Fishery

Lake Victoria is the second largest fresh Water Lake in the world (after Lake Superior in the U.S.) with a total surface area of 68,800 km^2 and an estimated stretch of 760 km on the Kenyan side with a drainage basin of 263,000 km^2. It is important to point out that this fishery is multi-species with the major ones being Lates *niloticus* (Nile perch) *R. argentea* (Omena or Dagaa) and Tilapiines (Ngege) contributing 57%, 20% and 22% (2000) respectively

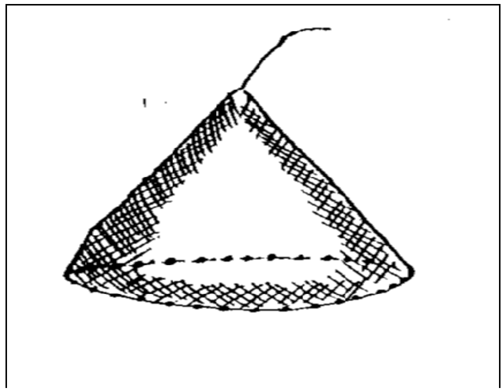
[1] There was an EU ban for fish (1997-2000) exported from L.Victoria due to the fear of *Salmonella* bacteria and cholera out breaks and fish poisoning. However, the fish exports value declined by 37% and 24% of the fish exports for 1998 and 1999, respectively over the 1996 value (Henson *et al* 2000). Alternative export market included Israel, Singapore, Japan and United Arab Emirates.

This fishery is operated by an estimated 11,505 canoes and 36,159 fishermen in about 300-gazetted beaches (MOARD 2000). These landing beaches are spread in eight districts (Busia, Bondo, Kisumu, Nyando, Rachuonyo, Homa Bay, Suba and Migori). All the districts are located in Nyanza Province with the exception of Busia, which is situated in Western Province. The highest number of beaches is found in Suba district where 32% of them are located, while, the second largest being found in Bondo with 23% and the smallest being Nyando and Homa Bay districts with 2% each of the total landing beaches (MOARD (2000).

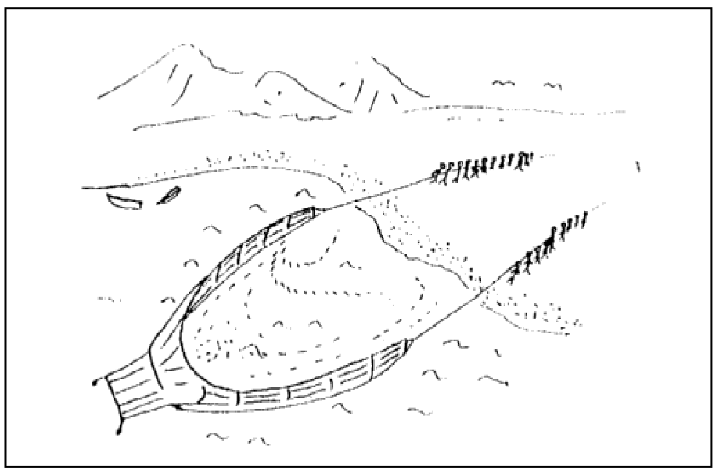
Three types of fishing gear categories are used in the lake. These include net gears, line gears and miscellaneous gears. The net and line gears are made up of textile fibres and are therefore called textile fibre devices, while the miscellaneous type may be referred to as non-textile devices because they are normally made up of materials other than textile such as wood, e.g. traps. The popular fishing gears include gillnets, long line, mosquitoe-seine and beach-seine in various sizes (Figure 1.2)

Gillnets nets have mesh sizes usually more than 127mm and are mainly used to catch Tilapiines, while bigger mesh size- (more than 5 inches) can be used to catch Nile perch. Beach seine has relatively smaller mesh sizes usually operated by dragging it at shallow waters close to the shoreline and because of its small size it catches all types of fish species including the juveniles. This is the main reason behind the government putting an embargo on the use of this fishing gear. Thirdly, we have the mosquitoe seine, which is a sheet of netting at least 10mm mesh size used in deep waters encircling a fishing ground

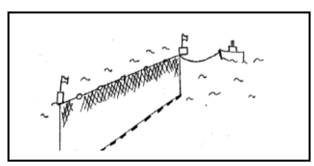
Cast net



Beach seines



Gillnets



Longlines

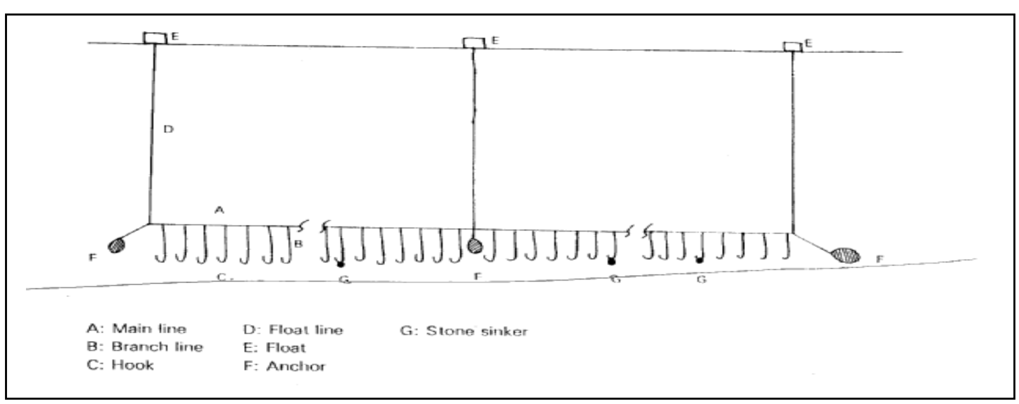


Figure 1. 2: Common fishing gears on L.Victoria (Kenya)

and used mainly to catch *R. argentea.* Just like the beach seine, its small mesh size allows it to catch any fish type and size depending on the nature of fishing ground. Fourthly, long-line consist of a manila with linear line with several hooks attached at intervals on short branches used in deep waters and catches *Clarias, Protopterus,* and *Lates niloticus* and adult Tilapiines.

Other methods of fishing on the lake include drift nets, hand line, cast net, traps, silencer and trawl nets. Trawl nets is a destructive fishing method and that is why it has been prohibited in the three East African countries waters within five nautical miles from the shore. It is a large bag-like net (conical shaped) pulled by one of the two vessels for a certain period of time mainly to catch fish appearing near or at the bottom of the lake. It catches all types of fish including juveniles. The relative importance of each fishing gear to the total fish catch in the lake has been changing over time. For example, in 1987 gillnets had the highest contribution by 55.8%, while mosquito seine had 25.7%, with beach seine and long line accounting for 8.8% and 9.7% respectively. This trend has been reversed in the present time with the gillnets now accounting for 18.2% and mosquito seine net (46.5%) and the beach seine, long line and mixed gears taking care of 20.7%, 5.2% and 10.4%, respectively for the year 2000 (Othina and Cowx 2002). This trend has serious implications on the conservation of the fish resources since the highest contributor is the mosquito net, which is officially banned by the Kenya government. The use of the mosquito net is dangerous to the fingerlings of *O. niloticus* and the *Lates niloticus* as well as the mature ones, when this type of fishing gear is used inshore. The government has regulated the fishing through the Fishing Act 1989 whereby it has instituted a ban of mesh size less than 50mm unless used on fishing *R. argentea* and prohibiting fishing of *R. argentea* with mesh size less than 10mm.

There are various types of fishing crafts used by fishermen to access the lake, namely, dug out canoe, Karua (flat bottomed), Sesse (made of planked wood), Taruma (with a V-shaped bottom), Jahazi/Chombo, Trawler, and parachute (Juenge). The fishing vessels are powered in three ways; paddles (using oars), sails and lastly the outboard engines. At the time of carrying out this study most vessels used paddles 65.7% (7561 units), followed by sails 28.8% (3313 units) and outboard engines 5.5% (631 units) on the lake (MOARD 2000). The relatively low number of outboard engines used might be due to the heavy capital required to purchase and service them.

There has been a change of fishing technology for mainly Nile perch where the industry witnessed the introduction of the use of trawlers and the drift nets ('Tembea') which both had the potential of landing over 1000kg of fish per day as compared to 500kg. However, there has been no change of fishing technology for the *R. argentea* over time. O'Riodan 1996 reported major declines of daily catch in the 1990's associated with increased fishing effort. In 1971 the number of fishermen was 11,000, rose to 24,000 (1992) and then to 36,159 (2000).

1.4 The invasion of L.Victoria Fishery by Water hyacinth weed

Water hyacinth, *Eichhornia crassipes* (Martius) Solms- Laubach, is a perennial, free floating fresh water plant belonging to the family Pontederiaceae (Gopal 1987). It originated from South America in the Amazon basin and has since spread throughout the tropical, subtropical and some warm temperate regions of the world (Hill *et al.* 1997). It is essentially a noxious weed and thrives best in fresh waters, although it has been spread around the world as an ornamental plant, which has been discarded into waterways and lakes. This plant undergoes rapid proliferation into thick mats of plants that engulf water bodies within a short time and hence depriving the water of light, oxygen and thus altering the fauna and flora life. This weed continues to be the world's most dangerous serious aquatic weed invading new waterways and wetlands (Julien *et al*. 1996). It multiplies vegetatively by use of stolons and is capable of doubling in biomass within 6-15 days under optimum conditions. The weed contains 95% of the weight being water (Harley 1990) rendering its potential use uneconomical.

During the 1890's water hyacinth appeared in Nile river (Egypt) where it was used as an ornamental, and then appeared in Natal Province South Africa in 1910, and in the 1930's it was spotted in several lakes in Zimbabwe. From this point onwards it then made its ways into the Congo river and the white Nile in Sudan in the 1950's and finally into the Pangani river in Tanzania. The 1960's and 1970's witnessed the expansion of the weed into the White Nile and Blue Nile, Congo and lower Zambezi and Shire river and several rivers in South Africa and lakes of Ethiopia, South Africa, and Zimbabwe and then on to the Central African Republic and Senegal (Hill *et al* 1997).

However, in the 1980's this waterweed made an extensive expansion in Africa. It was reported that it was spotted in several horticultural shows as a new ornamental plant in West Africa. This is the time when it spread to the coastal lagoons systems of West

Africa and by the end of the decade had colonized most of the coastal fresh water lagoons of Benin, Cote d'lvoire, Ghana, Nigeria, Mali and Niger. The final leg of water hyacinth expansion was in the late 1980's when through the White Nile it invaded River Kagera in Rwanda and then spread profusely to L. Victoria, Victoria Nile and Lakes Kyoga and George. The weed was reported in the lake and river systems in Angola, Malawi and Kariba Zimbabwe in 1995. In East Africa the weed was reported on Lake Victoria in 1988 on the Uganda side and in 1992 on the Kenyan side (LVEMP 1999, Mailu *et al* 1999). River Kagera was confirmed to be the main source of the water hyacinth (Taylor, 1993) to L.Victoria.

The water hyacinth weed can be classified in two categories; the stationary mat along the lakeshore and the mobile mat, which is often propelled about by wind and water currents (Twongo 1998). The stationary mat is found in areas sheltered from violent off-shore and along the shore winds or currents, flat or gently sloping shores that are relatively shallow and a soft mud bottom rich in organic matter. Whenever, one finds these kind of conditions, mats that are stationary and multiply very fast thus blocking the shoreline and hence making the lake or water body inaccessible to animals and human beings. In Kenya such mats have been located in beaches where the mat has been resident for even more than six months in a given year. This is the most destructive mat since it impairs all socioeconomic activities around the lake. Ecological succession has been very common in the areas covered with this kind of mat, especially with such plants as sedges, papyrus and hippo grass.

The mobile mats are generated from the resident or stationary mats by breaking away at some locations where rivers and small streams flow into the lake resulting from heavy winds or currents. These mats are often mobile and the time when they occupy a particular place will be dependent on the nature of winds and currents in that particular place. The ability for the water hyacinth to move depends on two main factors; the strength of the wind and the structure of the banks (Freidel, n.d.). The effect of the structure of the banks becomes significant when the wind blows the plants towards the banks. Water hyacinth situated near the shoreline anchor their roots in the mud hence not easy to be blown away as compared to those plants, which float on top of the water.

The rate of multiplication depends on the availability of nutrients. It has been reported that Kenya offers ideal conditions for this kind of mat due to heavy inflow of effluents from the agricultural and industrial environs releasing into the lake through the major rivers such as Nyando and Nzoia. The intensity of water hyacinth cover in a particular region fluctuates every year depending on the seasonal storms and the prevailing winds, which are responsible for the movement of the weed. Water hyacinth weed shelters in Nyanza Gulf particularly in Kisumu, Kendu Bay, and Nyakach bays between September and May and may shift to the Homa bay from June to September (Mailu *et al* ,1999, Ochiel 1999).

Water hyacinth thrives best in fresh water bodies so long as there is adequate nutrients flowing into the water. A map showing water hyacinth hotspots[2] on L.Victoria is

[2] Water hyacinth hot spots are areas or beaches on lake Victora, which experience a high concentration of nutrients including Phosphorous and Nitrogen and therefore are prone to high levels of infestation.

presented in Figure 1.3. In Kenya, the high water hyacinth infestation is being blamed mainly on the nutrient inflow of effluents into the lake through the rivers and runoffs. Ikiara (1999) reports that the main source of pollution results from the agricultural, industrial and municipal waste drained by the many rivers that flow into the lake. Pollution through agriculture and livestock activities is related to the use of inorganic fertilizers, and other chemicals (herbicides, fungicides and insecticides) that are washed into the lake together with the soil eroded materials. The seriousness of the nutrient inflows can be seen from the fact that 20kg of Phosphorous/km^2/year and 400kg of Nitrogen/km^2/year are off-loaded into the lake, which can cause acute and chronic toxicity (Ochumba *et al* 1991). The pollutants[3] to the lake include wastewater, suspended solids, foam, organic matter, chemical substances and toxins such as resin (Wangila 1993).

The effect of these inflows include the death of fish from oxygen poisoning and increased carbon dioxide and low oxygen concentration at night and finally depletion of the oxygen due to decomposition of the dead biomass of algae and phytoplankton (Gopal 1987). The ecological impacts of water hyacinth have been realized in both plant and animal life. Other major effects relate to ecological succession of other plants. When the weevils destroy water hyacinth, it rots forming a substrate on which other plants e.g., papyrus thrive on. On L. Victoria major impacts have been observed in the plant community where by pure mats of water hyacinth have been invaded initially by aquatic ferns/sedges (*Cyperus papyrus and Ipomea aquatica*) and followed by hippo grass (*Vossia cuspidator)* (Mailu 2001, Twongo 1998).

[3] A complete description and quantification of the point and non-point sources of pollution to L.Victoria (Kenya) can be found in Kirugara et al (1995).

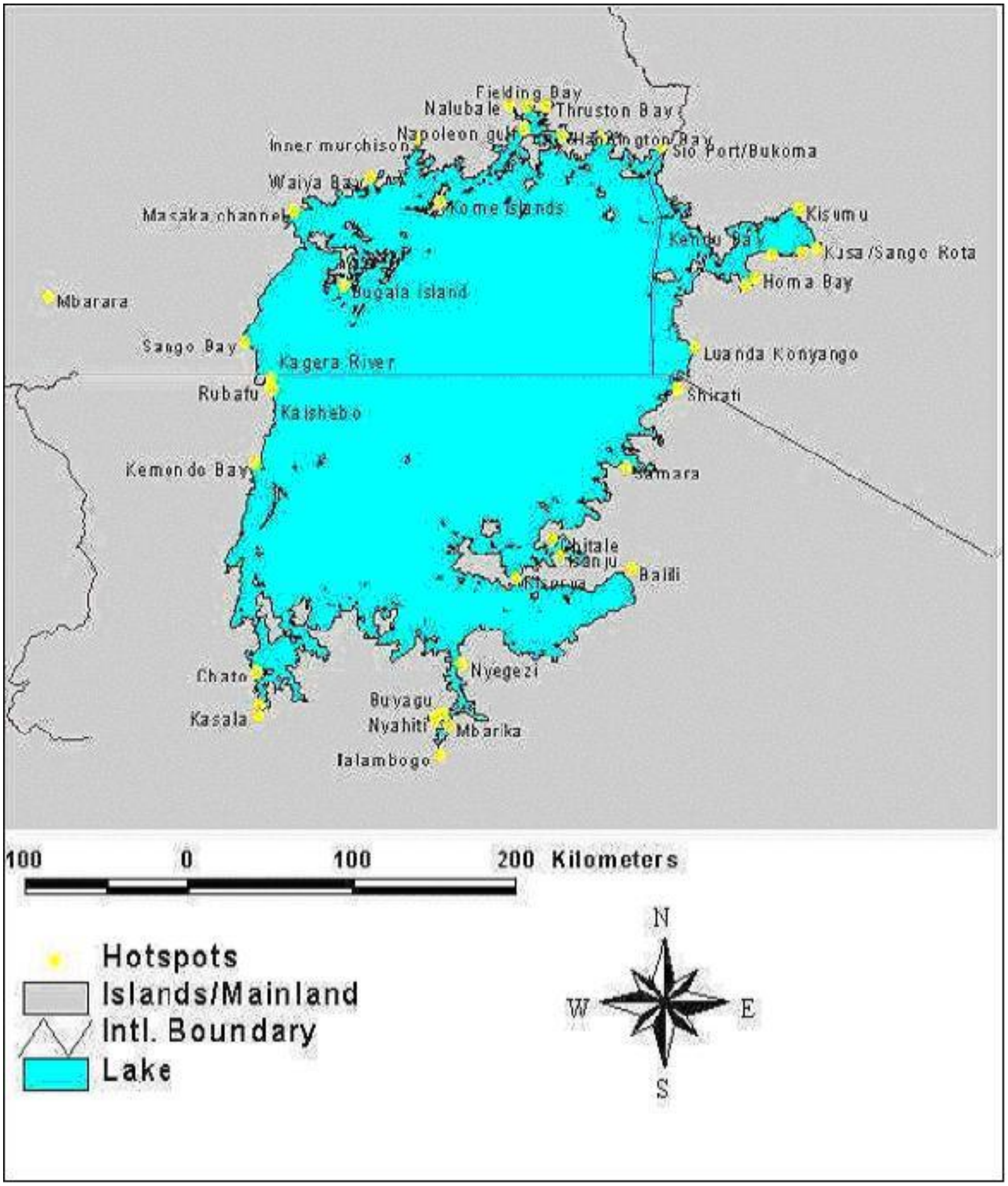


Figure 1. 3: Water hyacinth hot spots on L.Victoria

1.5 Significance of Water Hyacinth on L. Victoria

Water hyacinth infestation has been associated with negative effects although it may also have beneficial effects. With heavy infestation it causes serious disruption to commercial fishing, boat transport, and infrastructure such as water supply by blocking the intake points, port facilities and the hydro-electricity generation plant at the Owen Falls Dam. Under heavy infestation the socio-economic structure, food supply and health of the communities residing around the lake are seriously disturbed (Gopal 1987, Wawire Unpubl., Onditi 1997, Otieno 1997 and Carvine 1997, Mboya 2001). The increased water hyacinth infestation has, therefore, impacted negatively on the water quality and supply, fishing activities, plankton life, agriculture and health.

The problem of the water hyacinth weed on Lake Victoria can be understood better when one looks at the benefits that are derived from the lake that might be interfered with through water hyacinth infestation. This would call for a valuation of the Lake resources, which include activities such as industrial and domestic water supply, recreation and sports, transportation and commercial fishing which is outside the scope of this thesis. However, in the absence of this information a review of the role of the lake will suffice. Lake Victoria serves the three East Africa countries, namely, Tanzania, Uganda and Kenya constituting 51%, 43% and 6% of the total surface area, respectively. It forms the main source of food, water for domestic, industrial and agricultural activities and employment for the people residing around the lake and beyond (LVEMP 1999, GOK 2002b). In Kenya, water hyacinth has infested a number of beaches in several districts[4]

[4] The affected districts include Busia in Western Province and Bondo, Kisumu, Nyando, Rachuonyo, Homa Bay, Suba and Migori in Nyanza Province.

around the lake. In 1998 a Dutch Company, Snoptics using Geographic Information Systems (GIS) mapping, estimated that 6000 ha of the lake on the Kenyan side was covered by the water hyacinth (Snoptics 1998). The highest concentration being in Nyakach Bay (3200 ha), Osodo Bay (1200 ha), Kisumu Bay (1000 ha) and lastly, Sondu Miriu Bay (600 ha). This infestation appears at different intensities ranging from low to moderate and high (Plate 1.2). In areas with high infestation the impact of the hyacinth has been severe on fishing activities due to increased time to access the fishing ground and or landing site (Wawire, Unpubl.).

The water hyacinth effect has been greatly felt in the fish industry. Available literature (Gopal 1987, LVEMP, 1999, Onditi 1997, Otieno 1997, Carvine 1997) links water hyacinth infestation to fish production. In Kenya, fisheries sector employ about 48,400 artisanal fishermen, and an additional 500,000 people are directly or indirectly involved in fish processing and trade (GOK 2002b). Approximately two million people depend on the fish industry (LVEMP 1999). These include fishermen, their families (dependants), traders (middle men and hawkers), fish industry employees and investors, and auxiliary/tertiary traders. The performance of the fishery sector has been driven by the expansion of the Nile perch associated with the harvesting, processing and distribution sectors (Abila and Jansen 1997).

Any form of environmental degradation on the lake therefore would seriously impair the

Beach free of Wh infestation

Beach with low WH infestation

Beach with Moderate WH infestation

Heavy WH infestation

Plate 1. 2: Levels of WH infestation

socio-economic status of the local communities and the whole country at large through the loss of earnings from local trade and exports in terms of foreign exchange. A part from the activities (water supply, cargo and human transport, etc) being interfered with, there will be a loss of export earnings derived from fish fillet through artisanal fishing emanating from L. Victoria. The main export product is the Nile perch, which accounted for 88% by weight in 1996 (Henson *et al* 2000). This product is exported fresh and frozen mainly to the European market (EU). In 1996 the EU market accounted for 59% of the total exports by weight. Lake Victoria is the principal source of fish in Kenya, accounting for an average of 91.6% of the total fish landed in the country and 0.3% of the monetary gross domestic product and earning Ksh.8 billion per year (Fisheries Department). The export earnings for fish accounts for about 2% of the Kenyan total (GOK 2002b).

Although water hyacinth infestation on the Kenyan side of L.Victoria has been reduced from 6000 ha (1998) to 500-1000ha at present through biological, mechanical and manual controls, the available mats still cause problems particularly in Nyakach and Homa Bay beaches (LVEMP 2002,Ochiel 1999, Wawire and Ochiel 2001). Potentially, water hyacinth is still a threat to the socioeconomic activities and therefore the need to monitor and control this weed in order to develop an effective program for its containment. In order to generate this program there is need to have adequate information on the socio-economic and environmental effects of this weed.

1.6 Problem formulation

Water hyacinth mats of actively growing plants and the dead masses interfere with the movement of oxygen in the water bodies hence causing less diffusion of oxygen. In addition, to this, it lowers the temperature of the water PH, bicarbonate and alkalinity and dissolved oxygen content and increases the free carbon dioxide contents affecting the Biological Oxygen Demand (B.O.D) and nutrient levels (Obiero and Munyirwa 1998). The water hyacinth shading effect reduces photosynthesis activity required for the plants to manufacture their own food, which in turn provides food to the fish and other animals. All these conditions affect the food generation and availability to fish and subsequently interfere with fish production and other animals. On the other hand, when water hyacinth does not completely cover the water bodies it may prove to be useful by providing shelter underneath the plants where the fish feeds upon organisms and other detritus materials. Thus the presence of water hyacinth may have profound effect on the fish diversity. The WH cover interferes with the breeding grounds, protection of the certain fish species from predation by Nile perch and the fact that the traditional fish species thrive better under low oxygen levels (Othina *et al* 2000, Ochiel & Wawire 2001, Yongo 2000).

The water hyacinth cover also interferes with transport and communication on the lake. Heavy mats of water hyacinth makes the lake impenetrenable by blocking both transport and fishing boats, even those with very powerful engines. This makes fishing, transport and communication expensive, as the beneficiaries have to look for alternative means, which are often more costly.

Water hyacinth provides habitat and food required for several harmful animals and other vectors of diseases like malaria and filariasis. The water hyacinth weed harbours organisms around its roots that cause cholera (i.e. *Vibrio Cholerae*) that infects the local community. This could have a negative effect on the labour supply to the fishery industry.

Fish production has been affected by water hyacinth as its mat blocks the path for fishermen, and thus not only increases the time used to access the fishing ground but also leads to the destruction of fishing boats and the accompanying gears. This leads to increases in the cost of fishing and by so doing leading to diminished fish catch and profitability. In cases where there is resident or total cover of water hyacinth the fishermen are left with no option but to relocate to other beaches or join other businesses hence experiencing total loss in the catches for the period water hyacinth covers the beach.

Despite the significant effect caused by the water hyacinth on the L. Victoria fishery, there has been little scientific information available on this subject. As exemplified by Brown and Ikiara (1999) “Not much is known about water hyacinth, with the current information based largely on speculation”. This confirms the fact that there still exist gaps on information regarding the economic impact of WH in fish production. It is important to note that most of the studies (Okallo 1999, Hill *et al* 1999, Legallo Unpubl.) have dwelt on descriptive analyses, which do not bring out the quantitative relationships of WH and fish productions and other lake activities. The in-depth analysis documenting the impact of WH in fish production using both cross-section and time series data is lacking. The study approach, which uses both cross section and time series data, will reveal variation in fish catch among the local fishing communities and fish production over the period respectively with respect to water hyacinth infestation. This study is necessary when one realizes the water hyacinth problem in tropical Africa and how the WH has colonized various regions including L. Victoria since the 1980's (Hill 1997). The extensiveness of water hyacinth has led to the recognition of the studies in socio-economics and ecology as being important by the international community in providing information on the effect of water hyacinth on the socioeconomic activities.

In summary, we can say that water hyacinth has negatively impacted on the L.Victoria fishery through blockage of beaches, destruction of fishing gears and damage of boats and their engines. The magnitudes of these effects need to be assessed objectively and systematically.

1.7 Study Objectives and hypotheses

1.7.1 Objectives

There is no doubt about the seriousness of the water hyacinth weed on the socioeconomic activities of the lakeside communities of L.Victoria. As already indicated the lakeside is home to approximately forty million people from the three East African riparian countries, who directly or indirectly depend on the lake for their livelihood. In spite of this the L.Victoria has been infested with water hyacinth for the last 10 years and yet there has been no formal or scientific assessment undertaken to assert the effect of the weed on the socioeconomic activities including the fishery.

It is with this background that this study aims at estimating the economic impact of water hyacinth on fish production since the 1990's on L.Victoria. In particular the study focuses on the effect of water hyacinth on L.Victoria fishery in terms of productivity, profitability and fish species composition using both cross section and time series data. To undertake this study effectively there is need to develop an approach for modeling the effects since such studies have been limited or non- existent.

The specific objectives will seek:

- To develop a suitable analytical frame work for modeling impacts of water hyacinth in fish production
- To undertake a Cost Benefit Analysis (CBA) of the fishing under the presence of water hyacinth. An understanding of the costs and benefits of fishing with or without water hyacinth is crucial in assessing the impact of water hyacinth on the fishing enterprise.
- To assess the role of water hyacinth among determinants of fish production and income among fishing communities of Kenya in the short term. Although there is plenty of information on determinants of fish production, the effect of water hyacinth in such models has been absent.
- To assess the effect of climate, water hyacinth and prices on fish production among local communities of Lake Victoria. There is need to determine the effect of water hyacinth on fish production using time series data but it is also necessary to capture the effect of other factors such as climate (rainfall) and fish prices.
- To determine the impact of water hyacinth and fish prices on fish species composition

and of L. Victoria (Kenya). There have been numerous reports indicating that water hyacinth has to a large extent affected fish species composition (diversity). This fact requires validation.

- To document the water hyacinth incidence and selected impacts on L. Victoria, Kenya. This documentation is important since such information is scanty or not available. It is important to note that most of the information available is on biological controls using weevils and descriptive statistics.

1.7.2 Hypotheses

- Water hyacinth infestation leads to increased cost of fishing and hence a reduction in the net benefits in the fishing enterprise.
- Water hyacinth significantly affects the quantity of fish landed (production).
- Fishing effort (labour, boat size and fishing gear type) has significant effects on the quantity of fish produced.
- Socioeconomic factors (fishing experience) have a significant effect on the quantity of fish landed.
- Fish price is positively associated with the quantity of fish landed.
- Rainfall has a significant effect on the quantity of fish harvested.
- Water hyacinth has significant impact on fish species composition. The quantity of fish landed is used as a measure of species diversity.
- Fish price has significant effects on the fish species composition.

1.8 Justification of the study

Impact assessment can have different connotations depending on the discipline. In the research sector, impact analysis has focused on the mechanism and process of research, and in addition to the effect of the product (technology) on the farm (Anderson and Herdt 1990). On the mechanism and process of research observers are interested in the direct product of research, e.g. new varieties or compounds of new technology. The second approach looks at what has been the effect of the generated technology on farmers' fields or where research is applied. One of the popular studies has been looking at the effects of the spread of modern plant varieties on crop yields. The focus was mainly on the Green Revolution as observed on its effect on intensification and increased yields (Hazell 1995, 1983, 1982). Further, studies can be extended beyond looking at crop yields and crop intensification to the wider economic effects of the adoption of new technology at various levels, e.g. income levels.

On the same basis there has been need to assess and document the effect of water hyacinth on fish production. Over the last ten years L. Victoria has been infested with water hyacinth and hence impairing the socioeconomic activities. The cost of WH infestation for countries in the region has been estimated to be in billions of US $, for example, Lake Victoria, where infestation was said to cover up-to 40,000 ha in total and affecting livelihood of more than 40 million people in Kenya, Uganda and Tanzania (Amuyunzu and Navarro, 1999). The Lake Victoria Environmental Management Project (LVEMP) was set to spend US $ 8.3 million in the three East African countries in the control and management of water hyacinth in a period of five years, with Kenya's allocation being of US $ 2.3 million.

Considering the economic importance of WH in fish production one is tempted to measure the economic impacts among the fishing communities. This could be in a similar manner to the determination of the impact of the Green Revolution on cereal production whose effect was felt as from the 1960's with the generation of new varieties of such crops as wheat and rice.

The justification for such studies may be prompted by firstly pure inquisitiveness, and secondly, the need to assess the losses/gains associated with the impact of WH in fish production and lastly, to have a feed back on the efforts of research in WH control to direct the future course.

Although there have been scattered studies on water hyacinth impact of WH on various socioeconomic activities, there has been few attempts to determine the quantitative relationships through econometric approaches and other related methods. Brown and Ikiara 1999 have reported that there is no scientific information on the impact of water hyacinth on the L. Victoria fishery and this may be attributed to insufficient data for studying bio-economic aspects of fish dynamics and the effect of water hyacinth. The absence of this information lends policy makers in making decisions on water hyacinth management based on general information and speculations which may not be reflecting the actual case on the ground.

The main purpose of this study therefore was to evaluate the impact of water hyacinth on fish production and provide information that will assist policy makers with insights to aid in decisions about future investments in research and its control and monitoring procedures. In addition, this study was meant to provide scientific information on appropriate methodologies that can be used in the assessment of the impact of water hyacinth or related weeds on fish production.

1.9 The study Area

Nyanza Gulf (Winam Gulf) measures approximately 1400km^2 with a length of 60km with varying width of 3-30m. It has a mean depth of 6m with a maximum of 43m and an elevation of 1136m. It has an irregular shoreline of 300km with several large bays, including Berkley, Asembo, Nyakach, Osodo, Kendu, Homa, Karungu and Muhuru Bays.

1.9.1 Area and location

The study area covers the Western part of Kenya focusing on the lake Victoria basin on the Kenyan side (Figure 1.4). The area is bound by Longitudes 34^o 00’E and 35^o 40’E and altitude 1^o 30’S and 1^o 20’N. Lake Victoria is the second largest fresh water lake in the world with a total area of 68,800 km^2 on the Kenyan side covering approximately 6% of the total area.

The topography is variable, as there is the Mau hills to the East of the basin and Mt.

