A BIOECONOMIC ANALYSIS
OF THE GHANAIAN TUNA FISHERY (1980 – 2000)

By

MABEL BORTELEY BORTIER-VERSTRAATEN

Thesis submitted in partial fulfilment of requirement for the Master of Science in International Fisheries Management.

DEPARTMENT OF ECONOMICS
NORWEGIAN COLLEGE OF FISHERY SCIENCE
UNIVERSITY OF TROMSØ, NORWAY
May, 2002

A BIOECONOMIC ANALYSIS OF THE GHANAIAN TUNA FISHERY (1980 – 2000)

Masters Programme International Fisheries Management
Norwegian College of Fishery Science
University of Tromsø
9037 Tromsø
NORWAY

By:
Mabel Borteley Bortier-Verstraaten
Tema, GHANA

Supervisor:
Claire W. Armstrong
Associate Professor

ABSTRACT

The commercial tuna fishery of the East Atlantic and like wise the Ghanaian tuna fishery are based on the harvests of Bigeye, Skipjack and Yellowfin. In Ghana, baitboats and purse seiners commercially harvest these species of tuna.

This study analysed the CPUE for the Ghanaian tuna fishery. The analysis was made for the three species and also for the two vessel types. The effort was standardized to large purse seiner days. The results when compared to the CPUE per species for the East Atlantic revealed that the Ghanaian vessels (1980 – 2000) were in some cases up to 40 times more efficient than large purse seiners in the East Atlantic (1967-1980).

A single species bioeconomic analysis was conducted for each of the three species using biological parameters adopted from Conrad and Adu-Asamoah (1986). This showed that present harvest levels of Skipjack and Yellowfin for the East Atlantic region were in excess of the open access equilibrium. Thus a decline in future harvest levels of Skipjack and Yellowfin is expected.

Sustainable economic rents calculated for the two-vessel types revealed that, bioeconomically, baitboats are more profitable than purse seiners. It was observed that the FAD's might be the main cause of changes in the species composition ratio of the tuna catches over the past decade.

ACKNOWLEDGEMENTS

I am very much indebted to the following persons who were very helpful with my data collection: Mr. Patrick Amartey and Mr. Paul Bannerman of the Marine Fisheries Research Division in Tema, Ghana; Dr. Eric Kwei and Mr. David Verstraaten of Pioneer Food Cannery, Tema, Ghana; Mr. Michael Mensah of Tema Tuna Ventures, Tema, Ghana; Dr. Guillermo Fisch, Mr. Papa Kebe and Mr. Carlos Palma all of the International Commission for the Conservation of Atlantic Tuna, Madrid, Spain.

My sincere gratitude goes to Dr. Claire Armstrong of the Norwegian College of Fishery Science, University of Tromsø, Tromsø, Norway for her excellent supervision of this thesis and to Mr. David Verstraaten, my dear husband, who contributed his time and talents freely to the reviewing of this thesis. His efforts are very much appreciated. I also greatly appreciate the support of close friends and family especially the Adekoya family of Tromsø, Norway; my mother, Mrs. Theodocia Bortier and my sweet little daughter, Michelle Verstraaten, to these ones and all others I say, God richly bless you.

And to God, who makes all things beautiful in its time be praise, honour and thanksgiving for all the wonderful things He has brought me through during my time of study in Norway.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

1. INTRODUCTION

One of the major ports for landing tuna caught in the Gulf of Guinea is Tema, Ghana, where between 50,000 MT and 90,000 MT of tuna are landed annually. The commercial tuna fishery of Ghana is based on three major species: Bigeye (*Thunnus obesus*), Skipjack (*Katsuwonus pelamis*), and Yellowfin (*Thunnus albacares*) tuna and are harvested by baitboats and purse seiners. Elsewhere in the East Atlantic, longliners are also used especially for Bigeye catches.

Though the baitboat fleet of Ghana makes significant contributions to the total catch in the Eastern Atlantic region, it catches mainly small fish (1.9 – 3.2 kg) as against a recommended minimum of 3.2 kg by the International Commission for the Conservation of Atlantic Tuna (ICCAT). This undersized fish problem is especially more prevalent in the Bigeye catches. Thus the Tropical Tuna Species Group of ICCAT recommended in their 1999 Bigeye Detailed Report that, the "best size" substitution for the baitboat fishery in Ghana be made to replace the current undersized fish, which are predominant in the Ghanaian Bigeye catch (ICCAT, BET, 2000). While Bigeye tagging programmes are underway, there is currently insufficient data available on the Bigeye stocks to address this issue. Rather this study attempts to:

1. Describe the tuna fishery of Ghana.
2. Investigate open access (OA) versus optimal management of the tuna fishery.
3. Discuss any possible relationship(s) that may exist between the two vessel types.

The second section of the paper presents some background information about the East Atlantic tuna fishery and the Ghanaian tuna fishery in particular. It focuses on the historical developments of the Ghanaian commercial tuna fisheries, markets, employment, government policies & regulations and management.

The third section describes the single species model employed for this paper. The Gordon-Schaefer bioeconomic model was employed in an empirical investigation of this fishery. It was assumed that each species is ecologically independent and subject to harvests by selective gear. It also touches on the profit function employed for this study.

The fourth section, which is the data chapter, presents historical levels of catch and effort data, economic and biological data. Historical data on catch and effort (1980-2000) for both baitboat and purse seiner fleet for Ghana were gathered from the Marine Fisheries Research Division (MFRD) of the Fisheries Department of Ghana, in Tema. Secondary data on the tuna species were obtained from the ICCAT head office in Madrid, Spain. Costs of fishing and prices of fish were collected for both the baitboat and the purse seiner fishery from Tema Tuna Ventures Limited (TTV) and Pioneer Food Cannery Limited (PFC). Summary data of annual harvests by species and country for the East Atlantic region was downloaded from the ICCAT homepage (www.ICCAT.es). The biological data was adopted from work by Conrad and Adu-Asamoah (1986) on the three tuna species in the Eastern Tropical Atlantic.

Their results were used to compute the bioeconomic and open access equilibria for the three species for each vessel type. These are presented in the results i.e. the fifth chapter. Also presented in that chapter is the catch per unit effort (CPUE) by vessel and by species. The results show that CPUE for the Ghanaian fishery (1980 – 2000) are much higher than for the East Atlantic as a whole (1967 – 1980). It also revealed that bioeconomic wise, the baitboat fishery is more cost-effective than the purse seiner fishery.

The sixth chapter discusses the results of the entire study with respect to fishing with the aid of fish aggregating devices as well as its implications on policy and management. Fish aggregating devices may be responsible for changes in the species composition of Bigeye and Skipjack during the past decade.

The conclusions arrived at as a result of this study are presented in the final chapter. One of which is that future harvest levels of all three species are expected to be below the level of the 1999 landings.

To enable this study to be carried out, the following assumptions/hypotheses were made:

1. Species are ecologically independent and subject to perfect selective harvesting.
2. Tuna fishing in the East Atlantic Ocean is done by Ghanaian baitboats and purse seiners only.

3. Large purse seiners, small purse seiners and baitboats spend 291, 198 and 231 days at sea per vessel, and a small purse seiner is 0.48 of a large purse seiner, while bait boat is 0.29 of a large purse seiner.
4. The Ghanaian tuna fishery, since it is a part of the overall East Atlantic tuna fishery, was assumed to be similar with respect to biological parameters and CPUE trends during the period studied by Conrad and Adu-Asamoah (1967 – 1980) and that these have not changed in recent years (1980 – 2000).

Limitations or drawbacks encountered included the fact that biological parameters were adopted instead of being calculated specifically for the Ghanaian tuna fishery, the effort data obtained were in number of vessels and not days at sea, and harvests by species for each vessel type was not available.

2. BACKGROUND

2.1 Biology of the Tuna Species

Three species of tropical tuna are exploited in the East Atlantic Ocean fishery. These are Bigeye (*Thunnus obesus*), Skipjack (*Katsuwonus pelamis*), and Yellowfin (*Thunnus albacares*) tuna. They are pelagic and highly migratory species. World wide, Skipjack is the most widely distributed of the species and by far the largest population.

2.1.1 Bigeye *(Thunnus obesus)*

The geographical distribution of Bigeye tuna (Plate 2.1) is very wide and covers almost the entire Atlantic Ocean between 50°N and 45°S. This species dwells in deeper waters than other tuna species and exhibits extensive vertical movements. Spawning takes place in tropical waters. They tend to migrate from the spawning grounds into temperate waters, as they grow larger. Catch information from the surface gears (purse seine and pole & line) indicate that the Gulf of Guinea is a major nursery ground for this species. Various prey organisms such as fish, molluscs, and crustaceans are found in its stomach contents.

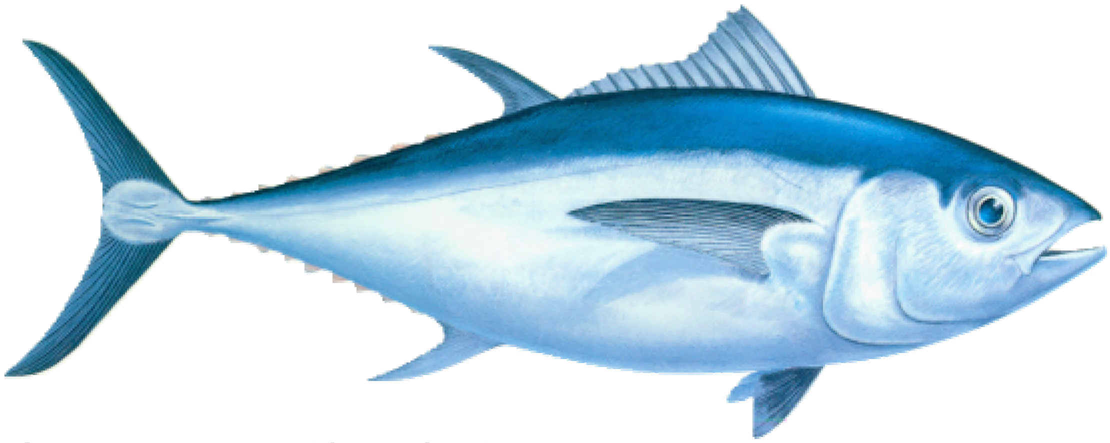

Plate 2.1 Bigeye Tuna *(Thunnus obesus)*

Bigeye exhibit relatively fast growth; fish of about 100 cm in fork length corresponds to three years of age, and this is when they become mature. Young fish form schools mostly mixed with other tunas such as Skipjack and Yellowfin. These schools are often associated with drifting objects, whales, sharks and sea mounts.

This association appears to be less and less as they grow larger. Juvenile Bigeye can hardly be distinguished from juvenile Yellowfin.

"Circumstantial evidence, such as time-area distribution of the fish and movements of tagged Bigeye tuna, suggests an Atlantic wide single stock" (ICCAT, BET, 2000).

2.1.2 Skipjack *(Katsuwonus pelamis)*

Skipjack (Plate 2.2) is a cosmopolitan species forming schools in tropical and subtropical waters of the three oceans. It spawns opportunistically throughout the year in vast areas of the Atlantic. The size at first maturity is about 45 cm for males and 42 cm for females in the East Atlantic and 52 cm for males and 51 cm for females in the West Atlantic.

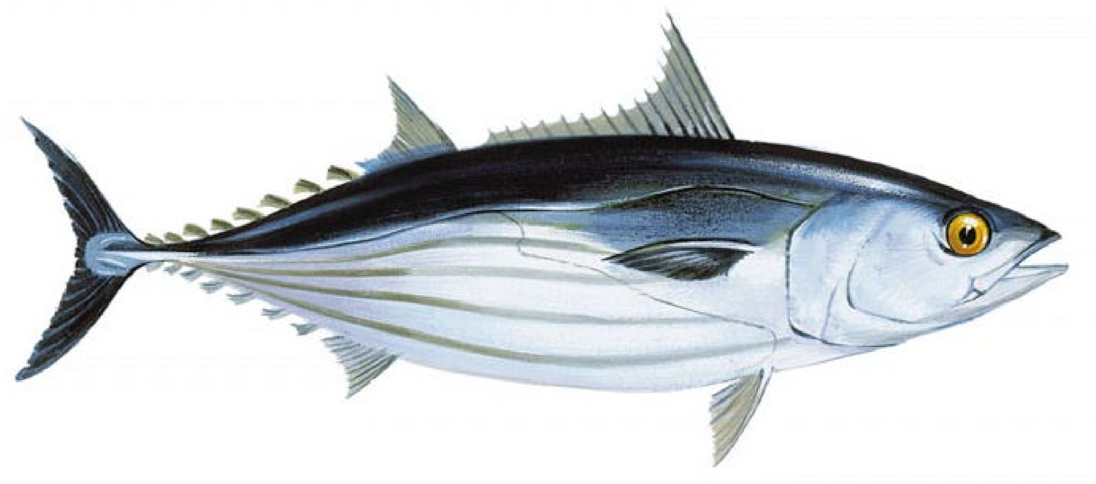

Plate 2.2 Skipjack Tuna *(Katsuwonus pelamis)*

Skipjack is a species often associated with floating objects; both natural objects and diverse fish aggregating devices (FAD's) have been used extensively since the early 1990s by purse seiners and baitboats. During the 1991 to 2000 period, 40% of Skipjack were caught with FAD's. Skipjack caught with FAD's is usually associated with small Yellowfin (20%) and small Bigeye (17%). A comparison by ICCAT, of size distribution of Skipjack between periods prior to and after the introduction of FAD's shows that in the East Atlantic, there has been an increase in the proportion of small fish in the catches, as well as a decline in the total catch in recent years.

The Skipjack Working Committee of ICCAT reviewed the current stock structure hypothesis, which claims that the stock consists of two separate management units, one in the East and another in the West Atlantic, separated at 30°N. Taking into account the large distances, various environmental restrictions, the existence of a spawning area in the East Atlantic as well as in the northern zone of the Brazilian fishery, and the lack of additional evidence (e.g. transatlantic migrations in the tagging data), the hypothesis of separate east and west stocks has been maintained as the more plausible alternative to an Atlantic wide single stock (ICCAT, SKJ, 2000).

