ASSESSMENT OF THE MAXIMUM SUSTAINABLE YIELD (MSY) OF THE TUNA FISHERY IN GHANA AND ITS APPLICATION IN MANAGEMENT

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BY

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DECLARATION

This thesis is the result of the research work undertaken by Ahiable Gabriel Mawuko, a student of the University of Ghana, Department of Marine and Fisheries Sciences under the supervision of Professor P.K. Ofori-Danson and Dr. (Mrs) A.M. Lamptey both of the same Department. I do hereby declare that the thesis consists entirely of my own work, except where due acknowledgement is made, and that no part of it has been previously published or submitted for a degree or diploma elsewhere.

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DEDICATION

I dedicate this work to the unforgettable memory of my beloved father, Mr. J. K. Mensah (late). I am always indebted to you for your love and upbringing. I miss you, Dad!

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TABLE OF CONTENTS

Page

Table of Contents (Continued)

Table of Contents (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

ABSTRACT

The Ghanaian tuna fishery is a thriving industry employing more than 15,000 people. Three major tuna species, Skipjack (*Katsuwonus pelamis*), Yellowfin (*Thunnus albacares*) and the Bigeye (*Thunnus obesus*) form the base of the fishery. High fishing effort, use of modern technologies, fish aggregating devices and increased number of vessels have increased total landings, largely composed of juveniles. This study assessed the catch trends and sustainability of the fishery in Ghana.

The results indicated that total tuna landings declined from 94,180 MT in 2010 to 79,447 MT in 2013. *K. pelamis* dominated the landings from 1987 to 2013 with an average component of 71 % of current landings. *T. obesus* contributed least of the three species, with 12.13 % composition of current landings. Catch per unit effort, (CPUE), of the fishery declined from 29.49 MT/fishermanday in 2001 to 17.12 MT/fishermanday in 2013, symptomatic of overfishing.

Using the equilibrium assumptions of the Schaefer's Surplus Production Model, 187.38 MT, 20,091.59 MT, 60,274.38 MT and 2,091.56 MT were the MSY estimates for *T. obesus*, *T. albacares. K. pelamis* and the artisanal fishery, respectively, making a total of 82,644.91 MT with average F_{MSY} of 3,076 fishermandays. The total MSY for the tuna fishery, 82,644.91 MT, compared favourably with the range of sustainable yield of the resource estimated to be in the Ghanaian waters. The current average total landings, 86,477.2 MT, is in excess of the estimated MSY. Current landings of both *T. obesus* and *K. pelamis* are also in excess of the MSY estimated.

The CPUE and MSY coupled with information on size composition of landings of the fishery provided evidence that the tunas in the Ghanaian waters are fully exploited and being overfished. With the stocks of *K. pelamis* viscous, local management actions would be very useful in managing the stock. The MSY and average F_{MSY} estimated can

be useful in setting catch quotas and implementing input controls for the Ghanaian tuna fishery.

Although regulations by the International Commission for the Conservation of Atlantic Tunas (ICCAT) have been helpful, national management actions are needed to keep the tuna stocks at sustainable levels to save the highly profitable tuna fishery and industry in Ghana from collapse in the near future. To this end, the cooperation of all stakeholders in the Ghanaian fisheries is needed to plan and enforce practical precautionary management actions including setting restrictive quotas and regulation of inputs of the fishery to moderate $F_{current}$ and regulate landings. This would not only ensure the sustainability of the fishery but increase its profitability too.

CHAPTER ONE

INTRODUCTION

1.1 Background

Ghana's Fisheries and Aquaculture Sector Development Plan, FASDP, for 2011 to 2016 noted that Ghana has valuable fisheries that generate in the order of US$ 1 billion in revenue each year. The estimated contribution of the sector to the nation's gross domestic product (GDP) increased from about 3.9 % in 2008 (Bank of Ghana, 2008) to 4.5 % in 2010 (FADP, 2011) but declined drastically to 1.4 % in 2013 (GSS, 2014). The FASDP (2011) attributes the drastic decline to too little investment in management and value addition and there too many vessels catching too few fish. Fish remains one of the most important and cheapest sources of animal protein in Ghana with as much as 60 per cent of animal protein in the Ghanaian diet country - wide thought to be from fish (Bank of Ghana, 2008).

According to Ghana's National Plan of Action to prevent, deter and eliminate illegal unreported and unregulated fishing, NPOA_IUU, (2014), Ghana's marine fisheries capture sector consists of three main types of fishing fleets: the artisanal canoes (about 75% motorized), semi-industrial boats (wooden-planked vessels) and industrial vessels (large-scale trawlers and tuna boats). Of all these sectors, the artisanal sector constitutes a major part (contributing about 70-80 %) of the national fish production (FAO, 1998). The Ghanaian fisheries support 135,000 fishers in the marine sub-sector alone and indirectly support the livelihoods of about 10 % (2.2 million people) of the Ghanaian population (FADP, 2011). Most fish resources of the Ghanaian marine fishery were suspected to be fully fished or overfished since 1994 (Heinbuch, 1994; FADP, 2011) and trends of catch in recent years have confirmed that most of the Ghanaian fish stocks are depleted (Atta Mills *et al*., 2004) except the tunas (Bank of Ghana, 2011).

The tuna fishery falls under the East Atlantic tuna fishery (Obeng, 2003). Bortier-Verstraaten (2002) noted that, 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 with the Bigeye (*Thunnus obesus*;Lowe, 1839), Skipjack (*Katsuwonus pelamis*; Linnaeus, 1758), and the Yellowfin tuna (*Thunnus albacares*; Bonnaterre, 1788) being the major species. Of the many gears that capture tunas in Ghana, the purse seines and baitboats (industrial tuna fisheries) are by far the two most important fleet (Addi, 2014). The Ghanaian tuna fishery is one of the few marine fisheries estimated to have huge potentials for exploitation (FADP, 2011; Bank of Ghana, 2008).

According to the then Marine Fisheries Research Department, MFRD, (1999 & 2000), there are no quotas allocated to ICCAT members. Ghana therefore has the right to increase the volume of catch at will. Furthermore, the use of destructive Fish Aggregating Device (FADs) likelogs, flotsam, dead and live whales and whale sharks and data buoys in the fishery is extensive (ICCAT, 2014). Current landings of tunas are predominantly juveniles with size range 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) (Bortier-Verstraaten, 2002).

The International Union for Conservation of Nature (IUCN) included *T. obesus* and *T. albacares* in its Red List as 'Threatened' and 'Near threatened' species, respectively (IUCN, 2011). Thus, like any other fishery, uncontrolled and unsustainable exploitation of tunas may present an inevitable problem of overfishing to the Ghanaian tuna fishery in the near future.

Biological reference points are useful indicators of the true state of fishery resources being exploited and presents a good indication for management actions (Caddy and Mahon, 1995). One of the most essential reference points for sustainable exploitation of fisheries is the experimentally derived Maximum Sustainable Yield (MSY) of the fish stock (Sissenwine, 1978; Garcia, 1984; Cadima, 2003). The available data for the Ghanaian tuna fishery are mainly time series catch and effort data. Using a surplus production model, the MSY for the fishery can be estimated from the available data. MSY is instrumental in preventing overfishing and in restoring overfished stock to stock size needed for sustainable exploitation (Ocean, 2012).

Although widely practiced by agencies regulating wildlife, forests, and fishing, MSY has come under heavy criticism by ecologists and others for both theoretical and practical reasons (Milner-Gulland, and Mace, 1998).While some believe the concept is sound but is seldom really implemented, others think it is fundamentally flawed (Safina, 2012). According to Larkin (1977) and Walters and Maguire (1996), it is dangerous and misused by several conservation biologists. MSY has tended to lead to the overharvest of stocks (Finley, 2011) and puts populations at too much risk because it neither accounts for spatial variability in productivity nor for species other than the focus of the fishery and it considers only the benefits, not the costs, of fishing (Larkin, 1977). Holt (2011) also noted that it is inadequate and its pursuit increases the likely unprofitability and even collapse of fisheries.

However, examining the advantages and draw backs of MSY, Safina (2012) concluded that where it has been applied, MSY seems useful despite its flaws. The author further noted that such limits are better than no limits in a world of too many people and too much fishing pressure citing the healthy fishery of Alaska (where MSY is used) and the burnt fisheries of New England (where MSY was rejected).

1.2 Objectives

The primary objective of the study was to determine the maximum sustainable yield (MSY) for use as a reference point of the tuna fishery in Ghana.

The specific objectives of the study were to:

- identify the annual trends of catch and catch per unit effort of the Ghanaian tuna fishery.
- determine the MSY for the major tuna species landed in Ghana.
- identify the implication of the MSY point for the management of the Ghanaian tuna fishery.

1.3 Justification

Global demand for tuna commodities increased steadily throughout the 1980s (Hassan, 1997). The Tuna fishery is one of the most important marine fisheries in terms of volume and value of landing (Addi, 2014) with landings of the three principal market tunas alone accounting for about 20.93 % of the total marine production in 2008. Currently, Ghana is one of the major landing and processing hubs for the West Africa tuna industry. However, generally, the current condition of Ghana's marine fisheries is both vulnerable and unstable because they are fully or over-exploited (FADP, 2011).

According to Ghana's Food and Agricultural Development Plan, 2011-2016 (FADP, 2011), the level of tuna landings into Ghana is essentially a function of the processing capacities of Ghanaian canneries. Falaye (2008) observed that Ghana has potentials of increasing tuna production considering the stock in its coastal waters. The FADP (2011) noted that unlike the other marine sectors, the Ghanaian tuna fishery can accommodate investment in fishing capacity and value addition. It called on government to consider means of increasing the fishing effort of the fishery by enhancing the introduction of new more efficient fishing vessels into the fishery.

It is very important that decisions to increase fishing effort and landings are based on current scientific findings on the state of the fishery. This is critical to preventing the tuna fishery from threats of collapse as other marine fisheries have experienced. This is particularly important for the Ghanaian tuna fishery because unlike the other authors, findings of Bortier-Verstraaten (2002) indicated that harvests of tuna were already in excess of the open access equilibrium levels necessitating decline of future harvests for Ghana below 83,552.5 MT. The author also recommended that effort levels should not be increased. Current landings of tuna have increased considerably with very high components of the landings being juveniles. This may be an indication of overfishing. Moreover, Drury O'neill (2013) reported lawless practices in the fishery and weak implementation of management regulations in the Ghanaian tuna fishery.

Although tuna stocks are generally shared resources, the stocks available to the Ghanaian fishery and from which the fishery can make maximum economic gains are exhaustible. It is therefore important to assess the sustainability of the resource being exploited as often as possible and to exploit the resources at sustainable levels to prevent the over-exploitation and collapse of this lucrative and extremely important fishery. Over the years, not much has been done on the sustainability of the fishery. Both previous works (Bortier-Verstraaten, 2002; Obeng, 2003) and the recent work by Drury O'neill (2013) on tuna fisheries in Ghana were bereft of direct estimations of the MSY of the Ghanaian tuna fishery. This study is therefore important to assess the state of the fishery in the face of continuously increasing landings over the past years.

MSY, the only reference point specified by UNCLOS (1982) for management of fisheries, is very instrumental to adopting effective management strategies to sustain fisheries and industries. Simulation studies have suggested that, management advice based on surplus production models may be as robust as population estimates based on age-structured analysis (Ludwig and Walters, 1985; Punt, 1994).This study is both important and timely to save the livelihood of at least three thousand people (3,000) employed directly by the industrial tuna fishery in Ghana (Drury O'Neill, 2013) and the over fifteen thousand (15,000) people employed by the tuna fishery and industry in Ghana (GBN, 2013). The MSY estimate would be useful not only to know the state of the fishery but also to adopt appropriate management actions for the sustainability of the fishery.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Marine Fisheries in Ghana

Ghana is an important and a powerful fishing nation and Ghanaian fishers can be found all over the continent of Africa for example in Namibia, Angola, Liberia, Mauritania and other African countries (Atta-Mills *et al*., 2004). The length of Ghana's coastline is about 536 km (Bampo, 2011) with a continental shelf, ranging from 20-90 km in width (Amador *et al*., 2006). Ayivi (2012) reported that of the ten administrative regions of Ghana, four, namely Volta, Greater Accra, Central and Western Regions are coastal and fishing is a popular economic activity in these regions with the Volta region being the least producer in terms of marine fisheries. The study further noted that both pelagic and demersal fish stocks exploited by the different fishing fleets operating in the Ghanaian coastal waters are shared by the neighbouring countries in the sub-regions, namely, Benin, Togo and La Cote d'Ivoire.

The marine capture fisheries are the main source of fish landings in Ghana and accounted for 65.54 % of the total country fish production in 2008 (FADP, 2011) and increased to 77 % in subsequent years (Ayivi, 2012). The marine fisheries sector is usually categorized into four subsectors: small scale (or artisanal), semi-industrial (or inshore), industrial and tuna (FAO, 2007). Of these, the small scale or artisanal fisheries sub-sector is the most important with respect to landed weight of fish, it accounts for approximately 70 to 80 percent of the national marine fish production (Quaatey, 1997; Amador *et al*., 2006; FAO, 2007).

Fisheries in the western Gulf of Guinea, have sustained the livelihoods of coastal dwellers and the economy of Ghana over the years (MoFA, 2011). In terms of labour occupation, fishing is second to farming and trading in Ghana (Lawson &Kwei, 1974). MoFA (2011) noted that, this sector directly engages about 10 % of the total country's population of 24 million. In Ghana, it accounted for 1.4 % of the country's Gross Domestic Product (GPD) and 6.3 % of the Agricultural Gross Domestic Product (AGDP) in 2013(GSS, 2014) a sharp decline in comparison to 2010 when it accounted for 4.5 % of GDP and 12 % of AGDP (MOFA, 2011).

According to Nunoo and Berchie(2013), fish is the preferred and cheapest source of animal protein in Ghana with about 75 % of total annual catch of fish in the country consumed locally making it a reliable source of food security. In Ghana, fish consumption is 25 kg/capita/yr, which is higher than the global average of 17.1kg/capita/yr (MOFA, 2011).

2.1.1 Industrial Fishery

According to the Ghana's National Plan of Action to prevent deter and eliminate illegal unreported and unregulated fishing, NPOA_IUU, (2014), the marine industrial fleet can be subdivided into the tuna purse seine fleet and the industrial trawler fleet. According to Quaatey (1997) and the FAO (2007), the industrial fleet has undergone radical expansion in numbers since the launching of the Ghana Economic Recovery Programme in 1984. There are currently more than 100 industrial demersal trawlers (NPOA_IUU, 2014). According to Ghana's Fisheries Act 625 (2002), the trawlers and shrimpers exploit demersal and semi-pelagic species with the trawlers required by law to operate in waters deeper than 30 m depth.The vessels operate from Tema and Takoradi where there are deepwater ports (FAO, 2007)with their fishing grounds extending beyond Ghana's Exclusive Economic Zone (EEZ) into the high seas (NPOA_IUU, 2014). This serves as a constraint to bait-boats which have to come close inshore to catch bait (NPOA_IUU, 2014).

These vessels target species such as cuttlefish, seabreams, groupers, snappers, soles and cassava fish for export (Bailey *et al*., 2010). The tuna fishing fleet is comprised of pole-and-line bait-boats and tuna purse seiners with the former being the main harvesters of tuna in Ghanaian waters, using live anchovies as bait (NPOA_IUU, 2014).

Unlike the artisanal and semi-industrial, the industrial fishing vessels are usually equipped with cold storage (freezing) facilities for preserving fish at sea and can stay for months at sea (FAO, 2007).

2.1.2 Semi-industrial fishery

The semi-industrial or inshore fleet consists of approximately 230 locally built wooden vessels fitted with inboard engines of up to 400 hp and have lengths ranging between 8 and 37 m. Vessels with lengths less than 12 m are referred to as small-sized while those between 12 and 22 m are referred to as medium sized vessels (Quaatey, 1997). The vessels are multi-purpose and are used for both purse seining and bottom trawling. They operate as purse seiners during the upwelling periods and switch to bottom trawling for the rest of the year. The purse seiners target the sardinellas, chub mackerel and other Carangidae species. They fish in the same coastal waters as the artisanal fleet during the upwelling seasons. Bottom trawling is done in waters greater than 30 m depth.

The semi-industrial vessels use ice for preserving fish at sea and a fishing trip usually variesfrom 3 to 5 days. The disappearance of *B. capriscus* from Ghanaian waters in the late 1980s has affected greatly the performance of the sector. The species was the main resource base for many of these vessels (Quaatey, 1997).

2.1.3 Artisanal Fishery

Atta-Mills *et al*. (2004) noted that the Ghanaian fishing sector has a long tradition of artisanal fisheries supplying the country with more than 70 % of the total fish landings with the fleet made of locally-built wooden vessels, ranging from 4 – 18m in length. The artisanal fishery is characterized by the use of several gears including purse seine nets, beach seine net, set nets, drifting gillnets and hook and line operated from dug-out canoes (Quaatey, 1997).

The marine artisanal sector comprises about 13000 canoes and employs 80% of Ghanaian fishers (NPOA_IUU, 2014) operating actively from over 300 landing sites located along the entire 550 km length of the coastline (Quaatey, 1997). About 75 percent of these canoes are powered by outboard motors (NPOA_IUU, 2014). Fish landed are predominantly small pelagics namely, sardinella, chub mackerel, anchovy, horse mackerel, etc., and large pelagics predominately tunas and billfishes and coastal demersal species such as Sparids (FAO, 2007).

2.2 Taxonomy and Biology of the tunas

The tunas are highly migratory pelagic species widespread in the warm waters of the oceans and seas and they play a significant role in the biological processes (Nguen and Bukharitryn, 2015). They are able to swim incredible distances as they migrate (WWF, 2015a).

The root of the word 'tuna' derived from the Latin word 'thunnus' is traced to the Ancient Greek word '*thýnō'* which means "rush, dart along" (Liddell and Scott, 1940) probably to describe its incredible speed movement.

