PRODUCTION TECHNOLOGY AND NATURAL RESOURCE SUSTAINABILITY: THE CASE OF KENYA'S LAKE VICTORIA FISHERIES.¹

By

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Abstract

The nature of production technology characterizing any fishery has serious implications for its management and, hence, sustainable exploitation. This paper specifies and estimates production functions for Kenya's Lake Victoria fisheries in order to characterize the technology used in their exploitation. Regulations for these fisheries were drawn up without sound empirical information about this important issue. The paper, in addition, assesses the relative sustainability implications of different fishing technologies by comparing them on the basis of their selectivity and their harvests of juvenile fish. The determinants of the amounts of juvenile fish harvested by fishing units engaged in the exploitation of these fisheries are also investigated as are the motivations behind the choice, by fishing firms, of technologies that are obviously pernicious to their only source of livelihood.

The Cobb-Douglas specification of the production functions is used for comparison across fisheries. The production process differs significantly from fishery to fishery and from individual fisheries to the aggregate fishery, indicating the inappropriateness of managing the fisheries as a single fishery. There are decreasing returns to scale in the set net fishery only, the rest being characterized by increasing returns to scale. Fishing time and net mesh size emerge as the "key" dimensions of effort. Fishing time is currently unregulated, yet it offers the largest scope in reducing pressure on the resources. Labour use is excessive and inefficient in two fisheries. Vessel size, vessel propulsion means, type and size of gear, spatial and seasonal stock variations, and inshore versus offshore fishing are other important factors in the fishery production functions.

Trawling, mosquito seining, beach seining and the use of set nets are found to pose the greatest risk to the sustainability of the fisheries whereas the gillnet, longline, traps and mosquito seine with lights technologies are appropriate. Important determinants of juvenile fish harvest levels are the type of gear, net mesh size, level of education, owner-head effects, inshore fishing, fishing time and size of crew.

Fishermen are rational in their choice of inappropriate technology. Not only are these relatively cheaper but most fishermen are faced with acute capital constraints. Being cheaper and illegal inappropriate technologies are, in addition, associated with less risk of theft. Moreover, their profitability is comparable to that of appropriate technologies, there being a market for the immature fish they harvest. The fisheries are open access, providing no incentives, thus, for conservation efforts. Management of these fisheries will only succeed through the creation of economic incentives to induce behavioural change.

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1.0 Introduction
INTRODUCTION

The management and regulation of fisheries resources aims at checking overproduction, conserving the resource stock, maintaining an all-year fishery, and enhancing economic rent: in a word, ensuring their sustainable exploitation. Such exploitation should, ideally, maintain resource stocks within levels thought to be consistent with ecosystem stability and resilience [Turner 1993]. To maintain flow of services from a healthy fishery or any other resource
system, it should be managed in a way that enables it to meet human needs and, simultaneously, supports species and biodiversity and enhance its resilience.

Overfishing compromises the sustainability of fisheries either because more is harvested than is added via growth in each period and/or stocks are driven to levels below the threshold, seriously impairing their regenerative capacity. Overfishing is caused by many factors. Principal among these is inappropriate access regimes. Work begun by Gordon [1954] and Scott [1955] has demonstrated that open accessibility into fisheries tends to attract an excessive amount of effort that fritters away resources.\textsuperscript{2} The crisis in capture fisheries is not entirely attributable to inappropriate access regimes, though. The finite nature of fish stocks means that increasing effort will ultimately face decreasing marginal returns. The size of these stocks is, in addition, not known with certainty as is the impact of environmental factors on them, substantially affecting their management.

In artisanal fisheries, the factors that lead to unsustainable exploitation through excessive effort or through other mechanisms include the influx of migrants into the fisheries driven by poverty and rapid population growth; meagre employment opportunities outside the fishery sector; disintegration of traditional fisheries management systems and other barriers to entry; use of more intensive fishing technology in response to pressure from middlemen exerted through controlled fish prices and/or high interest rates on credit; the use of destructive fishing techniques such as poison and dynamite; and the destruction of the ecosystem through unsustainable aquaculture and non-fishing activities [Konstapel and Noort (eds.) 1995]. Non-fishing activities such as transport, agriculture and tourism have led to serious degradation and pollution of the ecosystem in both artisanal and industrial capture fisheries. In industrial fisheries, pressure from rising demand for fish coupled with enormous subsidization by governments have wrought over-capitalization and over-exploitation. Overcapacity in the harvesting sector is a product of an excessive number of vessels, their sizes, engine power and gears, and fishing time.

\textsuperscript{2} The pioneering contribution to rent dissipation in open-access fisheries can actually be traced back to a Danish economist, Jens Warming, who demonstrated the process on two fishing grounds of different quality. His paper, written in Danish, remained largely unknown until 1983 when Peder Andersen translated it into English. Outside fisheries, the perniciousness of open accessibility was demonstrated in congested highways by Knight [1924].
Kenya's artisanal fisheries of Lake Victoria are overfished and their sustainability, therefore, seriously threatened. Not only have some endemic species disappeared from the catches but the average size of fish at capture and the catch per unit effort (CPUE) have declined over time. The factors identified as responsible for overfishing in the global artisanal fishery sector apply in these particular fisheries as well. Thus, the total effort and the intensity of its use have increased tremendously over time, spurred by poverty, population explosion, a shortage of alternative employment opportunities as a result of the area's low agricultural potential, ease of entry, and an intense demand pressure from the domestic and external markets coupled with a phenomenal rise in fish prices. Even though these fisheries have been under some form of public regulation as early as the first half of this century, lack of effective restriction on entry into the fisheries exacerbated by feeble enforcement of the regulations have meant that the fisheries remain essentially openly accessible to the community living around the lake. The fisheries, thus, do not operate under pure open access but under, in the semantics of Homans and Wilen [1997], regulated open access. Credit availability through contractual arrangements between the participants in the harvesting and processing sectors has, moreover, significantly relaxed previously severe capital constraints. There is, further, an increasingly greater use of destructive fishing methods and gears. It can, in fact, be argued that these fisheries are suffering from the condition of "Malthusian overfishing" in which fishers are driven by desperation to indiscriminate use of destructive harvesting technology such as fine-mesh nets, dynamite and poison [Charles et al. 1994].

The sustainability of these Kenyan fisheries is, additionally, threatened by serious pollution from industrial, agricultural and municipal effluent; invasion of the lake by the water hyacinth, *Eichornia crassipes*; enhanced fisheries, that is, the introduction of Nile perch and exotic tilapiine species; and the destruction of the ecosystem through the conversion of wetlands for agricultural and other uses and the damming of rivers for hydro-electric power generation and other development. Bacteria and other fish pathogens have also perniciously affected the fisheries.
Production technology[^3] is, arguably, the most important determinant of the sustainability of these fisheries. Inappropriate fishing technology threatens sustainability of fisheries either through low selectivity or through irreversible damage to the fish breeding surfaces via scraping and other abrasive forces. By harvesting immature fish on account of poor selectivity and by destroying fish breeding grounds, bad technology adversely affects the resource's future productivity, thereby compromising the quality and quantity of services that posterity is likely to receive from it. The resource stock will be exhausted in finite time and, therefore, cannot be sustainable if bad technology harvests fish that have not attained reproduction age. Realization of the sustainability implications of technology of exploitation could, perhaps, explain why net mesh size and other input restrictions are prevalent forms of fisheries regulations.

The way in which a fishing firm responds to economic stimuli is determined by the nature of the production process embodied in the fishing vessel [Doll 1988]. Travelling to the fishing grounds, searching for, catching and transporting fish to the ex-vessel market are the primary functions of the vessel. In multispecies fisheries, particularly, whether or not individual species could be targeted is an issue pertinent to management [Campbell and Nicholl 1994]. If fishing vessels cannot target individual species successfully, then output mix is technologically determined and the species cannot be managed independently. Reduction of effort in such a fishery, for instance, with the objective of relieving the overexploited species of some pressure will also result in the reduced harvests of jointly produced species that may be underexploited. Gear selectivity is an important determinant of the accuracy with which fishing vessels can target individual species in response to economic incentives such as relative species price.

In fishing technology utilizing nets, the major determinant of gear selectivity is the mesh size of the nets. Thus, external diseconomies are not involved in the level of fishing effort only but also in the choice of mesh size [Turvey 1964]. The optimal allocation of the fishery resource will therefore require the regulation of both fishing effort and mesh size. Moreover, control on

[^3]: Technology may be defined as the know-how and physical means, that is society's pool of knowledge, of transforming inputs or resources into outputs. In this paper, technology is used to refer not only to this pool of knowledge but also the fishing methods, techniques and gears used in the harvesting sector.
effort cannot be achieved by simply limiting the number of fishermen or vessels because as Wilen [1979:855] aptly notes, "...the concept of "effort" in most fisheries is excruciatingly nebulous since fishermen are free to choose vessel length, tonnage, engine size, gear type, hull configuration, etc. in an almost limitless way". With flexible production technology, fishermen will simply adjust the unregulated components of effort, effort being multidimensional, in response to the regulations, thereby making them ineffective. Nonetheless, regulations can reduce technical flexibility by limiting key dimensions of effort thereby increasing the chances of success for input-focused regulatory programs [Wilen 1979].

It is apparent, therefore, that management of fisheries is bound to fail if it either focuses on the industry level with the objective of managing an aggregate input, fishing effort, and total industry catch, or targets individual species and inputs without due consideration of their technological and cost interdependecies [Squires 1987]. It is also apparent that the actual form of the technology characterizing any fishery thus has serious implications for its management and regulation [Kirkley 1986; Kirkley and Strand 1988; Squires and Kirkley 1991; Squires 1987]. The relevance of a study of the technology used in the exploitation of Kenya's Lake Victoria fisheries and the determination of the key dimensions of effort incident on them cannot, therefore, be gainsaid.

1.1 The Research Issue.
In the last 20 years or so the number of fishermen exploiting the Kenyan fisheries of Lake Victoria has increased from 10,000 to 24,000 while that of boats has increased from 4,100 to 6,229 largely because there is open access into them. There has also been a proliferation of fishing gears and methods, some of which are developed by the fishermen themselves without observing any standards. Prado et al. [1991], thus, aver that unrestricted access and use of environmentally damaging fishing methods, particularly beach seining and trawling are the major setbacks to conservation efforts in Lake Victoria. These factors have led to the disappearance of some endemic fish species and a gradual decline in not only the average size or weight of fish caught but also the catch per unit effort (CPUE). Huge amounts of virtually useless juvenile fish are landed every day. The problem is now a vicious circle. Fishermen adjust to declining CPUE through increased use of fishing technologies that are very efficient in the short run. These technologies exert so much pressure on the fisheries that CPUE is
driven further down, forcing fishermen to adjust with more efficient but destructive technologies.

This wanton harvesting of juvenile fish from non-selective and inappropriate gears obviously threatens the sustainability of these Kenyan fisheries. Sound knowledge of the characteristics and impacts of the technology used in the exploitation of these fisheries is critical if this wanton destruction has to be stemmed. This crucial information is currently lacking and the serious deterioration of these fisheries could be attributed, at least partly, to feeble attempts at management in the absence of this information. While the qualitative effects of inappropriate gears are, perhaps, trite the same cannot be said about the quantitative aspects of the problem. The quantitative elaboration of any problem is, moreover, not only more illustrative but also attracts more corrective attention.

Characterization of the technology of production and an evaluation of the resultant management implications is, therefore, an important aspect of the study of the fishery overexploitation problem and is the object of this paper. A careful survey and characterization of the production technology (fishing gears and methods) used on the Kenyan side of Lake Victoria is made, with particular emphasis placed on the relative impact on resource sustainability. The motivation for this is conviction that quantitative elaboration of the inappropriate technology problem will jolt the authorities into taking cogent management measures to ensure sustainability of these fisheries.

Economists are largely and ultimately more interested in the choices that economic agents (households and firms) make and the motivations that drive these choices. In this paper, therefore, an attempt is also made to understand why fishing units engaged in these fisheries choose exploitation technologies that are so obviously deleterious to the long term welfare of their sole source of livelihood.

1.2 Objectives.
This paper seeks, broadly, to contribute towards improved management of Kenya's Lake Victoria fisheries by providing some insight into the nature of technology used in their exploitation. Currently, very little is known about this issue. In meeting this objective, the
describe the technologies used in the exploitation of the fisheries, making use of existing literature and the primary data collected;

ii) specifies and estimates production functions for each gear type (technology) and an aggregate production function for all gears put together, with appropriate dummy variables for seasonality and spatial resource abundance variability and management capability;

iii) evaluates effort elasticities and other relevant statistics from the estimated production function(s);

iv) assesses the relative resource sustainability implications of production technology;

v) examines the behavioural motivations that lead to choices, by fishermen, of apparently destructive technologies; and

vi) draws policy implications for improved management of the fisheries.

1.3 Relevance and Usefulness.

Findings of this study are expected to be useful not only to the managers of the Kenyan side fisheries but also to the Lake Victoria Environmental Management Programme (LVEMP), an initiative to oversee joint management of the entire lake. Moreover, to the extent that the results of the study can contribute to improved management of the fisheries, its ultimate real beneficiaries will be the resource users. Efforts to supply management relevant information for a resource body that is so grossly mismanaged and overexploited that its very survival is threatened hardly need justification.

1.4 Plan of the rest of the paper.

The remaining sections of this paper are presented in the following manner. In section 2.0 a detailed description of Kenya's Lake Victoria fisheries using both existing literature and the primary data collected is provided. Particular attention is paid to the nature of technology used in the exploitation of these fisheries and the nature of the fishing enterprise. The methodology applied in the study is the subject of section 3.0. The section starts with the development of the theoretical framework for the subsequent production function analysis. Data collection procedure is then described. Sections 4.0 and 5.0 constitute the core of the study. Production function estimation results for individual fisheries and the aggregate fishery are presented and discussed. The relative impact of production technologies on the fisheries' sustainability, including the determinants of juvenile fish production and an inquiry into the
motivations behind fishermen's choice of inappropriate technology, is analysed in section 5.0. The paper concludes in section 6.0 with a summary of the findings and policy recommendations.

2.0 THE KENYAN FISHERIES OF LAKE VICTORIA.

Lake Victoria is the world's second largest fresh water body (after U.S.A's Lake Superior), covering a surface area of 68,800 km². The entire Lake Victoria drainage basin actually covers a total area of 263,000 km² [Prado et al. 1991]. The lake is common property of the three East African countries, shared as follows: Kenya(6%); Uganda(45%); and Tanzania(49%). Kenya's share of the lake fisheries is not only the most heavily fished and commercialized of the three but also constitutes the largest fisheries in the country, accounting for more than 90% of its current total annual fish output.¹ Fish production in Kenya reached a maximum of 202,965 tonnes in 1994, about 95% of which was captured from Lake Victoria. Between 1994 and 1996, however, there was an average annual decline of 4.8% in fish production. The decline in output from Lake Victoria was higher than this national average, at 5.7%. The value of fish produced has, however, maintained growth every year largely because of rising fish prices but also inflation. Between 1994 and 1996, for instance, the value increased by 23% every year to reach Kshs 5.8 billion (approximately US$ 105.6 million). This, in spite of a higher inflation rate in 1994 compared to 1995 and 1996.

The fishing industry is, moreover, becoming an increasingly significant foreign exchange earner for Kenya. In 1995, for example, 12,052 tonnes of fish were exported earning the country about Kshs 1.5 billion (approximately US$ 27 million) in foreign currency. Nile perch, the main species produced in Lake Victoria, accounted for 91% and 92% of this volume and value, respectively. These forex earnings are substantial for a country whose current account balance in one of the best fiscal years, 1996/97, stood at only US$ 90 million.

Lake Victoria hosts a diversity of fish species unique to tropical lakes. It boasts of over 177

¹ This is calculated from data compiled annually by Fisheries Department.
species, 127 of which are cychlids mostly of the *Haplochromis* species. Unregulated fishing activities coupled with the introduction of exotic Nile perch and Tilapiine species in the 1960s, among other factors, have led to a drastic change in the species composition of the lake, however, to the extent that currently only three species dominate the fishery: Nile perch, *Lates niloticus* (‘Mbuta’); *Rastrineobola argentea*, (‘Omena’); and an exotic tilapia, *Oreochromis niloticus*, (‘Ngege’). The endemic species have literally disappeared from the catches, leaving what was once a multispecies fishery essentially a three-species multi-gear fishery.