2.1.3 Yellowfin (*Thunnus albacares*)

Just like the Skipjack, the Yellowfin species (Plate 2.3) is cosmopolitan and found in the tropical and subtropical waters of the three oceans where they form large schools. The exploited sizes range between 30 cm to 170 cm fork length. They occur in surface and subsurface waters. Since the inception of the Yellowfin tagging program, which has been carried out in the North American sport fishery since 1985, individuals of this species have often been recovered in the West Atlantic, but the majority of the long term recoveries are made in the East Atlantic where several recaptures are recorded each year.

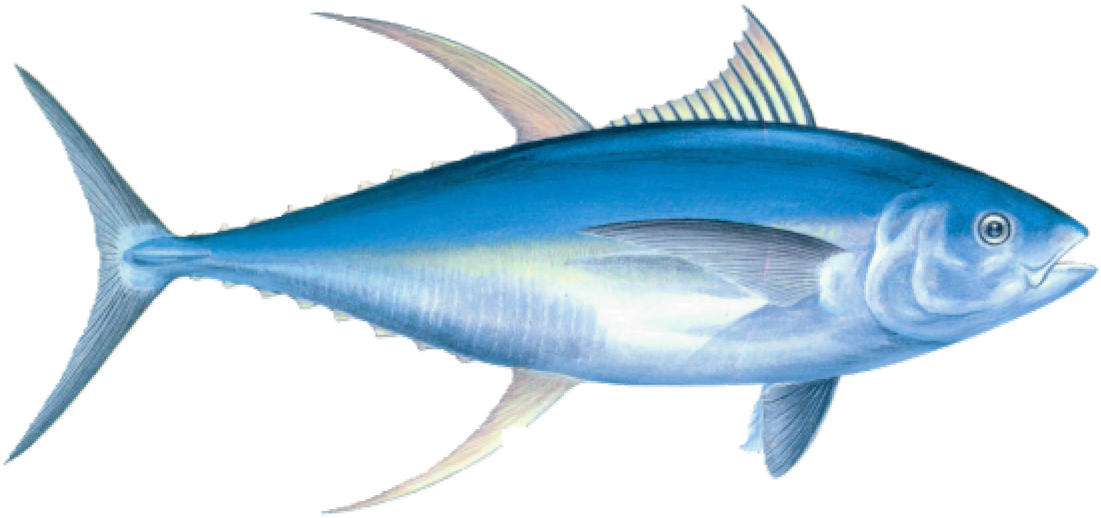

Plate 2.3 Yellowfin Tuna *(Thunnus albacares)*

The main spawning ground is the Gulf of Guinea, with spawning occurring from January to April. In addition, spawning occurs during May to August in the Gulf of Mexico and from July to November in the South-eastern Caribbean Sea, although the relative importance of these spawning grounds is not yet known. Such separate spawning areas might imply separate stocks or substantial heterogeneity in the distribution of the Yellowfin tuna. Nevertheless, taking into account the transatlantic migration indicated by tagging, as well as other information (e.g. time-area frequency distribution and location of spawning grounds), a single stock for the entire Atlantic was assumed as a working hypothesis by ICCAT. From the Gulf of Guinea, the juveniles move towards more coastal waters off Africa. When they reach a pre-adult stage (60-80 cm; fish from age 1.5 to 2 years), it is presumed that the majority of these migrate west towards the American coasts, with the majority of these in turn returning to the East Atlantic fishing grounds to spawn when they reach 110 cm in length.

A 40-year time series of longline catch data indicates that Yellowfin are distributed continuously throughout the entire tropical Atlantic Ocean. Growth patterns are variable with size, being relatively slow initially, and increasing at the time the fish leave the nursery grounds. Males are predominant in the catches of larger sized fish. Natural mortality is assumed to be higher for juveniles than for adults. This assumption is supported by tagging studies for the Pacific Yellowfin (ICCAT, YFT, 2000).

2.2 The East Atlantic Tuna Fishery

In the East Atlantic, Bigeye tuna is exploited by longliner, baitboat and purse seiner fisheries. The size of fish caught varies among the fisheries: medium to large, small to large, and small for longline, pole & line[1] and purse seine respectively. Corresponding average weights are 45-50 kg, 20-30 kg, and 5 kg. The economic value of the fish is also different. For instance, the price of longline catch at an unloading site is roughly six times higher than that of purse seine catch (ICCAT, BET, 2000).

---

[1] Pole & line is the gear used by baitboats.

Longline and pole & line fishing in the East Atlantic have a history dating back to 1960. Major baitboat fisheries are located in Ghana, Senegal, Canary Islands, Madeira and Azores. Unlike in other oceans, baitboats in the Eastern Atlantic catch significant amounts of medium to large sized Bigeye tuna except for Ghana, where only small fish (1.9 - 3.2 kg) are caught as against a recommended minimum size of 3.2 kg by ICCAT. Tropical purse seiner fleets operate in the Gulf of Guinea and off Senegal. Fleets comprise French, Spanish, Ghanaian and other flag vessels managed by EU countries. While Bigeye tuna is the primary target for most longline and baitboat fisheries, this species has been of tertiary importance for purse seine fisheries.

Since 1991, the purse seine and the Ghanaian baitboat fisheries introduced a fishing technique that utilizes fish aggregating devices (FAD's). Similarly fleets in Senegal and the Canary Islands have developed a method that makes use of baitboats as FAD's. These new techniques have apparently improved fishing efficiency and contributed to the increase in the Bigeye catches (ICCAT, 2000, BET).

Almost exclusively, surface gears such as purse seine and pole & line catch Skipjack in the entire Atlantic, although minor amounts are taken by longline as by-catch. Reported catches are considered to be under-estimated, due to the discards of small sized tunas, which include Skipjack by purse seine fleets and some baitboat fleets in the equatorial area of the East Atlantic. Though the main target species for the introduction of FAD's is Bigeye, this change in fishing technique has resulted in the increase in the exploitable biomass of the Skipjack stock (due to expansion of the fishing area; as the tunas follow the drift of objects) and in its catchability. At present the most important fisheries are the purse seine fisheries, mainly those of EC[2]-Spain, EC-France, the NEI[3] fleet (Vanuatu, Malta, Morocco, Belize, Guinea, Dutch Antilles, Panama, and St. Vincent) and Ghana, followed by the baitboat fisheries (Ghana, EC-Portugal, EC-Spain and EC-France) (ICCAT, SKJ, 2000).

Yellowfin tuna is caught between 45°N and 40°S by surface gear (purse seine and pole & line) and with sub-surface gear (longline). In 1975, the fishing area was

---

[2] EC: European Community.

[3] NEI: Not Elsewhere Included; The NEI fleet represents a group of small fishing nations that are not presented individually in ICCAT publications.

extended from the coastal waters to the high seas especially at the equator, where large sized Yellowfin are caught during the spawning season. In coastal areas, purse seiners catch juveniles in mixed schools with other tunas. This gear is very efficient as it catches a wide range of sizes (40 to 160 cm) while longline fisheries principally catch Yellowfin larger than 70 cm (ICCAT, 2000, YFT).

2.3 The Ghanaian Tuna Fishery

2.3.1 Historical Developments

Tunas have been caught by canoes using hand lines and gill nets for hundreds of years but the development of commercial tuna fishing began in 1959 when the Government of Ghana went into an agreement with Star-Kist Foods of U.S.A on a 50:50 cost basis to conduct a survey on the tuna resources in the Gulf of Guinea. The principal objectives amongst others were as follows:

1. To study the distribution and abundance of tuna and tuna bait fishes in the Gulf of Guinea.
2. To find means of increasing the range and efficiency of Ghanaian fishermen through the introduction of new fishing methods and modern equipment.
3. To contribute to the economy of Ghana through the sale of fish on the world market.

The survey was conducted from November 1959 to June 1960 and the results established that tuna species as well as the bait fishes were significantly abundant for the development of an economically sustainable tuna fishery in Ghana. Thereafter from 1962, there was a steady growth in the tuna fleet in Tema, the principal fishing harbour in Ghana. At the same time, infrastructure in cold storage, fish handling, docking and repair facilities were put in place. Since then, Tema has become one of the most important harbours for the tuna industry in the East Atlantic (Hammond, 1977).

Actual commercial tuna fishing in Ghana started with Japanese pole & line vessels (also known as baitboats). Currently, Ghanaian companies operating 36 vessels in all run the fishery. These are either partly owned in the form of joint ventures with foreigners or fully owned by Ghanaians. As of 2000 there were 27 baitboats and 9 purse seiners operating in Ghanaian waters. All the vessels were Ghana flagged with gross tonnages of baitboats between 250 and 500, and that of purse seiners ranging from 400-600.

Baitboats are the main exploiters of tuna in Ghanaian waters, using live anchovy (*Engraulis encrasicolus*) as the main bait for their operation. However young sardinellas are sometimes used. Operations of the baitboats are somewhat limited in that they periodically have to make trips inshore for baits, which are often readily available especially during the period between October and December. The bait is kept live in tanks on board. They are then put on unbarbed hooks on lines attached to 3-5 m poles. In an average fishing trip of 30 days, 8-10 days are used to fish for and prepare the bait. In addition to the use of baits to attract tuna, about 3000 bamboo rafts are used as fish aggregating devices. These are known to attract more juvenile fish (MFRD, 1999 & 2000).

The Ghanaian baitboat fleet is the largest fleet operating in the East Atlantic. In 1991, it accounted for 62% of the total baitboat catches of Skipjack and 16.6% of Skipjack catches by all types of gears in the East Atlantic region. For Yellowfin it accounted for 54% of the total baitboat landing and 7% of catches by all gears in the East Atlantic. It also contributed 14% of Bigeye catches by baitboats in the entire Atlantic, which was 3% of catches by all types of gear (MFRD, 2000).

2.3.2 Markets

Two major companies can much of the tuna landed at Tema (Ghana), namely Pioneer Food Cannery (PFC) owned by Heinz Europe, and Ghana Agro-Foods Company Limited (GAFCO). Both canneries are located in Tema. Fish of minimum size range of 1.2-1.5 kg are sold to the canneries. Any fish below that goes to the local market which are then sold usually smoked using traditional ovens with firewood. Pioneer Food Cannery was established in June 1994, currently processing an average of 175-200 tons (depending on the availability of the fish) of whole tuna per day whiles GAFCO, which commenced a year later, processes between 7 and 10 tons a day (MFRD, 2000). The products from the canneries are primarily for the export market in Europe.

2.3.3 Employment

The average number of fishermen on each baitboat is 47, three of which are usually Korean expatriates and the rest being Ghanaian crewmembers. On an average purse seiner, there are 25 crewmembers seven of which are Koreans. Direct employment of Ghanaian crew on the 27 baitboats and 9 purse seiners as of 2000 would therefore be 1894. In addition there are about 400 shore-based staff employed by the operational tuna companies. The canneries employ about 2200 workers. No estimates were available for those employed in the local marketing and processing (smoking) of tuna (Kwei, 1996).

2.3.4 Government Policy and Regulations

At present PNDC[4] Law 256 is the law governing the fishing industry. Under that law, no person shall import into Ghana any motorized fishing vessel which is more than five years old from date of construction or not more than seven years old from date of construction in the case of a tuna vessel. However if the vessel has been recently refurbished, it can be a factor in deciding whether the vessel is capable of performing like any of the vessels of the above-mentioned ages.

The tuna sector is open to foreign participation, but not less than 25% of the interest in the vessels should be owned by the Ghanaian government, a citizen of Ghana, a public corporation or a limited liability company registered in Ghana under the companies' code 1963 (Act 179).

2.3.5 Management

Ghana is a member of the International Commission for the Conservation of Atlantic Tuna (ICCAT) that is responsible for conducting research and management of the Atlantic tuna resources. There are no quotas allocated to ICCAT members. Thus Ghana has the right to increase the volume of catch as dictated by the market and the physical capacity of the tuna fleet (MFRD, 1999 & 2000).

Ghana participates in ICCAT management and research programmes such as tagging and addressing the problem of fishing with FAD's in the Gulf of Guinea. The problem with the rampant use of FAD's is that they attract and destroy more juvenile

---

[4] PNDC: Provisional National Defence Council.

fish to the detriment of the parent stock. Thus ICCAT places observers (including Ghanaian scientists and technicians) aboard tuna fishing vessels especially purse seiners that are the major culprits. This observer programme is enforced in the Gulf of Guinea during the three months period when ICCAT places a moratorium on fishing with FAD's (November to January). The observers not only ensure that the moratorium is respected, but also collect important scientific data on tunas caught, the by-catches as well as on environmental factors (Ofori-Adu, 2000).

3. MODELS

3.1 Single Species Bioeconomic Model

In order to achieve the second objective of this study which is to investigate open access (OA), versus optimal management of the tuna fishery, one needs to address questions such as the following: have the stocks of Bigeye, Skipjack and Yellowfin been reduced below the level which would sustain maximum yield, in other words has biological overfishing occurred? Has the effort exerted in the fishery increased to the point where the fishery rent has been dissipated; that is, has economic overfishing occurred? To properly address these questions, a bioeconomic Gordon-Schaefer model was adopted. These questions will be answered in the subsequent chapters.

The species were treated as ecologically independent and subject to perfectly selective harvest. It was also assumed that the resource could be adequately described by a variable $X(t)$ representing biomass. The instantaneous rate of change in biomass is given by

$$\dot{X} = \frac{dX(t)}{dt} = F(X(t)) - Y(t) \tag{1}$$

where $\dot{X}(t)$ is the time derivative of the fish biomass, $F(X(t))$ is the natural growth rate of the fish population and $Y(t)$ is the commercial harvest

Let $$p(t) = p(Y(t), X(t)) \tag{2}$$

represent the net revenue from commercial harvest $Y(t)$ which will depend on fish stocks if cost of fishing depends on stock abundance. Maximization of the present value of the net revenue would entail maximizing of

$$p = \int_0^\infty p(Y(t)X(t))e^{-dt}\,dt \tag{3}$$

with respect to Equation (1) and an initial condition of $X(0) = X_0$. The instantaneous discount rate is denoted by d.