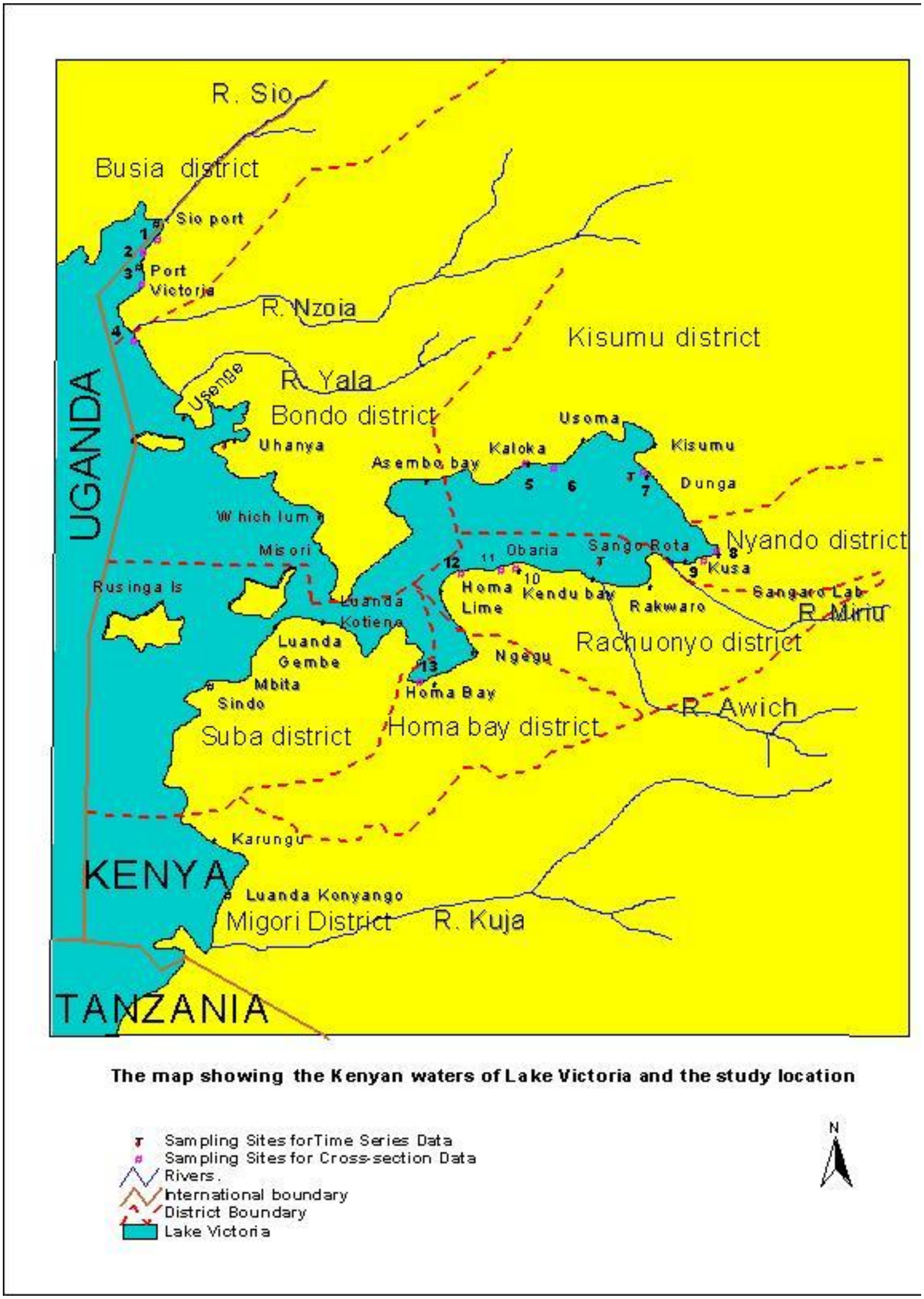


Figure 1. 4: A map of Lake Victoria showing the Kenyan Shoreline and Study Area

Elgon and Cherangani hills to the North. The altitude varies between 1100m around the lake to 3000m (Mt Elgon). The major affluent rivers include Kibos, Nyando, Sondu, Nzoia, Yala, Kuja, Awach, Mogus and Lambwe. Water exchange within the rest of the lake takes place through Rusinga channel while the major outflow from the lake is through river Nile.

1.9.2 Climate

Lake Victoria lies across the equator. The lake influences the climate due to strong circulation of winds in the lake and land breeze. Two rainfall patterns are experienced throughout the year with peaks in March-May (long rain season) and august-September (short rain season). The mean and annual rainfall varies from 2000mm along the Western edge to less than 700mm near the Eastern shores.

Daytime temperatures are modified by the lakeshore's breeze circulation. The Eastern shores receive a maximum daily temperature of 29-30^{o} C while the Western and Northern shores receive an average of 26^{o} C. The night temperatures range between 16 and 17^{o}C in the North and West, while the South and Eastern parts have a range of 17-18^{o}C.

1.9.3 Socioeconomic features

The lake basin (Kenyan side) has an estimated population of approximately 9 million people with a density of 22 people per sq. km including Western, Nyanza and parts of Rift Valley Provinces, while the people in the Lake region approximates to about 4 million encompassing Nyanza and Western Provinces. Because of the high population growth rate the area has suffered from insufficient job opportunities and therefore reduced incomes per capita.

1.9.3.1 Agriculture

Small-scale farmers practicing mixed farming with low levels of inputs dominate this region. Livestock commonly kept include cows, oxen, small ruminants and poultry. Food crops are grown both in the long and or short rain seasons. These include maize, sorghum, cassava, beans, groundnuts, and sweet potatoes. In addition various cash crops are also grown viz.: cotton, sugarcane, tobacco, tea and coffee. Fruits are grown around homesteads including bananas, papayas and citrus, while vegetables are grown mostly for subsistence purposes.

1.9.3.2 Fisheries

Fishery is one of the major resources in the study area. Lake Victoria is the main source of fish (source of cheap protein food and income to the local communities). As already reported the major fish species include Nile perch, *O.niloticus*, and *R. argentea*. Fish farming has become a major activity with the demonstration farm at Kibos playing a major role in knowledge dissemination. Over 1200 fishponds are spread in Busia, Siaya, Kisumu and the South Nyanza districts.

1.9.3.3 Industrial

Many agricultural based processing factories surround the shoreline, viz. sugar factories based in the Nyando Sugar belt (Miwani, Chemelil and Muhoroni) and the Sonysugar factory located in Migori district. Others include Mumias, Nzoia and West Kenya based in Western Province. There is a Paper factory located in Webuye town, Western Province and a few coffee-processing factories in Kisii, not to mention the tea factories around Kaimosi, Nandi, and Kericho. In addition, there are several fish processing and textile firms in the region. Breweries, soft drink bottling and dairy industries are also found in the study area. All these factories contribute to the flow of effluents into the lake hence increasing the level of nutrients, which in turn lead to water hyacinth proliferation.

1.9.3 Environmental Concerns

The lake basin region has been experiencing increased population growth rate and hence imparting pressure on the existing resources, which have impacted negatively on both the water and land resources. Among the activities, which have been affected, include declining biodiversity, increased deforestation, upsurge in soil erosion, over fishing in the lake and deterioration of the water quality. The recent problem is the infestation of the lake by water hyacinth.

1.9.4.1 Change in the biodiversity

There has been changing diversity in both the fauna and flora composition of the lake basin. The changes have been associated with destruction of wetlands, introduction of new fish species, over fishing in the lake and the increased discharge of the industrial and municipal effluents in the lake. These factors have led to the replacement of the original fish species. such as Haplochromines by Nile perch and O. *niloticus*. The destruction of the wetlands through cultivation has witnessed the disappearance of very precious medicinal plants and also the disappearance of some birds' species due to the destruction of their sanctuary.

Due to the increased population pressure there has been extensive destruction of forests particularly indigenous trees in search for agricultural land around the lake region. This has not only led to the destruction of the native tree species but also exposed the lands to heavy erosion and therefore loss of soil fertility, and hence compromising the productivity of these farms. The destruction of forests also alters the climatic characteristics of a given environment.

1.9.4.2 Over-fishing

There has been increased effort in the fishing industry being witnessed by the increased catch over time. The labor force involved in fishing on the Kenyan side has increased up to a current force of almost 36,159 (2000) from 31,270 (1989) while the number of boats over the same period has increased to 11505 from 8000 boats. This increase of the fishing labour (14%) and boats (30%) over this period may be an in indicator that the lake is being over fished. Additional evidence might be the fact that some of the fish species that were endemic in the lake have disappeared although they are reported to be reappearing, an effect being attributed to the water hyacinth infestation. If the over-fishing goes on unabated then the lake fishery may come to crumble with time.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The aim of this chapter is to review previous work done on the effect of water hyacinth on the fisheries. However, as it has already been noted there are very limited studies specifically assessing the impact of water hyacinth on fishing activities using quantitative techniques taking cognizance of time series or econometric models. With this in mind, this section reviews some of the socioeconomic studies undertaken focusing on the descriptive statistics and some of the econometric and time series models used in assessing water hyacinth impacts in the fishery sector and or other related sectors. This captures the models that have been used and their relevance to the current study identifying weaknesses and areas that may require further improvement. Information derived from this literature review will provide guidance on the development of a sound analytical framework required for this thesis.

2.2 Socioeconomic Impact Analysis of Water Hyacinth

Okallo (1999) looked at the socio-economic impact of WH on fishing communities in Kisumu district-Kenya. A questionnaire was used to collect information, which was analyzed using descriptive statistics and Kruskal Wallis Tests. The study showed that there were notable effects of WH on fish incomes, social life and livelihood. However, there was no quantitative analysis linking WH to fish output/income to determine any significant effects.

In addition, Hill *et al*. (1999) used semi-quantitative or descriptive Rural Appraisal survey techniques relying on group interviews and discussions in Malawi. Six fishing communities were interviewed with one hundred respondents from each community. The results were qualitative hence providing extensive valuable baseline data that could be used in the study of both environmental and economic impact of WH. Chikwenhere and Phiri (1999), using descriptive statistics showed that there was a decline in fish catch of 30% in Zimbabwe. He reported that with WH, fish catches which ranged between 50-60kg per day before infestation, but dropped to 2.5-3.0 kg per day and even nil with heavy water hyacinth infestation. Chikwenhere *et al*. (1999), studied the environmental and economic impact of WH in the Eastern reaches of Lake Kariba, Zimbabwe pointing out that WH infestation reduced by 60% both transport efficiency and the frequency by which fish and vegetables were sent to Kariba. The study also revealed that the costs of boat operations increased, i.e., repairs, travel time and therefore reduced fish catch and incomes in the fishing industry.

All the above studies were attempts to generate information on the impact of water hyacinth on the socioeconomic activities of the lake. In particular, these studies highlight on the effect of water hyacinth on the fishing activities, which is the major, lake activity. The studies used field questionnaires, personal interviews and observation to provide data that was used in the analysis and making these inferences. Descriptive statistics were heavily relied on to make inferences. However, this approach is very useful when you want to find out the status quo of a particular activity in a particular time but when the activity involved time series then this approach becomes deficient. ILRI 1999 asserts that 'descriptive statistics do not control for the other factors affecting the influence of the observed outcomes'. For example, in Lake Kariba (Zimbabwe) the study revealed that water hyacinth reduced both transport efficiency and the frequency of fish and vegetables sales by 60%. This inference presuppose that water hyacinth entirely account for the 60% reduction but the truth is that there are other factors such as weather which also played a role but assumed to be constant. To obtain a clear indication as to the effect of water hyacinth there is need to make some quantitative analysis using econometric or time series models which allows for the inclusion of other causal factors. However, descriptive statistics provide useful background information required during the development of the analytical models used in the empirical studies

2.3 Econometric and Times series models used in Impact analysis

There has been a few econometric and time series models used in the assessment of the determinants of the performance of fisheries. In Kenya, Ikiara (1999), used panel data to identify determinants of fish output/value on L. Victoria (Kenya) using production function approaches in Translog and Cobb Douglas functional forms. The results indicated that variation in fish output was related to such factors as number of days fished per month, crew size and mesh size. Although during the time the study was undertaken water hyacinth was becoming an important factor in L. Victoria, this variable was not included as one of the explanatory variables in the production function. Thus the effect of water hyacinth was not captured.

In another study Mkenda and Folmer (2001) focused on the scope of expanding the artisanal fishery in Zanzibar and used co-integration technique as the major econometric tool to estimate the maximum sustainable yield (MSY) in the fishery, using the Schaefer (1957) and Fox (1970) surplus production models. The main objective of the study was to estimate the relationship between the catch and effort and to test the presence of the long run equilibrium in the Zanzibar fishery, which is crucial for sustainability. The data used in the study were monthly catch and effort from the Fishery Department in Zanzibar covering the period 1980-1996. The variable catch was measured as the tones of fish landed while effort is represented by the number fishing days. The results appeared to indicate that there existed a long-term relationship between catch and effort using co-integration techniques and the computed MSY pointed to the fact that the fishery in Zanzibar is biologically over fished.

Dalton 2001 used Vector auto regressions (VARS) and dynamic linear rational expectations model to analyze the effects of sea surface temperatures and catch prices on the fishing effort for various fisheries in California. The VAR results indicated that fluctuation in sea surface temperatures, including *El Nino* events, have significant effects on effort and prices for these fisheries. The study used annual data for the period 1981 to 1999. Both first order and second order VAR were used in assessing the relationship between sea surface temperatures and the fish prices to the fishing effort for the four fisheries in California.

Error correction models (ECM) have become important in recent times in time series studies and modeling in view of the problems of non-stationarity of data (Thomas 1993;

Greene 1993). Although we have not come across any studies where ECM has been used in the fishery sector, it is used extensively in other studies involving production, consumption and prices with examples being seen in the works of Adjaye (2000) and Nasr *et al* (2000).

Nasr *et al* (2000) carried out a study using econometric models to investigate determinants of electrical energy consumption in the post war Lebanon. The co-integration test and ECM were used to establish the existence of long run relationships among the variables and the capture of both long and short run dynamics, respectively. This was necessary because time series data suffer from spurious regressions. For regression results to be meaningful when using time series data there has to be evidence of long-term association of the variables being studied. The variables under study were gross domestic product proxied by the total imports, degree-days (computed from temperature) and the electrical energy consumption investigated over the period 1993-1997 monthly. Three periods of time span were chosen based on the rationing level of electricity supply. The period 1993-1994 represented full rationing, 1995-1997 partial rationing and 1996-1997 free from power rationing. During the 1993-1994 total imports were found to be a significant of energy consumption whereas degree-days had a negative correlation. In the second period, all the factors were found to be significant at 1%, and the same to the period 1996-1997. Co-integration analysis revealed that there existed long-term relationship between variables in the last two periods. The ECM coefficients of the lagged error term were found to be to be –0.18 and –0.23 for both the second and third subsets respectively, and were significantly different from zero. The inconsistency in the results particularly in the first period may be associated with the rationing of power.

Adjaye 2000 undertook a study to establish the causal relationship between energy consumption, income and price for four countries; India, Indonesia, Philippines and Thailand using co-integration and error correction modeling techniques. Annual times series data were used covering the period 1971-1995 for Thailand and Philippines and 1973-1995 for India and Indonesia. Since the prices were not available they were proxied by consumer price index (CPI) with the base year put at the year 1987. The modeling was based on Engle-Granger methodology (Granger and Newbold, 1974;Engle and Granger 1987). Following the unit root test and co integration tests the error correction model was estimated. The ECM provides for identifying causality channel involving the significance of the lagged variables conditional to the optimum lags. The ECM results indicated that there was unidirectional Granger causality running from energy to income for India and Indonesia, while bi-directional Granger causality runs from energy to income for Thailand and Philippines. In the long run there was unidirectional Granger causality running from energy and prices to income for India and Indonesia. However, in the case of Thailand and Philippines energy, income and prices were mutually exclusive causal wise. Prices were found to be relatively insignificant in the causal chain. These findings are important in making policies in the energy sector.

The models reviewed above include production function, vector auto regressions and ECM. All the above models have been used in the fishery sector except the ECM, which has been used commonly in the energy sector. The production function has been used for a long time and can be very handy in drawing relationships between variables and when used in double log forms gives production elasticities which shows the magnitude of the effect of each explanatory variable. However, when used with time series data it breaks down due to what is referred to as spurious regression resulting from non-stationarity of the time series used. Therefore in the recent time there is less preference for the use of production function model with time series data because of this shortcoming.

Over the last few years scientists have developed models that correct for this problem and hence the inception of ECM and VAR which addresses the problem of spurious correlation. The ECM is used because of the fact that it corrects the data for stationarity and ensure long run relationship amongst variables. The data is often checked for stationarity and co-integration to ensure that the data conforms to the specification of the model. In view of this the ECM has become a stronger tool used by econometricians when analyzing times series data in the place of the production function.

On the other hand VAR is a model that addresses the problem of stationarity in data and its biggest advantage is that it assumes that all the variables being considered in the model are endogenous and hence become suitable for use when looking at interrelationships among variables. The causal relationship is what is referred to as Granger Causality.

In view of the above discussions all the three models (Production function, ECM and VAR) are used in this study where necessary, taking in account their shortcomings and or strength. In Particular for the time series data ECM and VAR are used while production function is used with the cross section data. As already indicated there are no econometric analyses available on the impact of water hyacinth on fish production.

2.4 Fish Species Composition

A few studies however, have looked at the fish species composition on the total fish landed on the lake within a certain period of time. Ochumba and Pollinger1991 looked at the decomposition of the total fish landed on the lake (Kenyan side) by species over a specified period of time. The study indicated that the trend of fish composition has been changing significantly since the introduction of the Nile Perch and *O. niloticus* since the 1950's. Three dominant fish species were identified as Nile perch, *O. niloticus* and *R. argentea*. Other studies (Namulemo 1999, Getabu and Nyaundi 1999) looked at the fish species composition based on bottom trawls in the lake with the aim of establishing the relative abundance. The results also showed the abundance of Nile perch, *R. argentea* and *O. niloticus* in the recent times.

However, there have been few specific studies looking at the impact of water hyacinth on fish production. KMFRI scientists have undertaken studies aimed at documenting the impact of water hyacinth on the L. Victorian fisheries (Njiru *et al* 2000, Othina *et al* 2000). The findings clearly pointed to the fact that *Clarias* and *Protopterus* which had disappeared in the 1980's had resurfaced in the 1990's and this resurgence is attributed to the invasion of the lake by water hyacinth. The increase was attributed to the fact that there was increased food availability and suitable breeding grounds due to the water hyacinth cover. The study was based on the catch per unit effort (CPUE) and total landings and trawl surveys in 1997-1999 between 0-9metres depths. Descriptive statistics were used to make the necessary assessment. The conclusions were based on the comparison of data on fish catch before and after the water hyacinth invasion.

In the decomposing of the fish species of the lake the above studies used two methods namely bottom trawley surveys and the actual quantity of fish landed in a particular time period. The two approaches gave similar results with Nile perch, O. *niloticus* and *R. argentea* being identified as dominant fish species. However, the most important studies in this case are those focusing on the impact of water hyacinth on the respective fish spp. The results, which have been reported, only looked at the fish species, which seem to reappear but overlooked the effect of water hyacinth on the major fish species. It would have been more complete if the study also looked at the effect of water hyacinth on the major fish species. The descriptive statistics, used in this study, however, do not bring out the quantitative relationships between the variables.

CHAPTER 3

METHODOLOGY AND ANALYTICAL FRAME WORK

3.1 Introduction

It is implicit in the problem statement and also, in the hypotheses that WH has had impacts on L.Victoria fish production. In assessing these impacts, one would consider one or two options. First one would consider comparing the before and after WH situations. As this option is likely to be fraught with conceptual difficulties of copping with effects of intervening events, it is usually better to consider with WH and the without WH situations. The main thrust of the analysis recognizes this.

This study undertakes to assess the effect of water hyacinth on L.Victoria fishery viz. productivity, net benefits and fish species composition. Analyses for this study are supported by two broad categories of data, cross section and time series from primary and secondary sources. Econometrics techniques are heavily relied on to make inferences about parameter relationships. The analytical framework is presented highlighting the models that are used and the rationale of the variables used in the study. Finally, information is provided on the primary and secondary data collection procedures.

3.2 Basic consideration of the model

Economic impacts of WH are hypothesized to include increased production costs as well as producer and consumer price changes. A general analytical approach to quantifying the value of such impacts may be described by equations 3.1.1- 3.1.4. Quantity supplied (Q_s) depends on producer price P, and technology, as does quantity demanded (Q_d) on consumer prices P, income and preferences. P and Q are related through their respective intercept and slope coefficients a and b. Recall that supply functions can be interpreted as marginal cost curves, and demand curves as the marginal value product curves (Gravelle and Rees 1990). Thus:

$Q_s = a_s + b_sP$ (Supply)---------------------------------3.1.1
$Q_d = a_d + b_dP$ (Demand)------------------------------- 3.1.2
$a_s + b_sP = a_d + b_dP$ (At equilibrium)------------------------3.1.3
$P = (a_s - a_d)/(b_d - b_s)$ (the model solution)------------------- 3.1.4

At equilibrium, $Q_s = Q_d = Q$ and $P_s = P_d = P$.

The benefit that accrues to society from production and consumption of a good, in this case, fish, in terms of its economic value in excess of production costs is the total economic surplus. This benefit can be measured as the difference between the marginal cost at a certain level of production and the price that consumers are willing to pay for a certain level of production. This benefit is partitioned between producers (cost of production) and consumers (willingness to pay).

The value of this framework in assessing the price and quantity effects, which may arise from changes in production cost i.e., supply function, occasioned by invasion by water hyacinth is apparent. If WH infestation engenders an upward shift in the marginal costs of production, this will lead to reduced benefits to society due to water hyacinth infestation. It is this reduction that is the focus of the research reported in this study. Without WH, total social benefit may be represented by the triangle P_1B'C in Figure 3.1. For any point to the left of A', additional benefit can be gained by expanding production while any point to the right of A', marginal costs exceed the marginal value of production. WH would have the effect of raising the equilibrium position from E' to E" while reducing the maximum quantity from A' to A". Total economic impact would be represented by P_1B'B"P_2. This can be partitioned between consumers and producers.

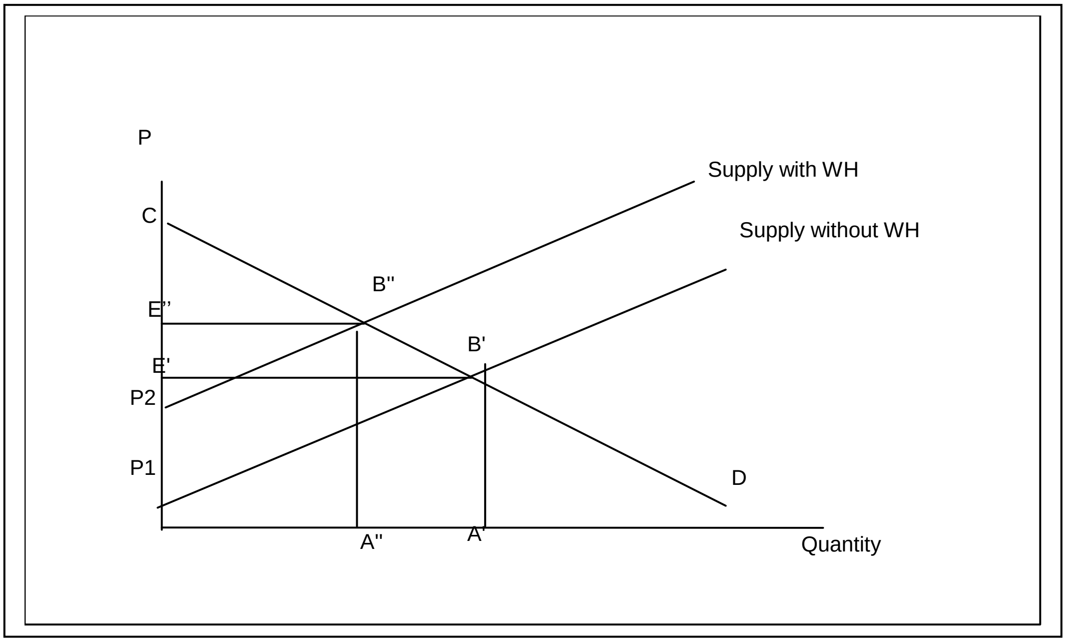


Figure 3. 1: Schematic representation of the impact of water hyacinth on the fishery

The model parameters underlying these hypothetical supply relationships are not known and need to be determined. It is necessary to use the neo-classical theory of the firm and its derivatives to analyze fish production and impacts of water hyacinth infestation of L. Victoria. This approach is novel, and implementation conceptually sound.

3.3 Microeconomic Theory of Production

Given a production possibilities set designated as *A(a)* where *a* (a vector of parameters) is the set of all input-output combinations, that set should satisfy the usual properties, i.e., *A(a)* is a non-empty, closed, convex, monotonic and bounded set. The production function may be written as:

$$F(X;a) \equiv \max_y [Y : (X,Y) \in A(a)] \ldots\ldots\ldots\ldots\ldots 3.1.5$$

Here, *X* is an *n* vector of inputs and *Y* is an output. The corresponding cost function is:

$$C(P_x, P_y, Y; a) \equiv \min_x [P_x^{\;A}, P_y^{\;A}, X : F(X,a) \geq Y] \ldots\ldots\ldots 3.1.6$$

where *p* represents input prices (p_x) and output prices price (p_y) respectively. The production function describes the *technical relationships between the levels of inputs and maximum output that can be obtained for a given technology*. It represents the technological restriction on the profit seeking behavior of the firm.

The basic statistical model used is:

$$Y = \beta_0 + \beta_k X + e \ldots\ldots\ldots\ldots\ldots\ldots 3.1.7$$

Let *Y*, the dependent variable, represent the level of output that is associated with the level of technology (inputs) *X*. Define β as a coefficient of transformation of *X* into *Y*, β_0 and *e* is an error term. *Y* is a vector of random variables with mean vector $X\beta$ and covariance $\sigma^2 I$ and *e* is a vector of random variables with mean 0 and variance $\sigma^2 I$.

Below is a description of the analytical framework of the specific models used in determining the impact of water hyacinth on fish production, net benefits and species composition.

3.4 Analytical Framework

3.4.1 Cost Benefit Analysis (CBA) of fishing under the Presence of Water Hyacinth

A cost benefit analysis remains an important part of carrying out impact analysis. The United Nations Environment Programme (UNEP) has published a series of books concerning the methodology and problems associated with CBA (UNEP Studies 4-6, 1981-1982). Although CBA is commonly used for project evaluation it is used extensively in the impact analysis particularly in analyzing the impact of research technologies (Kula 1994, Dasgupta and Pearce 1972; Norton 1984).

In this study CBA will be useful comparing costs and benefits arising from fishing with or without water hyacinth in the fishery sector. Profit for a single output is defined to be a function of output prices and input costs subject to the maximization of the difference between the total revenue and the total costs (Varian 1992; Nicholson 1992). In other words economic profit can be defined as the difference between the total revenue and the total economic costs. Based on this premise the major concern is to generate cost benefit ratios pertaining to fishing under the presence of water hyacinth[5]. This is meant to evaluate the effect of water hyacinth on the costs and benefits emanating from water hyacinth. In the ideal case this study is supposed to be undertaken in a situation where water hyacinth is present, and the results compared to the case when water hyacinth is absent. A situation of this kind is not easy to obtain since water hyacinth is a very mobile weed (migrates on hourly, daily or weekly basis) depending on the currents and the

[5] It is important to note that if the project benefits are spread over a period of time then you have to introduce time in the function and therefore generate the discounting factor. More information can be derived from Norton 1984 and Dasgupta and Pearce 1972.

direction of the winds. At the same time this study was undertaken after a successful implementation of an LVEMP control program undertaken by KARI through the release of weevils and provision of hand tools to the infested beaches. This was coupled with mechanical harvesting by an American firm in strategic sites, which had drastically reduced water hyacinth population by approximately 70%, in most beaches except in river mouths.

In view of these, this study was undertaken by establishing actual costs of fishing and estimated the costs of fishing under water hyacinth with socioeconomic data generated through the field survey. A comparison is therefore undertaken based on these two scenarios. There was need to estimate the fish catch per boat per day and the associated costs of fishing in order to determine the loss in terms of production and profitability associated with water hyacinth infestation. In order to generate this data a fish catch assessment (FCA) was undertaken in March, 2000 in the selected thirteen beaches on the basis of sampling procedures described above.

The main objective was to obtain data that could be used in doing an economic evaluation to ascertain the impact of water hyacinth on fish production, costs and net benefits.

This analysis is based on the following model:

$$NB_i = TR_i - TV_i - FC \qquad (3.2)$$

where, NB_i is the net benefits from fish production from individual i, TR_i (total revenue) is the fish catch for each species in kg/day multiply by the fish price and TV_i is the total variable costs, while FC refers to the fixed cost.

Since L. Victoria is a multi-species fishery where by the gears used are not entirely selective, the empirical model being estimated is as follows:

$NB_{ij} = \sum TR_{ij} - TV_i$ -----------------(3.3)

j is the specific fish species including Nile perch,Tilapiines, *R. argentea* and mixed fish. To summarize, the model shows that net benefits are computed from a summation of all incomes derived from various spp. and the total costs of fishing subtracted from it. The balance is the net benefit from fishing in a given period. It is important to note that the fixed cost is not included in the model as the values were not readily available.

3.4.2 Water Hyacinth, Socioeconomic Factors and Fish Catch/Value

3.4.2.1 Multiple Regression Model

This is a model where the variable under investigation is expressed as a single function (linear or non-linear) of regressors, which may be fitted using time series or cross section data. The single static multiple regression models are used based on the economic theory where it is postulated for example that demand for fish may be based on fish prices, income of the consumer, and other relevant variables. Time series data may be collected on these variables and may be used to estimate the model. Economists use production function approaches to determine economic impacts. Economic models are used to make decisions on production to abstract a model of production function. As already noted a production function is quantitative or mathematical description of the various technical production possibilities faced by a firm (Nicholson 1992; Pindyck and Rubinfield, 1981;

and Koutsoyiannis 1977). It gives maximum output in physical terms for each level of inputs.

In a simplified single equation regression may be expressed as:

$$Y_i = ß_0+ß_1X_{1i}+ß_2X_{2i}+_{\dots} ß_nX_{ni}+e_i \quad (i=1,2,\dots, n) \qquad (3.4)$$

where

Y_i is the dependent (random) variable, while X's is a group of regressors, ß's are coefficients to be estimated. e_i is a random error term to take care of the influence of the factors omitted from the model. This equation represents a linear relationship between Y and X's. Once the equation has been formulated the next thing is to estimate the coefficients (ß's) using available data. The main aim of establishing the coefficients is to be able to predict or estimate the relationship between Y and X's. The coefficients are often estimated using least squares methods which requires that the data used in the estimation conforms to the various assumptions including normality, meaning that the data should been drawn from a random sample.

Both cross and time series data should be subjected to diagnostic checks to ensure that they conform to the requirements of each specific model. This may include checks for multicollinearity and autocorrelation and more so stationarity and co-integration in the case of time series data.

When using time series data, economists use productivity indices as dependant variable with such variables as weather, education level of workers, lagged public expenditure on

Research and Development (R&D) as independent variables (Prey and Neumeyer, 1990). For more applications of Production Function Analysis, see Teng (1991), Dillon (1977) and Barnett *et al*. (1995). This model is commonly used in deriving economic relationships, the main assumption being that the changes in the dependent and independent factors are instantaneous.

As for this study the production function relates to either firms producing goods and services or households providing services that generate positive utility. A change in environmental quality (e.g. pollution level) alters the elements in a form of alternatives, which constrain the production choices, and so affects the decisions of the firm or agent in the pursuit of maximum profits. Therefore to assess the gain or loss of benefits resulting from such a change requires the analysis of biological processes technical possibilities, the interactions with the producer decisions and the effect of resulting production changes in a consumer/producer welfare (Hanley and Splash 1993).

The dose-response function takes the natural science information on the physical effect of environmental quality and uses this in an economic model. This method derives the pollutant dose and receptor response function and the choice of economic model and its application. Biological or production response data provide a link between pollutant dose and performance parameter of a production system. The response relationship may be quantified directly from biological experimentation, or indirectly from observed producer output and behavioural data such as secondary data or from some combination of different sources.

This technique is a measure of relationship between some cause of damage such as water hyacinth on fish production (Pearce and Moran 1994, Johansson & Lofgren 1985). It is a suitable method for valuing or measuring impacts on marketed goods but unsuitable for valuing non-use benefits. The dose response function may be multiplied by a price or value per unit of the physical damage to give a monetary damage function (marginal monetary value).