### 2.1 Overfishing.

The most serious problem facing the Kenyan fisheries of Lake Victoria is that of overfishing [FAO 1982; Garrod 1961; Cadwalladr 1968; Okemwa 1991], through the use of destructive fishing methods especially small meshed gillnets [Kudhongania 1972; Wanjala and Martens 1974], cropping of fish before they reproduce [Muller et al. 1982; Marten 1979] and a general increase in fishing effort. There is substantial evidence that these fisheries are now under both quantitative and qualitative overfishing. Quantitative overfishing is said to occur in a fishery when its total fish landings decline progressively every year [Achieng 1988]. Total catches from Lake Victoria (Kenya) have risen gradually over the years and attained the peak of 186,366 tonnes in 1991, suggesting an absence of quantitative overfishing over this period. However, "*Increasing production is consistent with unsustainable production*" [Dasgupta and Mäler 1995:2376]. There was a huge decline of 18.9% in 1992, followed by impressive increases of 15.6% and 10.8% in 1993 and 1994, respectively. In 1995, the fisheries recorded another decline of 6.1%, with landings of both *Lates niloticus* and *Rastrineobola argentea* declining in spite of a 20% increase in the number of fishermen and 7.7% in the number of vessels operating in the lake. There was another decline of 5.8% in 1996. These large and abrupt swings in landings are a new phenomenon, sufficient evidence of quantitative overfishing in the 1990s.

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5 For a detailed account of species composition of L.Victoria, see Kenya Fisheries Department, "Review of the Fisheries Sector in Kenya". Nairobi, Nov.1980.

Qualitative overfishing can be said to occur in a fishery when one or more of the following events are observed; decline in the average size of fish of one species or more, appearance of juvenile or immature fish among the catches in large numbers, and the progressive disappearance of some species or groups of species from the catches. That qualitative overfishing has been a feature of these Kenyan fisheries for a long time is suggested by Table 2.1.1. This observation is buttressed by reports of a gradual decline in the average size, at capture, of fishes of nearly all species [see, for example, Ochieng-Okach 1988; Achieng 1988; Getabu 1991]. Tilapia is under severe overfishing as there are a lot of immature fish in the catches [Getabu 1991]. Moreover, there has been a virtual disappearance of many species from the landings.

Studies by Zonneveld [1983] and Kongere [1979] indicate that the annual fish catch in the Kenyan waters of L.Victoria exceeds estimates of the Maximum Sustainable Yield (MSY), indicating biological overfishing. With Zonneveld's annual MSY estimate of 26,000 tonnes and assuming that the environmental carrying capacity has not changed, it could be argued that biological overfishing started as early as 1981 when the total landings from the lake amounted to 38,179 tonnes.

Overfishing is therefore one of the principal causes of the biodiversity loss that has occurred in these fisheries. Even low fishing pressures could lead to substantial biodiversity loss by interfering with species
interdependency in the ecosystem [Konstapel and Noort (eds.) 1995]. Yet, biodiversity is the key to the survival of ecosystems in that it provides them with resilience, defined as the ecosystem's capacity to absorb perturbations, shocks and other disturbances without suffering fundamental changes [Dasgupta and Mäler 1995].

The gradual increase in fishing pressure that has led to overfishing and biodiversity loss has emerged from several fronts. First, there has been a rapid growth in the population of fishermen, followed by an increase in the number and variety of fishing crafts and gears in response to the gradual commercialization of the fisheries. Table 2.1.2 depicts the growth in the number of fishermen and fishing vessels exploiting the fisheries. That the effort has grown phenomenally, notwithstanding the inaccuracy of its estimates, is unequivocal. Between 1973 and 1995, for instance, the number of fishermen increased by 200% while that of vessels increased by about 95%. This translates into an increase in the number of fishermen operating in one vessel from 2.5 to almost 4 over the period.

The highest fishing pressure in the entire lake is to be found in the Nyanza Gulf, a narrow section of the lake, amounting to about 33% of Kenya's lake share. It is the most productive and is variously referred to as Victoria Nyanza, Kavirondo Gulf, Winam Gulf and Nyanza Gulf [Dache 1991]. In 1985, for instance, it was estimated that between 25,000 and 30,000 fishermen operated in the gulf, representing about 50% of the fishermen exploiting the entire lake then [Ssentongo & Welcome 1985]. This means that 50% of the entire effort incident on the whole lake then was exploiting only 2% of the entire lake surface!. Gréboval [1989] attributes the intense fishing pressure in the Nyanza Gulf to a shortage of agricultural land and alternative employment and the specialization of the Luo to fishing.
Table 2.1.1: Species composition of fish landings in Lake Victoria (Kenya), 1968-1995 (% of total weight landed).

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Haplochromis</td>
<td>25.53</td>
<td>34.39</td>
<td>28.97</td>
<td>13.78</td>
<td>0.01</td>
<td>0.00</td>
<td>2.00</td>
<td>2.17</td>
<td>2.65</td>
</tr>
<tr>
<td>2. Protopterus</td>
<td>19.15</td>
<td>10.46</td>
<td>9.21</td>
<td>1.40</td>
<td>0.17</td>
<td>0.05</td>
<td>0.99</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>3. Tilapia niloticus</td>
<td>0.00</td>
<td>0.00</td>
<td>1.27</td>
<td>4.49</td>
<td>8.78</td>
<td>23.37</td>
<td>11.09</td>
<td>6.10</td>
<td>6.80</td>
</tr>
<tr>
<td>4. Other Tilapiine</td>
<td>16.50</td>
<td>28.95</td>
<td>2.76</td>
<td>14.52</td>
<td>2.17</td>
<td>0.34</td>
<td>4.00</td>
<td>1.97</td>
<td>2.65</td>
</tr>
<tr>
<td>5. Rastrineobola</td>
<td>4.99</td>
<td>3.36</td>
<td>28.52</td>
<td>35.80</td>
<td>30.00</td>
<td>28.52</td>
<td>23.42</td>
<td>35.70</td>
<td>31.24</td>
</tr>
<tr>
<td>6. Lates niloticus</td>
<td>0.00</td>
<td>0.18</td>
<td>0.32</td>
<td>16.34</td>
<td>58.02</td>
<td>43.64</td>
<td>51.14</td>
<td>53.70</td>
<td>56.31</td>
</tr>
<tr>
<td>7. All others</td>
<td>33.83</td>
<td>22.66</td>
<td>28.95</td>
<td>13.67</td>
<td>0.85</td>
<td>4.08</td>
<td>7.36</td>
<td>0.26</td>
<td>0.25</td>
</tr>
<tr>
<td>8. TOTAL</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>9. (3+5+6)*</td>
<td>4.99</td>
<td>3.54</td>
<td>30.11</td>
<td>56.63</td>
<td>96.80</td>
<td>95.53</td>
<td>85.65</td>
<td>95.50</td>
<td>94.35</td>
</tr>
</tbody>
</table>

* These three species currently dominate the fishery.

Source: compiled from issues of Fisheries Statistical Bulletin, Fisheries Department.
### Table 2.1.2: Number of fishermen and fishing vessels, L. Victoria (Kenya).

<table>
<thead>
<tr>
<th>Source of data</th>
<th>Fishermen</th>
<th>Vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graham, M. [1929]</td>
<td>5,000</td>
<td>2,000</td>
</tr>
<tr>
<td>FAO [1973]</td>
<td>10,000</td>
<td>4,100</td>
</tr>
<tr>
<td>Fisheries Dept. [1979]</td>
<td>18,000</td>
<td>4,600</td>
</tr>
<tr>
<td>Greboval D. &amp; J.E. Reynolds [1985]</td>
<td>21,500</td>
<td>5,500</td>
</tr>
<tr>
<td>Hoekstra, T.M. [1991]</td>
<td>24,000</td>
<td>6,229</td>
</tr>
<tr>
<td>Achieng, A.P. [1991]</td>
<td>30,000</td>
<td>7,000</td>
</tr>
<tr>
<td>Fisheries Department [1991]</td>
<td>25,000</td>
<td>7,279</td>
</tr>
<tr>
<td>Fisheries Department [1992]</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>Fisheries Department [1994]</td>
<td>&quot;</td>
<td>7,425</td>
</tr>
<tr>
<td>Fisheries Department [1995]</td>
<td>30,000</td>
<td>8,000</td>
</tr>
</tbody>
</table>

Source: compiled from various sources.

As the population of fishermen grew and the effort directed at the fisheries expanded, intensive non-selective fisheries emerged [Ochumba et al. 1991]. Indeed, according to Acere [1988], the introduction of gillnets raised CPUE but also initiated overfishing.

Fishing pressure has been aggravated by a large fish processing capacity in the country. This capacity has been attracted by the rapidly growing export market for Nile perch fillets fueled by low ex-vessel fish prices and a seemingly insatiable overseas demand [Gréboval and Mannini 1992]. Fish processing firms have been key in the commercialization of the lake fisheries. The demand for the Kenyan fish both in the external and domestic markets has grown so much that supply cannot meet it. This has resulted in an unprecedented rise in fish prices especially after the mid-1980s which have, in turn, fueled the pressure on the exploitation of the lake resources. Unutilized processing capacity coupled with the recent relocation of some of the fish processing firms to Uganda and Tanzania is further testimony of overfishing on the Kenyan side of Lake Victoria. Pressure resulting from high demand for fish has been accentuated by low production costs. Low production costs make fishing

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7 In 1992, Kenya had 14 of these with a total capacity of 25,000 tonnes [Gréboval and Mannini 1992]. By 1995, this number had risen to 35 mainly located in Kisumu, Mombasa and Nairobi. In 1995 these firms produced only 15,000 tonnes of Nile perch, leaving most of their capacity idle.
profitable even with low catch realisations.

Exploitative pressure on the lake resources has also been increased by substantial improvement in the communication network\(^8\) around the lake, fish handling facilities at the beaches, cold preservation facilities provided by the large fish processing firms and the development of better processing methods such as smoking and frying by the artisanal sector.

<table>
<thead>
<tr>
<th>Reason for being a fisherman</th>
<th>Freq.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only occupation/source of income and food</td>
<td>157</td>
<td>41.1</td>
</tr>
<tr>
<td>Lack of alternative employment</td>
<td>118</td>
<td>30.9</td>
</tr>
<tr>
<td>Ease of entry as it requires no qualifications</td>
<td>76</td>
<td>19.9</td>
</tr>
<tr>
<td>Likes and enjoys fishing and being his own boss</td>
<td>27</td>
<td>7.1</td>
</tr>
<tr>
<td>Family tradition (father is/was a fisherman)</td>
<td>30</td>
<td>7.9</td>
</tr>
<tr>
<td>Lives next to the lake; fishing a way of life</td>
<td>44</td>
<td>11.5</td>
</tr>
<tr>
<td>Fishing is highly profitable, with daily cash income</td>
<td>7</td>
<td>1.8</td>
</tr>
<tr>
<td>As a temporary job</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>Persuaded to try it</td>
<td>4</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Source: Own field data, 1995.

The underlying causes of this explosion in fishing pressure is of course more important to economists. Rapid population growth coupled with rising unemployment and underemployment levels in both rural and urban sectors of the Kenyan economy have meant that jobless youths enter the fisheries every year. This entry has been fueled by lack of effective restriction against entry and the relative ease of entry into the industry. Table 2.1.3 provides further details regarding the motivations for joining the fishing industry. Thus, fishermen are in their current enterprises not because it is profitable or desirable as a last

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\(^8\) Even though not much has been accomplished in terms of the road network, investments in boats powered by outboard engines have been attracted in the industry to the extent that it is now rare that fish can remain unsold even at the remotest beaches during the rainy season. These boats, belonging to the fish processing firms or their agents, are able to reach literally all beaches and buy the fish. Fish prices, however, fall due to reduced buyer competition in such circumstances.
resort (Table 2.1.3). 63.1% of the fishing units fish every day. Over 90% of these engage in daily fishing as fishing is their only occupation or source of income. Only 1.8% of the fishing units fish daily because they enjoy it, suggesting substantial disutility to daily fishing. This suggests that heads of fishing units may be willing, at times, to sacrifice potential returns from fishing for leisure.

2.2 Fishing Technology and Fishing Operations.
Capture technology is still underdeveloped in the Kenyan fisheries of Lake Victoria, having only marginally changed since the introduction of synthetic fibre nets in the early 1950s. Even the rapid development of the Nile perch fishery in the 1980s did not stimulate significant changes in the harvesting technology as the species is best caught by gillnets which were already in widespread use [Gréboval 1989]. With the exception of a short spell of trawling by the Nyanza Fishing and Processing Company, started in the mid-1970s, exploitation of the fisheries has remained under the control of small scale fishermen. Other technological changes experienced in the harvesting sector include gradual replacement of dugout canoes with planked ones, marginal motorization of the crafts, progressive decline in mesh size, increased specialisation or targeting in gillnet fisheries and a gradual shift from the use of traditional fishing techniques such as traps and weirs in favour of beach seines and mosquito nets [Gréboval 1989].

2.2.1. Fishing vessels.
The survey by Hoekstra et al. [1991] found 63.9% of the boats operating on the lake to be of the Sesse type and 22.6% of Taruma type. For transport, either larger Sesse-type canoes of up to 13 m length or bulky, old-fashioned dhow boats are used [Prado et al. 1991]. Sesse canoes are small, averaging a length of about 6.9 metres, old, generally poorly designed and rely on the direction of the wind for navigation [Hoekstra et al. 1991; Prado et al. 1991]. In our sample, the mean length of the vessels is 6.28 m. 75.4% of the vessels are 1-2 m wide at the widest point. In terms of hold capacity,

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9 This was also observed earlier by Oduor-Otieno et al. [1978].

10 This is quite comparable to the situation in late 1970s. It was estimated then that 60% of the boats in the lake were of the Sesse type, 23% Taruma and the rest Karuas [Oduor-Otieno et al. 1978]. In our data, boats are not categorised on a comparable basis.
96% of the vessels have a tonnage of 2 or less. Our data do not agree with the observation that the canoes are generally old. The mean age of the vessels is 4.5 years with the most common age being 2 years. The average expected life of the vessels, on the other hand, is 8.5 years suggesting that the average economic life of fishing vessels is 13 years. This is borne out by the fact that only 5.9% of the vessels are more than 13 years old.

Only 3.4% of all the boats are propelled by an outboard engine\textsuperscript{11}, the rest being either propelled by oars or by sails.\textsuperscript{12} In 1978, it was estimated that 30% of the vessels in the lake used sails and the rest were paddled [Oduor-Otieno et al. 1978]. In terms of propulsion, technology has improved over the years. Our data indicate that 46% of the vessels now use sails compared to about 49% that are paddled. The sails are usually manufactured locally using cotton, are 5 by 6 m or more in surface and have an expected life of about 2 years (Prado et al. 1991). In our sample, 4.2% of the vessels are powered by outboard engines, 0.8% by in-built engines (trawl vessels), and the rest by sails and oars. Engine power ranges from 6hp to 48hp.

\textbf{2.2.2. Fishing gear.}

\textbf{Table 2.2.2.1: Fishing gears used in Lake Victoria, Kenya (% of boats using gear).}

<table>
<thead>
<tr>
<th>Type of gear</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nile perch gillnet</td>
<td>31.3</td>
<td>27.4</td>
</tr>
<tr>
<td>Tilapia gillnet</td>
<td>16.3</td>
<td>14.7</td>
</tr>
<tr>
<td>Longline</td>
<td>16.8</td>
<td>9.2</td>
</tr>
<tr>
<td>Mosquito seine</td>
<td>6.6</td>
<td>5.8</td>
</tr>
<tr>
<td>Beach seine</td>
<td>9.2</td>
<td>12.9</td>
</tr>
<tr>
<td>Set net</td>
<td>0.2</td>
<td>6.1</td>
</tr>
<tr>
<td>Traps</td>
<td>1.3</td>
<td>0.8</td>
</tr>
</tbody>
</table>

\textsuperscript{11} These are either made of wood but larger than the average canoe or plastic boats introduced by fish processing firms to collect fish from remote landing beaches. These powered vessels collect fish from as far as Ugandan and Tanzanian waters. Transport vessels are usually also powered by outboard engines.

