FISHERIES TRAINING PROGRAMME
P.O. Box 1390, Skulagata 4
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Final Project 2007

MARINE FISHERIES RESOURCE MANAGEMENT POTENTIAL FOR MACKEREL FISHERIES OF CAMBODIA

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ABSTRACT

This paper estimates the maximum sustainable yield, virgin stock biomass and maximum economic yield of the mackerel fishery in Cambodia. Schaefer and Fox used the bio-economic, surplus production and biomass dynamic to determine the optimal utilisation of mackerel stocks. The estimated MSY is equal to 5,876 tonnes with an optimum level of effort corresponding to approximately 152 boats. The virgin stock biomass is at a level of 15,467 tonnes. The maximum profit and economic rents is estimated at US$ 2 million per annum. The paper examines alternative policies to reduce fishing effort in the inshore waters of Cambodia and improve the capacity of fishing vessels in offshore areas. The discussion emphasises initiating a cooperation policy between countries in the Gulf of Thailand for a cooperative management regime for the (residential) migratory species of mackerel. Therefore it is urgent to carry out a regional policy.

Keywords: potential for mackerel fisheries of Cambodia, maximum sustainable yield.

ACRONYMS

APIP	-	Agriculture Productivity Improvement Project
CFDO	-	Community Fishery Development Office
CPUE	-	Catch Per Unit Effort
DoF	-	Department of Fisheries
EEZ	-	Exclusive Economic Zone
FAO	-	Food and Agriculture Organization
FiA	-	Fisheries Administration
FJS	-	Fisheries Judicial System
FMR	-	Fisheries Management Regime
FMS	-	Fisheries Management System
GDP	-	Gross Domestic Production
hp	-	Horse power
HDR	-	Human Development Resource
IOs	-	International Organization
MAFF	-	Ministry of Agriculture, Forestry and Fisheries
MCS	-	Monitoring, Control & Surveillance
MEY	-	Maximum Economic Yield
MoP	-	Ministry of Planning
MoT	-	Ministry of Tourism
MSY	-	Maximum Sustainable Yield
NACA	-	Network of Aquaculture Centres in Asia-Pacific
NGOs	-	Non-Governmental Organization
OSY	-	Optimum Sustainable Yield
PPP	-	Purchasing Power Parity
SEAFDEC	-	Southeast Asian Fisheries Development Centre
TAC	-	Total Allowable Catch
UNDP	-	United Nations Development Programme
USA	-	United State of America
US$	-	United State Dollars

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1 INTRODUCTION

1.1 Problem statement

The rapid expansion of fisheries in the Gulf of Thailand, as well as in Cambodia has raised considerable economic and environmental concerns about their management. Modern technology has increased fishing capacity resulting in the decline of the resources and operations have become less profitable. This manifests itself in the increasing proportion of undersized fish and decreasing volume of commercially important species in the Gulf. Mackerel species are commercially valuable fish in the Gulf and contribute significantly to the marine fish production of most countries sharing the Gulf. Since the introduction of trawling, gillnets, driftnets and purse seines in the 1960s, the total landing of mackerel in the Gulf of Thailand increased and a peak production of around 140,000 tonnes was reached in 1968. Subsequently, catches gradually declined to the lowest level of 6,000 tonnes in 1978 (Sea Around Us 2005).

In Cambodia, where the major fishing effort is directed at the exploitation of these species, they have been subjected to increasing exploitation. A substantial effort is made to improve landing records and assess the status of the species for management purposes. However, for neighbouring countries, which have established fisheries for these species, even primary estimates are not available and exploitation continues without any knowledge of the trend.

Nowadays, these species play an important role for the marine fisheries sector, not only in Cambodia but also countries in the Gulf. They affect the fishermen as well as the local population, whose income relies on revenues from fishing. In general, the resources of the Gulf have declined due to over exploitation. However mackerel is a migratory species so local situations do not necessarily reflect the overall development. Landings of marine products in Cambodia have gradually increased in recent years. Particularly, landings of mackerel species have increased from roughly 1,000 tonnes in the 1990s to over 4,000 tonnes in the 2000s (FiA 2007). Due to relative stock abundance in Cambodian waters, other countries such as Thailand and Vietnam are major participants in the fishing in Cambodian waters. On the other hand, the capacity of the Cambodian offshore fishing fleet is small compared to the possible stock exploitation. A significant increase in Cambodian fishing and landings is possible by stricter regulations and monitoring of foreign fishing vessels.

1.2 Objective of the study

The objective for this study is to determine the biological and economic potential for the mackerel fishery in Cambodian waters by estimating biomass, optimum sustainable yield (OSY) and virgin biomass. The estimation of maximum economic and sustainable yield (MEY-MSY) is based on the steady-state relationship between resource stock size, fishing effort, and yield, adapted from Schaefer (1957) and Fox (1970) (Arnason, R. and Bjordal, T. 1991). This methodology is widely known as bio-economic modelling. It is a commonly used surplus production model for multi-species fisheries in the tropics. This approach outlines the effects of policy and management systems for fisheries economic growth.

The purpose of this study is to provide a current bio-economic analysis of the mackerel fishery in Cambodian waters and to estimate both economic and biological maximum levels of yield and effort given the nature of the fishery and the lack of joint management of the resource with other nations in the Gulf of Thailand. Corresponding measures to manage the mackerel species in Cambodia will be discussed, as well as implications for the management of the stock in the whole of the Gulf. This study attempts to put together available information from the fisheries to assess the current situation and to express views that are likely to stimulate further investigations to better understand and manage the resources.

1.3 Significance of the study

FAO (1999) indicates that the Gulf of Thailand is among the most productive fishing grounds in the world and APIP (2001b) states that Cambodia's coastal area is the most productive in the Gulf (Gillett, R. 2004). In fact, the total volumes of Cambodia's catches in the Gulf are probably low and low per unit compared to Thailand and Vietnam. The marine fishery of Cambodia is multi-species, and the main commercial species include mackerels, scads, anchovies and snappers, which are exploited from September to January.

Mackerels are coastal pelagic fish, which include short mackerel, Indian mackerel, island mackerel and king mackerel exploited in the late 1940s. At present, driftnets, purse seines and gillnets are common gears which fishermen use to catch mackerel. These fish have been caught mostly by Cambodia, Malaysia, Thailand and Vietnam from the Gulf of Thailand. However, situations of biomass growth, stock size, and environmental carrying capacity for mackerel species are not available.

Hopefully, this study will provide recommendations on sustainable biomass growth, sustainable harvesting and optimum fishing effort as well as suggestions on the necessary adjustments to policy in the marine fisheries sector in order to increase catchability and improve the management system of production. This is of great importance to the fisheries administration, fishermen associations and the current operation and management system.

1.4 Organisation of the study

The organisation of this paper is as follow: Chapter 2 provides a background the marine fisheries and the management system. Chapter 3 reviews the principles of fisheries management. Chapter 4 summarises the bio-economic model – the Gordon Schaefer model used to predict or estimates of maximum sustainable yield and optimal sustainable yield of mackerel fisheries. The data and results of estimation are presented in chapter 5. Chapter 6 discusses of optimum sustainable yield and fisheries economics. Chapter 7 discusses fisheries issues and Chapter 8 provides conclusion and recommendations to outline policy for Cambodian marine fishery sector and the Gulf of Thailand.

2 BACKGROUND

2.1 Country profile

Cambodia is a tropical country located in Southeast Asia, well known for its rich natural resources, especially in forestry and fisheries. These resources play an important role in the national economy. Agriculture is the main contributor to the national economy. Rice and fish products have been considered as the major means of generating food. The agricultural sector, including rice farming, livestock, fisheries, forestry, and cultivation of other cash crops, provides direct employment to 70.6 percent of Cambodia's labour force. Its share of the GDP decreased from some 45.2 percent in 1998 to 35.1 percent in 2005 (MoP 2006). The GDP in 2005 was about US$ 350 per capita, which places Cambodia as one of the poorest countries in the world where the daily income is less than US$ 1 (Table 1). Cambodia is ranked 131 out of 177 countries in achievement made in human development, with a GDP per capita (Purchasing Power Parity) of US$ 2,727 (UNDP-HDR 2007/2008).

Table 1: Demographic, geographic and economic information for Cambodia. (MoP 2006).

Total geographical area	181,035 km^2.
Population	13.7 million in 2005
Annual population growth rate	1.81% in 2005
Share of rural population	85% in 2005
Labour force, 10 years and above	7.5 million in 2004
Share in employment (2004)	
Agriculture	35.1%
Industry	26.3%
Service	38.6% (2006 est.)
Per capita GDP (US$)	350 in 2005
Annual GDP growth rate (constant prices)	7% in 2005

Agriculture, Forestry and Fisheries

Key indicator	Unit	1993	2000	2005 Estimates	2010 Projected
Annual GDP (constant prices)	Billion riels	8,494	14,089	19,294	25,747
Share of GDP:					
: Paddy & crops	%	18.8	16.5	14.2	12.7
: Livestock and poultry	%	8.9	5.4	4.6	4.3
: Fisheries	%	13.6	10.8	9.3	8
: Forestry	%	4.3	3.3	2	1.6

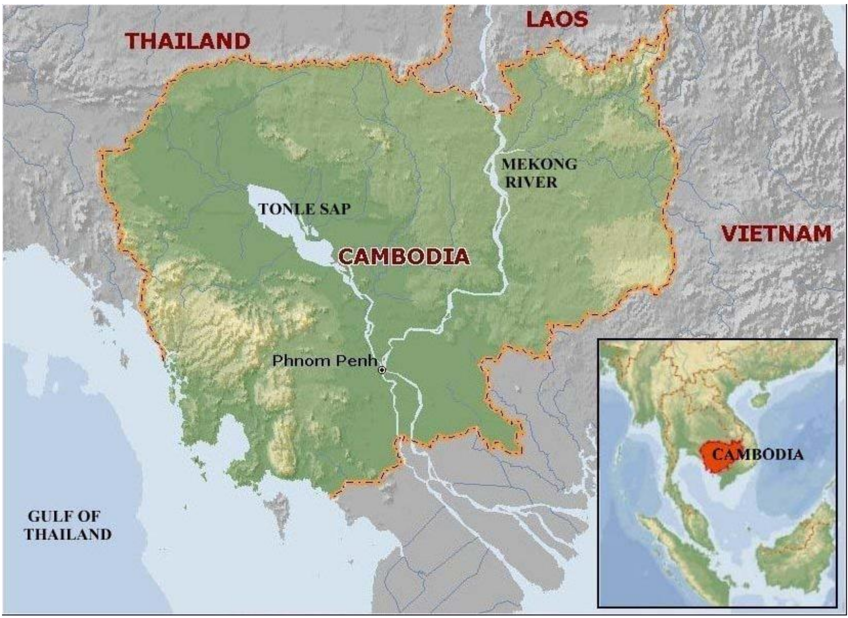

Figure 1: Map of Cambodia

2.2 Overview of the Cambodian marine fisheries sector

The marine fish stocks are a heavily exploited resource due to the high density of the coastal population around the Gulf of Thailand. Cambodia has a marine coastline of 435 km which covers two cities and two provinces. The Exclusive Economic Zone (EEZ) covers approximately 55,600 km^2 and is relatively shallow with an average depth of about 50 m. The marine fishing grounds are located on the eastern bank of the Gulf of Thailand. There are 525 species of marine finfish, 20 species of marine crabs, 42 species of marine gastropods, 24 species of marine bivalves and 11 species of marine mammals (Tana 1997, Try 2003). Marine fisheries development has been slow compared to the inland fisheries which are yielding approximately 400,000 tonnes of fish annually. The landed catch of marine fisheries was estimated at around 60,000 tonnes in 2006 (FiA 2007).

Figure 2: Map of the coastal areas of Cambodia

2.2.1 Marine catches

The Department of Fisheries statistics (2004) cited by the Community Fishery Development Office (CFDO 2005) reports that the annual marine catches were estimated at about 36,000 tonnes in 1994 – 2000. This number excludes the catches of subsistence and illegal foreign fishing. The Fisheries Administration has estimated the increase in fish production from 36,000 tonnes in 2000 to 60,500 tonnes in 2006 (Table 2) which includes catch in mangrove areas due to the fact that the harvest of mangroves is covered by the present fisheries law.

In fact, the actual catch of marine fisheries is higher than the official statistics suggest. This is because the catches from subsistence fishing, including family-scale fisheries, are largely unrecorded. Furthermore, catches from illegal fishing activities are not recorded. Csavas *et al.* (1994) state that information on the landing of marine fish in Cambodia can be inferred from records of fish landings from the Thai portion of the Gulf of Thailand. This is partly due to the Thai vessels fishing in Cambodian waters and some Cambodian fishing boats selling or transferring their catch to Thai mother-vessels at sea or landing in Thai ports. According to the DoF internal reports, catches from licensed Thai vessels in Cambodian water are estimated to be from 26,500 tonnes to 37,500 tonnes (Gillett 2004). Robert (Gillett, R. 2004) also concluded that if this is indeed the case, this amount would approach the total marine catch recorded for all Cambodian fishing vessels operating offshore. Substantial Thai catches in Cambodian waters complicate any management strategy for Cambodian fish resources because of difficulties associated with ensuring that rents from improved Cambodian management actually benefit Cambodian fishermen and not only the less regulated Thai fishing fleet.

The marine fishery involves coastal fishers in inshore areas and foreign fishers operating legally and illegally in offshore areas (NACA 2004). Cambodia currently does not have the capacity to exploit offshore areas. Since 1992, marine fisheries statistics have included estimates of catches by foreign fishers licensed to operate in the EEZ of Cambodia (DoF 2001d).

Table 2: Total fishery production, inland and marine fishery from 2000-2006 (FiA 2007)

Year	Total (tonnes)	Inland (ton)				Marine (tonnes)
		Total	Commercial fisheries	Family/subsistence fisheries	Rice field fisheries	
2000	281,600	245,600	85,600	110000	50,000	36,000
2001	427,000	385,000	135,000	140,000	110,000	42,000
2002	406,150	360,300	110,300	140,000	110,000	45,850
2003	363,500	308,750	94,750	120,000	94,000	54,750
2004	305,800	250,000	68,100	106,400	75,500	55,800
2005	384,000	324,000	94,500	137,700	91,800	60,000
2006	482,500	422,000	139,000	181,000	102,000	60,500

2.2.2 Catch by species and finfish production

Finfish is the main group of annual total catches by year (Table 3). Try (2003) indicated that 33 species of finfish are commonly exploited. Only five species are very abundant in the landings: *Megalaspis cordyla* (torpedo scad), *Scomberomorus commersoni* (narrowbarred Spanish mackerel), *Rastrelliger brachysoma* (short mackerel), *Rastrelliger kanagurta* (Indian mackerel) and *Atule mate* (yellowtail scad). The volume of finfish caught in 2006 decreased slightly compared to 2005, but the total catches have increased in 2006 as *Anadromous* fish (3,678 tonnes), were not record in 2005.

The catches of trash fish each year rank the second after finfish (Table 3). In 1960 the trawl gear was introduced to fishers in Cambodia that allows for catch of demersal fish and juveniles. During the past three decades, trash fish was discarded due to no demand and no value in the market. But after 1993 a factory was built in Sihanoukvill for processing trash fish for fish feed. Therefore, fishers catch and collect the trash fish resulting in that the volume of trash fish has recently increased.

As the market price of economic fishes has gradually been increasing trash fish have become food for local people, and particularly the poor coastal dwellers who have a low income. According to Try (2006), it was estimated that the trash fish caught by trawl in 1980 is about 30-40% of the total catch, but the percentage of trash fish was recently increased probably to 60-65% of marine fish catches by trawl. It seems that to be encouraging the fishers use a more efficient gear to fish in inshore waters than offshore. Perhaps they are also using illegal fishing gears such as trawlers, mosquito net push, and small mesh sizes of nets catching all fish species and sizes. The marine fish catches in 2006 have declined for all groups except shrimp from 2005 (Table 3).

Table 3: Statistics of marine fisheries caught by groups in Cambodian coastal waters (in tonnes), (Try *et al.* 2006 and FiA 2007).

Year	Finfish	Trash fish	Shrimp/ prawns	Rays	Squid/ cuttlefish	Lobsters	Crabs	Gastropods	Sea slug	Anadromous fish	Total marine fishery
2000	15,526	9,833	2,905	245	2,627	59	3,593	801	11	410	36,010
2001	16,873	10,847	3,872	209	2,355	40	3,462	3,681	0	661	42,000
2002	18,910	11,752	3,827	553	2,681	122	3,545	3,007	3	1,410	45,810
2003	26,596	14,859	4,055	727	3,577	169	4,028	648	2	61	54,722
2004	25,639	16,570	3,824	620	2,984	124	3,458	2,457	0	124	55,800
2005	26,141	18,265	4,124	996	3,723	1,233	4,301	1,215	2	0	60,000
2006	25,641	17,194	4,778	476	3,551	115	4,180	897	0	3,678	60,500

Almost 90% of the marine fisheries production in Cambodia is from two coastal provinces, Sihanoukvill and Koh Kong (Table 4). The total catches of finfish are mackerel fish amount 4,650 tonnes (FiA 2007). The trash fish is second in rank among the group species caught, of which Koh Kong and Sihanoukvill rank at the top.
Table 4: Statistics of marine product of four main coastal areas 2006 (FiA 2007)

City/ province	Finfish	Trash fish	Shrimp/ prawns	Rays	Squid/ cuttlefish	Lobsters	Crabs	Gastropods	Anadromous fish	Total marine fisheries
Kampot	2,103	1,674	386	32	130	5	635	415	2,000	7,380
Kep	300	-	35	5	10	-	45	17	18	430
Koh Kong	13,519	10,500	1,622	89	1,100	-	2,000	280	160	29,270
Sihanoukvill	9,709	5,020	2,735	350	2,311	110	1,500	185	1,500	23,420
Total	25,631	17,194	4,778	476	3,551	115	4,180	897	3,678	60,500

2.2.3 Costal fishers and employment

Most coastal fishers are poor and generally use small-scale fishing gear that is only adequate for use inshore and in mangroves. There are limited numbers of coastal fishers that have sufficient capital to invest in the necessary vessels and gear for offshore fishing. The capacity of fishers fishing offshore in the EEZ is not large compared to the potential exploitation.

