UNIVERSITY OF CAPE COAST

STOCK ASSESSMENT AND ASPECTS OF REPRODUCTION OF *TRICHIURUS LEPTURUS* AND *LUTJANUS FULGENS* IN GHANAIAN WATERS

BY

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature……………………………… Date ……………………

Name: Eugenia Amador

Supervisor's Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision laid down by the University of Cape Coast

Principal Supervisor's Signature…………….…… Date…………..……

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ABSTRACT

The ribbonfish, *Trichiurus lepturus* and golden African snapper, *Lutjanus fulgens* are actively and locally exploited by commercial fishers along the coast of Ghana. To bridge the knowledge gap on these species, size composition, growth and mortality as well as aspects of reproduction were assessed. Samples were collected from major fish landing sites along the coast of Ghana from September 2018 to August 2019. Length-frequency data were used to estimate growth and mortality rates and exploitation ratio. Total lengths of *T. lepturus* sampled ranged between 24.8 and 103.9 cm with a unimodal distribution of 55 cm. The length-weight relationship, $BW = 0.0002TL^{3.3437}$ (r = 0.98) indicated positive allometric growth. The asymptotic length (L_∞), growth coefficient (K) and age at zero length (t_o) for *T. lepturus* were estimated as 133.66, 0.46 yr^{-1} and -0.88, respectively. Total (*Z*), fishing (*F*) and natural (*M*) mortality rates of *T. lepturus* were estimated at 2.69 yr^{-1}, 2.03 yr^{-1} and 0.66 yr^{-1}, respectively. The length at first capture (L_c) was lower than the length at first maturity (L_m). Spawning occurred all year round with a peak spawning period from March to June. Fecundity was estimated to be 17,440 ± 1,250 eggs (mean ± SE). For *Lutjanus fulgens*, the total length sampled ranged between 16.2 and 45.6 cm with a length-weight relationship of $BW = 0.0192TL^{2.8959}$ (r = 0.97) indicating isometric growth. The L_∞, *K* and t_o were estimated as 51.09, 0.47 yr-^{1} and -0.30, respectively. *Z*, *F* and *M* of *L. fulgens* were estimated at 2.69 yr^{-1}, 1.91 yr^{-1} and 0.78 yr^{-1}, respectively. The study showed that the stocks enter the exploitation phase just before attaining maturity with L_c estimated at 31.51 cm and L_m at 33.7cm. Mean fecundity was estimated to be 77,833 ± 13,012 eggs. Peak spawning period of *L. fulgens* was observed from June to September. There was no significant difference observed in the sex ratio between males and females for both species. Stocks of both species were found to be vulnerable to overfishing. There is therefore the need for a reduction in fishing pressure of the stocks to promote proper management of the fishery resources.

KEY WORDS

Trichiurus lepturus

Lutjanus fulgens

Length-frequency distribution

Length-weight relationship

Growth parameters

Mortality parameters

Stock assessment

Gonadosomatic index

Fecundity

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DEDICATION

This thesis is dedicated to all who have the conservation of fishery resources at heart.

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BW	Body Weight
ELEFAN	Electronical LEngth Frequency ANalysis
F	Fishing Mortality
FAO	Food and Agriculture Organisation
FL	Fork Length
FSSD	Fisheries Scientific Survey Division
GSI	Gonadosomatic Index
GW	Gonad Weight
K	Growth Coefficient
L_∞	Asymptotic length
L_{max}	maximum observed length
L_c	Length at first capture
M	Natural Mortality
PAL	Pre-Anal Length
SL	Standard Length
SST	Sea Surface Temperature
TL	Total Length
t_o	Age at length 0
t_{max}	Longevity
VBGF	von Bertalanffy growth function
VPA	Virtual Population Analysis
Z	Total Mortality

CHAPTER ONE

INTRODUCTION

Background

Fish, since ancient times has been a key source of food for mankind. Fisheries provide employment and economic benefits all across the globe (Bene, Macfadyen & Allison, 2007). Increasing human population and knowledge of the health benefits derived from fish consumption has driven even more the demand for fish. Nutritionally, fish is an important source of dietary protein and contains all the essential amino acids (FAO, 2016). Over the years there has been notable development in the fisheries sector and an overall increase in production from both capture and culture fisheries. The rise of technology has a role to play in this increase (Bene *et al*., 2007). In Ghana, fisheries contribute immensely to the nutritional, economic and social well-being of the growing population. Fish is consumed across the demographic spectrum, by both poor and affluent, young and old, in all regions of the country. The mean per capita consumption of fish in Ghana is about 26 kg which is higher than that of the world's at 19 kg (FAO, 2016; Sarpong, Quaatey & Harvey, 2005). The Ghanaian fishing sector generates about $1.3 billion in total revenues in 2016, representing 1.03 percent of the national GDP (Lazar et al., 2017) and employs about 10 percent of the population. Thus, the fisheries sector plays a very important role in poverty alleviation in Ghana.

The fishing industry in Ghana is based on resources from the marine and inland fisheries, and aquaculture sectors. The inland fishery dominated by the Volta lake fisheries, produces about 16 percent of the total production. The marine sector is the most important source of local fish production in Ghana, contributing about 85 percent of the total fish supply (Nunoo, Asiedu, Amador, Belhabib & Pauly, 2014). The Ghanaian marine fisheries sector is characterized by three sub-sectors namely the artisanal, semi-industrial and industrial fisheries. Trawlers, shrimpers and tuna fishing fleets make up the industrial sector. This sector makes use of large steel-hulled foreign-built trawlers, shrimpers, tuna pole and line vessels and purse seiners which operate from two landing sites viz Tema and Takoradi fishing harbours (Kwadjosse, 2009). They mostly exploit tunas and high valued marine resources such as cephalopods.

The semi-industrial or inshore sector contributes about two percent of the total marine catch (Dovlo, Amador, & Nkrumah, 2016).The target species of this sector are both small and large pelagics as well as demersal species. In exploiting fish resources, locally built wooden boats about 9-12 meters in length and fitted with 30-90 horsepower engines that are dual purpose are employed, being able to use trawls or purse seines. Trawling is practiced during the thermocline period when there is no upwelling and demersal species are mostly landed. The purse seines are more commonly used during the major and minor upwelling seasons with most catches consisting of the pelagics; sardinellas, mackerels and anchovies (K. Amador, Personal Communication, August, 2018).

The most significant of the marine subsectors in terms of volume of output, with at least 70 percent of the total marine production, is the artisanal subsector (Nunoo *et al.*, 2014). About 1.5 million people depend on this sector for their livelihood. In exploiting the wide variety of fish species found in Ghanaian waters, the artisanal sector employs various gears which include purse seines (poli/watsa), beach seines, hook-and-line, drift gillnets, surface setnets among others. Report on the 2016 Ghana Marine Canoe Frame Survey states that the artisanal subsector operates from 292 landing sites in 186 fishing villages located along the entire coast. The fisheries are normally characterized by low technology and labour-intensive activities (Dovlo, Amador, & Nkrumah, 2016).

The wide variety of fish species targeted by these sectors are categorized into two groups, namely pelagic and demersal species. In Ghanaian fisheries, pelagic and demersal species contribute about equally to the national catch (Nunoo *et al.*, 2014). Pelagic species swim in large schools in the upper water layers and are abundant in Ghanaian waters and in waters of neighbouring countries. Their abundance is mostly related to the high plankton production, which is caused by upwelling of nutrient-rich water. Pelagic fish species in Ghanaian waters include the small pelagics consisting of the mackerels, sardines, anchovies and the large pelagics consisting of the tunas, swordfishes and others. Commercial landings of these fish species averaged 135,000 metric tons annually from 1996 to 2013 after a continuous decline from 250,000 metric tons in 1996. The small pelagic landings dominated the total marine production in Ghana for over 2.5 decades, however, in recent years the contribution of small pelagic landings of the total marine landings is rather low (Lazar *et al*., 2017). Much attention is now shifting to the demersal species as a result.

The demersal fish species include those of the families Haemulidae (grunts), Lutjanidae (snappers), Mullidae (goatfishes), Serranidae (groupers), Sparidae (seabreams), Polynemidae (threadfins), Penaeidae (shrimps), Sepiidae (cuttlefishes), Soleidae (soles) and Sciaenidae (croakers) among others. These fish species are very important in the marine fishery due to their numbers and their high value. In exploiting these demersal fish species, the artisanal fleet employs mostly gillnets and hook-and-line (Koranteng, 1998). Demersal species are of prime importance since they contribute about half of the total fish landings and are of high commercial value (Grainger & Garcia, 1996; Koranteng, 1998).

According to Koranteng (1998) there has been a reduction in the density of some high value demersal fish species such as the snappers, groupers and seabreams which could probably be due to overfishing. However, Cruise Reports from the "Dr. Fridtjof Nansen" Survey of the Pelagic and Demersal Resources during the Surveys of the Fish Resources of the Western Gulf Of Guinea (Bénin, Togo, Ghana & Côte d'Ivoire) indicated that demersals are of high abundance at the continental slopes in Ghanaian waters (Mehl, Oddgeir, & Quaatey, 2004; Mehl, Olsen, & Bannerman, 2005). Considering the fact that all natural resources are not infinite and are amenable to change and depletion if not exploited with care, it is essential that fish stocks are assessed periodically.

Snappers are amongst the most known, tasty and preferred demersal fish species in Ghana. They belong to the family Lutjanidae characterized by an active, voracious and carnivorous lifestyle. There are about five different species belonging to the family which occur in Ghanaian waters. The most common amongst them are the Golden African snappers, *Lutjanus fulgens* (Valenciennes, 1830) known as "Okpolo" or "tan" in the local Ghanaian dialect and can attain a length of about 60 cm (Kwei & Ofori-Adu, 2005). They are locally and actively exploited and of high commercial value.

Benthopelagic species are often grouped with demersals.The ribbonfish is but a few of such species. Their occurrence in appreciable quantities supplements the few commercially important demersal fish species landed. The ribbonfish, *Trichiurus lepturus*, (Linnaeus, 1758), also known as largehead hairtail, fisherman's belt or cutlass fish belongs to the family Trichiuridae and is characterized by extremely elongated and ribbon-shaped body which is naked and tapers to a hair-like tail. In Ghana, they are mostly caught with bottom trawls and beach seines and are commonly known in the local Ghanaian language as "Wawadzan" (Kwei & Ofori-Adu, 2005). They are scrubbed with sea sand to get the silvery reflections off and mostly eaten fried or smoked.

Research Problem and its Significance

Though renewable, fisheries resources is a finite resource. This therefore calls for sustainable exploitation, proper management and conservation to prevent the gradual depletion of our fishery resources. Both pelagic and demersal fish catches are dwindling over the years due to unsustainable exploitation. Demersal species however are species of prime importance and of high economic value in the Ghanaian fisheries. Improved technology employed in exploiting fish, illegal fishing methods and the notion that the sea is a vast resource and the resources therein is infinite are contributing factors influencing this decline in production (Koranteng 1998).

To successfully manage fisheries resources and prevent further decline and rebuild stocks, there is the need to know the biological characteristics of the fishery resources since that forms the basis of management. Most studies on stock assessment have focused on small pelagics and a few commercially important demersal fish species. The still remains much work to carry out on stock assessment to bridge the knowledge gap.

Statement of the Problem

There is a dearth in information on the population dynamics, stock assessment, biology and other basic biological characteristics of most demersal fish stocks which is a major problem. There is therefore the need to conduct stock assessment to know their status in Ghanaian waters. Globally, stock assessment options have been used by numerous marine researchers to evaluate the status of significant fish species. Knowledge from fish stock assessment studies has aided in managing sustainably, certain key fish species. This ensures food and nutrition security mostly within households whose livelihoods are dependent on fisheries resources. Assessing the status of fish stocks using stock assessment models generally involves the use of either length or age aggregated data. However, in tropical and developing countries like Ghana, where age estimation of fish data is not easily accessible, length-based data are mostly used in assessing fish stocks.

Stock assessment and other studies have been carried out on many commercially important fish species including *Bachydeuterus auritus*, (Asabere-Ameyaw & Blay Jr, 1999; Bannerman & Cowx, 2002; Amponsah, Abdulhakim, Ofori Danson & Femi Anyan, 2017); *Sarotherodon melanotheron*, (Arizi, Aggrey-Fynn & Obodai, 2015); *Balistes capriscus*, (Koranteng, 2001; Aggrey-Fynn, 2009; Aggrey-Fynn, 2013) *Sardinella aurita, Sardinella maderensis* (Osei, 2015) both in Ghanaian waters and other regional waters However, in Ghana no information on stock assessment of the snappers exists at present. Stock assessment and aspects of the biology and reproduction of the ribbonfish have also been carried out in other international waters, especially in India and China (Fritzsche, 1976; Fofandi, 2012; Ghosh et al., 2009; Cheng et al., 2013; Avinash et al., 2014; Cruz-Torres, 2014;

Guillena, 2017) but not in Ghanaian waters though it is actively exploited and contributes up to about 2.5 percent of the total catch landed in Ghana (Catch Data, FSSD). In waters of neighbouring countries, Nigeria, available information focuses on the diet and feeding behavior of the ribbonfish (Udo, Edem, Isangedighi, Umana & Akpan, 2014). It is expedient to know the status of these stocks to know whether they are underfished, overfished, or sustainably exploited to better plan for management. Against this backdrop, this study aims to assess the status of two demersal fish species; *Lutjanus fulgens* and *Trichiurus lepturus* in Ghanaian waters.

Research Objectives

This study aims to assess the status and aspects of reproduction of the *Lutjanus fulgens* and *Trichiurus lepturus* stocks in Ghanaian waters with a view of providing biological information needful in management of the fisheries resources.

The specific objectives that guided the study in achieving its set goal were to:

1. Determine the growth parameters of *Lutjanus fulgens* and *Trichiurus lepturus*.
2. Estimate the mortality parameters (natural mortality, *M*; total mortality, *Z;* fishing mortality, *F*) and exploitation ratio of each species.
3. Evaluate the reproductive status of the stocks of the two fish species.

Delimitations

Three important fish landing markets along the coastal zones of Ghana were selected for this study. The coastal zones of Ghana are divided into three geomorphologic zones; East Coast, Central Coast and West Coast. The study sites were Tema, Elmina and Sekondi in the Greater Accra, Central and Western Regions of Ghana, respectively. These sites were chosen for data collection since they represent sites in the three geomorphologic zones of Ghana's coast. In addition, these sites capture all the major fish markets where artisanal and semi-industrial catches are landed along the coastline of Ghana. Length-weight data, growth and mortality parameters, reproductive biology and gut content analyses are useful and standard information of fish sampling programs as well as aspects of fish population dynamics. All the aforementioned but gut content analysis was not carried out in this study. Stomach content analysis was not carried out due to the likelihood of food being partly or completely digested when landed.

Limitations

Some limitations were encountered in the course of the study and it is worth noting. Closed fishery was observed in the month of May, 2019 which made it impossible to sample hence accounts for no data on both fish species during that particular month in the study. For *Lutjanus fulgens*, there were no samples collected in October, 2018 due to the absence of the fish at the shores.

It is possible that errors occurred when determining fish sex visually, particularly those that were immature; this highlights the need for histological examination in further studies. In spite of these limitations the quality of the study was not affected.

Organization of the study

This study is structured into six chapters. It begins with Introduction as Chapter One. Chapter Two gives a theoretical framework of the study. It explores key concepts and theories on which this study is built as well as gives an in-depth review of literature that is of importance to this study. It focuses on global findings on growth, mortality and reproduction of *T. lepturus* and *Lutjanus fulgens* and related species. Chapter Three gives an account of how the study was carried out. It gives a description of the study area, data collection procedures, data processing and analyses. Chapter Four presents the findings of the study whilst Chapter Five deals with the discussion which gives an evaluation of each finding and examines their implication. Chapter Six deals with the conclusion and recommendations where an overview of the work is given together with insights gathered.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews relevant information and highlights key findings in literature regarding stock assessment of fishes. It as well provides constructive analysis of the findings and approaches of other studies relating to the aim of this study. This section gives an account of habitat and distribution of the two fishes, *Trichiurus lepturus* and *Lutjanus fulgens,* under study, their age, growth and mortality, as well as their reproductive status.

Trichiurus lepturus

The ribbonfish, *Trichiurus lepturus*, also known as largehead hairtail is a demersal species (benthopelagic) of commercial importance. It is also known as cutlass fish due to the extremely compressed and double-edged sword-like body. This species belongs to the Kingdom Animalia, Phylum Chordata, Class Actinopterygii, Order Perciformes, and Family Trichiuridae and is characterized by extremely elongated and ribbon-shaped bodies which is naked and tapers to a hair-like tail. Fresh specimens of the ribbonfish are steely blue with silvery reflections, becoming uniformly silvery gray sometime after death. Aside it being a food fish, in some countries, cosmetics are made from their skin and pearl essence obtained from their body hence there is an increasing demand for them (Mohite & Bradar, 2001).

The ribbonfish has a single long dorsal fin with spines and soft rays starting just behind the eyes, as well as a single nostril on each side. The pectoral fins are small and located near the rear corners of the gill covers, and the anus is nearer to the snout rather than the posterior tip of the body. There are long barbed fangs in front of its large mouth. Both pelvic and caudal fins are absent in the ribbonfish and the lateral line begins at the upper margin of the gill cover, running oblique to behind the tip of the pectoral fins, then straight close to the ventral contour (Sankar, 2015).

Mode of exploitation and importance of *T. lepturus* in Ghana

In Ghana, ribbonfishes are mostly caught with bottom trawls and beach seines and are commonly known in the local Ghanaian language as "Wawadzan". This species is actively and locally exploited mostly by the artisanal fleets though all three subsectors within the marine fishery namely artisanal, inshore and industrial fleets land it. The ribbonfish stands out among the highly exploited fishes and exported fishes worldwide. In Ghana, it contributed up to 8.78% and 10.26% of the total demersal landings in 2007 and 2015 and 2.46% and 2.28% among landings of both pelagic and demersal resources combined, respectively (Reports on Catch Data, FSSD). This shows that the species plays a key role in the marine resources of Ghana contributing significantly to food and nutritional security. Exploitation of *T. lepturus* also supports the livelihood of fishers in the country.

It is landed along the shores of most landing beaches and abundant in the Central and Western coastal regions of Ghana (Cruise Reports Dr. Fridtjof Nansen, 2017).

Habitat distribution and Ecology

The ribbonfish is a cosmopolitan fish normally found in warm and warm-temperate shelf waters (Martins & Haimovici, 2000). Although considered a worldwide species by several authors, *T. lepturus* is now known with certainty only from the western Atlantic and Indo-west Pacific regions (Collette et al., 2015). During the survey of the pelagic and demersal resources of the Western Gulf of Guinea by "Dr. Fridtjof Nansen", (Benin, Togo, Ghana & Cote D ’Ivoire) ribbonfishes were found in relatively high catch rates in the outer shelf (i.e. 51-100 m) of Ghanaian waters. In Ivory Coast, large ribbonfishes were the second most important group which occurred in the inner shelf (i.e. 0-50 m) waters. In Benin, ribbonfishes were only caught on the inner shelf (i.e. 0-50 m) waters (Mehl, Oddgeir, & Quaatey, 2004). This species can move between estuarine and marine ecosystems, including inshore and deep-sea areas, depending on its life-cycle stages and demand for food. They are distributed between the shallow and inshore waters to about 350 m depth in the offshore waters and mostly occur in dense schools along continental shores in tropical to temperate waters (Al-Nahdi, Al-marzouqi, Al-Rasadi, & Groeneveld, 2009). They mostly occur in muddy bottoms near estuaries or shallow coastal waters and are predacious with strong unequal teeth.

According to a study by Udo et al. (2014), feeding intensity of the cutlass fish is higher in the wet season than during the dry season. They are top predators feeding voraciously on fishes, cephalopods and crustaceans and also exhibit cannibalism thus playing a pivotal role in the energy transfer of tropical marine fish ecosystems (Ghosh et al., 2014). From various studies on aspects of the biology, gut contents indicate open and mid-water foraging. There is also reported ingestion of small amount of plant matter and sand grains which gives a clue that they feed probably close to the bottom. Some of the food items they feed on include algae, Chlorophyceae, crustaceans including, *Macrobrachium* sp, *Peneaus notialis,* Guinea mantis, Pisces (mostly juvenile fishes), juveniles of T*richiurus lepturus*, plant matter, mud and sand grains. Analysis of food items from some studies in relation to body size shows that while juveniles feed mostly on prawns and cephalopods, adults prefer finfishes (Ghosh et al., 2014).

Growth and Mortality of *T. lepturus*

While some studies take the pre-anal length of the ribbonfish for data analysis (Kwok & Ni, 1999; ElHaweet & Ozawa, 1996; Al-Nahdi et al., 2009) others also take the total length when taking length measurements (Ghosh et al., 2014; Udo et al., 2014). Commercial catches of *T. lepturus* across the globe show a wide variation in the size and usually ranges from 20 – 130 cm in length. Observed maximum length for various studies ranged from 90 cm to 130 cm. Ghosh, Pillai, & Dhokia (2009) observed a maximum length of 115.9 cm off Veraval, north-west coast of India whereas Avinash et al. (2014) reported maximum length of 125 cm TL in the same waters. Cruz-Torres, Martínez-Pérez, Franco-López, & Ramírez-Villalobos (2014) also reported maximum total length of 97.5 cm in Boca Del Rio, Veracruz, Mexico. In the Makran coast (northeast Arabian Sea), Muhammad et al., (2017) recorded a maximum length of 129.5 cm. On the Kenyan Coast (Mwakiti, Mlewa, & Ruwa, 2016) reported a maximum length of 99 cm. Mean sizes of *T. lepturus* from commercial catches in the world have wide ranges and is mostly dependent on the mode of exploitation or the fishing gear employed in its capture. Mwakiti et al. (2016) reported a mean size of 79. 67 cm and 57.4 cm from gillnet and bottom trawl net landings respectively from Malindi in Kenya. Al-Nahdi et al. (2009) reported a mean size of 92.6 ± 15.3 cm of fish caught by trawlers and 98.8±10.4 cm for fish caught by traditional fishers from the Arabian Sea Coast of Oman.

LWR parameters are key in determining fish health. Information gleaned from this parameters is useful in determining the condition index, GSI and the overall state of the fish (Muhammad, Farooq, Rabbaniha & Malik, 2017). The heavier a fish the better its condition of health. Length-weight relationships from various studies show that *T. lepturus* exhibits positive allometric growth (Fofandi, 2012; Avinash, 2014; Udo et al., 2014). On the contrary, Muhammad et al. (2017) reported negative allometric growth trend in *T. lepturus*.