Tuna is generally used to describe pelagic marine finfish of the tribe *Thunnini* and Family *Scombridae*, the family of the bonitos, mackerels, and Spanish mackerels (Graham and Dickson, 2004). The tribe, *Thunnini* is a monophyletic clade comprising fifteen species in five genera:*Allothunnus*(slender tunas), *Auxis* (frigate tunas), *Euthynnus*(little tunas) *Katsuwonus*(skipjack tunas), *Thunnus* (albacores, true tunas). The tunas have greatly varied sizes ranging from the smallest, the bullet tuna (maximum length: 50 cm and weight: 1.8 kg to the largest, the Atlantic bluefin tuna (maximum length: 4.6 m and weight: 684 kg).

Species of the Genus *Thunnus* are referred to as the 'true' tunas and made up of two sub-genera, sub-genus *Thunnus (Thunnus)* (the bluefin group) and sub-genus *Thunnus (Neothunnus)* (the yellowfin group). The genus is made up of eight species. Examples include Albacore tuna, (*Thunnusalalunga*, Bonnaterre, 1788), Bigeye tuna (*Thunnusobesus*, Lowe, 1839), Atlantic Bluefin tuna, (*Thunnusthynnus*, Linnaeus, 1758) and Blackfin tuna, (*Thunnusatlanticus*, Lesson, 1831).

Generally, tunas are active and agile predators, with sleek, streamlined body (Plates A, B and C), and are among the fastest-swimming pelagic fish – the *T. albacares*, for example, is capable of speeds of up to 75 km/h (Block *et al*., 1992). Several tuna species associate with dolphins and this association of tuna schools with dolphins are believed to be for protection against sharks, which are tuna predators (Gustavo, 2015).

They possess a near-unique circulatory and respiratory system among fish which enable them to maintain a body temperature higher than that of the surrounding water via the intertwining of veins and arteries in the body's periphery, which allows nearly all of the metabolic heat from venous blood to be "re-claimed" and transferred to the arterial blood via a counter-current exchange system, thus mitigating the effects of surface cooling (Cech*et al*., 1984). However, according to Sepulveda *et al*.,(2008) unlike "typical" endothermic creatures such as mammals and birds, tuna do not maintain temperature within a relatively narrow range. The ability of the tuna to elevate the temperatures of the highly-aerobic tissues of the skeletal muscles, eyes and brain (Landeira-Fernandez *et al*., 2003; Sepulveda *et al*., 2008) has been found very useful to faster swimming speeds and reduced energy expenditure, and to enable them to survive in cooler waters over a wider range of ocean environments than those of other fish.

According to Sepulveda *et al*.(2008), the muscle tissue of tuna ranges from pink to dark red unlike most fish, which have white muscles. These muscles are called red myotomal muscles which derive their colour from myoglobin, an oxygen-binding molecule expressed in tunas in quantities far higher than in most other fish and hence their colouration. The oxygen-rich blood further enables energy delivery to their muscles

(Sepulveda *et al*., 2008). The tunas are one of the most commercially valuable fish and are integral to the diet of millions of people (WWF, 2015a).

2.2.1 Biology and Ecology of *Katsuwonuspelamis*; Linnaeus, 1758

K. pelamis(Skipjack tuna) (Plate A) is a gregarious species that is found in schools in the tropical and subtropical waters of the Pacific, Indian and Atlantic oceans. It is the predominant species aggregated to FADs where it is caught in association with juvenile *T. albacares*, *K. pelamis* and with other species of epipelagic fauna. It spawns opportunistically in warm waters (above 25^{o}C) throughout the year in large areas of the ocean and reaches sexual maturity around one year. Its reproductive potential is thus considered to be high. 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 (ICCAT, 2006).

Plate A: Skipjack tuna, *Katsuwonus pelamis*. Source: Myers *et al.* (2015)

Also, the analysis of East Atlantic tagging data has confirmed that its growth was quicker in sub-tropical waters than in equatorial waters where it produces most of its spawn. These growth differences depending on latitude must be taken into account if the assessments are carried out on separate stocks between sub-tropical and tropical areas. It is also possible that the growth does not follow the conventional Von Bertalanffy model but rather a two-stanza model (ICCAT, SKJ, 2014).

The increasing use of fish aggregation devices (FADs) since the early 1990s, have changed the species composition of free schools. It is noted that, the free schools of mixed species were considerably more common prior to the introduction of FADs. The association with FADs may also have an impact on the biology (growth rate, plumpness of the fish) and on the ecology (distances, movement orientation) of this species and *T. albacares*, a concept known as the "ecological trap" concept.

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 Skipjack Working Committee of ICCAT maintained the hypothesis of separate east and west stocks as the more plausible alternative to an Atlantic wide single stock (ICCAT, SKJ, 2000, 2014)

2.2.2 Biology and Ecology of *Thunnus albacares*; Bonnaterre, 1788

T albacares, Yellowfin tuna, (Plate B) is a cosmopolitan species distributed mainly in the tropical and subtropical oceanic waters of the three oceans. The sizes exploited range from

30 cm to 170 cm total length (TL); maturity occurs at about 100 cm TL. Juveniles form mixed schools with *K. pelamis* and juvenile *T. obesus*, and are mainly limited to surface waters, while larger fish form schools in surface and sub-surface waters. The equatorial zone of the Gulf of Guinea is their main spawning ground. Spawning occurs primarily from December to April. Juveniles are generally found in coastal waters off Africa. Spawning also takes place in the Gulf of Mexico, in the southeastern Caribbean Sea, and off Cape Verde, although the peak spawning occurs at different times during the year. The relative importance of the spawning grounds is unknown. Although such separate spawning areas might imply separate stocks or substantial heterogeneity in the distribution of this species, a single stock for the entire Atlantic is assumed as a working hypothesis. This assumption is based upon information such as observed trans-atlantic movements (from west to east) indicated by conventional tagging and longline catch data that indicates their continuous distribution throughout the entire tropical Atlantic Ocean. However, movement rates and timing, routes, and local residence times remain highly uncertain. In addition, some electronic tagging studies in the Atlantic as well as in other oceans suggest that there may be some degree of extended local residence times and/or site fidelity (ICCAT, YFT, 2014).

Plate B: Yellowfin tuna, *Thunnus albacares*. Source: WPTT (2015)

The juveniles, 40-80 cm exhibit a strong association with FADs (natural or artificial fish aggregating devices/floating objects) increasing their vulnerability to surface gears and may also have a negative impact on the biology and on the ecology of the species due to changes in feeding and migratory behaviours.

Of the adults, males are predominant in the catches of larger sized fish (over 145 cm), while females are predominant in the catches of intermediate sizes (120 to 135 cm). There are distinct growth curves between males and females, with females having a lower asymptotic size (140 cm) than males (150 cm). There are still questions concerning the most appropriate growth model for Atlantic *T. albacares* because analyses of hard part growth increments support somewhat different growth patterns. Since these uncertainties in stock structure, natural mortality, and growth have important implications for the stock assessment, ICCAT hopes that the successful conduct of a proposed Atlantic Ocean

Tropical Tuna Tagging Program, should help resolve these uncertainties. (Adopted from ICCAT, YFT, 2014).

2.2.3 Biology and Ecology of *Thunnus obesus*; Lowe, 1839

Bigeye tuna, *T. obesus* (Plate C) are distributed throughout the Atlantic Ocean between 50ºN and 45ºS, but not in the Mediterranean Sea. This species swims at deeper depths than other tropical tuna species and exhibits extensive vertical movements. Similar to the results obtained in other oceans, pop-up tagging and sonic tracking studies conducted on adult fish in the Atlantic have revealed that they exhibit clear diurnal patterns: they are found much deeper during the daytime than at night. In the eastern tropical Pacific, this diurnal pattern is exhibited equally by juveniles and adults. In the western Pacific these daily patterns have been associated with feeding and are synchronized with depth changes in the deep scattering layer. Spawning takes place in tropical waters when the environment is favourable. From nursery areas in tropical waters, juvenile fish tend to diffuse into temperate waters as they grow larger. Catch information from surface gears indicate that the Gulf of Guinea is a major nursery ground for this species.

Plate C: Bigeye tuna, *Thunnus obesus*. Source: WPTT (2015)

T. obesus exhibit relatively fast growth: about 105 cm fork length at age three, 140 cm at age five and 163 cm at age seven. Recently, however, reports from other oceans suggest that growth rates of juveniles are lower than those estimated in the Atlantic. They reach maturity after they are 100 cm (that is at ages between 3 and 4 years old). Juveniles form schools mixed with other tunas such as *T. albacares* and *K. pelamis*. These schools are often associated with drifting objects, whale sharks and sea mounts. This association weakens as *T. obesus* grow larger. Natural mortality rates for juvenile fish, estimated from tagging data, are similar to those applied for other oceans. Like *T. albacares*various pieces of evidence, such as a lack of identified genetic heterogeneity, the time-area distribution of fish and movements of tagged fish, suggest an Atlantic-wide single stock for this species. However, the possibility of other scenarios, such as north and south stocks, should not be disregarded (ICCAT, BET, 2014).

2.3 Overview of the Global Tuna Fishery

Tuna and tuna-like species are very important economically and a significant source of food. They include approximately forty (40) species occurring in the Atlantic, Indian and Pacific Oceans and in the Mediterranean Sea (Majkowski, 2007). It further notes that tuna fisheries are among oldest in the world with Phoenician trap fisheries for Atlantic bluefin tuna operating around 2000 BC but were mostly restricted to coastal areas until the second part of the twentieth century. Industrial fisheries started during the 1940's and 1950's as a result of increasing demand for canned tuna. The rapid expansion of the fishery is first traced to the Pacific Ocean in the late 1950s and later in the Atlantic and Indian Oceans in the 1980s.

According to the International Seafood Sustainability Foundation (ISSF), a global, non-profit partnership between the tuna industry, scientists, and the World Wide Fund for Nature, the most important species for commercial and recreational tuna fisheries are yellowfin (*Thunnus albacares*), bigeye (*T. obesus*), bluefin (*T. thynnus*, *T. orientalis*, and *T. macoyii*), albacore (*T. alalunga*), and skipjack (*Katsuwonu spelamis*) (ISSF, 2012). The WWF (2015a), notes that the majority of the market is made up of four species: skipjack, yellowfin, bigeye and albacore, perhaps because the bluefin are globally overfished now (National Geographic, 2015). In 2010, their catch was approximately four million tonnes, which represents about 66 % of the total catch of all tuna and tuna-like species. Most catches of the principal market tuna species are taken from the Pacific (70.5 % of the total catch of principal market tuna species in 2008), with the Indian contributing much more (19.5 % in 2010) than the Atlantic and the Mediterranean Sea (10.0 % in 2010) (FIGIS, 2015).

The industrialized fisheries that started in the 1940s and 1950s, as a result of increasing demand for canned tuna, included Japanese longline and baitboat fishing in the Pacific, and United States baitboat fishing off California along the Mexican coasts (FAO, 2011). In 2010, in terms of fishing gear, 63 % of the landings is made by purse seining, followed by longline (14 %), miscellaneous gears (gillnets, handline, traps, etc., 13 %), and pole-and-line (10 %) (ISSF, 2012). Ghana is one of the major producers of tuna in the Atlantic tuna fisheries (Bortier-Verstraaten, 2002)

2.3.1 Overview of the Ghanaian Tuna Fishery

In Ghana, ICCAT identifies three commercial species of tuna *stock* namely, Yellowfin (*T. albacares*), Bigeye (*T. obesus*) and Skipjack (*K. pelamis*). Until 1973, the fishery was exploited by foreign-owned vessels (Finegold*et al.*, 2010) with the tuna caught predominantly for export (Acquay, 1992). Although the Ghanaian tuna fishery targets tuna by the use of a host of gears, such as the pole and line,poli/watsa, drift gill net, longline and trolling, the purse seines and baitboats are by far the most important fleet in the tuna fishery (Addi, 2014).

The tuna baitboat (pole and line) fishery in Ghana was started by the Japanese in the early 1960s. It expanded from 5 baitboats in 1962 to its height of 33 in 1990, and then to 25 in 2001 (Bannerman and Bard, 2001). The Ghanaian baitboat fleet is the largest fleet operating in the East Atlantic (MFRD, 2000) and was the most important tuna fleet in the Ghanaian fishery, landing 93.2 % of the total market tuna production in 1980 with 41 baitboats as against 6 purse seines. Since the 1990s, the purse seines have employed the use of FADs extensively, making catches from FAD activities as high as 80 % of their landings (Chassot *et al*., 2014). ICCAT, (2003) reported that a collaboration between the two fleet has led to a mixture of varying sizes of fish often landed by the baitboats, leading to some problems in stratification by gear.

As FAD activities result in catch of many juveniles, both Obeng (2003) and Bortier-Verstraaten, (2002) noted that, though the Ghanaian fleet make significant contributions to the total catch in the Eastern Atlantic region, their catches are mainly juveniles (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 *T. obesus* catches and ICCAT has since 1999 called these fisheries to make the "best size" substitution to replace the current undersized/juvenile fish, which are predominant in the Ghanaian Bigeye catch (ICCAT, BET, 2000).

2.4 Exploitation and Utilization of the three major tunas in the Atlantic Ocean

2.4.1 *Katsuwonus pelamis*

K. pelamis, which is mostly canned, accounts for the greatest proportion of the world catches of tuna. Its catches have increased over the entire period of its exploitation. In 2009, the skipjack catch was more than 2.5 million tonnes (the highest on record), being more than half of the total catch of all principal market tuna landed. In the early 1980s, catches of skipjack increased steadily as a result of expansion of fishing effort into the tropical western and central Pacific and into the western Indian Ocean.

In the Atlantic, currently, the major fisheries are the purse seine fisheries, particularly those of EU-Spain, Ghana, Curaçao, Belize, Panama, EU-France, Guinea and Cape Verde, followed by the baitboat fisheries of Ghana, EU-Spain, EU-Portugal and Senegal. The total catches of skipjack throughout the Altantic Ocean (including catches of "faux poisson" landed in Côte d'Ivoire) remain high at 221,600 MT with the historic record in 2012 (258,300 MT). In addition, following the expert missions carried out in Ghana, which have shown the existence of bias in the sampling protocol, and which aims to correct the multi-species compositions of the catches reported in the logbooks, Ghanaian statistics have been reviewed in several stages (1973-2005). The last review for the period 2006-2012 shows that the catches of *K. pelamis* reported by Ghana were underestimated by around 28 %, which gives an average of 12,000 MT/year. All of these historical data have consequently been corrected.

It is difficult to discriminate a fishing effort for free schools (composed of *T. albacares*) for FAD fishing (targeting *K. pelamis*) in the East Atlantic because the fishing strategies can change from one year to the next and in addition, the sea time devoted to activities on FADs and the assistance provided by supply vessels are difficult to quantify.

In recent years, nominal purse seine effort, expressed in terms of carrying capacity, has increased since 2007 due to the introduction of several European Union purse seiners transferred to the East Atlantic, due to piracy in the Indian Ocean, and a fleet of new purse seiners which started operating from Tema (Ghana), whose catches are probably underestimated. A steady decrease in average weight of catch was observed up to 2011which is consistent with the fact that the purse seine fleet has increased pressure on juvenile tunas. In all the oceans, the traditional stock assessment models are difficult to apply to *K. pelamis* because of their particular biological and fishery characteristics. In order to overcome these difficulties, several assessment methods, conventional and non-conventional (based solely on catches, or on development of average size) were applied to the two stocks of Atlantic *K. pelamis* in order to track the development of the state of the stock over time.

The most recent stock assessment for this species, (ICCAT, SKJ, 2014), highlighted difficulties with the estimation of the MSY in conditions of continuous growth of catches due to inability to obtain reliable indicators on the response of the stock to these increases for the East Atlantic fishery. No value was therefore arrived at as the MSY for the East Atlantic fisheries. It is noteworthy that, according to this model, although it is unlikely that the eastern skipjack stock is overexploited, current catches could be at, even above, the MSY. Although only a single stock is considered for the East Atlantic, due to the very low apparent exchange rates between the sectors, a decrease in abundance for a local segment of the stock would probably have little repercussion on abundance in other areas hence stocks of *K. pelamis* are said to be viscous (ICCAT, SKJ, 2014)

2.4.2 *Thunnus albacares*

Globally, *T. albacares* is commercially the second most important species of the principal tunas by volume. It is commercially, the second most important species of the principal tunas in the Atlantic tuna fisheries too. Its catches increased until 2003, reaching a maximum of 1.44 million metric tonnes. Since then, catches have decreased to about 1 million metric tonnes in 2008 and 2009. Most yellowfin is canned, but more and more of the catch is being sold in fresh-fish markets (also some as frozen fish). Catches in the

Atlantic reached a peak of 161,000 tonnes in 2001 but have since declined to about 120,000 tonnes. Global landings reached a maximum of almost 900,000 tonnes in 2002 and have recently fluctuated between 610,000 and 752,000 tonnes (Garibaldi and Limongelli, 2002).

Purse seine and baitboats are the major vessels employed in the capture of this species in the East and currently, long lines in the West Atlantic. The efficiencies of the purse seines have been increasing mainly because the newly introduced vessels from the Indian Ocean and Tema (Ghana) with greater fishing power and carrying capacities. On the whole, the overall Atlantic catches declined by nearly half from the peak catches of 1990 (193,114 tonnes) to the 102,294 tonnes estimated for 2012.

In 2010, although reported catches were well below MSY levels and fishing mortality rates most likely about 13 % below F_{MSY}, stock biomass was estimated to most likely be about 15 % below the Convention objective. The age-structured models indicate increasing fishing mortality rates and decline in stock levels over the last several years, although the production models indicate the opposite trends. These uncertainties are most probably due to the complex dynamics with the increasing landing of juveniles (ICCAT, YFT, 2014). It is therefore not surprising that *T. albacares* is classified as Near-threatened by the IUCN and is also listed in the Red List of Greenpeace International (Greenpeace International, 2013; IUCN, 2011).

