MODELLING THE FISHERIES OF LAKE MANZALA, EGYPT, USING PARAMETRIC AND NON-PARAMETRIC STATISTICAL METHODS

by

MEDHAT MOHAMED AHMED ABDELAAL

A thesis submitted to the University of Plymouth in fulfilment for the degree of

DOCTOR OF PHILOSOPHY

School of Mathematics and Statistics

Faculty of Technology

February 1999

MODELLING THE FISHERIES OF LAKE MANZALA, EGYPT, USING PARAMETRIC AND NON-PARAMETRIC STATISTICAL METHODS

by

MEDHAT MOHAMED AHMED ABDELAAL

A thesis submitted to the University of Plymouth in fulfilment for the degree of

DOCTOR OF PHILOSOPHY

School of Mathematics and Statistics

Faculty of Technology

February 1999

MODELLING THE FISHERIES OF LAKE MANZALA, EGYPT, USING PARAMETRIC AND NON-PARAMETRIC STATISTICAL METHODS

By: MEDHAT MOHAMED AHMED ABDELAAL

Abstract

Much attention has been given to the economic aspects of the fisheries in Egypt, while building a statistical or mathematical model for fish production has received little attention. This study is devoted to a comprehensive assessment of Lake Manzala fisheries; past, present and future. Lake Manzala is one of the main fisheries resources in Egypt, and there is evidence that the fisheries have been over-exploited in recent years. The study objectives were to determine the factors that affect fish catches by individual vessels, to compare between parametric and non-parametric models of the fish catches, and to produce a mathematical model of stock behaviour which can be used to suggest policies to manage the Lake Manzala fishery.

A new method of estimating the carrying capacity of the lake and intrinsic growth rate of *Tilapia* and its four species has been developed. Simulation had to be used to get error estimates of the biomass parameter estimates using the new method. Three catch strategies have been investigated and assessed, with discounted utility of future yields.

Two ways of modelling individual vessel catches in relation to their effort characteristics, a parametric and non-parametric analysis, have been investigated. Using generalised additive model gave an improved fit to the survey data compared with the parametric analysis. It also gave a lower allowable fleet size which leads to more conservative management policy.

A simulation approach was used to investigate the uncertainty in the predicted catches and stock levels, and to give insight into the risks associated with various levels of control. There was no evidence that a management strategy which aimed to fish at maximum sustainable yield would put the stock at risk.

Acknowledgement

Firstly, I would like to thank **GOD** to help me to finish this study. I would like to thank the **Department of Mathematics and Statistics, Faculty of Commerce, Ein Shams University, Egypt** which helped me to study in the University of Plymouth. I also would like to thank the **Egyptian Educational and Cultural Bureau in London** for their greatest support, facilities and encouragement during the period of this study. I would like to thank my supervisors **Dr. Chris Ricketts** and **Mr. Jim Shalliker** for the infinite amount of support and for their guidance and advice over the past number of years. They have always kindly shown me the highest level of consideration, patience and professionalism. Also, I would like to thank **Professor A.Barrania** for his great help and support he has given me over the study period. I also thank **Dr. Julian Stander** for the valuable time he spent with me, he is the greatest helpful gentleman.

I also thank my long suffering wife **Manal** and my children **Ramy** and **Yara** for their patience which has seemed to exceed my own.

There are many others who have helped me, to those I simply say, thank you.

Author's Declaration

At no time the registration for the degree of Doctor of Philosophy has the author been registered for any other University award.

This study was financed with the aid of scholarship from the Egyptian Government.

Signed Medhat A. Abdelaal

MEDHAT M. A. ABDELAAL

Date 8th March 1999

To my wife

MANAL

and my children

RAMY **and** YARA

To my father and the memory of my mother.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX A

APPENDIX B

APPENDIX C

APPENDIX D

APPENDIX E

Chapter 1 Introduction

1.1. Introduction

Nowadays the world is very aware of the problem of food supply, which has two major dimensions. The first is famine, an extreme and general shortage of food causing distress and death from starvation. The second is the increasing disparity between population and food production. The world is substantially out of balance with respect to production and distribution of necessary food supplies. At the 1996 World Food Summit in Rabat, sponsored by Food and Agriculture Organisation (FAO) of the United Nations, the report stated that more than 800 million people were undernourished in the early 1990s. Millions more suffer debilitating diseases related to micronutrient deficiencies and to contaminated food. Every day, one out of five people in the developing world cannot get enough food to meet his/her daily needs; in Africa, two out of five people do not have adequate food.

The total food demand does not exceed food production by reason of population increase alone, but also because incomes are rising around the world giving rise to an increase in the per capita demand for food. When this increase is added to the growth in population, the total demand for food has been increasing somewhat more rapidly than the food production rate, creating a serious economic problem that takes the forms of rising food prices, or empty food shops, or a combination of both.

Food is a prime necessity of life; the kind and the amount of food available play a vital role in the physical and mental well-being of individuals as well as of nations. The presence of essential nutrients in the food supply can determine the growth, health and efficiency of populations and each of these nutrients has its own special role. Many studies on nutritional status show that protein deficiency is very common among populations where most of the dietary protein is supplied from cereal grain and other plant sources, and that the ethnic groups who obtain their protein supplies from meat and other animal origin are well nourished. Protein malnutrition and under-nutrition are the major nutrition problems affecting the well-being of populations of the developing countries of the world. Protein malnutrition, with or without an associated infection, is the most common cause of ill health if both its direct and indirect effects are considered (Specialised National Councils, 1988).

Protein is one of the most important nutrients, found in every cell in the body and used in forming muscles, blood, hair and other tissues. Carbohydrates and fatty foods provide most of the energy used by the body. Protein can also provide energy when the body receives insufficient energy from food. Insufficient intake of protein and consumption of protein that fails to provide the essential amino acids are the most significant factors in human malnutrition which is so prevalent in many regions of the world today.

Protein in the human diet is obtained from both animal and plant sources. Among food-stuffs of animal origin meat, fish, eggs, milk and milk products are the most important. Plant protein is most available in cereal grains (wheat, corn, rice and barley), the seeds of legumes (peas and various kind of beans) and nuts, of which peanuts are perhaps the most important in the human diet. Animal proteins such as meat, fish and eggs provide protein of high biological value, but they are in short supply in many countries in the third world. This shortage can not be overcome solely by procedures such as increased production of animal products through agriculture, which in many developing countries is still primitive or inefficient, or which produces animal protein at great expense. As a consequence, the living resources of the sea and fresh water are protein resources which can be directly exploited and which may still maintain considerable stocks in reserve.

Many workers in the field of human nutrition conclude that fish is considered one of the main sources of animal protein, especially by poor nations where it fills the gap between starvation and subsistence more than does milk or meat. The protein content of different types of fish ranges between 30 to 90 percent of dry solids. The percentage of total protein calories indicates that the muscles of some lean fish contain exceptionally high levels of protein even when compared with the best meat. The amino acid composition of fish and fish products provides protein of the finest nutritive quality.

Great attention is now being given to exploring fishery resources and tapping their vast stores of animal protein food in the developing world. In most developing countries bordering a marine area, great emphasis has been put on fishing as a means of rapidly acquiring quality protein. In some countries such as Egypt, fish is cheap in comparison with other protein foods, because the investments and costs are limited to the capture, handling and processing rather than growth and reproduction of animal protein. Adding to that, animal protein has many problems, such as the long gestation period of cattle and their tendency to have few progeny, the limited agricultural area available, the low productivity of local breeds, the shortage of breeds which produce meat and milk and the costs of feeding and veterinary services. Similarly, poultry production is faced with many problems such as feed shortages, the lack of local suitable breeds and the sensitivity of poultry to environmental and veterinary conditions. On the other hand, increasing fish production can achieve the qualitative balance of food production with lower costs and higher investment efficiency than other protein sources.

For that reason, the sustainable development of Egyptian fisheries is regarded as one of the bases of the government strategy aiming to eliminate protein food shortage. This means that fisheries resources are to be protected and properly managed to maintain their capability for producing fish. Over-exploitation is the major factor affecting sustainable development of the fisheries. So the balanced continuous growth of fisheries, which means the protection and maintenance of fisheries resources to enable the continued production for current and future generations, is one of the most important goals of the development policies.

1.2. Egyptian fisheries

The fisheries of Egypt are among the most diverse and interesting. The present fish catch comes from four sources (Table 1.1):

(a) the marine fisheries of the Mediterranean Sea, Red Sea and Gulf of Suez,

(b) lake fisheries,

(c) fresh water fisheries in the River Nile and its canals,

(d) aqua-culture fisheries.

The lakes in Egypt can be classified into three categories: saline lakes where salinity is about the same as the sea; brackish lakes, where the salinity does not exceed 5 g/L in all its parts; and fresh water lakes. The brackish water lakes are among the most productive standing water bodies due to shallow depths, which usually do not exceed 2 metres and huge quantities of nutrient rich water from irrigation drainage pouring into them.

Table 1.1 Classification, areas and catch of Egyptian fisheries in 1997.

Fisheries	% of area	% of catch
A. Marine fisheries		
Mediterranean Sea	55.34	11.84
Red Sea, Suez Gulf and canal	35.81	11.63
B. Lakes		
B.1 Saline lakes		
Karon (natural lake)	0.45	0.20
Bardawill (lagoon)	0.81	0.38
Port Fouad (lagoon)	0.12	0.05
Raian (man made lake)	0.39	0.16
Mariot (man made lake)	0.11	0.92
B.2 Brackish lakes		
Manzala (natural lake)	1.06	12.16
Borols (natural lake)	0.84	11.75
Edico (natural lake)	0.18	3.35
B.3 Fresh water lake		
High Dam (man made lake)	2.60	11.52
C. Fresh water fisheries		
River Nile and its network	1.45	18.47
D. Aquaculture		
Fish farms	0.84	17.57
Grand total	**100**	**100**

Source: Central Agency for Public Mobilisation And Statistics (CAPMAS), yearbook of Fish production statistics in Arabic Republic of Egypt (ARE).

The agricultural area of Egypt is 3.2 million hectares, while the area of Egyptian fisheries is around 5 million hectares, which is nearly twice the cultivated area. In 1997 the value of fish production was about 3 billion Egyptian pounds (LE)[1], while the agricultural value was 64 billion LE. This means that contribution of fish production to agricultural production is modest considering the area of the two activities.

Fish production from all Egyptian fisheries changed from 107 kt in 1977 to 266 kt in 1997 (Table 1.2). The highest production was in 1994, while the lowest was in 1977.

The Egyptian lakes have been the main sources of fish production. The lakes' fish production has been changed from 65 kt in 1977 to 108 kt in 1997 (Table 1.2). From 1977 to 1997 the average annual fish production of all lakes represented 50 percent of total fish production. Lake Manzala is ranked number one among these lakes for fish production because its annual fish production average represents 39% of all the lakes production and 20% of the total fish catch in Egypt. The highest catch was 63 kt in 1987 and the lowest was 30 kt in 1997.

[1] 1£ = 5.55 LE is the average of exchange rate at March 1998.

Table 1.2 Relative importance of Lake Manzala catch in relation to all lakes catch and total catch during the period 1977-1997 (in kt).

Years	Lake Manzala	All lakes	Total catch	Manzala to all lakes %	Manzala to total catch %	All lakes to total catch %
1977	33	65	107	52%	31%	61%
1978	47	69	110	67%	42%	63%
1979	36	76	115	48%	32%	66%
1980	38	79	143	49%	27%	55%
1981	39	80	139	49%	28%	58%
1982	30	84	187	36%	16%	45%
1983	30	82	166	37%	18%	49%
1984	35	83	158	42%	22%	52%
1985	48	115	230	42%	21%	50%
1986	52	127	254	41%	21%	50%
1987	63	136	280	46%	22%	49%
1988	37	143	301	26%	12%	48%
1989	49	134	320	36%	15%	42%
1990	50	157	334	32%	15%	47%
1991	45	158	340	29%	13%	46%
1992	52	155	342	34%	15%	45%
1993	47	152	352	31%	13%	43%
1994	49	159	363	31%	13%	44%
1995	34	107	233	32%	15%	46%
1996	33	114	278	29%	12%	41%
1997	30	108	266	28%	11%	40%
Average	42	113	239	39%	20%	50%

Source CAPMAS, yearbook of Fish production statistics in ARE.

1.3. Previous studies

There have been many studies on Egyptian fisheries. Sherif (1974) conducted a study on the economics of fisheries in the Arabic Republic of Egypt (ARE), which concluded that many governmental bodies are supervising the fishing sector and that the poor co-ordination between them was one of the factors hampering fisheries development. It also mentioned that fish is an important source of cheap animal protein and that fisheries development could provide such protein at relatively low prices. It was recommended that reorganisation of the fishery sector was essential to provide fish at reasonable prices and high quality. Elbana (1988), also noted the lack of co-ordination between agencies controlling fishing activities as well as shortage of qualified staff. The study concluded that the value of fish production in 1985 represented 4 percent of the value of agriculture production and it recommended that contacts between executive agencies and research institutions should be strengthened.

Elbarawy and Awad (1980) stated the economic importance of fish production. That study concluded that the drop in fish production from 115 kt in 1961 to 107 kt in 1977 was mainly due to concentration of fishing in the inshore areas and decreased fertility rate of the fisheries sources. Shafay (1983) concluded in his study that the fish production from Egyptian lakes fluctuated from one season to another. In winter the production decreased from the annual average, while it increased in summer. It was suggested that fish import plans must consider seasonal fluctuations in production and consumption.

Basiony (1985) stated that although there has been an overall expansion of bodies of water fishing in Egypt, the production per hectare was low. This was mainly due to the poor efficiency of traditional fishing boats and gears. In Abosamra's study (1987) the estimated annual average of fish production per hectare from marine fisheries from 1966 to 1973 was 1.8 tonnes. Shahen (1980) gave an estimate of 0.5 tonne per hectare from the northern lakes during the period 1964 to 1978, while Saad (1988) estimated the average productivity per hectare from the northern lakes during the period 1974 to 1979 as 0.7 tonne.

The study conducted by the Specialised National Councils (1988) stated that the development in fish production could be achieved by introducing modern techniques in fish handling and storing. The provision of refrigerated lorries and storage, and other related marketing facilities would improve fish supply and prices.

Barrania and Nassar (1984) stated that bio-economic management of fisheries must aim at obtaining maximum sustainable yield (*MSY*) with protection of the stock and minimum cost. Abdelhafz (1985) maintained the importance of protecting fish stocks in the Gulf of Suez fisheries and not exceeding the optimum biological level of exploitation through proper control of fishing efforts. Elhawary (1992) maintained that many of the fisheries of Egypt have suffered as a result of by the absence of scientifically determined figures of maximum sustainable yield (*MSY*). Moreover, there is little effort as yet to identify all of the stocks that can be regulated separately, to determine the effects of fishing on stocks and to estimate the permissible levels of maximum yield. That study concluded that there is a difficulty in developing general public acceptance of the need for regulation because of the illiteracy of most of the fishermen and political pressure on policy makers in the government.

The study conducted by Barrania and Abdelaal (1994) stated that the development of Bardawill Lagoon should be done within the framework of a regional development plan which can reduce the over-fishing in that location.

In these studies, much attention has been given to the economic aspects of the fisheries, while building a statistical, biological, or mathematical model for fish production has received little attention as mentioned in that study carried out by Barrania and Nasser (1984).

1.4. Study objectives

Lake Manzala plays an important role in providing fish for the Egyptian population because it is the largest natural lake and its annual fish production represents around 20 percent of the national fish production. For these reasons Lake Manzala has been chosen as a case study to determine the factors which affect the lake exploitation, such as changes in number of fishing vessels and vessels characteristics, as well as to study the effect of these factors on stocks of the lake. The study covers the period from 1977 to 1997, and provides suggestions to improve management of that fishery in order to maintain and protect fish stocks and ensure sustainable fish production. The management strategies developed in this study can be extended to other Egyptian fisheries resources.

The main objectives of this study are:

- to develop models of changes in biomass of fish stocks and to estimate key parameters, so that changes in biomass in response to changing catches can be modelled and the stock size can be predicted;

- to determine factors that affect fish catches by individual vessels using parametric approaches, such as regression analysis, and non-parametric approaches, such as smoothing, and compare both approaches;

- to produce a model which can be used to suggest policies and means of proper management of the lake's fisheries,

- to explore the effect of uncertainty on the catches and stock prediction.

These objectives can be realised through the following chapters: chapter two describes the geographical characteristics, fishing efforts and catch in a time series analysis of Lake Manzala; chapter three describes the use of fisheries modelling to estimate the intrinsic growth rate and the carrying capacity of the fishery for the main species in Lake Manzala; chapter four shows the analysis of field survey data of Lake Manzala vessels using parametric approaches such as regression analysis; chapter five covers a non-parametric approach to the analysis of field survey data such as smoothing to improve the linear regression model described in chapter four; chapter six shows the effect of the two sources of uncertainty, in the biomass model (described in chapter three) and catch models (described in chapters four and five), on the biomass prediction; and chapter seven shows a comparison between parametric and non-parametric approaches, the results and the conclusions of the study.

Chapter 2 LAKE MANZALA FISHERIES

2.1. Introduction

The geographical characteristics, fishing efforts and fish catches of Lake Manzala are discussed in this chapter.

2.2. Geographical characteristics

2.2.1. Lake Manzala location

Lake Manzala is located in the north-east corner of the Nile Delta, and lies between longitudes 31° 45′ to 32° 5′ east and latitudes 31° to 31° 30′ north. The Mediterranean Sea borders it to the north, the Suez Canal to the east, the River Nile (branch Domiat) to the west and Sharkia Governorate to the south. (Figure 2.1).

2.2.2. Lake Manzala weather

The Lake Manzala area has a temperate climate, with mild weather in summer and moderate cold in winter. The average temperature during the summer days is between 28° and 32° and during winter days is between 8° and 10°. Humidity is high, varying between 65% and 95%. The rainfall is light with a range of 40 - 80 mm per year. The rainy months are December, January and February. The average wind speed is 15 km per hour. The wind in this area blows gently. Because Lake Manzala is a shallow lake (the maximum depth being one metre) the water temperature is similar to the air temperature. (Aero Methodological Authority AMA, yearbook 1996)

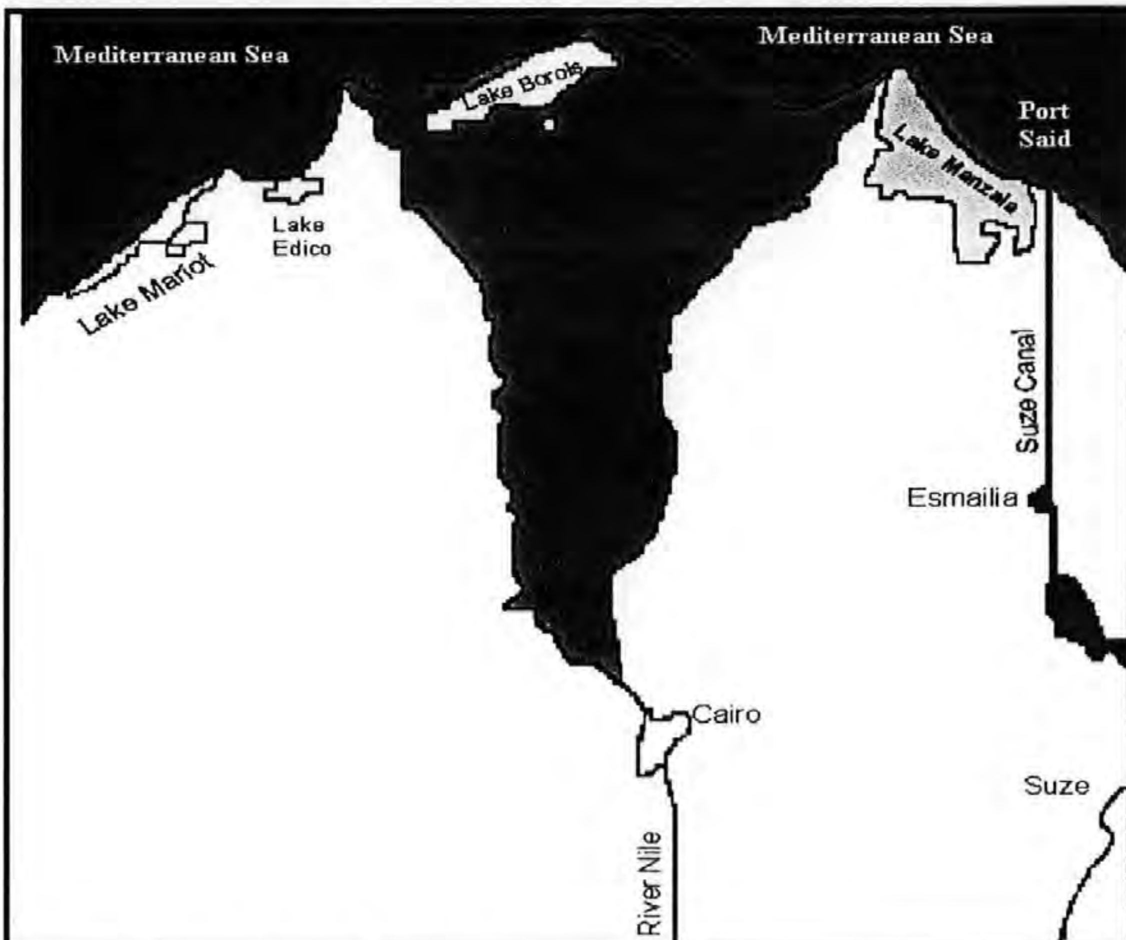


Figure 2.1 Lake Manzala Location

2.2.3. Lake Manzala area

The exploited area of Lake Manzala decreased by 41 thousand hectares during the period from 1973 to 1986 (Table 2.1). In the last three decades extensive agricultural reclamation activities on the southern and south-western sides of the lake, road building and settlements on the islands have reduced the open water area to 53 thousand hectares. Lake Manzala area decreased on three occasions during 1977 to 1986, from 94 to 53 thousand hectares in present (Figure 2.2). There has been no change in the area since 1986.

Table 2.1 Lake Manzala exploited area development during the period 1973 - 1986.

Year	Area in thousand hectare	Reclaimed area in thousand hectare	Reclaimed area percentage of previous area
(1) 1973	94		
(1) 1981	87	7	7.4
(2) 1982	72	15	17.2
(3) 1986	53	19	26.4

Source: (1) Turid, 1982, (2) CAPMAS, 1987 and (3) Etewa, 1993.

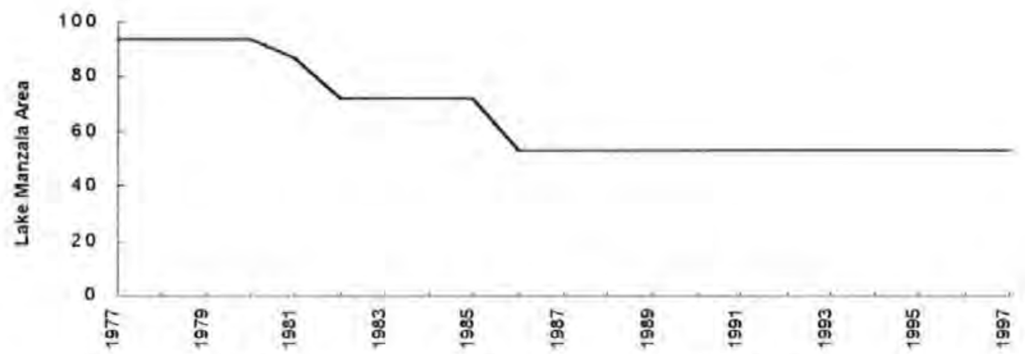


Figure 2.2 Area of Lake Manzala during 1977 to 1997 in thousand hectares.

2.2.4. Lake Manzala sectors

The lake is divided into four sectors for fisheries purposes (Figure 2.3). These sectors are Northern Sector, Southern Sector, Eastern Sector and Western Sector. The Northern Sector salinity is higher than in the Mediterranean Sea and it has the lowest fish production, so no fishing vessels operate in Northern Sector. The Southern Sector has low salinity and the highest fish production in the lake. *Tilapia*, Catfish, Mullet and Perch fish can be caught there. About 53% of Lake Manzala fishing vessels fish in Southern Sector. The Eastern Sector salinity is equivalent to the sea salinity and this sector supports considerable quantities of high value fish such as Trout and Seabass. The fishing vessels in the Eastern Sector represent about 15% of Lake Manzala fishing vessels. The Western Sector has the lowest salt content because some drains and canals pour fresh water into this sector. About 32% of Lake Manzala fishing vessels fish in Western Sector. This sector is suitable environment for Nile fish such as *Tilapia,* Perch fish and Catfish,.

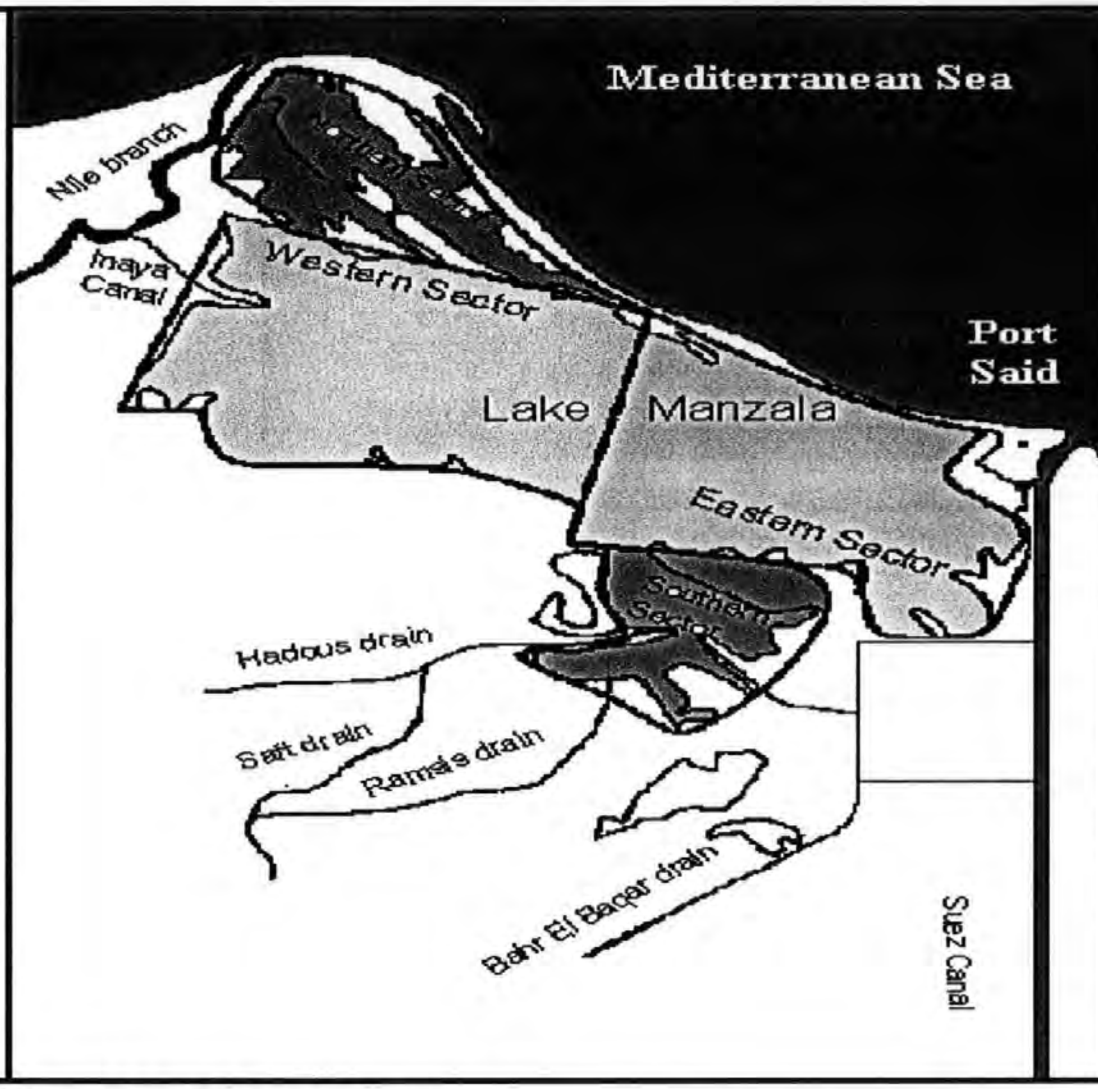


Figure 2.3 Lake Manzala sectors.

2.3. Fishing effort

There are many measures of fishing efforts such as catches, number of fishing units (vessels), number of fishermen and type of fishing gear. The total catch of all species, number of licensed vessels, number of fishermen and fishing area are listed below in Table 2.2.

Table 2.2 Total catch of all species in kt, number of vessels, number of fishermen and area in thousand hectares during the period 1977-1997 in Lake Manzala.

Year	Total catch	Vessels	Fishermen	Area
1977	33.46	2695	8286	94
1978	46.54	2752	8406	94
1979	36.44	2755	8313	94
1980	38.39	2959	8346	94
1981	39.30	2769	8358	87
1982	29.72	2689	8115	72
1983	30.23	2694	8130	72
1984	34.96	4543	13674	72
1985	47.70	6595	19824	72
1986	52.47	6586	19788	53
1987	62.91	5893	17969	53
1988	37.43	5651	16962	53
1989	48.57	5693	17079	53
1990	50.29	4743	14229	53
1991	45.48	3914	11742	53
1992	51.91	3911	11739	53
1993	47.49	5784	17861	53
1994	48.86	6364	19102	53
1995	33.78	5564	17054	53
1996	32.53	3838	11682	53
1997	30.00	3741	11114	53

Source: CAPMAS, yearbook of Fish production Statistics in ARE.

2.3.1. Lake Manzala vessels

Table 2.2 shows number of vessels each year from 1977 to 1997. The minimum number of vessels was 2689 in 1982 and the maximum number of vessels was 6595 in 1985. During the period 1977 to 1983, the number of vessels was approximately constant with average 2759 vessels, while the average was 5904 during the period 1984-1987 and decreased to 4920 during the period 1988 to 1997 (Figure 2.4). From 1984 to 1987 the unemployment problem came to the surface in Egypt, and the government put pressure on the Lake Manzala authority to issue more licences for vessels and fishermen. This caused a rapid increase in the effort during that period.

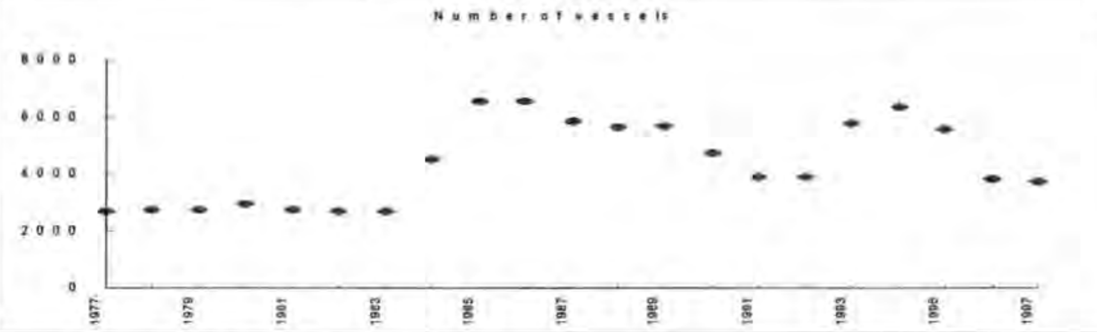


Figure 2.4 Number of vessels in Lake Manzala during 1977- 1997.

2.3.2. Lake Manzala fishermen

Table 2.2 shows the number of licensed fishermen each year from 1977 to 1997. The minimum number of fishermen was 8115 in 1982 and the maximum was 19824 in 1985. During the period 1977 to 1983, the average number of fishermen was 8279 fishermen. This figure doubled to be 17814 fishermen during the period 1984- 1987, while the average number of fishermen decreased to 14856 during the period 1988- 1997. So the changes in the number of fishermen are similar to the changes in the number of vessels.

2.3.3. Fishing gear in Lake Manzala

The type of fishing gear used on Lake Manzala during the last 20 years are Trap nets, Stand nets and Hook lines. Trap nets and Stand nets are used in Southern, Western and Eastern Sector of Lake Manzala, while Hook lines are used in Southern and Western Sector only. The proportion of vessels using each gear in each sector does not vary from year to year. 26% of the Lake Manzala fleet use Trap nets, 59% use Stand nets and 15% use Hook lines (Table 2.3). 53% fish in the Southern Sector, 32% in the Western Sector and 15% in the Eastern Sector.

Table 2.3 Fleet structure in each sector according to type of fishing gear in Lake Manzala.

Fishing gear	Southern Sector %	Western Sector %	Eastern Sector %	Total %
Trap nets	11	9	6	26
Stand nets	38	12	9	59
Hook lines	4	11	0	15
Total	53	32	15	100

2.3.3.1. Trap nets

Trap nets consist of three layers of netting. The mesh size of the outer layers is usually three times the inner. Trap nets are often used during day time hours, or over night. In day time operations, the fish are frightened into the net by threshing the water with poles and rhythmic beating on the boat's skeleton. Operating over-night, the nets are left in the water before the sun sets and lifted in the early morning.

2.3.3.2. Stand nets

Stand nets are used in huge numbers in Lake Manzala. Stand nets are large surrounding nets with a diameter of about 50 meters. The nets are operated by two vessels. Fishing with Stand nets depends on setting the net vertically on the lake bed by using sticks for many hours, then removing the nets and collecting the fish.

2.3.3.3. Hook lines

On Lake Manzala, Hook lines are used with and without bait. The horizontal rope is about 1000 m or more and floats on the water. Fixed to it are vertical lines carrying different types of hooks. The distance between each vertical line should be double its length.

2.4. Lake Manzala catch

Figures 2.5 shows the annual total catches during the period 1977- 1997. The annual catches shows a low level before 1984, a rapid increase from 1984 to 1987 followed by a period of slowly declining catches up to the present. The catch show a similar pattern to changes in fishing effort, as reflected in the number of vessels and number of fishermen which have been discussed earlier. The increase in effort during the period from 1984 to 1987 caused a rapid increase in catches. This was followed by a decrease in catches during next period from 1988 to 1997. During the period 1977 to 1983 Lake Manzala authority noted that there were a lot of young fishermen with no experience in fishing, resulting in low catches, and it decided to give a training course to the fishermen to increase their productivity. This course started in 1983 and continue for ten years, each year training 10% of the licensed fishermen.

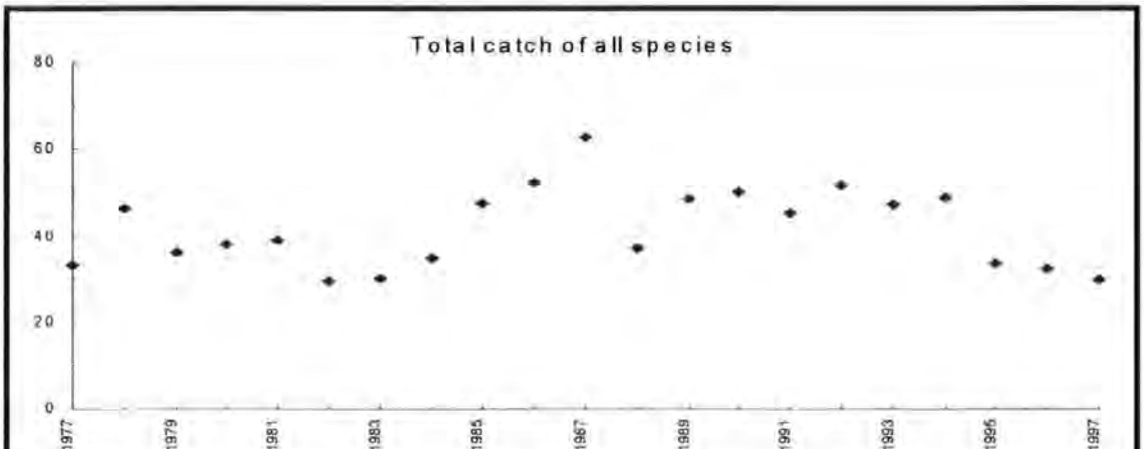


Figure 2.5 All species catch from Lake Manzala during 1977- 1997 in kt.

2.4.1. Catch composition

Over the last 20 years fish catches on Lake Manzala have been dominated by *Tilapia* species. Fish catches will be classified according to the main species as follows:

1. *Tilapia* species: This species consists of *Tilapia Nilotica, Tilapia Aurea, Tilapia Zillii* and *Tilapia Galilea*.

2. Non *Tilapia* species: this group consists of all other species.

Figure 2.6 show a comparison between total catch, *Tilapia* with its four species catch and non-*Tilapia* catch. The highest *Tilapia* catch was 56 kt in 1987, while the highest non-*Tilapia* catch was 19 kt in 1992. The lowest *Tilapia* catch was 21 kt in 1997, and the lowest non-*Tilapia* catch was 5 kt in 1982. From 1977 to 1983 there is slow upward trend for all species, *Tilapia* and non-*Tilapia*. During 1984 to 1987 *Tilapia* catch rate increased to a peak in 1987, then started to decrease from 1988 to 1997. While non-*Tilapia* catch shows slow a upward trend from 1977 to 1987, a peak at 1992 then a decrease from 1993. The annual average catch of *Tilapia* represents about 76% of annual total catch during 1977 to 1997, while the annual total *Tilapia* catch during 1988-1997 represents about 67% of the annual all species catch. This means that *Tilapia* is the most important species for proper management and development of the lake fisheries. So any policies aimed at improving fish production in Lake Manzala must be directed toward sustainable development of this species. In the following section the analysis will focus on time series data for monthly catches of the four *Tilapia* species, total *Tilapia* catch and all species catch.

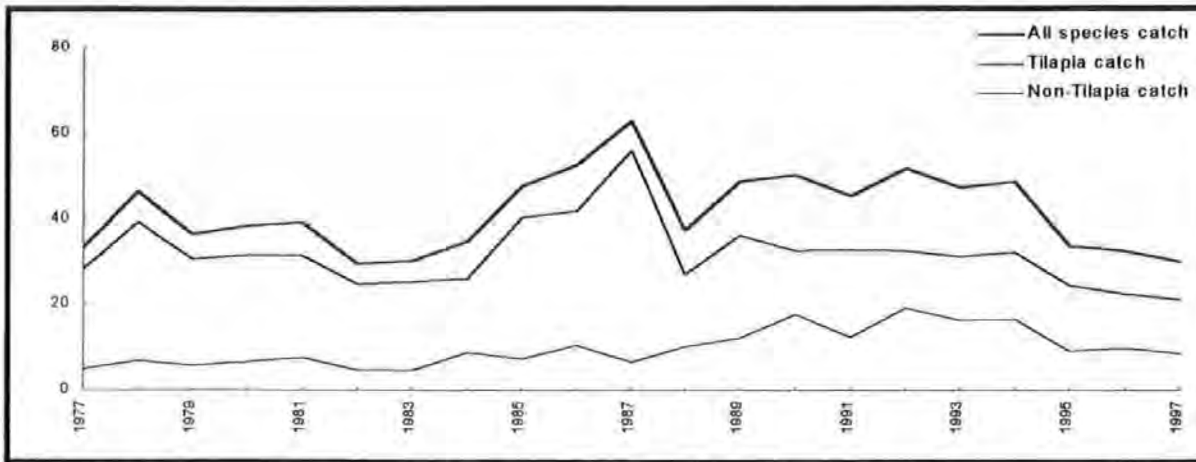


Figure 2.6 Comparison between all species catch, *Tilapia* catch and Non-*Tilapia* catch.

In summary, Lake Manzala is a shallow, brackish lake which produces about 20% of Egypt's fish catches. Since 1977 the fishery has undergone dramatic changes. The area of the lake has reduced three times as a result of land reclamation programmes, and the number of fishing vessels and fisherman approximately doubled in a 4 years period from 1985 to 1988. Intuitively one would conclude that prior to 1984 the fishery was under no threat of over-exploitation, but that since 1986 over-exploitation might have become a problem.

A mathematical model which allows estimation of stock size in relation to Lake Manzala's carrying ability is needed to clarify this issue. An appropriate model can also be used to predict the likely response of the stocks to different catch levels. Chapter 3 describes the building of a biomass model for the main species to estimate the biomass growth rate and biomass size. While chapter 4 will explore the catch strategies which will allow the biomass to recover. Chapters five and six show the fleet control while chapter seven shows the uncertainty of the biomass model parameters and catch model parameters.

Chapter 3 FISHERIES MODELLING

3.1. Introduction

Lake Manzala appears to be suffering from over-fishing as a result of decreasing area and increasing fishing effort. This chapter aims to suggest possible management policies by building a mathematical biomass model to estimate biomass size and growth rate of stocks. Also the biomass model can be used in developing a management strategy to enable the fisheries to begin to yield approximately the maximum sustainable yield (MSY).

The available biomass data for Lake Manzala are biomass estimates at the end of 1979 and 1993 for four *Tilapia* species. These are considered to be the estimates at the beginning of 1980 and 1994 respectively (Ministry of Development and New Communities in ARE in co-operation with Maclaren Engineers Planners and Statistics Inc., 1980 and Hussein, 1994 respectively). A continuous record for monthly catches, annual number of vessels, number of fishermen and fishing area are available for this study, but there are only two biomass estimates at widely separated times. A recruitment model and parameters estimates are required to control the fishing effort and to maintain the stocks.

3.2. Basic biomass model

"Biomass dynamic models are the most commonly used stock assessment model in most tropical fisheries and are widely applied in many temperate fisheries. Using biomass dynamic models in formulating fisheries management plans depends on the nature of the available data. When the fish biomass can be directly estimated, the relationship between biomass and biomass growth can be directly fitted and when the biomass can not be directly measured and only an index estimate is available the estimation procedures become more complex." (Hilborn, 1992).

The range of most species of fish is narrowly circumscribed by one or more of the following environmental factors; temperature, salinity, depth, bottom conditions and food supplies. If the catch is assumed to be absent then the biomass levels change as follows

- When the biomass level is low it increases slowly because growth is limited by reproductive capabilities of small numbers of fish and the small number of fish that are growing.

- When the biomass level is at intermediate range growth is more rapid, as larger number of fish produces more eggs than can survive growth is not limited by pressure on food supplies.

- When the biomass level is high the growth slows again as pressure on food supplies impedes the biomass growth and loss of biomass due to deaths in the biomass will just offset births and weight gains by the survivors.

To simplify the model to be compatible with the available data, we have to ignore all the complexities of age structure and spatial structure. We also have to assume that all environmental factors remain constant, and there is no immigration and emigration. Then the population can be described by a single biomass and a discrete-time biomass growth model can be written as follows:

$$B_{t+1} = B_t + G_t - C_t \qquad \textbf{(3.1)}$$

where:

B_t is the fish stock biomass at the start of time period t,

G_t is the net growth of biomass, which is the difference between growth and natural mortality in period t to $t+1$,

C_t is the catch in period,

The first biomass dynamic model was formulated by Schaefer (1954), this model can be written as follows

$$\Delta B = rB(1 - \frac{B}{K}) - C \qquad \textbf{(3.2)}$$

where:

ΔB is change in biomass = current biomass - previous biomass

r is intrinsic growth rate of population,

K is carrying capacity of the fishery environment,

$rB(1 - \frac{B}{K})$ represents the net growth,

C is the catch.

This model (equation 3.2) is a logistic growth model, with parameters r and K. The maximum sustainable yield (MSY) and stock size for maximum sustainable yield ($BMSY$) can be expressed in the terms of r and K as follows:

Maximum sustainable yield $MSY = \frac{rK}{4}$

Stock size for maximum sustainable yield $BMSY = \frac{K}{2}$

Figure 3.1 shows a simple representation of the relationship between the stock, net growth, *MSY* and *BMSY*. At low stock sizes there is low net growth because there are few individuals in the population to grow and reproduce. At large stock sizes the net growth must approaches to zero because of slower growth, higher mortality rates, and limitations on recruitment. If the stock is at *BMSY* this means the net growth is at maximum, so the catch is maximised.

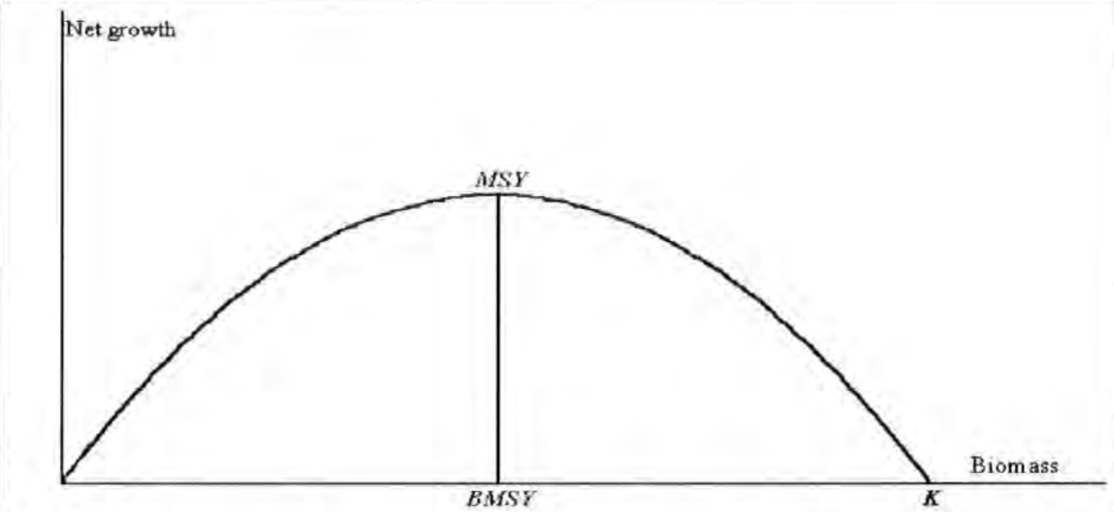


Figure 3.1 Relationship between biomass, net growth, *MSY* and *BMSY*.

Walters and Hilborn (1976) used a simple difference equation form of the Schaefer model as follows

$$B_{t+1} = B_t(1 + r - r\frac{B_t}{K}) - C_t \quad \textbf{(3.3)}$$

This model assumes that the catch is taken after the biomass growth has effect, or in other words the catch is taken at the end of the time period.

If the catch is assumed to be taken before the biomass growth takes effect then equation (3.3) can be rewritten as follows:

$$B_{t+1} = (B_t - C_t)(1 + r - r\frac{(B_t - C_t)}{K}) \qquad \textbf{(3.4)}$$

For annual data both equations 3.3 and 3.4 are not logical because biomass growth does not take effect before or after the catch, but both occur simultaneously.

If half of the catch is assumed to be taken at the beginning of a time period, followed by the biomass growth (based on the remaining biomass), and then the second half of catch, equation 3.3 can be then rewritten as follows, which is closer to reality

$$B_{t+1} = (B_t - 0.5C_t)(1 + r - r\frac{(B_t - 0.5C_t)}{K}) - 0.5C_t \qquad \textbf{(3.5)}$$

Equation 3.5 ignores the effect of changing Lake Manzala area, so it must be adapted to take account of the three changes in Lake Manzala area during the period 1977 to 1997. The change of available area for biomass causes changes in carrying capacity. If the available exploited area for biomass decreases the carrying capacity will decrease and likewise if the exploited area increases the carrying capacity will increase. It is assumed that biomass density, defined as the amount of biomass in one unit of exploited area, is the same across the lake, that all exploited areas are equally productive, and that there is no loss of stocks when the exploited area is reduced.

Let the basic exploited area be A_{80} which gives carrying capacity K_{80} in 1980, and let A_t be the exploited area in year t which gives carrying capacity K_t. This relationship can be expressed as follows:

$$K_t = K_{80}\frac{A_t}{A_{80}} \qquad \textbf{(3.6)}$$

Substitute K_t for K, equation 3.5 can then be written as follows:

$$B_{t+1} = (B_t - 0.5C_t)[1 + r - r\frac{(B_t - 0.5C_t)A_{80}}{K_{80}A_t}] - 0.5C_t \quad \textbf{(3.7)}$$

The parameters of this model (3.7) are K_{80} and r. Stock size for maximum sustainable yield $BMSY$ can be expressed as follows

Stock size for maximum sustainable yield $BMSY = \frac{K_t}{2} + \frac{rK_t}{8} = \frac{K_{80}A_t}{2A_{80}} + \frac{rK_{80}A_t}{8A_{80}}$ **(3.8)**

while MSY is the same as Schaefer model $MSY = \frac{rK_t}{4} = \frac{rK_{80}A_t}{4A_{80}}$ **(3.9)**

3.3. Parameter estimate for biomass model

Starting with known biomass B_{81} and using the known catches $C_{80}, C_{81}, \ldots\ldots, C_{93}$ in equation 3.7 will produce a trajectory of biomasses $B_{82}, B_{82}, \ldots\ldots, B_{94}$. Suitable values of r and K_{80} will enable the computed B94 to match the actual biomass. A difficulty arises because the values of r and K_{80} will not be unique, because there are 14 equations with 15 unknowns including the intermediate biomasses (13 biomass estimates 1981-1993) and r and K_{80}. An addition assumption is needed.

The description of the Lake Manzala fishery in chapter two suggests a stable fishery in the early years. In particular, the period 1980-1981 has no changes in exploited area and virtually constant catches and effort. Therefore we will assume that $B_{80} = B_{81}$ in equation 3.7. Then equation 3.7 for $t = 80$ can be written as follows

$$r(B_t - 0.5C_t)(K_{80} - B_t + 0.5C_t) = K_{80}C_t \quad \textbf{(3.10)}$$

Equation 3.10 gives additional information about the relationship between r and K_{80}, and provides the additional equation needed to uniquely determine the values of r and K_{80}.

Given an initial estimate for r we could calculate K_{80}, or given an initial estimate for K_{80} we could calculate r.

Successive application of equation 3.7 from 1981 until the next biomass figure in 1994 would lead to a high degree polynomial involving r and K_{80}. For example B_{t+2} can be expressed as follows

$$
\begin{aligned}
B_{t+2} = {} & [\{(B_t - 0.5C_t)\{1 + r - r\frac{(B_t - 0.5C_{t+1})A_{80}}{K_{80}A_t}\} - 0.5C_t\} - 0.5C_{t+1}] \\
& [1 + r - r\frac{[\{(B_t - 0.5C_t)(1 + r - r\frac{(B_t - 0.5C_{t+1})A_{80}}{K_{80}A_t}) - 0.5C_t\} - 0.5C_{t+1}]A_{80}}{K_{80}A_{t+1}}] - 0.5C_{t+1}
\end{aligned}
\tag{3.11}
$$

$$
\begin{aligned}
B_{t+2} = {} & \{A_{80}^3 r^3 (2B_t - C_t)^4 - 4A_{80}^2 A_t K_{80} r^2 (2B_t - C_t)^2 (2B_t(r+1) - C_t(r+2) - C_{t+1}) \\
& + 4A_{80}A_t K_{80}^2 r(4B_t^2(r+1)(A_t(r+1) + A_{t+1}) \\
& - 4B_t(r+1)(C_t(A_t(r+2) + A_{t+1}) + C_{t+1}A_t) \\
& * C_t^2(A_t(r+2)^2 + A_{t+1}(r+1)) + 2C_tC_{t+1}A_t(r+2) + C_{t+1}^2 A_t) \\
& - 8A_t^2 A_{t+1} K_{80}^3 (2B_t(r+1)^2 - C_t(r+1)(r+2) - C_{t+1}(r+2))\} / 16A_t^2 A_{t+1} K_{80}^3
\end{aligned}
\tag{3.12}
$$

If the initial estimates of r and K_{80} are correct then successively applying equation 3.7 from 1980 to 1994 would lead to the correct biomass estimate in 1994. A two-parameter search is required to find those values of r and K_{80} such that the trajectory of biomass over the period 1980-1994 passes through the correct point in 1994 while still satisfying equations 3.7 and 3.10.

The search for the values of r and K_{80} requires sensible initial estimates. Because Lake Manzala was not heavily exploited at the time of the first biomass estimate, the value of $(B_{80} + C_{80})$ has been chosen as an initial estimate of the carrying capacity. The initial value of r is calculated from this value of K_{80} using equation 3.10. A spreadsheet is an excellent environment for solving this two-parameters search problem through the following steps:

(1) Start with initial values of r and K_{80} where:

the initial value of K_{80} is $K^*_{80} = B_{80} + C_{80}$

and the initial value of r is $r^* = \dfrac{K^*_{80}\, C_t}{(B_t - 0.5C_t)(K^*_{80} - B_t + 0.5C_t)}$.

(2) Calculate successive values of B_t using equation 3.7 as far at 1994.

(3) Use non-linear search in a spreadsheet Solver to set the target cell containing the calculated value of B_{94} to be equal to the known value of B_{94}.

Using the non-linear search facility in a spreadsheet Solver, it was possible to find unique values of r and K_{80} for all four species of *T.Nilotica, T.Aurea, T.Zillii* and *T.Galilea*. Also it was possible to find unique values of r and K_{80} for the *Combined Tilapia* species when treated as a single species stock. The catch of the single stock (*Combined Tilapia*) is assumed to be the summation of the species catches, the 1980 single stock (*Combined Tilapia*) biomass is the summation of the species 1980 biomasses, and the same for the 1994 biomass.

Table 3.1 shows the biomasses in 1980 and 1994, the estimated carrying capacity in 1980 and in 1994 together, and the estimates of r for the four species of *Tilapia* and for the *Combined Tilapia* stock.

Table 3.1 Estimates of biomass (kt) and biomass model parameters for the four species and *Combined Tilapia* stock using annual data.

Species	B_{80}	B_{94}	K_{80}	K_{94}	r
T.Nilotica	92	20	105	59	0.766
T.Aurea	44	14	59	33	0.775
T.Zillii	75	18	83	47	0.671
T.Galilea	12	4	15	8	0.732
Sum of K and the average of r	222	56	262	148	0.736
Combined Tilapia	222	56	260	147	0.740

For each species the estimates of the 1980 carrying capacity K_{80} are greater than the biomass estimates B_{80}. The total 1980 biomass of the four species represents 85% of the total 1980 estimated carrying capacity for the four species and the same proportion for the *Combined Tilapia* as a single stock in 1980, which consistent with a low level of exploitation in the fishery. For each species the estimated values of the 1994 carrying capacity are considerably higher than the corresponding biomass estimates. The total biomass of the four species in 1994 represent only 38% of the total estimated carrying capacity for the four species 1994. The same analysis has been done for combined stock, giving B_{94} as the same proportion of K_{94}.

Figure 3.2 shows the estimated biomass for the four species and for the *Combined Tilapia* stock produced by using the non-linear search with equation 3.10 and successive implementation of equation 3.7. The estimated biomasses were stable during the period 1980 and 1981, then started to decline smoothly from year to the next except for *T.Galilea*, which shows stable biomass from 1993 to 1996 then a small increase in 1997. Also the estimated biomass of the four species and *Combined Tilapia* show a fast decrease from 1986 to 1988, reflecting the increase in the fishing effort during that period.

The estimated values of the intrinsic growth rate, *r*, is consistent with the most recent biological research carried out by Hafz (June 1998). This study estimated the annual growth rate of the *Tilapia* species in Lake Manzala and found it is vary between 0.73 to 0.97, 0.65 to 1.30, 0.62 to 0.91 and 0.65 to 1.02 for *T.Nilotica*, *T.Aurea*, *T.Zillii* and *T.Galilea* respectively. There have been other studies of the *Tilapia* species. Abdel-Latif (1974) estimated the annual growth rate of *T.Nilotica* and *T.Zillii* to be 0.73 and 0.84 respectively in Lake Nasser in Aswan. The study conducted by Ministry of Development and New Communities in ARE in co-operation with Maclaren Engineers, Planners and Statistics Inc. (1980) of current status of fishery and fish stocks of Lake Manzala found that *T.Aurea* growth rate varied between 0.71 and 1.02. Also the High Dam Lake Development Authority (1992) estimated the annual growth rate of *T.Galilea* to be 0.82.

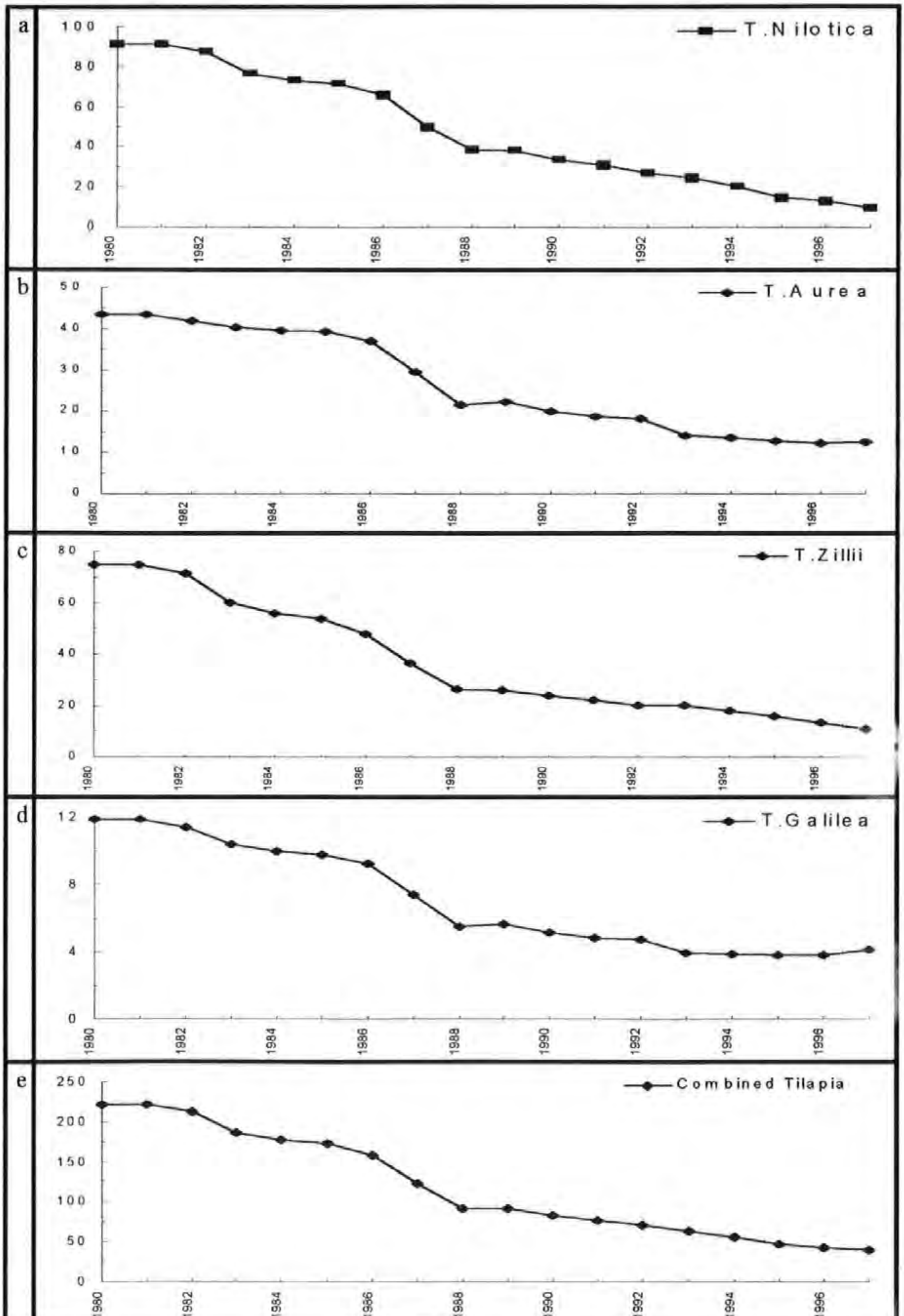


Figure 3.2 Estimated change in biomasses between 1980 and 1997 using non linear search for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Combined Tilapia* stock.

3.3.1. Sensitivity and convergence

Sensitivity and convergence of the estimates of r and K_{80} (using non-linear with equations 3.7 and 3.10) was investigated in two ways:

(1) The effect of the level of data aggregation on the estimates of r and K_{80}.

(2) Convergence to estimate the values of r and K_{80}.

3.3.1.1. Sensitivity to data aggregation

Because catch data are available monthly, it is reasonable to estimate the values of r and K_{80} for each species and for *Combined Tilapia* species by using 1, 2, 3, 4 and 6 months time series. Table 1A in Appendix A shows that there is a little change in the estimates of r and K_{80} as the level of data aggregation changes. There is a suggestion that the greater the degree of aggregation, the higher the estimate of r and the lower the estimate of K_{80}. The annual value of r is simply calculated by multiplying the estimated values of r by the number of time periods per year. So, the annual data set can achieve the main aim of this model which is assessment of strategies for enabling the stock to recover.

3.3.1.2. Convergence to parameters values

The problem of how good the initial values need to be will vary between fisheries. For this model, convergence was obtained from a quite wide range of initial values of K_{80} and the associated value of r, as shown in Table 2A in Appendix A. Convergence was achieved from initial estimates of r which were as much as a factor of 3 adrift in the maximum direction and were as much as a factor of 0.5 adrift in the minimum direction. Table 2A in Appendix A shows that it is better to chose an initial value of K_{80} which is overestimate rather than chose an initial value of K_{80} which is underestimate. This is because of the effect of this initial estimate on the estimates of r which rapidly becomes unstable. If the initial values of r and K_{80} are outside these ranges (listed in Table 2A in Appendix A) successive application of equation 3.7 can not converge to the correct estimate of r and K_{80}.

3.3.2. Uncertainty in the biomass parameter estimates

Because the non linear search uses as many equations as unknowns there are no error estimates for r and K. Error in the estimates of r and K may arise because of errors in the biomass estimates in years 1980 and 1994, or errors in the reporting the catches. There is no way of quantifying errors in catch reporting, and these are likely to be low as the recording of catches is closely monitored. Unfortunately, the biomass estimates in 1980 and 1994 were not reported with standard error. However, Robson and Regier (1967) suggested that 95% confidence limits of stock estimates are typically $\pm 10\%$ of the biomass. We will therefore use this to estimate errors in the biomass estimates and examine the effect on the estimates of r and K.

To determine the uncertainty in the parameter estimates it will be assumed that an error occurred in the estimation of the starting and ending biomass, and that this error is unbiased and normally distributed. The starting and ending biomasses are sampled with means B80 and B94 respectively and with standard error equal to 5% of the respective mean.

A VBA macro was used in Excel 7 to run the non-linear search in Solver and estimate the values of r and K_{80} for 100 sampled pairs of values for B_{80} and B_{94}. The outputs are 100 corresponding estimates values of r and K_{80}. From teach of these estimates K_{94}, MSY and $BMSY$ can be calculated. Figure 3.3 shows the envelope of predicted biomass trajectories based on the 100 paired estimates of r and K_{80} and the corresponding sampled values of B_{80} and B_{94}. The envelope of $BMSY$ values is also shown.

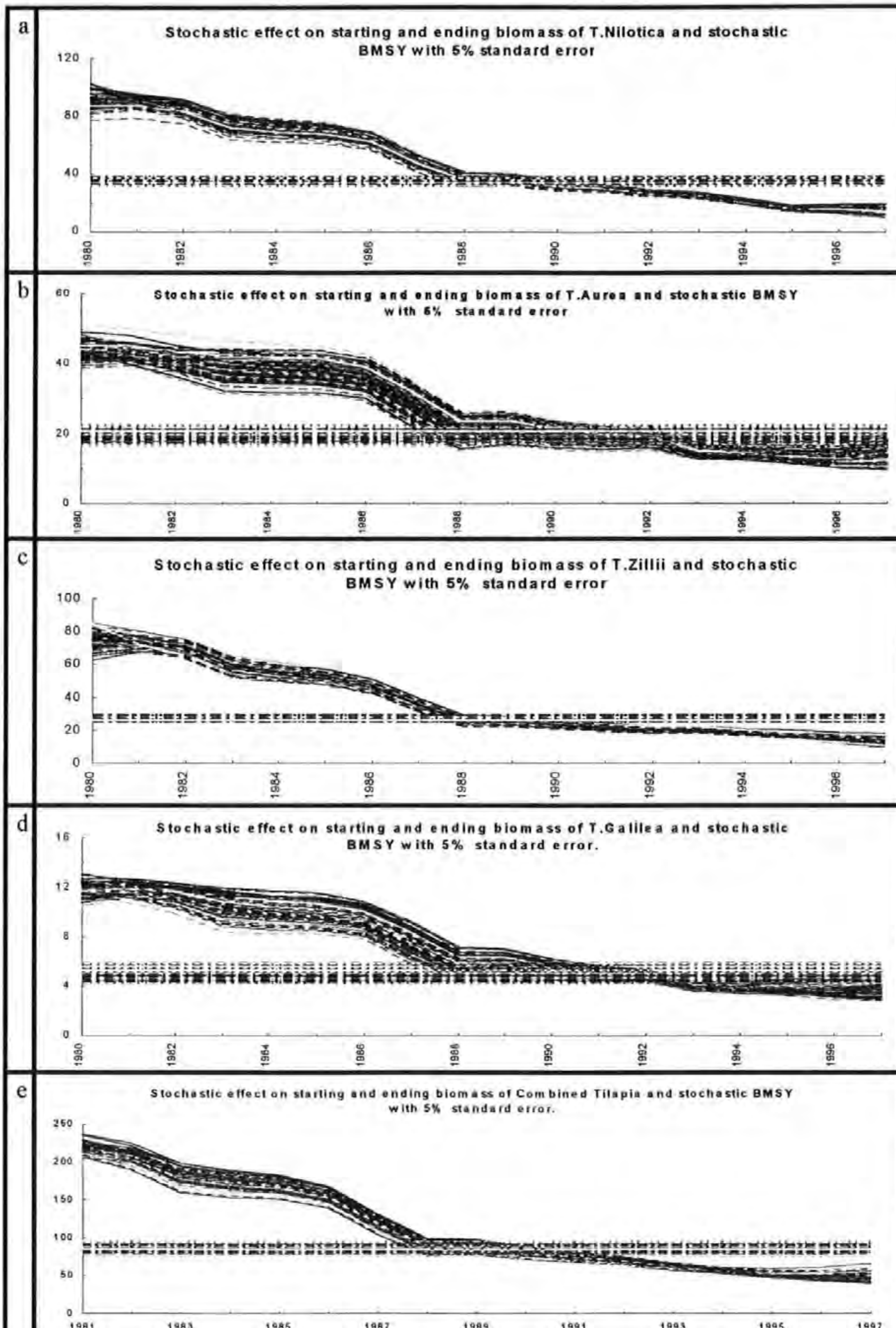


Figure 3.3 The stochastic effect with 5% standard error on starting and ending biomass and stochastic *BMSY* of (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii*, (d) *T.Galilea* and (e) *Combined Tilapia* stock.

Using Shapiro-Wilks Goodness-of-Fit statistic to compare the quantiles of the fitted normal distribution to the quantiles of the data distribution of 100 replicates of r, K_{80} and K_{94} produced P-values greater than 0.05 for the four species and *Combined Tilapia* stock, so there is no evidence that the values of r, K_{80} and K_{94} vary from the normal distribution. These 100 estimates are used to calculate 95% confidence intervals $(\bar{x} \pm 1.96\,SE)$ for r, K_{80} and K_{94}.

Table 3.2 shows the deterministic estimates for r, K_{80}, K_{94}, together with the 95% confidence intervals for each species and *Combined Tilapia* species, and standard error for r and K_{80} expressed as coefficient of variation CV = SE/ estimate. It is noted that if the coefficient of variation is 55 for B_{80} and B_{94}, then the coefficient of variation in the estimated value of r is 13%, the coefficient of variation in K_{80} and K_{94} is 8%, the coefficient of variation in the value of *MSY* is 5%, and the coefficient of variation in the estimated value of *BMSY* is 6%.

Table 3.2 The deterministic estimates values of r, K_{80}, K_{94} for each species and *Combined Tilapia* stock, coefficient of variation and 95% confidence level of them assuming the standard error of B_{80} and B_{94} is 5%.

Species		Estimate	CV	Upper	Mean	Lower
T.Nilotica	r	**0.766**	11%	0.933	0.772	0.612
	K_{80}	**105**	7%	119	105	92
	K_{94}	**59**	7%	67	59	52
T.Aurea	r	**0.775**	16%	1.039	0.789	0.538
	K_{80}	**59**	10%	72	60	48
	K_{94}	**33**	10%	40	34	27
T.Zillii	r	**0.671**	9%	0.785	0.665	0.545
	K_{80}	**83**	5%	93	84	76
	K_{94}	**47**	5%	52	47	43
T.Galilea	r	**0.732**	14%	0.946	0.739	0.532
	K_{80}	**15**	8%	17	15	12
	K_{94}	**8**	8%	10	8	7
Combined Tilapia	r	**0.740**	12%	0.922	0.751	0.579
	K_{80}	**260**	8%	298	259	221
	K_{94}	**147**	7%	168	147	125

The relationships between r and K_{80}, r and B_{80} , r and B_{94} , K_{80} and B_{80} and K_{80} and B_{94} for each species and for *Combined Tilapia* stock has also been investigated. It is not surprising there is almost a linear negative relationship between r and K_{80}, and almost a linear positive relationship between K_{80} and B_{80}. This is illustrated in Appendix A Figures 1A- 5A. Also the value of r is closely negatively related to the estimate of B_{80}. For sampled values of B_{80} which are less than the observed values, the estimated r value is greater than the deterministic estimate for all species because for a given B_{80} a small change in r after 14 iterations/years will give a relatively large change in predicted B_{94}. The changes in sampled B_{94} values have only marginal effect on the estimates for the values of r and K_{80}.

The same procedure has been used assuming that the standard error is 10% of B_{80} and B_{94}. Appendix A, Table 3A shows the estimates of the biomass model parameters, while Figure 6A shows the envelopes of predicted biomass trajectories. Figures 7A-11A show the relationships between the sampled biomasses and parameter estimates. When the standard error is assumed to be 10% of both B_{80} and B_{94} the relationships between corresponding estimates of r and K_{80}, r and B_{80}, r and B_{94}, K_{80} and B_{80}, and K_{80} and B_{94} for each species are similar to the relationships when the standard error was 5%, for all species.

It is noted that the biomass model using the 2 parameters search procedure converged each time to estimate r and K_{80} for each species either when the standard error is 5% or 10% of B_{80} and B_{94}. Also it is noted that adding random effects to the annual catches, assuming either a 5% or 10% coefficient of variation in reporting errors, has virtually no effect on the estimates of r and K_{80} because the mean error over the 14 years 1980-1994 is small.

3.4. Validation of parameters estimates

Although we take estimates of r and K_{80} which are reliable and consistent with other studies, it is useful to see whether they are consistent with those obtained using other methods of estimation. Clearly, if biomass estimates for the intervening years (1981-1993) were available, estimates of r and K_{80} can be found from equation 3.7. We will make simple assumptions about catchability which give intervening biomass estimates. In addition, standard fisheries models using catch per unit effort (CPUE) as a surrogate for biomass will be investigated.

3.4.1. Parameter estimation using imputed biomass time series

It is common to assume (e.g. Hilborn, 1976) that the catch per unit effort is proportional to biomass, and the simplest assumption is that the proportionality is constant. This proportionality constant is usually called "*catchability*". The relationship between catch per unit effort and biomass can be expressed as follows:

$$U_t = \frac{C_t}{E_t} = qB_t \qquad \textbf{(3.13)}$$

where:

U_t is the catch per unit of effort in year t,

E_t is fishing effort, where fishing effort measured by number of vessels and

q is *catchability coefficient* or the fraction of fish stock which is caught by a unit of fishing effort.

Equation 3.13 is based upon constant catchability and constant fishery exploited area. But in the case of Lake Manzala the exploited area decreased on three occasions during 1977 to 1997, so equation 3.13 must be modified to take into account the changes in the exploited area. Then equation 3.13 can be re-expressed as follows:

$$U_t = \frac{C_t}{E_t} = m\frac{B_t}{A_t} \qquad \textbf{(3.14)}$$

where m is *area-adjusted catchability* or the catch per unit of effort (a vessel) per unit of biomass density.

Because the estimates of B_{80} and B_{94} values are available for the four species and *Combined Tilapia* stock, annual catch data and number of vessels, then the *area-adjusted* *catchability* in 1980 can be estimated by using equation 3.14 as $m_{80} = \dfrac{C_{80}\, A_{80}}{E_{80}\, B_{80}}$ and in 1994 as $m_{94} = \dfrac{C_{94}\, A_{94}}{E_{94}\, B_{94}}$, for each species and for *Combined Tilapia* stock. There are number of assumptions that would be made in estimating the biomass time series by using these two estimates of the *area-adjusted catchability* such as:

1. Assume that the *area-adjusted catchability* is constant and known.

2. Assume that the *area-adjusted catchability* is a linear function of time.

<u>(1) Constant *area-adjusted catchability*</u>

According to this assumption, there are many ways to fix the *area-adjusted catchability* which can be as follows:

(A.1.) For each stock *area-adjusted catchability* is equal to the initial value.

(B.1.) For each stock *area-adjusted catchability* is equal to the final value.

(C.1.) For each stock *area-adjusted catchability* is equal to the average of m_{80} and m_{94}.

(D.1.) For each stock *area-adjusted catchability* is equal to the average of m_{80} and m_{94} of the *Combined Tilapia* stock.

We have four series of estimated biomasses based on these assumptions. Note that unless $m_{80} = m_{94}$, each estimated series will have wrong biomass estimates at one end or the other or both. However, all these assumptions give series which show a similar pattern (Figure 12A in Appendix A).

Now estimates are required for the values of r and K_{80} based upon these different assumptions. The estimation of r and K_{80} can be based upon equation 3.7 which can be rewritten as follows:

$$B_{t+1} - B_t + C_t = r\left[B_t - 0.5C_t\right] - \frac{r}{K_{80}}\left[B_t - 0.5C_t\right]^2 \left[\frac{A_{80}}{A_t}\right] \qquad \textbf{(3.15)}$$

Using multiple regression to estimate the parameters of equation 3.15 is not recommended because there are an interaction between the parameters. Estimating the parameters of equation 3.15 has been carried out using non-linear regression for each estimated series of biomass. The goal of non-linear regression is to find a least squares solution for a non-linear model, which cannot be done using matrix algebra as it is in linear regression (Neter et al. 1996 and Myers 1990). Table 3.3 shows the resulting estimates for r, K_{80} *and* K_{94} together with SE for r and K_{80} (expressed as CV= SE/estimates) for each species and for the *Combined Tilapia* stock. It is noted that:

- Parameter estimates are very sensitive to the assumption used.

- Parameter estimates are always not consistent with other studies.

- Parameter estimates are unreliable because the coefficients of variation are very high and the confidence interval for r and K_{80} are too big, and covering zero value.

- The available biomass data (B_{80} and B_{94}) not used.

Table 3.3 The estimated values of *r*, K_{80} and K_{94}, and the coefficient of variation (CV) for each species and for *Combined Tilapia* stock based on the four assumption of the constant *area-adjusted catchability*.