\textsuperscript{12} There are still, however, trawl vessels engaged in fish harvesting, albeit illegally. These have in-built engines.
Nile perch gillnet is the most prevalent gear, with 27.4% of the fishing units using it only and another 3.2% using it in combination with other gears. It is mainly combined with the longline gear. Mosquito seine with lights, used to target *R. argentea*, is the second most important gear in terms of usage. Since 1991 when the survey by Hoekstra et al. was carried out, there has been some shift of technological preference from the gillnets, longlines and traps in favour of beach seines and set nets [Table 2.2.2.1]. While the proportion of fishing units using mosquito seine technology has remained more or less constant, the percentage of those using it in combination with lights (the appropriate way to harvest *R. argentea*) has dropped from 70.2% to 67.8%. Prado et al. [1991] reported that the banned beach seines were used in isolated spots, usually at night. This is no longer true as beach seining is now in widespread use. The Nyanza Gulf is, in particular, heavily fished with small meshed gillnets and seine nets, most of which are mosquito and beach seines [Dache 1991].

Gillnets accounted for over 90% of the total fish landed from the Kenyan waters of Lake Victoria by the beginning of this decade [Prado et al. 1991]. This estimate is highly suspect as it substantially deviates from other estimates, including our own [see Table 2.2.2.2]. Evidence from the table buttresses the observation of gradual shift from gillnetting technology in favour of beach seining and mosquito seining.

**Table 2.2.2.2: Relative contribution to total catch by different fishing gears,**
percentages.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gillnets</td>
<td>72</td>
<td>63.1 55.8 45.8</td>
<td>28.2</td>
</tr>
<tr>
<td>Beach seines</td>
<td>7</td>
<td>8.2 8.8 9.6</td>
<td>13.6</td>
</tr>
<tr>
<td>Longlines</td>
<td>4</td>
<td>9.2 9.7 9.6</td>
<td>4.8</td>
</tr>
<tr>
<td>Mosquito seines</td>
<td>17</td>
<td>19.6 25.7 35.0</td>
<td>46.6</td>
</tr>
<tr>
<td>Trawl nets</td>
<td>-</td>
<td>- - -</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Following Hoekstra et al. [1991] and Prado et al. [1991], gear type is used to differentiate fisheries. The main fisheries are briefly described.

**Nile perch gillnet fishery.**

In this fishery, the species of fish targeted is Nile perch. Nets of mesh sizes ranging from 152mm (6 inches) to 305mm (12 inches) are used, with 7-8 inches being the most common [Hoekstra et al. 1991; Prado et al. 1991]. Our data confirm this to some extent. The most common mesh size is 7 inches with 19.1% of the fishing units engaged in this fishery. The range of mesh size according to our data is 1.8-8.0 inches with an average of 5.83 inches. 71.3% of the fishing units using this gear have nets of mesh size 5 inches and above. 5 inches is widely viewed as the minimum mesh size that allows adequate escapement and thus recruitment into the fishery.\(^\text{13}\)

These nets are manufactured at Kisumu but some fishermen import them from Uganda. Other fishermen make their nets by hand. Over the years, there has been a gradual tendency to use thinner twine (0.75mm-0.65mm-0.50mm) resulting in cheaper and more efficient nets [Prado et al. 1991]. Efficiency of these nets has, however, also suffered through the replacement of the ideal twine with cheaper alternatives. The nets are usually 18-26 meshes deep and are suspended with polystyrene floats and stone sinkers.

Each fishing unit uses 20-100 nets, with the most common number being 40-70 [Prado et al. 13]

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\(^{13}\) See, for example, Graham [1929], Getabu [1991] and Ogutu-Ohwayo et al. [1991].
In our sample, the number of nets ranged from 1 to 162 with an average of 42 nets per fishing unit. The mean length and depth of each net is, respectively, 66.94 m and 3.02 m. Two, or more often three, crew members are required to operate the nets. The nets are set close to the surface of the water during the phase of the new moon and near the bottom during the full moon. Fish is removed from the nets in the morning and these are either reset immediately or in the evening. Often the nets are set repeatedly for a month and then removed for cleaning and repair [Prado et al. 1991]. A canoe with 40-50 nets that catches 0.5 tonnes of fish is considered to have obtained a good catch [Prado et al. 1991]. This is rather exaggerated according to our data. The mean production for a fishing unit engaged in this fishery is 885.4 kgs per month or 29.5 kgs per day. Production data reported by Prado et al. is based on conjecture rather than actual measurement.

In 75.4% of all the fishing units using this type of gear, the nets are owned by the vessel owner. In another 12.3% of the units, the gears are owned jointly by the vessel owners and the crew members. It is only in 11.4% of the units that the crew own the gears in their entirety.

**Tilapia gillnet fishery.**

Tilapia is the main target in this fishery. The nets used have mesh sizes ranging from 102mm (4 inches) to 127-178mm (5-7 inches) but sometimes can be as large as 229mm (9 inches). In the Nyanza Gulf the most commonly used mesh sizes to harvest Tilapia are 3-6 inches [Dache 1991]. Our data indicate that 74.2% of the fishing units using Tilapia gillnet technology have nets of 4 inches and more. The mesh sizes range from 1.2 to 6.5 inches with a mean of 4.5 inches. The most common mesh size, according to our data, is 5.5 inches with 16.7% of the fishing units engaged in this fishery. Another 15.2% of the units use nets of 4 inches.

The number of nets per fishing unit ranges from 1 to 60 with an average of 13. Each of these nets is, on average, 68.27 m long and 3.55 m wide or deep. The number of fishermen per fishing unit in this fishery ranges from 2 to 4 with a mean of 3.

In this fishery, the average daily catch per fishing vessel is 8.5 kgs of Tilapia and 11.5 kgs of
all fish species put together. The technology mainly catches Nile perch besides Tilapia but also some amounts of "other" fish. Gears are, in this fishery too, generally owned by vessel owners. This is true for 72.7% of the fishing units engaged in the fishery.

**Longline fishery.**

Longline gear consists of a mainline with short branching lines (snoods) carrying hooks on which bait is attached. The size of the vessel places an upper bound on the number of hooks used by the fishing unit. Small boats can carry about 150 hooks while large ones can operate as many as 1500 [Hoekstra et al. 1991]. On average, there would be 250 hooks for each crew member. Thus, there are usually three crew members but the number could be as high as six. In our sample, the mean number of fishermen per fishing vessel engaged in this fishery is three and ranges from two to five. Boat size is therefore hypothesized to be an important determinant of catching power for this fishery. The main target of this fishery, too, is the lucrative Nile perch. This method of fishing is quite recent and is usually combined with gillnetting.

The efficiency of longline technology is critically hinged upon availability and quality of live bait. Thus, it is in the rainy season when *Haplochromis* are abundant that longliners realise good catches. Strong currents, however, kill the hooked bait and affects longline catches [Prado et al 1991]. Some fishing units operating in districts like Siaya obtain bait from Kisumu at high cost. While the efficiency of such bait is high, the price is high at Kshs 5 each. Transport, feeding and storage costs plus the high risk of death before use add to the cost of the bait. The bait, usually *Haplochromis* or *Clarias* caught from beach seining using mosquito net, is hooked by the tail to the line. The line is anchored at a depth that can be as much as 80 m but depends on the phase of the moon like gillnetting.

With 1250 hooks, a good catch according to Prado et al. [1991], would be 150-300 kgs of Nile perch and an expected average of 70-100 kg/canoe/fishing day from the Kenyan side of the lake. Our data, in contrast, put the average daily catch per fishing unit at 18.7 kgs only and
the maximum at 33 kgs\textsuperscript{14}. Assuming that the estimates of Prado et al. [1991] are fairly accurate, it would appear that CPUE has fallen drastically in the last five or so years.

In this fishery, crew ownership of gears is significant. In 22.9% of the fishing units the longlines are entirely owned by the crew members while in another 35.4% of the units the crew and vessel owner(s) jointly own the gears. This could be explained by the fact that hooks are relatively cheap and therefore affordable to the crew.

\textbf{Mosquito seine fishery.}

The nets used in this gear have hexagonal meshes which are only 7mm (4mm at the opening) in size. They are normally used for protection against mosquitoes in households, hence the name. These nets are used for seining. The technology lands not only \textit{R. argentea} but all other types of fish encountered including juvenile stages. Each fishing unit operates with 6 nets, on average. The number, however, varies from 2 to 10. Each net is 33.94 m long and 5.5 m wide or deep, on average. This seining technology requires more fishermen in relative terms, averaging five but ranging from four to six.

This gear is owned by the crew members in 87.5% of all the fishing units that use it. In another 4.2% of the units, the gear is owned jointly by the vessel owner(s) and the crew. Unlike other gears, crew ownership of mosquito seine nets is very large. This is largely because of its low relative price and the higher probability of catching "some fish". The average daily catch of mixed species of fish per fishing unit is 50.5 kgs. This technology is banned but is still in widespread use, mainly to catch bait for longlines.

\textbf{Beach seine fishery.}

The number of nets used by each fishing unit ranges from 1 to 50 with a mean of 6.82. The mean length of each net is 93.73 m but ranges from 6 m to 750 m. The mean depth of the nets is 3.09 m. Short beach seine nets, less than 100 m long, do not have a bag in the middle. Long beach seines of up to 150 m length, however, have a bag in the central part with various mesh

\textsuperscript{14} The average number of hooks per fishing unit, according to our data, is 620 and the maximum is 1,900. 75% of the fishing units using longline technology have between 100 and 1,000 hooks each.
sizes. Mesh size ranges from a few mm (mosquito net) to about 40mm with the most common being 28mm. The mean mesh size, in our sample, is 64 mm (2.54) inches even though there are meshes as small as 0.8 inches used. According to Ogutu-Ohwayo et al. [1991] most of the beach seines have mesh sizes of 2-4 inches and therefore harvest juvenile Nile perch and Tilapia. 70.8% of all the fishing units engaged in this fishery have nets of mesh size 3 inches and below. This technology is arguably the most labour intensive. Thus, each fishing unit has, on average, five fishermen although the number can be as large as 12. Moreover, more fishermen, women and children assist in pulling the nets.

According to Prado et al. [1991] beach seines are usually used at night and yield better catches during full moon periods. Based on our data, the average daily catch per fishing unit is 37.9 kgs.

This gear, being one of the most expensive, is almost exclusively owned by the vessel owners. In 93.9% of all the fishing units engaged in this fishery, the gears are owned by the vessel owners.

**Set net fishery.**

In this fishery, the target species is principally Tilapia. Each fishing unit with this technology operates an average of 13 nets, though this varies from a minimum of 3 to a maximum of 60. Each net is, on average, 69.3 m long and 2 m deep. The most common mesh size for this type of net is about 3.3 inches, used by 24% of the fishing units, but the mean is 3.6 inches. Mesh size of nets used in this fishery ranges from 1.8 to 7.0 inches. 72% of the firms using this gear have mesh size of less than 4 inches.

The ownership of this gear is also almost exclusively by vessel owners, with 92% of the total owned by them. In only 8% of the set net fishery participants are the gears owned by crew members.

**Traps fishery.**

Traps are one of the traditional fishing methods that are still in use, albeit by only few fishermen. These are usually made of bamboo and are located at river mouths to trap fish that
are swimming upstream to spawn. Their principal catches are Tilapia. The number of traps owned by each fishing unit ranges from 3 to 180, with the mean being 49. Being costless except for the labour cost, crew ownership of this gear is substantial. In 42.9% of the fishing units using traps, these are either owned by the crew only or jointly with the vessel owners.

**Mosquito seine with lights fishery.**

This technology was introduced from Tanzania about 25 years ago. The nets used in this fishery are the same as those used in the mosquito seine fishery described earlier. Each net is 20 m long and the total depth is 7-8 m. The average number of nets possessed by each fishing unit in this fishery is 7 and ranges from 1 to 15. They carry four to six lamps to attract the fish and 4-5 crew members are required for this. The lamps are lit in a line, 50-100m apart, and each lamp is encircled with the net to trap the fish surrounding the lamp. The trapped fish are hauled into the boat and then the next lamp is encircled. Encircling and hauling from each lamp takes 20-30 minutes and this can be repeated 3-4 times a night for each lamp [Prado et al. 1991]. Since it is based on light attraction of fish, this method can only be used during the dark lunar phase.

This fishery targets *Rastrineobola argentea*. High catches of up to 600-900 kg/canoe/night are reported in September during the windy season [Prado et al. 1991]. Our data, however, put the average daily catches at 134.3 kgs per fishing vessel averaged over the days fished only. Due to the lunar effects, the mean number of days fished per month in this fishery is only 19.5.

Although the legal minimum mesh size for this gear is 10mm (0.4 inches), there is widespread use of smaller meshes, nets normally used for protection against mosquito. This leads to harvesting of immature fish of this species. When used near the shores, this gear also harvests juvenile stages of other fish species.

In 23.8% of the fishing units engaged in this fishery, the gears are owned by the crew. Crew ownership of gear is substantial in this fishery because each crew member can afford at least one lamp.
**Combined gears fishery.**
In this fishery, fishing units own more than one type of gear and use them alternately but, at times, simultaneously. As Table 2.2.2.1 shows, the most common combination is that of Nile perch gillnet with other gears. Hoekstra et al. report that 25.6% of longline users, 17.1% of Tilapia gillnet users and 12.6% of Nile perch gillnet users also use secondary gears. Nile perch gillnets are frequently combined with longlines while mosquito seines are combined with the longlines. Tilapia gillnets are also commonly combined with Nile perch gillnets.

In this fishery, the average number of fishermen per fishing unit is 3 but can be as high as 6. The average daily catch per fishing unit is 23.3 kgs of all fish species put together.

**Other fisheries.**
There are other fisheries which are not described separately since they are rather insignificant. These include trawling, targeting Nile perch, and hand lines and pole and line for Tilapia. Trawling is banned but still goes on especially in the Siaya district. The daily catch per trawl vessel, averaged over all days in the month, is 418.2 kgs of Nile perch even though they fish only a few days a month due to mechanical problems and the illegal nature of their operations.

**2.3 Seasonal aspects of the lake fisheries.**
Seasonality factors are important determinants of fish breeding, growth and movement. Fishing in Lake Victoria is carried out throughout the year with seasons only indicating peak and slack production cycles. Rabuor [1989] has established a seasonal trend for the fisheries based on CPUE statistics calculated from catch and effort data for 1986-1988. He finds all CPUEs, with the exception of catch per boat haul, to be lowest between April and July and highest in August. The period April-August is generally believed to be the reproductive season for *R. argentea* and Tilapia and the growth period for juvenile Nile perch [Oduor-Otieno et al. 1978; Rabuor 1989]. Rabuor attributes the peak production in August to the influx of more fishermen into the fishery after the harvesting of agricultural crops in July and also to an increase in stock abundance on account of the closure of the fishery between April and end of July.

A close look at the Fisheries Department's monthly production data for the period 1993-1995
suggests a pattern that is broadly the same for all the major species. The lowest catches are realised between February and April and the highest between June and September. The period of moderate production is November-January, with slight variations from species to species. June and August appear to be the most productive for Nile perch while September is unambiguously the best month for *Rastrineobola argentea*. For Tilapia, the best months appear to be September and November. It should be noted, moreover, that seasonal patterns are not uniform over all the fishing locations.

### 2.4 Management and regulation of the fisheries.

Only a few of the management options legally open to the Director of Fisheries have been used in practice. Mesh size limitation was used to regulate fishing in Lake Victoria between 1930 and 1960 [Ogutu-Ohwayo et al. 1991]. At the time only nets of (stretched) mesh size 5 inches and above were allowed. The main goal of this regulation was the protection of juvenile *Oreochromis esculentus* (endemic Tilapia species), the species of commercial importance at the time. This legislation was, however, repealed in Uganda and Tanzania in 1956 and in Kenya in 1961, ushering in the use of small meshed nets that led to the collapse of this endemic tilapiine species [Ogutu-Ohwayo et al. 1991]. Restriction on mesh size was, however, re-introduced in Kenya. The minimum mesh size for Tilapia gillnets is specified as 10.2 cm or 4 inches. A system of fishing boat registration, in addition, has been in place since the 1960s [Hoekstra et al. 1991]. Beach seining is prohibited during the closed seasons and for closed breeding areas. Closed seasons and areas have been used mainly to protect the Tilapia fishery. Thus, beach seining and mosquito seining are illegal over April-August period\(^{15}\) as these methods harvest juvenile Tilapia. Known fish breeding areas such as sandy shores and shallow weed beds for Tilapia; river mouths for such species as *Labeo, Barbus, Alestes, Mormyrids* and *Clarias*; and swamps and wetlands for *Protoptrus* and *Clarias* are closed for specified periods. Trawling in the inland lake fisheries is also banned. Prior to its banning in 1993 trawling was legal so long as it was carried out outside five nautical miles of Kenya's territorial waters.