The condition factor (K) of a fish reflects physical and biological circumstances and fluctuations by interaction among feeding conditions, parasitic infections and physiological factors. Variations in the condition factor of a population indicates the changes in feeding intensity, nutritional quality and quantity as well as gonadal maturation, whether spawning or not and therefore an indicator of the general fish condition. Condition factor is also a useful index for the monitoring age and growth rates in fish. Condition factor decreases with increase in length and also has influence on the reproduction cycle of fish. It is strongly influenced by both biotic and abiotic environmental conditions and can also be used as an index to assess status of aquatic ecosystem in which fish live (Yousuf, Tabassum, & Elahi, 2012). Condition factor of fishes also show variations with respect to season and length groups. Various studies on the condition factor of the ribbonfish have noted that as the length of the fish increases the condition factor decreases (Yousuf et al., 2012).

Stock assessment methods essentially work with age composition. In temperate waters, age of individual fishes is easily determined by counting the annular rings on hard parts viz., otoliths and scales. The annular rings are formed due to extreme fluctuations in environmental conditions from summer to winter and vice versa. In tropical waters such extreme changes do not occur and it is difficult to use seasonal rings for age determination. Hence for age determination in tropical systems, the von Bertalanffy Growth Model is used which converts length-frequency data into age composition (Ghosh, Rao, Rohit, Rammohan, & Maheswarudu, 2014). In most studies conducted on the ribbonfishes, length-frequencies, whole or sectioned otoliths have been employed in aging the fish.

Sizes at which *Trichuirus lepturus* attain maturity vary quite slightly among various studies. Reuben, Vijayakumaran, Achayya, & Prabhakar (1997) in their study found out that the size at which 50 % of the fish attain maturity for *T. lepturus* was estimated to be 42.5 cm. This size according to the study was attained by the fish in nine months. The size at which 100 % of the fish mature was estimated as 48 cm which the fish attains in 11 months. James et al., (1983) found it to be 43.1 cm. According to Abdussamad, Nair, & Achayya (2006) the size at first maturity is 47.3 cm and age is 7.7 months. Their study also observed gonadal development and sexual maturity in the species to be from 38 cm onwards. Ghosh, et al. (2014) also observed length at first maturity to be 61.2 cm and 52.9 cm in the Arabian Sea and Bay of Bengal respectively.

Avinash, Desai, & Ghosh (2014) in their study using the ELEFAN I estimated the asymptotic length, growth coefficient and age at zero length of *T. lepturus* to be 131.25 cm, 0.13 and -0.0777 years, respectively. The growth performance index was found to be 3.35 along the Vevaral Coast as the study reveals with recruitment pattern being trimodal with peak during May to July.

The length at recruitment was 27 cm. Total, natural and fishing mortalities were 0.44, 0.13 and 0.31.

Reproductive status of *T. lepturus*

Major events in the life history of fishes include reproduction and recruitment and these contribute the main determinants of yield. Knowledge of the spawning ground and spawning seasons, gonadosomatic index, age at sexual maturity, fecundity, oocyte diameter and maturation are all helpful in determining the reproductive status of the fishery. Most reproductive studies on the ribbonfish have been carried out in Indian waters and in the Arabian seas (Al-Nahdi et al., 2009; Ghosh, et al., 2014). According to Khan (2006) spawning season of the ribbonfish in Indian waters is mostly within the period of October to May and the minimum size at maturity is 75 cm.

Females of *T. lepturus* in tropical regions spawn more than once in a reproductive season with sex ratio favouring females, particularly in larger size length classes (Al-Nahdi et al., 2009; Ghosh et al., 2014). Various studies have reported that females attain larger sizes and become heavier than males of the same age mostly after reaching sexual maturity (Al-Nahdi et al., 2009; Ghosh et al., 2014). This observation in differential growth may reflect a higher reproductive investment by males (Martins & Haimovici, 2000).

Trichiurus lepturus are typical of multiple spawners. Spawning has no regular periodicity and they spawn almost all year round with peaks from March to June (Kwok & Ni, 1999). In other waters such as the Arabian sea, peak spawning season was from December to March (Ghosh et al., 2014). Kwok & Ni (1999) reported that spawning takes place almost all year round and peaks from March to June from a study conducted in the South China Sea.

Al-Nahdi et al. (2009) also reported a mass spawning season of May to June in the Arabian Sea region. Again, Patadiya et al. (2017) reported peak spawning on the west coast from April – June and along the east coast from February to June in Indian waters.

Examining the size frequencies of ova in ribbonfishes of different stages of maturity showed the progression of only one major batch of ova developing from immature to mature stages. Different spent stages occurring in the fishery with the same sized dominant ova indicates that mature ova are not released at one time but in spurts over a period. James et al., (1983) stated that two major lots of ova mature and succeed one another, each lot being released at least in three batches.

The near absence of spawning fish in the commercial catches and the scarcity of eggs and larvae in routine plankton collections led some authors (Prabhu, 1950; Narasimham, 1972 and James et al., 1986) to presume that *T. lepturus* moves away from the usual fishing grounds for breeding in Visakhapatnam waters in India.

Findings of Reuben et al. (1997) corroborated that of the aforementioned authors. The aforementioned authors also stated the presence of specimens in various degrees of partial spawning in the fishery during breeding season could be an indication that the fishing ground is not far away from the breeding ground. It was also suggested that the breeding ground of the ribbonfish occurs in offshore waters beyond 30 m depth off Visakhapatnam coast. A certain degree of overlap is therefore expected between the breeding and fishing grounds.

Ovaries of the female *Trichiurus lepturus* are attached to the body cavity by the dorsal mesentery, are paired and elongate in shape. The left and right lobes, fused together are of equal length but are separated laterally by a membrane (Kwok & Ni, 1999). Khan (2006) reported that fecundity varies between 4,900 and 81,000 with a relative fecundity of 65 ova/gram of body weight. Total fecundity ranged between 23,756 and 208,300 along northern Arabian Sea and 21,672 and 156,695 along northern Bay of Bengal (Ghosh et al., 2014).

Lutjanus fulgens

Snappers are amongst the most known, tasty and preferred demersal fish species in Ghana. They belong to the family Lutjanidae characterized by an active, voracious and carnivorous lifestyle. The external diagnostic features of the golden African snappers, *Lutjanus fulgens* includes a moderately slender body, blunt head with short snout; which is much shorter than eye diameter. Compared with other various species of the Lutjanids, the head of the golden African snapper is relatively blunt. They are characterized by very large eyes; with a narrow pre-orbital bone, its width less than half the eye diameter. The meristic features of the golden African snapper include dorsal fin with 10 spines and 13 or 14 soft rays; and anal fin with 3 spines and 8 soft rays. The pectoral fins are short, not reaching level of anus and the tail fin is emarginate. Scales of the golden African snapper are moderate-sized, about 43 to 46 in lateral line. The golden African snappers have a red colouration; the dorsal side and sides of the fish are vivid pink with golden longitudinal bands; with a silvery white colouration on the lower sides and belly; sides with horizontal golden bands, one per scale row (Allen, 1985).

Mode of exploitation in Ghana

There are about five different types of snappers belonging to the family Lutjanidae which occur in Ghanaian waters. The most common amongst them are the red snappers (*Lutjanus fulgens)* known as "Okpolo" or "tan" in the local Ghanaian dialect and can attain a total length of about 60 cm (Kwei & Ofori-Adu, 2005). They are good food fishes and have high commercial value contributing about 1.08% of total catch in 2009 (Catch Data, FSSD). Following seabreams, snappers had the highest catch rates of (4.9 kg/h) in the outer shelf (51 - 100 m) among the most commercially important demersal species in the recent survey of the Dr. Fridtjof Nansen of the Pelagic and Demersal Resources in Ghanaian waters in 2019 (Nikolioudakis et al. 2019). In the report, the estimated total biomass of valuable demersal groups was 14,959 tonnes.There is the predominance of hook-based fishing gears in the exploitation of demersal species with a few caught in bottom trawls. Seabreams such as *Dentex gibossus, Pagrus caeruleosticus, Dentex canariensis* and snappers of which include, *Lutjanus dentatus*, *Lethrinus spp* and *Lutjanus fulgens* among other demersal species comprise of these catches. *Lutjanus fulgens*, in Ghana are mostly exploited by hook and line and a few bottom trawls and predominatntly exploited by the artisanal and inshore trawlers. They are sold in pans or wooden crates with other demersal fishes by women.

Habitat Distribution and Ecology of *Lutjanus fulgens*

These fish species normally occur on rocky bottoms to at least 60 m depth and could also be found in deeper offshore waters. Their diet primarily comprises of fishes and crustaceans. They are distributed along the West

African coast, primarily between Nigeria and Senegal, and in the Gulf of Guinea; also at the Cape Verde Islands (Allen, 1985). Snappers are voracious predators feeding mainly at night on a wide range of items, tending to be more piscivorous. Other component of their diet includes: crabs, shrimps, various other crustaceans, gastropods, cephalopods, and planktonic organisms.

Mehl, et al., (2004). reported in their findings following the survey of the pelagic and demersal resources of the Western Gulf of Guinea by "DR. FRIDTJOF NANSEN", (Benin, Togo, Ghana & Cote D'Ivoire) that snappers were found in relatively high catch rates in the outer shelf (i.e. 51-100 m) of Ghanaian waters but not in the outer shelf of neighbouring countries; Ivory Coast and Togo. Snappers were the second most important family on the inner shelf (i.e. 0-50) in Togo.

Growth and Mortality of *Lutjanus fulgens*

Various studies conducted on the age, growth and mortality estimates of populations of snappers especially the tropical ones indicate that they are slow-growing, long-lived and with low natural mortality. The maximum ages for the family Lutjanidae are species specific, and estimates range from 4 to > 40 years with an average maximum age of about 20 years (Fry & Milton, 2009; Nanami et al., 2010; Shimose & Nanami, 2014). Several studies have shown sex differences in growth exist among species. Nanami et al. (2010) among other authors have shown that males grow larger than females. In contrast, other previous studies have shown that females grow larger than males. Females tend to have maximum length than that of males for some lutjanid species, such as *Lutjanus fulvus* (Shimose & Nanami, 2014) and the Brazillian snapper, *Lutjanus alexandrei.* Conversely, other studies conducted on other lutjanid species have also shown that the maximum length of males is larger than that of females in species of which includes *L. adetii* and *L. quinquelineatus* in Australia, *Lutjanus gibbus* in Japan, *L. argentiventris* in Colombia and *L. guttatus* in Costa Rica (Newman, 1995; Fernandes, Oliveira, Travassos, & Hazin, 2012) .

Reproductive status of *Lutjanus fulgens*

Knowledge of the reproductive potential of fish stocks is an indispensable biological characteristic which should be included in quantitative assessments so as to provide fisheries scientists and managers with realistic tools for making firm and accurate predictions and management towards fish stock recovery (Domínguez et al., 2017). Information derived from reproductive studies can be used in ascertaining the age and size at which fish attain sexual maturity, the time and place of spawning and the duration of their reproductive cycle right from the beginning of the development of the ovary to the final stage of releasing eggs. Together with fecundity estimates this information can be used to calculate the size of the stock and its reproductive potential.

Lutjanids are known to be dioecious and display little or no sexual dimorphism in structure or in colour. They display a gonochoristic reproductive pattern; that is, following sexual differentiation, the sex remains constant throughout the life cycle. On the average, most lutjanids reach first maturity at about 43 to 51% of the maximum total length, with males maturing at a slightly smaller size than females (Allen, 1985). Lunar periodicity is associated with spawning aggregations of some *Lutjanus* species and such information is essential because targeting these aggregations at known times and locations could result in overexploitation (Shimose & Nanami, 2014).

Studies on sex ratio is very essential since it provides information on the proportion of male to female fish in a population as well as indicates the dominant sex of a particular population and provides basic information needed for fish reproduction and stock size assessment. In some studies on the reproductive biology of *Lutjanus* species, sex ratio often tends to favour females (Render, 1995; Nanami et al., 2010; Shimose & Nanami, 2014). Contrary, other studies find male dominance in the sex ratio (Fernandes et al., 2012). Some studies also find sex ratio not significantly different from the normal 1:1 (Luckhurst, Dean, & Reichert, 2000; White & Palmer, 2004; Fakoya, Anetekhai, Akintola, Saba, & Abass, 2015). Some snappers, however, spawn in offshore aggregations and usually a paired sex ratio is more common. Starck (1970) reported that males of *Lutjanus griseus* in Florida are generally more abundant in reef areas around islands while females are more abundant in coastal areas due to their spawning behaviour.

Gonadosomatic index acts as a good proxy of maturity stage in fish species. Gonad growth occurs at the expense of depletion of energetic reserves which accumulates in other tissues such as the liver, muscle, mesenteric fat, etc (Domínguez et al., 2017). Shimose and Nanami (2014) in their study found that individual GSI of females often exceeded a value of 6.0 and even more during the spawning season while that of males did not exceed 5.0 even in the peak spawning months. Nanami et al., (2010) also reported GSI of females as low as 0.05 and also as high as 15.0 as a result of monthly changes in the frequency of the gonadal phase for females. Lutjanids are known to be batch-spawners with individual females generally spawning several times each season. The eggs of lutjanids are pelagic and are generally spherical with diameters ranging between 0.65 to 3.02 mm, although the eggs of most species are less than 0.85 mm. They are characterized by a single, small oil droplet which provides buoyancy during the pelagic stage (Allen, 1985).

Information emerging from the literature review forms the basis for developing strategies and methods for this study. The succeeding chapter gives an overview of the materials and methods employed in achieving the objectives of this study.

CHAPTER THREE

MATERIALS AND METHODS

Study Area

The study was conducted along the coast of Ghana at three important fish landing sites. These study sites were Tema, Elmina and Sekondi in the Greater Accra, Central and Western Regions of Ghana respectively (Figure 1).

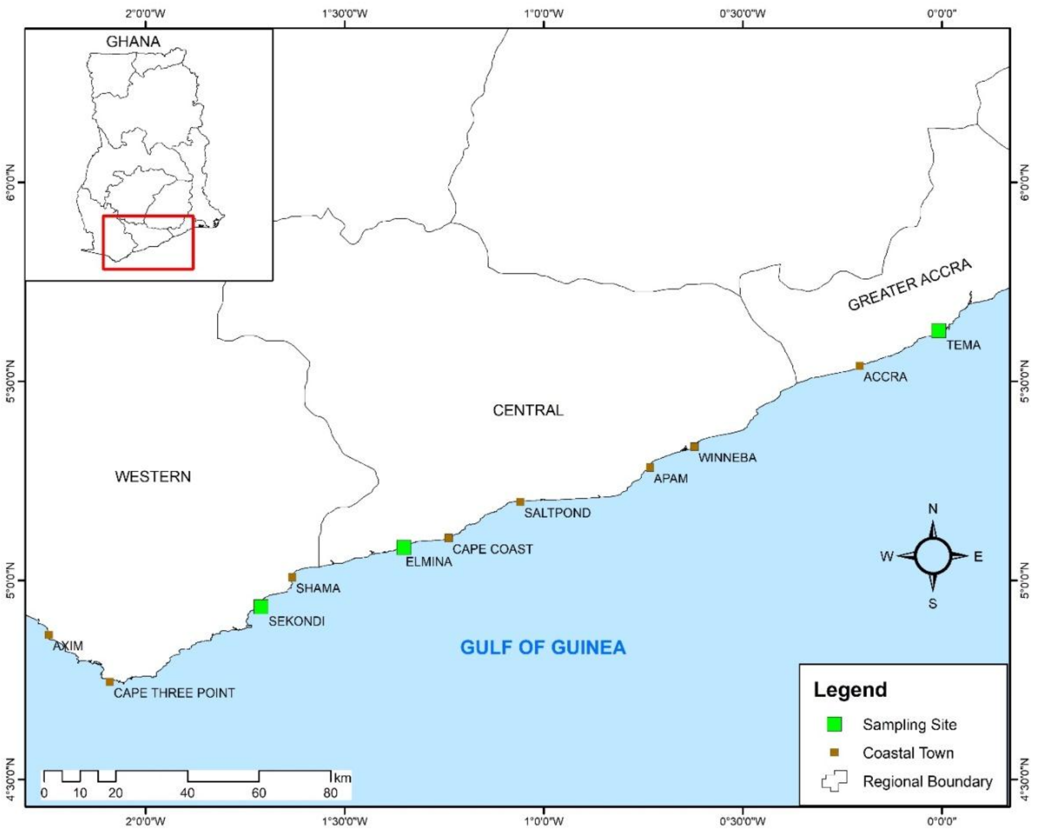

Figure 1: Fish sampling locations along the coast of Ghana

More intensive sampling may increase precision and reduce bias but identifying and accounting for the ecological, demographic, or habitat-related factors that affect sampling efficiency will produce the most reliable estimates of fish population parameters. Against this backdrop, the aforementioned sites were chosen for data collection since they represent sites in the three geomorphologic zones of Ghana's coast. In addition, these sites capture all the major fish markets where artisanal catches are landed along the coastline of Ghana.

According to Armah, (2005), the coastal zones of Ghana are divided into three geomorphologic zones; West Coast, Central Coast and East Coast. In Ghanaian waters, which is part of the Gulf of Guinea, sea surface temperatures in the region typically show two distinct periods, associated to upwelling periods - colder periods during the minor and major upwelling periods in any three weeks from December to March and July to September respectively, with temperatures averaging 26.5°C; and a warmer part of the year with temperatures increasing up to 28.5°C during the periods of no upwelling (Dovlo, Amador, & Nkrumah, 2016).

In the west coast geomorphologic zone of Ghana, fish samples were obtained from the Albert Bosomtwi-Sam Fishing Harbour (4°56’28.91’’N, 1°42’29.35’’W). The harbour is situated at Sekondi in the Western Region. Fish samples were obtained from fishermen and fishmongers at the canoe basin of the harbour.

In the east coast geomorphologic zone, fish samples were also obtained from the Tema Fishing Harbour (5°38’39.43’’N, 0°0’58.55’’E). Small pelagics and bentho-pelagics and demersal fish species are landed in the area.

The central coast geomorphologic zone captures Elmina Fish Market (05°4’57.14’’N, 1°21’2.29’’W) where fish samples were collected. Fish samples were collected monthly from landings of fishermen from September 2018 to June 2019 at all three landing sites except in May, 2019 due to closed fishery in Ghanaian waters. In July and August 2019, samples were collected onboard the Fridtjof Nansen Research Vessel during the Transboundary

Demersal and Pelagic Resources and Ecosystems Survey in the western Gulf of Guinea which covered Ghana and Cote d'Ivoire.

Sample Collection

There is the predominance of hook-based fishing gears in the exploitation of demersal species with a few caught in bottom trawls. Seabreams such as *Dentex gibossus, Pagrus caeruleosticus, Dentex canariensis* and snappers of which include, *Lutjanus dentatus, Lethrinus spp* and *Lutjanus fulgens* among other demersal species comprise of these catches. The species of interest to this study (*Lutjanus fulgens*) were mostly exploited by hook and line and a few bottom trawls. They were sold in pans or wooden crates with other demersal fishes by women. Ribbonfishes on the other hand were mostly caught with bottom trawls and beach seines along the coast of Ghana. Landed fish were sold in the early hours of the morning.

Trichuirus lepturus, a benthopelagic fish (Plate 1) and *Lutjanus fulgens* (Plate 2) were the species of interest to this study. These two species were of interest to study because they are commercially important species exploited for food in the waters of Ghana. They occur in Ghanaian coastal waters and are relatively long lived. They are easy to sample and are locally exploited.

Plate 1: Photo showing ribbonfish, *Trichuirus lepturus*

Plate 2: Photo showing golden African snapper, *Lutjanus fulgens*

Monthly samples were obtained randomly from the fisherfolks with a sample size of approximately 100-200 specimens of *T. lepturus* and 10-150 specimens of *L. fulgens* collected at all three landing sites per month. Samples collected were put on ice in an ice chest and carried to the laboratory of the Department of Fisheries and Aquatic Sciences for sorting and identification. From the Research Vessel, samples of *Lutjanus fulgens* were collected from bottom trawls whilst *T. lepturus* samples were collected from both pelagic and bottom trawls. The specimens were obtained and worked on onboard the vessel as and when they occurred in the sample.

Morphometric Measurements

Various length measurements including total length (TL), standard length (SL), and fork length (FL) for *L. fulgens* and total length (TL) and preanal length (PAL), for *T. lepturus* of each specimen were measured to the nearest 0.1 cm using a fish measuring board. Body weight (BW) for each specimen was also taken using Ohaus balance (Model: Ranger 7000) to the nearest 0.01g.

Length–Weight Relationships

The most commonly used relationships, that have been established for the majority of fishes are those relating weight to body length (in the majority of cases, total length (TL)), and different types of length (i.e., standard (SL) and fork (FL) length) to TL. Weight (W)-length (TL) relationships are of power type, i.e., $W = aTL^b$. In this equation, *a* is the coefficient of body shape and it gets values around 0.1 for fishes which are small sized and with a rounded body shape, 0.01 for streamlined-shaped fishes and 0.001 for eel-like shaped fishes. In contrast, *b* is the coefficient balancing the dimensions of the equation and its values can be smaller, larger or equal to 3. In the first two cases (i.e., $b<3$ and $b>3$) fish growth is allometric (i.e., when $b<3$ the fish grows faster in length than in weight, and when $b>3$ the fish grows faster in weight than in length), whereas when $b=3$ growth is isometric (Karachle & Stergiou, 2011). The weight–length relationships for each species was estimated following the most common approach by Froese (2006), using the log form of the equation:

$W = aTL^b$, where W is the total body weight (g) and TL is the fish total length (cm), *a* is the intercept of the regression and *b* is the growth coefficient. In order to confirm whether *b* values obtained were significantly different from the isometric value (3), a t-test (H_0: $b = 3$) with a confidence level of 95% ($\alpha = 0.05$) was applied. Goodness-of-fit of the regressions were given by the coefficients of determination (r^2) and coefficient of correlation (r). The regression analysis was carried out using MS Excel.

Condition Index

The condition factor (K) value for each species was also calculated following Froese (2006);

$K = W \times 100 / L^3$,

where W is the total body weight and L is the total length.

Growth Performance Index

The growth performance index for each species was calculated using the formula:

$Ø' = \log K + 2 \log L_\infty$

where Ø' = growth performance index, L_∞ = Asymptotic length, K= Growth coefficient.

Growth Parameters

The R package TropFishR (Mildenberger et al., 2017) was used to assess the growth and mortality parameters following the steps outlined in the vignette on TropFishR ELEFAN functions. TropFishR has traditional and updated versions of the Electronic LEngth Frequency ANalysis (ELEFAN) method (Pauly, 1980), used in growth parameter estimation, with new optimization techniques (Mildenberger et al., 2017) and a complete set of methods for fisheries analysis with Length Frequency data.