Species	Assumption	*r*	K_{80}	K_{94}	CV of *r*	CV of K_{80}
T.Nilotica	$m = m_{80}$	0.525	106	60	78%	56%
	$m = m_{94}$	1.184	56	32	43%	25%
	$m = (m_{80} + m_{94}) / 2$	0.608	105	59	59%	19%
	$m = (Tilapia\, m_{80} + Tilapia\, m_{94}) / 2$	0.661	89	50	66%	44%
T.Aurea	$m = m_{80}$	0.624	63	35	52%	22%
	$m = m_{94}$	1.314	43	24	23%	11%
	$m = (m_{80} + m_{94}) / 2$	0.898	44	25	30%	15%
	$m = (Tilapia\, m_{80} + Tilapia\, m_{94}) / 2$	0.870	62	35	30%	11%
T.Zillii	$m = m_{80}$	0.468	99	56	46%	16%
	$m = m_{94}$	1.151	55	31	37%	14%
	$m = (m_{80} + m_{94}) / 2$	0.889	64	36	44%	16%
	$m = (Tilapia\, m_{80} + Tilapia\, m_{94}) / 2$	0.687	75	42	10%	4%
T.Galilea	$m = m_{80}$	0.730	12	7	34%	9%
	$m = m_{94}$	0.963	11	6	44%	12%
	$m = (m_{80} + m_{94}) / 2$	0.887	12	7	47%	12%
	$m = (Tilapia\, m_{80} + Tilapia\, m_{94}) / 2$	0.863	12	8	48%	12%
Combined	$m = m_{80}$	0.616	275	155	70%	20%
Tilapia	$m = m_{94}$	1.102	163	92	23%	7%
	$m = (Tilapia\, m_{80} + Tilapia\, m_{94}) / 2$	0.852	203	115	14%	9%

(2) *Area-adjusted catchability* as a linear function of time

Because there are two available estimates of *area-adjusted catchability* (m_{80} and m_{94}) for each species, it is reasonable to assume that the *area-adjusted catchability* is a linear function of time $(m_t = a + bt_t)$, using the two estimates of *area-adjusted catchability* against the time starting from 1980. Then equation 3.14 can be modified to have the following form:

$$\frac{C_t}{E_t} = m_t \frac{B_t}{A_t} \tag{3.16}$$

where:

$$m_t = m_{80} + \frac{m_{80} + m_{94}}{14} t, \; t = 0, 1, 2, 3, \ldots \text{ in years from 1980.}$$

As before the estimated *area-adjusted catchability* function could be a separate function for each species or a common *area-adjusted catchability* function from the *Combined Tilapia* stock.

Clearly, when using species-specific catchability the estimated biomass series will pass through the correct values at the end-points, whereas this is not the case when a common value is assumed.

Figure 13A in Appendix A shows the estimated biomass series using equation 3.16 for the four species and for *Combined Tilapia* stock. It is noted that all series of estimated biomasses show the same behaviour despite the different assumptions.

Estimating the parameters r and K_{80} of equation 3.15 as before gives the results in Table 3.4.

If each species has its separate *area-adjusted catchability* values the estimates of the carrying capacity K_{80} are greater than the biomass estimates B_{80}. The total species biomass in 1980 represent 82% of the sum of 1980 carrying capacity estimates for the four species. The estimated values of the 1994 carrying capacity K_{94} are considerably higher than the biomass estimates B_{94} and the total species biomass in 1994 represent only 36% of the sum of 1994 carrying capacity estimates for the four species.

If the common *area-adjusted catchability* values is applied the estimates of the carrying capacity K_{80} are greater than the biomass estimates B_{80}. The total species biomass in 1980 represent 94% of the sum of 1980 carrying capacity estimates for the four species. The estimated values of the 1994 carrying capacity K_{94} are considerably higher than the biomass estimates B_{94} and the total species biomass in 1994 represent only 42% of the sum of 1994 carrying capacity estimates for the four species.

From the results of applying this method (Table 3.4), it is noted that using the common *area-adjusted catchability* values gives parameter estimates consistent with the other studies and not sensitive to the assumptions. The estimates are reliable because the coefficient of variation is reasonable; also these estimates are closer to those obtained from the non linear search than are the estimates from using separate *area-adjusted catchability* values.

Table 3.4 The estimated parameters of equation 3.16 and the coefficient of variation CV of each parameter based upon using separate *area-adjusted catchability* values and using common *area-adjusted catchability* values for each species and *Combined Tilapia* stock.

	Separate m				Common m			
	r	K_{80}	CV of r	CV of K_{80}	r	K_{80}	CV of r	CV of K_{80}
T.Nilotica	0.780	89	14%	8%	0.759	91	14%	8%
T.Aurea	0.815	52	18%	12%	0.708	58	17%	12%
T.Zillii	0.674	119	15%	6%	0.680	74	16%	7%
T.Galilea	0.840	12	17%	11%	0.735	12	15%	7%
Combined Tilapia	0.702	234	12%	10%				

The residuals from these fitted models (Figures 14A and 15A in Appendix A) indicate no problems with the fit. The positive and negative residuals are balanced, they have no pattern and the small residual are most common.

3.4.2. Parameter estimates using catch per unit effort time series

Hilborn (1976) attempted to use catch per unit effort (U) as a surrogate for biomass, assuming that the catchability is constant from year to the next where the unit of effort is a vessel. Hilborn (1992) transformed his model (by substituting equations 3.13 in 3.3) to get the following equation:

$$\frac{U_{t+1}}{q} = \frac{U_t}{q}(1 + r - r\frac{U_t}{qK}) - U_t E_t \qquad \textbf{(3.17)}$$

giving

$$\frac{U_{t+1}}{U_t} - 1 = r - \frac{r}{qK}U_t - qE_t \qquad \textbf{(3.18)}$$

Equation (3.18) has the practical advantage that r and K can be estimated without any biomass data. Also it has the computational advantage that it conforms to a standard multiple linear regression of the form $Y=b_o+b_1X_1+b_2X_2$,

where

$Y = \frac{U_{t+1}}{U_t} - 1$ the dependent variable is the rate of change of biomass,

$X_1 = U_t$ the first independent variable is catch per unit effort,

$X_2 = E_t$ the second independent variable is the fishing effort and

the regression parameters are $b_o = r$, $b_1 = -r / Kq$ and $b_2 = -q$.

Equation 3.18 is based on the assumptions that the catchability is constant and unknown, that the catch has been taken after the biomass growth had taken effect, and that K is constant. Modifying equation 3.18, allowing K to change with area and half the catch to be taken before growth, then equation 3.18 can expressed as follows

$$\frac{U_{t+1}A_{t+1}}{U_t A_t} - 1 = r - (m + \frac{mr}{2})\left(\frac{E_t}{A_t}\right) - \frac{r}{mK_{80}}\left(U_t\ A_{80}\right) + \frac{r}{K_{80}}\left(\frac{E_t}{A_t}\right)\left(U_t\ A_{80}\right) - \frac{mr}{4K_{80}}\left(\frac{E_t}{A_t}\right)^2\left(U_t\ A_{80}\right) \quad \textbf{(3.19)}$$

Using multiple regression method to estimate the parameters in this form is not recommended because of the confounding between the parameters.

Non-linear regression has been used to estimate model parameters (equation 3.19) for annual time series of the four species and for *Combined Tilapia* stock from 1980 to 1997. It is noted that these estimates of r and K_{80} are not reasonable because they are not consistent with the estimates values of r and K_{80} produced by using non linear search, or with parameter estimates using estimates of biomass time series, or with other studies. Also this method is based on a rigid assumption of the *area-adjusted catchability* and dose not use the available biomass data B_{80} and B_{94}.

Table 3.5 The biomass parameters estimates based on using catch per unit effort time series.

Species	r	m*10^5	K_{80}	CV of r	CV of K_{80}
T.Nilotica	0.527	2.2	166	51%	110%
T.Aurea	0.714	4.7	61	94%	127%
T.Zillii	0.624	1.3	246	31%	113%
T.Galilea	0.674	3.2	20	91%	124%
Combined Tilapia	0.619	4.3	257	40%	179%

Using linear regression to estimate the parameters of equation 3.19 gives poor results such as negative growth rate, but using non linear regression gives parameters estimates more reasonable than linear regression parameters estimates. This results are consistent with Hilborn's opinion, Hilborn said "When people first started experimenting with regression methods for estimating Hilborn model parameters, they often obtained negative parameters; r or q were estimated as less than zero, which is biologically impossible. It was felt that this indicated model failure, that the assumptions of the model were just too simple and that by not explicitly incorporating lags to recruitment and so on, these simple biomass dynamic models were failing to capture some important aspects of the data." (Hilborn, 1992).

3.5. Comparison between methods

Three approaches have been described for estimating the biomass model parameters which can be summarised as follows:

(1) Non linear search using a spreadsheet Solver:

This method is based on two biomass estimate (B_{80} and B_{94}) and catch data from 1980 to 1994, using equation 3.10 and successive implementation of equation 3.7 to estimate the values of r and K_{80}. The advantage of this method is the ability to produce good estimates for r and K_{80} which agree with other studies, while the disadvantage of this method is there is no estimate of the standard error of r and K_{80}. However we can get over this problem by adding uncertainty to the starting and ending biomasses and using simulation to estimate standard errors for r, K_{80} and K_{94}.

(2) Parameter estimation using imputed biomass time series:

This method is based on assumptions about *area-adjusted catchability* to estimate r and K_{80}. There are two sub-methods explored:

- assume that the *area-adjusted catchability* is constant and known
- assume a linear function for the *area-adjusted catchability* in 1980 and 1994 against time.

The first sub-method gave inconsistent estimates of the biomass parameters r and K_{80}. However the second sub-method, gave parameter estimates in good agreement with other studies and close to the non linear search estimates, and reasonable confidence intervals for the parameter estimates. This is especially true when using a common linear function of *area-adjusted catchability* for all species. Like the non linear search, this method uses the available biomass and catch data. However, it is necessary to assume a linear function for the *area-adjusted catchability*. *Area-adjusted catchability* values showed a slowly changing over the short term, but it might be increased or decreased in the long term for some reasons such as: changing of technical performance, increasing or decreasing the fishermen efficiency, changing recruitment from year to year or changing of fishing interference.

(3) Parameter estimates using catch per unit effort time series

This method is based on Hilborn's model to estimate the values of r, K_{80} and m using time series of catches and effort. An apparent advantage of this method is the ability to estimate the standard error of the biomass parameters. However, it fails to take advantage of biomass data from 1980 and 1994 and the parameter estimates are not in a good agreement with the other methods of estimation or with the other studies. The confidence interval of the parameters estimates are bigger than any other method.

From this discussion both the method based upon non-linear search facility or imputed biomass time series assuming a common linear function for the *area-adjusted catchability* gave reasonable and very similar parameter estimates. Because the non-linear search facility can give associated sets of the biomass parameters r, K and B_{94} which will be useful later in chapter seven, we are going to use this method to estimate the biomass parameters.

The next chapter will discuss the determination of good fisheries management strategies.

Chapter 4 Fisheries management

4.1. Introduction

There are many approaches to the management of fisheries. These include landing control, quota control, fish closed seasons, and effort control. Of course any management policy may have its negative impact in the short term from social and economic points of view.

Landing control appears to be an easy way to control the fishing. It means leaving the current fleet without any changes and closing the fishery when the total catch reaches some prescribe limit. This procedure can be repeated every year. But landing control does not control number of nets, number of fishermen, trip duration, and number of mesh. Unfortunately the allowable catch may be caught in less than a year, and non-fishing for the rest of a year may cause unemployment problems. Also fishermen will pay the annual fees for the fishing licence and there is no guarantee for them to fish all the year.

Quota control allows everyone to land a certain quantity of fish but quota control needs to determine an allowable number of vessels and the fair quota for each vessel. To implement a closed season policy modelling would be needed to determine how long a closed season would be required. To use effort control it is necessary to determine how many vessels should be allowed to fish. So, quota control, closed seasons, and effort control all required the development of a model to predict the catches from a given stock for a permitted fleet.

This study assumes that effort control will be used in this fishery with fewer vessels allowed to fish but allowing them to fish for the whole year. There will be unemployment, but there will be less uncertainty, so planning will be easier for the individual fishermen. Choosing effort control means that a model must be developed to predict the catches that would result from a given stock for any permitted fleet effort.

4.2. Stock behaviour

4.2.1. Assumptions

Figure 4.1 shows the effect of different levels of effort on the stock behaviour assuming that the catch is proportion to the biomass for a given effort. If the effort is at a critical level or above, the stock will collapse because catch is greater than the net recruitment. The critical effort is twice the optimum effort, where optimum effort is that fishing effort which can catch MSY amount of fish if the stock at $BMSY$ level. If the effort level is low, then the biomass will converge to the point B and if the effort is absent (zero gradient) the biomass will tend to the carrying capacity. If the effort is at optimum level the biomass will converge to $BMSY$ level with the catch equal to MSY. In the commonly used continuous-time net recruitment model the critical effort level is twice that needed for the optimum effort which can catch MSY.

This discussion can be summarised in the following points: for constant critical effort or above the stock will deplete, for low constant effort the stock will converge to equilibrium at some level and for no effort the stock will tend to the carrying capacity.

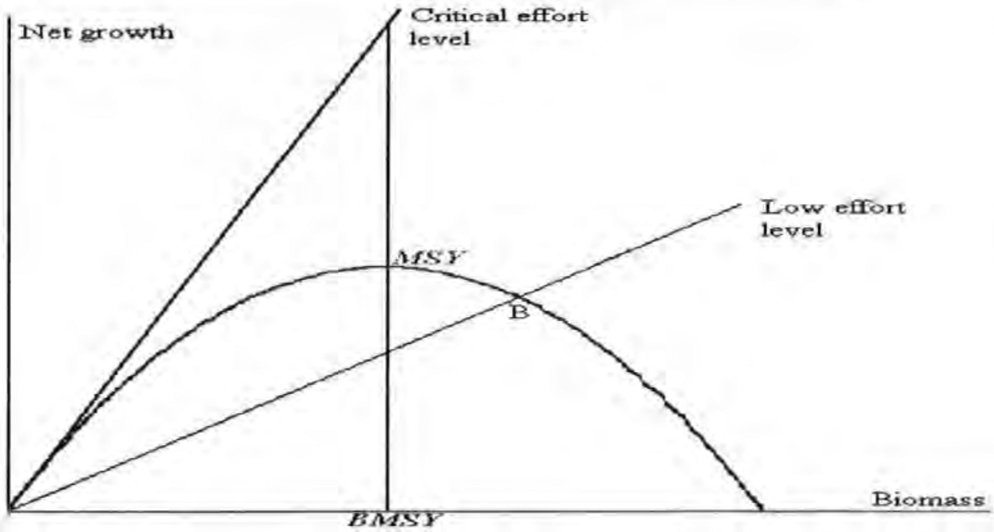


Figure 4.1 Relationship between biomass and net growth with different catch levels.

Assume that the fishing effort is constant since 1997, which means that the 1997 fleet (3741 vessels) is allowed to continue fishing. Because the 1997 fleet caught 21.42 kt of *Total Tilapia,* which represents 54% of the *Total Tilapia* biomass in 1997, the same fleet would catch the same proportion of the biomass during next period. Figure 1B in Appendix B shows the predicted catch and biomass estimates of the four species and *Total Tilapia* if the 1997 fleet continues fishing. It is clear that the continuation of fishing at the current level will further deplete the stock and the catches will be uneconomic because the effort is at too high a level and the stock is below the *BMSY* level.

4.2.2. Potential stock recovery

Lake Manzala authority banned fishing in 1998. Figure 4.2 shows the *Total Tilapia* stock behaviour if the fishing is stopped from 1998 to 2012. It is noted that stopping fishing for eight years will allow the stock to be close to the carrying capacity of the lake by 2005. (Figure 2B in Appendix B for the four species)

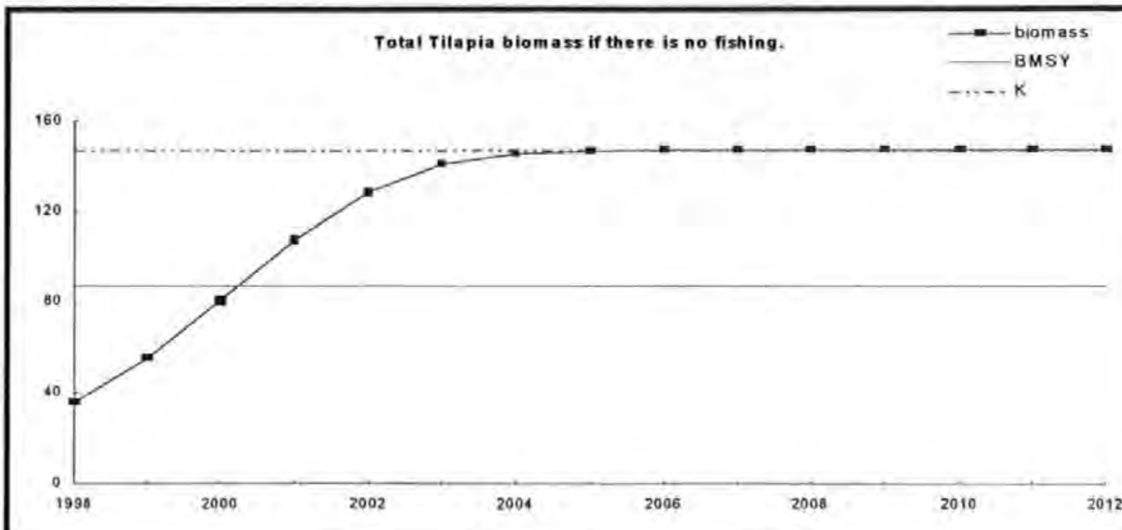


Figure 4.2 Biomass estimation, predicted catch, *MSY*, *BMSY* and *K* for *Total Tilapia* if the fishing is stopped for long time.

4.2.3. *Area-adjusted catchability*

Before we can model the effect of different effort on the individual *Tilapia* stocks, we need to make some assumptions about *area-adjusted catchability*. Figure 4.3 shows the *area-adjusted catchability* of the four species and *Total Tilapia* stock from 1980 to 1997 based on the trajectory of biomass estimates produced by using non linear search. This figure show that the four species have a similar pattern to the *area-adjusted catchability* over time. The variation from a common pattern may be the result of mis-classification of the catch data in the past, because there is little visible difference between the four species. This figure also shows that all species have similar *area-adjusted catchability* values. So, even when the *area-adjusted catchability* of each species changes they all remain approximately equal. In addition, the most consistent and reliable alternative method of estimating r and K_{80} was the one which assumed equal *area-adjusted catchability* for all species. Therefore, in future modelling of catches, the catch of each species will be proportional to its biomass.

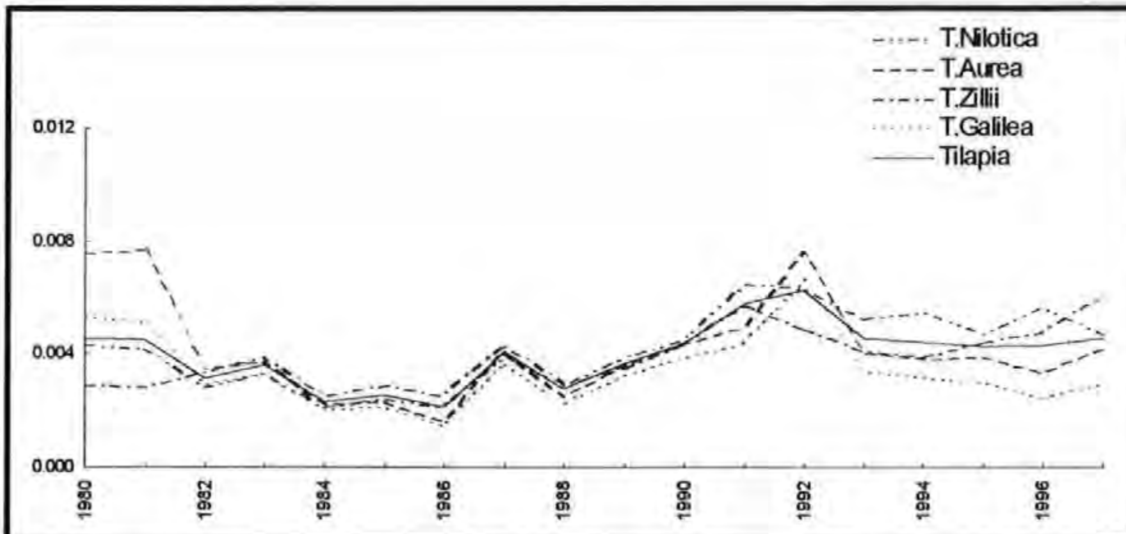


Figure 4.3 ***Area-adjusted catchability*** **estimation for each species during the period 1980-1994.**

From the previous discussion, subsequent modelling will based on the following assumptions:

- catch is proportional to biomass,
- the *area-adjusted catchability* is the same for each of the four species,
- stock can converge to equilibrium at some level if the effort is below critical level.

The next section will investigate the stock recovery rate in the light of this discussion.

4.3. Stock recovery rates

In the context of this study, stock recovery will be taken to mean that the stock grows until it is equal to or exceeds the *BMSY* level. However, stock recovery does not mean each species biomass must exceed its *BMSY* level, but it means the total stock must exceed the total *BMSY* level. Thus some species biomass could be above their *BMSY* level and the others could be below their *BMSY* level, but if the total stock exceeds the *BMSY* level and there are stability in the biomasses provided the effort is appropriate.

Now there is an immediate questions which is: what is the minimum non-fishing period to allow the stock to recover. It is found that stopping fishing for four years starting from 1998 will allow the *Combined Tilapia* stock to exceed the *BMSY*. Table 4.1 shows the estimations of each species and *Combined Tilapia* stock at the beginning of each year, together with *BMSY*. It is noted that non-fishing for four years allows *T.Nilotica* and *T.Zillii* exceed their *BMSY* levels by the beginning of 2002. *T.Aurea* by the start of 2000 and *T.Galilea* by the start of 1999. Also it is noted that *Combined Tilapia* stock will exceed its *BMSY* level by 2001 after three years of stopping fishing which means that the minimum period to stop fishing is three years. So, there is no need to stop fishing for four years, because three years of stop fishing will allow *Combined Tilapia* stock to recover.

Table 4.1 Estimations of the four species biomasses, *Combined Tilapia* biomass at the start of each year and *BMSY* if the fishing is stopped for 4 years then start to fish using the effort for *MSY*.

Years	*T.Nilotica*	*T.Aurea*	*T.Zillii*	*T.Galilea*	*Combined Tilapia*
1998	8.95	11.50	6.93	4.23	35.24
1999	14.78	17.34	10.90	**5.72**	55.05
2000	23.29	**23.78**	16.53	6.98	80.49
2001	34.15	29.06	23.69	7.73	**107.36**
2002	**45.28**	31.94	**31.58**	8.04	128.67
BMSY	**35.42**	**19.89**	**27.45**	**4.84**	**86.95**

4.4. Stock management strategies

Although in chapter three uncertainty in the biomass model has been investigated, this chapter will examine catch strategies which allow the stocks to recover based upon the deterministic biomass model to determine the effort for *MSY* which can achieve the catch strategies. Effort for *MSY* means the effort level which can catch *MSY* amount of fish if and only if the stock is at *BMSY* level. This effort will yield less than *MSY* if the stock is below *BMSY* level and more than *MSY* if the stock is above *BMSY* level. The actual fleet structure which gives effort for *MSY* will be determined in two ways in chapters five and six, then the effect of adding uncertainty to the biomass model parameters and to the catch model parameters will be discussed in chapter seven.

The deterministic biomass model will now be used to investigate different management strategies for the *Combined Tilapia* stock in Lake Manzala. The aim is to investigate the stock behaviour if the fishing stopped for less than four years. Biomass recovery requires a catch strategy each year whose impact on each species can be assessed. Catch strategies must start from 1998 to enable stocks to recover. There are a number of catch strategies, and the following three are investigated:

(1) Stop fishing for one year 1998 and from 1999 and beyond use effort for *MSY*.

(2) Stop fishing for two years 1998-1999 and from 2000 and beyond use effort for *MSY*.

(3) Stop fishing for three years 1998-2000 and from 2001 and beyond use effort for *MSY*.

Determine the fleet·size for *MSY* based on the assumption that the fleet has a fixed size and hence there is fixed effort once the fishing re-starts.

4.4.1. First catch strategy (S1)

The aim of using the first catch strategy is to reduce the non-fishing period to one year and investigate the stock behaviour. It is noted that this catch strategy produced catches which converge towards *MSY* for all species at a variety of rates, but generally by 2017 (Figure 4.4).

Figure 4.4 shows the biomass estimates, expected catch, *MSY* and *BMSY* for each species and *Combined Tilapia* stock for the first catch strategy. It is found that by the start of year 2017 the *Combined Tilapia* stock will exceed its *BMSY* level. The catch of some species is above the *MSY* level for some years and below that level in other years because the total catch in a year is split according to the biomass proportions at the end of the previous year. Thus, *T.Nilotica* biomass will exceed its *BMSY* level by 2010, *T.Aurea* will exceed its *BMSY* level by 2003, *T.Zillii* biomass will not exceed its *BMSY* levels but it will be stable at about 25 kt starting from 2013, *T.Galilea* biomass will exceed its *BMSY* level by 1999. Some species will give catches below *MSY* and the others will give catches above *MSY*, but starting from year 2017 the catch will equal the *MSY*. Table 4.2 shows the biomass prediction, catch estimates together with *BMSY* and *MSY* for the four species and *Combined Tilapia* stock.

Table 4.2 Biomass prediction, expected catch together with *BMSY* and *MSY* for the four species and *Combined Tilapia* stock using catch strategy 1.

S1	*T.Nilotica*		*T.Aurea*		*T.Zillii*		*T.Galilea*		*Combined Tilapia*	
Years	biomass	catch	biomass	catch	biomass	catch	biomass	catch	biomass	catch
1998	8.95	0	11.50	0	6.94	0	4.23	0	35.24	0
1999	14.78	4.60	17.34	5.39	10.92	3.40	5.72	1.78	55.05	17.18
2000	17.74	5.52	18.31	5.69	12.50	3.89	5.39	1.68	61.35	19.15
2001	20.81	6.47	19.04	5.92	14.11	4.39	5.19	1.61	66.99	20.91
2002	23.83	7.41	19.57	6.09	15.70	4.88	5.07	1.58	71.79	22.41
2003	26.62	8.28	19.94	6.20	17.21	5.35	4.98	1.55	75.69	23.62
2004	29.05	9.03	20.20	6.28	18.60	5.79	4.93	1.53	78.75	24.58
2005	31.06	9.66	20.37	6.33	19.85	6.17	4.89	1.52	81.07	25.30
2006	32.63	10.15	20.49	6.37	20.92	6.50	4.87	1.51	82.78	25.84
MSY		*11.39*		*6.46*		*7.89*		*1.50*		*27.14*
BMSY	*35.42*		*19.89*		*27.45*		*4.84*		*86.94*	

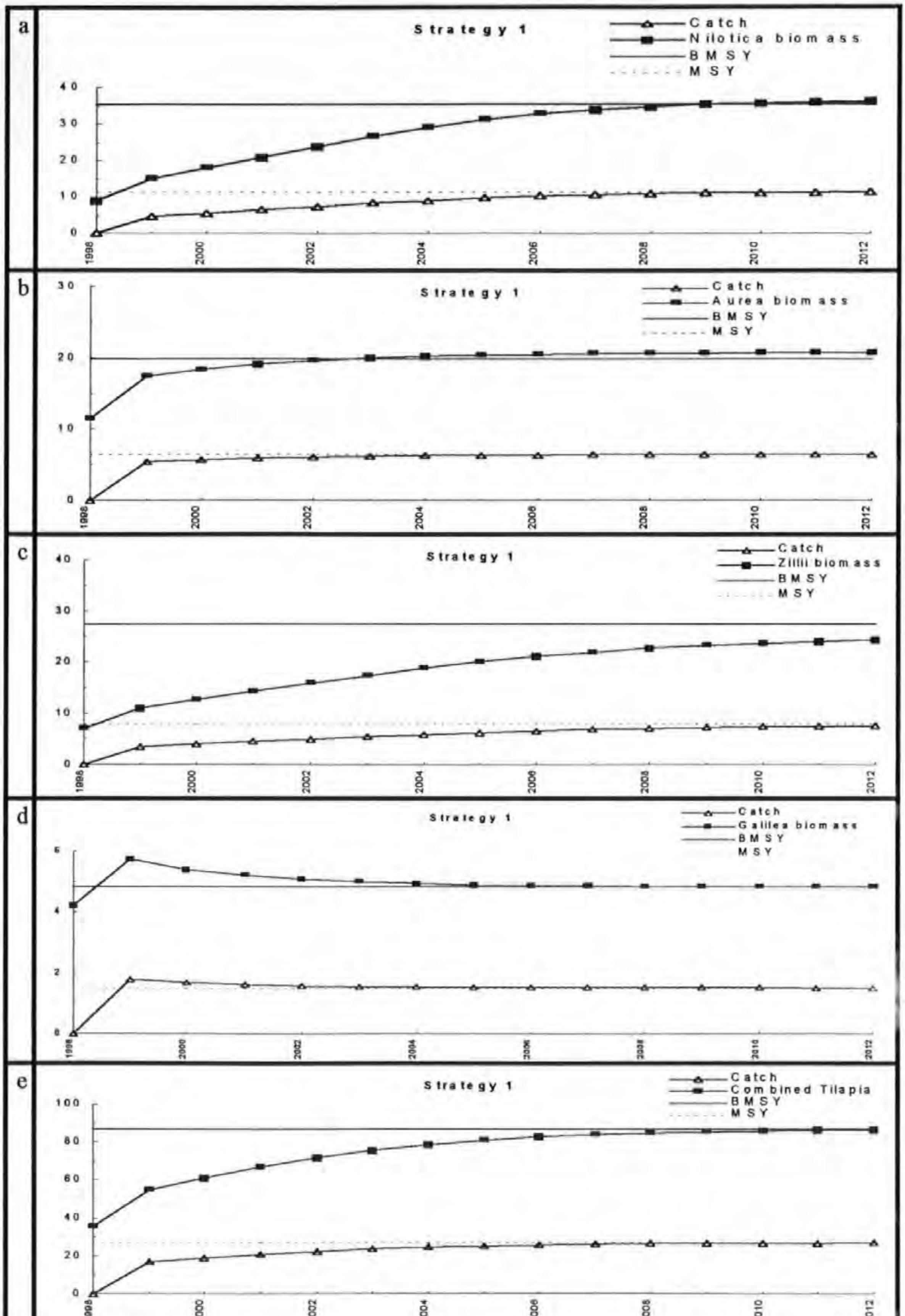


Figure 4.4 Biomass prediction, expected catch together with *BMSY* and *MSY* for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Combined Tilapia* stock using first catch strategy (S1).

4.4.2. Second catch strategy (S2)

If fishing stopped for two years, the *Combined Tilapia* stock would recover and reach to *BMSY* by year 2012. The results of biomass prediction, the expected catch, and the *BMSY* and *MSY* for the four species and *Combined Tilapia* stock are listed below in Table 4.3 and shown in Figure 4.5. The predicted catches will be equivalent to *MSY* for each species starting from year 2012 and beyond. The *Combined Tilapia* stock biomass can recover by 2012. According to this strategy (S2), *T.Nilotica* biomass will exceed its *BMSY* level by 2008, *T.Aurea* will exceed its *BMSY* level by 2000, *T.Zillii* biomass will keep stable with 25 kt starting from 2011 and beyond, and *T.Galilea* biomass will exceed its *BMSY* level by 1999.

Table 4.3 Biomass prediction, expected catch together with *BMSY* and *MSY* for the four species and *Combined Tilapia* stock using catch strategy 2.

S2	*T.Nilotica*		*T.Aurea*		*T.Zillii*		*T.Galilea*		*Combined Tilapia*	
Years	biomass	catch	biomass	catch	biomass	catch	biomass	catch	biomass	catch
1998	8.95	0	11.50	0	6.94	0	4.23	0	35.24	0
1999	14.78	0	17.34	0	10.92	0	5.72	0	55.05	0
2000	23.29	7.24	23.78	7.40	16.55	5.15	6.98	2.17	80.49	25.12
2001	26.13	8.13	22.57	7.02	18.00	5.60	6.01	1.87	82.36	25.70
2002	28.64	8.91	21.88	6.80	19.31	6.01	5.55	1.73	83.71	26.13
2003	30.73	9.56	21.45	6.67	20.46	6.36	5.29	1.64	84.68	26.43
2004	32.38	10.07	21.19	6.59	21.44	6.67	5.13	1.59	85.37	26.65
2005	33.63	10.46	21.02	6.54	22.25	6.92	5.03	1.56	85.85	26.80
2006	34.54	10.74	20.92	6.50	22.91	7.12	4.96	1.54	86.19	26.90
MSY		*11.39*		*6.46*		*7.89*		*1.50*		*27.14*
BMSY	*35.42*		*19.89*		*27.45*		*4.84*		*86.94*	

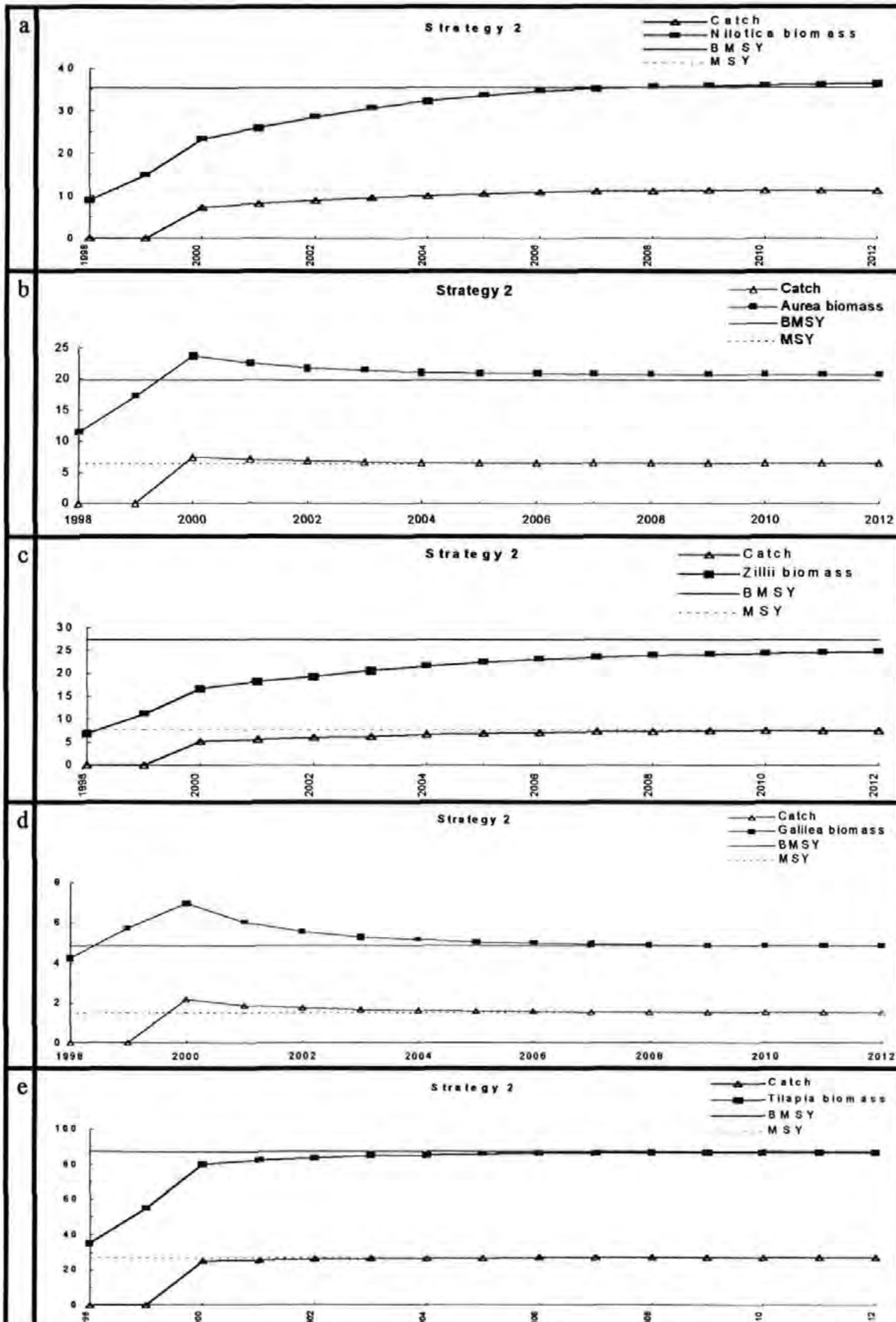


Figure 4.5 Biomass prediction, expected catch together with *BMSY* and *MSY* for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Combined Tilapia* stock using second catch strategy (S2).

4.4.3. Third catch strategy (S3)

If fishing stopped for three years (1998-2000), the *Combined Tilapia* stock can recover after three years. The results of biomass prediction, the catch estimates, and the *BMSY* and *MSY* for the four species and *Combined Tilapia* stock are listed below in Table 4.4 and shown in Figure 4.6. It is noted this catch strategy produced catches towards *MSY* for all species at a variety of rates, but generally converging by 2001 (Figure 4.6). According to this strategy *T.Nilotica* biomass will exceed its *BMSY* level by 2003, *T.Aurea* will exceed its *BMSY* level by 2000, *T.Zillii* will keep stable with 25 kt starting from 2008 and *T.Galilea* biomass will exceed its *BMSY* level by 1999 while the *Combined Tilapia* stock will exceed the *BMSY* level in year 2001.

Table 4.4 Biomass prediction, expected catch together with *BMSY* and *MSY* for the four species and *Combined Tilapia* stock using catch strategy 3.

S3	*T.Nilotica*		*T.Aurea*		*T.Zillii*		*T.Galilea*		*Combined Tilapia*	
Years	biomass	catch	biomass	catch	biomass	catch	biomass	catch	biomass	catch
1998	8.95	0	11.50	0	6.94	0	4.23	0	35.24	0
1999	14.78	0	17.34	0	10.92	0	5.72	0	55.05	0
2000	23.29	0	23.78	0	16.55	0	6.98	0	80.49	0
2001	34.15	10.62	29.06	9.04	23.75	7.39	7.73	2.40	107.37	33.51
2002	34.91	10.85	25.03	7.78	24.09	7.49	6.29	1.96	99.50	31.05
2003	35.44	11.02	23.24	7.23	24.35	7.57	5.70	1.77	95.01	29.66
2004	35.81	11.13	22.27	6.92	24.55	7.63	5.37	1.67	92.26	28.80
2005	36.06	11.21	21.69	6.75	24.70	7.68	5.18	1.61	90.50	28.25
2006	36.23	11.27	21.34	6.64	24.81	7.72	5.06	1.57	89.34	27.89
MSY		*11.39*		*6.46*		*7.89*		*1.50*		*27.14*
BMSY	*35.42*		*19.89*		*27.45*		*4.84*		*86.94*	

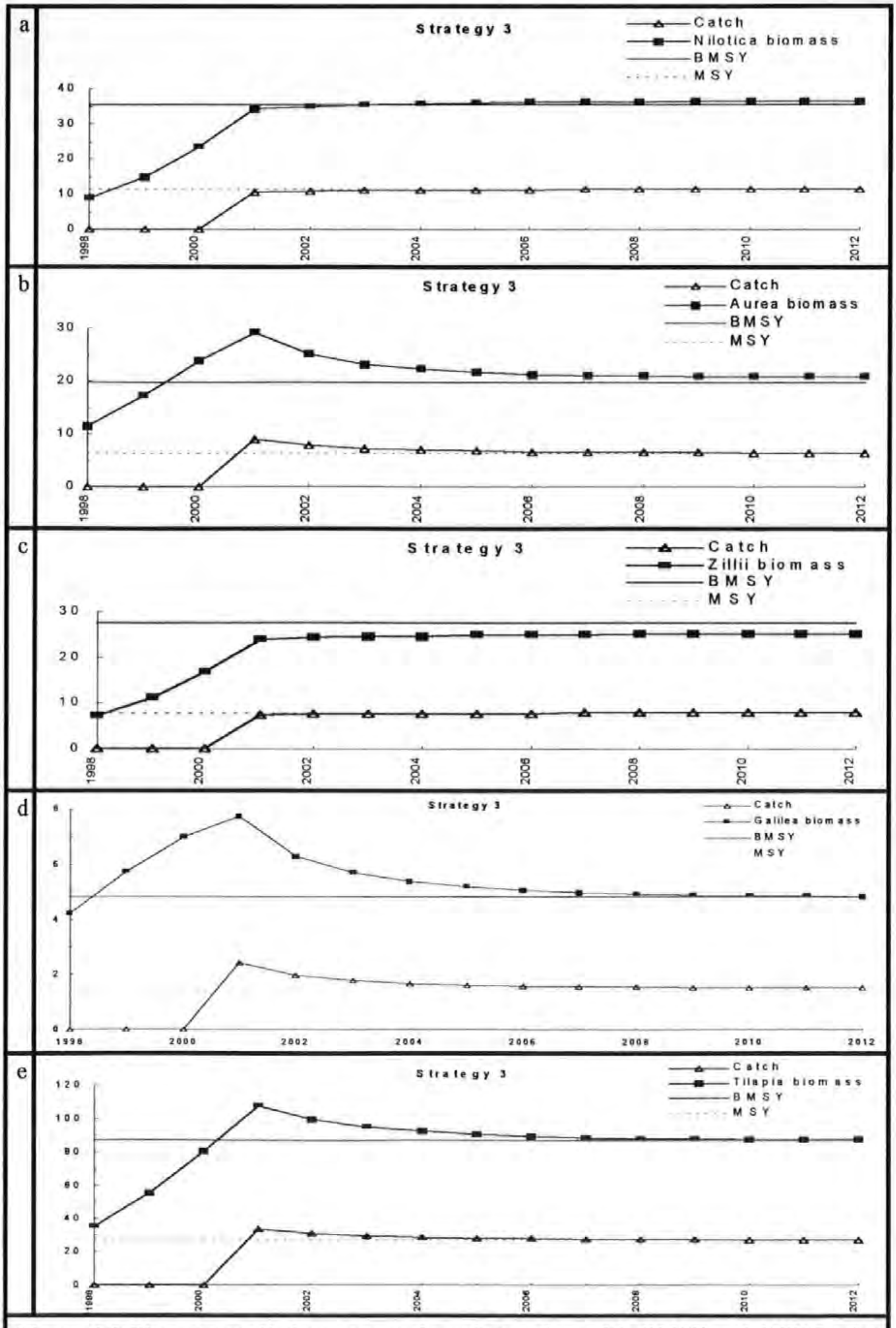


Figure 4.6 Biomass prediction, expected catch together with *BMSY* and *MSY* for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Combined Tilapia* stock using third catch strategy (S3).

4.5. Comparison between the three catch strategies

The three catch strategies which can achieve the biomass recovery have been discussed. Strategy 1 is non-fishing for one year (1998), strategy 2 is non-fishing for two years (1998-1999) and strategy 3 is stop fishing for three years (1998-2000) followed by fishing at *MSY* level in each case. The comparison between the three catch strategies could be explored through different perceptions which are: biomass recovery rate, catches and cumulative catches, and discounted value of catches.

4.5.1. Biomass recovery rate

The three catch strategies S1, S2 and S3 allow the stock to recover by 2017, 2012 and 2001 respectively. Figure 4.7 shows a comparison between the prediction of *Combined Tilapia* stock based on the three catch strategies. See Figure 3B in Appendix B for the four species biomasses.

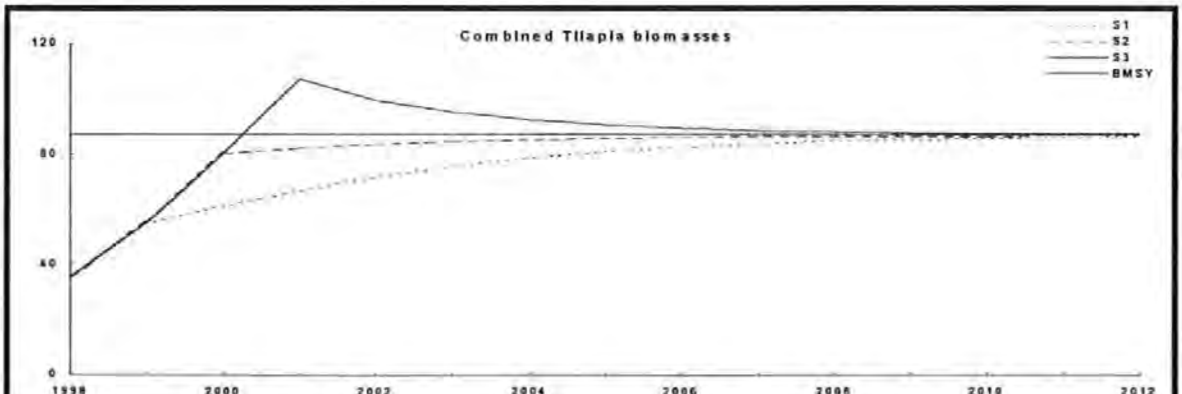


Figure 4.7 Comparison between the prediction of *Combined Tilapia* stock based on the three catch strategies.

4.5.2. Catches and cumulative catches

It is noted that catch strategy 1 can delay the recovery of the *Combined Tilapia* stock to 2017, while catch strategies 2 and 3 can allow the *Combined Tilapia* biomass to recover by 2012 and 2001 respectively. Figure 4.8 shows a comparison between the catches of the three catch strategies. It is noted that first and third strategy realise the same catch by 2006, while second catch strategy realise the greatest catch. (Figure 4B in Appendix B for the four species catches)

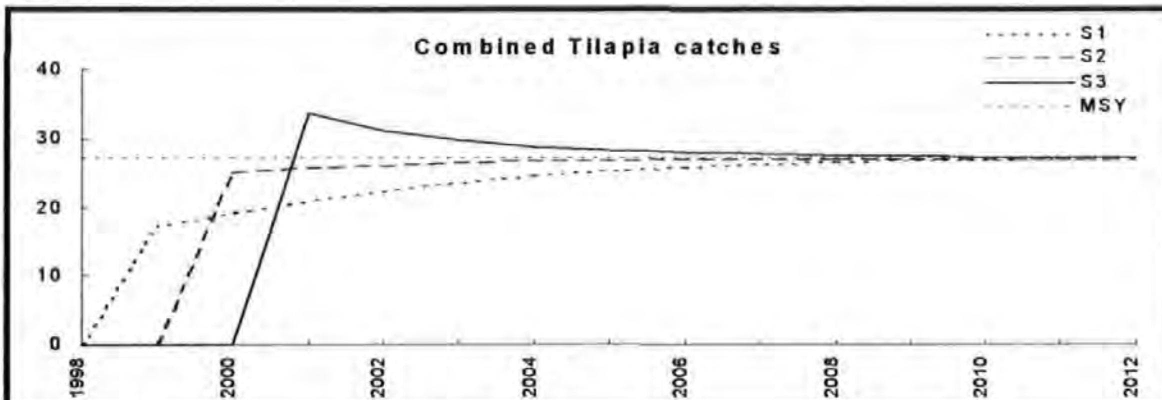


Figure 4.8 The catch estimates of the three catch strategies together with *MSY*.

Figure 4.9 and Table 4.5 shows a comparison between the cumulative *Combined Tilapia* catch. See Figure 5B in Appendix B for the four species cumulative catches.

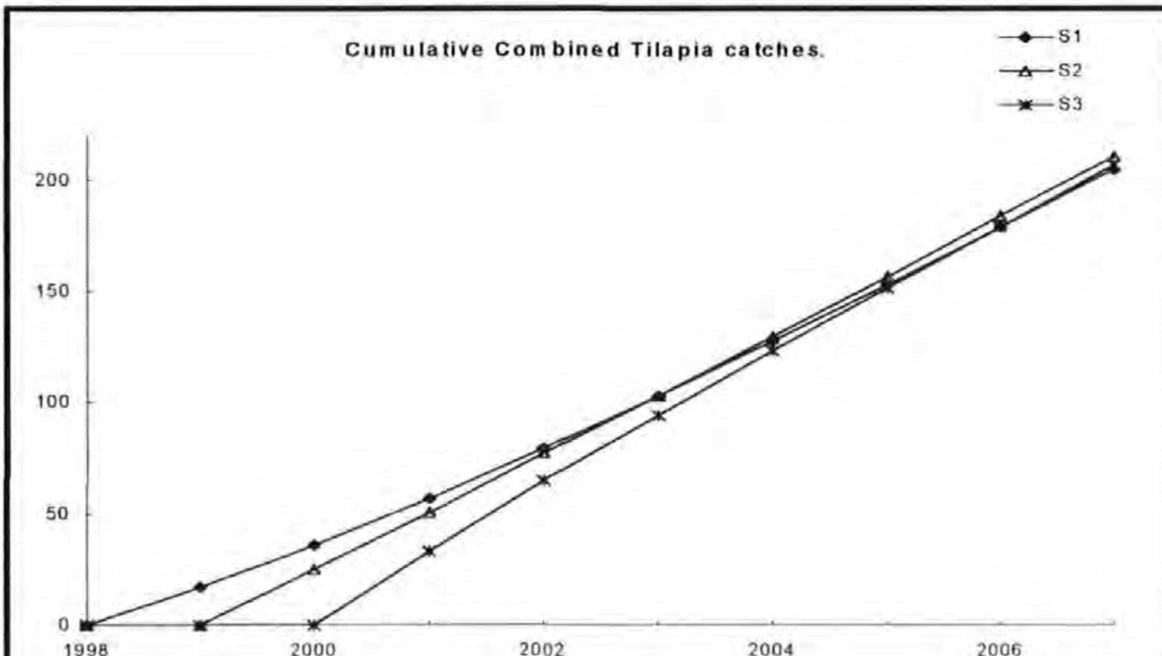


Figure 4.9 The cumulative catch estimates of the three catch strategies for *Combined Tilapia* species.

Table 4.5 Comparison between the cumulative *Combined Tilapia* predicted catch.

Years	Cumulative catch of *Combined Tilapia* Strategy 1	Cumulative catch of *Combined Tilapia* Strategy 2	Cumulative catch of *Combined Tilapia* Strategy 3
1998	0	0	0
1999	17	0	0
2000	36	25	0
2001	57	51	34
2002	80	77	65
2003	103	103	94
2004	128	130	123
2005	153	157	151
2006	179	184	179

It is noted that first and third strategy realise the same cumulative catch by 2006, while second catch strategy realise the greatest cumulative catch by 2006.

4.5.3. Discount rate

The discount rate is commonly used in the literature of finance to evaluate capital investments. The main purpose of using the discount rate is to take into account both the magnitude and timing of expected cash flows in each period of an investment project's life. In particular, the discount rate allows us to isolate differences in the timing of cash flows for various investments by discounting these cash flows to their present value. The present quantity of the catch in kt has been used rather than its cash value during the projected years because there are no available prices data. Using discount rate for the value of the catch in pounds or the quantity of the catch in kt is the same thing because the effect of using discount rate is similar on values or on quantities (Clark, 1985).

Table 4.6 shows a comparison between the total discounted catch of all species over the period 1998-2006 using different annual discount rates in steps of 5% for each catch strategy.

Table 4.6 Comparison between the total discounted catch of all species using different discount rates for each catch strategy.

Discount rate	Strategy 1	Strategy 2	Strategy 3
0%	267	**274**	267
5%	203	**205**	196
10%	**157**	**157**	147
15%	**125**	122	113
20%	**101**	97	87
25%	**83**	78	69
30%	**70**	64	55
35%	**59**	53	45
40%	**50**	45	36
45%	**44**	38	30
50%	**38**	32	25

Strategy 2 realises the greatest total discounted catch if the discount rate is 10% or less. Strategy 1 realises the greatest total discounted catch if the discount rate is greater than or equal 10%.

Now effort control is required to achieve the catch corresponding to the chosen strategy to allow the stock to recover. Chapters five and six will investigate the effort control to achieve the catch strategies, while chapter seven will investigate the effect of adding uncertainty to the biomass model parameters and effort control model parameters.

Chapter 5 EFFORT MANAGEMENT BASED ON PARAMETRIC ANALYSIS.

5.1. Effort control

In chapter four stock management has been investigated, assuming that the catch is proportional to the biomass density, equal *area-adjusted catchability* for the four species and constant effort. This chapter will attempt to define the characteristics of the fleet required to exact the given effort.

The future fleet must be based upon the existing fleet. Therefore, the existing operating fleet has been investigated to control effort in Lake Manzala. To control fishing effort some key data and information are needed such as fleet structure, vessel characteristics, catch per fishing unit, fishing gear utilised etc. The way to collect these data was through sample survey because most of these data and information are not available for Lake Manzala. The main aim of collecting Lake Manzala survey data was to make it possible to predict the individual vessel catch in relation to vessel characteristics.

To collect these data a sample survey was carried out in 1995. The data collected from the survey were to help in development of lake fisheries management by studying the effect of vessel characteristics on the catch per vessel, using parametric and non-parametric analysis. The parametric analysis will be discussed in this chapter, while the non-parametric analysis will be discussed in chapter six.

5.2. Survey methodology

During August and September 1995, a sector-by-sector sample of the lake perimeter was conducted. The survey covered the three sectors of the lake to assess the relationship between the amount of fish caught by an individual vessel and some indices of effort variables such as number of nets, number of fishermen, duration time per trip and number of mesh per 100 cm length of nets. At each sector the head of the fishermen's societies was interviewed and number of fishing vessels and type of fishing gear in each sector was established.

A sample survey was conducted to collect the required data. A questionnaire (Appendix C) was designed and pre-tested on 20 sampling units.

5.2.1. Sample size

Even though the aim of the survey was to model the individual vessel catch in relation to vessel characteristics, for the sake of simplicity the sample size was calculated as if a simple random sample had been used to give a reliable estimate of the average catch. This gave a sample size 376 vessels which was feasible given the effort available for data collection. The actual sample size was increased by 20% (75 units) as a precaution to avoid a possibility of collecting invalid questionnaires. Based on the available data the fishing fleet operating in Lake Manzala consisted of 5564 fishing vessels in 1995, of which 26% were using Trap nets, 59% were using Stand nets and 15% were using Hook lines (Table 2.3). Fifty three percent of the fishing vessels operated in the Southern Sector of the lake, 32% in the Western Sector and 15% in the Eastern Sector. So the sample size was split in proportion to fleet size to represent each sector and each type of gear. At each port, a proportion of the incoming fishing vessels each hour was sampled in a random manner.

Vessels were sampled throughout the day, in proportion to the number of arrivals each hour.

Fifteen invalid questionnaire sheets were rejected because some data were omitted, (8 in Southern Sector- Stand nets, 5 in Western Sector- Trap nets and 2 in Eastern Sector- Trap nets), these were removed from the sample, reducing the actual sample size from 451 vessels to 436 vessels (Table 5.1).

Table 5.1 Number of fishing units sampled according to each sector and each type of fishing gear in 1995.

	Southern Sector		Western Sector		Eastern Sector		Total	
Fishing gear	Number	%	Number	%	Number	%	Number	%
Trap nets	51	11	43	9	25	6	119	26
Stand nets	170	38	53	12	42	9	265	59
Hook lines	18	4	49	11	0	0	67	15
Total	239	53	145	32	67	15	451	100

Each vessel skipper was interviewed and the following items of information obtained by using the questionnaire. Variables names are in italic bold type. From the field survey the vessel characteristics and catch characteristics data are as follows:

<u>5.2.2. Vessels characteristic</u>

- skipper name and age.
- type of fishing gear.
- number of nets used per fishing trip, unit of nets for Trap nets and Stand nets and by hundred of hooks for Hook lines. (***Nets*, independent variable**).

• number of fishermen per trip per vessel (*Fishermen*, **independent variable**).

• average time per trip in hours (*Duration*, **independent variable**).

• number of mesh in 100 cm length of nets for Trap nets and Stand nets only. (***Mesh*, independent variable**) which means that high number of mesh means fine mesh size.

• number of trips each working day, after collecting the data it is noted that there is one trip per day for each vessel.

• working days each year, after collecting the data it is noted that the working days are virtually constant for all vessels with approximately 300 days each year.

• fishing grounds for each sector. (S_S for Southern Sector, S_W for Western Sector and S_E for Eastern Sector, **indicator variable**).

5.2.3. Catch characteristics

The average catch per trip in kg (***Yave*, dependent variable**)

The amount of fish sold by each vessel at the end of each trip is accurately recorded, but it was impossible to get information about the catch composition because the vessels owners sell their catch to the fish manager as a lot rather than by species.

5.2.4. Survey data analysis

There are two ways to analyse the survey data which are as follows:

• within each sector, using different fishing gear, or

• across all sectors, using a single fishing gear.

Analysis within each sector is not reasonable because there are different types of variables for each type of fishing gear, such as number of *Nets*, which means nets for Trap nets and Stand nets and number of hooks for Hook lines, also number of mesh which appears for Trap nets and Stand nets only. So analysis across all sectors, using a single fishing gear will be considered.

5.3. Fleet structure

Fleet structure means number of vessels and vessel characteristics. Number of *Nets* has been chosen as a key variable to identify the vessels characteristics because if the skippers have enough wealth they can purchase more nets to allow more fishermen to work. Also more nets may need longer duration time per trip. So number of fishermen as well as trip duration depend mainly on the number of nets. So the fleet structure can be explored through the relationship between each pair of the following variables:

- number of *Nets* and number of *Fishermen*.
- number of *Nets* and trip *Duration*.
- number of *Nets* and number of *Mesh* (per 100 cm length of nets).

5.3.1. Trap nets

Table 5.2 shows number of fishermen and the number of nets per trip, the minimum number of nets is one net while the maximum is 150 nets. About 70% of sampled vessels (80 vessels) using less than 30 nets. From the raw data there is a positive relationship between number of nets and number of fishermen per trip where the correlation coefficient is 0.73.

Table 5.2 Number of vessels using Trap nets in relation to number of *Nets* and number of *Fishermen* in 1995.

Fishermen / *Nets*	1	2	3	4	5	6	7	8	9	10	Total
001-029	12	34	22	4	5	2	1				80
030-059		2	10	1	1	1		1	1		17
060-089				4	4						8
090-119						2		1		3	6
120-150										1	1
Total	12	36	32	9	10	5	1	2	1	4	112

Table 5.3 shows the number of *Nets* and the *Duration* time per trip in hours. The minimum duration time per trip was 4 hours and the maximum was 18 hours. About 54% of sampled vessels using Trap nets fishing gear spend 10 to 12 hours. From the raw data there is a positive relationship between number of nets and duration time per trip where the correlation coefficient is 0.44.

Table 5.3 Number of vessels using Trap nets in relation to number of *Nets* and trip *Duration* in 1995.

Duration / *Nets*	4-6	7-9	10-12	13-15	16-18	Total
001-029	10	28	34	8		80
030-059			14	1	2	17
060-089			8			8
090-119			4	2		6
120-150				1		1
Total	10	28	60	12	2	112

Table 5.4 shows the number of *Nets* used per trip for Trap nets fishing gear and number of mesh per 100 cm length of nets. The minimum number of mesh was 25 per 100

cm length of nets and the maximum was 74. About 30% of the sampled vessels used 50 mesh or less per 100 cm length of nets. It is noted that from the raw data there is a negative relationship between number of nets and number of mesh, where the correlation coefficient is -0.46, which means the vessels owners who have less than 60 nets are using fine mesh to increase their fish catch, while the vessels owners whose have more than 60 nets are using 50 mesh or less per 100 cm length of nets.

Table 5.4 Number of vessels using Trap nets in relation to number of *Nets* and number of *Mesh* per 100 cm length of nets in 1995.

Mesh / *Nets*	25-34	35-44	45-54	55-64	65-74	Total
001-029		4	20	44	12	80
030-059		3	14			17
060-089		6	2			8
090-119	1	5				6
120-150	1					1
Total	2	18	36	44	12	112

5.3.2. Stand nets

The minimum number of *Nets* is one net and the maximum is 100 nets. About 77% of sampled vessels use less than 30 nets. From the raw data there is a positive relationship between number of nets and number of fishermen per trip where the correlation coefficient is 0.89. See Table 1C in Appendix C.

The minimum duration time per trip was 4 hours and the maximum was 21 hours. About 40% of the sampled vessels using Stand nets spend an average of 10 to 12 hours each trip. It is noted that some fishermen left their nets in the water to collect it next day so the average duration time for some vessels is up to 21 hours per trip and its duration measurer the fishing time rather than the time of trip. From the raw data there is a positive relationship between number of nets and duration time per trip where the correlation coefficient is 0.81. See Table 2C in Appendix C.

The minimum number of mesh was 25 per 100 cm length of nets and the maximum was 94. About 45% of vessels in the sample used 50 mesh or less per 100 cm length of nets. From the raw data there is a positive relationship between number of nets and number of mesh per 100 cm length of nets per trip where the correlation coefficient is 0.85. See Table 3C in Appendix C.

5.3.3. Hook lines

The minimum number of hooks were 10 hundreds hooks and the maximum were 250 hundreds hooks. About 51% of the sampled vessels used 10 - 50 hundred hooks per trip. From the raw data there is a positive relationship between number of hooks and number of fishermen per trip where the correlation coefficient is 0.84. See Table 4C in Appendix C.

The minimum duration time per trip was 4 hours and the maximum was 24 hours. About 20% of sampled vessels using Hook lines fishing gear spend 10 to 12 hours per trip. In the case of long duration trips the fishermen put out their lines and collect them next day, those vessels owners represent about 20% of number of sampled vessels using Hook lines fishing gear. From the raw data there is a positive relationship between number of hooks and duration time per trip where the correlation coefficient is 0.89. See Table 5C in Appendix C.

5.4. Catch modelling

The objective of the sample survey was to study the effect of variation of the vessel's characteristics on vessel's catch. So it was necessary to find out the best relationship between dependent variable (*Yave*) and independent variables (*Nets, Fishermen, Duration* and *Mesh*). Additive and multiplicative models could be considered; a linear additive model is not a reasonable one because the independent variables represent production factors or the input for fishing operators and adding number of nets to number of fishermen (for example) is not meaningful. Plotting *Yave* versus each independent variable for Trap nets data for example shows that the data does not follow the linear additive model pattern because there is no linear relationship between *Yave* and other independent variables as shown in Figure 5.1, so the linear additive model is not a useful one for the survey data. Figure 5.1 shows an example of the relationship between *Yave* and each independent variable for Trap nets. The other types of fishing gear have a similar pattern. (see Figures 1C and 2C in Appendix C)

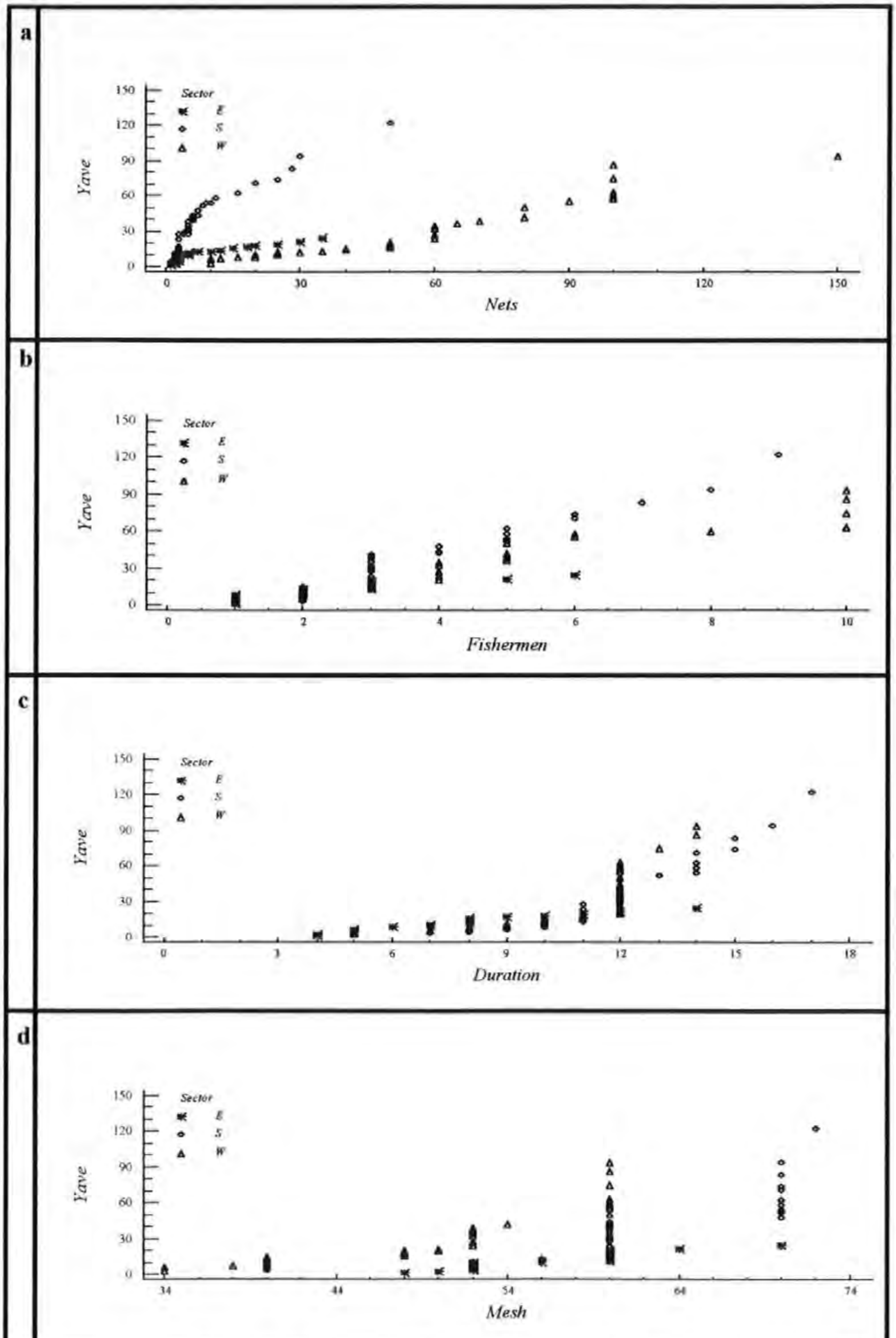


Figure 5.1 Plot *Yave* for Trap nets versus (a) *Nets*, (b) *Fishermen*, (c) *Duration* and (d) *Mesh*.

A production function (Cobb-Douglas function) is a function to determine the relation between the inputs to an enterprise and its output (Koutsoyiannis, 1979). The production function is a multiplicative function with a multiplicative error which can be written as follows:

$$Y = \alpha \prod_{i=1}^{p} X_i^{\beta_i} \exp^{e} \tag{5.1}$$

where:

α = intercept,

Y = dependent variable (*Yave*),

X_i*'s* = independent variables (*Nets*, *Fishermen*, *Duration* and *Mesh*),

β*'s* = parameters,

i = 1, 2,..., p number of independent variables,

e = error term, which is often assumed to be normally distributed.

This function can be transformed to give linear additive model using logarithmic transformation as follows:

$$LogY = Log\alpha + \sum \beta_i LogX_i + e \tag{5.2}$$

Plotting *LogYave* versus each independent variable for Trap nets fishing gear, for example in Figure 5.2, shows that the multiplicative model is a reasonable model to represent the survey data, because there is a nearly linear relationship between *LogYave* and each of *LogNets*, *LogFishermen*, *LogDuration* and *LogMesh*. The other types of fishing gear have the similar pattern. (see Figures 3C and 4C in Appendix C)

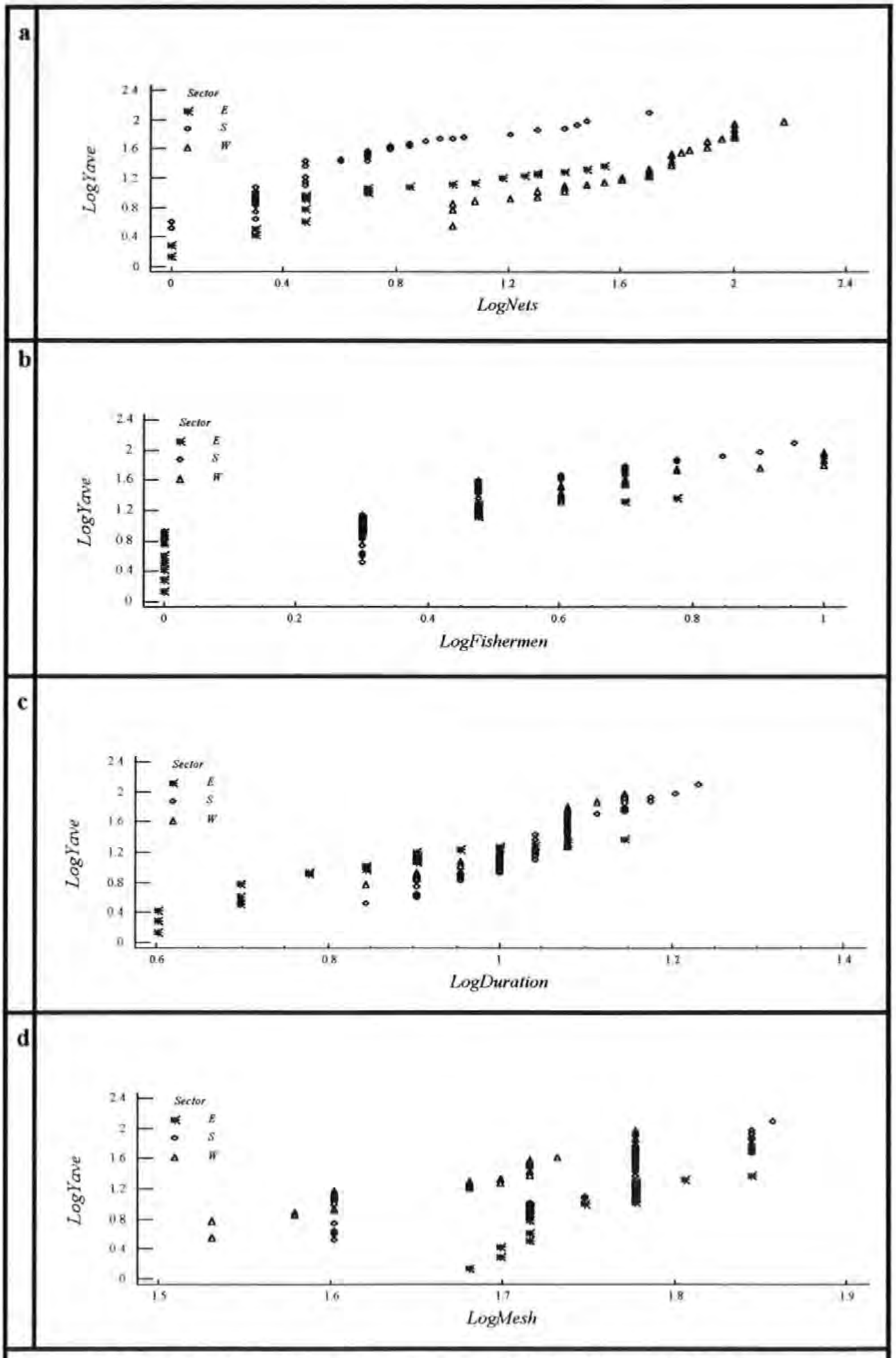


Figure 5.2 Plot *LogYave* for Trap nets versus (a) *LogNets*, (b) *LogFishermen*, (c) *LogDuration* and (d) *LogMesh*.

The survey data covered three different sectors in Lake Manzala. A comparison between the three sectors with regard to their separate multiple regression of *LogYave* on *LogNets*, *LogFishermen*, *LogDuration* and *LogMesh* is required.

To determine whether or not there is a significant difference between sectors, we can examine three different models. In Model 1 there is one multiple regression function for the three sectors. In Model 2 there are three parallel multiple regression functions one for each sector. In Model 3 there are three different multiple regression functions one for each sector. These models are as follows:

Model 1:

$$LogYave = \alpha + \beta_1 LogNets + \beta_2 LogFishermen + \beta_3 LogDuration + \beta_4 LogMesh + e$$

Model 2:

$$\begin{aligned} LogYave = \alpha &+ \beta_1 LogNets + \beta_2 LogFishermen + \beta_3 LogDuration + \beta_4 LogMesh \\ &+ \beta_5 S_S + \beta_6 S_W + e \end{aligned}$$

Model 3:

$$\begin{aligned} LogYave = \alpha &+ \beta_1 S_S LogNets + \beta_2 S_S LogFishermen + \beta_3 S_S LogDuration + \beta_4 S_S LogMesh \\ &+ \beta_5 S_W LogNets + \beta_6 S_W LogFishermen + \beta_7 S_W LogDuration + \beta_8 S_W LogMesh \\ &+ \beta_9 S_E LogNets + \beta_{10} S_E LogFishermen + \beta_{11} S_E LogDuration + \beta_{12} S_E LogMesh \\ &+ \beta_{13} S_S + \beta_{14} S_W + e \end{aligned}$$

Changes in Residual Sum of Squares and degrees of freedom are used for testing the difference between models assuming errors are Normally distributed. The F-statistic can be used compare models.

5.4.1. Trap nets

Table 5.5 shows the analysis of variance information from the three models for Trap nets data.

Table 5.5 Analysis of variance information for Trap nets.

Source	*df*	*SS*	*MS*
Model 1	4	16.677	4.169
Residual	107	1.428	0.013
Model 2	6	16.909	2.818
Residual	105	1.197	0.011
Model 3	14	17.314	1.238
Residual	97	0.776	0.008

Using these results to compare between models can be as follows:

- **Parallelism:**

$$F(Model3, Model\ 2) = \frac{(1.197 - 0.776)/(14-6)}{0.008} = 6.33$$

F value is greater than the critical value of F statistic ($F_{8,97,0.95}$=2.02), so there is a strong evidence to reject the idea of common coefficients for the three sectors. Because the common coefficients idea had been rejected, there is no need to check the coincidence of the three sectors.

From this analysis Model 1 and Model 2 are not adequate for Trap nets fishing gear data, while Model 3 is adequate comparing with Model 1 and Model 2. The parameters estimation of Model 3 are listed below in Table5.6.

Table 5.6 Model 3 parameters estimation for Trap nets (* not significant)

Variables	Estimation
Constant of S_S	-3.824*
Constant of S_W	-2.597*
Constant of S_E	0.101*
S_S*LogNets*	-0.051*
S_W*LogNets*	-0.085*
S_E*LogNets*	0.172*
S_S*LogFishermen*	0.711
S_W*LogFishermen*	0.637
S_E*LogFishermen*	-0.056*
S_S*LogDuration*	2.497
S_W*LogDuration*	0.513*
S_E*LogDuration*	1.810
S_S*LogMesh*	1.206
S_W*LogMesh*	1.859
S_E*LogMesh*	-0.459*

From Table 5.6, Southern Sector coefficient, Western Sector coefficient, Eastern Sector coefficient, *LogNets* in the three sectors, *LogFishermen* in Eastern Sector, *LogDuration* in Western Sector and *LogMesh* in Eastern Sector are not significant. Because there are some variables not significant in a sector while it is significant in other sectors, the need to estimate common parameters for each two sectors together to establish whether the effect of each explanatory variable is the same in each sector in which it has a significant effect (common parameters for two sectors). So new indicator variables must be created. The definition of the new indicator variables can be as follows: S_{SW} for Southern or Western Sector, S_{SE} for Southern or Eastern Sector and S_{WE} for Western or Eastern Sector. So

Model 3 can be reduced to the following models:

Model 3.1: combine Southern Sector and Western Sector together

$$LogYave = \alpha + \beta_1 S_{SW} LogNets + \beta_2 S_{SW} LogFishermen + \beta_3 S_{SW} LogDuration + \beta_4 S_{SW} LogMesh$$
$$+ \beta_5 S_E LogNets + \beta_6 S_E LogFishermen + \beta_7 S_E LogDuration + \beta_8 S_E LogMesh$$
$$+ \beta_9 S_{SW} + e$$

Model 3.2: combine Southern Sector and Eastern Sector together

$$LogYave = \alpha + \beta_1 S_{SE} LogNets + \beta_2 S_{SE} LogFishermen + \beta_3 S_{SE} LogDuration + \beta_4 S_{SE} LogMesh$$
$$+ \beta_5 S_W LogNets + \beta_6 S_W LogFishermen + \beta_7 S_W LogDuration + \beta_8 S_W LogMesh$$
$$+ \beta_9 S_{SE} + e$$

Model 3.3: combine Western Sector and Eastern Sector together

$$LogYave = \alpha + \beta_1 S_{WE} LogNets + \beta_2 S_{WE} LogFishermen + \beta_3 S_{WE} LogDuration + \beta_4 S_{WE} LogMesh$$
$$+ \beta_5 S_S LogNets + \beta_6 S_S LogFishermen + \beta_7 S_S LogDuration + \beta_8 S_S LogMesh$$
$$+ \beta_9 S_{WE} + e$$

The results of comparing Model 3 with Models 3.1, 3.2 and 3.3 are as follows:

F (Model 3, Model 3.1) = 7.56

F (Model 3, Model 3.2) = 9.50

F (Model 3, Model 3.3) = 3.13

Comparing these F values with $F_{5,97,0.95} = 2.29$, one can conclude that Model 3 is still the better model comparing with Models 3.1, 3.2 and 3.3.

