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University of Cape Coast

UNIVERSITY OF CAPE COAST

POPULATION DYNAMICS AND REPRODUCTIVE STUDIES OF THREE
COMMERCIALY IMPORTANT SPARID SPECIES FROM GHANAIAN
WATERS

BY

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College of Agriculture and Natural Sciences, University of Cape Coast, in
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degree in Fisheries Science

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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:

Supervisor's Declaration

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

Principal Supervisor's Signature..... Date

Name:

Co-Supervisor's signature Date

Name:

ABSTRACT

This study investigated the catch trends, spatial distributions, exploitation status, and reproductive potential of the sparids – *Pagrus caeruleostictus*, *Dentex canariensis* and *Dentex gibbosus*, in the coastal waters of Ghana. Samples of the species were obtained from commercial catches at Tema, Elmina and Sekondi from February 2016 to July 2017. Also used were secondary data from the Fisheries Scientific Survey Department and Fridtjof Nansen cruise reports. *P. caeruleostictus* was the most abundant of the three species, while *D. gibbosus* was the least abundant. The asymptotic length (TL_{∞}) and growth coefficient (K) values for *P. caeruleostictus*, *D. canariensis* and *D. gibbosus*, respectively were 52.7 cm and 0.52 yr⁻¹, 70.9 cm and 0.25 yr⁻¹, and 60.7 cm and 0.16 yr⁻¹. The fishing mortality (F) calculated for the three species was greater than natural mortality (M), accounting for a greater percentage of total mortality (Z), and leading to an exploitation ratio (E) higher than 0.5. Except for *D. gibbosus* which appeared underexploited ($E_{cur} < E_{msy}$), the other species were exploited above their maximum sustainable yield ($E_{cur} > E_{msy}$). The respective male and female length-at-first sexual maturity was estimated as 36.2 cm and 28.0 cm for *P. caeruleostictus*, 51.7 cm and 31.6 cm for *D. canariensis*, and 54.3 cm and 56.4 cm for *D. gibbosus*. *P. caeruleostictus* and *D. gibbosus* had two spawning periods in a year, occurring in September and March, and in January-February and July-October, respectively. *D. canariensis*, however, had one extended spawning period taking place between May and September. The oocyte diameter frequency distributions were unimodal and the fecundities ranged from about 250,000 to 6,000,000 for all three species.

KEYWORDS

Exploitation

Growth and mortality

Reproduction

Seabreams

Sparidae

Spawning season

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DEDICATION

To my *Daddy Mike, Mummy Albe, Jane, David*, and my “*special someone*”.

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CHAPTER ONE

INTRODUCTION

Background to the Study

Ghana is noted to have a fisheries sector that contributes about 1.2% to annual Gross Domestic Product (GDP), 6.6% to Agricultural GDP (Fisheries Commission, 2018) and generate about US\$ 1 billion annually (Republic Of Ghana Fisheries And Aquaculture Sector Development Plan, 2011). The fishing industry is thus very active and, for many, provides one of the major sources of good low-cost animal protein (Antwi, 2006; Dontwi, Dontwi, Buabeng, & Ashong, 2008). The per capita consumption of fish in Ghana is currently 20-30 kg, which is higher than the global average of 19.3 kg for developing countries and 14 kg for the ECOWAS zone (Ayivi, 2012; FAO, 2018; Fisheries Commission, 2018; Nunoo, Asiedu, Amador, Belhabib, & Pauly, 2014), with the consumption being usually higher in coastal and inland-water communities (FAO, 2018). Ghana's fisheries sector engages and sustains the livelihoods of about 2.2 million people which accounts for about 10% of the nation's 24 million people (Ayivi, 2012; Dontwi et al., 2008; Republic of Ghana fisheries and aquaculture sector development plan, 2011).