The empirical is formulated as Cobb Douglas PF:

$$QFbd = AE^{\alpha i} H^{\theta i} e^{(\beta_1 fm + \beta_2 Bp + \beta_3 sh + \beta_4 dw)} u \qquad (3.5)$$

where

QFbd - is the average quantity of fish landed in kg per boat per day or net income in Kshs per boat per day

E – is a vector of various quantitative inputs in terms of effort

H - is the quantitative socioeconomic factors

e - is the exponential function; consisting of a series of qualitative variables; fm = type of fishing gear used, Bp = boat propulsion method used, sh = type of segment, and dw = water hyacinth infestation status

u is the error term that is meant to capture the residual effect of the eliminated factors.

A, α's, θ's and β's are parameters to be estimated

It is hypothesized that water hyacinth has a significant effect on fishing activities hence affecting the output of fish in a given period of time. The $\partial Qfbd/\partial w>0$ is a positive partial derivative of quantity of fish to the environmental quality factor (i.e. water hyacinth) which indicates that a decrease in environmental quality will reduce fish output levels, *ceteris paribus*. The value of the change in dw can be estimated by valuing changes in production by using market price of fish.

The fish production function is estimated as log-log linear. Economists prefer the Cobb-Douglas function because its error specification allows for the use of logarithmic transformation and the least squares estimation techniques (Barr and Horell, 1976). Because of the criticisms that have arisen in the recent times concerning issues of stationarity and long term relationship of test variables multiple regression techniques are suitable for cross section but not time series data. The above empirical model is to be estimated using cross section data derived form the field survey and fish catch/value assessment carried out in the thirteen sample beaches.

3.4.2.2 Model specification and rationale

The fishery production function was estimated based on equation (3.5) above. The major aim was to determine the effect of the environmental quality (presence of water hyacinth) amongst other factors in the production of fish around Lake Victoria. This is consistent with the economic value measure, which requires that a change of status for proper economic valuation to take place. Below is a full description of the rationale and a priori signs of the hypothesis of the variables included in the model

3.4.2.2.1 Fisherman experience in fishing

The number of years a fisherman has been involved in fishing gives him/her an upper hand in knowing the correct time, seasons and strategies to be employed to maximize fish catch on every trip. On the other hand the fisherman with a high number of years of experience may be too old to go fishing hence may rely on hired labour which may not be as experienced, hence leading to reduced catches. This variable is expected to be either positively or negatively related to the fish catch depending on the person who actually participates in the actual fishing (i.e. head of the crew).

3.4.2.2.2 Fishing crew

The total number of people engaged in fishing is a measure of effort, which may determine the quantity of fish catch. This effort is commonly referred to as the fishing crew. Effort as an input in the fishery sector may also include the gears used in fishing, number of boats and fuel. Since we are measuring total catch per boat usually referred to as the catch per unit effort (CPUE) the number of boats cannot be used as a regressor. The higher the number of the fishing crew the more the fishing gears that can be handled and the further the crew may travel especially if they are using paddles in search of more fish. Okedi 1981 found that fish catch was positively related to the fishing crew for various species. It was therefore hypothesized that the fishing crew will be positively correlated with the fish catch and incomes.

3.4.2.2.3 Boat size

The size of the boat determines the maximum number of fishnets (gears), the crew and the quantity of fish that could be transported. In another context smaller boats may not be used to fish in the deeper waters of the lake, hence flexibility becomes a problem for the smaller boats. This shows that to some extent boat size could be an important factor in explaining the amount of fish landed. Muhoozi and Ogutu 1999 showed that fish catch was positively related with the boat size. The length (in metres) of the boat was used to approximate the boat size. It is hypothesized that the size of the boat is positively related to the fish catch.

3.4.2.2.4 Water hyacinth infestation

Water hyacinth may infest beaches at different times and intensities. The period water hyacinth covers a particular beach is quite variable: daily, weekly, monthly and yearly. This is because of the high mobility of this weed, which mostly depends on lake currents/winds direction. The total cover of WH provides good breeding ground for fish. However, the WH cover interferes with oxygen supply, which may affect some specific fish species. For example, Nile perch and *O. niloticus* requires more oxygen as compared to the local species such as *Protopterus* and *Clarias* The impact of the water hyacinth on fish production will be determined by the coefficients of accessibility and water hyacinth cover ($\partial Qfbd/\partial w$). Since there was no hyacinth in most of the beaches during the time of the survey a dummy variable for the presence and absence of water hyacinth was used in the production function, with a value of one representing those respondents who were in water hyacinth infested beaches and zero being otherwise. This variable is expected to have a positive or negative effect on the quantity of fish landed depending on the biological characteristics of the individual fish species.

3.4.2.2.5 Type of fishing gears

The type of fishing gears and mesh sizes is an important determinant of fish catch. As described in the introduction each fishing type targets a particular fish species and size, although this is not purely exclusive as the gears may also catch other types of fish depending on the type of fishing ground. As Rabuor and Manyala 1991 reports gillnet is one of the popular method used in targeting Nile perch and *O. niloticus* depending on the mesh size used, while mosquitoe seine targets mostly *R. argentea* which uses mesh size of 5 and 10 mm. In addition, the beach seine mainly catches Nile perch and *O. niloticus*, when used in shores. Similarly to longlines where hooks of various sizes are used and also targets Nile perch and *O. niloticus*. For example, if mosquitoe seine is used near the lakeshore it may catch Tilapiines, *Protopterus* and smaller Nile perch but when used in deep waters it captures *R. argentea*. The bigger the mesh size the larger the size of the fish caught, while the smaller the mesh size captures all fish targeted including juveniles. The type of fishing gears was used as a variable in the model but not the mesh size because of inadequate information. A dummy variable was used for each of the fishing gears (gillnets, beach seine, long line, mosquitoe sine and mixed gears) [6]. This variable was used to measure the productivity of each fishing gear as opposed to the mesh size. The productivity of each fishing gear is dictated by the mesh size that is used. Beach seines and mosquitoe nets are expected to have higher catches because of the small sizes used. The mixed fishing gears were used as a reference, hence, not included in the model to avoid multicollinearity. A value of one was used when a specific gear was used and zero for the rest.

[6] The mixed fishing gears consisted of hand line, cast nets, drift nets, silencer and combinations of the regular gears and others.

3.4.2.2.6 Propulsion method

The propulsion method was also used in the model to capture variation in catch associated with the use of different propulsion methods. The three propulsion methods included the paddle, sail and outboard engine. The use of paddle was taken as a reference method hence not included in the model. The dummy variable was used as in the case of the fishing gears. Because of the ease of maneuvering and the distance that can be covered the outboard engine propelled boats may be associated with a higher catch as compared to the paddle, which may be limited by the ability of the fishing crew. The effect though is expected to vary across the different fishing species.

3.4.2.2.7 Type of segment

The type of segment was used to account for the variation in fish catch as a result of weather, prices, rainfall and type of effluents existing in various fishing beaches. Three segments were used in the study, namely, Northern, Central and Southern (for the classification of the sample beaches see Table 3.1). The Southern segment was used as a reference. The rest were entered as dummies of one and zero. Although all the three segments may be exposed to various kinds of effluents and climate variation, the central segment, which is located around Kisumu town, may be exposed to more effluents emanating from numerous industries from near the town and the agricultural environs through the rivers Nyando and Kisat. In addition, the depth of the lake in the various segments may be a key determinant in the quantity of fish for the various species. Ligtvoet and Mkumbo 1990 reported that higher catches of Nile perch were found in the 16-35m depth. Tilapiines and mixed fish are known to exist in low depth waters less than

20m. On the other hand *R.argentea* exist in deep waters of the lake as in the case of the Nile perch.

3.4.3 Water hyacinth, Rainfall, Prices and Fish Productivity, 1990-2000.

3.4.3.1 Error Correction Model

During the last twenty years scientists (Noriega-Muro 1993, Thomas 1993) have tried to address the problem that arises when dealing with time series data, which are mainly hinged on the fact that most economic data series are non-stationary and only become stationary[7] when first differenced. The ECM was initiated by Sargan (1964) and in recent years it has been associated with Hendry Approach to econometrics particularly addressing the problem of spurious correlation. The spurious correlations are experienced when the variables being considered show consistent trends upwards or downwards over time.

In order to avoid this problem economists have tried to use differenced data hence considering the rate of change of variables rather than focusing on their absolute levels. The aim of using the rate of change is to eliminate any trend element (Thomas 1993) based on the premise that most economic time series become stationary when they are first differenced[8]. The major shortcoming of using rate of change has been that the long run relationship between levels of the variables will be lost.

[7] A stochastic process is said to be stationary if the mean and variance remain constant overtime. The covariance and hence the correlation between the two values (e.g., y and x) taken from different periods depends on the difference apart in time between the two values. If the series do not meet these conditions then it is referred to as having unit roots. See Kendall 1990 for more details.

[8] The use of the first differences in a regression may also be used to solve some special problems of serial correlation in order to transform the data so that it conforms to OLS assumptions. See Wonnacott and Wonnacott (1979).

For example, if the series

$$Y_t = \beta_0 + \beta_1 X_{1t} + \beta_2 X_{2t} + \varepsilon_t \qquad (3.6)$$

Where ε_t is the disturbance term,

$$Y_t - Y_{t-1} = \beta_1(X_{1t} - X_{1t-1}) + \beta_2 (X_{2t} - X_{2t-1}) + u_t \qquad (3.7)$$

where $u_t = \varepsilon_t - \varepsilon_{t-1}$

when Equation (3.7) is estimated there is no information obtained on β_0. This equation specifically focuses on the short run relationship between X and Y ignoring the long run relationship even if it exists. It is on this basis that Sargan developed the ECM results in equations, which are first differenced, and hence stationary dependent variables.

An ECM implies an underlying equilibrium relationship, as Engle and Granger (1987) show that if two variables are co-integrated (i.e. if an equilibrium relationship exists) then the short run' dis-equilibrium' relationship between the variables can always be represented by an ECM popularly referred to as the Granger representation theorem. This also means that if there is no equilibrium relationship then one should not represent the short run behaviour by the ECM.

A simplified ECM can be represented in the following format:

Assume in equilibrium or 'steady state' two variables bear the following relationship

$$Y_t = KX^{\gamma 2}{}_t \qquad (3.8)$$

where γ_2 and K are constants.

Letting small letters denote natural logarithms of the variables:

$$y_t = \gamma_1 + \gamma_2 x_t \qquad (3.9)$$

If y and x are at all times in equilibrium then, $y_t - \gamma_1 + \gamma_2 x_t = 0$. However, in practical sense there are many cases when this equilibrium value will be non-zero hence measuring the extent of dis-equilibrium between x and y. The values generated, $y_t - \gamma_1 + \gamma_2 x_t$ are referred to as dis-equilibrium errors.

The underlying principle is that since x and y are not always in equilibrium therefore we cannot observe the long run equilibrium relationship, therefore what can be observed is the disequilibrium relationship involving lagged values of x and y, when in equilibrium

This dis-equilibrium relationship can be depicted as:

$$y_t = ß_0 + ß_1 x_t + ß_2 x_{t-1} + \alpha y_{t-1} + u_t \qquad 0<a<1 \qquad (3.10)$$

where u_t is the disturbance term

Equation (3.10) is expressed in the levels of variables that are prone to non-stationarity. This equation can be re-arranged and reparameterised as follows:

By subtracting from either side y_{t-1}

$$\Delta y_t = ß_0 + ß_1 \Delta x_t + (ß_1 + ß_2) x_{t-1} - (1-\alpha) y_{t-1} + u_t \qquad (3.11)$$

Where $\Delta y_t = y_t - y_{t-1}$ and $\Delta x_t = x_t - x_{t-1}$ and Δ denotes the first difference and $_{t-1}$ is the one period lag of the variable considered.

Equation (3.11) can be reperamaterised as:

$$\Delta y_t = ß_0 + ß_1 \Delta x_t - (1-\alpha)\{y_{t-1} - \gamma_1 - \gamma_2 x_{t-1}\} + u_t \qquad (3.12)$$

Where $\gamma_2 = (ß_1 + ß_2)/(1-\alpha)$

Therefore equation (3.12) can further be reparameterised as

$$\Delta y_t = ß_1 \Delta x_t - (1-\alpha)\{y_{t-1} - \gamma_2 x_{t-1}\} + u_t \qquad (3.13)$$

Where $\gamma_1 = ß_0 /1-\alpha)$

This final equation can be interpreted as the changes in y depends on the changes in x and the term in the square brackets which is the disequilibrium error from the previous period. The value of Y is being corrected for the previous disequilibrium hence the term error correction model.

In determining the coefficients ordinary least squares can be used to estimate the long run parameters γ_1 and γ_2 and similarly to short run estimates ß$_1$ and a using the residuals from the log run equation in

$$\Delta y_t = ß_1 \Delta x_t - (1-\alpha)\{y_{t-1} - \gamma_2 x_{t-1}\} + u_t \qquad (3.14)$$

which is similar to:

$$\Delta y_t = ß_1 \Delta x_t - (1-\alpha)e_{t-1} + {}_t$$

An alternative to this approach is to estimate the long run and short run parameters simultaneously using equation 3.12), reformulated as:

$$\Delta y_t = ß_0 + ß_1 \Delta x_t - (1-\alpha)y_{t-1} + \gamma_2(1-\alpha)x_{t-1} + u_t \qquad (3.15)$$

Where $ß_0 = \gamma_1(1- \alpha)$.

The long run parameter can be derived from the ratio of the estimated coefficients of x_{t-1} and y_{t-1} while that of γ_1 is obtained from the ratio of the constant term to the coefficients of $y_{t-1.}$

Because ECM involves the differenced variables and not trending, it is therefore appropriate to use the R^2 without worrying about the spurious correlation problems. In this model ECM is estimated using the first order lag errors from the co-integration model with appropriate lags on different variables using the following equation:

The ECM used in this study is specified as :

$\Delta LCbm_t = \beta_1 \Delta Lrfl_t + \beta_2\ \Delta Lfpc_t - (1-\alpha)(\ LCbm_{t-1} - \gamma_1 - \gamma_2 Lrfl_{t-1} - \gamma_3 Lfpc_{t-1}) + \omega Dumw + u_t$ ……….(3.16)

which may also be rewritten as:

$\Delta LCbm_t = \beta_1 \Delta Lrfl_t + \beta_2\ \Delta Lfpc_t - (1-\alpha)\ e_{t-1} + \omega Dumw + u_t$ …………(3.17)

where the short run parameters are $\beta_{1,}$ β_1 and α, while ω is the coefficient meant to capture the effect of water hyacinth on the fish catch. Δ is the first difference operator.

This model is estimated using monthly data derived from three sample beaches. In this model there is a particular interest to determine the effect of water hyacinth on fish productivity and that is the reason why this variable is added in the model as a dummy variable. There were no data available for the surface cover of water hyacinth across the sample beaches and even the entire lake.

3.4.3.2 Co-integration Techniques

It is important that the data used in the regressions model are non-stationary and the variables should be co-integrated[9]. It is on this basis that the data used should be checked and corrected for these deficiencies in order to avoid making what economists call spurious correlations. According to Granger and Newbold (1974), 'as a rule of thumb, if R^2 is greater than the Durbin Watson Statistic (i.e. R^2>DW) then there is suspicion that the estimated regression suffers from spurious correlation' where by the variables exhibits long term upward or downward trends over time.

[9] Co-integration is the statistical implication of a long-run relationship between economic variables. The existence of an equilibrium relationship between x and y requires them to be integrated to the same order or vice versa and that a linear combination of the two series be I(0) or stationary or vice versa.

The co-integration test[10] may be done using a variety of tests such as Dickey and Fuller (DF), Augmented Dickey and Fuller (ADF), Philipps and Perron (PP) and Johansen. The Johansen test (1988) is preferred because it is the most powerful of the tests. As it is also able to determine multiple co-integration. Johansen has proposed two likelihood ratio tests:

The first method is the trace statistic test:

$$\lambda_{trace}(r) = -T\sum_{i=r+1}^{n}\ln(1-\lambda_i) \text{ --}(3.18)$$

where λ_i is the estimated value of the ith characteristic root of the Π, while T is the number of observations and Π is the coefficient measuring the long-run relationship between the variables in the co-integration equation. If co-integration exist then the expression Π=vk' whereby v represents the speed of adjustment to equilibrium and k' is a matrix of long-run steady state coefficients.

The null hypothesis states that the number of distinct co integrating vectors is less than or equal to r: where r:

$$H_0:\lambda_i=0,\ i=r+1,\ldots,n \qquad (3.19)$$

The second test is maximum eigenval or λ-max test. The null hypothesis states that the number of co integrating vectors is r against the an alternative of r +1.

$$\lambda_{max}(r,r+1) = -T\ln(1-\lambda_{r+1}) \qquad (3.20)$$

The computed statistics are compared with the critical values, which can be found in Johansen and Juselius (1990) and various time series textbooks.

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[10] To read more about co-integration analysis contact the following references Mkenda and Folmer 2001 and Thomas1993.

3.4.3.3 Model specification and rationale

3.4.3.3.1 Quantity of fish landed (Lcbm)

This variable was defined to be the quantity of fish landed in tonnes per boat per month for the four major species in the three sample beaches covering the period 1990-2000. This is also referred to as the catch per unit effort (CPUE) in the language of the fishery. It measures the productivity of the effort invested in fishing for labor, fishing boat and fuel. This variable was preferred to the total catch per month per boat/beach because there was no adequate and reliable data to compute this variable for the entire beach. The value of the fish caught could also be used as dependent variable but since price appears as one of the regressors then this could create the problem of multicollinearity. In defining a supply function the quantity may be expressed as a function of the price and technology.

3.4.3.3.2 Fish price (Lfpc)

From economic theory, fish price is hypothesized to influence the total quantity of output supplied to the market (Chaston 1983, Ranaweera 1991). In the short run supply is assumed to be fixed whereby in this case the price is only used to ration demand, therefore the price may vary depending on the quantity demanded. The short run supply elasticity measures the proportionate change in the market price to the changes in the total output[11]. However, when firms experience high prices in the short run they will respond by increasing their production through expanding their variable inputs such as labour, while in the long run they may have to vary their fixed inputs (e.g. purchase more

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[11] For the mathematical representation of the supply price elasticity see Nicholson 1992

fishing gears and boats) (Norton 1984). In view of this analysis two forces in the market being the quantity supplied and the quantity demanded may determine price of a commodity. The nature of the changes in the price will therefore depend on the price elasticities. Although it may be difficult to differentiate between the quantity supplied to the quantity demanded in the case of some of agricultural commodities (Tomek 1990). Fishery could be counted as a commodity, which behaves the same way. In Kenya in most cases the quantity landed is sold out unless the buyers fail to show up because of poor weather making roads impassable. In particular since the artisanal fishery has poor or no storage facilities there are no stocks for fishery since all the quantities should be sold out to avoid getting spoilt. SEDAWOG 1999 and Hannesson 1993 infer that that fish prices depend on the fish size, weight and buyers influence.

Therefore the fish price for each spp. would be dependent on the forces of demand and supply in the market for each species. Of course in the market a higher price signals higher profit margins hence the increased incentive to spend more time fishing to capture the market. The fish price is an indicator of the fisherman's profitability hence the higher the price the increased incentive to produce more. On the other hand, the increased quantity landed will have the effect of depressing the prices offered by the consumers. SMEC 2002 and Abila et al 2002 observed that the L.Victoria (Kenya) fisheries had generally experienced decreased fish landings and excessive demand which subsequently led to an increase in the fish prices. As Ikiara 1999 and Jansen *et al* 1999 have pointed out over-fishing has been due to excessive demand for fish both locally and externally hence increased prices. It is hypothesized that fish price will have a positive relationship with the quantity of fish landed.

In a number of studies (e.g., Adjaye 2000) consumer price index (CPI) has been used where reliable records on the prices are absent as this represents the general movement of price levels for a selected basket of goods over a given period of time. The beach officials and or the Fisheries Department do not keep records on monthly prices of fish. Abila and Jansen 1992 demonstrated that there was a very close movement of fish prices (Nile perch and *R.* for the period 1991-1993 and the CPI. Therefore in the absence of reliable monthly records fish prices, the CPI was selected as the most suitable approximation of the monthly fish prices in this study, with 1992 chosen as the base year

3.4.3.3.3 Water hyacinth surface cover (Dumw)

As indicated in Section 3.4.2.2.4 the impact of water hyacinth cover is expected to be positively or negatively related to the quantity of fish landed. The impact of the water hyacinth on fish production will be determined by the coefficient of water hyacinth cover (∂Lcbm/∂Dumw). In the absence of actual data on the water hyacinth coverage per month a dummy variable was used. This variable was used to measure the effect of water hyacinth on the fish landed. The period under investigation 1990-2000 was subdivided as 1990 to 1995 being considered having low water hyacinth infestation, while 1996 to 2000 having high infestation. This categorization is based on information provided by KARI, the Fisheries Department and Beach Management officials.

3.4.3.3.4 Rainfall (Lrfl)

It has been reported that the flow of water into the lake carries with it effluents and nutrients washed away from the agricultural farms and industrial environs. These provide the nutrients to the plants and living organisms in the lake. These inflows lead to rapid growth of plants, which become food for the fish for example, planktons. The water hyacinth also proliferates on these inflows. Rainfall provides the water that runs to the lake as it carries the effluents and the nutrients. In the short run rainfall may interfere with fishing activities and also making the roads impassable to the buyers. Therefore its intensity is expected to affect fish availability (stocks) and what is harvested. There are reports indicating that rainfall has been associated with increased fish catches (Othina and Ntiba, 1995, and Othina and Cowx 2002, Othina *et al* 2000, Welcome 1970). This variable may have either positive or negative effect on the fish catch. The rainfall variable was measured in millimeters (mm) per month.

3.4.4 Water hyacinth, Prices and Fish Species Composition on L. Victoria, Kenya.

3.4.4.1 Introduction

Species are a population within which gene flows occur under natural condition. Biologists' measure species diversity to determine the relative abundance of a particular species in a given environment. Species diversity is a function of its distribution and abundance of species, i.e. the number of species in a region or a given area. In recent times the concern of ecologists and economists has been valuing biological diversity. The attempt has been to measure people's preferences through the willingness to pay (WTP) for their conservation. The valuation is based on its value in money terms, that is preference revelation as determined through the WTP or by inferring their WTP through other means (Pearce and Moran 1994).

The total economic value (TEV) of an environmental resource consists of its use value (UV) and non-use value (NUV). The UV is further subdivided to include direct use value (DUV), which refer to the use value such as fishing, timber extraction, etc and indirect use values (IUV) which refers to the benefits derived from an ecosystem functions such as forest function in protecting the water shed; and option values (OV), which is a value approximating an individual willingness to pay to safe guard an asset for the option of using it in future. The non-use values (NUV) on the other hand are not very clearly defined and estimated, but are usually divided between a bequest value (BV) and an existence or ‘passive’ use value (XV). The former measures the benefit accruing to an individual from the knowledge that others may benefit from a resource in future while the latter are unrelated to current use or option values, deriving simply from the existence of any particular asset.

In totality then we have the following function:

$$TEV = UV + NUV = (DUV + IUV + OV) + (XV + BV) \qquad (3.21)$$

There have been numerous studies on the L. Victoria giving trends of the fish species composition during the last two decades (Okemwa 1981, Namulemo 1999 and Ochumba *et al* 1991). Two main approaches have been used to study the composition of fish in the lake. The first method involves scientists carrying out trawl surveys in the lake on the targeted location or environment or species. The various fish types are then sorted out into their distinct taxonomic groups or species. The weight and counts of the various species is used to determine their relative abundance in the lake. The second method is where analysis is based on the total annual weight of the various species landed in all the beaches and reported in the year. These records are used to determine the relative proportion of each species landed in a given period.

The results emanating from both approaches gives an indication that Nile perch, *O. niloticus* and *R. argentea* have become dominant in the lake in the recent times, replacing the endemic Haplochromines and other local species. However, there has been little attempt to capture some of the factors responsible for the changing scenario (composition) through econometric approaches. Biologists have cited a number of factors that may be responsible for this trend including the introduction of Nile perch and *O. niloticus*, changing lake environment and the appearance and proliferation of water hyacinth.

This has created the need to undertake a study to determine the effect of water hyacinth in the changing fish composition. In this study the value of the lake was based on the total amount of fish caught by each fish species over the time. The study sought to assess the impact of water hyacinth and fish prices on the abundance of individual fish species. An econometric model was developed that could explain the impact of water hyacinth and the fish prices on the quantity of fish landed.

An increase in the fish catch over the period by a particular species implies that there is an increase in the value/ or importance or availability of that species in the fishery. The reappearance of some of the species and disappearance of others gives a connotation that there is an imbalance in species diversity which is a case being experienced in L. Victoria and being associated with water hyacinth among other factors (See Okeyo 1999).

3.4.4.2 Vector Autoregressive Regression

According to Sims (1980) if there is true simultaneity among a set of variables then all variables should be treated equally hence no categorization of endogenous or exogenous variables. The vector auto regression (VAR) methodology resembles the simultaneous equation models in that several endogenous variables are considered together. The crux of this model is that each endogenous variable is explained by its lagged, or past values and the lagged values of all other indigenous variables in the model. In this model there are no exogenous variables. The term autoregressive is due to the fact that the model uses a lagged value of the dependent variable as one of the regressors while the term vector expresses the fact that the model has a vector of two or more variables (Gujarati 1995, Griffiths *et al* 1993).

A VAR model may be formulated as follows:

$AS_t = \alpha + \sum \beta_j AS_{t-j} + \sum \gamma_j TB_{t-j} + u_{1t}$, where j=2 (3.22)

$TB_t = \alpha' + \sum \theta_j AS_{t-j} + \sum \lambda_j TB_{t-j} + u_{2t}$, where j=2

AS and TB are two time series which are assumed to be endogenous and have no serial correlation.

The α, β,γ,θ and λ's are variables whose coefficients are to be estimated j refers to the number of lags used in the model, while t=refers to the time period and u's are the stochastic error terms, referred to as impulse or innovations in VAR with each equation having two lags.

The variable estimates are obtained using any of the Computer Soft ware such as TSP and Pc Give. These estimates are derived using ordinary least squares and hence the interpretation of the results is the same as when you are handling singular regression equation. However, it is important to note that with several lags of the same variable, each estimated coefficient will not be significant statistically but probably as a result of multicollinearity but may be significant collectively based on the F-test.

The impulse response function (IRF) are used to detect the response of the dependent variable in the VAR system to shocks in error terms, such as u's. for several periods in the future. In order for the VAR to generate valid inferences it is necessary that the times series used in the estimation of the coefficients are jointly stationary. As indicated earlier, the VAR model assumes that there is no serial correlation in the reduced form errors and in addition to these standard errors assumptions the VAR process is stationary. These assumptions means that the time series may not have trends, or seasonal patterns, or variances that change over time. In order to obtain these conditions some transformation on the data may be necessary. To have the data in the required form the data used in this analysis was first differenced.

The VAR model was specified as:

$$FQ_t = \alpha + \sum\theta_j FQ_{t-j} + \sum \beta_j FP_{t-j} + \sum\gamma_j WH_{t-j} + u_{1t}, \text{ where } j=1$$

$$FP_t = \alpha' + \sum\delta_j FQ_{t-j} + \sum \rho_j FP_{t-j} + \sum\eta_j WH_{t-j} + u_{2t}, \text{ where } j=1 \qquad (3.23)$$

$$WH_t = \alpha'' + \sum\pi_j FQ_{t-j} + \sum \tau_j FP_{t-j} + \sum\mu_j WH_{t-j} + u_{3t}, \text{ where } j=1$$

where

FQ_t = Quantity of fish landed in tons per year in year t;

FP_t = Fish price per ton in year t;

WH_t = Water hyacinth intensity for year t;

There is an economic theoretical basis of deriving interrelationships between fish catch and price. The VAR model defined above with Water hyacinth as one of the endogenous variables require some explanation. The inclusion of the third equation is dictated by the VAR system of equations, which treats all explanatory variables as endogenous. Secondly through expectations an increase in the price of fish could give the fishermen the impetus to remove water hyacinth from the beaches in order to gain access to the fishing ground. In the same token low catch of fish due to water hyacinth infestation may similarly prompt the fishermen into water hyacinth removal hence reducing its incidence.

The basic aim of this study is to establish if there is any relationship between fish production, price and water hyacinth. The major question is to find out whether water hyacinth is responsible for the decline or increase of production in certain fish species or not.

3.4.4.3 Model specification and rationale

3.4.4.3.1 Quantity of Fish landed (Lfishwt)

Quantity in tons per year for each fish species is used as a dependent variable. Eight fish species are used in this study. They include three commercial species, namely *Lates niloticus*, *R. argentea* and *O. niloticus*. The remaining ones include mixed Tilapiines, Haplochromines, *Clarias, Mormyrus* and *Protopterus*. These are the major spp. being landed on the Kenya side of L. Victoria. It is important to note that approximately 36 fish species are landed on the Kenyan side of L.Victoria out of a total of about 500 fish species.

3.4.4.3.2 Water hyacinth intensity (Lwindex)

This variable was represented as a proxy by the intensity of water hyacinth (surface cover). The amount of water hyacinth cover is hypothesized to influence the amount of fish catch. This influence may vary depending on the species type and feeding habits. Moderate to heavy water hyacinth infestations blocks both the landing beach and fishing ground such that accessing the fishing ground and landing at the beaches becomes cumbersome and hence more effort spent in terms of extra labour, fuel, and damages on boat and fishing gears. This is the negative part while the positive factor indicates that water hyacinth may lead to increased catch when the resident mat moves away. Therefore it is hypothesized that water hyacinth will have positive or negative sign to the quantity of fish catch depending on the type fish species and the fish habits. Fish species have different characteristics pertaining to their habitats.

This variable was estimated using the intensity of water hyacinth cover since 1991 as shown in Table 4.2. The severity index obtained from the field survey is taken to be a close approximation of the quantity of water hyacinth cover over the time in the respective segments since the actual data for water hyacinth coverage on the lake over time is unavailable.

3.4.4.3.3 Fish price (Ldfspric)

This price is as defined in Section 3.4.3.2.2. However, the prices were deflated using the consumer price index for Kisumu town with the base year being 1992. This is meant to take care of inflation and ensure the use of real prices in the production model over the period.

3.4.4.3.4 Time (Tindex)

Time was used in the regression model for all fish species studied. It is important to include this variable as it helps to measure the technological effect (autonomous growth) on the production processes. Trend analysis used this variable in order to determine the nature of change in the fish production by the various fish species over time.

3.4.5 Other models; Simultaneous regression models

Other econometrics models that are available and could be used in this study include the multi-equation simulation models where the variable to be estimated may be a function of several regressors which are related to each other as well as the to the variable being investigated through a set of equations. A set of individual relationships each are developed and fitted to the available data. Simulation is defined as a process where these equations are solved simultaneously over some range of time. Partial adjustment models may be used in the impact assessments particularly where there is no instantaneous response of the explanatory variable to the dependent variable.

3.5 Data collection Procedures

Cross section data was collected from 13 sample beaches (out of a total of 297 registered beaches) dotting the Lake Victoria (Kenya) shoreline divided into three segments (Northern, Central and Southern) at different WH infestation levels. This was meant to ensure that the impact of WH is captured spatially and at different intensities. Three sample beaches were earmarked for time series data collection on fish productivity. Time series data on fish catch for the entire Kenyan lakeside were collected from the Fisheries Department. Additional data were obtained through secondary sources. The various methods used in gathering data are described below in details.

3.5.1 Field Surveys

A structured questionnaire was used to elicit information on the effect of water hyacinth on fish production among the fishing communities of Lake Victoria (Appendix 1). Data was collected on various activities viz. farm resources (i.e., land, labor and income), enterprise type and off-farm employment, fishing activities and water hyacinth infestation. The sample area covered the Winam gulf, which was sub-divided into three segments Table 3.1. The three segments were Segment one, two and three referred to as Northern, Central and Southern, respectively. A multi-stage sampling technique was used. The first stage consisted of segment while the second involved the choice of the sample beaches. In each segment a minimum of three beaches were selected purposefully ensuring that they represented three levels of water hyacinth infestation (low, moderate and high).

The sample beaches were classified according to the intensity of water hyacinth cover and the time the beach is covered in a year. The choice of the various beaches into different categories was based on information derived from KARI scientists and the fisheries department staff. The beach membership register formed the main sampling frame. The respondents were selected randomly, however, where the beach had a relatively small number of boat owners, all the units were enumerated. A total of 293 respondents were interviewed from thirteen landing beaches (Table 3.1). The questionnaires were administered between December 2000 and February 2001 in all the sample beaches. Table 3.1 gives the details of the sample beaches by location, segment, size in terms of registered boats and water hyacinth infestation levels.