Back to Model 3 (Table 5.6) one can suggest improving the model by:

- *LogNets* can be dropped out from Model 3 because it is not significant in the three sectors

- Southern and Western Sectors could be combined together for *LogFishermen*.

- Southern and Eastern Sectors could be combined together for *LogDuration*.

- Southern and Western Sectors could be combined together for *LogMesh*.

So according to that Model 3 could reduced to Model 3.4 which can be expressed as follows

Model 3.4 for Trap nets

$$\begin{aligned} LogYave = \alpha &+ \beta_1 S_{SW} LogFishermen + \beta_2 S_{SE} LogDuration + \beta_3 S_{SW} LogMesh \\ &+ \beta_4 S_{SW} + \beta_5 S_{SE} + e \end{aligned}$$

Comparing Model 3 with Model 3.4 gave the following result:

F (Model 3, Model 3.4) = 0.60 which is less than $F_{9,97,0.95} = 1.91$, so Model 3.4 is better than Model 3.

Residual scatter plot of Model 3.4 versus predicted *LogYave* (Figure 5.3) for Trap nets, shows that there is no pattern of the residuals and the negative and positive residuals are balanced, so the error term e have constant variance for all levels of the independent variables can be accepted.

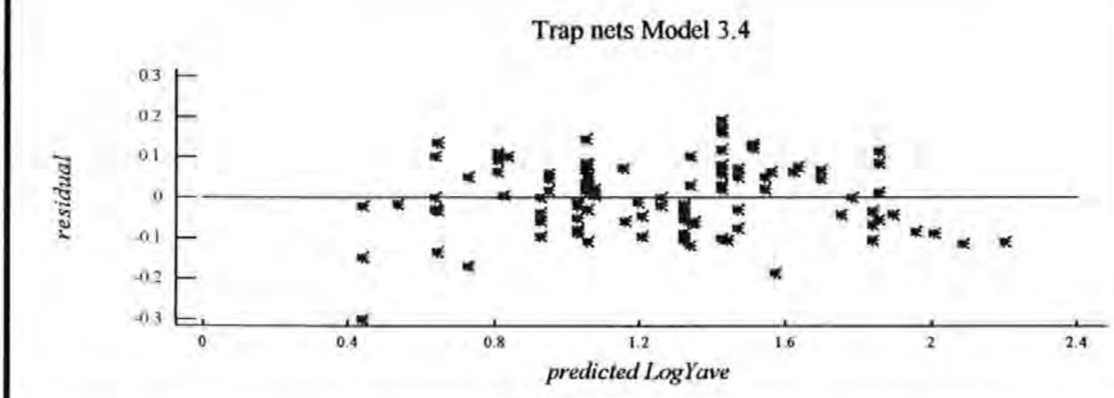


Figure 5.3 Residual plot vs. predicted *LogYave* of Trap nets using Model 3.4.

Figure 5.4 shows that the normal probability plot of residuals for Trap nets which produce a straight line to ensure the normality of the residuals, In spite of there were few observations produced residuals greater than 2 in absolute value which look like outliers, using Shapiro-Wilks Goodness-of-Fit statistic to test the normality of the residuals (Madansky, 1988) produced P-value greater than 0.05, so there is no evidence that the distribution of residuals varies significantly from normal distribution.

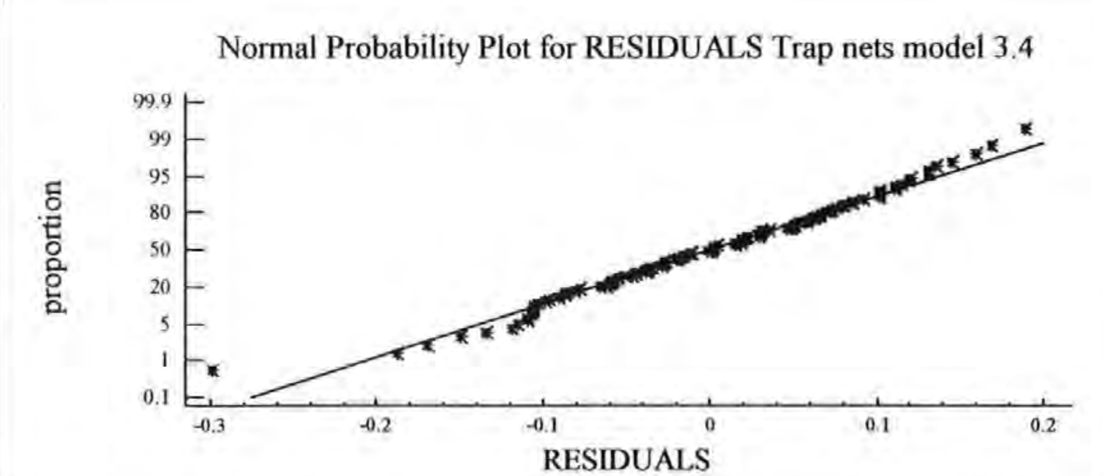


Figure 5.4 Normal Probability plot for residual of Trap nets using Model 3.4

5.4.2. Stand nets

The same analysis has been carried out for Stand nets fishing gear data. The best model for it can be expressed as follows:

Model 3.5 for Stand nets

$$LogYave = \alpha + \beta_1 S_S LogNets + \beta_2 S_W LogNets + \beta_3 S_E LogNets + \beta_4 S_{SW} LogFishermen + \beta_5 S_S LogDuration + \beta_6 S_S LogMesh + \beta_7 S_{SW} + \beta_8 S_{SE}$$

Scatter plot of the residuals versus predicted *LogYave* (Figure 5.5) for Stand nets shows that the residual have sinusoidal pattern, so the assumption of linearity can not be accepted. Stand nets data need more complicated model than a linear multiple regression model.

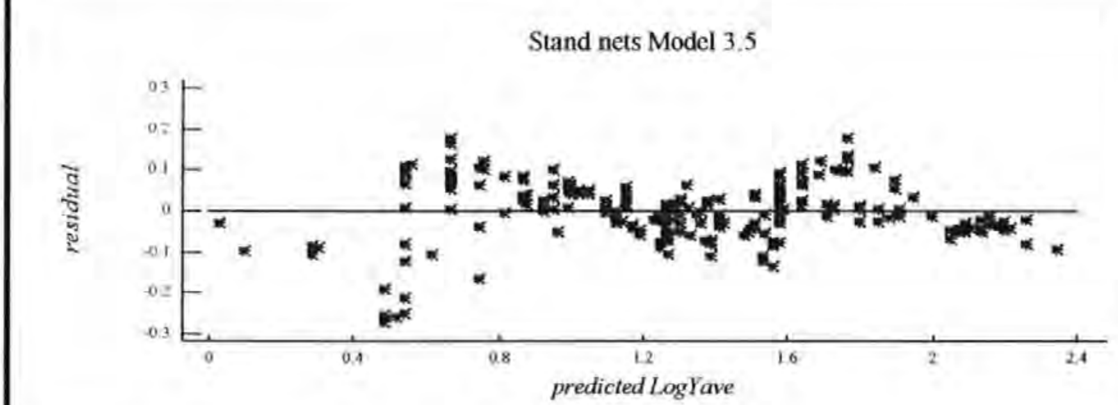


Figure 5.5 Residual plot vs. predicted *LogYave* of Stand nets using Model 3.5.

Figure 5.6 shows that the normal probability plot of residuals for Stand nets to test the normality of the residuals. In spite of there were few observations produced residuals greater than 2 in absolute value which look like outliers, Shapiro-Wilks Goodness-of-Fit statistic produced P-value greater than 0.05, so there is no evidence to reject the idea that the residuals are normally distributed.

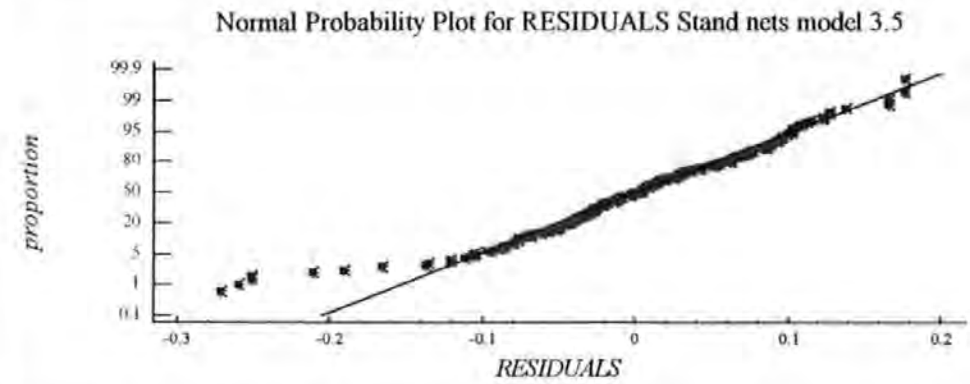


Figure 5.6 Normal Probability plot for residual of Stand nets using Model 3.5.

5.4.3. Hook lines

Hook lines data does not include the variable *Mesh* and also Hook lines fishing gear does not operate in Eastern Sector. So Hook lines model can be the same as Trap nets or Stand nets model except it will not include variable *Mesh* and indicator variable for Eastern Sector. According to F values Model 3 can be accepted as an adequate model for Hook lines comparing with Model 1 and Model 2. But in Model 3 for Hook lines *LogDuration* in Western Sector is not significant variable, so this model can be reduced to the following form:

Model 3.6 for Hook lines

$$LogYave = \alpha + \beta_1 S_S LogNets + \beta_2 S_S LogFishermen + \beta_3 S_S LogDuration + \beta_4 S_W LogNets + \beta_5 S_W LogFishermen + \beta_6 S_S + e$$

Scatter plot of the residuals versus predicted *LogYave* (Figure 5.7) of Model 3.6 for Hook lines shows that the residuals have a sinusoidal pattern, so the assumption of linearity can not be accepted. So Hook lines data may need more complicated model like Stand nets data.

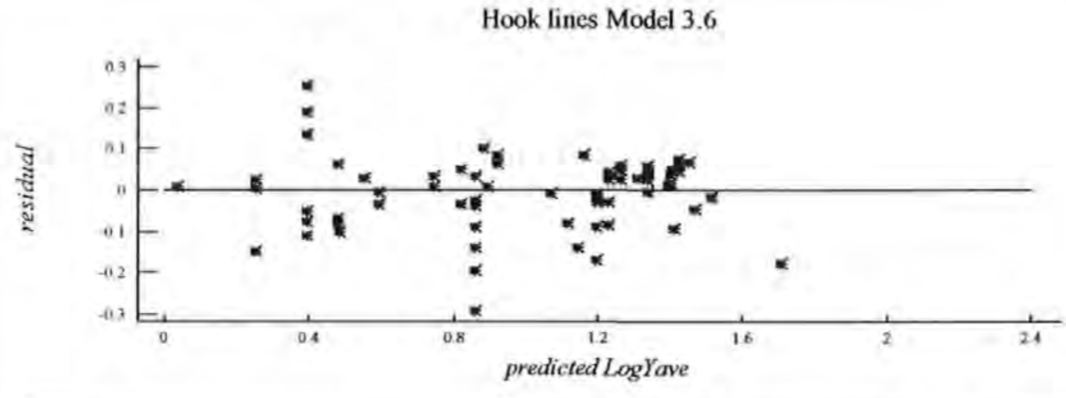


Figure 5.7 Residual plot vs. predicted *LogYave* of Hook lines using Model 3.6.

Figure 5.8 shows that the normal probability plot of residuals for Hook lines to test normality of the residuals. In spite of there were few observations produced residuals greater than 2 in absolute value which look like outliers, Shapiro-Wilks Goodness-of-Fit statistic produced P-value greater than 0.05, so there is no evidence to reject the idea that residual are normally distributed.

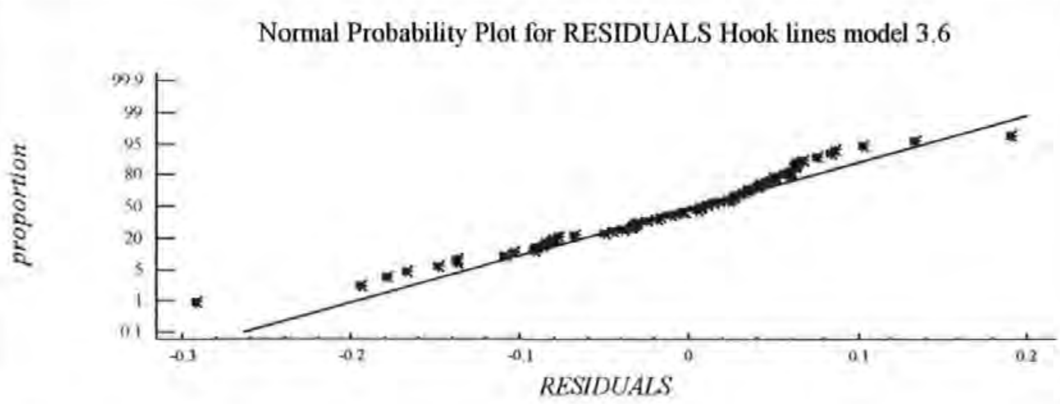


Figure 5.8 Normal Probability plot for residual of Hook lines using Model 3.6.

On the basics of statistics tests Model 3.4 for Trap nets, Model 3.5 for Stand nets and Model 3.6 for Hook lines are good models for the three fishing gear data. However to control the fishing effort in practice a model including all explanatory variables is required, because if the non-significant variables are removed from the model people behaviour can change to fish more without control the number of *Nets*, number of *Fishermen*, trip *Duration* or number of *Mesh*. So the model which include all explanatory variables will be used to evaluate the regression model and then to estimate catch per vessel in the fleet control model below. The parameters estimation for that model for each type of fishing gear are listed below in Table 5.7.

Table 5.7 Parameters estimation using Model 3 for each type of fishing gear (* not significant).

Variables	Trap nets	Stand nets	Hook lines
Constant of S_S	-3.824*	0.131*	-2.206
Constant of S_W	-2.597*	1.666	-0.480
Constant of S_E	0.101*	-1.215	not included
S_S*LogNets*	-0.051*	0.597	1.079
S_W*LogNets*	-0.085*	0.728	0.283
S_E*LogNets*	0.172*	0.329	not included
S_S*LogFishermen*	0.711	0.519	-1.131
S_W*LogFishermen*	0.637	0.416	0.992
S_E*LogFishermen*	-0.056*	-0.134*	not included
S_S*LogDuration*	2.497	.512	1.903
S_W*LogDuration*	0.513*	-0.235*	0.651*
S_E*LogDuration*	1.810	0.887*	not included
S_S*LogMesh*	1.206	0.071	not included
S_W*LogMesh*	1.859	-0.029*	not included
S_E*LogMesh*	-0.459*	0.887*	not included

5.5. Catch model validation

Multiple regression model has been used to estimate the parameters and it will use to predict catch per individual vessel. However, a regression model deemed to be an adequate predictor of the dependent variable may perform poorly when applied in practice. "There is no assurance that a model that fits the sample data well will be a successful predictor of the dependent variable when applied to new data. For this reason, it is important to assess the validity or reliability of the model in addition to its adequacy before using it in practice" (Mendenhall, 1989). Model validation is an assessment of how the fitted model will perform in practice, that is how successful it will be when applied to new or future data. Where it is impossible or impractical to collect new data, the original data can be split into two parts, with one part used to estimate the model parameters and the other part used to assess the fitted model's predictive ability and to estimate the error distribution. There are many methods for evaluating reliability of a model based on split samples or re-sampling the data such as: (1) split sample or hold-out validation, (2) cross validation and (3) Shrinkage statistic. (Kleinbaum and others, 1998).

Split sample is the most commonly used method for evaluating reliability of a model. The technique involves splitting the data into two sets, the estimation data set (EDS) and the validation data set (VDS), using EDS to fit a model, then estimating the error from VDS. The disadvantage of split sample validation is that it reduces the amount of data available for the parameter estimation and for the validation.

Cross validation is an improvement on split sample validation which allows all of the data to be used for estimation. The disadvantage of cross validation is that it must fit the model many times. In K-part cross validation, the data is divided into K subsets of approximately equal size. Each iteration leaves out one of the subsets, fits a model to the remaining subsets and uses only the omitted subset to compute the error. If K equals the sample size, this is called "Leave-one-out" cross validation. "Leave-V-out" is a more elaborate version of cross validation that involves leaving out each subset of V cases. Leave one out cross validation often works well for continuous error functions such as the mean squared errors (MSE).

Shrinkage statistics depends on splitting the sample data into two approximately equal data sets. The first data set (EDS) is used to fit a model. Then the squared multiple correlation between the observed and predicted response values, which will be called $R^2(1)$ is calculated. Next the prediction equation from the first data set EDS is used to compute predicted values for the second data set (VDS). Finally compute the squared multiple correlation between these predicted values and the observed response in VDS, which will be called $R_*^2(2)$. The quantity $R_*^2(2)$ is called ***cross validation correlation*** and the quantity $R^2(1) - R_*^2(2)$ is called ***shrinkage on cross validation***. "The cross-validation correlation $R_*^2(2)$ is a less biased estimator of the population squared multiple correlation than is the (positively) biased $R^2(1)$. Hence, the shrinkage statistic is almost always positive. How large must shrinkage be to cast doubt on model reliability? No firm rules can be given. Certainly the fitted model is unreliable if shrinkage is .90 or more. In contrast, a shrinkage values less than .10 indicate a reliable model." (Kleinbaum, Kupper, Muller and Nizam, 1998).

Cross validation and shrinkage statistic can be used for the sample data to check the reliability of the regression model.

5.5.1. Applying cross validation

Cross validation has been applied to the survey data for each gear in each sector.

When the survey data were collected, the actual sample size was increased by 20% as a precaution to avoid an possibility of collecting invalid questionnaires and to use the additional observations to check the validity of a model. So, each data set for each gear in each sector was split to 5 parts. But as Efron in 1982 suggested to split the data to 10 parts, each data set was also split to 10 parts. So applying cross validation will include splitting the data to 2 parts to compute shrinkage statistic, to 5 parts according to the data collected assumption and to 10 parts according to Efron suggestion and a comparison between these procedures will be carried out. The steps of applying cross validation can be summarised as follows:

1. Split the data to K (2, 5,and 10) parts randomly.

2. Leave first part out (validation data set VDS), use the remaining parts (estimation data set EDS) to estimate the parameters of the multiple linear regression (using all explanatory variables) and calculate the mean squared error (MSE) of the EDS.

3. Use the estimated parameters from the previous step to predict the values of the response using given values of the independent variables in the VDS and calculate MSE of the VDS, and calculate shrinkage statistics if $K = 2$.

4. Repeat steps 2 and 3 until each part has been left out. So, each iteration produces K values of MSE for VDS and another K values of MSE for ESD.

5. Repeat all the previous steps 200 times as suggested by Efron and Tibshirani in 1993.

These procedures have been applied to each data set for each fishing gear in each sector. The next section is the illustration in detail for applying cross validation to Trap nets in Southern Sector as example.

5.5.1.1. Splitting the data to 2 parts

To avoid any error in splitting data into two approximately equally parts and to have the same base to compare this analysis (splitting the data into 2 parts) with the other analysis (splitting the data into 5 and 10 parts), this test was repeated 200 times, each time the data set being split randomly.

It is noted that MSE of VDS is higher than MSE of EDS, their ratio varies from 124% to 200%. Also it is found that 6 iterations of VDS (3%) produced normal residual (P-value of Shapiro-Wilks Goodness-of-Fit statistic greater than 5%). It is found that the minimum value of shrinkage statistic was 0.000147 while the maximum was 0.058880, which means that the multiple regression is reliable model for prediction.

5.5.1.2. Splitting the data to 5 parts

By comparing MSE of EDS and VDS, it is found that MSE of VDS is higher than MSE of EDS. Their ratio varies from 178% to 182%. Also it is found that 39 iterations (19.5%) produced normal residual (P-value of Shapiro-Wilks Goodness-of-Fit statistic greater than 5%).

5.5.1.3. Splitting the data to 10 parts

By comparing MSE of EDS and VDS, it is found that MSE of VDS is higher than MSE of EDS. Their ratio vary from 148% to 188%. Also it is found that 29 iterations (14.5%) produced normal residual (P-value of Shapiro-Wilks Goodness-of-Fit statistic greater than 5%).

The summary of applying cross validation with splitting the data into 2, 5 and 10 parts using multiple regression model for Trap nets in Southern Sector are listed below in Table 5.8.

Table 5.8 The summary of the results of splitting the data into 2, 5 and 10 parts for the Trap nets in Southern Sector.

	2 parts	5 parts	10 parts
Number of observations	51	51	51
Number of iterations	200	200	200
Minimum value of MSE of VDS	0.068	0.064	0.068
Minimum value of MSE of EDS	0.055	0.036	0.046
Minimum ratio of MSE of VDS/MSE of EDS	124%	178%	148%
Maximum value of MSE of VDS	0.190	0.160	0.160
Maximum value of MSE of EDS	0.095	0.088	0.085
Maximum ratio of MSE of VDS/MSE of EDS	200%	182%	188%
Proportion of iterations produced normal residual	3%	19.50%	14.50%

The same analysis has been investigated for each fishing gear data set in each sector and all results are similar to the results mentioned above. From these results splitting the data into 2 parts was used to confirm the reliability of the catch model for prediction which ensure that the multiple regression catch model are reliable for prediction. Splitting the data to 5 parts has been performed because when the survey data were collected the actual sample size was increased by 20% as a precaution to avoid an possibility of collecting invalid questionnaires and to use the additional observations to check the validity of a model.

5.6. Effort control using parametric model

Now that the regression model has been confirmed as reliable for prediction, it can be used to calculate the fleet size required to achieve a catch of *MSY* if the stock is at *BMSY* level. This will be based upon the deterministic model, while the effect of uncertainty will be covered in chapter seven.

Effort control will control the existing operating fleet by using the existing operating fleet specification and limiting the number of *Nets*, number of *Fishermen*, trip *Duration* and number of *Mesh*. The multiple regression model with all explanatory variables will be used to predict the individual vessel catch per trip (total catch of all species) for each fishing gear in each sector. According to survey data analysis, the individual vessel catch depends on type of fishing gear, fishing sector and vessels characteristics (number of *Nets*, number of *Fishermen*, trip *Duration* and number of *Mesh*). The fleet model aims to control fishing effort by controlling characteristics of each vessel and fleet size to catch a certain amount of fish to conserve fish stocks. All catch strategies use a constant fleet size once the fishing re-start.

The biomass model has been applied to four species of *Tilapia* species, but the fleet can catch all species. So an estimate of the *Total Tilapia* catch is required. From the catch time series (1977-1997) the total *Tilapia* catch average was 77% of all species catch, while this proportion was 67% during the period 1989 to 1997. Comparing the proportion of the catches of *Tilapia* and the non *Tilapia* species with the all species catch over the study period, it is noted that there is a complex interaction between *Tilapia* and non *Tilapia* catches. The catch proportion of non *Tilapia* to all species catch was nearly constant during 1977 to 1987, then it showed a small increase during 1988 to 1997. This may have happened because the *Tilapia* species growth has been suppressed by the increased proportion of non *Tilapia* species, or it may be due to the growth of non *Tilapia* species at different rate. There are two assumptions that could be made in future predictions, as stock recover, the proportion of *Tilapia* to all species will return to the previous level, or as stocks recover the proportion will remain around more recent level. The complex interaction between *Tilapia* and non *Tilapia* catches will not explained in this study. So *Total Tilapia* catch can be estimated by multiplying the fleet catch (all species catch) by 0.67 because this proportion (1989-1997) is closer to the future and the stock recovery need a short period 3 to 5 years. Then the estimates of *Total Tilapia* catch can be split to the four species catches based upon the proportion of the biomasses in the end of the previous year.

From the survey data the maximum annual working days are 300 days per year (one trip per day). The maximum annual working days are assumed to be 300 days in each projected year.

5.6.1. Mesh control

In a study carried out by National Institute of Oceanography and Fisheries in Alexandria (1994), it concluded that the best mesh dimensions to protect *Tilapia* species stocks is 2-2.5 cm, which means about 40-50 mesh per 100 cm length of nets. So the maximum allowable number of mesh per 100 cm length of nets must be 50. This study will confine itself to strategies which include this restriction. However, the modelling methodology would allow any restriction on the number of mesh.

5.6.2. Limits of individual vessels

Effort control will be achieved by allowing the vessels to fish with the same vessels characteristics as the 1995 fleet, but controlling number of vessels. From the survey data the upper limits for number of *Nets* and *Fishermen* were used to control effort, while the *Duration* time was reduced to 15 hours per trip for Trap nets and Stand nets, and 18 hours per trip for Hook lines, to be similar to trip duration in other lakes in Egypt. Table 5.9

shows the upper limit for the vessel characteristics which any skipper must not exceed. This means that if a skipper currently exceeds the following limits he may be allowed to fish, but only if he restrict his operating characteristics to be equal the following limits.

Table 5.9 Upper limits for each independent variable.

Gear and sector	*Nets*	*Fishermen*	*Duration*	*Mesh*
Trap south	150	10	15	50
Trap west	150	10	15	50
Trap east	150	10	15	50
Stand south	100	10	15	50
Stand west	100	10	15	50
Stand east	100	10	15	50
Hooks south	250	9	18	
Hooks west	250	9	18	

5.6.3. Calculation of fleet size

Spreadsheet is a good environment to estimate the required allowable fleet size through the following steps:

1. insert all variables (dependent and independent) for each sample vessel in a spreadsheet.

2. reduce the duration time per trip to 15 hours for Trap nets and Stand nets if the duration time per trip is greater than 15 hours, and reduce the duration time per trip to 18 hours per trip if it is greater than 18 hours for Hook lines. Both number of nets and fishermen need no change because we use the upper limits of them from the survey data as the maximum allowable.

3. use Model 3 for Trap nets, Stand nets and Hook lines (Table 5.7) to estimate the individual catch per vessel for the remaining vessels, then calculate the total estimated catch.

4. adjust the total estimated catch using the ratio of the estimated biomass in that year to the 1995 biomass.

5. calculate the number of vessels required to give the planned catch on the bases of the fleet composition in steps 1- 2 and the catch in steps 3-4. This assumes that any reduced or augmented fleet will have the same relative composition as the 1995 fleet.

5.6.4. Catch strategies

The required fleet size during projected years, estimated number of fishermen, expected catch of all species, estimated *Tilapia* biomass and estimated all species biomass during 1998-2006 for the three catch strategies are shown in Table 5.10. Comparing the fleet size with the actual fleet size in 1997, it is noted that the fleet size for *MSY* is approximately one third of the 1997 fleet. It has already been shown that the 1997 fleet size represents a high effort level and to continue using 1997 fleet size will cause further depletion of the stock.

Table 5.10 Number of vessels, estimated number of fishermen, expected catch of *Total Tilapia*, expected catch of all species, estimated *Total Tilapia* biomass and estimated all species biomass during 1998-2006 for the three catch strategies.

Years	1998	1999	2000	2001	2002	2003	2004	2005	2006
Catch strategy 1									
No. of vessels	0	1140	1140	1140	1140	1140	1140	1140	1140
No. of fishermen	0	3764	3764	3764	3764	3764	3764	3764	3764
Total Tilapia catch	0	17.18	19.15	20.91	22.41	23.62	24.58	25.30	25.84
All species catch	0	25.64	28.58	31.21	33.44	35.26	36.69	37.76	38.56
Total Tilapia biomass	35.24	55.05	61.35	66.99	71.79	75.69	78.75	81.07	82.78
All species biomass	52.60	82.16	91.57	99.98	107.14	112.97	117.54	120.99	123.55
Catch strategy 2									
No. of vessels	0	0	1140	1140	1140	1140	1140	1140	1140
No. of fishermen	0	0	3764	3764	3764	3764	3764	3764	3764
Total Tilapia catch	0	0	25.12	25.70	26.13	26.43	26.65	26.80	26.90
All species catch	0	0	37.50	38.36	39.00	39.45	39.77	39.99	40.15
Total Tilapia biomass	35.24	55.05	80.49	82.35	83.71	84.68	85.37	85.85	86.19
All species biomass	52.60	82.16	120.13	122.92	124.94	126.39	127.42	128.14	128.64
Catch strategy 3									
No. of vessels	0	0	0	1140	1140	1140	1140	1140	1140
No. of fishermen	0	0	0	3764	3764	3764	3764	3764	3764
Total Tilapia catch	0	0	0	33.51	31.05	29.66	28.80	28.25	27.89
All species catch	0	0	0	50.02	46.35	44.26	42.98	42.16	41.62
Total Tilapia biomass	35.24	55.05	80.49	107.37	99.50	95.01	92.26	90.50	89.34
All species biomass	52.60	82.16	120.13	160.26	148.50	141.81	137.70	135.07	133.35

Strategy 1, strategy 2 and strategy 3 are compared in Table 5.11. This comparison is made on the basis of the expected catches (chapter four) and cumulative fishermen-years as a guide to the social impact in terms of unemployment.

Table 5.11 Cumulative all species catch, number of vessels-years and number of fishermen-years for each catch strategy.

Year	Strategy 1			Strategy 2			Strategy 3		
	Cumulative vessels-years	Cumulative fishermen-years	Cumulative catch of all species	Cumulative vessels-years	Cumulative fishermen-years	Cumulative catch of all species	Cumulative vessels-years	Cumulative fishermen-years	Cumulative catch of all species
1998	0	0	0	0	0	0	0	0	0
1999	1140	3764	26	0	0	0	0	0	0
2000	2280	7528	54	1140	3764	37	0	0	0
2001	3420	11292	85	2280	7528	76	1140	3764	50
2002	4560	15056	119	3420	11292	115	2280	7528	96
2003	5700	18820	154	4560	15056	154	3420	11292	141
2004	6840	22584	191	5700	18820	194	4560	15056	184
2005	7980	26348	229	6840	22584	234	5700	18820	226
2006	9120	30112	267	7980	26348	274	6840	22584	267

It is clear that strategy 1 and 3 are similar on the basis of producing the same amount of the catch, while strategy 2 realises the greatest amount of the catch and also realises the greatest total discounted catch if the discount rate is 10% or less as mentioned in chapter four. Strategy 1 realises the greatest total discounted catch if the discount rate is greater than or equal 10% as mentioned in chapter four. Because strategy 1 allows fishing to start earliest, it allows the greatest cumulative employment in terms of both fishermen-years and vessels-years. Because strategy 3 prevents fishing for an addition two years, it gives the lowest cumulative employment. Strategy 2, which has the advantage of the greatest cumulative catch, has an intermediate level of cumulative employment over this time period.

CHAPTER 6 EFFORT MANAGEMENT BASED ON NON-PARAMETRIC ANALYSIS

6.1. Introduction

A production function is a reasonable way to represent the relationship between the dependent variable and independent variables because the plot of the dependent variable versus each independent variable in logarithm scale showed an approximately linear relationship. In chapter five, multiple regression analysis was carried out for the survey data of Lake Manzala by using a multiple log function to represent the relationship between the catch average and the fishing effort variables ($LogY = Log\alpha + \sum \beta_i LogX_i + e$). In despite of using multiple log function there was still some curvature which can not be ignored. So some other non-linear modelling is necessary to pick the data curvature. This chapter describes the use of generalised additive model for the purpose of improving the linear model.

There has been limited research using generalised additive models (GAM) in fisheries. Borchers, Buckland and Ahmadi (1996) conducted a study on improving the precision of the daily egg production estimation using generalised additive model for western mackerel and horse mackerel stocks. The application of generalised additive model to survey data produced a substantial reduction in coefficients of variation of egg abundance. They used generalised additive model methods to estimate the daily egg production, in which presence/absence is modelled separately from non zero observations and used a new form of the bootstrap which accommodated clustered count data without requiring explicit knowledge of the form of clustering. In addition to the increased estimation precision, the use of generalised additive models have several advantages over stratified sample survey methods. To a large degree they allow the data to determine the function form of the response on the explanatory variables and they accommodate a wide variety of forms of stochastic variation of the response.

Swartzman, Silverman and Williamson (1994), used generalised additive models to model the trend in mean abundance of Bering Sea walleye pollock as a function of ocean environmental conditions including water column depth, temperature at 50 m and depth of the thermocline. Acoustic survey data collected in 1988 and 1991 was used to test these relationships. The authors assumed that the biomass abundance estimate came from a normal distribution. They chose the logarithm of bottom depth as a covariate instead of depth to avoid having the large range of depth overemphasise the effect of points near the tail of the distribution. The generalised additive model was applied to both 1988 and 1991 data. In both surveys, all explanatory variables were significant except thermocline depth.

Swartzman, Stuetzle, Kulman and Powojowski (1994) used generalised additive models to explore the relationship between the distribution of pollock schools in the Bering Sea and environmental factors such as depth and temperature. They assumed that the school density came from the Poisson distribution, while normality was assumed for total school area and average school mass.

Swartzman, Huang and Kaluzny (1992) applied generalised additive models to trawl survey data in the eastern Bering Sea to detect trends in ground fish distributions and improve abundance estimates by including the trend. Generalised additive models provided reasonable fits to the spatial distribution of five flat fish species and was able to define a spatial signature for each species, namely their preferred depth and temperature range.

6.2. Generalised Additive Model

Generalised linear model can be used if the relationship between the response and the explanatory variables is not linear (Green and Silverman, 1995). So a linear model can extend to a generalised linear model by using the following formula:

$$Y = g^{-1}(\alpha + \sum_{i=1}^{p} \beta_i X_i) + e$$

where

Y is a dependent variable,

g is a ***link*** function (in generalised linear model the link function is known),

α is intercept,

β_i is a parameter,

X_i is independent variable,

e is an error term, which does not have to be Normally distributed.

By using generalised linear model, data can be fitted with Gaussian, Binomial, Poisson, Gamma or inverse Gaussian error which extends dramatically the kind of data for which one can build regression models.

Even with a non-linear link function the model linearity assumption imposes many restrictions on the relationships between the dependent and independent variables that can be studied. "In some cases it is possible to use a transformation of an independent or dependent variable to partially alleviate the problem, but in other cases, non-linearities in these relationships may be difficult or impossible to state analytically" (Spector, 1994). In such cases the class of models known as generalised additive model can be used to overcome this difficulty by modelling the relationship a dependent variable in the following way:

$$Y = g^{-1}\{\alpha + \sum_{i=1}^{p} f_i(X_i)\} + e$$

where:

$f_i(\bullet)s$ are unknown functions which can be determined by the nature of the relationship between the dependent and independent variables,

e represents the error term of the model.

In the generalised additive model there is no need to determine the exact analytical form of the transformation of the independent variables used in the additive part of the model. The modelling process finds those transformations that are most appropriate and the nature of the relationship can be viewed graphically. In applying generalised additive models there are two kind of variables to enter the formula:

- variables for which the function $f_i(X_i)$ is known; they are entered in generalised additive model formula, as linear effect as in a regression model, and

- variables for which the function $f_i(X_i)$ is unknown; they can be estimated using a smoothing function.

6.3. Smoothing

A 'smoother' is a tool for summarising the value of a dependent variable Y as a function of a predictor variable X. A 'smoother' is a non-parametric regression technique because it does not assume a rigid form for the dependence of Y on X. A smoother is useful in two ways, first as a descriptive tool to help eyes to pick out the relationship between Y and X from the scatter plot and second to estimate the dependence of the mean of Y on the predictor which can help for estimation of the additive models. There are several methods of smoothing of which cubic smoothing spline and locally weighted regression smoothing are probably the most well known methods. "The spline smoothing approach avoids this implausible interpolation of the data by quantifying the competition between the aim to produce a good fit to the data and the aim to produce a curve without too much rapid local variation." (Härdle, 1995). So cubic smoothing spline was preferred.

6.3.1. Cubic smoothing spline

The cubic smoothing spline is a powerful and robust non-parametric regression technique that allows one to uncover the function form of the dependence between predictor and response variables. The smoothing that non-parametric regression performs can be thought of as a process where each data point is replaced by a local average of the surrounding data points. Different non-parametric regression techniques define and calculate this local average in different ways. The smoothing spline's determination of what is 'local' is based on the data itself (Silverman 1985), making it a particularly flexible smoother. With the underlying mathematical form of the interpolation spline, the smoothing spline has the ability to model a wide range of functional forms while the flexibility of the smoothing procedure makes smoothing splines especially robust.

Like most non-parametric regression techniques, the smoothing spline is itself a function of a smoothing parameter. This parameter determines the balance between fidelity to the data and the smoothness of the curve. Consequently, the successful use of smoothing splines to separate the signal from the noise depends on the choice of the 'optimal' smoothing parameter. The residual sum of squares $\sum_{j=1}^{n}(y_j - f(x_j))^2$ (where y_j and x_j are j^{th} observations of the dependent variable Y and independent variable X respectively and n is the number of observations) is a measure of fidelity of the smoothed curve to the data. "If f is allowed to be any curve then the distance measure can be reduced to zero by any f that interpolates the data. Such a curve would not be acceptable on the grounds that it is not unique and that it is too rough for a structure oriented interpretation." (Härdle, 1995). To quantify local variation one must define measures of roughness which may be based on the first, second and subsequent derivatives. The roughness $\int (f''(t))^2 dt$ can be used to determine the quantity of local variation (Green and Silverman, 1995). So, the residual sum of squares can be penalised by using the roughness as follows:

$$S_\lambda(f) = \sum_{j=1}^{n} (y_j - f(x_j))^2 + \lambda \int_a^b (f''(t))^2 dt$$

where:

$S_\lambda(f)$ is the penalised sum of squares,

λ is the smoothing parameter, which controls the trade-off between fidelity to the data and smoothness,

[a, b] is a closed interval satisfying the following condition $a < x_1 < x_2 < .... < x_n < b$ where x_j's are called ***knots***, and

t is a target point.

The problem of minimising $S_\lambda(\bullet)$ over the class of all twice differentiable functions on the interval $[a,b]=[x_1,x_n]$ has a unique solution $f_\lambda(x)$ which is defined as cubic spline. "Suppose f is any curve that is not a natural cubic spline with knots at the x_j. Let f^* be the natural cubic spline interpolant to the values $f(x_j)$; since, by definition, $f^*(x_j)=f(x_j)$ for all j, it is immediate that $\sum\{y_j - f^*(x_j)\}^2 = \sum\{y_j - f(x_j)\}^2$. Because of the optimality properties of the natural cubic spline interpolate, $\int f^{*''2} < \int f^{''2}$, and hence, since $\lambda > 0$, we can conclude that $S(f^*) < S(f)$. This means that, unless f itself is a natural cubic spline, we can find a natural cubic spline which attains a smaller value of the penalised sum of squares; it follows at once that the minimizer $\hat{f}$ of S must be a natural cubic spline." (Green, and Silverman, 1995). So, the estimated curve $f_\lambda(\bullet)$ has the following properties:

- $f_\lambda(x)$ is a cubic polynomial between two successive values of x,

- at the observation points x_j, the curve $f_\lambda(\bullet)$ and its first and second derivatives are continuous.

- at the boundary points x_1 and x_n the second derivative of $f_\lambda(x)$ is equal to zero.

The smoothness of the curve $f_\lambda(\bullet)$ depends on the value of λ, There are two extremes for λ:

- first when $\lambda \to \infty$, the penalty term forces $f''(x)=0$ everywhere, in that case the smoothing produces the least squares line.

- second when $\lambda \to 0$, the penalty term disappears and the solution tends to an interpolating twice-differentiable function.

So large values of λ produce smoother curves while smaller values produce rougher curves.

6.4. Choosing the smoothing parameter

The problem of deciding how much to smooth is of great importance in non-parametric regression. The value of the smoothing parameter depends on the proportion of data points used as knots. Then the smoothing parameter has the main effect in determining the degrees of freedom, so when the smoothing parameter increases, the degrees of freedom decrease, using 50% of data points as knots corresponding to about four degrees of freedom, while using 100% of data points as knots will produce a linear regression with one degree of freedom (Hastie and Tibshirani, 1990). So the problem is how one can choose the smoothing parameter to balance between degrees of freedom of a smoother and the smoothness of the curve. This number of degrees of freedom is a function of the smoothing parameter and the predictor values in the data, and it is not a function of the dependent variable Y.

Choosing the smoothing parameter aims to minimise the mean squared error *(MSE)* at each x_j and give a constant variance (σ^2) where:

$$MSE(\lambda) = \frac{1}{n}\sum_{j=1}^{n} E\{f_\lambda(x_j) - f(x_j)\}^2$$

where:

x_j is an observation of variable X.

There are many methods available to estimate the smoothing parameter λ. One of these methods is known as "***Cross Validation***" which is essentially an automatic method for choosing the smoothing parameter. Cross validation has been used in chapter five to check the reliability of the model for prediction. In this chapter cross validation will be used to guide the choice of the smoothing parameters.

The basic idea behind cross validation is that for a fixed smoothing parameter, one point (x_j, y_j) is left out and the smooth estimated at x_j, based on the remaining (n-1) points. Repeating for all n points, the CV sum of squares (cross validation score function) can be expressed as follows:

$$CV(\lambda) = \frac{1}{n}\sum_{j=1}^{n}(y_j - f_\lambda^{(-1)}(x_j))^2$$

where $f_\lambda^{(-1)}(x_j)$ is the fit at x_j computed by leaving out the j^{th} data point. The idea of cross validation is to choose the value of smoothing parameter λ which minimises the cross validation score function $CV(\lambda)$ (Hastie and Tibshirani, 1990).This procedure is loosely justified by the fact that $E\{CV(\lambda)\} \approx MSE + \sigma^2$, although a strong justification requires evidence that minimum of $CV(\lambda)$ is close to the minimum of $MSE+\sigma^2$.

When cross validation was used to select a smoothing parameter for Lake Manzala survey data (Figures 6.1 - 6.4), the spline appeared too smooth, "It can not be guaranteed that the function CV has a unique minimum, so care has to be taken with its minimisation, and simple grid search is probably the best approach" (Green and Silverman, 1995). Hastie and Tibshirani suggested that number of degrees of freedom will be {1, 4, 7} because df=1 for a term means this term has a linear fit, and when df > 1 means shrinking smoother, so the larger the degrees of freedom, the rougher the fit. The cross validation method simply gives an idea of the size of the smoothing parameter should be selected. So for that reasons chosen smoothing parameter value will be based upon a comparison between the following two criteria:

• using cross validation to determine the smoothing parameter value, and

• manually using different values of degrees of freedom (1, 4 and 7).

From chapter four the variable *Sector* has a significant effect on the dependent variable (*LogYave* catch average per vessel). For that reason the dependent variable will smooth versus each independent variable(*LogNets, LogFishermen, LogDuration* and *LogMesh*) in each sector separately to determine the best degrees of freedom in each sector.

Using cross validation techniques to determine degrees of freedom for each independent variable versus the dependent variable for each type of fishing gear in each sector gave three degrees of freedom for all relationships between each independent variable and the dependent variable for each type of fishing gear in each sector. Figures 6.1-6.4 shows the smoothing spline smoother for each independent variable (*LogNets, LogFishermen, LogDuration* and *LogMesh*) versus *LogYave* for Trap nets fishing gear in Southern Sector using 1, 3, 4 and 7 degrees of freedom. (see Appendix D for the other fishing gear in each sector).

Figure 6.1a shows using one degree of freedom produces a straight line which is equivalent to linear effect. Figure 6.1b shows that smoothing spline by using cross validation, where degrees of freedom was three is reasonably faithful but it does not pick up all the curvature of the data. Figure 6.1c shows that spline with four degrees of freedom, which produces a less smooth curve than three degrees of freedom had seems to follow the data better. Seven degrees of freedom (Figure 6.1d) gives a rougher curve than using four degrees of freedom. Figures 6.2-6.4 shows the same results as Figure 6.1. It is noted that the independent variables data points does not spread over the horizontal axis because those variables have discrete values.

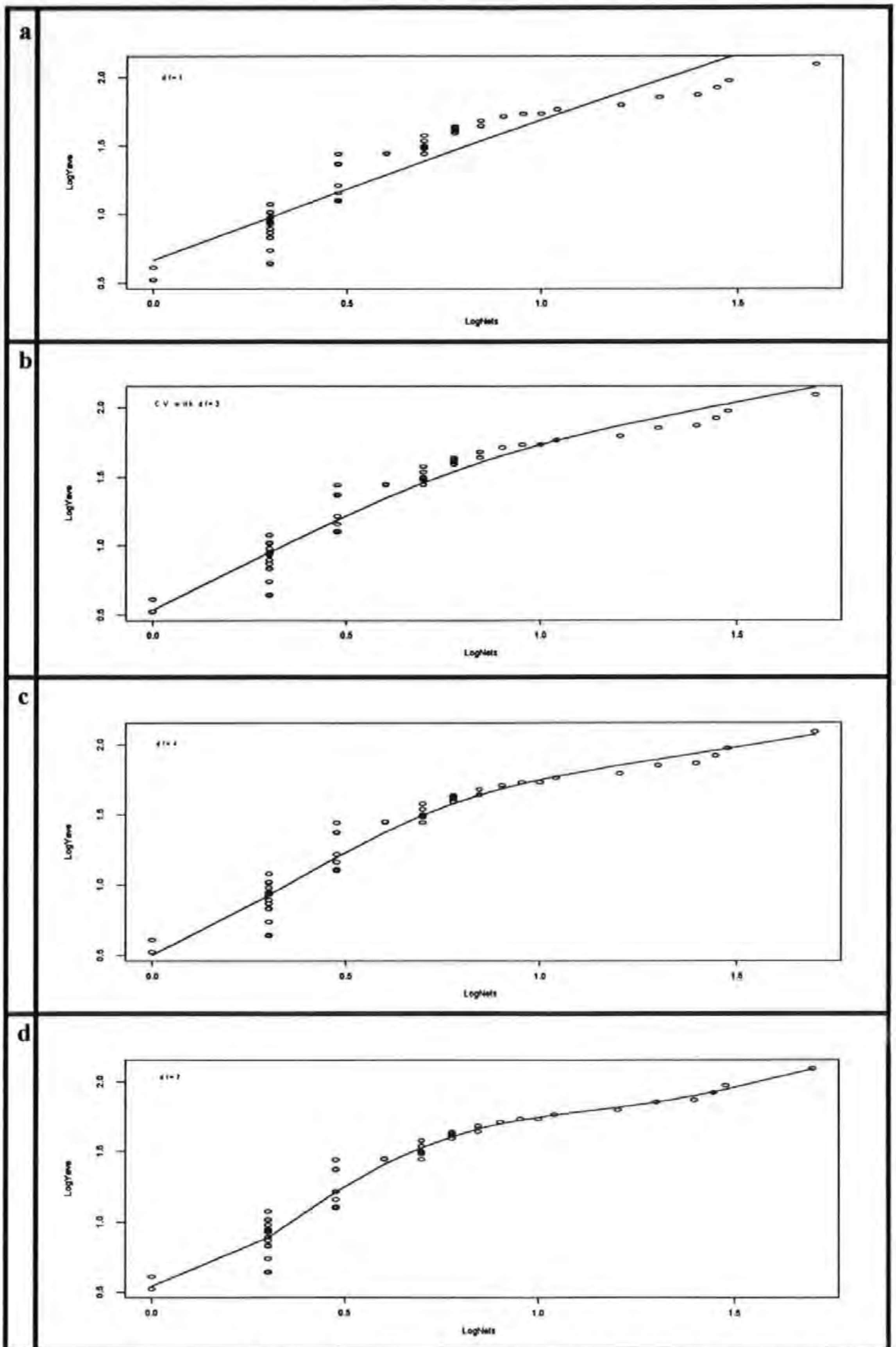


Figure 6.1 Smoothing spline smoother of *LogYave* vs. *LogNets* for Trap nets in Southern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

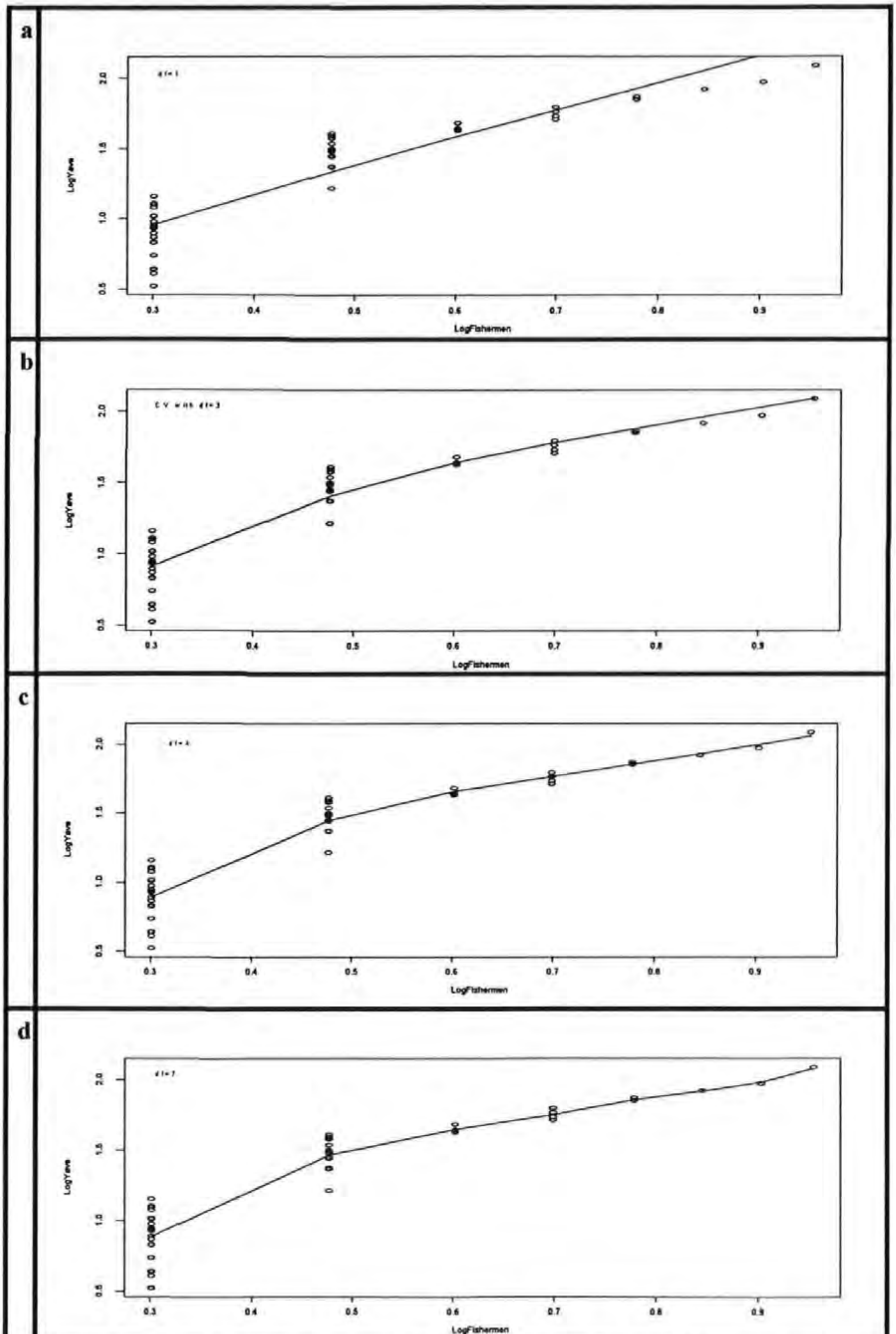


Figure 6.2 Smoothing spline smoother of *LogYave* vs. *LogFishermen* for Trap nets in Southern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

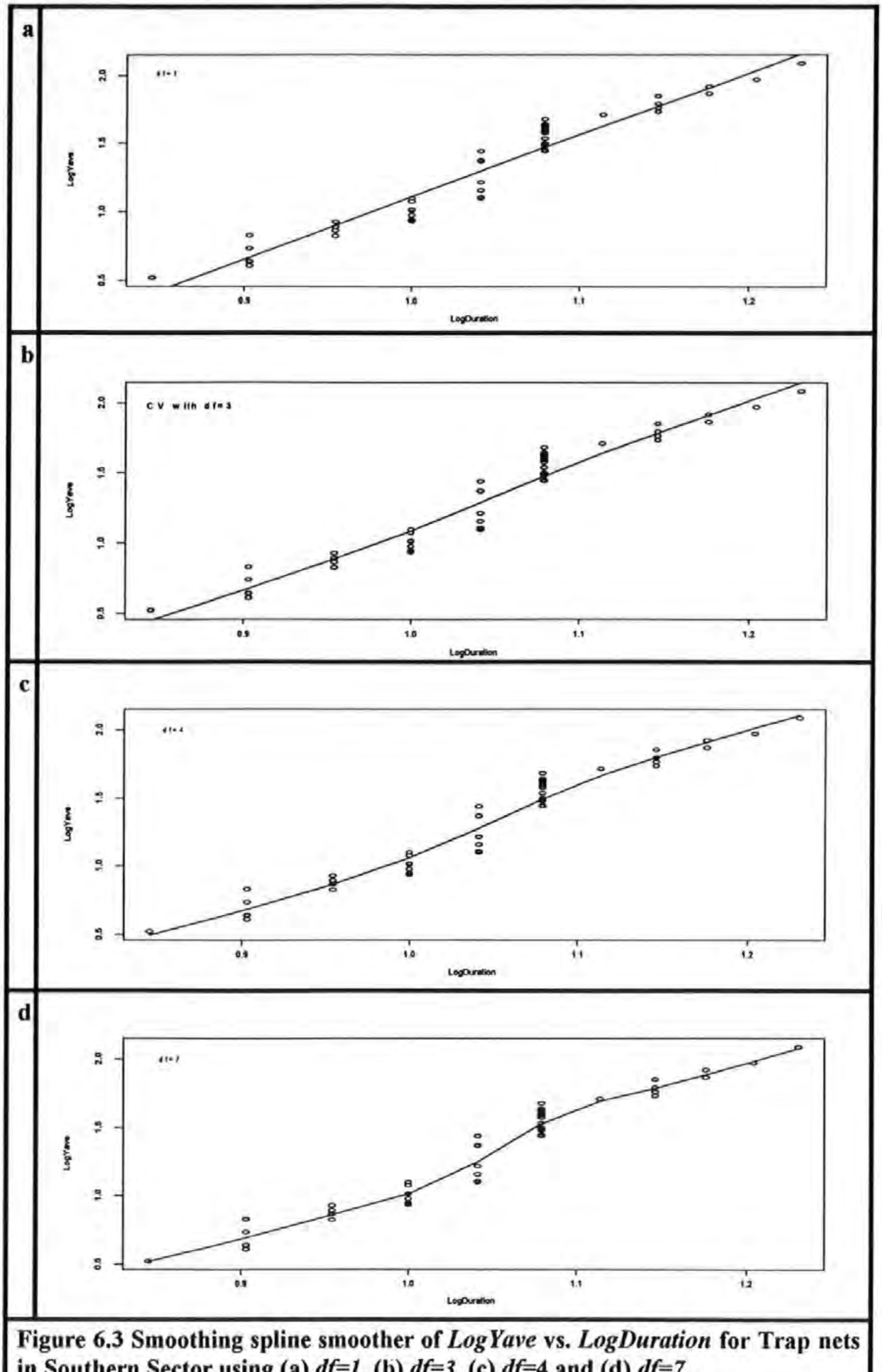


Figure 6.3 Smoothing spline smoother of *LogYave* vs. *LogDuration* for Trap nets in Southern Sector using (a) *df=1*, (b) *df=3*, (c) *df*=4 and (d) *df=7*.

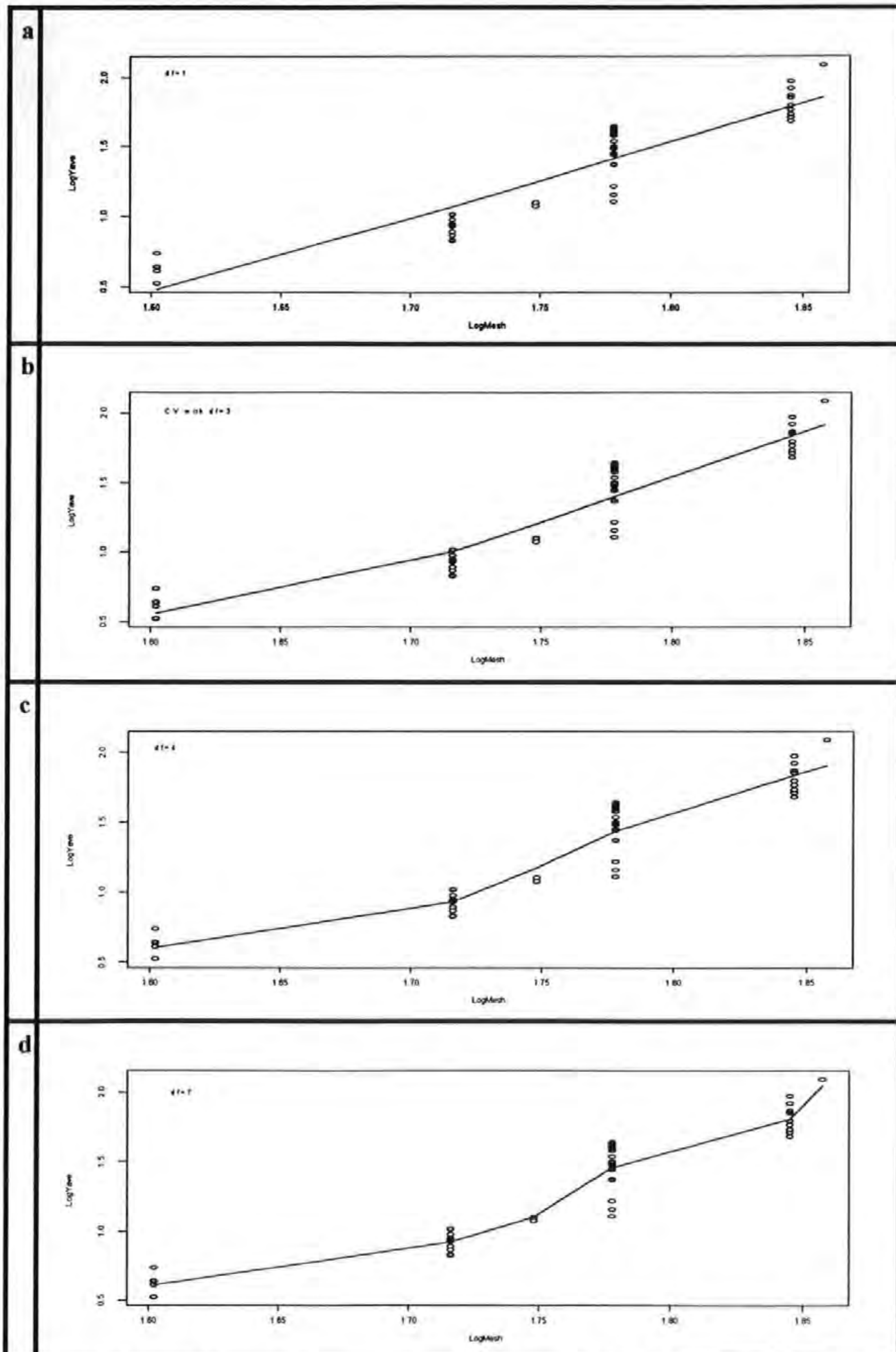


Figure 6.4 Smoothing spline smoother of *LogYave* vs. *LogMesh* for Trap nets in Southern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

6.5. Model selection

The dependent variable in Lake Manzala survey data is a vessel's average daily catch (*LogYave*), the errors are distributed according to the *Gaussian* distribution (supported by residual analysis in chapter 5) and the link function is *identity*.

On the grounds of improving the linear model for each type of fishing gear in each sector, generalised additive model will be used. The initial model will be the linear model including all independent variables for Trap nets and Stand nets in the three sectors, while the initial model for Hook lines will not include the variable *LogMesh* and it operates in Southern and Western Sectors only. The initial model can be expressed as follows

$$LogYave = \alpha + \beta_1\, LogNets + \beta_2\, LogFishermen + \beta_3\, LogDuration + \beta_4\, LogMesh$$

To select the best non-parametric model, fitting generalised additive models was used in finding spline for the independent variables *LogNets*, *LogFishermen*, *LogDuration* and *LogMesh*, and stepwise procedure was used to decide which covariate should be included in the model and how many degrees of freedom to minimise the residual sum of squares. At each stage any covariates can be either dropped or transformed from a linear fit to smooth fit.

The measure of fit of the generalised additive models is the residual deviance and change in deviance is useful for comparing different models. Because the error is Normally distributed, so residual deviance leads to F test. F statistic can be used to judge the effects of dropping out a variable or smoothing a variable.

In chapter five, a complete model for each type of fishing gear in each sector had been chosen to predict the individual catch per vessel in spite of non significance of some independent variables. This model has been chosen to allow tight control of the fishing effort in Lake Manzala. To compare the prediction of the effects of different effort control strategies using parametric and non-parametric models both must include the same explanatory variables. Selection of the best non-parametric model based upon dropping out a covariate or smoothing a covariate. This procedures could produce a model which does not include all explanatory variables. If the best non-parametric model include all explanatory variables it can be used to estimate the individual vessel catch average, but if not it will not be used. So a non-parametric model including all explanatory variables (call it non-parametric control model) is required. To select a non-parametric control model which include all explanatory variables, fitting generalised additive models steps were used in finding spline for the independent variables *LogNets*, *LogFishermen*, *LogDuration* and *LogMesh* to decide how many degrees of freedom to minimise the residual sum of squares. At each stage any of the covariates can be transformed from a linear fit to smooth fit without dropping out a covariate.

6.5.1. Model selection for each fishing gear

Backward and forward stepwise selection was carried out to select the best non-parametric model and the same procedure was repeated without omitting any covariate to select the control model.

The comparison between the initial linear model, non-parametric models which includes all independent variables with 3, 4 and 7 degrees of freedom, the best model non-parametric and the control model (if the best non-parametric model does not include all the explanatory variables) are listed below in Table 6.1 for the Trap nets in each sector together with F value of the results of comparing the initial model with the other models (for example, see Tables 1D and 2D in Appendix D for the other fishing gear). From this table there is a significant difference between the initial model and the best model. Also the best non-parametric models for Trap nets in Southern Sector and Western Sector include all explanatory variables, so there is no need to select a control model for them and the best non-parametric model can be used to control the effort. While the best non-parametric model for Trap nets in Eastern Sector does not include the variable *LogMesh* so the control model is required for this fishing gear in that sector.

Table 6.1 The main steps of using stepwise selection Trap nets fishing gear.

	Model	Deviance	*df*.residual	Δ Deviance	Δ *df*	*F* value
Trap South	Initial model with df=1	0.331	46			
	Model with *df*=3	0.084	38	0.247	8	4.291
	Model with *df*=4	0.077	34	0.254	12	2.942
	Model with *df*=7	0.066	25	0.265	21	1.754
	Best model *LogYave* = β_1 *LogNets* + s(*LogFishermen*, *df*=3) + β_3 *LogDuration* + β_4 *LogMesh*	**0.107**	**44**	**0.224**	**2**	**15.565**
Trap West	Initial model with df=1	0.171	37			
	Model with df=3	0.039	25	0.132	12	2.380
	Model with *df*=4	0.032	21	0.139	16	1.880
	Model with *df*=7	0.023	9	0.148	28	1.144
	Best model *LogYave* = β_1 *LogNets* + s(*LogFishermen*, df=4)+ β_3 *LogDuration* + β_4 *LogMesh*	**0.047**	**30**	**0.124**	**7**	**3.833**
Trap East	Initial model with df=1	0.274	18			
	Model with df=3	0.041	10	0.233	8	1.913
	Model with *df*=4	0.033	6	0.241	12	1.342
	Model with *df*=7	0.016	2	0.258	16	1.040
	Best model *LogYave* = s(*LogNets*, *df*=3) + s(*LogFishermen*, *df*=1) + β_3 *LogDuration*	**0.064**	**17**	**0.210**	**1**	**13.796**
	control model *LogYave* =s(*LogNets*, *df*=4) + β_2 *LogFishermen* + β_3 *LogDuration* + β_4 *LogMesh*	**0.057**	**16**	**0.217**	**2**	**7.128**

From chapter five Trap nets (Figure 5.4) there was no pattern in the residuals, but the residuals of Stand nets and Hook lines had a sinusoidal pattern. Figure 6.5 shows the residuals plot of *LogYave* versus predicted values for the best non-parametric model for Stand nets in Southern, Western and Eastern Sectors, and Hook lines in only Western Sector because the best model to represent the Hook lines data in Southern Sector was the linear model (see Table 2D in Appendix D). It is clear that there is now no pattern in the residuals in the three sectors for Stand nets and in Western Sector for Hook lines. So generalised additive model has followed the underlying non-linearity in these data.

Figure 6.6 shows the normal probability plot of residuals for the best non-parametric model for Stand nets in Southern, Western and Eastern Sectors, and Hook lines in Western Sector. Using Shapiro-Wilks Goodness-of-Fit statistic produced P-value greater than 0.05 for the best non-parametric models. So there is no evidence that the residuals of the best non-parametric model vary from a normal distribution.

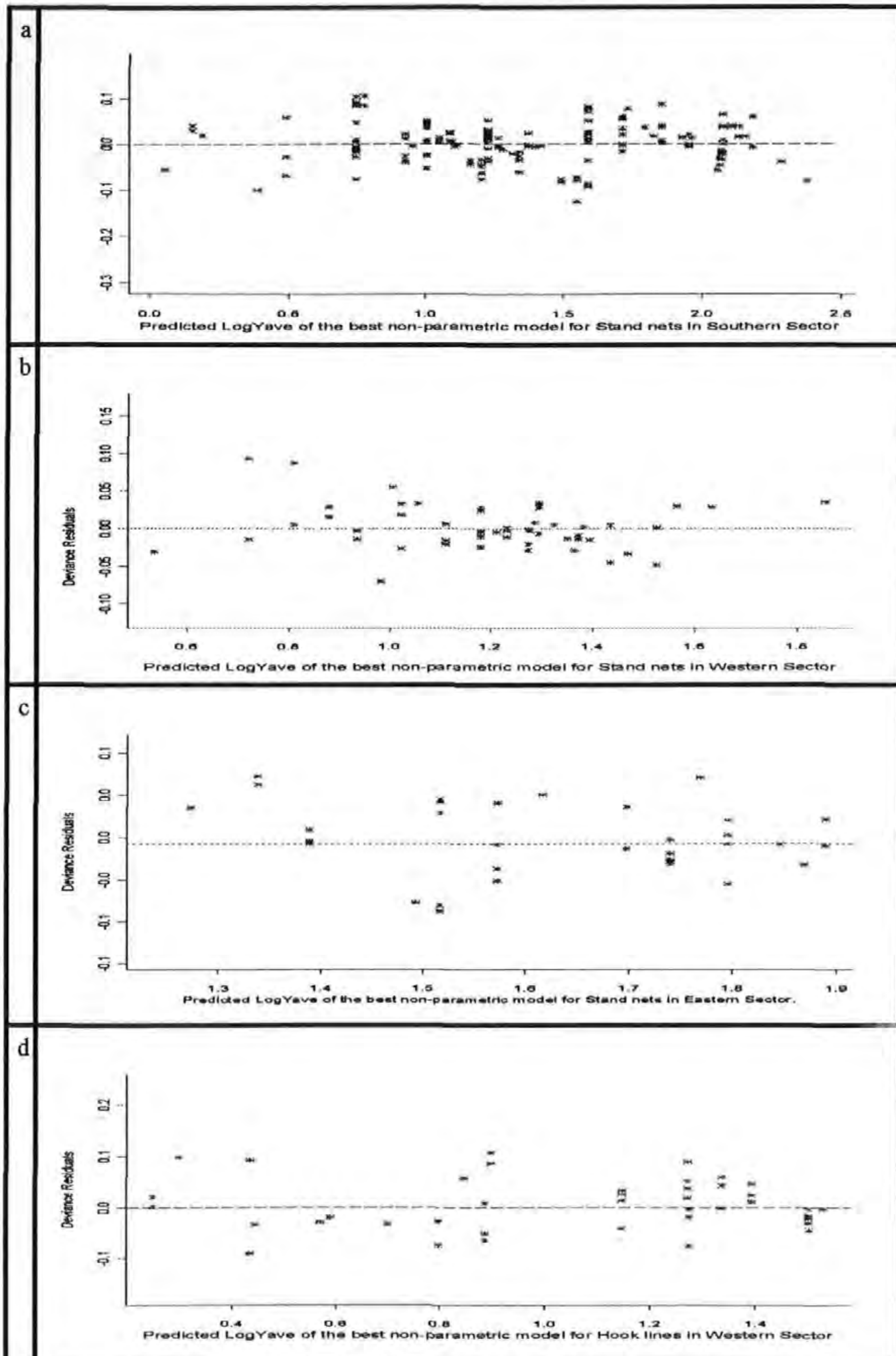


Figure 6.5 Residuals plot vs. predicted *LogYave* for the best non-parametric model of Stand nets in (a) Southern Sector (b) Western Sector and (c) Eastern Sector, and (d) Hook lines in Western Sector.

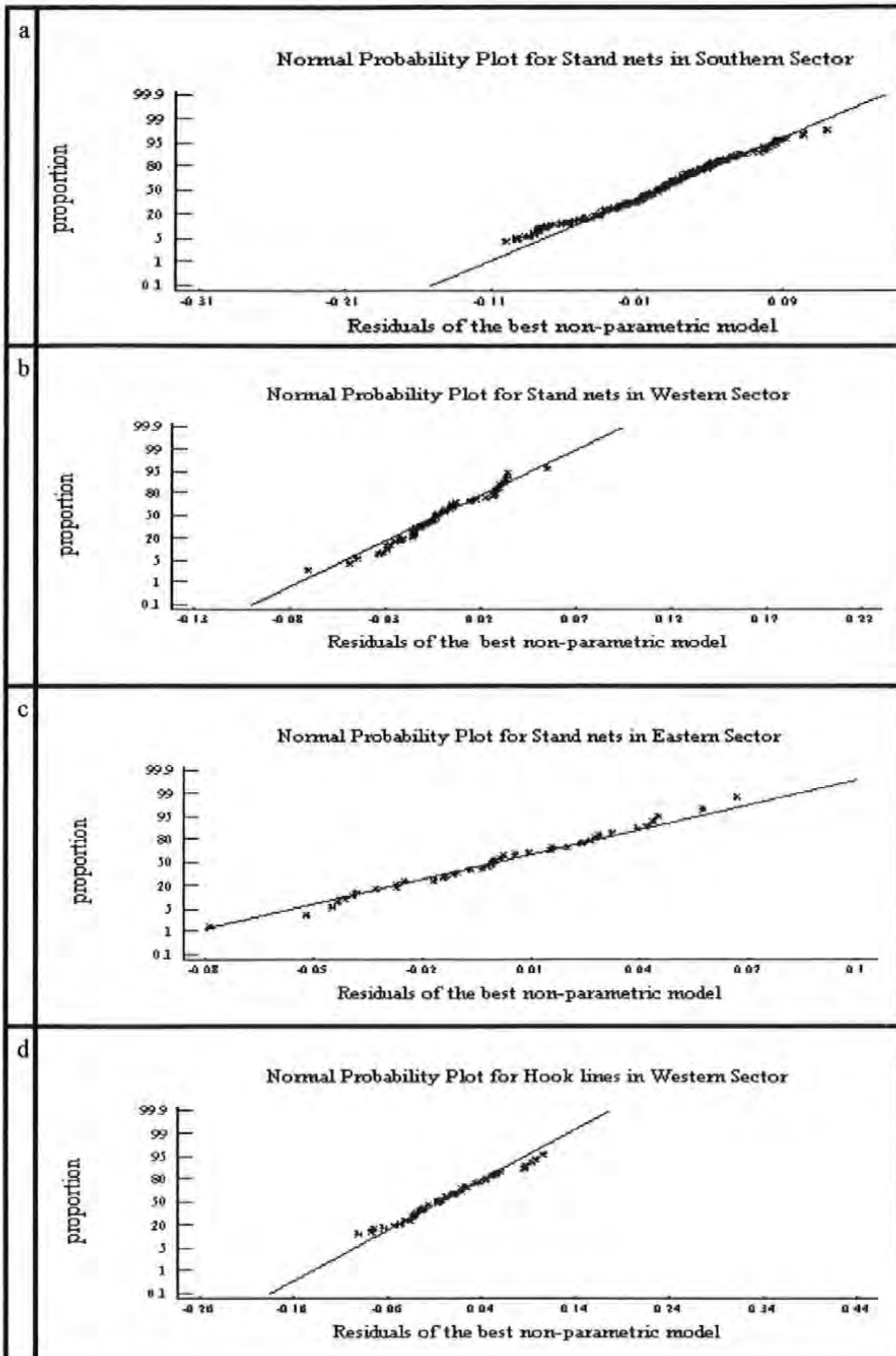


Figure 6.6 Normal probability plot of the best non-parametric model for Stand nets in (a) Southern Sector, (b) Western Sector and (c) Eastern Sector, and (d) Hook lines in Western Sector.

6.6. Non-parametric catch modelling validation

GAM used to estimate the parameters as well as to predict catch per individual vessel. However, GAM deemed to be an adequate predictor of the dependent variable may perform poorly when applied in practice. Cross validation and shrinkage statistic can be used for the sample data to check the reliability of the GAM, in the same way as far the linear regression in chapter five.

6.6.1. Splitting the data to 2 parts

It is noted that MSE of VDS is higher than MSE of EDS, their ratio varies from 151% to 159%. Also it is found that 19 iterations (9.5%) produced normal residual (P-value of Shapiro-Wilks Goodness-of-Fit statistic greater than 5%). It is found that the minimum value of shrinkage statistic was 0.000107 while the maximum was 0.042225, which means that the GAM is reliable model for prediction.

6.6.2. Splitting the data to 5 parts

By comparing MSE of EDS and MSE of VDS, it is found that MSE of VDS is higher than MSE of EDS. Their ratio varies from 145% to 158%. Also it is found that 106 iterations (58.5%) produced normal residual (P-value of Shapiro-Wilks Goodness-of-Fit statistic greater than 5%).