Officially, the statistics of fisheries employment have shown only the number of people involved in fisheries harvesting, processing and culturing. There are no statistics on other numbers of people employed in fisheries related activities. The number of fishers and the number of fish processor is reflected in Table 5 below:

Table 5: Statistics of fishers and processors, 1999-2006 (DoF's Statistics 2000-2006)

Year	**Harvesting labour force in marine sector**						**Processing labour force**	
	Family/rice field		**Mobile/artisanal Fisheries**		**Total fishers**			
	No of families	No of fishers	No of families	No of fishers	No of families	No of fishers	No of families	No of processors
1999	0	0	3,910	11,721	3,910	11,721	373	1,527
2000	0	0	6,557	14,647	6,557	14,647	379	1631
2001	6,445	8,067	4,137	15,350	10,582	23,417	370	1499
2002	24,818	45,940	9,648	26,130	34,466	72,070	1,472	2,379
2003	16,047	28,638	13,159	40,014	29,206	68,652	990	1,815
2004	16,475	31,657	10,865	33,274	27,340	64,931	1,407	4,234
2005	-	-	-	-	-	-	-	-
2006	18,949	37,990	12,006	36,582	30,955	74,572	1,226	29,412

2.2.4 Number of vessels

Non-motorised and motorised vessels are used in Cambodia's marine fisheries. Most non-motorised vessels are used by the small-scale fishers who carry out subsistence fishing. The Fisheries Department has statistically categorised the non-motorised vessels based on their dead weight. The three categories are: less than 5 tonnes, more than 5 tonnes and Duk-boats, but the Duk-boat is not directly used for fishing (i.e., it is used for transporting the fisheries products).

The motorised vessels are divided into four categories based on engine power: less than 10 hp, 10 to 30 hp, 30 to 50 hp, and more than 50 hp. This classification does not include data on the number of vessels involved in small-scale and large-scale fisheries.

The number of non-motorised vessel in 2000 was only 255 and increased to 841 boats in 2002 operating within Cambodia's coastal zone, then it dropped dramatically to 272 boats in 2004 and increased again to 821 boats in 2005 and 1,059 boats in 2006 as illustrated in Figure 3.

Noticeably, the number of motorised fishing vessels seems to increase linearly from 5,037 boats in 2000 to 7,027 boats in 2005 and drop to 6,236 boats in 2006. Most of the motorised fishing vessels with large fishing gears are required to have licenses to operate. Two systems exist of motorised fishing vessels licenses: one is a license issued by the provincial fisheries office for all motorised vessels equipped with engine power under 33 horse power (hp) and another is a license issued by the Fisheries Administration for all motorised vessels equipped with an engine power above 33 horse power (hp).

Referring to regulations on offshore and inshore vessels, it can be assumed that all the motorised vessels, which have small engine power (below 50 hp), and non-motorised vessels operate inshore. Motorised vessels equipped with engine power greater than 50 hp should operate offshore.

Fishing vessels equipped with engine power higher than 50 hp may use a labour force from 5 to 15 people depending on the fishing gear used. For boats with an engine power higher than 100 hp, the labour force may be 15 to 30.

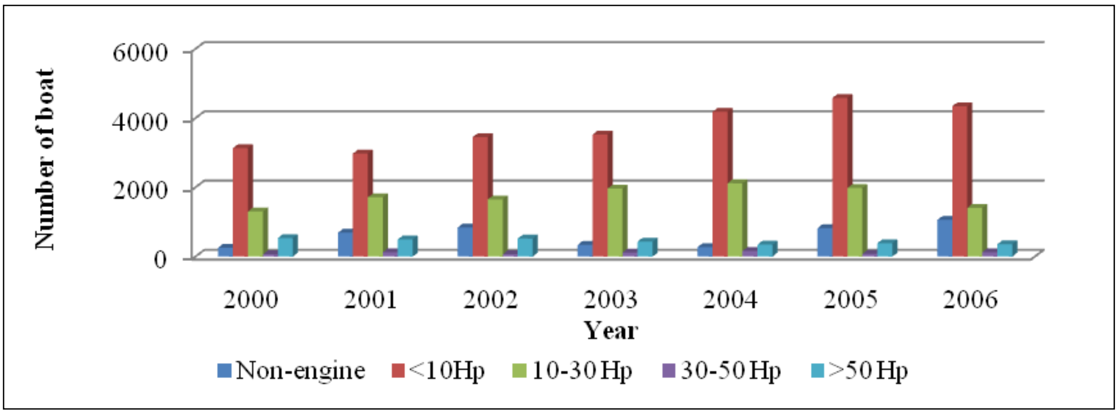

Figure 3: Number of marine fishing vessel from 2000-2006 (FiA 2007)

2.2.5 Annual contribution of marine fisheries to the economy

According to a government report, the marine capture fishery has increased from 36,000 tonnes in 2000 to 60,500 tonnes in 2006 (Table 2). Thus the average marine capture fishery was around of 50,700 tonnes per year from 2000 to 2006. Try *et al.* (2006) mentioned that the average market price of marine fish is US$ 1 per kg. The marine capture fishery can be estimated to value US$ 50.7 million a year at the market site. If the tourism industry in Cambodia shows a steady increase of 20% yearly (MoT 2007), the demand for food consumption for tourists will increase. This leads to an increase in the domestic market price of marine fish in Cambodia and the marine capture fisheries in 2006 can be estimated to value in total revenue around US$ 63.5 million. According to Try *et al.* (2006) the capture marine fishery values account of US$ 15 million to US$ 30 million, excluding the illegal export which is un-reported. This estimation was at the average market price of trashfish at 500 Cambodian Riels per kg. The share of fisheries in the GDP or government revenue was 10.8% in 2000 and the estimate for 2005 is 9.30% (Table 1).

2.2.6 Fisheries landing ports

Landing locations are not separated from fishing locations and harbour facilities are limited. Much of the catch is transferred to Thai vessels at sea for landing in Thailand (FAO 2005). Landing sites of four main coastal areas are used for statistics a total of about 131 locations landings exist: in Sihanoukvill 69, Koh Kong 55, Kampot 4 and

Kep City 3. Most landing ports are small and rural, services and facilities are poor. It may be concluded that fishery landing ports of four main coastal provinces are not of interest to the private sector to invest in, rather these are subsidised by the government.

2.3 Mackerel fisheries

Mackerel consists of commercial pelagic groups which include short mackerel, Indian mackerel, Indo-Pacific mackerel, Spanish mackerel and island mackerel. They are the most important pelagic species in the Gulf of Thailand harvested by commercial and traditional gears. The local name "Plathu, Kamong" is used loosely to refer to all these fish species.

2.3.1 Mackerel production

The highest recorded annual landing of mackerel *(Rastrelliger)* was 139,220 tonnes and contributing 14% to all the marine fish landed in 1968 in the whole Gulf of Thailand. Second to this, 122,156 tonnes or 11% of the marine fisheries landings were recorded in 1969 (Sea Around Us 2005). These species supported the purse seine and gillnet fisheries since the early 1960s and have remained important until now. In fact, mackerel is the most dominant commercial food fish in the Gulf of Thailand.

The catch of mackerel declined from about 40,000 tonnes in the 1950s to around 20,000 tonnes in the 1980s. An unusually sharp increase in catch occurred though in 1965-1971 when the catch reached 140,000 tonnes. The pressure from the industry in Thailand has resulted in overexploitation. Ahmed *et al.* (2007) state that "for a number of decades fisheries development in the Gulf of Thailand has concentrated on increasing fishing effort to maintain or increase the production volume". Most important pelagic fish in the Gulf of Thailand are fully exploited, especially, Indo-Pacific mackerel, anchovies, round scad and sardines and demersal resource stocks are over-fished (FAO 1995).

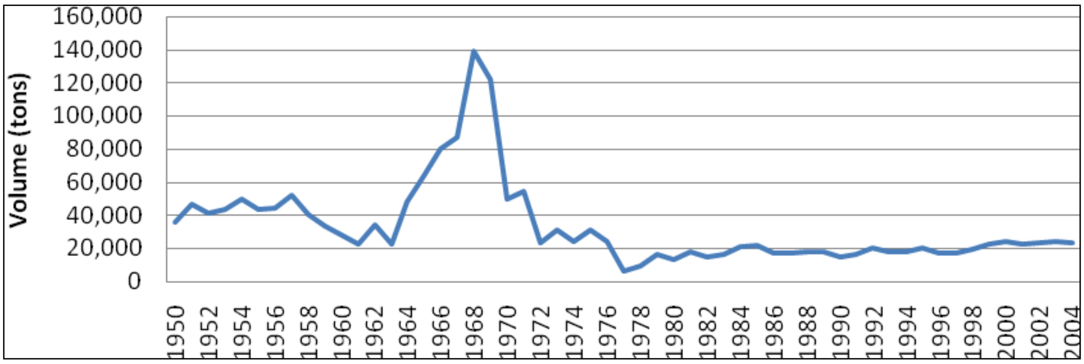

Figure 4: Volume of mackerel caught in the Gulf of Thailand from 1950-2004 (Sea Around Us 2005).

2.3.2 Mackerel fisheries exploitation and its catch effort in Cambodia

Mackerel is not only sold on the domestic market but is also exported to Thailand every year both fresh and processed. Mackerel in Cambodia is caught by artisanal fishermen as well as the industrial fishery. The artisanal fishery operates from small boats with outboard engines of less than 33 hp. Most of these fishing boats use gillnets to catch in inshore areas. The industrial mackerel fishery is operates offshore using purse seines or driftnets with boat engines up to 50 hp. The commercial fishing boat can stay at sea fishing 2 to 5 days. This type of boat has facilities to keep fish for long time.

Since 1990, the catch of mackerel by Cambodia had increased from about 1,000 tonnes to 4650 tonnes in 2006 (Table 6). From 2002 to the present the catch has been stable at around 4,500 tonnes but the effort has increased with a corresponding reduction in CPUE.

The gillnet boats fish for mackerel approximately 25 days a month, 8 months a year. The purse seine operates only during the dry season period of 5 months (20 days per month). The purse seine boats have crews of about of 15 to 30 people. The gillnet boats can on the other hand operate with a labour force of only 2 to 3 people.

Table 6: Volume caught, fishing effort and CPUE of mackerel from 1990-2006 (FiA 2007)

Year	Catches volume (tonnes)	Fishing effort						CPUE (Kg/person /day)
		Boat used gillnet		Boat used purse seine		Total boat	Total labour	
		Boat	Labour (person)	Boat	Labour (person)			
1990	1,395	-	-	-	-	-	-	-
1991	1,212	-	-	-	-	-	-	-
1992	1,101	3	9	13	260	16	269	40
1993	1,424	9	27	14	280	23	307	43
1994	1,513	31	93	15	300	46	393	31
1995	1,683	10	30	16	320	26	350	44
1996	1,452	14	42	6	320	30	362	36
1997	1,278	114	342	15	300	129	642	13
1998	1,447	122	366	15	300	137	666	14
1999	1,738	172	516	8	160	180	676	15
2000	1,559	155	465	10	200	165	665	14
2001	1,731	56	168	10	200	66	368	32
2002	4,300	50	150	10	200	60	350	86
2003	4,421	73	219	13	260	86	479	63
2004	4,764	117	351	10	200	127	551	53
2005	4,906	250	750	4	80	254	830	31
2006	4,650	181	543	6	120	187	663	39

2.3.3 Mackerel fish processing products

The mackerel in Cambodia is traditionally processes by salted or steaming. For steamed fish “short body mackerel” is the local name called as Trey Chom Houy, but for salting “Spanish mackerel” is used, the local name is Trey Borb. Most production is for the domestic market. Data is limited on export.

2.3.4 Marketing and price of mackerels

Locally, the price of mackerel and its products can be different between markets throughout the land. However, the difference between the markets of the four Cambodian coastal areas is small. The Sihanoukville market site is the main distribution centre of marine fisheries products into the local market, thus the market price of Mackerel fishes and its products in Sihanoukvill can be assumed as the local market standard price of Mackerel fishes and its products. According to monthly reports of the Marine Fishery Division the price of mackerel at the landing site and domestic market is actually increasing, especially in the wet season when catch is small and but demand is high.

In 2006, the price of short mackerel at the landing site from January to September fluctuated from US$ 450 to US$ 625 per tonne[1] (Figure 5). Based on data estimated by the Fishery Administration, the landing volume of mackerel species in 2006 was about 4,650 tonnes and can be estimated at around US$ 2.52 million or 4% of the marine fishery revenue in 2006. Spanish mackerel is selling at a high price at the landing and market site, but the landing volume is small compared to short mackerel. The landing price of Spanish mackerel within a 9 month period in the year 2006 fluctuated increasingly from US$ 1,375 to US$ 3,500 per tonne. Figure 5 illustrates the price of short mackerel and Spanish mackerel correlated at two sites, domestic market and local landing site.

In general, the price of marine fish at landing as well as market site has increased over the years, due to an increase in the fishing operational cost. Moreover, increased population leads to high market demand for human consumption, whereas the natural resources are gradually decreasing. Thuok *et al*. (2001) stated that marketing channels for marine products are not so well developed for food security and economy reasons; it is believed that emphasis should be placed by the administration in support of the private sector on the development and enhancement of marketing of marine fishery products.

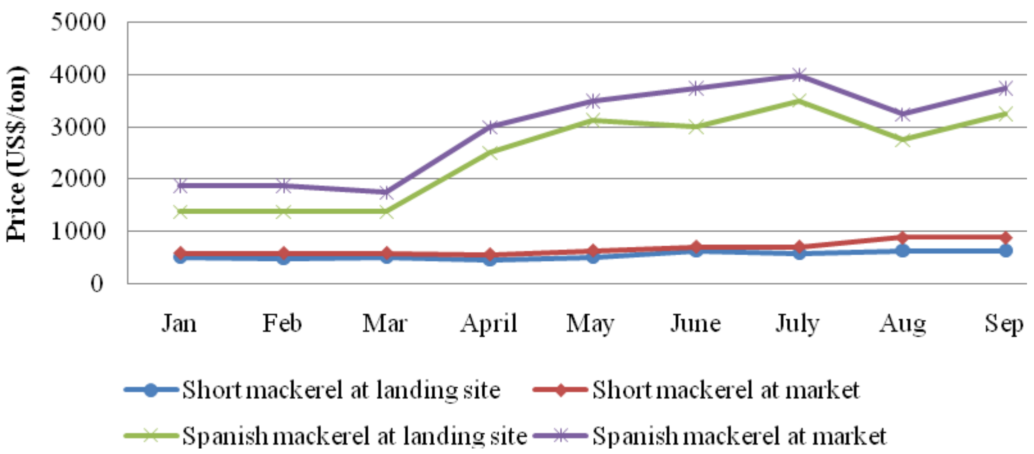

Figure 5: Price of mackerels at landing and market site for 9 months in 2006 (FiA 2007)

[1] The price of mackerel at landing site was conducted and reported to the Fishery Administration by Marine Fishery Division from January to September in 2006.

2.4 Marine fisheries resources management in Cambodia

2.4.1 Law and regulation

The Cambodian marine fishery is managed under the Fisheries Law of 2006 which is an improved and updated version of the law from 1987. The main objective of the law and regulation is to manage and conserve the marine fishery resources in a sustainable manner. Additional objectives are to generate governmental revenue, improve the livelihood of local communities and achieve ecologically sound management by an improved statistical system, gear restrictions, area limitations, and time closures. Management objectives other than those in the Fishery Law 2006 exist and are attained by the Ministry of Agriculture, Forestry and Fishery (proclaim issue), i.e. closed season from 15 January to 31 March for mackerel species.

For management purposes, the marine fisheries are divided into two groups:

Coastal fisheries: small family-scale fishing, operating in fishing zone 1, which extends from the coast to a depth of 20 m, this fishing zone was almost managed by community fisheries. The coastal community fisheries were established after the government recognised the poor management of the fisheries sector which resulted in a movement for reform in 2000. Nowadays, 40 community fisheries have been established along the coast to encourage coastal dwellers to participate in the management of their resources. Fishers use boats without engines or with engines of less than 50 hp. Licenses are not required for boats with no engine or with engines below 33 hp, but for boats with more than 33 hp engines, a license fee of 27,000 Riels (US$ 7) per horsepower per year is required. Fishing activities are not allowed to include other fishing gears such as trawls, or light fishing.

Commercial fisheries refer to large-scale fishing from 20 m depths to the limits of the EEZ. Boats used have engines with more than 50 hp, which must be licensed for a fee of 27,000 Riels (US$ 7) per horsepower per year. Prohibited fishing gears and methods include pair trawling, light fishing and other illegal fishing gears. All marine fisheries are open year round, apart from mackerel, for which fishing is banned from 15 January to 31 March (DoF 2001d). Most of the small boats (engine < 50 hp) marine fishing fleets use alternative multi-fishing practices following the seasonal appearance of marine resources, including purse-seines, gill nets, push nets and trawling. Foreign poachers use prohibited gears such as large bottom trawls, long drift nets, pair trawlers, light fishing and explosives (DoF 2001d).

2.4.2 Management and administration

Despite a few limitations on the fisheries in the Gulf of Thailand, fisheries there fall under the framework of unregulated open access. In addition, there are no limits placed on the amount of gears that can be used, the amount of time that can be spent fishing, or on the quantity of fish that may be captured.

Generally, coastal fishers can operate all year round by using many different types of fishing gears. However, the use of fishing gears is dependent on a number of critical factors, including: (1) the capital invested, (2) experience and traditions of the fishing communities in different locations along the coast, (3) seasonal abundance of different species, (4) seasonal weather conditions, and (5) ecological conditions associated with the fishing grounds (e.g. inshore, offshore, mangrove, coral reef etc).

Fishing in offshore areas is still a challenge and there is a lack of strong law enforcement measures against illegal fishing from neighbouring countries. It is a problem represented in the low annual production of marine fisheries. The present management of data collection is not sufficient to develop plans for scientific management of marine fish stocks. The lack of knowledge of fish biology, ecology and their dynamics results in a poor understanding of the recent changes in marine fish stocks (MAFF-DoF 2004).

On the other hand, the fisheries competency is still inadequate. This is true in terms of inspection specialists and the lack of adequate physical means to enforce legislation such as protection against illegal fishing (i.e. the Fisheries Administration is less able to set up or install the right technology, a high speed boat, radio communication and other facilities for coast guard operations). Furthermore, in the 1990s the political environment was unstable which affected the business environment and led to less investment capital.