3.5.2 Fish/Catch Value

This source consisted of collecting information on actual field catch, value and costs for the individual boat/gear owners undertaken in all the sample beaches in the month of March 2001. Out of the total number of boat owners interviewed, between 13 and 30 boats from each sample beach were recruited for the fish catch value assessment. Records on the quantity of fish catch (by fish species), fishing frequencies and expenses (through actual measurements) and water hyacinth infestations were collected on a daily basis for the whole month and filled in a data sheet (Appendix 2). These records were taken on the sample boats in the entire period for the days the boats were engaged in fishing.

Table 3. 1: Distribution of Sample Size by beach, district and segment

Name of beach	District	Type of segment	Registered no. of boats	No. of boat owners	WH intensity rating	Sample size
Busembe	Busia	1	29	26	L	15
Bumbe	Busia	1	31	27	L	15
Bukoma	Busia	1	97	72	M	38
Namabusi	Busia	1	157	100	H	33
Kaloka	Kisumu	2	43	28	L	29
Ogal	Kisumu	2	62	58	L	30
Dung	Kisumu	2	72	58	L	30
Kusa	Nyando	2	57	53	H	27
Ng’ou	Nyando	2	10	10	H	3
Obaria	Rachuon yo	3	38	35	M	16
K’Amolo	Rachuon yo	3	25	18	M	14
K’Oberio	Rachuon yo	3	50	38	L	30
K’Oginga	Homa Bay	3	37	20	H	13
Total			708	543		293

Note: L-Low, M-Moderate and H-Heavy infestation.

Segment 1=Northern; 2=Central; and 3=Southern

3.5.2.1 Fish catch and income

The survey enumerators[12] separated all the fish landed in the sample boats, took the weight of each species, and recorded the value of the fish sold. These records were kept for the three major species; *Lates niloticus, R. argentea,* Tilapiines and the fourth category consisted of all other mixed species. The weights were determined using weighing scales. The value of the fish was based on the prevailing market price especially for Nile perch while for other fish species through actual sales.

3.5.2.2 Fishing costs

The cost of fishing was estimated by enumerators through daily interviews on how much they actually spend on fishing on a daily basis (or fishing trip). These were mainly variable costs which included: expenditures on food, boat and gear repairs, retention for boat, baits, fuel and other miscellaneous expenses for each propulsion method including paddles, sail and outboard engine. It was not possible to obtain reliable estimates of the fixed costs that include purchase of boat and fishing gears, annual levies, etc.

3.5.2.3 Net benefits

The net-benefits were computed by getting the difference between the gross incomes and fishing costs (variable costs). In practice most fishermen have an agreed formula for apportioning costs and computing the net income. Often the expenditures on food, boat and gear repairs, retained fund for boat repairs (in some beaches), baits for specific gears, and other miscellaneous expenditures are deducted from the gross sales from the catch on

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[2] The survey enumerators were earlier trained on the survey methodologies, identification of different fishing gears, fish species, their weight and value estimation prior to undertaking this exercise

that day (trip) and the balance is shared equitably between the boat/gear owner and the fishing crew. There exist some small variation on the sharing ratios by beach and fishing gear types of the proceeds. The fishing crew has no fixed income as it entirely depends on the value of fish.

3.5.3 Water hyacinth

The enumerators were required to give a comprehensive report on the water hyacinth status on a daily basis as they recorded the fish catch at the beaches. This included the presence or absence of water hyacinth at the beach and the degree of infestation. However, it is important to note that only two beaches in the sample (Kusa and Ngo'u) in segment two had substantial water hyacinth infestations at the time of the survey. The two beaches are adjacent to one another and have had the longest period of water hyacinth cover over the period because of their location being in a hidden bay where winds and water currents blow the mat in but not easy to blow them out in the way.

3.5.4 Secondary data

3.5.4.1 Lake wide fish Production data

Lake wide fish production data was derived from the Fisheries Department (Headquarters). This information included tonnage and value for the landed fish by species for the period 1986-2000 on the entire Kenyan side of L. Victoria. The fish species considered included; Nile perch, O. *niloticus*, Mixed Tilapiines and *R. argentea*, in addition to *Clarias*, Haplochromis, *Mormyrus* and *Protopterus.* These data were used in the establishment of trends in the fish species composition in terms of weight and value and in assessing the impact of water hyacinth.

3.5.4.2 Fish Production data from sample beaches

Monthly data on fish production data (fish catch and effort for sample beaches were sourced from Kenya Marine and Fisheries Research Institute (KMFRI) for the period 1990 and 2000. The six sample beaches included; Dunga (Kisumu district), Kendu Bay (Rachuonyo district), Sori Karungu (Migori district) and Bukoma (Busia district) and Kusa beach (Kisumu). Marenga beach was considered only for *R. argentea*, which formed part of the data for Bukoma Beach.

Out of these three beaches (Dunga, Kendu Bay and Uhanya) were used in the study. The rest of the data from Sori Karungu, and Bukoma were excluded from the study as they had incomplete data mainly for the major fish species being investigated, while Kusa beach had no data records for the period when it was completely covered with water hyacinth from 1994. As in the case of cross section data Kendu Bay, Dunga and Uhanya represented beaches with heavy, moderate and low water hyacinth infestation, respectively, over the period when the beaches were infested with water hyacinth.

This period has been subdivided into two, with the first being 1990-1995 classified as the period with low water hyacinth infestation while 1996 to 2000 being the period with heavy water hyacinth infestation. The categorization is based on reports from KARI and Fisheries Department and the fishermen who experienced the water hyacinth infestation. The data on actual surface area covered by water hyacinth on the lake over the period for different months/years is unavailable.

3.5.5 Additional information from various institutions

Additional socioeconomic data was derived from Central Bureau of Statistics (CBS) and Statistical Abstracts for various years (1996-2001). These included Consumer Price Index (CPI) and some additional fish production data. Rainfall data were obtained from the Water Department (Kisumu district). More information was obtained from the Kenya Marine and Fisheries Research Institute, Fisheries Department, Kenya Agricultural Research Institute.

CHAPTER 4

WATER HYACINTH INCIDENCE AND ITS SOCIO-ECOLOGICAL IMPACTS

4.1 Introduction

This section attempts to collate and analyze information that was obtained through the field survey focusing on the water hyacinth incidence, social and ecological impacts. The section attempts to give some insights on the water hyacinth incidence and quantitative analyses on the impacts and thus augmenting the limited information available. The section draws its conclusions from the information obtained from the primary and secondary sources.

4.2 Inter-temporal and spatial distribution of Water hyacinth

Community interviews with fishermen gave an account that can assist in visualizing the severity of water hyacinth over time since 1991 in the absence of the relevant records on the water hyacinth cover on L.Victoria. Table 4.1 and Figure 4.1 show the proportion of responses of fishermen on the severity of water hyacinth over time. From the responses it can be seen that the critical periods of water hyacinth were in the years 1996 to 1999. The data shows that the most critical effect was noticed in 1998 with 81% of the fishermen reporting the seriousness. The incidence for the different segments was more or else the same except the Northern, which indicated that the most critical years, were 1996 to 1998. However, notable impacts of water hyacinth were realized as from 1994 as it can be shown by responses showing that the impact started picking up from 1994 with 24%

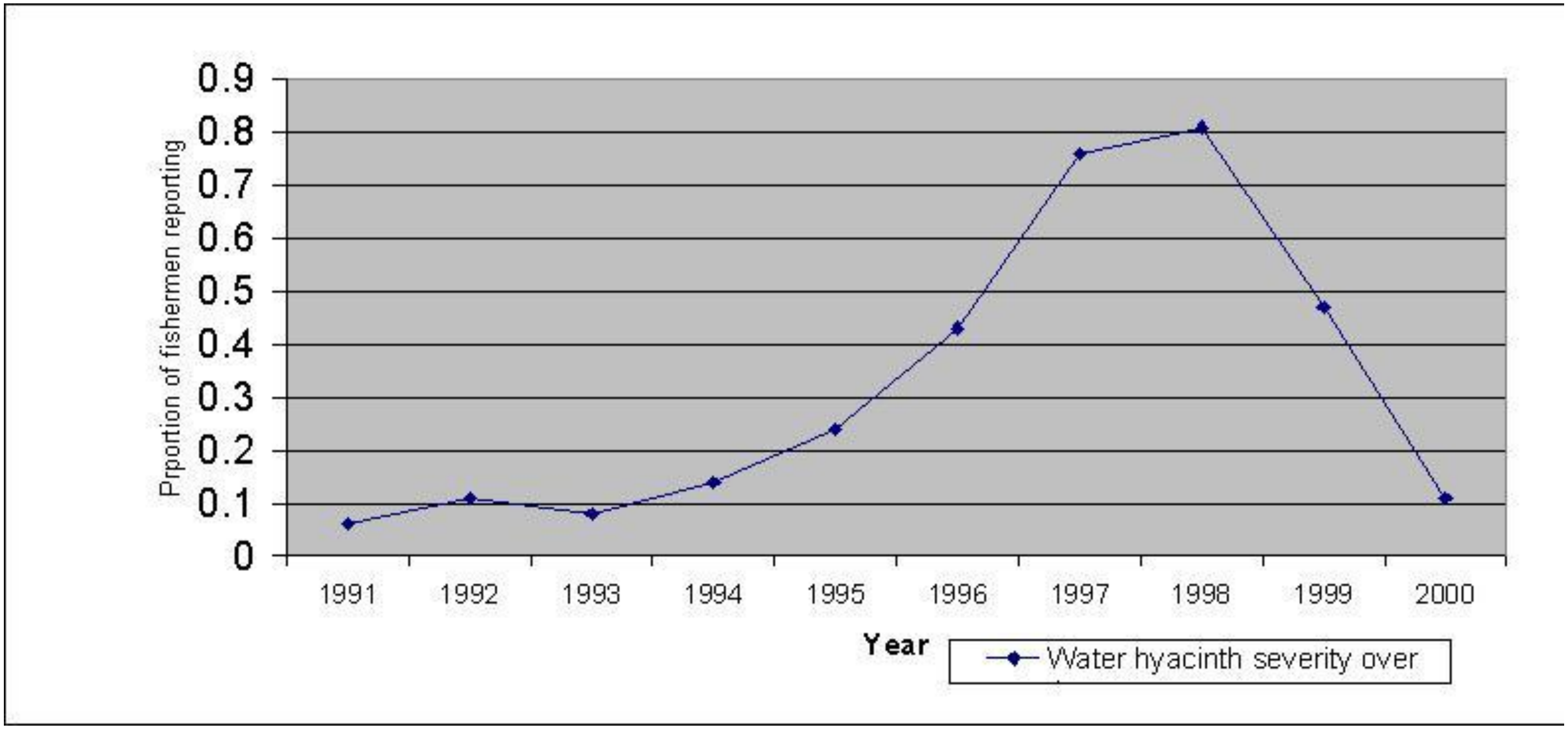


Figure 4. 1: The severity rating of water hyacinth over time, L.Victoria (Kenya)

Table 4. 1: Proportion of respondents that reported the Water Hyacinth Severity/Intensity, 1991-2000

Type of shore line	Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Northern	(%)	18	33	19	34	39	**40***	**77***	**82***	22	00
	N	98	98	99	99	99	99	99	99	98	99
Central	(%)	00	0.8	2	3	14	42	**76***	**93***	**58***	24
	N	119	119	119	118	119	119	119	119	119	119
Southern	(%)	00	00	4	4	18	47	**84***	**60***	**60***	3
	N	73	73	73	73	73	73	73	73	73	73
Entire	(%)	6	11	8	14	24	43	**76***	**81***	**47***	11
	N	291	290	291	290	291	291	291	291	290	291

Notes:

* - Indicates the critical periods of water hyacinth severity

N - Sample size

of the respondents reporting the seriousness. What is important to note is that from 1999 the effect of water hyacinth started tapering off, which is explained by the reduction of the water hyacinth mats through a successful implementation of the control program by the government through biological control implemented by KARI and the mechanical control coupled with manual removal (Appendix 10). The major problem has been lack of data to show the trend of water hyacinth infestation in terms of area covered on the lake over time.

According to the results water hyacinth incidence was widely felt by the fishermen from the early 1990’s. This was the period when there was a lot of hue and cry from the fishermen, local leaders, politicians and international community which culminated in the inception of LVEMP with the objective of improving the L. Victoria environment and its basin in the whole of the three East African countries. One of the basic aims was to control the spread of water hyacinth on the lake.

Table 4.1 and Figure 4.1 therefore gives an accurate approximation of the intensity of water hyacinth on the Kenyan side of L.Victoria over the time. Otherwise, reliable estimate of water hyacinth coverage of L. Victoria could be derived from the satellite imageries. It has been reported that the maximum water hyacinth coverage reached 6000 ha. in 1998 (Dutch Company Snoptics) on the Kenyan side of L.Victoria. An attempt was made to compute the surface area of water hyacinth on L.Victoria using the severity index as reported by fishermen for the period 1991 to 2000. The values are reported in Table 4.2. The results indicated that in 1991 there was an estimated water hyacinth cover

Table 4. 2: Estimated water hyacinth cover (ha) on L.Victoria (Kenya), 1991-2000.

Year	Water hyacinth intensity	Computed water hyacinth cover* (ha)
1991	0.06	444
1992	0.11	815
1993	0.08	593
1994	0.14	1037
1995	0.24	1778
1996	0.43	3185
1997	0.76	5630
1998	**0.81**	**6000****
1999	0.47	3481
2000	0.11	815

Notes:
* = Value computed based on the severity index of water hyacinth as derived from responses from fishermen. The base year was 1998 when L.Victoria (Kenya) had the highest water hyacinth cover of 6000ha.
** = This is an actual (official) figure reported by Snoptics, a Dutch Company.

of 444 ha which surged overtime reaching a peak in 1998 (6000ha) and declining to approximately 815 ha in the year 2000. This reduction was attributed to the intensive control strategies undertaken by the government through LVEMP.

The results further show that water hyacinth was reported to be critical during the rainy seasons in the months of April, May and August (Table 4.3). This case may be explained by the fact that the water runoffs carry with them effluents that contain nutrients for water hyacinth. As reported earlier, the main source of these effluents includes industrial and agricultural plantations, which use a lot of herbicides, pesticides and other chemicals. Experiments on seasonality of water hyacinth in Haiti indicated that water hyacinth

Table 4. 3: Proportion of respondents that reported the water hyacinth severity/intensity, by month and segment, 2001

Segment	Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Northern	%	19	19	15	**86***	**44***	16	15	**84***	29	12	14	17	31
	N	99	99	99	99	99	99	99	99	99	99	99	99	99
Central	%	19	31	30	**54***	**50***	**38***	38	26	8	6	19	35	29
	N	119	119	119	119	119	119	118	119	119	119	119	119	119
Southern	%	26	36	47	**68***	**71***	**66***	63	37	25	19	19	21	42
	N	73	73	73	73	73	73	73	73	73	73	73	73	73
Entire	%	21	28	29	**68***	**53***	37	37	**47***	19	11	18	25	33
	N	291	291	291	291	291	291	291	291	291	291	291	291	291

Notes:

* - Indicates the critical periods of water hyacinth severity

N - Sample size

thrived more during the summer (February –June) period but decayed after wards due to the heavy monsoon winds and the prevailing high temperature (Sen *et al* 1990).

There have been conflicting reports on the actual time water hyacinth was noticed on L.Victoria (Kenya). The interviews with fishermen indicate that water hyacinth was present on the Kenyan side of L.Victoria beginning late 1980's (although the official report puts it at 1992) particularly in the sample beaches in Busia district. These could have been the mats, which had broken off from the Uganda side of the lake. These findings indicate that water hyacinth appeared on the Kenyan side of the lake earlier than 1992 although may have had no significant economic effect.

From the secondary sources the highest water hyacinth infested districts include Kisumu, Nyando, Rachuonyo and Homa Bay, while the least affected include Migori, Suba, and Bondo and Busia districts. The most stubborn mat has been the one circulating between Nyakach bay and Homa Bay and sometimes Kisumu. According to the assessment by KARI, Fisheries Department and beach officials infestation levels for sample beaches with heavy infestation were Namabusi, Kusa, Ngo'u and K'Oginga, while moderate infestation were reported at Obaria, K'Amolo and Bukoma, while Dunga, K'oberio, Kaloka, Ogal, Bumbe and Busembe were classified as having low infestation. Although this was highly a subjective judgment, since there were no records on the quantity of water hyacinth covering the beaches and for how long. On the other hand, this study rated the intensity of water hyacinth at each sample beach on the number of months water hyacinth covered the beach based on the responses given by fishermen (Table 4.4). The beaches with the highest average months covered included Kusa, Ng'ou, and K'Oginga having at least six months of WH cover in a year, followed by Namabusi, Dunga, and K'Oberio having greater than 4 but less than six months. The rest had equal to or less than four month including Bumbe, Busembe, Bukoma, Kaloka, Ogal, Obaria and K'Amolo. On average, the Northern segment was the least covered with water hyacinth (3.76 months) followed by Central (3.93 months) and the highest being Southern (5.04 months)(See Table 4.4). On average water hyacinth covered the beaches for 4.15 months in a given year. There has been no clear explanation for this pattern but it must be linked to the wind patterns and the location of the bays, which are protected from the currents and strong winds.

Table 4. 4: Water hyacinth infestation by Sample beaches and segment as reported by fishermen, 2001

Name of beach	District	Beach code	No. of months infested per year		
			Mean	**Std.**	**N**
Busembe	Busia	1	4.00	1.00	15
Bumbe	Busia	2	3.87	0.83	15
Bukoma	Busia	3	2.00	0.00	36
Namabusi	Busia	4	5.51	1.60	33
Kaloka	Kisumu	5	1.79	0.86	29
Ogal	Kisumu	6	3.00	1.26	30
Dung	Kisumu	7	4.47	0.96	28
Kusa	Nyando	8	6.39	1.27	27
Ng’ou	Nyando	9	6.67	0.58	3
Obaria	Rachuonyo	10	3.82	0.53	17
K’Amolo	Rachuonyo	11	4.00	0.41	13
K’Oberio	Rachuonyo	12	5.47	0.78	30
K’Oginga	Homa Bay	13	6.69	0.48	13
Segment					
Northern	Beach (1-4)		3.76	1.81	99
Central	Beach (5-9)		3.93	2.05	117
Southern	Beach (10-13)		5.04	1.22	73
Overall	All beaches		4.15	1.86	289

Notes:
Std. - Standard deviation
N - Sample size

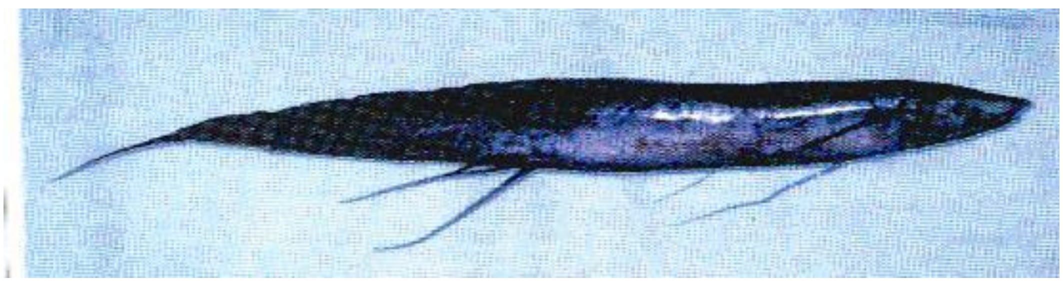
The regional distribution of water hyacinth on the Kenyan side of L.Victoria has been very sporadic and depends on the wind patterns and the time of the year. As already indicated water hyacinth infested all the segments (Northern, Southern and Central) at different intensities. This was the same case to the districts affected. Because of the nature of water hyacinth the only accurate way of ascertaining the intensity of this weed would be through ground truthing, aerial photographs and or satellite imageries. Although this may be an expensive undertaking reliable information will be generated on the temporal, seasonal and spatial distribution of water hyacinth on the lake.

However, in the absence of such approaches this study has used field survey data and secondary information to document the incidence of water hyacinth on the Kenyan side of L.Victoria.

4.3 Ecological impacts

Fishermen were asked to give a list of the fish species that they felt increased or decreased with the infestation of water hyacinth (Plate 4.1). The respondents indicated that *R. argentea* and *Schilbe* declined by 52% and 21% respectively, while *Protopterus* and *Clarias* were reported to have increased by 91% and 95% of the respondents, respectively (Table 4.5, Plate 4.1). There were mixed responses for Nile perch, Tilapiines and although most of the respondents felt that Nile perch declined while Tilapiines increased with water hyacinth infestation. There was no consensus on the part of the Haplochromis and *Synodontis* based on the responses from the fishermen.

Clarias spp



Protopterus aethiopicus

Haplochromis

Plate 4. 1: Fish species associated with water hyacinth infestation

Table 4. 5: % Responses by fishermen on the changes in the fish species composition associated with water hyacinth infestation by segment type, 2001

Fish species	NORTHERN		CENTRAL		SOUTHERN		TOTAL	
	Decreased %	Increased %	Decreased %	Increased %	Decreased %	Increased %	Decreased %	Increased %
Bagrus spp.	20.30	-	0.00	-	0.00	-	9.70	-
Haplochromis	6.30	7. 00	2.20	1.90	4.00	16.70	4.50	7.20
L. niloticus	76.60	0.00	9 1.10	19.00	100	23.30	85.80	15.30
R. argentea	49.90	-	55.60	-	60.00	-	52.20	-
Schilbe	10.00	-	46.70	-	0.00	-	20.90	-
Synodontis	10.90	9.10	35.60	15.20	0.0	6.70	17.20	9.90
Tilapiines	6.30	85.50	37.80	53.30	48.00	60.00	24.60	62.60
Protopterus	-	75.40	-	98.10	-	95.00	-	91.40
Clarias	-	87.70	-	97.10	-	98.30	-	95.00
Mormyrus	-	0.00	-	1.10	-	1.70	-	0.90
Other species	32.80	5.30	42.20	20.00	13.00	13.30	32.60	14.40
No. of cases	64	57	45	105	23	60	134	222

Source: Survey data

These results show that although water hyacinth is known for its negative effects it may have also some positive attributes by protecting the breeding ground for the locally relished fish species which thrives better in the low oxygen environment and the fact that they are shielded from the predator (Nile perch). In fact there is a raging debate on whether there should be a complete or partial removal of water hyacinth from the lake. This is due to the fact that there are some fishermen who strongly feel water hyacinth is associated with an increase in fish stocks (not only the local fish spp). If this assertion is proved to be true then it will be in the interest of the fishermen for the government to adopt a policy of partial removal of water hyacinth. Although the truth of the matter is that once water hyacinth infests any water body then one can only control its intensity but it is not easy to eliminate it.

Otherwise, there is need for scientists to undertake studies on the behaviour of different fish species under water hyacinth ecosystem. This will provide information that will assist in making decisions on conservation policies that should be adopted particularly in an environment with water hyacinth and provide guidance on how much resources should be invested in its control.

4.4 Social Impact of Water Hyacinth

Although the socio-economic impact of water hyacinth on the local communities has not been quantified scientifically, there are strong feelings that water hyacinth has significantly affected fish catches, increased disease incidence (especially malaria), increased transportation costs, and difficulties associated with the availability of clean water. However, when respondents from the affected communities were asked to estimate the effect of water hyacinth on the local communities in their respective beaches, the results indicated that the effect varied from low to heavy. In all the segments 39% respondents felt that it was heavy while 35% indicated it was low, while the rest said it was moderate (26%). The effect seems to have been the same as perceived by the fishermen in the Northern since the rating was almost the same. The most critical one was in the Central segment where 52% of the respondents seem to agree that the effect was heavy (Table 4.6). The impact was visualized on the effect of water hyacinth on fishing activities, water supply, disease incidence, etc.

About 29% of the fishermen interviewed indicated that they had migrated to neighboring beaches because of the water hyacinth infestation. This was in search of accessibility to the lake to enable them catch more fish. This study also shows that migration was more pronounced in the Central segment (47%) as compared to the Northern and Southern at 15% and 18%, respectively.

These results show that the Central segment had more serious effect than the other two segments. This might be due to the fact that this segment has had major water hyacinth mats being resident for most part of the year. This is where one finds beaches such as Kusa and Ng’ou, which have had water hyacinth residing on their beaches for an average of over six months per year. This impact is exemplified more if one looks at the migration rate, which was highest in the Central segment due to the blockage of the beaches.

Table 4. 6: Impact of water hyacinth on local communities as rated by fishermen, 2001

	% of fishermen reporting			
Classification	**Northern**	**Central**	**Southern**	**Entire***
Low	34.3	29.1	46.6	35.3
Moderate	34.3	18.8	24.7	25.6
Heavy	31.3	52.1	28.8	39.1
Total	100	100	100	100
Number of cases	99	117	73	289

*Refer to Table 3.1 on the sample beaches included in each segment

There was an indication that consumption of fish was affected by water hyacinth. Survey findings showed that consumption of Tilapiines increased while that of Nile perch and *R. argentea* decreased (Table 4.7), although there were no significant differences for the mixed species. The decline in the consumption may be associated with inability for the fishermen to access the fishing ground due to water hyacinth blockage hence reduced catch, while the increased consumption may be associated with the fact that fishermen report that water hyacinth provided conducive conditions especially for some fish types.

It may be interesting to corroborate these findings with a nutrition study in the local community in order to determine the effect of water hyacinth on the nutrition status of the fishing communities. An accurate assessment of the impact of this nature could provide information that could assist in resource allocation in the management of water hyacinth and provision of micro-projects. Thus the impact can be used as a measure of the water hyacinth effect on the local communities.

Table 4. 7: The Impact Of Water Hyacinth On Fish Consumption as reported by Fishermen in Sample beaches, 2001

Activity	**Without W/hyacinth**			**With W/hyacinth**			**P-Value**
Fish consumption	**Mean**	**Std.**	**N**	**Mean**	**Std.**	**N**	
Nile perch (kg)/day	2.41	1.57	219	1.81	1.53	219	0.000
Tilapiines (Kg)/day	2.26	1.57	218	2.48	1.78	218	0.000
R. argentea (kg)/day	2.03	1.20	50	1.48	1.05	50	0.001
Mixed fish (kg)/day	0.96	1.19	84	2.02	1.31	84	0.247

CHAPTER 5

COST BENEFIT ANALYSIS OF FISHING UNDER THE PRESENCE OF WATER HYACINTH

5.1 Introduction

This section analyses the effect of water hyacinth on the fishing input levels, costs and net benefits. A comparison of these factors is undertaken between the two scenarios with and without water hyacinth. T-tests are used in making the necessary comparisons and deriving inferences for the test variables using data collected from the field survey. One of the basic concerns of the society has been to answer the question: Does water hyacinth lead to increased benefits in the fishing enterprise? This section therefore addresses this pertinent issue and seeks to shed some light on this important subject.

5.2 Water hyacinth, fishing effort, Costs and benefits

The water hyacinth effect was estimated through interviews with the fishermen who were able to give a comparison of the activities with and without water hyacinth. Table 5.1 gives these estimates. One of the activities is the frequency of fishing per week, where by it was reduced from an average of 6.15 to 3.72 times per week. There was a significant difference between the two because of the fact that water hyacinth blocks the beach completely or even if it blocks it partially then it makes the fishing ground and landing sites inaccessible to the fishermen and hence more labour expended on clearing the way.

Secondly, there was an increased expenditure on the labour engaged per boat. Most fishermen interviewed indicated that to clear the way of water hyacinth additional labor

Table 5. 1: The Impact Of Water Hyacinth On Fishing Activities as Reported by fishermen in Sample beaches, 2001.

Activity	Without W/hyacinth			With W/hyacinth			P-Value
	Mean	**Std.**	**N**	**Mean**	**Std.**	**N**	
Frequency of fishing per week	6.15	2.69	206	3.72	1.72	206	0.000
Time taken to access fishing ground (hrs)	1.67	1.14	212	3.26	1.66	212	0.000
Time taken for the boat to land (hrs)	1.62	0.95	210	3.29	1.57	210	0.000
Number of crew per boat	3.63	2.12	285	3.99	2.11	285	0.000
Total fish catch per month (kg)/month	1838	2354	288	2013	2789	288	0.286

was hired. The number of crew accompanying the boat increased significantly from 3.63 to 3.99 people.

Thirdly, extra expenditures were realized in the time taken to access the fishing ground and time taken to land at the beach with the catch. There was a significant difference in the time taken from 1.67 to 3.26 hours while accessing the fishing ground and 1.62 to 3.29 hours for landing at the beach. The frequency of fishing was reduced by 40% while labour requirement is increased by 10%. The time taken accessing the fishing ground went up by 95% while that of landing skyrockets by 103%. The effects through increases in the fishing time and reduced frequency of fishing have a direct bearing on the profitability of the fishing enterprise.

Table 5.2 shows the results of economic analyses of the various fisheries by gears and propulsion methods using the scenario of with and without water hyacinth infestation. In particular there is an attempt to measure the impact of water hyacinth on the fishing costs and net benefits. Given these results overall water hyacinth increased the cost of fishing by 35% from an average of Ksh 623 to 843.46 per boat per day for all fisheries and given the different types of gears. To simplify the analysis, the fish catch and price are assumed hence no change in the income received by the fisherman. With this assumption the net benefits realized by the fishermen was reduced from Ksh 422.38 to 201.90 per boat per day signaling a decline of 52.2%.

To get a picture of the effect of water hyacinth across vessel propulsion methods and the different fishing gears, it is important to look at the break down. What comes out clearly is that the increase in cost is highest at 55.81% on the gill nets hence the largest reduction in the net income of 70.16%. This is dictated by the fact that this fishery use outboard engines and hence a heavy expense on the fuel. The reduction in the cost of fishing where no out-board engine is used is minimal as in the case of the long line where there was a mere increase in the fishing cost of only 7.15% and reduction of net income by 12.29%. This also applies to other fishing gears where no outboard engines are used.

Table 5. 2: Cost Benefit Analysis of fishing with and without water hyacinth by fishing Gears and Propulsion methods, in Sample beaches, 2001

Type of fishing gear	Without water hyacinth*				With water hyacinth**				Impact of water hyacinth(%)			
Gill net fishery	**Oar**	**Sail**	**Engine**	**Total**	**Oar**	**Sail**	**Engine**	**Total**	**Oar**	**Sail**	**Engine**	**Total**
Input costs (Ksh./day)	276.92	295.37	1151.32	315.06	312.41	325.99	1638.76	490.91	12.82	10.37	42.34	55.81
Fish catch (kg /day)	12.26	18.53	26.12	15.98	12.26	18.53	26.12	15.98	0.00	0.00	0.00	0.00
Gross income (Ksh./day)	439.97	601.45	1711.52	565.68	439.97	601.45	1711.52	565.68	0.00	0.00	0.00	0.00
Net income (Ksh./day)	163.05	306.08	560.20	250.62	127.56	275.46	72.76	74.77	-21.77	-10.00	-87.01	-70.16
Beach seine fishery												
Input costs (Ksh./day)	1056.53	1003.54	1787.60	1148.11	1175.34	1101.08	2303.06	1523.18	11.25	9.72	28.84	32.67
Fish catch (kg /day)	44.11	43.92	94.15	50.76	44.11	43.92	94.15	50.76	0.00	0.00	0.00	0.00
Gross income (Ksh./day)	1805.88	1663.23	3412.66	2004.27	1805.88	1663.23	3412.66	2004.27	0.00	0.00	0.00	0.00
Net income (Ksh./day)	749.35	659.69	1625.1	856.16	630.54	562.15	1109.6	481.09	-15.86	-14.79	-31.72	-43.81
Longline fishery												
Input costs (Ksh./day)	733.44	727.67	-	728.7	810.26	776.22	-	780.78	10.57	6.68	-	7.15
Fish catch (kg /day)	20.14	17.92	-	18.33	20.14	17.92	-	18.33	0.00	0.00	-	0.00
Gross income (Ksh./day)	1122.39	931.22	-	966.63	1122.39	931.22	-	966.63	0.00	0.00	-	0.00
Net income (Ksh./day)	388.95	203.60	-	237.93	312.93	155.00	-	185.85	-19.75	-23.87	-	21.89
Mosquitoe seine												
Input costs (Ksh./day)	710.99	853.94	-	714.32	789.00	924.98	-	791.56	10.97	8.32	-	10.81
Fish catch (kg /day)	77.28	88.83	-	77.54	77.28	88.83	-	77.54	0.00	0.00	-	0.00
Gross income (Ksh./day)	1340.39	1446.06	-	1342.85	1340.39	1446.06	-	1342.85	0.00	0.00	-	0.00
Net income (Ksh./day)	629.84	592.11	-	628.53	551.39	521.08	-	551.29	-12.39	-12.00	-	-12.29
Other types of fisheries												
Input costs (Ksh./day)	310.98	450.64	-	357.53	350.54	486.01	-	385.77	12.63	7.85	-	7.90
Fish catch (kg /day)	19.42	19.4	-	19.42	19.42	19.40	-	19.42	0.00	0.00	-	0.00
Gross income (Ksh./day)	525.14	826.58	-	625.14	525.14	826.58	-	625.65	0.00	0.00	-	0.00
Net income (Ksh./day)	214.17	375.94	-	268.12	174.9	340.57	-	239.38	-18.33	-9.41	-	-10.53
Combined fishery												
Input costs (Ksh./day)	634..56	526.62	1575.5	623.00	702.26	561.86	2064.12	843.46	10.67	6.69	31.02	35.59
Fish catch (kg /day)	40.88	20.21	71.47	33.44	40.88	20.21	71.47	33.44	0.00	0.00	0.00	0.00
Gross income (Ksh./day)	1102.60	813.13	2845.61	1045.38	1102.6	813.13	2845.61	1045.38	0.00	0.00	0.00	0.00
Net income (Ksh./day)	468.04	286.51	1270.01	422.38	400.34	251.27	781.49	201.90	-14.46	-12.30	-38.42	-52.20

Notes:
- * Computed from the survey data over a period of one month
- ** Computed using a formula
- \- Not applicable

In the case of the propulsion methods, the out board engine experienced an increase in the fishing cost by 31.02% and a decline in the net income of 38.42%, compared with the sail which experienced an increase in the fishing costs of only 6.69% with a subsequent slump in the net income of 12.30%. The paddle propulsion methods also experienced less effect as no expenditures are incurred on the fuel.