2.4.3 *Thunnus obesus*

In the Atlantic, *T. obesus* stock has been exploited by three major gears (longline, baitboat and purse seine fisheries) and by many countries throughout its range of distribution. The size of fish caught varies among fisheries. Ghana has one of the major baitboat and purse seine fisheries in the Eastern Atlantic. In the surface fishery, unlike *T. albacares*, *T. obesus*are mostly caught while fishing on floating objects such as logs or man-made fish aggregating devices (FADs).

After a historic high catch in 1994, all major fisheries exhibited a decline of catch while the relative share by each fishery in total catch remained relatively constant. These reductions in catch are related to declines in fishing fleet size (longline) as well as decline in CPUE (longline and baitboat). Illegal unreported and unregulated (IUU) fishing is reported of this species, like others, with unreported catches as high as 25,000 tonnes 1998. Although there is reported decline in IUU fishing for this species, it is feared that such activities are being underestimated because the magnitude of this problem has not yet been quantified, due to insufficient available statistical data collection mechanisms to provide alternative means to calculate unreported catch. Revision of the catch data from Ghana has shown that catches of *T. obesus* by Ghanaian fleets were significantly lower (by an average of 2,500 tonnes) than it was previously estimated over the periods 1996-2005 but greater for the period 2006-2012.

The median of the plausible range of MSY estimated from a joint distribution using three types of abundance indices (from non-equilibrium production models) was 92,000 tonnes (80 % confidence limits). It is noteworthy that these estimates reflect the current relative mixture of fisheries that capture small or large *T. obesus.*

Historical estimates show large declines in biomass and increases in fishing mortality, especially in the mid-1990s when fishing mortality exceeded F_{MSY} for several years. It is estimated that in the last five or six years there have been possible increases in biomass and declines in fishing mortality.

In the recent, as in previous assessments, a considerable number of uncertainties have been identified in the assessment of stock status and productivity for bigeye tuna. The sources of uncertainty include which method represents best the dynamics of the stock, which method is supported more by the available data, which relative abundance indices are appropriate to be used in the assessment, and what precision is associated with the measurement/calculation of each of the model inputs. These factors, including the lack of detailed historical information on catch and fishing activities of IUU fleets (e.g., size, location and total catch), compelled recent assessments to make many assumptions about the catch-at-size for an important part of the overall catch. In the Atlantic, annual harvest of 85,000 tonnes is deemed sustainable with higher odds of rebuilding to and maintaining the stock at levels that could produce MSY are associated with lower catches and lower odds of success with higher catches than such constant catch. Because the TAC does not affect all countries that can land bigeye tuna, in theory the total catch removed from the stock could exceed 85,000 tonnes (ICCAT, BET, 2014).

2.5 Overfishing Challenges in the Global Tuna Fishery

According to the FAO, overfishing may be growth overfishing, recruitment overfishing or ‘local’ overfishing. “Growth overfishing” occurs where the fishing mortality (or fishing pattern) is such that fish are caught before they have a chance to reach their growth potential. The term “Local overfishing” describes a peculiar case of growth overfishing.

This is a situation where the observed catches are not increasing as a response to higher local fishing mortality. This type of local overfishing can be sustainable in biological terms when the stock itself is in good shape, but the low catch rates and stable catches corresponding to this situation may not be profitable in economic terms. “Recruitment overfishing” describes a situation where an excessive fishing mortality has produced an excessive decline of the spawning stock, and consequently low recruitment. This recruitment overfishing may lead to a temporary or long term collapse of the stock.

The US National Geographic traces the causes of overfishing to the international efforts to increase the availability and affordability of protein-rich foods in the mid-20th century, which led to concerted government efforts to increase fishing capacity. It notes that favourable policies, loans, and subsidies spawned a rapid rise of big industrial fishing operations, which quickly supplanted local boatmen as the world's source of seafood (National Geographic, 2015).

As much as 85 % of the world's fisheries may be over-exploited, depleted, fully exploited or in recovery from exploitation (Block *et al.*, 1992). According to the FAO fisheries department, 53 % of the world’s fisheries are fully exploited, and 32 % are overexploited, depleted, and 1 % recovering from depletion (FAO, 2010). The report further noted that, most of the top ten marine fisheries, accounting for about 30 % of all capture fisheries production, are fully exploited or overexploited. Overfishing threatens coastal nations down to the local level, devastating communities whose chief source of labour and revenue hinges on healthy, plentiful stocks of fish (WWF, 2015b). Notable examples are the 1992 decision by Canada to impose an indefinite moratorium on the Grand Banks due to the collapse of the cod fishery off Newfoundland. Some forty thousand (40,000) people lost their jobs overnight, including ten thousand (10,000) fishermen as a result and for about twenty years now, the cod have still not recovered, despite management practices, probably due to substantial change to the ecosystem (WWF, 2015b).

Five of the eight species of tuna are in the threatened or Near Threatened IUCN Red List Categories. These include: Southern Bluefin (*T. maccoyii*), Critically Endangered; Atlantic Bluefin (*T. thynnus*), Endangered; Bigeye (*T. obesus*), Vulnerable; Yellowfin (*T. albacares*), Near Threatened; and Albacore (*T. alalunga*), Near Threatened (IUCN Red List, 2011). The Greenpeace International seafood red list is a list of fish that are commonly sold in supermarkets around the world, and which have a very high risk of being sourced from unsustainable fisheries (Black, 2007; Greenberg, 2010). Like the IUCN, Greenpeace International in 2010, added the *T. alalnunga*, *T. obesus*, *T. orientalis*, *T. thynnus*, *T. maccoyii* and *T. albacares* to its seafood red list.

According to the ISSF (2013), globally, 65 % of tuna stocks are at a healthy level of abundance, 26 % are overfished and 9% are at an intermediate level. In terms of exploitation, 39 % of the stocks are experiencing a low fishing mortality rate, 22% are being over-exploited and 39 % have a high fishing mortality that is being managed adequately. When viewed from the point of view of total catch, 94 % of the catch are healthy stocks due to the fact that skipjack stocks contribute more than one half of the global catch of tunas and they are all in healthy situation. In contrast, most Bluefin stocks and three out of six stocks of albacore are overfished. These however make a relatively small fraction of the total catch when combined.

Although no stock of skipjack tuna (which makes up roughly 60% of all tuna fished worldwide) was considered to be overfished, Worm *et al*., (2006) noted that unless the current situation improves, stocks of all species currently fished for food may collapse by 2048. In the same vein, a 2010 tuna fishery assessment report, released in January 2012 by the Secretariat of the Pacific Community (SPC), support findings of threats of overfishing and stock depletion of the tunas and recommends that all tuna fishing should be reduced or limited to current levels and that limits on *K. pelamis* fishing be considered (SPC, 2012).

2.6 Management of Global Tuna Fisheries.

Many scientists postulate that most fish populations could be restored with aggressive fisheries management, better enforcement of laws governing catches, and increased use of aquaculture (National Geographic, 2015). The tunas are part of the important highly migratory species listed in the United Nations' Convention on the Law of the Sea (UNCLOS) Annex I. Article 64 of the UNCLOS reflects the view that the management of highly migratory species requires cooperation between the coastal State and other states fishing for the resource (FAO, 2015).

To this end, globally, there are five main Regional Fishery Management Organizations (RFMOs) in the management of tuna: the Western Central Pacific Ocean Fisheries Commission (WCPOFC), the Inter-American Tropical Tuna Commission (IATTC), the Indian Ocean Tuna Commission (IOTC), the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the Commission for the Conservation of Southern Bluefin Tuna, each with its area of jurisdiction/'convention area'. Together with tuna, these RFMOs are also responsible for the conservation of tuna-like fishes and other migratory species within their respective jurisdictions. The species of interest are mainly the major tunas (*T. Thynnus thynnus*, *T. albacares*, *T. alalunga*, *T. obesus*, *K. pelamis*), the billfishes; swordfish (*Xiphias gladius*), white marlin (*Tetrapturus albidus*), blue marlin (*Makaira nigricans*), sailfish (*Istiophorus albicans*); mackerels such as spotted Spanish mackerel (*S. maculatus*) and king mackerel (*S. cavalla*) and sharks.

Due to the high global commercial value of the tunas, many other international organisations including scientific research institutions, NGOs and conservation groups like the ISSF, US National Oceanic and Atmospheric Administration (NOAA) and the Pew Environmental Group also play very important roles in the management of tunas (eg. WWF, 2015a). The RFMOs have management powers to set catch and fishing effort limits, technical measures, and control obligations. Most of them also manage other very highly migratory fishes and other marine resources. The RFMOs perform their task based on research. To this end, each RFMO has a scientific research entity which collect and analyse data on catch of fish (sizes, quantities and locations of catch), the amount of fishing effort generated to make the catches, as well as biological information on age, growth, and reproduction for analysis purposes.

Recommendations are accepted by unanimous consent of all members. Members reserve the right to accept the recommendations, accept them with modifications, or reject them. Each member government bears the responsibility to implement national legislation to ensure that vessels flying their flag comply with the program the RFMOs monitor compliance (ISSF, 2015b). The Ghanaian tuna fisheries fall under the Eastern Atlantic which is under the jurisdiction of the ICCAT.

2.6.1The International Commission for the Conservation of Atlantic Tunas (ICCAT)

Increasing capitalization and declining catch-per-unit-effort (CPUE) trends in the Atlantic during the 1960s drew concern by the international scientific community regarding the abundance, health, and reproductive capacity of tuna. Recognizing the need for coordinated international management (as emphasized later by the UNCLOS 1982), the International Convention for the Conservation of Atlantic Tunas was negotiated and signed in Rio de Janeiro in 1966. Member nations of the convention established the International Commission for the Conservation of Atlantic Tunas (ICCAT) in 1969 to recommend conservation and management measures for tuna and other highly migratory species (Obeng, 2003).

ICCAT is the second oldest regional tuna management organization. Its Convention is open to any government that is a member of the United Nations or any specialized agency of the United Nations. As of 2015, it has fifty (50) contracting parties (ICCAT homepage). The ICCAT is responsible for the management and conservation of tuna and tuna-like species in the Atlantic Ocean and adjacent seas (ICCAT Homepage). The Commission's responsibility is to make scientifically based recommendations designed to maintain the populations of tunas and tuna-like species under their jurisdiction at levels of abundance which will permit maximum sustainable yields (MSY) (ISSF, 2015c). ICCAT is comprised of four panels: Panel 1 is for tropical tunas (*T. albacares*, *T. obesus*, and *K. pelamis*); Panel 2 for northern temperate species (northern *T. allalunga* and *T. thynnus*); Panel 3 for southern temperate species (southern *T. allalunga* and southern *T. thynnus*); Panel 4 is for other species.

The ICCAT meets every year, and receives scientific advice, which it uses to make management recommendations, from the Standing Committee on Research and Statistics (SCRS), a subsidiary body of ICCAT, comprised of scientific experts from ICCAT's member governments. ICCAT can accept, reject, or modify the recommendation. ICCAT may also initiate recommendations without input from the panel. Management decisions are binding on the members, unless they object. There is a well- defined system for nations to object to any management resolution approved, and any member that properly files its objections is not bound by the resolution (ISSF, 2015c).

In years past, the organisation has been strongly criticised by scientists and environmental groups for its weak recommendations considered insufficient to assure the sustainability of the tuna fishery under its jurisdiction (WWF, 2009; BBC News, 2007; Buck, 1995). However, in recent years, the trends of performance of ICCAT has appreciated attracting commendations the switch to relying on sound science, insisting on compliance and following a good governance model (Pew Environment Group, 2012; WWF, 2013)

According to Nandan (2005) some RFMOs lack capacity and in nearly all of them, participation is not sufficiently broad to ensure compliance with conservation and management measures and eliminate the problem of "free riders". In this vein, Due to the politics associated with inter-governmental organisations like ICCAT, it is noteworthy that there is a limit to the force that can be applied to cause a country to accept more stringent regulations than what it would do voluntarily. This brings to the fore, the need for domestic management regimes to provide adequate protection of the tuna (especially the viscous) stocks.

2.6.2 Domestic Management Regime

Ghana’s acquisition of the Extended Fisheries Jurisdiction from 12 Nautical miles to 200 Nautical miles, a continental shelf of 23,700 km^2 and an Exclusive Economic Zone (EEZ) stretching over 218,000 km^2 empower (according to provisions of UNCLOS 1982) her to manage her marine resources in addition to measures taken by international management organisations like ICCAT.

According to Obeng (2003), Ghana has adopted a number of direct and indirect controls to regulate the fisheries resources to make sure its citizens employed in the fishing sector gets a secure job. Ghana’s membership in ICCAT suggests strongly her readiness to improve tuna management through better international cooperation. To implement Ghana’s participation in ICCAT, PNDC Law 256 of 1991 was enacted. Under this law, all tuna vessels are operated on joint-venture basis with Ghanaians owing at least 50 % of the shares.

According to reports of the then Marine Fisheries Research Division (MFRD, 1999 & 2000), Ghana has the right to increase the volume of catch if she so desires because there are no quotas allocated to ICCAT members. The domestic management authorities have allowed the use of extensive Fish Aggregating Device (FADs) in the fishery (Obeng, 2003; Bortier-Verstraaten, 2002). Often, the two major tuna fleet in Ghana, purse seines and baitboats work together and catches off FADs are shared (Chassot *et al.*, 2014) and this collaboration according to ICCAT (2003), has led to a mixture of varying sizes of fish landed and some problems in stratification by gear.

The trend of juveniles increasingly dominating the catches of the Ghanaian tuna fishery as confirmed by previous and recent studies (Bortier-Verstraaten, 2002; Obeng, 2003; Addi, 2014) calls for additional local management practices in addition to those of ICCAT. According to Rosenberg and Restrepo, (2014),the precautionary approach to fishery management, protects fishery resources from fishing practices which might put their long-term viability in jeopardy and appropriate precautions including control of fishing activities need to be employed even before there is clear scientific evidence that current practices cannot be sustained by the resource. The study further noted that in order to develop fishery control policies, biological reference points are needed for measuring current resource status and the projected effects of fishing.

2.7 The Maximum Sustainable Yield, MSY, as a Biological Reference Point

In order to protect the resource and the fishing industry against long-term damage, it is important to define and agree on a 'red area' where the continuity of resource production is in danger, and immediate action is needed, such as a substantial reduction in fishing effort/mortality, or in the extreme case, closure of the fishery for a period of time (ICES, 1988).

Caddy and Mahon (1995) defined a reference point as a conventional value, derived from technical analysis, which represents a state of the fishery or population, and whose characteristics are believed to be useful for the management of the unit stock. To implement fishery management it must be possible to convert the conceptual Reference

Point into a Technical Reference point, which can be calculated or quantified on the basis of biological or economic characteristics of the fishery (Caddy and Mahon, 1995).

Biological Reference Points (BRPs) are described in terms of the relationships between fishing mortality, biomass of the stock and yield (Caddy and Mahon, 1995). According to Cadima (2003), the BRPs are the values beyond which the self-renovation of the stock might be seriously affected. Caddy and Mahon, (1995) noted two types of biological reference points: target reference points (TRPs) and limit reference points (LRPs). Cadima (2003) noted a third type of reference point, the Precautionary reference points (PRPs).

A LRP may either correspond to some minimum condition like a dangerously low spawning biomass or some maximum condition like a high rate of decline in stock size, or a high mortality rate, at which point a management response must be appropriated (Caddy and Mahon, 1995).The LRP values are mainly concerned with the conservation of marine stocks and are therefore also referred to as *reference points for conservation* in contrast with F_{target}. Several LRP exist; Minimum Biological Acceptable Level, MBAL, the smallest spawning biomass *observed* in a series of annual values of the spawning biomass (B_{loss}), a limit that corresponds to a very high value of F, showing a great probability of collapse of the fishery (F_{crash}) and F_{loss}, usually defined as the fishing level F which will produce a long-term spawning biomass per recruit (S/R) associated to B_{loss} are some examples.

PRPs are based on the Precautionary Principle, proposed by FAO in the Conduct Code for Responsible Fisheries (FAO, 1995). Compared to LRPs, the limits (Fpa or Bpa), are more restrictive and the regulation measures designed to control the fishing effort, more severe than in those cases where there is appropriate data (Cadima, 2003). PRPs are thus the price to pay for not having the appropriate conditions to make available reliable data and information.

A TRP indicates the state of fishing and/or resource which is considered to be desirable and at which management action, whether during development or stock rebuilding, should aim (Caddy and Mahon, 1995). TRPs are also designated as *Reference Points for Management* for this reason (Cadima, 2003). The commonest examples of TRPs include the maximum sustainable yield (MSY), biomass at which the MSY can be produced, B_{MSY} and the fishing mortality needed to produce the MSY, F_{MSY}.

The ICES Advisory Committee on Fishery Management (ACFM) report in 1987 noted that biological reference points are intended to provide guidance concerning management, and that no biological reference point can serve as a universal target (Caddy and Mahon, 1995).

The maximum sustainable yield, MSY, can be defined as the maximum annual catch which on average can be taken year after year from a fish stock on a sustainable way -without deteriorating the productivity of the fish stock (Beverton and Holt, 1957). When a stock is excessively large, yield is restricted due to competition for food, cannibalism or the limitations in the carrying capacity of the environment. In between the situation of overfishing and excessively large stock, lies a stock size at which the sustainable catch is at the highest level –MSY. For fishing fleet to catch an annual amount of fish equal to the MSY, the fish population/biomass must be at a level, B_{MSY} which supports taking the MSY and the fishing mortality at a level, $F_{MSY,}$ which supports the MSY.