However, the government and Fisheries Administration have overcome many obstacles to develop and manage marine fisheries resources as well as the fisheries sector in the past years. Especially, a recent achievement is the Fishery Law completely promulgated public using in 2006 (FiA 2007). The new law was updated from the previous Fishery Law of 1987 which was based on legislation from 1956, 1958, and 1960 (revised). The updated law was also drafted with participation from stakeholders, IOs, NGOs and relevant partners through research study and sustainable development projects on the fisheries sector framework. In terms of gains, marine production through fishing effort as well as improve capacity of fishing and biomass management in EEZ.

3 THE PRINCIPLES OF FISHERIES MANAGEMENT

This chapter has been adapted from the lecture notes in the UNU-FTP specialist course on Fisheries Policy and Planning, by Prof. Ragnar Arnanon.

The need for fisheries management stems fundamentally from the fact that fish resources are common property. It is well known, both from theory and experience, that common property resources will be overexploited and possibly irreversibly depleted unless subjected to appropriate fisheries management. Essentially, the fisheries management regime is a set of social prescriptions and procedures that control the fishing activity. Similarly, fisheries management requires either collective action at the industry level or external, usually government, intervention.

The principles of fisheries management or fisheries management regimes consist of i) the fisheries management system (FMS), ii) monitoring, control and surveillance (MCS), and iii) fisheries judicial system (FJS). These three components of the fisheries management regime are strongly interdependent. All three components of the fisheries management regime are crucial to its success. They are links in the same chain. If one of them fails, the fisheries management regime as a whole fails.

3.1 The fisheries management system (FMS)

The fisheries management system specifies the regulatory framework for the fishing activity. It consists of all the rules that the fishing activity must obey such as gear and area restrictions, fishing licences, catch quotas etc. In many countries, most fisheries rules are based on explicit legislation. In others, they are primarily based on social customs and conventions.

The fisheries management system is basically a set of rules about how the fishery should be conducted. These rules may be formal – for instance in the form of published laws and regulations – or they may be informal – a part of the social culture governing fishing behaviour. In most fisheries both types of fisheries management rules, the formal and the informal, apply. The purpose of the fisheries management system is to contribute to the generation of net economic benefits flowing from the fishery.

The fisheries management represents the application of specific fisheries management instruments or tools. Typical fisheries management tools are, for instance, fishing gear restrictions, limitations on the number of allowable fishing days during the year, area closures and so on. Thus, the fisheries management tools are like variables or more precisely, control variables and the fisheries management measures the values that can be chosen for these control variables.

Now, fisheries management systems consist of particular combinations of one or more of these tools. Thus, obviously, the number of possible fisheries management systems increases very fast with the number of available fisheries management systems. Most of them may, however, be grouped into two broad classes: i) Direct fisheries management and ii) indirect fisheries management as illustrated in Figure 6.

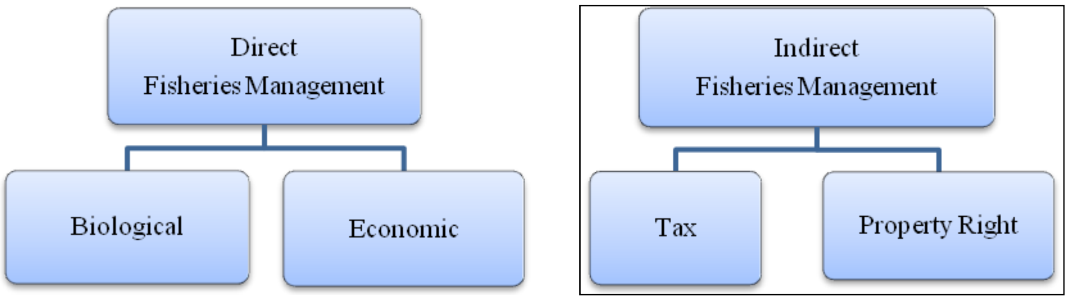

Figure 6: Fisheries management systems: a classification (adapted from lecture notes UNU-FTP 2007, introduced by professor Arnason)

Direct fisheries management attempts to control the components of the fishing activity directly by commands or, more often, restrictions that must be adhered to. Indirect economic fisheries management, by contrast, attempts to induce the fishing firms to behave differently by modifying the operating conditions of the fishery without imposing direct constraints. The difference between direct biological and economic fisheries management lies in what they seek to control. Direct biological fisheries management attempts to alter the biological yield of the fishery. Thus, under biological fisheries management, for instance, the sustainable yield curve is normally shifted. Direct economic fisheries management attempts to alter the behaviour of the fishing firm days, vessel size etc. Thus, direct economic management generally affects the cost structure of the fishery directly.

Indirect fisheries management alters the operating conditions of the fishing industry. There are, of course, many ways to do this. Most, however, belong to two main categories; (a) taxes (and subsidies) which basically alter the prices facing the fishing industry, and (b) property rights, which alter the nature of the external effects imposed by the fishing firm on one another.

Most fisheries management tools are fall quite naturally into one of the fisheries management categories in Figure 6. The main exception is the total harvesting restriction or total allowable catch (TAC). Of all the fisheries management systems considered above, only (i) certain property right arrangements and (ii) tax on catch seem to be theoretically capable of delivering the full potential economic benefits of fisheries. Direct fisheries management, irrespective of whether it is based on biological or economic restrictions, seems particularly inept for this purpose.

3.2 Monitoring, control and surveillance (MCS)

The primary task of the monitoring, control and surveillance system is to observe the fishing industry's activities and to enforce its adherence to the rules of the fisheries management system. Its secondary, but nevertheless very important, task is to collect data about the fishery that can be used to improve both the fisheries management and fisheries judicial system as well as the monitoring, control and surveillance system itself. Broadly speaking the phrase refers to two activities: i) the monitoring of the fishery and the activities of the fishing (harvesting) industry, and ii) the enforcement of fisheries management rules.

MCS is, as already discussed, a crucial component of any fisheries management regime. Logically, it is the management authority that must conduct and co-ordinate the MCS activity although it may engage contractors, it is the central fisheries manager, i.e. the government, that operates the MCS activity.

The monitoring part of MCS involves collection of the relevant biological data about the fish stocks and the surrounding ecosystem, as well as the relevant technical, economic and behavioural data about the fishing industry and its activities. The monitoring activity is conducted for essentially two purposes: i) to gather information for improving the fisheries management, i.e. data generation monitoring; and ii) to gather information for the purpose of enforcing existing fisheries management rules, i.e. enforcement monitoring. It is important to realise that in order to transform fisheries data into sensible decisions on fisheries management measures and modifications of the fisheries management system, a good deal of biological and economic research has to take place. Hence, is should be clear that research, both biological and economic, is an integral part of the monitoring part of the MCS activity.

The enforcement part of MCS consists of acting upon alleged violations of fisheries management rules. It generally takes place where and when the violating activity occurs. The action taken may be of several degrees of severity: i) induce the violator end the illegal activity; ii) impose a penalty, i.e. an administrative penalty, typically a fine or a temporary revoking of fishing licence; iii) indict the alleged violator; and iv) apprehend and indict the alleged violator. In this case the alleged violator is apprehended (a penalty in itself) and also formally charged for the offence.

It should be clear that if the fishing firms are profit maximisers, enforcement action will, in general, not suffice to generate sufficient adherence to the fisheries management rules, unless the level of monitoring and enforcement is extremely highly relative to the fishing activity. Since the former implies that a decentralised fishery can never be efficient and the latter is obviously far too expensive compared to the value of the fishery, we may conclude that any reasonable MCS system must rely on (ii)-(iv) to a significant extent. For later reference it is useful to note that the enforcement part of MCS, especially degrees (iii) and (iv) above, is linked to the operations of the fisheries judicial system and, in fact, depends on it, if it is to be effective.

The cost of MCS in fisheries is by no means negligible. The available indications (Arnason. *et al*. 2002) suggest that this cost usually ranges between 2% and 10% of the total landed value of national the fisheries. According to Arnason *et al.* (2002) the most important MCS cost items appear to be: i) enforcement at sea and on land, ii) data collection and research, and iii) policy formulation and system administration. Enforcement costs, especially those at sea, are generally very high and as a whole usually account for well over half of the total MCS costs. Data collection and research costs typically account for over a third of the total MCS costs with the most costly item being biological research. The rest of MCS costs are accounted for by policy formulation and general administration costs.

3.3 Fisheries judicial system (FJS)

The fisheries judicial system is part of the general judicial system. It should be noted, however, that in most societies, the formal judicial system is to process alleged violations of fisheries management rules and issue sanctions to those deemed to have violated the rules. The fisheries judicial system thus complements the monitoring, control and surveillance activities in enforcing the fisheries management rules.

The purpose of the fisheries judicial system (FJS) is to: i) process alleged violations of fisheries rules, and ii) apply sanctions as appropriate. It follows that the FJS must contain well defined procedures as to how to process alleged violations. What are the courts, how may cases be referred to the courts, what are the appeal procedures, time limits and so on? Without the support of the fisheries judicial system, the MCS activity would not work. Alleged violators would simply go to court and get off with penalties insufficient to deter them from their illegal activities. Hence, the MCS activity would be of little use. In particular, it would not succeed in enforcing the fisheries rules.

It is often found that the fisheries judicial system is the weakest link in the fisheries management regime. The public information and awareness of the judicial system is not well distributed and the people then are not well-informed. Fundamentally, the judiciary system is fairly independent of the executive and legislative branches of government. As a result, the fisheries management regime is much less amenable to reform and change than the other two components. The trials and judgements are passed according to law, custom and convention. The judicial system in executing laws and judgements generally has little understanding of the intricacies of the FMR. This suggests the need to include carefully designed laws concerning the treatment of fisheries violations, the burden of proof, penalties etc. in the fisheries legislation defining the fisheries management regime.

The main objective of the FJS is to endorse the enforcement part of the MCS activity. In particular the FJS determines crucial components of the probability that a violator of fisheries legislation will suffer penalties. The adherence to fisheries management rules requires sufficiently high administrative costs in processing these allegations. Generally, any expected cost of violations can be generated by the appropriate combination of enforcement and penalties. To find this appropriate combination, it is necessary to obtain an empirical estimation from the increased enforcement activity and improved FJS and its implications to the expected costs of violations.

4 MODELLING

The bio-economic model applied in this chapter has been adapted from the lecture notes in the UNU-FTP specialist course on Fisheries Policy and Planning, by Prof. Ragnar Arnanon.

The model applied in this report is used to explain the mackerel fishery in Cambodia and investigate improvements in its utilisation; it is a simple bio-economic model of the fishery resources. The model chosen is based on the work of Gordon (1954) and Schaefer (1957) (Anderson, G. L. 1981) who developed a basic bio-economic model for fisheries management. The main elements of this model are i) a biomass growth function which represents the biology of the model, ii) a harvest function which constitutes the link between the biological and economic part of the model, and iii) a fisheries profit function which represents the economic part. Particularly, for prediction of the maximum sustainable yield (MSY) of the mackerel fishery, we apply the "surplus production models" a simple model introduced by Graham (1935) (Anderson, G. L. 1981), but they are often referred to as "Schaefer models". This approach was selected for the following reasons: i) the Cambodian mackerel fishery data is very limited and thus does not support an advanced bio-economic model, ii) the model developed here can later be extended and refined when more and better data becomes available. More precisely the model is as follow:

$$\dot{x} = G(x) - y \qquad \text{(Biomass growth function)} \qquad (1)$$

where x represents biomass, $\dot{x}$ is biomass growth and y is harvest. The function G(x) is natural biomass growth.

$$y = Y(e,x) \qquad \text{(Harvesting function)} \qquad (2)$$

The volume of harvest is taken to depend positively on fishing effort as well as the size of the biomass to which the fishing is applied.

$$\pi = p \cdot Y(e,x) - C(e) \qquad \text{(Profit function)} \qquad (3)$$

Where p represents the price of fish landing and $C(e)$ is the cost function of fishing effort. The profit function depends on the fish price, the sustainable fish yield and the fishing operation costs. The fishing costs depend on the use of economic inputs, which is the fishing effort can represent the profit function equation.

The above model comprises three elementary functions: the natural growth function $G(x)$, the harvesting function $Y(e,x)$ and the cost function $C(e)$. It adopts the widely used specific form for these functions:

4.1 The biomass growth function

Populations of organisms cannot grow infinitely, the growth of organisms is constrained by environmental conditions and food availability. It has been shown that populations of organisms strive to stabilise at the highest possible population size for a given set of conditions (Schaefer 1954) (Anderson, G. L. 1981). Marginal growth of a population increases when the size of the population decreases, and marginal growth decreases when the size of the population increases, this may be called density dependent growth. Biological growth of such populations may be expressed as follows:

$$G(x) = rx - sx^2 \qquad (4)$$

Where x is population size, r is the growth rate of the population and s is the mortality rate which is negative. This is the parabolic equation also referred to as Verhults' equation or the logistic growth equation (Schaefer 1954) (Anderson, G. L. 1981).

When the population reaches the environmental carrying capacity *(K)*, growth and mortality of the population is equal, and rate of change of population size with respect to time *(dx/dt)* becomes zero. The mortality rate s can now be expressed in terms of r and K as:

$$s = -\frac{r}{K} \qquad (5)$$

From equation (5) substitute s in equation (4), we get the most commonly used expression of the logistic growth equation and equation (4) can be rewriten as:

$$G(x) = r \cdot x(1 - \frac{x}{K}) \qquad (6)$$

Fox (1970) (Arnason, R. 2007) outlined an alternative surplus yield model; assuming the Gompertz growth function, resulting in an exponential relationship between fishing effort and population size and an asymmetrical harvest curve (Fox 1970) (Arnason, R. 2007). The generalised form of the Gompertz curve can be represented as (Winsor 1932) (Arnason, R. and Bjorndal, T. 1991):

$$F(x) = \mu \cdot x(\ln K - \ln x) \qquad (7)$$

In this formulation the carrying capacity of the biomass is K, as in the logistic formulation. However, unlike the logistic, the Fox-Gompertz growth function is not symmetric and the intrinsic growth rate $\lim_{n \to \infty} \frac{F(x)}{x}$, is infinite compared to r for the logistic.

The major difference between the logistic model and the Fox model is that at lower population sizes the Fox model predicts a higher growth rate than the logistic model. At higher population sizes, the logistic model predicts a higher growth rate than the prediction by the Fox model. In the logistic model, maximum growth occurs at half of the maximum population level. In the Fox model, maximum growth occurs at a population level of less than the half of the maximum population, around 37% of the maximum population. On the other hand, the population growth curve of the Fox model is skewed to the left while the population growth curve of logistic model is symmetrical.

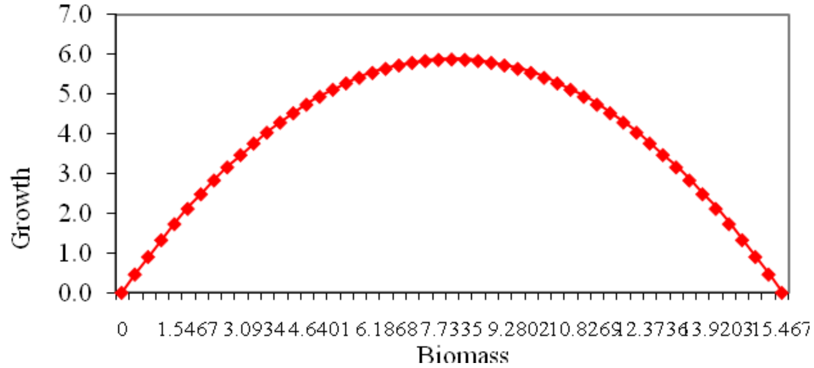

Figure 7: Illustrates the logistic biomass growth model, G(x)

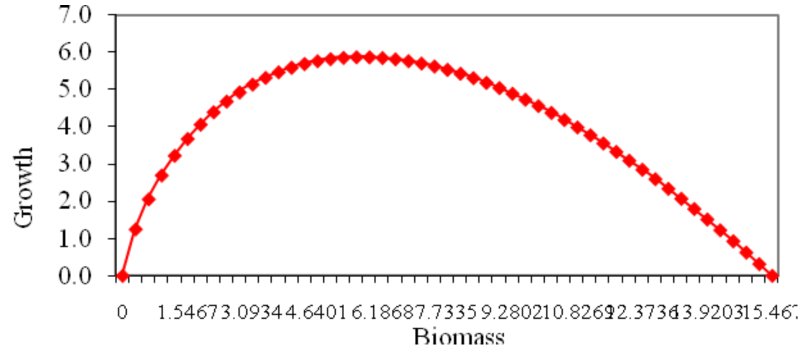

Figure 8: Illustrates the Fox biomass growth model, G(x)

For biomass growth we consider the logistic and the Fox:

$$G(x) = \alpha \cdot x - \beta \cdot x^2 \quad (8)$$

$$F(x) = \alpha \cdot x - \beta \cdot ln(x) \cdot x \quad (9)$$

4.2 The harvesting function

Assuming that each unit of effort harvest equals the amount from the targeted stock and an equilibrium situation where catch equals natural growth, the equilibrium stock size *(x)* may be expressed in terms of carrying capacity *(K)*, catchability coefficient *(q)* and fishing effort *(e)*. For the harvesting model in accordance to the generalised Schaefer (1954) (Anderson, G. L. 1981) version:

$$Y(e,x) = q \cdot e \cdot x^b \qquad (10)$$

Where the coefficient *b* indicates the degree of schooling behaviour by the fish, which *b €[0,1]*.

4.3 The cost function

Consequently, the costs of fishing effort will be a linear function of the amount of effort – index of economic input in the form of labour, investment, fuel, maintenance and supplies, fixed costs and overhead that is devoted to the fishery on an annual basis. The annual cost of fishing *C(e)* is proportional to effort *(e)*. For this report, it was assumed that the fishing boats are homogeneous. The cost function is expressed as:

$$C(e) = c \cdot e + fk \qquad (11)$$

Where *c* represents marginal costs, and *fk* represents fixed costs.

4.4 The complete model

The complete model based under those function specifications becomes:

Biomass growth function:

- $\dot{x} = \alpha \cdot x - \beta \cdot x^2 - y$ (Logistic) (12)
- $\dot{x} = \alpha \cdot x - \beta \cdot ln(x) \cdot x - y$ (Fox 1970) (13)

Harvesting function:

- $y = q \cdot e \cdot x^b$ (14)

Profit function:

- $\pi = p \cdot y - c \cdot e + fk$ (15)

The last two equations can be combined to yield a simpler version of the model:

- $\pi = p \cdot y - (c/q) \cdot y \cdot x^{-b} + fk$ (16)

The ratio *(c/q)* is viewed as a single parameter known as the normalised marginal cost. It is shown that the marginal cost and catchability, *c* and *q* are not displayed in an independent role in this model. What counts in the model is the ratio of the two constant parameters.