The current-value Hamiltonian[5] for the problem is

$$H(t) = p(Y(t), X(t)) + m(t)[F(X(t)) - Y(t)] \tag{4}$$

where µ(t) is the current shadow price[6] associated with an incremental change in fish stock. The first order conditions required for a maximum are as follows

$$\frac{\partial H(t)}{\partial Y(t)} = \frac{\partial p(\cdot)}{\partial Y(t)} - m(t) = 0 \tag{5}$$

$$\dot{m}(t) = \frac{-\partial p(\cdot)}{\partial X(t)} - m(t)[d - F'(\cdot)] \tag{6}$$

$$\dot{X} = F(\cdot) - Y(t). \tag{7}$$

In steady state $\dot{m}(t) = \dot{X}(t) = 0$ and (5) and (6) imply

$$F'(\cdot) + \frac{\frac{\partial p(\cdot)}{\partial X}}{\frac{\partial p(\cdot)}{\partial Y}} = d \tag{8}$$

which is the fundamental equation for the basic bioeconomic model. Where the first term on the left hand side of the equation is the rate of change of net growth associated with an increment on the fish stock, and the second term is the marginal stock effect which reflects the effect that the fish population has on the future growth

---

[5] The current-value Hamiltonian refers to the total rate of increase of total assets (accumulated dividends + capital assets).

[6] The term “shadow price” refers to the fact that the asset’s (in this case the stock) value is not its direct sale value but the value imputed on it from its future productivity.

of the fishery (Hartwick and Olewiler, 1998). The sum of which is called the resource's own rate of return.

For a logistic growth model, the population growth rate r is the difference between births and mortality which are proportional to the population size X. For a continuous time model, $dx/dt = rx$, but as population increases, some environmental factors force the growth rate to decline. To model this effect, $dx/dt = rx$, is modified to $dx/dt = r(x)X$, therefore $r(x)X = F(X)$. Let $r(x) = r(1 - X/K)$ which is a decreasing function in X.

So that when the production function for a fishery is described by the equation

$$Y(t) = qE(t)X(t), \tag{9}$$

and both per unit price, p, and per unit cost, c, are constant, the Gordon–Schaefer model presumes that Equation (1) and (2) take the following form:

$$\dot{X} = \frac{dX}{dt} = rX(t)[1 - X(t)/K] - Y(t) \tag{10}$$

and

$$p(t) = \left[p - \frac{c}{qX(t)}\right]Y(t) \tag{11}$$

respectively. Where $E(t)$ is effort, q is catchability coefficient, r is the growth rate for the species and K is carrying capacity. Thus substituting Equations (10) and (11) into Equation (8) and differentiating it, leads to a quadratic equation where the optimal stock, X*, is a positive root and depends on the bioeconomic parameters *c, p, q, d, r,* and K according to the following relationship:

$$X^* = \frac{K}{4}\left[\left(\frac{c}{qpK} + 1 - \frac{\delta}{r}\right) + \sqrt{\left(\frac{c}{qpK} + 1 - \frac{\delta}{r}\right)^2 + \frac{8c\delta}{qpKr}}\right] \tag{12}$$

For a logistic growth model, such as the Gordon-Schaefer model, the maximum sustainable yield (Y_{msy}) is $rK/4$ which occurs at $X_{msy} = K/2$ (Figure 3.1). The open access equilibrium is reached when the fishery rents are dissipated i.e. $p(\cdot) = 0$. This occurs at $X_{\infty} = c/q$, when the fishery has a positive stock. The optimal yield or harvest is given by $Y^* = rX^*\left(1 - X^*/K\right)$, as determined by (12), when optimal effort applied is $E^* = Y^*/qX^*$.

Equation (12) can alternatively be written in a two-equation system as in equations (13) and (14) below:

$$Y = \phi(X) = [\delta - r(1 - 2X/K)][X(qpX/c - 1)], \tag{13}$$

and

$$Y = rX(1 - X/K) \tag{14}$$

Equation (13) is referred to as the catch locus (Gould, 1972; Conrad and Adu-Asamoah, 1986) while Equation (14) is the sustainable yield curve equating harvest to logistic growth. Figure 3.1 shows four catch loci and a sustainable yield curve. A combination of high discount rates, low harvest costs and high market prices would give catch locus $\phi_1(X)$. Under such circumstances it may be optimal to harvest the resource to extinction. Locus $\phi_2(X)$ shows a situation where the marginal stock effect is greater than the discount rate. Therefore, it would be optimal to maintain the stock in excess of X_{msy}. Locus $\phi_3(X)$ might correspond to a situation of high harvest costs and low market prices making commercial harvests unprofitable. Locus $\phi_{msy}(X)$ is the catch locus whose equilibrium point gives the maximum sustainable yield for the fishery.

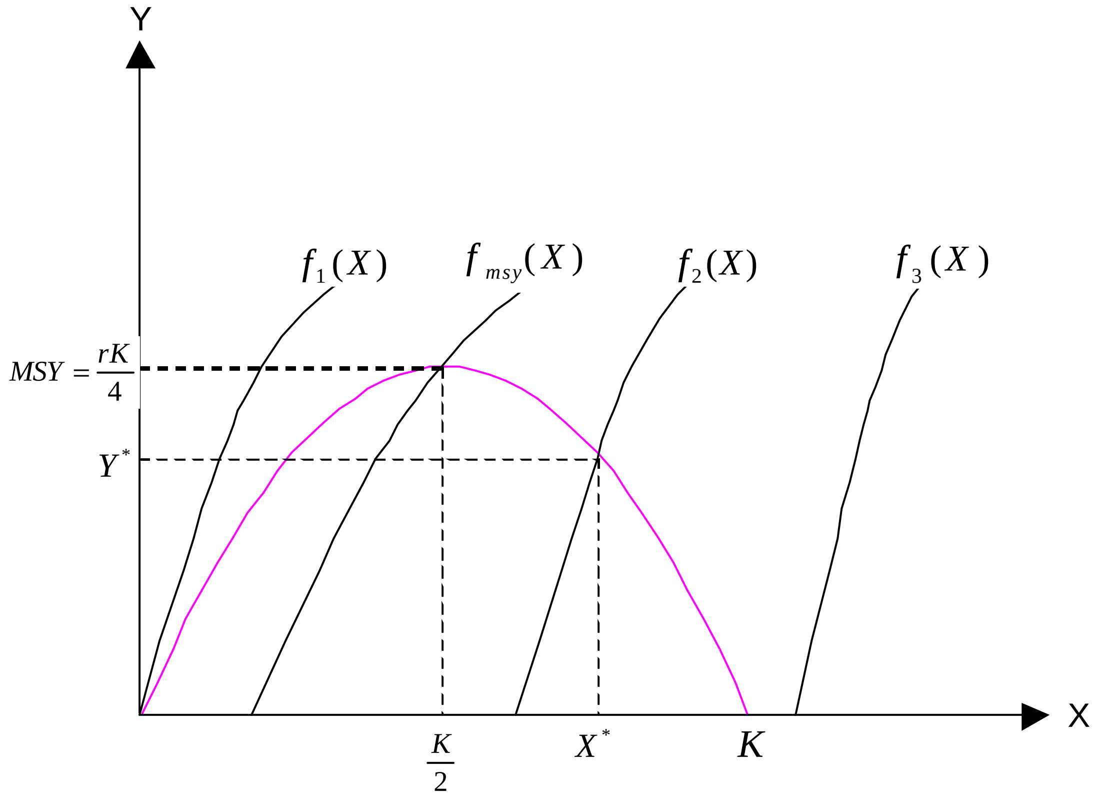

Figure 3.1 Catch loci and the sustainable yield curve of the Gordon-Schaefer model

3.2 Profit Function

For the Gordon-Schaefer model, each point on the sustainable yield curve corresponds to a yield Y(E), resulting from the application of a given level of fishing effort *E*. Assuming a constant price per unit of fish harvested, the total sustainable revenue is given by

$$TR = pY(E) \tag{15}$$

and assuming a constant cost per unit effort *c*, then the total costs of fishing is giving by

$$TC = cE \tag{16}$$

The difference between the total sustainable revenue and the total cost is known as the sustainable economic rent (profit) provided by the fishery resource at any given level of effort E:

$$\text{Sustainable economic rent} = TR - TC = pY(E) - cE \qquad (17)$$

At open access the sustainable economic rent is completely dissipated i.e. $TR = TC$.

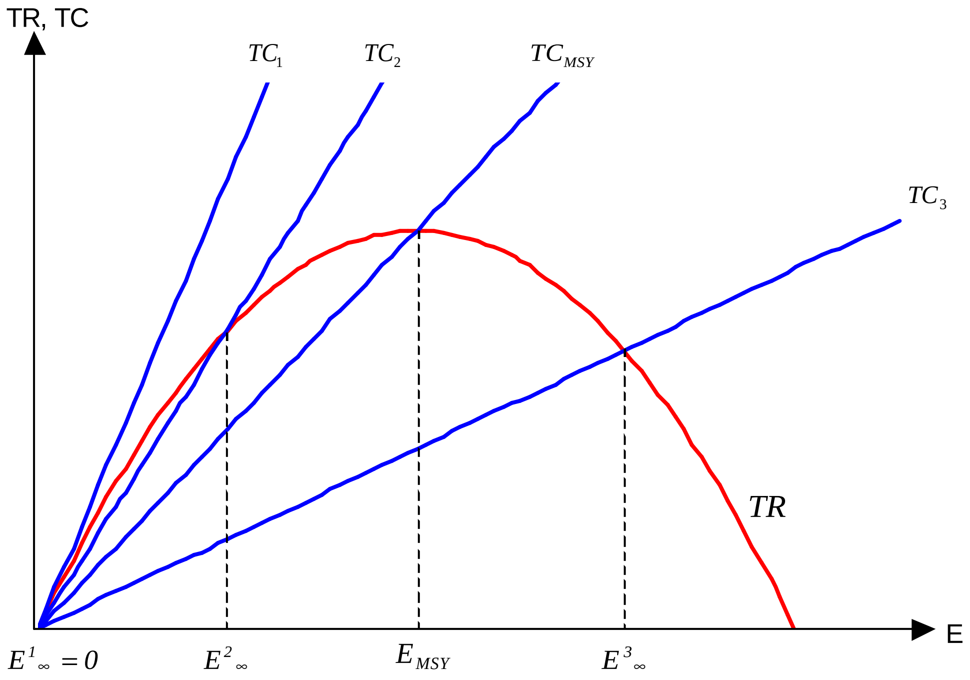

Figure 3.2 Bionomic equilibrium[7] levels

Figure 3.2 shows bionomic equilibrium levels from E^1_∞ to E^3_∞, which correspond to progressively lower cost-price ratios Clark (1976). Total cost curve TC_1 occurs when fishing costs are sufficiently high relative to the price of fish such that the cost-price ratio is greater than the carrying capacity thus the fishery will not be exploited at all. This is the case with fish species that do not support any commercial fishery. Bionomic equilibrium E^2_∞ occurs when the effort exerted in the fishery is below the effort that gives the maximum sustainable yield i.e. E_{MSY}, hence

---

[7] Bionomic equilibrium is the simultaneous equilibrium of both fish population and fishing effort.

biological overfishing does not occur. Biological overfishing occurs when equilibrium is established at an effort level that is in excess of E_{MSY} such as $E^{3}{}_{\infty}$. The bionomic equilibrium that gives the MSY occurs when the total cost curve TC_{MSY} intersects the total revenue curve at effort level E_{MSY}. Since bionomic equilibrium occurs when $TR = TC$, irrespective of whether the effort level is in excess of or less than the E_{MSY} profits or sustainable economic rents are always zero.

4. DATA

4.1 Catch and Effort Data

Annual total catch and effort data (Table 4.1) for the baitboats and purse seiners fishing in Ghanaian waters were obtained from the MFRD, Ghana. These were later used to calculate the CPUE for each vessel.

Table 4.1

Annual tuna catches and corresponding effort by vessel type in Ghana

Year	**Baitboat Fleet**		**Purse seine Fleet**	
	Effort (No. of vessels)	*Yield (MT)*	*Effort (No. of vessels)*	*Yield (MT)*
1980	41	33,399.0	6	2,456.9
1981	41	38,829.2	6	6,343.5
1982	41	37,461.9	6	8,785.1
1983	33	34,263.0	5	5,766.0
1984	30	23,000.0	4	8,266.4
1985	27	27,227.0	6	7,179.8
1986	25	29,062.8	6	5,657.1
1987	20	31,657.6	2	1,807.5
1988	29	35,433.6	-*	-
1989	33	32,294.3	-	-
1990	34	40,802.9	-	-
1991	29	37,794.6	-	-
1992	28	30,777.0	-	-
1993	25	36,855.6	-	-
1994	26	36,973.3	-	-
1995	29	33,904.5	-	-
1996	33	28,650.0	2	8,605.0
1997	29	38,337.9	5	15,286.9
1998	24	55,296.4	7	10,271.2
1999	24	51,507.2	8	32,045.3
2000	27	32,364.0	9	20,891.0

Source: Marine Fisheries Research Division (MFRD) of the Ministry of Food and Agriculture Ghana

* No purse seining for the years with a dash.

On the whole, catch levels have increased while effort levels have decreased especially for the baitboat fleet. Baitboats are the main harvesters of tuna in the

Ghanaian waters since commercial tuna fishing started in the early 1960's. Until 1987, foreign purse seiners were allowed to fish in the Ghanaian waters as long as they had permits. These were however phased out and allowed back into the fishery in 1997 but this time round they had to be in a joint venture with a Ghanaian fishing company. With a higher efficiency than before they have contributed greatly to the annual tuna harvests. By the early 1980's total catch levels were between the range of 35,000 MT and 40,000 MT. The 1984 to 1989 period saw a drop in catch to levels between 31,000 MT and 35,000 MT. This was likely due to a decrease in the number of fishing vessels particularly baitboats, which was half as much as in 1980. This however did not give a corresponding decrease in harvest. Then came a bumper harvest of 40,800 MT in 1990. Catches generally fluctuated over the next seven years then there came a sharp increase in harvest in 1997 with about 53,000 MT. This was mainly due to the re-introduction of purse seiners into the fishery. Catch levels continued to increase to approximately 84,000 MT in 1999. The comparatively low catches recorded for year 2000 (53,255 MT) could be the result of excess harvesting in the previous years.