The concept of MSY as a fisheries management strategy developed in Belmare New Jersey in the early 1930s (Russel, 1931; Hjort *et al.*, 1933; Graham, 1935). It became more popular in the 1950s with the advent of surplus-production models which explicitly estimate MSY (Schaefer, 1954). As an apparently simple and logical management goal, combined with the lack of other simple management goals of the time, MSY was adopted as the primary management goal by several international organizations (e.g., IWC, IATTC, ICCAT, ICNAF), and individual countries (Mace, 2001). The MSY may be used as a target or limit reference point. It may also be a basis for implementing precautionary management actions.

Not all scientists agree to the usefulness of MSY as a tool for fisheries management. For example MSY has come under heavy criticism by ecologists and others for both theoretical and practical reasons (Milner-Gulland and Mace, 1998). Larkin (1977) argued that the MSY put populations at too much risk because it did not account for spatial variability in productivity, it did not account for species other than the focus of the fishery, it considered only the benefits, not the costs, of fishing; and it was sensitive to political pressure.

However, Safina (2012) noted that despite its flaws, it (MSY) has been very useful, where it is applied, citing the thriving US fisheries (where MSY is applied) and the collapsed UK fisheries (where MSY was not accepted many years ago). The MSY approach has been widely accepted as an objective for fisheries management. It is the only reference point mentioned in the United Nations Convention on the Law of the Sea, UNCLOS, 1982, document. WSSD (Johannesburg, 2002) also tasked States to maintain or restore stocks to levels that can produce the maximum sustainable yield where possible not later than 2015.

In Europe, the decision by the European Commission to implement the maximum sustainable yield (MSY) principle led ICES to introduce a new MSY-based approach for providing advice in 2009 (Lassen *et al.*, 2013). In the US, the 2006 Reauthorization of the

Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) emphasized an MSY-based approach that requires overfishing to stop and for depleted stocks to be rebuilt (NOAA, 2007). In Canada, new MSY-based fisheries policies were developed under the Sustainable Fisheries Framework (DFO, 2009). In 2008 the Northwest Atlantic Fisheries Organization expanded its Convention to include MSY-based objectives (NAFO, 2008)

2.7.1 Models for Estimating the MSY

Two main models are used for estimating MSY: the analytical model and production models.

Yield per Recruit/Analytical Model

It is an analytical and multi-parameter model. Length-frequency distributions are a first step in determining the numbers and sizes of different ages or year classes in the catch that are needed for an analytical assessment of a stock. These measurements, based on samples taken regularly over a number of years, can be used to establish the age structure of the population, the growth of the fish, the age at which the fish become liable to capture, and how quickly the population is reduced as a result of fishing and natural mortality (FAO, 2014). According to the NOAA Fisheries box tool (2013), the yield per recruit is a major revision of earlier implementations of the basic Thompson-Bell (1934) model for estimating the expected lifetime yield and biomass from a cohort subjected to varying levels of fishing mortality. This model provides estimates of life-history parameters like mean age, generation time and expected number of spawning. It is useful in investigating the resulting age composition of catch and abundance under different levels of fishing mortality with the incorporation of uncertainties in weights at age, natural mortality, maturity and fishery selectivity. The Beverton-Holt (1957) or Ricker (1954)stock recruitment coefficients are used to estimate the effort at which MSY is obtained (F_{MSY}) and the biomass (B_{MSY}).

Production models

These are much simpler than analytical methods with less demanding data requirements. There is for example no need to determine cohorts and therefore no need for age determination. This is one of the main reasons for the relative popularity of surplus production models in tropical fish assessment (FAO, 2014). The main data required are yield by species and of the effort expended over a certain number of years. The commonest are the Schaefer and Fox models. MSY is obtained by plot from catch-effort data. The major limitations of these models are that they treat the stock as a whole and neglect the biology of the fish, and effect of factors like mesh size.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study involved the use of data from landings of tuna nationwide. Ghana has an EEZ of 228,000 km^2 (NPOA_IUU, 2014) and continental shelf area of 24,300 km^2 (Ayivi, 2012). The shelf varies in width from 20km off the East (Volta Region) to about 90 km between Cape Coast in the Central Region and Takoradi in the Western Region. A substantial part of the continental shelf is rocky. Beyond 75 m depth the substrate is rocky except off Axim-Half Assini (Western Region) (Ayivi, 2012). The Tema Fishing Harbour, part of the Tema Harbour (Figure 3.1), is the major landing site for the (industrial) tuna fleets due to the lack of berthing facilities and most probably, lack of tuna processing companies in other parts of the country.

The Tema harbour (Figure 3.1), lies along the Gulf of Guinea and is about 18 miles from Accra (Portside, 2015). The harbour has a water-enclosed area of 1.7 million square metres and covers a total land area of 3.9 million square metres (Portside, 2015). The Fishing Harbour is to the east of the lee break water and has an inner harbour approach of 4.9 metres deep and an outer harbour approach of 7.6 metres deep for bigger vessels (PMAESA, 2010). The publication (PMAESA, 2010) further noted that the fishing harbor has net mending wharf, shed for fishmongers and canoe basin dedicated for artisanal fishing.

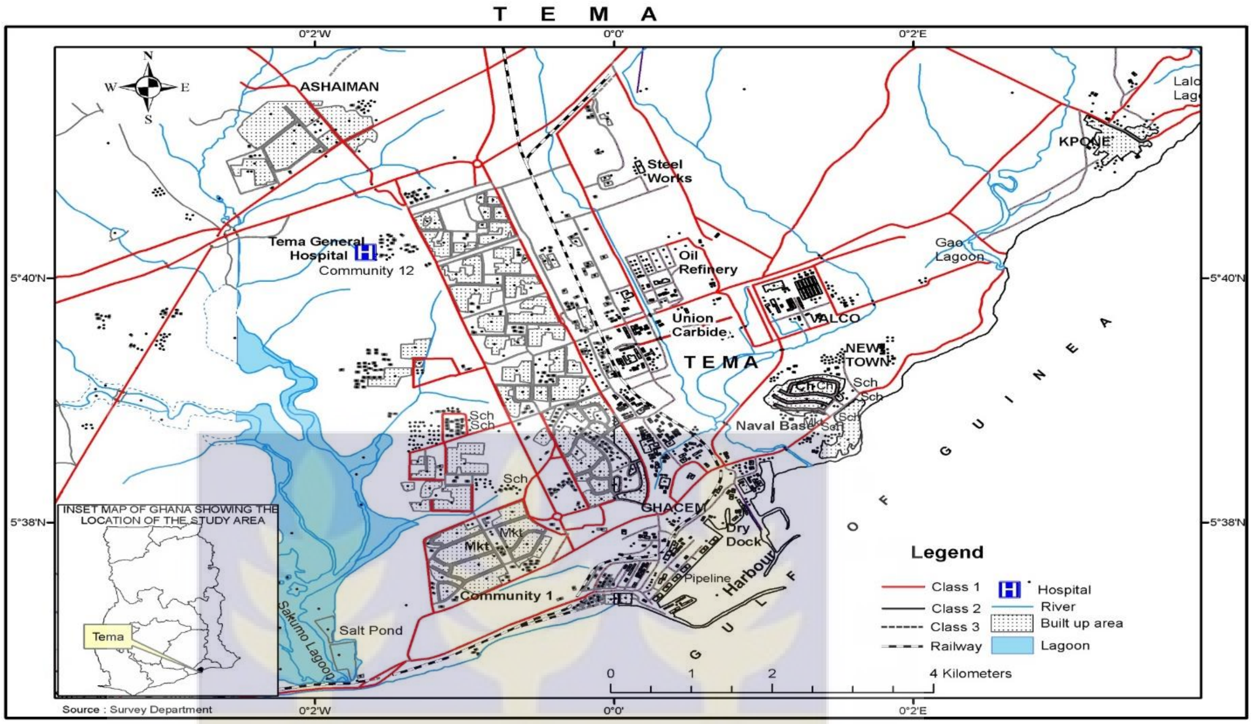

Figure 3.1. A map of coastal Greater Accra showing the Tema Harbour.

3.2 Data Source

The Fisheries Scientific Survey Division, FSSD, is a Division under the Ghana Fisheries Commission. Secondary data of total annual landings and fishing effort for the industrial tuna fishery and the artisanal fishery from the FSSD were used for this study.

Reported landings data of Ghana by ICCAT were also downloaded from http://www.iccat.int/en/scrs.htm for comparison with data from the FSSD when analysing the data. Also, data on reported landings of tuna in Ghana were obtained from the Executive Summary on the tuna species in the report of the Standing Committee on Research and Statistics (SCRS) presented to ICCAT in 2014 (ICCAT, 2014). These were meant to make comparison.

3.3 Nature of the Data

The catch data were in metric tonnes (MT) and the effort in number of baitboats and purse seines deployed each year. For the industrial fishery, the data were on species basis for the three major tunas however, the catch data for the artisanal sector were accumulated (for all tuna species). These data were tabulated and accessed in soft copy (artisanal) and hard copy (industrial).

Data on landings by species and hence total landings of the industrial tuna fishery was available for the years 1987 to 2013 (Appendix I). Effort data for the fishery were available for the years 1996 to 2013 (Appendix I) while data on landings by the vessels (purse seines and baitboats) were available for only the duration, 2000 to 2013 (Appendix II). Data on tuna landings and effort by the artisanal sector covered the years 2000 to 2013.

Data extracted from the SCRS report to ICCAT were solely landings data by species of the industrial Ghanaian tuna fishery which covered 1989 to 2013.

3.4 Procedure for data collection

The Ghanaian tuna fleets usually fish within the east-central Atlantic off latitudes 5^{o} N-2°S and longitudes 5°E and 10° W. Occasionally purse seiners (the more seaward fleet) move off this area in search of larger schools of fish. The sampling of tunas at port (quayside) is done following the ICCAT Field Manual (Miyake & Hayasi, 1972) by trained staff from the FSSD prior to the catch being sorted by the stevedores into individual bins (containers). There is no sampling by size or species at sea (Bannerman, 2010b).

Baitboats and purse seiners land at the port of Tema after each fishing trip lasting 30 and 50 days, respectively. Hundred (100) fish specimens, of the landed fish, were selected at random per vessel and measured (using measuring boards or tapes graduated at 1 cm intervals to the next lowest fork length: the measurement of the fish's length from the tip of the nose to the end of the middle caudal fin rays; used for fish with stiff caudal fins like tunas). During measurements, species were also identified using the keys for identification of the tuna species by Chapman *et al.* (2006).

Since there is mixing of catches from different sets into the same well, it is generally not possible to associate samples in a well to a particular set (position). The result of each sampling is entered into an Excel spreadsheet and then summarized by boat type (baitboat/purse seine), month and year prior to its presentation to the ICCAT Secretariat (Bannerman, 2010b).

3.5 Data Analysis and Basic Assumptions

The Ghanaian tuna fishery is a multi-species fishery where all fleet types target all tuna species. Therefore, to compute the CPUE for each fleet, the total annual landing of each year was used. The ratio of the total annual landings of all the three major tunas to the number of baitboats and purse seines employed for the respective years gave the CPUE for the baitboats and purse seines, respectively.

In order to determine the CPUE of each species, the effort (in the number of vessels of each fleet) was standardized into a standard large purse- seiner- day (fishermanday). Like Bortier-Verstraaten (2002) and Conrad & Adu-Asamoah (1986), it was assumed that baitboats spent an average of 231 days at sea each year. However, unlike these authors, (who assumed an annual average of 198 days for purse seines), this study assumed purse seine fleets spent an average of 281 days at sea each year. This is because from data available from the FSSD for this work, the purse seiners in the Ghanaian tuna fishery spend more days at sea than baitboats.

The Ghanaian purse seines were considered to be small purse seines (400 to 600 MT capacities) since their capacities are generally below 1000 MT and above, which capacities are characteristic of large purse seines (Bortier-Verstraaten, 2002). Compared to a standard large purse seine, the fishing power of a small purse seine is 0.48. To convert bait boats to standard purse seines, the ratio of the average daily catches of baitboats and small purse seiners, 0.6, (Bortier-Verstraaten, 2002) was multiplied by the ratio of small purse seine to a standard large purse seine, 0.48. By this method, baitboats are found to have 0.29 the fishing power of a standard purse seine after Bortier-Verstraaten (2002).

To convert the nominal effort (in the number of vessels) to a standard effort, the product was found of the number of vessels, the fishing power (compared to a standard large purse seine) and the annual average number at sea of the respective fleets. The assumptions above were made in order to be able to compare findings of this work with similar works, especially that of Bortier-Verstraaten (2002).

Graphs were produced with the catch-effort data from Microsoft excel to show the trend of catch of the major tunas and effort applied.

Rate of change in CPUE for a particular year Y_1, was determined by the difference in CPUE of that year ($CPUE_1$) and the previous year, Y_0, ($CPUE_0$) divided by $CPUE_1$, expressed in decimals and as percentage.

That is:

Rate of change in $CPUE_1 = (CPUE_1 – CPUE_0)/CPUE_1$, in decimals, (or multiply result by 100 to convert to percentage).

3.5.1 Estimating the MSY Using the Schaefer's Surplus Production Model

Both the Schaefer's model and Fox's model, which are the commonest surplus production models are known to produce almost the same estimates with none of the two being superior to the other (FAO, 2014). For this study, the Schaefer's model, as proposed by Graham (1935), was used to estimate the MSY and the fishing effort, F_{MSY}, needed to produce the MSY for the Ghanaian tuna fishery using the equilibrium assumptions. In equilibrium conditions it is assumed that the biomass does not change between two consecutive time periods hence the removal in the form of annual yield is equivalent to the production (Masters, 2007). The Schaefer model assumes that yield is related to fishing effort by a symmetrical parabola.

The effort *(f)* in years and catch per unit effort (CPUE) in metric tonnes per year were plotted with the effort on the horizontal axis and CPUE on the vertical axis. This was done for each of the major tuna species, *T. albacares*, *T. obesus* and *K. pelamis* for the industrial fishery and with the accumulated catch data from the artisanal fishery. The intercept *(a)* and the slope *(b)* of the scatter, from Microsoft Excel, are determined. The following equations were used:

(1) $CPUE = a + bf$ ……… (1)

(2) $Y = af + bf^2$ ………. (2)

Where: a = intercept of plot; b = slope; f = effort and Y = yield.

(3) $MSY = -a^2/4b$ ……….. (3)

(4) $F_{MSY} = -a / 2b$ ………. (4)

(Graham, 1935; Schaefer, 1954)

CHAPTER FOUR

RESULTS

4.1 Trends of total landings of tuna in Ghana

Total landings of tuna by the industrial tuna vessels in Ghana were comparatively low and stable, between 30,000 MT and 40,000 MT, from 1987 to 1996 (Fig.4.1). Landings sharply increased from 1997 to a peak of 83,246 MT in 1999. In 2000, there was a sharp decline by more than 30,000 MT of the yield in 1999. Another sharp incline to 88,078 MT, was observed in 2001 which was the highest landing since 1987 per data available for this work. Another trend of decline is observed for three years after which production seems to have stabilized between 60,000 MT and 76,000 MT.

A similar trend was observed using ICCAT-reported data. However, ICCAT reported consistently higher landings for Ghana since 2009 with the highest peak, 94,180 MT in 2010 which is 21,089 MT higher than what FSSD recorded (Appendix 5).

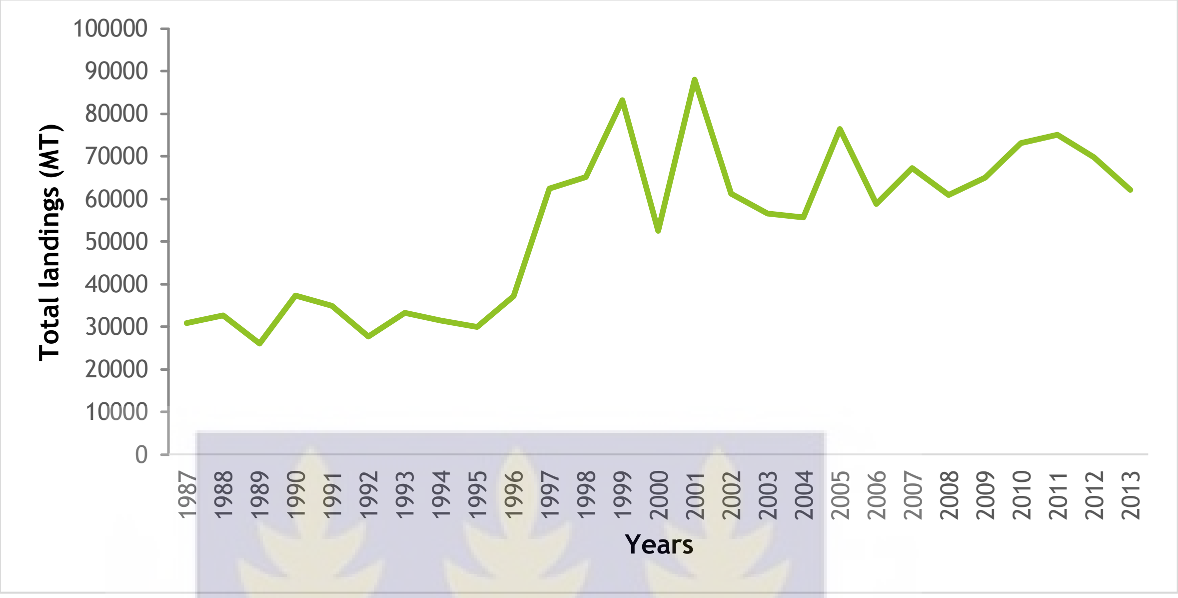

Fig.4.1: Trends of total industrial tuna landings in Ghana from 1987 to 2013.