6.6.3. Splitting the data to 10 parts

By comparing MSE of EDS and MSE of VDS, it is found that MSE of VDS is higher than MSE of EDS. Their ratio vary from 144% to 173%. Also it is found that 83 iterations (41.5%) produced normal residual (P-value of Shapiro-Wilks Goodness-of-Fit statistic greater than 5%).

The summary of applying cross validation with splitting the data into 2, 5 and 10 parts using multiple regression model and GAM for Trap nets in Southern Sector are listed below in Table 6.2.

Table 6.2 The summary of the results of splitting the data into 2, 5 and 10 parts for the Trap nets in Southern Sector.

	2 parts	5 parts	10 parts
Number of observations	51	51	51
Number of iterations	200	200	200
Minimum value of MSE of VDS	0.0473	0.0352	0.1270
Minimum value of MSE of EDS	0.0313	0.0242	0.0088
Minimum ratio of MSE of VDS/MSE of EDS	151%	145%	144%
Maximum value of MSE of VDS	0.1831	0.1672	0.0202
Maximum value of MSE of EDS	0.0524	0.0425	0.0117
Maximum ratio of MSE of VDS/MSE of EDS	159%	158%	173%
Proportion of iterations produced normal residual	9.5%	58.5%	41.5%

The same analysis has been investigated for each fishing gear data set in each sector and all results are similar to the results mentioned above. From these analysis splitting the data into 2 parts was used to check the reliability of the catch model for prediction which ensure that both catch model are reliable for prediction. Splitting the data to 5 parts has been performed because when the survey data were collected the actual sample size was increased by 20% as a precaution to avoid an possibility of collecting invalid questionnaires and to use the additional observations to check the validity of a model.

Comparing the results of splitting the data into 2, 5 and 10 parts when using multiple regression model and generalised additive model (Table 5.8 and Table 6.2), it is noted that using generalised additive model gives better results which can be noted in the proportion of the iterations produced normal residual because generalised additive model picked up the curvature of the data better than multiple regression model.

In this section catch model validation has been investigated. Now effort control will be investigated based upon deterministic catch and biomass models to determine the fleet size which can achieve the allowable catch. The study of uncertainty of the catch model and biomass model will discussed in chapter seven.

6.7. Effort Control using non-parametric models

Chapter five described the use of a parametric model to predict the effects of different effort control strategies. These strategies were; strategy 1 stop fishing for one year 1998, strategy 2 stop fishing for two years 1998-1999 and strategy 3 stop fishing for three years 1998-2000. To compare between the parametric and non-parametric model, the prediction of the effect of different effort control strategies using non-parametric model is required. The generalised additive model prediction is given by the product of the model matrix and the coefficients, plus the smooth matrix. Assume that the vessels characteristics will be the same as specified in chapter five.

It is noted that the best non-parametric models for some fishing gear within each sector does not include all the explanatory variables. This means that the effort control strategies will not be tight, because if the non significant variables are not under control the people can change their behaviour to fish more without control those variables. To compare the prediction of the effects of different effort control strategies using parametric and non-parametric model both must include the same explanatory variables. For these reasons the best non-parametric models will be used if they include all explanatory variables and if not the non-parametric control models will be preferred.

6.7.1. Catch strategies

The fleet size for *MSY* during projected years by fishing gear in each sector, estimated number of fishermen, expected catch of all species, estimated *Tilapia* biomass and estimated all species biomass during 1998-2006 for the three catch strategies are shown in Table 6.3.

Table 6.3 Number of vessels, estimated number of fishermen, expected catch of *Total Tilapia*, expected catch of all species, estimated *Total Tilapia* biomass and estimated all species biomass during 1998-2006 for the three catch strategies.

Years	1998	1999	2000	2001	2002	2003	2004	2005	2006
Catch strategy 1									
No. of vessels	0	1070	1070	1070	1070	1070	1070	1070	1070
No. of fishermen	0	3537	3537	3537	3537	3537	3537	3537	3537
Total Tilapia catch	0	17.18	19.15	20.91	22.41	23.62	24.58	25.30	25.84
All species catch	0	25.64	29.58	31.21	33.44	35.26	36.69	37.76	38.56
Total Tilapia biomass	35.24	55.05	61.35	66.99	71.79	75.69	78.75	81.07	82.78
All species biomass	52.60	82.16	91.57	99.98	107.14	112.97	117.54	120.99	123.55
Catch strategy 2									
No. of vessels	0	0	1070	1070	1070	1070	1070	1070	1070
No. of fishermen	0	0	3537	3537	3537	3537	3537	3537	3537
Total Tilapia catch	0	0	25.12	25.70	26.13	26.43	26.65	26.80	26.90
All species catch	0	0	37.50	38.36	39.00	39.45	39.77	39.99	40.15
Total Tilapia biomass	35.24	55.05	80.49	82.35	83.71	84.68	85.37	85.85	86.19
All species biomass	52.60	82.16	120.13	122.92	124.94	126.39	127.42	128.14	128.64
Catch strategy 3									
No. of vessels	0	0	0	1070	1070	1070	1070	1070	1070
No. of fishermen	0	0	0	3537	3537	3537	3537	3537	3537
Total Tilapia catch	0	0	0	33.51	31.05	29.66	28.80	28.25	27.89
All species catch	0	0	0	50.02	46.35	44.26	42.98	42.16	41.62
Total Tilapia biomass	35.24	55.05	80.49	107.37	99.50	95.01	92.26	90.50	89.34
All species biomass	52.60	82.16	120.13	160.26	148.50	141.81	137.70	135.07	133.35

Table 6.4 shows a comparison between cumulative number of vessels-years and number of fishermen-years during the projected years (1998-2006) to compare between the different catch strategies using non-parametric models to control the effort.

Table 6.4 Cumulative all species catch, number of vessels-years and number of fishermen-years for each catch strategy.

	Strategy 1			Strategy 2			Strategy 3		
Year	Cumulative vessels-years	Cumulative fishermen-years	Cumulative all species catch	Cumulative vessels-years	Cumulative fishermen-years	Cumulative all species catch	Cumulative vessels-years	Cumulative fishermen-years	Cumulative all species catch
1998	0	0	0	0	0	0	0	0	0
1999	1070	3537	26	0	0	0	0	0	0
2000	2140	7074	54	1070	3537	37	0	0	0
2001	3210	10611	85	2140	7074	76	1070	3537	50
2002	4280	14148	119	3210	10611	115	2140	7074	96
2003	5350	17685	154	4280	14148	154	3210	10611	141
2004	6420	21222	191	5350	17685	194	4280	14148	184
2005	7490	24759	229	6420	21222	234	5350	17685	226
2006	8560	28296	267	7490	24759	274	6420	21222	267

It is clear that strategy 1 and 3 are similar on the basis of producing the same amount of the catch, while strategy 2 realises the greatest amount of the catch and also realises the greatest total discounted catch if the discount rate is 10% or less as mentioned in chapter four. Strategy 1 realises the greatest total discounted catch if the discount rate is greater than or equal 10% as mentioned in chapter four. Because strategy 1 allows fishing to start earliest, it allows the greatest cumulative employment in terms of both fishermen-years and vessels-years. Because strategy 3 prevents fishing for an addition two years, it gives the lowest cumulative employment. Strategy 2, which has the advantage of the greatest cumulative catch, has an intermediate level of cumulative employment over this time period.

CHAPTER 7 EFFECT OF UNCERTAINTY IN MODEL PARAMETER ESTIMATES.

7.1. Introduction

In chapter 3 the biomass modelling was used to predict the trajectory of stock size with three different catch strategies, and the effect of uncertainty in biomass estimates on parameters estimates was determined. In chapters five and six two different catch models have been developed and model validation has been discussed. These models were used to obtain estimates of catch per vessel and determine the allowable fleet size for each catch strategy depending on the deterministic biomass predictions. There are two sources of uncertainty which can affect the biomass prediction:

(1) uncertainty in the biomass model parameters and

(2) uncertainty in the catch modelling parameters.

This chapter will explore the effect of these two sources of uncertainty on the biomass prediction. The aim is to generate a distribution of predicted biomass trajectories. These can be used to give insight about the risks associated with various levels of fleet control.

There are two ways to investigate the effects of uncertainty on predicted biomasses: analytically and by simulation. Adding uncertainty to a catch model analytically will not be perused because the interaction between the error distributions of the catch model and the biomass model, even with simplifying assumption such as normal distribution, make the prediction too complex. For that reason adding uncertainty to the catch model parameters and biomass model parameters has been investigated through a simulation process.

This chapter discusses the use of simulation to investigate the effect of uncertainty in the biomass model parameters and the catch model parameters on the prediction of future catches and biomasses.

7.2. Effect of uncertainty on the catch and biomass prediction

In chapter three the effect of adding random effects to the starting and ending biomass has been explored assuming that the standard error of B_{80} and B_{94} is 5%. This procedure has been run 100 times to produce B_{80}, B_{94}, r and K_{80} for each run. These output are stored in a matrix which will be called "*Stochastic biomass matrix*". This matrix has 100 rows and four columns contains 100 simulations of possible parameters estimates. Note that each row contain a related set of values which must be kept together during the simulation.

In chapter five, the 1995 fleet (survey 1995 data) was used to determine the required fleet size for *MSY*. This procedure produces a fleet in which no vessel exceeds the limit allowed. This fleet will be called "*Adjusted fleet*". The number of vessels in the *Adjusted fleet* is not necessary equal to the required vessels. Sample the *Adjusted fleet* to obtain the required vessels. This step produces a fleet which will be called "*Projected fleet*". Then the individual vessels' catch (*LogYave*) for the *Projected fleet* vessels can be predicted.

In chapters five and six, cross validation (split the data set into five parts) has been applied. The uncertainty in the predicted catch of individual vessels can be obtained by computing the residuals from validation data set (VDS), which is the difference between the predicted values of the VDS and the observed values of the dependent variable in the same data set. The residuals are stored in a column which will be called "*VDS residual column*". The first n rows represent the residuals for n data points of the first iteration. Number of rows are n*200 where the cross validation run 200 times. These can be regarded as independent errors which would be applied to any vessel.

Now the effect on the biomass prediction of the two sources of uncertainty can be explored through the following steps:

(1) Use the values of B_{94}, r and K_{80} from the first row of the *Stochastic biomass matrix* to predict the biomass from 1995 to 1997. For the stop fishing years predict the biomass with zero catches, which means that let the catches equal zero in 1998, 1998-1999 and 1998-2000 for strategies S1, S2 and S3 respectively.

(2) From the *VDS residual column* select randomly with replacement a set of residuals equal to the number of vessels in the first allowable fishing year. Add this set of residuals individually to the predicted *LogYave* values. Calculate the corresponding *Yave* and the total of *Yave* over all vessels to obtain all species catch estimates for the first allowable fishing year. This catch assumes that the biomass is still at the 1995 level.

(3) Compute *Total Tilapia* catch by multiplying the all species catch by the 1995 ratio of *Tilapia* to all species and split it to the four species catch according to the proportion of the species biomasses at the end of the previous year. Adjust each of the four species catches using the ratio of the estimated species biomass in the first allowable fishing year to the corresponding 1995 biomass. This step produces a catch which will be called "*Computed species catch*".

(4) Insert the *Computed species catch* for the first allowable fishing year in the corresponding species biomass model, then predict the biomass for the start of the next year.

(5) Repeat the steps 2-4 for each successive year until 2012, which means that these steps must be repeated 14 times for strategy 1 (1999-2012), 13 times for strategy 2 (2000-2012) and 12 times for strategy 3 (2001-2012).

These step give a single iteration of the stochastic catch and stochastic biomass predictions up to 2012 for each species.

(6) These process was replicate 100 times using the successive rows of the *Stochastic biomass matrix* in step 1 and sampling the residuals with replacement for each sub-iteration in steps 2-4 is required.

The results of these steps show the effect of the uncertainty of the catches and the uncertainty of the biomass together on the prediction of the catches and biomasses.

This analysis has been carried out for each catch strategy and for *T.Nilotica, T.Aurea, T.Zillii, T.Galilea* and *Total Tilapia* species. *Total Tilapia* predicted catch is the sum of the four species predicted catches, *Total Tilapia* predicted biomass is the sum of the four species predicted biomasses, *Total BMSY* is the summation of the four species *BMSY* values and *Total MSY* is the summation of the four species *MSY* values.

7.2.1. Predicting catches using the multiple regression model

Analysis of the stochastic effects on the combined catch and biomass prediction has been carried out for each catch strategy. Figure 7.1 shows the plot of 95% confidence intervals limits of the biomasses, and Figure 7.2 shows the plot of 95% confidence intervals limits of the catches for each species and *Total Tilapia* if catch strategy 1 takes effect.

It is noted that: the lower limit of 95% confidence interval of the biomass is below *BMSY* during the whole period, but the biomass shows stability from 2010, 2006, 2010, 2005 and 2010 for *T.Nilotica*, *T.Aurea*, *T.Zillii*, *T.Galilea* and *Total Tilapia* respectively.

Also it is noted that the upper limit of 95% confidence interval of the catch is greater than the *MSY* from 1999 to 2012 for the four species and for *Total Tilapia.*

Figures 7.3 and 7.4 show the plot of 95% confidence intervals limits of the biomasses for each species and *Total Tilapia* for the second and third catch strategies with the *BMSY* level. Figures 1E to 6E in Appendix E show stochastic catches and stochastic biomasses for each species and *Total Tilapia* and for each catch strategy. Tables 1E to 6E show 95% confidence intervals for the stochastic catches and the stochastic biomass for each species and *Total Tilapia* and for the three catch strategies. It is noted that all three catch strategies has roughly the same confidence intervals for the catches and biomasses by the year 2010.

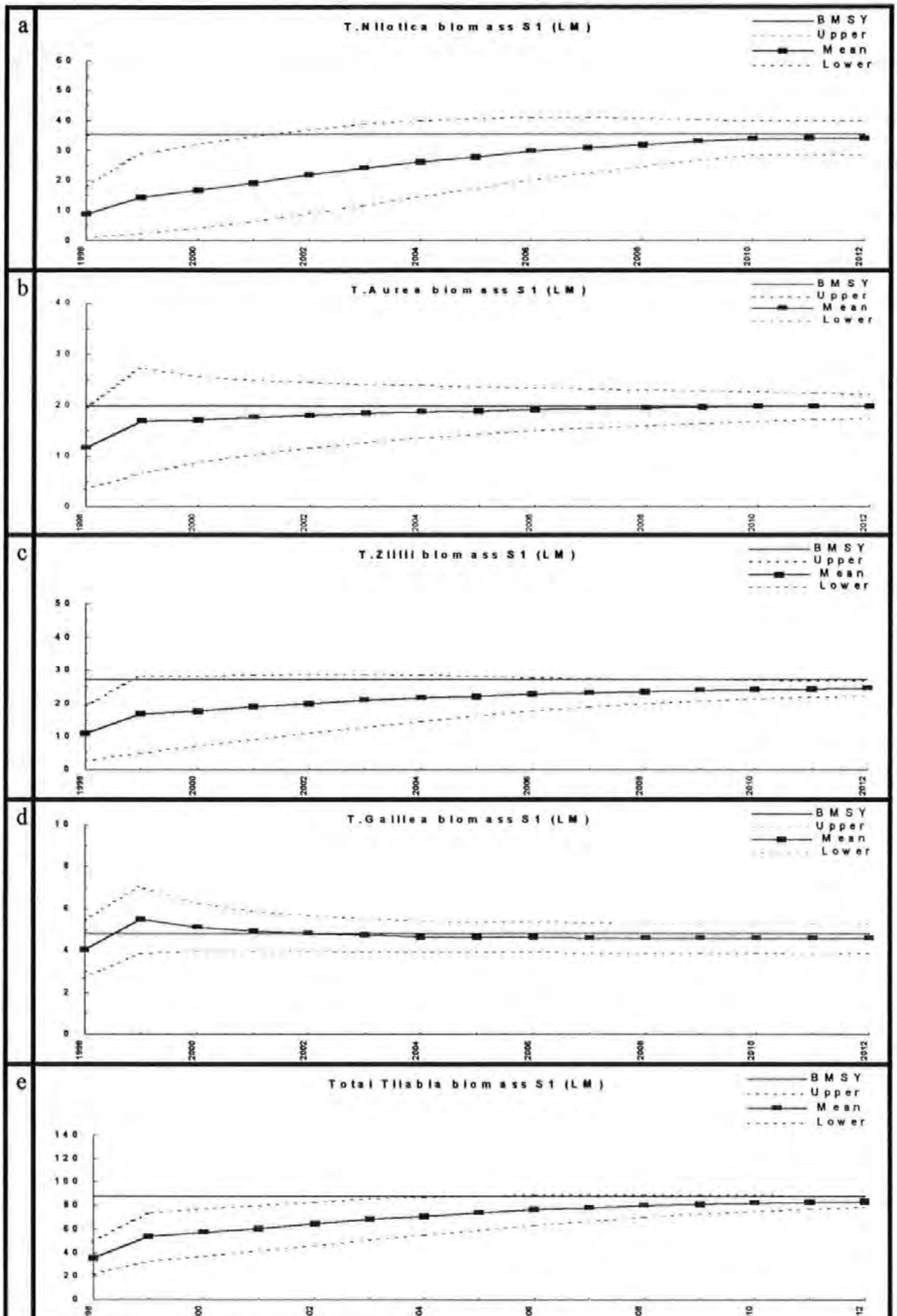


Figure 7.1 The upper and lower limits of 95% confidence interval of stochastic biomass and *BMSY* (multiple regression model) of each species and *Total Tilapia* stock using catch strategy 1 with stochastic catch (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

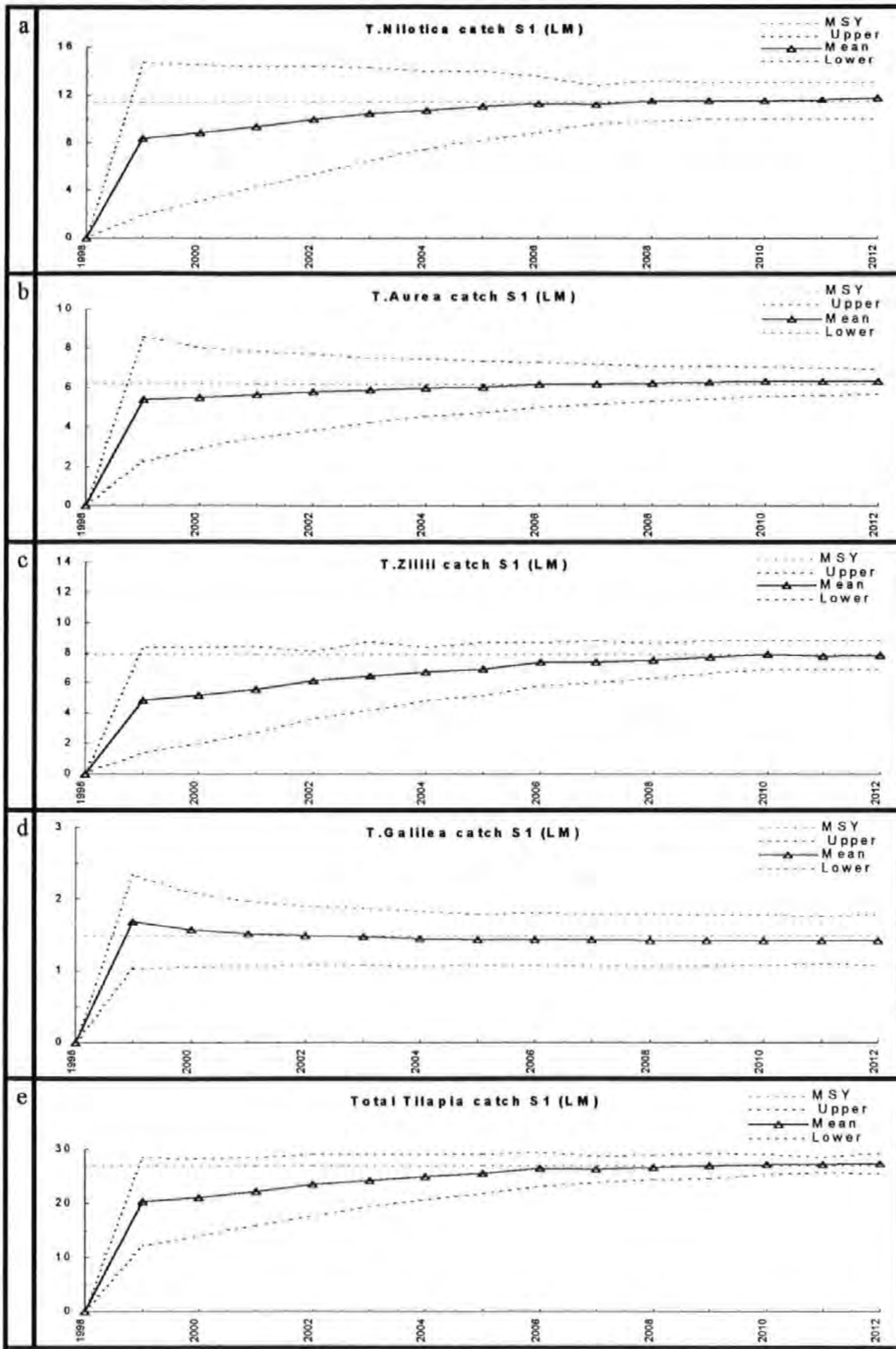


Figure 7.2 The upper and lower limits of 95% confidence interval of stochastic catch and *MSY* (multiple regression model) of each species and *Total Tilapia* catch using catch strategy 1 with stochastic biomass (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

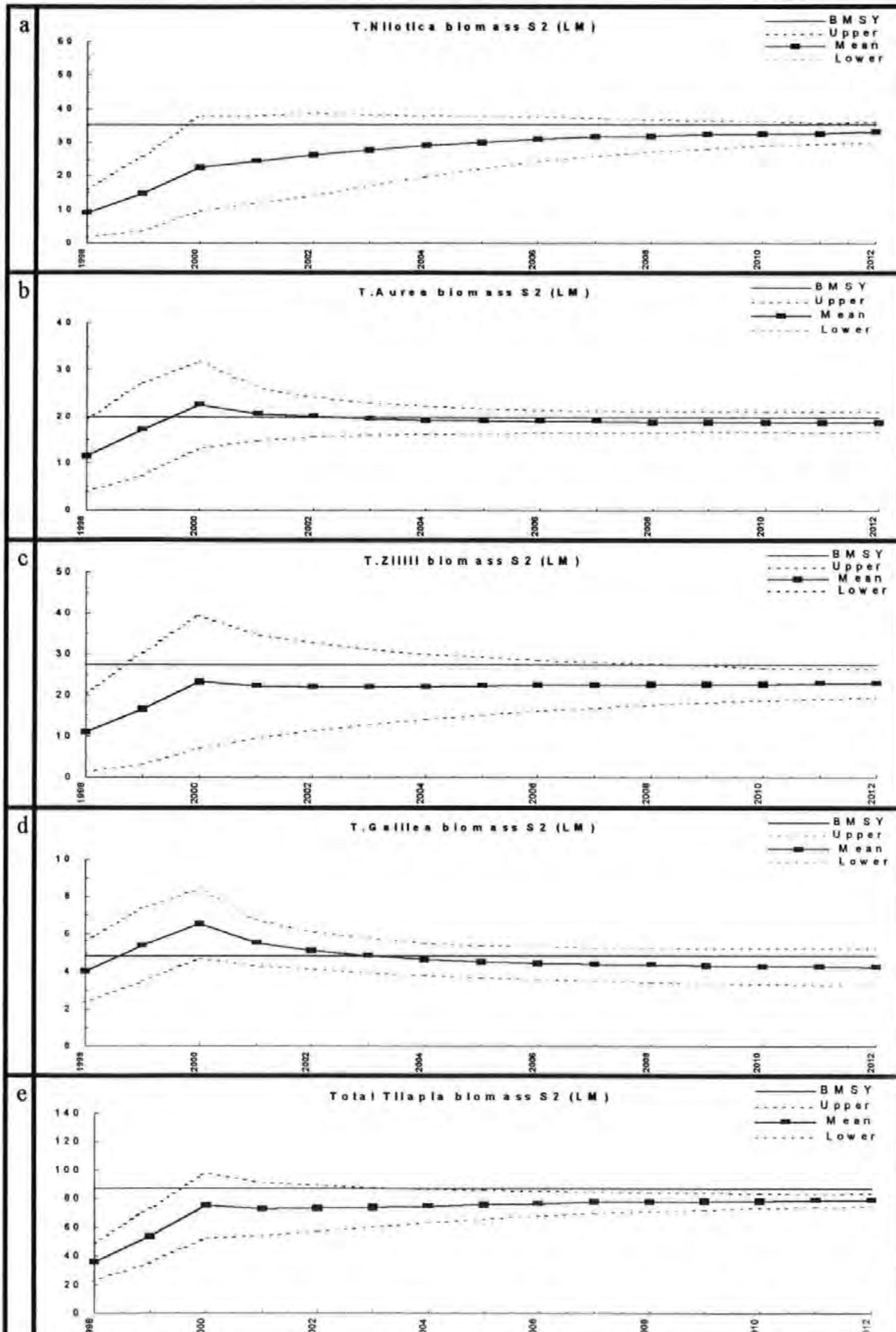


Figure 7.3 The upper and lower limits of 95% confidence interval of stochastic biomass and *BMSY* (multiple regression model) of each species and *Total Tilapia* stock using catch strategy 2 with stochastic catch (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

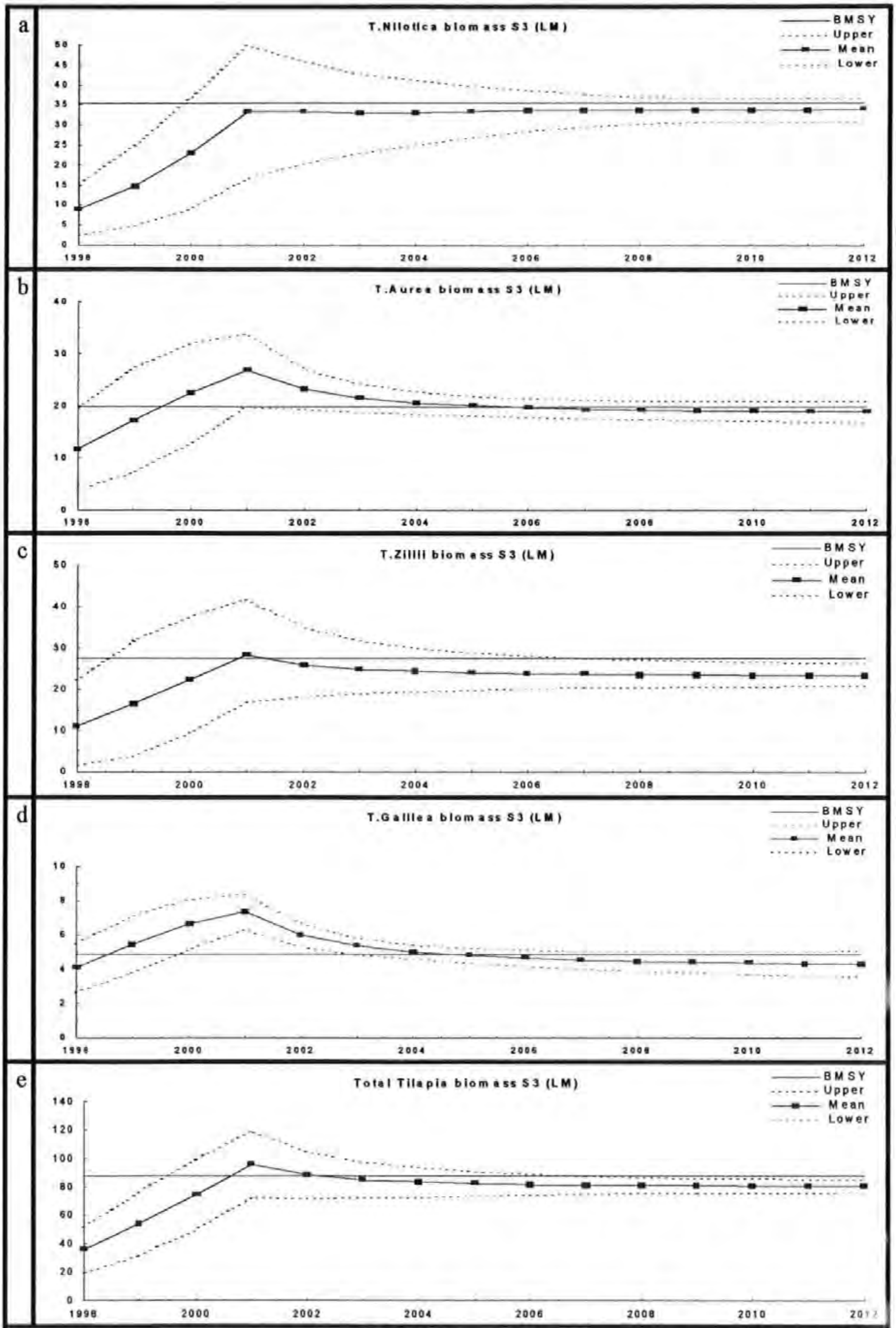


Figure 7.4 The upper and lower limits of 95% confidence interval of stochastic biomass and *BMSY* (multiple regression model) of each species and *Total Tilapia* stock using catch strategy 3 with stochastic catch (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

Figure 7.5 shows comparison between 95% confidence interval of the cumulative catch prediction for the three catch strategies. It is noted that the confidence interval of the catches for the strategy 1 is more wide than strategy 2 and more wide than strategy 3. Because strategy 1 allows fishing to start earliest, it allows the greatest cumulative uncertainty in terms of catches. Because strategy 3 prevents fishing for an addition two years, it gives the lowest cumulative uncertainty of the catch. Strategy 2, which has an intermediate level of cumulative uncertainty of the catch over this time period. But comparing the 95% confidence interval width for the three catch strategy after certain number of fishing years, it is found that there is a very little difference between the three catch strategy, which can return to a random error in the biomass estimates or the estimation of r and K.

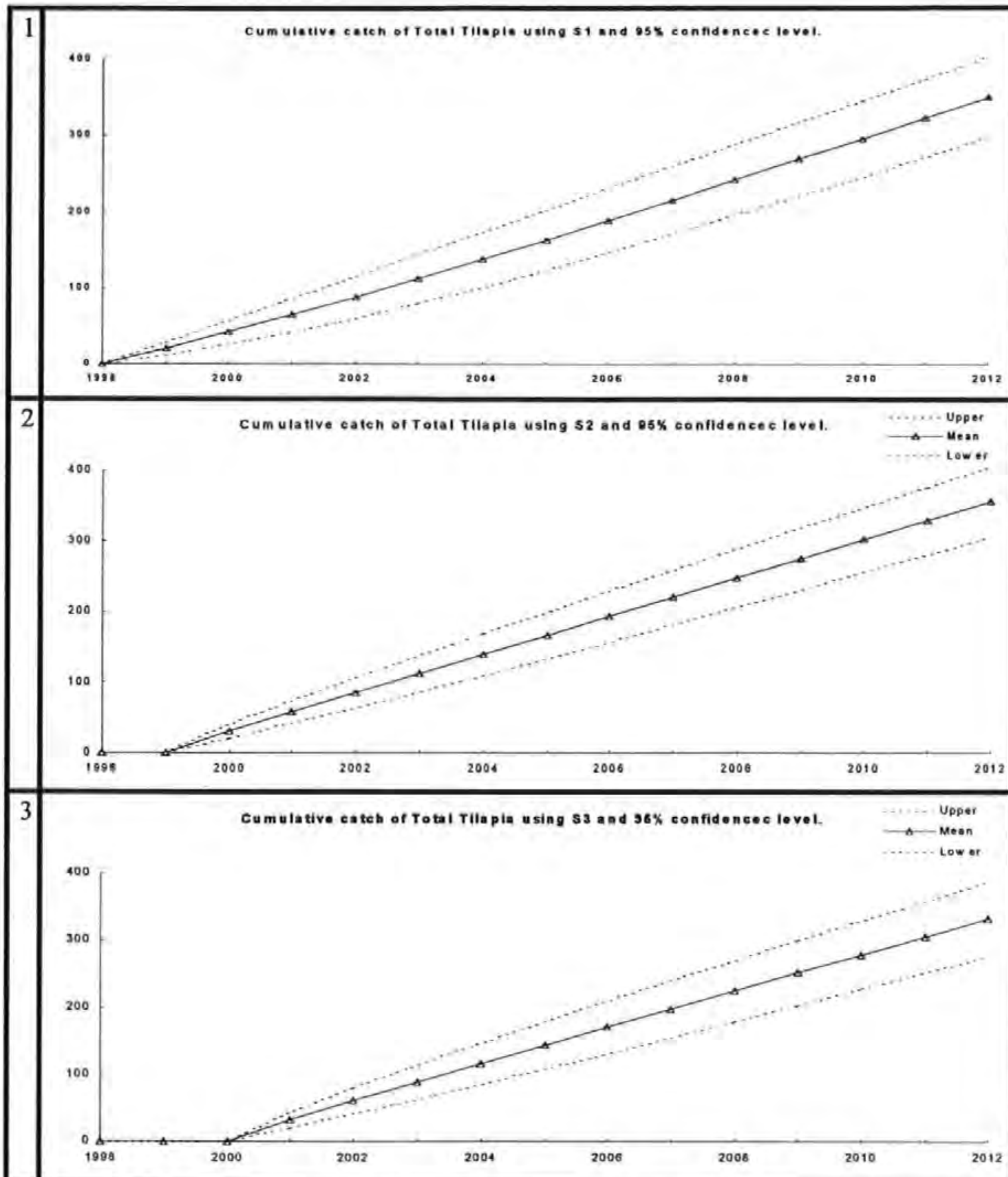


Figure 7.5 The upper and lower limits of 95% confidence interval of cumulative stochastic catch (multiple regression model) of *Total Tilapia* catch with stochastic biomass for each catch strategy (1) S1, (2) S2 and (3) S3.

7.2.2. Predicting catches using generalised additive model (GAM)

Analysis of the stochastic effects in the combined catch and biomass prediction has been carried out for each catch strategy. Using the three catch strategies shows a similar pattern as the multiple regression model. Figure 7.6 shows the stochastic biomass of *Total Tilapia* using the GAM to estimate the catches. Figures 7E to 12E in Appendix E show the stochastic catches and stochastic biomasses. Tables 7E to 12E show 95% confidence intervals for the stochastic catches and stochastic biomass for each species and *Total Tilapia* and for each catch strategy.

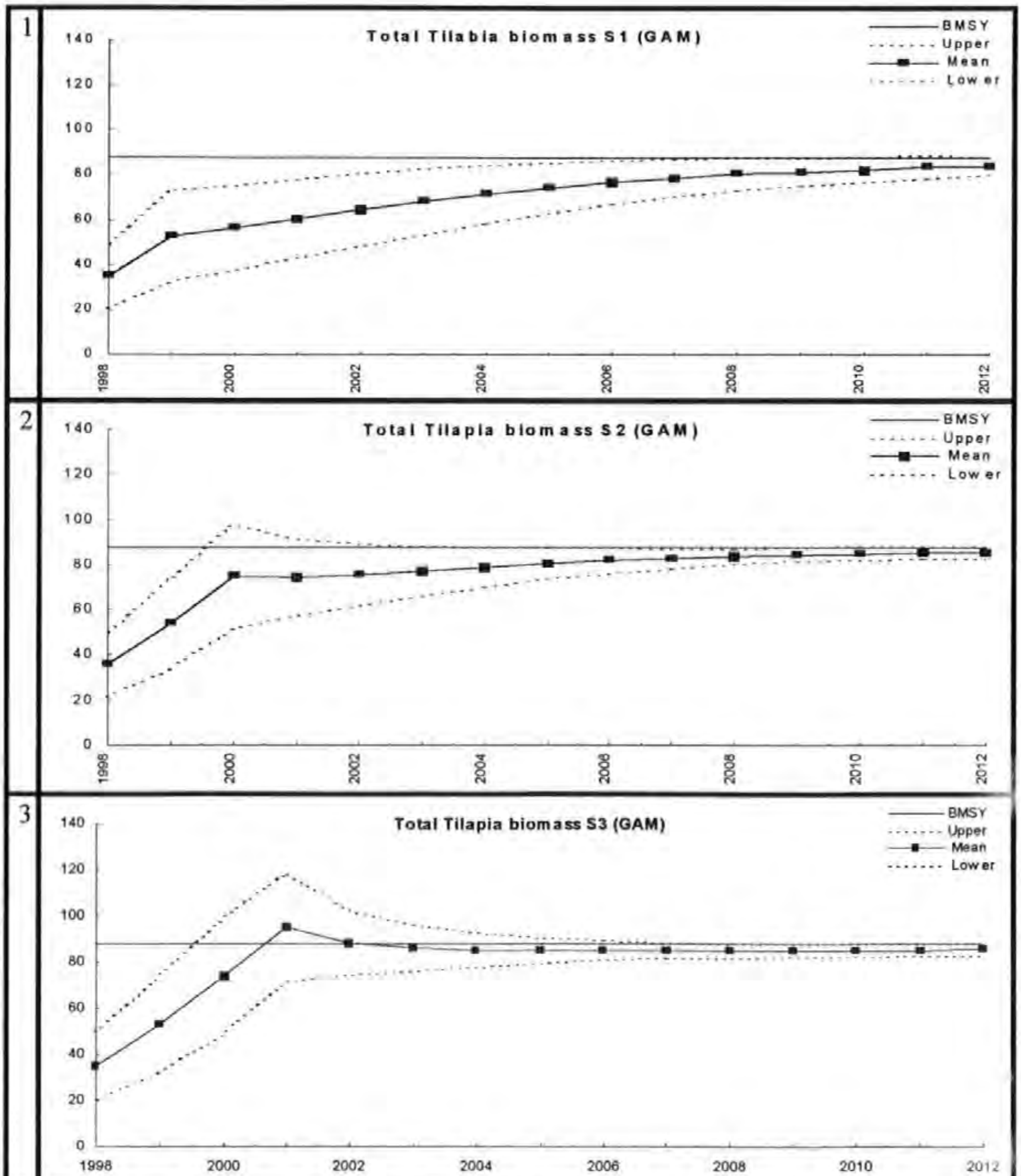


Figure 7.6 The upper and lower limits of 95% confidence interval of stochastic biomass and *BMSY* with stochastic catch for *Total Tilapia* using GAM for each catch strategy (1) S1, (2) S2 and (3) S3.

The results can be summarised in the following points:

(1) The upper limit of 95% confidence interval of the catches for the four species exceed the MSY for the three catch strategies and for both catch models but the catches are stable.

(2) The lower limit of 95% confidence interval of the biomass for the four species is below the $BMSY$ for the three catch strategies and for both catch models.

(3) The stock shows stability after few years of recovery, this is clear for the three catch strategies and for both catch models (multiple regression model and GAM).

There are some sources of error which are not explicitly included in the catch model or biomass model. These errors may cause some bias in the catch or biomass prediction or in the determination of the fleet size.

For example, catch models (multiple regression model and GAM) validation was investigated under the circumstances which pertained in 1995, where there was high fleet size and low stock and the data were collected from only a sample of landing port during short time period. The use of these models to predict the catch when the fleet is controlled to a lower fleet size and the biomass has recovered to a high stock could cause some errors in catch and stock predictions, and hence the required fleet size. Also the relationship between catch and effort may be not linear over this range. As well as, future changes in Lake Manzala pollution, nutrients, salinity or average water temperature could change the value of r and/or K or all these reasons together.

In addition, one of the catch model assumptions is that the random errors are independent. This may not be the case, because of the data collection method. However, if the error term between vessels is correlated it is not possible to determine it from the data, since vessels data are in cross section form. If the error are correlated, then the variability in the predictions is likely to be greater than found here. Also, there may be a bias leading to underestimating the actual vessel catch because the recorded catches are the catch which is sold. Fishermen may retain a small part of catch for themselves. However, this is may not affect the predictions as this behaviour is likely to continue even when the fleet is managed appropriately.

As well as, the values of r and K might be correlated, so if there are a correlation between estimates values of r and K, the net recruitment will tend to be compensated; if K is underestimated, r will be overestimated, then time needed to recover the stock will be underestimated and likewise if K is overestimated r will be underestimated and time needed to recover the stock will be overestimated. It is known that the estimates of r and K are regularly correlated (chapter 3). However, MSY is calculated as $\frac{rK}{4}$ so any bias in one parameter is likely to be largely cancelled out in the calculation of MSY.

7.3. Worst case scenario

There is an important question which is what would happen if all the fishermen try to use the maximum limit of the nets, number of fishermen, duration time and number of mesh. So if all the fishermen in the *Projected fleet* do that the fleet will be called "*Greedy fleet*". *Greedy fleet* size is the same as the *Projected fleet* size but the vessels characteristics are at the maximum limits.

If all the fishermen go to the maximum limit of the vessel characteristic, the potential catch will be greater than the catch produced by using the *Projected fleet* by about 20%. It has been already noted that number of vessels when using multiple regression model are greater than number of vessels when using GAM while both fleets catch the same amount of fish. This means that the estimate of the catch per vessel using GAM is greater than the estimates of the catch per vessel using multiple regression model. So the worst case is to allow the *Greedy fleet* to operate and to use GAM to estimate the catch. Figure 7.7 shows the plot of 95% confidence intervals limits of the catches for the *Total Tilapia* species catch with GAM, if the *Greedy fleet* operate for the three catch strategies. It is noted that for the first few years the *Greedy fleet* catch is higher than the *Projected fleet* catch, then the *Greedy fleet* catch start to be smaller than the *Projected fleet* catch because higher catches in the first few years cause a decrease in the stock which will in turn produce small catches. It is noted that applying the *Greedy fleet* with GAM will not allow the stock to exceed the *BMSY* level, but the stock shows clear stability from 2007, 2005 and 2007 for the three catch strategies respectively.

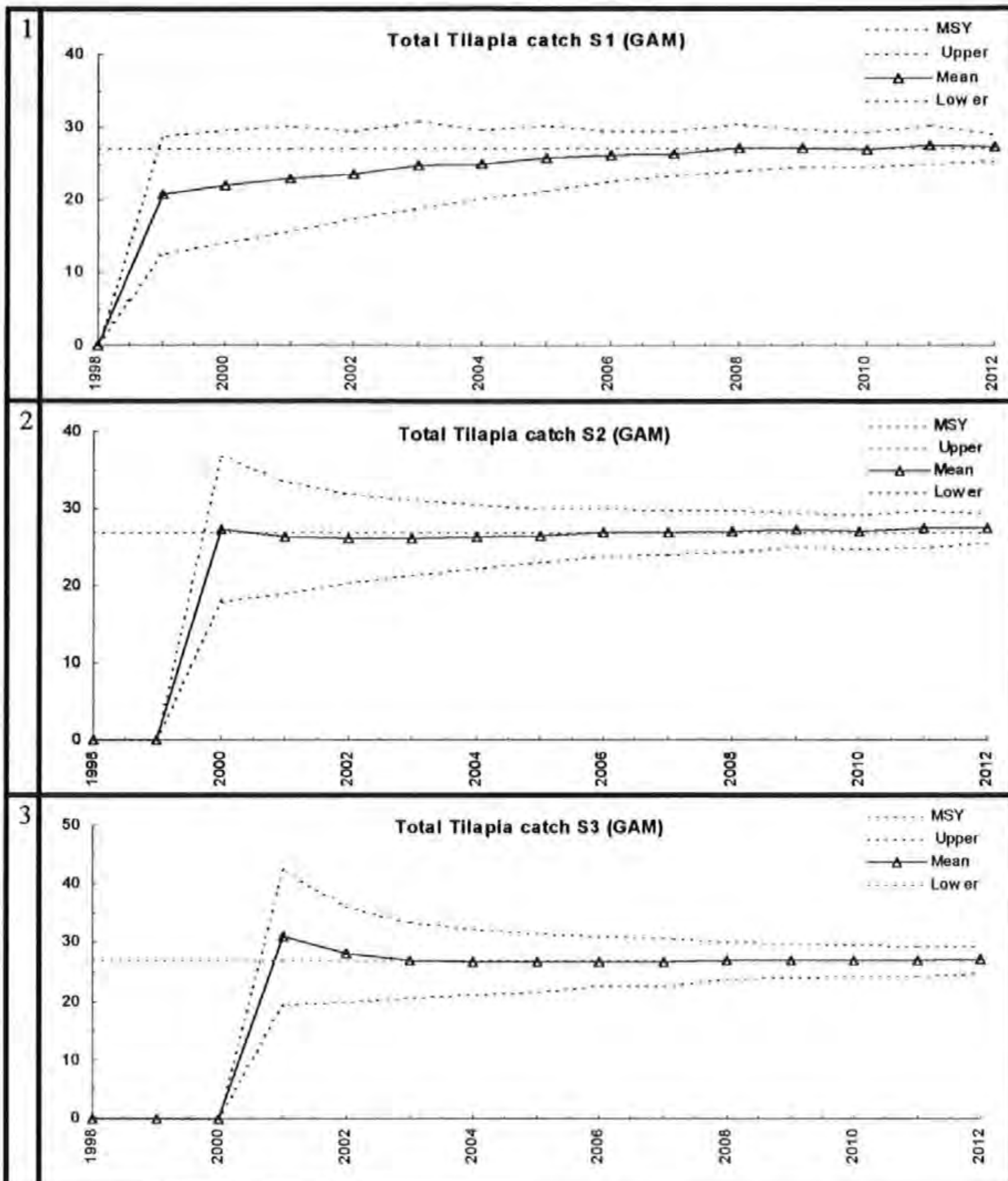


Figure 7.7 The upper and lower limits of 95% confidence interval of stochastic catches and *MSY* with stochastic biomass for *Total Tilapia* using *Greedy fleet* for each catch strategy (1) S1, (2) S2 and (3) S3 with GAM.

The effect on the catch and biomass prediction of the two sources of uncertainty is analysed for the *Greedy fleet*. Figure 13E in Appendix E shows the 95% confidence interval of the stochastic catch of *Total Tilapia* using the *Greedy fleet* and applying GAM to estimate the catches based on the stochastic biomass. It is noted that the upper limit of 95%

confidence interval of the catch is above the *Total MSY*, but the upper limit of 95% confidence interval of the catch shows a clear stability.

Figure 7.8 shows the stochastic biomass of *Total Tilapia* using the *Greedy fleet* and applying GAM to estimate the catches. It is noted that the lower limit of 95% confidence interval of the biomass is far from the *Total BMSY*, but the lower limit of 95% confidence interval of the biomass shows a clear stability. It is noted that the stock did not crash for any iteration of adding uncertainty effects to catches and biomass prediction simulation which consists of 100 iterations.

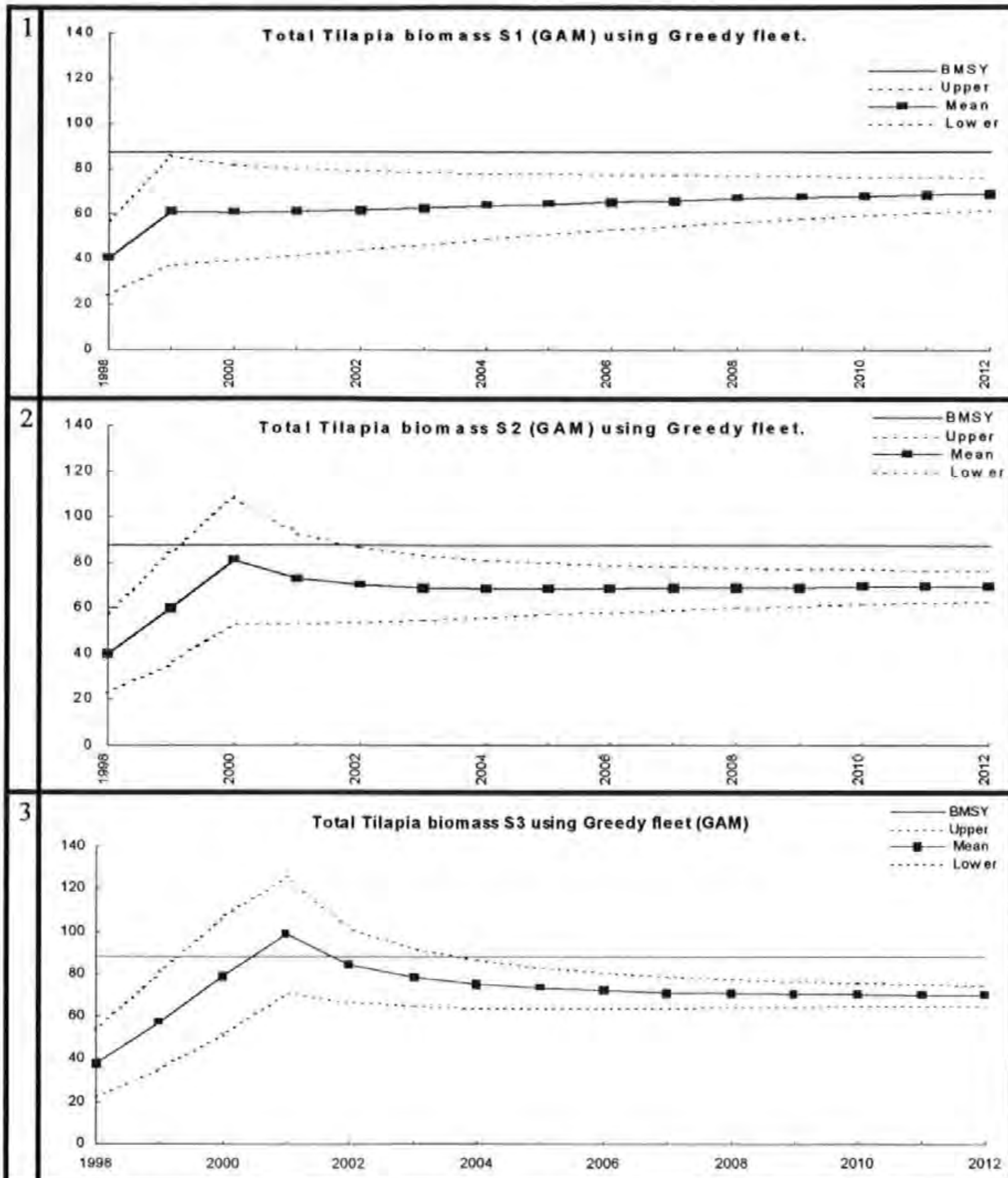


Figure 7.8 The upper and lower limits of 95% confidence interval of stochastic biomass and *BMSY* with stochastic catch for *Total Tilapia* using *Greedy fleet* for each catch strategy (1) S1, (2) S2 and (3) S3 with GAM.

So, adding uncertainty in the GAM catch model parameters and biomass model parameters with the *Greedy fleet* does not show the biomass can deplete even when we assume standard errors is 10% of B_{80} and B_{94} in the biomass model. Figures 7.9 and 7.10 show the catch estimate and biomass prediction. It is noted that the catch and the biomass are stable. The difference between using standard error 5% of B_{80} and B_{94} and using standard error 10% of B_{80} and B_{94} with the *Greedy fleet* is the delay in the stability of the catch and the biomass. It is noted that the stock did not crash for any iteration of adding uncertainty effects to catches and biomass prediction simulation which consists of 100 iterations.

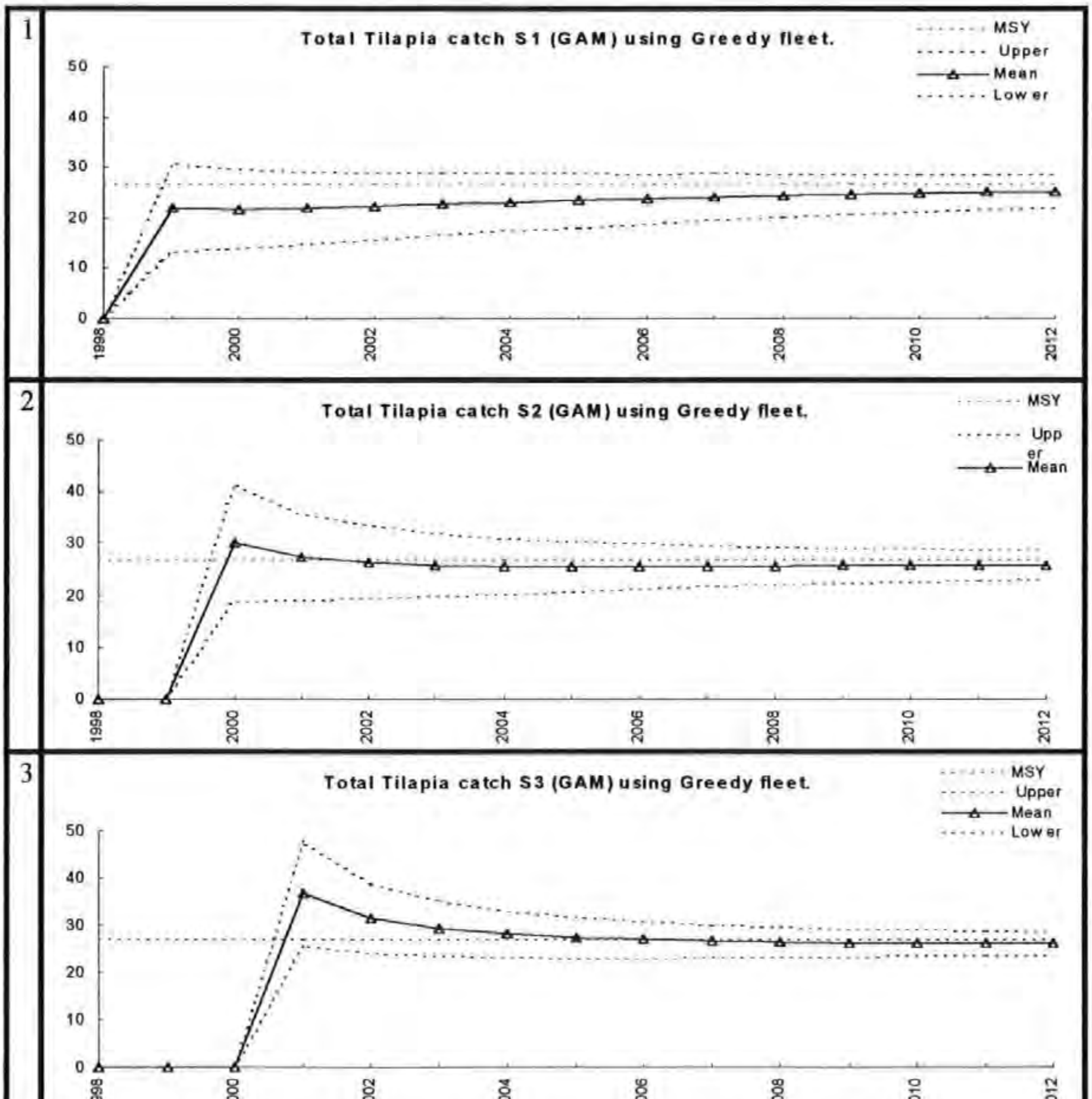


Figure 7.9 The upper and lower limits of 95% confidence interval of stochastic catch and *MSY* with stochastic biomass for *Total Tilapia* using *Greedy fleet* for each catch strategy (1) S1, (2) S2 and (3) S3 with GAM and with standard error 10% of B_{80} and B_{94}.

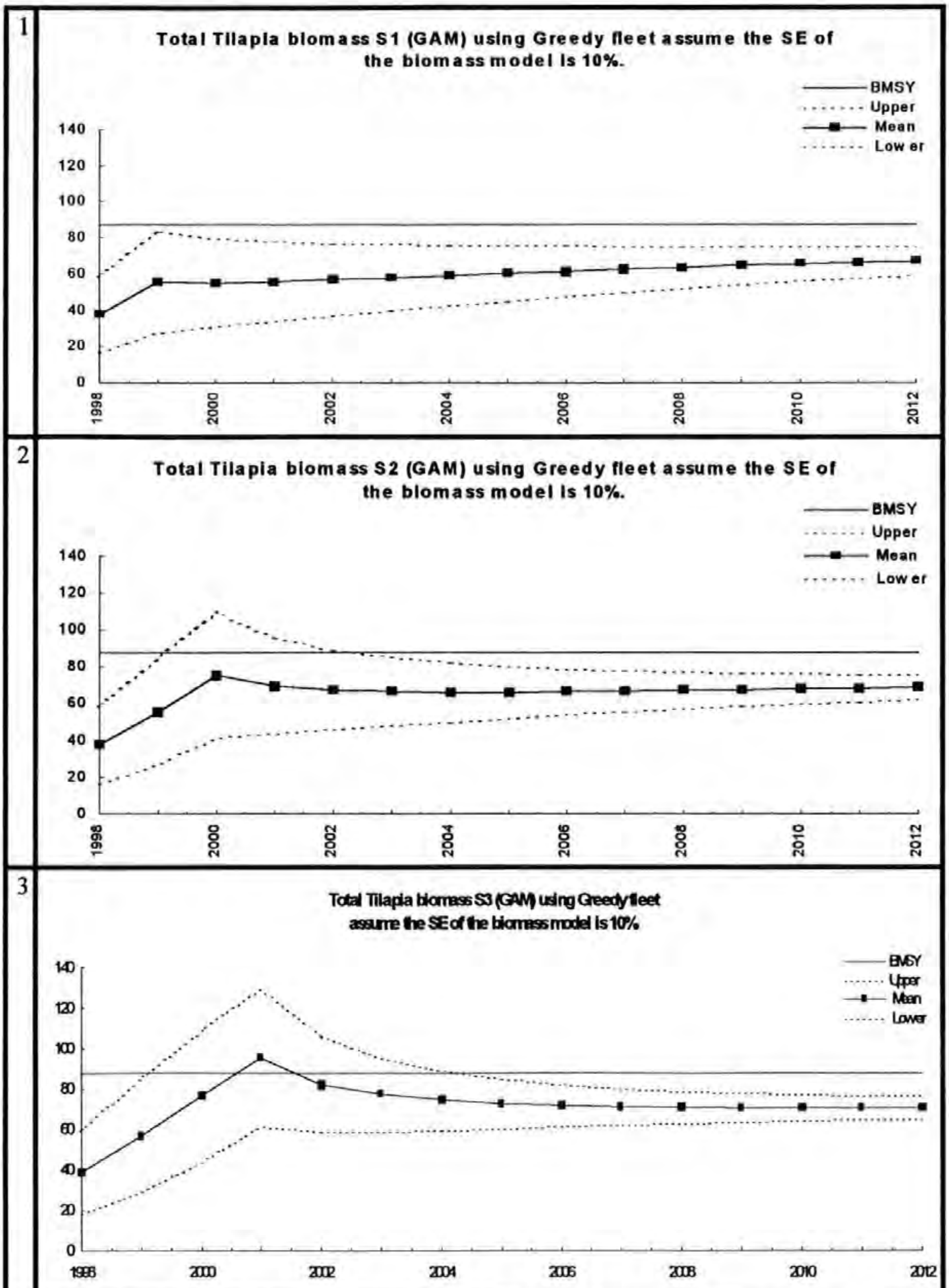


Figure 7.10 The upper and lower limits of 95% confidence interval of stochastic biomass and *BMSY* with stochastic catch for *Total Tilapia* using *Greedy fleet* for each catch strategy (1) S1, (2) S2 and (3) S3 with GAM and with standard error 10% of B_{80} and B_{94}.

So this analysis can be summarised in the following points:

- There is an uncertainty in the estimates of the biomass parameters r and K_{80}, assuming that the standard error is 5% for B_{80} and B_{94}.

- There is an uncertainty in the catch prediction.

- In the biomass prediction there is variability in the values of r and K_{80} from one iteration to other, these values have been used during the simulation process.

A possible approach to the management of the fishery might be to control the fleet so that the biomass exceeds *BMSY* with a given probability especially because of the possible biases and additional uncertainty discussed in the end of previous section. There are a possible errors in catch predictions because of possible errors in estimating r and K, so a reduction in the fleet size has been investigated to allow the lower limit of 95% confidence intervals of the biomass to be greater than or equal to *BMSY*. It is found that a 10% reduction from the *Projected fleet* size will allow the lower limit of the 95% confidence interval of the biomass to exceed *BMSY* level by 2012, 2011 and 2010 for the three catch strategies respectively, while a 50% reduction from the *Projected fleet* size will allow the lower limit of the 95% confidence interval of the biomass to exceed *BMSY* level by 2004, 2003 and 2001 for the three catch strategies respectively. In the light of the above, it can be concluded that the greater the reduction in fleet size, the more safety for the biomass over the short term, and vice-versa. Clearly, once the biomass exceeds *BMSY* with 97.5% probability, it is possible to increase the fleet size again. The parabolic shape of the biomass/recruitment curve (chapter 3) shows that catches will be close to *MSY* when the stock is safely above *BMSY* (Figure E in Appendix E).

Finally, it is noted that there was no one iteration of the optimum effort level for which the stock crashed, even if the *Greedy fleet* had been allowed to operate, and assuming the standard error is 10% of B_{80} and B_{94}. So, according to this analysis if we use the effort for *MSY*, this will be below the critical effort and the biomass is extremely unlikely to crash.

CHAPTER 8 COMPARISON AND CONCLUSIONS

Lake Manzala plays an important role in providing fish for the Egyptian population because it is the largest natural lake, and its annual fish production represents around 20 percent of the national fish production. Since 1977 the area of the lake has reduced three times and fishing effort doubled, so that over-exploitation has become a major problem. For these reasons Lake Manzala has been chosen as a case study to investigate the factors which affect the exploitation. The study covered the period from 1977 to 1997 and provided suggestions to improve management of that fishery in order to maintain fish production while protecting fish stocks.

Two existing approaches for estimating the intrinsic growth rate of the four *Tilapia* species biomasses and the carrying capacity of the fishery have been carried out using the catch and effort data from 1980 to 1997. The inclusion of two biomass estimates in 1980 and 1994 has led to a new method to estimate these parameters. The new method gives reasonable parameter estimates comparing with the results of the other two approaches and with other biological studies. However, simulation had to be used to get error estimates of the biomass parameters estimates using the new method.

A number of catch strategies to manage the effort have been investigated. It was noted that stopping fishing for eight years would allow the *Total Tilapia* stock to be close to the carrying capacity, while stopping fishing for three years would allow the *Total Tilapia* stock to exceed the *BMSY* level. Three catch strategies have been investigated which were stop fishing for one, two and three years respectively. It is noted that the second catch strategy achieves the greatest amount of discounted catch over eight years if the discount rate is 10% or less, while first catch strategy realise the greatest discounted catch if the discount rate is 10% or more.

Two ways of modelling individual vessel catches in relation to their effort characteristics were investigated. A parametric regression analysis for the vessel survey data used a multiplicative model, which had been transformed to linear additive model by using logarithm transformation, to represent the relationship between average catch per vessel and number of nets, number of fishermen, duration time per trip and number of mesh. Fleet control had been developed using this multiple regression analysis to estimate number of vessels which can achieve the expected catch to allow the biomasses to recover. Although the logarithm multiple regression model appeared to give a reasonable fit to the data, it was noted that there was some curvature in the survey data which the parametric model did not pick up. For these reasons generalised additive model had been used to improve the parametric model. Using generalised additive model gave an improved fit. It also gave lower planned fleet size which should lead to a more conservative fishing policy.

This analysis showed that Lake Manzala stocks are currently over-exploited, the current effort (1997) is clearly above the critical effort level, it represents about three times the required effort for maximum sustainable yield. So, if fishing continue at the current effort level, which is above the critical effort level, the stocks will crash.

A simulation approach was used to investigate the effect of uncertainty on the projected catches and on the stock prediction, and to give insight into the risks associated with various levels of control. There was no evidence that a management strategy which aimed to fish at maximum sustainable yield would put the stock at risk.

There are non-statistical sources of error in modelling both the predicted catches and the biomasses estimates. These could result in under-estimate or over-estimate or exact estimate in each case. The actual biomass during the projected years would be higher than expected for example if the estimated catch is exact-estimate and estimated net recruitment was under-estimated. There are another two cases which are the predicted catch and the estimated net recruitment both are under-estimate or both are over-estimate, in such cases the effect of one of them might cancel the other, but it is not possible to determine the effect of one of them on the other. Unless other studies are undertaken, the only data available for monitoring the fishery will be the catch data. This is not sufficient for deciding how the fishery is operating. So other classical researches are still required such as biological biomass estimation or cohort analysis.

In conclusion, this study has produced a new method to estimate the carrying capacity and the intrinsic growth rate based on the historical data and also to predict the biomass size in the future. Also it used generalised additive models to predict the catch which is a new development for fleet control modelling. This study has developed a methodology for investigating the effect of any management strategy for Lake Manzala fishery. Also includes calculation of the fleet size required for a given catch and the effect of uncertainty in the prediction.

Bibliography

Bibliography

(1) Anonymous. (1980). *Lake Manzala study.* Ministry of Development and New Communities in ARE in co-operation with Maclaren Engineers, Planners and Statistics inc. Report. Cairo, Egypt. Vol. UNDP/EYY/80/007/117.

(2) Anonymous. (1984). *Development of fish resources in Northern lakes (in Arabic).* Report. Ministry of Agricultural (MA). Cairo, Egypt. pp 183-190.

(3) Anonymous. (1988). *Animal protein production policies (in Arabic).* Specialised National Councils. Report. Cairo, Egypt. Vol. 4, pp 21-23.

(4) Anonymous. (1992). *Review of the state of world fishery resources.* Food and Agriculture Organisation of the United Nations. FAO fisheries circular. Report. Rome, Italy. Vol. 710.

(5) Anonymous. (1993). *Reference points for fishery management. Their potential application to straddling and highly migratory resources.* Report. Food and Agriculture Organisation of United Nations. Rome, Italy. Vol. 864.

(6) Anonymous. (1994). *Fishing gear and methods.* National Institute of Oceanography and Fisheries (NIOF). Report. Alexandria, Egypt. Vol. 6.

(7) Anonymous. (1996). *World food summit, food security situation and issues in the Near East.* Conference Proceeding. Food and Agriculture Organisation of the United Nations. Rabat, Morocco. Vol. 710, pp 1-8.

(8) Anonymous. (1996). *Yearbook of Fish production statistics in ARE.* Central Agency for Public Mobilisation And Statistics (CAPMAS). Report. Cairo, Egypt. Vol. Different reports.

(9) Anonymous. (1996). *Year book of Weather in Egypt.* Weather in Egypt. Aero Methodological Authority (AMA).

(10) Anonymous. (1997). *S-Plus 4 for Windows.* Computer Program. Seattle, Washington. MathSoft, Inc. USA.

(11) Anonymous. (1997). *Statgraphics 3.0 for Windows.* Computer Program. Manugistics. USA.

(12) Abdel-Latif S.M. (1974). *Tilapia in Lake Nasser (in Arabic).* High Dam Lake Development Authority. Report. Aswan, Egypt.

(13) Abdelhafz, M.S. (1985). *Egyptian fish production function in Suez Gulf (in Arabic).* PhD. Muonif University. Muonif, Egypt.

(14) AbdelMonsef, M. (1989). *On boards of lakes of Egypt, Lake Manzala and Lake Borols (in Arabic).* Chain from east and west. Cairo, Egypt.

(15) Abosamra N.M. (1987). *Economical fish body building in ARE (in Arabic).* PhD. Zagazig University. Zagazig, Egypt.

(16) Allsopp, W.H.L. (1985). *Fishery development experiences.* Farnham, Fishing news books Ltd. Surrey, England. pp 9-10.

(17) Ames, G.R. (1990). *Traditional and modern post harvest technologies for increased food and income supply from Inland fisheries in Africa.* Symposium on post harvest in Africa. Food and Agriculture Organisation of the United Nations. Report. Rome, Italy. pp 96-97.

(18) Anderson, J.A. (1998). *Regression and ordered categorical variables.* Journal of Royal Statistical Society B. Vol. 1, pp 1-30.

(19) Barrania, A. (1979). *The exploratory socio-economic survey of Egyptian Red Sea fisheries.* Food and Agriculture Organisation of the United Nations. Report. Rome. Vol. RAB/77/008/1, pp 33-36.

(20) Barrania, A. (1983). *Socio-economic aspects of Red Sea fisheries in Egypt, Sudan, Jordan, Saudi Arabia, Djibouti, Yemen and Quseir region.* Food and

Agriculture Organisation of the United Nations. Report. Rome, Italy. Vol. RAB/77/008/83/023.

(21) Barrania, A. (1983). *Study of costs, prices and marketing of fresh fish.* Food and Agriculture Organisation of the United Nations. Report. Rome, Italy. Vol. RAB/77/088/83/24.

(22) Barrania, A. (1985). *The Egyptian northern lakes, fisheries development versus agriculture development (in Arabic).* Institute of National Planning. Report. Cairo, Egypt.

(23) Barrania, A. (1988). *Establishment of the cooperative fishing centres and its socio-economic implication.* Food and Agriculture Organization of the United Nations. Report. Rome, Italy.

(24) Barrania, A. (1988). *Study of fish pricing and marketing in Egypt.* Food and Agriculture Organisation of the United Nations. Report. Rome, Italy.

(25) Barrania, A. (1990). *Technological prospects and fisheries development (in Arabic).* Institute of National Planning. Report. Cairo, Egypt.

(26) Barrania, A. (1990). *Plan of fisheries industries location in Egypt in year 2000 (in Arabic).* Institute of National Planning. Report. Cairo, Egypt.

(27) Barrania, A. (1992). *Aqua-culture in Egypt and it's development limitation.* Institute of National Planning. Report. Cairo, Egypt. pp 12-50.

(28) Barrania, A. and Abdelaal, M.M. (1994). *Socio-economic aspects of Bardawill Lagoon.* Institute of National Planning. Report. Cairo, Egypt.

(29) Barrania, A. and Nassar, A. (1984). *Bio-economic management of fisheries Gulf of Suez case study (in Arabic).* Institute of National Planning. Report. Cairo, Egypt. pp 6-21.

(30) Basiony, S.A. (1985). *Economical study of fresh fish consumption in ARE (in Arabic).* PhD. Ain Shams University, Cairo, Egypt. pp 28-35.

(31) **Bazigos, G.P.** (1970). *Volta lake research project reports (statistical studies).* Food and Agriculture Organisation of the United Nations. FAO fisheries technical report. Rome, Italy. Vol. 241.

(32) **Bazigos, G.P.** (1974). *The design of fisheries statistical surveys in land water.* Food and Agriculture Organisation of the United Nations. FAO fisheries technical report. Rome, Italy. Vol. 133.

(33) **Bazigos, G.P.** (1975). *Applied fishery statistics.* Food and Agriculture Organisation of the United Nations. FAO fisheries technical report. Rome, Italy. Vol. 135.

(34) **Bazigos, G.P.** (1976). *The design of fisheries statistical surveys in land water, supplement 1.* Food and Agriculture Organisation of the United Nations. FAO fisheries technical report. Rome, Italy. Vol. 183.

(35) **Billard, L.** and **LePage, R.** (1992). Exploring the limits of bootstrap. John Wiley and Sons, Inc. New York, USA.

(36) **Borcher, D.L., Buckland, S.T. and Ahmadi, S.** (1996). *Improving the precision of the daily egg production method using generalised additive models.* Thesis. University of At Andrews.

(37) **Borgstrom, G.** (1962). *Fish as food, nutrition, sanitation and utilisation.* Academic press, New York. First edition.

(38) **Bracewell, R.N.** (1983). *The fourier transform and its applications.* McGraw - Hill Inc. London, UK.

(39) **Bracewell, R.N. and O'Connell, R.** (1993). *Forecasting and time series, an applied approach.* Duxbury press. California. Third edition.

(40) **Brander, K.** (1975). *Guidelines for collection and compilation of fisheries statistics.* Food and Agriculture Organisation of the United Nations. FAO fisheries technical report. Rome, Italy. Vol. 148.

(41) Bromley, D.W. (1989). *Economic efficiency in common property resources.* Working paper. Bureau of commercial fisheries. Canada. Vol. 28.

(42) Carlson, E.W. (1980). *An economic theory of common property fishery resources.* Bureau of commercial fisheries. Working paper. Canada. Vol. 72.

(43) Chambers, J.M. and Hastie, T.J. (1993). *Statistical models in S.* Chapman and Hall. New York.

(44) Chanpney, D.C. (1973). *Fourier transforms and their physical applications.* Academic Press. London, UK.

(45) Chatfield, C. (1989). *The analysis of time series.* Chapman and Hall. London, UK. Fourth edition.

(46) Chochran, W.W. (1969). *The world food problem, a gradually optimistic view.* University of Minnesota. USA. First edition.

(47) Chong, G.U. (1993). *Smoothing spline density estimation.* Journal of the American Statistical association. Vol. 88, pp 495-504.

(48) Clark, K.R. (1993). *Non-parametric multivariate analysis of changes in community structure.* Journal of Australian Journal of Ecology. Vol. 18, pp 117-143.

(49) Clark, K.R. and Green, R.H. (1988). *Statistical design and analysis for a biological effects' study.* Journal of Marine Ecology. Vol. 46, pp 213-226.

(50) Clark, W.C. (1985). *Bio-economic modelling and fisheries management.* John Wiley and Sons, Inc. New York. Second edition.

(51) Cleveland, W.S. and Devlin, S.J. (1988). *Locally weighted regression: An approach to regression analysis by local fitting.* Journal of the American Statistical Association. Vol. 83, No. 403, pp 596-610.

(52) Cooper, R.A. and Weekes, A.J. (1983). *Data model's and statistical analysis.* Philip Allan Publishers limited. Oxford, UK.

(53) **DE Sapio, R.** (1978). *Calculus for the life sciences.* W.H. Freeman and company. San Francisco.

(54) **Edward, E.F. and Megrey, B.A.** (1989). *Mathematical analysis of fish stock dynamics.* Journal of the American Fisheries Society. Bethesda, USA.

(55) **Elbana, A.S.** (1988). *Economical prospects of fish resources development (in Arabic).* PhD. Azhar University, Cairo, Egypt. pp 466-481.

(56) **Elbarawy, A. and Awad, S.** (1980). *Economical productivity of the Egyptian fisheries (in Arabic).* Report. Researches Institute. Cairo, Egypt.

(57) **Elharawy, E.** (1992). *The economic of sustainable development for fisheries.* Food and Agriculture Organisation of the United Nations. Report. Rome Italy. Vol. GF/6105-92-02-2205.

(58) **Elkholy, O.A.** (1985). *Economical analysis of aqua-culture in Northern lakes (in Arabic).* Ministry of Agriculture (MA). Report. Cairo, Egypt. pp 421-470.

(59) **Etewa, I.** (1993). *Fishing gear in Egypt (in Arabic).* General Authority for Fisheries Development (GAFD). Report. Cairo, Egypt. pp 125-137.

(60) **Everitt, B.S.** (1994). *A handbook of statistical analysis using S-Plus.* Chapman and Hall. London, UK. First edition.

(61) **Glonek, G.F.V. and McCullagh, P.** (1995). *Multivariate logistic models.* Journal of Royal Statistical Society B. Vol. 3, pp 533-546.

(62) **Gross, S.T. and Lai, T.L.** (1996). *Non-parametric estimation and regression analysis with left-truncated and right-censored data.* Journal of the American Statistical Association. Vol. 91, pp 1166-1180.

(63) **Gulland, J.A.** (1969). *Fisheries management and the limitation of fishing.* Food and Agriculture Organisation of the United Nations. FAO fisheries technical report. Rome, Italy. Vol. 92.