Estimated landings for all three species of tuna by major gear for all the countries fishing in the East Atlantic was downloaded from the ICCAT homepage. However only the summery data for Ghana is presented here in Table 4.2. The annual total catch data from both ICCAT and MFRD are almost the same for all the years except 1980, 1981 & 1982 when the difference was very large. This could be because Ghana was not yet reporting all the tuna landed in Ghana to ICCAT for those years.

With respect to the use of FAD's to increase catches since 1991, it is not clearly evident from either Table 4.1 or Table 4.2.

Table 4.2

Estimated annual tuna landings (MT) by species for Ghana

Year	Bigeye	Skipjack	Yellowfin	Total
1980	332	5,812	1,974	8,118
1981	780	7,858	5,510	14,148
1982	791	18,272	9,797	28,860
1983	491	24,376	7,689	32,556
1984	2,162	20,697	9,039	31,898
1985	1,887	19,082	12,550	33,519
1986	1,720	22,268	11,821	35,809
1987	1,178	24,347	10,830	36,355
1988	1,214	26,597	8,555	36,366
1989	2,158	22,751	7,035	31,944
1990	5,031	24,251	11,988	41,270
1991	4,090	25,052	9,254	38,396
1992	2,866	18,967	9,331	31,164
1993	3,577	20,225	13,283	37,085
1994	4,738	21,258	9,984	35,980
1995	5,517	18,607	9,268	33,392
1996	5,805	19,602	12,160	37,567
1997	7,431	27,667	16,504	51,602
1998	13,252	34,150	17,807	65,209
1999	11,460	43,460	28,328	83,248
2000	5,586	29,950	17,010	52,546

Source: ICCAT homepage (www.ICCAT.es)

Also obtained from MFRD are the actual monthly size (fork length) frequency data by species and vessel type for 1997. Presented in Table 4.3 are the size ranges, median, mode and mean of the three species caught by baitboat and purse seiner in Ghana. The sampling was done while the vessels were unloading and the data recorded onto a standard ICCAT form. They record among other things: gear type, species, port, number of samples taken, total number of specimen in the samples and their weights, and the total weight of the catch from which samples were taken. It can be seen from Table 4.3, that for all three species, purse seiners catch slightly larger fish than baitboats. The most common size range of Bigeye caught by baitboat and purse seiner is 48.0 – 48.9 and 52.0 – 52.9 respectively. The most common size range of Skipjack caught by baitboat and purse seiner is 46.0 – 46.9 and 48.0 – 48.9 respectively. Unlike Bigeye and Skipjack, the most common size range of Yellowfin caught by baitboat (50.0 – 50.9) is higher than that caught by purse seiner (48.0 – 48.9). However, both the median and the mean are higher for purse seiners for all three species.

Table 4.3

Size range, median, mode and mean[8] of tuna catches by species and vessel type in Ghana for 1997

	Bigeye	**Skipjack**	**Yellowfin**
Baitboat			
- **Size range**	32.0 – 71.9	32.0 – 60.9	30.0 – 73.9
- **Median**	49.0 – 49.9	46.0 – 46.9	50.0 – 50.9
- **Mode**	48.0 – 48.9	46.0 – 46.9	50.0 – 50.9
- **Mean**	49.7	47.0	49.9
Purse Seiner			
- **Size range**	33.0 – 80.9	31.0 – 69.9	34.0 – 169.9
- **Median**	52.0 – 52.9	48.0 – 48.9	52.0 – 52.9
- **Mode**	52.0 – 52.9	48.0 – 48.9	48.0 – 48.9
- **Mean**	52.2	48.2	54.7

Shown in Table 4.4 are the percentage species compositions for the decade prior to and subsequent to the introduction of FAD's. The percentage of Yellowfin remained virtually constant, Skipjack declined by about ten percent while Bigeye increased by ten percent.

Table 4.4

Decadal percentage species composition

Decade/Species	**Bigeye**	**Skipjack**	**Yellowfin**
1980-1989	4.4%	66.3%	29.3%
1990-1999	14.0%	55.7%	30.3%

---

[8] Median = the middle measurement when items (in this case tuna) are arranged in order of sizes, Mode = the member of a series of measurements that occurs most often (James and James, 1992) Mean = the value which is obtained by adding a number of values together and dividing the total by the number of values that there were (= average) (Cambridge, 1996).

4.2 Economic Data

This comprises of prices of the different tuna species and fishing costs for the two vessel types, which are in US$.

4.2.1 Tuna Prices

Monthly fish prices by species and weight categories were obtained from Pioneer Food Cannery (PFC), a subsidiary of Heinz Europe. About 80% of the canned tuna exported from Ghana is made by PFC. The headquarters of Heinz European Seafood in Paris, France, does research on world market tuna prices. These prices are then relayed to PFC. Pioneer Food Cannery has long term contracts with some fishing companies that have been provided with financial assistance, to deliver all their tuna catches to them. They also have contracts with other vessels which could be on a trip-to-trip basis or otherwise.

Figure 4.1 Monthly Skipjack Prices (1995 – 2000)

Shown in Figure 4.1 is the trend in prices of the most common fish (Skipjack of 1.8 to 3.4 kg which is about 40 to 50 cm in length) and was assumed to be the average monthly price. There are huge variations in prices in any particular year. Per ton prices vary from $340 to $1,155, a sharp decline in prices reported by Conrad and Adu-Asamoah (1986) that were around $1,300 from the late 1960's to 1980.

Consistent with the observation made by Conrad and Adu-Asamoah (1986) is the fact that Bigeye and Yellowfin tuna fetched the same price while Skipjack prices were \$50 to \$100 less per metric ton during the 1967 to 1980 era as it is in the 1980-2000 period. Campell and Nicholl (1994) also noted that market prices for Yellowfin were consistently higher than for Skipjack. The prices for Yellowfin and Bigeye are not shown since they follow the same trend as the Skipjack prices.

Over the six-year period, 1998 was the year with the highest monthly prices while the lowest prices were recorded in 2000. The prices for these two years (Table 4.5) were used in the model to compare their corresponding optimal points (X*, Y*, and E*).

Table 4.5

Average tuna prices for 1998 and 2000

Year/Species	Bigeye	Skipjack	Yellowfin
1998	\$1,050	\$1,000	\$1,050
2000	\$450	\$400	\$450

4.2.2 Fishing Costs

Average cost price of fishing was obtained from Tema Tuna Ventures (TTV), a tuna fishing company that owns a third of the total purse seiner fleet in Ghana as well as five baitboats and a carrier vessel. About 75-80% of the tuna landed by the TTV vessels is sold to PFC; the rest is sold on the local market. On average they land 28,000 tons of tuna annually, which is more than 50% of the total landings for the year 2000. The average variable cost per ton is \$314 and \$370 for purse seiners and baitboats respectively. This includes trip costs (i.e. fuel, food & provisions, vessel supplies & spares) and crew costs (i.e. crew earnings[9], insurance, social security fund, medical and travel expenses), but excludes vessel costs (i.e. charter fees, vessel

---

[9] Crew earnings are made up of fixed salaries plus bonus per ton of tuna landed. The latter, is adjusted with respect to fish prices, but once they are set they stay so for a period of time. Usually this amounts to 50% of total crew costs. Thus it was assumed for the purposes of this study, that, fishing costs = total trip costs + 50% of total crew costs.

insurance, fishing licence fees) and depreciation & amortisation costs, which are the fixed costs.

Unlike Conrad and Adu-Asamoah's paper in which costs of fishing were postulated, actual costs of fishing were used to run the Gordon-Schaefer model in this study. The bioeconomic model employed requires the cost of fishing for the two vessel types to be in cost per sea day. Hence fishing costs per ton for each vessel type had to be converted to cost per sea day. It must be noted that tuna fishing vessels do not selectively harvest a particular species. In that sense the same effort is used to harvest all three species simultaneously. Cost per sea day rather than costs per large-purse-seiner day was used in the model, since the latter will result in the overestimation of the cost parameter. Thus to determine the cost per sea day of fishing each species[10], the total costs per sea day were divided according to the percentage species composition for 1999, which was 13.8%, 52.2% and 34.0% for Bigeye, Skipjack and Yellowfin respectively. The year 1999 species composition was chosen because the cost data obtained were based on actual costs incurred in that year.

The actual costs used in this study are presented in Table 4.6 below.

Table 4.6

Fishing costs per sea day by vessel and species

Vessel/Species	Bigeye	Skipjack	Yellowfin	Total
Baitboat	$393	$1,488	$969	$2,550
Purse Seiner	$577	$2,184	$1,422	$4,183

---

[10] "Fishing cost per sea day" calculation for Yellowfin harvested by purse seiner.

Trip cost per ton = $188; Crew cost per ton = $126

Recall that Fishing Costs = Trip cost + 50% of Crew costs = $251per ton

Number of tons per trip =500; a trip is made up of 30 days

Therefore Fishing cost per day = $251 x 500/30 = $4183.33

Note that $4183.33 is the cost of harvesting all three species together.

With reference to 1999 species composition, Yellowfin was 34% of the total catch

Therefore Cost per day of harvesting Yellowfin by a purse seiner = $4183.33 x 34/100 = $1422.22.

Baitboats are cheaper than purse seiners because of the passive nature of their operations. The same observation was made by Conrad and Adu-Asamoah (1986), where fishing costs per sea day for longliners were assumed to be less than those for purse seiners.

4.3 Biological Data

For the single species model, it was assumed that each species of tuna is ecologically independent of the other, implying that harvesting of one species is also independent of the other species. Values of q, r and K, and for each species (Table 4.7) were adopted from Conrad and Adu-Asamoah (1986) since their study area was the same as that of this paper and also covered the period immediately preceding the study period for this paper. They solved for the values of q, r and K based on their landings and effort data according to a technique described by Fox, 1975 which produced estimates of $a = qK$ and $b = q^2 K / r$.

Table 4.7

Estimates of q, r, and K for tuna in the Eastern Tropical Atlantic

Species	q(x 0.01)	r	K (x 1000 MT)
Bigeye	2.11	1.90	48.65
Skipjack	1.24	1.57	264.94
Yellowfin	1.37	1.29	351.22

Source: Conrad and Adu-Asamoah (1986)

5. RESULTS

5.1 Catch Per Unit Effort

Catch per unit effort (CPUE) calculated for each vessel type in Ghana is shown in Table 5.1 while that for each tuna species is shown in Figure 5.1.

5.1.1 CPUE for Vessels

Table 5.1

Annual tuna landings in Ghana (MT), Effort (no. of vessels), Standardised effort (Sea days) and CPUE by vessel type

	BAITBOAT FLEET				PURSE SEINER FLEET			
Year	**Catch**	**Effort**	**St.Effort**	**CPUE**	**Catch**	**Effort**	**St.Effort**	**CPUE**
1980	33,399	41	2,728	12.24	2,457	6	570	4.31
1981	38,829	41	2,728	14.24	6,344	6	570	11.12
1982	37,462	41	2,728	13.73	8,785	6	570	15.41
1983	34,263	33	2,195	15.61	5,766	5	475	12.13
1984	23,000	30	1,996	11.52	8,266	4	380	21.74
1985	27,227	27	1,796	15.16	7,180	6	570	12.59
1986	29,063	25	1,663	17.47	5,657	6	570	9.92
1987	31,658	20	1,331	23.79	1,808	2	190	9.51
1988	35,434	29	1,929	18.37	-*	-	-	-
1989	32,294	33	2,195	14.71	-	-	-	-
1990	40,803	34	2,262	18.04	-	-	-	-
1991	37,795	29	1,929	19.59	-	-	-	-
1992	30,777	28	1,863	16.52	-	-	-	-
1993	36,856	25	1,663	22.16	-	-	-	-
1994	36,973	26	1,730	21.38	-	-	-	-
1995	33,905	29	1,929	17.57	-	-	-	-
1996	28,650	33	2,195	13.05	8,605	2	190	45.27
1997	38,338	29	1,929	19.87	15,287	5	475	32.17
1998	55,296	24	1,597	34.63	10,271	7	665	15.44
1999	51,507	24	1,597	32.26	32,045	8	760	42.15
2000	32,364	27	1,796	18.02	20,891	9	855	24.42

* No purse seining for the years with a dash.

To make the CPUE's comparable, the effort measure was standardised to a large-purse-seiner-day (standard day). It was assumed that baitboats spend an average of 231 days per year at sea while large and small purse seiners spend 291 and 198 days per year at sea respectively (Conrad and Adu-Asamoah, 1986). According to Fonteneau & Caryé (1981), the fishing power of a small purse seiner was 0.48 of a large purse seiner (as quoted by Conrad & Adu-Asamoah). Average daily catch rates for baitboats were divided by the average daily catch rates for small purse seiners, and the resulting fraction (0.6) was used to convert baitboats into small seiners and further into large seiners by multiplying it by 0.48. Thus baitboats are 0.29 of a large purse seiner. To convert the nominal effort, which is in number of vessels, to standardised effort (large-purse-seiner-day), the former was multiplied by its corresponding number of days at sea and again by the conversion factor of 0.48 and 0.29 for purse seiners and baitboats respectively. These conversions were done in order to make comparison with Conrad & Adu-Asamoah's work possible. It must be noted that the Ghanaian purse seiners were considered to be small since they are in the range of 400 to 600 MT capacities, while large purse seiners generally have a capacity of 1000 MT or more.

Generally the CPUE by vessel type has increased over the years with some fluctuations. The 1987-year had an outstanding peak for the baitboat fishery when it recorded a big jump from 17.5 for the previous year to 23.8. The same pattern seams to re-occur when the CPUE increased from 16.5 to 22.2 from 1992 to 1993. Afterwards, it was on the decline with a few fluctuations here and there till it reached the highest (34.6 in 1998) in two decades. For the purse seiners, the efficiency of the vessels has increased dramatically after their reintroduction in 1996. For the first year after the reintroduction, CPUE was at a record high of 45.27.