4.5 Sustainable yield

The annual rate of renewal of fish stock depends on three major factors: biological environment, physical environment and magnitude of the remaining population. Biological and physical environment may be considered to be constant in the long run (Schaefer 1954) (Anderson, G. L. 1981). Population size is reduced by natural and fishing mortality. Harvesting increases the total mortality. As the fish population strives to balance the total mortality with growth, the population reaches a new equilibrium at a point where the growth rate equals total mortality, which occurs at a lower population size than the environmental carrying capacity level *K*. When the fish stock reaches equilibrium with a given effort level, all biological growth of the population is harvested and there is no need for change in the population size.

$$y(e,x) = G(x) \qquad (17)$$

$$G(x) = r \cdot x\left(1 - \frac{x}{K}\right) = q \cdot x \cdot e \qquad (18)$$

and when $x \neq 0$

$$x = K\left(1 - \frac{q \cdot e}{r}\right) \qquad (19)$$

by substituting *x* in the equation (18) with equation (19), we get the long term catch equation.

$$y = q \cdot k \cdot e - \frac{q^2 \cdot K \cdot e^2}{r} \qquad (20)$$

This implies that although harvest is a function of effort and stock size for the short term, in the long run stock size becomes only a function of effort (given that environmental conditions are constant) and the sustainable yield too becomes a function of effort only.

Equation (8) takes the form of a parabolic equation, which allows us to use linear regression in order to estimate the parameters of the function of sustainable harvest *(y)*. Dividing both sides of equation (8) by effort *(e)* we get the linear equation of catch per unit effort (CPUE).

$$CPUE = q \cdot K - \frac{q^2 \cdot K \cdot e}{r} \qquad (21)$$

Assuming that biological growth of the subjected population follows the model suggested by Gowpertz, and also assuming the fleet is homogenous and all vessels have the same fishing power:

$$G(x) = \mu \cdot x \cdot \ln\left(\frac{K}{x}\right) = q \cdot e \cdot x \Longrightarrow x = K \cdot exp\left(\frac{-q \cdot e}{\mu}\right) \qquad (22)$$

by substituting x in equation (6) with (22) the equation became as below:

$$y(e, x) = q \cdot e \cdot K \cdot exp\left(\frac{-q \cdot e}{\mu}\right) \qquad (23)$$

Dividing both sides of equation (23) by fishing effort (e) yields:

$$CPUE = \frac{y}{e} = q \cdot K \cdot exp\left(\frac{-q \cdot e}{\mu}\right) \qquad (24)$$

A long-linear expression is found by:

$$\ln(CPUE) = \ln(qK) - \left(\frac{q}{\mu}\right) \cdot e \qquad (25)$$

4.6 Maximum sustainable yield (MSY)

The objective of the application of the “surplus production models” is to determine the optimum level of effort that is the effort that produces the maximum yield that can be sustained without affecting the long-term productivity of the stock, the so-called maximum sustainable yield (MSY). Because holistic models are much simpler than analytical models, the data requirements are also less demanding. There is, for example, no need to determine cohorts and therefore no need for age determination.

This is one of the main reasons for the relative popularity of surplus production models in tropical fish stock assessment. Surplus production models can be applied when data are available on the yield (by species) and of the effort expended over a certain number of years. The fishing effort must have undergone substantial changes over the period covered. The basic models were expressed as follows:

4.6.1 Surplus production models

The maximum sustainable yield (MSY) can be estimated from the following input data:

- $f_{(i)}$ = effort in year i, where *i* = 1, 2, 3, …. , n
- $Y_{(i)}$ = yield in year i, where *i* = 1, 2, 3, …. , n
- Y/f = yield (catch in weight) per unit of effort in year *t*.

Y/f may be derived form the yield, $Y_{(i)}$, of year *i* for the entire fishery and the corresponding effort, $f_{(i)}$, by:

(i) $Y/f = Y_{(i)} / f_{(i)}$, where $i = 1, 2, 3, \ldots, n$ (26)

The simplest way of expressing yield per unit of effort, Y/f, as a function of the effort, f, is the linear model suggested by Schaefer (1954) (Anderson, G. L. 1981):

(ii) $Y_{(i)} / f_{(i)} = a + b * f_{(i)}$ if $f_{(i)} \leq -a/b$ (27)

The intercept *"a"* is the Y/f value obtained just after the first boat fishes on the stock for the first time. The intercept therefore must be positive. The slope *"b"* must be negative if the catch per unit of effort, Y/f, decreases for increasing effort f. Thus, -a/b is positive and Y/f is zero for "f" = -a/b (Sparre. P. and Venema. C. S. 1998). The equation (27) is a statistically estimable version of equation of equation (21) Schaefer model.

An alternative model was introduced by Fox (1970) (Arnason, R. 2007). It gives a curved line when Y/f is plotted directly on effort "f", but a straight line when the logarithms of Y/f are plotted on effort:

(iii) $Ln(Y_{(i)} / f_{(i)}) = c + d * f_{(i)}$, where *"c"* is *"a"* and *"d"* is *"b"* (28)

Equation (28) is called the "Fox model", which can also be written:

(iv) $Y_{(i)} / f_{(i)} = exp(c + d * f(i))$ (29)

Equation (29) is a statistically estimable version of equation (25) Fox model.

Both models conform to the assumption that Y/f declines as effort increases, but they differ in the sense that the Schaefer model implies one effort level for which Y/f equals zero, namely when f = -a/b whereas in the Fox model, Y/f is greater than zero for all values of *"f"*.

However, to obtain an estimate of the maximum sustainable yield (MSY) and to determine at which level of effort MSY may be rewritten equations (27) and (29) expressing the yield as a function of effort, by multiplying both sides of the equation by $f_{(i)}$:

Schaefer:

(v) $Y_{(t)} = a * f_{(i)} + b * f_{(i)}^2$ if $f_{(i)} < -a/b$ (30)

Or $Y_{(i)} = 0$ if $f_{(i)} = -a/b$

(vi) $Y_{(i)} = f_{(i)} * exp(c + d * f_{(i)})$ (31)

From equation (30), the Schaefer model, is a parabola, which has its maximum value of $Y_{(i)}$, the MSY level, at an effort level:

(vii) $$f_{MSY} = -\frac{a}{2b}$$ (32)

and the corresponding yield:

(viii) $$Y_{MSY} = -\frac{a^2}{4b}$$ (33)

From equation (31), the Fox model, is an asymmetric curve with a maximum sustainable yield level, with a fairly steep slope on the left side and a much more gradual decline on the right of the maximum. The Y_{MSY} and f_{MSY} for the Fox model can be calculated by formulas which are derived from equation (31) by differentiating Y with respect to *"f"* and solve dY/df = 0 for *"f"*:

(ix) $$f_{MSY} = -\frac{1}{d}$$ (34)

(x) $$Y_{MSY} = -\left(\frac{1}{d}\right) exp(c-1)$$ (35)

The estimation procedures for the parameters (Schaefer: *a* & *b*, Fox: *c* & *d*) will be explained on the basis of the data given in Table 7. Since we are dealing with a straight line in the case of the Schaefer model and a curve which has been linearised by taking the logarithm in case of the Fox model, the determination of *a, b* and *c, d* requires two linear regressions of $f_{(i)}$ on $Y_{(i)}/f_{(i)}$ and $f_{(i)}$ on $\ln(Y_{(i)}/f_{(i)})$ respectively. The results of the two regressions are presented in Table 7, including a maximum sustainable yield and its correspondent optimum level of effort. Thus are determined the relationships between catch per unit of effort and effort for both models.

4.6.2 Biomass dynamic models

The formulation of the Schaefer surplus production model in its continuous and discrete form, the logistic model to include catch we obtain:

(xi) $$B_{t+1} = B_t + rB - \frac{r}{K} B^2 - C_t$$ (36)

Where *r* is the intrinsic rate of increase, *K* the carrying capacity, B_t the abundance (biomass), and C_t is the catch at time *t*. It is common practice to assume that catch is proportional to fishing effort and stock size (Hilborn and Walters 1992, Haddon 2001). In the Schaefer model, the biomass level that sustains the maximum sustainable yield denoted by B_{msy} is at one half of K. Maximum sustainable yield is defined as:

(xii) $$Y_{MSY} = \frac{rK}{4}$$ (37)

And the effort that sustains the maximum sustainable yield is:

(xiii) $$f_{MSY} = \frac{r}{2q}$$ (38)

where q is the catchability coefficient, also called a nuisance or scaling parameter. One major assumption in the use of the surplus production model is that the catchability coefficient remains constant over time (Haddon 2001).

4.6.3 Specifying priors

The quality of data and lack of prior results forces me to consider alternative methods of measuring growth rate *(r)*. To overcome this limitation, r was estimated using the equation proposed by Sullivan (1991) (Pauly, D. 1983) for non-gadoid species. In this formulation r is a function of the von Bertalanffy growth coefficient *(k)*, asymptotic (W_∞) weight fish, so growth rate function can be expressed: $r = 0.947 + 1.189k - 0.095\ ln(W_\infty)$ which asymptotic (W_∞) equation is $W_\infty = \mathring{a}(L_\infty)^{\mathring{b}}$, *where* $L_\infty \frac{L_{mas}}{0.95}$ (Pauly's formula).

Where $\mathring{a}$ and $\mathring{b}$ are the coefficient of the length-weight relationship for *Rastrelliger* species, L_∞ is asymptotic length, L_{max} (cm) is maximum length of mackerel fish, mackerel asymptotic weight (W_∞) was calculated with available parameter estimates $\mathring{a} = 0.0061$, $\mathring{b} = 3.213$, $L_{max} = 35$ *cm, and* $k = 0.6\text{-}1.6$ (data is available at the website Fishbase.org). In this report k is assumed *1* for mackerel fisheries in Cambodian coastal waters as well as the whole of the Gulf of Thailand.

5 ESTIMATION OF MODEL

5.1 Data sources

The data for this report was collected from different sources. The data required was classified into two categories: biological and fisheries data. The Fisheries Administration (FiA), previously called the Department of Fisheries (DoF), is the main institution responsibly for the fisheries sector of Cambodia. Therefore, most of the data used in this report is derived from the Fisheries Administration's data sources and they were considered to be the prime sources for this study.

Most of the data of the FiA are only available from 1990 to 2006, i.e. total landed of marine fisheries production, statistics of fishing boats, gears (fishing effort). However, the data on catches by species or group is very poor for the past three decades. Since 2000 the data collection in this category was made more systematic.

The Fisheries Administration of Cambodia provides economic input data such as total cost of fishing effort (cost of boat – engine, fuel consumption and labour costs), landing price of the mackerel fishery in base year 2006, fixed costs and overheads.

Therefore, this data is based on quick interviewing or communications between fishery officers and the fishing ground costal guards, and also from fishing experimentalists.

Whereas, the biological data such as the fish stock status, virgin stock biomass (X_{max}), maximum sustainable yield (MSY), fish abundance, density, distribution and mackerel schooling parameter *(b)* are not available for mackerel in Cambodia or the Gulf of Thailand. In terms of projects for regional research study for mackerel species in the Gulf of Thailand, it seems that previous research has not yet been taken into account. Even though some projects were carried out in parts of Thailand waters, this seems to be representative of the Gulf, it's limited biological data and specifying analysis of mackerel species.

Most are only focused on multi-species or demersal species i.e. *Theory and management of tropical multi-species stocks* (Pauly, D. 1983), *Development of fisheries in the Gulf of Thailand Large Marine Ecosystem: Analysis of an unplanned experiment, Overfishing in the Gulf of Thailand: Policy challenges and bioeconomic analysis* (Ahmed *et al.* 2007), *Status of demersal fishery resources in the Gulf of Thailand; Potential yield of marine fishery resources in Southeast Asia* etc.

However, the articles named above are considered as the basis of assumable knowledge in this report such as schooling parameters, biomass stock of mackerel, catchability coefficient, in order to predict or estimate MSY, virgin biomass stock of mackerel for Cambodia as well as the general status of this species in the Gulf of Thailand.

Moreover, for estimating the growth rate *(r)* of mackerel, the report subscribed to data which was relevant for maximum length *(L_{max})*, growth coefficient *(k)* and length-weight relationship *(ả & b̉)* of *Rastrelliger* species in the Gulf of Thailand which was available at FAO or the Fishbase.org website.

Some data had to be derived through calculation of the available ones so as to meet the needs of this research study. Data that had never been collected nor documented but available from fishery officers, fishing ground guardians and fishermen was communicated both by means telephone and e-mail.

The bio-economic model of fisheries is specified above, containing six unknown parameters, there are *α, β, c, q, b* and *fk* but *c* and *q* can be performed as a normalised marginal cost *(c/q)* formatting. In addition to calculating profits and rents of fisheries exploitation, information on landed volume *(y)*, fishing effort *(e)* and biomass *(x)* is required. Suppose that optimal equilibrium, harvest and biomass will be determined by the optimality conditions, so only the six unknown parameters need to be known in order to calculate rents. It is reflected, if the position of profits is zero, the position of rents in this model (linear in *y*) will be simply the parameter *fk* and pieces of information to calculate rents would be take in account or calculated. There are many ways to estimate the unknowns in the fisheries model defined by equations (12), (13) and (16). The following details based on a number of available data on fisheries, which are included:

- Biological data which are available could be guessed.
- Fisheries data for a specific year are available and could be guessed.

Based on available data, it is straight forward to calculate the unknowns of equations (12), (13) and (16) as listed below:

Table showing the formulas used to determine the unknown using the data available

Formula to calculate the parameters of models	
Unknowns	**Formula**
Logistic function	
A	$\alpha = 4 \cdot \frac{MSY}{X_{mas}}$
B	$\beta = 4 \cdot \frac{MSY}{X_{mas}^2}$
Biomass in base year, x*(t*)*	$x(t^*) = \frac{\alpha}{2\beta}\left(1 \pm \left(1 - \frac{4 \cdot \beta \cdot (y(t^*) + \dot{x}(t^*))}{\alpha^2}\right)^{0.5}\right)$
Fox function	
A	$\propto = MSY \cdot \ln(X_{max}) \cdot \frac{exp}{X_{mas}}$
B	$\beta = MSY \cdot \frac{exp}{X_{mas}}$
Biomass in base year x*(t*)*	$(\alpha - \beta \cdot \ln(x(t^*))) \cdot x(t^*) = \dot{x}(t^*) + y(t^*)$
Normalise marginal cost, $\left(\frac{c}{q}\right)$	$\left(\frac{c}{q}\right) = \frac{(p(t^*) \cdot y(t^*) - \pi(t^*)) \cdot (1 - \varepsilon)}{y(t^*) \cdot x^{-b}(t^*)}$
Fixed cost, *fk*	$fk = (P(t^*)) \cdot y(t^*) - \pi(t^*) \cdot \varepsilon(t^*)$
The schooling parameter, *b*	*b*
Landing in base year *t**, *y(t*)*	*y(t*)*
Price of landing in base year *t**, *p(t*)*	*p(t*)*
Formula to calculate the MSY and f_{MSY} by the surplus production model	
Schaefer	
MSY	$Y_{MSY} = -\frac{a^2}{4b}$
f_{MSY}	$f_{MSY} = -\frac{a}{2b}$
Fox	
MSY	$Y_{MSY} = -\left(\frac{1}{d}\right) exp(c - 1)$
f_{MSY}	$f_{MSY} = -\frac{1}{d}$
Intercept	Schaefer *(a)*, Fox *(c)*
Slope	Schaefer *(b)*, Fox *(d)*
Formula to calculate the carrying capacity *(K)* and catchability coefficient *(q)* by the biomass dynamic model	
Carrying capacity *(K)*	$K = \frac{4 * Y_{MSY}}{r}$
Catchability coefficient *(q)*	$q = \frac{r}{2 * f_{MSY}}$
Growth rate *(r)*	$r = 0.947 + 1.189k - 0.095\ln(W_\infty)$
Asymptotic weight *(W_∞)*	$W_\infty = \mathring{a}(L_\infty)^b$
Asymptotic length *(L_∞)*	$L_\infty = \frac{L_{max}}{0.95}$ *(Pauly's formula)*
Growth coefficient	*k*
Length-weight relationship	*å & b*
Maximum length *(cm)*	L_{max}

The data suggested are as follows:

Table showing biological and fisheries data necessary for estimating model's unknown values

1- Biological data	
Maximum sustainable yield	*MSY*
Virgin stock biomass	X_{max}
The schooling parameter	b
Maximum length	L_{max}
Length-weight relationship	$\dot{a}$ & $\dot{b}$
2- Fisheries data in a base year	
Biomass growth in year t*	$\dot{x}(t^*)$
Landing in base year t*	$y(t^*)$
Price of landing in year t*	$p(t^*)$
Fishing effort t*	$e(t^*)$
Profit in base year t*	$\pi(t^*)$
Fixed cost ratio in base year t* *(fk/TC(t*))*	$\varepsilon(t^*)$

These are pieces of information. However, it is worth noting that there are many other ways to obtain the estimates of the model's unknowns based on different sets of data.

5.2 Parameter estimation

5.2.1 Maximum sustainable yield (MSY)

Information on the biomass and sustainable yield of fisheries is among the most crucial required for the management of fisheries resources. In Cambodia the actual mackerel fish biomass is not known. However, based on landed data time series and fishing effort of mackerel from 1992 – 2006, we can estimate the maximum sustainable yield and optimum level of effort by using surplus production models Graham (1935) (Pauly, D. 1983). Cambodia has been a small actor in the mackerel fisheries in the Gulf of Thailand in recent decades. Only during recent years has it been increasing its catches and improving its management of the resource. It is therefore necessary to check for model stability to verify if the relationship between effort and catch has remained stable over the period of the data. I apply the CUSUM test for structural stability since no obvious structural break point is available to test explicitly. The CUSUM test results for the Schaefer and Fox models for the whole period 1992 to 2006 are presented in Figures 9 and 10.