ELEFAN is a method to estimate growth parameters of the von Bertalanffy Growth Function (VBGF) from the progression of LFQ modes through time (Pauly, 1980). It requires a vector with the mid-lengths of defined length classes, a matrix with catches in numbers per length class (rows) and per sampling time (columns), and a vector with the dates of the sampling times. The ELEFAN estimates the growth parameters following 3 steps: (i) "restructuring" of LFQ data according to a procedure that scores length bins based on deviations from a moving average across neighboring bins, (ii) calculation of the cumulative score for a given set of VBGF parameters based on the bin scores that are intersected by resulting growth curves, and (iii) search for VBGF parameters that result in the maximum score value (Mildenberger et al., 2017). After the LFQ adjustments, a bootstrapped ELEFAN with genetic algorithm optimization function (bootstrapped ELEFAN_GA) was applied to the LFQ, allowing assessment of the uncertainties around the growth estimates. Total length measurements grouped into bins of 2 cm class intervals for *Lutjanus fulgens* and *Trichiurus lepturus* were used to assess the growth parameters of the species using von Bertalanffy growth function. The VBGF parameters were assessed using a moving average (MA) over 7 size intervals.

Growth rate (K), asymptotic length (L_∞) and the growth performance index (ϕ') of each species was estimated using the VBGF. The Z/K ratio was calculated using Powell-Wetherall Plot. Pauly's empirical equation: $\log10(-t_o) = -0.3922 - 0.275 * \log10 L_\infty - 1.038 K$ was used to estimate the theoretical age at birth (t_o).

Mortality Parameters and Exploitation Ratio

The length-converted catch curve of each species was used to estimate the total mortality rate (Z). Natural mortality rate (M) was calculated using the empirical formula as suggested by Pauly (1983):

$$\log(M) = -0.0066 - 0.279 \log(L_\infty) + 0.6543 \log K + 0.4634 \log(T),$$

where M = natural mortality, L_∞ is the asymptotic length of the fish and K refers to the growth coefficient. The value of T is the annual mean temperature (in °C) of the sea.

The difference between (Z) and (M) from the equation; F = Z – M was used to calculate the fishing mortality rate, F and the exploitation ratio (E) was calculated by the quotient between fishing and total mortality:

E = F/Z, (Pauly, 1984).

Longevity of the various fishes was also calculated by using the formula:

$t_{max} = 3/K$, where t_{max} is the longevity of the fish in question.

Reproductive Biology

Sex ratio

Each specimen was dissected and the gonads excised. The sex of each specimen was identified by examination of the gonads. The proportion of the two sexes relative to each other was used to calculate the sex ratio for each species.

Length at first sexual maturity

Lengths at first sexual maturity of both males and females of *T. lepturus* and *L. fulgens* were estimated using logistic ogives in a graphical plot fitted to the proportion of mature fish in 2 cm length classes.Specimens with gonads stage three (III) and above were considered mature. Length at which 50 % of the individuals mature, L_{50} was estimated as the point on the x-axis corresponding to the point at 50% on the y-axis. The maturity curve was fitted by the equation:

$P_L = 1/\ 1 + e^{-b(L - L50)}$ where P_L = the proportion of mature individuals in each length class, *L* = Total length class and *b* = the slope

Stages of gonadal development

By eye examination or macroscopic observation, sexes of *Trichiurus lepturus* and *Lutjanus fulgens* could be easily determined especially in specimens which were beyond the immature virgin stage; ovaries are usually tubular, orange, and granular while the testes are more flattened and whitish. Gonadal stages were examined macroscopically and graded on a scale adopted by Holden & Raitt (1974) as follows:

I- Immature:

II- Maturing virgin and recovering spent

III- Ripening

IV- Ripe

V- Spent

Gonadosomatic index

Gonadosomatic index (GSI) was determined separately for males and females to assist in determination of spawning period. The recorded fish body weight and ovarian weights were used to calculate the gonadosomatic index according to Devlaming, Grossman, & Chapman, (1982) as:

$$GSI = 100 \times GW/W$$

where GW is the gonad weight and W is the fish body weight.

Fecundity

For fecundity estimation, ripe gonads in specimens bearing them were extracted and weighed on Ohaus micro scale to the nearest 0.01 g and preserved in Gilson's fluid in labeled containers for over ninety (90) days. The containers were thoroughly shaken to free the eggs completely from the ovarian tissues. The eggs were then washed gently using distilled water and decanted to get rid of immature eggs and excess water. The eggs were then poured unto labeled 150 mm diameter filter paper in a funnel to get rid of excess water. After draining completely, they were thoroughly spread on the labeled filter papers and put to dry in the oven at a temperature of 50°C for 12 hours. The dried samples were kept in a desiccator until they were ready to be worked on. Remnants of the ovarian tissues were carefully picked out and clamped eggs were gently separated. The dried eggs were weighed using Ohaus Micro Balance to the nearest 0.0001g and recorded. Three random subsamples were taken from the dried eggs of each specimen, weighed and counted. The number of eggs was estimated by sub-sampling method where the total number of eggs was weighed and three (3) random samples weighed and counted.

Fecundity for the various specimens was calculated using the formula by Bagenal, (1978):

$$F = nG/g$$

where F = fecundity

n = number of eggs in the subsample

G = total weight of the ovaries

g = weight of the subsample in the same units.

Data analysis

Data analysis was carried out according to each research objective using Microsoft Excel 2016 and the routines in TropFishR package in the R software. The means of male and female Gonadosomatic Index and Condition Index were subjected to a Students t-test to infer whether there were any significant differences at 95% confidence interval (ρ = .05). Results of the b-values from the length weight relationships were also subjected to a

Student's t-test ($p<0.05$) in order to confirm whether *b* values obtained were significantly different from the isometric value of 3. Chi-squared test was used to test for differences in sex ratios for the various species. Unless otherwise stated, the means are expressed as mean ± standard error (Mean ± SE).

CHAPTER FOUR

RESULTS

Trawl stations along the coast of Ghana where populations of *T. lepturus* and *L. fulgens* were captured during the Fridtjof Nansen survey are shown in Fig. 2. Denser populations of *T. lepturus* and *L. fulgens* were observed in the western and central part of the coast as compared to a sparse distribution in the eastern part.

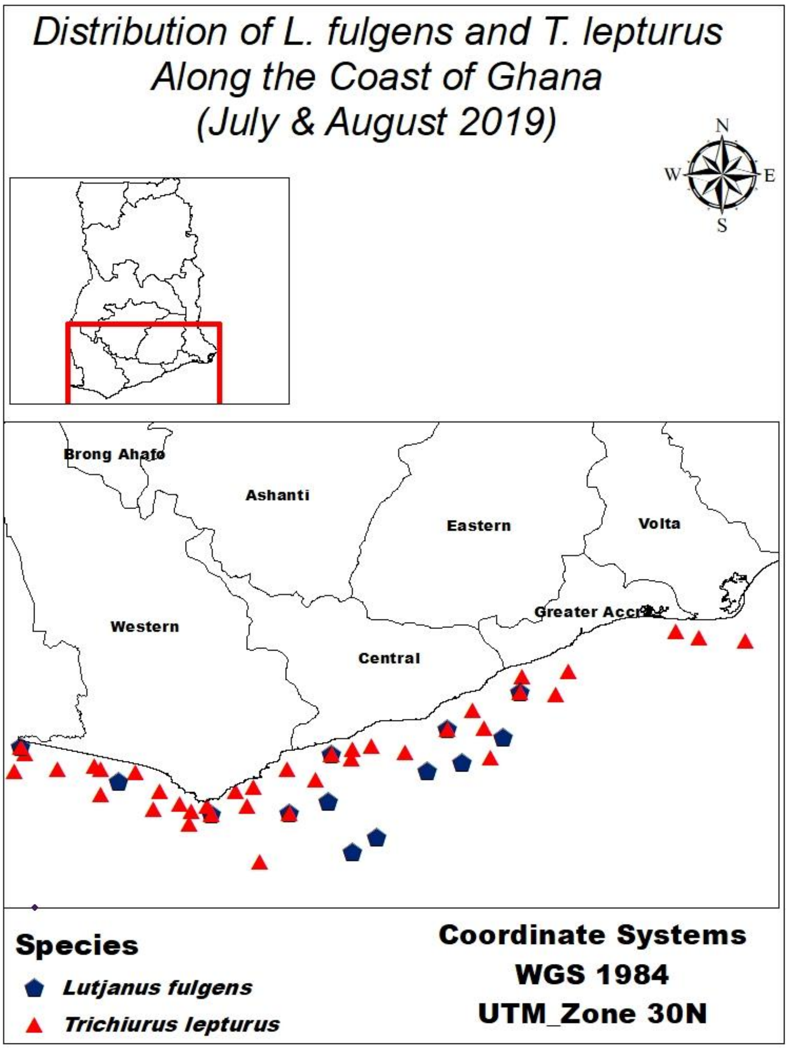

Figure 2: Distribution of *T. lepturus* and *L. fulgens* along the coast of Ghana (July and August, 2019)

Length Compositions of Fish Species

Trichiurus lepturus

A total of 1,677 specimens of *T. lepturus* (754 males, 696 females and 227 indeterminate individuals) were sampled from along the coast of Ghana during the study period. Total length ranged from 24.8 to 103.9 cm with a mean length of 57.2 ± 0.28 cm. The overall length-frequency distribution showed a modal length class of 50.0 – 59.9 cm indicating a unimodal distribution of *T. lepturus* (Fig 3).

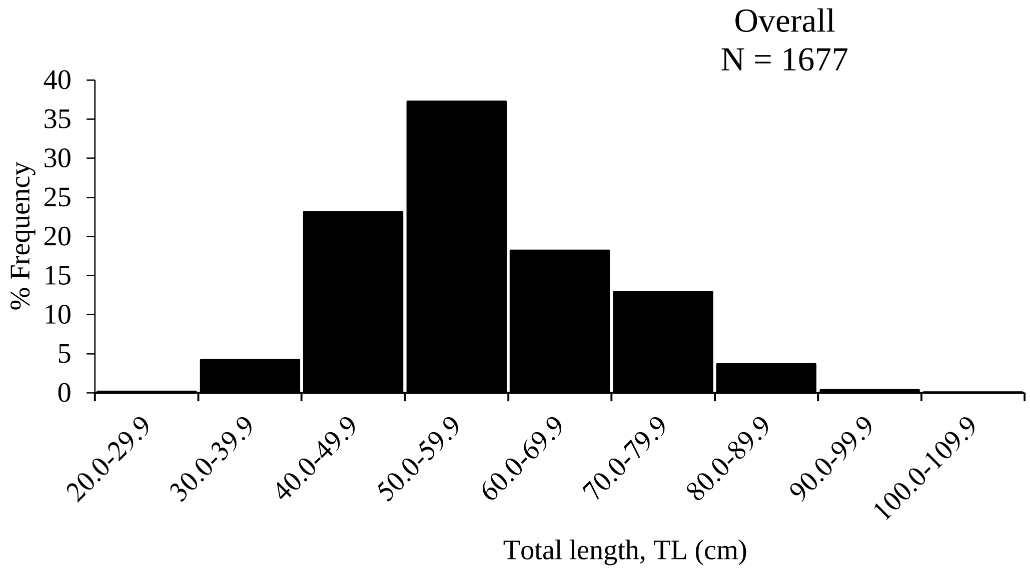

Figure 3: Length-frequency distribution of *T. lepturus*

Total length among the males ranged between 34.6 to 91.8 cm with a mean length of 57.9 ± 0.38 cm and weight ranging between 24.5 to 605.2 g with a mean weight of 142.9 ± 3.39 g (Fig. 4)

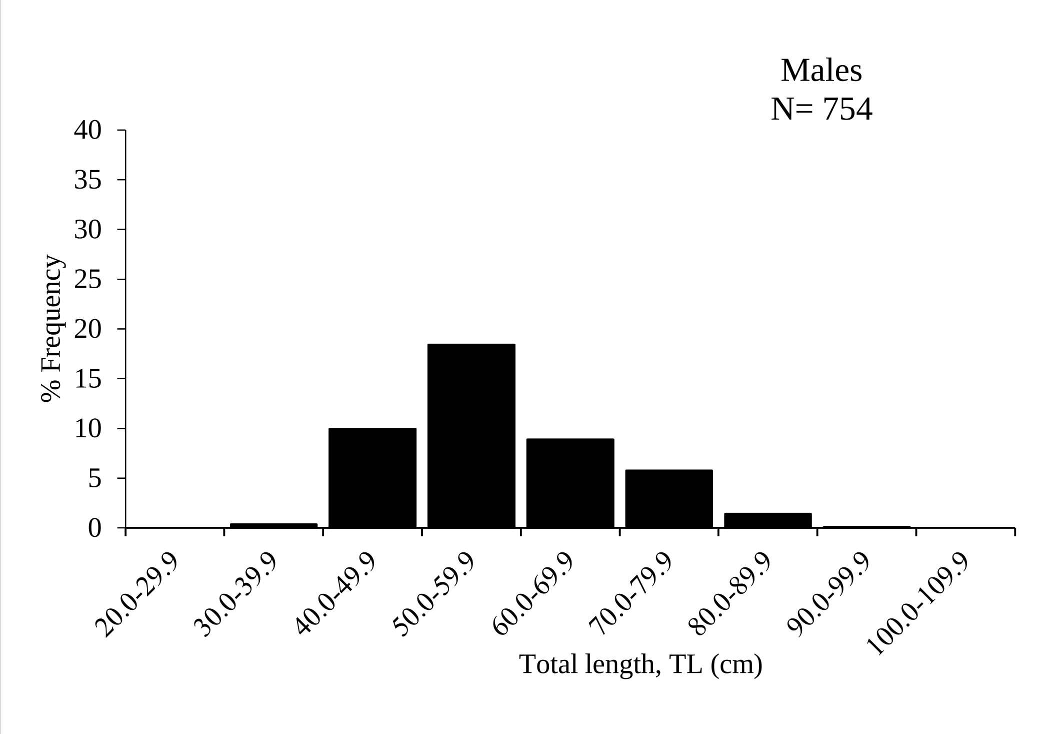

Figure 4: Length-frequency distribution of male *T. lepturus*

For the females, total length ranged between 35.7 to 103.9 cm with a mean length of 60.6 ± 0.43 cm and weight ranging between 25.0 to 939.9 g with an average weight of 167.3 ± 4.50 g. The length-frequency distributions of male and female *Trichuirus lepturus* show that larger fish were more likely to be females (Fig. 5).

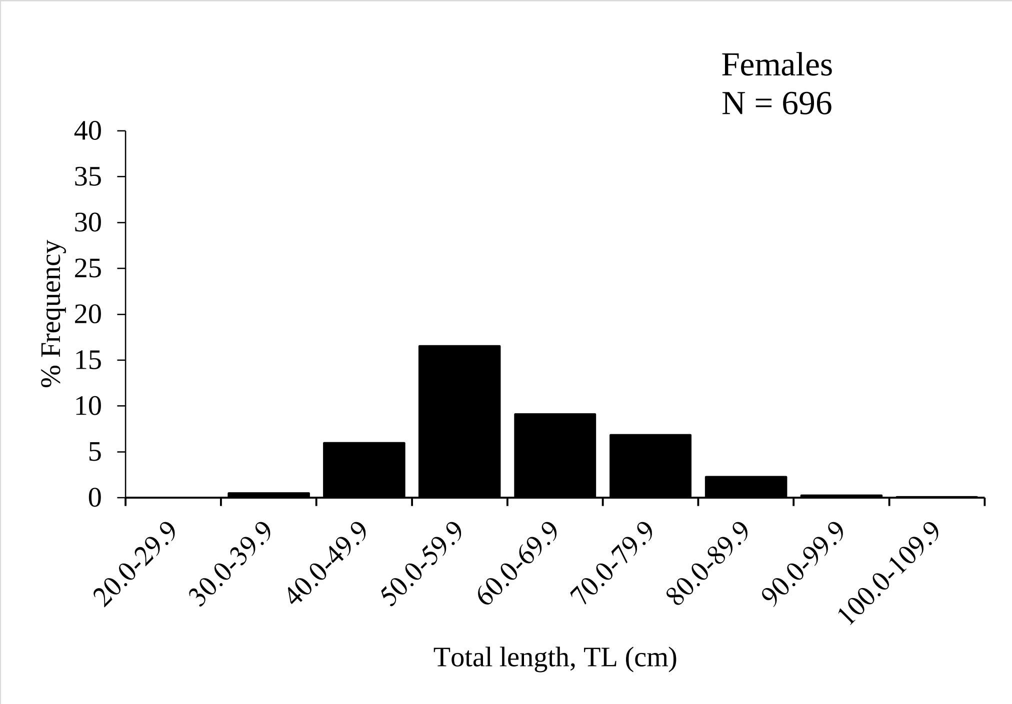

Figure 5: Length-frequency distribution of female *T. lepturus*

The indeterminate sexes are specimens whose sexes could not be determined macroscopically due to their size and state of immaturity. Total length ranged between 24.8 to 59.5 cm with a mean length of 44.4 ± 0.41 cm

Lutjanus fulgens

The size distribution of *L. fulgens* sampled from along the coast of Ghana during the study period were 906 specimens comprising of 425 males, 443 females, 38 indeterminate sexes. The total lengths ranged from 16.2 to 45.6 cm with a mean length of 28.2 ± 0.19. The overall length-frequency distribution showed a modal length class of 20.0 – 24.9 cm (Fig. 6).

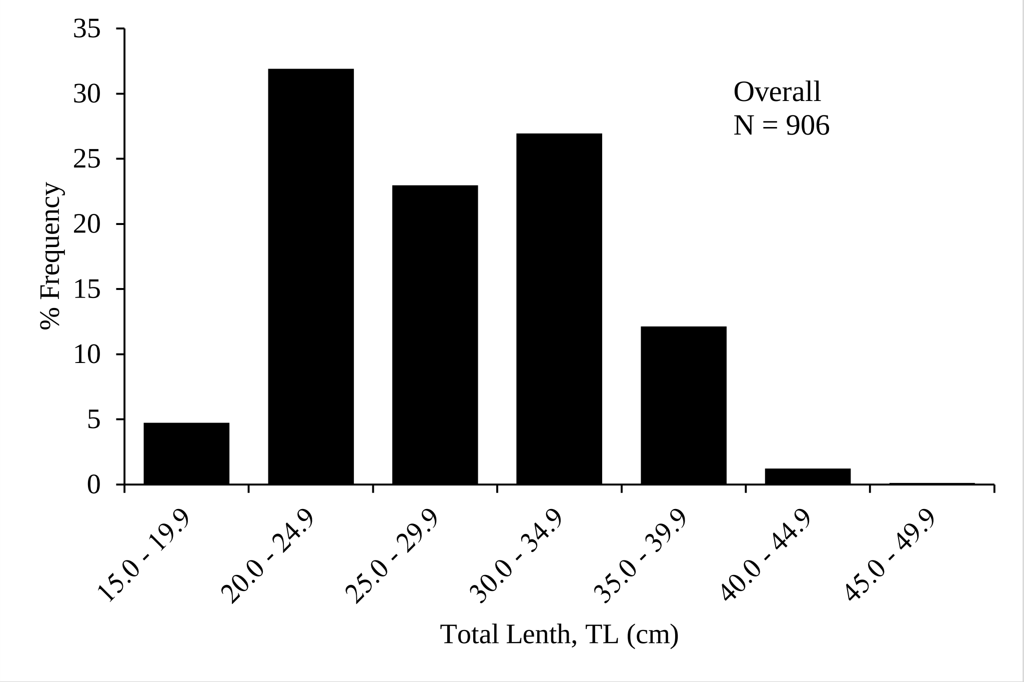

Figure 6: Length-frequency distribution of *L. fulgens*

Total length among the males ranged between 17.7 to 43.0 cm with an average length of 28.3 ± 0.29 cm and weight ranging between 69.8 to 1200.8 g with an average of 351.1 ± 10.51 g (Fig 7).

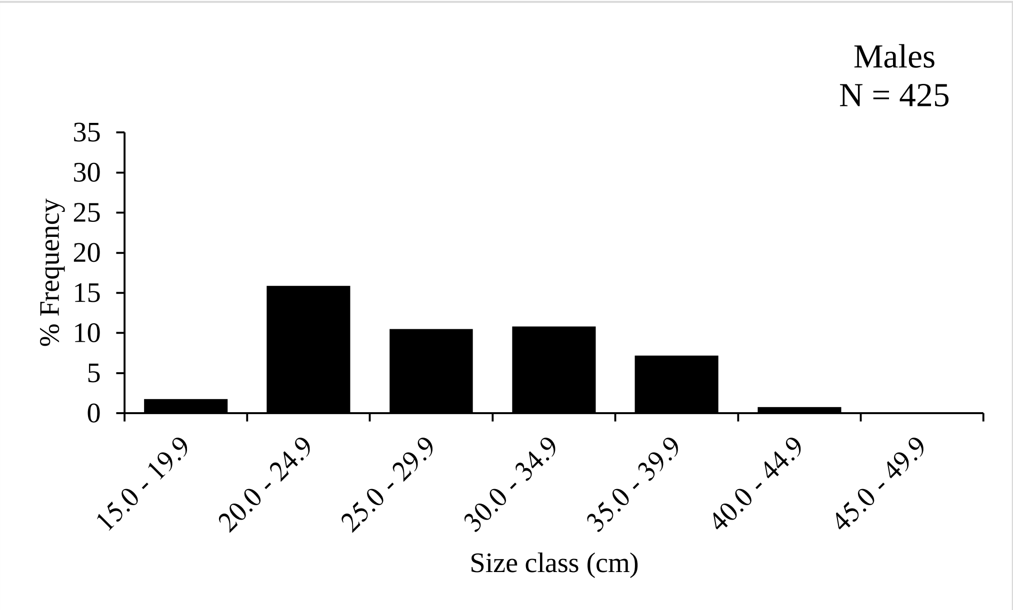

Figure 7: Length-frequency distribution of male *L. fulgens*

For the females, total length ranged between 16.2 to 45.6 cm with an average length of 28.6 cm and weight ranging between 58.0 to 1271.8 g with an average of 350.6 g. The length frequency of male and female *Lutjanus fulgens* shows that larger fish are more likely to be females (Fig 8).