The fisheries sector is largely dependent on resources from the marine fisheries with little support from the inland or freshwater fisheries and aquaculture (Research Department - Bank of Ghana (RD-BoG), 2008). The marine fisheries is very important as it contributes over 80% of the total fish catch in the country (Nunoo, Asiedu, Amador, Belhabib, Lam, et al., 2014; Nunoo, Asiedu, Amador, Belhabib, & Pauly, 2014; RD-BoG, 2008). The marine resources of the Gulf of Guinea are exploited chiefly by 7 countries

including Ghana (Marine Resources Service, 2005). Among 36 coastal countries, the fisheries in Ghana is thought to be the fourth most productive in the Atlantic region (Dontwi et al., 2008). Ofori-Adu (1988) listed about 347 species from Ghana's waters as being exploited, which made up 72% of the 485 species reported by FishBase as at August 2013 (Nunoo, Asiedu, Amador, Belhabib, & Pauly, 2014).

The marine fisheries is exploited by fleets which fall under three main sectors; namely: the small-scale or artisanal, the semi-industrial or inshore and the industrial (Koranteng, 1998; Nunoo, Asiedu, Amador, Belhabib, Lam, et al., 2014; Nunoo, Asiedu, Amador, Belhabib, & Pauly, 2014). Antwi (2006) reported that the marine fishing industry started as artisanal fishery and employed the use of very simple and inefficient methods and gears. The operations were often close to shore and the fish caught were mainly for domestic consumption. This sector has evolved over the years to what exists currently with modern fleets, efficient gears and methods, as well as increased volumes of fish landed.

Statement of the Problem

The assumption that fishery resources are unlimited and hence “immune to man's activities” has led to the depletion of fish stocks through overfishing over the last five decades (Sustainable Fisheries Management Project (SFMP), 2015). The result of this has been the low records of fish stocks being experienced worldwide (FAO, 2018). The fishery resources of Ghana's coastal waters are heavily exploited, and the fish species landed comprise of both pelagic and demersal species (Nunoo et al., 2014). RD-BoG (2008) categorises pelagic fish species as mobile and/or migratory species which are coastal and

live in open waters; whereas the demersal fish species could be “found near and just beneath the sea bed”. Commercially important pelagic species are the sardinellas, skipjacks, yellowfin, bumper and chub mackerel. Pelagic species make up majority of the fish catches that are landed which is about 80% of the total fish catch (Ayivi, 2012). Hence, many studies have been conducted on the status of some of these pelagic species (Aggrey-Fynn & Sackey-Mensah, 2012; Antwi, 2006; Atta-Mills, Alder, & Sumaila, 2004; Koranteng, 1998; Nunoo, Asiedu, Amador, Belhabib, Lam, et al., 2014).

The demersal species, however, which make up 20% of total fish catches according to Ayivi (2012), have paucity of data or information on their status. Ayivi (2012) further reports that since the demersal species are not properly assessed, they may become overexploited in some years to come as there are fluctuations in the catches of the pelagic species and probably due to their commercial value. Marine Resources Service (2005) also noted that the demersal resources from the Gulf of Guinea have been documented to be either fully exploited or overexploited due to the inconsistencies in the input data and hence, a precautionary approach limiting or avoiding increases in access is recommended.

Demersal species of importance occurring in Ghana’s coastal waters belong to the families Lutjanidae (snappers), Haemulidae (grunts), Mullidae (goatfishes), Sparidae (seabreams), Serranidae (groupers), Soleidae (soles), Sciaenidae (croakers) and Polynemidae (threadfins) (Ayivi, 2012; Koranteng, 2001b; RD-BoG, 2008), but those being greatly exploited belong to the families Sparidae, Sciaenidae and Lutjanidae (Koranteng, 1998). In addition, the species belonging to the families Lutjanidae, Sparidae and Serranidae are high value

fishes and hence have been experiencing low densities in catches due to increasing fishing pressure. Bannerman & Cowx (2002) added that generally, there has been some decline in the landings of demersal fishes which suggests that the estimated Maximum Sustainable Yield (MSY) for the demersal fisheries has been exceeded, which calls for management interventions.