(64) **Gulland, J.A.** (1986). *The concept of the maximum sustainable yield and fishery management.* Food and Agriculture Organisation of the United Nations. FAO fisheries technical report. Rome, Italy. Vol. 70.

(65) **Gulland, J.A.** (1991). *Fish stock assessment.* John Wiley and Sons. New York. Fifth edition.

(66) **Gulland, J.A.** and **Robinson, M.A.** (1973). *Economic of fisheries management.* Food and Agriculture Organisation of the United Nations. FAO fisheries technical report. Canada. Vol. 152.

(67) **Hafz, F.** (1998). *Tilapia growth rate in fishing regions of Lake Manzala.* Abbasa Research Center for Inland Fisheries and Aqua-culture. Egypt.

(68) **Hall, P**. (1992). *The bootstrap and Edgeworth expansion.* Springer-Verlag. New York, USA.

(69) **Hamlisch, R.** (1989). *Methodology and guidelines for fisheries development planning.* Food and Agriculture Organization of the United Nations. Rome, Italy.

(70) **Härdle, W.** (1995). *Applied non-parametric regression.* Cambridge University Press. New York. Second edition.

(71) **Hastie, T.J.** and **Tibshirani, R.J.** (1991). *Generalised additive models.* Chapman and Hall. London, UK. Second edition.

(72) **Hector, M.** (1987). *Over-fishing an economic analysis.* Food and Agriculture Organisation of the United Nations. FAO fisheries technical report. Rome, Italy. Vol. 514.

(73) **Hemdan, G.** (1992). *Characteristics of Egypt, study genius of the place (in Arabic).* Book world. Cairo, Egypt. Fifth edition.

(74) Henderson, H.F. (1975). *A fish stock monitoring program for Lake Nasser.* Food and Agriculture Organisation of United Nations. FAO fisheries technical report. Rome, Italy. Vol. 6.

(75) Hilborn, R. and Walters, C.J. (1976). *Adaptive control of fishing systems.* Journal of Fish Res Bd Can, Vol. 33, 145-159.

(76) Hilborn, R. and Walters, C.J. (1992). *Quantitative fisheries stock assessment choice, dynamics and uncertainty.* Chapman and Hall Inc. New York. First edition.

(77) Hinkley, D.V. and **Davison, A.C.** (1997). *Bootstrap methods and their application*. Cambridge University Press. UK.

(78) Hjorth, J.S.U.(1994). *Computer intensive statistical methods, validation model selection and bootstrap.* Chapman and Hall. London, UK.

(79) Huet, S. Bouvier, A. Gruet, M.A. and Jolivet, E. (1996). *Statistical tools for nonlinear regression.* Springer-Verlag New York Inc. New York.

(80) Hussien, K.A. (1994). *Fishing technology, fishing gear and methods.* National Institute of Oceanography and Fisheries (NIOF). Report. Alexandria, Egypt. pp 5-22.

(81) Izenman, A.J. (1991). *Recent developments in non-parametric density estimation.* Journal of the American Statistical association. Vol. 86, pp 205-220.

(82) Jones, R. (1981). *The use of length composition data in fish stock assessment with notes on VPA and cohort analysis.* Food and Agriculture Organisation of United Nations. Rome, Italy.

(83) Kennedy, J.O.S. (1989). *Approximately optimal recovery of a multicohort fishery from depleted stocks and excess vessel capacity.* Journal of Operation research society Ltd. Vol. 40, pp 231-241.

(84) **Kleinbaum, D.G.** and **Kupper, L.L.** (1987). *Applied regression analysis and other multivariable methods.* Duxbury Press. USA.

(85) **Khamis, A.** (1994). *Tilapia in Lake Manzala.* National Institute of Oceanography and Fisheries (NIOF). Report. Alexandria, Egypt. Vol. 13.

(86) **Kleinbaum, D.G., Kupper, L.L., Muller, K.E.,** and **Nizam**, A. (1998). *Applied regression analysis and multivariable methods.* Third edition. Duxbury Press. USA.

(87) **Koutsoyiannis, A.** (1979). *Theory of econometrics.* The Macmillan press Ltd. London, UK.

(88) **Krause, A.** and **Olson, M.** (1997). The basic of S and S-Plus. Springer-Verlag. New York, USA.

(89) **Landgrebe, D.A. and Joen, B.** (1994). *Fast parzen density estimation using clustering- based branch and bound.* Journal of IEEE Transactions on pattern analysis and machine intelligence. Vol. 16, pp 950-954.

(90) **Lipman, A. and Lay, S.R.** (1994). *Non-parametric multivariate density estimation.* Journal of IEEE Transactions on pattern analysis and machine intelligence. Vol. 42, pp 2795-2809.

(91) **Malty, S.K.** (1960). *Northern Egyptian lakes (in Arabic).* PhD. Cairo University. Cairo, Egypt. pp 140-151.

(92) **McCleary, R.** and **Hay, R.A.** (1983). *Applied time series analysis.* SAGE Beverly Hills. London, UK.

(93) **Mendenhall, W.** and **Sincich, T.** (1989). *A second course in business statistics: Regression analysis.* Collier Macmillan Publishers. London, UK. Third edition.

(94) **Montasser, A.H.** (1977). *Ecology of lake Manzala (in Arabic).* Report. Faculty of Science, Cairo University. Cairo, Egypt. pp 12-50.

(95) **Mooney, C.Z.** and **Duval, R.D.** (1995). *Bootstrapping a non-parametric approach to statistical inference.* SAGE Publications, International Educational and Professional Publisher. London, UK.

(96) **Myers, R.H.** (1990). *Classical and modern regression with applications.* Belmont, California, Duxbury Press. Second edition.

(97) **Nelder, J.A.** and **Wedderburn, W.M.** (1972). *Generalised linear models.* Journal of Royal Statistical Society A. Vol. 135 part 3, pp 370-384.

(98) **Neter, J., Kutner, M.H., Nachtsheim, C.J.** and **Wasserman. W.** (1996). *Applied linear statistical models.* Chicago: Richard D. Irwin, Inc. and Times Mirror Higher Education Group Inc. Fourth edition.

(99) **Nussbaumer, H.J.** (1981). *Fast fourier transfer and convolution algorithms.* Springer series in Information Sciences. London, UK.

(100) **Nychka, D.** and **Ruppert, D.** (1995). *Non-parametric transformations for both sides of the regression model.* Journal of Royal Statistical Society B. Vol. 3, pp 519-532.

(101) **Nychka, D., Gray, G., Haaland, P., Martin, D. and O'Connell, M.** (1995). *A non-parametric regression approach to syringe grading for quality improvement.* Journal of the American Statistical Association. Vol. 90, pp 1171-1179.

(102) **Panayotou, T.** (1982). *Management concepts for small-scale fisheries. Economic and social aspects.* Food and Agriculture Organisation of the United Nations. Report. Rome, Italy. Vol. 228.

(103) **Priestley, M.B.** (1984). *Spectral analysis and time series.* Academic press, Inc. London, UK. Third edition.

(104) Ricker, W.E. (1975). *Computation and interpretation of biological statistics of fish populations.* Department of the environment fisheries and marine service. Ottawa, Canada.

(105) Ricketts, C. and Burchett, M.S. (1983). *The population dynamics of Notothenia rossii from South Georgia (Antarctica).* Journal of Polar Biology. pp 35-38.

(106) Robson, D.S. and Reiger, H.A. (1967). *Estimation of population number and mortality rates.* Black-well Scientific Publication. Oxford, UK. Third edition, pp 365-370.

(107) Royston, P. and Altman, D.G. (1994). *Regression using fractional polynomials of continuous covariates: parsimonious parametric modelling.* Journal of Royal Statistical Society B. Vol. 43, pp 429-467.

(108) Saad, M.M. (1988). *Development of fisheries in Fayom (in Arabic).* PhD. Muonif University. Muonif, Egypt.

(109) Schucany, W.R. (1995). *Adaptive bandwidth choice for Kernel regression.* Journal of the American Statistical Association. Vol. 90, pp 535-540.

(110) Shafay, M.A. (1983). *Seasonal fish production from salinity lakes in Egypt (in Arabic).* International conference for statistical and social researches. Report. Cairo, Egypt.

(111) Shahen, M.F. (1980). *Economical development in the northern lakes in Egypt (in Arabic).* PhD. Muonif University. Muonif, Egypt.

(112) Sherif, S.Y. (1974). *Economical study of fish resources in ARE (in Arabic).* PhD. Ain Shams University. Cairo, Egypt. pp 211-219.

(113) Silverman, B.W. (1985). *Some aspects of the spline smoothing approach to non-parametric regression curve fitting.* Journal of Royal Statistical Society B. Vol. 1, pp 1-52.

(114) Silverman, B.W. (1986). *Density estimation for statistics and data analysis.* Chapman and Hall. London, UK.

(115) Silverman, B.W. and Green, P.J. (1995). *Non-parametric regression and generalized linear models.* Chapman and Hall. London, UK. Second edition.

(116) Snee, R.D. (1977). Validation of regression models: Methods and Examples. Technometrics Journal, Vol. 19, No. 4. Pp 415-428.

(117) Sparre, P., Ursin, E. and Venema, S.C. (1989). *Introduction to tropical fish stock assessment.* Food and Agriculture Organization of the United Nation. Rome, Italy.

(118) Spector, P. (1994). *An introduction to S and S-Plus.* Duxbury Press. California, USA.

(119) Thomas, G.H. and Fahmy, W.W. (1994). *Efficiency of multivariate technique for studying the Egyptian Mediterranean fisheries fluctuation.* Journal of Agricultural research. Vol. 39.

(120) Swartzman, G., Huang, C. and Kaluzny, S. (1992). *Spatial analysis of Bering Sea Groundfish survey data using generalised additive models.* Can. Journal of Fish Aquat. Science. Vol. 49, pp 1366-1378.

(121) Swartzman, G., Silverman, E. and **Williamsom, N.** (1994). *Relating trends in walleye pollock (Theragra chalcogramma) abundance in the Bering Sea to environmental factors.* Can. Journal of Fish Aquat. Science. Vol. 52, pp 369-380.

(122) Swartzman, G., Stuetzle, W., Powojowski, M. and **Kulman, K. (1994).** *Relating the distribution of pollock schools in the Bering Sea to environmental factors.* Journal of ICES Sci. Vol. 51, pp 481-492.

(123) Tibshirani, R.J. and **Efron, B.** (1993). An introduction to the bootstrap. Chapman and Hall. New York, USA.

(124) Tu, D. and **Shao, J.** (1995). The Jackknife and bootstrap. Springer-Verlag, New York, USA.

(125) Turid, R. (1982). *Fisheries management in northern Nile Delta lakes of Egypt.* Ministry of Agriculture in ARE in cooperation with University of California. Report. Cairo, Egypt. Vol. 179, pp 616-621.

(126) Venables, W.N. and Ripley, B.D. (1994). *Modern applied statistics with S-Plus.* Springer-Verlage New York, Inc. New York.

(127) Wahby, S.D. (1989). *Further studies on the hydrography and chemistry of lake Manzala.* National Institute of Oceanography and Fisheries (NIOF). Report. Alexandria, Egypt. pp 401-422.

(128) Wang, N. and Ruppert, D. (1995). *Non-parametric estimation of the transformation in the transform-both-sides regression model.* Journal of the American Statistical Association. Vol. 90, pp 522-533.

(129) Yamane, T. (1967). *Elementary sampling theory.* Prentice-Hall Inc., Englewood Cliffs. London, UK.

(130) Zaki, M.I. (1992). *Aqua-culture in Lake Manzala (in Arabic).* National Institute of Oceanography and Fisheries (NIOF). Report. Alexandria, Egypt. Vol. Lake/002/001/027, pp 2-14.

Appendix A

Table 1A The effect of different levels of data aggregation on the parameter estimates.

Species	data period	r	annual r	K_{80}
T.Nilotica	Monthly	0.058	0.695	107
	2 months	0.117	0.699	107
	3 months	0.176	0.702	106
	4 months	0.237	0.711	106
	6 months	0.358	0.715	105
	annual		**0.766**	**105**
T.Aurea	Monthly	0.055	0.661	62
	2 months	0.113	0.678	61
	3 months	0.171	0.685	61
	4 months	0.235	0.706	60
	6 months	0.355	0.710	60
	annual		**0.775**	**59**
T.Zillii	Monthly	0.046	0.552	89
	2 months	0.094	0.563	88
	3 months	0.149	0.597	85
	4 months	0.202	0.605	85
	6 months	0.305	0.610	84
	annual		**0.671**	**83**
T.Galilea	Monthly	0.047	0.569	16
	2 months	0.106	0.637	15
	3 months	0.167	0.667	15
	4 months	0.229	0.688	15
	6 months	0.346	0.692	15
	annual		**0.732**	**15**
Total Tilapia	Monthly	0.056	0.672	280
	2 months	0.120	0.720	268
	3 months	0.183	0.732	264
	4 months	0.245	0.735	262
	6 months	0.368	0.736	260
	annual		**0.740**	**260**

Table 2A The range of initial estimates of r and K_{80} for which convergence was obtained to the given estimated value.

Species	Estimate r	Minimum	Maximum	Estimate of K_{80}	Minimum	Maximum
T.Nilotica	**0.77**	0.33	2.21	**105**	68	165
T.Aurea	**0.78**	0.40	2.51	**59**	44	260
T.Zillii	**0.67**	0.25	2.50	**83**	71	130
T.Galilea	**0.73**	0.46	2.40	**15**	11	21
Combined Tilapia	**0.74**	0.23	1.70	**260**	207	303

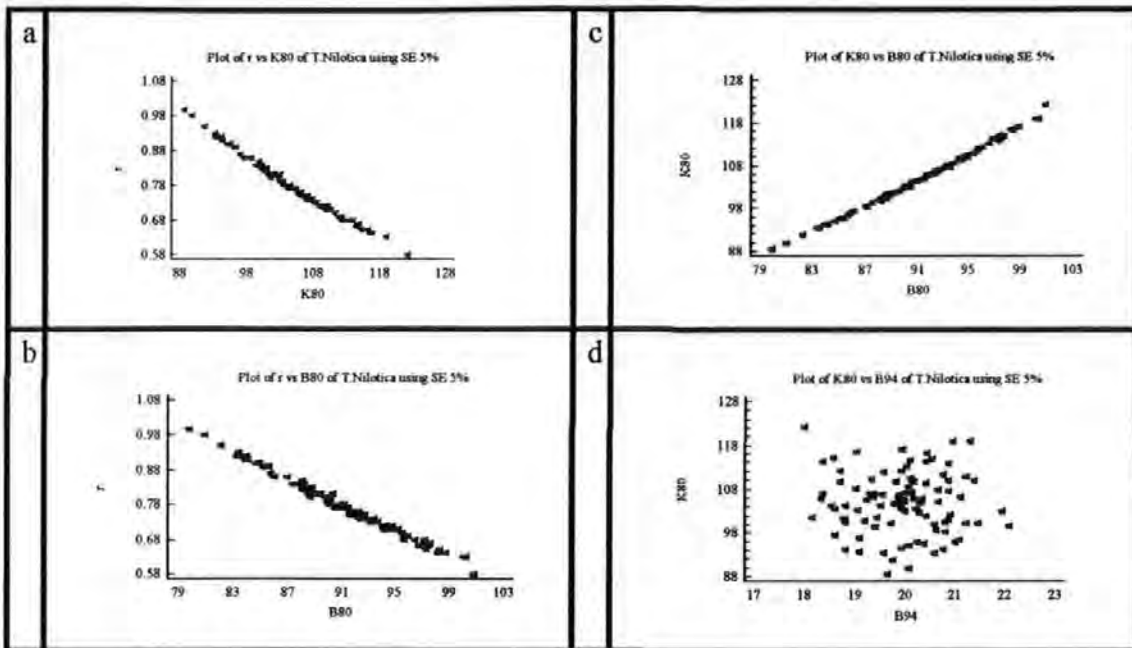
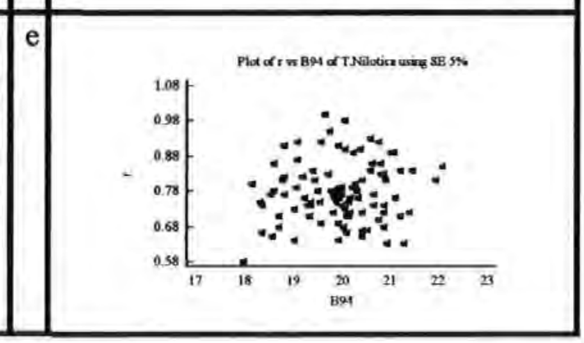


Figure 1A The relationship between (a) stochastic *r* and stochastic *K*, (b) stochastic *r* and B_{80}, (c) stochastic *r* and B_{94}, (d) stochastic *K* and B_{80} and (e) stochastic *K* and B_{94} for *T.Nilotica* assuming the error is 5% of B_{80} and B_{94}.



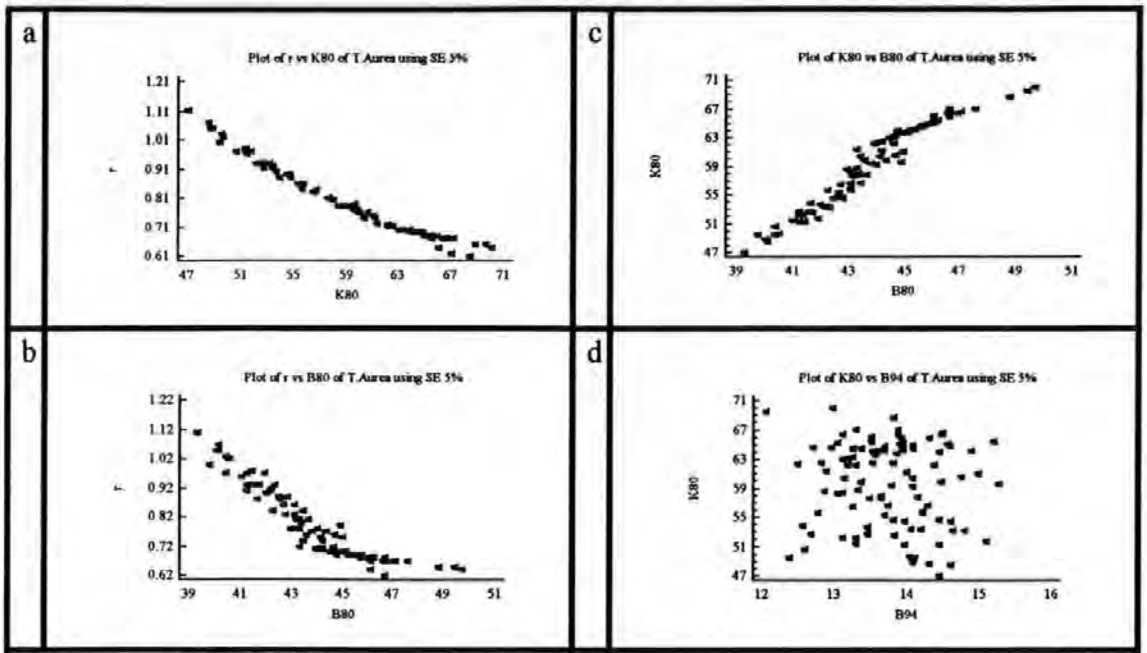
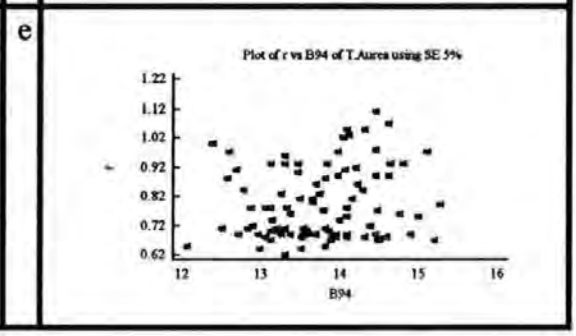


Figure 2A The relationship between (a) stochastic *r* and stochastic *K*, (b) stochastic *r* and B_{80}, (c) stochastic *r* and B_{94}, (d) stochastic *K* and B_{80} and (e) stochastic *K* and B_{94} for *T.Aurea* assuming the error is 5% of B_{80} and B_{94}.



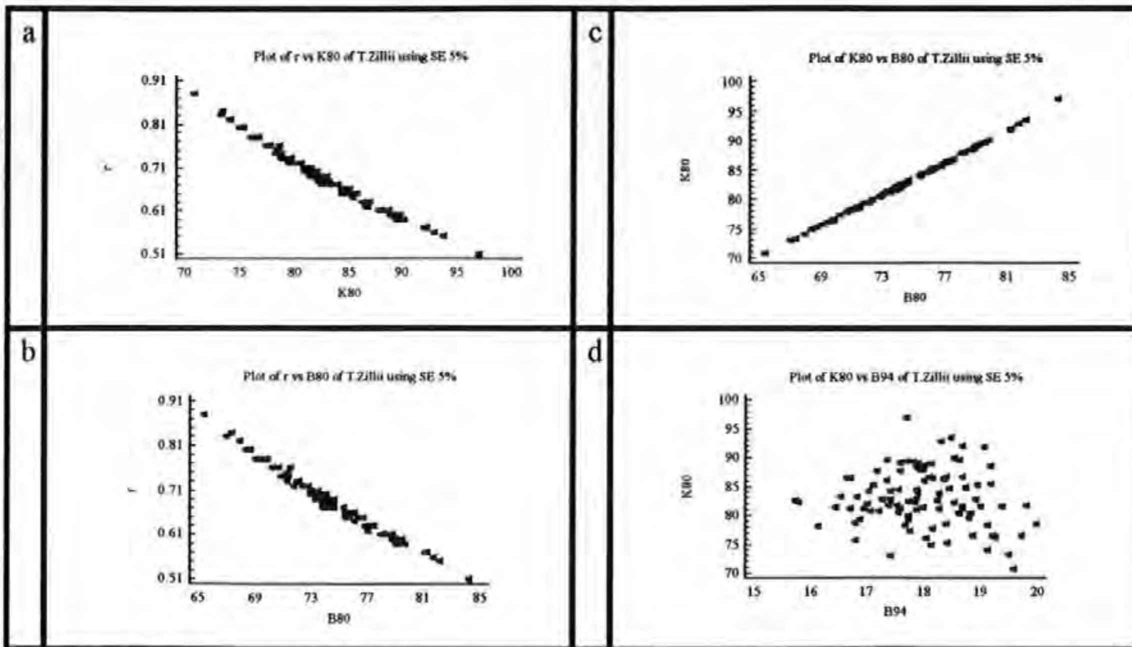
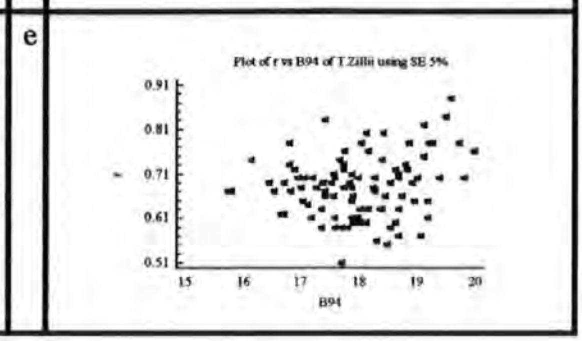


Figure 3A The relationship between (a) stochastic *r* and stochastic *K*, (b) stochastic *r* and B_{80}, (c) stochastic *r* and B_{94}, (d) stochastic *K* and B_{80} and (e) stochastic *K* and B_{94} for *T.Zillii* assuming the error is 5% of B_{80} and B_{94}.



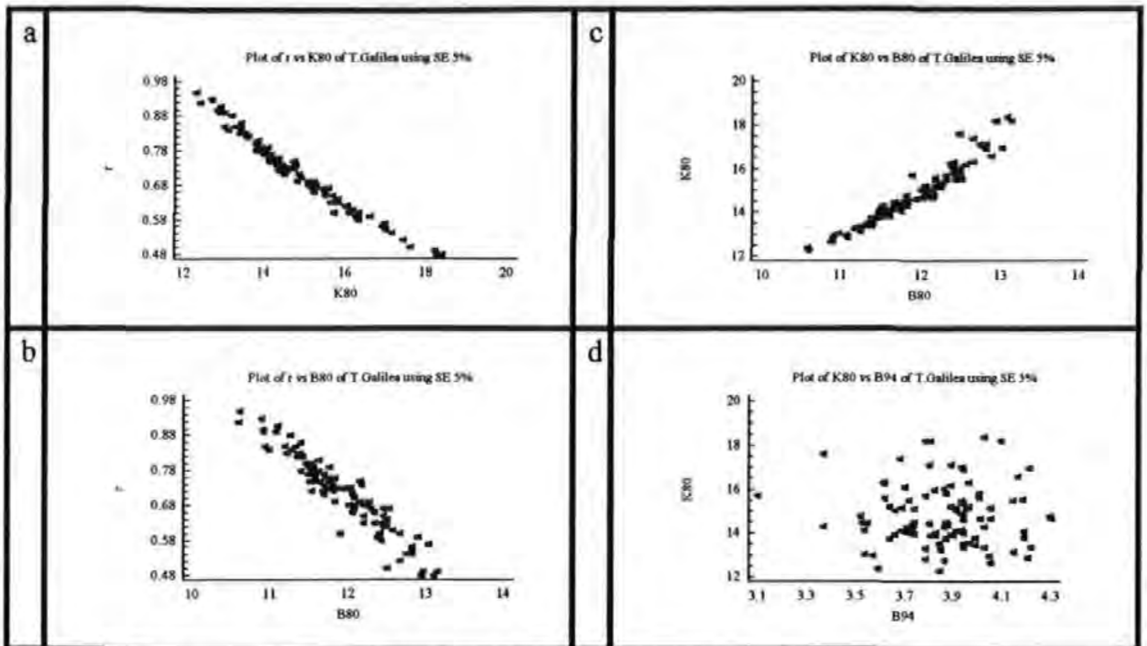
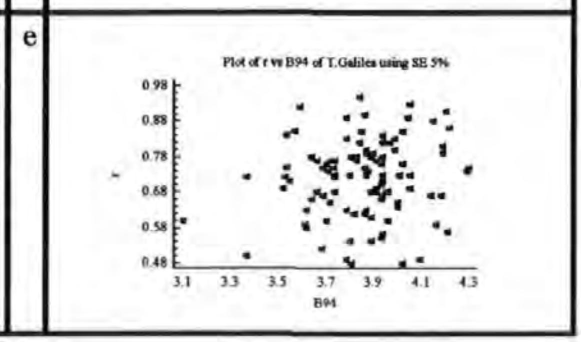


Figure 4A The relationship between (a) stochastic *r* and stochastic *K*, (b) stochastic *r* and B_{80}, (c) stochastic *r* and B_{94}, (d) stochastic *K* and B_{80} and (e) stochastic *K* and B_{94} for *T.Galilea* assuming the error is 5% of B_{80} and B_{94}.



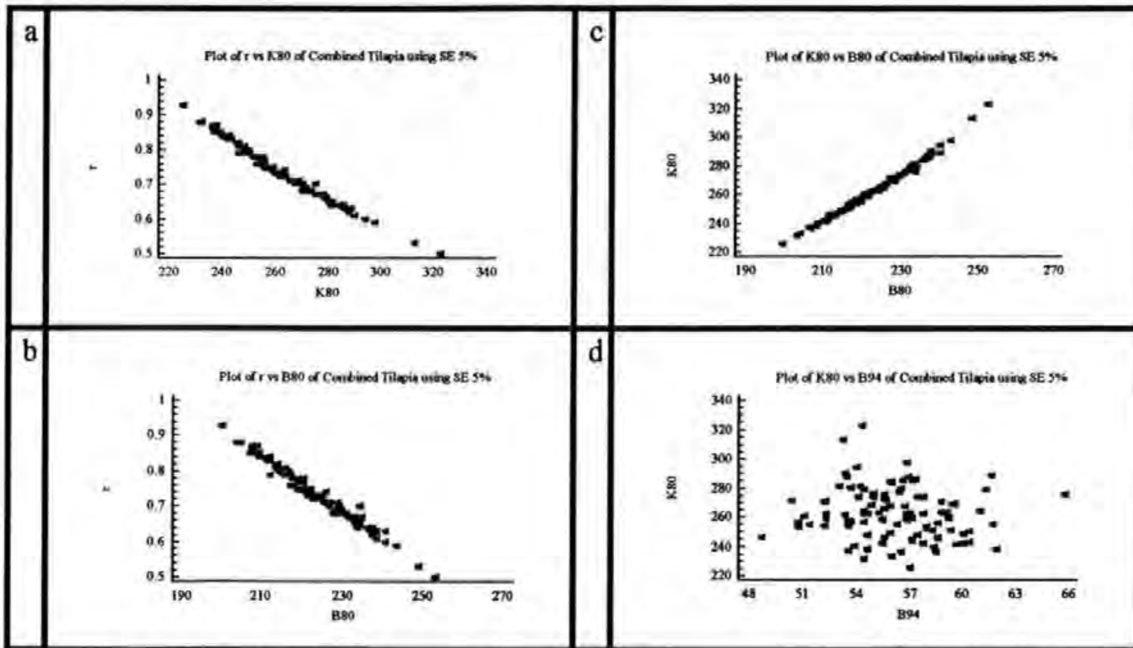


Figure 5A The relationship between (a) stochastic *r* and stochastic *K*, (b) stochastic *r* and B_{80}, (c) stochastic *r* and B_{94}, (d) stochastic *K* and B_{80} and (e) stochastic *K* and B_{94} for *Combined Tilapia* assuming the error is 5% of B_{80} and B_{94}.

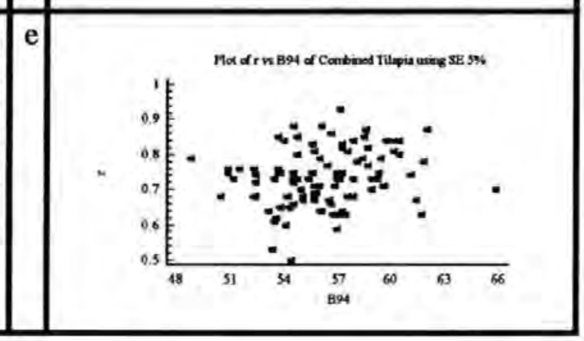


Table 3A The deterministic estimates values of r, K_{80}, K_{94} for each species and *Combined Tilapia* species, coefficient of variation and 95% confidence level of them assuming the standard error is 10% of B_{80} and B_{94}.

Species		Estimation	CV	Upper	Mean	Lower
T.Nilotica	r	**0.766**	15%	0.950	0.734	0.519
	K	**105**	9%	129	109	90
	K_o	**59**	9%	73	62	51
T.Aurea	r	**0.675**	22%	1.101	0.772	0.442
	K	**66**	13%	77	61	45
	K_o	**37**	13%	43	34	26
T.Zillii	r	**0.671**	10%	0.805	0.678	0.551
	K	**83**	6%	92	83	74
	K_o	**47**	6%	52	47	42
T.Galilea	r	**0.732**	13%	0.891	0.707	0.522
	K	**14**	8%	18	15	13
	K_o	**8**	8%	10	9	7
Combined Tilapia	r	**0.740**	13%	0.935	0.740	0.545
	K	**260**	8%	304	261	219
	K_o	**147**	8%	171	147	123

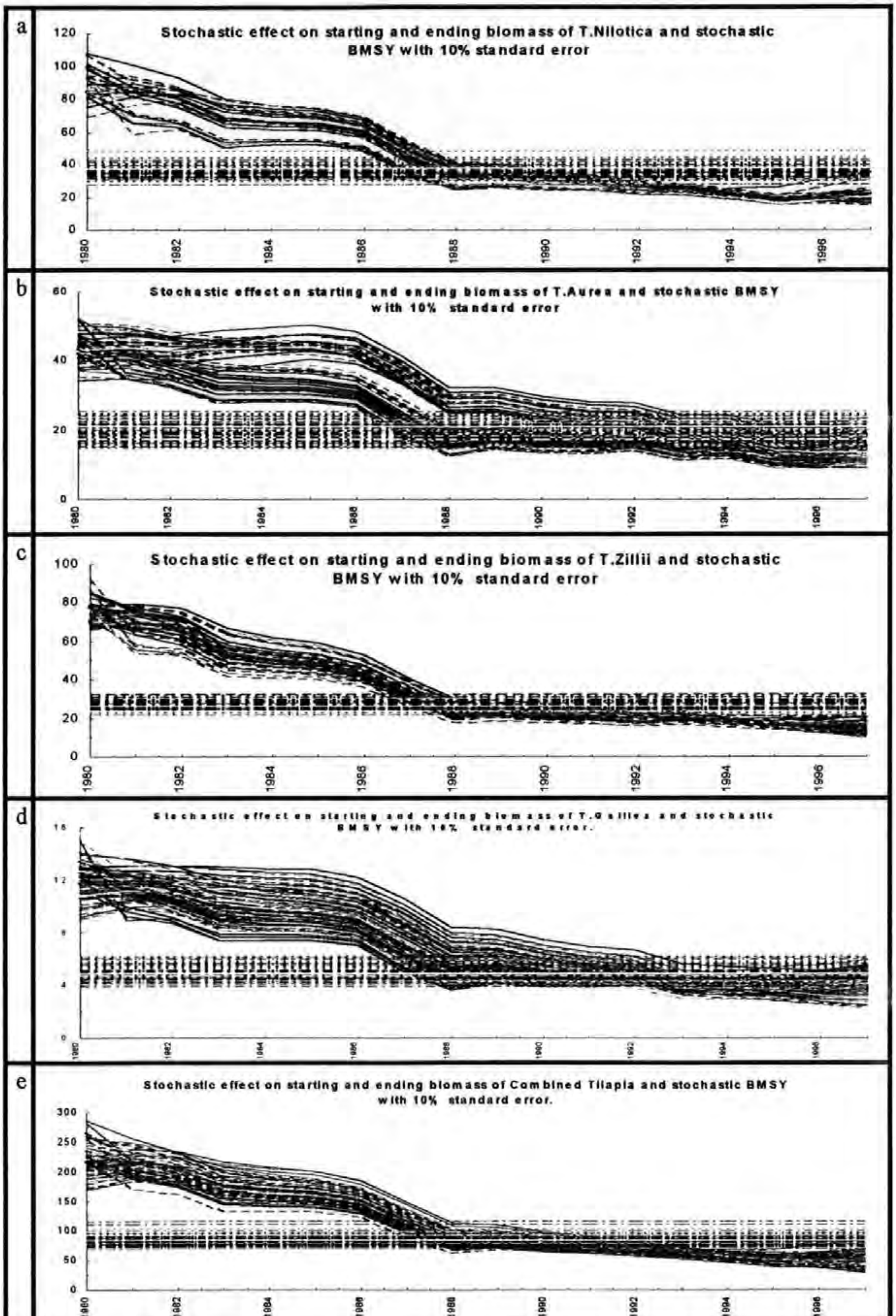


Figure 6A The stochastic effect with 10% error on starting and ending biomass and stochastic *BMSY* of (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii*, (d) *T.Galilea* and (e) *Combined Tilapia.*

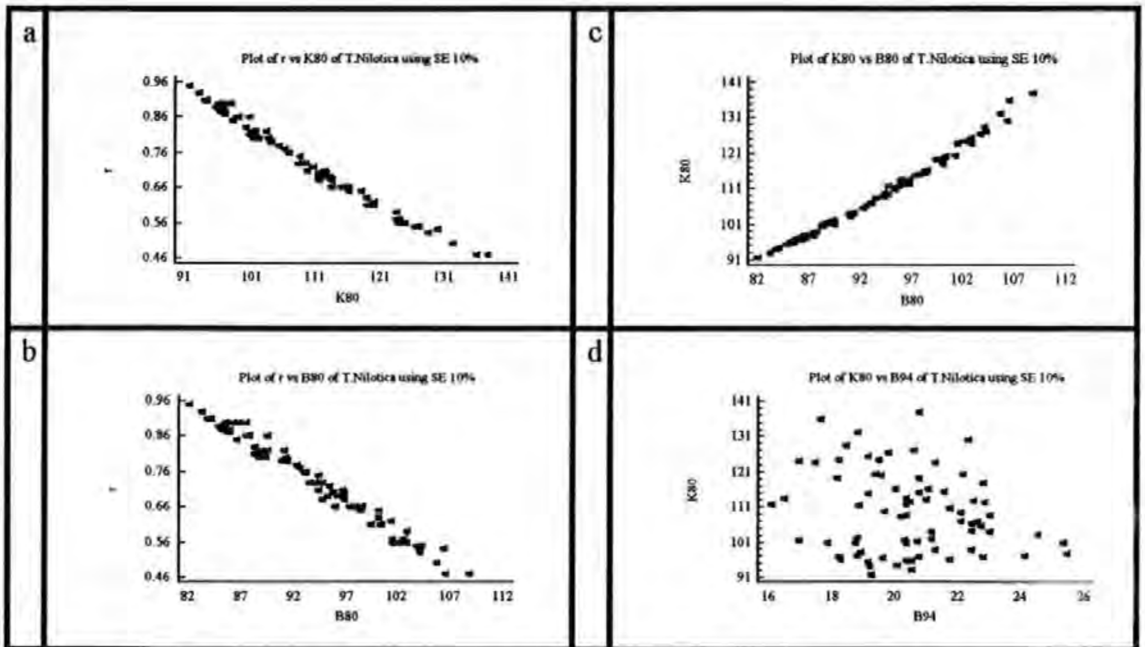
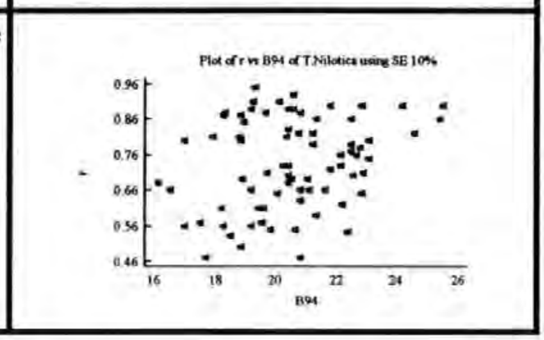


Figure 7A The relationship between (a) stochastic *r* and stochastic *K*, (b) stochastic *r* and B_{80}, (c) stochastic *r* and B_{94}, (d) stochastic *K* and B_{80} and (e) stochastic *K* and B_{94} for *T.Nilotica* assuming the error is 10% of B_{80} and B_{94}.



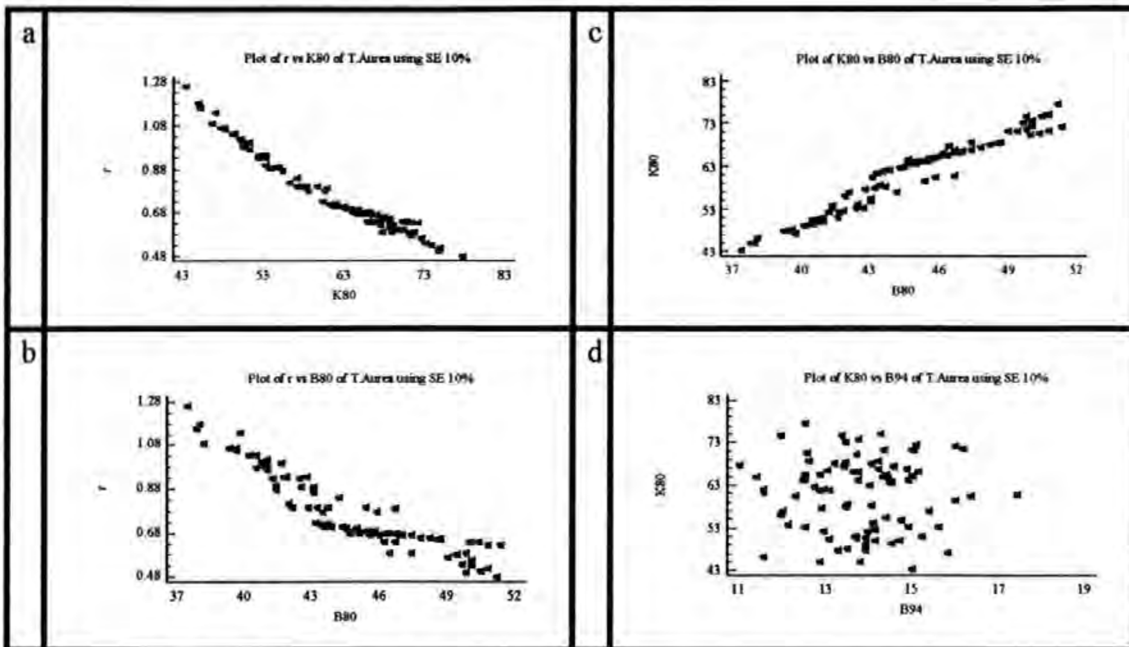
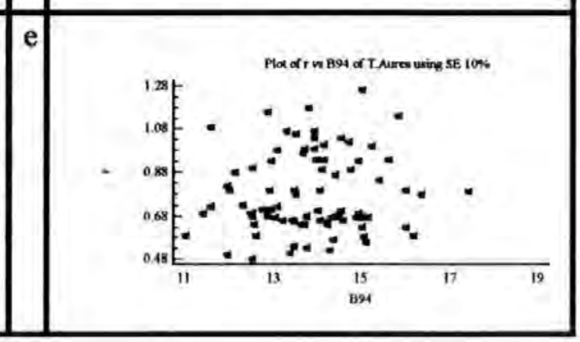


Figure 8A The relationship between (a) stochastic *r* and stochastic *K*, (b) stochastic *r* and B_{80}, (c) stochastic *r* and B_{94}, (d) stochastic *K* and B_{80} and (e) stochastic *K* and B_{94} for *T.Aurea* assuming the error is 10% of B_{80} and B_{94}.



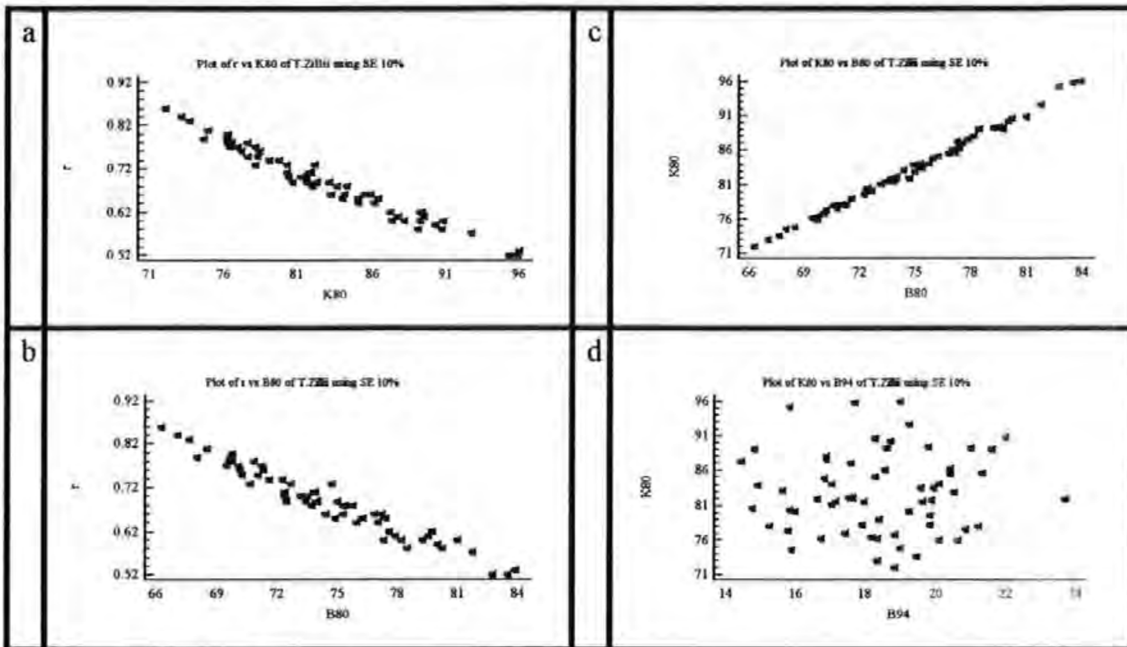
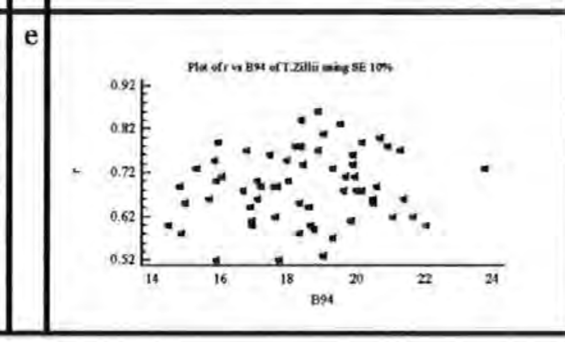
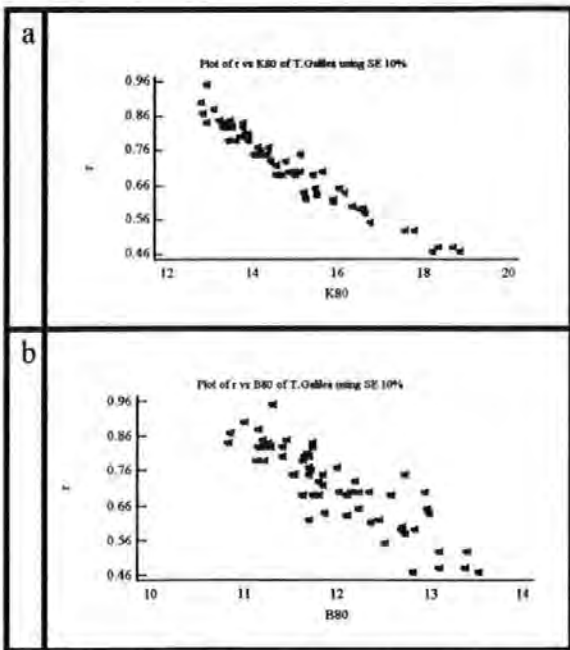


Figure 9A The relationship between (a) stochastic r and stochastic K, (b) stochastic r and B_{80}, (c) stochastic r and B_{94}, (d) stochastic K and B_{80} and (e) stochastic K and B_{94} for *T.Zillii* assuming the error is 10% of B_{80} and B_{94}.





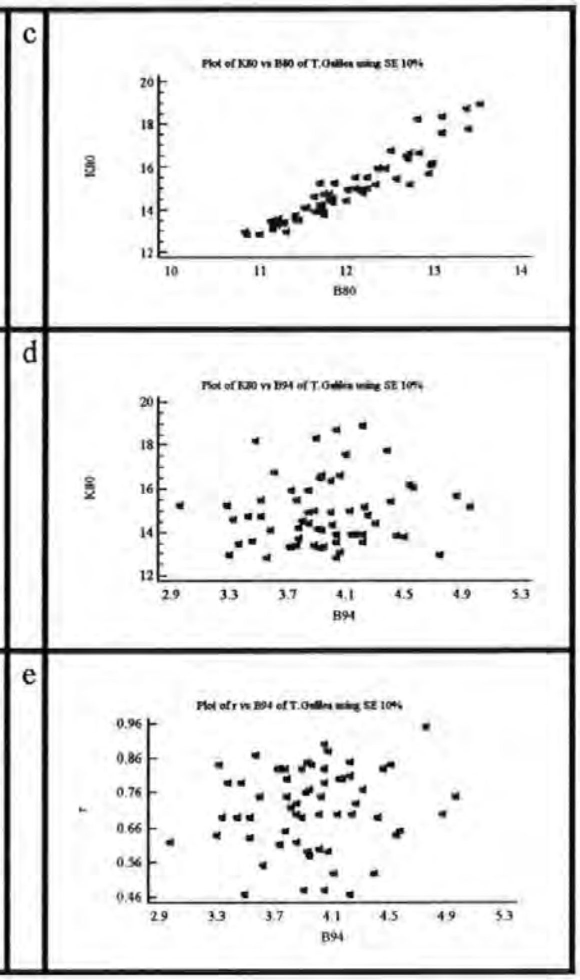
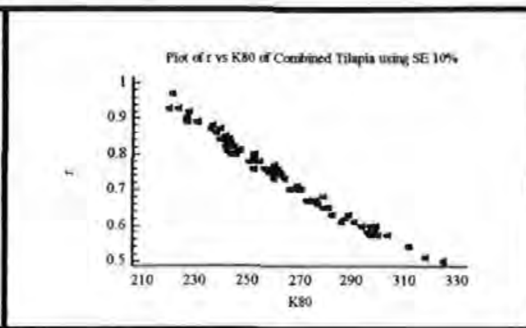
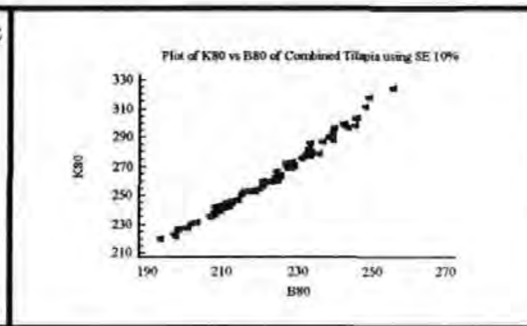


Figure 10A The relationship between (a) stochastic r and stochastic K, (b) stochastic r and B_{80}, (c) stochastic r and B_{94}, (d) stochastic K and B_{80} and (e) stochastic K and B_{94} for *T.Galilea* assuming the error is 10% of B_{80} and B_{94}.

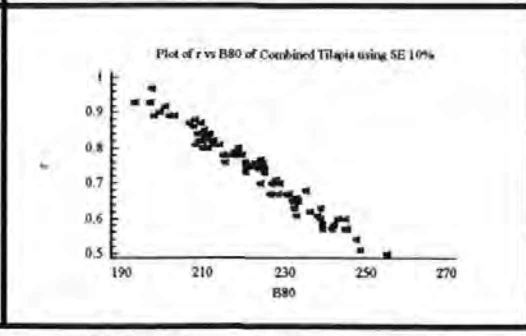
a



c



b



d

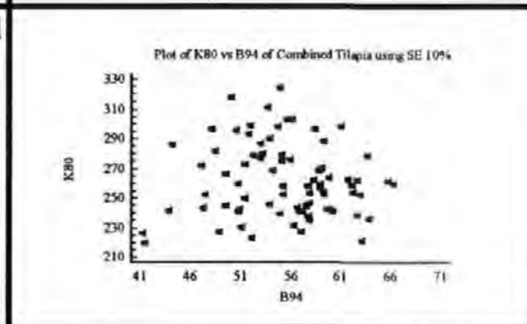
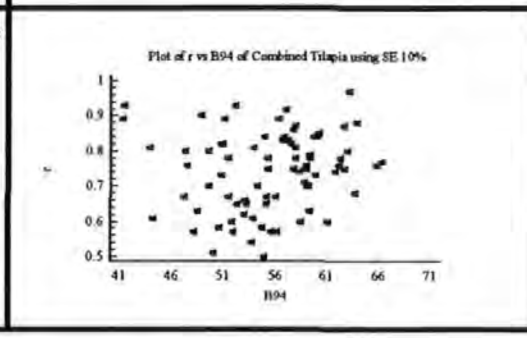


Figure 11A The relationship between (a) stochastic *r* and stochastic *K*, (b) stochastic *r* and B_{80}, (c) stochastic *r* and B_{94}, (d) stochastic *K* and B_{80} and (e) stochastic *K* and B_{94} for *Combined Tilapia* assuming the error is 10% of B_{80} and B_{94}.

e



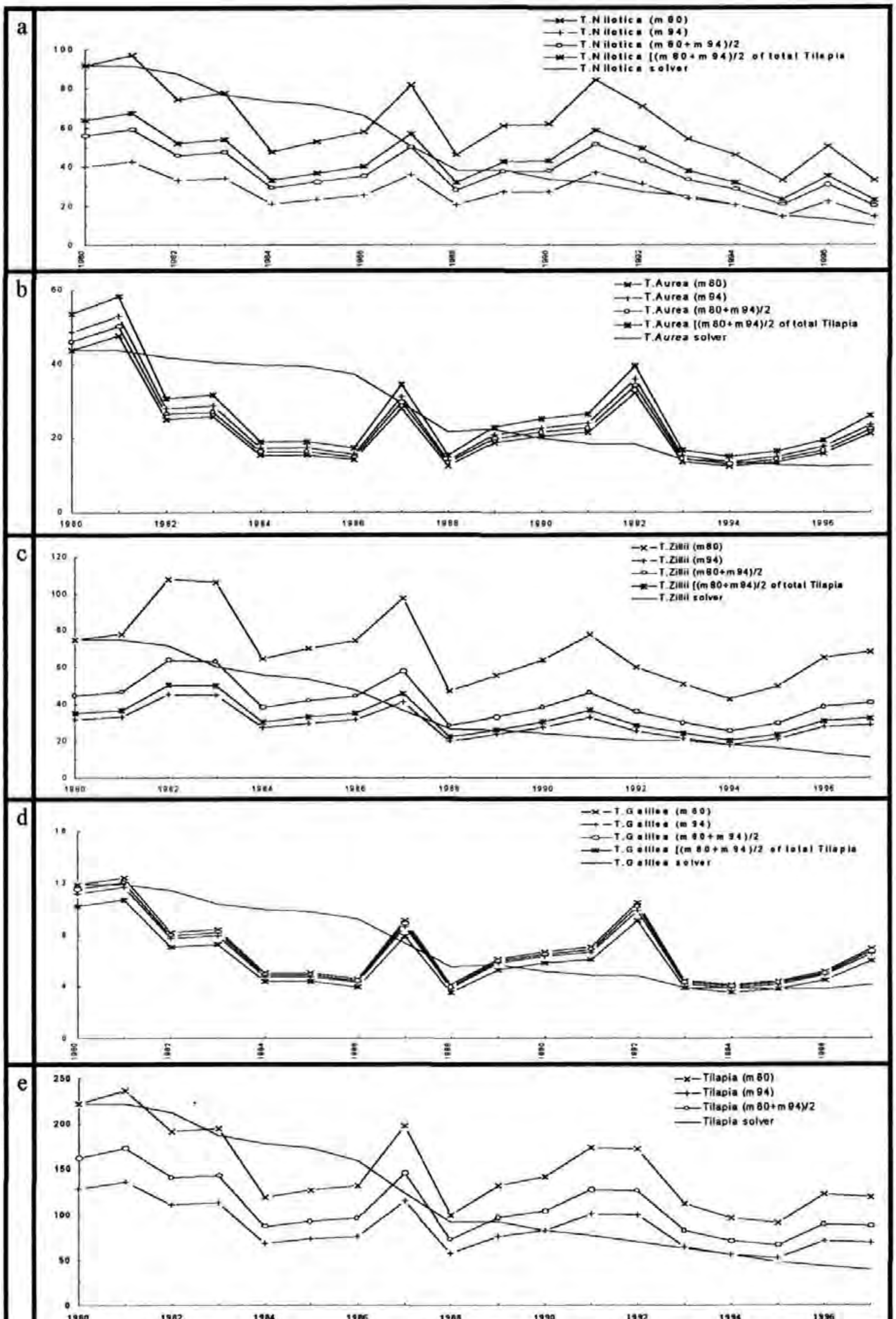


Figure 12A The estimated biomass based upon each assumption of the constant *area-adjusted catchability* and the biomass estimates produce by using Solver technique for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Combined Tilapia* stock.

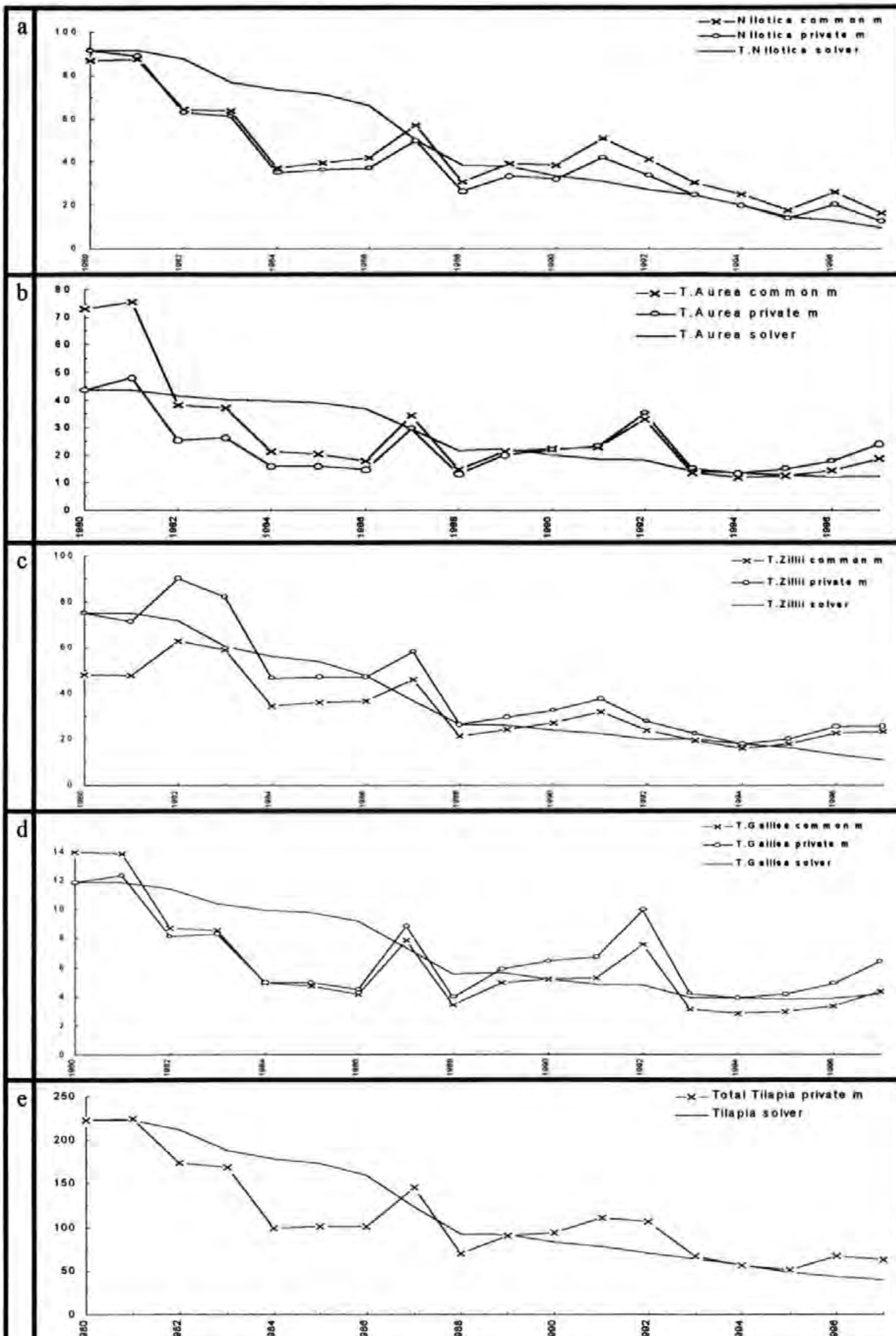


Figure 13A Estimated change in biomasses between 1980 and 1997 using equations 3.16 with estimated separate *m* for each species and use a common *m* from the *Combined Tilapia* species with the Solver biomass estimates for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Combined Tilapia* stock.

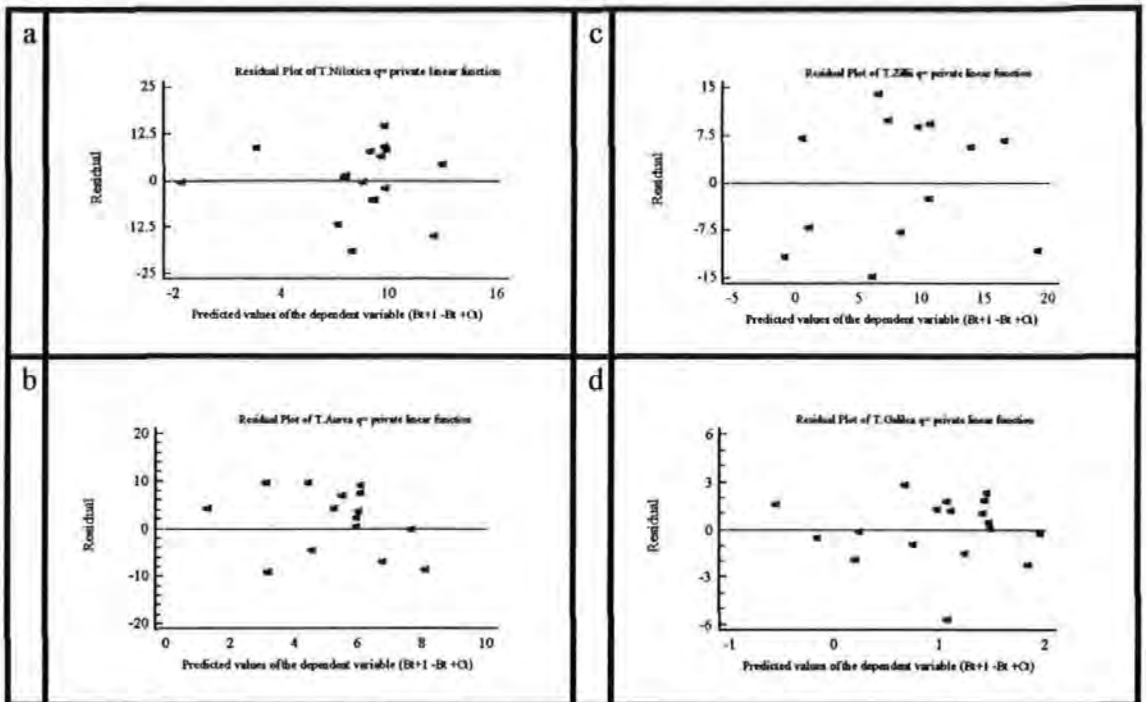


Figure 14A Residual versus predicted values of the dependent variable in equations 3.16 assuming that *area-adjusted catchability* is a linear function of time and there is a separate *m* for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* and (d) *T.Galilea.*

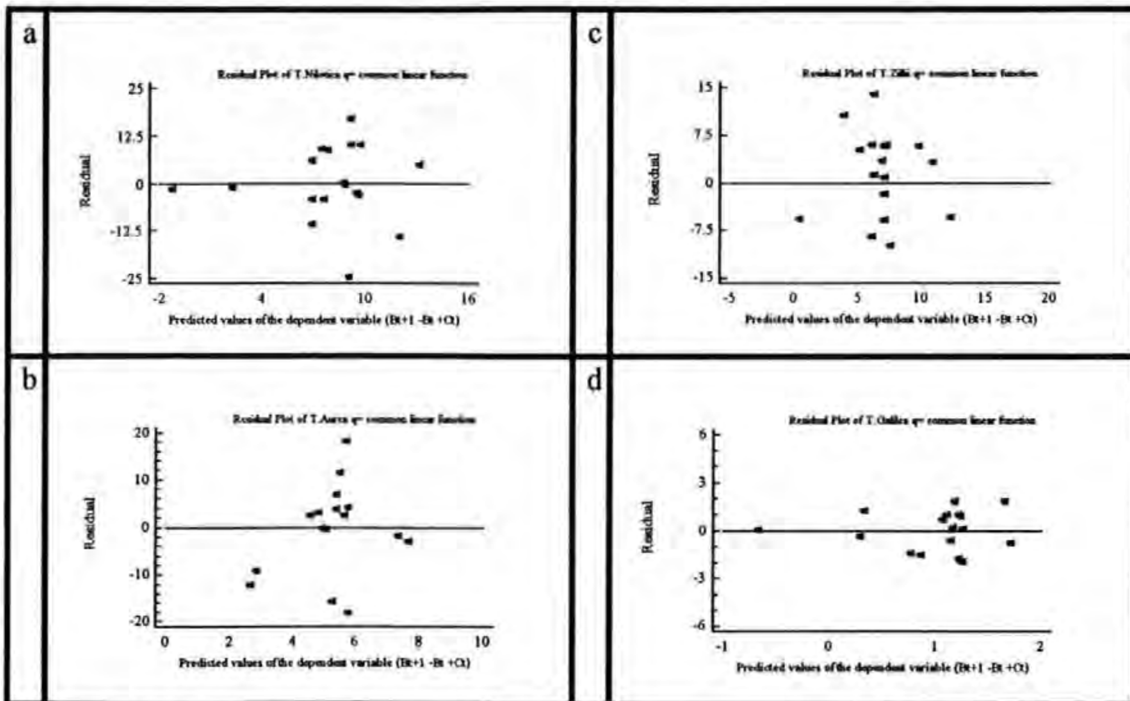
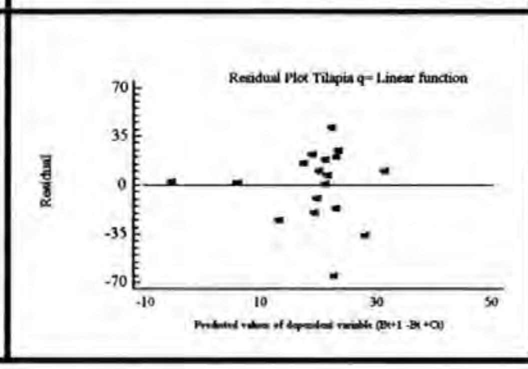


Figure 15A Residual versus predicted values of the dependent variable in equations 3.16 assuming that *area-adjusted catchability* is a linear function of time and there is a common *m* for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Combined Tilapia.*



Appendix B

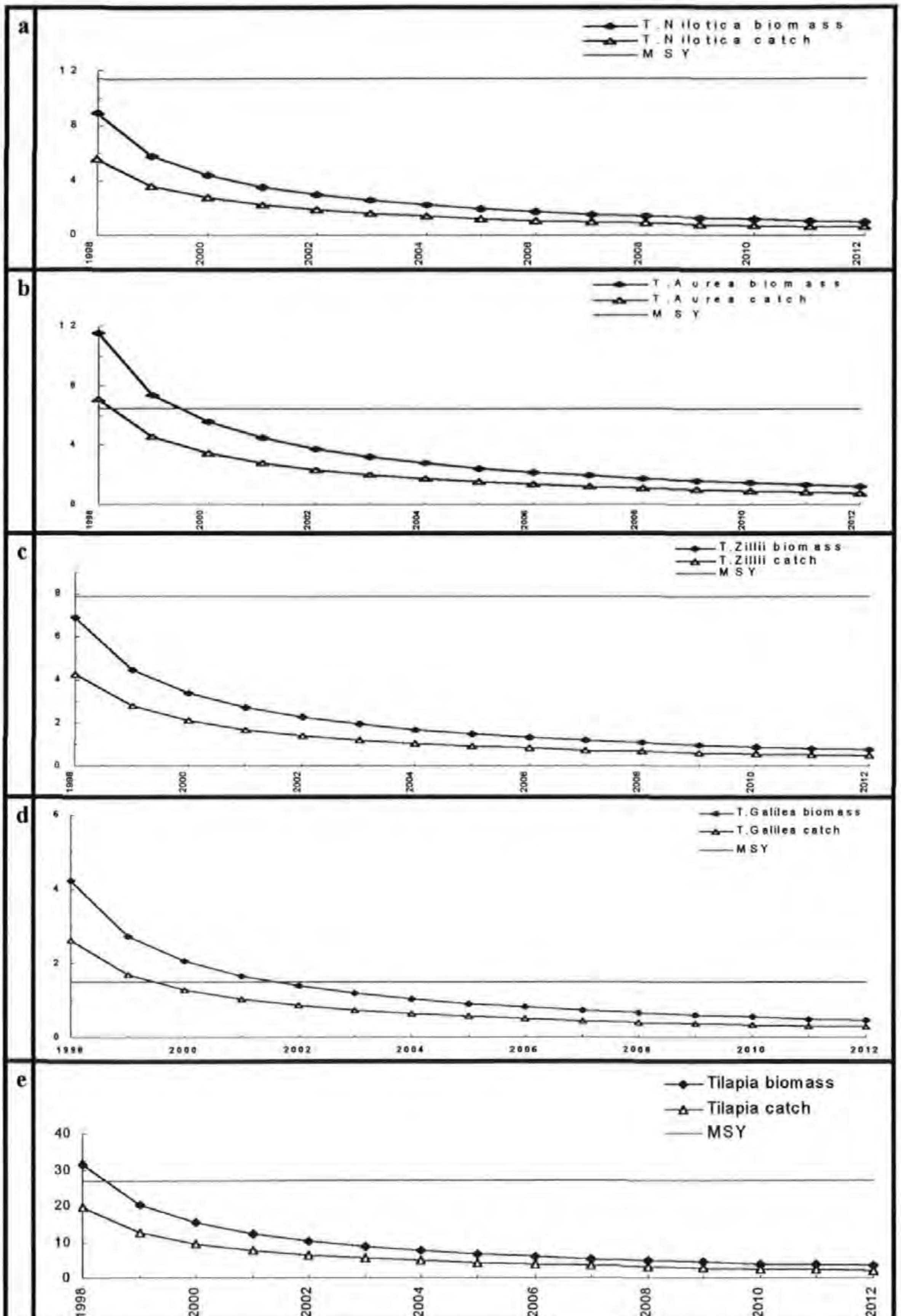


Figure 1B Biomass estimation, predicted catch and *MSY* for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Combined Tilapia* stock if the fishing is continue with constant and high effort level.

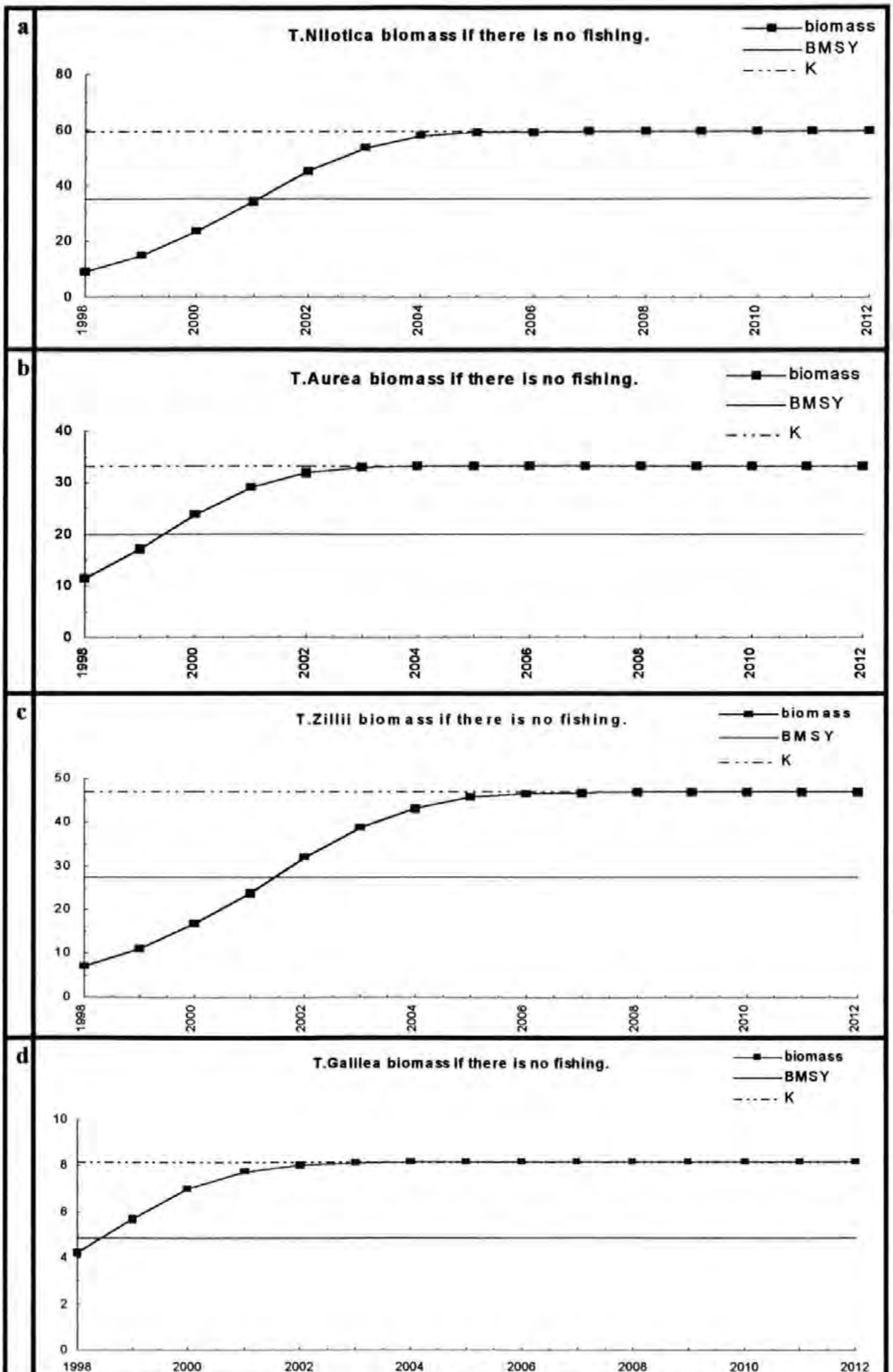


Figure 2B Biomass estimation, predicted catch, *MSY* and *BMSY* for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* and (d) *T.Galilea* if the fishing stopped for a long time.

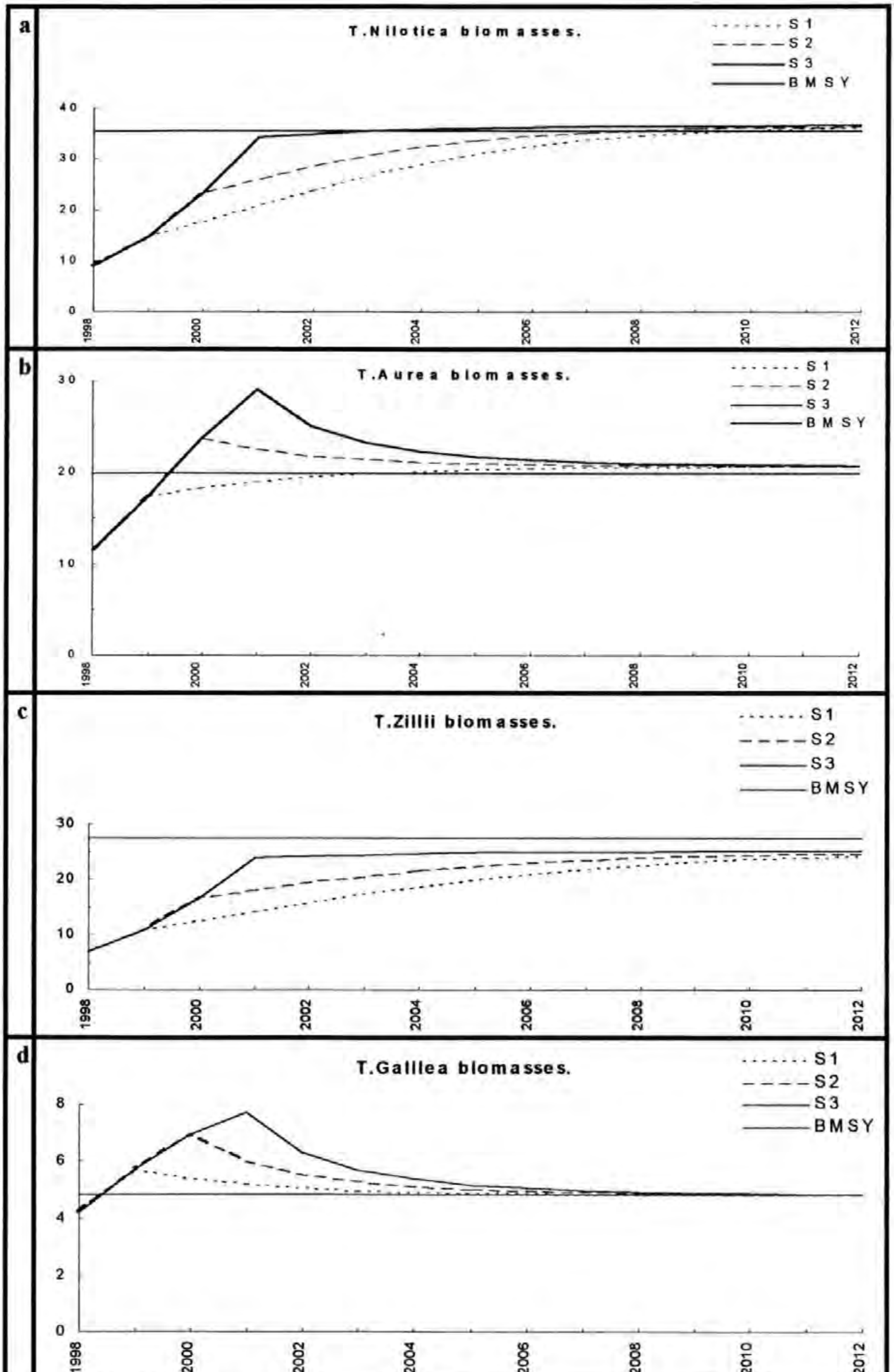


Figure 3B Comparison between the prediction of biomass based on the three catch strategies for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* and (d) *T.Galilea*.