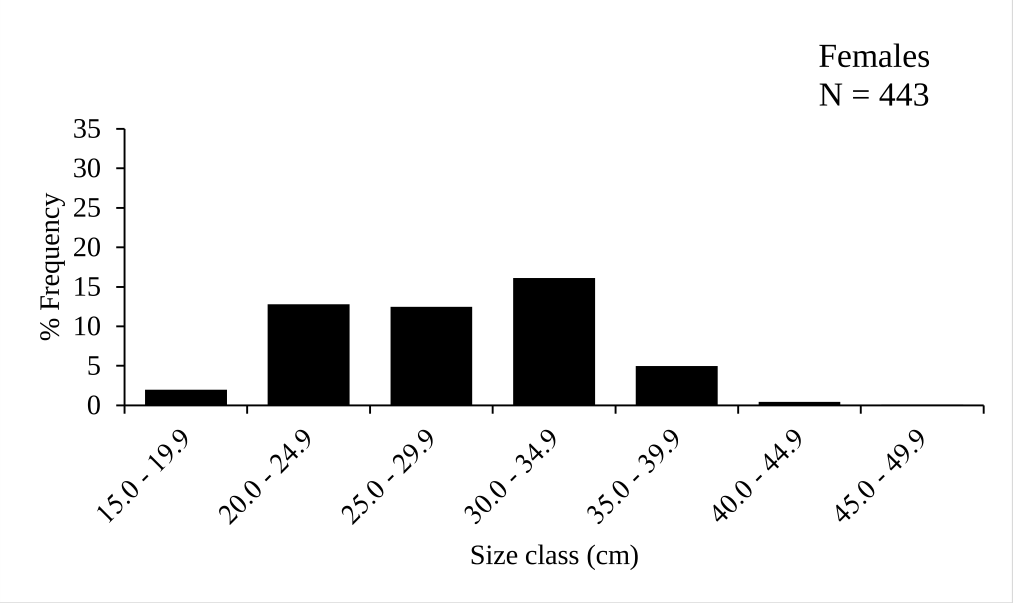

Figure 8: Length-frequency distribution of female *L. fulgens*

There were 38 specimens whose sexes were indeterminate due to the immature state and size of their gonads. Total length of these indeterminate individuals ranged between 16.5 to 24.8 cm with an average length of 21.0 cm.

Length-Weight Relationships

T. lepturus

The length-weight relationship of the *T. lepturus* population was described by the equation: $BW = 0.0002TL^{3.3437}$ (r = 0.98) where BW = body weight in grams and TL = total length in centimetres (Fig. 9). The power of the equation (b = 3.3437) was significantly different (t-test = 192.072; $p \leq 0.05$)

from the hypothetical value 3 indicating positive allometric growth. However, the regression coefficient (r) of the equation (0.98) indicated that there was a strong positive correlation between weight and length of the *T. lepturus* population.

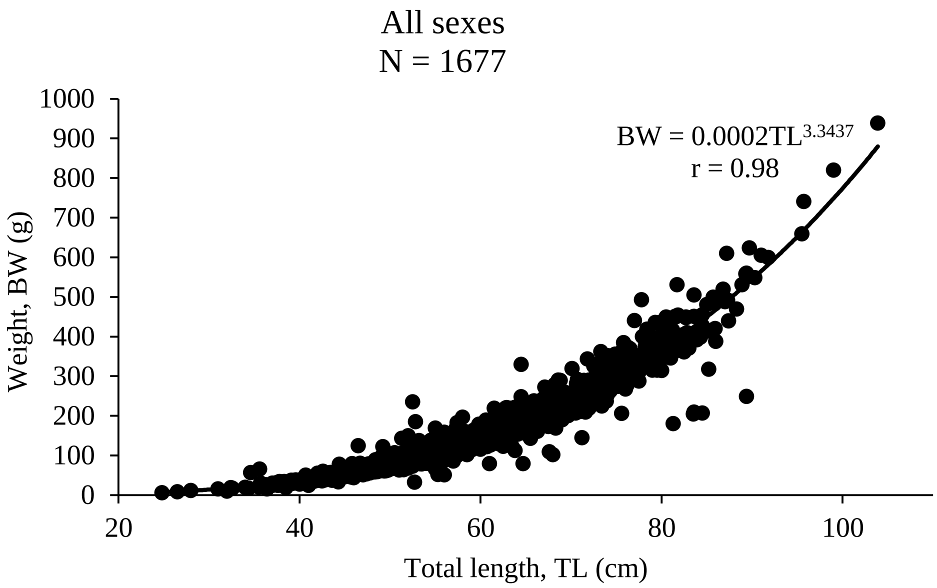

Figure 9: Length-weight relationship of *T. lepturus* along the Coast of Ghana

Length-weight relationships were also determined separately for the two sexes (male and female) of *T. lepturus* (Fig. 10 & 11 respectively).

The parabolic equations obtained from the regression analysis are as follows:

Males: $W= 0.0002TL^{3.2902}$ $(r = 0.97)$

Females: $W = 0.0002TL^{3.3698}$$(r = 0.98)$

Indeterminate sex: $W = 0.0001TL^{3.4665}$$(r = 0.96)$

The slope of the regression (b-value) obtained from the length weight relationship individually for males and females were each significantly different from the isometric value of 3 [(t-test = 111.044; $p \leq 0.05$ for males) (t-test = 118.347; $p \leq 0.05$ for females) indicating positive allometric growth.

For indeterminate sexes, the b-value also showed a deviation from the isometric value of 3 (t-test = 48.539; p≤0.05) and it shows that the fish grows at a higher rate than the cube of the length.

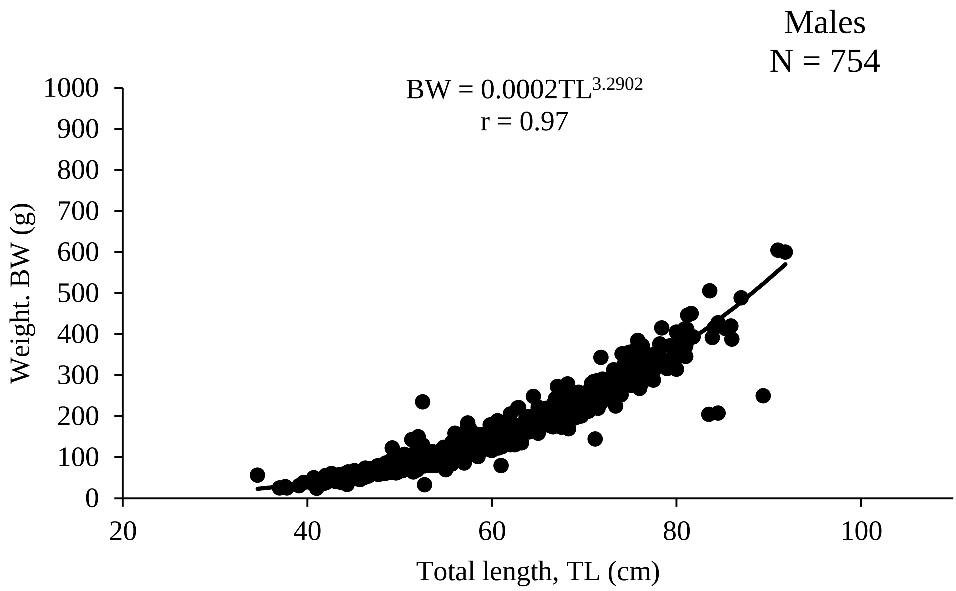

Figure 10: Length-weight relationship of male *T. lepturus* along the Coast of Ghana

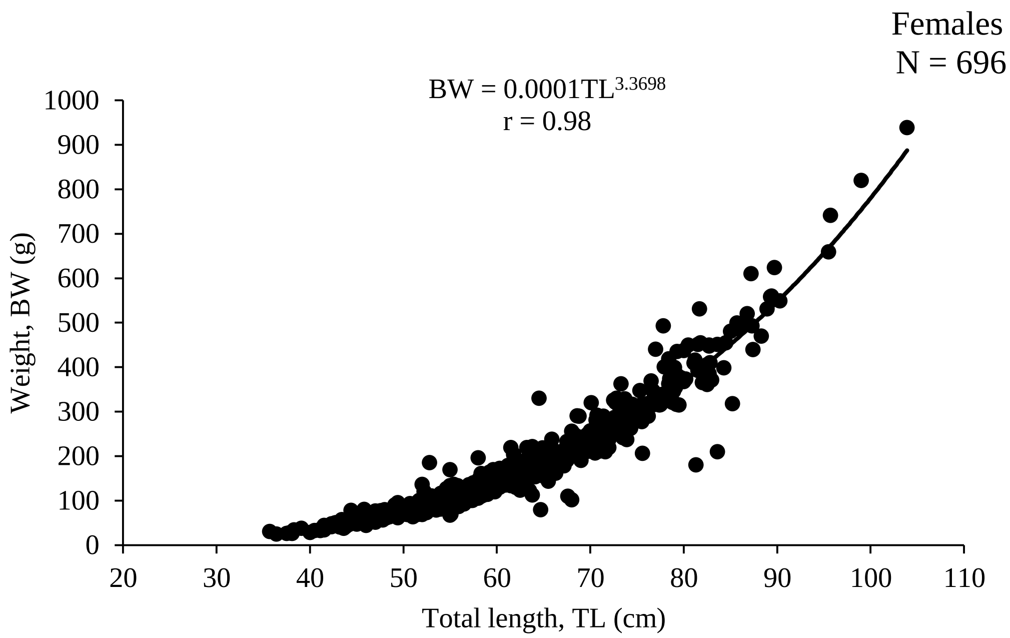

Figure 11: Length-weight relationship of female *T. lepturus* along the Coast of Ghana

L. fulgens

The relationship between body weight and total length of *L. fulgens* was established with the use of scatter plots. The length-weight relationship of the *L. fulgens* population was described by the equation: BW= $0.0192TL^{2.8959}$ (r = 0.97) where BW = body weight in grams and TL = total length in centimetres (Fig. 12). The power of the equation (b = 2.8959) was not significantly different (t-test = 126.3194; $p<0.05$) from the hypothetical value (3). The regression coefficient (r) of the equation (0.97) indicated that there was a strong positive correlation between weight and length of the *L. fulgens* population.

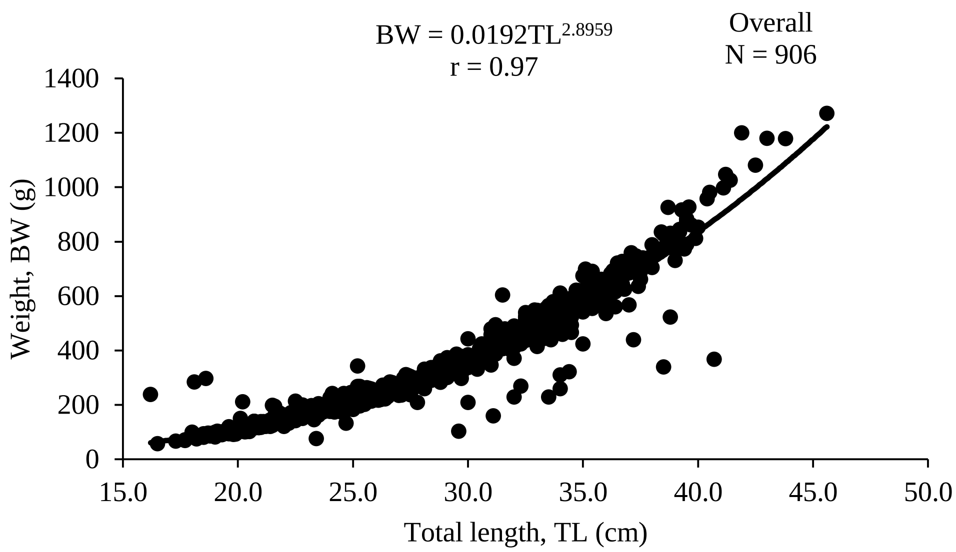

Figure 12: Length-weight relationship of *L. fulgens* along the Coast of Ghana

Length-weight relationships were also determined separately for the two sexes (male and female) and indeterminate sexes of *L. fulgens* (Fig. 13 & 14 respectively).

The parabolic equations obtained from the regression analysis were as follows:

Males: W= $0.0189TL^{2.9022}$ (r = 0.98)

Females: W = $0.0206TL^{2.874}$ (r = 0.96)

Indeterminate sex: W = $0.0166TL^{2.9362}$ (r = 0.98)

The slope of the regression (b-value) obtained from the length-weight relationships of males and females indicated isometric growth.

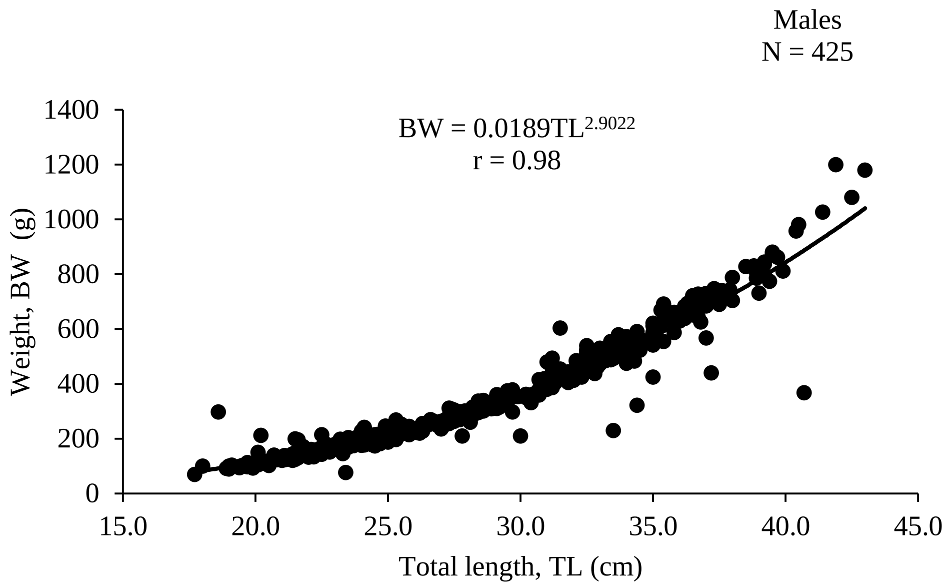

Figure 13: Length-weight relationship of male *L. fulgens* along the Coast of Ghana

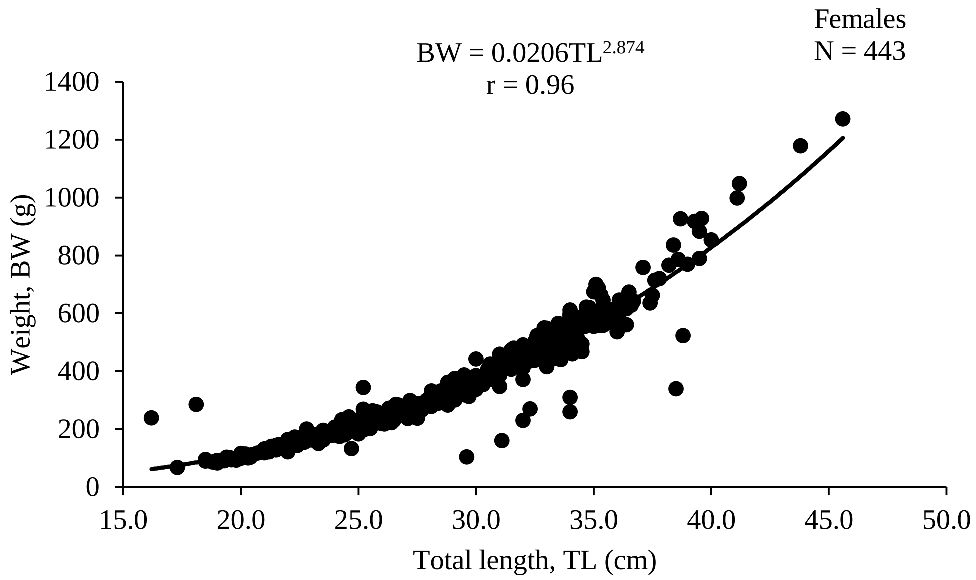

Figure 14: Length-weight relationship of female *L. fulgens* along the Coast of Ghana

Growth and Mortality Parameters

T. lepturus

The final estimates of growth and mortality parameters of *T. Lepturus* with 95% confidence interval is shown in Table 1.

Table 1: Growth and mortality parameters of *T. lepturus* and *L. fulgens* along the coast of Ghana (September 2018 – August 2019)

Growth parameters and Mortality parameters	*Trichiurus lepturus*
Asymptotic length (L_∞)	133.66 cm
Maximum observed length (L_{max})	103.9cm
Longevity (t_{max})	6.59 yr
Theoretical age at length, 0 (t_0)	-0.236yr
Growth constant (K)	0.46yr^{-1}
Length at first capture (L_c)	47.11cm
Length at first sexual maturity (L_m)	70.5 cm
Age at first capture (t_c)	0.95 yr
Total mortality (Z)	2.69 yr^{-1}
Natural mortality (M)	0.66 yr^{-1}
Fish mortality (F)	2.03 yr^{-1}
Exploitation ratio (E)	0.75

The VBGF describing the growth of *Trichiurus lepturus* sampled along the coast of Ghana from September 2018 to August 2019 can be computed as follows:

$$L_t = 133.66\{1 – \exp [-0.46(t + 0.236)]\}.$$

The fish attained lengths of 57.96, 85.87, 103.49, 114.62, and 121.64 cm, respectively by the end of 1, 2, 3, 4 and 5 years (Fig. 15). The maximum observed length of *T. lepturus* was 103.9 cm and using the VBGF equation, the corresponding age was estimated as 3 years.

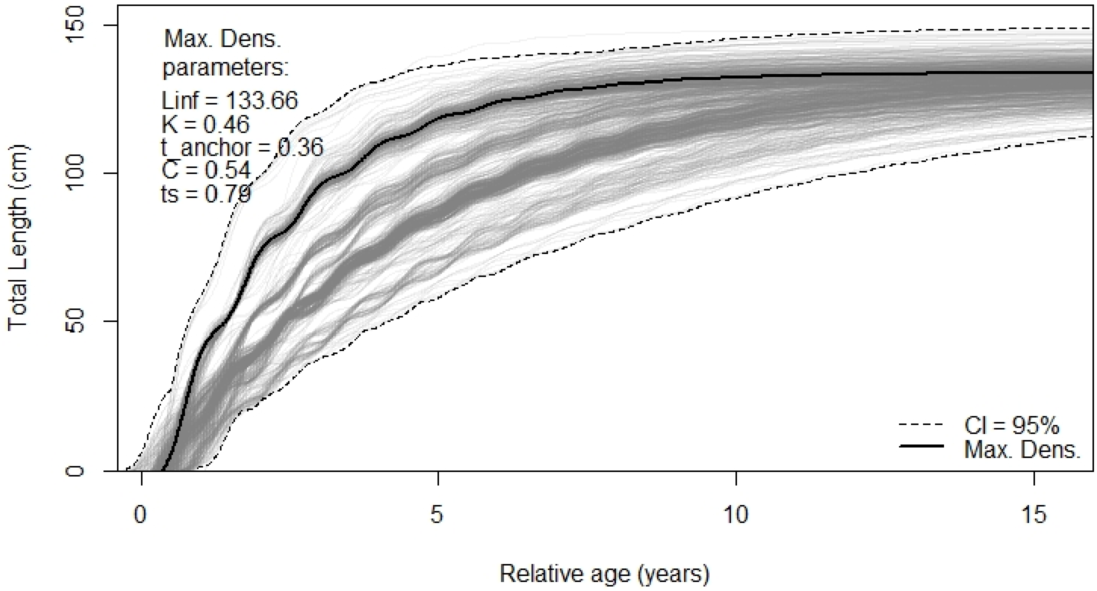

Figure 15: von-Bertalanffy growth curve of *Trichiurus lepturus* along the Coast of Ghana

Total mortality obtained by the length-converted catch curve was 2.69 yr^{-1}. The total mortality of *T. lepturus* was determined based on fishes that were fully exploited (Fig. 16). The natural mortality (M), and fishing mortality (F) of *T. lepturus* were estimated as 0.66 yr^{-1} and 2.03 yr^{-1} respectively with the current exploitation ratio estimated to be 0.75 indicating overexploitation.

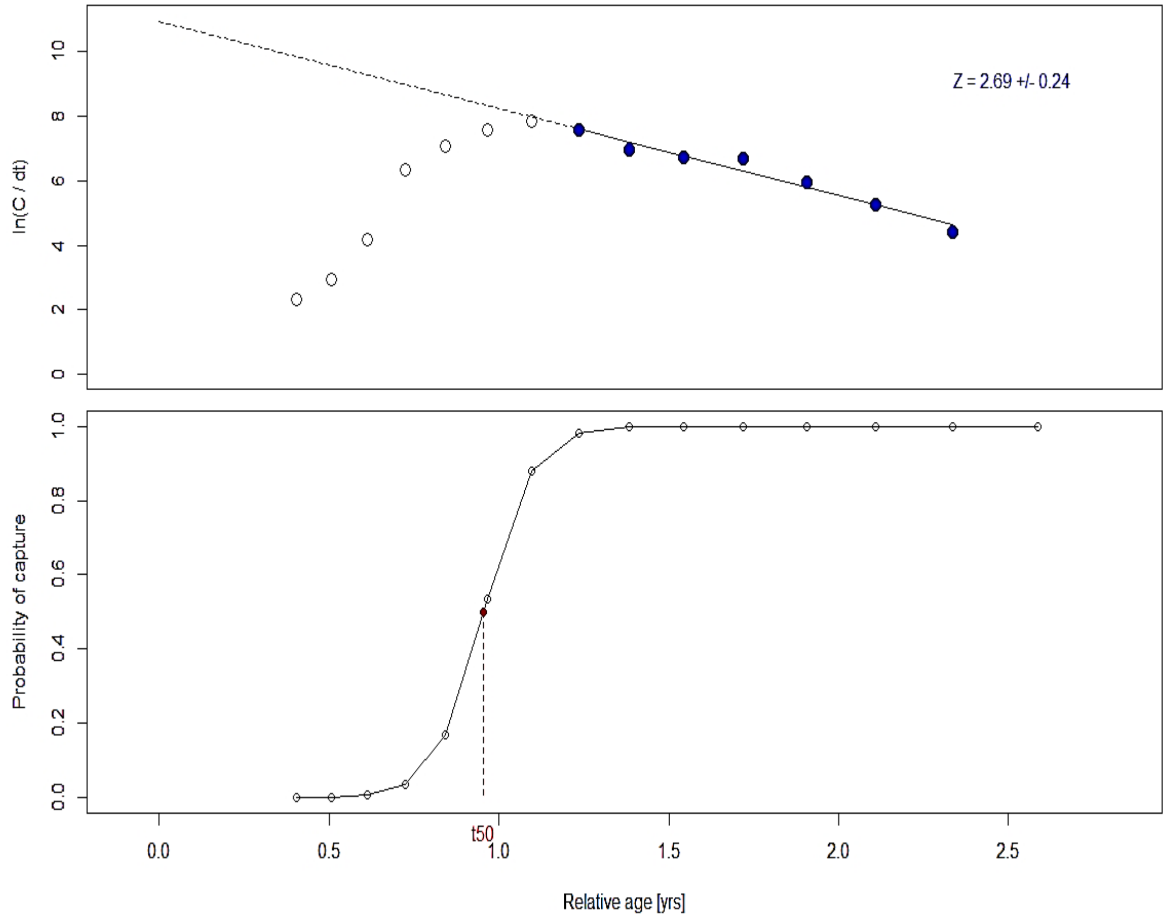

Figure 16: Length-converted catch curve for estimation of Z and probability of capture of *Trichiurus lepturus*

The input parameters used for VPA were L_∞ of 133.66, K of 0.46 and M of 0.66, *a* as 0.0002 and *b* as 3.3437 from length-weight relationship of the species. The Virtual Population Analysis (VPA) (Fig. 17) indicated that major loss in the stock up to 37.5 cm was due to natural causes. Fishes became more vulnerable to the gear after this size, and mortality due to fishing increased eventually. The highest fishing mortality was found to be in the midlength class of 87.5 cm followed by midlength class of 72.5 cm indicating higher fishing mortality in larger length groups (Fig. 19). High fishing mortality was observed in the midlength classes of 52.5 cm to 57.5 cm which coincides with the modal class of the length-frequency distribution (see Fig. 3).