The seabreams (Sparidae) are of commercial importance due to their high value, occurrence and abundance in most operations of semi-industrial fleets (trawlers) and some artisanal fleets which employ the use of gears such as the long-lines, set nets and beach seines (Aggrey-Fynn & Sackey-Mensah, 2012; Koranteng, 2001; Nunoo, Asiedu, Amador, Belhabib, & Pauly, 2014; Nunoo & Asiedu, 2013). These three, *Pagrus caeruleostictus* (bluespotted seabream; Valenciennes, 1830), *Dentex canariensis* (canary dentex; Steindachner, 1881), and *Dentex gibbosus* (pink dentex; Rafinesque, 1810), are among the most valued seabreams caught and landed in higher numbers along the coast of Ghana by the artisanal fisheries. All three are among the 10 species quoted by FAO (2015) as the main demersal species exploited by artisanal canoes and industrial trawlers. These landings go a long way to provide some form of food security for the coastal populations. They are enjoyed in various processed forms, and the most preferred is the fried fish.

These seabreams, though high in value and very important for the various coastal communities along the coast of Ghana, are thought to be “unsatisfactorily assessed” (Ayivi, 2012). It is, therefore, important to take stock of the fish species that are landed and of commercial importance to ascertain their status – whether they are overexploited, underexploited or have reached their maximum sustainable yields. "Republic of Ghana fisheries and

aquaculture sector development plan" (2011) reports that generally, there are lower fish catches in Ghana currently as compared to catches from a decade or two ago, and that with proper management, the fisheries sector could improve and generate economic returns to a tune of about US\$ 300 million per year and also contribute to food security. Hence, the study assessed the status of the seabream fisheries so as to gather enough information for the sustainable management of these fisheries.

Purpose of the Study

Despite the commercial importance of these seabreams, they have not been the subject of investigations in Ghana as is necessary for sustainable exploitation. Therefore, the primary goal of the study was to determine the current exploitation status and reproductive potential of the stock of each of the three sparid species in the coastal waters of Ghana, by assessing the catch trends in their landings by the artisanal fleets, which would serve as an indicator for the sustainable management of the fisheries.

Research Objectives

The objectives of the study were to:

1. determine the relative composition, abundance and distribution of the three seabreams landed from Ghanaian waters;
2. provide information on the CPUE, fish catches, fishing methods, fishing effort and other information needed for the sustainable management of the seabream fishery;
3. investigate aspects of the life history and population dynamics of the three species including growth, mortality and longevity, which are important inputs for stock assessment;

4. assess the exploitation levels and provide information on the relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) of the three species;
5. provide information on some aspects of the reproductive biology (spawning season, sexual maturity and fecundity) of the three seabreams.

Significance of the Study

The results of the study would provide a good baseline for the management of the three sparid species. Very few research have been conducted and published on the population dynamics and reproductive biology of the species from the Gulf of Guinea. Thus, the findings of this research will contribute to scientific knowledge on the species which will benefit fisheries managers, as well as policy makers, in understanding the current status of the species and the right methods to employ in the sustainable management of the species.

Delimitations

The study focused on the seabream fishery in the Greater Accra, Central and Western regions of Ghana, and thus the models generated in this study were based on estimates of fish samples from commercial catches in these regions. This was due to the fact that the hook and line fishers targeted in the study operated solely in these regions. Also, the study did not include the activities of the fishers and processors in the fishery; the study focused solely on the stock assessment and biology of the species.

Limitations

It was assumed that the areas from which the fishes were caught were their habitats. Data on the seabream fishery by the artisanal fleets were not collected by the Fisheries Scientific Survey Division until the year 2000, which did not provide adequate historical information on the catches of the species. Even with the late start data acquisition, no data was available on *Dentex canariensis*, which made it difficult to assess the catch trends of this species. The primary data were acquired from samples collected from commercial catches and not from a research vessel, which put the sizes and fishing grounds where the fishes were obtained at the mercy of the fishers. Very few samples of *Dentex gibbosus* were obtained over the sampling period which would have affected the quality of data used for the analyses of this species. However, the bootstrapping approach used to analyse the data lent some credence to the results. The CPUE calculations from the catch and effort data were assumed to be standardised as there were no further information (vessel size, number of crew, number of vessels, number of fishing operations in a day, number of hooks deployed) available to calibrate the CPUE. The type of hermaphroditism exhibited could not be determined by histological examination. Thus, the examination of the gonads was done macroscopically. Manual processes of washing, drying and counting of eggs used to determine fecundity may have led to over/under estimation or inaccuracies in fecundity estimates.