Personal communications with District Fisheries Officers (DFOs) confirm that minimum

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\(^{15}\) According to Gréboval [1989] this closed period runs from March 21 to August 1.
mesh size of gillnets, ban on trawling, closure of fish breeding areas during the rainy season, trade in undersize fish and prohibition of beach seining in fish breeding areas are the regulatory instruments being used in the current management of the fisheries. The regulations are, however, not uniformly enforced in all districts. Thus, while some districts enforce the minimum mesh size as 3.5 inches, others enforce 4 or 5 inches. Some districts, in fact, allow the use of beach seine nets with meshes as small as 2.5 inches. The regulatory instruments used in the current management of the fisheries, then, control only specific aspects of technology and do not restrict the amount of effort at all, reflecting the previously widely held opinion that the type of gear and fishing practices used were responsible for overexploitation [Gréboval 1989]. For example, the decline of tilapiine species, Clarias, Labeo, Barbus, Bagrus and Mormyrid fishes has been attributed to overfishing using illegal, small meshed gear.16

Lethargic enforcement of fishery regulations has led to an inexorable use of banned fishing technology and maintained these Kenyan fisheries as, essentially, open access resources.17 Thus in their survey of vessels exploiting these fisheries, Hoekstra et al.[1991] report that 20% of the boats are unregistered and that 9.2% of the boats operate the prohibited beach seine gears. Licensing appears to have been motivated more by revenue collection than by management objectives [Van Marlen 1991]. The annual licence fees are simply too low to influence entry/exit decisions. A typical fishing unit consisting of a canoe, 4 fishermen and their gears, for instance, requires only about Kshs 1,000 (US$ 15) for its annual licensing (boat, fishing, etc.) expenditure. Such a fishing unit could earn much more than this amount of money from a single day’s catch. Moreover, since there is no policy of restricting the number of participants in the fishery, anyone interested in joining the fishery requires only fishing capital. Mesh size restriction and the banning of such fishing methods as beach seining have simply not been effective in the management of the lake fisheries [Okemwa 1991]. Moreover, trawlers continue operating in the lake illegally. The regulation of closed season,


17 It has been suggested that enforcement of regulations relating to the use of banned gears, illegal mesh sizes and landing of juvenile fish is inherently difficult since the fishermen need to understand the need for them in order to comply [Gulland 1982]. We argue, however, on the basis of field work experience that fishermen already understand the usefulness of these regulations but lack incentives for compliance due to the absence of property rights.
April-August, for designated fish breeding areas has not been successful either [Okemwa 1991].

According to DFOs, fishermen compliance with the regulations is extremely poor, with the most violated regulations being the use of small mesh nets and fishing in the breeding areas. This is because these nets and these areas guarantee higher catches and because small meshed nets are relatively cheaper. Registration of vessels and fish movement licensing are also widely violated. Some of the junior fisheries officers have become fishermen, using the same illegal gears they are supposed to guard against, or fish traders completely forgetting their primary duty of data collection and enforcement of fishery regulations and provision of extension services. This is a problem aggravated by the practice of keeping officers at one station for excessively long periods and by lack of regular improptu supervisory visits from senior fisheries officers. Fishermen are, additionally, reported to be using poison to catch fish. Fishermen in Siaya district have, for instance, been recently reported to be using chemicals that are normally used to kill ticks in cattle dips as a fishing technology.\(^{18}\)

DFOs and other officials of the Fisheries Department cite financial and thus logistical bottlenecks as the leading hindrance to effective enforcement of fishing regulations. While many districts have either one or no patrol boats and an equal number of old landrovers, there is usually no money for fuel. Moreover, trawlers use more powerful vessels and are usually armed. Trawling was administratively banned but was not legislated. Thus, in May 1995 for instance, a Kisumu court acquitted 10 trawl owners who had pleaded guilty to the charge of trawling as the charge is non-existent under the Fisheries Act.\(^ {19}\) Serious corruption also hampers the enforcement of fishing regulations. This corruption takes many forms. At the highest level, senior and politically connected people, including former or current senior officials of the Fisheries Department, own the trawl boats and buy protection from the authorities. Fisheries officers often find themselves powerless against their current or previous bosses. At a lower level juniour fisheries officers solicit for bribes from fishermen who use banned fishing gears and methods. Arrested fishermen, moreover, rarely reach the

\(^{18}\) The Daily Nation, 22 April, 1998.

\(^{19}\) This was reported in the largest Kenyan daily, Daily Nation, of May 13, 1995.
courts because they can easily secure their freedom. The people charged with the responsibility of enforcing regulations at the local level, Chiefs, double up as fishermen, suffering from conflict of interest. It is also difficult to enforce the restriction on mesh size for gillnets as these nets are, in most cases, left set in the water. Fishnet dealers apparently sell prohibited nets. These have been found in warehouses belonging to Fishermen Cooperative Societies who buy them from manufacturers for resale to their members.

2.5 Invasion by the water hyacinth, *Eichornia crassipes*.

Lake Victoria is now facing an ecological crisis following invasion by the water hyacinth (*Eichornia crassipes*). This invasion can be partly\(^{20}\) attributed to eutrophication resulting from sediment and nutrient deposition into the lake. The water hyacinth is seriously affecting fish production, lake transport, power generation, water supply and human health. The massive floating vegetative cover hampers navigation and landing of fishing boats, leads to overheating of ferry engines and outboard motors and depletes the shallow waters of oxygen. The latter effect interferes with the biological functioning of fish, thereby impacting negatively on production levels. The water weed is also affecting production by disrupting important food chains. Through its vegetative cover, the weed shades phytoplanktons from sunlight, an important ingredient in photosynthesis. On transport, the weed, for instance, led to the indefinite closure of Kendu Bay pier at one time. In Uganda the effects on transport have been worse, necessitating huge financial and other resource expenditures in the weed's mechanical and manual removal. The weed at one time completely choked the power generation plant at Jinja and also clogged Kisumu's water supply pipes. The underside of the weed is said to harbour poisonous snakes and snails that carry disease vectors for bilharzia.

The weed has had at least one positive contribution. It has created such an outcry from the fishing industry that the governments of the three countries have had to come together in an

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\(^{20}\) There is uncertainty regarding the origin of the water hyacinth and how it found its way into Lake Victoria. One story is that the weed was brought into Africa from South America by foreign soldiers during the Second World War [*Kenya Times*, October 2, 1996]. As it had beautiful flowers and could survive for long in the sea, the soldiers found it the natural sentimental link to their homes while abroad. The weed subsequently found its way into River Kagera and was swept down into Lake Victoria, Ugandan side.
attempt at finding joint solutions. This has resulted, with the assistance of donor agencies such as the Global Environmental Facility (GEF) and the World Bank, in the establishment of LVEMP. LVEMP is charged with not only the removal of the water weed but with the broader task of environmental management of the entire lake. The three countries signed the agreement for the establishment of LVEMP in 1994. The control of the weed is expected to be achieved through an integrated approach, worked out with the assistance of FAO, that consists of mechanical methods and limited chemical intervention in restricted areas for short-term control and biological methods coupled with reduced nutrient inflows into the lake for long-term control. Already, the programme has carried out a study on the ecology of Lake Victoria and is applying biological control of the weed.

3.0 THEORY AND DATA.
3.1 The Production function.
The production function is the simplest and most prevalent way of representing firm technology [Varian 1992]. The function shows, for a given technology, the maximum output attainable from a given level of inputs. In a fishery, the production function is defined as the relationship between effort applied and the amount of catch realised [Anderson 1986]. The short-run production function or short-run yield curve is this relationship for a given population level while the long-run production function or sustainable yield curve is the relationship between effort and amount of fish that can be harvested period after period without affecting the stock. Stated differently, the fishery production model is the long-run response of total stock to aggregate homogeneous effort [Doll 1988]. Doll (1988) differentiates between two types of fishery production models: the production function for vessels which represents the traditional relationship between inputs and outputs; and the production response for a fishery. The latter depicts the yield or catch resulting from various levels of effort and biomass.

The vessel production function that we develop and estimate in this paper is essentially a short-run yield curve as it is based on cross-section data. Nevertheless, cross-section data

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21 The weed has potential real economic value, however. It has been reported, for instance, that the weed is being used to produce biogas energy, purify water contaminated by raw sewage, produce manure and provide a substratum for the nourishment and breeding of some fish species [Daily Nation, November 13, 1997].
reflect long-run behaviour, making such data the most appropriate for structural analysis of certain long-run elasticities [Intriligator et al. 1996]. While the appropriate production cycle for a fishing unit is the trip or the day in a case such as ours where most of the fishing units make one trip per day, we build a monthly vessel production function because we lack information regarding the number of hours fished each trip. Moreover, observations of hourly effort produced by a fishing unit may not vary significantly over the unit's trips [Doll 1988]. This is, in fact, the case in the fisheries under study where fishing firms fish for roughly the same number of hours each day to ensure that they reach the market at the appropriate time.

Fishery resource models are only one example of resource harvesting models that are based on the elementary differential equation,

\[ \frac{dX}{dt} = F(X) - h(t) \]

where \( X(t) \) denotes the size of the resource population at time \( t \); \( F(X) \) is the population's natural growth rate and \( h(t) \) the rate of harvesting at time \( t \) [Clark 1990]. Thus, the basic model in fisheries economics, the Schaefer-Gordon model, has a biological component, represented by fish stock \( (X) \) and an economic component represented by effort \( (E) \) as follows:

\[ \frac{dX}{dt} = F(X) - qE_x = rX \left( 1 - \frac{X}{K} \right) - qE_x \]

where \( t \) is time in days; \( E_x \) is effort in standardized vessel units per day; \( X \) is fish stock in tonnes; \( h = qE_x \) is catch rate in tonnes per day; \( q \) is catchability\(^2\), per vessel day; \( r \) is the intrinsic growth, per day; and \( K \) is the environmental carrying capacity in tonnes.

From this model an estimable yield/effort relationship can be derived. Schaefer chose the Cobb-Douglas specification, with constant returns to scale imposed, for this relationship:

\[ h = A E^l X^2 \]

where \( h \) is the harvest rate, \( E \) the fishing effort, \( X \) the fish stock, and \( A \) a constant. Fishery-harvesting models are, therefore, simply a specification of the appropriate production function [Clark 1990]. \( h = qE_x X \) cannot be derived without the assumption of

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\(^2\) \( q \) equals the proportion of fish in a cubic meter of water that is caught by the gear multiplied by the number of cubic meters of water screened by one standardized fishing unit in an hour.
constant abundance or density of fish, that is, constant concentration of fish in the water (kilograms of fish per cubic meter) [Clark 1985].

The output or catch of fish, h, is a function of the stock of fish, X, and effort, E [Anderson 1986; Panayotou 1985; Clark 1990; Khaled 1985]. The (long-run) fishery production function can, thus, be specified in general terms as:

\[ h = F(E, X); \quad -F/-E \leq 0, \quad -F/-X \leq 0, \quad \frac{\partial F}{\partial E} \geq 0, \quad \frac{\partial F}{\partial X} \geq 0 \]

This function is characterized by positive but diminishing marginal products of stock and effort [Khaled 1985]. The catch rate will always increase with E in the short-run, declining only in the long-run when population dynamics lead to decreased fish stock [Clark 1990].

The estimation of fish stock size, X, is often hampered by insurmountable difficulties, rendering the empirical estimation of (4) difficult and therefore rare. As a coping strategy, proxies for fish stock, such as CPUE, have been used but found to create econometric problems [Campbell 1991]. X can vary considerably across fishing grounds and over seasons (or different time periods). Nevertheless, in the short-run (for time-series analyses) or in a specific location (for cross-sectional analyses) fish stock (X) is constant [Panayotou 1985; Campbell 1991; Bjørndal 1989]. If this assumption is valid it implies that the production function is separable, that is,

\[ h = F(g(E), X). \]

Hannesson [1983], using time series independent estimates of stock, could not reject the null hypothesis of separability in the production function for the Lofoten cod fishery. Fish stock can therefore be eliminated as an explanatory variable in the production function under such circumstances. Fleet participation, a measure of crowding externality, can be ignored in the production function on similar grounds [Bjørndal 1989].

The production function subsequently takes the following form:

\[ h = f(E) = N(E_i) \]

where h is an output index based on the composition of catch weighted by the corresponding prices and \( E_i \), \( i = 1, 2, \ldots, n \), stands for different components of the composite input (E) such as capital, labour, materials and fishing time. Capital can be broken up further into boat size,
engine power, net mesh-size and length or size of gear [Panayotou 1985; Khaled 1985].

Capital combines with labour and materials to determine a fishing unit's catching power. The
time spent fishing, in turn, determines the rate of utilization of the existing fishing capacity.
Thus, fishing time should be the most important determinant of a fishing unit's catch, given
vessel technology, fish abundance, and other inputs [Doll 1988].

In the construction of the output index it is assumed that price differences among fishermen
reflect differences in species and size composition of the catch rather than differential
monopsonistic power of middlemen [Panayotou 1985]. This assumption is valid in the
Kenyan case as gradually intensifying competition between buyers has eroded virtually all
monopsonistic tendencies. This competition is, however, reduced in the rainy seasons and
particularly in the case of remote inaccessible landing beaches. During some months of the
year, therefore, price differences will not only reflect species and quality differences but also
beach and season effects. Even though the production function is a relationship between
quantities rather than values, the value of output is a good measure of output when dealing
with heterogeneous goods or services [Intriligator et al. 1996]. In our model output is
heterogeneous not only because it is composed of different fish species but also because fish
captured are of different sizes and, thus, quality. We, nevertheless, experiment with the
quantity and value of fish output as alternative dependent variables to glean aspects of the
production process that would otherwise be lost from a specification that relied exclusively
on either.

**Model Specification and Rationale.**
The models we estimate are a combination of (5) and (6). Rather than eliminate the stock
variable entirely, we capture it by dummy variables. We assume that **spatial and seasonal stock variations** lead to shifts in the intercept of the production function, effectively
accounting for productivity variations among fishing firms that are attributable to stock
effects. Structural stock differences among the five districts that border the lake on the
Kenyan side and among three staggered months are tested. The rationale for this is the
substantial productivity differences, both spatially and seasonally, that is suggested by a
casual glance at fish production figures.
The stock effect is further captured by a dummy variable differentiating those fishing units that exploit both the *inshore and offshore fisheries* from those that exploit the former only. Fishing units that have technological flexibility of exploiting either inshore or offshore fisheries are expected to be more productive and to harvest, in general, less amounts of juvenile fish relative to those that can exploit the inshore fishery only. Nile perch and Tilapia are generally believed to breed in the inshore fishery, particularly in the rainy breeding season [Ogutu-Ohwayo et al. 1991].

**Fishing time** is used as a composite input to capture the effect of all the variable inputs. This is equivalent, formally, to the assumption of Leontief input separability. This is justified as inputs are commonly combined in fixed proportions [Bjørndal 1989; Squires & Kirkley 1991]. In these Kenyan fisheries, fishing time is one of the choice variables available to fishermen in the short-run. Fishermen can choose to supply labour or enjoy leisure on Sundays and public holidays, for instance. As already mentioned fishing time determines the rate at which existing fishing capacity is utilized. The number of days fished in a month and the average number of daily fishing trips are chosen as measures of fishing time.

Fixed factors could be measured by such variables as vessel length, width, depth, tonnage, construction material, engine power, number of regular crew, type of gear, age of the boat, and so on [Campbell 1991; Bjørndal 1989]. But since, as noted by many researchers on this issue, most of these are highly correlated they cannot all be included in the model. Based on the vessel characteristics of the fishing units that exploit the fisheries under study, we choose the vessel length or surface area, age, means of propulsion, the size of crew, and the type and size of gear as measures of fixed capital.

**Vessel length or surface area** is a measure of its size and therefore its potential cargo capacity. It sets the upper limit on catch per trip. This is unlikely to be a constraint in these fisheries as fishing trips are usually day-long. Vessel size may, however, affect fish production by placing an upper bound on the size of crew and gear that can be accommodated and by limiting the choice of fishery (inshore, offshore or both) to exploit. Vessel size also determines the fishing unit's vulnerability to weather changes and thus the number of days fished per month. A larger vessel may allow more fishing days per month, fishing in more
distant waters and use of more gears [Campbell 1991]. Vessel age represents technological progress and, moreover, may influence catch levels in the same way that size does. Dummy variables are used to capture differences in the means of vessel propulsion which, like vessel size, determines the fishing unit's range of operations and degree of vulnerability to weather.