Besides the first two years when the CPUE's of both vessel types increased, whenever CPUE for baitboat increased, that for purse seiner decreased and vice versa. In 1996 when CPUE for baitboat was at its lowest (13.05) for the entire two decades, that for purse seiner was at its highest. From then on CPUE for baitboats increased consecutively for the next two years while that for purse seiner dropped. Then in 1999 there was a switch, CPUE for baitboats dropped but increased for purse seiners. At the close of the second decade, i.e. 2000 they both dropped.

5.1.2 CPUE for Species

As seen in the section above, apart from a few fluctuations, the CPUE is on the increase (see Figure 5.1 below). Bigeye shows a clear distinction between the CPUE's for the 1980's, which are in the range between 0.73 and 7.14, and CPUE's in the 1990's, which are in the range between 11.2 and 42.5 (See Appendix A). This coincides perfectly with the time when fish aggregating devices (FAD's) were introduced into the fishery. Recall that this new fishing technique has apparently improved fishing efficiency and contributed to the increase of Bigeye catch. Before their introduction, the CPUE of Skipjack was higher than for Yellowfin, which in turn was higher than that for Bigeye. This is no longer the case. Commencing 1995 to 1999, the CPUE for Bigeye has been the highest of the three species.

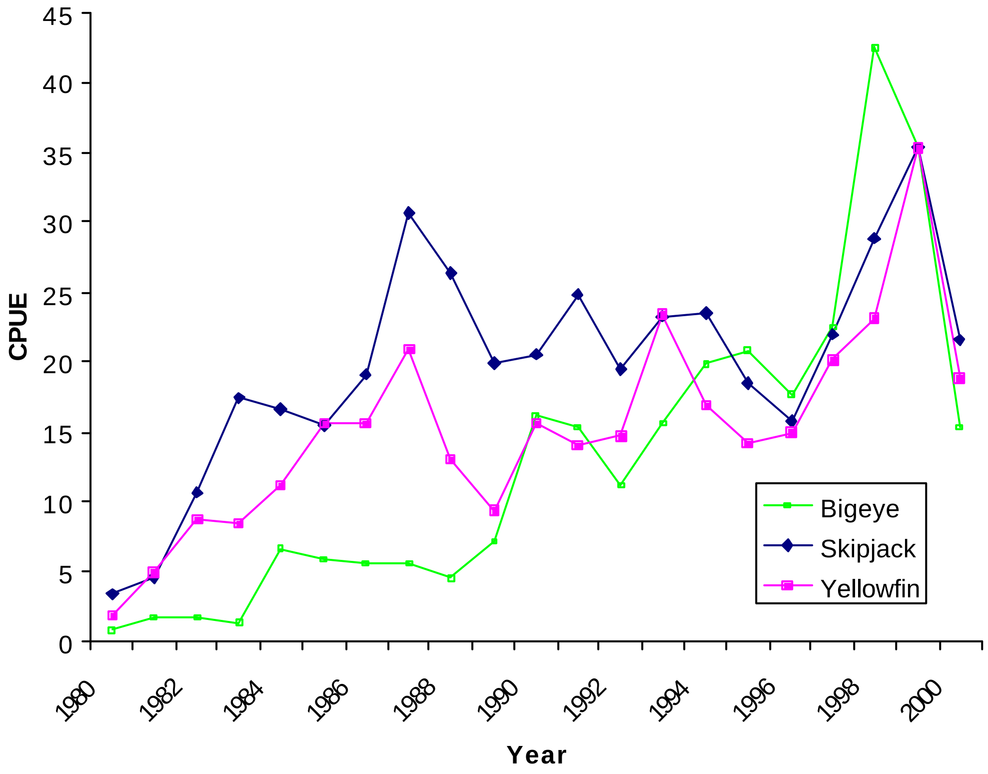

Figure 5.1 CPUE per Species

Catch per unit effort for all three species coincided at 35.3 in 1999 because the standard effort was indexed to the 1999 species composition ratio[11]. The Ghanaian fishery is a multi-species fishery implying that any one particular vessel harvests all three species of tuna simultaneously. So in order to get the effort per species, it was assumed that harvests of individual species were directly related to the amount of effort exerted on it. Therefore the total standard days at sea were split according to the 1999 species composition ratio. The year 1999 was chosen because it was the year with the largest harvest and even more importantly because it was the year for which data on costs of fishing are available. Recall that cost of fishing each species was also obtained by splitting the total fishing cost according to the same 1999 species composition ratio. For the fishery as a whole, the CPUE trend follows more after the total catch trend than the effort trend.

5.2 Bioeconomic and Open Access Equilibria

Results obtained from the bioeconomic model (bioeconomic and open access equilibria) are shown below in Tables 5.2a, 5.3a and 5.4a. Results from Conrad and Adu-Asamoah's paper have been presented in Tables 5.2b, 5.3b and 5.4b for easy comparison. The unit of measurements for X^* is in 1000 MT; Y^* is also in 1000 MT; E^* is in 1000 sea days (SD); c is in US$/SD; and p is in US$/MT.

For all three species, (Tables 5.2a, 5.3a and 5.4a) the optimal stock levels tend to decrease with increasing discount rate as expected. This is not so for Skipjack at lower prices for both vessels and neither Bigeye at lower prices in the baitboat fishery. In that case optimal biomass is larger than the carrying capacity thus making the optimal yield and effort to be negative. These decrease even further as discount rates are increased. For all combinations of discount rates and prices, both the bioeconomic and open access yield for all three species harvested by baitboats are always higher than for purse seiners.

In the case where optimal stock is less than K and optimal yield is positive, X* is lower for higher prices than for lower prices. This makes Y* and E* higher for

---

[11] The use of 1999 species composition ratio as index introduces a bias in the CPUE calculations since the results would be different if a different year's species composition ratio, say 1985 which was before the introduction of FAD's into the fishery, was used.

high prices than for when prices are low. This is so for all species as long as the catch locus is to the right of the maximum sustainable yield. For Yellowfin at open access, the optimal yield at higher prices is less than that at a lower price. This is because high prices tend to push the catch locus to the left of MSY.

Discount rates follow exactly the same trend as the price effect described above, in that low/high prices affect the results of the model in much the same way as low/high discount rates. However differences in optimal yield between discount rates of 0.05 and infinity are more pronounced at lower prices.

For Bigeye harvested by baitboats at lower prices, both bioeconomic and open access equilibria occurred at stocks in excess of X_{msy} thus yield is much lower than MSY. At open access and high prices, the yield for purse seine (23.02) is almost the same as MSY of 23.13 while the yield for baitboat is 21.44. At lower prices, the open access and optimal equilibria for purse seiner is similar to the catch locus $f_3(X)$ of Figure 3.1 and does not intersect with the sustainable yield.

Like Bigeye, fishing for Skipjack either by baitboat or purse seiner is not commercially profitable when prices are low. At high prices, the open access yield for baitboat (102.97) is very close to the MSY (103.8).

Open access yield for Yellowfin harvested by baitboats when prices are low is 111.84, which is very close to the MSY of 113.12. Again when prices are low, the open access yield for Yellowfin harvested by purse seiner (102.12) is not too far from the MSY. However, when prices are high, the open access yield and biomass for both vessels are significantly lower than the MSY and X_{msy}, indicating biological overfishing.

Conrad and Adu-Asamoah's results showed that for Bigeye the bioeconomic equilibrium occurred at stocks in excess of X_{msy}. At open access the stocks were less than X_{msy} except for the highest cost estimate of $700. The corresponding yield of 23.08 was the closest to the MSY of Bigeye (24.33).

For Skipjack, both bioeconomic and open access equilibria occurred at stocks in excess of X_{msy}. The open access yield at the lowest estimated cost price ($2,000) comes very close to the MSY.

For their Yellowfin, as with their Bigeye, the bioeconomic equilibrium occurred at stocks in excess of X_{msy} while open access status lead to equilibria with stocks less than MSY, for all but the highest cost estimate.

Direct comparison of Conrad and Adu-Asamoah's study and this study cannot be easily done since they use different assumed costs and prices. What can be said though is the fact that for Bigeye, the results from Conrad and Adu-Asamoah's study when the assumed unit cost of effort, c is \$700 and fish price per ton, p is \$1,300 are very similar to that obtained for this study when c is \$577 and p is \$1,050.

Table 5.2a

Bioeconomic & Open Access Equilibria: Bigeye

Bigeye parameters: q = 0.0211, r = 1.9018, K = 48.654
Maximum sustainable: X_{msy} = 24.327, Y_{msy} = 23.1325, E_{msy} = 45.0664

δ	Baitboat, c = $393		Purse seiner, c = $577	
	p = $450	p = $1050	p = $450	p = $1050
0.00	X^* = 45.04	X^* = 33.20	X^* = 54.73	X^* = 37.36
	Y^* = 6.37	Y^* = 20.05	Y^* = -12.99	Y^* = 16.50
	E^* = 6.70	E^* = 28.62	E^* = -11.25	E^* = 20.93
0.05	X^* = 44.99	X^* = 32.91	X^* = 54.80	X^* = 37.16
	Y^* = 6.45	Y^* = 20.25	Y^* = -13.16	Y^* = 16.69
	E^* = 6.79	E^* = 29.17	E^* = -11.38	E^* = 21.28
0.10	X^* = 44.94	X^* = 32.62	X^* = 54.87	X^* = 36.98
	Y^* = 6.53	Y^* = 20.44	Y^* = -13.32	Y^* = 16.88
	E^* = 6.88	E^* = 29.70	E^* = -11.51	E^* = 21.63
$\delta \to \infty$	X_∞ = 41.42	X_∞ = 17.75	X_∞ = 60.80	X_∞ = 26.06
	Y_∞ = 11.71	Y_∞ = 21.44	Y_∞ = -28.87	Y_∞ = 23.02
	E_∞ = 13.40	E_∞ = 57.25	E_∞ = -22.50	E_∞ = 41.86

Table 5.2b

Bioeconomic & Open Access Equilibria: Bigeye (Conrad & Adu-Asamoah, 1986)

Bigeye parameters: q = 0.0211, r = 1.9018, K = 48.654, p = $1300
Maximum sustainable: X_{msy} = 24.327, Y_{msy} = 23.1325, E_{msy} = 45.0664

δ	c = $400	c = $500	c = $600	c = $700
0.00	X^* = 31.62	X^* = 33.44	X^* = 35.26	X^* = 37.09
	Y^* = 21.05	Y^* = 19.89	Y^* = 18.46	Y^* = 16.77
	E^* = 31.56	E^* = 28.18	E^* = 24.81	E^* = 21.43
0.05	X^* = 31.28	X^* = 33.15	X^* = 35.02	X^* = 36.89
	Y^* = 21.24	Y^* = 20.09	Y^* = 18.66	Y^* = 16.96
	E^* = 32.19	E^* = 28.72	E^* = 25.25	E^* = 21.79
0.10	X^* = 30.94	X^* = 32.87	X^* = 34.79	X^* = 36.70
	Y^* = 21.42	Y^* = 20.28	Y^* = 18.85	Y^* = 17.15
	E^* = 32.81	E^* = 29.24	E^* = 25.69	E^* = 22.15
$\delta \to \infty$	X_∞ = 14.58	X_∞ = 18.23	X_∞ = 21.87	X_∞ = 25.52
	Y_∞ = 19.42	Y_∞ = 21.68	Y_∞ = 22.90	Y_∞ = 23.08
	E_∞ = 63.12	E_∞ = 56.36	E_∞ = 49.61	E_∞ = 42.86

Table 5.3a

Bioeconomic & Open Access Equilibria: Skipjack

Skipjack parameters: q = 0.0124, r = 1.5686, K = 264.9435
Maximum sustainable: X_{msy} = 132.4718, Y_{msy} = 103.8976, E_{msy} = 63.25

	Baitboat, c = $1488		Purse seiner, c = $2184	
δ	p = $400	p = $1000	p = $400	p = $1000
0.00	X^* = 282.44	X^* = 192.46	X^* = 352.60	X^* = 220.52
	Y^* = -29.26	Y^* = 82.59	Y^* = -183.00	Y^* = 57.99
	E^* = -8.35	E^* = 34.61	E^* = -41.85	E^* = 21.21
0.05	X^* = 282.70	X^* = 190.89	X^* = 353.64	X^* = 219.69
	Y^* = -29.72	Y^* = 83.69	Y^* = -185.70	Y^* = 58.86
	E^* = -8.48	E^* = 35.36	E^* = -42.35	E^* = 21.61
0.10	X^* = 282.95	X^* = 189.37	X^* = 354.64	X^* = 218.87
	Y^* = -30.16	Y^* = 84.73	Y^* = -188.34	Y^* = 59.70
	E^* = -8.60	E^* = 36.09	E^* = -42.83	E^* = 22.00
$\delta \rightarrow \infty$	X_∞ = 299.94	X_∞ = 119.98	X_∞ = 440.26	X_∞ = 176.10
	Y_∞ = -62.15	Y_∞ = 102.97	Y_∞ = -456.98	Y_∞ = 92.63
	E_∞ = -16.71	E_∞ = 69.22	E_∞ = -83.71	E_∞ = 42.42

Table 5.3b

Bioeconomic & Open Access Equilibria: Skipjack (Conrad & Adu-Asamoah, 1986)

Skipjack parameters: q = 0.0124, r = 1.5686, K = 264.9435, p = $1200
Maximum sustainable: X_{msy} = 132.4718, Y_{msy} = 103.8976, E_{msy} = 63.25

δ	c = $2000	c = $2500	c = $3000	c = $3500
0.00	X^* = 199.68	X^* = 216.48	X^* = 233.28	X^* = 250.08
	Y^* = 77.16	Y^* = 62.12	Y^* = 43.73	Y^* = 22.01
	E^* = 31.16	E^* = 23.14	E^* = 15.12	E^* = 7.10
0.05	X^* = 198.32	X^* = 215.55	X^* = 232.71	X^* = 249.83
	Y^* = 78.23	Y^* = 63.04	Y^* = 44.41	Y^* = 22.35
	E^* = 31.81	E^* = 23.59	E^* = 15.39	E^* = 7.22
0.10	X^* = 196.99	X^* = 214.64	X^* = 232.17	X^* = 249.59
	Y^* = 79.25	Y^* = 63.92	Y^* = 45.05	Y^* = 22.68
	E^* = 32.44	E^* = 24.02	E^* = 15.65	E^* = 7.33
$\delta \rightarrow \infty$	X_∞ = 134.41	X_∞ = 168.01	X_∞ = 201.61	X_∞ = 235.22
	Y_∞ = 103.88	Y_∞ = 96.42	Y_∞ = 75.59	Y_∞ = 41.40
	E_∞ = 62.33	E_∞ = 46.28	E_∞ = 30.24	E_∞ = 14.19