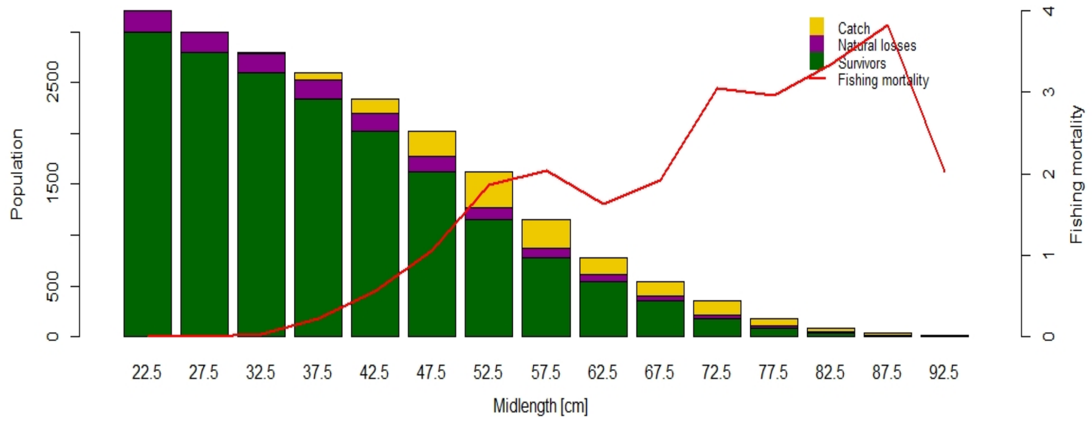

Figure 17: Length structured VPA indicating the catch, natural losses, survivors and fishing mortality of *Trichiurus lepturus*

L. fulgens

Estimates of the growth and mortality parameters from the length-frequency data are shown in Table 2.

Table 2: Growth and mortality parameters of *L. fulgens* along the coast of Ghana (September 2018 – August 2019)

Growth parameters and Mortality parameters	*Lutjanus fulgens*
Asymptotic length (L_∞)	51.09 cm
Maximum observed length (L_{max})	45.6 cm
Longevity (t_{max})	6.41yr
Theoretical age at length, 0 (t_0)	-0.30yr
Growth constant (K)	0.47yr^{-1}
Length at first capture (L_c)	31.51cm
Length at first sexual maturity (L_m)	33 cm
Age at first capture (t_c)	2.0 yr
Total mortality (Z)	2.69 yr^{-1}
Natural mortality (M)	0.78 yr^{-1}
Fishing mortality (F)	1.91 yr^{-1}
Exploitation ratio (E)	0.71

The VBGF describing the growth of *L. fulgens* sampled along the coast of Ghana can be computed as follows:

$L_t = 51.09\{1 – \exp [-0.47(t + 0.301]\}$.

The maximum observed length of *L. fulgens* was 45.6 cm and the corresponding age was estimated as 4.4 years.

The length at first capture (L_c) for *L. fulgens* was estimated at 31.51 cm, which corresponds to an age (t_c) of 2 years The fish attained lengths of 23.37, 33.77, 40.26, 44.32, and 46.86 cm, respectively by the end of 1, 2, 3, 4 and 5 years (Fig. 18)

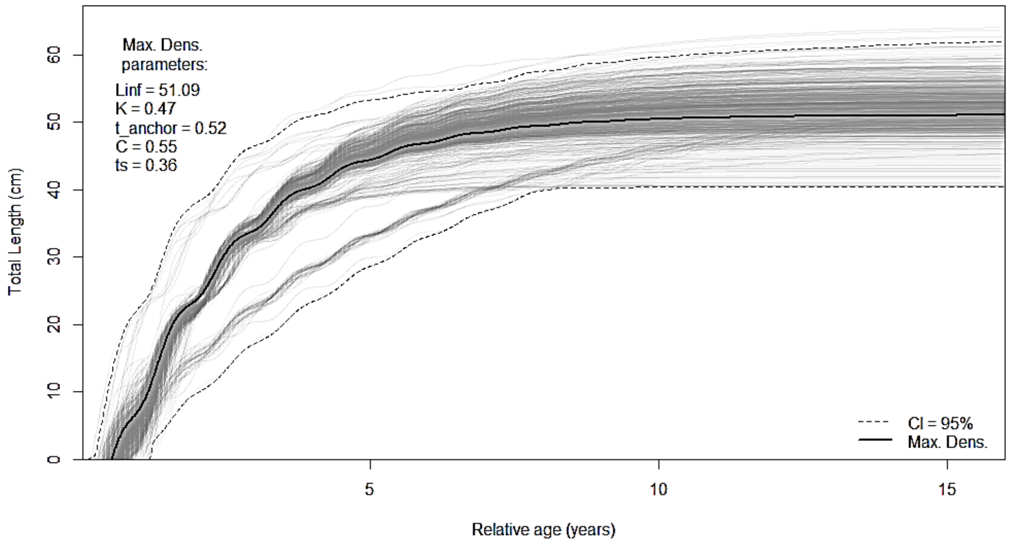

Figure 18: von-Bertalanffy growth curve of *L. fulgens* along the Coast of Ghana

The total mortality of *L. fulgens* was determined based on fishes that were fully exploited (Fig. 19). For *L. fulgens*, the total mortality (Z), natural mortality (M), and fishing mortality (F) were estimated as 2.69 yr^{-1}, 0.78 yr^{-1} and 1.91 yr^{-1} respectively with the current exploitation ratio estimated to be 0.71.

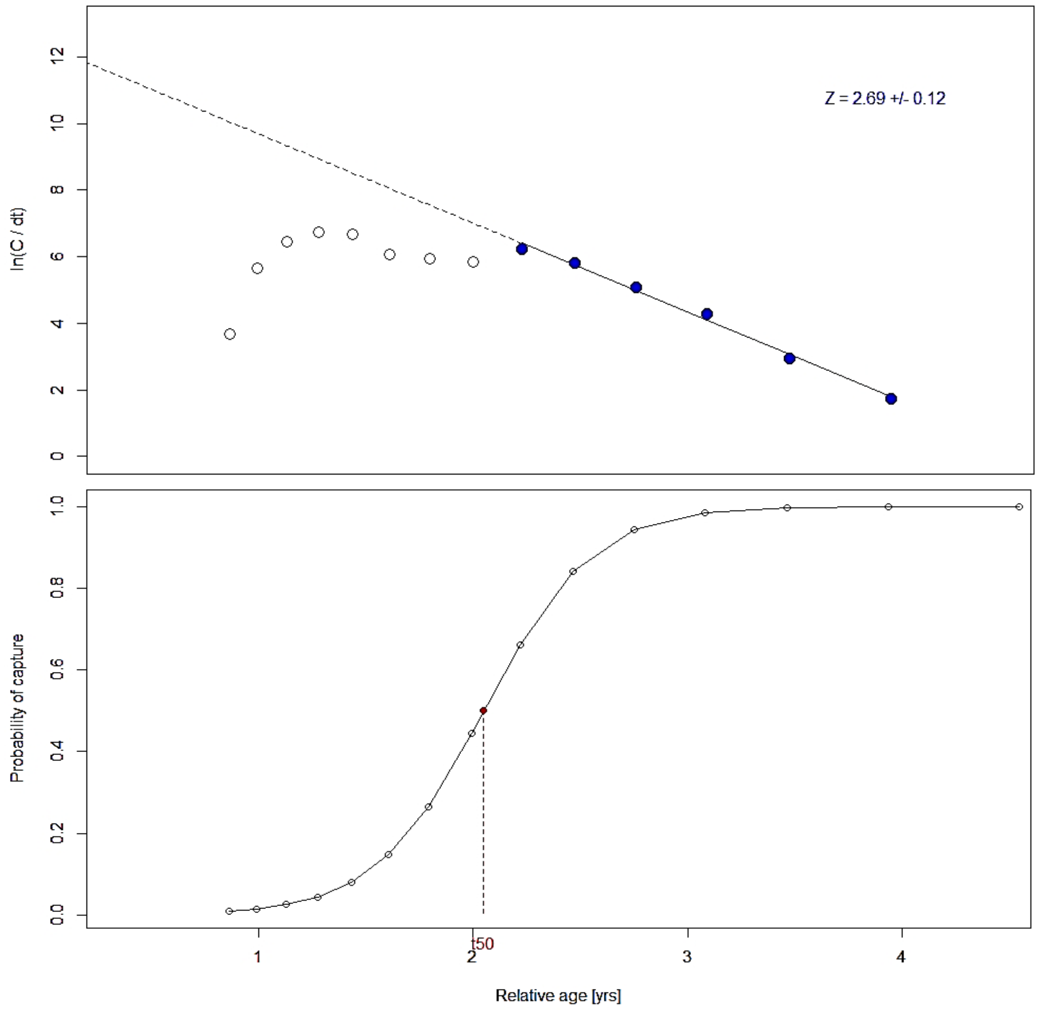

Figure 19: Length converted catch curve for estimation of Z and probability of capture of *L. fulgens*

The input parameters used for VPA were L_∞ of 51.09, K of 0.47 and M of 0.78, *a* as 0.0192 and *b* as 2.8959 from length-weight relationship of the species. High fishing mortality in larger length groups was observed as compared to the smaller length groups, however relatively high fishing mortality was observed in the midlength class of 25 which coincides with the modal class of the length-frequency distribution. Mortality in the population due to natural causes was observed in fishes less than 19 cm. Fishing mortality started at 19 cm midlength and continued to increase. The highest fishing mortality was found to be in the midlength class of 39 cm (Fig. 20).

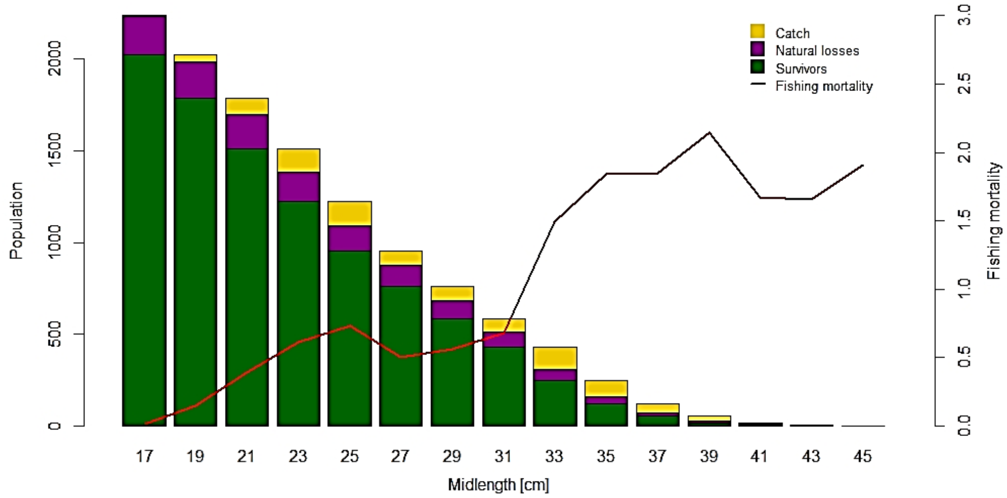

Figure 20: Length structured VPA indicating the catch, natural losses, survivors and fishing mortality of *L. fulgens*

Reproductive Status of *Trichiurus lepturus*

Sex ratio

Of the 1,677 specimens of *T. lepturus* sampled, 45% comprised of males; 41.5% of females and 13.5% of indeterminate sex. The monthly sex ratios of *T. lepturus* indicated that the females dominated the population apart from the months of September and October, 2018 and April and August, 2019. Conversely, the overall sex ratio (M:F) of *T. lepturus* was 1.1:1 and did not differ significantly from the normal expected ratio of 1:1 of fish populations (Table 3).

Table 3: Sex ratios of *T. lepturus* along the coast of Ghana as estimated from September 2018 to August 2019

Months	Total number	No. of males	No. of females	Sex ratio M:F	χ^2	$\rho = .05$
September	74	51	23	2.2:1	10.595	S
October	199	125	74	1.7:1	13.070	S
November	238	105	133	1:1.27	3.294	NS
December	131	60	71	1:1.18	0.923	NS
January	168	81	87	1:1.07	0.214	NS
February	101	49	52	1:1.06	0.089	NS
March	89	28	61	1:2.18	12.235	S
April	107	85	22	3.9:1	37.093	S
May**		-	-	-		
June	149	73	76	1:1.04	0.060	NS
July	88	37	51	1:1.38	2.227	NS
August	106	60	46	1.3:1	1.579	NS
Total	1450	754	696	1.1:1*	2.239	NS

*indicates overall monthly sex ratio, S = significant and NS = not significant, *df* = 1

** no sampling due to closed fishery

Condition index and Gonadosomatic index (GSI)

The monthly mean condition indices of both male and female *T. lepturus* shows that the values of males experienced major fluctuations with the highest peak in October followed by March and December respectively. Condition index of both sexes followed the same pattern generally. Apparently, for the females, the highest peak recorded was in February. Mean condition index of males was 0.065 ± 0.00037 and that of females, 0.0652 ± 0.0004 (Fig. 21)

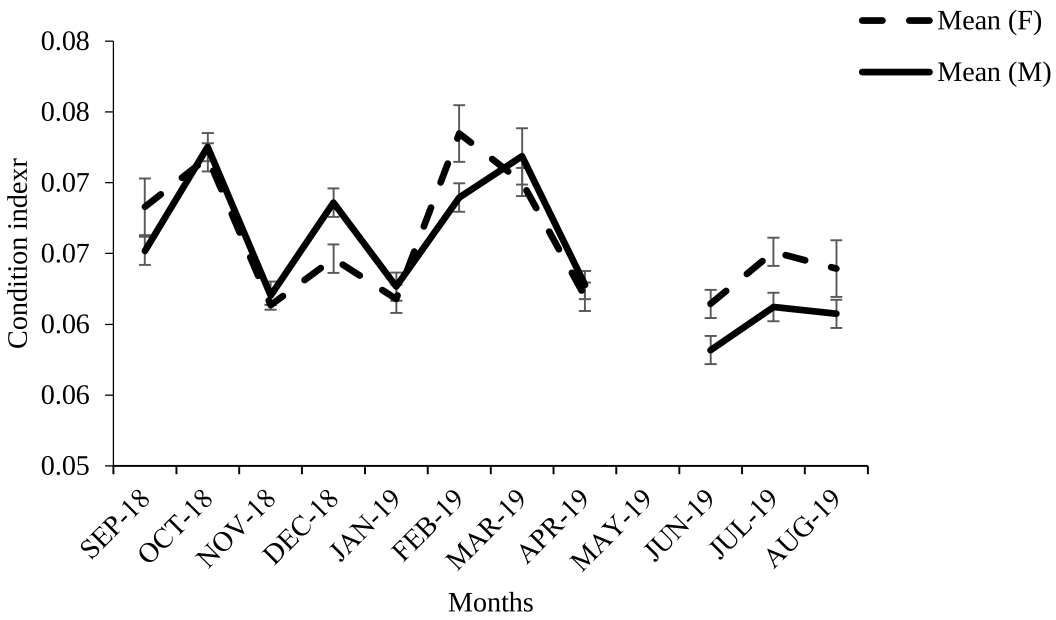

Figure 21: Monthly mean condition indices of male and female *T. lepturus* estimated along the Coast of Ghana (vertical bars represent standard errors)

There was significant monthly variation in the GSI of both male and female *T. lepturus*, t(9) = 2.26 , p =.008 with females (*M* = 0.59, *SD* = 1.30) attaining higher values than males (*M* = 0.35, *SD* = 0.42) where *M* and *SD* stand for mean and standard deviation respectively. The mean GSI of the males varied from 0.12 to 0.70. The GSI of the males sharply rose from November 2018 to December 2018 after which it reduced gradually and was followed by a gentle rise until the highest peak in March 2019. The female GSI of *T. lepturus* on the other hand ranged from 0.14 to 1.43. The pattern of GSI for the females was more or less similar to that of the males. Comparatively, the GSI of the females in general were higher than those of the males. Two peaks were observed in the trend of GSI of female *T. lepturus*. Of the peaks identified, the highest observed occurred in March and June 2019 whilst the lowest peak was observed in November, 2018 (Fig. 22).

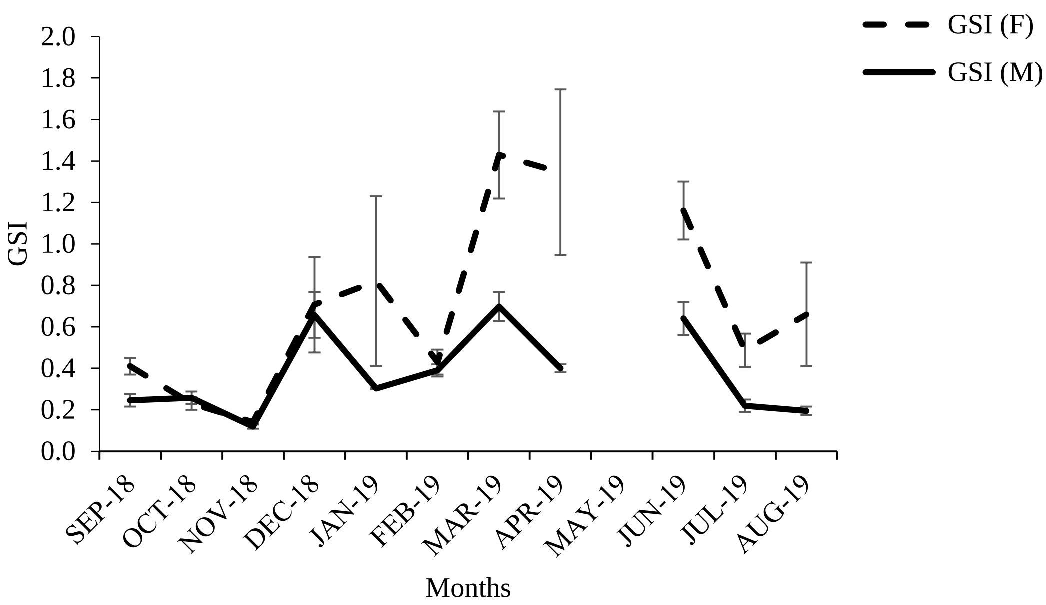

Figure 22: Monthly mean Gonadosomatic index of male and female *Trichiurus lepturus* during September'18 to August'19 (vertical bars represent standard errors)

*Data was not collected in the month of May due to closed season observed

Stages of Gonadal Development

Following the examination of the gonads, six stages of gonadal development were observed in males and five in the females. Females with ripe eggs (Stage IV) were recorded in almost all the months except in September with their peak occurrence observed in March. This suggests an all round spawning period with a peak spawning in March. For the males, males with ripe gonads were absent in November and December 2018.(Fig. 24 and

25). About 64% of the females and 43% of the males encountered within the month of March had ripe gonads.

Males with spent gonads (Stage V) occurred only in September representing 2% of the various gonadal stages. Stage III males and females occurred throughout the period with the the highest proportion represented in March for males (36%) and in July for the females (43%). Stages I and II males and females were present in all the months with lesser proportions occurring in the month of March for both sexes. This further suggests spawning occurs in March.

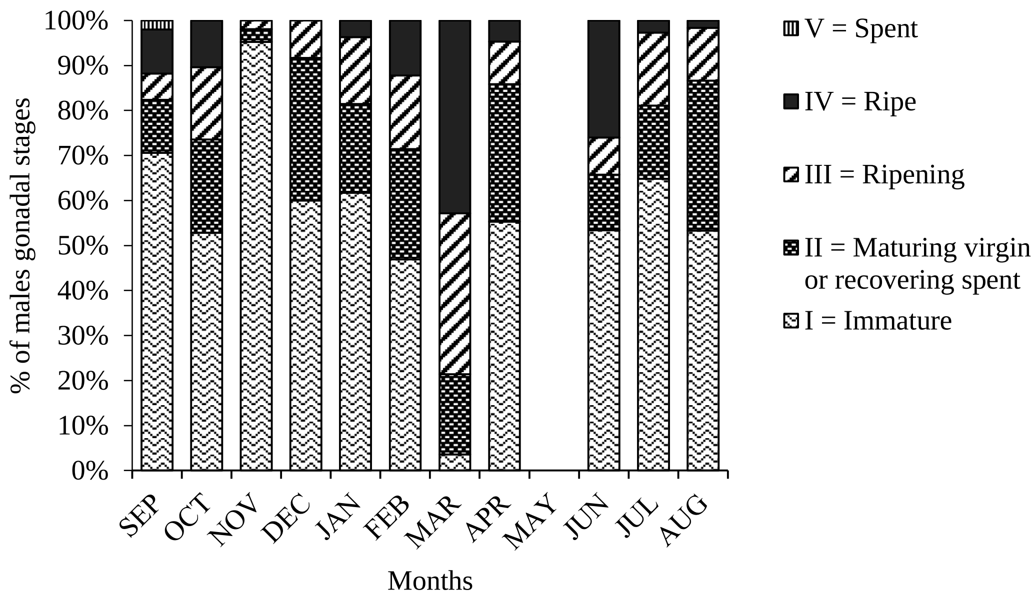

Figure 23: Monthly variation for maturity stages for males of *T. lepturus*

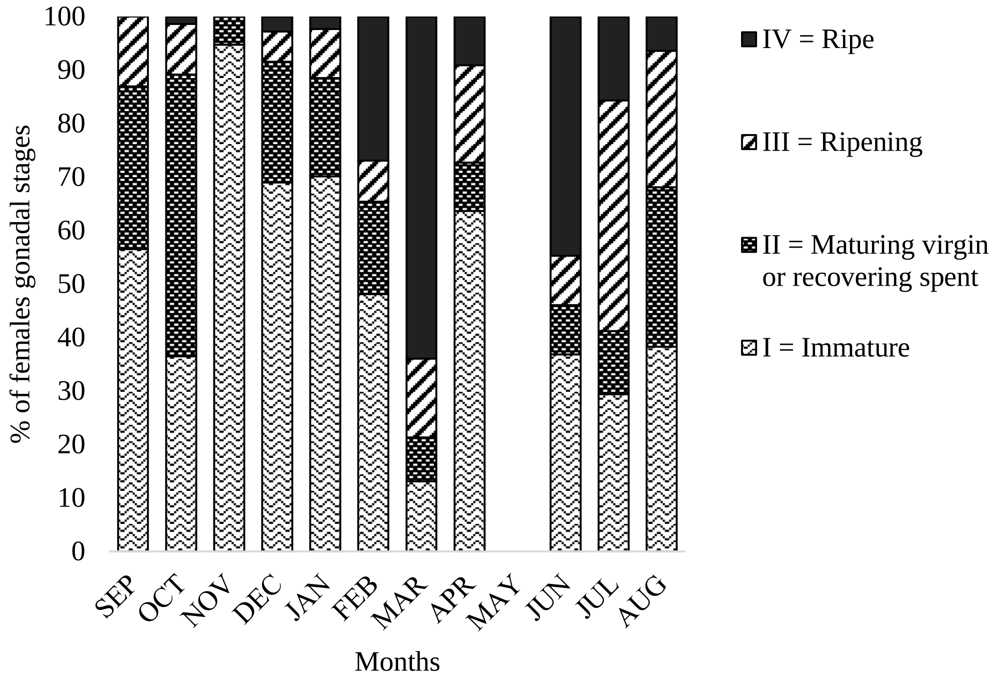

Figure 24: Monthly variation for maturity stages for female *T. lepturus*.