The bigger a fishing unit's size of crew is, the faster would be its operations and the higher, therefore, its expected catch, provided the gear and vessel constraint levels at which diminishing returns begin are not violated. With a fixed size of gear, increasing labour may be expected to have a positive marginal product until that level of labour at which the gear constraint becomes binding. Further increase of labour beyond this level will not increase total catches and diminishing marginal returns will set in when the labour input increases sufficiently to violate, also, the vessel size constraint [Oduor-Otieno et al. 1978].

**Type and number or size of fishing gear** a boat possesses is an important determinant of its catching power as it determines the quantity of output and the output mix in terms of size and species. The model is thus estimated separately for fisheries categorised on the basis of gear or technology used. This is justified by the fact that fishing technology is heterogenous, consisting of different types of fishing gears and methods which cannot be quantitatively compared or described. The number of nets (or hooks in the particular case of longline technology) is used as the measure of gear size in the models for specific fisheries. In the aggregate production function for all the fisheries put together, dummy variables are used to capture technological heterogeneity qualitatively. For the nets fisheries, mesh size is an important determinant of catching power. Turvey [1964] was the first to incorporate mesh size in a bioeconomic framework. He observed that the mesh size of trawl nets determines the minimum size or age of fish caught and, thus, the size or age at which the fish are "recruited" to the fishery. An increase in mesh size, ceteres paribus, will initially reduce catch but ultimately raise it by enhancing stocks [Turvey 1964].

Besides stock and technological factors, management is an important determinant of catch levels. Fishermen vary in the catch they land because of one or more of differences in technology, input combination, fishery resource abundance, and technical efficiency or due to pure luck [Panayotou 1985]. Management or organisation is acknowledged as an important
variable in the supply function of any good or service. In fishing enterprises, organisation is required in the daily decisions on such issues as whether or not to fish, stock areas to exploit, size of crew to use, beach or port to land and sell fish, maintenance of vessel and gear, night or day fishing, strategies against theft of gear and mode of remuneration and type of incentives for the crew. Indeed, according to the "good captain" hypothesis, the strongest factor input in the economic performance of a fishing unit is not the vessel size or type of gear or its location but the quality of its captain [Gates 1984]. Management differences among firms means that "intrafirm" production functions have the same slope but different intercepts [Mundlak 1961]. Mundlak, further, finds management or firm effect to be correlated to the inputs in the production function, suggesting that the estimation of production functions in the absence of this effect would yield biased coefficients.

We have chosen fishing experience (the number of years that the head of the fishing unit has worked on a similar capacity), the owner-head versus employee-head effect (that is, a dummy variable differentiating owner-headed fishing units from those headed by employed captains) and the level of education as proxies for management capability. Hilborn and Ledbetter [1985] find skipper skill and motivation to be major determinants of catching power in the British Columbia salmon purse seine fleet. We expect, therefore, fishing units headed by more experienced skippers to be relatively more productive, ceteris paribus. Owner-headed fishing units are likely, on average, to be better managed relative to those headed by employees because of higher motivation to maximize returns and thus recoup investment costs. This hypothesis is motivated by reports that absentee fishing unit owners often provide bonuses and perks to the captain and net caster and other employees when high catches are realized. The problem of cheating in which employees sell some of the catch before landing at the regular beach where the owner is located is serious to the extent that it discourages fishermen from owning more than two vessels. Fishermen rarely own more than one or two vessels as this would reduce their control and therefore frustrate their efforts at maximising returns to their investments. The skipper's level of education may influence the quantity and quality of his fishing unit's catches in a number of ways. First, more educated skippers are expected to be relatively wealthier or, at the least, better poised to tap from existing credit sources. This, relaxing capital constraints, would be expected to provide greater latitude in the choice of the desired fishing technology. Second, more educated fishermen can
be expected to be better planners and more responsive to stock and price changes.

The purpose of specifying and estimating an aggregate fishery production function is to assess the validity or otherwise of managing the fisheries at the overall industry level. This is assessed through the comparison of estimation results for the separate fishery production functions with those of the aggregate production function.

**Functional form of the Model.**

The Transcendental Logarithmic (translog) and Cobb-Douglas functional forms are chosen for the production functions. The Cobb-Douglas is chosen for its relative simplicity, interpretational convenience, and because it has been found to be appropriate by, for example, Comitini and Huang [1967] for the North Pacific halibut fishery and by Bjørndal [1987] for the North Sea herring fishery. Khaled (1985), however, rejected it for the Bangladesh riverine fisheries. A serious limitation of the Cobb-Douglas function is that it constrains the elasticities of substitution between all inputs to unity. Yet, the nature of technology in fishing is such that substitution between the various inputs is limited with some of the inputs actually being complementary [Khaled 1985]. The translog form is very flexible as it does not place prior restrictions on substitution elasticities. It is for this flexibility and the facility to investigate the existence and degree of input substitution that the translog functional form is also chosen. Campbell [1991] used the translog form for the Tasmanian rock lobster fishery but could not reject the CES form. In the CES form, the elasticity of substitution between any two inputs is constrained to constancy but not necessarily to unity. This form is also, therefore, quite limited. The estimation of the translog and other flexible functional forms is, unfortunately, complicated by serious multicollinearity between the explanatory variables and the degrees of freedom problem. The Cobb-Douglas form is thus chosen to provide an alternative in the event that these problems hamper the successful estimation of the translog.

The linearised versions of the production functions that we estimate, then, take the following general forms:

(7) \[ \ln h = A[d_s, d_g, d_{vp}, d_m, \ldots] + \beta_i \ln E_i + (Cobb-Douglas) \]

(8) \[ \ln h = A[d_s, d_g, d_{vp}, d_m, \ldots] + \beta_i \ln E_i + \rho_{ij} \ln E_i \ln E_j + \text{translog} \]
where  $i_j = j_i$, i d j, by symmetry, and where $A[.]$ is the constant term modified by stock, gear, vessel propulsion, management and other dummies. is a stochastic error term, assumed to be independently identically distributed, IID(0, $\sigma^2$). It captures the effects of relevant but omitted variables such as luck and other 'noise' due to measurement error, for instance. The actual number and type of inputs and dummy variables included in each model depends on the specific fishery it is specified for.

Cross-section data pooled over three months is used in (7) and (8). This specification is not appropriate for capturing seasonality effect. The following specification is also, therefore, used in some cases to capture this effect more adequately through monthly dummy variables.

(9) \[
\ln h_{at} = A[d_{mo\ldots}] + \sum_i \ln E_{iat} + \epsilon_{at}
\]
where a refers to fishing units (a = 1, ..., 382), t to time periods (t = 1,2,3) and i, like in (7) and (8), to the components of effort, E.

One of the crucial assumptions underlying the theory of the firm upon which production and cost functions are based is that the goal of the firm is profit maximization within the production period. Is this a valid assumption for fishing firms? In situations where output is stochastic due to "acts of nature" such as weather, firms can be assumed to choose inputs with the objective of maximizing expected profit [Zellner et al. 1966]. This is a reasonable assumption for fisheries. Not only are the other goals that fishermen may pursue consistent with profit maximization but this assumption has been discussed and generally accepted in textbooks on fisheries economics [Doll 1988].

In fisheries, the choice of optimal input levels can be assumed to be subject to human errors that are uncorrelated to the stochastic error term in the production function [Campbell 1991]. Ordinary Least-Squares (OLS) estimation of the production function under such assumptions yields consistent estimates of the parameters.

**Determinants of juvenile fish harvests.**

To evaluate the relative implications of fishing technologies to the sustainability of the fishery resources, the same production function framework is employed. Thus, the amount of
immature fish\textsuperscript{23} harvested is specified as a function of the type and size of gear and other variables such as boat size and means of propulsion, size of crew, seasonality and spatial stock distribution, inshore breeding effects, level of education and fishing experience of the captain and owner-head effects. Because of many cases with no catches of immature fish, however, a linear rather than log-linear model is used in this case. This is because the logarithm of zero is not defined and use of the log-linear specification would yield biased estimates.

We carry the analysis of the determinants of juvenile harvests further by developing a slightly different model. In developing this model, we argue that there is no conceivable reason to believe that the number of days fished, the size of crew, vessel size and other vessel characteristics and fishing experience have an influence on juvenile fish harvests that is independent from their influence on total firm catches. In the model the effects of these variables is captured by using the quantities of Nile perch and Tilapia caught as explanatory variables. We argue, further, that mesh size is the single most important determinant of juvenile fish production. Mesh size determines the minimum size of fish caught, that is the age or size at which fish are "recruited" into the fishery and therefore the age and size composition of stock [Anderson 1976; Turvey 1964]. Thus, yield from the fishery is not a function of stock size and total effort only but also mesh size. The model is then specified as follows:

\begin{equation}
\ln A_{it} = A[\text{dummy, dummy,...,dummy}] + \ln QNP_{it} + \ln QT_{it} + \ln \text{Mesh}_i + \epsilon_i
\end{equation}

where $A_{it}$ is the amount of immature fish produced by fishing unit $i$ in month $t$; $QNP_{it}$ and $QT_{it}$ is the amount of Nile perch and Tilapia, respectively, produced by unit $i$ in month $t$ and $\text{Mesh}_i$ is the mesh size in inches of the nets used by unit $i$. The dummy variables represent different types of gears, districts, months, level of education, inshore vs offshore fishing and owner-headed vs employee-headed fishing units. As before, $\epsilon_i$ is the stochastic error term, assumed to be independently identically distributed. To estimate this log-linear model which is preferable over the linear one in terms of interpretation, we use only those units that produced juvenile fish.

\textsuperscript{23} We consider only the immature fish of Nile perch and Tilapia species because it is very difficult to separate immature and mature fish of \textit{R. argentea} species.
3.2. Hypotheses.

With regard to the fishery production functions, we hypothesize that:

i) vessel length, fishing time, size of crew, number of nets (or hooks), fishing experience and level of education positively and significantly explain the level of catches realised by fishing units while the effect of vessel age and mesh size is negative.

ii) vessels powered by outboard engines are more productive compared to sailed and paddled ones.

iii) elasticities of output with respect to such fishing inputs as boat, gear, time, and labour are low due to overexploitation of the fisheries.

iv) fishing time is a highly significant determinant of catch with a high elasticity relative to other inputs.

v) there are significant differences in gear productivity with trawling, mosquito seining and beach seining being more productive relative to the other fishing technology.

vi) there are substantial seasonal and spatial differences in resource abundance.

vii) owner-headed fishing units realise better catches in terms of value and quantity compared to those headed by employed skippers, *ceteris paribus*.

viii) fishing units that are able to exploit only the inshore fisheries produce less catches in terms of value because of harvesting predominantly lower priced juvenile fish.

ix) the fisheries are characterised by "decreasing returns to scale" because of past overexploitation, that is, \( f(tE_1, \ldots, tE_k) < tf(E_1, \ldots, E_k) \) \( t > 1 \). The Law of Diminishing Returns does not, in a strict sense, apply in this case. The law "...applies to a particular production process and not to aggregate or industry analysis." [Doll 1988: 111]. Since the production cycle for a fishing unit is a trip, the law should strictly apply to the trip production function.

For the models evaluating the determinants of the amount of juvenile fish produced by fishing units, it is hypothesized that:

i) fishing gears such as trawl nets, beach seines, mosquito seines and gillnets of small mesh sizes produce more immature fish relative to the other gears and, thus, have serious implications for the sustainability of Kenya's Lake Victoria fisheries.

ii) mesh size is a negative and significant determinant of juvenile fish harvests.
iii) fishing units that are restricted to the inshore fishery by technological and other factors harvest more juvenile fish, irrespective of the gear technology they use. In this respect, it is also expected that the means of vessel propulsion significantly explains the size of its juvenile harvest, with paddled vessels producing more, \textit{ceteris paribus}.

iv) owner-headed fishing units, \textit{ceteris paribus}, perform better than employee-headed competitors by catching the highly abundant and valuable species of the optimal marketable size and less immature fish.

v) fishing units headed by better educated captains may be expected to produce, on average, lower amounts of juvenile fish for at least two reasons. First, they are likely to have more latitude, in financial terms, to acquire more appropriate fishing technology. They would be expected, for instance, to be more likely to seek out loans and negotiate better credit deals with fish buyers. Second, educated fishermen are better endowed, in general, to grasp profitability implications of harvesting undersized fish.

3.3 The Data.

This paper is primarily based on micro-primary data collected, through the administration of a structured questionnaire, from a sample of 382 fishing units exploiting the Kenyan fisheries of Lake Victoria. Being the basic unit of production in fisheries, we use the term "fishing unit" to mean the vessel, its head, crew and fishing gear. The head of the fishing unit was the respondent to our questionnaire and any conclusions drawn and attributed to fishermen, therefore, relate to the vessel captains rather than crew members unless stated explicitly. Production related data were obtained from these units for three staggered months (May, August and November 1995) to capture seasonality effects. The study uses secondary data also, obtained from the Fisheries Department and existing publications.

3.3.1 Data collection procedure.

A two-stage sampling method was used to draw the sample of fishing units. In the first stage, a sample of 30 out of an estimated total of 208 landing beaches\textsuperscript{24} was drawn with each of the five districts adjacent to the lake (Busia, Siaya, Kisumu, Homabay and Migori) contributing to the sample proportionately. The actual 30 landing beaches were picked by the method of

\textsuperscript{24} This is the figure reported by the most recent survey of fishing vessels, Hoekstra et al. [1991].
systematic selection, using as the frame survey results of Hoekstra et al. [1991]. In this frame, landing beaches are listed by district and by division within each district.

The method of systematic sampling is advantageous over random sampling if neighbouring population units resemble one another, like they do in this case, as the method distributes the sampling units more evenly over the entire population just like stratified random sampling [Monga 1989:517]. Moreover, a major disadvantage of random sampling is that ".....some areas may not be considered at all by chance and others may be over-represented by chance." [Monga 1989:515]. In drawing the first stage sample, therefore, the main goal was to have it as spatially representative as possible.

The final sample was made up of 10-15 fishing units drawn from each of the 30 landing beaches as randomly as possible. Random selection is ideal as each fishing unit gets an equal chance of being selected. However, proper random sampling was not achieved for two major reasons. First, a frame constructed from vessel registration records (the best available in our case) would be grossly inaccurate because about 20% of the vessels are not registered. Secondly, random sampling would yield a sample that has very few engine-propelled boats, inadequate for their separate modelling. For these two reasons, engine powered fishing units and trawl vessels in particular were included in the sample purposively. This is justified on the grounds that the overriding objective of the study is analytical rather than descriptive. It should be emphasized, nevertheless, that even for descriptive purposes, our sample is quite appropriate since there is not much variation in vessel characteristics from district to district.

Randomness was achieved by visiting each beach prior to the first month of enumeration and drawing a sample of 10 fishing units as follows: units landing at regular intervals were picked, with the interval determined from the estimated number of active boats operating in the beach. This effectively accounted for vessels exploiting proximate and/or distant fishing grounds. Fishing units picked in this manner but who opted not to participate were replaced by those

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Although the optimal sample size (as determined from sampling theory) is the most desirable for cost, time and efficiency reasons, often there is lack of the required information to ensure that the sample size chosen is the best one [Cochran 1977:72]. In this study, the sample is chosen, albeit arbitrarily, with the aim of having it large. The advantages of a large sample include reduction in sampling error by a factor of \( \sqrt{n} \) as the sample of size \( n \) is doubled. A large sample further ensures adequate degrees of freedom for purposes of sub-sample modelling.
landing immediately after them. Any engined boats encountered that had not been selected randomly were, subject to their cooperation, included in the sample.

Even though landing beaches vary considerably in the number of resident fishing units, a more or less equal number was selected from each of them in order to distribute workload equitably among the enumerators and at the same time to ensure a large sample. The final sample size realized was 382, an average of 12.7 fishing units per beach. The number of fishing units in the initial sample ranged from a minimum of 6 in one of the beaches to a maximum of 15 in one third of the beaches. Only 3 beaches had less than 10 fishing units in the sample. Not the entire 382 units participated in the three months, however, due to migrations, retirement or exit, and a few instances of withdrawn cooperation. In the end, therefore, we have an unbalanced panel data set.