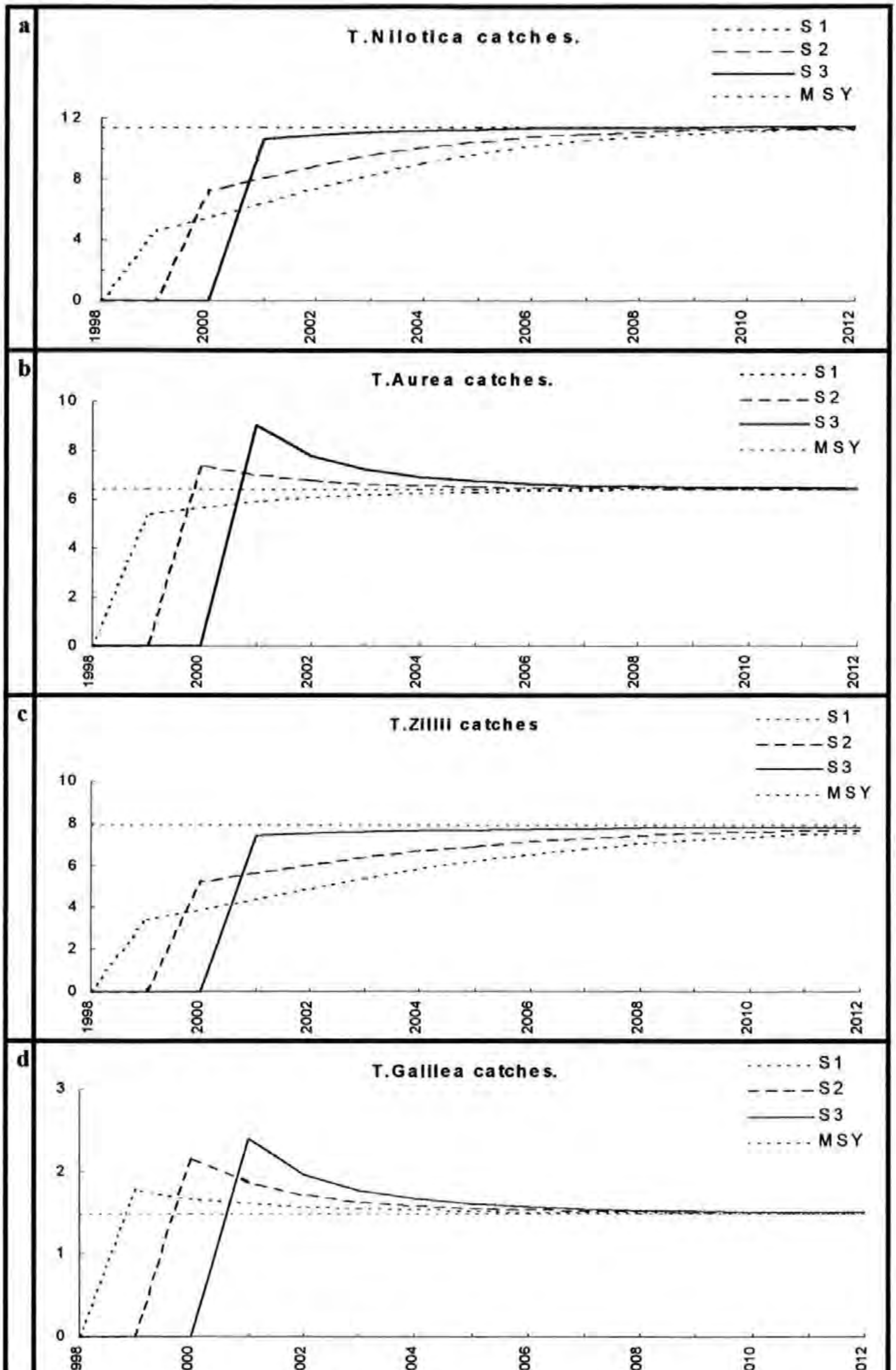


Figure 4B The catch estimates of the three catch strategies together with *MSY* for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* and (d) *T.Galilea*.

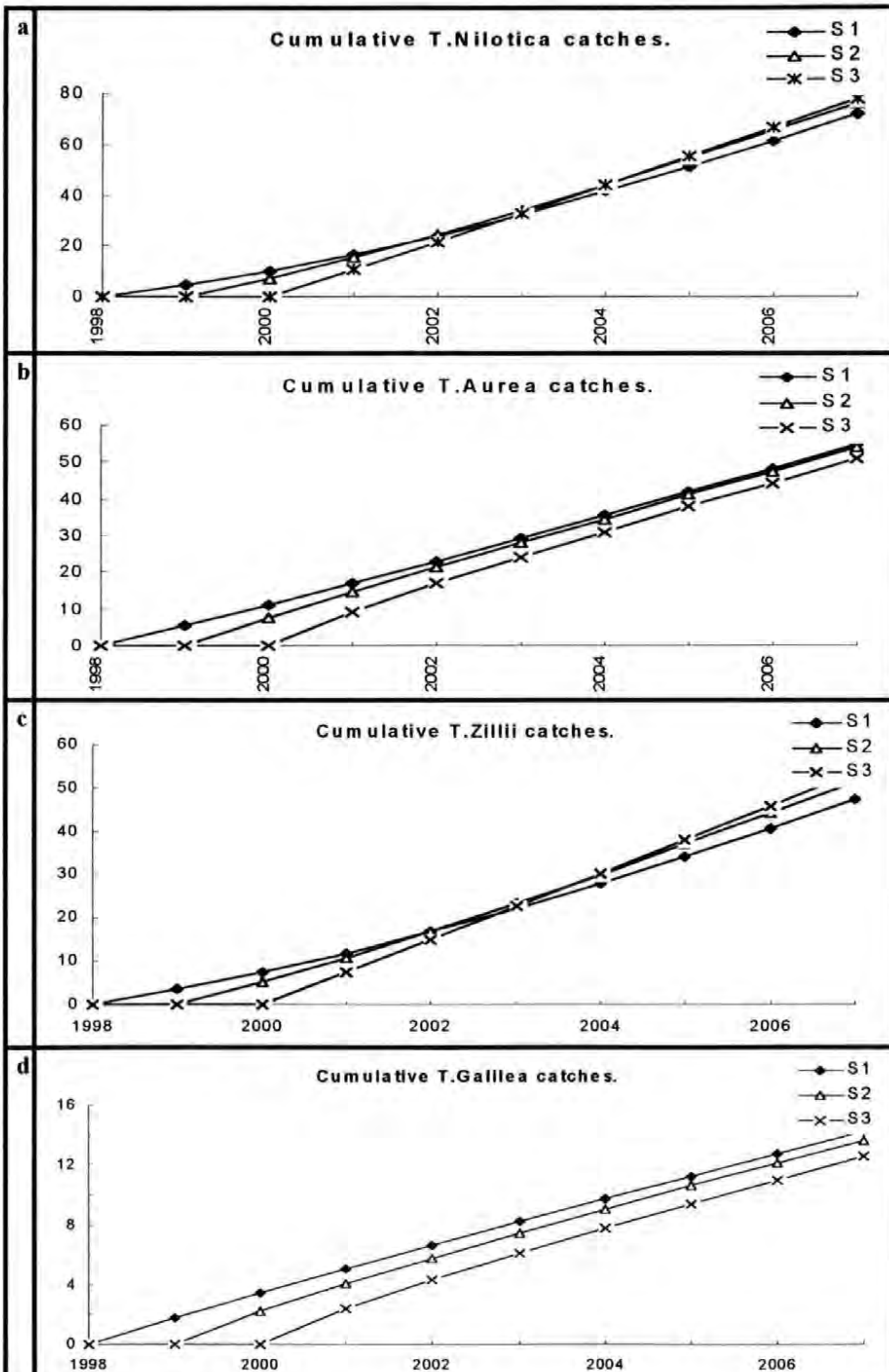


Figure 5B The cumulative catch estimates of the three catch strategies for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* and (d) *T.Galilea*.

Appendix C

Lake Manzala questionnaire - during August - September 1995

1. What is your name?---

2. How old are you?--years

3. Determine the used fishing gear

□ Trap □ Stand □ Hook lines

3. What is the sector you fish in ?

□ South □ West □ East

4. What is the average quantity of fish you catch each trip?----------kg

5. How many nets you use each trip?

   □ -----nets for Trap nets

   □ -----nets for Stand nets

   □ -----hundred hook for Hook lines

6. How many fishermen work on your boat each trip?--------fisherman

7. How many hours you spend each trip?---------hours

8. How many mesh in each 100cm of length of nets if you use Trap nets or Stand nets?

   ------------mesh

9. How many working days each year?--------------------days

10. How many trip each working day?------------------------trip

11. Can you classify your catch to species in kg each trip?

T.Nilotica	kg	Sea Bass	kg
T.Aurea	kg	Meagr	kg
T.Zillii	kg	Gilt head SeaBre	kg
T.Galilea	kg	Spotted Sea	kg
Grey Mullet	kg	Soles	kg
Mullet	kg	Catfish	kg
Mugil	kg	Nile Perch	kg
Shrimps	kg	Jackes	kg
Crabs	kg	Unclassified	kg
Eels	kg		

Table 1C Number of vessels using Stand nets in relation to number of *Nets* and number of *Fishermen* in 1995.

<u>*Fishermen*</u> *Nets*	1	2	3	4	5	6	7	8	9	10	11	12	Total
001-029	3	62	101	28	4	1							199
030-059			12	2	15	2	2						33
060-089					2	9	3	7					21
090-100									2	1		1	4
Total	3	62	113	30	21	12	5	7	2	1	0	1	257

Table 2C Number of vessels using Stand nets in relation to number of *Nets* and trip *Duration* in 1995.

<u>*Duration*</u> *Nets*	4-6	7-9	10-12	13-15	16-18	19-21	Total
001-029	53	51	83	12			199
030-059			17	16			33
060-089				18	3		21
090-100					2	2	4
Total	53	51	100	46	5	2	257

Table 3C Number of vessels using Stand nets in relation to number of *Nets* and number of *Mesh* per 100 cm length of nets in 1995.

<u>*Mesh*</u> *Nets*	25-34	35-44	45-54	55-64	65-74	75-84	85-94	Total
001-029		55	54	61	27	1	1	199
030-059	4	18	11					33
060-089	6	15						21
090-100	4							4
Total	14	88	65	61	27	1	1	257

Table 4C Number of vessels using Hook lines in relation to number of Hooks in hundred and number of *Fishermen* in 1995.

Fishermen / *Hooks 100s*	1	2	3	4	5	6	7	8	9	Total
010-050	12	12	10							34
051-100			17		3					20
101-150			8		1	1				10
151-200							1			1
201-250							1		1	2
Total	12	12	35	0	4	1	2	0	1	67

Table 5C Number of vessels using Hook lines in relation to number of Hooks in hundred and trip *Duration* in 1995.

Duration / *Hooks 100s*	4-6	7-9	10-12	13-15	16-18	19-21	22-24	Total
010-050	3	10	13	8				34
051-100				14	3	2	1	20
101-150					3	6	1	10
151-200							1	1
201-250							2	2
Total	3	10	13	22	6	8	5	67

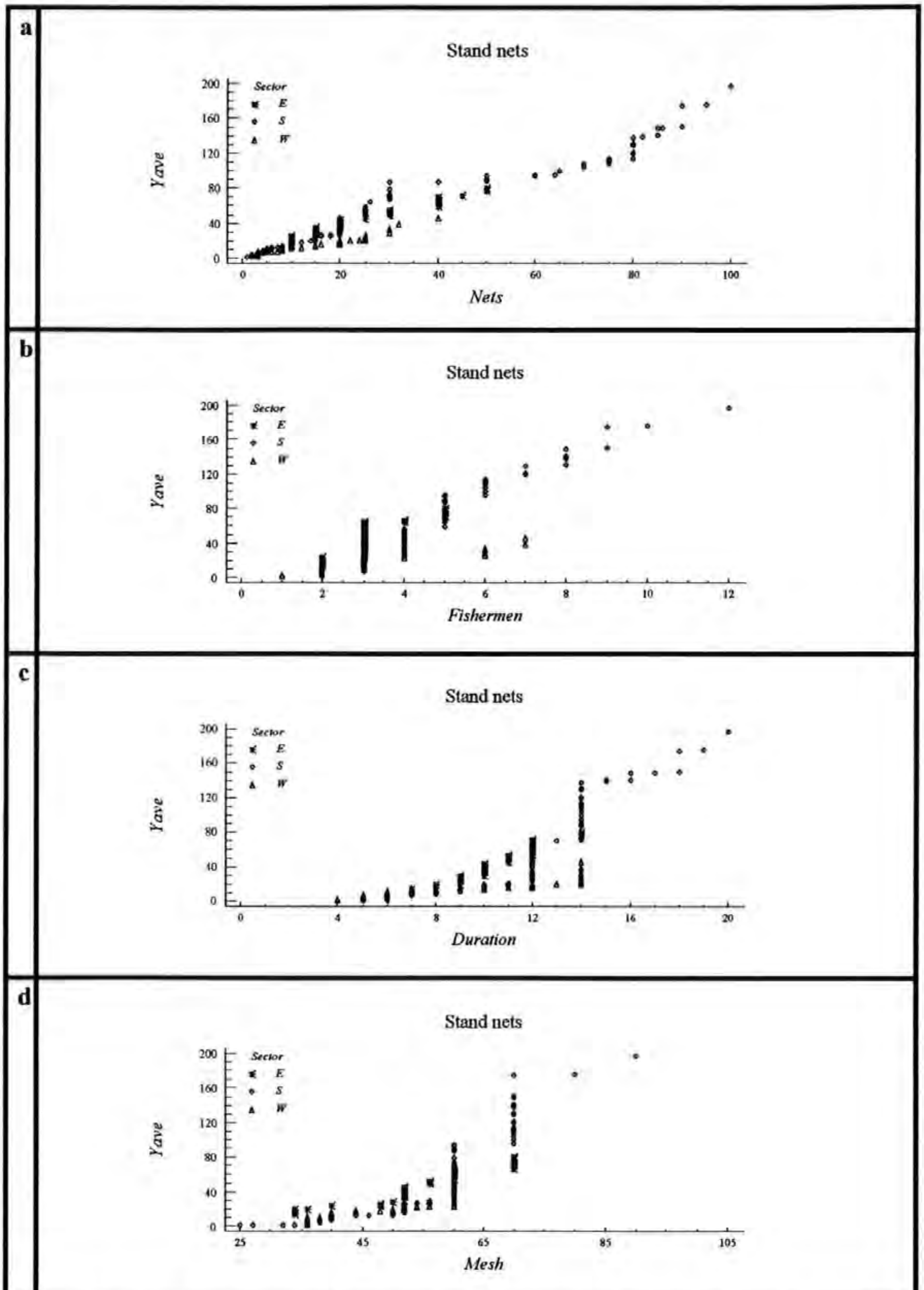
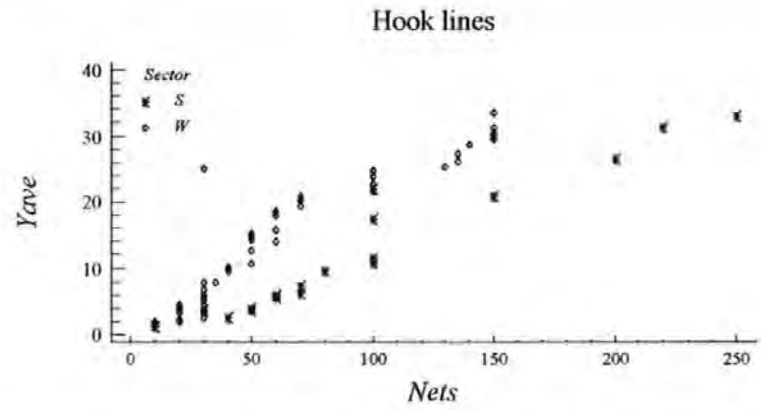
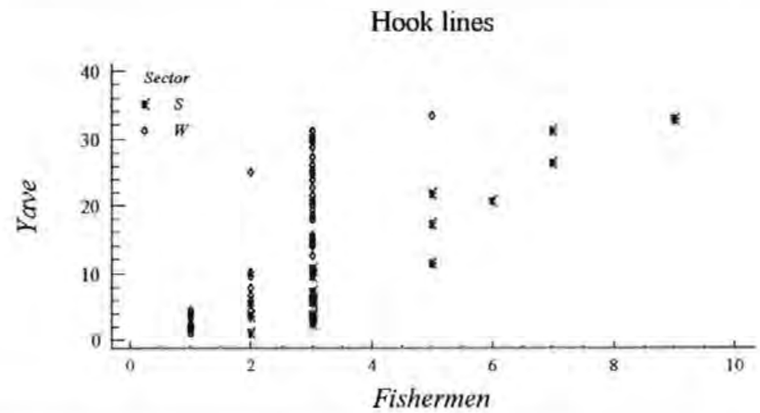


Figure 1C Plot of *Yave* vs. (a) *Nets*, (b) *Fishermen*, (c) *Duration* and (d) *Mesh* for Stand nets.

a



b



c

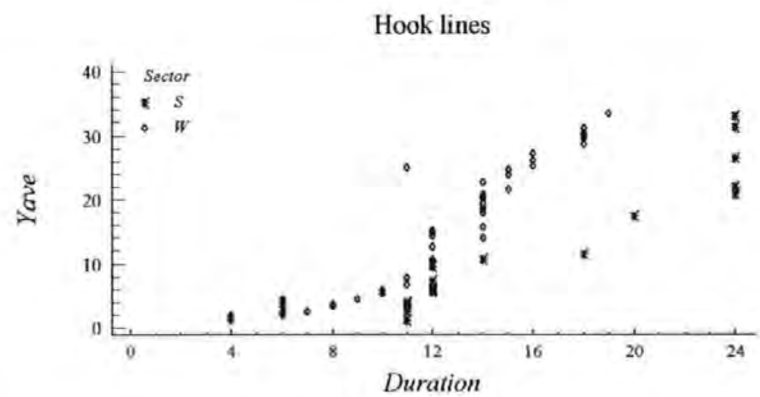


Figure 2C Plot of *Yave* vs. (a) *Nets*, (b) *Fishermen* and (c) *Duration* for Hook lines.

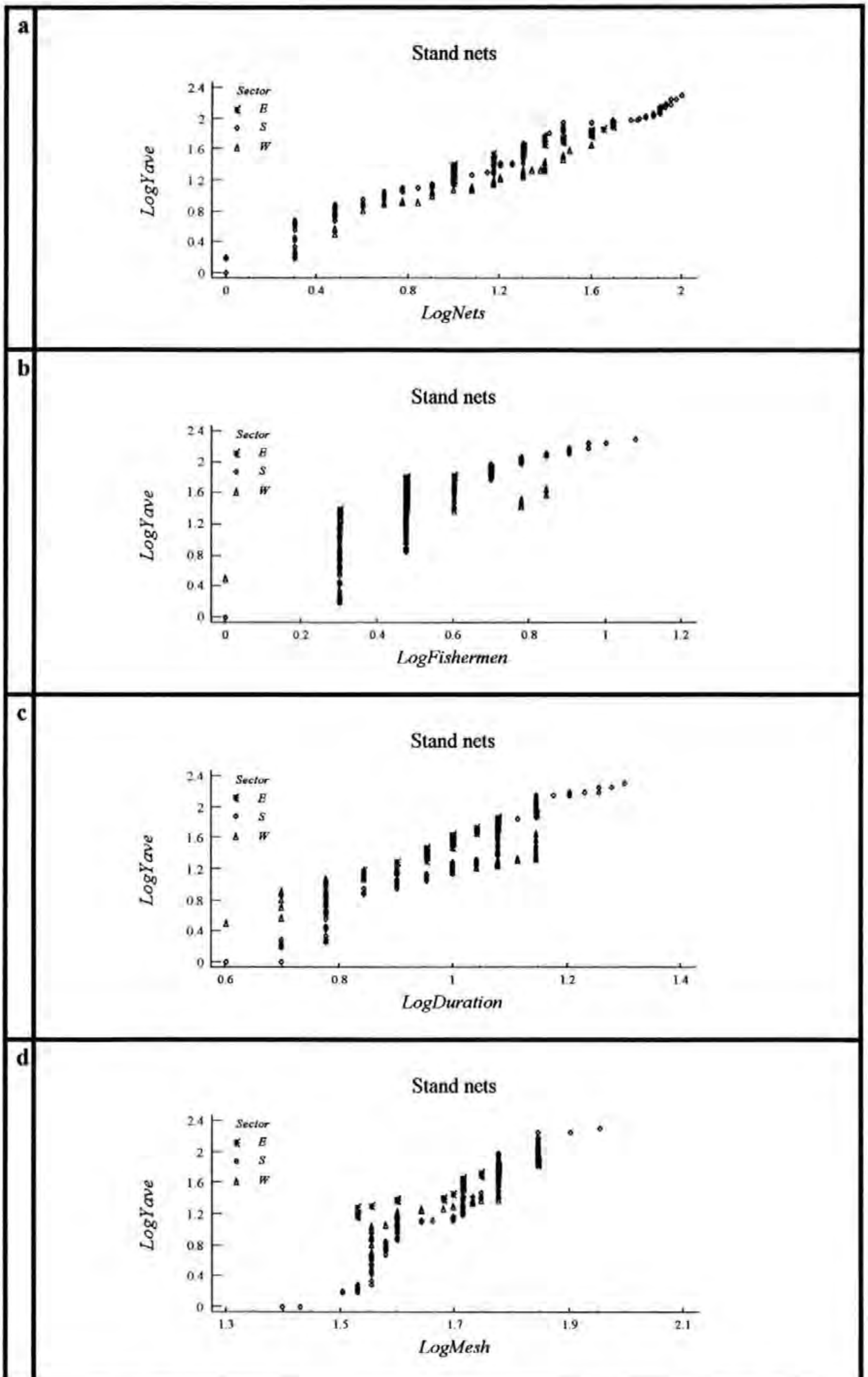
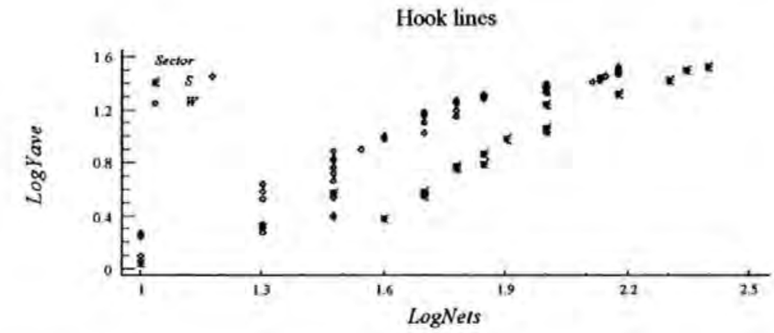
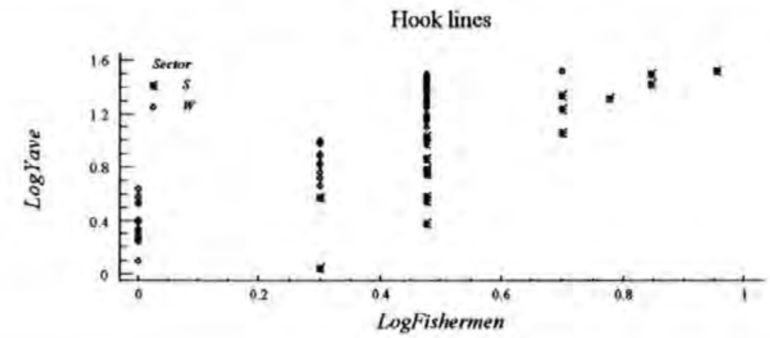


Figure 3C Plot of *LogYave* vs. (a) *LogNets*, (b) *LogFishermen*, (c) *LogDuration* and (d) *LogMesh* for Stand nets.

a



b



c

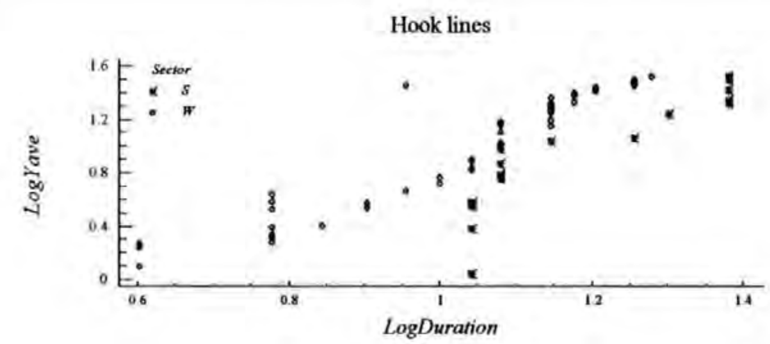


Figure 4C Plot of *LogYave* vs. (a) *LogNets*, (b) *LogFishermen* and (c) *LogDuration* for Hook lines.

Appendix D

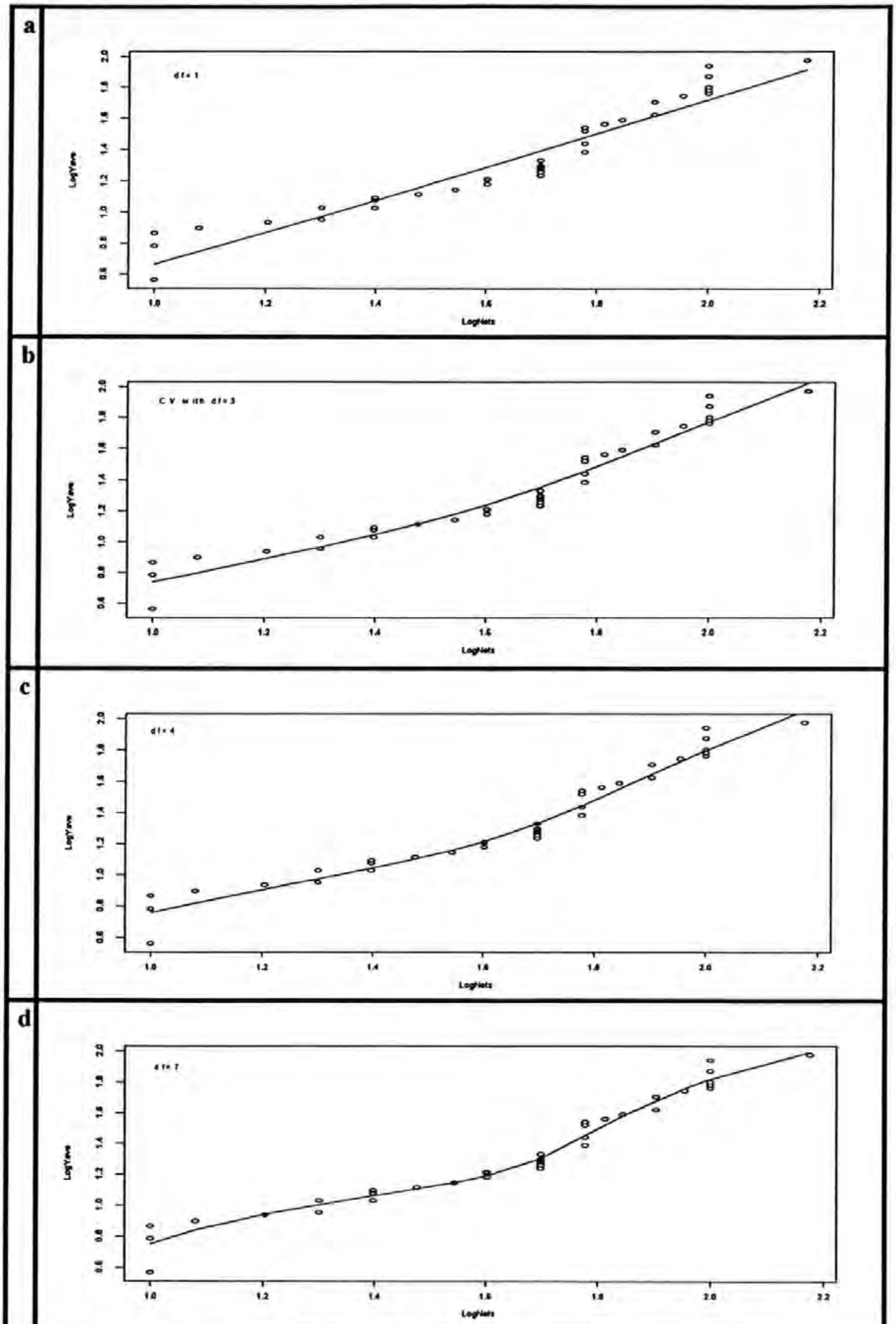


Figure 1D Smoothing spline smoother of *LogYave* vs. *LogNets* for Trap nets in Western Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

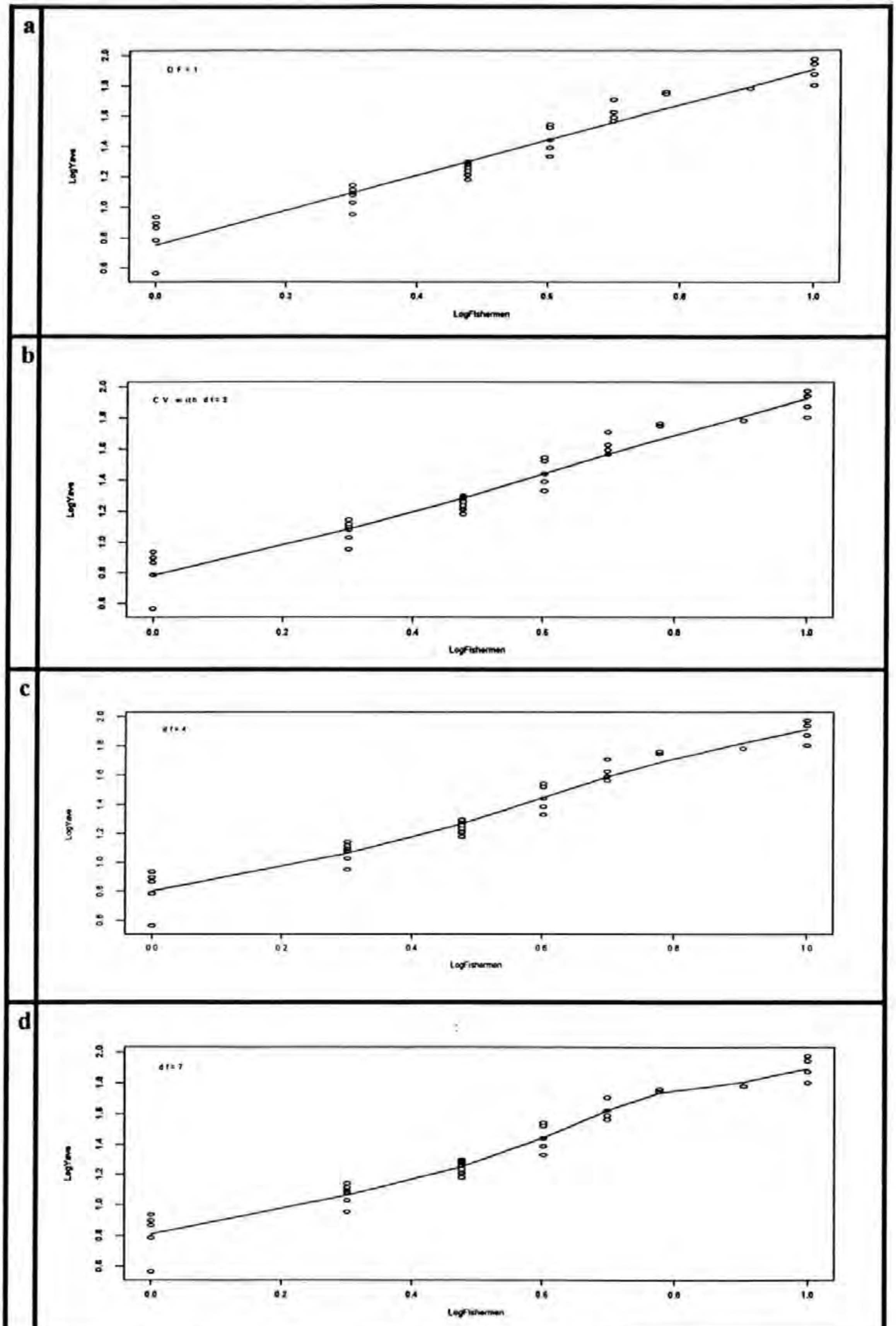


Figure 2D Smoothing spline smoother of *LogYave* vs. *LogFishermen* for Trap nets in Western Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

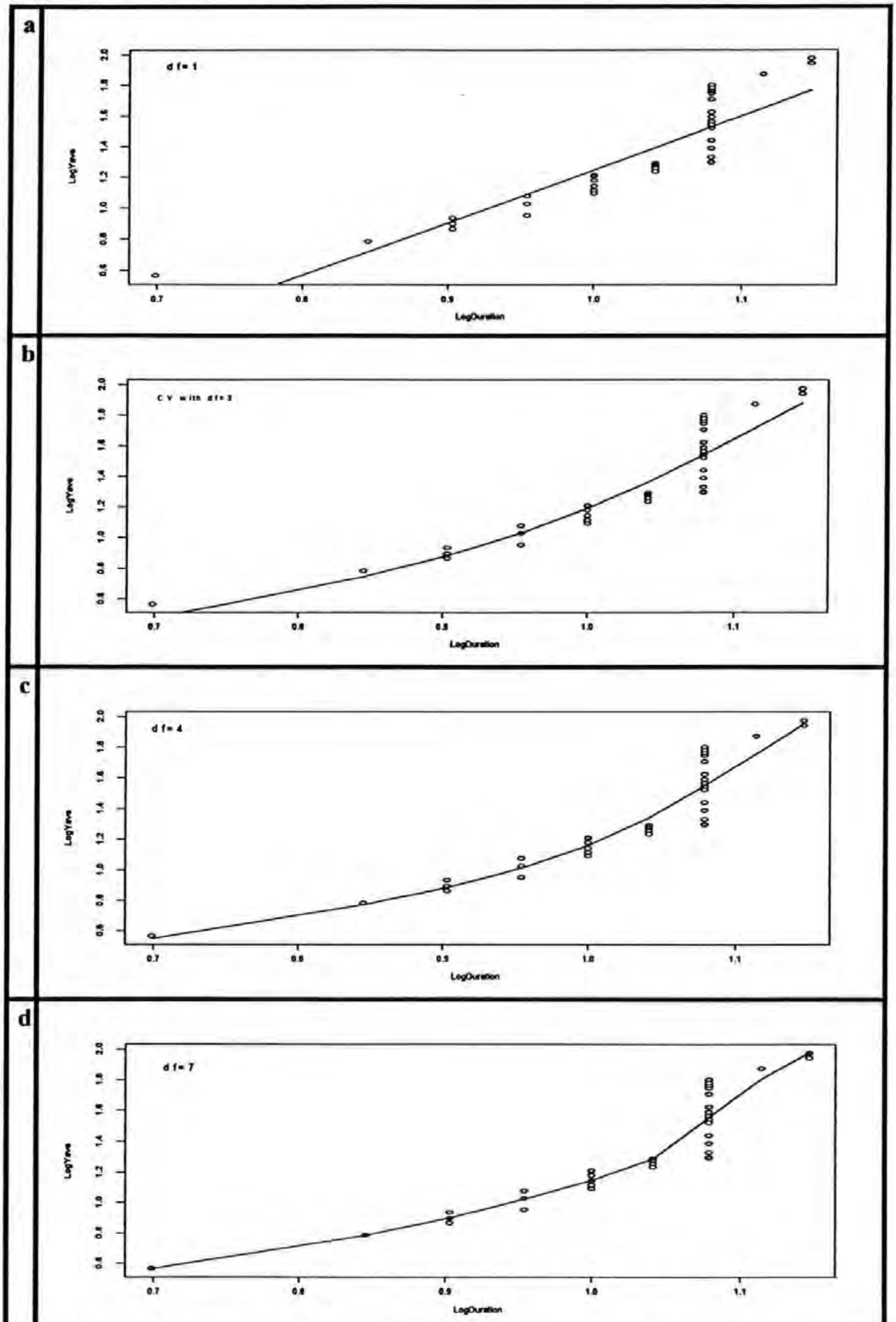


Figure 3D Smoothing spline smoother of *LogYave* vs. *LogDuration* for Trap nets in Western Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

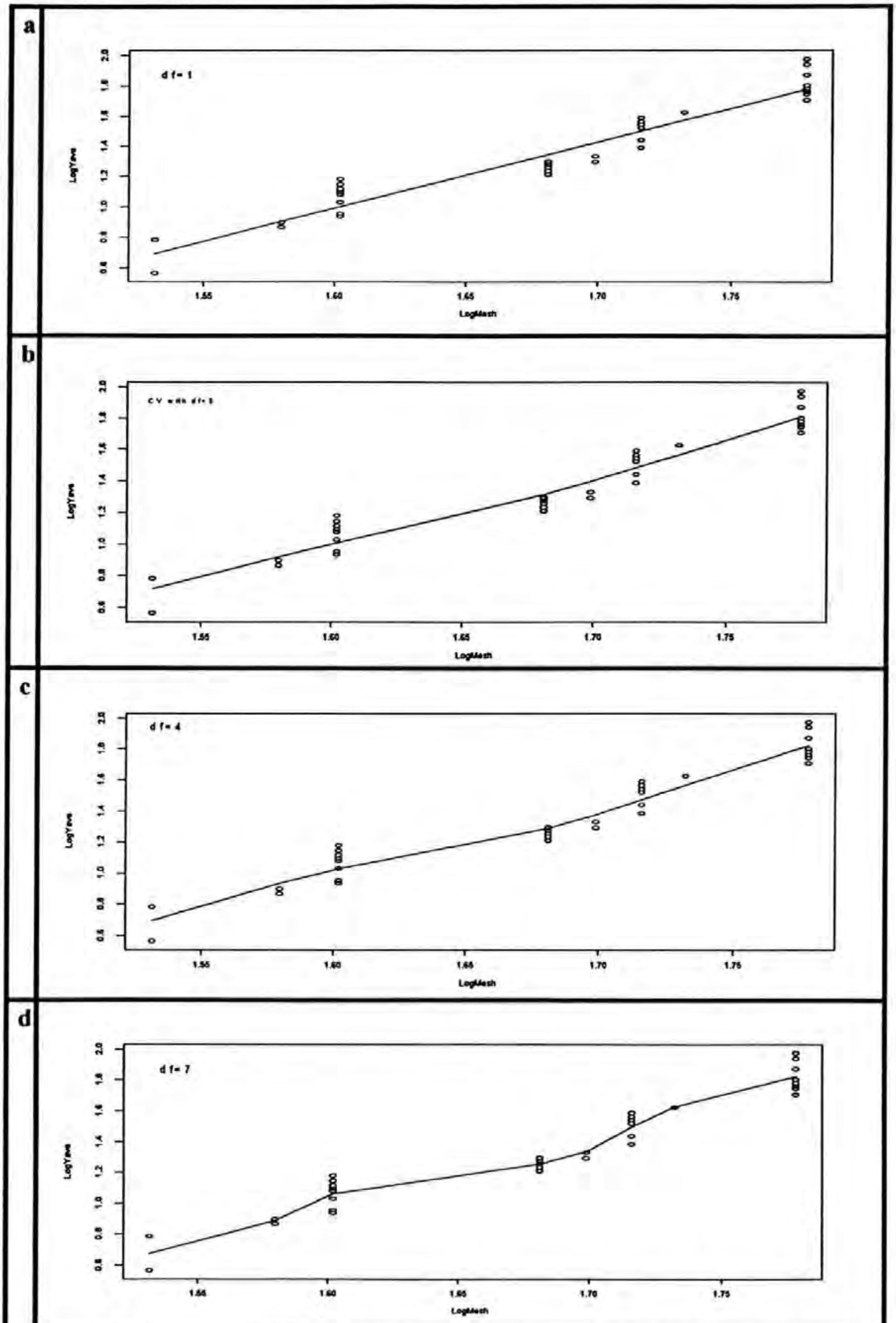


Figure 4D Smoothing spline smoother of *LogYave* vs. *LogMesh* for Trap nets in Western Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

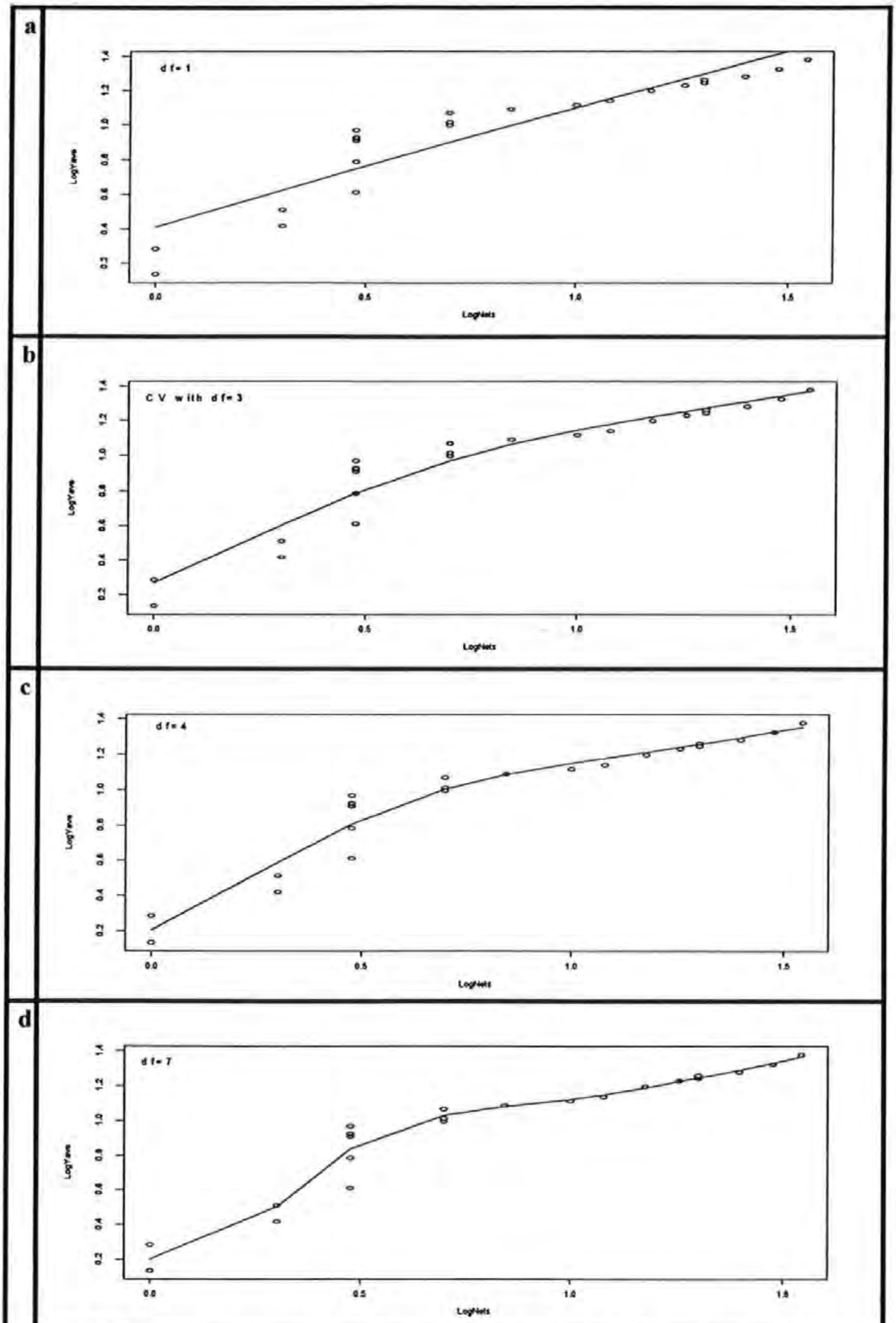


Figure 5D Smoothing spline smoother of *LogYave* vs. *LogNets* for Trap nets in Eastern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

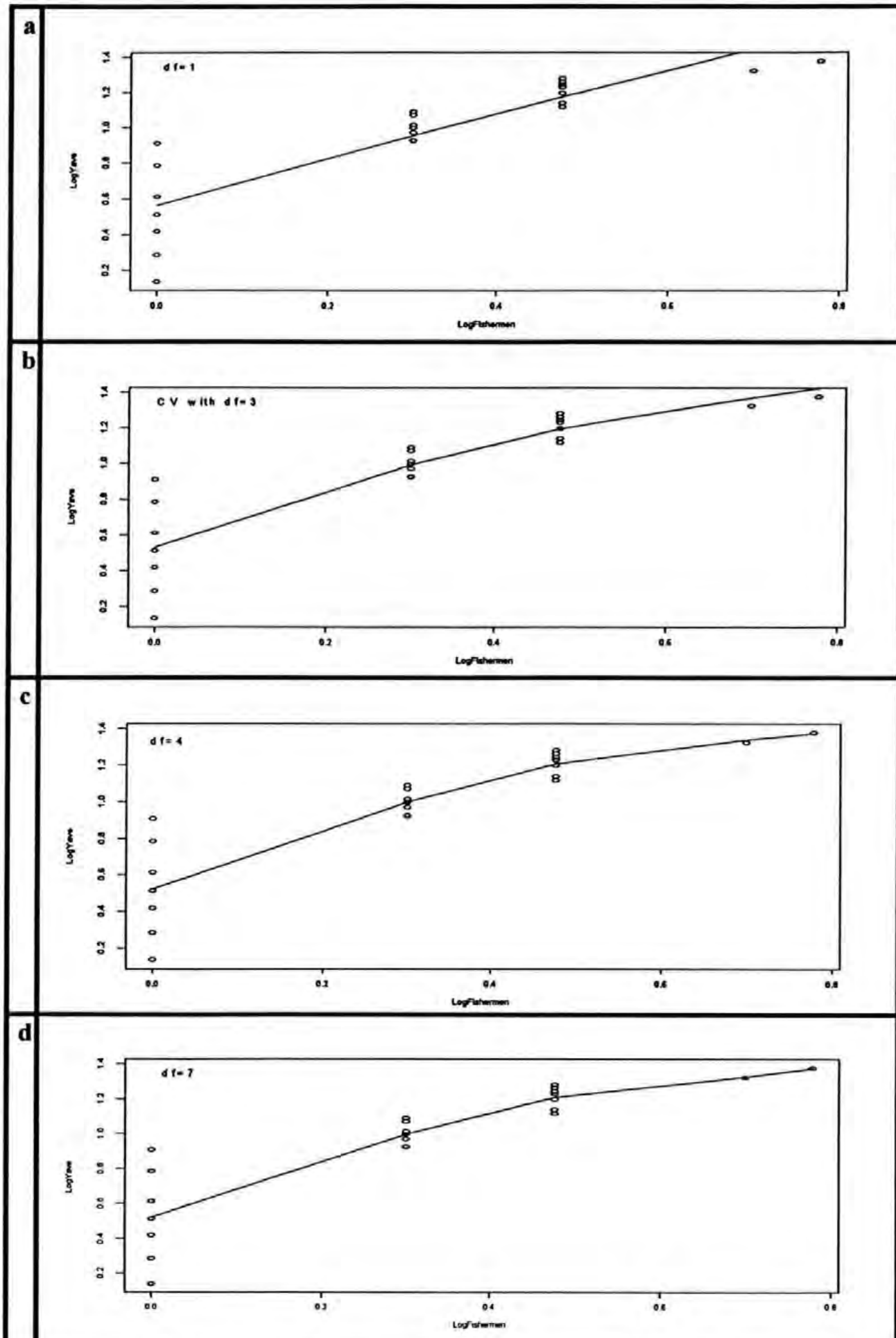


Figure 6D Smoothing spline smoother of *LogYave* vs. *LogFishermen* for Trap nets in Eastern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

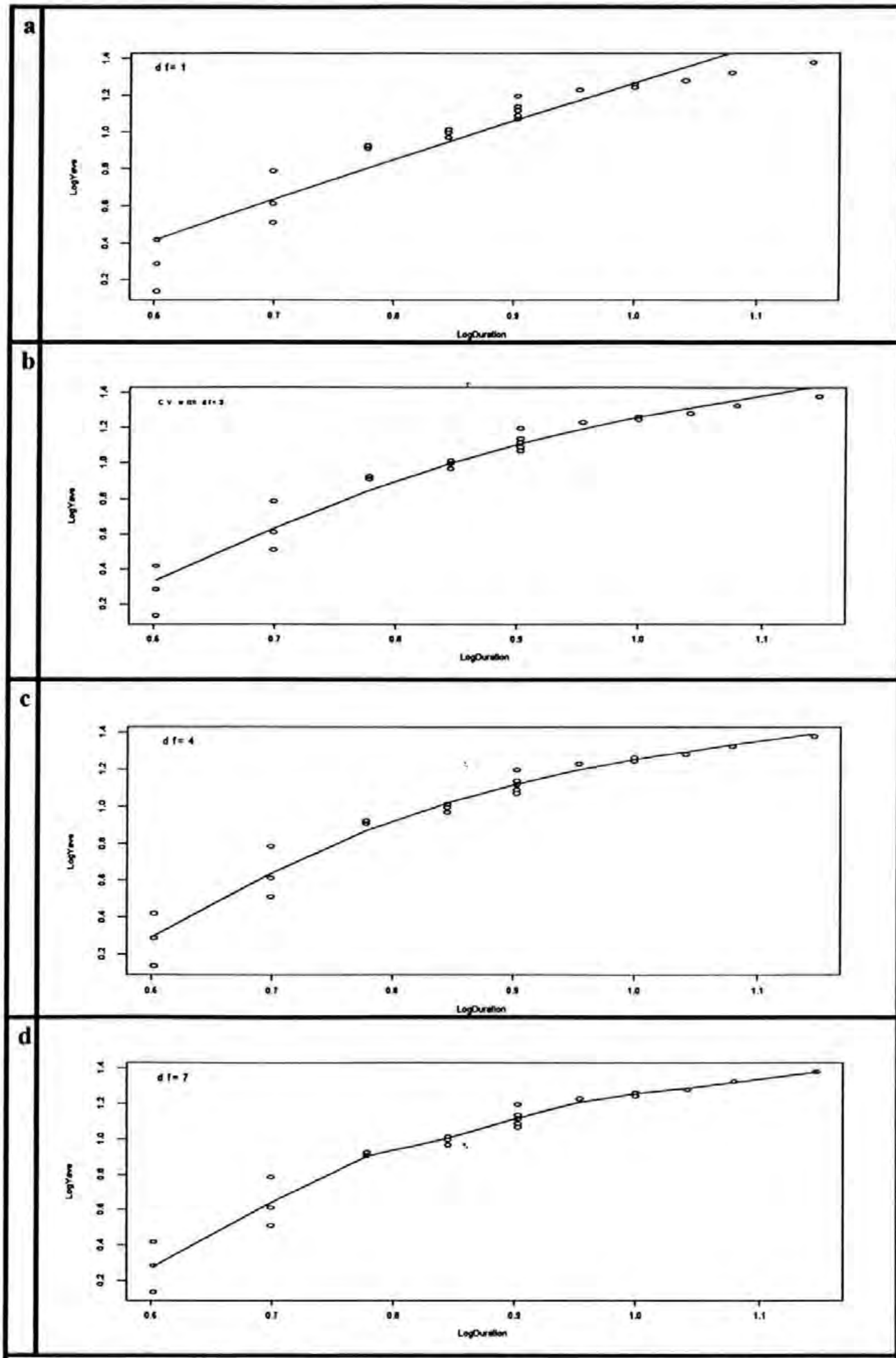


Figure 7D Smoothing spline smoother of *LogYave* vs. *LogDuration* for Trap nets in Eastern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

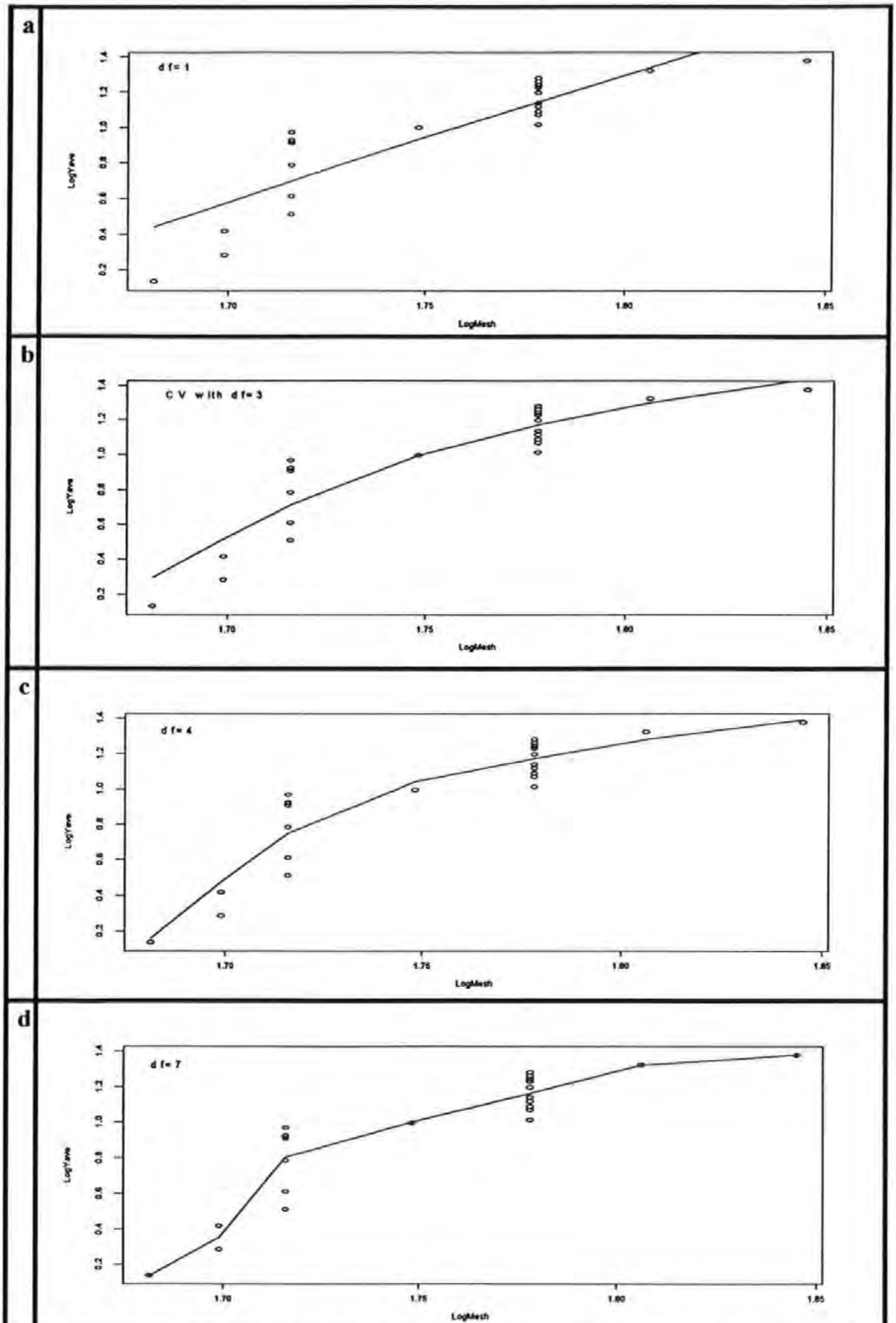


Figure 8D Smoothing spline smoother of *LogYave* vs. *LogMesh* for Trap nets in Eastern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

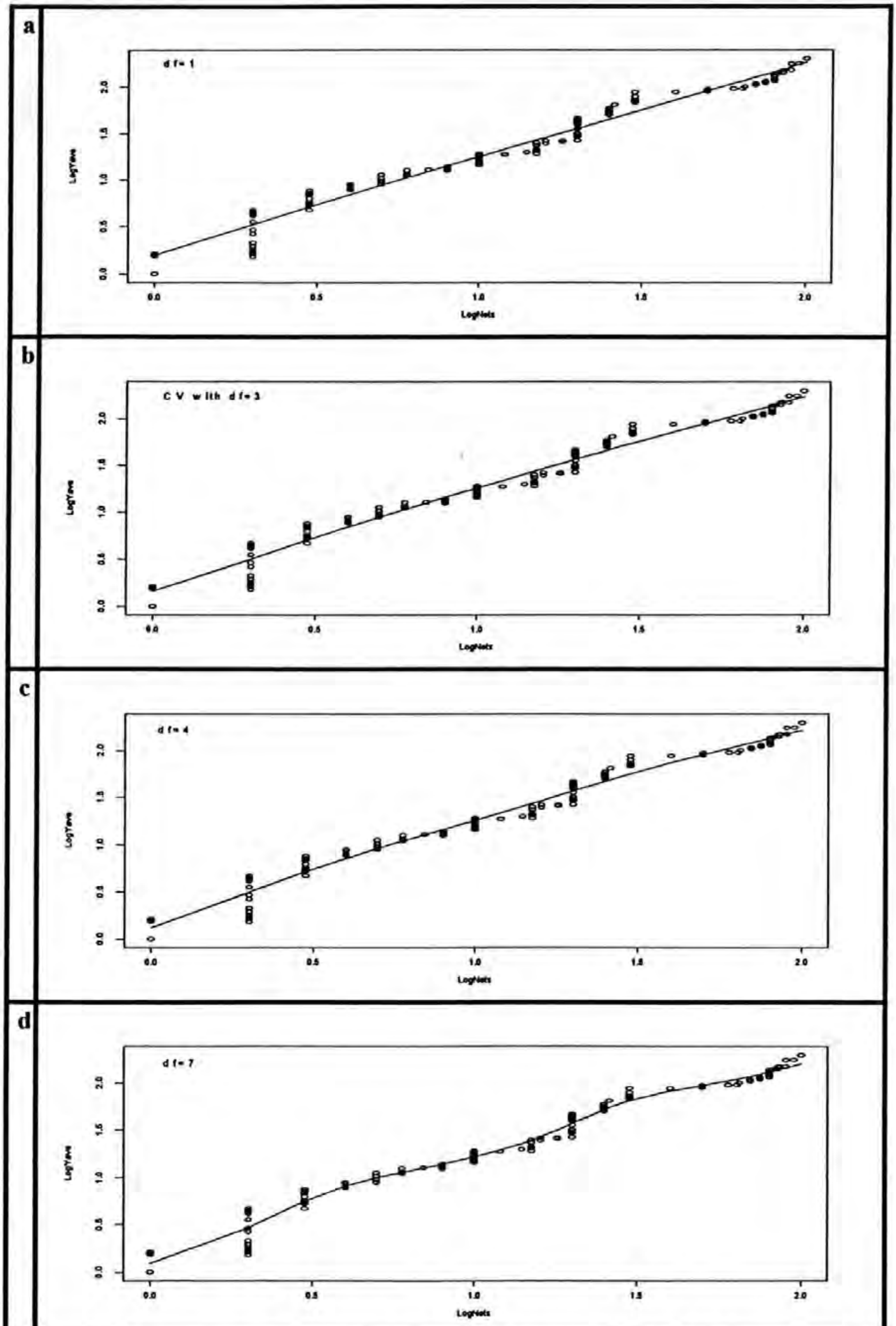


Figure 9D Smoothing spline smoother of *LogYave* vs. *LogNets* for Stand nets in Southern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

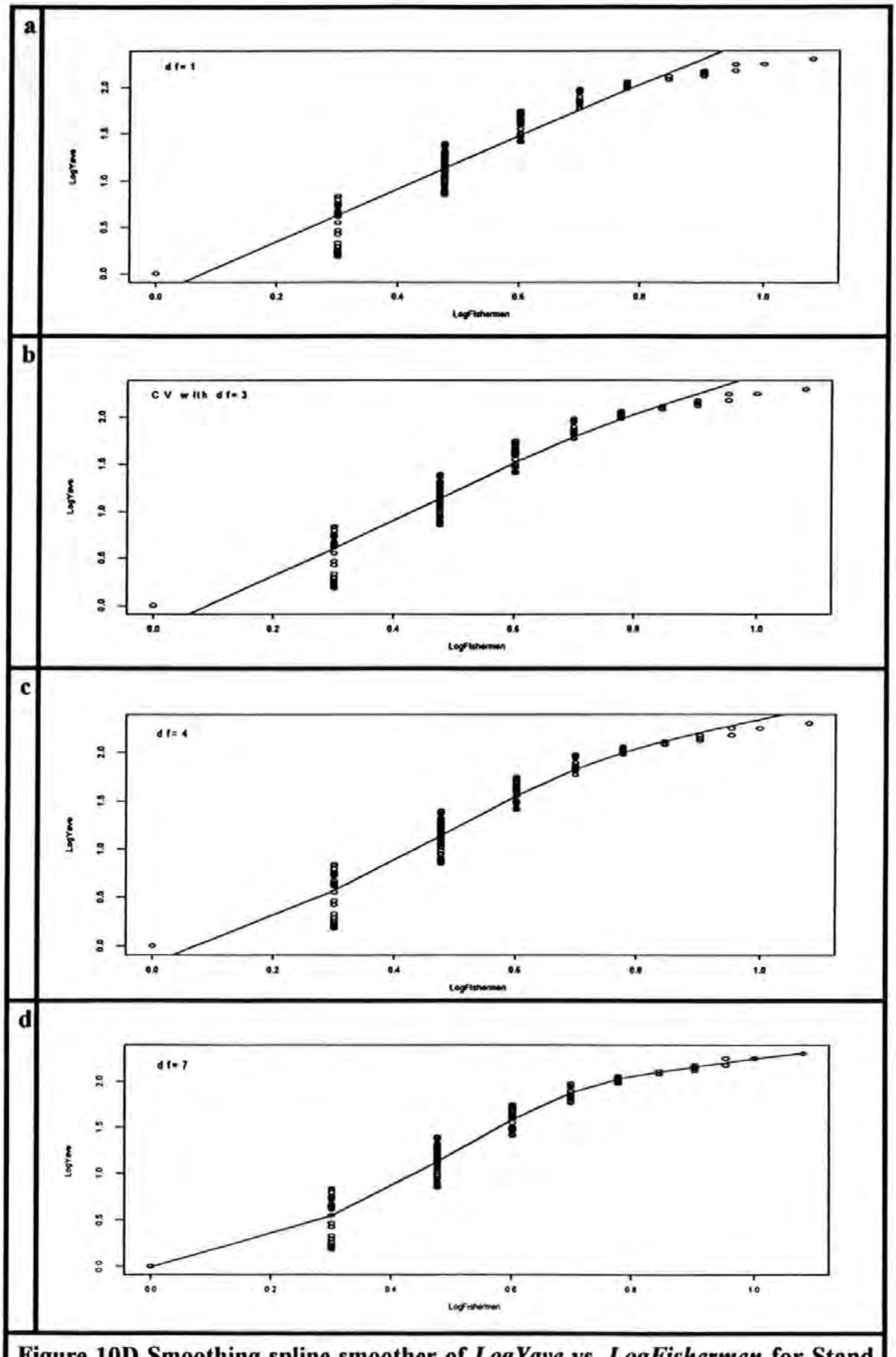


Figure 10D Smoothing spline smoother of *LogYave* vs. *LogFishermen* for Stand nets in Southern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

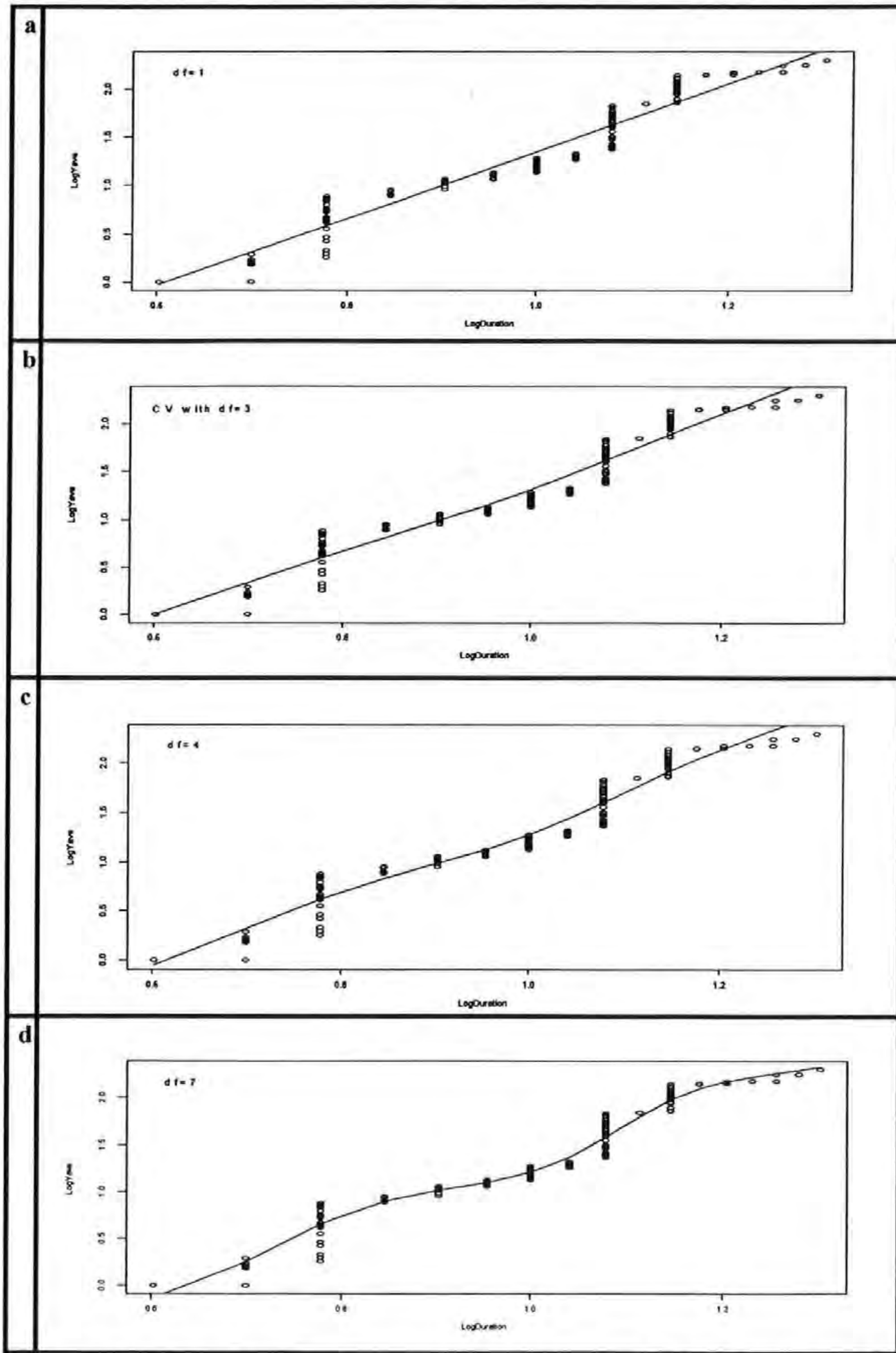


Figure 11D Smoothing spline smoother of *LogYave* vs. *LogDuration* for Stand nets in Southern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

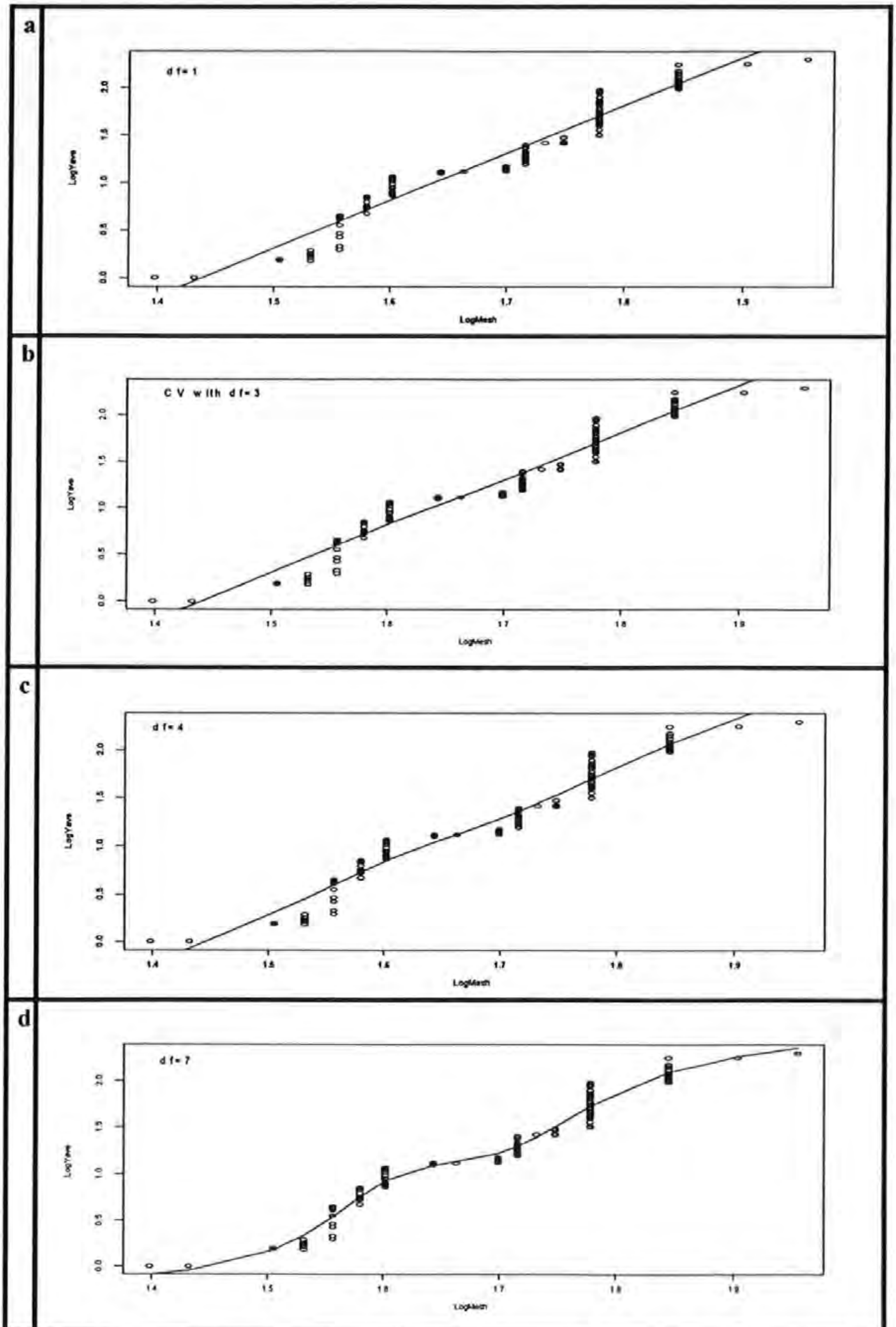


Figure 12D Smoothing spline smoother of *LogYave* vs. *LogMesh* for Stand nets in Southern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

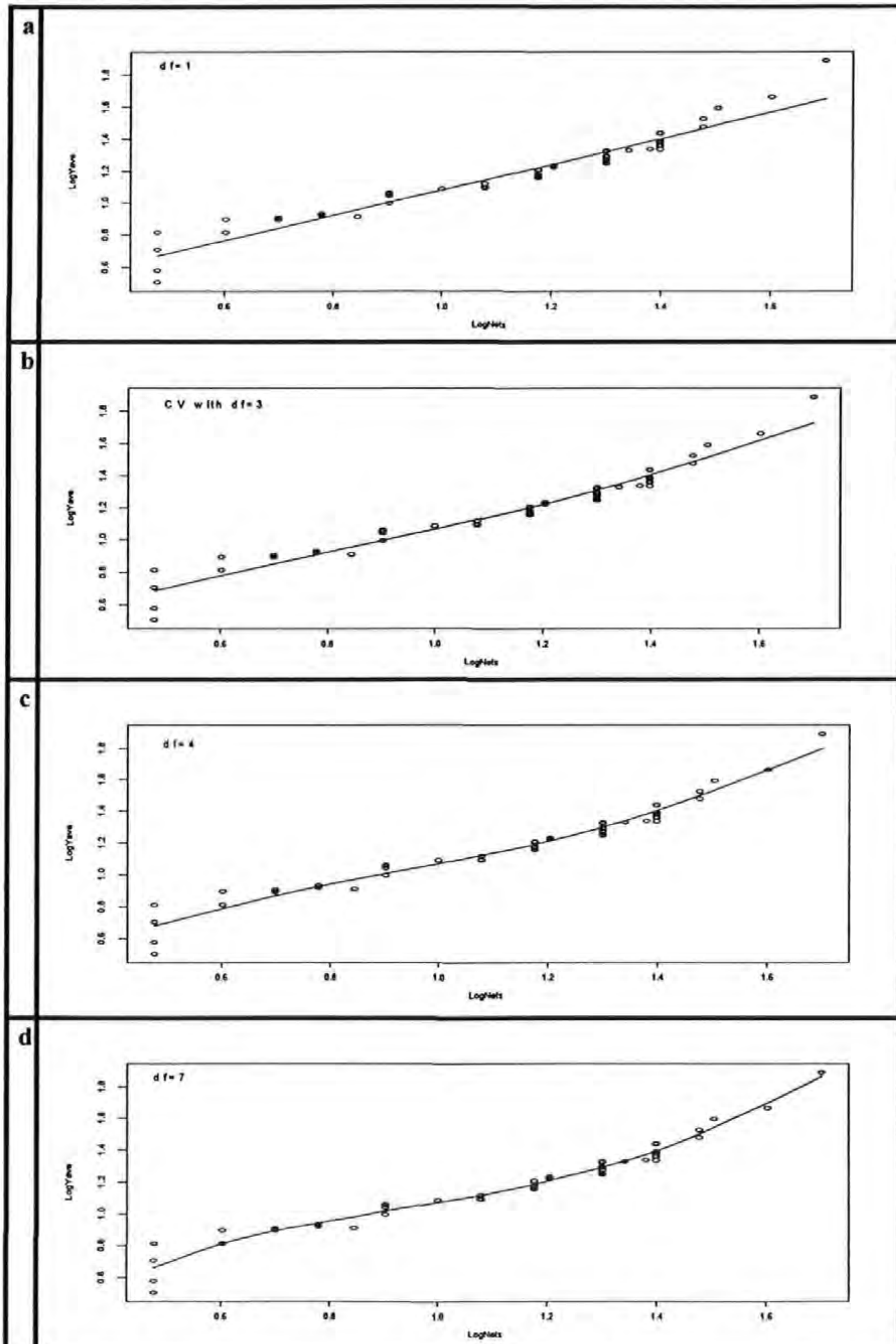


Figure 13D Smoothing spline smoother of *LogYave* vs. *LogNets* for Stand nets in Western Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