Size at first maturity

Total length at first sexual maturity was estimated at 70.5 cm for males and 71.1 for females (Fig. 25a, 25b). However gonadal development and sexual maturity was observed to commence from 52 cm in males and 58 cm in females. All males above 82 cm and females above 80 cm were sexually mature.

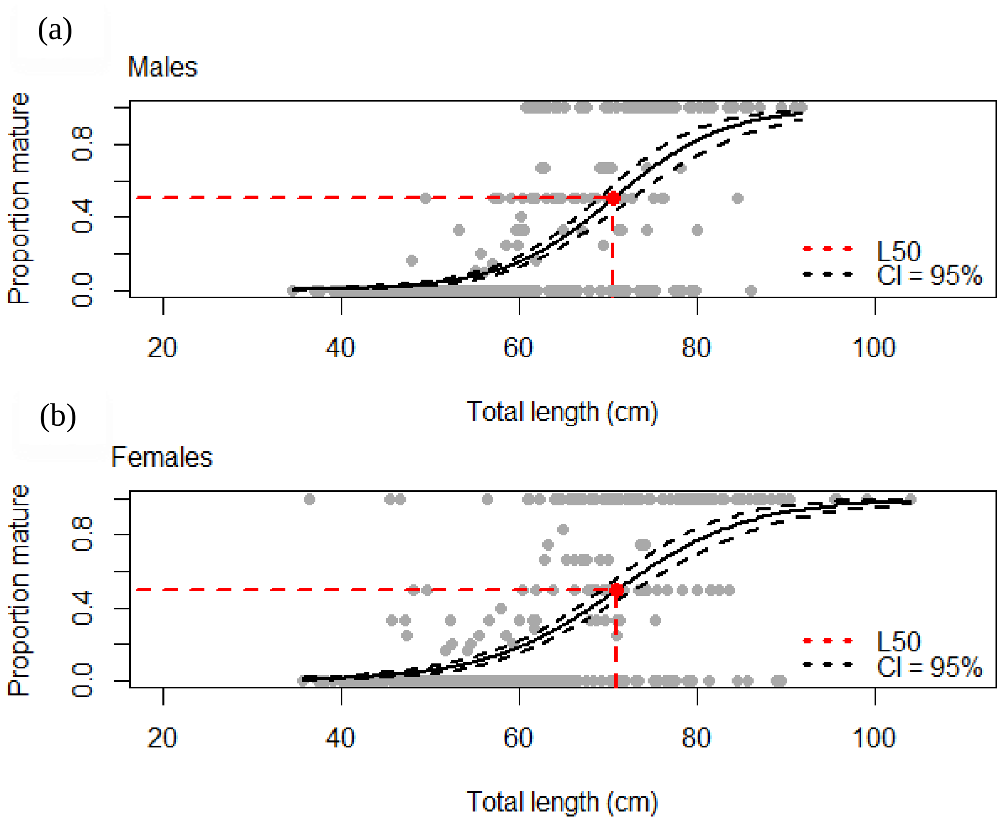

Figure 25: Length at first sexual maturity for male (a) and female (b) *T. lepturus*.

Fecundity

The fecundity of *T. lepturus* was presented as a scatter plot relating total number of eggs to the total length, body weight and gonad weight of individual fish with ripe ovaries (Fig. 26, 27 and 28). The number of ripe eggs of *T. lepturus* ranged from 4,876 to 43,410 eggs with a mean of 17,440 ± 1250 eggs (mean ± SE) based on 50 ovaries of fishes ranging in total length from 58.6 – 89.7 cm and weight 124.6 – 624.2 g. The relationship between fecundity (F) and total length (TL) of *T. lepturus* was represented as:

$$F = 592.99TL - 26012 \ (r = 0.50)$$

The relationship between fecundity and body weight (BW) was represented as:

$$F = 39.871BW + 5164.6 \ (r = 0.55)$$

The relationship between fecundity and gonad weight (GW) was represented as: F = 1138.5GW + 9663.6 (r = 0.50)

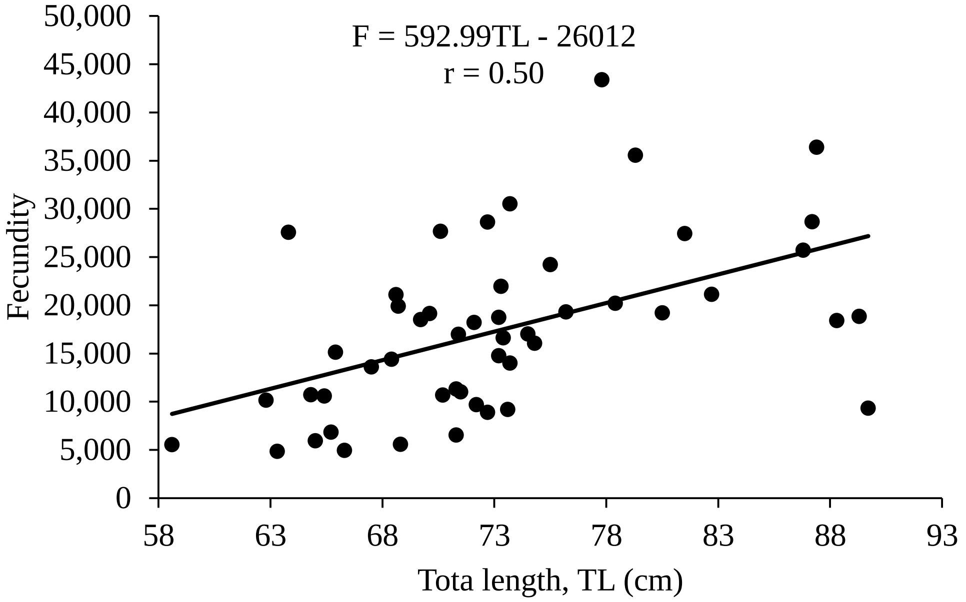

Figure 26: Relationship between Fecundity and Total length of *T. lepturus*

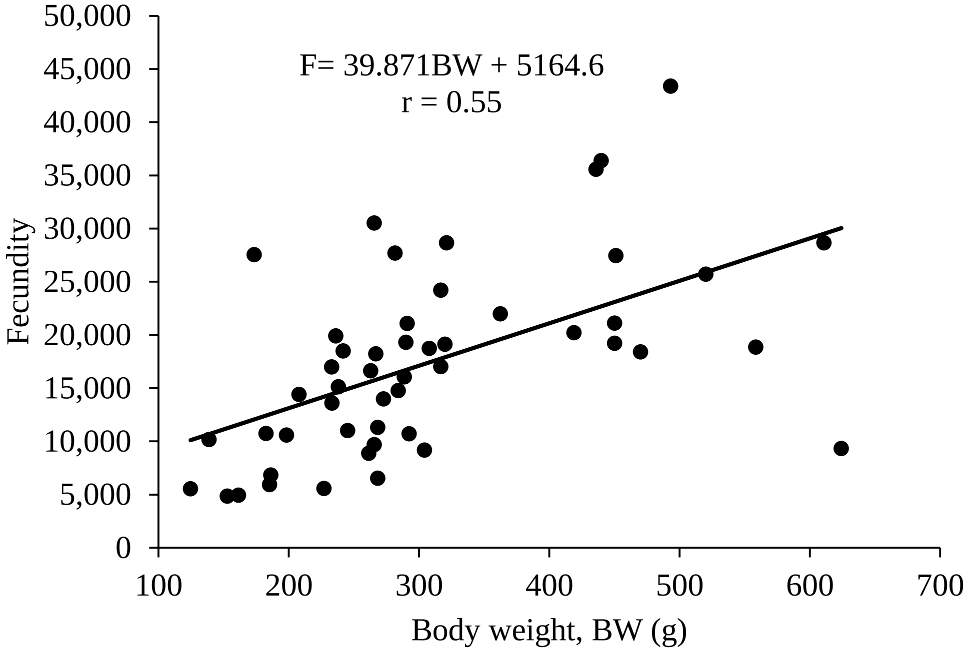

Figure 27: Relationship between Fecundity and Body weight of *T. lepturus*

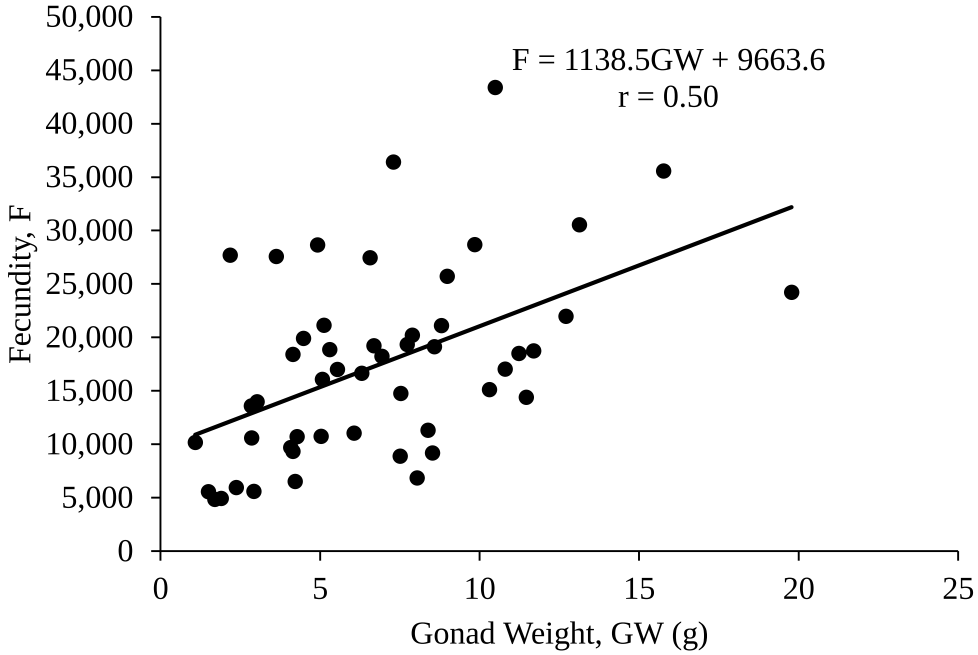

Figure 28: Relationship between Fecundity and Gonad weight of *T. lepturus*

It can be inferred that fecundity increases as weight of the fish increases. The highest correlation co-efficient of (r = 0.55) was observed between fecundity and body weight indicating a moderately correlated relationship between these two variables. This suggests that body weight proves to be the better index of fecundity in *T. lepturus.*

Reproductive Status of *Lutjanus fulgens*

Sex ratio

Of the 906 specimens of *Lutjanus fulgens* sampled, 46.9% comprised of males; 48.9% of females and 4.2% of indeterminate sex. The monthly sex ratios of *Lutjanus fulgens* indicated that the males dominated the population apart from the months of January, February and August, 2019. Conversely, the overall sex ratio (M:F) of *L. fulgens* was in favour of the females with a ratio of 1:1.04 but did not differ significantly from the normal expected ratio of 1:1 of fish populations (Table 4).

Table 4: Sex ratios of *L. fulgens* along the coast of Ghana as estimated from September 2018 to August 2019

Month	Total number	No. of males	No. of females	Sex ratio χ^2	M:F	$\rho = .05$
September	9	5	4	0.111	1.3:1	NS
October**	-	-	-		-	
November	139	81	58	0.331	1.4:1	NS
December	144	82	62	2.777	1.3:1	NS
January	125	44	81	10.952	1:1.84	S
February	143	63	80	2.021	1:1.27	NS
March	55	28	27	0.018	1:1	NS
April	108	66	42	5.333	1.6:1	S
May***	-	-	-		-	
June	44	22	20	0.095	1.1:1	NS
July	19	11	8	0.474	1.4:1	NS
August	84	23	61	17.190	1:2.65	S
Total	868	425	443	0.373	1:1.04*	NS

*indicates overall monthly sex ratio, S = significant and NS = not significant, *df* = 1

** data not available

*** no sampling due to closed fishery

Size at first sexual maturity

The mean size at first sexual maturity (L_{50}) was estimated for both sexes by fitting the logistic function to the proportion of mature fish in 2 cm (*L*F) size categories. The mean size at first sexual maturity was taken as the size at which 50% of individuals were mature. From the current study it was gathered that male *L. fulgens* tend to mature at 36.7 cm while the females do so at 33.7 cm (Fig. 29a , 29b).

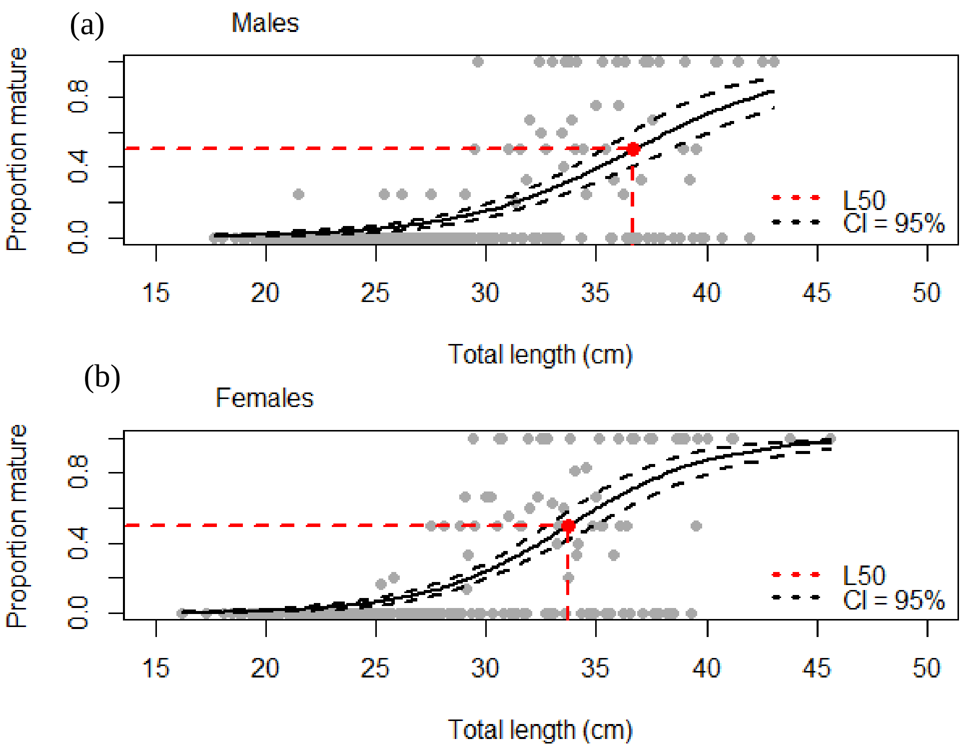

Figure 29: Length at first sexual maturity for male (a) and female (b) *L. fulgens.*

Condition index and Gonadosomatic index (GSI)

The monthly mean condition indices of *L. fulgens* shows that the values of males showed a steady decline from September through to June and experienced a dip in July and further rose in August. Condition index of the females did not vary substantially from that of the males, they followed the same pattern generally and apparently a steep dip during July. Mean condition index of males was 1.38 ± 0.0106 and that of females was 1.37 ± 0.0141 (Mean ± Standard error) (Fig.30).

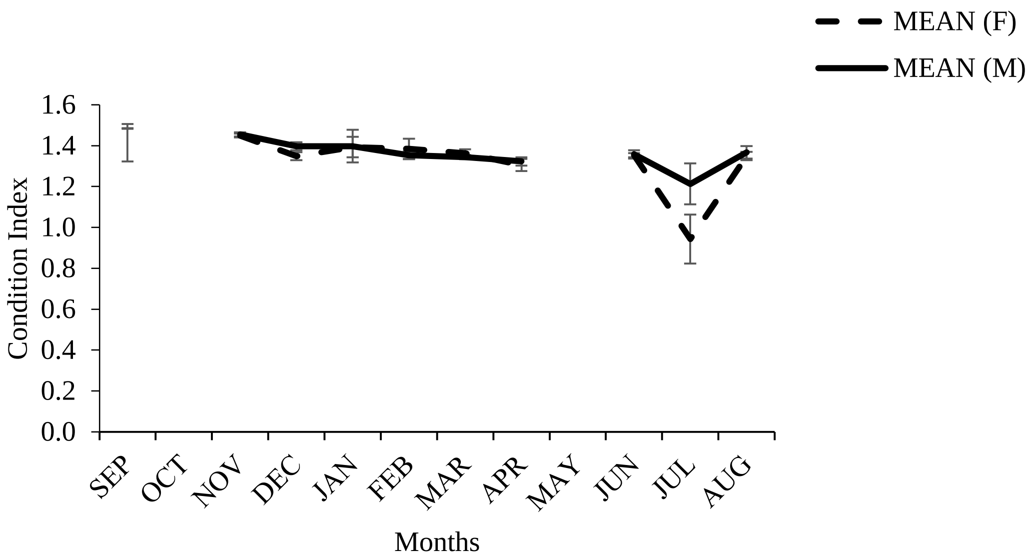

Figure 30: Monthly mean Condition index of male and female *L. fulgens* estimated along the Coast of Ghana (vertical bars represent standard errors) Note: Samples were not collected during October and May due to no fish landed and closed fishery respectively.

There were distinct monthly variations in the GSI of both male and female *L. fulgens* (Fig. 31). This variation was significantly different t(8) = 2.31 , p =.002 with females (*M* = 1.19, *SD* = 0.06) attaining higher values than males (*M* = 0.62, *SD* = 0.04) where *M* and *SD* stands for mean and standard deviation respectively. Four peaks were observed in the trend of GSI of female *L. fulgens.* The GSI of the males peaked in September and in July. The pattern of GSI for the females was quite similar to that of the males. Of the peaks identified, the highest observed occurred in September 2018 and July 2019.

Gravid and ripe females were recorded in all the months with their peak occurrence observed in September (Fig. 33).

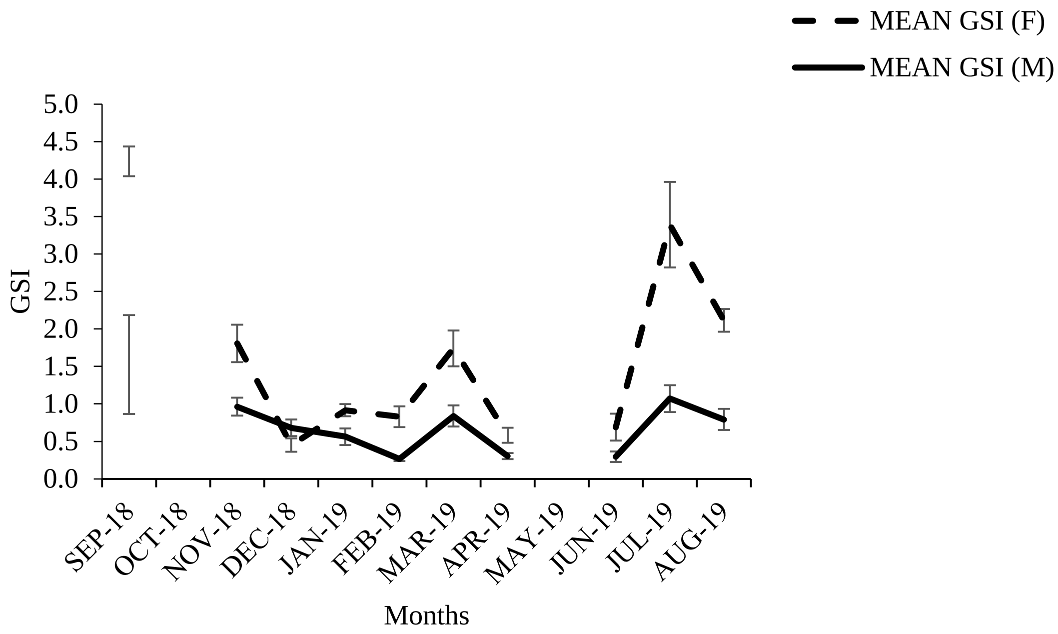

Figure 31: Monthly mean Gonadosomatic index of males and females *L.fulgens* during September'18 to August'19 (vertical bars represent standard errors).

Stages of Gonadal Development

Six stages of gonadal development were observed in males and five in female *L. fulgens*. Females with ripe eggs (Stage IV) were recorded in almost all the months except in November, December, February and April with their peak occurrence observed in July to September. About 50% of all females encountered within those months were gravid with ripe eggs. This suggests a reproductive window from June to September. (Fig. 32) Males with ripe gonads occurred less during the entire period, however, about 14% and 26% were present in June and August 2019, respectively (Fig. 33). Males with spent gonads (Stage V) occurred only in December, January and April representing 5%, 5% and 2% respectively. Stage III males and females occurred throughout the period with the the highest proportion represented in July for males (55%) and in September for the females (50%). Stages I and II males and females were present in all the months with higher proportions occurring in the males. Lesser proportions were observed from July to September especially in the females. This further suggests a spawning window from July to September.