Data collection involved interview, measurement and observation. Catch, sales, amount of fish consumed at home by the fishing crew, size of crew, amount of fish spoilt, cost of fishing, number of nets or hooks used, amount of immature fish landed and many other data were recorded, on a daily basis, for three months staggered over the year (May, August and November, 1995) to capture seasonality. Besides production related data, measurement of vessel sizes and their gears as well as collection of relevant background information was done in the first month of enumeration.

**4.0. PRODUCTION FUNCTION REGRESSION ANALYSIS AND RESULTS.**

**4.1 Translog production functions.**

The Translog functional form performed well in some fisheries but very poorly in others, largely due to multicollinearity. It was, moreover, not "well behaved" in some fisheries as some marginal products were negative and some cross-product terms positive. Results of the Translog production functions whose estimation was successful were, however, unequivocal in rejecting the Cobb-Douglas specification. Even though almost all the cross-product terms were not (statistically) significantly different from zero, second-order terms were significant at the 5% or better levels of significance. From a fitted translog model only failure to reject the null hypothesis that all cross-product and second-order terms jointly equal zero would justify the Cobb-Douglas specification.
In spite of the poor performance of the translog production functions, it is worthwhile to highlight some of their estimation results. For the aggregate fishery model, there are diminishing marginal returns to fishing time and labour but not to vessel size. There is no evidence (at the 10% level of significance) of substitutability or complementarity between any two pairs of inputs. Complementarity between vessel size and number of nets is indicated in the Nile perch gillnet fishery. In mosquito seine with lights fishery, there is substitutability between labour and the number of nets and diminishing marginal returns to labour. Substitutability between fishing time and vessel size and complementarity between fishing time and the number of nets are indicated for the beach seine fishery. In this fishery, therefore, smaller vessels and vessels with more nets fish for relatively more days in a month.

4.2. Cobb-Douglas Production functions.
To facilitate comparison across fisheries the Cobb-Douglas form was chosen because the Translog could not be implemented for all of them. For brevity, only results for the Nile perch gillnet, and the aggregate fishery production function are reported in full. The models explain 59-93% (adjusted $R^2$) of all variation in the value of catch among the fishing units. This is very satisfactory given that the data is cross-sectional, pooled over 3 months or 92 days. The unexplained variation could be attributed to random variables including pure luck. In the Cobb-Douglas specification estimated coefficients, except for the dummy variables, are production (or catch) elasticity of the fishing inputs, defined as the percentage change in catch resulting from a 1% change in the quantity of the particular input used, holding all other factors constant.

The aggregate fishery production function and all the individual fishery production functions except the set net exhibit increasing returns to scale. The production function for the set net fishery, on the other hand, exhibits decreasing returns to scale. Other estimation results of the production functions are discussed below, variable by variable.

**Number of days fished (fishing time).**

This rejects the hypothesis by Oduor-Otieno et al. [1978] that capital (nets, gear, boats) and labour can only be used in fixed proportions.
This variable is used as the composite variable input. It is statistically highly significant in all fisheries. The estimated coefficient for this variable is highest in the case of the aggregate fishery (1.36) and lowest in the beach seine fishery (0.68). It may be argued that the statistical significance of this variable is spurious in that all the other variables in the model determine daily catch levels with the number of days then merely acting as a scaling factor in explaining monthly catch. We reestimated some of the models with the dependent variable being the log of average daily catch rather than the monthly totals. The number of days fished is found to be a significant determinant of the average daily catch although the coefficient is generally low. In the case of Nile perch gillnet fishery, for example, this coefficient is 0.26. This indicates that other than the effect that the included explanatory variables have on the average daily catch, the number of days fished in a month has an independent effect. It may be that more productive fishing units, perhaps those headed by "good captains or high liners" fish for more days, on average.

Table 4.1.1: Regression results for C-D production function, Nile perch gillnet fishery.

Dependent variable: Natural log of the value of the average monthly fish catch.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coeff.</th>
<th>S.E.</th>
<th>t-ratio</th>
<th>Sig.</th>
<th>INDEX**</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln number of days fished</td>
<td>1.257</td>
<td>0.145</td>
<td>8.685</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>ln number of nets</td>
<td>0.315</td>
<td>0.074</td>
<td>4.260</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>ln size of crew</td>
<td>0.383</td>
<td>0.170</td>
<td>2.251</td>
<td>0.027</td>
<td></td>
</tr>
<tr>
<td>ln length of vessel, metres</td>
<td>0.577</td>
<td>0.284</td>
<td>2.027</td>
<td>0.046</td>
<td></td>
</tr>
<tr>
<td>ln net mesh size, inches</td>
<td>0.790</td>
<td>0.212</td>
<td>3.732</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Dummy: Busia district</td>
<td>1.712</td>
<td>0.284</td>
<td>6.019</td>
<td>0.000</td>
<td>2.04</td>
</tr>
<tr>
<td>Dummy: Homabay district</td>
<td>1.180</td>
<td>0.215</td>
<td>5.477</td>
<td>0.000</td>
<td>1.20</td>
</tr>
<tr>
<td>Dummy: Migori district</td>
<td>0.892</td>
<td>0.196</td>
<td>4.548</td>
<td>0.000</td>
<td>0.90</td>
</tr>
<tr>
<td>Dummy: Siaya district</td>
<td>1.219</td>
<td>0.232</td>
<td>5.260</td>
<td>0.000</td>
<td>1.24</td>
</tr>
<tr>
<td>Dummy: Kisumu district</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td>0.37</td>
</tr>
<tr>
<td>Constant</td>
<td>0.564*</td>
<td>0.681</td>
<td>0.828</td>
<td>0.410</td>
<td></td>
</tr>
</tbody>
</table>

* The constant with dummy influences netted out is 1.56.
** see the definition of this index in the key to Table 4.1.2
Adjusted R_2 = .81791  Standard Error .46916  n = 104. F = 52.40704  Signif F = .0000  
Durbin-Watson Test =  1.49510

In the Nile perch gillnet, mosquito seine with lights and the aggregate fisheries, there are increasing returns to the number of days fished as a 1% increase in them would result into an increase of the value of catch of about 1.3%. The hypothesis of a low marginal product for fishing time is, therefore, rejected. For the Cobb-Douglas production function, the marginal product of fishing input i, MP_i = b_i(h/E_i) where b_i is the elasticity. The magnitude

Table 4.1.2: Regression results for the aggregate fishery C-D production function.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coeff.</th>
<th>S.E.</th>
<th>t-ratio</th>
<th>Sig.</th>
<th>B+K*</th>
<th>INDEX**</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln no. of days fished</td>
<td>1.361</td>
<td>0.116</td>
<td>11.758</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln no. of months</td>
<td>0.255</td>
<td>0.090</td>
<td>2.859</td>
<td>0.005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln size of crew</td>
<td>0.716</td>
<td>0.085</td>
<td>8.375</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln fishing experience</td>
<td>-0.038</td>
<td>0.029</td>
<td>-1.327</td>
<td>0.185</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln length of vessel</td>
<td>0.570</td>
<td>0.178</td>
<td>3.196</td>
<td>0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln age of vessel, yrs</td>
<td>-0.042</td>
<td>0.032</td>
<td>-1.300</td>
<td>0.194</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nile perch gillnet</td>
<td>0.158</td>
<td>0.094</td>
<td>1.679</td>
<td>0.094</td>
<td>-0.043</td>
<td>0.96(0.73)</td>
</tr>
<tr>
<td>Tilapia gillnet</td>
<td>0.226</td>
<td>0.112</td>
<td>2.027</td>
<td>0.043</td>
<td>0.026</td>
<td>1.03(0.66)</td>
</tr>
<tr>
<td>Longline</td>
<td>0.229</td>
<td>0.123</td>
<td>1.860</td>
<td>0.064</td>
<td>0.028</td>
<td>1.03(0.88)</td>
</tr>
<tr>
<td>Mosquito seine</td>
<td>0.197</td>
<td>0.154</td>
<td>1.281</td>
<td>0.201</td>
<td>-0.004</td>
<td>1.00(1.21)</td>
</tr>
<tr>
<td>Beach seine</td>
<td>0.221</td>
<td>0.132</td>
<td>1.669</td>
<td>0.096</td>
<td>0.002</td>
<td>1.00(0.70)</td>
</tr>
<tr>
<td>Set net</td>
<td>0.198</td>
<td>0.155</td>
<td>1.279</td>
<td>0.202</td>
<td>-0.002</td>
<td>1.00(1.11)</td>
</tr>
<tr>
<td>Mosq. seine, lights</td>
<td>0.375</td>
<td>0.116</td>
<td>3.243</td>
<td>0.001</td>
<td>0.175</td>
<td>1.19(2.50)</td>
</tr>
<tr>
<td>Combined gears</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td>-0.201</td>
<td>0.82(0.82)</td>
</tr>
<tr>
<td>Busia district</td>
<td>0.703</td>
<td>0.129</td>
<td>5.432</td>
<td>0.000</td>
<td>0.189</td>
<td>1.21(0.89)</td>
</tr>
<tr>
<td>Homabay district</td>
<td>0.783</td>
<td>0.094</td>
<td>8.323</td>
<td>0.000</td>
<td>0.269</td>
<td>1.31(1.46)</td>
</tr>
<tr>
<td>Migori district</td>
<td>0.549</td>
<td>0.132</td>
<td>4.177</td>
<td>0.000</td>
<td>0.035</td>
<td>1.04(0.91)</td>
</tr>
<tr>
<td>Siaya district</td>
<td>0.537</td>
<td>0.107</td>
<td>5.044</td>
<td>0.000</td>
<td>0.023</td>
<td>1.02(1.09)</td>
</tr>
<tr>
<td>Kisumu district</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td>-0.514</td>
<td>0.60(0.78)</td>
</tr>
<tr>
<td>inshore fishing</td>
<td>-0.172</td>
<td>0.081</td>
<td>-2.132</td>
<td>0.034</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Coefficient 1</td>
<td>Coefficient 2</td>
<td>Coefficient 3</td>
<td>Coefficient 4</td>
<td>Coefficient 5</td>
<td>Coefficient 6</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>---------------</td>
<td>---------------</td>
<td>---------------</td>
<td>---------------</td>
<td>---------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Owner-headed units</td>
<td>-0.117</td>
<td>0.076</td>
<td>-1.540</td>
<td>0.125</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sail boats</td>
<td>-0.200</td>
<td>0.066</td>
<td>-3.010</td>
<td>0.003</td>
<td>-0.808</td>
<td>0.45(0.50)</td>
</tr>
<tr>
<td>Outboard engined boats</td>
<td>0.569</td>
<td>0.181</td>
<td>3.144</td>
<td>0.002</td>
<td>-0.039</td>
<td>0.96(1.14)</td>
</tr>
<tr>
<td>Trawling vessels</td>
<td>2.063</td>
<td>0.402</td>
<td>5.128</td>
<td>0.000</td>
<td>1.455</td>
<td>4.28(3.00)</td>
</tr>
<tr>
<td>Paddled boats</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td>-0.608</td>
<td>0.54(0.58)</td>
</tr>
<tr>
<td>Constant</td>
<td>2.864(^1)</td>
<td>0.486</td>
<td>5.897</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* This column shows the deviation of the particular dummy variable from the lakewide average for that category of dummies. The value of -0.043 for the Nile perch gillnet, for instance, indicates that the value of catch produced by a fishing unit using this gear is about 4.3% lower than that produced by the unit using the average gear.

** This index shows the value of production for the particular dummy variable as a ratio of the average case for that category of dummies. The value of 1.21 for Busia district, for example, is the ratio of the value of fish produced by a fishing vessel operating in this district to the production by the average lakewide vessel. The figures in brackets are indices calculated from estimation results of the model with log of amount of fish as the dependent variable.

1 The overall constant with the influences of the various dummies netted out is 4.187.

Adjusted R\(_2\) = .64659; Standard Error .51318; F = 29.44107 Signif F = .0000
Total Cases = 382; Durbin-Watson Test = 1.99057

of the elasticity is, therefore, a good indicator of the marginal product. In terms of the relative magnitude of the estimated coefficients, fishing time is the most important determinant of firm catch levels and is, therefore, a "key" dimension of effort in these fisheries.

**Size of crew.**

The size of crew, a measure of labour input in the fishery production function, is a statistically significant determinant of the value of catch in all fisheries with the exception of the mosquito seine and beach seine fisheries. In the latter fishery, however, the variable is a significant determinant of the amount or weight of catch realised. Production elasticity with respect to labour is highest (at 0.84) in the Tilapia gillnet fishery and ranges from this value to 0.38 in the Nile perch gillnet fishery. In the aggregate fishery model, the coefficient is 0.72. In two fisheries, set net and mosquito seine with lights, elasticity with respect to labour is negative and statistically significant (-0.58\(^2\) and -0.67, respectively). In these two fisheries, therefore, there is excessive and inefficient use of labour. As hypothesized, marginal products

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\(^{27}\) In fact, this coefficient is -1.42 in the model with weight of catch rather than value as the dependent variable.
to labour are low and, in fact, negative in two fisheries. Moreover, the translog production functions indicate diminishing returns to labour.

**Vessel size.**
The importance of vessel length, used as a measure of its size, varies considerably among different fisheries. It is not statistically significant at the 10% level in the Tilapia gillnet, longline and set net fisheries. There is no evidence to support the view projected by Hoekstra et al. [1991] that vessel size determines the number of hooks that a vessel can operate with. An interaction term between the number of hooks and vessel length is not statistically significant. Vessel size is, on the other hand, very important in the mosquito seine fishery being significant at 1% level with a coefficient of 4.09, implying that a 1% increase in vessel length increases its monthly value of catch by 4.1%\(^2\). It is rather surprising that vessel size is so important in a fishery that is largely inshore. Vessel length is significant at 1% level in the aggregate fishery model but with a lower coefficient of 0.57. For the Nile perch gillnet and beach seine fisheries, vessel size is significant at the 5% level with the respective coefficients being 0.58 and 0.69. In the mosquito seine with lights fishery, vessel size is significant at the 5% level with a coefficient of -0.90, suggesting that unnecessarily large vessels are being used in the exploitation of this fishery.

**Age of the vessel.**
Age of vessel is used to capture technological progress. It is statistically significant (at the 10% level of significance) only in the case of the beach seine fishery with a coefficient of -0.105. Thus, an increase in the age of the vessel by 1% leads to a 0.11% fall in the value of catch. It is rather surprising that the age of the vessel appears important in the fishery where it is least expected to be. In this method of fishing, the role of the vessel, besides ferrying the fishermen to the desired fishing ground, is minimal largely because fishing is carried out near the shores. Its importance may be related to the latitude it provides the fishermen in the choice of stock areas. Vessel age is not a significant determinant of the value of catch in the aggregate fishery production function.

\(28\) This coefficient is lower, at 1.74, in the model with the amount of catch as the dependent variable.
**Vessel mode of propulsion.**

Dummy variables used to capture vessel propulsion differences are not statistically significant in any of the fisheries with the exception of the aggregate fishery production function. In the aggregate model, vessel propulsion dummies are highly significant as Table 4.1.2 shows. In the table, the indices calculated for the propulsion dummy variables indicate relative technical efficiency of these different types of vessels. Trawlers realise much larger fish catches relative to the average lakewide fishing vessel. Indeed, inclusion of these trawl boats in the sample raises the lakewide average catch level to an extent that all the other types of boats produce less than the lakewide average. Strangely, oar propelled fishing units are more productive compared to sailed ones and, statistically, highly significantly so. This is unexpected as sails are thought to increase the range of vessel operation and to allow it greater freedom in the choice of stock areas. This result may be explained by the fact that most vessels use the two means of propulsion in combination and also because most of the sails are made of poor sack material. Moreover, paddled vessels are more likely to use the more productive beach seining technology. The only indices that change when trawl boats are excluded from the analysis are those in respect of means of propulsion.

**Number of nets (hooks).**

The number of nets variable is not statistically significant at the 10% level for beach seine, set net and mosquito seine with lights fisheries. The variable is, on the other hand, highly significant (at the 1% level) for the Nile perch gillnet, Tilapia gillnet and mosquito seine fisheries with the elasticities being, respectively, 0.32, -0.16 and 0.72. It is suggested, therefore, that nets are probably in excessive use in the Tilapia gillnet fishery. These results cannot reject the hypothesis of low marginal product to nets. Diminishing marginal returns to the number of nets is suggested only for the beach seine fishery, although even this is statistically significant only at the 12% level.