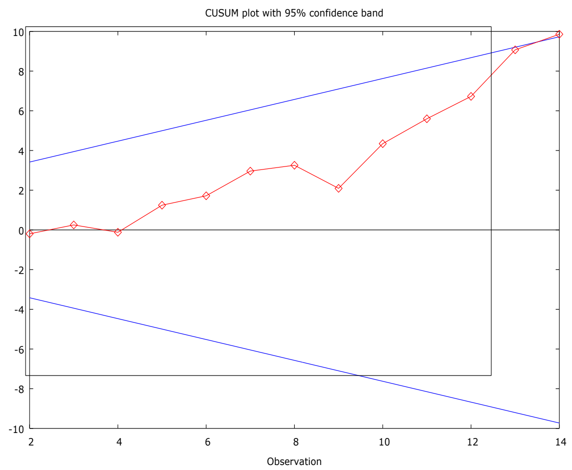

Figure 9: CUSUM plot of Schaefer model

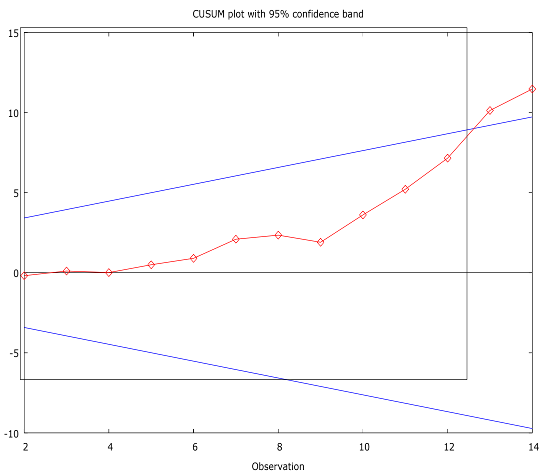

Figure 10: CUSUM plot of Fox model

The CUSUM test results clearly indicate that a structural change occurred during the period. According to the test, the most likely breakpoint is 2001. In order to estimate a model with a separate Y_{MSY} and f_{MSY} for the two periods now identified, before and after the break, we introduce a dummy variable for the period 2002-2006 and an interaction between the dummy variable and the effort (f). The results for the different slope and intercepts are reported in Table 8.

The estimation was carried out in the statistical package GRETL. The full output is available in Appendices 2 and 3. The hypothesis that one model can sufficiently explain the relationship between CPUE and effort during the whole period was tested and clearly rejected for both the Schaefer and the Fox models at 1% level of significance in favour of the alternative hypothesis that a structural break occurred in 2001.

The results from estimations during the period 2002-2006 are: Schaefer model (intercept: 0.07739, slope: -0.000255) and Fox model (intercept: -2.356298, slope: 0.006642). These figures are used to determine the optimum level of effort and maximum sustainable yield according to the equation shown in Table 7.

Table 7: The calculation procedure for estimating the MSY and f_{MSY} by the Schaefer model and by the Fox model using catch and effort data from 1992-2006 of the EEZ of Cambodia.

Year (i)	**Yield (y_i) (1,000 tonnes)**	**Effort (f_i) (boat) (x)**	**Schaefer Y_i/f_i (y)**	**Fox Y_i/f_i (y)**
1992	1.101	16	0.068	-2.690
1993	1.424	23	0.063	-2.761
1994	1.513	46	0.033	-3.422
1995	1.683	26	0.064	-2.756
1996	1.452	30	0.049	-3.012
1997	1.278	129	0.010	-4.615
1998	1.447	137	0.011	-4.552
1999	1.738	180	0.010	-4.642
2000	1.559	165	0.009	-4.662
2001	1.731	66	0.026	-3.645
2002	4.300	60	0.072	-2.636
2003	4.421	86	0.052	-2.963
2004	4.764	127	0.037	-3.284
2005	4.906	254	0.019	-3.947
2006	4.650	187	0.025	-3.694
Mean value		102.1751	0.0365	-3.5521
Standard deviation (sx & sy)		72.7333	0.0231	0.7702
1- Results of calculates intercept and slope				
Whole period (1992-2006)				
Intercept (a or c)			0.059014636	-2.762864933
Slope (b or d)			-0.000228367	-0.007727171
Period 1992-2001				
Intercept (a or c)			0.063230899	-0.605339532
Slope (b or d)			-0.000353678	-0.013085091
Period 2002-2006				
Intercept (a or c)			0.077391095	-2.356298149
Slope (b or d)			-0.00025484	-0.00664217
2- Calculation MSY and f_{MSY} based on surplus production models				
Maximum sustainable yield (MSY)			$Y_{MSY} = -0.25 \cdot \frac{a^2}{b}$	$Y_{MSY} = -\left(\frac{1}{d}\right) \cdot exp(c-1)$

Optimum level of fishing effort (f_{MSY})	$f_{MSY} = -0.5 \cdot \frac{a}{b}$	$f_{MSY} = -\frac{1}{d}$
Whole period (1992-2006)		
Y_{MSY}	3.813	3.005
f_{MSY}	129	129
Period 1992-2001		
Y_{MSY}	2.826	2.077
f_{MSY}	89	76
Period 2002-2006		
Y_{MSY}	5.876	5.249
f_{MSY}	152	151

The results for the period 2002-2006 of MSY estimate 5.876 (Schaefer), 5.249 (Fox) and f_{MSY} equal to 152 (Schaefer) and 151 (Fox). Since the dependent variable is not the same for the two models it is not possible to test statistically the superiority of one model over the other (Sparre. P. and Venema. C. S. 1998). However, careful examination of the data and the suggested models lead to the conclusion that the Schaefer model is more reasonable for the current situation. Its MSY equals 5,876 tonnes and effort 152 boats. This figure was applied to estimate carrying capacity *(K)* or virgin stock biomass (X_{max}) and other parameters in the report.

5.2.2 Virgin stock biomass (X_{max})

The information about virgin stock biomass of mackerel in the Gulf of Thailand as well as in parts of Cambodia is not known. To determine carrying capacity *(K)* or virgin biomass stock (X_{max}) and catchability coefficient *(q)* the report study uses the biomass dynamic models of the Schaefer surplus production models. Based on the results for MSY and corresponding effort reported in Table 8, the value of MSY is equal to 5,873 tonnes and f_{MSY} is equal to 153 boats. Based on these estimates the parameters *K* can be estimated by the follow equations:

$$Y_{MSY} = \frac{rK}{4} \Longrightarrow K = 4 \cdot \frac{Y_{MSY}}{r}$$

Growth parameters of the Sullivan (1991) (Pauly, D. 1983) equation:

$$r = 0.947 + 1.189k - 0.095\ln(W_\infty)$$

$W_\infty = \acute{a}(L_\infty)^{\acute{b}}$ where $\acute{a} = 0.0061;\ \acute{b} = 3.213$

$L_\infty = \frac{L_{max}}{0.95}$ where $L_{max} = 35\ cm$ (Pauly's formula)

Table 8: Estimates of *r* and *K* at different levels of assumptions of growth coefficient *(k)* of *Rastrelliger brachysoma* in the Gulf of Thailand.

Categories of data	Y_{MSY}	L_{max}	$\acute{a}$	$\acute{b}$	L_∞	W_∞
	5.876	35	0.0061	3.213	36.8	657.6
	k	*k*	*k*	*K*	*k*	*k*
	0.6	0.8	1.00	1.2	1.4	1.6
Parameters						
r	1.04398	1.28178	1.51958	1.75738	1.99518	2.23298
K	22.514	18.337	15.467	13.374	11.780	10.526

Assuming that the MSY is 5.876, f_{MSY} is 152 and growth coefficient *(k)* is 1, the result of estimated basis parameters for *r* and *K* is 1.51958 and 15.467 respectively. Therefore, the value of carrying capacity *(K)* or virgin biomass stock (X_{max}) estimated (Table 9) is 15,467 tonnes.

5.2.3 The schooling parameter (b)

Mackerel is the prey, it swims fast, is known to gather in medium schools and travel great distances. The mackerel fish can be found in estuarine habitats with slightly reduced salinities and in areas where surface temperature ranges between 20° and 30°C. Their migratory and schooling nature, forming schools of equally sized individuals. The species which aggregate together have a small schooling parameter < 1. On the basis of this argument, the schooling parameter of mackerel fish could be between 0.5 to 0.75. Therefore, for the purpose of this study the value of mackerel schooling parameter was assumed to be 0.65. This needs to be subjected to sensitivity analysis to evaluate its effect on the economic benefit of the fisheries.

5.2.4 Alpha and beta parameter (α)

This parameter was calculated by using the formula below and we considered that the value of virgin biomass stock and the MSY are known, so the alpha and beta was calculated as follows:

$$\alpha = 4 \cdot \frac{MSY}{X_{mas}}$$

X_{max} = 15.467 (1,000 tonnes)
MSY = 5.876 (1,000 tonnes)
$\alpha = 1.5196$

$$\beta = 4 \cdot \frac{MSY}{X_{mas}^2}$$

X_{max} = 15.467 (1,000 tonnes)
MSY = 5.876 (1,000 tonnes)
$\beta = 0.0983$

5.2.5 Landings in base year t y(t*)*

According to the annual fishery report 2006 of the Fisheries Administration, it was estimated that the total landings of marine fisheries in the year 2006 were approximately 60,500 tonnes. Particularly, the volume landed of mackerel in year 2006 was 4,650 tonnes. This was the figure adapted for this study.

5.2.6 Price of landings in base year t p(t*)*

The price of marine fish in every year is based on the price at Sihanoukville market site which is the main distribution in the local and export market. According to the monthly report of the Marine Fishery Division, the landing price of mackerel in base year 2006 in the period January to September fluctuated from US$ 450 to US$ 625 per tonne. For the purposes of this study, this figure is calculated as the average price of the 9 months at US$ 542 per tonne.

5.2.7 Fixed cost ratio in base year eps(t)*

For the purposes of this report, this figure was calculated depending on the fixed cost and fishing total cost. First, the fixed cost was calculated at the rate 3% of total landing revenue of mackerel. The total fishing cost can be see in Appendix 1 of the cost calculation procedure.

Fixed cost *(fk)* = 3% of landing revenue in base year t*

= 3% x US$ 2,520,300 = US$ 75,609

Calculation of the fixed cost ratio as follow:

eps (t*) or ε(t*) = fixed cost / total fishing cost

= 75,609/1,438,203 = 0.053 or 5.3%

So, eps (t*) or ε(t*) is 5.3%

5.2.8 Fishing effort in base year

Based on the annual fishery report 2006 of the Fisheries Administration, the total of marine motorised fishing boats is 6,326 boats. The number of fishing boats registered for fishing mackerel was a total of 187 boats, which included 181 fishing boats using gillnets and six boats using purse seines. For this report, we standardised them so that all the boats would be homogenous. Therefore, we assumed the six boats using purse seines to be boats using gillnets. The figure was assumed with the original gillnet boat, so to come up with the figure 187 gillnet boats. This was the value adopted in this study as the fishing effort.

5.2.9 Profit in base year (π)

The profit of the base year is the result of subtracting the total fishing cost from the total landing revenue. The total landing revenue and total fishing cost were calculated as follow:

Profit (π) = Revenue (R) – Total cost (TC)

- Revenue:

  Revenue (R) = Landing in base year x Price landing in base year

  Revenue (R) = 4,650 tonnes x US$ 542 = US$ 2,520,300

- Total cost

Table 9 shows the total cost as a summary of different costs namely fuel, labour, food, maintenance, license, depreciation, fixed cost and overhead cost. These items were calculated as follow:

Table 9: Cost of fishery economic inputs

Items	Cost (US$)
Fuel and lubricating oil	289,850
Labour	636,548
Food	130,900
Maintenance	98,175
Licenses	2,805
Depreciation value	88,488
Fixed cost	75,609
Overhead cost	115,828
Total cost (TC)	**1,438,203**

- Profit (π) = 2,520,300 – 1,438,203

  π = US$ 1,082,097

5.3 Assumption and estimation

Table 10: The assumed mackerel fishery biological and fisheries parameters necessary for calculating the unknown estimates.

1- Biological data	**Symbol**	**Assumed value**
Maximum sustainable yield (tonnes)	*MSY*	5,876
Virgin stock biomass (tonnes)	X_{max}	15,467
The schooling parameter	*b*	0.65
2- Fisheries data in base year		
Biomass growth in base year (tonnes)	$\dot{x}(t^*)$	4,200
Landing in base year (tonnes)	$y(t^*)$	4,650
Price of landing in base (US$/tonne)	$p(t^*)$	542
Fishing effort (boat)	$e(t^*)$	187
Profit in base year (US$)	$\pi(t^*)$	1,082,097
Fixed cost ratio in base year	$eps(t^*)$ or $\varepsilon(t^*)$	0.053
3- Estimated value (calculated)		
Logistic function		
Alpha	α	1.5196
Beta	β	0.0983
Biomass in base year (tonnes)	$x(t^*)$	4,200
Normalised marginal cost	$\left(\frac{c}{q}\right)$	0.745
Fox function		
Alpha	α	2.828
Beta	β	1.033
Biomass in base year (tonnes)	$x(t^*)$	9,700
Normalised marginal cost	$\left(\frac{c}{q}\right)$	1.286
Fixed cost (US$)	*fk*	76,000
Price of landing in base year (US$)	$p(t^*)$	0.542

5.4 Empirical results

The results of the two models, derived from the *Arnason* modelling approach programme using Microsoft Office Excel Macro, are given in Table 11. The table shows the estimated results of biomass, harvest, effort, profits and rents at current and optimal level. These results are very useful to outline the effects of different marine fisheries policies in order to manage the resource. It also shows the trend as the results of operation of mackerel fishery in Cambodian waters in the past years. Based on the Schaefer model, the level of current mackerel biomass growth is 4,200 tonnes in terms of optimal biomass level was estimated probably at 8.800 tonnes, while according to the Fox results, the current biomass growth level is 9.700 tonnes stock available and optimal biomass level is slightly higher (9.000 tonnes).

Harvest, effort and profits were estimated at optimal level. According to Schaefer the optimal level of harvesting is 5.800 tonnes with effort correspondence of about 143 boats and profit around US$ 2 million. The Fox model gave an estimated level of harvest that was lower (5.000 tonnes) and a higher effort level (213 boats).

Both models indicate optimal biomass and profits as higher than the current fishing status of the mackerel fishery. However, the effort level indicated by the Schaefer is lower than the current effort level. The reason for this is of course that a bigger stock is less expensive to harvest since catch per unit effort is much higher than at the current stock size. It would therefore be optimal to reduce effort in the short run to allow the stock to reach an optimal size. This would mean that the government should limit effort, e.g. by implementing a scheme for compensating fishermen for stopping fishing. One such suggestion is depreciation allowances.

Economic rent or opportunity cost was also estimated from these two models, which is the cost involved in not engaging in one's most profitable alternative activity. For natural resources, i.e. if a high value and low cost fishery will be heavily exploited and possibly overexploited. Conversely, a low value and high cost fishery will be lightly exploited, or even unexploited. However, fishermen will enter or leave a given fishery after comparing their expected net revenues with income opportunities elsewhere. These common sense predictions are a useful feature of the Gordon model.

The results for estimating the rent level are given in Table 11 for the Schaefer and Fox models. The results indicate that the fishermen are unlikely to leave fishing and look for income opportunities elsewhere. As long as positive profits are maintained it is likely that more and more fishers will enter the fishery unless other more profitable opportunities are available to them. This will ultimately lead to overexploitation. Similarly, Christy and Scott (1965) (Flaaten, O. 1988) state that "Bionomic equilibrium of the unregulated open-access fishery is thus characterised by the complete dissipation of economic rent. Assuming that thing could be otherwise, this dissipated rent constitutes a loss of wealth to society at large" (Clark 2006). Therefore, fishery management must be taken seriously by local communities and central administrations of Government and enforced by both levels of government.

Table 11: Main results from estimations of the mackerel fisheries.

Categories	Units	Current		Optimal		Difference	
		Logistic	Fox	Logistic	Fox	Logistic	Fox
Biomass	1,000.mt	4.2	9.7	8.8	9.0	4.6	-0.7
Harvest	1,000.mt	4.7	4.7	5.8	5.0	1.1	0.4
Effort	boat	187	187	143	213	0.0	0.0
Profits	m.US$	1.082	1.082	2.004	1.099	0.920	0.017
Rents	m.US$	1.158	1.158	2.080	1.176	0.922	0.017

5.5 Model simulation and results

The estimates in Table 11 were calculated on the basis of the rent definitions by *Arnason* (Arnason, R. 2007). The calculations were based on the *Arnason* modelling approach programme using Microsoft Office Excel Macro, the same approach used in an on-going World Bank Programme in determining the world fisheries rent.

It's simplicity and robustness in generating output based on limited or scanty data made it the modelling approach of choice in this study. The programme is convenient to use and to apply to data. The outputs are reports on profits, rents, fishing capacity and resources biomass on any base year in logistic and Fox distributions. Thus, the results in Table 11 are derived from the *Arnason* modelling approach programme which was run by Microsoft Office Excel Marco.

Iso-profitable curves: the curves in Figures 11 and 12 illustrate the summary description of the mackerel fishery. The figure was drawn in the space of biomass and landings and applies at each point of time and, therefore, in equilibrium. The parabolic graph illustrates the biomass growth function. The biomass function covers biomass from zero to the carrying capacity of about 15,467 tonnes and a maximum sustainable yield at a level of 5,876 tonnes. The iso-profit curves are in harvest units (multiples of MSY). For the purposes of this fishery, the harvest units are in thousand tonnes. The equation for an iso-profit curve is:

$$y = \frac{gam \cdot X_{MSY} \cdot P(x) + fk}{P(x) - \left(\frac{c}{q}\right) \cdot x^{-b}}$$

Where gam = 0.0, when Iso-profits = 0
gam = 0.25, when Iso-profits = 0.25*MSY
gam = 0.50, when Iso-profits = 0.50*MSY

In order to convert this into monetary units the harvest units should be multiplied by the landing price as follows:

Profit $(\pi) = p \cdot y$ where *p* is the landing price and *y* is landing volume.