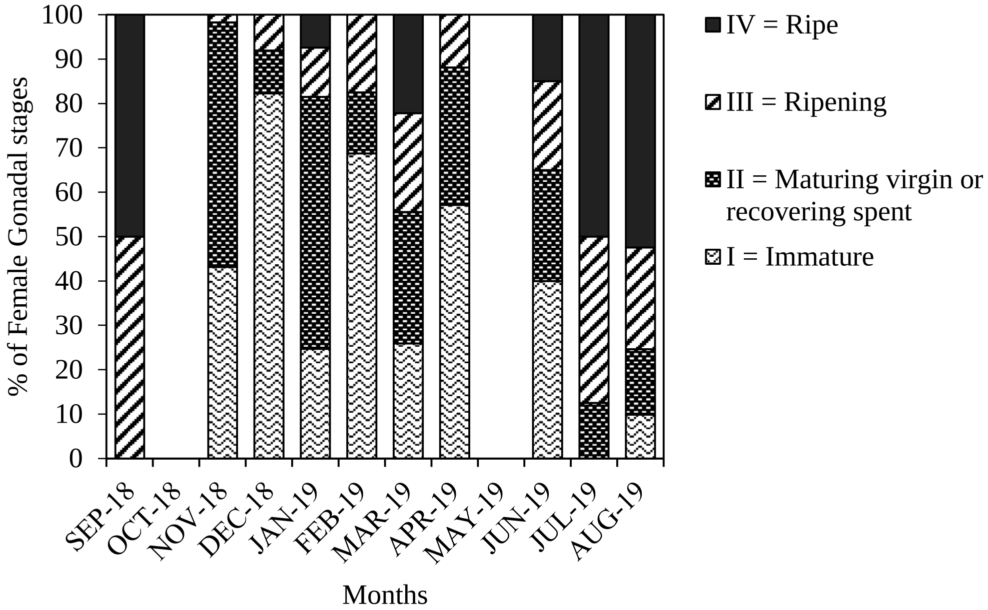

Figure 32: Monthly variation for maturity stages for female *L. fulgens*

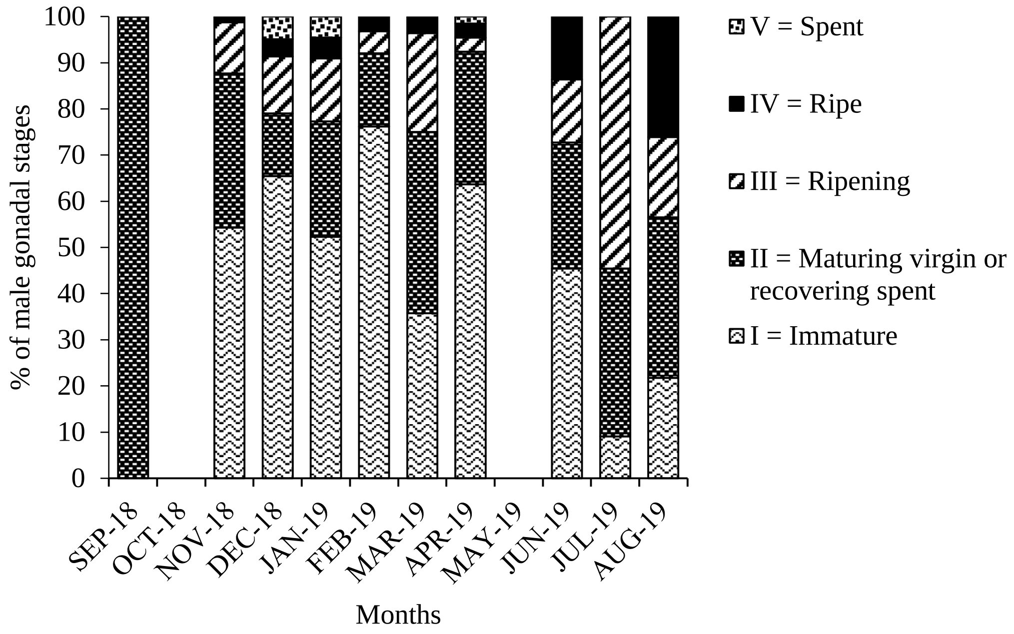

Figure 33: Monthly variation for maturity stages for male *L. fulgens*.

Fecundity

The fecundity of *Lutjanus fulgens* was presented as a scatter plot relating total number of eggs to the total length, body weight and gonad weight of individual fish with ripe ovaries (Fig. 34, 35 and 36 respectively). The number of ripe eggs of *Lutjanus fulgens* ranged from 10,136 to 219,994 eggs with a mean of 77,833 ± 13,012 eggs (mean ± SE) based on 30 ovaries of specimens ranging in total length from 29.0 - 43.8 cm and weight 350.6 – 1179.2 g. The relationship between fecundity (F) and total length (TL) of *L. fulgens* was represented as:

F = 7441.8TL – 175388 (r = 0.28) (Fig 34).

The relationship between fecundity and body weight (BW) was represented as:

F = 168.15BW - 7843.4 (r = 0.42) (Fig 35).

The relationship between fecundity and gonad weight (GW) was represented as:

F = 7584.7GW – 33821 (r = 0.73) (Fig 36).

It can be inferred that fecundity increases more with weight than with length of the fish. The highest correlation co-efficient of (r = 0.73) was observed between fecundity and gonad weight indicating a high degree of relationship between these two variables. This suggests that gonad weight proves to be the better index of fecundity in *Lutjanus fulgens.*

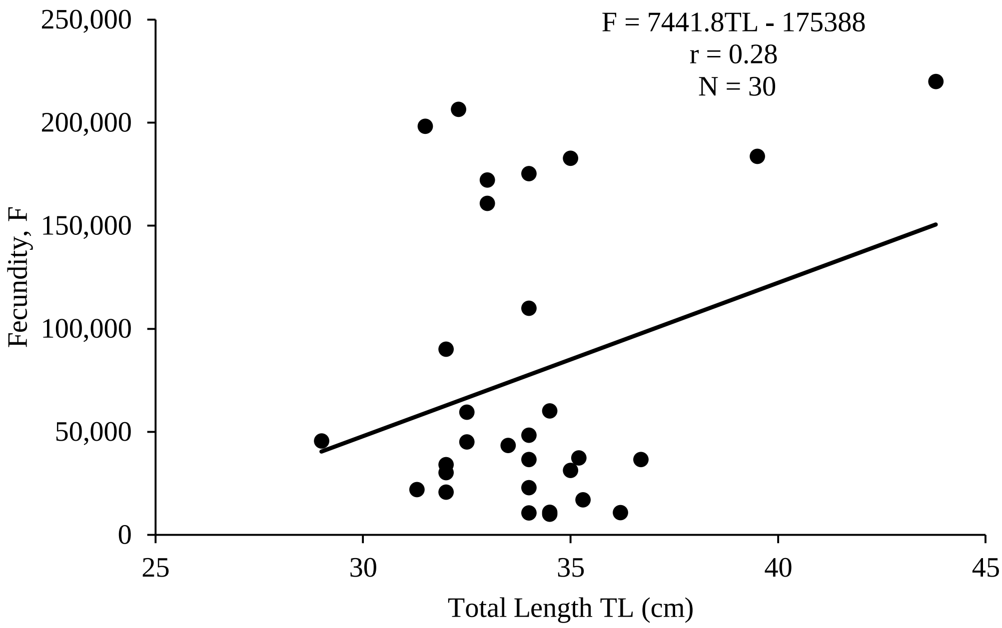

Figure 34: Relationship between Fecundity and Total length of *Lutjanus fulgens*

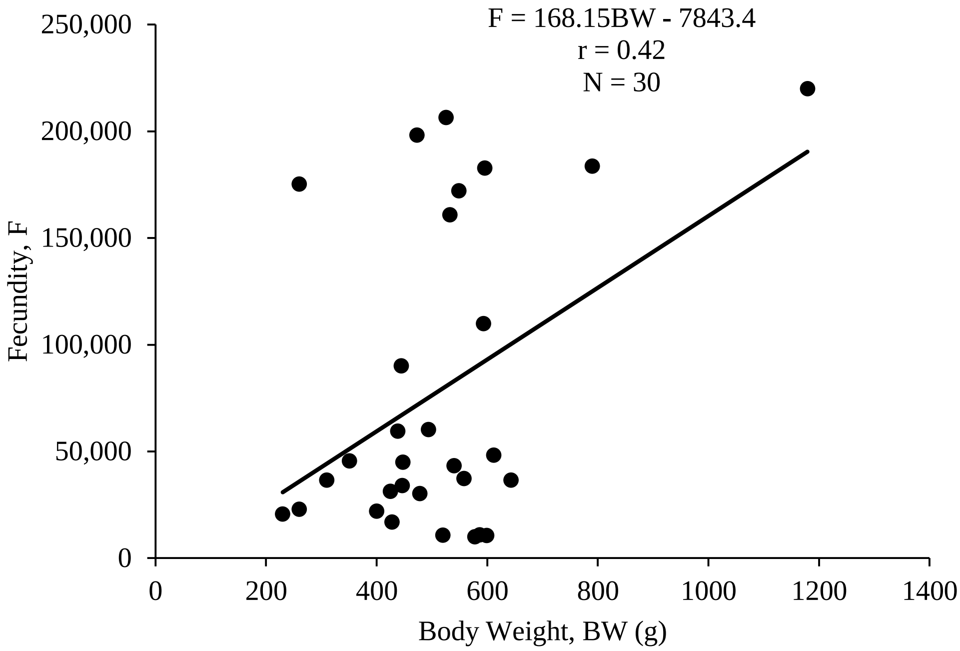

Figure 35: Relationship between Fecundity and Body weight of *Lutjanus fulgens*

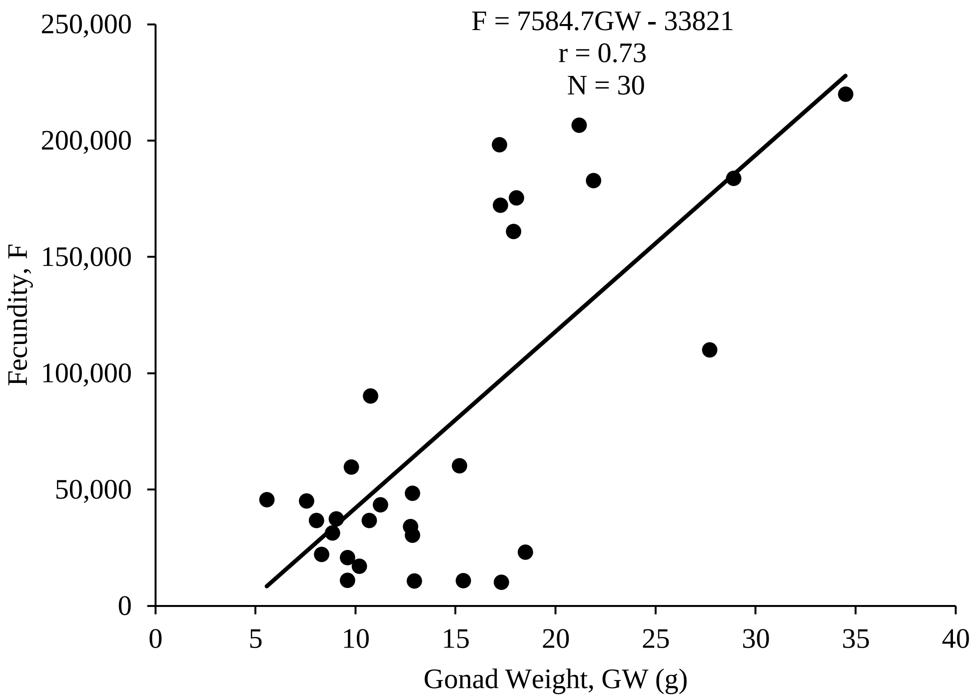

Figure 36: Relationship between Fecundity and Gonad weight of *Lutjanus fulgens*

CHAPTER FIVE

DISCUSSION

Limitations of the study

Some limitations were encountered in the course of the study and it is worth noting. Closed fishery was observed in the month of May, 2019 which made it impossible to sample hence accounts for no data on both fish species during the study. For *Lutjanus fulgens*, there were no samples collected in October, 2018 due to the absence of the fish at the shores.

It is possible that errors occurred when determining fish sex visually, in particular those that were immature, this highlights the need for histological examination in further studies.

Gut content analysis was not carried out on both *T. lepturus* and *Lutjanus fulgens* in this study. In spite of these limitations the quality of the study was not affected.

Distribution and Abundance

T. lepturus and *L. fulgens* were densely populated in the western and central part of the coast of Ghana as compared to the eastern part. This is attributed to the the fact that there is a wider continental shelf along the western coast up to 50 NM as compared to the eastern of less than 20NM (Staby et al., 2017). The continental shelf is characterized by an enhanced productivity and biological activity due to the input of nutrient from rivers and more importantly, from the transfer of nutrient-rich deep ocean waters during upwelling (Wollast, 2002). Thus the wider the shelf, the more shallow the water and the higher the productivity. Wider continental shelves teem with productivity because of the sunlight available in shallow waters. This therefore accounts for the high numbers of both species in the western part of the coast.

Length-frequencies and Length-weight Relationships

The study observed that the length composition of *T. lepturus* was characterized by a unimodal size class of 50 – 59.9 cm. Comparatively, a modal size class of 60 – 69.9 cm was observed by Muhammad et al. (2017) in the Makran coast (northeast Arabian Sea). This may well be attributed to gear selectivity. Ghosh, Pillai, & Dhokia (2009) observed a maximum length of 115.9 cm off Veraval, north-west coast of India whereas Avinash et al. (2014) reported maximum length of 125 cm TL in the same waters. Cruz-Torres, Martínez-Pérez, Franco-López, & Ramírez-Villalobos (2014) also reported maximum total length of 97.5 cm in Boca Del Rio, Veracruz, Mexico. In the Makran coast (northeast Arabian Sea), Muhammad et al. (2017) recorded a maximum length of 129.5 cm. By comparison, the maximum total length of 103.9 cm observed for *T. lepturus* in the present work is within range for the species across the globe. Females dominated in size classes > 90 cm. Martins & Haimovici (2000) stated that females attain larger sizes and become heavier than males of the same age mostly after reaching sexual maturity. Differential growth may reflect a higher reproductive investment by males. The species *Trichiurus japonicas* belonging to the family Trichuridae also exhibits the same trait where the female attain larger sizes than males.(El-Haweet & Ozawa, 1996).

Again, a unimodal size class was observed for *L. fulgens* in this study, 20.0 – 24.9. This modal class was followed by yet another modal class of 30.0 – 34.9 cm. Upon interactions with the ffisherfolks, there is the predominance of hook-based fishing gears which is a highly selective gear in the exploitation of demersal species with a few caught in bottom trawls. Seabreams such as *Dentex gibossus*, *Pagrus caeruleosticus*, *Dentex canariensis* and snappers of which include, *Lutjanus dentatus*, *Lethrinus spp* and *Lutjanus fulgens* among other demersal species comprise of these catches.

The fishers tend to fish for larger sizes since the fishes are sold by their sizes; the bigger the fish, the higher its price. The length-frequencies of male and female *L. fulgens* show that larger fish are more likely to be females. Various studies on lutjanids have reported similar observations of larger sizes dominated by female fishes (Hay, Knuckey, Calogeras, & Errity, 2005; Almamari et al., 2017; Pradeep, 2018)

Length-weight relationships play major role in assessing the biology of fish fauna and also helpful in estimating the weight of fish corresponding to a given length. Previero, Minte-Vera, Freitas, de Moura, & Tos (2011) stated that length-weight relationships have diverse applications, viz. for studies on fish biology, physiology, ecology, and fisheries assessment. This is because size is generally more biologically relevant than age; consequently, variability in size has important implications for diverse aspects of fisheries science and population dynamics.

The relationship between total length and body weight of *T. lepturus* along the coast of Ghana was described by the equation $BW = 0.0002TL^{3.3437}$ ($r = 0.98$). *T. lepturus* in this study exhibited positive allometric growth ($b > 3$) which implies that the fish increase in width more than in length as Froese (2006) stated that if $b > 3$, then large specimens have increased in height or width more than in length, either as a result of a notable ontogenetic change in body shape with size, which is rare, or because most large specimens in the sample are thicker than small specimens, which is common. The latter was observed for *T. lepturus* in this study. The result from the length-weight relationship corroborates the findings of Ghosh et al. (2009). Similar results on length-weight relationship was also reported by Khan (2006) and Al-Nahdi et al. (2009) from Arabian Sea Coast of Oman. However, a higher 'b' value was recorded in the present study as compared to Muhammad et al. (2017) who reported b values of 2.584 in Makran coast (northeast Arabian Sea). This variation is possibly due to factors related to ecosystem and biological phenomena like maturity stages, feeding behavior and competition for food.

Again, the relationship between total length and body weight of *L. fulgens* along the coast of Ghana was described by the equation $BW = 0.0192TL^{2.8959}$ ($r = 0.97$) exhibiting isometric growth. The measured *b* value were within the expected value for most fishes (Froese, 2006) and in accordance with other members of the family Lutjanidae (Garcia et al., 2000; Razi & Noori, 2018).

Condition factors

Fluctuations in the condition factor of ribbonfishes during different months could be attributed to several reasons. In male and female of *T. lepturus* the higher values of k, during October and in February to March might be due to higher feeding intensities and gonadal maturation. A sharp rise in K in the *T. lepturus* reported in October is related to feeding intensity. It was observed that about 90 per cent of the sample for that month had full gut content. The gut content revealed traces of anchovies, juvenile squids and other partially digested fishes. The weight of the prey could reasonably be expected to add to the body weight of the fish and thereby increase the K values. The peak breeding of the species was found during March to June. The sharp rise in k, during February to March appears to be due to gonadal maturation, as the ovaries attain larger size and weight.

Again, *L. fulgens* showed quite a steady condition factor throughout the year with a dip observed in July for both males and females. Although the males showed higher K values than females, condition index was but almost the same. In fish the condition factor, K reflects through its variation, information on the physiological state of the fish in relation to its well-being. From nutritional point of view, it indicates accumulation of fat and gonadal development (Le Cren, 1951). The k value is also influenced by reproductive status of fish. The evaluation of the condition index indicates low values coinciding with higher GSI values, demonstrating that the condition index is an adequate reproductive indicator for *L. fulgens*. Higher values of the condition factor before the peak spawning in July for *L. fulgens* could be attributed to maturation of gonads and the deposition of lipids and fats as an energetic source for the coming spawning periods (Das, Choudhury, Das, & Nanda, 2017). This finding corroborates that of Azevedo, de Castro, & Silva (2017) in a study on the whitemouth croaker, *Micropogonias furnieri* in the Eastern Amazon, Brazil, they reported that there was an inverse relationship between condition index and gonadosomatic index.

Growth and Mortality Parameters

The present estimate of L_∞ value of 131.25 cm for *T. lepturus* in this current study compares well to 135.09 cm reported by Avinash et al. (2014), 134.1 cm reported by Ghosh et al. (2009) off Veraval, north-west coast of India and 128.2 cm reported by Abdussamad et al. (2006) off Kakinada, east coast of India. Comparatively, lower values of 116.75 cm and 114.4 cm were reported by Rajesh, Rohit, Vase, Sampathkumar, & Sahib (2015) and Ghosh et al. (2014) off Karnakata, south-west coast of India and in the northern Bay of Bengal respectively.

The length at first capture (Lc) was estimated at 47.11 cm and is lower than length at first maturity (Lm) of about 70.5 cm. This indicates that the species enter the exploitation phase before attaining sexual maturity. This results in stress on spawning stock and could be addressed by enhancing their size and age at exploitation, which means that increase in mesh size of gears should be enforced to avoid the catch of young fishes (Ghosh et al., 2009).

The growth coefficient of 0.46 per year is in full agreement to Al-Nahdi et al. (2009), but different values of growth coefficient ranging from 0.29 to 0.82 were reported by other authors (Reuben et al., 1997; Abdussamad et al., 2006; Ghosh et al., 2009; Rajesh et al., 2015). Consequently, the growth performance index of 3.92 in the present study matches with that of earlier published reports of Rajesh et al. (2015). The length at first capture of 47.11 cm was quite similar to that reported by the aforementioned author but higher than 14.11 cm reported by Ghosh et al. (2009). Beverton and Holt (1957) indicated that natural mortality coefficient of a fish is directly related to the growth coefficient (K) and inversely related to the asymptotic length (L_∞). The life span. *T. lepturus* which had lower growth coefficient of 0.46 per year and a lifespan of 6.6 years was found to have relatively lower natural mortality coefficient of 0.67 per year. The fishing mortality (2.03) of *T. lepturus* recorded was similar to that reported by Khan (2006) but higher than that of Ghosh et al. (2009) in the Arabian seas. The high exploitation ratio (E = 0.75) observed is an indication of intensive fishing of this species and is similar to 0.73 as reported by Rajesh et al., (2015) from the South-West Coast of India.

However, *Lutjanus fulgens* is known only from the West African coast primarily in the Gulf of Guinea (Carpenter & De Angelis, 2016) and it appears no work has been carried on the growth and mortality parameters in the region as at now. According to Carpenter & De Angelis (2016), it is known to grow to a maximum size of 60 cm but most common at 50 cm. The growth parameters, L_∞ and L_{max} derived from the length-based estimates of *Lutjanus fulgens* in this study were: 51.09 cm and 45.6 cm respectively which agree with the aforementioned size. According to Shimose & Nanami (2014), maximum body sizes vary among *Lutjanus* species indicating that there are smaller sized species. For example, *Lutjanus cyanopterus* grows up to a total length of 160 cm whilst *Lutjanus biguttatus* grows up to 20 cm in total length. Longevity was estimated at 6.59 years, with a K value of 0.47. Total (Z),) fishing (F) and natural mortality (M) coefficients were estimated as 2.69, 1.91, 0.78 yr^{-1} respectively. The growth parameters, L_∞, K and t_o derived from the length-based estimates of *Lutjanus fulviflamma* conducted by Kaunda-Arara & Ntiba (2001) in Kenya were: 35.0 cm TL, 0.59 and -0.55 years, respectively. Comparatively higher values of these parameters were observed for *L. fulgens* in Ghanaian waters. The Z, F and M derived for *Lutjanus fulviflamma* from length converted catch-curve and Pauly's empirical formula were, 1.97, 0.27 and 1.70/year, respectively. The low fishing mortality together with low exploitation rate of 0.137, derived for the stock of *L. fulviflamma* in Kenya's nearshore fishery suggests that the stocks are under exploited. Again, higher values were recorded in this study. Exploitation rate was estimated at 0.71 which indicates overexploitation of the fishery resources. The length virtual population analysis showed an increasing trend of fishing mortality, *F* for large size groups. The reason for this is attributed to the fact that fishers prefer and target large sizes mainly because there is high economic value for larger snappers as compared to the smaller size groups. It is therefore not surprising that death for the small size group was mainly due to the natural causes. The length at first capture (Lc) was estimated at 31.51 cm and is slightly lower than length at first maturity (Lm) of 33.7 cm. This indicates that the species enter the exploitation phase just before attaining sexual maturity.

Reproductive Studies

It was observed from the study that females *T. lepturus* outnumbered males in general but there was no significant difference in the M:F ratio. Chi-square values indicated significant [$\chi^2(1, 1450) = 2.239$ $\rho = .05$)] dominance by females during March which happens to be the peak breeding season (Table 3). This observation has been reported by (Narasimham, 1972; Abdussamad et al., 2006). The proportion of females higher in March could be due to the possibility that spent males must have left the spawning grounds before the females or perhaps the possibility that few males can contribute to the fertilization of numerous eggs considering the type of spawning exhibited by *T. lepturus*. Females of *T. lepturus* spawn more than once in a reproductive season with sex ratio favouring females, particularly in larger size length classes (Al-Nahdi et al., 2009; Ghosh et al, 2014).