The equivalent of nets in the longline fishery is the number of hooks. This is statistically significant, as expected, at the 1% level and indicates that a 1% increase in the number of hooks leads to a 0.54% increase in the value of catch, *ceteris paribus*. The null hypothesis of

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29 Gear capacity, calculated as the product of the number of nets, the length and width of each net, is, however, statistically significant.
a low marginal product to this input cannot, therefore, be rejected.

**Net mesh size.**

Mesh size of nets is an important determinant of the amount and value of fish produced in virtually all fisheries. Except for the Tilapia gillnet fishery, mesh size is highly significant in all the other fisheries. The
highest elasticity obtained for this input is for the mosquito seine fishery where a 1% increase in mesh size leads to a 320% fall in the value of catch. This fall arises largely but not entirely from the reduction in the amount of fish harvested. Thus, the same 1% increase in mesh size leads to a 120% decline in the amount (weight) of fish produced. For the Nile perch gillnet fishery, net mesh size is not important in explaining the total amount of fish produced but is a statistically significant determinant of the amount of fish of marketable size, and therefore value, produced. The elasticity with respect to mesh size in the model with the value of catch as the dependent variable is 0.79.

In the case of the beach seine fishery, mesh size positively and, statistically, significantly influences the value of catch (0.309) but negatively and significantly influences the amount of catch (-0.317). Thus, the impact of mesh size on value of catch in this fishery is largely through the harvesting of immature fish.

In the set net and mosquito seine with lights fisheries, mesh size negatively and significantly determines the value and weight of fish catches. The coefficients are, respectively, -0.378 and -0.834. In these two fisheries, the effect of larger mesh sizes is largely through reduced catches but also through quality effects.

**Seasonal stock variability.**

In the model fitted on data pooled over the 3 months or 92 days (model 7), seasonality is captured by the number of months that each fishing unit participated in the fishery, that is, the number of months used in obtaining monthly averages. The number of months positively and significantly influences the value of catch in the aggregate fishery, beach seine, set net and mosquito seine with lights fisheries. The coefficients on this variable are, respectively, 0.255, 0.917, 0.514 and 0.213. In the aggregate and mosquito seine with lights models the number of months do not significantly, at the 10% level, explain the amount of fish produced, suggesting that the value of catch rose over the three months not because of rising production levels but because of price increases. In the other two fisheries, the number of months influenced the amount of catches positively but with lower coefficients; 0.584 for the beach seine and 0.479 for the set net. This suggests that, for these fisheries, the rise in the value of catches with the increasing number of months was
largely but not entirely attributable to rising production. Price increases may have played a part, too.

For the longline fishery, the number of months variable had a negative and significant elasticity, -0.349, in the model with the value of catch as the dependent variable. In the model with amount of catch (weight) as the dependent variable, the coefficient on the number of months was also negative but not statistically significant at the 10% level of significance. Though the evidence is not unambiguous, results for the longline fishery suggest that the productivity of this technology declined in August and November compared to May.

It would probably be more appropriate to capture seasonality through dummy variables since the variable 'number of months' does not vary adequately. We have done precisely this by estimating (9) using data pooled over the days in each of the three months. The results indicate that the seasonality effect is strong and differs from species to species. In the aggregate model, that is, where all fisheries are considered together, fishing units realise lower catches in November compared to May, ceteris paribus. There is no significant difference between May and August, however. In terms of the value of catch, both August and November are significantly better than May. The results for the aggregate model hold for Nile perch analysed separately. In the case of Tilapia species, there is no significant difference between May and August and between May and November in the amount of fish harvested per fishing unit, all else remaining the same. Both August and November are, however, significantly better than May in terms of the value of fish produced per fishing unit. In the case of the other important fish species, Rastrineobola argentea, productivity (in quantity harvested) in August is not significantly different from that in May at the 10% level. Productivity in November is, however, significantly lower than that obtaining in May. In terms of value of fish, both August and November are significantly better. The results discussed here reflect the effect of price increase over the year, particularly in November.

**Spatial stock variability.**

This variable is captured by location or district dummy variables. Following Suits (1984), spatial indices that express the average monthly value of fish produced per fishing unit in each district as a ratio of the lakewide average are calculated to ease comparison. Thus, the value of
the average fish produced by each fishing unit engaged in the Nile perch gillnet fishery in Homabay district, for example, is 1.2 times higher than the lakewide average (Table 4.1.1). There are substantial differences in not only the value but also the amount of fish catches from district to district, indicating significant spatial stock differences. With the exception of beach seining where there are no significant differences in the value of monthly catch obtained by a fishing unit operating in Kisumu and those operating in other districts, there are varying degrees of variation among districts in both the value and amount of catches. It could be concluded, therefore, that there is substantial spatial variation in stocks of all fish species. In the aggregate fishery production model, Homabay district has the highest relative technical efficiency in terms of both the amount and value of catches. Kisumu district has the lowest relative efficiency. Busia has a better ranking in terms of the value compared to the amount. This implies that in Busia district, high fish values are attributable to high prices and not necessarily to large catches. This is not surprising since Busia district beaches are frequented by many fish processing firms on account of large fish landings from the Ugandan side of the lake. Competition between many of these firms bid up fish prices.

Management capability.
Several variables, principally age of fisherman, number of years as a fisherman, number of years as the head of a fishing unit and the level of education were tried out as measures of the fishing unit's management ability. Most of these were not significant in the estimations for different fisheries. Fishing experience as measured by the number of years the fishing unit's head had worked in a similar capacity was statistically significant in the set net fishery where a 1% increase in fishing experience led to a 0.106% (0.102%) increase in the value (weight) of the unit's monthly catches, ceteris paribus. The only other fishery in which fishing experience proved statistically significant at the 10% level is mosquito seine with lights. In this fishery, however, the coefficient was negative, -0.188 in the value model and -0.126 in the amount model, suggesting that the more the fishing experience, the lower the productivity, ceteris paribus. In the aggregate fishery production function, fishing experience has a negative elasticity but this is not statistically significant at the 10% level of significance.

Inshore versus offshore fishing.
The dummy variable differentiating those fishing units that fish near the shore from those that fish both near the shore and in the deep parts of the lake is statistically significant. This
dummy variable takes the value of 1 if the unit fishes near the shore and zero otherwise. In conformity to our expectations the units that fish near the shore only have lower value of catch compared to those that fish near the shore and also in the deeper parts of the lake (indeed, according to our results the value of catch for these units is 15.8\% less in relative terms) because they tend to catch small sized fish that have a lower price.

**Type of gear dummy variables.**

The indices presented in Table 4.1.2 indicate the relative technical efficiency of different fishing gears. For instance, the index of 0.96 for Nile perch gillnet indicates that fishing units using this gear produce fish whose value as the ratio to the value of fish produced by the average gear (averaged over all the districts and types of boats) is 0.96. The same ratio but in terms of the amount of fish produced rather than its value is 0.73. In terms of technical efficiency, mosquito seine with lights is more productive compared to the other gears, with the exception of trawling. This is followed by longline and Tilapia gillnet technologies.

**Owner-headed versus employee-headed fishing units.**

Owner headed fishing units, *ceteris paribus*, produce 14.4\% less fish (in weight) relative to those headed by employed captains. In terms of value of fish, however, there is no significant difference between these two types of fishing units. This may suggest that employee headed fishing units harvest, on average, more fish per month by producing more juvenile fish which have a lower price.

**5.0. SUSTAINABILITY IMPLICATIONS OF FISHING TECHNOLOGY.**

**5.1. Gear differences in selectivity and juvenile fish production.**

Table 5.1.1 shows relative selectivity and immature fish production, used as indicators of sustainability implications, of different fishing gears. The last two columns of the table show, respectively, selectivity (the amount of the main species in the catch as a percentage of the total catch) and production of immature fish (the percentage of juvenile Nile perch and Tilapia in the total catches of these two species).

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30 This is obtained, following Berndt [1991], as the antilog of the coefficient for the dummy variable less one.
None of the technologies used in the exploitation of Kenya's Lake Victoria fisheries is completely selective. This is to be expected in multispecies fisheries. Evidence of joint production of Nile perch and Tilapia, in particular, is adduced by the finding that the amount of Nile perch harvested by a fishing unit is a positive and significant determinant of the amount of Tilapia it produces.

With the exception of Tilapia gillnet, mosquito seine, set net and the gears used in combination, however, the other technologies are quite selective with the main species of fish accounting for more than 80% of their total catches. Contrary to expectations, beach seines and trawl nets appear to be highly selective, suggesting that perhaps the most important determinant of the selectivity of a technology is the specific stock area it is used to exploit. Trawling is mainly carried out in the deep parts of the lake where Nile perch is mainly found. Moreover, even though beach seining is carried out near the shore where fish are known to breed, there are some districts or resource areas where only Nile perch is available. A good example is Musoma beach in Busia. This may explain why beach seines appear to be highly selective. The technology that involves the use of gears in combination, mainly alternately but also simultaneously, is the most non-selective as would be expected and also produces substantial amounts of juvenile fish. This technology is relatively more flexible compared to the others and as Wilen [1979] predicts fishing units endowed with such flexibility are more liable to circumvent input- or output-based regulations.

On both selectivity and juvenile harvesting criteria, Nile perch gillnet, longline, traps and mosquito seine with lights are the most appropriate technologies in these fisheries and ought to be encouraged. Gillnets are found to be highly selective in lakes Victoria and Kyoga, with each mesh size harvesting a specified fish size range [Ogutu-Ohwayo et al. 1991]. Thus, an increase in mesh size by one millimetre is found to increase the average length of fish caught by 0.35 cm for Nile perch and by 0.21 for Tilapia.

Mosquito seine with lights appears to have a high production of juvenile fish but this is highly non-selective.

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31 These two technologies are, however, very inappropriate in terms of the amount of juvenile fish they harvest. If the definition of selectivity is broadened to treat different sizes of the same species as different outputs, these two technologies will be highly non-selective.
because it is highly selective and the small amounts of Nile perch and Tilapia that it produces are at juvenile stages. This technology produces very little immature fish. 69.6% of all the

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32 Total immature fish as a percentage of the total fish production, rather than total Nile perch and Tilapia produced, for this gear is only 0.01%.
fishing firms using this technology produced, on average, no juvenile fish. Moreover, only 16.1% of the firms produced an average of 10-236 kgs per month. Use of 5mm mesh mosquito seines yields *R. argentea* catches, 70% of which are immature with standard length of 19mm-58mm compared to 10mm mesh mosquito nets that catch mature fish, 42mm-62mm long [Ogutu-Ohwayo et al. 1991]. When used in off-shore waters, mosquito seine nets are found to be quite selective, capturing mainly the target species *R. argentea* with negligible quantities of Nile perch and Tilapia by-catches.

Trawling, mosquito seine, beach seine and set nets, either separately or combined with other gears are particularly inappropriate in terms of their threat to resource sustainability. Trawl nets and beach seines are detrimental as they destroy the egg and larval stages by scraping the lake bottom and disrupting courtship [Getabu 1991; Dache 1991; Ogutu-Ohwayo et al. 1991]. Seines are used in the shallow waters, with the consequence that the net width covers the whole water column, effectively catching all fish sizes [Dache 1991]. Most juveniles are, however, landed by fishermen using smaller meshed nets to target *R. argentea* and *Haplochromis* particularly in the inshore fishery.

5.2. Determinants of vessel catches of juvenile fish.

On account of the significance of juvenile fish harvesting on the sustainability of a fishery resource, the factors that determine the level of production are investigated in this section. Like before, models for individual fisheries and an aggregate fishery model are estimated. The models explain 25-96% of the variation in the amounts of juvenile fish harvested every month by fishing units. The estimation results for model (10) are reported in equation (11). In the equation the figures in parentheses are t-values.

\[
\ln \text{AIF} = 1.16\text{[dummies]} + 0.604 \ln \text{QNP} + 0.109 \ln \text{QT} - 0.238 \ln \text{Mesh}.
\]

\[\begin{align*}
(10.69) & & (2.88) & & (-2.23) & & \text{Adj. R}_2 = 0.35
\end{align*}\]

A remarkable result is that while the level of education does not explain the level or value of total fish catches, it does negatively influence the amount of immature fish produced. More educated fishermen are, *ceteris paribus*, producing less immature fish. The evidence is, however, ambiguous as this variable is not significant in (11). The hypothesis that owner-headed fishing units harvest less immature fish relative to those
headed by employed captains cannot be rejected. Estimation results of (10) suggest that a fishing unit whose owner doubles up as its head produces about 26% less of immature fish per month compared to one headed by a hired skipper. This is of particular policy relevance. The hypothesis that vessel renters, under pressure to catch enough to ensure payment of boat rental, are more likely to harvest any sort of fish, including immature fish was also tested. This hypothesis is rejected. Vessel renters do not produce amounts of immature fish that are (statistically) significantly different from owner headed fishing units.

The total catches of Nile perch and Tilapia that a fishing unit realises is an important determinant of its juvenile fish harvests as (11) demonstrates. This explains why variables such as the number of days fished, the number of fishing trips, size of crew, vessel size and other characteristics significantly explain juvenile fish harvests. These and other important determinants of the amount of immature fish produced are briefly discussed, in turns.

i) the number of days fished. This variable is not only highly significant in the aggregate model but also in all individual fishery models with the exception of the beach seine and mosquito seine with lights fisheries. Thus, a one day increase in the number of days fished per month results in an increase of juvenile fish production ranging from 5.03 kgs in the aggregate model to a high of 40.27 kgs in the set net fishery.

ii) seasonality. We don't find evidence of significant seasonal effects in any of the models. Both August and November are not significantly different from May in terms of per firm juvenile fish production.

iii) spatial stock variation. Although locational stock differences do not significantly explain the amount of immature fish produced in the aggregate model, they are important in explaining juvenile harvests in individual fisheries. In (10), only Migori is significantly different from Kisumu in per firm juvenile harvests. It would appear, then, that Migori is the best district in terms of harvesting lower amounts of immature fish.

iv) size of crew (labour). This variable is highly significant (at the 1% level) in the Nile perch gillnet, mosquito seine and aggregate fishery models with the coefficients being, respectively, 57.49, -184.87 and 40.87. Thus, while in the Nile perch gillnet and aggregate fisheries an increase in crew size results in increased production of immature fish, the opposite is true for the mosquito seine fishery. Size of crew is not significant at the 10% level of significance for
Table 5.1.1: Comparison of various technologies in terms of selectivity and harvesting of juvenile fish.