Table 5.4a

Bioeconomic & Open Access Equilibria: Yellowfin

Yellowfin parameters: $q = 0.01372$, $r = 1.2883$, $K = 351.2244$
Maximum sustainable: $X_{msy} = 175.6122$, $Y_{msy} = 113.1206$, $E_{msy} = 46.9497$

		Baitboat, c = $969		Purse seiner, c = $1422	
δ		p = $450	p = $1050	p = $450	p = $1050
0.00	X^* =	254.09	209.24	290.80	224.98
	Y^* =	90.53	108.97	64.45	104.18
	E^* =	25.97	37.96	16.15	33.75
0.05	X^* =	251.52	204.67	289.41	221.20
	Y^* =	91.98	110.02	65.62	105.50
	E^* =	26.65	39.18	16.53	34.76
0.10	X^* =	249.05	200.19	288.07	217.53
	Y^* =	93.34	110.90	66.73	106.67
	E^* =	27.32	40.38	16.88	35.74
$\delta \to \infty$	X_∞ =	156.95	67.26	230.37	98.73
	Y_∞ =	111.84	70.06	102.12	91.44
	E_∞ =	51.94	75.92	32.31	67.50

Table 5.4b

Bioeconomic & Open Access Equilibria: Yellowfin (Conrad & Adu-Asamoah, 1986)

Yellowfin parameters: $q = 0.01372$, $r = 1.2883$, $K = 351.2244$, $p = \$1300$
Maximum sustainable: $X_{msy} = 175.6122$, $Y_{msy} = 113.1206$, $E_{msy} = 46.9497$

δ		c = $2000	c = $2500	c = $3000	c = $3500
0.00	X^* =	231.68	245.70	259.71	273.73
	Y^* =	101.59	95.10	87.18	77.81
	E^* =	31.96	28.21	24.47	20.72
0.05	X^* =	228.21	242.81	257.35	271.83
	Y^* =	102.97	96.56	88.61	79.16
	E^* =	32.89	28.98	25.10	21.23
0.10	X^* =	224.85	240.02	255.07	270.00
	Y^* =	104.23	97.90	89.96	80.44
	E^* =	33.79	29.73	25.71	21.71
$\delta \to \infty$	X_∞ =	112.13	140.17	168.20	196.23
	Y_∞ =	98.34	108.51	112.92	111.56
	E_∞ =	63.92	56.43	48.93	41.44

Sensitivity of the model was tested with regard to variation in the discount rate d. It was varied in 0.05 increments from $d = 0.00$ to $d = 0.10$. Again the sensitivity was tested with respect to a 5% change in *K*, *c* and *p* for each species at lower fish prices (i.e. \$400-\$450) and higher prices (i.e. \$1000-\$1050). The resulting changes in percentages are presented in Appendix B. A graphical presentation of this is shown in Figure 5.2 using Yellowfin harvested by baitboat as an example. For all the sensitivity tests performed the marginal stock effect never exceeded 5%. And for open access the marginal stock effect was zero, because harvesters place no value on any harvests received in the future thus they operate at an infinite discount rate.

No sensitivity analysis was performed for *r* and *q* since they were obtained from the same Fox technique used for finding *K*, thus they are related.

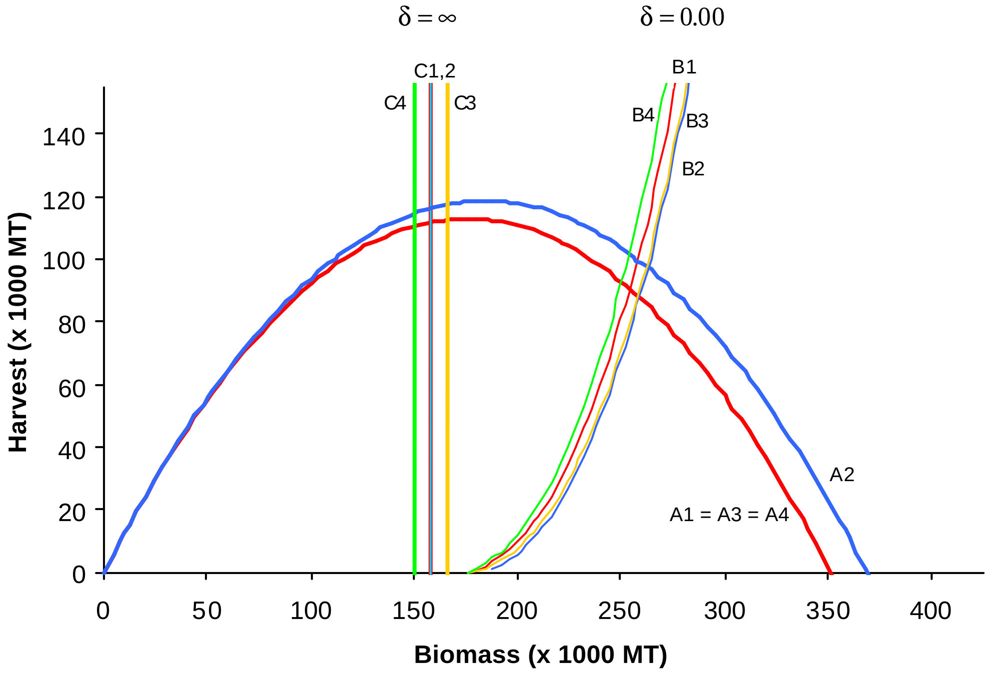

Figure 5.2 Sensitivity Analyses on Yellowfin harvested by baitboat.

Letter *A* represents the sustainable yield curve; *B* is the catch loci at $d = 0$ and, *C* is the catch loci at $d = \infty$; whereas number 1 represents the original parameters, 2, 3 and 4 are for the sensitivity due to 5% increments in *K*, *c* and *p* respectively.

The model was more sensitive when prices were low. Of the three species, Skipjack was the most sensitive followed by Bigeye. Yellowfin was the least sensitive. For both baitboat and purse seiner fisheries the model was very sensitive to *K* at lower prices. Increasing the discount rate not only shifts the catch loci to left but also straightens them. Increasing the costs shift catch loci to the right of their original position while an increase in price shifts the catch loci to the left. All the catch loci in Figure 5.2 are the optimal ones described by Equation (13) of chapter three.

Shown below in Tables 5.5a, b & c are the sustainable economic rents or profits obtained for the bioeconomic and open access optimal results of Tables 5.2a, 5.3a and 5.4a. These profit results will be expanded upon in the discussion chapter. The general observation made for all the three species is the fact that sustainable economic rents are higher for baitboats than for purse seiners.

Table 5.5a

Bioeconomic & Open Access Profits[12]: Bigeye

Bigeye parameters: $q = 0.0211$, $r = 1.9018$, $K = 48.654$
Maximum sustainable: $X_{msy} = 24.327$, $Y_{msy} = 23.1325$, $E_{msy} = 45.0664$

	Baitboat, c = $393		Purse seiner, c = $577	
δ	p = $450	p = $1050	p = $450	p = $1050
0.00	R = $2,865	R = $21,056	R = n/a	R = $17,322
	C = $2,635	C = $11,257	C = n/a	C = $12,083
	P = $230	P = $9,798	P = n/a	P = $5,239
0.05	R = $2,902	R = $21,267	R = n/a	R = $17,525
	C = $2,672	C = $11,472	C = n/a	C = $12,288
	P = $230	P = $9,795	P = n/a	P = $5,238
0.10	R = $2,937	R = $21,466	R = n/a	R = $17,720
	C = $2,708	C = $11,682	C = n/a	C = $12,487
	P = $230	P = $9,784	P = n/a	P = $5,233
δ → ∞	R = $5,269	R = $22,515	R = n/a	R = $24,166
	C = $5,269	C = $22,515	C = n/a	C = $24,166
	P = $0	P = $0	P = n/a	P = $0

---

[12] Where R = Total revenue; C = Total Cost; P = Total Profit or Sustainable Economic Rent and n/a = not applicable.

Table 5.5b

Bioeconomic & Open Access Profits: Skipjack

Skipjack parameters: q = 0.0124, r = 1.5686, K = 264.9435
Maximum sustainable: X_{msy} = 132.4718, Y_{msy} = 103.8976, E_{msy} = 63.25

	Baitboat, c = $1488		Purse seiner, c = $2184	
δ	p = $400	p = $1000	p = $400	p = $1000
0.00	R = n/a	R = $82,592	R = n/a	R = $57,995
	C = n/a	C = $51,487	C = n/a	C = $46,313
	P = n/a	P = $31,106	P = n/a	P = $11,682
0.05	R = n/a	R = $83,692	R = n/a	R = $58,864
	C = n/a	C = $52,601	C = n/a	C = $47,186
	P = n/a	P = $31,091	P = n/a	P = $11,677
0.10	R = n/a	R = $84,734	R = n/a	R = $59,699
	C = n/a	C = $53,685	C = n/a	C = $48,034
	P = n/a	P = $31,049	P = n/a	P = $11,665
δ → ∞	R = n/a	R = $102,973	R = n/a	R = $92,626
	C = n/a	C = $102,973	C = n/a	C = $92,626
	P = n/a	P = $0	P = n/a	P = $0

Table 5.5c

Bioeconomic & Open Access Profits: Yellowfin

Yellowfin parameters: q = 0.01372, r = 1.2883, K = 351.2244
Maximum sustainable: X_{msy} = 175.6122, Y_{msy} = 113.1206, E_{msy} = 46.9497

	Baitboat, c = $969		Purse seiner, c = $1422	
δ	p = $450	p = $1050	p = $450	p = $1050
0.00	R = $40,739	R = $114,420	R = $29,004	R = $109,391
	C = $25,165	C = $36,782	C = $22,977	C = $48,006
	P = $15,575	P = $77,639	P = $6,027	P = $61,384
0.05	R = $41,393	R = $115,525	R = $29,529	R = $110,771
	C = $25,829	C = $37,967	C = $23,506	C = $49,441
	P = $15,564	P = $77,558	P = $6,023	P = $61,330
0.10	R = $42,003	R = $116,450	R = $30,030	R = $112,008
	C = $26,471	C = $39,126	C = $24,015	C = $50,837
	P = $15,533	P = $77,323	P = $6,014	P = $61,171
δ → ∞	R = $50,329	R = $73,563	R = $45,954	R = $96,013
	C = $50,329	C = $73,563	C = $45,954	C = $96,012
	P = $0	P = $0	P = $0	P = $0

6. DISCUSSION

For this study, the Ghanaian tuna fishery was "superimposed" onto the Eastern Atlantic tuna fishery by using catch, effort, fishing cost and tuna price data from Ghana for two fishing vessel types that harvest the three major Atlantic tunas with the biological data of the East Atlantic. Discussed below are mainly the issues concerning CPUE's, the bioeconomic optimal points, open access and management.

6.1 CPUE

For all three species, CPUE for the Ghanaian fishery were much higher than for the whole East Atlantic when studied by Conrad & Adu-Asamoah (1986). The figures for the Ghanaian fishery are up to ten times as high as reported by Conrad & Adu-Asamoah. For all three species, they reported that CPUE has shown a declining trend during the 1967 to 1980 era. Such trends they said may be symptomatic of overfishing. This is in sharp contrast with the findings of this study where it is rather on the incline with some fluctuations. Fish aggregating devices may have contributed to this as a result of improved fishing efficiency.

Traditionally CPUE have been used as an index of stock abundance assessments, including assessments of tuna resources (Fonteneau, 1997). For schooling and highly migratory species, it is not the most reliable index for stock assessments and its use may lead to setting of high catch quotas, which in the long run can lead to the total collapse of the fishery.

Vessel wise, purse seiners tend to have higher CPUE's than baitboats. This could be due to technological advances like the use of sonars and radars to detect schools of fish, more efficient mechanical ways of hauling large amounts of catch onto the vessels and larger storage capacities as well as employment of expatriate expertise. Though both the CPUE and the size of tuna caught by purse seiner are higher than for baitboats, the quality of the fish flesh from baitboats is better. This is because the purse seine squashes the whole school of fish. This is not so in fishing with baits, which also pose no risk to dolphins. Though this does not reflect in the prices of tuna caught by the different vessels, some clients/customers of canned tuna do prefer "dolphin safe" tuna (Verstraaten, pers. comm.).

Catch per unit effort for the Ghanaian fishery was much larger than the CPUE for the East Atlantic studied by Conrad and Adu-Asamoah. According to Wise (1986), there is a striking difference between Skipjack CPUE of the Tema-based fleets and those of the other fleets fishing for Skipjack in the Eastern Atlantic. He continued to say that the figures for the Tema baitboats average from five to nearly ten times as high as those for the French, Ivorian, Senegalese, and Moroccan (FISM), and in recent years (i.e. as of 1982) fifty percent or more higher than the large purse seiners. He made his study over the period from 1969 to 1982. This implies that Ghanaian vessels have been much more efficient than their contemporaries even during the era studied by Conrad & Adu-Asamoah. Thus it is of no wonder that when Ghanaian vessels are standardised to large purse seiner days the resulting CPUE's are as high as 45.

Since Ghanaian vessels are much more efficient than the other vessels fishing in the East Atlantic, the hypothesis that the Ghanaian tuna fishery, as a part of the overall East Atlantic tuna fishery is similar with respect to biological parameters (see below) and CPUE trends during the period studied by Conrad and Adu-Asamoah (1967 – 1980) and that these have not changed in recent years (1980 – 2000) can be safely rejected.