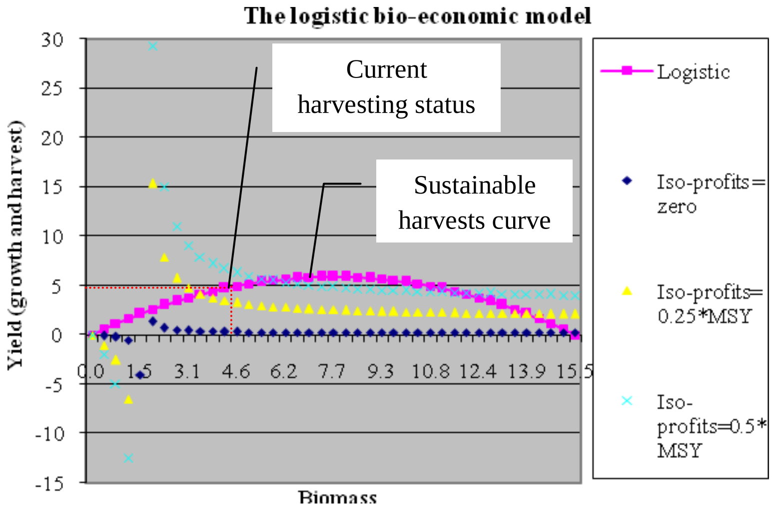

Figure 11: The fishery in biomass-yield (biomass growth, harvest) space for the logistic distribution.

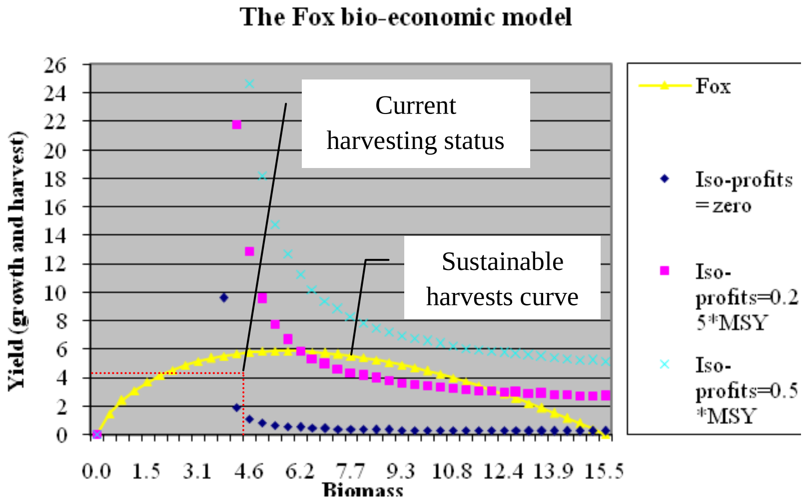

Figure 12: The fishery in biomass-yield (biomass growth, harvest) space for the Fox distribution.

For any biomass level, if catches lie within this curve, then a biological equilibrium prevails. The other curves in this diagram are variable iso-profit curves (e.g. location of biomass and harvests which presents constant variable profits measured in mackerel volume units. The highest sustainable profits are obtained where an iso-profit curve is a tangent to the biomass growth function. As the two diagrams suggest, this occurs at a biomass of some 8.800 tonnes for logistic and Fox at a level of 9.000 tonnes to quarantine harvest at about 5.800 tonnes (logistic) and 5.000 tonnes. Therefore, at this point, the profits and rent from the mackerel fishery from the two models is US$ 1,1 million to US$ 2,1 million per year.

6 OPTIMUM SUSTAINABLE YIELD AND FISHERIES ECONOMICS

The concept of optimum sustainable yield (OSY), or more simply optimum yield (OY), has become increasingly common both in theory and as the basis of actual management schemes. The OSY is generally defined as MSY modified by relevant economic, social, environmental and other factors. The term of MSY often underpins the practical definition of OSY. Furthermore, although the term OSY may give the impression of being some long-run goal to be attained and maintained on a continuing basis, in fact the optimum yield may have to be less than sustainable in some years and more in others, if full use is to be made of a stock (Cunningham *et al.* 1985). Therefore, the greater the environmental fluctuations, the greater the difference should be between biological optimum sustainable yield and MSY.

6.1 Maximum sustainable yield of mackerel fishery and current catches

The concept of maximum sustainable yield (MSY), defined by Punt and Smith (2001) (FAO 2001) as the largest annual catch or yield that may be taken from a stock continuously without affecting the catch in future years, has had a fluctuating history of favour and scorn in fisheries management (King 2007). This concept adapted from the original MSY concept in the 1930s and mathematical models that related yield to fishing mortality began to appear in the 1950s. Therefore, Schaefer (1954, 1957) (Anderson, G. L. 1981) constructed the first model that is most associated with MSY which is the surplus production model.

Figure 13 illustrates MSY derived from the two models and actual volume catches of mackerel. It can be seen that the two models give slightly different results. According to Schaefer the MSY level is 5.876 tonnes, at an effort level f_{MSY} of 152 boats, while according to the Fox model the MSY level is a little bit lower (5.249 tonnes) and at an effort level f_{MSY} of 151 boats. According to both models the effort level surpassed f_{MSY} in 2005 (254 boats) and the yield was below MSY.

The maximum sustainable yield occurs when the fish population growth rate reaches a maximum. It is the maximum that can be caught on a sustainable level without reducing the long-term stock, and it is obtained by exerting that level of effort at which total sustainable revenue is maximised (Van den Bergh, *et al.* 2006). An equilibrium point to the right of the MSY is inefficient in terms of the bio-economic model. Based on results from the Schaefer and Fox models, it is possible for Cambodian fishers to increase catches of mackerel to a maximum level between about 5.249 and 5.876 tonnes per year. However, fishing effort should be reduced from 187 boats (current) to a level of effort correspondent to around 150 boats.

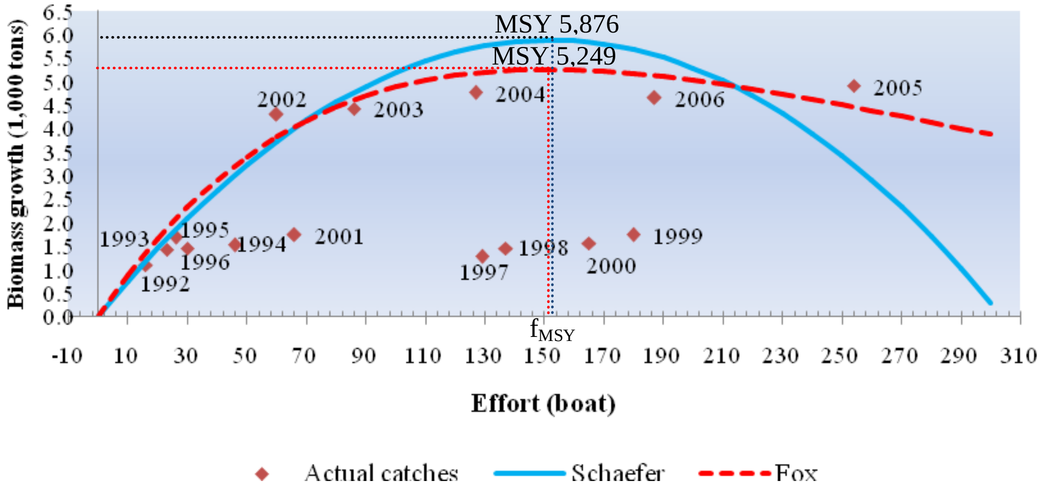

Figure 13: Maximum sustainable yield and actual catches

6.2 Maximum economic yield

This section presents a discussion of economic output based on the results derived from the *Arnason* modelling approach. It uses MSY and virgin biomass stock, estimated using alternative modelling of the surplus production and biomass dynamic models, as input. Therefore, effort corresponding to an optimum level may be different to the optimum level of effort that was estimated using the surplus production model. However, the two results are a useful basis to compare effort between MSY and OSY or MEY. The optimal biomass, harvest, profits and rents are not available from the surplus production and biomass dynamic models. The summary of main results from the modelling approach programmed is given in Table 11.

Economic variables are often included in the biological Schaefer model to model the relationship between sustainable revenue, fishing costs and fishing effort (King 1995). The relationship between revenue, fishing costs and fishing effort is used to show how a fishery with no limits on the number of participating fishers (an open-access fishery) will become overexploited in the economic as well as the biological sense (King 2007).

The fishing cost line cuts the yield (revenue) curve at the break even (open access) point, where revenue balances fishing cost. Maximum economic yield is reached where the distance between the revenue curve and the cost line is the greatest. The effort that maximises economic yields, f_{MEY}, is generally different from MSY effort. The level is determined by the development of unit effort cost as stock size increases.

The relationship between revenue, fishing costs and fishing effort of mackerel fished in Cambodia is illustrated in Figures 14 and 15. According to the Schaefer curve (Figure 14), the maximum economic yield (MEY) of mackerel at a total profit equal to US$ 2 million that the total revenue is probably US$ 3.15 million with an optimum biomass level of 8,800 tonnes to guarantee a harvest of 5,800 tonnes (Table 11). The corresponding effective effort level is about 143 standard boats. Building up the stock would increase catch per unit effort and reduce the harvesting cost. The optimum would be to employ only 143 vessels, where each vessel catches more and at a lower cost per unit catch. The optimal harvest and effort levels are lower than the level of

MSY (5,876 tonnes) and effort (152 boats) from the Surplus production model. According to the theory of economic yield, MSY is always higher than OSY and its corresponding effort. Focusing on economic yield rather than maximising catch guarantees that the fisheries contribute a maximum amount of rents into Cambodian society to aid development.

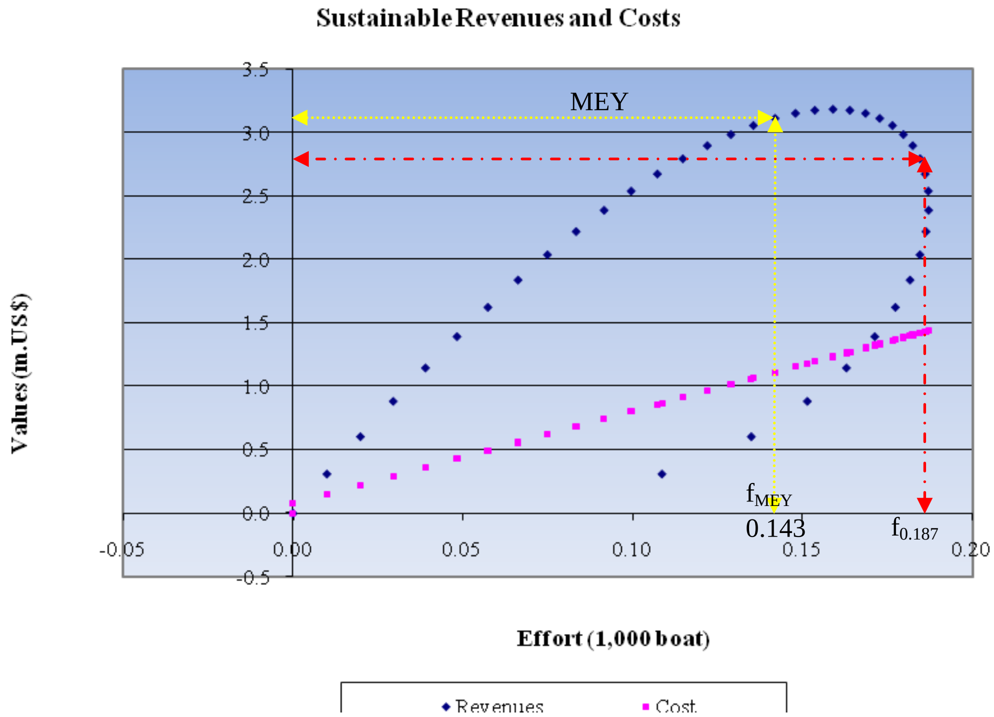

Figure 14: Schaefer curve of relationship between revenue, costs and effort

The results from the Fox model (Figure 15) indicate that the fishing cost line cuts the revenue curve at a break even point, where that revenue just balances fishing costs, at around US$ 3 million with corresponding fishing effort (f_{OA}) at a level of around 420 boats. This is the "open-access" solution with no revenues. In an open-access, fishery effort is expected to move to equilibrium where the economic forces affecting fishermen and the biological productivity of the resources are in balance (Van Den Bergh *et al*. 2006). However, the Fox curve illustrates the maximum economic yield (US$ 1.099 million), at the optimum effort level at a 213 boats corresponding with a yield (catch) of around 5,000 tonnes (Table 11). It is very important that the fisheries resources in Cambodia are well managed because improved management has the potential to create new jobs and improve the economic situation for the population of coastal areas.

The optimum effort given by this solution is much higher than Schaefer's optimum effort, and is even higher than the current fishing effort (187 boats). This seems quite odd. It seems that the earlier conclusion is true that the Fox model does not describe the Cambodian mackerel fishery adequately. No emphasis will therefore be put on the results from the Fox model.

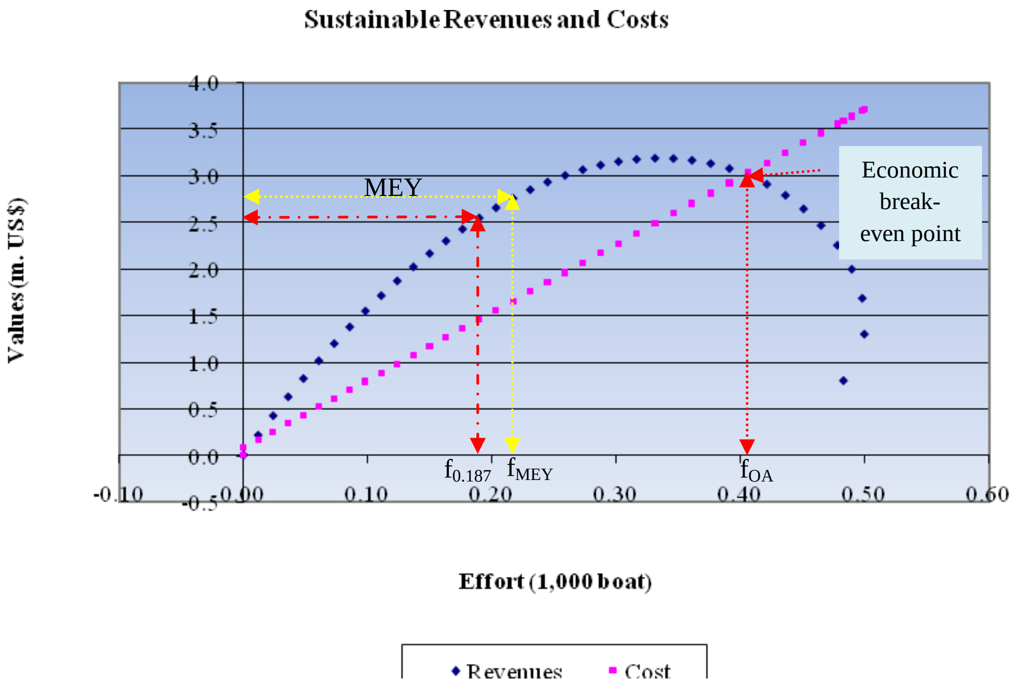

Figure 15: Fox curve of relationship between revenue, cost and effort

6.3 Sensitivity analysis of optimal fisheries policy

The model used to calculate the optimal mackerel policy discussed above is subject to considerable uncertainty. Among other things, the parameter estimates used in the model may well be erroneous. To check the robustness of the calculated optimal policy to parameter misspecification, a sensitivity analysis of the optimal policy to parameter values was conducted. More precisely, we calculated the optimal profit for other values of the parameters. The results of this exercise are reported in Table 12 and Figures 16 and 17.

The sensitivity results on optimal profits (economic rents) of the mackerel fishery based on changed assumptions of the base year (2006) indicate that the net profits of mackerel are in the range between US$ 1.277 million and US$ 2.923 million when the MSY is assumed to change between -20% and 30% (logistic). According to the Fox model, the profit of mackerel increased from US$ 1.166 million to US$ 1.241 million, when changing MSY -20% to 30%. Similarly, the parameter of landing price increased from -30% to 30% (logistic), profit gain from US$ 1.66 million to US$ 2.356 million and Fox model, profit gain from US$ 1.082 million to US$ 1.171 million with the price of landed decreasing from 30% to -30%. It was observed that the optimal profits have slightly changed or no sensitivity on changes made on base year profit, fishing effort and virgin stock status (Table 12).

The sensitivity analysis further indicates that even if the biological parameter estimations and information on price and costs are incorrect or erroneous, the mackerel fishery has the potential to generate economic rents ranging between US$ 1.166 million and US$ 2.923 million from both models.