On the other hand, being dioecious, *L. fulgens* would not be expected to have a sex ratio that differs significantly from 1:1. The overall sex ratio observed for *L. fulgens* did not differ significantly from a 1:1 ratio. However, slightly more males than females were observed in most months which corroborates previous reports (Luckhurst, Dean, & Reichert, 2000; White & Palmer, 2004). Relatively high number of females dominated the catch during spawning periods and a principal factor that might explain the observation could be that females become most vulnerable to fishery exploitation at spawning grounds.

From the current study it was gathered that female *L. fulgens* tend to mature at 33.7 cm while the males do so at 36.7 cm. White & Palmer (2004) and Almamari et al. (2017) reported that male snappers tend to mature earlier than females, a common life history trait found in lutjanid species however the results of this study was contrary. The sexual maturity records obtained were consistent with reports for other lutjanid species; *Lutjanus jocu* in the tropical western South Atlantic (Brulé, Colás-marrufo, Pérez-díaz, & Carlos, 2016) and *Lutjanus goreensis* in Nigeria (Fakoya et al., 2015). For some lutjanid species, females have been shown to grow larger than males as reported by (Grandcourt, Zahran, Abdessalaam, & Francis, 2006) in the Southern Arabian Gulf, and this was true for *L. fulgens* in Ghanaian waters. In contrast, other studies in Okinawa, Japan have also shown that males grow larger than females (Nanami et al., 2010). Thus, sex differences in growth exist among species.

T. lepturus from different localities and regions mature at different body sizes. In this particular study, size at first maturity of *T. lepturus* was estimated as 70.5 cm for males and 71.1 cm females. Length at first maturity of *T. lepturus* was 61.2 cm in the northern Arabian sea and 59.2 cm in the Bay of Bengal according to a study conducted by Ghosh et al., (2014). Abdussamad et al. (2006) also in their study in Kakinada, east coast of India, estimated the size at first maturity as 47.3 cm at age 7.7 months. In that same study, gonadal development and sexual maturity in the species was observed from 38 cm onwards. However, higher values were encountered in other parts of the world. In Southern Brazil, Martins & Haimovici (2000) had an estimate of 63 to 69 cm length at first maturity, whilst Kwok and Ni (1999) in South China Sea reported 71 cm. Al-Nahdi et al. (2009) reported even higher values of 79 cm in the Arabian Sea coast of Oman. The differences in exploitation rates across the globe could account for the variations in length at first maturity, as fish tends to mature early when the fishing pressure is very high or when they are overexploited. A wide range of sizes at maturity in different parts of the world also demonstrate the adaptability of the ribbonfish to different environments.

Spawning season of females can be indicated based on the changes in gonad weight in relation to the body weight which emphasizes the importance of the GSI. In this study, monthly GSI values of females of *T. lepturus* reached a peak in March to June, followed by a decline in July and a series of lower values in September to December. This suggests that ovaries were ripe and ready for spawning by March and dwindled between July and December. Hence, it could be inferred that the major breeding activity occurred during the major rainy season (April to June). The major breeding which coincides with the rainy season could be ascribed to a strategy for ensuring maximum survival of offspring as the wet season is characterized by high volume of water and availability of food. It is reported that several peaks observed in GSI trends of fish populations suggest that the fish breed more than once a year. Hence, GSI of female *T. lepturus* which exhibited several peaks indicated that the fish spawned multiple times in a year. This result concurs with the observation by Kwok & Ni (1999) who reported that spawning takes place almost all year round and peaks from March to June from a study conducted in the South China Sea. Al-Nahdi et al. (2009) also reported a mass spawning season of May to June in the Arabian Sea region. Patadiya et al. (2017) also reported peak spawning on the west coast from April – June and along the east coast from February to June in India. In this study, the monthly variation in gonadal stages validates the inference drawn on peak spawning from March to June. The proportion of spawning females (females with ripe gonads) indicated a reproductive period from February to July, 2019 with a peak activity in March.

On the other hand, it was observed that GSI of the females of *L. fulgens* were generally higher than that of the males. Shimose and Nanami (2014) in their study found that individual GSI of females often exceeded a value of 6.0 and even more during the spawning season while that of males did not exceed 5.0 even in the peak spawning months. This finding could be attributed to perhaps smaller testes of male blacktail snapper being sufficient for short spawning days and also the ability of males to recover their testicular size until the next spawning. According to Rajesh et al., (2015), trophic enrichment during the upwelling season probably provides a favourable reproductive regime for the spawning of *L. fulgens*. Upwelling activities replenish seawater nutrients leading to better productivity offering enough food for the larvae, giving them a better chance to grow faster and pass quickly through critical stages (Koranteng, 1998). It cannot be confidently concluded on the spawning seasonal pattern of *L. fulgens* since there were gaps in the monthly data collection. In Ghana, the major upwelling period spans from June to September. It is apparent from the GSI pattern and monthly variation in gonadal stages (Figures 32 & 33), spawning takes place during the major upwelling season from June to September. According to Moncrief, Brown-Peterson, & Peterson (2018), GSI patterns that defined the spawning season for Vermilion snapper ranged from April to September in the North Central Gulf of Mexico. Shimose & Nanami (2014) also reported same for the spawning season of blacktail snapper around the Yaeyama Islands, Okinawa, Japan.

Fecundity of *T. lepturus* ranged between 4,876 to 43,410 eggs and the average number of eggs was 17,440 ± 1250 eggs (mean ± SE) (n = 50). Khan (2006) reported fecundity of *T. lepturus* in India ranging from 4,900 to 81,000 eggs. Numerous studies have been conducted on the relationship between fecundity and body parameters such as total length, body weight and gonad weight (Martins & Haimovici, 2000; Ghosh et al., 2014; Guillena, 2018). Linear relationships between fecundity and the total length, body weight and gonad weight have been reported by the aforementioned authors. The values of correlation coefficient, r in the present study indicates that among the parameters identified, it is the body weight that has the closest correlation with fecundity (r = 0.55) thus, body weight is the best index for fecundity followed by gonad weight (r = 0.50) and total length (r = 0.50). This finding is contrary to that of Guillena (2018) in the coastal waters of Zamboanga del Norte, Philippines, who reported that ovary weight was the best index for fecundity followed by body length and body weight in *T. lepturus*. Fecundity in teleosts could be affected by food availability, female condition index, size and environmental conditions. Thus, for a given fish, females in better condition exhibit higher fecundity indicating that size and condition are the key parameters to properly assess fecundity at the population level.

On the other hand, observations from studies conducted on fecundity of snappers and the relatively long spawning periods indicate that a relatively high fecundity could be expected. Fecundity ranged between 10,136 to

219,994 and the average number of eggs for *L. fulgens* was 77,833 ± 13,012 (mean ± SE) eggs (n = 30). This finding is relatively similar to that of other snappers worldwide. The batch fecundity of the Brazilian snapper, *Lutjanus alexandrei* off the northern coast of Pernambuco, Brazil ranged between 33,990 and 323,738 eggs (Fernandes et al., 2012). The average number of eggs for *L.quinquelineatus* was 389,880 eggs (n = 34) as reported by Baker, Soliman, Mehanna, & Soliman (2017) from the Red Sea off Hurghada, Egypt. Again, it was observed that the number of ripe eggs of the individual females were at variance with one another. Fecundity varies widely for fish of the same length, as found in the snapper, *Chrysophrys auratus* (Crossland, 1977) and reported by other workers for many species of fish (Devlaming et al., 1982; Arizi et al., 2014). Much of this variation was probably because of real differences in fecundity, but some may be caused by the stage in developmental maturity of the ovary at sampling. The exact timing of sampling is likely to be the most critical factor influencing the accuracy of fecundity determinations for serial spawning fishes (Crossland, 1977).

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter presents a summary, conclusions and recommendations of the study. It summarizes the main findings of the study, draws conclusions on the findings and makes recommendations towards sustainable management of the fisheries resources.

Summary

This study sought to assess the status of the *Lutjanus fulgens* and *Trichiurus lepturus* in Ghanaian waters with a view of providing biological information needful in proper management of the fisheries resources. The assessment specifically focused on:

1. the growth parameters of the two fish species, *Lutjanus fulgens* and *Trichiurus lepturus*;
2. the mortality parameters (M, Z, F) and exploitation ratio of each species; and;
3. the reproductive status of the two fish populations.

Data was collected over a period of twelve (12) months along the coast of Ghana, specifically from commercial landings of fishermen from three major fish landing sites in Ghana. Data was also collected on board the Research Vessel Dr. Fridtjof Nansen during a joint cruise in Ghanaian waters. Standard methods and procedures employed in stock assessment were followed critically to achieve the aims of the study.

Conclusions

Information collected during this study provides an overview for growth, mortality and reproduction of *Trichiurus lepturus* and *Lutjanus fulgens* along the coast of Ghana from the period of September 2018 to August 2019. The conclusions that were reached are as follows:

1. It was observed that the ribbonfish, *T. lepturus*, grows allometrically, regardless of sizes and sex and for *Lutjanus fulgens*, growth observed was isometric for both sexes. Fishery was dominated by one-year-old fishes for *T. lepturus* and one and two-year-old classes for *L. fulgens.*
2. The present exploitation ratio observed for both species indicates that they are overexploited and should be subjected to controlled decrease in fishing pressure to obtain maximum sustainable yield.
3. Virtual Population analysis indicated that main loss in the stock up to 37.5 cm size for *T. lepturus* and 19.0 cm size for *L. fulgens* was due to natural causes. Fishes became more vulnerable to the gear after this size and mortality due to fishing increased.
4. Sex ratio did not differ significantly from 1:1 in the two species. Gravid and ripe females were recorded in almost all the months for both species with their peak occurrence observed in March for *T. lepturus* and July to September for *L. fulgens*.
5. Fecundity was relatively high in both species and especially in the golden African snapper. Body weight proved to be the better index of fecundity in *T. lepturus.* For *L. fulgens*, a high degree of relationship was observed between fecundity and gonad weight.

6. Length at first capture for *T. lepturus* was low when compared to the length at first maturity indicating that majority of the fishes were caught before they could mature and spawn at least once in their life.
7. The study also concludes that both the species are vulnerable to recruitment overfishing based on the observation that they are exploited before they attain maturity in the marine environment. Consequently, this advocates for proper management (the need for reduction in fishing pressure, gear restrictions and observation of closed fishery during spawning) of the fishery resources.

Recommendations

The following recommendations were derived from the study:

1. From the observation of the information gathered, a ban on all fishing activities during peak spawning periods should be encouraged by appropriate bodies in the country (Fisheries Commission, Civil Society Organizations or Non-Governmental Organizations, among others) to prevent recruitment overfishing and help conserve the over-exploited stocks.
2. It is also evident from the results that both stocks are under higher fishing pressure thus warrants immediate reduction in fishing effort.

Suggestions for Further Research

1. Due to a sizeable number of indeterminate sexes in both fish species, it was possible some errors occurred when sexing fish in the study, this highlights the need for histological examination in further studies.
2. A comprehensive study should be conducted to investigate the gut content analysis and feeding behaviour with reference to monthly and seasonal variations in feeding intensity and food composition of the species.
3. Finally, this study represents the first report on the growth, mortality and reproduction of *Lutjanus fulgens* in the Gulf of Guinea therefore, there is the need to conduct future stock assessments of this species allowing for increased accuracy.

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APPENDICES

APPENDIX A: Definition of Terms

Allometric growth - Growth in which fish becomes lighter or heavier for its length as it grows.

Closed season - The banning of fishing activity (in an area or of an entire fishery) for a few weeks or months, usually to protect juveniles or spawners.

Cohort analysis - A retrospective analysis of the catches obtained from a given year class at each age (or length interval) over its life in the fishery. It allows estimation of fishing mortality and abundance at each age as well as recruitment.

Condition factor (K) - A mathematical measurement of the degree of "plumpness," or the general health of a fish or group of fishes.

Demersal - Living in close relation with the bottom and depending on it.

Exploitation rate - The proportion of a population at the beginning of a given time period that is caught during that time period (usually expressed on a yearly basis).

Fecundity - the number of ripe or ripening eggs in the ovary prior to the next spawning activity.

Fishing mortality - is a technical term which refers to the proportion of the fish available being removed by fishing in a small unit of time.

Fork length - A measurement used frequently for fish length when the tail has a fork shape. Projected straight distance between the tip of the snout and the fork of the tail.

Growth - change in length (axial growth) or weight (bulk) over a defined time.

Growth rate (K) - The increase in weight of a fish per year (or season), divided by the initial weight. In fish this is often measured in terms of the parameter K of the von Bertalanffy curve for the mean weight as a function of age.

Isometric growth - Growth in fish where fish shape remains same throughout life i.e. all parts of the fish increase in length at the same rate.

Length at first maturity - Length at which 50 percent of the individuals of a given sex (normally females) are considered to be reproductively mature.

Length Frequency - A length frequency distribution is an arrangement of recorded lengths (in a total catch, a stock, or a sample) which indicates the number of individuals encountered in each length interval.

Length-frequency distribution - The number of individuals of a catch or catch sample in each length interval. The modal size is the length group with the higher number of individuals. Distributions may be uni- or bimodal but are more generally multimodal, reflecting multiple age-groups.

Length-weight relationship - A mathematical formula for calculating the weight of a fish in terms of its length. When only one parameter is known, the formula can determine the other parameter.

Natural mortality (M) - Deaths of fish from all causes except fishing (e.g. ageing, predation, cannibalism, disease, and perhaps increasing pollution). It is often expressed as a rate that indicates the percentage of fish dying in a year.

Pelagic fish - Fish that live in the open ocean at or near the water surface and usually migrate long distances.

Population dynamics - The study of fish populations and how fishing mortality, natural mortality, growth and recruitment affect them.

Recruitment overfishing - A situation in which the rate of fishing is (or has been) such that annual recruitment to the exploitable stock has become significantly reduced. The situation is characterized by a greatly reduced spawning stock, a decreasing proportion of older fish in the catch, and generally very low recruitment year after year. If prolonged, recruitment overfishing can lead to stock collapse, particularly under unfavorable environmental conditions

Size-at-first-maturity - Length or weight of the fish when it attains maturity as defined by: 1) the minimal size at which maturity is reached; 2) the size at which 50 percent of the fish of that size is mature.

Spawning - Release of ova, fertilized or to be fertilized.

Total length (TL) - The length of a fish defined as the straight-line distance from the tip of the snout to the tip of the tail (caudal fin).

Total mortality (Z) - A measurement of the rate of removal of fish from a population by both fishing and natural causes. It is also the sum of natural (M) and fishing (F) mortality rates.

Virtual Population Analysis (VPA) - A retrospective analysis of the catches from a given year class which provides estimates of fishing mortality and stock size at each age over its life in the fishery (Blackhart, Stanton, & Shimada, 2006).

APPENDIX B: Summary Output of Regression Statistics of Length-weight relationship of *T. lepturus* (Overall)

Multiple R	0.978043
R Square	0.956569
Adjusted R Square	0.956543
Standard Error	0.062491
Observations	1677

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	144.0654	144.0654	36891.8	0
Residual	1675	6.541007	0.003905		
Total	1676	150.6064			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-3.79872	0.030476	-124.647	0	-3.85849	-3.73894	-3.85849	-3.73894
X Variable 1	3.343727	0.017409	192.0724	0	3.309582	3.377872	3.309582	3.377872

APPENDIX C: Summary Output of Regression Statistics of Length-weight relationship of *T. lepturus* (Males)

Multiple R	0.970835
R Square	0.94252
Adjusted R Square	0.942444
Standard Error	0.062863
Observations	754

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	48.72908	48.72908	12330.82	0
Residual	752	2.971762	0.003952		
Total	753	51.70084			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-3.70195	0.052071	-71.0938	0	-3.80417	-3.59973	-3.80417	-3.59973
X Variable 1	3.290161	0.029629	111.0442	0	3.231995	3.348327	3.231995	3.348327

APPENDIX D: Summary Output of Regression Statistics of Length-weight relationship of *T. lepturus* (Females)

Multiple R	0.976109
R Square	0.952789
Adjusted R Square	0.952721
Standard Error	0.059966
Observations	696

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	50.3649	50.3649	14006.03	0
Residual	694	2.495586	0.003596		
Total	695	52.86048			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-3.8473	0.050588	-76.0521	0	-3.94662	-3.74798	-3.94662	-3.74798
X Variable 1	3.369772	0.028474	118.3471	0	3.313867	3.425677	3.313867	3.425677

APPENDIX E: Summary Output of Regression Statistics of Length-weight relationship of *T. lepturus* (Indeterminate Sex)

Multiple R	0.95542
R Square	0.912828
Adjusted R Square	0.91244
Standard Error	0.067789
Observations	227

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	10.82723	10.82723	2356.1	3.4E-121
Residual	225	1.033966	0.004595		
Total	226	11.8612			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-4.00231	0.117426	-34.0836	8.15E-91	-4.23371	-3.77091	-4.23371	-3.77091
X Variable 1	3.466537	0.071417	48.53967	3.4E-121	3.325806	3.607268	3.325806	3.607268

APPENDIX F: Summary Output of Regression Statistics of Fecundity-Total Length relationship of *T. lepturus*

Multiple R	0.541795	
R Square	0.293542	0.541795
Adjusted R Square	0.278824	
Standard Error	0.202886	
Observations	50	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.820978	0.820978	19.94459	4.83E-05
Residual	48	1.97582	0.041163		
Total	49	2.796798			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-1.42479	1.255852	-1.13452	0.262209	-3.94985	1.100265	-3.94985	1.100265
X Variable 1	3.009937	0.673977	4.465937	4.83E-05	1.654816	4.365057	1.654816	4.365057

APPENDIX G: Summary Output of Regression Statistics of Fecundity-Body weight relationship of *T. lepturus*

Multiple R	0.618313	
R Square	0.382311	0.618313
Adjusted R Square	0.369443	
Standard Error	0.189712	
Observations	50	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.069247	1.069247	29.70902	1.71E-06
Residual	48	1.727551	0.035991		
Total	49	2.796798			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.981968	0.404576	4.898871	1.14E-05	1.168512	2.795423	1.168512	2.795423
X Variable 1	0.89536	0.164268	5.450598	1.71E-06	0.565077	1.225644	0.565077	1.225644

APPENDIX H: Summary Output of Regression Statistics of Fecundity-Gonad weight relationship of *T. lepturus*

Multiple R	0.579311	
R Square	0.335601	0.579311
Adjusted R Square	0.32176	
Standard Error	0.196754	
Observations	50	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.938609	0.938609	24.24576	1.04E-05
Residual	48	1.858189	0.038712		
Total	49	2.796798			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	3.802391	0.082018	46.36043	1.61E-41	3.637483	3.9673	3.637483	3.9673
X Variable 1	0.501111	0.101769	4.923998	1.04E-05	0.29649	0.705731	0.29649	0.705731

APPENDIX I: Summary Output of Regression Statistics of Length-weight relationship of *L. fulgens* (Overall)

Multiple R	0.972823
R Square	0.946384
Adjusted R Square	0.946325
Standard Error	0.141469
Observations	906

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	319.3455	319.3455	15956.6	0
Residual	904	18.0921	0.020013		
Total	905	337.4376			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-3.95322	0.076194	-51.8839	2.8E-273	-4.10276	-3.80369	-4.10276	-3.80369
X Variable 1	2.895869	0.022925	126.3194	0	2.850877	2.940861	2.850877	2.940861

APPENDIX J: Summary Output of Regression Statistics of Length-weight relationship of *L. fulgens* (Males)

Multiple R	0.97689
R Square	0.954314
Adjusted R Square	0.954206
Standard Error	0.132027
Observations	425

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	154.0193	154.0193	8835.91	1.4E-285
Residual	423	7.373342	0.017431		
Total	424	161.3927			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-3.96851	0.102791	-38.6078	1E-140	-4.17056	-3.76647	-4.17056	-3.76647
X Variable 1	2.902191	0.030875	93.99952	1.4E-285	2.841504	2.962877	2.841504	2.962877

APPENDIX K: Summary Output of Regression Statistics of Length-weight relationship of *L. fulgens* (Females)

Multiple R	0.963127
R Square	0.927614
Adjusted R Square	0.92745
Standard Error	0.154741
Observations	443

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	135.3202	135.3202	5651.31	1.4E-253
Residual	441	10.55971	0.023945		
Total	442	145.8799			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-3.88391	0.127743	-30.4042	2.7E-110	-4.13497	-3.63285	-4.13497	-3.63285
X Variable 1	2.874041	0.038231	75.1752	1.4E-253	2.798903	2.949179	2.798903	2.949179

APPENDIX L: Summary Output of Regression Statistics of Length-weight relationship of *L. fulgens* (Indeterminate Sex)

Multiple R	0.980473
R Square	0.961327
Adjusted R Square	0.960253
Standard Error	0.055354
Observations	38

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.742035	2.742035	894.894	5.04E-27
Residual	36	0.110307	0.003064		
Total	37	2.852342			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-4.09891	0.29848	-13.7326	7E-16	-4.70426	-3.49357	-4.70426	-3.49357
X Variable 1	2.936179	0.098151	29.91478	5.04E-27	2.737119	3.13524	2.737119	3.13524

APPENDIX M: Summary Output of Regression Statistics of Fecundity-Gonad weight relationship of *L. fulgens*

Multiple R	0.929641	
R Square	0.864233	0.929641
Adjusted R Square	0.841605	
Standard Error	0.154289	
Observations	8	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.909199	0.909199	38.19324	0.000825
Residual	6	0.142831	0.023805		
Total	7	1.05203			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	3.588821	0.203555	17.63072	2.14E-06	3.09074	4.086902	3.09074	4.086902
X Variable 1	1.155784	0.187018	6.180068	0.000825	0.698168	1.613401	0.698168	1.613401

APPENDIX N: Summary Output of Regression Statistics of Fecundity-Total Length relationship of *L. fulgens*

Multiple R	0.467255				2.14E-06
R Square	0.218327	0.467255			2.14E-07
Adjusted R Square	0.088048				
Standard Error	0.370212				
Observations	8				

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.229687	0.229687	1.675844	0.243063
Residual	6	0.822344	0.137057		
Total	7	1.05203			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.276322	3.497479	0.079006	0.939597	-8.2817	8.834345	-8.2817	8.834345
X Variable 1	2.9734	2.29687	1.294544	0.243063	-2.64684	8.593639	-2.64684	8.593639

APPENDIX O: Summary Output of Regression Statistics of Fecundity-Gonad weight relationship of *L. fulgens*

Multiple R	0.566988	
R Square	0.321475	0.566988
Adjusted R Square	0.208388	
Standard Error	0.344922	
Observations	8	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.338201	0.338201	2.84271	0.142765
Residual	6	0.713829	0.118971		
Total	7	1.05203			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.288844	2.08653	0.617697	0.559474	-3.81671	6.394399	-3.81671	6.394399
X Variable 1	1.29311	0.766954	1.686034	0.142765	-0.58356	3.169778	-0.58356	3.169778