6.2 Biological Parameters

The biological parameters adapted from Conrad & Adu-Asamoah show that the carrying capacity, K, and catchability coefficient, q, are higher for Yellowfin than for Skipjack. Thus the actual harvest and CPUE for Yellowfin is expected to be higher than for Skipjack. This is the case in Conrad & Adu-Asamoah's paper but not in this study. On average, twice as much Skipjack as Yellowfin is landed in Ghana. Yellowfin gets scarce especially during the months of January, February and March when catches of Bigeye and Skipjack are high. Scarcity of Yellowfin in Ghana during these months can get so severe that the canneries have to import Yellowfin from neighbouring countries especially the Ivory Coast. This implies that K and q for Yellowfin and Skipjack calculated for the entire East Atlantic are not the same as for Ghana. In fact, Skipjack has been described as being a viscose stock. A viscose stock may have the following characteristics:

- A local decline of a segment of the stock;

- Over-fishing of that segment will have little, if any, repercussion on the abundance of the stock in other areas;
- There is a minor proportion of the fish that make large-scale migration.

It is also known that since the start of fishing with FAD's, a large part of the Skipjack catches is made up of juveniles and yet catches along the coast of Senegal have neither reduced in size or quantity. This again points to the viscose nature (low interchange between areas) of Skipjack. Thus it might as well be that the Skipjack in Ghanaian waters are of an exclusive sub-stock with its own unique catchability that is much higher than that for the entire Eastern Atlantic.

It would have been ideal to calculate the intrinsic growth rate, r, catchability coefficient, q, and the carrying capacity, K, for each species specifically for the Ghanaian tuna fishery. However due to the very limited time, it falls outside the scope of this study.

6.3 Effects of Fishing with FAD's

According to ICCAT's Executive summaries on species: Skipjack (2000), a comparison of size distribution of Skipjack between periods prior to and after the introduction of FAD's show that in the East Atlantic, there has been an increase in the proportion of small fish in the catches, as well as a decline in the total catch in recent years. As with the decrease in the size of Skipjack harvested, data needed to confirm or disagree with ICCAT's observation for the Eastern Atlantic region was not at hand. However, with regard to the decline in the total Skipjack catches in recent years, the contrary was observed for the Ghanaian fishery as well as for the entire East Atlantic fishery. What can be said with certainty is the fact that there has been a drastic change in species composition of the tuna landed in Ghana over the last two decades. It is apparent that since the inception of fishing with FAD's the Bigeye tuna component landed in Ghana has gone up by 10% while the Skipjack component has declined by about the same percentage. This is in conformity with findings by ICCAT that fishing with FAD's has resulted in improved fishing efficiency and contributed to the increase of Bigeye catches (ICCAT, BET, 2000).

6.4 Bioeconomic and Open Access Equilibria

To make the results obtained from the bioeconomic model more understandable it was translated into sustainable economic rent or profit terms (Tables 5.5a, b & c). Naturally, profits increased with increase in prices and decreased with increase in discount rates until there was no rent left when the discount rate got to infinity i.e. at open access. Sustainable economic rents calculated for the bioeconomic equilibria showed that baitboats were more profitable than purse seiners for all three species of tuna. This may seem rather strange at first glance as per ton wise purse seiners are more cost-effective. However, with bioeconomic optimality being the objective, the baitboat fishery has a better sustainable economic rent due to the fact that it has a cheaper cost per day at sea. Baitboats are also cheaper to operate because of a number of reasons including the fact that the vessels are smaller, do not go as far out into the sea, have much less expatriate crew on board and do not have to incur costs as a result of fishing with nets as do purse seiners. The costs of the fishing nets are about US$800,000 (Verstraaten, pers. Comm.).

Socio-economically the baitboats are also better than purse seiners in the sense that it offers direct employment to some 40 – 56 Ghanaian fishermen while purse seiners employ only 18. Fishing communities in Ghana practise the extended family system so that indirectly one baitboat supports up to three times more extended families than purse seiners.

At open access status profits were zero, as expected. This is because in the open access fishery, effort tends to reach equilibrium (bionomic equilibrium, Figure 3.2) at the level $E = E_{\infty}$ at which total sustainable revenue equals total sustainable costs (i.e. economic rents are completely dissipated). Actual effort data for the East Atlantic region was not readily at hand hence it cannot be said for sure whether the actual effort currently exerted on the fishery is greater or less than the effort that would bring about the MSY. It is very likely that the East Atlantic tuna fishery is operating at a high discount rate and not yet at an open access equilibrium. As for the Ghanaian tuna fishery, the CPUE results have shown that they are much more efficient than the average of the overall East Atlantic. This implies that less effort is used in harvesting than is required. The Ghanaian tuna fishery is still making quite good profits despite the fall in the prices of tuna thus the actual effort is at the level where $E < E_{\infty}$.

The actual amount of Skipjack landed for the entire East Atlantic in 1999, was 138,985 MT. This is in excess of both the MSY (103,890 MT) and the open access yield obtained for baitboat (102,970 MT) and purse seine (92,630 MT) when prices are high. This high level of landings is not just peculiar to 1999, in fact 180,398 MT of Skipjack was landed in 1990 and though it has been on the decline since, it has consistently been higher than its MSY. The actual 1999 Yellowfin harvests of 107,099 MT are also higher than the open access yield obtained for baitboats (70,600 MT) and purse seiners (91,440 MT) at high prices. The actual landings of Yellowfin recorded its highest (157,112 MT) in 1990 and since then it has been slowly on the decline. Current landing levels are less than its MSY of 113,120 MT though more than the open access equilibrium. As for Bigeye, the actual amount landed in the entire Atlantic (123,235 MT) rather than for the East Atlantic was available. Hence one cannot say whether or not the actual harvests are in excess of the open access yields calculated for baitboats (21,440 MT) and purse seiners (23,620 MT).

Since current catches of Skipjack and Yellowfin are higher than can be sustained under open access status, future harvests are expected to decline even if the current effort levels remain the same.

Actual Ghanaian landings make up 31% and 26% of the total Skipjack and Yellowfin respectively landed for the East Atlantic. It is possible that Bigeye landed in Ghana could amount to 50% of the total for Bigeye landings in the East Atlantic. Data to confirm this was not available.

6.5 Baitboat-Purse Seiner Relationship

There seems to be a rather interesting relationship that exists between the two vessel types in Ghana. A close look at actual landings showed that one complemented the other in such a way that when there is a decline in harvest by one, the other records an increase in harvest and vice versa, thus they sort of fill in for each other. This could be due to the fact that rather than being competitors, the same fishing companies own both types of vessels which normally fish together. Sometimes when a school of fish is spotted the purse seiners surround it while baitboats fish out of the encircled school. Hence the catchability of either vessels is compromised. Also, the baitboats act as carriers by transporting fish from purse seiners to the landing site. Thus landings attributed to baitboats may actually be for purse seiners.

6.6 Management and Policy Implications

It is recommended by ICCAT that the minimum size for Bigeye and Yellowfin harvested be 3.2 kg. Length-weight relationship for the three species by Kume, 1986, indicated that all three species must exceed 54 cm fork length to surpass 3.2 kg in weight. From Table 4.4, the modal class (or the size range most frequently caught) of all three species were below this fork length.

Recall that it is mostly the young tuna species that form mixed schools. Apparently the FAD's encourage more mixing of the species, as Skipjack, small Bigeye and small Yellowfin all get attracted to these floating objects. Since the vessels do not have perfect selectivity with regard to what species to target, the best they could do is to fish only on "pure" schools of the individual species. This would mean that no fishing should be done with FAD's. According to Kume, 1986, if mixed schools of Bigeye and Yellowfin were avoided, in other words, if pure schools of Bigeye or Yellowfin were harvested, the catch of undersized Bigeye and Yellowfin could be reduced by only 1% to 2%. Again if schools of Bigeye and/or Yellowfin mixed with Skipjack were to be avoided, the catch of Skipjack would be reduced by 95%!

Thus the possibility of reducing catches of undersized Bigeye and Yellowfin by not fishing from mixed schools is not a practical solution for the management of the tuna fishery.

As to whether stock sizes have changed for the worse (i.e. biological overfishing occurred) from the time Conrad and Adu-Asamoah conducted their study until presently, generally, this does not seem to be the case even though the fishery has come under very intense fishing pressure especially since the introduction of FAD's. Having said that, caution must still be taken when dealing with schooling species such as tuna. For now there seems to be no need for any extra management practice to be put in place as the costs of doing so, will outweigh the benefits (if any).

Multi-species interactions and the application of non-selective multi-vessel fishing technology are likely to change the results have they been factored into the model.

7. CONCLUSION

In the study of the bioeconomic analysis of the Ghanaian tuna fishery, the following conclusions were arrived at:

1. There is a very low possibility of replacing the current size of fish especially Bigeye and Yellowfin harvested by the Ghanaian flagged vessels. As it stands the "best size" is the small (1.9 –3.2 kg) size of fish that is predominant in the Ghanaian tuna fishery. If larger fish has to be specifically targeted then the Ghanaian tuna fishery will cease to be commercially feasible.
2. The general characteristics e.g. biological parameters and CPUE trends, of the East Atlantic tuna fishery may not necessarily be the same for the Ghanaian tuna fishery. The Ghanaian tuna vessels were found to be much more efficient than the average of the entire East Atlantic tuna fleets.
3. Future harvests for the entire East Atlantic are expected to decline below the 1999 harvest levels. It is therefore recommended that effort levels should not be increased as current harvests are already in excess of open access equilibrium levels. Since the East Atlantic tuna fishery is more of an open access fishery, management bodies must be cautious when comparing harvest levels to the MSY as this can erroneously encourage more harvesting to attain such levels which might lead to total depletion of stocks. For a better understanding of this fishery it is proposed that the tuna fishery of Ghana be studied again this time round using multi-species and multi-vessel models.
4. The baitboat fishery of Ghana is "biosocio economically" better than the purse seiner fishery. It will be interesting to expand this study into a biosocioeconomic[13] study that employs both a behavioural model[14] and an optimisation model.

---

[13] Bioeconomics seek to understand the dynamics of fish and fleets while biosocioeconomics specifically seeks to understand fishers (in the form of fishing effort and labour dynamics) in addition to fish and fleet.

[14] For a description of a behavioural model see Charles, 2001.

REFERENCES

Bannerman, P., "Preliminary report on the moratorium on the use of FAD's by purse seiners in tuna fishing in Ghana", Fisheries Department, Tema, Ghana.

Bannerman, P.O. and D.W. Ofori-Adu, "Report on the ICCAT Bigeye tuna year tagging programme, opportunistic tagging operations in Ghana, April/May 2000", MFRD, Tema, Ghana (2000).

Cambridge, "International Dictionary of English", Cambridge University Press, Cambridge (1996).

Campbell, H.F. and R.B. Nicholl, Can Purse Seiners Target Yellowfin Tuna? *Land Economics*, **70** (3), pp. 345-354 (1994).

Charles, A.T., "Sustainable Fishery Systems", Blackwell Science, Oxford (2001).

Clark, C.W., "Mathematical Bioeconomics: The Optimal Management of Renewable Resources", John Wiley & Sons, New York (1976).

Conrad, J.M. and R. Adu-Asamoah, Single and Multispecies Systems: The Case of Tuna in the Eastern Tropical Atlantic, *Journal of environmental economics and management*, **13**, pp. 50-68 (1986).

Fisheries Department, "Tuna fishing with aggregating devices: Paper presented to the Fisheries Commission on the allegation made by the Inshore and Canoe Fisheries Associations on the petition to ban the use of 'payaos' in Tuna fishing in Ghana", MFRD, Tema, Ghana (2000).

Fonteneau, A., "Atlas of Tropical Tuna Fisheries; World Catches and Environment", ORSTOM Editions, Paris (1997).

Fox, W.W., Jr., Fitting the generalized stock production model by least-squares and equilibrium approximation, *Fishery Bulletin*, **73** (1), pp. 23-37 (1975).

Gould, J.R. Extinction of a fishery by commercial exploitation: A note, *Journal of Political Economy*, **80**, pp. 1031-1038 (1972).

Hammond, D.A., "Tuna fisheries in Ghana", Information Report number 14, Fishery Research Unit, Tema (1977).

Hartwick, J.M. and N.D. Olewiler, "The Economics of Natural Resource Use", Second ed., Addison-Wesley, USA (1998).

International Commission for the Conservation of Atlantic Tunas, Executive summaries on species, BET - Bigeye tuna, *Report for biennial period, 2000-01*, **2** (1), pp. 23-30 (2000).

International Commission for the Conservation of Atlantic Tunas, Executive summaries on species, SKJ - Skipjack tuna, *Report for biennial period, 2000-01*, **2** (1), pp. 31-38 (2000).

International Commission for the Conservation of Atlantic Tunas, Executive summaries on species, YFT - Yellowfin tuna, *Report for biennial period, 2000-01*, **2** (1), pp. 15-22 (2000).

James, G. and R. C. James, "Mathematics Dictionary", Fifth ed., Van Nostrand Reinhold, New York (1992),

Kume, S., Species Composition of Tuna Schools Caught by a Baitboat Fishery in the Gulf of Guinea, *Proceedings of the ICCAT conference on the international Skipjack year program*, ICCAT, Madrid, pp. 122-126 (1986).

Kwei, E.A., The social and economic effect of the development of tuna fisheries on the Ghanaian economy: presentation at a symposium held in Sao Miguel, Azores, 10-18 June 1996, ICCAT.

Marine Fisheries Research Division, "Background to Ghana's fishing industry with particular reference to the tuna industry", Ministry of Food and Agriculture, MFRD, Tema, Ghana (2000).

Marine Fisheries Research Division, "Report on tuna resources 1998/99", Ministry of Food and Agriculture, MFRD, Tema, Ghana (1999).

Mensah, M. and E. Kwei, Catch Per Unit Effort of Tema-based Baitboats and Length Frequency of Skipjack, *Proceedings of the ICCAT conference on the international Skipjack year program*, ICCAT, Madrid, pp. 118-121 (1986).

Ofori-Adu, D.W., "Observer's report on: ICCAT Moratorium on the use of Fish Aggregating Devices by Tuna Purse Seiners", MOFA, Tema (2000).

Verstraaten, D.P.J., Financial Controller, Pioneer Food Cannery Limited, Tema, Ghana (pers. comm.).

Wise, J.P., "The baitboat fishery for Skipjack in the Gulf of Guinea, 1969-82", *Proceedings of the ICCAT conference on the international Skipjack year program, ICCAT*, Madrid, pp. 111-117 (1986).