<table>
<thead>
<tr>
<th>Type of gear</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Selectivity</th>
<th>Juvenile harvesting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nile perch gillnet</td>
<td>3</td>
<td>1</td>
<td>Nile perch</td>
<td>789.21</td>
<td>890.26</td>
<td>51.74</td>
<td>88.7</td>
<td>6.4</td>
</tr>
<tr>
<td>Tilapia gillnet</td>
<td>3</td>
<td>2</td>
<td>Tilapia</td>
<td>245.86</td>
<td>356.20</td>
<td>64.06</td>
<td>69.0</td>
<td>18.5</td>
</tr>
<tr>
<td>Longline</td>
<td>3</td>
<td>1</td>
<td>Nile perch</td>
<td>489.60</td>
<td>559.70</td>
<td>42.91</td>
<td>87.5</td>
<td>8.2</td>
</tr>
<tr>
<td>Mosquito seine</td>
<td>4</td>
<td>4</td>
<td>R. argentea</td>
<td>959.75</td>
<td>1514.26</td>
<td>147.77</td>
<td>63.4</td>
<td>39.4</td>
</tr>
<tr>
<td>Beach seine</td>
<td>3</td>
<td>1</td>
<td>Nile perch</td>
<td>1093.52</td>
<td>1135.62</td>
<td>289.97</td>
<td>96.3</td>
<td>25.3</td>
</tr>
<tr>
<td>Set net</td>
<td>3</td>
<td>2</td>
<td>Tilapia</td>
<td>459.64</td>
<td>618.35</td>
<td>230.89</td>
<td>74.3</td>
<td>38.9</td>
</tr>
<tr>
<td>Traps</td>
<td>1</td>
<td>1</td>
<td>Tilapia</td>
<td>554.33</td>
<td>577.34</td>
<td>85.50</td>
<td>96.0</td>
<td>15.4</td>
</tr>
<tr>
<td>Mosquito seine with lights</td>
<td>4</td>
<td>1</td>
<td>R. argentea</td>
<td>2612.56</td>
<td>2638.93</td>
<td>16.25</td>
<td>99.0</td>
<td>64.3</td>
</tr>
<tr>
<td>Trawling</td>
<td>3</td>
<td>1</td>
<td>Nile perch</td>
<td>8012.78</td>
<td>8431.33</td>
<td>2302.56</td>
<td>95.0</td>
<td>28.7</td>
</tr>
<tr>
<td>Gears used in combination</td>
<td>4</td>
<td>3</td>
<td>Nile perch</td>
<td>348.36</td>
<td>700.35</td>
<td>118.91</td>
<td>49.7</td>
<td>26.5</td>
</tr>
</tbody>
</table>

Column definitions:
1. The number of species caught by the particular technology.
2. The number of the species whose mean kgs/month/fishing unit is higher than 50.
3. The main species of fish caught by the gear, in terms of weight.
4. The mean weight, kgs/vessel/month, of the main species caught by the gear.
5. The mean weight, kgs/vessel/month, of all the species caught by the gear.
6. The mean weight, kgs/vessel/month, of immature Nile perch and Tilapia harvested by the gear.
Selectivity (or 'accuracy of targeting') is the proportion of the main species caught in the total catches, i.e. (4/5)%.
Juvenile harvesting is the proportion of juvenile N. perch and Tilapia in total N. perch and Tilapia produced.
Source: Own field data, 1995.
all the other fisheries.

v) number of nets (hooks). This variable is significant, at the 10% level, in the set net fishery only where an increase in the number of nets by one leads to a fall by 21.92 kgs the amount of juvenile fish produced in a month. This suggests that poverty is one factor that contributes to harvesting of immature fish since it is the poor fishermen who have few nets.

vi) Net mesh size. Mesh size is not a significant, at the 10% level, determinant of the amount of juvenile fish harvested by Tilapia gillnet, set net and mosquito seine with lights technologies. It is, however, highly significant in the Nile perch gillnet, mosquito seine and beach seine fisheries. A one inch increase in mesh size, ceteris paribus, leads to a reduction in the monthly immature fish harvest of 47 kgs in the Nile perch gillnet fishery, 1570.95 kgs in the mosquito seine fishery and 192.85 kgs in the beach seine fishery. This is, therefore, one of the most important determinants of juvenile fish harvests. This conclusion is supported by (11). A 1% increase in mesh size would lead to, ceteris paribus, a 24% decrease in the amount of immature fish produced.

vii) vessel characteristics. Vessel characteristics such as size, mode of propulsion and age are not important determinants of immature fish production in all the fisheries. In the set net fishery, however, vessel length has a negative coefficient significant at the 12% level while vessel age has a negative coefficient significant at the 5% level. A one year increase in vessel age in this fishery, all else remaining constant, leads to a reduction in the monthly immature fish production of 19.07 kgs.

viii) fishing experience. Fishing experience significantly, at the 10% level, explains the fishing unit's monthly production of immature fish only in the set net and mosquito seine with lights fisheries. In both technologies, the coefficient on this variable is positive, indicating that the higher the fishing experience, the larger the monthly juvenile fish production, all else remaining the same. The coefficients are, however, not large; 11.89 in the set net fishery and 3.62 in the mosquito seine with lights fishery.

ix) inshore fishing. Fishing units exploiting the inshore fishery harvest more immature fish, on average, compared to those that exploit the off-shore fishery. Evidence of this is, however, not found in all the fisheries.

5.3. Why do fishermen choose inappropriate technology?

The widespread use of small meshed nets and other inappropriate fishing technology is
apparent from the preceding sections of this paper. A pertinent issue, then, is the motivations driving the choice of such so obviously internecine means of production. To succeed, management of the fisheries must take cognizance of the economic motivations behind fishermen's choice of gears and create incentives to alter these motivations. Regulatory systems that produce desirable behaviour such as efficient fishing practices are very effective as they attempt to remove the cause of inefficiency rather than attack the symptoms [Wilén 1979].

Fishermen choose small meshed nets rationally. Our discussions with fishermen indicated that not only are such nets relatively cheaper but are also less likely to be stolen and have comparable profitability since the small fish they catch has a market value that is not substantially lower than the value of larger fish. While one Nile perch gillnet unit of mesh size 7.5-8.5 inches may cost as much as Kshs 3,200, a similar unit of smaller mesh size costs only half or less this amount. That cost is a significant determinant of gear choice is supported by our earlier finding of a negative correlation between the extent of crew ownership of fishing technology and the cost of technology, crew members being poorer relative to vessel owners. Moreover, our regression results suggest that poverty is an important determinant of the amount of immature fish harvested. The role of capital constraints in the choice of fishing technology has, previously, been noted by Dache [1991] and Mokua [1992]. Capital remains a permanent constraint to fishermen since, faced with urgent education, housing and other needs, fishermen hardly reinvest any of their income in fishing equipment. The preference of beach seine technology over the gillnets and longlines has been attributed to relative profitability by Dache [1991] and Rabuor and Manyala [1991]. While there is serious theft of large mesh nets, no thief goes for nets of small mesh size.

If it can be assumed that there is a minimum marketable size of fish and that the objective of the fishermen is then to maximize the marketable value of his catch given a level of costs, then the fishermen may also be expected to maximize the weight of their catch above the minimum marketable size by choosing the appropriate mesh [Turvey 1964]. In Lake Victoria, it can be reasonably argued that the minimum marketable size of fish is hardly a binding constraint. Even the smallest fish have value as they can be consumed at home, releasing all the fish of marketable size for the market. Moreover, owing to high demand there is a price for virtually
all sizes of fish. For example, there are at least four prices for Nile perch on the basis of size. The price of immature Nile perch (the lowest of the four prices) is, at worst, only about 30% lower than the highest. The fact that the price of "table" fish (that is, fish served whole or in pieces rather than as an ingredient to sauces and other food preparations) does not decrease with its size and that "table" fish lacks readily available substitutes in the lake region, in addition, have implied high prices for fish whose size is appropriate for individual servings and thus created incentives for use of gillnets of small mesh sizes [Gréboval 1989].

Fishermen's attitude towards resource conservation may also be important in explaining their choice of fishing technology. Fishermen often question the results of stock assessment surveys and maintain that there is more fish in the sea than biologists can count [van Marlen 1991]. In Lake Victoria (Kenya), fishermen often express their opinion that the fish in the lake can never be finished and wonder why the Government is restricting the exploitation of a resource freely given by God. That this opinion is driven by competitive self-interest rather than veritable belief is, however, apparent from responses to a question put to the fishermen about the changes they had observed, over time, regarding the fisheries. Responses by 61.6% of the fishermen reflected their awareness of stock reductions. They had observed such changes as reduced fish catches, reduced average size of fish caught, significant fluctuations in catches and reduced species diversity. Prodded further on the specific issue of the trend of catch per fishing unit, 90.8% of the fishermen indicated that this had declined. Moreover, enlarged effort in terms of increased fishermen, vessels and gears was cited as an observed change by 33% of the fishermen. The fishermen's oft-stated opinion that there is enough fish in the lake is, therefore, a strategic response aimed at buttressing their appeals for assistance to expand their effort. As van Marlen notes, therefore, the structure of the fishing industry where many competitive entrepreneurs are harvesting an open access resource is not ideal for conservation as each fisherman acts individually, driven by self interest (the "tragedy of the commons"). This militates against the choice of appropriate gear by even those fishing firms that are aware of the deleterious effects associated with bad technology. If an individual fisherman were to use a larger mesh, for instance, he would suffer extra production costs as more hauls would be required to maintain a given weight of the catch but would lower the long run cost of production for all fishermen [Turvey 1964]. However, since the fisherman can not be assured that other fishermen will reciprocate, he has no incentive to choose large meshes.
In summarising this section, we argue that fishermen operating on the Kenyan side of Lake Victoria choose the gear and mesh size with the objective of maximizing the marketable value of their catch but subject to cost (and therefore capital and wealth) constraints and theft risk considerations. The general poverty associated with fishermen, the widespread theft of the legal and expensive large meshed nets, the open access nature of the fisheries and the high demand for fish that ensures a market even for small sized fish make the choice of small meshed gillnets, set nets and mosquito seine nets rational. High relative profitability coupled with lethargic enforcement of regulations and technological constraints that hinder the exploitation of off-shore fisheries have led to the preference of beach seining over gillnetting and longlining.

6.0. Conclusions and policy recommendations.
This study targeted the analysis of production functions for Kenya's Lake Victoria fisheries and an investigation into the relative implications of different fishing technologies on their sustainability. The main objective of carrying out the production function analysis was to identify the "key" dimensions of effort for each fishery and for the aggregate fishery to serve as effective control variables for the regulatory agency. The analysis, in addition, intended to find if any inputs were in excessive and therefore inefficient use. To assess relative sustainability implications of different fishing technologies, the main gears were compared on the basis of their selectivity and their harvests of juvenile fish and the determinants of the latter investigated for each fishery and the aggregate fishery.

The Cobb-Douglas form of the production function was used to facilitate comparison across different fisheries. The Translog form could not be used for this owing to degrees of freedom and multicollinearity problems. Regression results indicate significant variation of the production process from one fishery to the other, pointing to the inappropriateness of managing all the fisheries as a single fishery. Fishing time and net mesh size have emerged as the most important or key dimensions of effort in literally all the fisheries. They are, moreover, important determinants of the amount of juvenile fish produced by fishing units. The mesh size is currently regulated but fishing time is not. Contrary to prior and common
expectations, the aggregate fishery and all the individual fisheries, except the set net fishery, are characterised by increasing returns to scale. There are decreasing returns to scale in the set net fishery. The Translog form for the aggregate fishery indicates diminishing marginal returns to fishing time and labour but not to the vessel size. While no evidence for the substitutability or complementarity between any two pairs of inputs is found for the aggregate model, there is some evidence of this in some of the individual fisheries. Elasticity of catch with respect to labour is found to be low in all the fisheries and negative in the set net and mosquito seine with lights fisheries. These results suggest that labour use is inefficient in the two fisheries. Vessel size, the measure of capital, is not important in three of the fisheries and its elasticity varies quite substantially in the other fisheries. As expected trawl and outboard-engined vessels are technically more efficient relative to sailed and paddled vessels. In the case of gear technology, trawling is the most technically efficient followed by mosquito seine with lights and then longline. The regression results indicate significant spatial and seasonal stock differences. Moreover, inshore fishing leads to lower catch values due to harvesting of predominantly juvenile fish. Fishing experience is, in general, not important, being statistically significant only in the set net and mosquito seine with lights fisheries.

Trawling, mosquito seining, beach seining and set nets pose the greatest risk to the sustainability of Kenya's Lake Victoria fisheries on the basis of selectivity and juvenile harvesting criteria. Nile perch gillnet, longline, traps and mosquito seine with lights are the most appropriate fishing technologies and should be promoted. Tilapia gillnet technology is quite non-selective, particularly the nets with small mesh sizes. Regression results indicate that the type of gear and net mesh size are very important determinants of juvenile fish harvest levels. Other important determinants are the level of education, owner-head effects, inshore fishing, fishing time and size of crew. Vessel characteristics such as size, means of propulsion and age and fishing experience are generally not important. In this model, too, there are substantial differences from one fishery to the other and from the individual fisheries to the aggregate fishery.

Fishermen choose inappropriate technologies, including small mesh sizes for several reasons. First, there is demand for even small sized fish. Second, the appropriate technologies are more expensive and only relatively well-to-do fishermen can afford them. Our results indicate that
crew gear ownership is more significant in the case of cheap but destructive technologies compared to the more appropriate technologies, with the exception of the longline technology. Poverty and capital constraints coupled with price of technology leave most fishermen with no alternative but the continued use of bad technology. In addition, due to regulations and the production of big-sized fish, the appropriate technologies are associated with higher theft risk. Finally, there is no incentive for any fisherman to use the appropriate technology because the fisheries are essentially open access.


Results of this study lead to the following recommendations:

1. Owing to the substantial variation of the production process from one fishery to the other, it is inappropriate to manage the lake as if it were one fishery. Mosquito seine with lights fishery, for example, is quite distinct from the other fisheries and should be managed separately.

2. Regulation of only qualitative aspects of effort cannot be effective as the experience with mesh size, closed areas and seasons, trawling, registration of vessels and fish trade has shown. There is need, therefore, to regulate the quantitative dimensions of effort, too. Fishing time is one of the key dimensions of effort and its regulation should receive first priority for two reasons; first, because the elasticity of catch with respect to it is high, and second, because it effectively leads to control on total effort. This should be complemented with entry restrictions to avoid increased number of fishing units during the times fishing is allowed. Experience from other countries has demonstrated the superiority of total effort control over individual input restriction in fisheries management.

3. Qualitative aspects of effort, however, also need to be regulated. Trawling, mosquito seine, beach seine and set nets have been found to pose the greatest threat to the sustainability of the fisheries and should be banned, not just through administrative decrees but through legislation. The ban on these technologies has been recommended by others. Dache [1991], for instance, finds Tilapia to be highly vulnerable to trawl nets and supports their ban. Dache further recommends the use of mosquito seine nets to harvest *R. argentea* only in open waters that are at least 10 m deep to avoid by-catch of juvenile Tilapia. The use, manufacture and trade of these bad technologies should be regulated. Regulation will be more effective, however, if it changes the incentive structure to favour the use of the desired technology and
severely punish the use of inappropriate gear. Incentives such as selective taxation, transfer
grants or special credit schemes and preferential accessibility to closed areas for those using
appropriate technology are recommended to encourage a shift towards greater use of the
desired technology.

4. For the appropriate technologies such as the gillnets and longlines, size of net meshes and
hooks should be controlled to maximize their selectivity and reduce their harvests of juvenile
fish. Minimum mesh sizes for gillnets have been suggested as follows: 4 inches for Tilapia and
6 inches for Nile perch by Gréboval [1989], 5 inches for Tilapia by Getabu [1991], and 5
inches for both Tilapia and Nile perch by Ogutu-Ohwayo et al. [1991]. The latter provide
two reasons in support of their choice of the minimum mesh size. First, 5 inches will ensure
that 100% of Tilapia attain breeding size and age by the time of capture to correct the effects
of past overexploitation. Second, this size of mesh will crop Nile perch of at least 50 cm total
length (the species' size at first maturity\textsuperscript{33}) before attaining a size that is inappropriate in
terms of predation pressure. Young Nile perch feeds on invertebrates but shifts to \textit{R. argentea},
its own juvenile fish and Tilapia when it is longer than 50 cm [Ogutu-Ohwayo et al. 1991]. On attaining a total length of 95 cm Nile perch feeds exclusively on Tilapia.

5. Since the existence of a market for small-sized fish was identified as one of the motivations
for the prevalent use of inappropriate technology, proper control on the size of fish traded in
by making both the seller and buyer liable would probably help.

6. Only gillnets, traps, hooks and longlines are recommended for the inshore fishery [Dache
1991]. Our regression results support this recommendation as inshore fishing is found to
result in lower value of catches by harvesting predominantly immature fish. The gillnets
should, however, have a mesh size of at least 5 inches.

7. This study finds evidence of excessive and inefficient use of labour in some of the fisheries.
Moreover, in the remaining fisheries including the aggregate one, labour has low and
diminishing marginal returns. It would therefore be best not only for the fishery sector but the
economy as a whole if an integrated development approach could be initiated for the lake
region to attract some of the redundant labour from the fisheries. Resistance to exit would not
be substantial since the majority of the fishermen are in the enterprise as a last resort.

8. Regression results indicate that an education and general awareness campaign targeted at

\textsuperscript{33} \textit{Size at first maturity is defined as the average size of an individual fish when 50\% of its species are mature, ready for breeding.}
fishermen would pay dividends in terms of reduced juvenile harvests and, hence, improved welfare of the fishery resources. This is, consequently, highly recommended. Education to create awareness and creation of clear incentives change attitudes and behaviour [van Marlen 1991]. This should be complemented with the gradual transfer of ownership of the fisheries to the fishing community. This would reduce open accessibility and provide incentives for the adoption of appropriate technology and other conservation relevant measures. Involvement of fishermen in the management of the fisheries is particularly important on account of the study findings that financial and logistical bottlenecks and corruption seriously hamper public regulation. Shared ownership and responsibility may change competitive behaviour [van Marlen 1991].

9. Since our regression results indicate that owner-headed fishing units harvest, on average, fewer amounts of juvenile fish, it is recommended that absentee ownership of vessels be discouraged via taxation and licensing measures. This may, in fact, serve a dual purpose of forcing those vessel owners whose opportunity cost of heading their fishing units themselves is high to exit.

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