4.2 Time Series trends of landings and CPUE by fleet

Figure 4.2 shows a sharp incline in landings by purse seines from 2000 to 2001where it recorded its highest landing, 55,809 MT, since the year 2000. In subsequent three years (up to 2003), there was a sharp decline in landings of the purse seines to its lowest, 23,161 MT, since the year 2000. Landings increased by almost 15,000 MT in 2004 and remained fairly stable with some minor fluctuations until 2009. Purse seine landings have since steadily increased to a peak of 52,783 MT in 2011 after which a minor decline of less than 2,000 MT is observed in 2013.

Baitboats show a trend of fluctuating landings from 2000 to 2009 within ranges, 20,000 MT and 45,000 MT. Its landings have however steadily declined since 2009.

Generally, the two fleets show a trend of inverse relationship, where landings of baitboats decrease with increasing purse seine landings and vice versa.

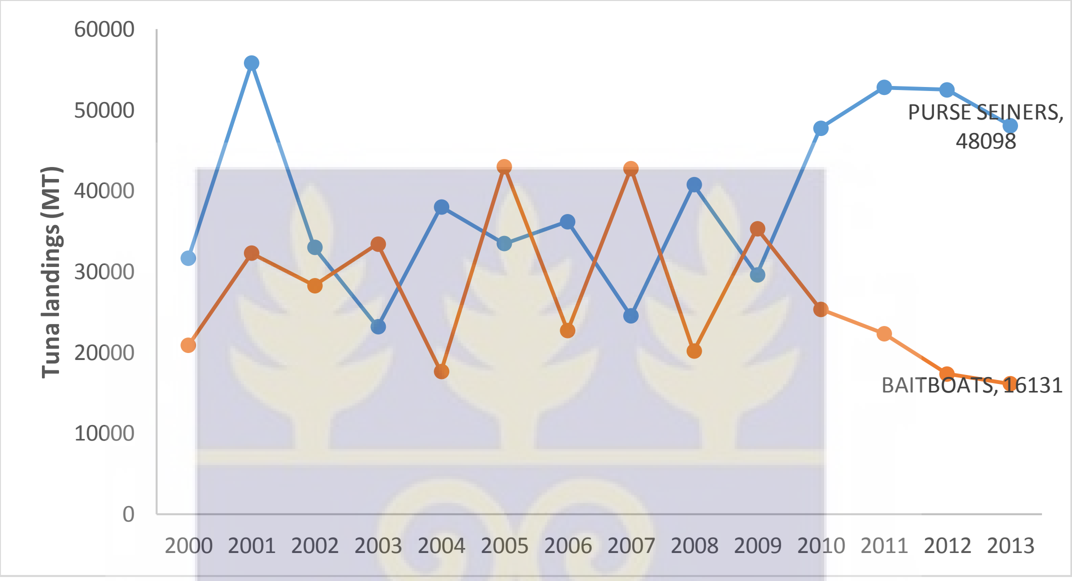

Figure 4.2: Tuna landings by purse seines and baitboats from 2000 to 2013.

The CPUE per year of each fleet is ratio of the total annual landings to fishing effort applied for the respective years. The catches are in metric tonnes (MT) with the effort, in the number of vessels of each fleet, standardized to large-purse seiner sea days (fishermandays), in order to be able to compare the CPUE of the different fleets. Hence CPUE herein stated are in metric tonnes per large-purse seiner sea days also called metric tonnes per fishermandays (MT/f'day).

It can be seen from Figure 4.3 that both baitboats and purse seines showed a similar trend of increasing efficiency from 2000, when yield fell (Figure 4.1), to 2001, when landings were highest, with the purse seines comparatively far more efficient (CPUE = 41.38) than baitboats (CPUE= 19.27). Although both vessels showed a decline in CPUE in 2002, like observed in the catch trends (Figure 4.2), the CPUE of the fleets also showed an inverse relationship in 2003, while purse seines fell further to 15.29, baitboats inclined to 22.70. The trend of inverse relationship between the CPUE of the two fleets was observed throughout most years covered by this study (except 2005 and 2006) and became more pronounced (Figure 4.3) since 2010, from which time CPUE of purse seines have increased steadily to 2012 while CPUE of baitboats steadily declined. Both fleets showed a minor fall in CPUE in 2013.

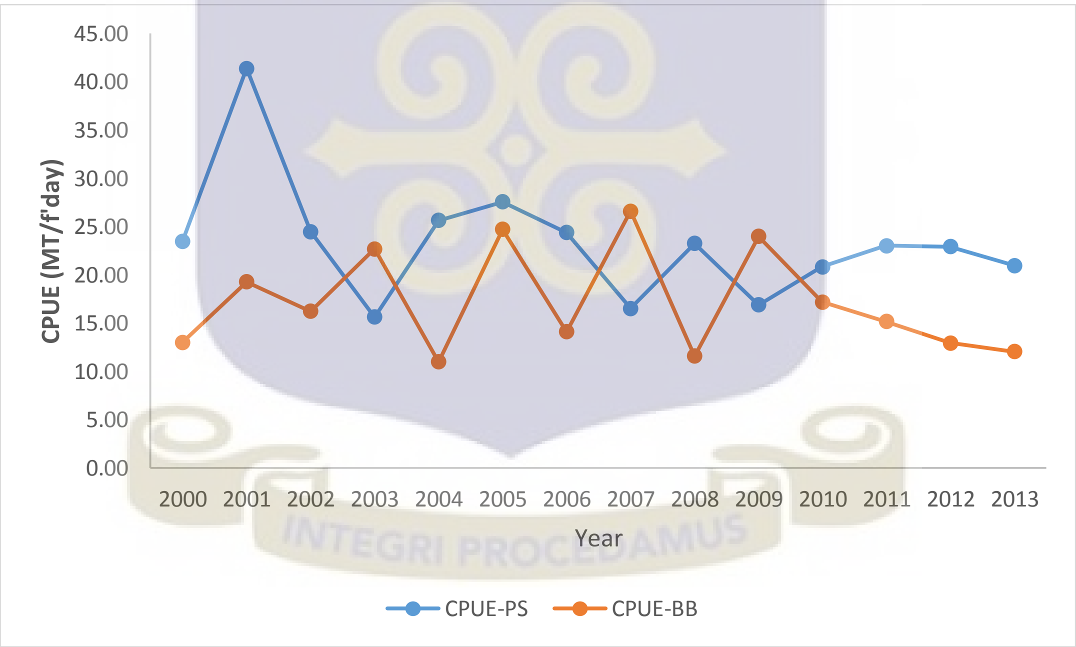

Figure 4.3: CPUE of Baitboat (BB) and Purse seines (PS) from 2000 to 2013.

On the whole, the CPUE of purse seines after 2001 was a consistent decline (average 47.2 %) while the CPUE of baitboats showed a trend of fluctuations until 2010 when it began to decline (at an average rate of 21.7 %).

4.3 Catch trends and CPUE by species

Of the three major tuna species exploited by the Ghanaian tuna fishery, Skipjack (*K. pelamis*) dominated the landings since 1987 (Figures 4.4a and 4.4b). Landings of *K. pelamis* were fairly constant from 1987 to 1996 from which year it increased sharply to a peak of 51,284 MT in 1999. *K. pelamis* landings fell remarkably in 2000 by over 16,000 MT but rose to 56,418 MT in 2001. Per data from the FSSD, (Figure 4.4a), landings declined for three consecutive years and subsequently fluctuated for five years until another trend of consistent increased landings was observed from 2010, reaching the highest landing of this species, for the period of over three decades which data this study analysed, in 2012 (57,284 MT). The landing data available for 2013 showed a decline.

However, as evident from Figure 4.4b, ICCAT's records indicate consistently higher landings (in comparison with FSSD data) of this species in Ghana for more than a decade now with ICCAT's record for 2013 over 17,000 MT more than data from the FSSD.

Per FSSD data, the yellowfin tuna, *T. albacares*, production showed a uniform increment of landings from 4, 259 MT in 1987 to its highest peak (for the years covered by this study), 29,303 MT, in 2001 with few minor fluctuations (Figure 4.4a). After 2001, however, a trend of consistent steep decline of landings was observed to 14,549 MT in 2006 after which landings remained fairly constant with very minor fluctuations up until 13,167 MT landings in 2013.

ICCAT records generally strongly compare with FSSD records for this species for the past decade with FSSD records higher in few instances (Figure 4.4b), the highest in 2005 with a difference of 6,814 MT.

The *T. obesus* fishery has been the least productive fishery of the three major tunas exploited by the Ghanaian tuna fishery (Figures 4.4a and 4.4b). While data from FSSD showed a flat curve for landings of *T. obesus* from 1987 to 1997, (Figure 4.4a) (with landings for 1993 as low as 3 MT), ICCAT records have consistently been higher landings for over two decades now (Figure 4.4b), with percentage increase of ICCAT figures over FSSD's reaching as high as 119,133 % (difference of 3,574 MT) and 258 % (difference of 10,647 MT) in 1993 and 2011, respectively. Landings showed a pattern of minor fluctuations with a peak of 17,744 MT (in excess of FSSD data by 10,800 MT) in 2004 (Figure 4.4b), while FSSD data showing the highest peak 10,554 MT in 2009. The 2013 landing, 2, 786 MT, of *T. obesus* was a huge decline of landings in recent years.

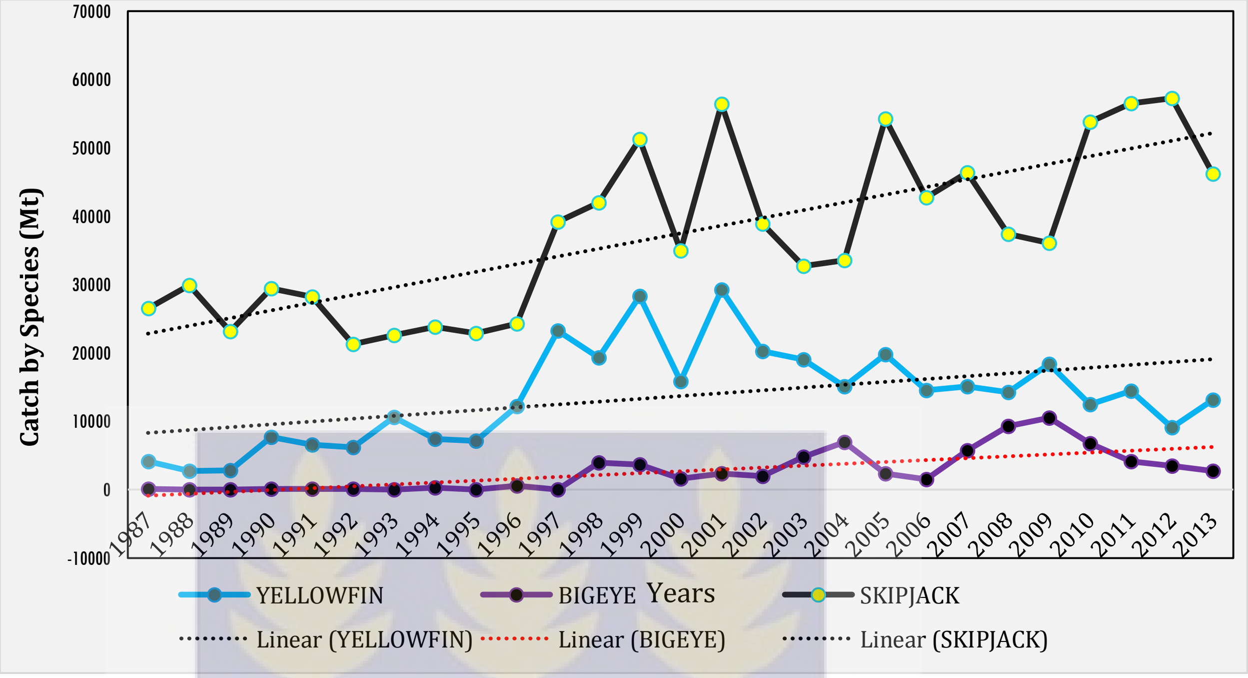

Figure 4.4a: Catch by species of tuna from 1987 to 2013.

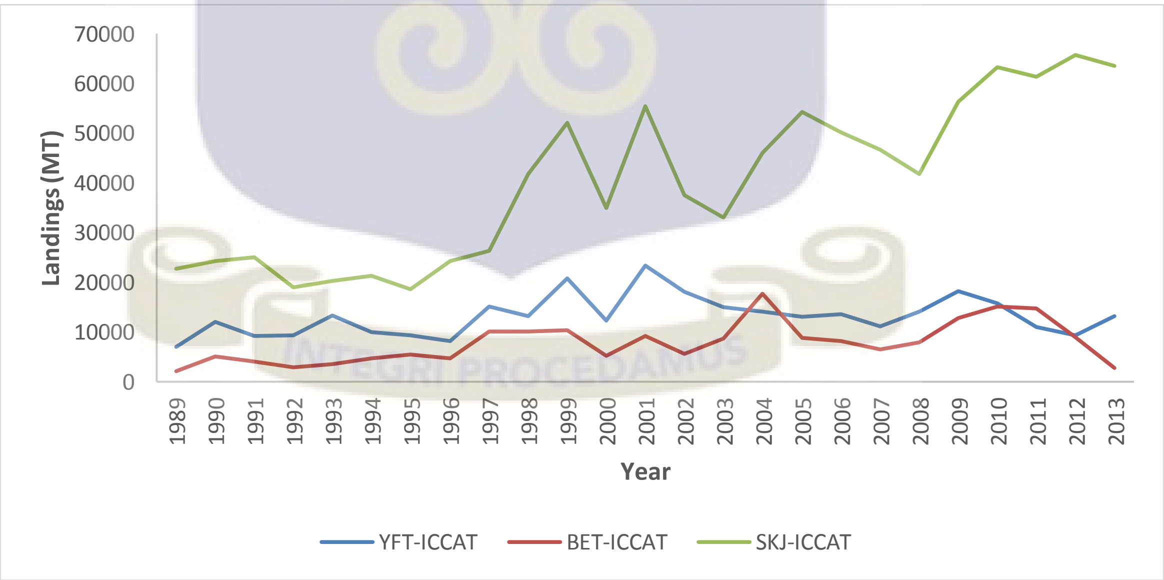

Figure 4.4b: Trends of landings of the major market tunas in Ghana from 1989 to 2013 according to ICCAT.

4.3.1 Per cent Species Composition of landings

Table 4.1 below shows the marked dominance of *K. pelamis*, (SKJ), in landings of the Ghanaian tuna fishery for the past three decades. *K. pelamis* component of landings was highest (80 %) in the first decade covered by this study (1987-1995). Its composition decreased to 62.80 % for the next decade but showed an inclination to 70.77 % over the past decade (2005-2013).

T. albacares (YFT) increased in the catch from 19.53 % in the first decade to 32.50 % in the second decade but has declined by almost 11 % to 21.59 % of landings for the past decade. *T. obesus* (BET) showed a consistent and enormous increment from 0.20 % in the first decade to 7.65 % in the third decade.

Table 4.1: Decadal trends of catch composition by species from 1987 to 2013

Year (in decades)	**YFT**		**BET**		**SKJ**	
	FSSD	ICCAT	FSSD	ICCAT	FSSD	ICCAT
1987-1995	19.53%	-	0.20%	-	80%	-
1996-2004	32.50%	24.43%	4.60%	14.29%	62.80%	61.28%
2005-2013	21.585	16.85	7.65%	12.13%	70.77%	71.02%

4.3.2 Time Series of CPUE by Species

The time series catch-effort data available for this study portrayed the Ghanaian tuna fishery as a perfect multi-species fishery with the two major fleets targeting all the major tuna species at any time. Hence the CPUE per year for each species is the ratio of the respective annual total landings of each species and the total effort (standardized effort) applied that year.

From Figure 4.5, *K. pelamis* had the highest CPUE of the three major market tunas and *T. obesus*, the least. However, as can be seen from the graph (Figure 4.5), its CPUE followed no regular pattern. The CPUE of *K. pelamis* sharply increased by 71.36 % from 10.65 MT/fishermanday in 1996 to 18.25 MT/fishermanday in 1997. It fairly remained constantly high for three years but fluctuated markedly for the years 2000 and 2001: declining by 35.18 % to 11.83 in 2000 (from 1999) and sharply rising to 18.66 in 2001 (Figure 4.5). Its CPUE showed another sharp decline for three consecutive years reaching one of its least for the past two decades, 10.87 in 2004. The trend of its CPUE showed another marked incline, an upsurge of about 69 % from 2004 to 2005 (18.38). The years 2006 to 2009 showed a sharp decline in CPUE but a uniform rise is observed from 2010 to 2012 after which it fell by 19.3% to 12.73 in 2013 (Figure 4.5).

The CPUE of *T. obesus* was least, 0.01 MT/fishermandays, in 1997. It sharply inclined by as high as 16, 600 % to 1.67 MT/fishermanday in 1998. It has since fluctuated for several years until its peak, 3.27 MT/fishermanday, in 2009. After this year (2009), another trend of steady decline was observed until 2013 when it reached 0.77 MT/fishermanday. Despite the decline, its present production (CPUE of 0.77) is by far, better than in 1996 and 1997 (CPUE of 0.27 and 0.01, respectively).

Like the other two species, the catch per unit effort of *T. albacares* also shot up from 1996 to its peak at 10.82 MT/fishermandays in 1997. Notable fluctuations are evident between 1996 and 2003 with its CPUE least, 2.51 MT/fishermanday, in 2012 and a slight increment to 3.62 in 2013 (Figure 4.5).