Table 12: Sensitivity analysis of optimal mackerel fisheries policy

	Change						
Logistic	**-30%**	**-20%**	**-10%**	**0%**	**10%**	**20%**	**30%**
MSY (1,000 tonnes)	N/A	1.277	1.678	2.004	2.315	2.621	2.923
X_{max} (1,000 tonnes)	2.004	2.004	2.004	2.004	2.004	2.004	2.004
Schooling parameter	1.842	1.899	1.953	2.004	2.053	2.1	2.144
Biomass growth	2.268	2.184	2.097	2.004	1.9	1.772	N/A
Harvest (1,000 tonnes)	2.591	2.394	2.2	2.004	1.797	1.555	N/A
Price (m US$/1000 tonnes)	1.66	1.773	1.888	2.004	2.121	2.238	2.356
Effort (boat)	2.004	2.004	2.004	2.004	2.004	2.004	2.004
Initial Profit (m US$)	1.755	1.837	1.92	2.004	2.089	2.174	2.26
Fox							
MSY (1,000 tonnes)		1.166	1.082	1.099	1.138	1.187	1.241
Virgin stock (1,000 tonnes)	1.099	1.099	1.099	1.099	1.099	1.099	1.099
Schooling parameter	1.135	1.12	1.108	1.099	1.093	1.088	1.085
Biomass growth (1,000 tonnes)	0.914	0.967	1.028	1.099	1.187	1.307	N/A
Harvest (1,000 tonnes)	1.521	1.302	1.17	1.099	1.084	1.14	N/A
Price (m US$/1000 tonnes)	1.171	1.137	1.115	1.099	1.09	1.084	1.082
Effort (boat)	1.099	1.099	1.099	1.099	1.099	1.099	1.099
Initial Profit (m US$)	0.758	0.866	0.98	1.099	1.224	1.355	1.49

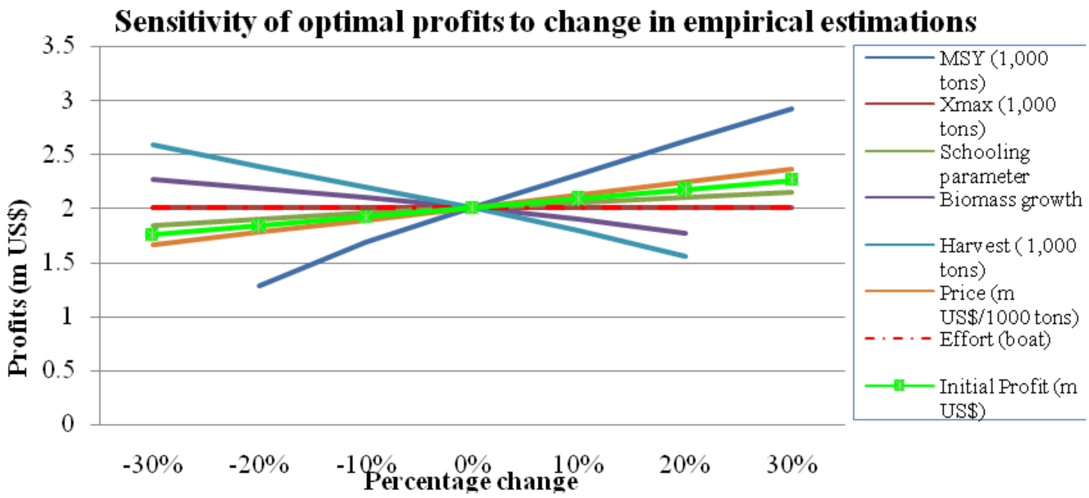

Figure 16: Sensitivity analysis Schaefer chart of mackerel fisheries in Cambodia

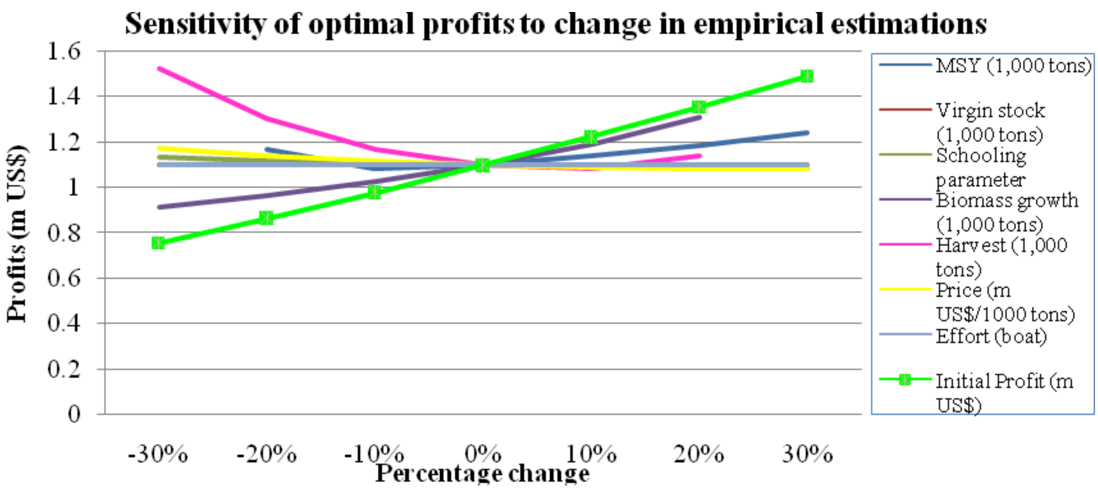

Figure 17: Sensitivity analysis Fox chart of mackerel fisheries in Cambodia

7 DISCUSSION

This study has aimed to provide an overview of the mackerel fisheries in Cambodian waters. The major obstacle has been the lack of good data on catches and effort by foreign vessels in the Cambodian EEZ and the Gulf off Thailand as a whole. However, the biological data of mackerel such as maximum length of fish, length-weight relationship and growth coefficient for the species as whole in the Gulf are available. With better data it would have been possible to address the issues of fair sharing of resource rents and optimal management of the mackerel stocks of the Gulf of Thailand as a whole. But, as mentioned, this is beyond the scope of this particular paper due to data problems. The estimates obtained here are, however, believed to be fairly realistic in terms of describing the current situation and the possibilities for improvements in Cambodian management of the mackerel stock if the issues of foreign catches is not addressed. The method employed in this paper can be regarded as a modification of the extrapolation method with biological and environmental information of mackerel fisheries aspects.

The bio-economic models developed here show that the mackerel fishery is generally quite profitable. It further shows that proper effort management can substantially increase profits. As the estimated results in Table 11 and sensitivity analysis Table 12 clearly show that stock size should be allowed to increase and that optimum stock size would allow for annual caches of approximately 6.000 tonnes per year with economic rents (profits) of about US$ 2 million under efficient management and good enforcement.

However, the results indicate that in order to reach the optimum sustainable yield and maximise economic yield, mackerel fishers needed to reduce fishing effort from 187 boats to about 150 boats. These are mostly inshore boats since very few boats have the capacity to operate offshore. To optimise resource utilisation and maximise economic rents from fisheries in the Gulf of Thailand, it would be necessary to address the issues of management in cooperation between all the nations surrounding the Gulf. The potential rent increases for Cambodia from such cooperation are very large. To stimulate the interest for and development of such cooperation some action must be taken. On one hand, to further intensify research of the resources, biological studies and upgrading of catch and effort statistics need to be made on a national basis and to establish the comparability of these data in the region. On the other hand, there is an urgent need for information on the capacity of resources fishing grounds to model the effects of the improved management measures in the coastal zone (EEZ) as well as the Gulf.

The trans-boundary fish stocks of the Gulf of Thailand are not a unique case. Consider for example the case of the Norwegian spring-spawning herring fishery (Bjorndal *et al.* 2004) where the cooperation between three nations in managing its fish stock is very similar to the mackerel stock in the Gulf of Thailand between Thailand, Vietnam, Malaysia and Cambodia. The dynamic bio-economic model used for the tri-nations in managing their herring stocks showed that the benefits of international cooperation far exceed the returns of a competitive open access fishery. Therefore, this model does well in forecasting the outcome of competitive open access fisheries showing an increased and sustained fishing effort by all fleets while harvest levels decline (Bjorndal *et al.* 2004).

8 CONCLUSION

This paper estimated the Schaefer and Fox economic models for the mackerel fisheries in Cambodia. The results from the Schaefer and Fox models indicate that the mackerel fish stocks are both biologically and economically overexploited and there are opportunities to increase the rents from the mackerel stocks in the EEZ by reducing effort and allowing the stocks to increase in size. The reason for the overexploitation may lie in the nature of the fishing boats that are most common in the Cambodian fleet, i.e. small inshore vessels. Their small size and limited operation capacity confines them to inshore areas leading to over-fishing of these areas.

According to the results of this study, the mackerel fishery could increase its total allowable catch (TAC) to the maximum level of OSY and maximise the economic rents by curtailing both the excessive fishing effort and exploitation in the inshore areas and expand the fishing capacity in the offshore areas. Therefore, this study suggests that the marine fisheries sector/Fisheries Administration set up a development scheme to extend these policies to mackerel fishing.

Prior to outlining the policy, this study should be aware of the national concerns. An optimal resource utilisation based solely on achieving economic efficiency inadequately addresses the broader social issues. In this regard, a policy aimed at maximum sustainable yield should be modified according to the precautionary principle rather than basing it on the maximum economic yield. This has advantages, since it offers to alleviate employment and distributional concerns in the coastal dwellers. In terms of payments, the winners and the losers in this fishery may perhaps be financed by increasing the license fees or limiting access for foreign fishing vessels.

Cooperation with neighbouring countries is very important in order to achieve efficient management of marine fisheries resources of migratory species in the Gulf of Thailand. Such cooperation should include all the country members in the Gulf area. The mackerel fishery is complex in nature due to the multi-nation exploitation and the local migratory behaviour of the species moving between several coastal EEZs, especially the overlapping fishing zones in the Gulf. Thereby, for sustainable management of the fisheries resources, there is a need for regional cooperation with all the relevant member countries.

Although this study is limited to the mackerel fishery in Cambodia, the bionomic model presents the basis for future policy analysis for a regional fisheries management approach in the Gulf of Thailand.

ACKNOWLEDGMENTS

I would like to express my gratitude to my supervisor Dr. Dadi Mar Kristofersson of the University of Iceland for his excellent technical guidance, criticism and comments during the time of developing and writing this report.

I am grateful to Dr. Tumi Tomasson, Mr. Thor Asgeirsson, Ms. Sigridur Ingvarsdottir and Mr. Gudni Magnus Eiriksson for their hospitality, support and guidance during the six months of study in Iceland. I am thankful to the Board of the UNU-FTP and United Nations University for offering me the opportunity to participate in this course and funding my studies. I would also like to extend my gratitude to the General Director of the Marine Research Institute and staff for their very good support, for hosting this learning environment.

I am thankful to Prof. Ragnar Arnason for his support and allowing me to use his approach programme in this report.

Finally, I would like to thank the General Director of the Fisheries Administration of Cambodia for allowing me to participate on this training course.

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Appendix 1: Cost calculation of marine fishing operating in Cambodia 2006

Unit: US$

Categories	Boat	Cost per boat	Total
1- Investment cost		**3,380**	**632,060**
Boat	187	2,500	467,500
Engine	187	370	69,190
Gear box	187	280	52,360
Nets	187	125	23,375
Shaft	187	75	14,025
Propeller	187	30	5,610
2- Depreciation value *(14% per year of investment capital)*			***88,488***
3- Operation cost		***6,194***	***1,158,278***
Fuel	187	1,350	252,450
Lubricating oil	187	200	37,400
Food	187	700	130,900
Labour cost	187	3,404	636,548
Boat repairing	187	350	65,450
Engine repairing	187	125	23,375
Nets repair	187	50	9,350
License	187	15	2,805
Overhead (10% of operation cost)			**115,828**
Fixed cost (3% of total landing revenue)			**75,609**
Total cost (TC)			**1,438,203**

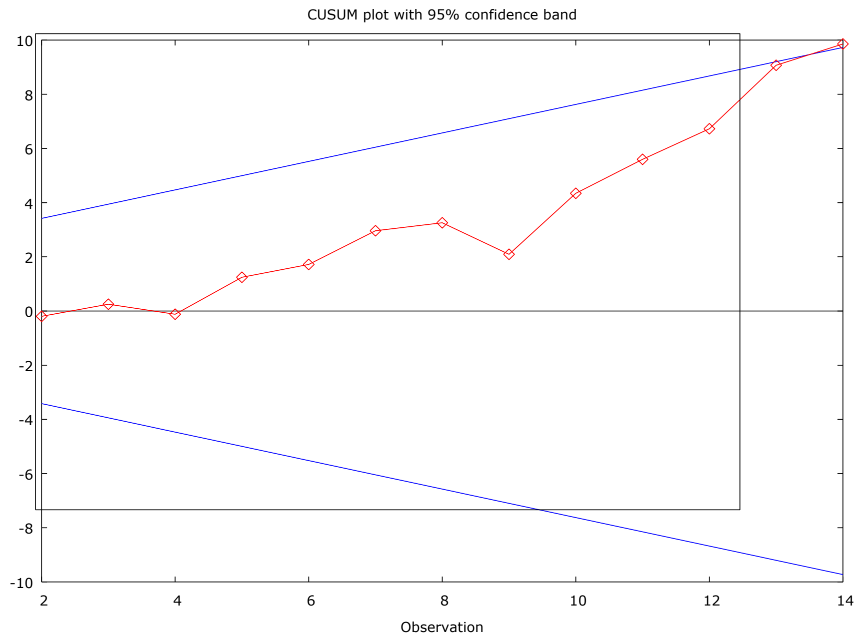
Appendix 2: Use GRETL checking the parameter stability (intercept and slope)

Model 1: OLS estimates using the 15 observations 1992-2006
Dependent variable: Schaefer model;

VARIABLE	COEFFICIENT	STDERROR	T STAT	P-VALUE	
const	0.0613596	0.00704380	8.711	<0.00001	***
e	-0.000243077	5.68248E-05	-4.278	0.00090	***

Mean of dependent variable = 0.0365333
Standard deviation of dep. var. = 0.0231142
Sum of squared residuals = 0.00310676
Standard error of residuals = 0.015459
Unadjusted R-squared = 0.584643
Adjusted R-squared = 0.552692
Degrees of freedom = 13
Durbin-Watson statistic = 1.39926
First-order autocorrelation coeff. = 0.276578
Log-likelihood = 42.3326
Akaike information criterion (AIC) = -80.6652
Schwarz Bayesian criterion (BIC) = -79.2491
Hannan-Quinn criterion (HQC) = -80.6803

CUSUM test for parameter stability –
Null hypothesis: no change in parameters
Test statistic: Harvey-Collier t(12) = 2.73394
with p-value = P(t(12) > 2.73394) = 0.0181338



Chow test for structural break at observation 2001 -
Null hypothesis: no structural break
Test statistic: F(2, 11) = 4.42883
with p-value = P(F(2, 11) > 4.42883) = 0.0388201
Augmented regression for Chow test
OLS estimates using the 15 observations 1992-2006
Dependent variable: sche

VARIABLE	COEFFICIENT	STDERROR	T STAT	P-VALUE
const	0.0653294	0.00686756	9.513	<0.00001 ***
e	-0.000360326	6.53109E-05	-5.517	0.00018 ***
splitdum	-0.00342892	0.0127541	-0.269	0.79302
sd_e	0.000180322	9.77605E-05	1.845	0.09218 *

Mean of dependent variable = 0.0365333
Standard deviation of dep. var. = 0.0231142
Sum of squared residuals = 0.00172097
Standard error of residuals = 0.0125081
Unadjusted R-squared = 0.769916
Adjusted R-squared = 0.707166
F-statistic (3, 11) = 12.2695 (p-value = 0.000783)
Durbin-Watson statistic = 2.6802
First-order autocorrelation coeff. = -0.366056
Log-likelihood = 46.7628
Akaike information criterion (AIC) = -85.5256
Schwarz Bayesian criterion (BIC) = -82.6934
Hannan-Quinn criterion (HQC) = -85.5558

Chow test for structural break at observation 2001:
F(2, 11) = 4.428825 with p-value 0.038820

Model 2: OLS estimates using the 15 observations 1992-2006
Dependent variable: Schaefer;

VARIABLE	COEFFICIENT	STDERROR	T STAT	P-VALUE
const	0.0632309	0.00531711	11.892	<0.00001 ***
e	-0.000353678	5.21717E-05	-6.779	0.00003 ***
d	0.0141602	0.0114717	1.234	0.24279
ed	9.88389E-05	8.24769E-05	1.198	0.25595

Mean of dependent variable = 0.0365333
Standard deviation of dep. var. = 0.0231142
Sum of squared residuals = 0.00110648
Standard error of residuals = 0.0100294
Unadjusted R-squared = 0.85207
Adjusted R-squared = 0.811725
F-statistic (3, 11) = 21.1198 (p-value = 7.19e-005)
Durbin-Watson statistic = 2.65039
First-order autocorrelation coeff. = -0.392424
Log-likelihood = 50.0756
Akaike information criterion (AIC) = -92.1512
Schwarz Bayesian criterion (BIC) = -89.319
Hannan-Quinn criterion (HQC) = -92.1814

Excluding the constant, p-value was highest for variable 5 (ed)
Restriction set
1: b[d] = 0
2: b[ed] = 0

Test statistic: F(2, 11) = 9.94285, with p-value = 0.00341974

Restricted estimates:

VARIABLE	COEFFICIENT	STDERROR	T STAT	P-VALUE
const	0.0613596	0.00704380	8.711	<0.00001 ***
e	-0.000243077	5.68248E-05	-4.278	0.00090 ***
d	0.000000	0.000000	undefined	
ed	0.000000	0.000000	undefined	

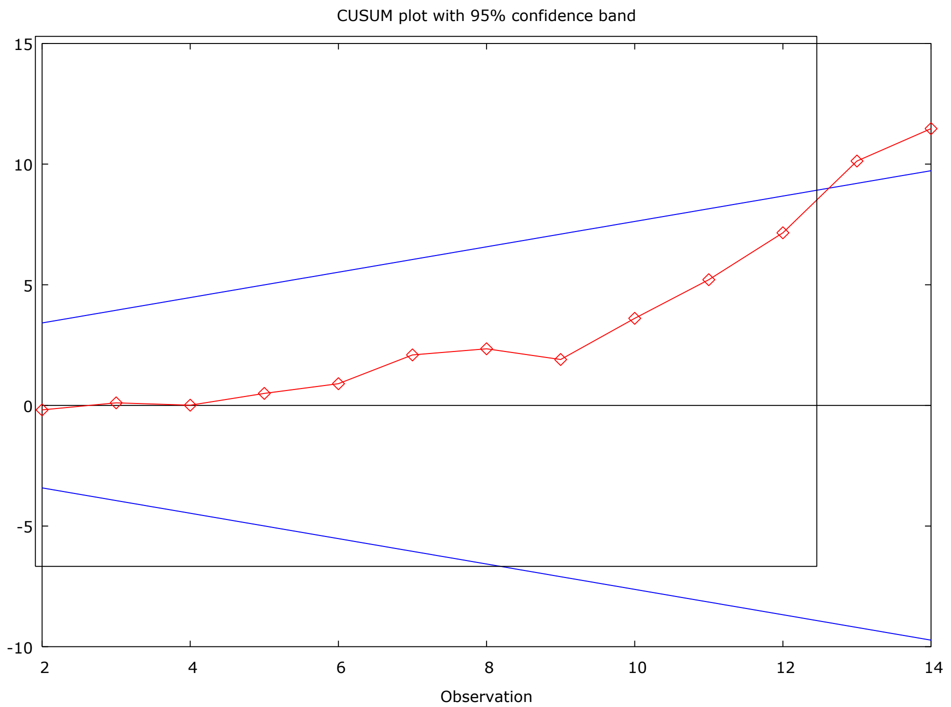
Standard error of residuals = 0.015459

Model 3: OLS estimates using the 15 observations 1992-2006
Dependent variable: Fox;

VARIABLE	COEFFICIENT	STDERROR	T STAT	P-VALUE
const	-2.76286	0.249072	-11.093	<0.00001 ***
e	-0.00772717	0.00200935	-3.846	0.00202 ***

Mean of dependent variable = -3.55207
Standard deviation of dep. var. = 0.770141
Sum of squared residuals = 3.88459
Standard error of residuals = 0.546639
Unadjusted R-squared = 0.532183
Adjusted R-squared = 0.496197
Degrees of freedom = 13
Durbin-Watson statistic = 0.648362
First-order autocorrelation coeff. = 0.683309
Log-likelihood = -11.1513
Akaike information criterion (AIC) = 26.3027
Schwarz Bayesian criterion (BIC) = 27.7188
Hannan-Quinn criterion (HQC) = 26.2876