This analysis gives an indication of the effect of water hyacinth on the fishing expenses and profitability. The fishing costs without water hyacinth are actual costs collected from the fishermen within a period of a month, while those for with water hyacinth are computed based on the responses given by the same fishermen through the questionnaire interviews. This was based on the fishermen' impression on the changes on the cost of fishing resulting from water hyacinth infestation (See Appendix 1). The breakdown of the fishing expenses is presented in Appendix 3. The fish catch were assumed to be constant because there is no scientific backing on the effect of water hyacinth on the fish catch, although the fishermen claim certain species increased while others declined in terms of fish catch realized.

In addition, there were no significant differences in the fish landed with and without water hyacinth based on the data derived from the interviews with the fisher folks. The total fish catch reported by fishermen per month before the infestation was 1838 kg and after the infestation it rose to 2013 kg and thus not significantly different from each other (Table 5.1). This issue is not easy to ascertain. In the first place the weed is very mobile hence having a controlled experiment to ascertain the differences becomes a problem.

The easiest scenario is where one assumes heavy water hyacinth infestation where fishermen are not able to access the lake hence they experience nil catch (i.e. 100% loss of catch), but the other argument is that when the water hyacinth moves away it leaves behind large stocks of fish hence increased catch. Some fishermen strongly feel the presence of water hyacinth can be beneficial to fishermen as long as the weed does not completely block the beach. Therefore this calls for a balance in the control strategy, which ensures partial removal of water hyacinth to allow for some weed in order to realize the fishermens' aspirations. It could also be argued that since L. Victoria fishery is multi-species, an increase in the catch for one species may be offset by a decrease in the other species hence leaving the total catch unchanged. This is given by the fact that the gears used in fishing are not 100% exclusive. To add on this although, the total catch may not be different with and without water hyacinth, fish catch of low value may be being landed when the water hyacinth is present, hence reduced net benefits.

The results therefore indicate that there were major increases in the input levels and costs associated with water hyacinth infestation, which significantly affected the net benefits in the fishing enterprise, particularly with the gillnets. This was due to the reliance on the outboard engines, which use significantly higher quantities of fuel, by the fishermen using gillnets.

CHAPTER 6

ECONOMETRIC ANALYSIS OF THE IMPACT OF WATER HYACINTH ON FISH CATCH AND INCOMES

6.1 Introduction

This study is undertaken to shed some light on the quantitative effect of water hyacinth on fish catch and income among the local communities of L.Victoria. An econometric model was fitted on four fish species and combined data using cross section data. The fish species included Nile perch, Tilapiines, *R. argentea* and mixed fish. The dependent variable was the fish catch. Several socioeconomic factors and water hyacinth were used as explanatory factors. In addition, another model was fitted with the fish net income as the dependent variable but only for the combined species, with the same explanatory factors. Cobb Douglas functional form was preferred.

6.1.1 Cobb Douglas Production Model

All the regression models for the fish catch functions were significant at 1% and had adjusted R-square ranging from 0.352 to 0.710 (Table 6.1), while the results for the net fish income function are shown in Table 6.2. The data set was also tested for multicollinearity and autocorrelation to satisfy the requirement of Ordinary Least Square. The Durbin Watson test generally indicated that there were no problems of autocorrelation as inferred from the high computed DW values when compared to the critical values. The data set showed no problems of multicollinearity as shown by satisfactory conditional indices[13] which in most cases, ranged from16.72 to 29.68. The

[13] Contact Gujarati 1995 for the interpretation of the conditional indices as a measure of multicollinearity.

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Table 6. 1: Cobb Douglas regression results on the determinants of fish production along lake Victoria, 2001

Variable	Combined fish	Nile perch	Tilapiine ssp	R. argentea	Mixed fish
Constant	1.782***	-2.552***	2.965**	3.796*	-3.014**
Log of experience in fishing	-0.096***	-0.123^{NS}	-0.129^{NS}	-0.007^{NS}	-0.062^{NS}
Log of fishing crew	0.193^{NS}	0.980***	0.748*	-0.138^{NS}	0.500^{NS}
Log of boat size	0.389***	0.814***	-0.547^{NS}	0.005^{NS}	0.488^{NS}
Presence of water hyacinth (d.v)	-0.293**	0.408^{NS}	-0.932**	-	2.571***
Fishing with gillnets (d.v)	-0.340***	-0.215^{NS}	-0.351^{NS}	-	-0.212 ^{NS}
Fishing with beach seine (d.v)	0.383**	0.503^{NS}	0.426^{NS}	-	0.814 ^{NS}
Fishing with longline (d.v)	-0.263**	0.647^{NS}	-1.087**	-	0.404 ^{NS}
Fishing with mosquito seine (d.v)	1.138***	-0.911*	-0.440^{NS}	1.078***	-0.162 ^{NS}
Sail as Propulsion method (d.v)	0.167**	1.264***	-0.991***	0.001^{NS}	0.094 ^{NS}
Engine as propulsion method (d.v)	0.708***	1.391***	0.451^{NS}	-	0.280 ^{NS}
Northern shore line (d.v)	-0.118^{NS}	0.611***	-0.937***	-0.820***	0.259 ^{NS}
Central segment (d.v)	-0.157*	0.210^{NS}	0.710***	-0.780***	1.077***
R-square	0.724	0.573	0.449	0.616	0.391
Adjusted R-square	0.710	0.549	0.414	0.520	0.352
F-value	50.752***	23.597***	13.087***	6.426***	10.051***
Condition Index	17.298	21.648	16.715	29.678	20.019
No. of cases	245	224	206	36	201
DW statistic	1.696	1.567	1.615	1.539	1.860

Dependent variable: Log of average fish catch in kg per boat per day; Significance levels: ***= 1%; **= 5%; *= 10%

Note:

Reference fishing gear method	- Mixed gears
Reference boat propulsion method	- Oar
Reference segment	- Southern
d.v.	-dummy variable

Table 6. 2: Cobb Douglas regression results on the determinants of fish income in sample beaches, 2001

Variable	Log-linear	
	Coefficient	**Std. Error**
Constant	4.719***	0.723
Experience in fishing	-0.143**	0.058
Fishing crew	0.973***	0.244
Boat size	0.009 NS	0.218
Presence of water hyacinth(d.v.)	0.376*	0.218
Fishing with gillnets (d.v.)	-0.161 NS	0.206
Fishing with beach seine (d.v.)	0.004 NS	0.320
Fishing with longline(d.v.)	-0.595**	0.229
Fishing with mosquitoe seine(d.v.)	0.451*	0.256
Sail as propulsion method (d.v.)	0.455***	0.131
Engine as propulsion method (d.v.)	1.054***	0.297
Northern segment(d.v.)	-0.274*	0.150
Central segment (d.v.)	-0.540***	0.154
R-square	0.469	
Adjusted R-square	0.441	
F-value	16.807***	
Condition Index	17.300	
No. of cases	240	
DW statistic	1.853	

Dependent variable: Log of average fish income in Kshs per boat per day
Significance levels: ******= 1%; **= 5%; *= 10%***
Note:

Reference fishing gear method	- Other mixed gears
Reference boat propulsion method	- Oar
Reference segment	- Southern
d.v.	-dummy variable

models were estimated using the linear and log linear forms[14]. Since the results from Log-log linear models had the expected signs and better explanatory powers the discussions that ensue are based on this functional form. The results for the linear models are presented in Appendix 4 and 5. An attempt was made to estimate similar models based on the fish gear types but they were abandoned because of the inadequate sample size and non-significance of the factors.

6.2 Experience in fishing

The variable on the experience of fishing was not statistically significant in all the fisheries, except in the combined regression function at 1% level of significance with a negative coefficient of 0.096. This was against the hypothesized relationship. The combined fishery actually accounts for the entire fish catch by the individual fishermen per boat and therefore this indicates that the experience reduces total catch. The reduction in catch might be due to the fact that most of the fishermen who are old may no longer be participating in actual fishing where their experience could have been important in deciding on the fishing ground and timing of the fishing trips. Such old boat owners often employ the services of young men who may be inexperienced in fishing. This variable was significant and bears the same sign with regression on the fish net income. The effect on the net fish income is larger (-0.143) than that on fish catch as seen from the magnitude of the coefficients.

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[14] Some of the hypothesized variables tested and found to be insignificant included the age of the fishermen, education level, price and time taken to access the fish ground. These were excluded from the models. There was a close correlation between the age of the fishermen and the experience in fishing given by years. The factor on prices of fish did not vary much as expected with cross section data.

These results support the view that older fishermen may not be participating in the actual fishing so that they could exploit their experience in fishing. About 30% of all the boat owners reported not personally participating in the fishing on the lake. It might be that, most of the ones not participating in fishing might be due to old age. It is important to note that the oldest boat owner was 90 years.

6.3 Fishing effort

The fishing effort (crew) was statistically significant for Nile perch (1%) and Tilapiines (10%). Both species had the expected sign implying that increased labour was associated with high fish catch. Fishing effort is one of the most important input in the fishing process as the labour is required to set the gears and keep on adjusting them until when they have caught adequate fish. The fishery process may be described as labour intensive. In the case where, the propulsion of the boat is the paddle, then, labour becomes more crucial as the movement depends on how much the fishermen can row. The findings in this study indicate that 1% increase of a labour unit increases the quantity of fish catch by approximately 0.98% for the Nile perch fishery and by 0.75% for the Tilapiines fishery. On the fish net income regression equation, the coefficient (0.97) of this variable is significant and bears the expected sign implying that higher labour increases the revenue due to increased catches. The significance of labour on both Nile perch and the Tilapiines is due to the fact that these species use more or else the same fishing gears (i.e. long line, beach seine and gillnets), which are labour intensive. These findings support the hypothesis that the larger the size of the crew the more the quantity of fish caught. However, the results show no significance effect of labour on *R. argentea,* mixed fish and combined output**.**

6.4 Boat size

The boat size variable was found to significantly affect the fish catch for the combined fish and Nile perch at 1% level of significance with the expected sign on the coefficient. Nile perch had a higher coefficient (0.81) than the combined (0.39) fish regression function implying that the response to the change in the quantity of fish landed is more sensitive for the Nile perch as compared to the combined. The boat size may be taken as a close approximation of the expected catch. It determines the number and type of fishing gears that could be carried and accessibility of the fishing ground, therefore dictating the size and weight of the fish caught.

These findings can be explained by the fact that the catch of large sized fish such as Nile perch may require the fishermen to go deeper in the lake in order to get such size. This requires a large boat to maintain stability and be able to transport large quantities of fish. Some fully grown up Nile perch fish weigh[15] over 100kg each and therefore require large capacity boats. However, the boat size was not significant in the income regression function.

Given that boat size may influence the size and weight of fish catch its regulation is an important tool in the management of the lake Victoria fishery by the fisheries management licensing boats of particular sizes in order to conserve certain fish species.

[15] In Uganda the heaviest Nile perch has been reported to weigh 170kg.

6.5 Water hyacinth effect

On fish catch, the impact of water hyacinth was significant and negative on the combined and Tilapiine functions, while mixed fish species function had a positive coefficient. The findings of the mixed fish species seems to support the views of the researchers and fishermen that water hyacinth is associated with increased catch for the mixed fish species which were rampant in the past but had disappeared. The mixed fish species mostly included the *Protopterus, Clarias and* Haplochromis. These species can thrive better in water hyacinth-infested areas as they are able to survive under low oxygen environment and given that they hide away from predation.

These results show that the total catch (combined function) of the fish is reduced by water hyacinth, which also support the view that water hyacinth, reduces fish catch through reduced frequency of fishing and destruction of the nets. This explains the outcry that was raised by the fishing communities at the height of the water hyacinth infestation in Kenya between the periods 1996-1999 when most of the fish landing beaches were heavily infested with water hyacinth. The impact of the mixed fish species seems to be apparent indicating that those fishermen operating in water hyacinth infested areas realized higher fish catches for the native fish species which are reported to have resurfaced. The catch for the Tilapiines fishery seems to have been depressed due to the water hyacinth cover. The reduction in the Tilapiines might be explained by the fact that *O. niloticus* relatively requires more oxygen as compared to most of the other Tilapiines (mixed) which is deficient in areas covered with water hyacinth. Secondly, because of the water hyacinth cover it was not possible for the fishermen to capture more Tilapiines because it was not possible to use the beach seine. On the other hand the gillnets that are used to capture the large mixed fish (*Clarias* and *Protopterus* may not easily capture the Tilapiines because of the relatively big mesh size. The impact on the *R. argentea* could not be established because of the fact that the sample beaches, which were infested by water hyacinth, were not dealing with this species.

The water hyacinth variable was positive and significant at 10% on the income regression equation implying that income was higher for the fishermen who were located in water hyacinth infested beaches possibly as a result of the higher prices of fish due to reduced fish supply. However, there was no significant effect of water hyacinth on Nile perch. This species is found deep in the lake hence, water hyacinth cover along the beach at low intensities may not affect it. The results, therefore show that water hyacinth infested areas were associated with increased catches of the mixed spp. but reduced catches for both the combined fish spp. and the Tilapiines. The marginal effect of water hyacinth on the individual fishery could not be determined since a dummy variable was used to capture the effect of water hyacinth on the quantity and income. There were no quantitative records on actual water hyacinth cover that could indicate the intensity of water hyacinth in the sample beaches.

6.6 Type of fishing gears

The analysis was carried out on the effect of different fishing gears on the quantity of fish catch, as there was inadequate information on mesh sizes of the fishing gears. The mixed fishing gears were used as the reference point. Significant effects were realized using gillnets on the combined regression function with a negative coefficient of 0.340 at 1% significance level. This means that those fishermen who had gillnet realized less quantity of fish catch than those who had mixed gears. The relatively low catches with gillnets may be associated with the fact that those fishermen who used mixed gears aimed at maximizing the catches hence choosing gears depending on the conditions at the lake and the abundance of the individual fish species. However, in the income regression function, the gillnet variable was not significant.

Beach seine had significant effect on the quantity of fish caught with a positive sign only on the combined regression function. It had a coefficient of 0.383 at a significance level of 5%. The beach seine fishery realized higher fish quantities as compared to those who had mixed fishing gears. The higher catch is associated with the fact that beach seines catch all types of fish including juveniles because of its small mesh size. This is one of the fishing gears outlawed by the government although fishermen continuously use it. This factor was not significant in the income regression equation. Although the catch is heavy for the beach seine the number of crew used is also high hence an increase on the cost of labour which result in lower net incomes.

The long line was significant for both the combined and the Tilapiines and had a negative coefficient in both cases implying that there were inferior catches for fishermen using long line on Tilapiines and the combined catch. This factor was significant and bore the same sign in the income regression equation. The same reason as in the case of the gillnets might be applicable whereby the fishermen using mixed gears may want to maximize their catch hence choose their gears depending on the prevailing conditions.

The mosquitoe nets targets *R. argentea* when used in deep waters, however when used inshore catches any other fish species. The results show that it had significant and positive coefficients on the combined and *R. argentea* regression functions. It had a negative coefficient (0.91) at 10% level of significance in the Nile perch function. This indicates that there are less catches of Nile perch when mosquitoe seine is used in comparison to the mixed fishing gears. This factor was significant at 10% in the net income function and bears the same sign as the fish catch regression equation.

These fishing gears are not 100% exclusive as the fish type caught depends on the mesh size and the location where the fishing is being undertaken. Gill nets are normally used to capture Tilapiines and Nile perch but when compared with the mixed gears, then lower catch is realized because the mixed gears use combinations, sometimes using mosquitoes seine and the like. The beach seines are non-selective and are used inshore to catch any fish spp. coming its way and that is why its catches are more than those of the mixed gears. On the other hand, long line may be selective targeting mainly Nile perch and Tilapiines. The mosquitoe seine is purely selective as it catches *R. argentea* when used in deep waters. The results show that in terms of combined fishery and *R. argentea* more fish is caught as compared to the mixed fishing gears.

6.7 Type of propulsion method

Sail, as a propulsion method was significant for combined and Nile perch regression functions with positive coefficients. This implies that fishermen with sail realized higher output than the reference method (the oar) in the case of Nile perch and the combined fishery. However, the Tilapiines function was significant and had a negative coefficient. The outboard engine as a propulsion method was significant in the case of the combined analysis and the Nile perch and with positive coefficients indicating its superiority over the oar method. The outboard engine is not used as a propulsion method in the case of the *R. argentea* fishery. Both the sail and outboard engines propulsion methods were significant at 1% with a positive coefficient in the income regression equation.

The fishermen with the sail propulsion may be inflexible as most of the operations depend on the wind. This is different from the paddle which enables fishermen to access any region they feel might have more fish in the lake. This case seems to explain the Tilapiines but not the Nile perch and the combined fish functions, which had higher catches above those, realized by the reference propulsion method. The explanation for the Nile perch might be that the boats using the sail are able to cover a longer distance as opposed to the paddle given the right weather in terms of wind direction. Those using the sail may catch less Tilapiines, because it is used deep inside the lake where not much Tilapines are available. Most of the Tilapiines are found near the shoreline.

The outboard engine on the other hand gives the fishermen a high level of maneuverability and in terms of accessing any given location in the lake. The distance to be covered to the fishing ground is not limiting. This enables the fisherman to obtain more fish catch as compared to those fishermen using the paddle.

6.8 Type of segment

The Northern segment is significant with positive coefficient on the Nile perch and *R. argentea,* while it had a negative effect on the Tilapiines. This means that the catches realized on Nile perch and *R. argentea* are more than what is realized from the southern segment, which is the reference segment and the vice versa for the Tilapiines. The central segment was significant in all the regressions except the Nile perch. The combined and the *R. argentea* regressions had negative coefficients indicating that the quantity of fish caught was less than what was realized in the Southern segment. However, there were no significant catches of Tilapiines and the mixed fish in the Central segment. In the net income equation both the Central and Northern were significant and positive.

The results therefore show that there is more catch of fish in the Southern segment as compared to the Northern and Central Segments. The results also show that Northern segment has more catch of Nile perch and *R. argentea* than the Southern segment. However, there is less Tilapiines in the Northern segment. The Central segment has more Tilapiines and mixed fish spp. as compared to the Southern segment, although there is less *R. argentea* and the combined catch. This is because of the relatively low depth in the Gulf and plentiful of food brought through the many river systems found in this area.

The less Tilapiines and more catch of Nile perch in the Northern segment may be explained by the high population of Nile perch which predates on the Tilapiines and hence reducing its stock in the lake. The other reason, which is more important, may be that the lake is deeper hence providing a suitable environment for both the Nile perch and the *R. argentea* in the Northern segments. In the Central segment the Tilapiines and mixed fish spp. abundance when compared to the Southern may be explained by the high mass of water hyacinth, which has been resident in some of the sample beaches such as Kusa and Ngo'u at the time of the survey. But more important is the fact that there is a high rate of inflow of the nutrients that provide food for the fish (especially the mixed fish and Tilapiines) as a result of the high concentration of river systems draining into the gulf that thrive in shallow depth, up to 20m.

CHAPTER 7

THE IMPACT OF WATER HYACINTH, CLIMATE AND PRICE ON FISH PRODUCTIVITY

7.1 Introduction

This section is aimed at assessing the impact of water hyacinth, fish prices and climate on the catch per unit effort (CPUE) over the period 1990-2000 in Kendu Bay, Dunga and Uhanya beaches. Four major fish species are considered namely, Nile perch, *R. argentea*, Tilapiines and the mixed fish. The CPUE for the four fish categories is considered as a dependent variable. Error correction model (ECM) is used as main tool of analysis. The results of the stationarity and co-integration tests are presented here. These are meant to ensure that the data used in the analysis satisfy the requirements of an ECM model.

7.2 Stationarity and co-integration analysis for the time series data

Since it has been established that regression models may generate spurious correlations when time series are non-stationary (Granger and Newbold, 1974), the variables used in the regression model were tested for the order of integration using the Augmented Dickey and Fuller (ADF) test (Nelson and Plossier, 1982). The computed ADF statistics are compared with the ADF critical values at various significance levels. If the absolute computed statistics are less than the critical ADF values then it is concluded that the series are non-stationary.

The stationarity tests[16] were done on the four fish species (Nile perch, Tilapiines, *R.*

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[16] Contact Thomas 1993, Kendall and Ord 1990 and Greene 1993 for stationarity test.

argentea and the mixed fish) in three beaches (Kendu Bay, Dunga and Uhanya). The results are presented in Table 7.1. The null hypothesis of non-stationarity cannot be rejected for most of the series. The results for Kendu Bay beach show that all the time series appear to be non-stationary except the fish catch for the Nile perch, which has a computed value of 3.990 and is slightly higher than the critical value of 3.960 at 1% level of significance. These results generally show that almost all the series are non-stationary hence requiring differencing to make them stationary. With these results it can be concluded that the series are integrated of order one. The time series become stationary on first differencing as shown in the same table, with the exception of the price, which could be integrated of order 2 or higher.

In the case of Dunga beach all the time series appear to be non- stationary except for the rainfall factor which has a value of 4.697 and fish catch for the mixed fish. Similarly, the results for Uhanya beach show that the time series were non-stationary except rainfall, which had a value of 3.979 as compared to the critical value of 3.960. Most of the series also become stationary on first differencing as in the case of the Kendu Bay beach.

Although ADF tests show that the price is non-stationary on first differencing the Philipps-Perron test shows that the series become stationary when first differenced. This also applies to both Dunga and Uhanya beaches. The rainfall computed values (3.979) for Uhanya beach are very close to the critical value at 1% of 3.960. It is important to note that the rainfall value is the same for each fish species in a given beach, as the beach

Table 7. 1: ADF Results for stationarity test for Kendu Bay, Dunga and Uhanya Beaches, 1990- 2000

	Levels			First difference		
	Kendu B	**Dunga**	**Uhanya**	**Kendu B**	**Dunga**	**Uhanya**
Nile Perch						
Ln Fish catch	-3.990	-2.408	-3.656	-4.897	-4.133	-5.532
Ln Rainfall	-1.724	-4.697	-3.979	-3.541	-6.316	-5.105
Ln price	-1.484	-1.478	-1.484	-2.682	-2.682	-2.682
Tilapiines						
Ln Fish catch	-2.216	-2.285	-2.381	-4.244	-5.009	-6.935
Ln Rainfall	-1.724	-4.697	-3.979	-3.441	-6.316	-5.087
Ln price	-1.484	-1.478	-1.484	-2.682	-2.682	-2.682
R. argentea						
Ln Fish catch	-	-3.850	3.268	-	-5.220	-4.685
Ln Rainfall	-	-4.697	-3.979	-	-6.316	-5.087
Ln price	-	-1.478	-1.484	-	-2.682	-2.682
Mixed species						
Ln Fish catch	-3.039	-4.119	-3.126	-3.983	-6.059	-4.461
Ln Rainfall	-1.724	-4.697	-3.979	-3.541	-6/316	-5.087
Ln price	-1.484	-1.478	-1.484	-2.682	-2.682	-2.682
Critical value						
10%	-3.130					
5%	-3.410					
1%	-3.960					

Note: Ln- Natural logarithm

received same amounts of rain. The price is the same for all the species and beaches as the CPI was used in the absence of actual prices for the individual fish species per month.

Since most of the time series in all beaches across the various fish species show non-stationarity and become stationary on first differencing, the next step was to check for long-run relationship between the time series (Greene 1993, Engle and Granger, 1987). The presence of this relationship is an important precondition for estimating an ECM.

The equilibrium relationship for all the time series was tested using the Pc Give, Version 9.0, and an Econometrics Computer Package. The Co-integration test was based on the Johansen multivariate maximum likelihood procedure[17] (intercept, no trend) and the results appear in Table 7.2a-c. Johansen test has an advantage over most of the other tests (ADF and PP) since it allows for the testing of multiple co-integrating relationships. The null hypothesis of no-co-integration is tested against the alternative of one of the presence of co-integrating relationship. The results suggested the existence of long run equilibrium. Using both the maximum eigen value and Trace statistics the results show that there is at most two co-integration relationships for all the fish species considered in Kendu Bay beach. This can easily be seen in the case of Nile perch, which show that the computed value at $P \leq 1$ of 30.12 is greater than the critical value of 14.10 for the maximum eigen value at 1% significance level. The same results are observed in the Trace tests confirming the existence of at most two co-integration relationships for Nile perch. Apparently, the Tilapiines and the mixed fish species show similar results in

[17] Read more on the interpretation of the Johansen Maximum Likelihood Test results, from Hendry & Doornik 1996.

Table 7.2a: Results for Co-integration analysis on four fish species for Kendu Bay Beach, 1990-2000

P=number of Co integrating vectors	Maximum eigenvalue $-T\ln(1-\lambda_{r+1})$			Trace $-T\sum\ln(1-\lambda_i)$		
	Unadjusted For df	Adjusted for df	Critical value	Unadjusted for df	Adjusted for df	Critical value 95%
Nile perch						
P = 0	79.59**	77.77**	21.00	110.90**	108.30**	29.70
P≤1	30.82**	30.12**	14.10	31.26**	30.54**	15.40
P≤2	0.44	0.43	3.80	0.44	0.43	3.80
Tilapiines						
P = 0	79.14**	77.33**	21.00	119.00**	116.20**	29.70
P≤1	39.50**	38.60**	14.10	39.82**	38.91**	15.40
P≤2	0.32	0.31	3.80	0.32	0.31	3.80
Mixed fish						
P = 0	78.16**	76.37**	21.00	111.90**	109.30**	29.70
P≤1	33.36**	32.60**	14.10	33.70**	32.92**	15.70
P≤2	0.33	0.33	3.80	0.33	0.33	3.80

Significance levels: **= 1%; *= 5%;

Table 7.2b: Results for Co-integration analysis on four fish species for Dunga beach, 1990-2000

P=number of Co-integrating vectors	Maximum eigenvalue $-T \ln(1-\lambda_{r+1})$			Trace $-T \Sigma \ln(1-\lambda_i)$		
	Unadjusted for df	Adjusted for df	Critical value	Unadjusted for df	Adjusted for df	Critical value 95%
Nile perch						
P = 0	64.30**	62.83**	21.00	117.20**	114.50**	29.70
P≤1	52.57**	51.37**	14.10	52.87**	51.66**	15.40
P≤2	0.30	0.30	3.80	0.30	0.30	3.80
Tilapiines						
P = 0	60.82**	59.42**	21.00	104.40**	102.00**	29.70
P≤1	43.16**	42.17**	14.10	43.62**	42.62**	15.40
P≤2	0.46	0.45	3.80	0.46	0.45	3.80
R. argentea						
P = 0	59.92**	58.55**	21.00	108.40**	106.00**	29.70
P≤1	48.18**	47.08**	14.10	48.51**	47.40**	15.70
P≤	0.33	0.32	3.80	0.33	0.32	3.80
Mixed fish						
P = 0	66.29**	64.77**	21.00	116.70**	114.00**	29.70
P≤1	50.04**	48.89**	14.10	50.39**	49.24**	15.40
P≤2	0.36	0.35	3.80	0.36	0.35	3.80

Significance levels: ***= 1%; *= 5%;***

Table 7.2c: Results for Co-integration analysis on four fish species for Uhanya beach, 1990-2000

P=number of Co-integrating vectors	**Maximum eigenvalue $-T \ln(1-\lambda_{r+1})$**			**Trace $-T \Sigma \ln(1- \lambda_i)$**		
	Unadjusted for df	**Adjusted for df**	**Critical value**	**Unadjusted For df**	**Adjusted for df**	**Critical value 95%**
Nile perch						
P = 0	61.30**	59.90**	21.00	120.10**	117.40**	29.70
P≤1	58.47**	57.13**	14.10	58.85**	57.50**	15.40
P≤2	0.38	0.37	3.80	0.37	0.37	3.80
Tilapiines						
P = 0	62.44**	61.01**	21.00	98.36**	96.11**	29.70
P≤1	35.52**	34.71**	14.10	35.92**	35.10**	15.40
P≤2	0.40	0.40	3.80	0.40	0.40	3.80
R. argentea						
P = 0	60.29**	58.91**	21.00	110.60**	108.10**	29.70
P≤1	50.02**	48.87**	14.10	50.36**	49.20**	15.70
P≤2	0.34	0.33	3.80	0.34	0.33	3.80
Mixed fish						
P = 0	71.58**	69.94**	21.00	122.40**	119.60**	29.70
P≤1	50.44**	49.28**	14.10	50.79**	49.63**	15.40
P≤2	0.35	0.34	3.80	0.35	0.34	3.80

Significance levels: ***=1%; *=5%;***

Kendu Bay beach. All the results for both Dunga and Uhanya beaches are the same as those of Kendu Bay beach.

Given the above results for both the stationarity and co-integrating tests the series amongst the three beaches satisfy the conditions for estimating an ECM. ECM assists in the determination of the short and long-term relationships between fish catch, climate and price.

7.3 Short and Long run Production elasticities and Error Correction Models

The preference of the first order lag ECM over the second order was tested using F test and imposing restriction on the two functions. The null hypothesis of no restriction was rejected hence suggesting no problems of misspecification in the first order ECM. The ECM displayed reasonable goodness of fit based on the adjusted R^2, F-statistic test for misspecification and autocorrelation. The ECM model for the Kendu Bay fishery showed fairly good explanatory powers ranging from 32% to 38% of the dependent variable (Appendix 6a-c). In Dunga beach the models showed less explanatory power than in Kendu Bay ranging from 18% (Nile perch) to 39.5% (mixed fish). Lastly, in Uhanya beach the explanatory power ranged from 18.8% (Tilapiines) to 30.2% (Nile perch). The co-integration analysis indicates that there is an underlying equilibrium relationship between fish catch, prices and rainfall over the study period for all the models.