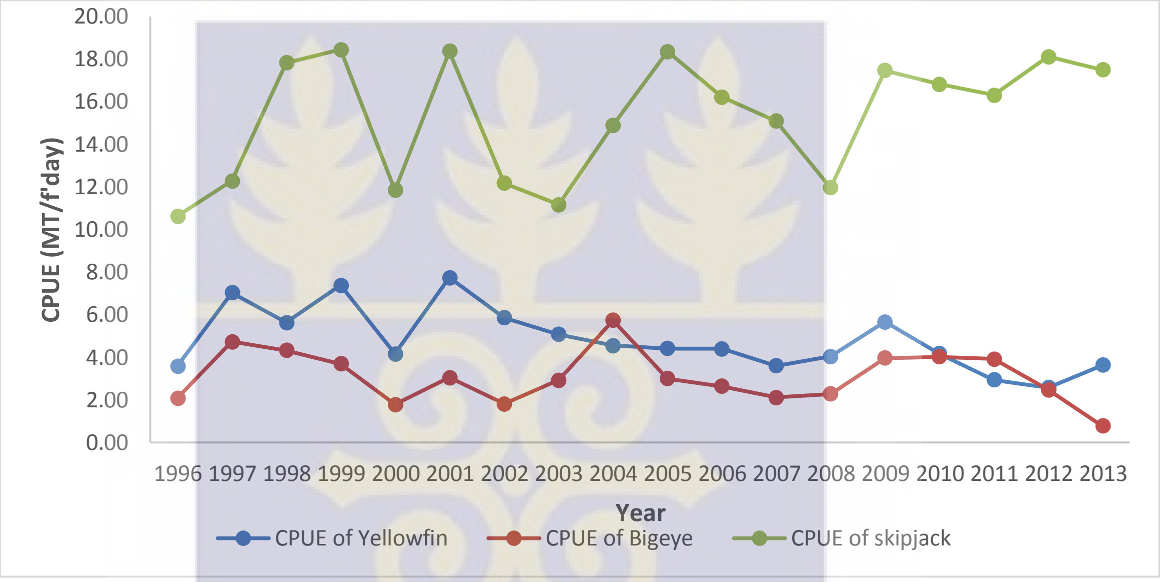

Figure 4.5: CPUE of the major tunas landed in Ghana from 1996 to 2013 per ICCAT data.

4.4 Estimates of MSY and F_{MSY} by Species and by the Artisanal Sector

The assumption that the dominant component of landings of the Ghanaian tuna fishery form is/are stock(s) highly localized, forming a unique sub-stock is used here. It is further assumed that the stock size allows a consistently sustainable catch equivalent to 40% (between 80, 000 MT and 100, 000 MT) of the MSY for the entire East Atlantic, 200, 000

MT (Falaye, 2008). This MSY for the Ghanaian fishery is assumed to be obtained by adding the MSY of the various fisheries that harvest the tunas in Ghana.

According to Addi (2014), the Ghanaian tuna fishery is mainly based on the industrial (tuna) fishery with minor contribution from the artisanal and semi-industrial fisheries. Of the three fisheries, he noted that the semi-industrial is the least producer of tuna. Therefore, this study used data from the two major fisheries; the industrial/tuna fishery and the artisanal fishery. While data per species is available for the industrial/tuna fishery, data from the artisanal were lumped for all the three major tunas. The MSY was thus estimated per species for the industrial fisheries and a crude MSY for the artisanal.

From the plots of CPUE against effort for the three tuna species, (Figures, 4.6 to 4.9 below), using data from the FSSD, the slope, b, and intercept, a, for each plot were used to compute the MSY and F_{MSY} of the respective species using the formulae, MSY = $-a^2/4b$ and $F_{MSY} = -a/2b$ (Graham, 1935; Schaefer, 1954).

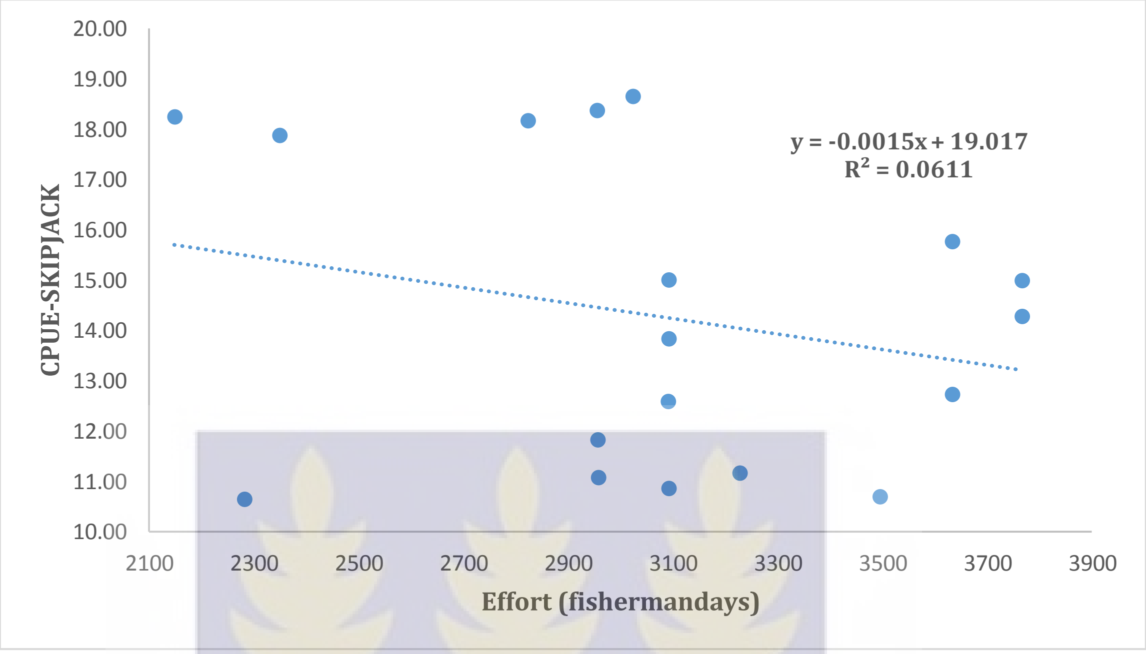

Figure 4.6: CPUE Against Effort applied for *K. pelamis*.

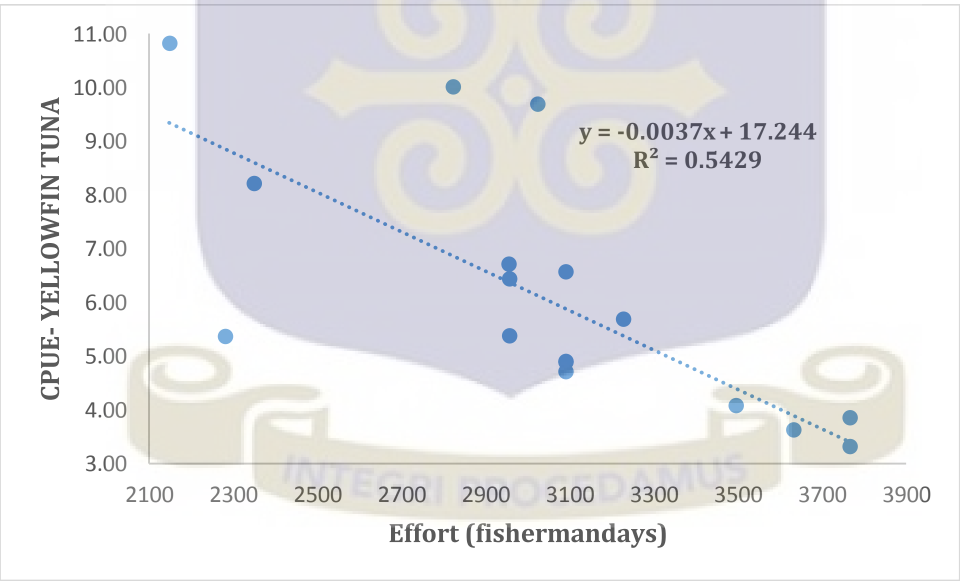

Figure 4.7: CPUE Against Effort applied for *T. albacares.*

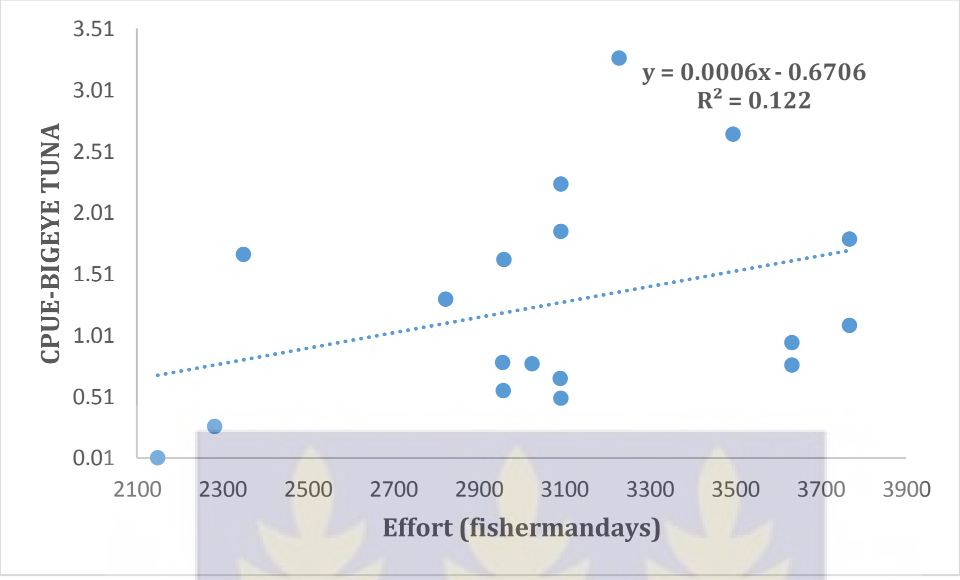

Figure 4.8: CPUE Against Effort applied for *T. obesus*.

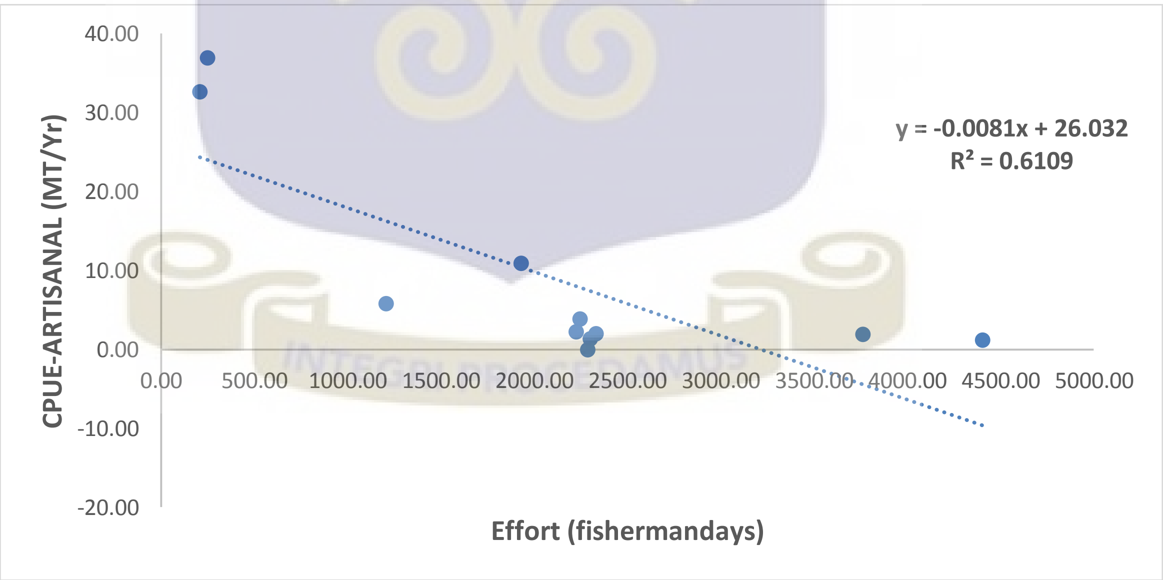

Figure 4.9: CPUE against Effort for tuna landed by the Ghanaian Artisanal fishery.

Evident from Table 4.2, *K. pelamis* had the highest MSY and F_{MSY} (60, 274.38 MT and 6, 339.0 fishermandays, respectively) followed by *T. albacares* with MSY of 20, 091.59 MT and fishing effort of 2, 330.27 fishermandays. *T. obesus* has the least values, both for MSY and F_{MSY} (187.38 MT and 558.83 fishermandays, respectively per MFRD data and 9,670.93 MT and 4,014.75 fishermandays, respectively per landings data from ICCAT).

The annual production of *T. albacares* was in excess of the MSY estimated for the years, 1997, 1999, 2001 and 2002 with the peak production (in 2001) more than 9, 000 MT higher than the MSY (Table.4.2).

The production of *T. obesus* has been extremely higher than the MSY estimate from FSSD data, 187.38 MT, from 1996 to 2013. However, FSSD's reported landings from 1987 to 1995, and for 1997, were consistently below the MSY estimated, except 1994 (Appendix1). In 2009, landings of *T. obesus* was as high as 5,543.65 % (55.44 times higher) in excess of the MSY. Also, over the past decade, landings have been below the MSY estimate from reported landings by ICCAT, except in 2005, 2009, 2010 and 2011, when landings were higher than the MSY.

Since 1996, the annual landings of *K. pelamis* have been consistently lower than the estimated MSY. The highest production in recent years was 57, 284 MT (in 2012) which was about 2, 990 MT lower than the MSY.

From Figure 5.1, using reported landings by ICCAT from 2009 t0 2013, the average productions of *K. pelamis* and *T. obesus* were slightly in excess of the MSY estimated by (3 % and 12.6 %, respectively while average landings of *T. albacares* were short of the MSY by 32.8 %. Using the MSY estimated for *T. obesus*, (187.38 MT), from data from FSSD, average landings were as high as 5,721.4 % in excess of the MSY.

The fishing mortality needed to produce the MSY per species revealed that the effort applied (standard large purse-seiner sea days) was at all times higher than that required to produce the MSY of *T. obesus* (Table 4.2 and Appendix 3). Also, the standard effort applied in catching *T. albacares* has been consistently higher than its F_{MSY} since 1999, while the F_{MSY} estimated for *K. pelamis* (6,339 fishermandays) was consistently higher than the $F_{current}$ by both baitboats and purse seines from 1996 to 2013. The artisanal sector had at all-time expended effort far higher than the F_{MSY} required to produce the MSY estimated.

Table 4.2: MSY and F_{MSY} of the three major tunas and the artisanal sector from the Schaefer's Surplus Production method

Species	***T. albacares* (MT)**	***T. obesus* (MT)**	***K. pelamis* (MT)**
MSY	20, 091.59	187.38	60, 274.38
F_{MSY} (fishermandays)	2, 330.27	558.83	6, 339.00
Artisanal MSY (MT)	2, 091.56		
Artisanal F_{MSY} (f'days)	58, 651.85		
TOTAL MSY	**82,644.91 MT**		
Average F_{MSY} (industrial)	**3,076 fishermandays**		

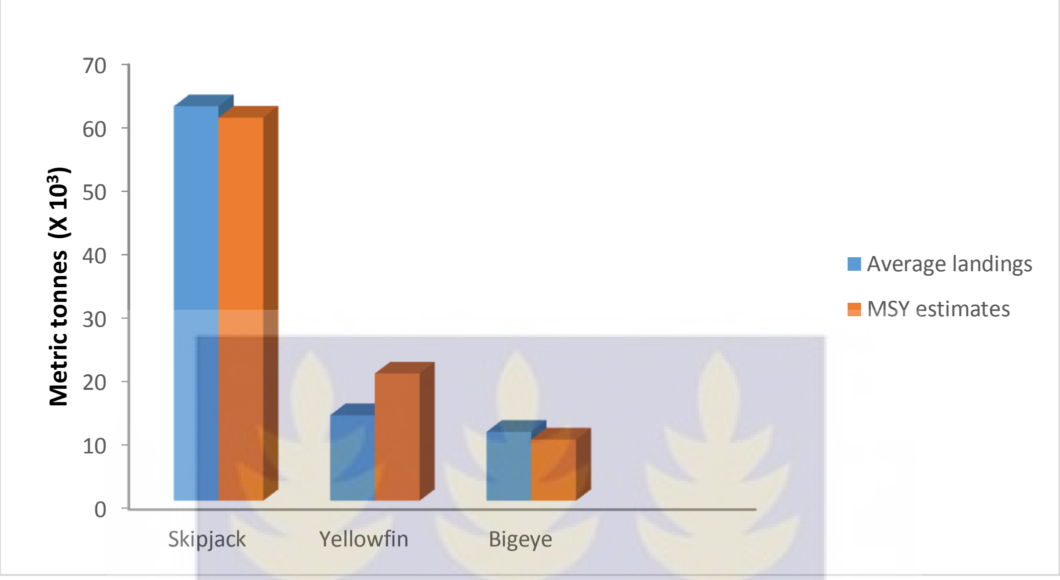

Figure 5.1: Average catch per species from 2009-2013 per catch data from ICCAT compared with MSY estimates.

CHAPTER FIVE

DISCUSSION

The observed results were compared to both data from the FSSD and ICCAT. However, conclusions on the state of stocks were made based on comparison with reported landings by ICCAT. This is because the reported landings by ICCAT are based on comparison of landings reported by the FSSD with information from canneries and ports where tuna harvested from Ghanaian waters are landed (ICCAT, 2014). This makes ICCAT's data more representative of the reality of landings in Ghana as opposed to FSSD-reported landings which are usually from sampling at the Tema fishing harbour and log books which cannot be very accurate due to transhipments and under-reporting by some vessels (Bannerman and Anaba, 2009).

5.1 Species Composition of tuna landings in Ghana

The Ghanaian tuna fishery is based on only three tuna species (*T. albacares*, *T. obesus* and *K. pelamis*). This result is consistent with findings of Addi (2014), ICCAT (2014) and Miyake *et al.* (2004). *K. pelamis* has dominated the tuna landings in Ghana since 1987. Miyake *et al*. (2004) and ICCAT SKJ (2014) also made a similar observation with respect to tuna landings in the entire Atlantic Oceans. This is expected because Ghana is part of the East Atlantic area. The species composition is also consistent with composition of tuna landings globally (Miyake *et al*., 2010; ISSF, 2013).