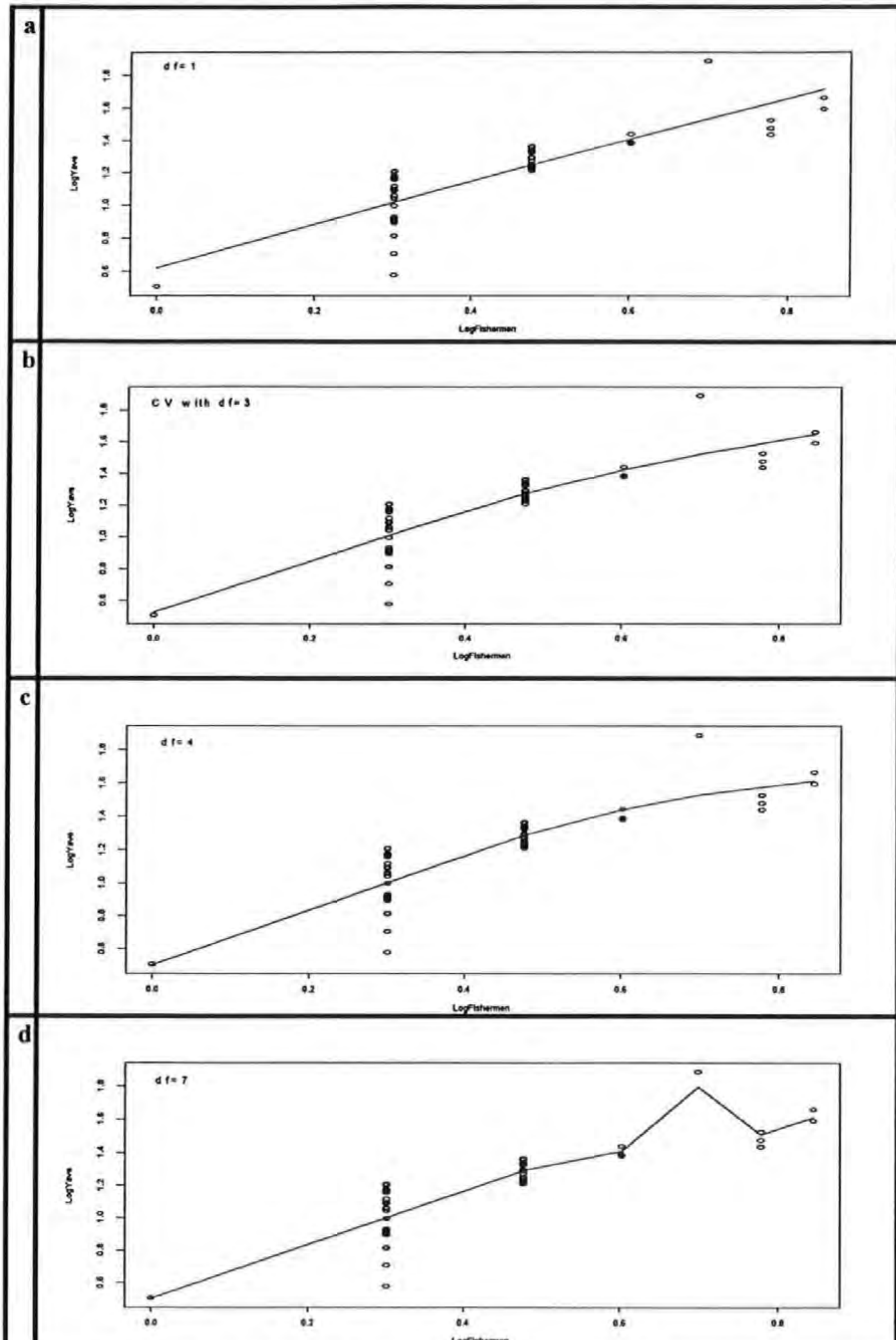


Figure 14D Smoothing spline smoother of *LogYave* vs. *LogFishermen* for Stand nets in Western Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

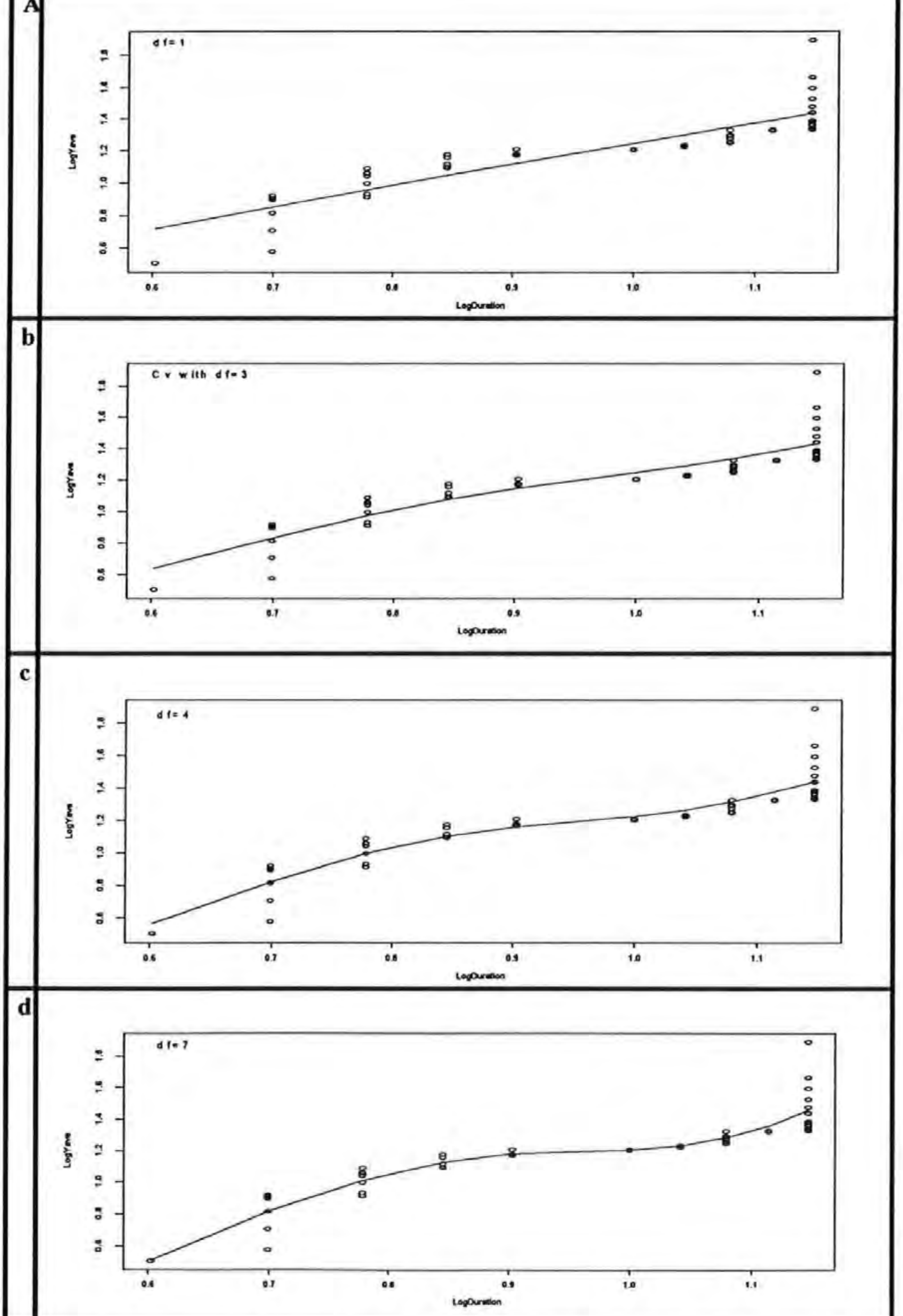


Figure 15D Smoothing spline smoother of *LogYave* vs. *LogDuration* for Stand nets in Western Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

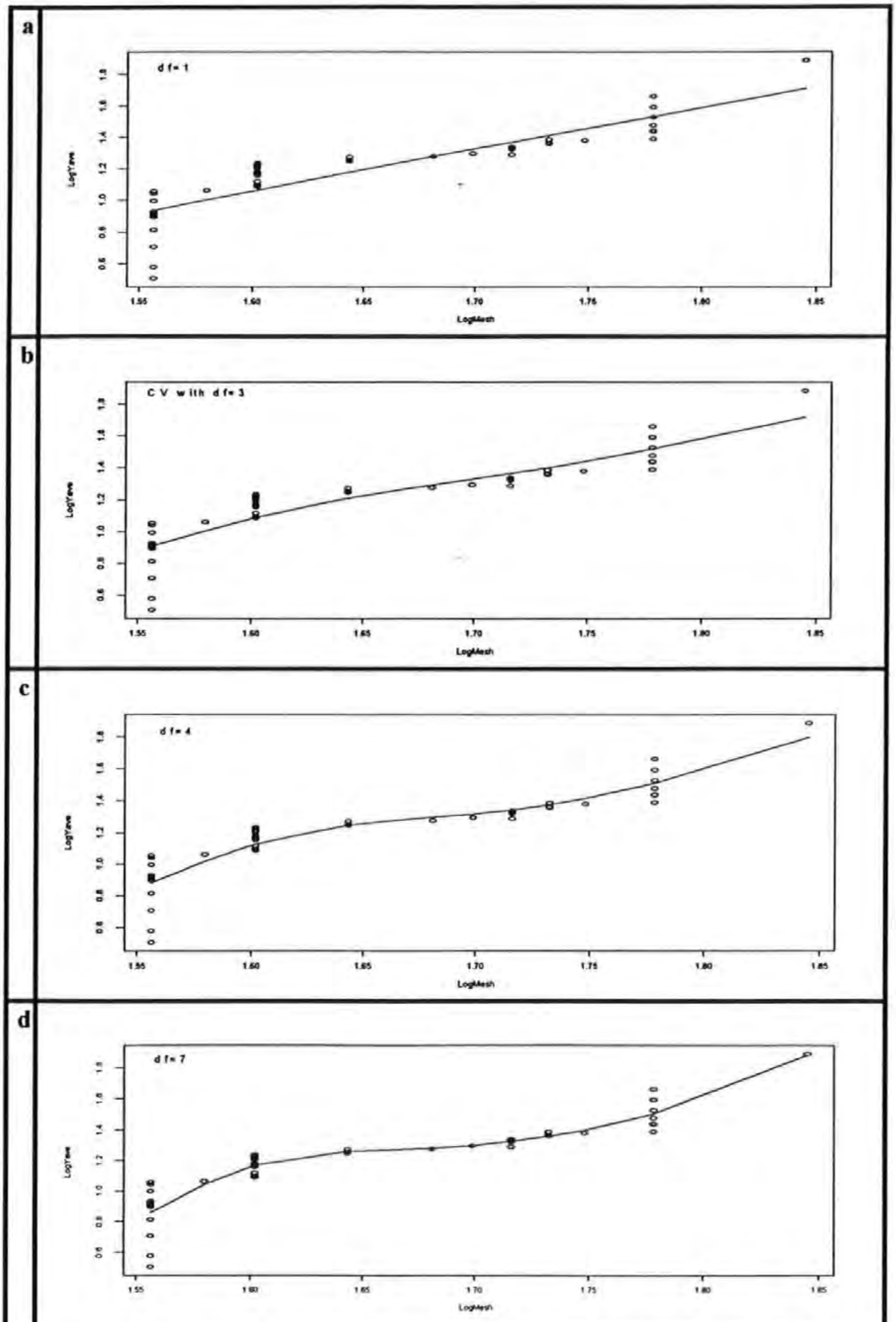


Figure 16D Smoothing spline smoother of *LogYave* vs. *LogMesh* for Stand nets in Western Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

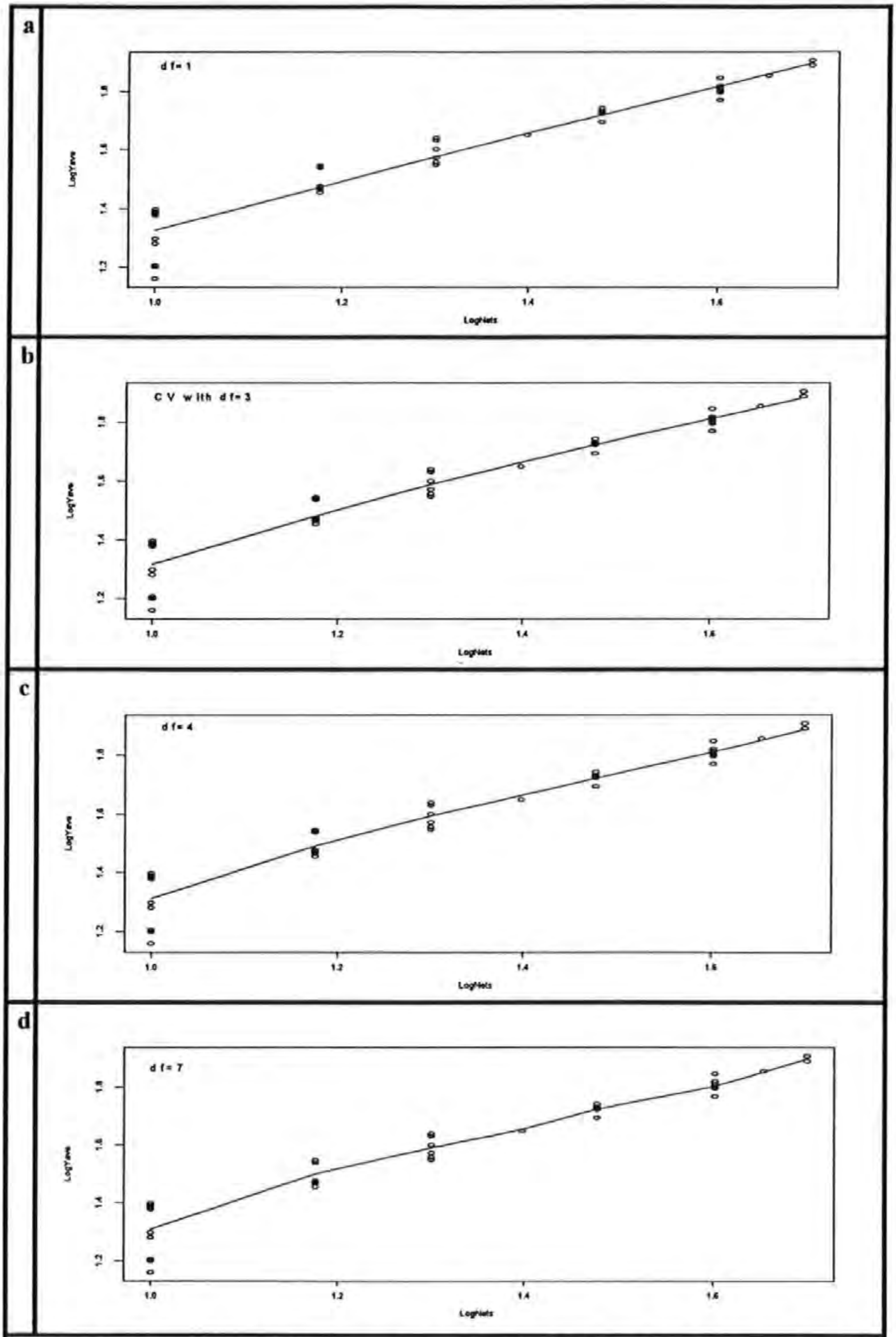


Figure 17D Smoothing spline smoother of *LogYave* vs. *LogNets* for Stand nets in Eastern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

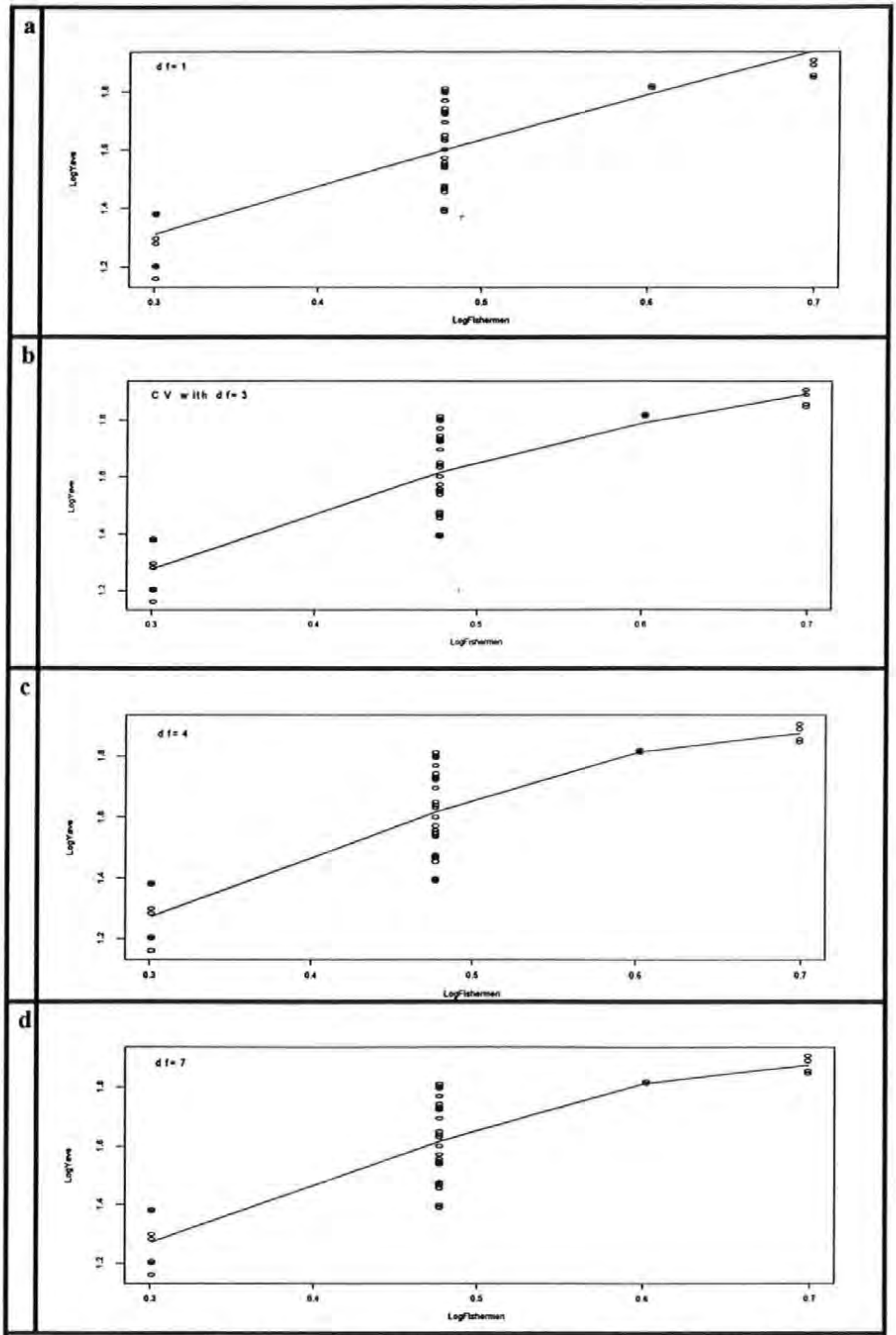


Figure 18D Smoothing spline smoother of *LogYave* vs. *LogFishermen* for Stand nets in Eastern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

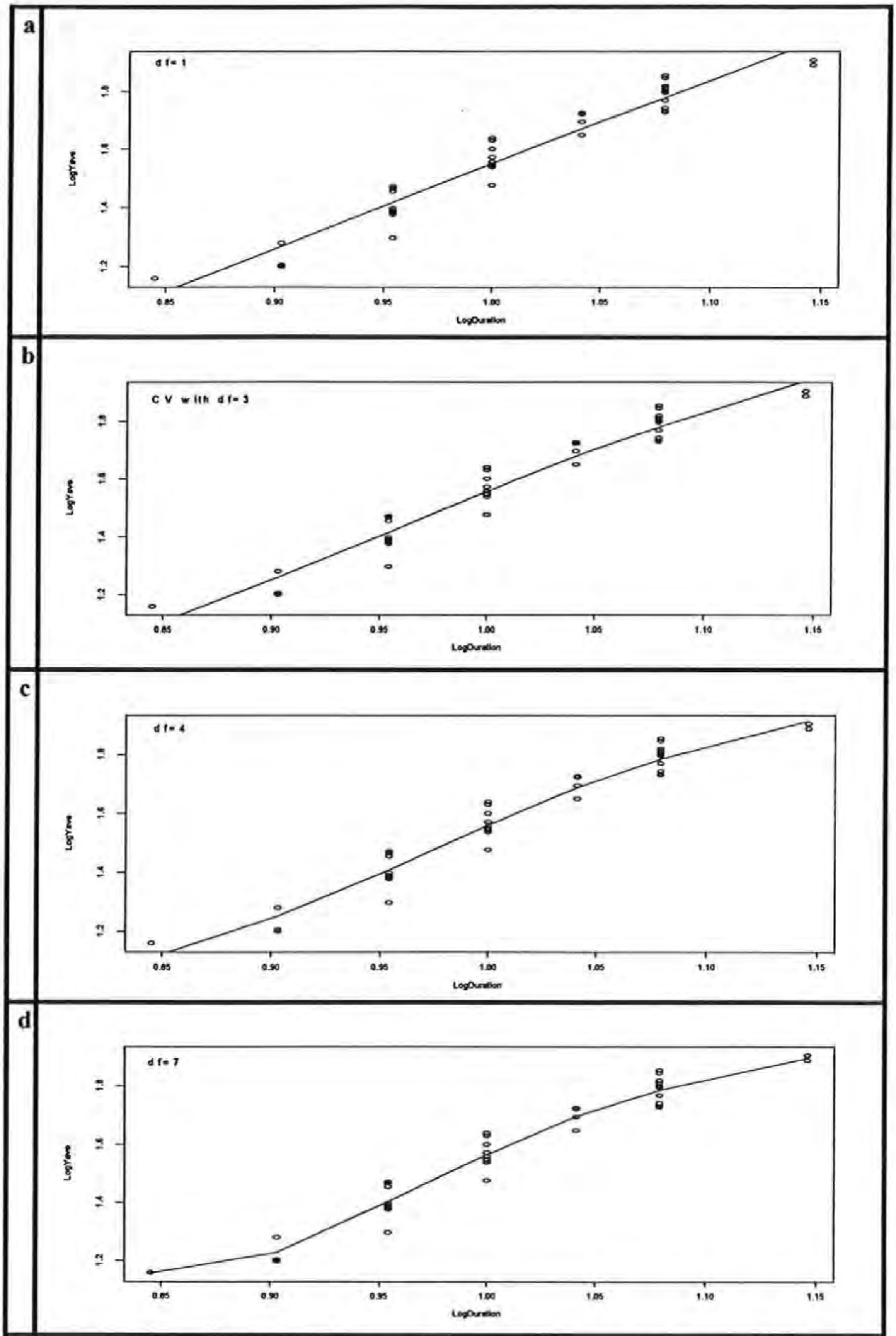


Figure 19D Smoothing spline smoother of *LogYave* vs. *LogDuration* for Stand nets in Eastern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

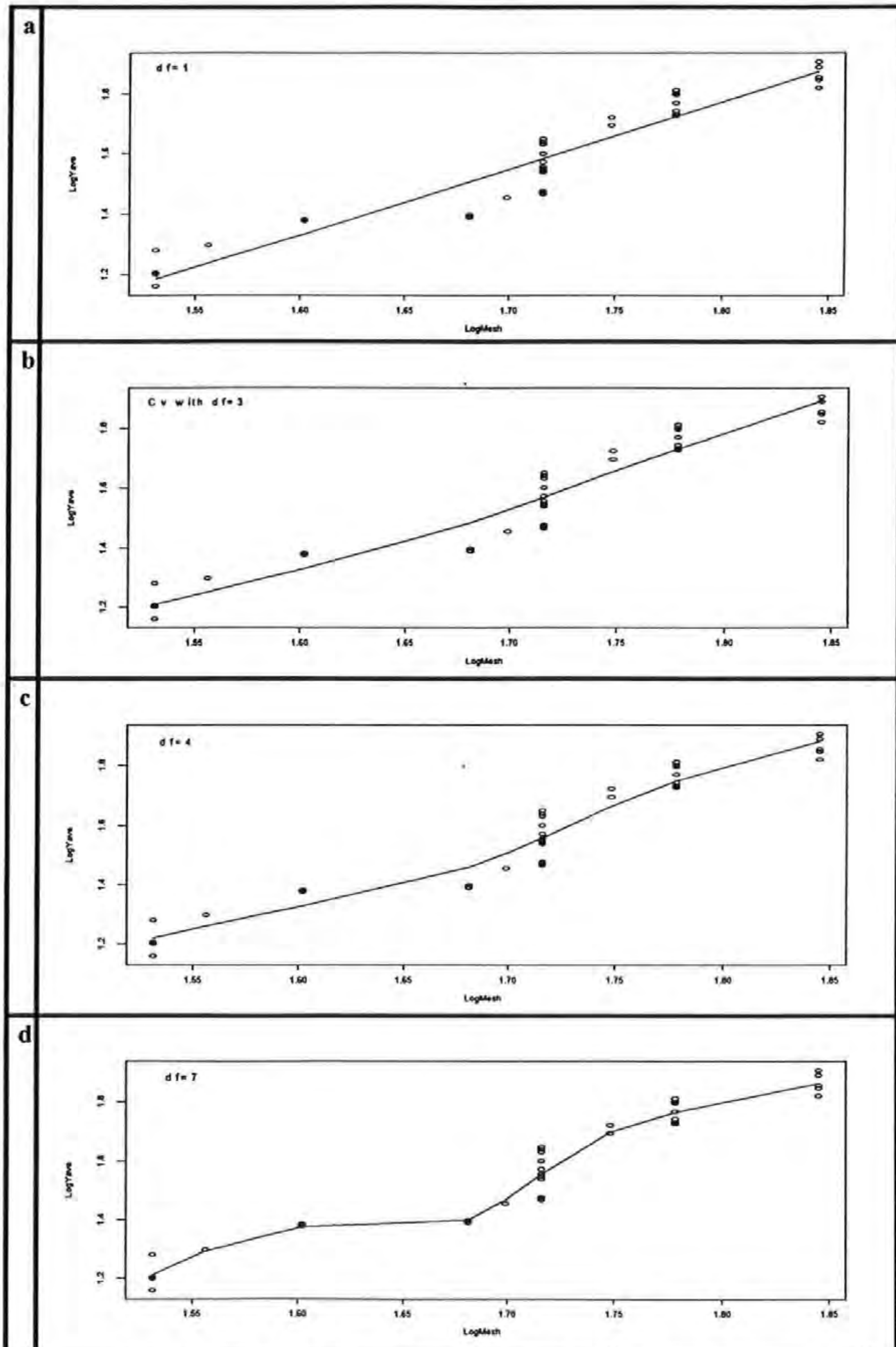


Figure 20D Smoothing spline smoother of *LogYave* vs. *LogMesh* for Stand nets in Eastern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

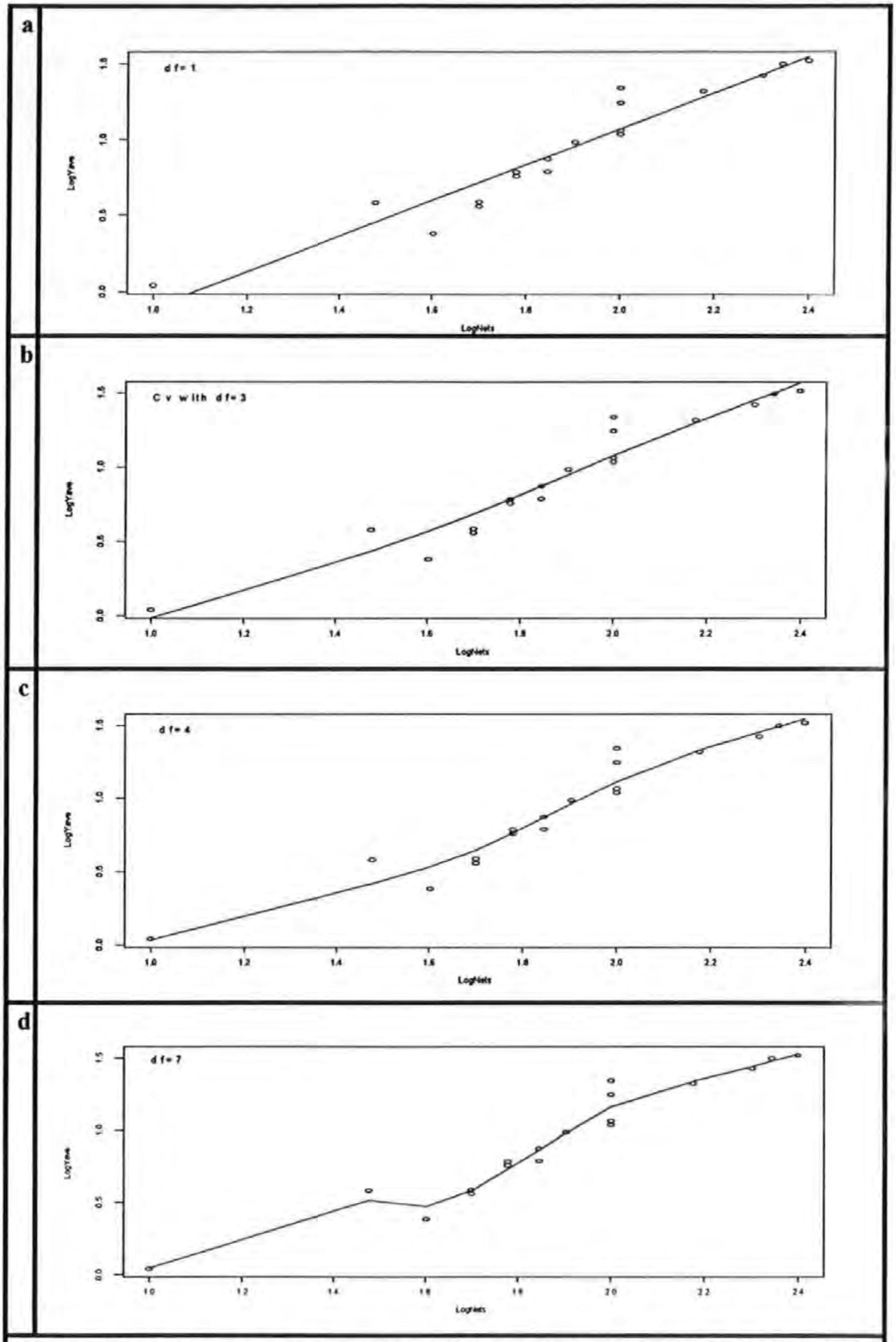


Figure 21D Smoothing spline smoother of *LogYave* vs. *LogNets* for Hook lines in Southern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

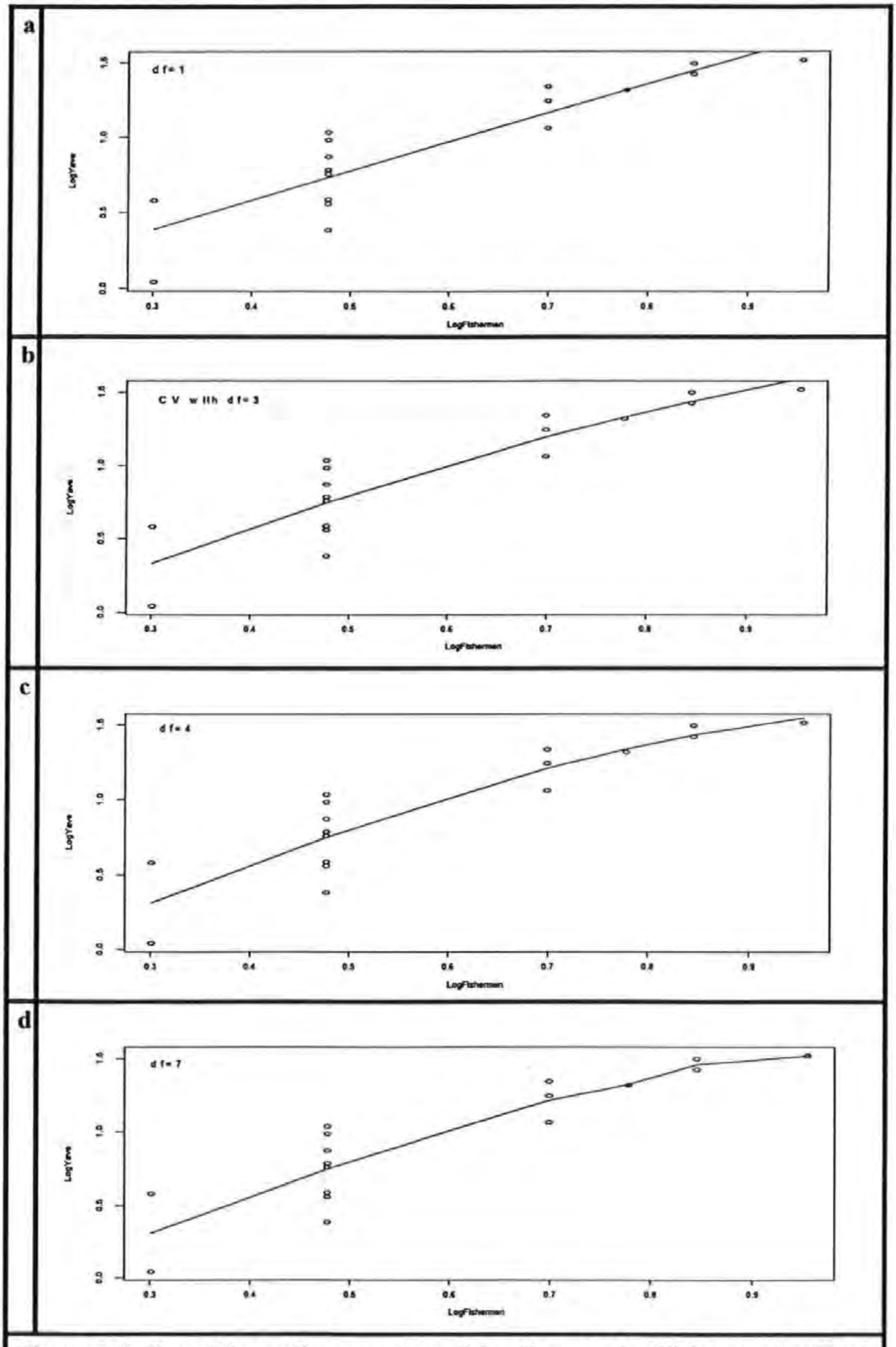


Figure 22D Smoothing spline smoother of *LogYave* vs. *LogFishermen* for Hook lines in Southern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

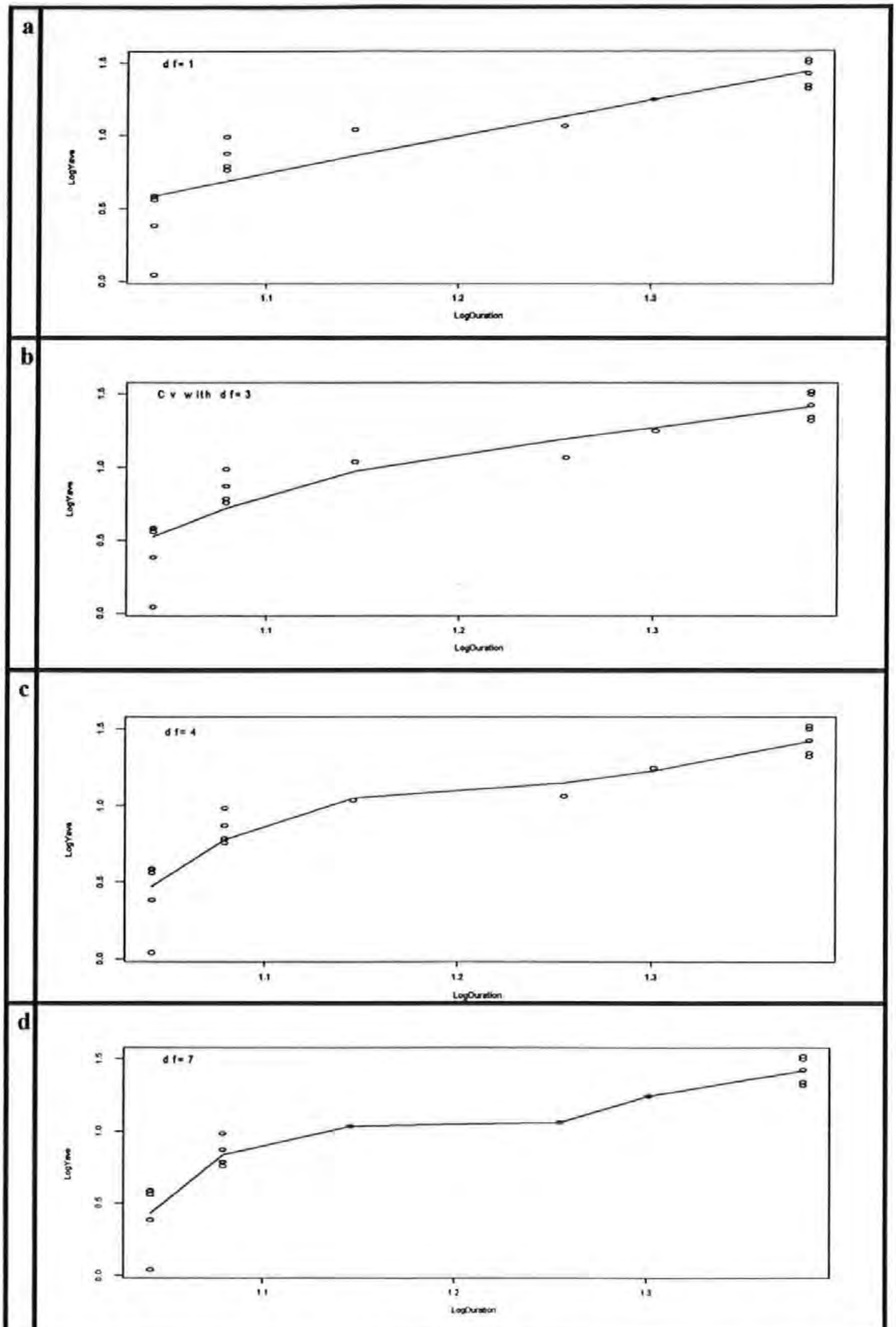


Figure 23D Smoothing spline smoother of *LogYave* vs. *LogDuration* for Hook lines in Southern Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

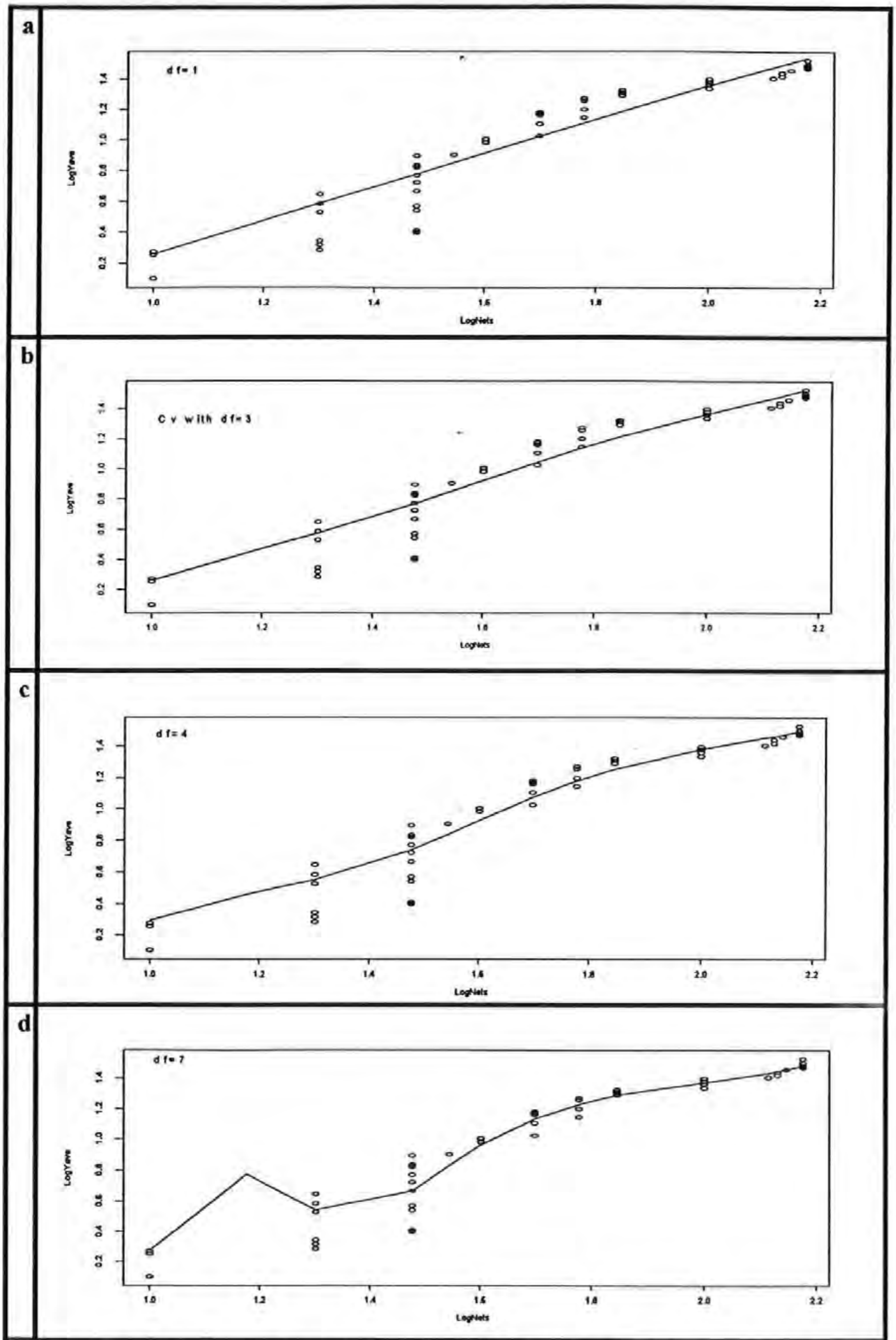


Figure 24D Smoothing spline smoother of *LogYave* vs. *LogNets* for Hook lines in Western Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

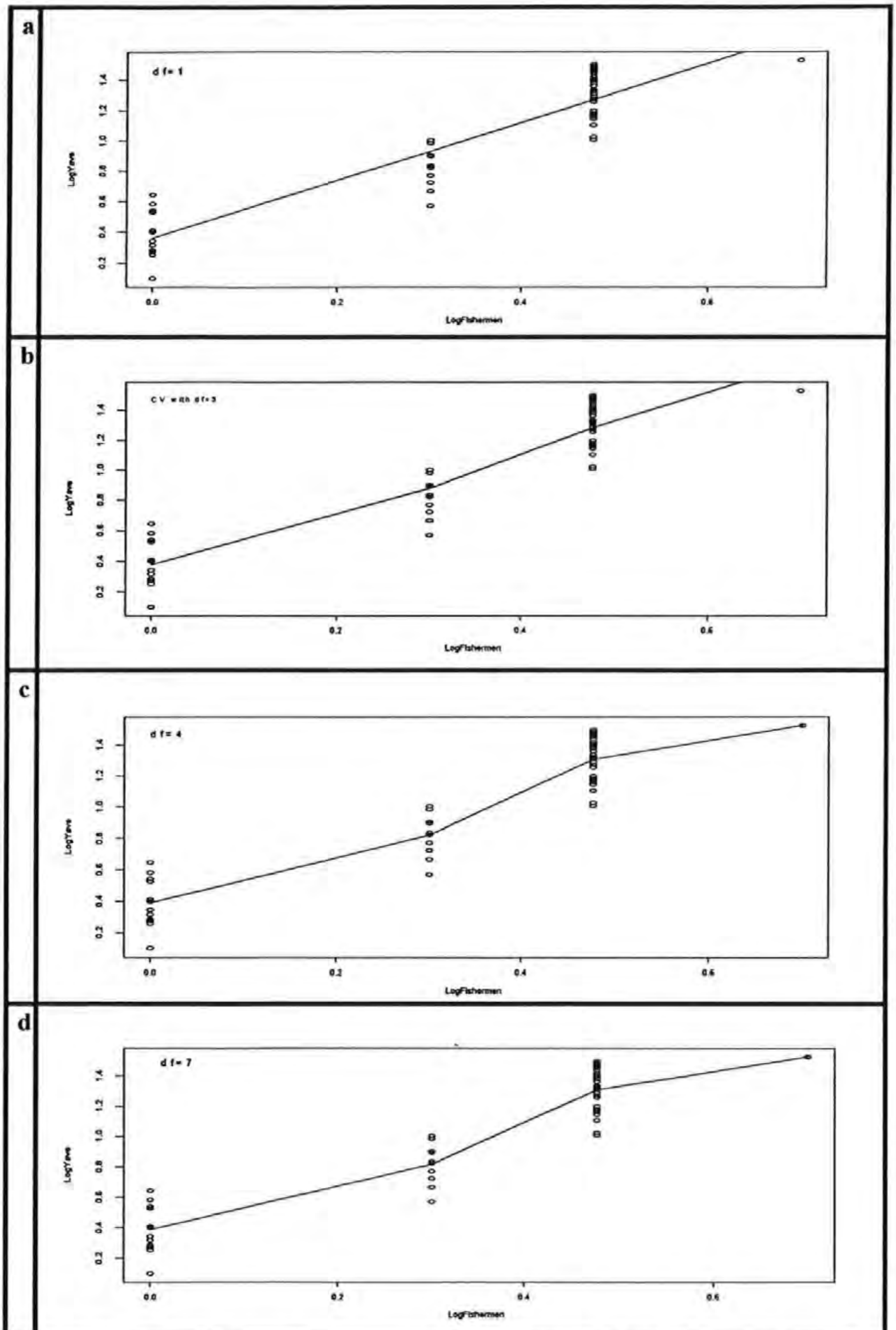


Figure 25D Smoothing spline smoother of *LogYave* vs. *LogFishermen* for Hook lines in Western Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

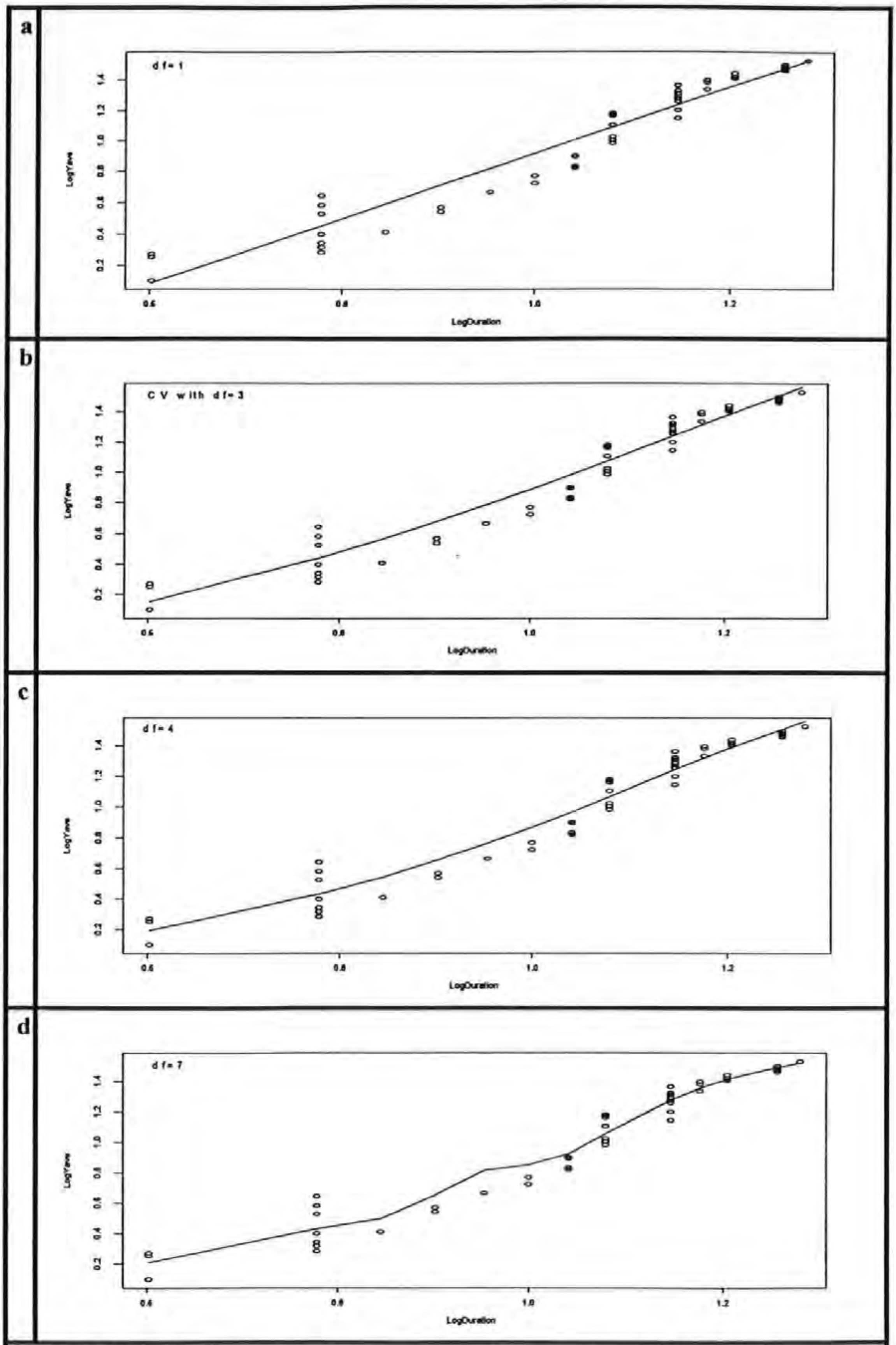


Figure 26D Smoothing spline smoother of *LogYave* vs. *LogDuration* for Hook lines in Western Sector using (a) *df*=1, (b) *df*=3, (c) *df*=4 and (d) *df*=7.

Table 1D The main steps of using stepwise selection for Stand nets fishing gear.

Sector	Model	Deviance	df.residual	Δ Deviance	Δdf	F value
Stand South	Initial model with df=1	1.303	157			
	Model with df=3	0.858	149	0.445	8	6.702
	Model with df=4	0.683	145	0.620	12	6.225
	Model with df=7	0.398	133	0.905	24	4.544
	Best model *LogYave* **=s(***LogNets*, **df=7)+** β_3 *LogDuration* + β_4 *LogMesh*	**0.633**	**152**	**0.670**	**5**	**16.146**
	Control model *LogYave* =s(*LogNets*, df=7)+ β_2 *LogFishermen* + β_3 *LogDuration* + β_4 *LogMesh*	**0.629**	**151**	**0.674**	**6**	**13.535**
Stand West	Initial model with df=1	0.124	49			
	Model with df=3	0.066	41	0.058	8	2.865
	Model with df=4	0.057	37	0.067	12	2.206
	Model with df=7	0.047	26	0.077	23	1.340
	Best model *LogYave* = β_1 *LogNets* + s(*LogFishermen*, df=3)+ s(*LogMesh*, df=4)	**0.068**	**45**	**0.056**	**4**	**5.532**
	Control model *LogYave* = β_1 *LogNets* + s(*LogFishermen*, 3)+ β_3*LogDuration* + s(*LogMesh*, 4)	**0.067**	**44**	**0.057**	**5**	**4.505**
Stand East	Initial model with df=1	0.030	37			
	Model with df=3	0.019	29	0.011	8	1.717
	Model with df=4	0.019	26	0.011	11	1.245
	Model with df=7	0.017	18	0.013	19	0.862
	Best model *LogYave* = β_1 *LogNets* + s(*LogFishermen*, df=3) + β_3*LogMesh*	**0.023**	**36**	**0.007**	**1**	**8.633**
	Control model *LogYave* = β_1 *LogNets* + β_2*LogFishermen* + s(*LogDuration*, 3)+ β_4*LogMesh*	**0.022**	**35**	**0.008**	**2**	**4.933**

Appendix E

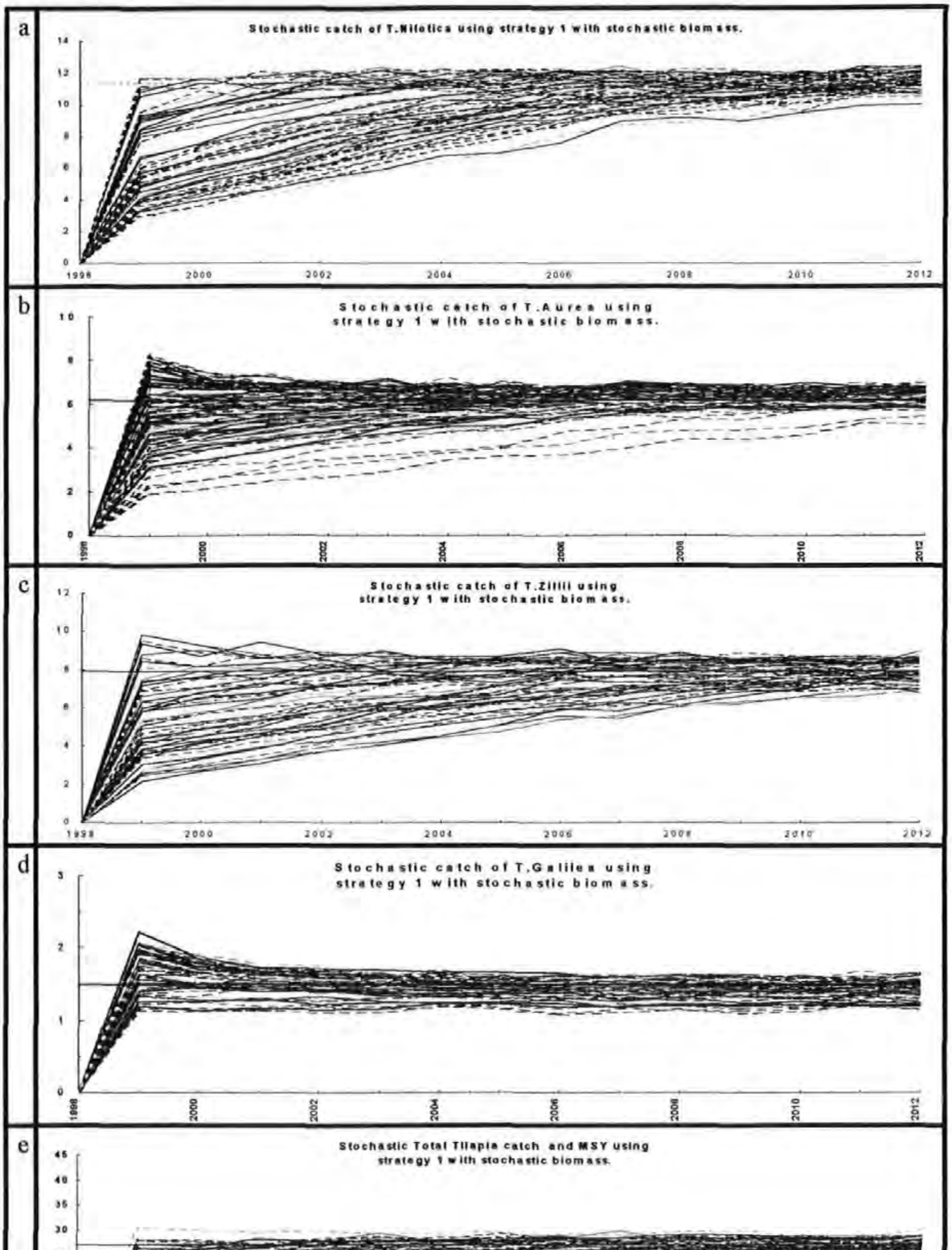


Figure 1E Stochastic catch (multiple regression model) of each species using catch strategy 1 with stochastic biomass for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

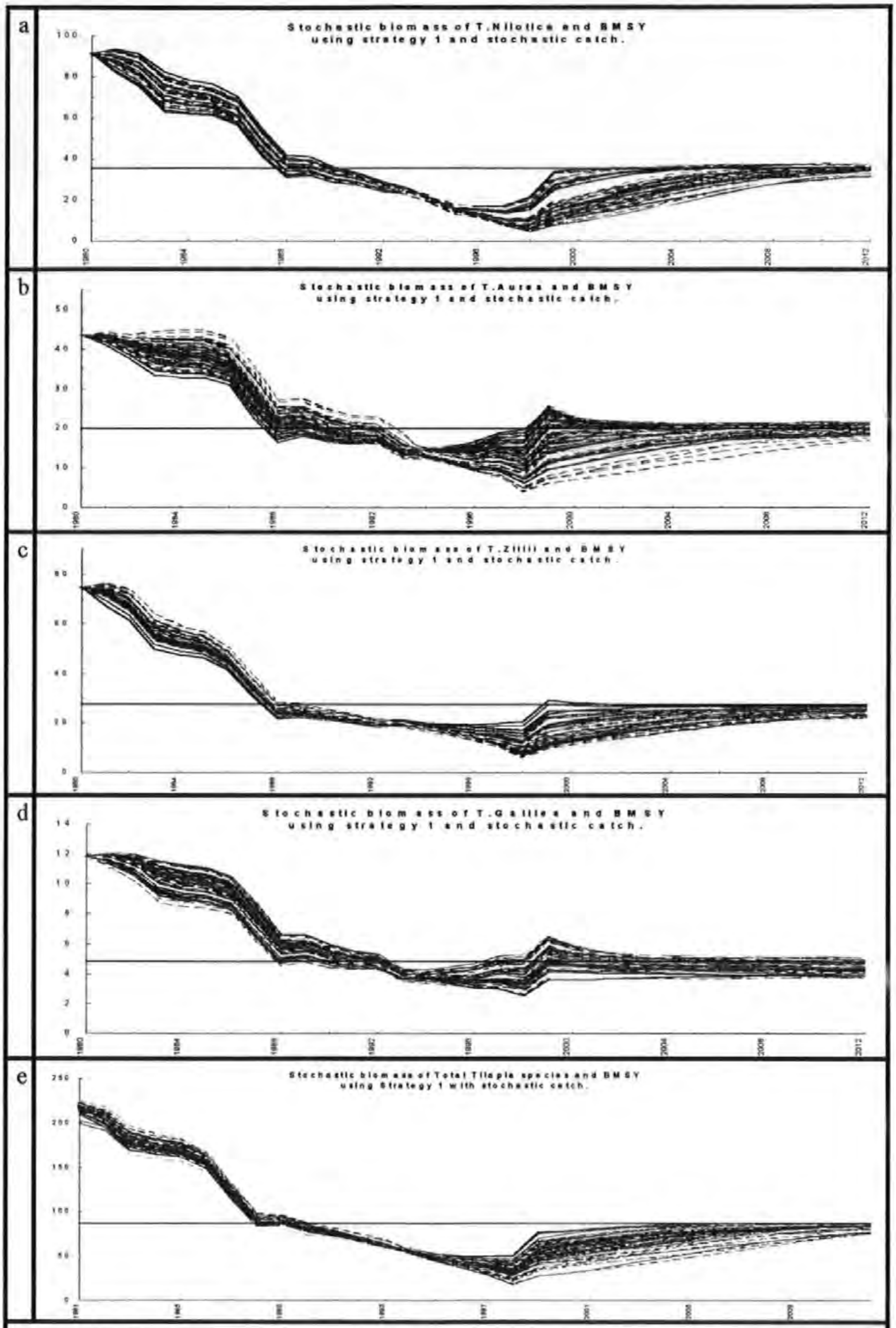


Figure 2E Stochastic biomass (multiple regression model) of each species using catch strategy 1 with stochastic catch for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

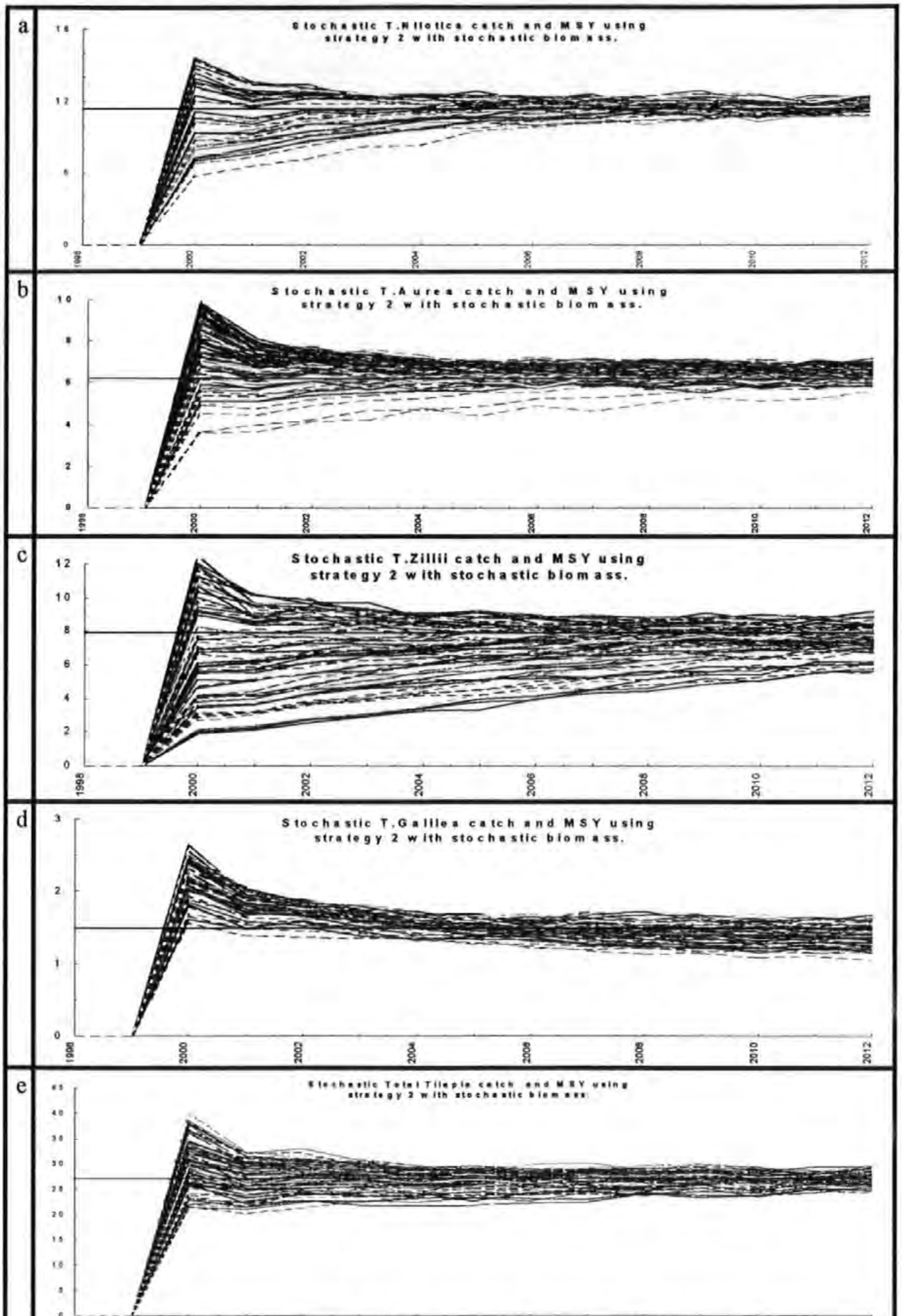


Figure 3E Stochastic catch (multiple regression model) of each species using catch strategy 2 with stochastic biomass for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

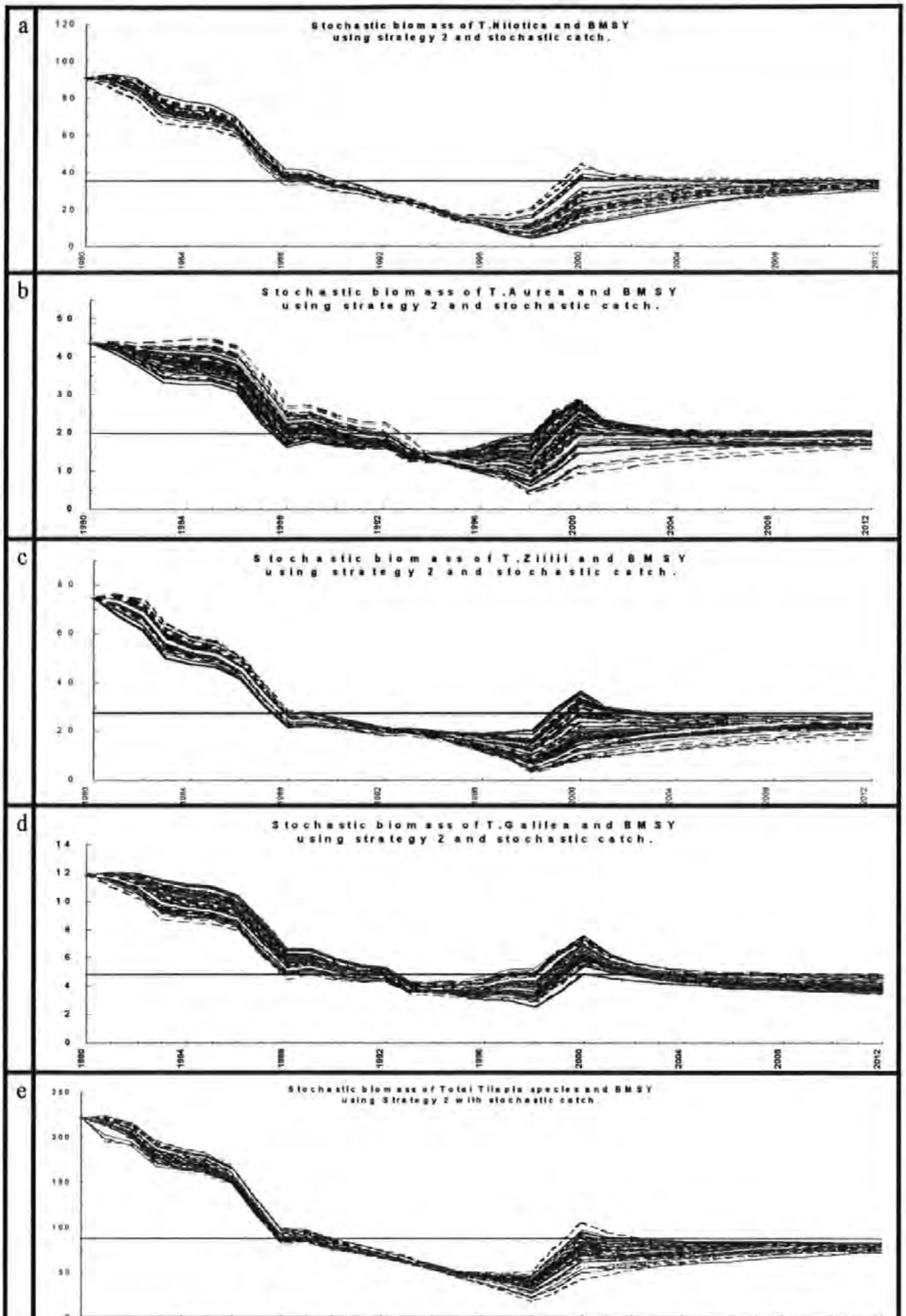


Figure 4E Stochastic biomass (multiple regression model) of each species using catch strategy 2 with stochastic catch for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

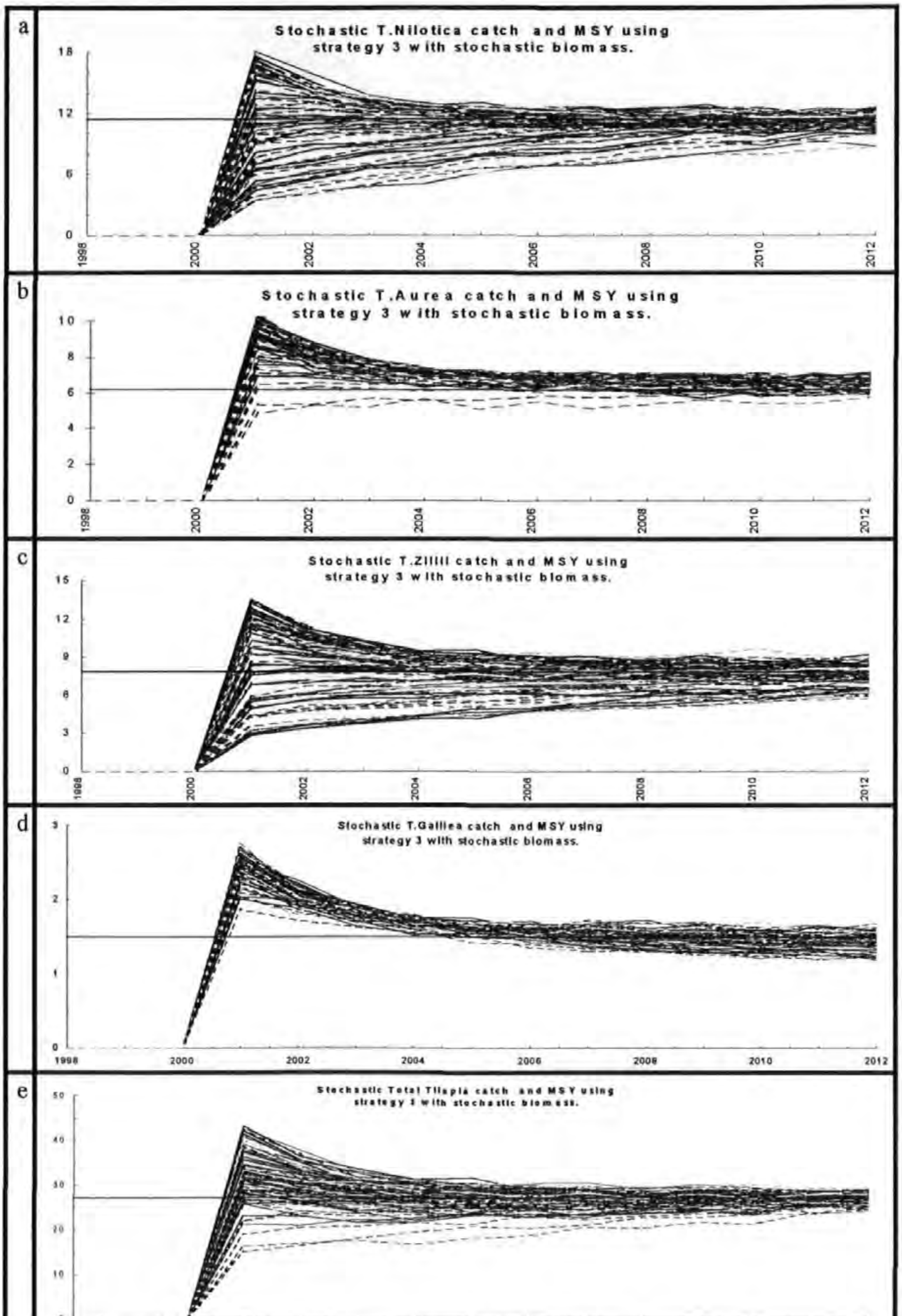


Figure 5E Stochastic catch (multiple regression model) of each species using catch strategy 3 with stochastic biomass for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

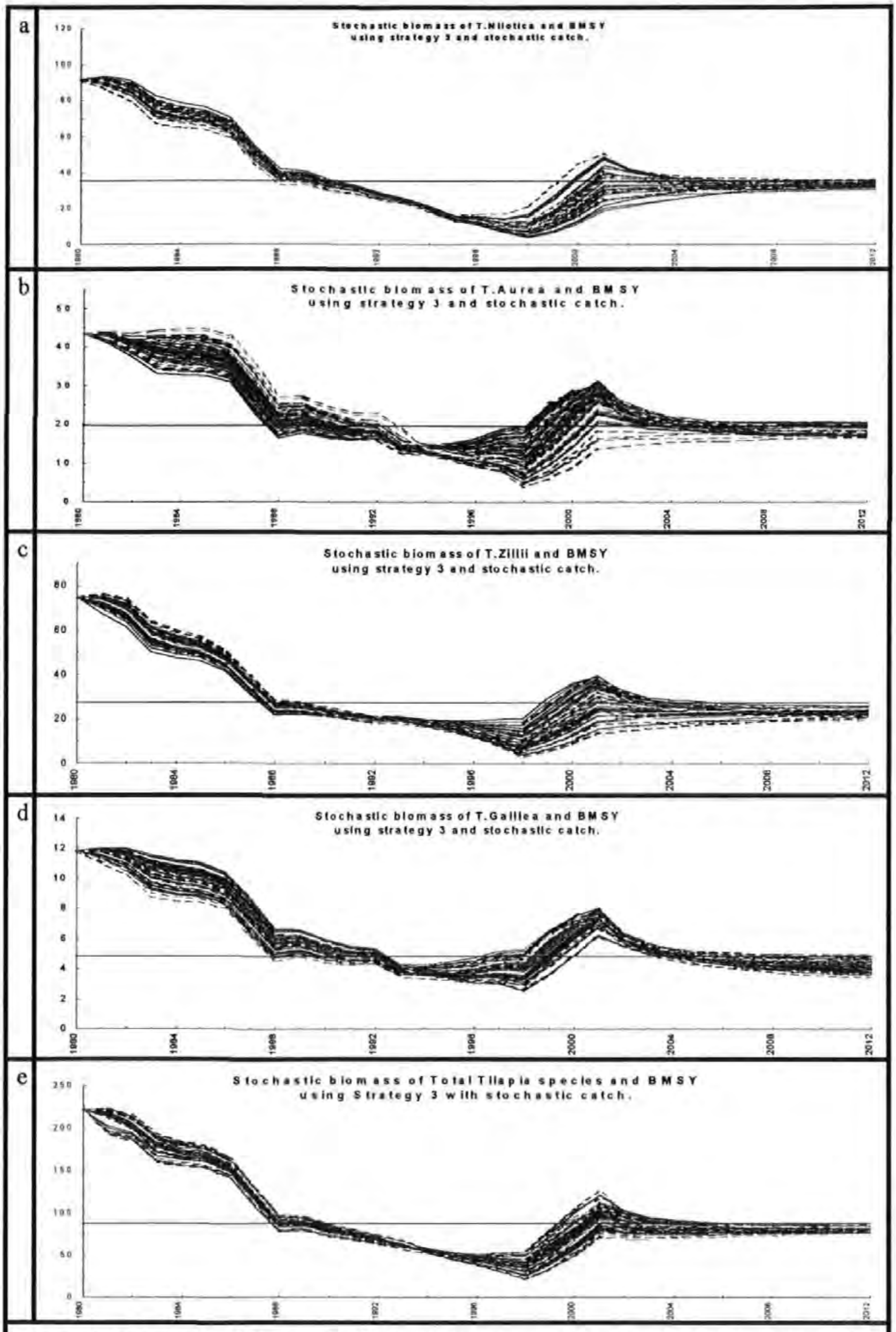


Figure 6E Stochastic biomass (multiple regression model) of each species using catch strategy 3 with stochastic catch for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

Table 1E Confidence intervals 95% of the catches using strategy 1 during the planning year using stochastic biomass (multiple regression model).