Table 7.3 shows the short and long run production elasticities. The results points to the fact that in the short run that there is no effect of rainfall on the fish catch on most of the

Table 7. 3: Short run and long run production elasticities for major fisheries across sample beaches, 1990-2000

Beach/Fish type	Water	Short run		Long run	
	Hyacinth	Rainfall	Fish price	Rainfall	Fish price
Kendu bay					
Nile perch	0.352*	0.0028NS	-5.1621 NS	0.0287 NS	-1.0732***
Tilapiines	-1.010***	-0.0232 NS	-6.0569 NS	-0.1480 **	3.0679***
R. argentea	-	-	-	-	-
Mixed fish	1.859***	0.1181***	-7.3067 NS	0.2489***	0.1371 NS
Dung beach					
Nile perch	-0.101 NS	-0.0313 NS	-0.2164 NS	-0.0599 NS	-0.8280***
Tilapiines	-0.658***	-0.0726 NS	3.8832 NS	0.0261 NS	2.1007***
R. argentea	0.092 NS	-0.0007 NS	2.0856 NS	0.0681 NS	-0.7012**
Mixed fish	0.157 NS	-0.0739 NS	1.6275***	0.1760 NS	1.1974***
Uhanya beach					
Nile perch	0.020 NS	0.0368 NS	1.1408 NS	0.0656 NS	-0.6877***
Tilapiines	-0.394**	0.0118 NS	7.8293***	-0.0124 NS	-0.2712 NS
R. argentea	-0.080 NS	0.0105 NS	1.0833 NS	-0.0464 NS	-0.4050 NS
Mixed fish	1.223**	0.0899 NS	0.2911 NS	0.2057 NS	-1.6734*

Significance levels: ***=1%; **=5%; *=10%

NS - Not significant

fish species considered across the three beaches except mixed fish in Kendu Bay. The fish price effect in the short run is apparent on the mixed fish and Tilapiines in Dunga and Uhanya beaches respectively.

The high catch experienced for mixed fish with rainfall in Kendu Bay in the short run may be associated with the fact that fishing boats may not be able to move to distant fishing grounds (deeper waters) to go fishing due to heavy rains. The rainfall may interfere with fishing activities offshore hence limiting the number of boats fishing inshore where mixed fish are plentiful. In addition an increase in the water levels due to increased rains makes the mixed fish to shift to more exposed grounds hence easily caught. These factors lead to increased catches per boat. On the other hand Nile perch and *R. argentea* are unaffected as they are found in deeper waters in the lake.

In the short run fish price is expected to have a small effect on the fish catch. However, these results show that there was a positive relationship between the fish catch with the prices of mixed fish and Tilapiines. In the short run the positive relationship between fish catch and prices of Tilapiines and Mixed fish may be associated with the fact that when prices are high fishermen may be forced to maximize their catch and hence income by increasing the hours fished, using larger boats and increasing the number of nets used per boat (or increasing the number of hauls in the case of beach seine per day). Both of these species are mostly found inshore where it might be easy to increase the fishing effort. This could apply to those fishermen who are using beach seine and traditional fishing gears, which may not require large expenses.

The long run effect for rainfall was only felt in Kendu Bay for the Tilapiines and mixed fish. Kendu Bay beach is served by River Awach and therefore brings in a lot of effluents (in periods with plentiful rainfall) from the surroundings areas (including Kisii highlands) through runoffs, which contains phosphates, nitrates and silicates. In the long-run increased rainfall provides the needed nutrients for the plants and insects that fish feed on hence in turn provide food and hiding places for mixed fish. The increase in the mixed fish is associated with an increase in the breeding and feeding sites as more wetlands are filled with water. It appears like an increase in the water level interferes with the breeding grounds of the Tilapiines, hence reduced stocks and therefore availability. The other fish species were unaffected by different rainfall intensities.

In the long run fish price was significant for Nile perch in all the three beaches with a negative coefficient, while *R. argentea* was significant and negative in Dunga beach. Both Nile perch and *R. argentea* have negative coefficients indicating that an increase in price will lead to decline in the fish catch. These signs do not agree with the price expectations because an increase in the price is expected to step up the supply. Note that these are the two major commercial species, which are sold to factories for processing in the country. It is important to note that Nile perch on average accounts for 51% of the total quantity of fish landed on the Kenyan side of L.Victoria. It also has a well-coordinated market within and outside Kenya. This makes the price to be very sensitive to the quantity of fish landed. However, the unexpected sign on the prices might be due to the fact that the CPI used in the analysis may not be accurately approximating their prices. While the CPI indicates a progressive increase in its value the fact is that Nile perch price is very sensitive to the export market hence the ban on the EU ban led to decreased prices between 1997-2000. This divergence might be responsible for the unexpected signs for both species.

On the other hand the fish prices in the long run for the Tilapiines were significant and positive both in Kendu Bay and Dunga beaches, and for the mixed fish in Dunga beach. The positive relationship between fish catch and price for both Tilapiines and Mixed fish in the long run is consistent with the economic theory. Both of these fish species are sold locally or consumed by the fishermen themselves. Therefore their prices are based on the quantity of fish landed since the demand is always there. The selling prices are determined by the sizes and availability through negotiation.

It is important to note that there are differences in the beaches considered with respect to market proximity. For example, Dunga beach is located close to the large market of Kisumu, while Kendu Bay and Uhanya are situated further from the larger market and therefore price expected to be more sensitive in Dunga beach. This might explains why we have all price coefficients being significant in Dunga Beach unlike in the two other beaches.

The effect of water hyacinth on the four fisheries appears to be variable. Across beaches one observation that was common was that the Tilapiines were associated with significant and lower catches. The magnitudes of the elasticities followed the hypothesized impact in the presence of water hyacinth infestation. The elasticity of this variable was highest in

Kendu Bay (-1.010) followed by Dunga (-0.658) and Uhanya (-0.394). This effect seems to confirm the contention that the impact of water hyacinth on fish catch depends on the intensity of infestation. Kendu Bay beach had the highest water hyacinth infestation, followed by Dunga beach and the lowest being Uhanya beach.

The effect of water hyacinth on the Nile perch was significant at 10% level only in Kendu Bay beach. The results show that there was a significant increase of Nile perch fish catch in Kendu Bay during the time when there was water hyacinth, while there was no significant difference in Dunga and Uhanya beaches. This shows that the effect on Nile perch was realized at high intensity of water hyacinth infestation. On the other hand there were no significant differences in the CPUE for *R. argentea* in the two periods in all the three beaches. However, there were significant increases in the catches of the mixed fish species as evidenced by the significance of the water hyacinth factor in Kendu Bay and Uhanya beaches with coefficients of 1.859 and 1.223, respectively. The larger coefficient for Kendu Bay may have been associated with a higher intensity of water hyacinth infestation as compared to that of Uhanya. The mixed fish species consisted of primarily *Protopterus* and *Clarias.* It may have been possible to catch the mixed fish species since fishermen mostly use traps and traditional gears (mixed gears), which may be easier to maneuver in water hyacinth infested areas.

Water hyacinth provides shade to fish when the depth of water is comparatively low and also gives shelter to forage fish. In addition, algae, the main food for fish and other plants and animals attach themselves to water hyacinth leaves, petioles and roots, which are eaten by certain fish species. The increased water hyacinth mats results in oxygen depletion and mortality among gill respiring fishes. As already discussed these conditions suit the mixed fish (*Clarias, Protopterus, etc.*) and some particular Tilapiines species and this explains the high catches of the mixed fish. These conditions however, are not favourable to the Nile perch, which is herbivorous and require a lot of oxygen when still young but changes to omnivorous when it grows up. The *R. argentea* does not thrive under these conditions and because of its size, it is found in deep waters of the lake. Because of the fact that large Nile perch and *R. argentea* are found offshore particularly in areas, which were not prone to water hyacinth there was little effect on Nile perch and *R. argentea.* Although, there may be beneficial effects for some mixed Tilapiines (except the *O. nilticus*) provided by water hyacinth, its blockage grossly interferes with fishing activities hence reduced fish catch. The Tilapiines are mostly found at the inshore (in areas less than 20m), areas, which were intensely covered by water hyacinth. In this condition setting up of the fishing gears such as gillnets and beach seine, which are used to catch Tilapiines, was a problem.

The findings of *R. argentea* and mixed fish seem to be consistent with the study expectations, given their ecological characteristics. However, an increase in the CPUE for Nile perch in Kendu Bay is fairly weak observed at 10% significance level. The increased CPUE might be associated with high levels of WH intensity, which provide food to other fish types including the juvenile Nile perch. It is also important to note that Nile perch also feeds on other fish species including Tilapiines, *R. argentea* and mixed fish. Therefore an increase in mixed fish available may lead to its increased stocks.

CHAPTER 8

THE IMPACT OF WATER HYACINTH ON FISH SPECIES COMPOSITION

8.1 Introduction

This section of the study seeks to identify trends in the fishery composition in L. Victoria (Kenya) between 1986 and the year 2000. Regression analyses are used to establish the production trends. This in a nutshell, will provide information on the trend of the individual fishery composition. Secondly, this study aspires to test the hypotheses regarding the impact of water hyacinth and fish prices on the quantity of fish landed on the entire Kenya shoreline during the study period, using the vector auto regression (VAR) techniques. A total of eight major fish species were considered, viz. Nile perch, *R. argentea*, *O. niloticus* and mixed Tilapiines. Others include Haplochromis, *Clarias*, *Mormyrus* and *Protopterus*.

8.2 Trend in fish species composition L.Victoria (Kenya), 1986-2000

8.2.1 Changing fish species composition over time

At the beginning of the 20th century Lake Victoria had between 350-500 fish species, which have been reduced to 177-200 species at present. The Kenyan waters of L. Victoria currently have a total of 14 major fish species landed annually (Appendix 9). In recent times (2000) Nile perch has established itself as a major commercial spp. (57%) followed by Tilapiines (22%) and *R. argentea* (20%) (Table 8.1). This can be compared to the early 20th century when Haplochromis accounted for over 80% of the total catches but

Table 8. 1: Fish species composition on Lake Victoria (Kenya), 1986-2000

(% of the total)

Year	**Nile perch**		***R. argentea***		**Tilapiines**		**Mixed fish**		**Total**	
	Catch %	Value %	Catch %	Value %	Catch %	Value %	Catch %	Value %	Tons	Value '000'
1986	55.5	48.2	33.5	20.0	9.0	27.8	2.3	4.0	103163	237340
1987	60.4	57.2	29.2	15.2	9.0	25.7	1.4	1.0	113552	317020
1988	48.9	38.7	32.7	23.0	14.0	34.4	4.4	3.9	125071	493020
1989	42.0	39.6	33.6	21.3	13.0	28.1	11.4	11.0	135429	647060
1990	38.2	49.9	25.1	9.8	20.9	30.4	15.8	9.9	185101	1547420
1991	28.2	42.7	32.2	21.3	26.0	25.5	13.4	10.5	186366	1586620
1992	51.1	31.1	23.4	7.0	15.1	37.3	10.4	24.6	151216	3144300
1993	57.1	68.4	24.3	13.2	10.7	11.6	7.9	6.8	174829	3482790
1994	53.7	76.7	35.7	9.6	8.1	10.9	2.5	2.8	193652	3637600
1995	56.3	78.8	31.2	7.0	9.5	12.2	3.0	2.6	181888	4678140
1996	57.9	78.8	29.8	10.7	9.5	8.9	2.8	1.6	166400	6129840
1997	48.3	57.7	26.6	13.8	21.2	23.6	3.9	4.9	151293	4152000
1998	48.3	58.4	26.6	12.8	21.1	23.9	4.0	4.9	158876	6268700
1999	57.4	73.0	20.1	9.8	21.9	16.6	0.6	0.6	200153	7194940
2000	56.6	75.4	20.2	9.5	22.5	14.7	0.7	0.4	192738	7468960
Mean	**50.7**	**58.3**	**28.3**	**13.6**	**15.2**	**22.1**	**5.8**	**6.0**	**161319**	

Source: Computed from the Fisheries Department. Annual Statistical Bulletins now accounts for less than 3%. The reduction in this species has been attributed to the introduction of the Nile perch, which has been preying on the Haplochromis. This scenario in L.Victoria indicates a severe erosion of the biodiversity in the fishery sector, hence the need to undertake an investigation by delineating the factors, which may be responsible for the changing species in the lake.

Figures 8.1 and 8.2 shows the trends of the fish composition for the four major fish species landed by tonnage and value, respectively in L. Victoria for the period 1986 to 2000 (Table 8.1). The composition of Nile perch ranged from 28% (1991) to 60.4% (1987) with an average of 50.7% by weight over the study period. *R. argentea*[18] has fluctuated between 20.1% (1999) to 35.7% (1994) with an average of 28.3% by weight but seem to have a downward trend, while Tilapiines also fluctuated between 8.1% (1994) to 26 %(1991) with an average of 15.1%. The mixed fish species registered a minimum of 0.6% (1999) to a maximum of 15.8%(1990) with an average of 5.8% during the study period. This fluctuation reflects the changes in the quantities of fish landed over the period under study by individual fish species. The changes in the composition may be attributed to biological and socioeconomic factors.

A part from other factors, water hyacinth is postulated to have played a significant role in the quantity of fish landed and even the composition of the different fish species. There was a positive change (by tonnage) for the Nile perch over the period except in 1998

[18] The harvesting of *R.argentea* depends on the following three major factors; natural conditions (wind and rain), the phase of the moon where by the fish is more concentrated during the dark lunar cycles and the nature of the beach and surrounding habitat to allow for maneuverability with the lamps and fishing nets (Okedi 1981).

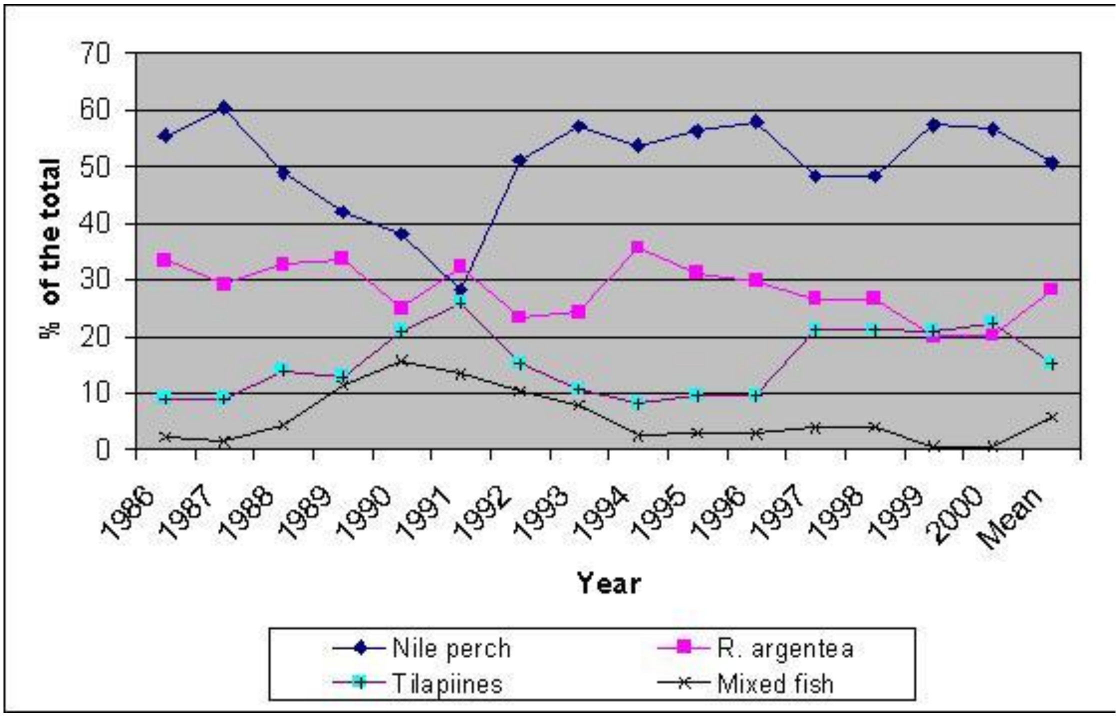

Figure 8. 1**: Fish species composition on L. Victoria (Kenya) by tonnage,1986-2000**

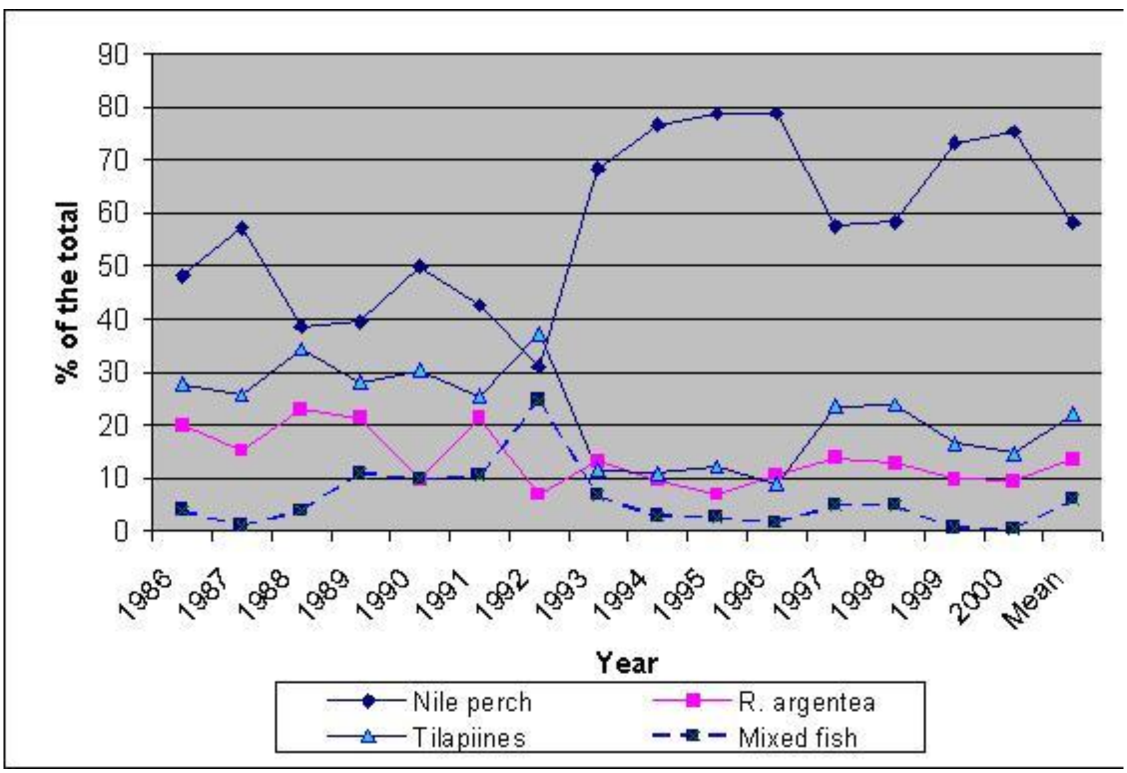

Figure 8. 2: Fish species composition on L. Victoria (Kenya) by value, 1986-2000

when there was a decline in the proportion by 9%. *R. argentea* has experienced a negative trend over the period except the year 1994. There was a variable trend for both Tilapiines and mixed fish, which registered negative growth up to 1994 but became positive after that.

The average composition by value over the study period on average is 58.3, 13.6, 22.1 and 6.0% of the total earnings for Nile perch, *R. argentea*, Tilapiines and mixed fish species respectively over the study period. The value of the Nile perch was dictated by the quantity of fish catches as can be noted from the trends depicted by Figures 8.1 and 8.2. It can be noted that a drop in the catch for this spp. in 1997-1998 is also reflected by a drop in the proportion for the value composition in the same period. Although *R. argentea* has a higher proportion in the total fish catch than the Tilapiines, the reverse occurs when one looks at the composition by value, which shows that the Tilapiines have a higher proportion than the *R. argentea*. This means that the value (price) of one tonne of Tilapiines was higher than that of *R. argentea*. Most of the Tilapiines are consumed domestically and are cherished by the local community hence pushing the prices upwards due to excessive demand as compared to *R. argentea* which is consumed domestically and a significant proportion send to factories for processing into animal feeds.

There was a notable decline in the percentage of the Nile perch realized between the period 1996-1999 apparently being the period when there was water hyacinth and the EU ban of fish exports from L.Victoria. This decline is reflected in the drop of the value composition over the same period and could be attributed to the decline in the price offish and the quantities as a result of the export ban. However, the Tilapiines show a different scenario whereby there is a significant increase in the composition by weight during the period 1997-2000. This effect is also shown in the composition of this species by value, especially for the period 1997-1998, although with a decline in the period 1999-2000. *R. argentea* showed a decline in the proportion by weight over the period 1996-2000, but experienced an increase in the value composition over the same period probably as a result of lower prices for the Nile perch. On the other hand the mixed fish had a stable proportion of weight over the period 1994-1998 although the value composition increased for the period 1996-1998. The higher value composition might also be attributed to the lower price of the Nile perch.

The changing fish species composition during the study period with and without water hyacinth shows an interesting picture making it suspect among other factors to explain the variability of fish by species over time.

8.2.2 Trend analysis

Trend analysis was undertaken using regressions analyses for all the eight principal fish species for the period 1986-2000. Time was the main explanatory factor.

The trend was estimated as a linear function (Klein 1985) defined as:

$\pi_{it} = a + ßT$

where

π_{it} = Given as the proportion of fish spp i catch to the total annual fish catch for all species in year t, while a = constant, ß = is the slope coefficient and T is the time used to capture the trend. The regression results are presented in Table 8.2. The model t-statistics are significant for the rest of the fish species except Nile perch, *O. niloticus*, Haplochromis and *Clarias*. The results show that *R. argentea* and *Mormyrus* have negative coefficients over the study period indicating that catches have been declining over the time. The mixed Tilapiines[19] and the *Protopterus* had positive signs indicating that their proportions and hence catch increased during the period.

This analysis gives a better picture of the trend in the fish species composition over the study period. These results show that the fish species can be categorized into three, increasing, 'stable' and decreasing proportions. The mixed Tilapiines and the *Protopterus* species showed increasing trends, while *R. argentea* and *Mormyrus* displayed a declining trend over the period. On the other hand that for Nile perch, *O. niloticus*, Haplochromis and *Clarias* was neither increasing nor decreasing during the period. Harvesting and natural regrowth were balancing out.

8.3 Estimation of the VAR model

The Augmented Dickey and Fuller (ADF) and Phillips-Perron (PP) unit roots tests were undertaken using the Shazam version 7.0, Econometrics Computer Program to check for the existence of unit roots in the time series on three variables (fish weight, fish price and water hyacinth intensity (WHI)). The estimated statistics were compared with the critical values of the various tests. If the computed statistics (absolute) are less than the critical values then it is concluded that the series have unit roots. The results are presented in

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[19] Mixed Tilapiines may include the endemic spp. *T. variabilis* and *T.esculenta*, while the exotic ones include *T. zilli*, *T. melenoplenora* and the *T. leucostica* introduced in the early 1950's. The Tilapiines are particularly popular in East Africa and subjected to intensive fishing (Wambayi 1981).

Table 8. 2: Results of Trend analysis for fish species composition, on Lake Victoria, (Kenya) 1986–2000

Variable	**Nile perch**	***R. argentea***	***O. niloticus***	**Mixed Tilapiines**	**Haplochromis**	**Clarias**	***Mormyrus***	***Protopterus***
Constant	-0.782***	-1.082***	-2.277***	-4.942***	-7.030***	-5.585***	-5.991***	-8.086***
Time	0.011NS	-0.244**	-0.036 NS	0.185***	0.213 NS	-0.031NS	-0.194**	0.171**
R^2	0.057	0.356	-0.009	0.510	0.133	0.0311	0.317	0.343
Adj. R^2	-0.015	0.306	-0.068	0.472	0.066	-0.044	0.265	0.290
Pvalue	0.391	0.019	0.743	0.003	0.182	0.532	0.029	0.022
DW	1.142	1.735	0.923	2.840	2.030	1.451	0.898	1.744

Dependent variable: Proportion of the annual total catch for each spp to the total annual fish caught for all fish species
Significance levels: ***=1%; **=5%; *=10%

Appendix 7. The ADF test indicated that there were unit roots for all the series using both the ADF and PP tests except for fish weight for Haplochromis at 1% significance level. Therefore it became necessary to transform the data through first differencing to conform with the VAR model. The results show that when the time series are first differenced they all became stationary.

The model was estimated as the VAR[20] order of one and thus denoted as VAR (1). This was dictated by degrees of freedom whereby there are only 15 observations (years) against 9 variables compared to 18 variables when the model is estimated as VAR (2). Despite this, the estimated results for VAR (2) were not different from the first one. The coefficients α_1, α_2 and α_3 stand for fish catch, deflated fish price and water hyacinth

[20] This model was estimated using a Time Series Processor (TSP) Computer Package Version 4.2, Hall B.H. 1994.

intensity, respectively all lagged one period. All the time series data are natural logarithms transformations. Based on the results the models which explained better and satisfied conditions of absence of autocorrelation included *Protopterus*, *R. argentea*, mixed Tilapiines and Haplochromis[21]. The results and discussions that follow are based on these four fish species (Table 8.3a-b), while the results for the rest are presented in Appendix 8a-b.

The R^2 for *Protopterus* are fairly high except for the Water hyacinth intensity equation, which is very low (0.043). In the fish catch equation the quantity of fish catch is significant and positively (0.603) affected by water hyacinth intensity, while in the price equation the fish price is significantly and positively (0.329) affected by the water hyacinth. The water hyacinth equation has no significant variables. *R. argentea* had fairly high-adjusted R^2 for the fish weight and fish price equations except for the water hyacinth intensity equation (0.181), which was relatively low. However, looking at the fish catch equation the quantity of fish landed is negatively (-0.109) affected by water hyacinth intensity. In the fish price equation the fish price is influenced significantly by the fish catch negatively. All the variables in the water hyacinth intensity equation were insignificant. On average the R^2 for mixed Tilapiines indicates a better performance of the model. The results in the fish catch equation show that quantity of fish is significantly and positively (0.782) affected by the water hyacinth intensity. On the other hand the results for the water hyacinth equation also show that fish catch significantly affects

[21] There were four other fish species, which had evidence of serial autocorrelation, with the VAR results showing very low R^2 and insignificance of factors under investigation. The four fish species included Nile perch, *O. niloticus*, *Mormyrus* and *Clarias*. See Appendix 8a-b.

Table 8.3 a: First-order VARS results for *Protopterus* and *R. argentea*

	Protopterus				*R. argentea*			
	Estimate	**Std.**	**T.stat**	**P-val**	**Estimate**	**Std.**	**T.stat**	**P-val**
Parameter	Ln weight				Ln weight			
α_1	-0.301	0.302	-0.997	0.342	-0.108	0.241	-0.447	0.664
α_2	-0.370	0.651	-0.569	0.582	0.075	0.099	0.751	0.470
α_3	0.603	0.226	2.669	0.024	-0.109	0.041	-2.636	0.025
R^2	0.386				0.429			
	Ln price				Ln price			
α_1	0.011	0.130	0.084	0.935	-1.314	0.467	-2.813	0.018
α_2	-0.285	0.279	-1.021	0.331	-0.505	0.192	-2.627	0.025
α_3	0.329	0.097	3.396	0.007	-0.034	0.080	-0.424	0.680
R^2	0.549				0.632			
	Ln WHI				Ln WHI			
α_1	0.571	0.398	1.435	0.182	0.715	1.927	0.371	0.718
α_2	-1.162	0.858	-1.355	0.205	0.047	0.793	0.060	0.953
α_3	0.114	0.298	0.383	0.710	0.147	0.330	0.446	0.665
R^2	0.043				-0.181			

Notes:
Std.- Standard deviation
WHI- Water hyacinth intensity

Table 8.3 b: First-order VARS results for mixed Tilapiines and Haplochromis

	Mixed Tilapiines				Haplochromis			
	Estimate	**Std.**	**T.stat**	**P-val**	**Estimate**	**Std.**	**T.stat**	**P-val**
Parameter	Ln weight				Ln weight			
α_1	-1.281	0.292	-4.393	0.001	-0.098	0.348	-0.283	0.783
α_2	-0.739	0.734	-1.006	0.338	3.281	1.354	2.424	0.036
α_3	0.782	0.271	2.884	0.016	0.248	0.719	0.345	0.737
R^2	0.593				0.487			
	Ln price				Ln price			
α_1	0.127	0.076	1.687	0.122	-0.105	0.064	-1.646	0.131
α_2	-0.411	0.190	-2.162	0.056	-0.975	0.249	-3.921	0.003
α_3	0.086	0.071	1.230	0.247	0.262	0.132	1.983	0.076
R^2	0.664				0.594			
	Ln WHI				Ln WHI			
α_1	-1.139	0.510	-2.231	0.050	-0.333	0.139	-2.391	0.038
α_2	-0.669	1.285	-0.521	0.614	0.357	0.542	0.658	0.526
α_3	1.152	0.475	2.428	0.036	0.714	0.288	2.483	0.032
R^2	0.298				0.530			

Notes:
Std.- Standard deviation
WHI- Water hyacinth intensity

water hyacinth in the water hyacinth intensity equation. All the three equations for *Haplochromis* have fairly reasonable R^2. There is a significant and positive relationship between quantity of fish landed and the fish price in the fish catch equation, while the fish price is accounted for significantly and positively with the water hyacinth in the fish price equation. As in the case of the mixed Tilapiines model fish catch significantly affected water hyacinth negatively in the water hyacinth equation.

As defined by Granger (1969) and Sims (1980) Granger causality[22] may be inferred when lagged values of a variable say x_t, have explanatory power in a regression of a variable y_t on lagged values of y_t and x_t. Since all the models estimated are VAR (1)[23], the significance of the test variables implies an existence of the Granger Causality. The discussion below focuses on the Granger Causal relationships between the test variables among the different fisheries.

In the case of *Protopterus* there is only one Granger Causality running from water hyacinth to the quantity of fish produced. There is no Granger causality running from the quantity of fish landed to the water hyacinth. This might be due to the fact that most of the water hyacinth is affected by natural factors more than the actual removal by man. As already pointed out water hyacinth provides a suitable environment to the local fish species such as *Protopterus* and *Clarias.* This confirms the hypothesis that water hyacinth infestation has led to increased availability of the *Protopterus* fish. In the case of

[22] The properties of Granger causality, economic exogeneity and omitted variables are discussed in Granger (1969), Sims (1972) and Sargent (1981).

[23] In the case where there is VAR of order 2 and above, then one has to compute the F-test and use it to decide on the significance of all the lagged variables.

fish price there is also unidirectional Granger Causality running from water hyacinth to the fish price. The results indicate that an increase in water hyacinth leads to an increase in the fish price. Ideally, since water hyacinth increases the catch it is expected to lower the price because of the increased production. However, an increase in the price might be due to the increased demand (change of taste) as a result of the popularization of the species with the advent of water hyacinth. Finally, there is no Granger Causality running in any direction as depicted by the results in the water hyacinth equation where there are no significant factors.

For *R. argentea* there is Granger Causality running from water hyacinth to the quantity of fish landed. The results show that an increase in the water hyacinth leads to a reduction in the quantity of fish landed. This might be attributed to the fact that the blockage of the landing beaches and fishing ground makes it difficult for the fishermen to access the lake. Although the fishing activities of the *R. argentea* are majorly based on the position of the moon, it becomes problematic to operate the fishing gears and handling of the fishing lamps in the presence of water hyacinth hence resulting into fewer fishing boats. Ultimately, this lowers the fishing frequencies and therefore reduces the fish catch. The results also show that there is a Granger Causality running from the fish quantity to the price. This means that an increase in the quantity of fish landed leads to a decline in the price offered. This concurs with the price theory, which asserts that an increase in the quantity supplied will lead to a fall in the price of the commodity being considered. The *R. argentea* price is unaffected with the change in the intensity of water hyacinth.

Similarly, there is no Granger Causality running amongst the three variables in the water hyacinth equation.

In the mixed Tilapiines there is bi-directional Granger causality between the fish catch and water hyacinth. This means water hyacinth causes the weight of fish and the vice versa. Thus an increase in the quantity of mixed Tilapiines with water hyacinth can be attributed to reduced predation by Nile perch as this fish hides under the water hyacinth mat and also by the reduced competition for habitat hence better access to food. Unlike the *O. nilticus* most of the other Tilapiines can survive under less oxygen environment. The results means that there is increased fish stocks and therefore leading to increased catches when the water hyacinth mats finally moves away from the landing beaches and fishing ground. The fact that there is a negative relationship between fish catch and water hyacinth in the water hyacinth intensity equation imply that fish catch depresses the water hyacinth incidence. This is a difficult relationship to explain since it is not easy to discern how increased fish catch may lead to reduced water hyacinth intensity. Even if one had to assume that increased catches might provide incentives for the fishermen to remove weed manually from the landing beaches the quantity involved might be so small to make any impact.

Amongst the *Haplochromis* there is unidirectional Granger Causality running from water hyacinth intensity to price. This implies that an increase in the intensity of water hyacinth leads to an increase in the fish price, thus not consistent with the expectations. The expectation could be that any factor that increases fish catch should lower the price.