The increase in percent composition of *K. pelamis*, from 61% (1996-2004) to over 70% of landings in the past decade (2005-2013) confirmed the findings that Ghana is increasingly becoming an important producer of *K. pelamis* globally (Miyake *et al*., 2004). While the percent composition of *K. pelamis* increased over the past decade, those of *T. albacares* and *T. obesus* have declined by 7.58 % and 2.16 %, respectively. The dominance and seemingly resilience of the *K. pelamis* to the intense fishing pressure is consistent with reports about its prolific reproductive potentials (ICCAT, SKJ, 2014). Although all the three major market tunas do not perfectly conform to the Von Bertallanfy model of growth (ICCAT, 2012; Matsumoto and Miyabe, 2002), *K. pelamis* grows fastest, reaching sexual maturity at age one (1) (ICCAT, SKJ, 2012). Also, *K. pelamis* stocks in the Atlantic Ocean, unlike *T. albacares* and *T. obesus*, spawn throughout the year (ICCAT, SKJ, 2012 & ICCAT, SKJ, 2014). *T. albacares* and *T. obesus* demonstrate seasonality in spawning with January to February being the peak for *T. albacares* (ICCAT, YFT, 2014). Also, *T. albacares* reaches sexual maturity between ages two (2) and three (3) (Sustainable.com) while *T. obesus* reaches sexual maturity from ages three (3) and four (4) (ICCAT, 2012). Another likely reason for the dominance of *K. pelamis* in the landings is the fact that it inhabits surface waters unlike adults of *T. albacares* and *T. obesus* which inhabit sub-surface and deeper waters, respectively (ICCAT, 2014). A third reason is the fact that *K. pelamis* (especially its juveniles) are the most attracted to FADs compared to the two others, making them highly vulnerable to the current trends of fishing. This is consistent with reports of ICCAT (2014).

5.2 Catch trends and CPUE by fleet and species

Given efficient fishing methods, the annual trends of catch are important indicators of the state of the fish stock. Large, productive and sustainable fish stocks produce continuously high landings with use of appropriate fishing methods while declining landings despite efficient fishing methods suggests stock size depletion. Total tuna landings in Ghana were consistently low, between 20,000 MT and 40,000 MT, from the late 1980s to 1996 (Figure 4.1). This may be due to the drastic decline in the number of baitboats in the late 1980 and early 1990s as compared to their number after 1996. Bortier-Verstraaten (2002) made a similar observation and reported that baitboat numbers from the late 1980s to 1995 represented a fall by about half of their number in 1980. This could be the most appropriate explanation for the low landings. This is in sharp contrast with reports of Million (2014) that the general decline in landings in the Atlantic Oceans from 1994 was due to full exploitation or depletion of the tuna stocks.

In 1996, purse seines which were hitherto phased out of the Ghanaian tuna fishery were reintroduced into the fishery (Bannerman, 2010a). This probably accounted for the sharp rise in landings after 1996 to a peak of 83,246 MT in 1999 (Figure 4.1). The high efficiency of purse seines coupled with their extensive use of fish aggregating devises (FADs) could also be the reason for the stable high landings of tuna from 2002 to 2013. This is consistent with findings of Bortier-Verstraaten, (2002). However, the decline from 88,081 MT in 2001 to 61,281 MT in 2002 and the subsequent stabilisation of landings between 60,000 MT and 75,000 MT from 2002 to 2008 could be an indication that the tuna tuna resource in the coastal waters of Ghana were fully exploited at this point.

The rise in tuna landings to 94,180 MT in 2010 (Appendix VII) and high landings in 2011 and 2012 are most like due to the introduction of new more efficient purse seines into the fishery. These purse seines thus increased the efficiency and hence output of the already efficient purse seine fleets. ICCAT (2014) reported a similar reason for the increasing landings in Ghana. It is not likely that this trend of increase is indicative of stock rebuilding and large stock sizes in the Ghanaian waters. This is because unlike 1997, 1998 and 2009 where CPUE increased, from 2010 to 2012, change in CPUE was consistently negative (average change rate = - 14.61 %), thus CPUE declined (Appendix VI) despite the high landings. Generally, decline in CPUE indicates a corresponding decline in stock size (Hoof & Salz, 2001). Although only 10 purse seines operated in 2001, the reported landing, 88,081 MT, was higher than landings of either 2011 or 2012 (87,194 MT and 84,097 MT, respectively) with 17 purse seines deployed. Therefore, the high landings could be attributed to corresponding increased effort as evident by the data (Appendix I).

From Figure 4.2, the high yield recorded in 2001 was marked by increased landings of both fleets with purse seines landing 22,000 MT more than the baitboats. However, after 2002 when they both declined, the time series landing by the purse seines and baitboats generally showed an inverse relationship where landings of purse seines increased, while those of baitboats declined and vice versa (Figure 4.2). This trend of inverse relationship between the two fleet from 2003 to 2009 is not very clear or understood. The same trend was observed by Bortier-Verstraaten (2002) from 1996 to 2000. However, the steady decline of baitboats as opposed to steady incline of purse seines from 2010 to 2012 (Figures 4.2 and 4.3) could be due to the fact that the Ghanaian baitboats are aged and less productive. This is because efficiency of fishing vessels strongly relate with the age of the vessels (Drury O'neill, 2013). Most Ghanaian baitboats are averagely 39 years old hence less efficient. It is also probable that the cost of fishing, especially the high cost of fuel since 2010 is contributing to making the baitboats unprofitable. Drury O'neill (2013) made a similar finding that baitboats are becoming unprofitable due to high cost of fuel (69-81 % of total cost of fishing). It is also important to note that the decline has persisted despite reports that most landings of baitboats are actually catches of purse seines shared at sea (Bannerman, 2010b). This highlights the severity of unprofitability of the baitboats in recent years at fishing.

The consistent decline in catch and CPUE of baitboats, (Appendix II), is also another indication of stock decline in the Ghanaian waters. This is because, baitboats primarily fish only in the territorial waters of Ghana. Unlike purse seines, baitboats do not have the capacity to fish in the high seas (Obeng, 2003). The drastic decline in landings and CPUE (Figures 4.2 and 4.3) therefore may be symptomatic of depletion of the tuna stocks in the coastal waters of Ghana.

Most of the tuna landings in Ghana are associated with the purse seines (Figure 4.2). The trend of steady increase of landings and CPUE of purse seiners from 2010 to 2012 (Figures 4.2 and 4.3) could be misunderstood to mean that the tuna stocks in the Ghanaian waters is ecologically healthy and sustainable. In contrast, the increased landings and CPUE of purse seines could most probably be attributed to three reasons:

i. Firstly, it could be due to the extensive use of FADs in fishing. FADs are known to increase fishing mortality tremendously. *K. pelamis* and juveniles of *T. obesus* and *T. albacares* are reportedly very gullible to this method of fishing. Since current tuna landings in the East Atlantic and Ghana are predominantly juveniles and *K.*

pelamis, the introduction of FADs could account for the increased landings of purse seines. FADs thus pose a threat of growth overfishing. This is consistent with reports by Bortier-Verstraaten (2002), Bannerman and Anaba (2010), Dury O'neill (2013) and ICCAT (2014).

ii. Secondly, the employment of highly advanced technologies by purse seiners could account for the observed increment of landings and CPUE: purse seines fish with very advanced technologies like the use of Sound Navigation and Ranging (SONAR) and RAdio Detection and Ranging (RADAR) to detect schools of fish, modern hydraulic gadgets enabling the vessel to maneuver, whilst encircling shoals of tuna fish for capture, more efficient mechanical ways of hauling large amounts of catch onto the vessels and larger storage capacities of purse seines in fishing. These technological advances not only increase landings but also increase fishing effort concomitant with reduced CPUE as observed after 2001 (Figure 4.3). The use of these technologies, like FADs, is also destructive, as it also contributes to landing of juveniles (Bannerman, 2010a; Bannerman and Anaba, 2009). Similar findings are reported by ICCAT (2014).

iii. Thirdly, the spatial deployment of purse seines could be a contributing factor to the increased landings. Purse seiners are able to fish deep in the high seas. It is most probable therefore, that the landings of purse seines include added catches emanating from the high seas and Exclusive Economic Zones (EEZ) of other nations. This assertion is validated by the reported engagement of Ghanaian purse seines in illegal, unreported and unregulated (IUU) fishing resulting in sanctions from the European Union in 2013 (DailyOnline, 2013; Drury O'neill, 2013).

The observed trend of general decline in total annual CPUE (Appendix VI) is most likely a product of the increased effort as evident in the gradual increase in purse seine number from nine (9) in 2005, to elven (11) 2006, thirteen (13) in 2008 and seventeen (17) since 2010. It is likely that with proper quantification of effort to incorporate the effect of FADs and the growing high fishing technologies the CPUE could have been lower, as effort would be increased greatly by these factors. This observation was reported by Conrad and Adu-Asamoah (1986) and Bannerman (2010b).

The declining CPUE also presents evidence that the tuna stocks in the coastal waters of Ghana are getting depleted and/or may be getting overfished. Obeng (2003) made a similar prediction for the future of the Ghanaian tuna fishery. These findings, however, sharply contrast the conclusions of Bortier-Verstraaten (2002). This could be due to differences in time of the two studies, which implies that the dynamics of landings from 2000 to 2013 are different from the prevailing trends from 1996 to 2000.

Per species, the CPUE for *K. pelamis* remained fairly high, since 1998 with few notable declines and has consistently been higher than CPUE of *T. albacares* or *T. obesus* (Figure 4.5, Appendix VII). This could be attributed to high catchability coefficient of *K. pelamis* and the extreme vulnerability of this species to the current methods of fishing. This is consistent with findings of Bortier-Verstraaten (2002) who reported that *K. pelamis* has the highest catchability coefficient of the three major species.

T. albacares demonstrated a fairly constant CPUE (between 2.5 and 4.5) since 1989, with few minor fluctuations. *T. obesus* had the least CPUE of the three species. Reported landings by both ICCAT and MFRD revealed a trend of steady decline of CPUE of *T. albacares* from 2001 but unlike with MFRD data, ICCAT's data indicated a rise in 2010 before another decline in 2012. MFRD values for landings of *T. obesus* were extremely low in the 1980s hence the low CPUE until 1997. This low landing recorded by MFRD are attributed to difficulties in distinguishing between juveniles of *T. albacares* and *T. obesus* (which form the highest landings of the two species) (Bannerman, pers.com, 2015). The fact that both ICCAT and the MFRD repoted the same landings, 2,786 MT for *T. obesus* in 2013 is an evidence that ICCAT's efforts at improving the sampling protocol for the Ghanaian tuna fishery yielded good results in 2013.

5.3 MSY Estimates for the Ghanaian tuna fishery

Per species, *T. obesus* had the least MSY estimate (187.38 MT per MFRD data and 9,670.93 MT). While the MSY estimate for *T. obesus* from data from MFRD is extremely lower compared to the TAC allocated to Ghana (difference of 4,534.62 MT), the MSY estimate from ICCAT landings data of Ghana was more than two times the TAC. The extremely low MSY (187.38 MT) from the MFRD data could be an indication of extreme sensitivity of the Schaefer's Surplus Production model used to extremely low CPUE as was the case for *T. obesus*.

ICCAT (2012 & 2014) rejected the reported landings of this species by the MFRD due to inconsistencies with information available to ICCAT. As a result, the reported landings have since 2012 been reviewed. Landings of *T. obesus* by the Ghanaian fishery were consistently far higher than 187.38 MT from 1989 to 2013, per ICCAT records (Appendix VII). The average landings of *T. obesus* over the last decade (from 2004-2013) was also higher than 9,670.93 MT (MSY from ICCAT data). The landings over the last five years

(2009-2013) have been consistently higher than the TAC except in 2013 where it declined by 69% from 8,974 MT in 2012 to 2,786 MT in 2013. It is not clear what accounted for such huge decline. However, generally *T. obesus* landings in Ghana are in excess of the MSY. The stock of this species in Ghana is thus being overfished. The IUCN Red List (IUCN, 2011) rated the *T. obesus* stocks in the Atlantic as healthy because total landings in the Atlantic have been lower than its MSY. The observed trend of landings in excess of the MSY estimate and TAC for Ghana may threaten the sustainability of the stock available in the Ghanaian waters. The fact that most landings of this species are juveniles caught off FAD activities also may be an indication of growth overfishing. The decline of stock of this species may not easily reflect in Ghana's landings because the Gulf of Guinea is a major spawning ground for this species (ICCAT, BET, 2012).

The MSY estimated for *T. albacares* population in the Ghanaian waters was 20,091.59 MT. The annual landings over the past five years ranged from 18,355 MT in 2009 to 13, 167 MT in 2013. Annual productions exceeded the estimated MSY in past years (2002, 2001, 1999 and 1997). However, landings since 2004 have been consistently lower than the MSY estimated. This could mean that the population of this species in the Ghanaian waters are being fished sustainably. A similar trend of landings below the MSY is reported in the entire Atlantic Ocean (ICCAT, YFT, 2014). However, like *T. obesus*, landings of this species in Ghana, like other parts of the Atlantic, are predominantly juveniles. Furthermore a stock assessment by ICCAT in 2011 indicated 70% probability that the stock of *T. albacares* in the Atlantic is overfished. *T. albacares* is classified as 'Near threatened' by the IUCN because of declines in the landings in the Indian Ocean. It is not clear whether the consistently lower landings are indicative of an overfished stock which can no more yield the MSY. Consistent with the precautionary principle of management, it is suggested that landings should not exceed current levels. This is consistent with ICCAT's recommendation for the exploitation of this species in the Atlantic Ocean.

The annual landings of *K. pelamis* in Ghana have been above the estimated MSY, 60, 274.38 MT, since the 2010 (per data from ICCAT) with an average landing of 63,494.25 MT which does not agree with MFRD data (Appendices I and VII). According to ICCAT, SKJ, (2014), findings from the ports, canaries and countries that import tuna from Ghana suggest that Ghana's catch data of this species were underestimated by about 28 %. Thus the current high landings of *K. pelamis* are reportedly short of the reality by 12, 000 MT per year. It is thus indicative that current landings are far more than the MSY estimated. For example when the underestimated landings were factored into the computations, landings in 2012 exceeded the estimated MSY by more than 9,000 MT. There is thus evidence per results of this study that the stock of *K. pelamis* in the territorial waters of Ghana are being fished beyond its sustainable level.

A similar trend of landings exceeding the MSY is reported for the entire East Atlantic tuna fisheries. However, unlike ICCAT (ICCAT, SKJ, 2014) per results of this study, continuous fishing at the current level of fishing mortality could lead to 'local' overfishing of the stock of *K. pelamis* in the territorial waters of Ghana due to the viscosity of the stock. This is consistent with findings of ISSF (2012) that the stock of this species in the Pacific Ocean has declined to 60% of its original size due to consistently high fishing effort being mounted on the stock. Better management of stocks of this species, including input controls, in the Ghanaian is very necessary and urgent.

The F_{MSY} estimated for the various species [tuna (industrial) fisheries] were (in fishermandays) 2,330.27, 558.83 and 6, 339 for *T. albacares*, *T. obesus* and *K. pelamis*, respectively. The applied fishing mortality, *F*, for *T. obesus* has been extremely higher than its F_{MSY} (the least difference was 1, 589.35 fishermandays) since 1996. Thus the multi-species nature of the Ghanaian tuna fishery is not helpful for the sustainability of *T. obesus*. The $F_{current}$ for *T. albacares* has also been in excess of the F_{MSY} since 1998 (Appendix III). The lack of information on the TAC for Ghana made it difficult to tell if Ghana is producing beyond its allowable catch and hence if there is need to reduce *F*.

The F_{MSY} estimated for *K. pelamis*, 6, 339.0 fishermandays, implied that the $F_{current}$ for this species has been comparatively lower since 1996. This could be due to the high catchability of this species and its high vulnerability to the prevailing methods of fishing, including the use of FADs and thus not likely a depiction viability and sustainability of the stocks in the territorial waters of Ghana. A similar trend was observed in the assessment of this species in the East Atlantic, where the $F_{current}$ was lower than the F_{MSY} and yet landings in the East Atlantic were higher than the MSY (ICCAT, SKJ, 2014).

The total MSY estimate for the Ghanaian tuna fishery, based on catch and effort data from 1996 to 2013 from the MFRD (using the Schaefer model – equilibrium assumption), was 82, 644.91 MT (including the artisanal tuna production). This compared favourably with the range of sustainable catch estimated to be in Ghanaian waters. Over the last five years, the maximum annual production is 94,180 MT (in 2011) and the least, 79,447 MT in 2013 resulting in an average of 86,447.2 MT. Thus current tuna production by the Ghanaian fishery is above the estimated MSY from this study. Consistent with precautionary use of the MSY, it is preferable that landings are lower than the MSY. This is particularly important under the prevailing circumstances because the estimated MSY range of 80,000 - 100,000 MT (Falaye, 2008) was determined many years ago. Since the Ghanaian tuna fishery has continuously mounted heavy fishing pressure on the tuna stock for several years now, it is likely that the stocks in the Ghanaian waters have declined producing a lower MSY than before. This is consistent with findings of ISSF (2012) in the Pacific Ocean. Therefore, consistent with the precautionary use of the MSY in management, the Ghanaian tuna fishery could not be considered sustainable.

5.4 Implications for Local Management of Ghana's tuna fishery for Sustainability.

Although tuna stocks are generally shared resources, the stocks available to the Ghanaian fishery from which the fishery can make maximum economic gains are exhaustible. This brings to bear, the importance and urgency of good management practices to ensure sustainability of the fishery.