S1	*T.Nilotica catches*				*T.Aurea catches*				*T.Zillii catches*				*T.Galilea catches*				*Total Tilapia catch*			
Years	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower
1998	*11.4*	0.0	0.0	0.0	*6.2*	0.0	0.0	0.0	*7.9*	0.0	0.0	0.0	*1.5*	0.0	0.0	0.0	*27.0*	0.0	0.0	0.0
1999	*11.4*	6.7	3.9	1.1	*6.2*	8.6	5.4	2.2	*7.9*	8.4	4.9	1.4	*1.5*	2.3	1.7	1.0	*27.0*	21.3	15.9	10.4
2000	*11.4*	8.0	4.7	1.3	*6.2*	8.1	5.5	2.9	*7.9*	8.4	5.2	2.0	*1.5*	2.1	1.6	1.1	*27.0*	22.2	16.9	11.6
2001	*11.4*	9.3	5.5	1.7	*6.2*	7.8	5.6	3.5	*7.9*	8.4	5.6	2.8	*1.5*	2.0	1.5	1.1	*27.0*	23.4	18.3	13.1
2002	*11.4*	9.3	6.9	1.1	*6.2*	7.7	5.8	3.9	*7.9*	8.1	6.1	3.7	*1.5*	1.9	1.5	1.1	*27.0*	27.0	20.4	13.8
2003	*11.4*	13.1	7.6	2.1	*6.2*	7.5	5.9	4.3	*7.9*	8.7	6.5	4.2	*1.5*	1.9	1.5	1.1	*27.0*	27.6	21.4	15.3
2004	*11.4*	13.4	8.2	3.0	*6.2*	7.5	6.0	4.5	*7.9*	8.4	6.8	4.8	*1.5*	1.8	1.5	1.1	*27.0*	28.2	22.4	16.7
2005	*11.4*	13.4	8.7	4.0	*6.2*	7.4	6.1	4.8	*7.9*	8.7	6.9	5.2	*1.5*	1.8	1.4	1.1	*27.0*	28.3	23.1	18.0
2006	*11.4*	13.5	9.3	5.2	*6.2*	7.3	6.2	5.0	*7.9*	8.7	7.4	5.9	*1.5*	1.8	1.4	1.1	*27.0*	28.9	24.4	19.8
2007	*11.4*	13.4	9.7	5.9	*6.2*	7.2	6.2	5.2	*7.9*	8.8	7.4	6.0	*1.5*	1.8	1.4	1.1	*27.0*	29.0	24.8	20.5
2008	*11.4*	13.3	10.0	6.7	*6.2*	7.1	6.2	5.4	*7.9*	8.7	7.5	6.3	*1.5*	1.8	1.4	1.1	*27.0*	28.7	25.1	21.6
2009	*11.4*	13.1	10.3	7.5	*6.2*	7.1	6.3	5.4	*7.9*	8.8	7.7	6.7	*1.5*	1.8	1.4	1.1	*27.0*	29.0	25.8	22.5
2010	*11.4*	13.1	10.7	7.5	*6.2*	7.1	6.3	5.6	*7.9*	8.8	7.9	6.9	*1.5*	1.8	1.4	1.1	*27.0*	29.1	26.4	23.6
2011	*11.4*	13.1	10.8	7.5	*6.2*	7.0	6.3	5.7	*7.9*	8.8	7.8	6.9	*1.5*	1.8	1.4	1.1	*27.0*	28.7	26.3	23.9
2012	*11.4*	13.1	10.9	7.5	*6.2*	7.0	6.3	5.7	*7.9*	8.8	7.8	6.9	*1.5*	1.8	1.4	1.1	*27.0*	28.9	26.5	24.0

Table 2E Confidence intervals 95% of the biomasses using strategy 1 during the planning year using stochastic catches (multiple regression model).

S1	*T.Nilotica biomass*				*T.Aurea biomass*				*T.Zillii biomass*				*T.Galilea biomass*				*Total Tilapia biomass*			
Years	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower
1998	*35.4*	18.2	8.91	1.1	*19.9*	19.6	11.5	3.5	*27.5*	19.2	10.9	2.6	*4.8*	5.4	4.1	2.7	*87.6*	49.5	35.4	21.3
1999	*35.4*	29.0	14.6	2.5	*19.9*	27.3	16.9	6.5	*27.5*	28.4	16.7	4.9	*4.8*	7.0	5.5	3.9	*87.6*	74.1	53.6	33.1
2000	*35.4*	32.1	17.0	4.3	*19.9*	25.6	17.2	8.7	*27.5*	28.4	17.8	7.1	*4.8*	6.3	5.1	4.0	*87.6*	77.0	57.0	37.0
2001	*35.4*	34.8	19.4	6.5	*19.9*	24.9	17.6	10.3	*27.5*	28.6	18.9	9.2	*4.8*	5.9	4.9	4.0	*87.6*	80.2	60.9	41.5
2002	*35.4*	37.0	21.8	9.2	*19.9*	24.5	18.0	11.6	*27.5*	28.8	20.0	11.2	*4.8*	5.7	4.8	4.0	*87.6*	83.2	64.7	46.2
2003	*35.4*	38.8	24.1	11.9	*19.9*	24.2	18.4	12.7	*27.5*	28.8	20.9	12.9	*4.8*	5.5	4.7	3.9	*87.6*	85.6	68.1	50.6
2004	*35.4*	39.9	26.1	14.6	*19.9*	23.9	18.7	13.6	*27.5*	28.5	21.6	14.6	*4.8*	5.4	4.7	3.9	*87.6*	87.3	71.1	54.9
2005	*35.4*	40.6	28.0	17.4	*19.9*	23.6	19.0	14.4	*27.5*	28.3	22.3	16.3	*4.8*	5.4	4.6	3.9	*87.6*	88.5	73.9	59.3
2006	*35.4*	41.0	29.6	20.1	*19.9*	23.4	19.2	15.0	*27.5*	27.9	22.9	17.8	*4.8*	5.4	4.6	3.9	*87.6*	89.2	76.4	63.6
2007	*35.4*	40.9	30.9	22.5	*19.9*	23.2	19.4	15.6	*27.5*	27.5	23.2	19.0	*4.8*	5.3	4.6	3.9	*87.6*	89.2	78.1	67.1
2008	*35.4*	40.7	32.0	24.7	*19.9*	23.0	19.6	16.1	*27.5*	27.5	23.7	20.0	*4.8*	5.3	4.6	3.9	*87.6*	89.4	79.9	70.3
2009	*35.4*	40.2	32.9	26.8	*19.9*	22.9	19.7	16.5	*27.5*	27.2	24.0	20.8	*4.8*	5.3	4.6	3.9	*87.6*	89.2	81.2	73.2
2010	*35.4*	39.9	33.7	28.5	*19.9*	22.7	19.8	16.9	*27.5*	27.0	24.2	21.4	*4.8*	5.3	4.6	3.9	*87.6*	89.1	82.3	75.6
2011	*35.4*	39.9	34.1	28.5	*19.9*	22.5	19.9	17.2	*27.5*	26.9	24.4	21.9	*4.8*	5.3	4.6	3.9	*87.6*	88.7	83.0	77.3
2012	*35.4*	39.9	34.1	28.5	*19.9*	22.4	19.9	17.5	*27.5*	27.0	24.6	22.3	*4.8*	5.3	4.6	3.9	*87.6*	88.5	83.7	78.8

Table 3E Confidence intervals 95% of the catches using strategy 2 during the planning year using stochastic biomass (multiple regression model).

S2	*T.Nilotica catches*				*T.Aurea catches*				*T.Zillii catches*				*T.Galilea catches*				*Total Tilapia catch*			
Years	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower
1998	*11.4*	0.0	0.0	0.0	*6.2*	0.0	0.0	0.0	*7.9*	0.0	0.0	0.0	*1.5*	0.0	0.0	0.0	*27.0*	0.0	0.0	0.0
1999	*11.4*	0.0	0.0	0.0	*6.2*	0.0	0.0	0.0	*7.9*	0.0	0.0	0.0	*1.5*	0.0	0.0	0.0	*27.0*	0.0	0.0	0.0
2000	*11.4*	18.5	12.7	6.8	*6.2*	11.0	7.7	4.4	*7.9*	13.7	7.4	1.1	*1.5*	2.9	2.2	1.5	*27.0*	39.4	29.9	20.4
2001	*11.4*	15.0	11.6	8.1	*6.2*	8.7	6.8	4.8	*7.9*	11.7	6.9	2.0	*1.5*	2.2	1.8	1.3	*27.0*	33.5	27.0	20.4
2002	*11.4*	14.6	11.9	9.2	*6.2*	8.3	6.8	5.3	*7.9*	11.4	7.1	2.8	*1.5*	2.1	1.7	1.4	*27.0*	33.1	27.5	22.0
2003	*11.4*	14.0	11.8	9.7	*6.2*	7.9	6.6	5.4	*7.9*	11.0	7.1	3.3	*1.5*	2.0	1.6	1.3	*27.0*	32.1	27.2	22.4
2004	*11.4*	13.2	11.6	10.1	*6.2*	7.5	6.5	5.5	*7.9*	10.4	7.1	3.8	*1.5*	1.9	1.6	1.2	*27.0*	30.7	26.8	22.9
2005	*11.4*	13.1	11.7	10.4	*6.2*	7.5	6.5	5.5	*7.9*	10.4	7.3	4.2	*1.5*	1.8	1.5	1.2	*27.0*	30.8	27.0	23.2
2006	*11.4*	12.7	11.6	10.5	*6.2*	7.3	6.5	5.6	*7.9*	10.1	7.3	4.6	*1.5*	1.8	1.5	1.2	*27.0*	30.2	26.9	23.7
2007	*11.4*	12.9	11.9	10.9	*6.2*	7.3	6.4	5.6	*7.9*	10.0	7.4	4.9	*1.5*	1.8	1.5	1.1	*27.0*	30.3	27.2	24.1
2008	*11.4*	12.9	11.8	10.7	*6.2*	7.3	6.4	5.5	*7.9*	9.9	7.5	5.1	*1.5*	1.8	1.5	1.1	*27.0*	30.1	27.1	24.2
2009	*11.4*	13.1	12.0	10.9	*6.2*	7.2	6.4	5.6	*7.9*	9.8	7.6	5.4	*1.5*	1.8	1.4	1.1	*27.0*	30.3	27.5	24.7
2010	*11.4*	12.6	11.6	10.6	*6.2*	7.2	6.4	5.6	*7.9*	9.5	7.6	5.6	*1.5*	1.8	1.4	1.1	*27.0*	29.6	27.0	24.5
2011	*11.4*	12.4	11.7	11.0	*6.2*	7.2	6.4	5.6	*7.9*	9.3	7.6	5.8	*1.5*	1.8	1.4	1.1	*27.0*	29.2	27.1	25.0
2012	*11.4*	12.9	11.9	10.9	*6.2*	7.1	6.4	5.7	*7.9*	9.5	7.7	5.9	*1.5*	1.8	1.4	1.1	*27.0*	29.8	27.5	25.2

Table 4E Confidence intervals 95% of the biomasses using strategy 2 during the planning year using stochastic catches (multiple regression model).

S2	*T.Nilotica biomass*				*T.Aurea biomass*				*T.Zillii biomass*				*T.Galilea biomass*				*Total Tilapia biomass*			
Years	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower
1998	*35.4*	16.1	8.99	1.9	*19.9*	19.5	11.7	3.9	*27.5*	20.5	11.0	1.4	*4.8*	5.7	4.0	2.4	*87.6*	48.9	35.7	22.4
1999	*35.4*	25.7	14.7	3.7	*19.9*	26.9	17.1	7.3	*27.5*	30.3	16.7	3.1	*4.8*	7.4	5.4	3.5	*87.6*	72.7	53.9	35.2
2000	*35.4*	38.0	22.9	9.8	*19.9*	31.8	22.5	13.2	*27.5*	39.7	23.3	7.0	*4.8*	8.4	6.6	4.7	*87.6*	98.2	75.3	52.4
2001	*35.4*	38.0	24.5	12.1	*19.9*	26.2	20.5	14.9	*27.5*	34.9	22.2	9.6	*4.8*	6.8	5.6	4.3	*87.6*	91.3	72.8	54.4
2002	*35.4*	38.7	26.5	14.2	*19.9*	24.3	20.0	15.7	*27.5*	32.9	22.2	11.4	*4.8*	6.2	5.2	4.1	*87.6*	89.9	73.8	57.7
2003	*35.4*	38.3	27.7	17.2	*19.9*	23.1	19.6	16.0	*27.5*	31.3	22.1	12.9	*4.8*	5.8	4.9	3.9	*87.6*	88.0	74.2	60.5
2004	*35.4*	38.1	28.9	19.8	*19.9*	22.3	19.3	16.3	*27.5*	30.0	22.1	14.1	*4.8*	5.5	4.7	3.8	*87.6*	86.7	75.0	63.3
2005	*35.4*	37.8	30.0	22.2	*19.9*	21.9	19.2	16.5	*27.5*	29.3	22.3	15.2	*4.8*	5.4	4.6	3.7	*87.6*	86.1	76.0	65.9
2006	*35.4*	37.5	30.9	24.3	*19.9*	21.5	19.1	16.6	*27.5*	28.6	22.4	16.2	*4.8*	5.3	4.5	3.6	*87.6*	85.6	76.9	68.2
2007	*35.4*	37.2	31.6	25.9	*19.9*	21.3	19.0	16.6	*27.5*	28.1	22.6	17.0	*4.8*	5.3	4.4	3.5	*87.6*	85.1	77.5	69.9
2008	*35.4*	36.7	32.0	27.3	*19.9*	21.2	18.9	16.7	*27.5*	27.7	22.7	17.6	*4.8*	5.3	4.4	3.4	*87.6*	84.6	78.0	71.4
2009	*35.4*	36.6	32.4	28.1	*19.9*	21.1	18.9	16.7	*27.5*	27.2	22.7	18.2	*4.8*	5.3	4.3	3.4	*87.6*	84.2	78.3	72.5
2010	*35.4*	36.3	32.6	28.9	*19.9*	21.1	18.9	16.7	*27.5*	26.8	22.7	18.7	*4.8*	5.2	4.3	3.3	*87.6*	83.7	78.5	73.4
2011	*35.4*	35.9	32.7	29.6	*19.9*	21.1	18.9	16.7	*27.5*	26.6	22.8	19.1	*4.8*	5.2	4.3	3.3	*87.6*	83.4	78.7	74.0
2012	*35.4*	36.1	33.1	30.0	*19.9*	21.0	18.9	16.8	*27.5*	26.5	23.0	19.4	*4.8*	5.3	4.3	3.3	*87.6*	83.7	79.2	74.7

Table 5E Confidence intervals 95% of the catch using strategy 3 during the planning year using stochastic biomass (multiple regression model).

S 3	*T.Nilotica catches*				*T.Aurea catches*				*T.Zillii catches*				*T.Galilea catches*				*Total Tilapia catch*			
Years	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower
1998	*11.4*	0.0	0.0	0.0	*6.2*	0.0	0.0	0.0	*7.9*	0.0	0.0	0.0	*1.5*	0.0	0.0	0.0	*27.0*	0.0	0.0	0.0
1999	*11.4*	0.0	0.0	0.0	*6.2*	0.0	0.0	0.0	*7.9*	0.0	0.0	0.0	*1.5*	0.0	0.0	0.0	*27.0*	0.0	0.0	0.0
2000	*11.4*	0.0	0.0	0.0	*6.2*	0.0	0.0	0.0	*7.9*	0.0	0.0	0.0	*1.5*	0.0	0.0	0.0	*27.0*	0.0	0.0	0.0
2001	*11.4*	20.7	11.9	3.1	*6.2*	11.6	8.7	5.8	*7.9*	14.8	8.7	2.5	*1.5*	2.9	2.4	1.8	*27.0*	43.0	31.7	20.3
2002	*11.4*	17.9	11.4	4.9	*6.2*	9.6	7.8	6.0	*7.9*	12.7	8.2	3.7	*1.5*	2.3	2.0	1.7	*27.0*	37.3	29.4	21.4
2003	*11.4*	16.4	11.1	5.9	*6.2*	8.7	7.2	5.8	*7.9*	11.5	7.9	4.2	*1.5*	2.1	1.8	1.5	*27.0*	34.5	28.0	21.6
2004	*11.4*	15.5	11.0	6.5	*6.2*	8.1	6.9	5.7	*7.9*	10.9	7.8	4.6	*1.5*	1.9	1.7	1.4	*27.0*	32.9	27.3	21.8
2005	*11.4*	14.7	11.0	7.3	*6.2*	7.8	6.7	5.7	*7.9*	10.6	7.8	4.9	*1.5*	1.8	1.6	1.4	*27.0*	31.9	27.1	22.3
2006	*11.4*	14.3	11.1	7.9	*6.2*	7.7	6.7	5.7	*7.9*	10.3	7.8	5.2	*1.5*	1.8	1.6	1.3	*27.0*	31.4	27.1	22.8
2007	*11.4*	14.0	11.1	8.2	*6.2*	7.5	6.5	5.6	*7.9*	10.0	7.7	5.4	*1.5*	1.8	1.5	1.2	*27.0*	30.9	26.9	22.9
2008	*11.4*	13.3	11.0	8.7	*6.2*	7.4	6.5	5.6	*7.9*	9.7	7.7	5.6	*1.5*	1.8	1.5	1.2	*27.0*	29.9	26.7	23.5
2009	*11.4*	13.4	11.3	9.1	*6.2*	7.3	6.5	5.6	*7.9*	9.7	7.8	5.8	*1.5*	1.8	1.5	1.2	*27.0*	30.1	27.0	23.8
2010	*11.4*	13.1	11.2	9.3	*6.2*	7.3	6.4	5.6	*7.9*	9.7	7.8	5.8	*1.5*	1.8	1.5	1.1	*27.0*	30.0	26.8	23.7
2011	*11.4*	12.8	11.3	9.7	*6.2*	7.2	6.4	5.5	*7.9*	9.5	7.8	6.0	*1.5*	1.8	1.4	1.1	*27.0*	29.3	26.9	24.4
2012	*11.4*	13.0	11.4	9.8	*6.2*	7.2	6.4	5.7	*7.9*	9.5	7.8	6.1	*1.5*	1.8	1.4	1.1	*27.0*	29.7	27.1	24.4

Table 6E Confidence intervals 95% of the biomasses using strategy 3 during the planning year using stochastic catches (multiple regression model).

S3	*T.Nilotica biomass*				*T.Aurea biomass*				*T.Zillii biomass*				*T.Galilea biomass*				*Total Tilapia biomass*			
Years	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower
1998	*35.4*	15.3	8.94	2.6	*19.9*	19.6	11.7	3.9	*27.5*	22.1	10.97	1.7	*4.8*	5.5	4.1	2.6	*87.6*	51.7	35.7	19.7
1999	*35.4*	24.7	14.8	4.8	*19.9*	27.2	17.1	7.1	*27.5*	31.6	16.5	3.8	*4.8*	7.2	5.5	3.8	*87.6*	76.0	53.9	31.8
2000	*35.4*	37.0	23.1	9.1	*19.9*	32.1	22.5	12.9	*27.5*	37.8	22.4	9.4	*4.8*	8.1	6.6	5.2	*87.6*	99.0	74.6	50.2
2001	*35.4*	49.7	33.2	16.8	*19.9*	33.9	26.9	19.8	*27.5*	41.9	28.3	16.8	*4.8*	8.4	7.4	6.3	*87.6*	119.1	95.8	72.4
2002	*35.4*	46.0	33.2	20.3	*19.9*	27.1	23.2	19.4	*27.5*	34.9	25.9	18.3	*4.8*	6.7	6.0	5.3	*87.6*	104.5	88.2	72.0
2003	*35.4*	42.7	32.9	23.0	*19.9*	24.3	21.5	18.8	*27.5*	31.8	24.8	19.0	*4.8*	5.9	5.4	4.9	*87.6*	97.1	84.6	72.2
2004	*35.4*	41.3	33.1	25.0	*19.9*	22.8	20.6	18.5	*27.5*	30.1	24.3	19.5	*4.8*	5.4	5.0	4.6	*87.6*	93.5	83.1	72.7
2005	*35.4*	39.7	33.3	26.9	*19.9*	22.0	20.1	18.2	*27.5*	29.0	24.0	19.8	*4.8*	5.2	4.8	4.4	*87.6*	90.8	82.2	73.5
2006	*35.4*	38.8	33.6	28.5	*19.9*	21.5	19.7	17.9	*27.5*	28.2	23.8	20.2	*4.8*	5.1	4.7	4.2	*87.6*	89.2	81.8	74.5
2007	*35.4*	37.6	33.6	29.5	*19.9*	21.2	19.4	17.6	*27.5*	27.6	23.6	20.3	*4.8*	5.1	4.5	4.0	*87.6*	87.5	81.2	74.9
2008	*35.4*	37.0	33.7	30.3	*19.9*	21.1	19.3	17.4	*27.5*	27.2	23.6	20.5	*4.8*	5.0	4.5	3.9	*87.6*	86.5	80.9	75.4
2009	*35.4*	36.7	33.6	30.6	*19.9*	21.1	19.2	17.3	*27.5*	26.9	23.5	20.6	*4.8*	5.1	4.4	3.8	*87.6*	86.0	80.7	75.4
2010	*35.4*	36.6	33.7	30.7	*19.9*	21.0	19.1	17.1	*27.5*	26.6	23.4	20.6	*4.8*	5.1	4.4	3.7	*87.6*	85.6	80.5	75.4
2011	*35.4*	36.6	33.7	30.7	*19.9*	21.1	19.0	16.9	*27.5*	26.4	23.3	20.7	*4.8*	5.1	4.4	3.6	*87.6*	85.0	80.4	75.8
2012	*35.4*	36.6	33.9	30.7	*19.9*	21.0	19.0	16.9	*27.5*	26.3	23.3	20.8	*4.8*	5.1	4.3	3.6	*87.6*	85.2	80.5	75.8

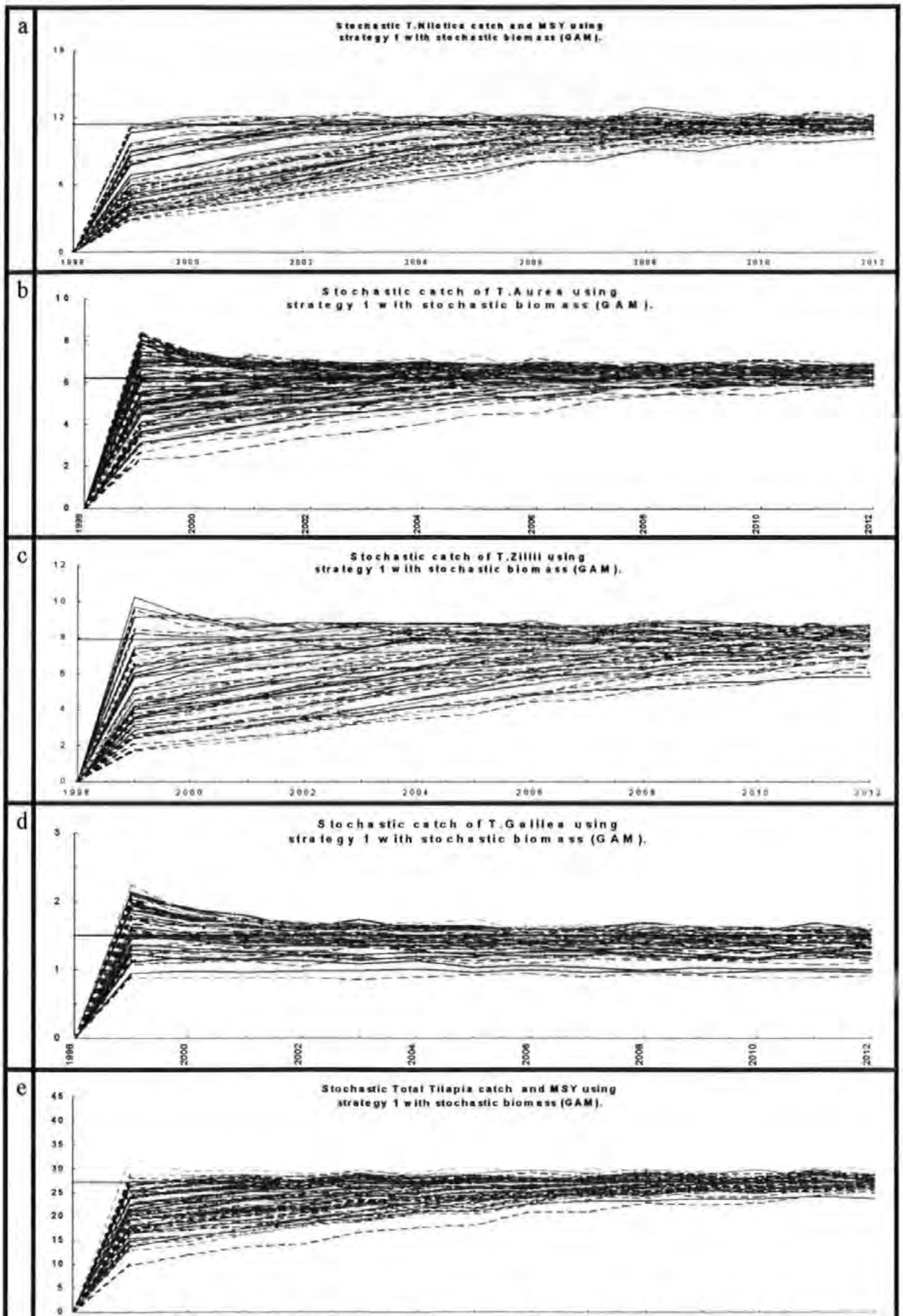


Figure 7E Stochastic catch (GAM) of each species using catch strategy 1 with stochastic biomass for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

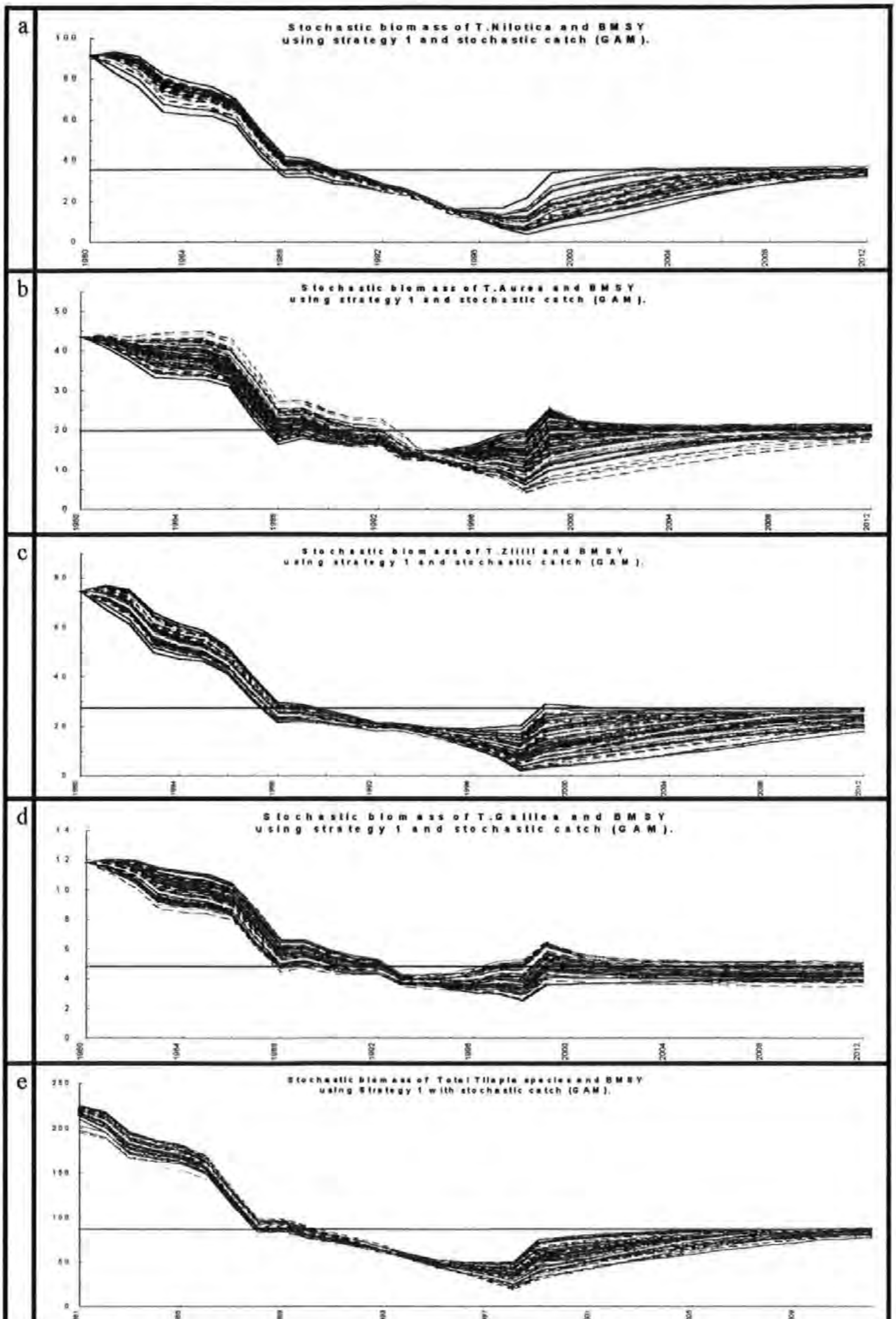


Figure 8E Stochastic biomass (GAM) of each species using catch strategy 1 with stochastic catch for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

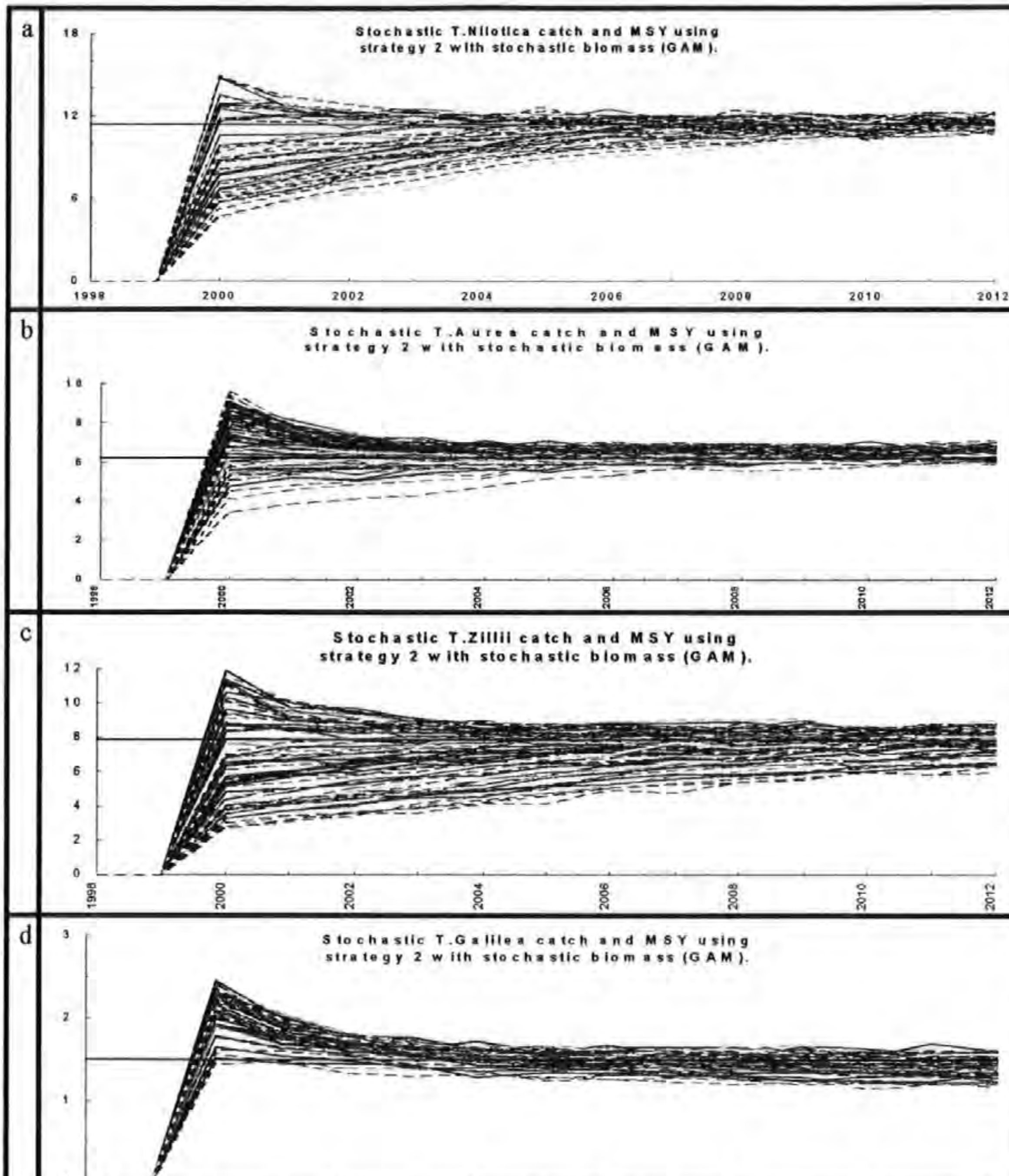


Figure 9E Stochastic catch (GAM) of each species using catch strategy 2 with stochastic biomass for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

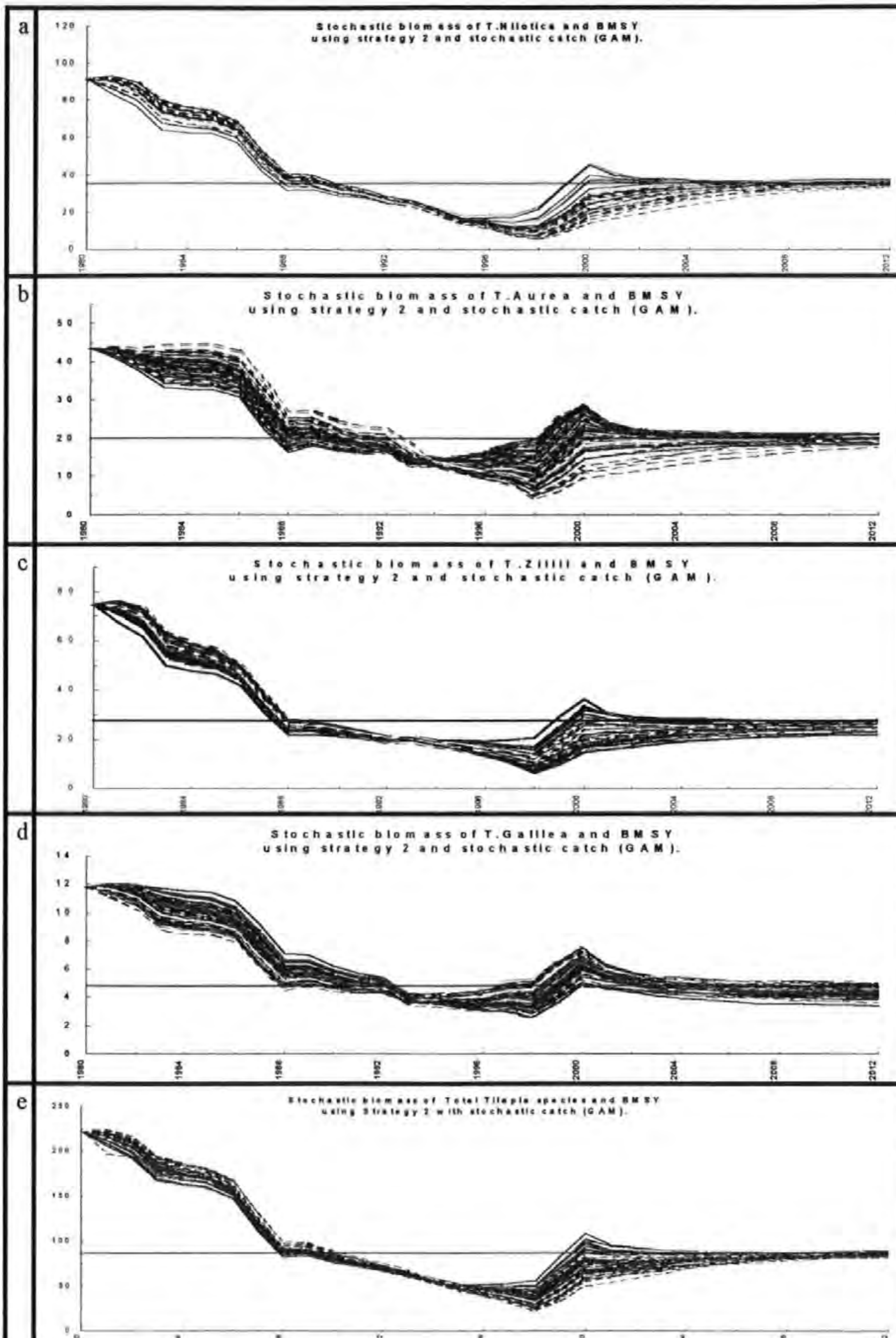


Figure 10E Stochastic biomass (GAM) of each species using catch strategy 2 with stochastic catch for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

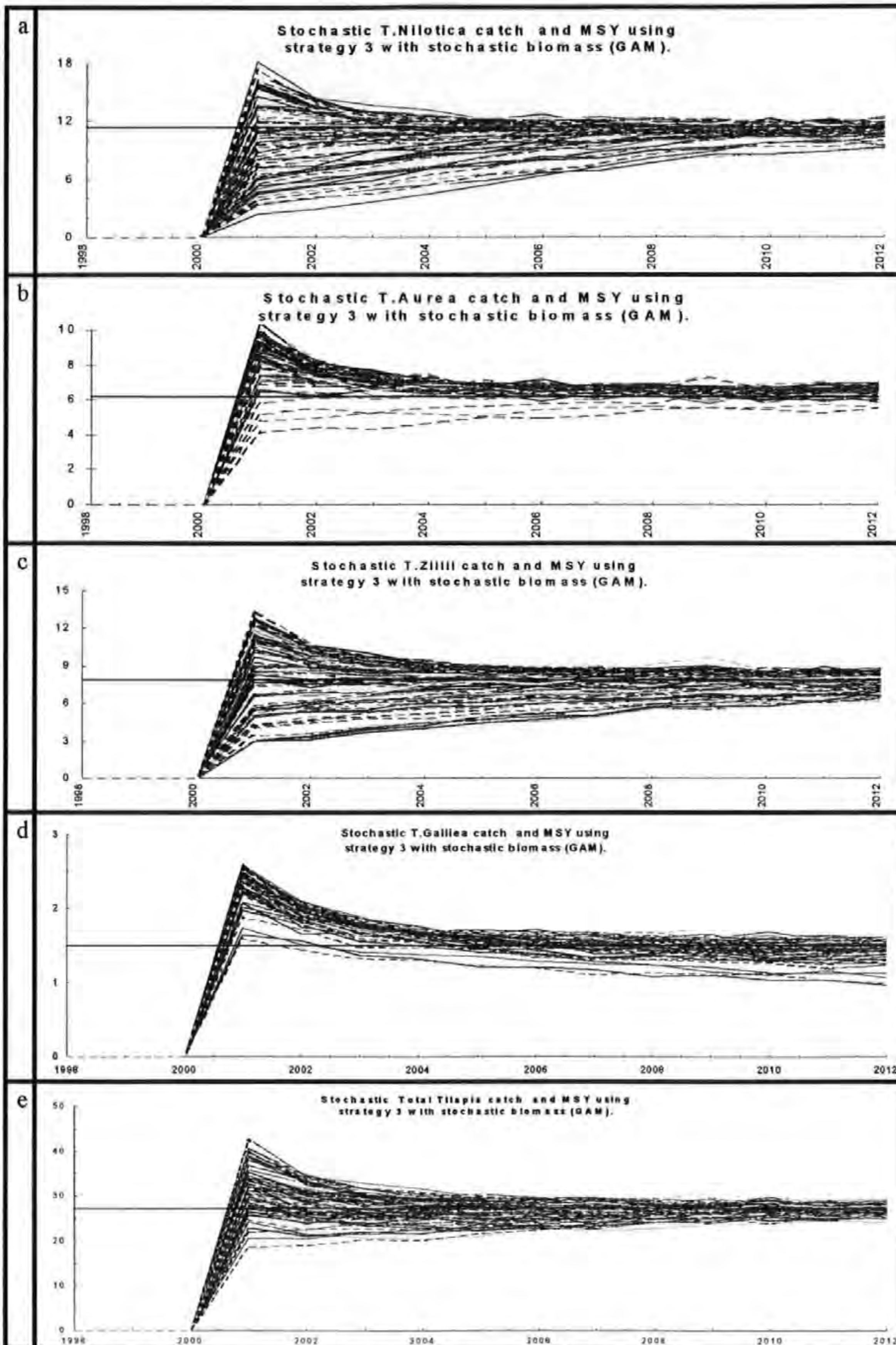


Figure 11E Stochastic catch (GAM) of each species using catch strategy 3 with stochastic biomass for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

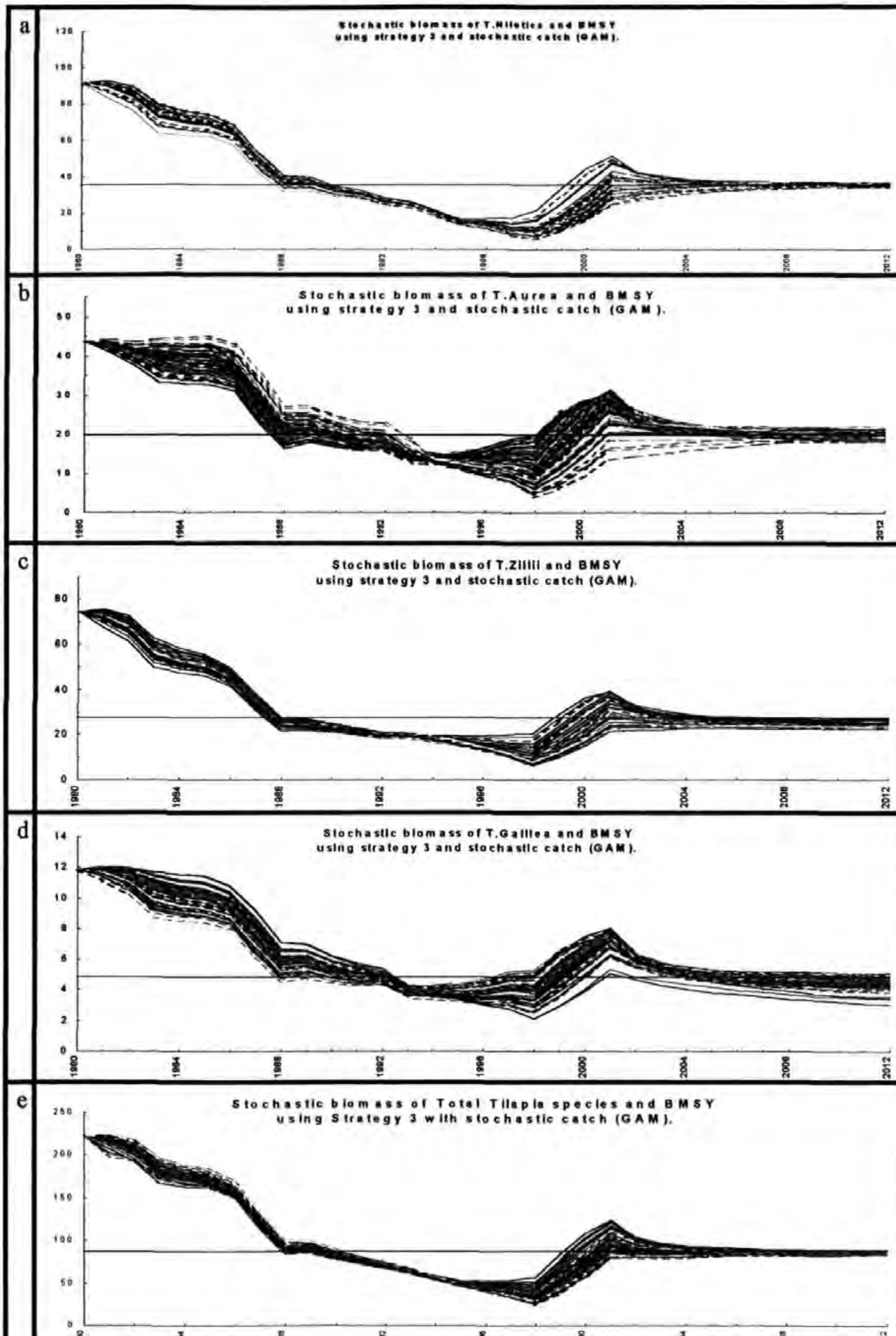


Figure 12E Stochastic biomass (GAM) of each species using catch strategy 3 with stochastic catch for (a) *T.Nilotica*, (b) *T.Aurea*, (c) *T.Zillii* (d) *T.Galilea* and (e) *Total Tilapia*.

Table 7E Confidence intervals 95% of the catches using strategy 1 during the planning year using stochastic biomass (GAM) and stochastic biomass.

S1	*T.Nilotica catches*				*T.Aurea catches*				*T.Zillii catches*				*T.Galilea catches*				*Tilapia catch*			
Years	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower
1998	*11.4*	0.0	0.0	0.0	*6.2*	0.0	0.0	0.0	*7.9*	0.0	0.0	0.0	*1.5*	0.0	0.0	0.0	*27.0*	0.0	0.0	0.0
1999	*11.4*	14.1	8.0	1.9	*6.2*	8.6	5.5	2.3	*7.9*	9.9	5.6	1.3	*1.5*	2.4	1.7	1.0	*27.0*	28.9	20.8	12.6
2000	*11.4*	14.6	8.7	2.8	*6.2*	8.0	5.5	3.1	*7.9*	10.1	6.0	1.9	*1.5*	2.1	1.6	1.1	*27.0*	29.6	21.9	14.1
2001	*11.4*	14.9	9.4	3.9	*6.2*	7.7	5.7	3.6	*7.9*	10.3	6.4	2.4	*1.5*	2.0	1.5	1.1	*27.0*	30.3	23.0	15.7
2002	*11.4*	13.9	9.6	5.3	*6.2*	7.6	5.9	4.1	*7.9*	9.9	6.5	3.1	*1.5*	1.9	1.5	1.1	*27.0*	29.4	23.5	17.5
2003	*11.4*	14.7	10.4	6.1	*6.2*	7.4	5.9	4.5	*7.9*	10.5	7.0	3.4	*1.5*	1.9	1.5	1.1	*27.0*	30.7	24.8	18.9
2004	*11.4*	13.6	10.4	7.3	*6.2*	7.4	6.1	4.8	*7.9*	9.9	7.0	4.1	*1.5*	1.8	1.5	1.1	*27.0*	29.7	25.0	20.3
2005	*11.4*	13.7	10.8	7.9	*6.2*	7.2	6.1	5.0	*7.9*	10.1	7.3	4.5	*1.5*	1.8	1.5	1.1	*27.0*	30.2	25.7	21.2
2006	*11.4*	13.0	11.0	8.9	*6.2*	7.2	6.2	5.2	*7.9*	9.8	7.4	5.0	*1.5*	1.8	1.4	1.1	*27.0*	29.4	26.0	22.6
2007	*11.4*	13.1	11.2	9.3	*6.2*	7.1	6.2	5.4	*7.9*	9.7	7.5	5.4	*1.5*	1.8	1.4	1.1	*27.0*	29.4	26.4	23.3
2008	*11.4*	13.5	11.6	9.6	*6.2*	7.1	6.3	5.6	*7.9*	10.0	7.8	5.6	*1.5*	1.8	1.4	1.1	*27.0*	30.5	27.2	23.9
2009	*11.4*	12.9	11.5	10.0	*6.2*	7.0	6.3	5.6	*7.9*	9.6	7.8	6.0	*1.5*	1.8	1.4	1.1	*27.0*	29.6	27.0	24.4
2010	*11.4*	12.4	11.4	10.3	*6.2*	7.0	6.3	5.6	*7.9*	9.3	7.7	6.2	*1.5*	1.8	1.4	1.1	*27.0*	29.2	26.8	24.5
2011	*11.4*	13.2	11.7	10.2	*6.2*	7.0	6.4	5.7	*7.9*	9.7	8.0	6.3	*1.5*	1.8	1.4	1.1	*27.0*	30.2	27.5	24.9
2012	*11.4*	12.4	11.5	10.6	*6.2*	7.0	6.4	5.8	*7.9*	9.2	7.9	6.6	*1.5*	1.8	1.4	1.1	*27.0*	29.0	27.2	25.4

Table 8E Confidence intervals 95% of the biomass using strategy 1 during the planning year using stochastic catches (GAM) and stochastic biomass.

S1	*T.Nilotica biomass*				*T.Aurea biomass*				*T.Zillii biomass*				*T.Galilea biomass*				*Tilapia biomass*			
Years	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower
1998	*35.4*	16.4	8.96	1.5	*19.9*	19.5	11.7	3.9	*27.5*	20.0	10.21	0.4	*4.8*	5.5	4.1	2.7	*87.6*	49.3	34.9	20.6
1999	*35.4*	26.1	14.7	3.3	*19.9*	27.1	17.1	7.1	*27.5*	29.6	15.6	1.6	*4.8*	7.1	5.5	3.9	*87.6*	73.1	52.9	32.7
2000	*35.4*	29.0	17.4	5.8	*19.9*	25.3	17.4	9.4	*27.5*	29.8	16.6	3.5	*4.8*	6.3	5.1	4.0	*87.6*	75.3	56.6	37.8
2001	*35.4*	31.4	20.1	8.8	*19.9*	24.5	17.8	11.1	*27.5*	30.1	17.7	5.2	*4.8*	5.9	4.9	4.0	*87.6*	78.0	60.5	43.1
2002	*35.4*	33.6	22.8	11.9	*19.9*	24.0	18.2	12.5	*27.5*	30.3	18.6	7.0	*4.8*	5.7	4.8	3.9	*87.6*	80.6	64.4	48.3
2003	*35.4*	35.0	25.3	15.6	*19.9*	23.5	18.6	13.7	*27.5*	30.5	19.6	8.7	*4.8*	5.5	4.7	3.9	*87.6*	82.9	68.2	53.5
2004	*35.4*	36.1	27.5	18.9	*19.9*	23.2	18.9	14.6	*27.5*	30.2	20.4	10.5	*4.8*	5.4	4.7	3.9	*87.6*	84.5	71.5	58.5
2005	*35.4*	36.5	29.4	22.2	*19.9*	22.9	19.2	15.5	*27.5*	30.1	21.1	12.2	*4.8*	5.4	4.7	3.9	*87.6*	85.6	74.3	63.0
2006	*35.4*	36.7	31.1	25.5	*19.9*	22.7	19.4	16.1	*27.5*	29.8	21.8	13.7	*4.8*	5.3	4.6	3.9	*87.6*	86.5	76.9	67.2
2007	*35.4*	37.0	32.3	27.6	*19.9*	22.4	19.5	16.7	*27.5*	29.6	22.4	15.1	*4.8*	5.3	4.6	3.9	*87.6*	87.3	78.8	70.3
2008	*35.4*	37.1	33.4	29.7	*19.9*	22.3	19.7	17.1	*27.5*	29.3	22.9	16.4	*4.8*	5.3	4.6	3.9	*87.6*	87.9	80.5	73.2
2009	*35.4*	37.0	34.1	31.1	*19.9*	22.1	19.8	17.4	*27.5*	28.8	23.2	17.6	*4.8*	5.3	4.6	3.9	*87.6*	87.8	81.6	75.3
2010	*35.4*	36.9	34.7	32.5	*19.9*	22.1	19.9	17.6	*27.5*	28.4	23.5	18.6	*4.8*	5.3	4.6	3.9	*87.6*	88.1	82.6	77.1
2011	*35.4*	37.3	35.4	33.4	*19.9*	22.1	19.9	17.8	*27.5*	28.3	23.9	19.4	*4.8*	5.3	4.6	3.9	*87.6*	88.7	83.7	78.8
2012	*35.4*	37.2	35.6	33.9	*19.9*	22.0	20.0	18.0	*27.5*	27.9	24.0	20.2	*4.8*	5.3	4.6	3.9	*87.6*	88.3	84.2	80.0

Table 9E Confidence intervals 95% of the catches using strategy 2 during the planning year using stochastic biomass (GAM) and stochastic biomass.

S2	*T.Nilotica catches*				*T.Aurea catches*				*T.Zillii catches*				*T.Galilea catches*				*Tilapia catch*			
Years	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower
1998	*11.4*	0.0	0.0	0.0	*6.2*	0.0	0.0	0.0	*7.9*	0.0	0.0	0.0	*1.5*	0.0	0.0	0.0	*27.0*	0.0	0.0	0.0
1999	*11.4*	0.0	0.0	0.0	*6.2*	0.0	0.0	0.0	*7.9*	0.0	0.0	0.0	*1.5*	0.0	0.0	0.0	*27.0*	0.0	0.0	0.0
2000	*11.4*	17.3	10.9	5.2	*6.2*	10.5	7.1	3.8	*7.9*	12.6	7.2	1.9	*1.5*	2.7	2.1	1.4	*27.0*	36.9	27.3	17.8
2001	*11.4*	15.4	10.8	6.1	*6.2*	8.9	6.6	4.4	*7.9*	11.4	7.2	2.9	*1.5*	2.2	1.8	1.4	*27.0*	33.6	26.4	19.1
2002	*11.4*	14.5	10.9	7.3	*6.2*	8.2	6.5	4.7	*7.9*	10.9	7.2	3.5	*1.5*	2.0	1.7	1.3	*27.0*	32.0	26.2	20.4
2003	*11.4*	13.9	11.0	8.1	*6.2*	7.9	6.4	4.9	*7.9*	10.4	7.3	4.1	*1.5*	1.9	1.6	1.3	*27.0*	31.1	26.2	21.3
2004	*11.4*	13.5	11.2	8.8	*6.2*	7.7	6.3	5.0	*7.9*	10.2	7.4	4.5	*1.5*	1.8	1.5	1.2	*27.0*	30.6	26.4	22.2
2005	*11.4*	13.0	11.2	9.5	*6.2*	7.5	6.3	5.2	*7.9*	9.8	7.5	5.1	*1.5*	1.8	1.5	1.2	*27.0*	29.9	26.5	23.1
2006	*11.4*	12.9	11.5	10.0	*6.2*	7.5	6.4	5.3	*7.9*	9.8	7.6	5.4	*1.5*	1.8	1.5	1.2	*27.0*	30.0	26.9	23.8
2007	*11.4*	12.8	11.5	10.1	*6.2*	7.4	6.3	5.3	*7.9*	9.6	7.7	5.7	*1.5*	1.8	1.5	1.2	*27.0*	29.8	26.9	24.1
2008	*11.4*	12.9	11.6	10.3	*6.2*	7.3	6.3	5.4	*7.9*	9.5	7.7	5.9	*1.5*	1.8	1.5	1.2	*27.0*	29.9	27.1	24.4
2009	*11.4*	12.5	11.6	10.7	*6.2*	7.2	6.4	5.6	*7.9*	9.4	7.8	6.2	*1.5*	1.8	1.5	1.1	*27.0*	29.4	27.2	25.0
2010	*11.4*	12.6	11.6	10.5	*6.2*	7.1	6.3	5.5	*7.9*	9.1	7.7	6.4	*1.5*	1.7	1.4	1.1	*27.0*	29.2	27.1	24.9
2011	*11.4*	12.8	11.7	10.5	*6.2*	7.1	6.4	5.6	*7.9*	9.5	7.9	6.4	*1.5*	1.8	1.4	1.1	*27.0*	29.9	27.4	24.9
2012	*11.4*	12.5	11.7	10.9	*6.2*	7.1	6.4	5.7	*7.9*	9.2	7.9	6.6	*1.5*	1.7	1.4	1.1	*27.0*	29.4	27.5	25.5

Table 10E Confidence intervals 95% of the biomasses using strategy 2 during the planning year using stochastic catches (GAM) and stochastic biomass.

S2	*T.Nilotica biomass*				*T.Aurea biomass*				*T.Zillii biomass*				*T.Galilea biomass*				*Tilapia biomass*			
Years	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower
1998	*35.4*	18.9	8.94	0.6	*19.9*	19.4	11.6	3.9	*27.5*	17.6	10.98	4.4	*4.8*	5.6	4.1	2.6	*87.6*	49.6	35.6	21.6
1999	*35.4*	29.7	14.5	0.6	*19.9*	26.8	17.0	7.2	*27.5*	25.7	16.7	7.8	*4.8*	7.2	5.5	3.7	*87.6*	73.7	53.8	33.8
2000	*35.4*	40.9	22.1	3.3	*19.9*	31.8	22.4	13.1	*27.5*	33.8	23.8	13.8	*4.8*	8.2	6.6	5.1	*87.6*	98.3	75.0	51.7
2001	*35.4*	38.3	23.9	9.6	*19.9*	26.7	20.9	15.1	*27.5*	31.3	23.8	16.3	*4.8*	6.7	5.7	4.7	*87.6*	91.6	74.4	57.2
2002	*35.4*	37.7	26.0	14.3	*19.9*	24.8	20.4	16.0	*27.5*	29.7	23.8	17.9	*4.8*	6.1	5.3	4.5	*87.6*	89.3	75.5	61.7
2003	*35.4*	37.5	27.9	18.3	*19.9*	23.7	20.2	16.6	*27.5*	28.7	24.0	19.4	*4.8*	5.8	5.1	4.3	*87.6*	88.3	77.1	66.0
2004	*35.4*	37.3	29.7	22.1	*19.9*	23.1	20.1	17.1	*27.5*	27.9	24.2	20.4	*4.8*	5.6	4.9	4.2	*87.6*	87.8	78.9	70.0
2005	*35.4*	37.0	31.2	25.4	*19.9*	22.6	20.1	17.5	*27.5*	27.5	24.4	21.3	*4.8*	5.5	4.8	4.1	*87.6*	87.4	80.6	73.7
2006	*35.4*	37.0	32.5	28.0	*19.9*	22.4	20.1	17.8	*27.5*	27.2	24.6	21.9	*4.8*	5.4	4.8	4.1	*87.6*	87.6	81.9	76.3
2007	*35.4*	36.7	33.4	30.2	*19.9*	22.2	20.1	18.0	*27.5*	27.0	24.7	22.4	*4.8*	5.4	4.7	4.0	*87.6*	87.3	82.9	78.5
2008	*35.4*	36.6	34.3	32.0	*19.9*	22.0	20.1	18.2	*27.5*	26.7	24.6	22.6	*4.8*	5.4	4.7	4.0	*87.6*	87.3	83.8	80.2
2009	*35.4*	36.8	35.0	33.2	*19.9*	21.9	20.2	18.4	*27.5*	26.5	24.7	22.8	*4.8*	5.4	4.7	3.9	*87.6*	87.5	84.5	81.4
2010	*35.4*	36.9	35.4	34.0	*19.9*	21.9	20.1	18.4	*27.5*	26.6	24.8	23.0	*4.8*	5.4	4.6	3.9	*87.6*	88.0	85.0	82.0
2011	*35.4*	37.0	35.8	34.5	*19.9*	21.9	20.2	18.5	*27.5*	26.6	24.7	22.9	*4.8*	5.4	4.6	3.9	*87.6*	88.1	85.3	82.5
2012	*35.4*	37.1	35.8	34.6	*19.9*	21.9	20.2	18.5	*27.5*	26.6	24.8	23.0	*4.8*	5.4	4.6	3.8	*87.6*	88.2	85.4	82.7

Table 11E Confidence intervals 95% of the catch using strategy 3 during the planning year using stochastic biomass (GAM) and stochastic biomass.

S 3	*T.Nilotica catches*				*T.Aurea catches*				*T.Zillii catches*				*T.Galilea catches*				*Tilapia catch*			
Years	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower	*MSY*	Upper	Mean	Lower
1998	*11.4*	0.0	0.0	0.0	*6.2*	0.0	0.0	0.0	*7.9*	0.0	0.0	0.0	*1.5*	0.0	0.0	0.0	*27.0*	0.0	0.0	0.0
1999	*11.4*	0.0	0.0	0.0	*6.2*	0.0	0.0	0.0	*7.9*	0.0	0.0	0.0	*1.5*	0.0	0.0	0.0	*27.0*	0.0	0.0	0.0
2000	*11.4*	0.0	0.0	0.0	*6.2*	0.0	0.0	0.0	*7.9*	0.0	0.0	0.0	*1.5*	0.0	0.0	0.0	*27.0*	0.0	0.0	0.0
2001	*11.4*	20.5	11.5	2.6	*6.2*	11.0	8.6	6.1	*7.9*	14.9	8.6	2.3	*1.5*	2.8	2.3	1.8	*27.0*	42.6	31.0	19.5
2002	*11.4*	17.1	10.7	4.4	*6.2*	8.8	7.5	6.1	*7.9*	12.7	8.0	3.4	*1.5*	2.2	1.9	1.6	*27.0*	36.2	28.1	20.0
2003	*11.4*	15.7	10.6	5.4	*6.2*	8.0	7.0	6.0	*7.9*	11.4	7.7	4.1	*1.5*	2.0	1.7	1.5	*27.0*	33.4	27.1	20.7
2004	*11.4*	15.0	10.6	6.3	*6.2*	7.6	6.8	6.0	*7.9*	10.8	7.7	4.5	*1.5*	1.9	1.6	1.4	*27.0*	32.2	26.7	21.2
2005	*11.4*	14.6	10.8	6.9	*6.2*	7.3	6.6	6.0	*7.9*	10.5	7.7	4.9	*1.5*	1.8	1.6	1.4	*27.0*	31.6	26.7	21.7
2006	*11.4*	14.2	10.9	7.6	*6.2*	7.2	6.6	5.9	*7.9*	10.1	7.7	5.3	*1.5*	1.8	1.5	1.3	*27.0*	31.0	26.8	22.6
2007	*11.4*	14.0	11.0	8.0	*6.2*	7.0	6.5	5.9	*7.9*	10.0	7.7	5.5	*1.5*	1.7	1.5	1.3	*27.0*	30.9	26.7	22.6
2008	*11.4*	13.4	11.1	8.8	*6.2*	7.0	6.5	6.0	*7.9*	9.6	7.8	5.9	*1.5*	1.7	1.5	1.3	*27.0*	30.0	26.9	23.7
2009	*11.4*	13.1	11.1	9.2	*6.2*	7.0	6.5	5.9	*7.9*	9.5	7.8	6.1	*1.5*	1.7	1.5	1.2	*27.0*	29.8	26.9	23.9
2010	*11.4*	13.2	11.3	9.4	*6.2*	7.0	6.4	5.9	*7.9*	9.4	7.8	6.2	*1.5*	1.7	1.5	1.2	*27.0*	29.7	27.0	24.4
2011	*11.4*	12.7	11.2	9.7	*6.2*	7.0	6.4	5.8	*7.9*	9.2	7.8	6.4	*1.5*	1.7	1.5	1.2	*27.0*	29.4	26.9	24.4
2012	*11.4*	12.8	11.4	9.9	*6.2*	7.0	6.4	5.9	*7.9*	9.1	7.9	6.6	*1.5*	1.7	1.5	1.2	*27.0*	29.4	27.1	24.8

Table 12E Confidence intervals 95% of the biomasses using strategy 3 during the planning year using stochastic catches (GAM) and stochastic biomass.

S3	*T.Nilotica biomass*				*T.Aurea biomass*				*T.Zillii biomass*				*T.Galilea biomass*				*Tilapia biomass*			
Years	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower	*BMSY*	Upper	Mean	Lower
1998	*35.4*	18.3	8.92	0.4	*19.9*	19.4	11.6	3.8	*27.5*	17.9	10.60	3.3	*4.8*	5.6	4.0	2.5	*87.6*	49.5	35.1	20.8
1999	*35.4*	28.9	14.5	0.2	*19.9*	26.9	17.0	7.0	*27.5*	26.7	16.1	5.6	*4.8*	7.3	5.4	3.6	*87.6*	73.9	53.0	32.2
2000	*35.4*	40.2	22.2	4.1	*19.9*	31.9	22.3	12.8	*27.5*	35.0	22.8	10.5	*4.8*	8.3	6.6	4.9	*87.6*	98.8	73.9	48.9
2001	*35.4*	49.0	31.3	13.5	*19.9*	33.8	26.8	19.8	*27.5*	41.0	29.7	18.3	*4.8*	8.6	7.4	6.1	*87.6*	118.8	95.1	71.4
2002	*35.4*	42.6	31.5	20.4	*19.9*	27.3	23.4	19.5	*27.5*	33.7	27.4	21.1	*4.8*	6.8	6.0	5.3	*87.6*	102.4	88.4	74.3
2003	*35.4*	40.3	32.2	24.2	*19.9*	24.8	22.1	19.3	*27.5*	30.6	26.2	21.9	*4.8*	6.1	5.5	4.9	*87.6*	96.0	86.0	76.0
2004	*35.4*	38.9	33.0	27.1	*19.9*	23.5	21.4	19.2	*27.5*	29.2	25.7	22.2	*4.8*	5.7	5.2	4.7	*87.6*	92.7	85.2	77.7
2005	*35.4*	38.1	33.9	29.6	*19.9*	22.7	20.9	19.1	*27.5*	28.2	25.3	22.5	*4.8*	5.5	5.0	4.5	*87.6*	90.8	85.1	79.5
2006	*35.4*	37.3	34.5	31.7	*19.9*	22.3	20.7	19.1	*27.5*	27.5	25.1	22.8	*4.8*	5.4	4.9	4.3	*87.6*	89.3	85.2	81.2
2007	*35.4*	36.9	34.8	32.7	*19.9*	22.0	20.5	19.0	*27.5*	27.0	24.9	22.8	*4.8*	5.4	4.8	4.2	*87.6*	88.4	85.0	81.7
2008	*35.4*	36.9	35.0	33.2	*19.9*	22.0	20.4	18.8	*27.5*	26.8	24.7	22.7	*4.8*	5.4	4.7	4.1	*87.6*	88.0	84.9	81.8
2009	*35.4*	36.8	35.2	33.7	*19.9*	21.9	20.3	18.7	*27.5*	26.7	24.7	22.7	*4.8*	5.4	4.7	4.0	*87.6*	87.8	84.9	82.0
2010	*35.4*	36.7	35.4	34.0	*19.9*	21.9	20.2	18.6	*27.5*	26.6	24.8	23.0	*4.8*	5.4	4.6	3.9	*87.6*	87.8	85.0	82.2
2011	*35.4*	36.8	35.8	34.8	*19.9*	21.8	20.2	18.6	*27.5*	26.5	24.5	22.6	*4.8*	5.4	4.6	3.9	*87.6*	87.7	85.2	82.7
2012	*35.4*	36.8	35.8	34.8	*19.9*	21.8	20.2	18.6	*27.5*	26.5	24.7	22.9	*4.8*	5.4	4.6	3.8	*87.6*	87.8	85.3	82.8

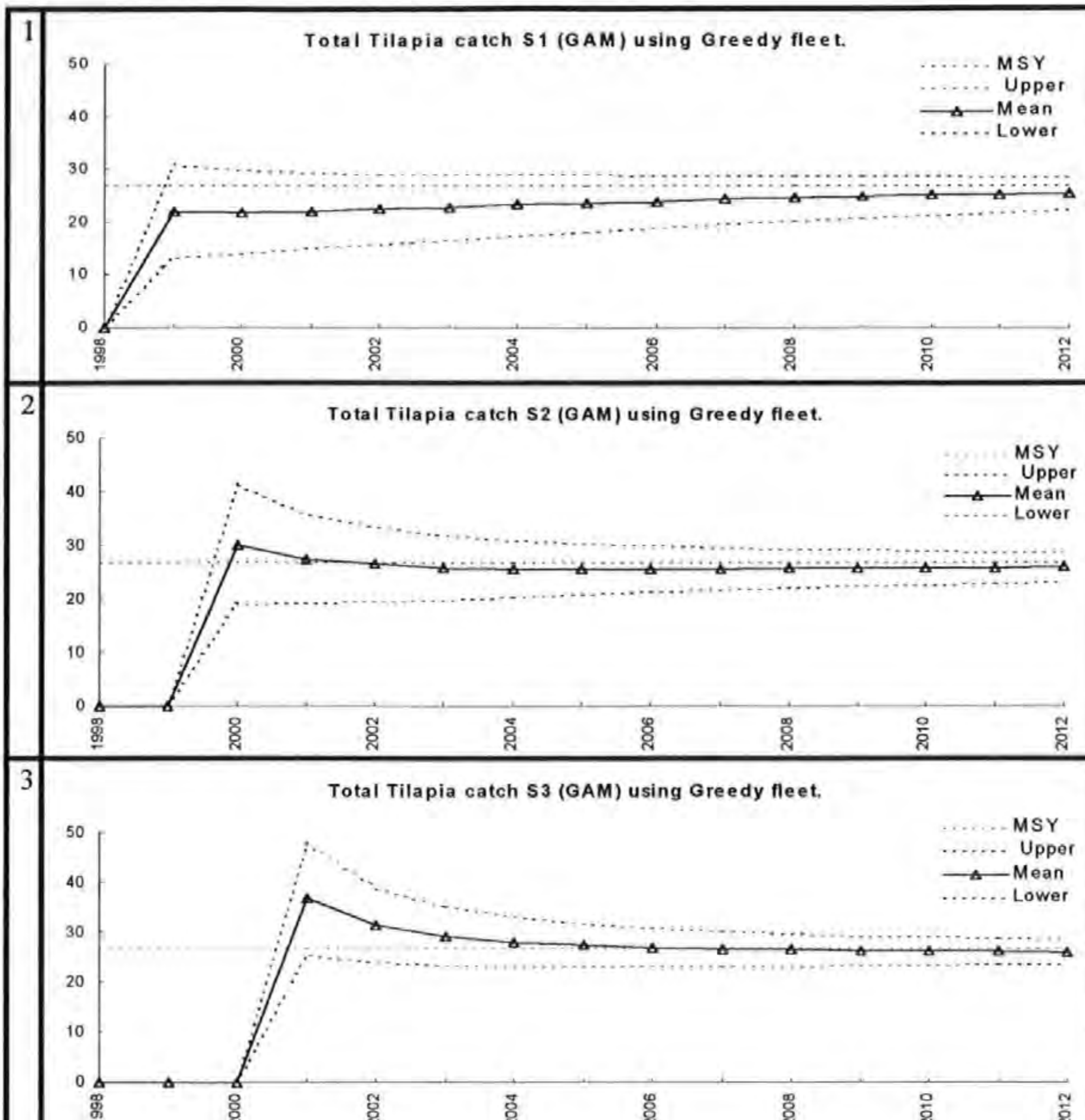


Figure 13E The upper and lower limits of 95% confidence interval of stochastic catch and *MSY* with stochastic biomass for *Total Tilapia* using *Greedy fleet* for each catch strategy (1) S1, (2) S2 and (3) S3 with GAM.

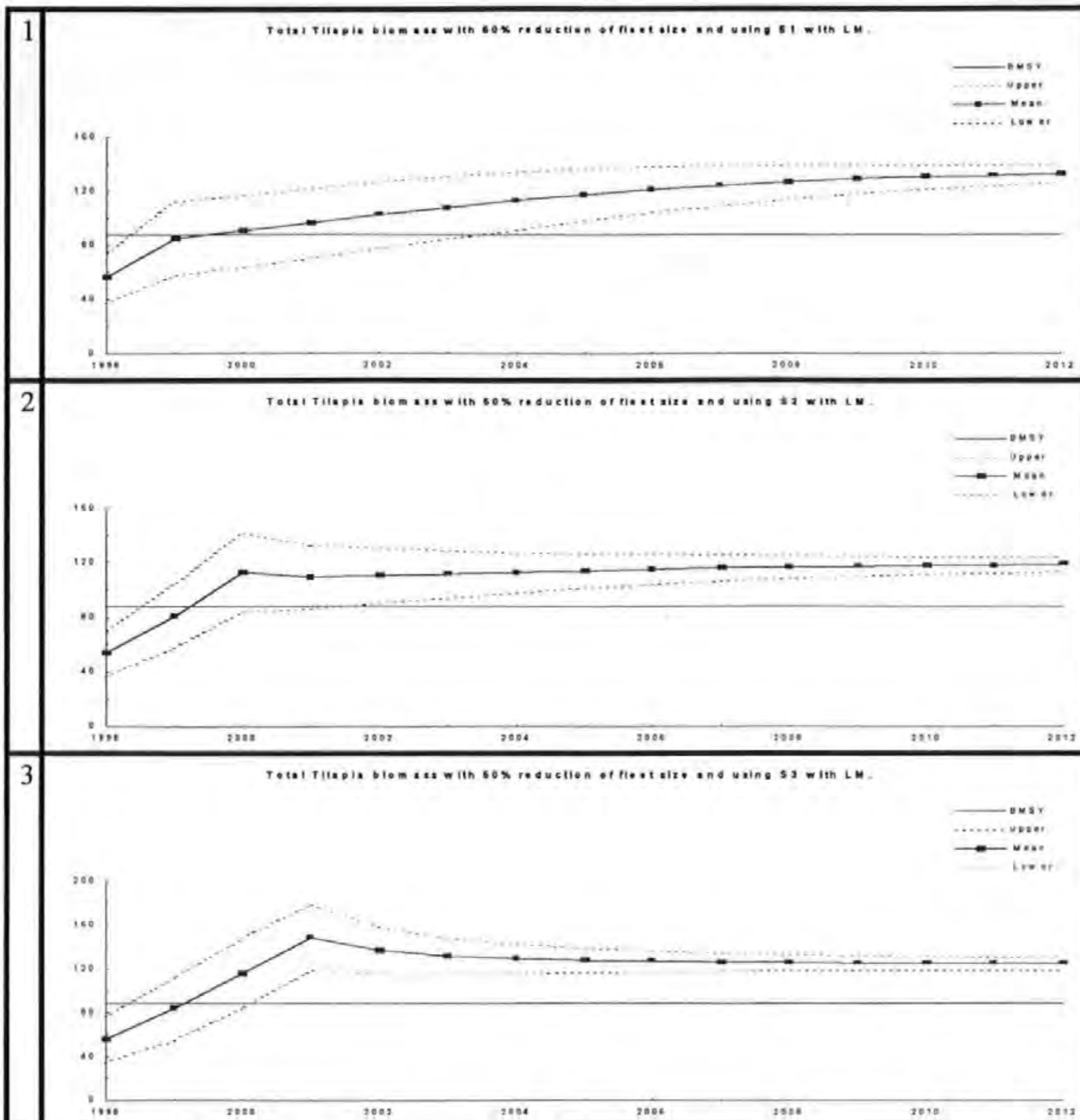


Figure 14E The upper and lower limits of 90% confidence interval of stochastic biomass and *Total BMSY* (multiple regression model) of *Total Tilapia* species using 50% of the *Projected fleet size* for the three catch strategies (1) Strategy 1, (2) Strategy 2 and(3) Strategy 3.