As in the case of the *Protopterus* the price of fish continues to rise because of the popularization of this species with the coming of water hyacinth. However, there was no significant effect of water hyacinth on this species (Haplochromis). As in the case of the mixed Tilapiines there is a Granger causality running from fish catch to water hyacinth, a case which has already been explained above.

Based on the VAR analyses it is evident that water hyacinth leads to increased fish catch for the mixed fish *(Protopterus* and others) and mixed Tilapiines, while there is a reduction of the *R. argentea*. Although the analysis failed to detect any effect on the Nile perch and the *O. niloticus*, these results show that these changes are capable of creating an imbalance in the fish species diversity.

8.4: Impulse Response Analysis on Water Hyacinth effect on fish production

The results for the impulse response function of fish catch and prices to water hyacinth are presented in Figures 8.3a-d. In this study the shocks are inflicted on the water hyacinth intensity to observe the change in the quantity of fish landed and the fish price when there is 10% increase in the water hyacinth intensity. The water hyacinth initial shocks on the catch of *R. argentea* show that there was a decline of 1.5% and 0.5% for catch and price respectively. The response to the water hyacinth shocks in *R. argentea* is

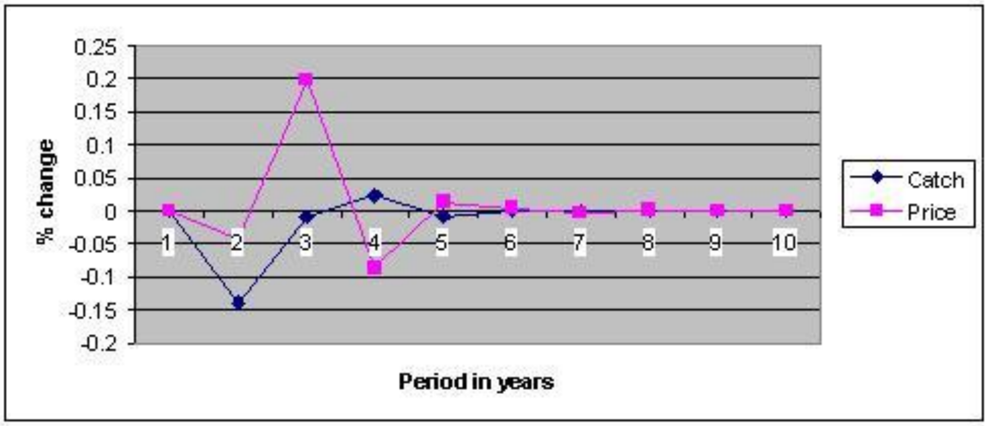

Figure 8.3 a: Impulse response function of fish catch and price on water hyacinth for *R. argentea*, 2001

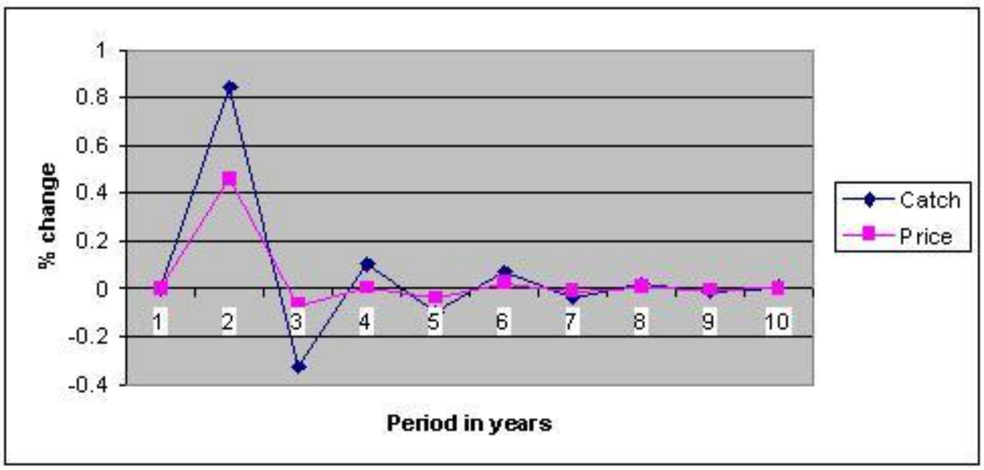

Figure 8.3 b: Impulse response function of fish catch and price on water hyacinth for *Protopterus*, 2001

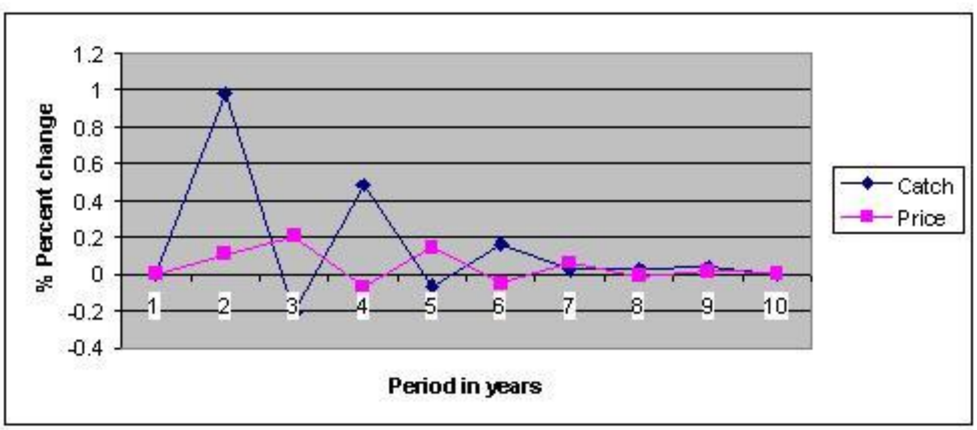

Figure 8.3 c: Impulse response function of fish catch and price on water hyacinth for Mixed Tilapiines, 2001

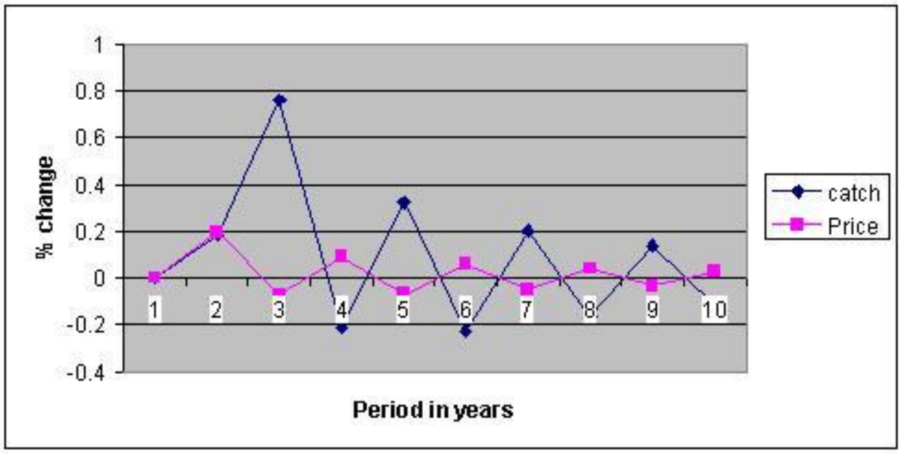

Figure 8.3 d: Impulse response function of fish catch and price on water hyacinth for *Haplochromis*, 2001

experienced by both catch and price declining initially and then changing to a positive trend. In the fourth period the two move in opposite direction indicating that when catch increases there is a decline in the price. Stability is attained as from the seventh year.

The effect of the same shock on the *Protopterus* results in a catch increase by 8%, while the price also increased by over 4%. Both the fish catch and price respond by moving upwards and then declining in the third period. The movement in the opposite direction sets in during the fourth year as in the case of *R. argentea*. The differences are ironed out as from the eighth year.

On the other hand the mixed Tilapiines had the highest increase by 10% of the catch while the price also went up by 1%. From the third period both the price and catch started moving in opposite direction indicating that an increase in the catch leads to a decline in the price. There was a fluctuation of the two factors with the divergences narrowing up from the seventh period. The catch and price for the Haplochromis shot up 2% each responding to the initial water hyacinth shock. The Haplochromis display a clear trend, which show that the price and catch start moving in the opposite direction from the third year and maintain this trend beyond the ten-year period. This means stability is attained beyond the ten-year period.

Water hyacinth shocks are not easy to predict given the mobile nature of the weed, which depend on the wind patterns and currents. The results indicate that there is an immediate respond to the shocks depending on the type of fish species but one observation, which is clear, is that from the third/fourth year the price and catch move in the opposite direction. Except for the *R. argentea* the WH shocks leads to increased landings of the three fish species (*Protopterus*, *Haplochromis* and mixed fish) for reasons already advanced. The above results are based on the prevailing conditions in the last ten years

The upward movement of prices and fish catch in the three fish species (mixed Tilapiines, *Protopterus* and Haplochromis) given the initial water hyacinth shock, indicates that price increases are associated with increased catches (supply) which is consistent with the price theory. In addition, the increase in the demand for these traditional fish species may be responsible for the increasing prices. The same interpretation may be given for the *R. argentea.*

CHAPTER 9

SUMMARY, CONCLUSIONS AND IMPLICATIONS

9.1 Introduction

This chapter gives a summary and conclusions of the study. The study was aimed at assessing and documenting the impact of water hyacinth on the L. Victoria fishery, Kenya. Both primary and secondary data were used to provide information about the temporal and spatial distribution of water hyacinth, ecological, social and economic impacts of the water hyacinth on fish production. An in depth analysis of the water hyacinth effects on fish catch, net benefits and species composition was conducted. Summaries of the key findings of the impact assessment of water hyacinth on fish catch at the sample beaches and for lake wide production were also undertaken. Salient features arising from the study pertaining to research, control and surveillance of water hyacinth were also addressed in this chapter. Finally, a note on the shortcomings of the study is provided.

9.2 Water hyacinth Incidence, Economic, Social and Ecological impacts

This study aimed at documenting the water hyacinth incidence and its economic, social and ecological impacts using the cross section data. One major concern has been to estimate the quantity of water hyacinth on L. Victoria (Kenya) and hence attempt to measure its impact on the fishing enterprise. Based on the fishermen’s assessment the results indicate that the water hyacinth effect was experienced at different intensity levels between 1991-2000. However, the study indicates that the peak period for water hyacinth infestation was 1996 to 1999, when over 43% of the respondents reported that water hyacinth severely hampered their socioeconomic activities. The study attempted to interpolate the area covered by water hyacinth based on the water hyacinth intensity levels with the benchmark being 6000 ha recorded in the year 1998. The results also found out that water hyacinth was more intense during the rainfall seasons implying that it benefited from the inflows of the effluents, which contain plant nutrients. On average the sample beaches were infested by water hyacinth for four months per year. The fact that water hyacinth was found to be more serious during rainfall seasons confirms the fact that the pollution from the agricultural environs and industrial areas in towns pose a somber problem to the efforts of water hyacinth control as these effluents provide nutrient to the water hyacinth. Monitoring and control of these pollutions needs to be given priority if the efforts of water hyacinth have to yield any dividends.

Responses from the fishermen indicated that water hyacinth led to the decline of R. *argentea* and *Schilbe* fish species, while *Protopterus* and *Clarias* were reported to increase. There was no clear response from the fishermen regarding the catch for Nile perch and Tilapiines in the presence of water hyacinth. The study also showed that water hyacinth significantly led to increased costs of fishing due to increased fishing effort including additional labour for clearing the water hyacinth and time taken to access the fishing ground and landing. This had profound negative effect on the fishing costs particularly for the motorized engines, which experienced considerable plummet in net incomes. Overall, water hyacinth increased the cost of fishing by 35% with a subsequent decline in the net benefits of 52.2% considering all fisheries and different types of gears. The principal impact on net benefits was felt on those fishing gears, which used outboard engines for boat propulsion such as gillnets. A reduction in the net benefits of fishermen by 52% imply a colossal loss of the fishermen's income indicating that the level of poverty is going to be increased for the fishing community if remedial steps are not taken against water hyacinth spread. The Central segment required more attention as 52% of the respondents reported that WH affected their socioeconomic activities. Both the Northern and Southern segments were less affected. This could have a bearing on the resource allocation in the management of the weed.

9.3 Water hyacinth and other determinants of fish Productivity and income

Information and modeling approaches in the determination of the impact of water hyacinth effect on fish productivity and income are scanty, hence the need to address these issues. This study sought to establish suitable modeling approaches to determine the impact of water hyacinth on fish production using the case of L. Victoria (Kenya). Since price is also directly or indirectly affected by water hyacinth through changes in the fish catch it was also studied. Both cross section and time series data were used. A production function (PF) was used on the cross section data while ECM was preferred for the time series data because of analytical problems which arise, hinging on non-stationarity and hence spurious regression when ordinary least Squares method is used.

In the cross section data analysis, four fish species were investigated, namely Nile perch, *R. argentea*, Tilapiines and the mixed fish. The fishing crew (labour) had positive effect on the quantities of Nile perch and the Tilapiines, while the boat size was found to have positive effects for both the combined fish and Nile perch functions. The years of experience in fishing were negatively associated with the combined fish catch. On the propulsion method, the sail method was found to have higher catches over the oar in the combined output and Nile perch. The Tilapiines had inferior catches when the sail was compared with the oar. This is due to the fact that sail is used deep in the lake where Tilapiines are not plentiful. The outboard engine had higher catches over the oar in the combined output and the Nile perch functions because of making maneuverability easier and long distance to be covered. Fishing gears had varied effect on the fish catch, for example fishermen with gillnets realized less fish catch than those with the mixed gears in the combined output. Long line had similar effect as gillnets although the lower fish catch was also experienced in the Tilapiines. The mosquitoe seine had superior catches in both the combined output and for the *R. argentea* but with lower catches for the Nile perch. The beach seine had higher catches for the combined output against the mixed fishing gears. These results show that fishing gear type is a function of the fish catch and therefore the income.

In the case of the fish net income for the combined fish income the years of experience had negative effect while the fishing crew was found to increase income. Fishing with gillnets had lower income as compared to the mixed gear, while mosquitoe seine had higher incomes. Both the sail propulsion method and the outboard engine displayed higher incomes above the oar propelled boats. The boat size, fishing with gillnets and beach seine had no significant effects on the fish income. The higher catches realized by both mosquitoe seine and the beach seine over the mixed fishing gears is a clear indication of higher catch rate and therefore leading to over-exploitation of the targeted species. These findings justify the ban of these fishing gears by the government.

The differences in the regions (segments) Southern, Central and Northern were captured using a dummy with the Southern segment being the reference point. In the Northern segment the combined output and the mixed fish were not significantly different with that of the Southern. However, the fish catch were higher for the Nile perch and lower for the *R. argentea* and Tilapiines in the Northern. On the other hand the Central segment had higher catches for both the Tilapiines and Mixed fish, although it had lower fish catches for the combined out put and *R. argentea*. In the net income both the Northern and Central segments had higher net incomes.

The PF results indicate that water hyacinth was associated with increased catches of the mixed fish and lower catches of the combined output and the Tilapiines. There was no effect of water hyacinth on the Nile Perch while the there was no information for *R. argentea* as there was no landing of this species in the sample beaches which were affected by water hyacinth. The ECM results on the other hand show that water hyacinth was associated with lower CPUE of Tilapiines in all the three sample beaches. Nile perch showed positive relationship of CPUE with water hyacinth in the Kendu Bay beach only. Water hyacinth was found to have had no effect on *R. argentea* both in Dunga and Uhanya beaches. There was no data on *R. argentea* available for Kendu Bay beach to allow similar analysis. The CPUE for mixed fish increased with increased water hyacinth in all the beaches except in Dunga Beach. The coefficients indicated that the impact of water hyacinth on the CPUE depended on the intensity of water hyacinth cover, at the beaches. The beach, which had a higher intensity of water hyacinth, showed a higher impact on the CPUE, particularly on the Tilapiines and mixed fish.

Both the PF and ECM results showed similar effects on the fish catch. WH had significant negative and positive effects on the Tilapiines and mixed fish, respectively. There was no evidence of WH effect on the CPUE for *R. argentea*, while the effect on the Nile perch appeared remote. These results therefore show that water hyacinth has had both negative and positive effect on the L.Victoria fishery. It is important to note that mixed fish accounts on average for about 5.8% while the Tilapiines for 15.2% of the total landings.

The results showed that there was relatively a smaller effect of both rainfall and price on CPUE in the short run, as evidenced by lack of significance of these two factors among the models in the three beaches. The rainfall factor was significant only in Kendu bay for the mixed fish. This shows that rainfall had little effect on the CPUE for the other fish species. However, in the long run the results showed significant effects of rainfall on Tilapiines and mixed fish only in Kendu Bay beach. Although there have been reports linking rainfall intensities directly with fish quantity realized there was little evidence on this except in the Kendu bay beach which might be associated with increased effluents from as far as the Kisii highlands through the Awach river.

The price effect was realized for mixed fish in Dunga beach and Tilapiines in Uhanya in the short run. This confirms the fact that price is the driving force in fish production as evidenced by the increased significance of most of the factors. Except for the mixed fish, the Nile perch, Tilapiines and *R. argentea* are the major commercially traded species accounting for over 94% of total fish quantity landed in L.Victoria (Kenya). Both Nile perch and *R. argentea* had unexpected signs as the results show that increased prices leads to a fall in the CPUE. This anomaly could be related to the fact that the CPI was not able to effectively map out the fish prices as there were declining prices for the Nile perch during EU fish ban period, while the CPI continued to rise. The positive relationship between the price and fish catch for both Tilapiines and mixed fish is consistent with the economic theory, whereby an increase in the price is expected to increase in the supply.

9.4 Water hyacinth, Fish price and Species Composition

The findings of the trend analysis of the fish species composition since 1986 indicated that the proportion of mixed Tilapiines and *Protopterus* were on the increase, while *R. argentea* and *Mormyrus* declined over the study period. The trend for the rest of the fisheries (Nile Perch, Haplochromis, *O. niloticus* and *Clarias*) was undefined. In terms of policy there might be no cause for alarm when the fish species are on the increase or stable but there might be concern with the decreasing fish species as was the case of *R. argentea* and *Mormyrus.* The reduction might be due to overexploitation as a result of increased fishing effort or because of ecological factors. In this particular case there have been fingers pointing at the increased fishing effort as shown by increased number of fishermen and fishing boats.

The results of the VAR analysis point to the fact that the presence of water hyacinth has been associated with increased production of *Protopterus* and mixed Tilapiines, while there was a negative relationship with *R. argentea*. However, there was no evidence of any effect of water hyacinth on the Haplochromis. This analysis provides evidence that there was increased fish production on L.Victoria (Kenya) for *Protopterus* and mixed Tilapiines with increased water hyacinth infestation, indicating that there are benefits that can be derived from this dreaded weed. These benefits were realized irrespective of the blockage that the weed causes in the landing beaches and fishing grounds. These findings concur with those of the ECM indicating that the CPUE of the mixed fish increased under water hyacinth infestation. The improved CPUE may explain the increase in the production of *Protopterus.* Although the Tilapiines in general showed a lower CPUE consistently, these results indicate that there was an increase in the mixed Tilapiines with increased water hyacinth infestation. The mixed Tilapiines can survive better in low oxygen environment than the *O. niloticus*. On the other hand *R. argentea* production was reduced by increased water hyacinth intensity, although there was no effect of water hyacinth on the CPUE as inferred from the ECM results. Therefore the increased production may be associated with the increased fishing pressure. Although, Nile perch showed a small effect of water hyacinth on the CPUE, trend analysis indicated that there has been no significant change in the proportion landed. This is evident from the weight composition, which averaged 51% over time since 1986.

Prices were found to have insignificant effects on the quantity of the fish landed, except with the Haplochromis, unlike the effects on the CPUE's. This showed that, as the price increased there was increased catch of the Haplochromis. The effect of price on fish production was not apparent for *Protopterus* and mixed Tilapiines and similarly to the *R.argentea*. Water hyacinth was found to increase the price of *Protopterus and* Haplochromis. This is expected to reduce price, however this was not the case as this finding is not consistent with the price theory. This might be due to an increase in the demand of these local species, which had disappeared but were resurfacing due to water hyacinth infestation.

The bottom line of the VAR analysis is the impulse response function, which shows the effect of the water hyacinth shock on fish production and fish prices over a ten-year period. The results indicate that inflicting of initial shock by 10% will lead to a decline in fish catch and price by 1.5% and 0.5% respectively for *R. argentea.* This shock will lead to *Protopterus* increases of fish catch by 8% and the price by 4%. The mixed Tilapiines shows the highest increase in catch by 10% and price by1%, while the Haplochromis increase in catch of 2% and the same value for the price. The initial movement in price and catch arising from the water hyacinth shock is consistent to the price theory.

These results therefore show that WH was associated with increased production of *Protopterus* and mixed Tilapiines while there was a decline of the *R. argentea*. There was no evidence of WH effect on the production of Haplochromis, Nile perch, O. *niloticus*, *Mormyrus* and *Clarias*.

9.5 Implications and Recommendations

9.5.1 Surveillance and management of Water Hyacinth

Despite the demonstrated benefits realized by the mixed fish associated with water hyacinth infestation through increased CPUE and total production there is need to monitor and control water hyacinth infestation on the lake. Water hyacinth does not only hamper the fishing activities but also affect water quality and in addition provide breeding ground for various diseases vectors such as malaria and Cholera, hence require surveillance to know whether the infestation are getting out of control. The major concern with control efforts is to decide whether to maintain water hyacinth at the expense of *O. niloticus, R. argentea* and Nile perch, which don't seem to make any gains from water hyacinth. The findings from this study indicate that only the less commercial fish species seems to benefit from water hyacinth. In fact there is evidence that *R. argentea* catches are reduced by water hyacinth. The level of water hyacinth infestation seem to be directly related to its impact on the fishing activities as demonstrated by this study, hence implying that if water hyacinth is not checked beyond a certain threshold then it may lead to the extinction of some of the major commercial species. This therefore calls for the government to invest resources in order to contain the water hyacinth below economic injury levels.

To effectively control water hyacinth there will be need for the government to obtain a data bank containing information on the infestation levels, mobility and duration of water hyacinth in specific shorelines/beaches. There will be need to establish an elaborate surveillance system, which will assist in monitoring the water hyacinth infestation in the lake. This will be an important undertaking since it has been difficult to get information on the severity of water hyacinth over time for any particular beach. The generated information will be useful in the allocation of funds for the water hyacinth control. One of the key determinants of the resource allocation would be the intensity of water hyacinth in a given location.

This information will also useful in planning on the type of control that should be instituted in a particular beach given the intensity of water hyacinth infestation. The control of water hyacinth will necessitate costs savings that the fishermen incur while fishing under water hyacinth infestation and also ensure increased fish production. In addition the creation of a data bank will help in carrying out impact assessments on the effect of water hyacinth on fishing and also in forecasting. These benefits will justify the expenditures on the control of water hyacinth.

9.5.2 Fish regulation and management

There has been need to regulate the fishing industry in order to ensure sustainable utilization of this important resource. This study has identified various factors that can be used in the regulation, conservation and management of the lake. These include control of the fishing effort, viz. labour, boat size, fishing gears and propulsion method. The positive correlation between labour and fish catch for the Tilapiines and Nile perch shows that the harvesting of these species can be controlled through the regulation of the number of people fishing during specific times, for example during spawning periods and in specific places. The government can undertake this through restricting the number of licenses issued for fishing as the case might be.

Boat size was also found to positively affect the combined output and also the Nile perch. Therefore limiting the size of boats engaged in fishing can control the quantity of fish harvested. If the intention by the government is to control over fishing of Nile perch then the best strategy is to limit fishing by large boats. As it is already known Nile perch requires larger boats because of its size and the fact that it is mostly found in deeper waters, which may also require larger boats.

In addition, regulation of fishing can be done through fishing gears. This study found out that mosquito seine and beach seine were associated with higher catches as compared to mixed fishing gears. These two fishing gears have already been banned on L. Victoria because of their relatively small mesh size hence catches even juvenile fish. The use of mosquitoe seine is only permitted for use on *R. argentea* with a mesh size of at least 10mm. The mosquito seine had higher catches of the combined output and *R. argentea*, while the beach seine was associated with higher catches of the combined output.

The last option that may also be implemented by the government in regulating over fishing from the lake include the use of motorized outboard engines. This study showed that outboard engine led to higher fish catches over the paddle-propelled boats with a larger elasticity than the sail propelled boats. This was noted for both the combined and Nile perch functions. This shows that if the government wants to limit the quantity fished from the lake it can do this by banning or licensing outboard engines with a specific HP to be used in the L.Victoria fishery.

A combined enforcement of these strategies and continued ban of fishing in breeding grounds and in certain seasons may be imperative in sustainable utilization of the L.Victoria fishery.

9.5.3 Socioeconomic and Biophysical research

This study concentrated on the impact of water hyacinth on the supply side of fish sector because of the fact that it has been prudent to quantify the impact of water hyacinth on fish output and net benefits. The issues of fish species composition raised a lot of concerns hence requiring some investigation. It might be interesting to further research that may focus on the demand side of the fishery sector and try to assess/isolate the impact of water hyacinth from the EU ban, which appeared more or else at the same time.

Another important topic requiring attention is the health and nutrition of the local communities as they were affected by the water hyacinth. These could beef up the studies on the effect of water hyacinth on the different fish species consumption and effect on nutrition and health of the community. The effect of water hyacinth on the incidence of diseases such as malaria, cholera and S*histosomiasis* and cost implications on family expenditures, should well be understood. Under water hyacinth infestation this could be a significant budget item for the fishermen hence affecting their welfare and labour supply.

The other pertinent issue, which has not been addressed, is the ecological effect of water hyacinth on the specific fish species. For example what is the effect of water hyacinth on Nile perch and *R. argentea.* This analysis show that the CPUE for the *R. argentea* declines with increasing water hyacinth intensity while mixed Tilapiines increases. A study of this nature coupled with the economic assessments will provide a clear understanding of the on the economic impact of water hyacinth on the fishery and its bio-diversity.

9.5.4 Water Hyacinth Impact Assessment Models

The major concern in this study was to develop suitable methodology or model that can effectively assist in the assessment of the water hyacinth impact on fish production. The derivation of such methodology has been complicated by the fact that water hyacinth is a highly mobile plant with its occurrence changing by hour, day and month. It is on this basis that this study focused on developing such an approach. In order to make a good judgment of a suitable model it is important to have in mind the following properties *theoretical plausibility, explanatory ability, accuracy of the parameters, forecasting ability, simplicity of model and time and costs constraints.*

This study used both cross and time series data in trying to estimate the economic impacts of water hyacinth on fish productivity, net benefits and fish species composition. Cross section data was used to give background information on the socioeconomic impacts of water hyacinth on the fishing sector. The economic, social and ecological effects were derived from the cross section data. A closer view of the findings helped in the definition of the relevant hypotheses that were henceforth tested. On the other hand time series data was used in the analysis and provided valuable information that was used in testing of the hypothesis generated from the various models with respect to the impact of water hyacinth and other factors on fishing activities. Given the mobile nature of water hyacinth time series data seemed to be the ideal data to be used in the testing of the models and the hypothesis. This proposition is supported by the fact that fish takes up to three months to reach maturity for harvesting, and therefore using one single visit data may not be able to give a true reflection of the water hyacinth impact on fish production. Therefore to undertake a realistic analysis one will require time series data.

The choice of the model to be used is the hardest part of the study. In a way the type of model selected will dictate the type of data to be used in view of the restriction placed on each particular model. Two model types were used on the cross section data including CBA and PF. The CBA is suitable for analyzing the economic viability of investment or projects. This is based on the premise that enlarging the difference between total revenue and cost may maximize profit. This tool could be very useful in assessing the profitability of fishing under the influence of water hyacinth. This is practical where one has two distinct scenarios fishing with and without water hyacinth. In the normal case this situation, may not be easy to obtain, but it is not impossible. If time and money is allows and the relevant data is availed on costs and benefits on the two scenarios, then one is bound to get a clear impact of water hyacinth on the profitability of water hyacinth on fish production. This is a simple model that can be used and may not require a lot of resources but requires accurate input and output data on the two scenarios in order to make reliable comparisons. Time series data may be more useful in this study hence it is important to take note of discounting the costs and benefits.

The PF (Cobb Douglas functional form) was used with the cross section data in this study. The advantage of this model is that it is easy to derive the production elasticities. It is based on the theory of the firm and hence may be important in making decisions about fishing in the presence of the water hyacinth. However, based on the findings from this study in order to obtain a reasonable estimate of the parameters it is important that one has a longer time series at least three months in order to allow the fish to mature and be exposed to harvesting. Therefore a longer period term will be recommended if this function has to yield reliable estimates. The production function becomes problematic when used on time series data in view of problems related with stationarity and lack of long run equilibrium relationships amongst the test variables. One of the major problems of the production function is the multicollinearity when closely correlated variables are used in the model. This creates the need to closely monitor this problem in order to avoid coming up with biased estimates. Therefore in the recent times there has been a switch from the use of multiple regression techniques in the estimation of production relationships to more robust techniques in the case of time series data.

Another set of two models were also used and fitted on the time series data. In this study ECM was used to assess the effect of fish price and rainfall on the CPUE for various fish species. In particular the model sought to determine the short run and long run production elasticities, which assisted in establishing the impacts on fish productivity. ECM was preferred for this assessment as it takes in account non-stationarity problems and ensures that there is a long run equilibrium relationship between variables in order to avoid spurious regressions. The ECM is a model that attempts to draw relationships between production systems, for given inputs and output and hence generate production relationships that are crucial in making policy statements that might help improve production. It is a model based on the theory of the firm hence making it theoretically sound in making decisions on production. Because it takes care of the spurious regressions it allows for in-depth analysis of time series data that may be required in trying to measure the impact of water hyacinth on fish production.

As any other time series model it requires adequate series to make reliable estimates. This model becomes cumbersome to estimate particularly when there are many lags involved and also checking for autocorrelation and other relevant properties. The major advantage of this model over others is that it is possible to estimate both short and long run elasticities.

Secondly, the VAR model was selected to estimate the effects of water hyacinth on the lake wide (Kenya) production of fish. This model was used to draw interrelationships between three variables in the fishery sector including water hyacinth intensity, fish catch and price. Although this model is not based on any theoretical foundation its major advantage is that it is simple to estimate and allows for the testing of variables for interrelationships as its treats all test variables to be endogenous to the model. The model checks for stationarity and incase of any problem differencing is used to correct the data. It is possible to establish Granger Causality and exogeneity of the variables. The strongest part of the model is the fact that it uses impulse response analysis to instill shocks to the model and the effect observed on the test variables over a certain fixed period of time. For example, in this study the shocks were inflicted on water hyacinth and the effect determined on the fish catch and price over a period of ten years. This model may be used for forecasting purposes since it uses time series data.

It is interesting to note that the three models (PF, ECM and VAR) give more or else similar results in terms of the effect of water hyacinth on the individual fish species. The PF indicates that higher catches of mixed fish, were realized, while the reverse occurred for the Tilapiines and combined output under the presence of water hyacinth. On the other hand the ECM also indicated that higher CPUE were realized for the mixed fish and to a limited extent Nile perch in Kendu Bay while the reverse was noted for the Tilapiines. In both models there were no significant differences in the catch for the *R. argentea*. Based on these findings one may be indifferent in choosing between the two. However, the choice may be based on the objectives of the study and data availability. The VAR model, which is like the simultaneous equation, may be very useful when one wants to draw interrelationships amongst variables since all the study variables are treated as endogenous. The information provided can be useful in making policies based on variable relationships such as unidirectional or bi-directional Granger causalities. If there are bi-directional causalities then one has to be careful using a single equation model for making policies or forecasting.

Therefore depending on the objectives of the study and data availability one may use any one of these approaches (CBA, Production function, ECM and VAR).

9.6 Short-Comings of the Study

Data availability was a serious constraint in this study. Firstly, this kind of study required actual data on water hyacinth surface cover in order to be able to determine the marginal impacts on the various fisheries. This data was not available and that is why we used a dummy variable in the case of the PF and ECM, and the estimated water hyacinth intensity (WHI) for the VAR model. This made it difficult to derive marginal effects of water hyacinth on the individual fisheries in the PF and ECM models.

Secondly, the fish price data was not available for the individual fish species on the monthly data used in the ECM model. These information was not kept by KMFRI nor the fisheries Department and hence the use of CPI in the price approximation. The problems related to prices might have been responsible for some of the unexpected signs in some of the estimations. Lastly, the series particularly for the data used in the VAR model of 15 years was relatively short and hence required longer series to give better results and forecasting purposes.