In consonance with the precautionary principle of management, contrary to postulations that the fishery can withstand more fishing pressure (FADP, 2011), findings from this study indicated that per the most recent data available (1987 to 2013), the trends of production observed showed that the Ghanaian tuna fishery is fully exploited and being overfished. This was evident both in the declining trend of CPUE of the fleets and landings as of 2013 compared to the MSY for the fishery. Increasing fishing mortality may thus be very detrimental to the sustainability of the stocks and hence to the highly lucrative and important fishery and tuna industries dependent on it. The current trend of increasing fishing mortality is thus not sustainable. Urgent national management actions are required to complement ICCAT's management actions and regulations in order to prevent severe depletion of the stocks and to keep the fishery at a sustainable level.

As evident from Table 4.1, Ghana's tuna fishery is backboned on *K. pelamis*. This has an important implication for management. Consistent with scientific findings, *K. pelamis* is the least migratory of the three species of tuna under consideration (Bortier-Verstraaten, 2002; ICCAT, SKJ, 2014). Stocks of *K. pelamis* are described as viscous which means there is little or no mixing between stocks in different geographical locations. In fact the Ghanaian stock is postulated to be a unique sub-stock (Bortier-Verstraaten, 2002). This property of *K. pelamis* makes it possible for Ghana to effectively manage the stock of *K. pelamis* in its territorial waters effectively. This is key to the sustainability of the tuna fishery since *K. pelamis* forms more than 70% of Ghana's tuna landings. Although movement rates and local residence times for *T. albacares* and *T. obesus* remain uncertain, ICCAT (2014) reported that there may be some degree of extended local residence times and/or site fidelity. This implies local management actions may be useful in managing these species too.

Although the results of this study have revealed that the prevailing trend of CPUE and landings, in comparison with MSY estimated, it is possible that the stocks are not severely depleted. This is evident in the fact that landings from 2009 to 2013, neither the rate of change of CPUE nor the difference between landings and the MSY estimated was 3,802.29 MT (4.6 %) which is not large. This suggests that timely management will not be too restrictive and costly. The situation may, however, deteriorate if immediate management actions are not implemented.

Per species, landings of *K. pelamis* from 2009 to 2013 were in excess of the MSY estimated by 1,782 MT representing only 3 %, difference (Figure 5.1). That is, it is possible that the stock of *K. pelamis* is not severely depleted. It is possible however, that the stocks in the territorial waters of Ghana are depleted more than shown by the available data. This is because, landings used for this study are total landings of the species in Ghana, including catches from the high seas and EEZ of other countries. However, due to the high reproductive capacity of *K. pelamis* (ICCAT, SKJ, 2014), rebuilding its stock should not be difficult with good management practices like catch restrictions and input control.

The MSY estimated, 60,274.38 MT and 20,091.59 MT and 82,644.91 MT can be useful in setting catch quotas for *K. pelamis, T. albacares* and total tuna landings from Ghanaian waters, respectively. The TAC, 4,722 MT, for *T. obesus* could serve as its quota but the quota should be less than the highest MSY estimated 9,670.93 MT.

Also to curb this trend of over-exploitation, FAD-based fishing should be minimised in the Ghanaian waters for more months than the two months coverage by ICCAT's moratorium. This could yield good results in stock rebuilding and be effective because of the vessel monitoring systems reportedly installed on all tuna vessels (Bannerman pers. com, 2015). This is because the moratorium against FAD fishing in January and February reduced landings of all the major tunas (and hence juveniles) in those months (unpublished MFRD data on monthly landings of tunas).

The quotas, coupled with reduction in FAD-based fishing and reduction of fishing mortality, to the average F_{MSY}, 3,076 fishermandays, could be useful in rebuilding the stocks to sustainable levels.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

From available data and information, the following are the conclusions from this study with respect to the study objectives:

- Total tuna landings had increased from 1987 to 2013 but the total CPUE of baitboats and purse seines declined from 27.82 MT/fishermandays to 21.87 MT/fishermandays in 2013.
- The MSY estimated were 20,091.59 MT, 187.38 MT and 60,274.38 MT for *T.albacares*, *T. obesus*, and *K. pelamis*, respectively.
- The total MSY estimated for the Ghana fishery (82,644.91 MT) compared favourably with ICCAT's estimated sustainable catch, (80,000 MT to 100,000 MT) in the coastal waters of Ghana.
- Total tuna landings in Ghana and landings of *K. pelamis* and *T. obesus* had been in excess of the MSY from 2009 to 2013by 4.6 %, 3 % and at least 12.6%, respectively. Average fishing mortality, $F_{current}$, 3,375 fishermandays, is also in excess of the average F_{MSY}, 3,076 fishermandays.
- The stocks of tuna in the territorial waters of Ghana are fully exploited and being overfished requiring urgent management actions to reduce effort and landings from the territorial waters of Ghana.

6.2 RECOMMENDATIONS

From findings of this study, the following recommendations are thought helpful to the sustainability of the Ghanaian tuna fishery:

- Consistent with the precautionary principle of management, all stakeholders in the fisheries sector should work urgently at and implement workable national management actions including setting precautionary (restrictive) quotas and introducing input controls (to regulate fishing effort) until there is enough evidence that the fishery can be sustainable with increased fishing mortality. This is urgent and must be done locally because *K. pelamis* which forms the backbone of the tuna fishery in Ghana is viscous and may be locally overfished. *T. obesus* and *T. albacares* also demonstrate some level of local residence and hence can be fairly managed. Including this in Ghana's Marine Fisheries Management Plan will enhance the sustainability of the fishery.
- More and detailed research work on the status of the tuna stocks, including current biomass of the stocks in the coastal waters of Ghana is needed to establish the state of the standing stocks.
- Data on fish resources of Ghana should be made more and easily accessible by the Fisheries Scientific Survey Division and other institutions with such data. This could be done by uploading such data online, at the Ministry/Division's website, to enhance research by students, academics/scientists and others.

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APPENDICES

Appendix I: Catch-Effort data from the Marine and Fisheries Research Division (MFRD), Ghana.

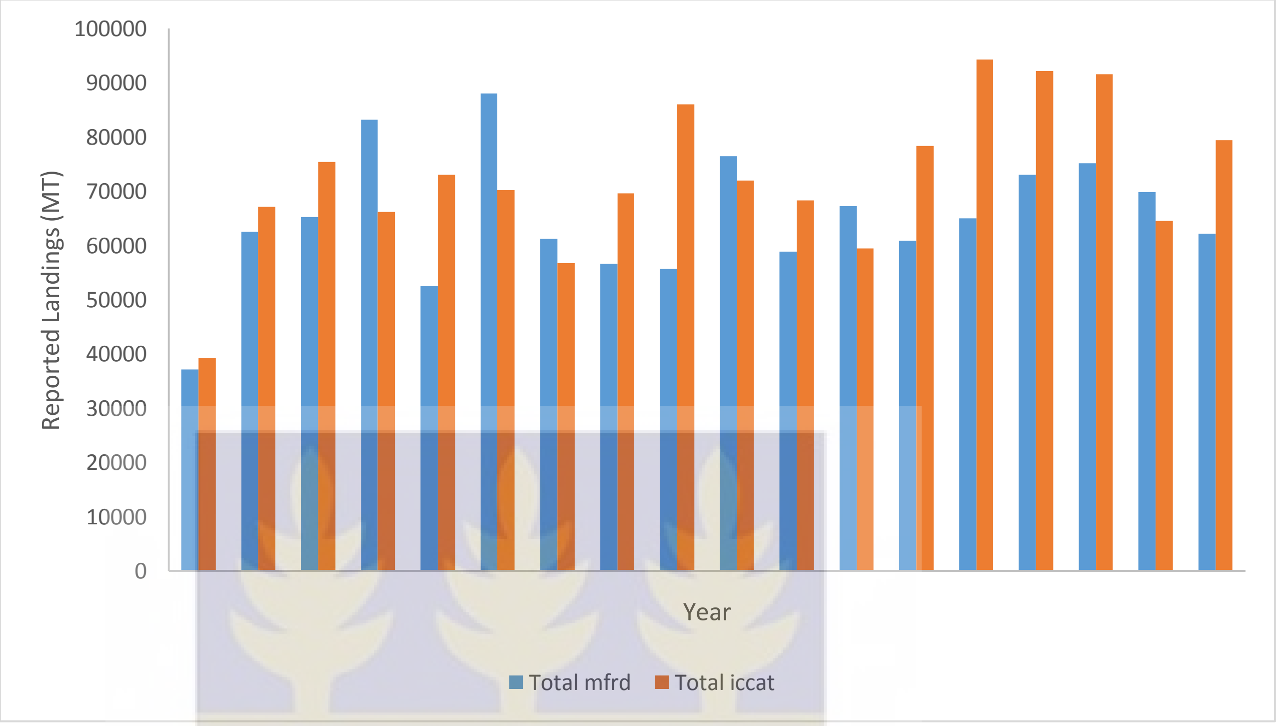
Year	YFT	BET	SKJ	TOTAL	Effort (No. of Vessels)	
1987	4159	124	26576	30859	Purse seines	Baitboats
1988	2770	52	29936	32758	-	-
1989	2883	16	23154	26053	-	-
1990	7710	98	29499	37307	-	-
1991	6629	138	28249	35016	-	-
1992	6254	96	21336	27686	-	-
1993	10647	3	22639	33289	-	-
1994	7394	291	23863	31548	-	-
1995	7119	4	22923	30046	-	-
1996	12242	615	24285	37142	4	26
1997	23250	28	39205	62483	5	22
1998	19291	3921	41998	65210	5	25
1999	28282	3680	51284	83246	10	22
2000	15910	1651	34986	52547	10	24
2001	29303	2357	56418	88078	10	25
2002	20311	2034	38934	61279	10	26
2003	19030	4816	32766	56612	11	22
2004	15138	6944	33600	55682	11	24
2005	19833	2333	54322	76488	9	26
2006	14549	1540	42789	58878	11	24
2007	15107	5748	46415	67270	11	24
2008	14250	9269	37387	60906	13	26
2009	18355	10554	36064	64973	13	22
2010	12511	6768	53812	73091	17	22
2011	14500	4122	56500	75122	17	22
2012	9113	3455	57284	69852	17	20
2013	13167	2786	46257	62210	17	20

Appendix II: Nominal effort, Standard effort and CPUE of Purse seines and Baitboats from 1996 to 2013.

FLEET	PURSE SEINERS				BAIT-BOATS			
YEAR	**CATCH (MT)**	**EFFORT (Vessel No.)**	**ST. EFFORT (f'days)**	**CPUE-PS (MT/f'day)**	**CATCH (MT)**	**EFFORT (Vessel No.)**	**ST. EFFORT (f'days)**	**CPUE-BB (MT/f'day)**
2000	31656	10	1348.8	23.47	20891	24	1607.76	12.99
2001	55809	10	1348.8	41.38	32269	25	1674.75	19.27
2002	33008	10	1348.8	24.47	28271	26	1741.74	16.23
2003	23161	11	1483.68	15.61	33451	22	1473.78	22.70
2004	38033	11	1483.64	25.63	17649	24	1607.76	10.98
2005	33466	9	1213.92	27.57	43022	26	1741.74	24.70
2006	36189	11	1483.64	24.39	22689	24	1607.76	14.11
2007	24506	11	1483.64	16.52	42764	24	1607.76	26.60
2008	40743	13	1753.44	23.24	20163	26	1741.74	11.58
2009	29629	13	1753.44	16.90	35344	22	1473.78	23.98
2010	47757	17	2292.96	20.83	25334	22	1473.78	17.19
2011	52783	17	2292.96	23.02	22339	22	1473.78	15.16
2012	52512	17	2292.96	22.90	17340	20	1339.8	12.94
2013	48098	17	2292.96	20.98	16131	20	1339.8	12.04

Appendix III: Catch (in MT), Effort (in fishermandays) and CPUE (in MT/fishermanday) of *K. pelamis* (SKJ), *T. albacares* (YFT), *T. obesus* (BET) from 1996 to 2013 from MFRD.

Year	Skipjack	Total Effort (f'days)	CPUE-SKJ MT/fdy	Yellowfin	CPUE-YFT MT/fdy	Bigeye	CPUE-BET MT/fdy
1996	24285	2281.26	10.65	12242	5.37	615	0.27
1997	39205	2148.18	18.25	23250	10.82	28	0.01
1998	41998	2349.15	17.88	19291	8.21	3921	1.67
1999	51284	2822.58	18.17	28282	10.02	3680	1.30
2000	34986	2956.56	11.83	15910	5.38	1651	0.56
2001	56418	3023.55	18.66	29303	9.69	2357	0.78
2002	38934	3090.54	12.60	20311	6.57	2034	0.66
2003	32766	2957.46	11.08	19030	6.43	4816	1.63
2004	33600	3091.4	10.87	15138	4.90	6944	2.25
2005	54322	2955.66	18.38	19833	6.71	2333	0.79
2006	42789	3091.4	13.84	14549	4.71	1540	0.50
2007	46415	3091.4	15.01	15107	4.89	5748	1.86
2008	37387	3495.18	10.70	14250	4.08	9269	2.65
2009	36064	3227.22	11.17	18355	5.69	10554	3.27
2010	53812	3766.74	14.29	12511	3.32	6768	1.80
2011	56500	3766.74	15.00	14500	3.85	4122	1.09
2012	57284	3632.76	15.77	9113	2.51	3455	0.95
2013	46257	3632.76	12.73	13167	3.62	2786	0.77



Appendix IV: Differences in Reported Total Landings of tuna (by ICCAT and MFRD) in Ghana from 1996 to 2013.

Appendix V: Percentage Difference between ICCAT-Reported Landings for Ghana and MFRD Data from 1989 to 2013.

YEAR	ICCAT TOTAL	MFRD TOTAL	Difference	%Difference
1989	31944	26053	5891	22.61
1990	41270	37307	3963	10.62
1991	38396	35016	3380	9.65
1992	31164	27686	3478	12.56
1993	37085	33289	3796	11.40
1994	35980	31548	4432	14.05
1995	33392	30046	3346	11.14
1996	37138	37142	-4	-0.01
1997	51609	62483	-10874	-17.40
1998	65217	65210	7	0.01
1999	83255	83246	9	0.01
2000	52553	52547	6	0.01
2001	88081	88078	3	0.00
2002	61281	61279	2	0.00
2003	56625	56612	13	0.02
2004	77818	55682	22136	39.75
2005	76088	76488	-400	-0.52
2006	71845	58878	12967	22.02
2007	64284	67270	-2986	-4.44
2008	63881	60906	2975	4.88
2009	87318	64973	22345	34.39
2010	94180	73091	21089	28.85
2011	87194	75122	12072	16.07
2012	84097	69852	14245	20.39
2013	79447	62210	17237	27.71
Total Difference from 2004-2013			**121680**	**189.14**
Average Annual difference for the past decade (2004-2013)			**12168**	**18.91%**

Appendix VI: Rate of change of Total CPUE (MFRD and ICCAT) from 1996 to 2013 Compared

Year	CPUE-MFRD	CHANGE RATE	%CHANGE	CPUE-ICCAT	CHANGE RATE	%CHANGE
1996	16.28	-	-	17.23	-	-
1997	29.09	0.79	78.65	31.23	0.81	81.29
1998	27.76	-0.05	-4.56	32.10	0.03	2.78
1999	29.49	0.06	6.25	23.46	-0.27	-26.92
2000	17.77	-0.40	-39.74	24.71	0.05	5.33
2001	29.13	0.64	63.90	23.21	-0.06	-6.06
2002	19.83	0.00	0.00	18.34	-0.21	-20.97
2003	19.14	-0.03	-3.46	23.56	0.28	28.45
2004	18.01	-0.06	-5.90	27.82	0.18	18.07
2005	25.88	0.44	43.67	24.36	-0.12	-12.44
2006	19.05	-0.26	-26.40	22.12	-0.09	-9.20
2007	21.76	0.14	14.25	19.23	-0.13	-13.07
2008	17.43	-0.20	-19.92	22.43	0.17	16.66
2009	20.13	0.16	15.54	29.23	0.30	30.33
2010	19.40	-0.04	-3.62	24.49	-0.16	-16.23
2011	19.94	0.03	2.78	24.31	-0.01	-0.70
2012	19.23	-0.04	-3.59	17.78	-0.27	-26.89
2013	17.12	-0.11	-10.94	21.87	0.23	23.02
Average Annual Rate of change:		**0.629**	**6.29 %**		**0.432**	**4.32 %**

Appendix VII: ICCAT Records of tuna landings in Ghana since 1996 to 2013

Year	Total Effort	YFT-ICCAT	CPUE-YFT	BET-ICCAT	CPUE-BET	SKJ-ICCAT	CPUE-SKJ	Total
1996	2281.26	8182	3.59	4751	2.08	24205	10.61	37138
1997	2148.18	15080	7.02	10165	4.73	26364	12.27	51609
1998	2349.15	13222	5.63	10155	4.32	41840	17.81	65217
1999	2822.58	20815	7.37	10416	3.69	52024	18.43	83255
2000	2956.56	12304	4.16	5269	1.78	34980	11.83	52553
2001	3023.55	23392	7.74	9214	3.05	55475	18.35	88081
2002	3090.54	18100	5.86	5611	1.82	37570	12.16	61281
2003	2957.46	15002	5.07	8646	2.92	32977	11.15	56625
2004	3091.4	14044	4.54	17744	5.74	46030	14.89	77818
2005	2955.66	13019	4.40	8860	3.00	54209	18.34	76088
2006	3091.4	13595	4.40	8139	2.63	50111	16.21	71845
2007	3091.4	11115	3.60	6531	2.11	46638	15.09	64284
2008	3495.18	14127	4.04	7963	2.28	41791	11.96	63881
2009	3227.22	18237	5.65	12778	3.96	56303	17.45	87318
2010	3766.74	15732	4.18	15123	4.01	63325	16.81	94180
2011	3766.74	11043	2.93	14769	3.92	61382	16.30	87194
2012	3632.76	9347	2.57	8974	2.47	65776	18.11	84097
2013	3632.76	13167	3.62	2786	0.77	63494	17.48	79447