APPENDIX A: ANNUAL TUNA LANDINGS (MT), STANDARDISED EFFORT (SEA DAYS), AND CPUE BY SPECIES

	BIGEYE			**SKIPJACK**			**YELLOWFIN**		
Year	**Catch**	**St.Eff.**	**CPUE**	**Catch**	**St.Eff.**	**CPUE**	**Catch**	**St.Eff.**	**CPUE**
1980	332	454	0.73	5,812	1,722	3.38	1,974	1,122	1.76
1981	780	454	1.72	7,858	1,722	4.56	5,510	1,122	4.91
1982	791	454	1.74	18,272	1,722	10.61	9,797	1,122	8.73
1983	491	368	1.34	24,376	1,394	17.48	7,689	909	8.46
1984	2,162	327	6.61	20,697	1,240	16.69	9,039	809	11.18
1985	1,887	326	5.79	19,082	1,235	15.45	12,550	805	15.58
1986	1,720	307	5.59	22,268	1,166	19.10	11,821	760	15.55
1987	1,178	209	5.63	24,347	794	30.67	10,830	517	20.93
1988	1,214	266	4.57	26,597	1,007	26.41	8,555	657	13.03
1989	2,158	302	7.14	22,751	1,146	19.85	7,035	747	9.42
1990	5,031	311	16.16	24,251	1,181	20.54	11,988	770	15.57
1991	4,090	266	15.40	25,052	1,007	24.87	9,254	657	14.10
1992	2,866	256	11.18	18,967	972	19.50	9,331	634	14.72
1993	3,577	229	15.62	20,225	868	23.29	13,283	566	23.47
1994	4,738	238	19.90	21,258	903	23.54	9,984	589	16.96
1995	5,517	266	20.77	18,607	1,007	18.47	9,268	657	14.12
1996	5,805	328	17.68	19,602	1,245	15.74	12,160	812	14.98
1997	7,431	331	22.45	27,667	1,255	22.04	16,504	818	20.17
1998	13,252	311	42.56	34,150	1,181	28.92	17,807	770	23.13
1999	11,460	324	35.32	43,460	1,230	35.32	28,328	802	35.32
2000	5,586	365	15.30	29,950	1,384	21.64	17,010	902	18.85

APPENDIX B1: SENSITIVITY TEST FOR BIOECONOMIC MODEL AT 5% CHANGE IN ”K”

Increase of K by 5%

	BE	SJ	YF		BE	SJ	YF
q =	0.02110	0.01240	0.01372		0.02110	0.01240	0.01372
r =	1.9018	1.5686	1.2883		1.9018	1.5686	1.2883
K_1 =	48.6540	264.9435	351.2244		48.6540	264.9435	351.2244
K_2 =	51.0867	278.1907	368.7856		51.0867	278.1907	368.7856
p =	$450	$400	$450	p =	$1,050	$1,000	$1,050

Baitboat

	c =	$393	$1,488	$969	c =	$393	$1,488	$969
δ		BE	SJ	YF		BE	SJ	YF
0.00	ΔX^* =	2.7%	2.3%	3.5%	ΔX^* =	3.7%	3.4%	4.2%
	ΔY^* =	30.7%	39.4%	7.4%	ΔY^* =	6.5%	7.5%	5.4%
	ΔE^* =	27.3%	40.8%	3.8%	ΔE^* =	2.7%	3.9%	1.1%
0.05	ΔX^* =	2.7%	2.3%	3.4%	ΔX^* =	3.6%	3.4%	4.1%
	ΔY^* =	30.7%	39.4%	7.4%	ΔY^* =	6.5%	7.5%	5.3%
	ΔE^* =	27.3%	40.8%	3.9%	ΔE^* =	2.8%	4.0%	1.2%
0.10	ΔX^* =	2.6%	2.3%	3.3%	ΔX^* =	3.6%	3.3%	4.1%
	ΔY^* =	30.7%	39.4%	7.4%	ΔY^* =	6.4%	7.5%	5.3%
	ΔE^* =	27.4%	40.8%	3.9%	ΔE^* =	2.8%	4.0%	1.2%
$\delta \to \infty$	ΔX_∞ =	0.0%	0.0%	0.0%	ΔX_∞ =	0.0%	0.0%	0.0%
	ΔY_∞ =	27.3%	40.8%	3.8%	ΔY_∞ =	2.7%	3.9%	1.1%
	ΔE_∞ =	27.3%	40.8%	3.8%	ΔE_∞ =	2.7%	3.9%	1.1%

Purse Seiner

	c =	$577	$2,184	$1,422	c =	$577	$2,184	$1,422
δ		BE	SJ	YF		BE	SJ	YF
0.00	ΔX^* =	2.2%	1.9%	3.0%	ΔX^* =	3.3%	3.0%	3.9%
	ΔY^* =	22.1%	10.3%	12.4%	ΔY^* =	8.9%	12.7%	5.8%
	ΔE^* =	23.8%	12.0%	9.1%	ΔE^* =	5.5%	9.4%	1.9%
0.05	ΔX^* =	2.2%	1.9%	3.0%	ΔX^* =	3.2%	2.9%	3.8%
	ΔY^* =	22.1%	10.3%	12.3%	ΔY^* =	8.9%	12.7%	5.8%
	ΔE^* =	23.8%	11.9%	9.1%	ΔE^* =	5.5%	9.5%	1.9%
0.10	ΔX^* =	2.2%	1.8%	2.9%	ΔX^* =	3.2%	2.9%	3.8%
	ΔY^* =	22.1%	10.3%	12.3%	ΔY^* =	8.9%	12.7%	5.8%
	ΔE^* =	23.8%	11.9%	9.2%	ΔE^* =	5.5%	9.5%	1.9%
$\delta \to \infty$	ΔX_∞ =	0.0%	0.0%	0.0%	ΔX_∞ =	0.0%	0.0%	0.0%
	ΔY_∞ =	23.8%	12.0%	9.1%	ΔY_∞ =	5.5%	9.4%	1.9%
	ΔE_∞ =	23.8%	12.0%	9.1%	ΔE_∞ =	5.5%	9.4%	1.9%

APPENDIX B2: SENSITIVITY TEST FOR BIOECONOMIC MODEL AT 5% CHANGE IN ”c”

Increase of c by 5%

		BE	SJ	YF		BE	SJ	YF
	q =	0.02110	0.01240	0.01372		0.02110	0.01240	0.01372
	r =	1.9018	1.5686	1.2883		1.9018	1.5686	1.2883
	K =	48.6540	264.9435	351.2244		48.6540	264.9435	351.2244
	p =	$450	$400	$450	p =	$1,050	$1,000	$1,050
					Baitboat			
	c_1 =	$393	$1,488	$969	c_1 =	$393	$1,488	$969
	c_2 =	$413	$1,562	$1,017	c_2 =	$413	$1,562	$1,017
δ		BE	SJ	YF		BE	SJ	YF
0.00	ΔX^* =	2.3%	2.7%	1.5%	ΔX^* =	1.3%	1.6%	0.8%
	ΔY^* =	-27.0%	-46.6%	-2.6%	ΔY^* =	-1.6%	-2.6%	-0.4%
	ΔE^* =	-28.6%	-42.9%	-4.0%	ΔE^* =	-2.9%	-4.1%	-1.2%
0.05	ΔX^* =	2.3%	2.7%	1.6%	ΔX^* =	1.4%	1.6%	0.9%
	ΔY^* =	-27.0%	-46.6%	-2.5%	ΔY^* =	-1.6%	-2.6%	-0.4%
	ΔE^* =	-28.7%	-42.8%	-4.1%	ΔE^* =	-2.9%	-4.2%	-1.2%
0.10	ΔX^* =	2.4%	2.7%	1.7%	ΔX^* =	1.4%	1.7%	0.9%
	ΔY^* =	-27.0%	-46.6%	-2.5%	ΔY^* =	-1.5%	-2.6%	-0.3%
	ΔE^* =	-28.7%	-42.7%	-4.1%	ΔE^* =	-2.9%	-4.2%	-1.2%
$\delta \to \infty$	ΔX_∞ =	5.0%	5.0%	5.0%	ΔX_∞ =	5.0%	5.0%	5.0%
	ΔY_∞ =	-25.1%	-50.0%	0.8%	ΔY_∞ =	2.0%	0.7%	3.8%
	ΔE_∞ =	-28.6%	-42.9%	-4.0%	ΔE_∞ =	-2.9%	-4.1%	-1.2%
					Purse Seiner			
	c_1 =	$577	$2,184	$1,422	c_1 =	$577	$2,184	$1,422
	c_2 =	$606	$2,293	$1,493	c_2 =	$606	$2,293	$1,493
δ		BE	SJ	YF		BE	SJ	YF
0.00	ΔX^* =	2.8%	3.1%	2.0%	ΔX^* =	1.7%	2.0%	1.1%
	ΔY^* =	-28.5%	-16.1%	-7.7%	ΔY^* =	-4.1%	-8.1%	-0.9%
	ΔE^* =	-25.0%	-12.6%	-9.5%	ΔE^* =	-5.8%	-9.9%	-2.0%
0.05	ΔX^* =	2.8%	3.1%	2.0%	ΔX^* =	1.8%	2.0%	1.2%
	ΔY^* =	-28.5%	-16.0%	-7.7%	ΔY^* =	-4.1%	-8.1%	-0.8%
	ΔE^* =	-25.0%	-12.5%	-9.6%	ΔE^* =	-5.8%	-9.9%	-2.0%
0.10	ΔX^* =	2.8%	3.2%	2.1%	ΔX^* =	1.8%	2.1%	1.2%
	ΔY^* =	-28.5%	-16.0%	-7.7%	ΔY^* =	-4.1%	-8.1%	-0.8%
	ΔE^* =	-25.0%	-12.5%	-9.6%	ΔE^* =	-5.8%	-10.0%	-2.0%
$\delta \to \infty$	ΔX_∞ =	5.0%	5.0%	5.0%	ΔX_∞ =	5.0%	5.0%	5.0%
	ΔY_∞ =	-31.3%	-18.2%	-5.0%	ΔY_∞ =	-1.1%	-5.4%	2.9%
	ΔE_∞ =	-25.0%	-12.6%	-9.5%	ΔE_∞ =	-5.8%	-9.9%	-2.0%

APPENDIX B3: SENSITIVITY TEST FOR BIOECONOMIC MODEL AT 5% CHANGE IN ”p”

Increase of p by 5%

	BE	SJ	YF		BE	SJ	YF
q =	0.02110	0.01240	0.01372		0.02110	0.01240	0.01372
r =	1.9018	1.5686	1.2883		1.9018	1.5686	1.2883
K =	48.6540	264.9435	351.2244		48.6540	264.9435	351.2244
p_1 =	$450	$400	$450	p_1 =	$1,050	$1,000	$1,050
p_2 =	$473	$420	$473	p_2 =	$1,103	$1,050	$1,103

Baitboat

	c =	$393	$1,488	$969	c =	$393	$1,488	$969
δ		BE	SJ	YF		BE	SJ	YF
0.00	ΔX^* =	-2.2%	-2.5%	-1.5%	ΔX^* =	-1.3%	-1.5%	-0.8%
	ΔY^* =	24.5%	42.3%	2.3%	ΔY^* =	1.4%	2.4%	0.4%
	ΔE^* =	27.3%	40.8%	3.8%	ΔE^* =	2.7%	3.9%	1.1%
0.05	ΔX^* =	-2.2%	-2.6%	-1.5%	ΔX^* =	-1.3%	-1.5%	-0.8%
	ΔY^* =	24.5%	42.3%	2.3%	ΔY^* =	1.4%	2.4%	0.3%
	ΔE^* =	27.3%	40.8%	3.9%	ΔE^* =	2.8%	4.0%	1.2%
0.10	ΔX^* =	-2.3%	-2.6%	-1.6%	ΔX^* =	-1.4%	-1.6%	-0.9%
	ΔY^* =	24.5%	42.3%	2.3%	ΔY^* =	1.4%	2.3%	0.3%
	ΔE^* =	27.4%	40.8%	3.9%	ΔE^* =	2.8%	4.0%	1.2%
$\delta \to \infty$	ΔX_∞ =	-4.8%	-4.8%	-4.8%	ΔX_∞ =	-4.8%	-4.8%	-4.8%
	ΔY_∞ =	21.2%	43.6%	-1.1%	ΔY_∞ =	-2.2%	-1.0%	-3.7%
	ΔE_∞ =	27.3%	40.8%	3.8%	ΔE_∞ =	2.7%	3.9%	1.1%

Purse Seiner

	c =	$577	$2,184	$1,422	c =	$577	$2,184	$1,422
δ		BE	SJ	YF		BE	SJ	YF
0.00	ΔX^* =	-2.6%	-3.0%	-1.9%	ΔX^* =	-1.7%	-1.9%	-1.0%
	ΔY^* =	25.9%	14.6%	7.0%	ΔY^* =	3.7%	7.4%	0.8%
	ΔE^* =	23.8%	12.0%	9.1%	ΔE^* =	5.5%	9.4%	1.9%
0.05	ΔX^* =	-2.7%	-3.0%	-1.9%	ΔX^* =	-1.7%	-2.0%	-1.1%
	ΔY^* =	25.8%	14.6%	7.0%	ΔY^* =	3.7%	7.3%	0.8%
	ΔE^* =	23.8%	11.9%	9.1%	ΔE^* =	5.5%	9.5%	1.9%
0.10	ΔX^* =	-2.7%	-3.0%	-2.0%	ΔX^* =	-1.8%	-2.0%	-1.2%
	ΔY^* =	25.8%	14.5%	7.0%	ΔY^* =	3.7%	7.3%	0.7%
	ΔE^* =	23.8%	11.9%	9.2%	ΔE^* =	5.5%	9.5%	1.9%
$\delta \to \infty$	ΔX_∞ =	-4.8%	-4.8%	-4.8%	ΔX_∞ =	-4.8%	-4.8%	-4.8%
	ΔY_∞ =	27.5%	16.2%	3.9%	ΔY_∞ =	0.5%	4.2%	-3.0%
	ΔE_∞ =	23.8%	12.0%	9.1%	ΔE_∞ =	5.5%	9.4%	1.9%