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APPENDICES

APPENDIX 1: MAIN FIELD QUESTIONNAIRE

Serial no

KARI/MOI UNIVERSITY

MAIN QUESTIONNAIRE

A SURVEY ON THE ECONOMIC IMPACT OF WATER HYACINTH ON FISH PRODUCTION AMONG THE LAKESIDE COMMUNITIES OF LAKE VICTORIA

SECTION 1.0: GENERAL INFORMATION

1.1 Name of respondent :---

1.2 Age------------Years

1.3 Gender: Male------[ ] Female-----------[ ]

1.4 Locality: District:---------- Division:--------Location:-----------Beach:------------

1.5 Occupation: Boat owner ------[ ] Fisherman-------[ ] Farmer--------[ ]
Trader------[ ] Employed-------------Others (specify)----------------------[ ]

1.6 Name of household Head:……….……………………
Gender: Male------[ ] Female-----------[ ]

1.7 Marital status: Married----[ ] Single-------[ ] Divorced………[ ]
If male state the number of wives:----------------------

1.8 Family members in the household:

	0-4 years	5-14years	15-64 years	> 65 years	Total
Male					
Female					

1.9 Number of those employed off-farm including household head-------

1.10 Number of years in formal education:-----------Highest class attained----------

1.11 Farm size: Self------- (acres) Hired------------(acres) Total.-----acres)

1.12 Do you have the land title deed for the said piece?..Yes..[ ] No….[ ]→**2.1**

SECTION 2.0: RESOURCE OWNERSHIP

2.1 Livestock and Related Assets:

Asset Type	Number	Remarks
1Cattle		
2 Sheep		
3 Goats		
4 Chicken		
5 Sheep		
6 Tractor		
7 Ox-plough		
8Other (Specify) ----------------		

2.2 Crop Enterprise Production data

Enterprise type	Area(acres)	Total out put (bags/tons/kg)	Price (Ksh/unit)
1. Sugarcane			
2. Cotton			
3 Tobacco			
4 Maize			

5 Rice			
5Millet/Sorghum			
6 Beans			
7 Cassava			
8 Grazing land			
9 Others (specify) --------------------			

2.3: Fishery Resources

2.3.1 Do you own a fishing boat? Yes ---[ ]No--[ ] Fishing gears? Yes---[ ]No---[ ]→**3.9**

2.3.2 If the answer is yes, how many boats do you own?……

2.3.3 What is the ownership of the boat?…. Self?….[ ] Hired….[ ] Other(Specify)………….[ ]

2.3.4 State their propulsion method: Oar propelled---[ ]Sail propelled…[ ]Outboard engine…..[ ] Others (specify)…[ ]

2.3.5 Provide the following information for each propulsion method:

Propulsion	Unit	Quantity	Price /unit	Life/span (Yrs)	Operation Cost/boat /week	Repair cost/boat/ week
Oar	Pieces					
Sail	Pieces					
M/ Engine	No.					
Other(specify)- --------						

2.3.6. What type of fishing gear do you own? Gillnets…[ ].Beach seine….[ ] Longline…[ ]

. Mosquitoe seines………[ ] Trawl nets……[ ] Other(specify)………… [ ]

2.3.7 Provide the following information for each fishing gear under your control:

Type of gear	Unit	Quantity	Price/ unit	Life span (Yrs)	Repair cost /boat/week	No.of crew/ unit
Gill nets	Pieces					
Beach seine	Pieces					
Longline	Hooks					
Mosq.Seine	Pieces					
Trawl nets	Pieces					
Other(specify)						

2.3.8. Do you physically participate in fishing on the lake?..Yes ….[ ]. No…..[ ] →**2.3.10**

2.3.9 If yes, what is the proportion of your time spent on fishing? … ≤25% …[ ]. 26-50%…[ ] 51-75%……[ ] 76 -100%….[ ]. of the time.

2.3.10. Are some of your family members participating in fishing? Yes…..[ ] No…[ ] →**2.3.13**

2.3.11. If yes, then how many members are involved in actual fishing?………

2.3.12 What proportion of their time is spent on fishing?…≤25% …[ ] 26-50%…..[ ] 51-75%……[ ] 76 -100%….[ ] of the time.

2.3.13. Do you employ casual labour to take care of your fishing chores? Yes…[ ] No….[ ]→**3.1**

2.3.14 If yes, then how many people in total per day?…… and per boat?…….

SECTION 3.0: FISHERY MANAGEMENT PRACTICES

(Questions to be answered by boat owners)

3.1 Are all the boats you own operating?.....Yes ……[ ]→**3.4**No…….[ ]→**3.2**

3.2 If no, then how many are operating?………. and how many are currently grounded?…..

3.3 If grounded then explain , why?…………………………………………………………

3.4 Which year did you start fishing business?………

3.5 Provide the following information for each of the boats:

Variable	Boat 1	Boat 2	Boat 3	Boat4	Boat5
Length(m)					
Width(m)					
Capacity(kg)					
Price (Ksh)					
Life span(yrs)					
Repairs/boat/week					
Frequency of fishing/week					

3.6 Fill the table below with information about the fish caught per day:

Fish type	Container	Kg/ Container	No. of fish	No.of containers	Ksh/Container/ Or kg	Fish catch(kg)
Tilapia (Ngege)						
Dagaa(R. argentea)						
Nile perch(Mbuta)						
Lungfish(Kamongo)						

Total catch						

3.7 State the fish catch in kg as follows:

	Boat 1	Boat 2	Boat 3	Boat 4	Boat 5
Per day(kg)					
Per week(kg)					
Per month(kg)					

3.8 What is the distance in km from your home to the beach?….. km Beach to the fishing ground?…..km

(Questions to be answered by fishermen)

3.9 If you don't own a boat/fishing gear then how do you get access to fishing facilities:

Hired..........[ ]Borrowed……..[ ]Employed as crew…..[ ]

3.10 If employed as a fishing crew/ or participate in fishing, then how often do you go fishing?

In a day ………times
In a week ………times
In a month ………times
In a year ………times

3.11 How many hours do you take fishing?…………hours.

3.12 What time to you set off fishing?……………

3.13 How are you paid? In kind…..[ ] Cash……[ ] Other(specify)……………..…[ ]

3.14. If in kind then specify how?……………………………………………………………..

3.15. If in cash then how much are you paid per hour?………fishing trip?……..Per day?…..…

3.16. What is the distance in km from your home to the beach?….. km and beach to the fishing ground?……..km

SECTION 4.0: WATER HYACINTH IMPACT

(Questions to be answered by both fishermen and boat owners)

4.1. When did you first notice water hyacinth on the lake?…Year……… Month……….

4.2. When did you first notice the water hyacinth at your beach?..Year……… Month……….

4.3. State on average the number of months water hyacinth covers your beach/fishing ground in a year?……

4.4. Which month are critical in water hyacinth infestation at your beach/fishing ground?

Month 1- [ ] 2- [ ] 3-[ ] 4-[ ] 5-[ ]6-[ ] 7-[ ] 8-[ ] 9-[ ] 10- [ ] 11-[ ] 12- [ ]

4.5. Which year(s) have been critical in water hyacinth infestation?

Year 199- = 1- [ ] 2- [ ] 3-[ ] 4-[ ] 5-[ ]6-[ ] 7-[ ] 8-[ ] 9-[ ] =2000- [ ]

4.6 Can you please classify the impact of WH on local communities around your beach: Low….[ ] Moderate….[ ] Heavy….[ ]

4.7. How has water hyacinth affected you in particular?

Positive effects	Negative effect
1	**1**
2	**2**
3	**3**
4	**4**

4.8 What is the frequency of fishing during WH infestation?

In a day? ………times
In a week? ………times
In a month? ………times
In a year? ………times

4.9. Do you realize a reduction in the fish catch associated with WH? Yes..[ ] No..[ ] →**4.11**

4.10 .If yes, by how much ? ≤25% …. 26-50%…..51-75%…..76 -100%…..

4.11. Have you experienced any change in the fish species composition associated with WH? Yes…[ ] No……[ ]→**4.15**

4.12. If yes, what has been the trend of the composition? Decreased …[ ] Constant ….[ ] Increased?……[ ]

4.13. If decreased what fish species have disappeared?

a)………………..b)………………c)…………………d)…………….e)…………
………

4.14. If increased what fish species have appeared/reappeared?

a)………………..b)………………c)…………………d)…………….e)…………
………

4.15. Did you experience any reduction in the fish consumed in your family resulting from WH infestation?..Yes….[ ] No………[ ]]→**4.17**

4.16. What was the fish price during this period? Low…..[ ] Moderate…[ ] High….[ ].

4.17. Were you fully engaged in fishing during WH infestation period?…Yes……[ ] No….[ ]→**4.18**

4.18. If not, then state the activities involved in and % time allocation..

Activity	% time taken	Estimated income/month
Fishing		
Farming		
Business		
Employed		
Other(specify)---------------		

4.19. Do you migrate from your beach with WH infestation? Yes…[ ] No…..[ ]→**4.21**

4.20. If yes where did you migrate to: Nearby beach…[ ] Urban centre….[ ]Other(specify) ------------.[ ]

4.21 What diseases are linked with WH infestation? (a)………………(b)…………(c)…………….(d)……………….

4.22 What has been your expenditures on water hyacinth related diseases?…Low…[] Moderate………[ ]…. High…..…[ ]

(Questions to be answered by boat owners)

4.23 Fill the table below with information about the fish caught per day during WH infestation

Fish type	Container	Kg/ Container	No. of fish	No.of containers	Ksh/Container or kg.	Fish catch(kg)
Tilapia (Ngege)						
Dagaa(R. argentea)						
Nile perch(Mbuta)						
Lungfish(Kamongo)						

Total fish catch						

4.24 How much fish catch do you realize under the presence of WH?

	Boat 1	Boat 2	Boat 3	Boat 4	Boat 5
Per day(kg)					
Per week(kg)					
Per month(kg)					

4.25. Do you fish with all your boats during WH infestation?.. Yes……[ ] No………[ ]→**4.26**

4.26. What proportion of your fish catch is consumed at home in kg per day:

Type of fish	Quantity consumed =WH	Quantity consumed =No WH
Tilapia		
R. argentea		
Mbuta		
Other(Specify)… ……		

4.27. Has there been any problem in obtaining casuals for fishing during WH infestation? Yes….[ ] No….[ ]

4.28 State the number of crew per boat: With WH ………Without WH……..

4.29 How of many of your boats have been destroyed by WH?:…. No. of boats?…

4.30 How many of your fishing gears have been destroyed by WH?

Type of fishing gear	No. destroyed by WH
Gill nets(Pieces)	
Beach seine(Pieces)	
Longline(No. of hooks)	
Mosquitoe seine (pieces)	
Other (specify)…………………………..	

.

(Questions to be answered by fishermen)

4.31 How much time do you take to access the fishing ground under WH infestation?….(hours). Without WH……..hours.

4.32. How much time do you take coming to land under WH infestation?…hours. Without WH……..hours.

4.33 How much are you paid in ksh. during WH infestation per hour?……fishing trip……..? Per day……….

SECTION 5.0 :COPING STRATEGIES?

(Questions to be answered by both fishermen and boat owners)

5.1 Are you currently involved in fishing activities? Yes------[ ]→**5.7.** No----[ ] →**5.2**

5.2 If not, explain why?---

5.3 When did you abandon fishing due to water hyacinth infestation?------

5.4 What is your current source of income? (a)------------- (b)------------

5.5 Is the current income better than income from fishing?.….Yes…[ ] No….[ ]→**5.6**

5.6 If not, how else would you like to improve your financial status?

(a)---

(b)---

(c)---

5.7 A part from WH, has there been any other problem hindering your fishing activities?…Yes…[ ] No….. [ ]→**5.9**

5.8 If yes, what kind of problem(s)

(i) Lake weed (Salvinia Molesta) [ ]

(ii) The presence of papyrus reeds [ ]

(iii) Other(specify)---------------- [ ]

5.9 Do you carry out fishing activities in areas covered by water hyacinth? .

Yes…..[ ] No…..[ ]→**5.11**

5.10 If yes, what problems do you experience when you encounter water hyacinth?

(i) Hindrance to boat movement……………………….. [ ]
(ii) Breakages of the boat [ ]
(iii) Migration of fish to areas covered by hyacinth [ ]
(iv) Destruction of nets placed in certain areas [ ] .
(v) Other (specify)----------------------------------- [ ]

5.11 How long have you been fishing at this beach?………years

5.12 Did you move from another beach?-----Yes… [ ] No…. [ ]→**5.14**

5.13 If yes, explain why?---

5.14 During the last five years has your fish price been: decreasing?------[ ]-increasing?------[ ] Constant?---------[ ]

5.15 Explain the trend in 5.14…………………………………………….……..
…………………………………………………………………………………

5.16 If you use lake water, has the supply been affected by the water hyacinth infestation? ---Yes…..[ ] No….[ ]→**5.19**

5.17 If yes then what alternative source do you have?------------------------

5.18 Is the alternative source more expensive than the lake source? Time wise…[ ] Yes…[ ] No….[ ]**.** Money wise-----[ ]Yes…..[ ] No….[ ]→**5.19**

5.19 Have you noticed the presence of dangerous animals associated with water hyacinth infestation? If yes, specify-(a)----------------(b)-----------------

5.20 During the last five years have snakebites been declining? ----[ ]-increasing---[ ] or Constant-----[ ]-

(Questions to be answered by boat owners)

5.21 Did you sell any of your fishing gears due to WH infestation?…Yes…[ ] No….[ ] →**5.22**

5.22 If yes then how many have you sold?…………………………………………………..

5.23. Do you employ extra casuals per day during WH infestation? Yes…[ ] No.[ ]→**6.1**

5.24 If yes, then how many more? ……….

5.25 Please specify their role:……………………………………………………………….

5.26 Are they paid more? Yes…[ ] No…[ ].

5.27 If yes then how much more money is paid per person / hour?……Per trip….Per day……

SECTION 6.0: WATER HYACINTH CONTROL ASSESSMENT

6.1 What method(s) are you currently employing in the control of water hyacinth at your beach?… Mechanical…….[]..Biological……..[ ] Manual……[] Other (Specify)…….[ ]

6.2 Is the method used above (i) effective…. Yes….[ ] No…...[ ].→**6.3**

6.3 If not, then suggest alternative control measures.

6.4 Has the government been concerned about solving this problem?.. Yes…[ ]

No-….[ ]→**6.6**

6.5 If yes, what action has the government undertaken to solve this problem?

(a) provision of tools for manual removal (Physical) [ ]
(b) Mechanical removal [ ]
(c) Biological control [ ]
(d) Chemical control [ ]
(e) Other (specify)-------------------------- [ ]

6.6 Is there any NGO involved in solving this problem in your area? Yes..[ ]

No….[] →**6.9**

6.7 If yes, then which one?….(a) WORLD VISION [ ] (b) UNEP [ ] (c) CARE-Kenya [ ] (e) Other (specify)----------------------[ ]

6.8 What has been the form of assistance or involvement?….

(a) Creating awareness [ ]
(b) Providing financial assistance [ ]
(c) Providing equipment to fishermen [ ]
(d) Other (specify)…………………… [ ]

6.9 Have you attended any field demonstration on how to control WH? Yes…..[ ]

No…[ ]→**END**

6.10. If yes, then what methods were demonstrated: Use of weevils [ ] Use of hand tools [ ] Use of machines [] Other(specify)………..[ ]

Thank you for the information given to us.

Enumerator' s name:-------------- Signature--------------- Date -----------

Checked by Name………………….Signature…………. Date……….

Comments on the progress of the interview:

APPENDIX 2: FISH CATCH/VALUE ASSESSMENT DATA SHEET

DATA SHEET 9: FISH CATCH/VALUE ASSESSMENT

Beach Name……………………………………
Boat Name…………………………….…Boat size………………………Fishing gear mesh size…………………………………….
Boat owner…………………………….…. Serial No……………………………………………
Month…………………………………………….

Date	Tofg	Fish Catch(Kg)				Revenue from fish (Ksh)				Crew	Fish Freq	Fish consumption				Expenditure (Ksh)			
		Lat	Ome	Til	Oth	Lat	Ome	Til	Oth			Lat	Ome	Til	Oth	Food	Repair	Crew	Other
1																			
2																			
3																			
4																			
5																			
6																			
7																			
8																			
9																			
10																			
11																			
12																			
13																			
14																			
15																			
16																			

APPENDIX 2:Continued….

DATA SHEET 9: FISH CATCH/VALUE ASSESSMENT

Beach Name……………………………………
Boat Name…………………………………Boat size………………………Fishing gear mesh size…………………………………….
Boat owner………………………………. Serial No…………………………………………
Month…………………………………………….

Date	Tof g	Fish Catch(Kg)				Revenue from fish (Ksh)				Crew	Fish Freq	Fish consumption				Expenditure (Ksh)			
		Lat	Ome	Til	Oth	Lat	Ome	Til	Oth			Lat	Ome	Til	Oth	Food	Repair	Crew	Other
17																			
18																			
19																			
20																			
21																			
22																			
23																			
24																			
25																			
26																			
27																			
28																			
29																			
30																			
31																			
Sum																			

APPENDIX 3: BREAKDOWN OF THE AVERAGE OPERATION COSTS OF FISHING BY DIFFERENT FISHING GEARS AND PROPULSION METHODS PER DAY IN KSH. FOR THE YEAR 2001.

Types of gears	Boat fund	Crew Expense	Food cost	Fuel cost	Miscell. cost	Repair costs	Bait costs	Total costs
Gillnet								
Oar	48.18	127.11	50.95	0.00	15.78	35.17	0.00	277.20
Sail	53.76	141.78	43.71	0.00	31.60	24.52	0.00	295.37
Engine	0.00	563.00	138.16	393.75	0.00	56.41	0.00	1151.32
Total	26.15	76.24	26.15	158.79	12.60	15.75	0.00	315.69
Beach seine								
Oar	128.90	565.24	223.98	0.00	57.05	81.35	0.00	1056.53
Sail	114.40	541.91	164.58	0.00	127.45	55.19	0.00	1003.54
Engine	135.86	900.94	252.05	353.94	37.54	105.47	0.00	1785.78
Total	101.03	477.61	173.36	281.29	50.52	64.29	0.00	1148.11
Longline								
Oar	99.75	481.87	71.88	0.00	16.87	45.47	16.87	732.71
Sail	93.14	312.88	53.12	0.00	82.22	23.28	163.71	728.35
Engine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	91.82	334.47	55.38	0.00	65.58	26.96	154.48	728.70
Mosquitoe seine								
Oar	67.54	396.73	154.28	0.00	47.64	45.50	0.00	711.70
Sail	0.00	614.84	76.85	0.00	136.63	18.79	0.00	847.11
Engine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	67.15	400.73	152.15	0.00	49.29	45.00	0.00	714.32
Mixed gears								
Oar	0.00	204.00	59.09	0.00	35.45	17.10	0.00	315.64
Sail	0.00	231.63	48.22	0.00	54.53	16.22	99.59	450.19
Engine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.00	171.97	44.69	0.00	34.32	13.59	92.96	357.53
All gears								
Oar	87.57	323.63	126.28	0.00	34.90	46.32	15.86	634.56
Sail	76.36	203.28	46.34	0.00	44.76	21.06	134.81	526.62
Engine	133.92	760.96	207.96	351.33	36.24	86.65	0.00	1577.06
Total	53.58	180.05	58.56	187.52	24.92	23.67	94.07	622.38
% of total	9	29	9	30	4	4	15	100

Notes:

Gnet	-	Gillnets
Bseine	-	Beach seine
Mseine	-	Mosquitoe seine
Othgears	-	Other Mixed gears

APPENDIX 4: LINEAR REGRESSION RESULTS ON THE DETERMINANTS OF FISH PRODUCTION ALONG LAKE VICTORIA (KENYA)

Variable	Combined fish	Nile perch	Tilapiine ssp	R. argentea	Mixed fish
Constant	-	-	-	-	-
Experience in fishing	-0.076*	-0.011 NS	-0.075 NS	-0.108 NS	0.013 NS
Fishing crew	-0.143*	-0.168 NS	0.318**	-0.225 NS	0.043 NS
Boat size	0.101*	0.135**	-0.192**	-0.060 NS	-0.009 NS
Presence of water hyacinth (d.v)	-0.154***	-0.045 NS	-0.076 NS	-	0.664***
Fishing with gillnets (d.v)	-0.163**	-0.055 NS	-0.339***	-	-0.029 NS
Fishing with beach seine (d.v)	0.280***	0.613***	-0.291*	-	0.331**
Fishing with longline (d.v)	-0.173**	0.085 NS	-0.478***	-	0.130 NS
Fishing with mosquito seine (d.v)	0.635***	-0.003 NS	-0.328***	0.307*	0.190 NS
Sail as Propulsion method (d.v)	-0.023NS	0.193***	-0.162**	0.050 NS	0.066 NS
Engine as propulsion method (d.v)	0.190***	0.374***	0.055 NS	-	0.039 NS
Northern shore line (d.v)	-0.181***	0.102*	-0.216**	-0.644***	0.115*
Central shoreline (d.v)	-0.189***	0.078 NS	0.049 NS	-0.497***	0.149**
R-square	0.683	0.593	0.260	0.543	0.527
Adjusted R-square	0.666	0.570	0.214	0.428	0.497
F-value	41.618***	25.670***	5.663***	4.746***	17.472***
Condition Index	17.298	21.648	16.715	29.676	20.019
No. of cases	244	223	205	35	200

Dependent variable: Average fish catch in kg per boat per day

The coefficients are betas

d.v. - Dummy variable

Significance level- 10%-*; 5%-**; 1%-***

APPENDIX 5: LINEAR REGRESSION RESULTS ON THE DETERMINANTS OF FISH INCOME ALONG L. VICTORIA

Variable	Coefficient	Std. Error
Constant	429.44***	112.27
Experience in fishing	-3.88**	1.74
Fishing crew	37.72*	20.25
Boat size	-0.95 NS	2.39
Presence of water hyacinth(d.v.)	66.58 NS	74.93
Fishing with gillnets (d.v.)	-66.30 NS	72.93
Fishing with beach seine (d.v.)	281.94**	114.77
Fishing with longline(d.v.)	142.38*	79.99
Fishing with mosquitoe seine(d.v.)	253.78***	85.84
Sail as propulsion method (d.v.)	45.76 NS	45.77
Engine as propulsion method (d.v.)	720.57***	106.87
Northern shoreline(d.v.)	-159.48***	52.19
Central shoreline (d.v.)	-218.17***	53.14
R-square	0.536	
Adjusted R-square	0.512	
F-value	23.33***	
Condition Index	17.30	
No. of cases	245	
DW statistic	1.872	

Dependent variable: Log of average fish income in Kshs per boat per day
*Significance levels: ***= 1%; **= 5%; *= 10%*

Notes:

Reference fishing gear method - Other mixed gears
Reference boat propulsion method - Oar
Reference shoreline - Southern
d.v. - Dummy variable

APPENDIX 6.a: ECM RESULTS FOR VARIOUS FISH SPECIES IN KENDU BAY BEACH

Variable	Nile perch	Tilapiines	*R.argentea*	Mixed fish
Constant	5.871***	-8.559***	-	-2.951*
∆ lnrainfall	0.003NS	-0.023 NS	-	0.118 ***
∆ lnprice	-5.162NS	-6.057 NS	-	-7.307 NS
Lncatch(-1)	-0.695***	-0.602***	-	-0.800***
Lnrainfall(-1)	0.020 NS	-0.098**	-	0.192***
Lnprice(-1)	-0.746***	1.846***	-	0.110 NS
Dum2	0.352*	-1.010***	-	1.859***
Adj. R^2	0.325	0.315	-	0.377
DW-statistic	2.105	2.188	-	2.178
F-statistic	11.444	10.969	-	14.084

Notes

∆ - First difference operator
Ln - Natural logarithm
(-1) - One lag period
Dum2 - Water hyacinth dummy variable
NS - Not significant

APPENDIX 6.b: ECM RESULTS FOR VARIOUS FISH SPECIES IN DUNGA BEACH

Variable	Nile perch	Tilapiines	*R. argentea*	Mixed fish
Constant	3.554***	-4.956***	2.917***	-5.224***
∆lnrainfall	-0.031NS	-0.073 NS	-0.001 NS	-0.074 NS
∆lnprice	-0.216NS	3.883 NS	2.086 NS	1.628***
Lncatch(-1)	-0.470***	-0.525***	-0.394***	-0.731***
Lnrainfall(-1)	-0.028NS	0.014 NS	-0.027 NS	0.129 NS
Lnprice(-1)	-0.389***	1.104***	-0.276**	0.875***
Dum2	-0.101NS	-0.658***	0.092 NS	0.157 NS
Adj. R^2	0.181	0.234	0.174	0.395
DW-statistic	2.072	2.086	2.061	2.000
F-statistic	5.786	7.604	5.534	15.230

APPENDIX 6.c: ECM RESULTS FOR VARIOUS FISH SPECIES IN UHANYA BEACH

Variable	**Nile perch**	**Tilapiines**	***R. argentea***	**Mixed fish**
Constant	5.002***	1.608*	4.276***	3.740NS
∆ lnrainfall	0.036NS	0.012NS	0.011NS	0.090NS
∆ lnprice	1.141NS	7.829***	1.083 NS	0.291NS
Lncatch(-1)	-0.657***	-0.388***	-0.538***	-0.538***
Lnrainfall(-1)	0.043 NS	-0.005NS	-0.025NS	0.111NS
Lnprice(-1)	-0.452***	-0.105NS	-0.218NS	-0.899*
Dum2	0.020NS	-0.394**	-0.080NS	1.223**
Adj. R^2	0.302	0.188	0.239	0.289
DW-statistic	2.051	2.220	2.020	2.097
F-statistic	10.355	6.000	7.763	9.886

Significance levels: ******= 1%; **= 5%; *= 10%***

APPENDIX 7: RESULTS ON STATIONARITY TESTS IN ALL FISH SPECIES, L. VICTORIA (KENYA) 1986 – 2000

	A. Dickey Fuller (ADF)		Phillips Perron (PP)	
Nile Perch	**Levels**	**First difference**	**Level**	**First difference**
Ln weight	- 2.597	-4.057	-2.632	-4.065
Ln price	- 3.162	-2.851	-3.138	-6.405
Ln WHI	- 1.020	-3.032	-1.208	-3.012
R. argentea				
Ln weight	-2.319	-4.210	-2.300	-4.269
Ln price	-2.523	-1.941	-3.975	-6.698
Ln WHI	-1.020	-3.032	-1.208	-3.012
O. niloticus				
Ln weight	-2.134	-1.902	-2.123	-3.826
Ln price	-2.889	-2.300	-2.859	-5.737
Ln WHI	-1.020	-3.032	-1.208	-3.012
Mixed Tilapiines				
Ln weight	-2.352	-3.425	-5.250	-8.658
Ln price	-3.671	-2.662	-3.674	-6.422
Ln WHI	-1.020	-3.032	-1.208	-3.012
Haplochromis				
Ln weight	-4.016	-3.867	-4.068	-6.021
Ln price	-0.967	-2.398	-3.187	-9.064
Ln WHI	-1.020	-3.032	-1.208	-3.012
Clarias				
Ln weight	-2.671	-2.082	-2.734	-3.428
Ln price	-2.448	-2.378	-2.462	-4.802
Ln WHI	-1.326	-3.032	-1.208	-3.012
Mormyrus				
Ln weight	-1.645	-6.763	-1.415	-6.280
Ln price	-2.320	-0.766	-2.283	-4.222
Ln WHI	-1.020	-3.032	-1.208	- 3.012
Protopterus				
Ln weight	-3.366	-2.732	-3.364	-4.500
Ln price	-1.963	-4.102	-1.992	-4.154
Ln WHI	-1.020	-3.032	-1.208	-3.012
Critical value				
10%	-3.130		-3.130	
5%	-3.410		-3.410	
1%	-3.960		-3.960	

Notes:
Ln - Natural logarithm
WHI - Water hyacinth intensity

APPENDIX 8. a: FIRST-ORDER VARS FOR NILE PERCH AND *O. niloticus*

	Nile perch				*O. niloticus*			
Parameter	**Estimate**	**Std.**	**T.stat**	**P-val**	**Estimate**	**Std.**	**T.stat**	**P-val**
	Ln weight				Ln weight			
α_1	0.042	0.292	0.143	0.889	-0.267	0.313	-0.851	0.415
α_2	-0.093	0.122	-0.762	0.464	-0.105	0.361	-0.290	0.778
α_3	0.081	0.049	1.675	0.125	-0.120	0.094	-1.269	0.233
R^2	0.115				0.179			
	Ln price				Ln price			
α_1	0.597	0.567	1.055	0.316	-0.183	0.205	-0.893	0.393
α_2	-0.448	0.237	-1.892	0.088	-0.381	0.237	-1.609	0.139
α_3	-0.113	0.095	-1.193	0.260	0.129	0.061	2.082	0.064
R^2	0.463				0.513	7		
	Ln WHI				Ln WHI			
α_1	0.921	1.863	0.494	0.632	2.300	0.895	2.569	0.028
α_2	1.378	0.779	1.769	0.107	0.896	1.033	0.868	0.406
α_3	0.253	0.311	0.812	0.435	0.393	0.269	1.460	0.175
R^2	0.057				0.235			

Notes:
Std.- Standard deviation
WHI- Water hyacinth intensity

APPENDIX 8. b: FIRST-ORDER VARS FOR *Clarias and Mormyrus*

	Clarias				**Mormyrus**			
	Estimate	**Std.**	**T.stat**	**P-val**	**Estimate**	**Std.**	**T.stat**	**P-val**
Parameter	Ln weight				Ln weight			
α_1	0.088	0.301	0.293	0.776	-0.185	0.315	-0.586	0.571
α_2	-0.489	0.426	-1.146	0.278	0.129	0.900	0.144	0.889
α_3	-0.279	0.202	-1.380	0.198	-0.230	0.259	-0.886	0.396
R^2	0.176				-0.083			
	Ln price				Ln price			
α_1	0.070	0.130	0.542	0.600	-0.082	0.099	-0.834	0.424
α_2	-0.337	0.184	-1.831	0.097	0.045	0.282	0.159	0.877
α_3	0.295	0.087	3.384	0.007	0.171	0.081	2.104	0.062
R^2	0.666				0.260			
	Ln WHI				Ln WHI			
α_1	0.226	0.531	0.424	0.680	0.373	0.375	0.995	0.343
α_2	-0.506	0.754	-0.671	0.517	-0.800	1.070	-0.748	0.472
α_3	0.111	0.358	0.309	0.763	0.173	0.308	0.562	0.586
R^2	-0.093				-0.028			

APPENDIX 9: MAJOR FISH SPECIES LANDED IN L. VICTORIA (KENYA)

No.	Fish type	Name used in the text	Local name
1.	*Alestes*	*Alestes*	Osoga
2.	*Bagrus dogmac*	*Bagrus*	Sewu
3.	*Clarias gariepinus*	*Clarius*	Fwani
4.	Haplochromis species	Haplochromis	Fulu
5.	*Labeo victorianus*	*Labeo*	Ningu
6.	*Lates niloticus*	Nile perch	Mbuta
7.	*Mormyrus kannume*	*Mormyrus*	Suma
8.	*Oreochromis niloticus*	O. *niloticus*	Ngege
9.	*Other Tilapiines*	Mixed Tilapiines	------
10.	*Protopterus aethiopicus*	*Protopterus*	Kamongo
11.	*Rastrineobola* argentea	*R. argentea*	Omena
12.	S*chilbe intermedius*	*Schilbe*	-------
13.	*Synodontis victoriae*	Synodontis	Okoko
14.	All types of Tilapians	Tilapiines	Ngege
15.	All fish types except Tilapiines, Nile perch & *R. argentea*	Mixed fish	-------

APPENDIX 10:THE WATER HYACINTH SITUATION AND CONTROL EFFORTS IN KENYA.

Year	Activity
1989	Water hyacinth noticed on L.Victoria
1992	Water hyacinth reported on the Kenyan side of the lake
1995	Water hyacinth reported as a major problem on the Kenyan side
1996	KARI imports first batch of weevils for mass rearing
1997	Purchase and distribution of hand tools for manual WH removal
1997	LVEMP inception. Start of Control and Monitoring activities
1996-1999	Peak infestation and major effect of the water hyacinth felt
"	Mass rearing of weevils (*Neochetina eichhorniae* and *N. bruchi*) and
"	release into the lakes
1999	Mechanical harvesting of water hyacinth on the lake
2000/01	Water hyacinth resurgence observed