CUSUM test for parameter stability -
Null hypothesis: no change in parameters
Test statistic: Harvey-Collier t(12) = 3.18135
with p-value = P(t(12) > 3.18135) = 0.00790142



Chow test for structural break at observation 2001 -
Null hypothesis: no structural break
Test statistic: F(2, 11) = 18.3004
with p-value = P(F(2, 11) > 18.3004) = 0.000316801

Augmented regression for Chow test
OLS estimates using the 15 observations 1992-2006
Dependent variable: fox

VARIABLE	COEFFICIENT	STDERROR	T STAT	P-VALUE
const	-2.57874	0.156848	-16.441	<0.00001 ***
e	-0.0131694	0.00149163	-8.829	<0.00001 ***
splitdum	-0.158563	0.291290	-0.544	0.59706
sd_e	0.00836782	0.00223275	3.748	0.00322 ***

Mean of dependent variable = -3.55207
Standard deviation of dep. var. = 0.770141
Sum of squared residuals = 0.897686
Standard error of residuals = 0.285671
Unadjusted R-squared = 0.891893
Adjusted R-squared = 0.862409
F-statistic (3, 11) = 30.2502 (p-value = 1.31e-005)
Durbin-Watson statistic = 2.46393
First-order autocorrelation coeff. = -0.240326
Log-likelihood = -0.164188
Akaike information criterion (AIC) = 8.32838
Schwarz Bayesian criterion (BIC) = 11.1606
Hannan-Quinn criterion (HQC) = 8.29821

Chow test for structural break at observation 2001:
F(2, 11) = 18.300353 with p-value 0.000317

Model 4: OLS estimates using the 15 observations 1992-2006
Dependent variable: Fox;

VARIABLE	COEFFICIENT	STDERROR	T STAT	P-VALUE
const	-2.60534	0.104820	-24.855	<0.00001 ***
e	-0.0130851	0.00102850	-12.722	<0.00001 ***
ed	0.00644292	0.00162593	3.963	0.00222 ***
d	0.249041	0.226150	1.101	0.29431

Mean of dependent variable = -3.55207
Standard deviation of dep. var. = 0.770141
Sum of squared residuals = 0.430015
Standard error of residuals = 0.197718
Unadjusted R-squared = 0.948214
Adjusted R-squared = 0.93409
F-statistic (3, 11) = 67.1372 (p-value < 0.00001)
Durbin-Watson statistic = 2.29763
First-order autocorrelation coeff. = -0.181381
Log-likelihood = 5.35581
Akaike information criterion (AIC) = -2.71163
Schwarz Bayesian criterion (BIC) = 0.120575
Hannan-Quinn criterion (HQC) = -2.74179

Excluding the constant, p-value was highest for variable 3 (d)

Restriction set
1: b[ed] = 0
2: b[d] = 0

Test statistic: F(2, 11) = 44.1849, with p-value = 5.53047e-006

Restricted estimates:

VARIABLE	COEFFICIENT	STDERROR	T STAT	P-VALUE
const	-2.76286	0.249072	-11.093	<0.00001 ***
e	-0.00772717	0.00200935	-3.846	0.00202 ***
ed	0.000000	0.000000	undefined	
d	0.000000	0.000000	undefined	

Standard error of residuals = 0.546639

Appendix 3: Summary output of model

1- SUMMARY OUTPUT OF SCHAEFER MODEL

Regression Statistics	
Multiple R	0.92307626
R Square	0.852069782
Adjusted R Square	0.811725177
Standard Error	0.010029405
Observations	15

ANOVA

Regression	3	0.0063733	0.00212442	21.119795	7.19144E-05
Residual	11	0.0011065	0.00010059		
Total	14	0.0074797			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.0632309	0.00531711	11.892	0.0000001	0.051528	0.074934	0.0515280	0.0749338
d	0.0141602	0.01147168	1.2344	0.242789	-0.01109	0.039409	-0.011089	0.0394092
e	-0.000354	0.00005217	-6.7791	0.00003	-0.00047	-0.00024	-0.000469	-0.000239
ed	0.0000988	0.00008248	1.1984	0.25595	-0.000083	0.000280	-0.0000827	0.0002804

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7326175
R Square	0.5367283
Adjusted R Square	0.4981224
Standard Error	0.0157419
Observations	14

ANOVA 0.00344518 13.902728 0.002881089

	df	SS	MS	F	Significance F
Regression	1	0.00344518	0.00344518	13.902728	0.00288109
Residual	12	0.00297367	0.00024781		
Total	13	0.00641886			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.0590146	0.00785405	7.5139	0.000007	0.04190214	0.076127	0.0419021	0.0761271
16	-0.000228	0.00006125	-3.7286	0.0029	-0.00036181	-0.00010	-0.0003618	-0.0000949

2- SUMMARY OUTPUT OF FOX MODEL

Regression Statistics	
Multiple R	0.72951
R Square	0.53218
Adjusted R Square	0.49620
Standard Error	0.54664
Observations	15

ANOVA

	df	SS	MS	F	Significance F
Regression	1	4.41906	4.41906	14.78864	0.00202
Residual	13	3.88459	0.29881		
Total	14	8.30365			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-2.762865	0.24907237	-11.09262	0.00000005	-3.300953	-2.224777	-3.300953	-2.224777
e	-0.007727	0.00200935	-3.845599	0.002024	-0.0120681	-0.003386	-0.012068	-0.0033862

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.973763
R Square	0.948214
Adjusted R Square	0.934090
Standard Error	0.197718
Observations	15

ANOVA

	df	SS	MS	F	Significance F
Regression	3	7.873634	2.624545	67.137177	0.000000
Residual	11	0.430015	0.039092		
Total	14	8.303649			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-2.605340	0.104820	-24.855249	0.000000	-2.836048	-2.374631	-2.836048	-2.374631

d	0.249041	0.226150	1.101220	0.294314	-0.248713	0.746795	-0.248713	0.746795
e	-0.013085	0.001029	-12.722470	0.000000	-0.015349	-0.010821	-0.015349	-0.010821
ed	0.006443	0.001626	3.962599	0.002224	0.002864	0.010022	0.002864	0.010022

Appendix 4: Summary result from Excel Spreadsheet

	Landings Price		***Natural biomass growth***		**Iso-profits**			***Iso-profits (% of MSY)***		
Biomass	Logistic	Fox	Logistic	Fox	0%	25%	50%	0%	25%	50%
0.0	#NUM!	#NUM!	0.0	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
0.4	0.5	0.5	0.6	1.5	-0.1	-1.0	-2.0	0.0	-0.5	-0.9
0.8	0.5	0.5	1.1	2.4	-0.2	-2.6	-4.9	-0.1	-0.9	-1.7
1.2	0.5	0.5	1.6	3.1	-0.6	-6.5	-12.4	-0.1	-1.4	-2.7
1.5	0.5	0.5	2.1	3.7	-4.1	-46.5	-88.9	-0.2	-2.0	-3.9
1.9	0.5	0.5	2.6	4.2	1.3	15.3	29.3	-0.3	-2.9	-5.6
2.3	0.5	0.5	3.0	4.5	0.7	7.8	15.0	-0.4	-4.3	-8.2
2.7	0.5	0.5	3.4	4.9	0.5	5.7	11.0	-0.6	-6.6	-12.7
3.1	0.5	0.5	3.8	5.1	0.4	4.7	9.0	-1.0	-11.6	-22.1
3.5	0.5	0.5	4.1	5.4	0.4	4.1	7.9	-2.5	-29.2	-55.8
3.9	0.5	0.5	4.4	5.5	0.3	3.7	7.2	9.6	109.9	210.2
4.3	0.5	0.5	4.7	5.7	0.3	3.5	6.6	1.9	21.8	41.7
4.6	0.5	0.5	4.9	5.8	0.3	3.3	6.2	1.1	12.9	24.7
5.0	0.5	0.5	5.2	5.8	0.3	3.1	5.9	0.8	9.5	18.2
5.4	0.5	0.5	5.3	5.9	0.3	3.0	5.7	0.7	7.7	14.8
5.8	0.5	0.5	5.5	5.9	0.3	2.9	5.5	0.6	6.6	12.7
6.2	0.5	0.5	5.6	5.9	0.2	2.8	5.3	0.5	5.9	11.2
6.6	0.5	0.5	5.7	5.8	0.2	2.7	5.2	0.5	5.3	10.2
7.0	0.5	0.5	5.8	5.7	0.2	2.6	5.0	0.4	4.9	9.4
7.3	0.5	0.5	5.9	5.6	0.2	2.6	4.9	0.4	4.6	8.8
7.7	0.5	0.5	5.9	5.5	0.2	2.5	4.8	0.4	4.3	8.3
8.1	0.5	0.5	5.9	5.4	0.2	2.5	4.8	0.4	4.1	7.9
8.5	0.5	0.5	5.8	5.3	0.2	2.4	4.7	0.3	3.9	7.5
8.9	0.5	0.5	5.7	5.1	0.2	2.4	4.6	0.3	3.8	7.2
9.3	0.5	0.5	5.6	4.9	0.2	2.4	4.5	0.3	3.6	7.0
9.7	0.5	0.5	5.5	4.7	0.2	2.3	4.5	0.3	3.5	6.7
10.1	0.5	0.5	5.3	4.5	0.2	2.3	4.4	0.3	3.4	6.5
10.4	0.5	0.5	5.2	4.2	0.2	2.3	4.4	0.3	3.3	6.4
10.8	0.5	0.5	4.9	4.0	0.2	2.3	4.3	0.3	3.2	6.2
11.2	0.5	0.5	4.7	3.7	0.2	2.3	4.3	0.3	3.2	6.1
11.6	0.5	0.5	4.4	3.4	0.2	2.2	4.3	0.3	3.1	5.9
12.0	0.5	0.5	4.1	3.2	0.2	2.2	4.2	0.3	3.1	5.8
12.4	0.5	0.5	3.8	2.9	0.2	2.2	4.2	0.3	3.0	5.7
12.8	0.5	0.5	3.4	2.5	0.2	2.2	4.2	0.3	2.9	5.6
13.1	0.5	0.5	3.0	2.2	0.2	2.2	4.1	0.3	2.9	5.5
13.5	0.5	0.5	2.6	1.9	0.2	2.2	4.1	0.2	2.9	5.5
13.9	0.5	0.5	2.1	1.5	0.2	2.1	4.1	0.2	2.8	5.4
14.3	0.5	0.5	1.6	1.2	0.2	2.1	4.1	0.2	2.8	5.3
14.7	0.5	0.5	1.1	0.8	0.2	2.1	4.0	0.2	2.7	5.3
15.1	0.5	0.5	0.6	0.4	0.2	2.1	4.0	0.2	2.7	5.2
15.5	0.5	0.5	0.0	0.0	0.2	2.1	4.0	0.2	2.7	5.1

Appendix 5: Schaefer model estimates the sustainable fishery

Results (The sustainable fishery)						
Biomass	**Biomass growth**	**Harvest**	**Revenues**	**Costs**	**Profits**	**Rents**
0	0.0	0.0	#NUM!	#DIV/0!	#NUM!	#NUM!
0.30934	0.5	0.5	0.2	0.8	-0.6	-0.5
0.61868	0.9	0.9	0.5	1.0	-0.5	-0.4
0.92802	1.3	1.3	0.7	1.1	-0.4	-0.3
1.23736	1.7	1.7	0.9	1.2	-0.3	-0.2
1.5467	2.1	2.1	1.1	1.3	-0.1	0.0
1.85604	2.5	2.5	1.3	1.3	0.0	0.1
2.16538	2.8	2.8	1.5	1.4	0.2	0.3
2.47472	3.2	3.2	1.7	1.4	0.3	0.4
2.78406	3.5	3.5	1.9	1.4	0.5	0.6
3.0934	3.8	3.8	2.0	1.4	0.6	0.7
3.40274	4.0	4.0	2.2	1.4	0.8	0.8
3.71208	4.3	4.3	2.3	1.4	0.9	1.0
4.02142	4.5	4.5	2.5	1.4	1.0	1.1
4.33076	4.7	4.7	2.6	1.4	1.1	1.2
4.6401	4.9	4.9	2.7	1.4	1.2	1.3
4.94944	5.1	5.1	2.8	1.4	1.3	1.4
5.25878	5.3	5.3	2.9	1.4	1.4	1.5
5.56812	5.4	5.4	2.9	1.4	1.5	1.6
5.87746	5.5	5.5	3.0	1.4	1.6	1.7
6.1868	5.6	5.6	3.1	1.4	1.7	1.8
6.49614	5.7	5.7	3.1	1.3	1.8	1.8
6.80548	5.8	5.8	3.1	1.3	1.8	1.9
7.11482	5.8	5.8	3.2	1.3	1.9	2.0
7.42416	5.9	5.9	3.2	1.3	1.9	2.0
7.7335	5.9	5.9	3.2	1.2	2.0	2.0
8.04284	5.9	5.9	3.2	1.2	2.0	2.1
8.35218	5.8	5.8	3.2	1.2	2.0	2.1
8.66152	5.8	5.8	3.1	1.1	2.0	2.1
8.97086	5.7	5.7	3.1	1.1	2.0	2.1
9.2802	5.6	5.6	3.1	1.1	2.0	2.1
9.58954	5.5	5.5	3.0	1.0	2.0	2.1
9.89888	5.4	5.4	2.9	1.0	2.0	2.0
10.20822	5.3	5.3	2.9	0.9	1.9	2.0
10.51756	5.1	5.1	2.8	0.9	1.9	1.9
10.8269	4.9	4.9	2.7	0.9	1.8	1.9
11.13624	4.7	4.7	2.6	0.8	1.8	1.8
11.44558	4.5	4.5	2.5	0.8	1.7	1.8
11.75492	4.3	4.3	2.3	0.7	1.6	1.7
12.06426	4.0	4.0	2.2	0.7	1.5	1.6
12.3736	3.8	3.8	2.0	0.6	1.4	1.5
12.68294	3.5	3.5	1.9	0.6	1.3	1.4
12.99228	3.2	3.2	1.7	0.5	1.2	1.3
13.30162	2.8	2.8	1.5	0.5	1.1	1.1
13.61096	2.5	2.5	1.3	0.4	0.9	1.0
13.9203	2.1	2.1	1.1	0.4	0.8	0.9
14.22964	1.7	1.7	0.9	0.3	0.6	0.7
14.53898	1.3	1.3	0.7	0.2	0.5	0.5

14.84832	0.9	0.9	0.5	0.2	0.3	0.4
15.15766	0.5	0.5	0.2	0.1	0.1	0.2
15.467	0.0	0.0	0.0	0.1	-0.1	0.0

Appendix 6: Fox model estimates the sustainable fishery

Results(The sustainable fishery)

Biomass	Biomass growth	Harvest	Revenues	Costs	Profits	Rents
0	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
0.30934	1.2	1.2	0.7	3.5	-2.8	-2.8
0.61868	2.1	2.1	1.1	3.7	-2.6	-2.5
0.92802	2.7	2.7	1.5	3.7	-2.3	-2.2
1.23736	3.2	3.2	1.7	3.7	-1.9	-1.9
1.5467	3.7	3.7	2.0	3.6	-1.6	-1.6
1.85604	4.1	4.1	2.2	3.6	-1.4	-1.3
2.16538	4.4	4.4	2.4	3.5	-1.1	-1.0
2.47472	4.7	4.7	2.5	3.4	-0.9	-0.8
2.78406	4.9	4.9	2.7	3.3	-0.7	-0.6
3.0934	5.1	5.1	2.8	3.3	-0.5	-0.4
3.40274	5.3	5.3	2.9	3.2	-0.3	-0.2
3.71208	5.5	5.5	3.0	3.1	-0.1	0.0
4.02142	5.6	5.6	3.0	3.0	0.0	0.1
4.33076	5.7	5.7	3.1	2.9	0.2	0.3
4.6401	5.8	5.8	3.1	2.8	0.3	0.4
4.94944	5.8	5.8	3.2	2.7	0.4	0.5
5.25878	5.9	5.9	3.2	2.6	0.5	0.6
5.56812	5.9	5.9	3.2	2.6	0.6	0.7
5.87746	5.9	5.9	3.2	2.5	0.7	0.8
6.1868	5.9	5.9	3.2	2.4	0.8	0.9
6.49614	5.8	5.8	3.2	2.3	0.9	0.9
6.80548	5.8	5.8	3.1	2.2	0.9	1.0
7.11482	5.7	5.7	3.1	2.1	1.0	1.0
7.42416	5.6	5.6	3.0	2.0	1.0	1.1
7.7335	5.5	5.5	3.0	2.0	1.0	1.1
8.04284	5.4	5.4	2.9	1.9	1.1	1.1
8.35218	5.3	5.3	2.9	1.8	1.1	1.2
8.66152	5.2	5.2	2.8	1.7	1.1	1.2
8.97086	5.0	5.0	2.7	1.6	1.1	1.2
9.2802	4.9	4.9	2.7	1.6	1.1	1.2
9.58954	4.7	4.7	2.6	1.5	1.1	1.2
9.89888	4.6	4.6	2.5	1.4	1.1	1.2
10.20822	4.4	4.4	2.4	1.3	1.1	1.1
10.51756	4.2	4.2	2.3	1.2	1.0	1.1
10.8269	4.0	4.0	2.2	1.2	1.0	1.1
11.13624	3.8	3.8	2.0	1.1	1.0	1.0
11.44558	3.6	3.6	1.9	1.0	0.9	1.0
11.75492	3.3	3.3	1.8	0.9	0.9	0.9
12.06426	3.1	3.1	1.7	0.9	0.8	0.9
12.3736	2.9	2.9	1.5	0.8	0.8	0.8
12.68294	2.6	2.6	1.4	0.7	0.7	0.8
12.99228	2.3	2.3	1.3	0.6	0.6	0.7
13.30162	2.1	2.1	1.1	0.6	0.6	0.6
13.61096	1.8	1.8	1.0	0.5	0.5	0.6

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13.9203	1.5	1.5	0.8	0.4	0.4	0.5
14.22964	1.2	1.2	0.7	0.4	0.3	0.4
14.53898	0.9	0.9	0.5	0.3	0.2	0.3
14.84832	0.6	0.6	0.3	0.2	0.1	0.2
15.15766	0.3	0.3	0.2	0.1	0.0	0.1
15.467	0.0	0.0	0.0	0.1	-0.1	0.0