Organisation of the Study

The thesis is made up of six chapters, with the first chapter being the introduction, second – literature review, third – materials and methods, fourth –

results, fifth – discussion and sixth – conclusion and recommendation. There is also a references section at the end, followed by the appendices and vita.

Chapter One: this is the Introduction chapter which gives a background to the study, taking into consideration the problem statements and gaps in the study area. The purpose of the study is stated and the research objectives are also outlined.

Chapter Two: this chapter makes up the Literature Review. Relevant literature on the methods applied in the study, observations made on the species, and the current status of the seabream fishery were reviewed.

Chapter Three: this is the Materials and Methods chapter which gives a description of the study sites, and details all the procedures, equipment and materials employed to carry out the research, as well as the analyses carried out on the data. Some limitations of the study were also outlined.

Chapter Four: the Results chapter gives an interpretation of all the maps, graphs, tables and pictures derived from the analyses of the datasets.

Chapter Five: this is the Discussion chapter which explains all the results obtained from the study and deliberated in relation to similar works conducted on the species and in other parts of the world.

Chapter Six: this chapter comprises of the Summary, Conclusions and Recommendations. A summary of the work is given, together with some conclusions derived from the work. Suggestions for further research are also outlined, alongside some recommendations from the study.

CHAPTER TWO

LITERATURE REVIEW

Global Distribution of the Seabreams

The seabreams, belonging to the Family Sparidae, are mostly coastal fishes that have been noted to inhabit tropical, subtropical and temperate coastal waters (some in deeper waters) around the world (Atlantic, Indian and Pacific oceans), with over 150 species in over 35 genera recorded (K E Carpenter, 2001; Edwards, Gill, & Abohweyere, 2001; Orrell & Carpenter, 2004). They are known to be distributed from southern Spain to Angola, and also widespread in the Mediterranean, constituting an important part of their fishery (K E Carpenter, 2001; Fattah, El-Sayed, & Abdel-Bary, 1995; Mehanna, 2007; Sayed & Fattah, 1994; Soykan, İlkyaz, Metin, & Kinacigil, 2015).

They are demersal species which inhabit the continental shelf and slope, and known to occur in a wide range of marine habitats of various substrates, ranging from sandy to rocky bottoms at depths from 0 to 500 m, though they are found more often at depths less than 150 m (K E Carpenter, 2001; Hamida, Abdallah, Ghorbel, Jarboui, & Missaoui, 2010; Soykan et al., 2015). The adult and large species are solitary and occur more in deeper waters, while the young ones and small sized species form aggregations and inhabit inshore waters; though sporadically they are located in estuaries which are utilised as nurseries (K E Carpenter, 2001; Mehanna, 2007; Russell, 2014; Russell, Carpenter, & Pollard, 2014).

The seabreams serve as an important food source for many people around the world and are of great commercial importance (Asabere-Ameyaw & Blay, 1999; K E Carpenter, 2001; Edwards et al., 2001; Mehanna, 2007; Sayed

& Fattah, 1994). They are exploited mainly by trawling, hook and line, beach seines and set nets, with catches from trawling and hook and line constituting a greater percentage (Mehanna, 2007; Russell, 2014; Russell, Carpenter, et al., 2014). The hook and line gear, however, is the gear that catches most of the seabreams due to the habitat preferences of the species (Ayivi, 2012; Russell, Carpenter, et al., 2014). The conservation status of the seabreams around the world have been considered to be either of least concern, endangered, underexploited, exploited (sustainably), heavily exploited, fully exploited, or may be susceptible to overexploitation. For others, there are no evidence of overexploitation, stocks declining, stock in steady state, current stock unknown or having very little information on their current stock status (Bonanomi, Colombelli, Malvarosa, Cozzolino, & Sala, 2017).

The Seabream Fishery in Ghana

The seabream species in Ghana are exploited by the artisanal, semi-industrial and the industrial fisheries, using gears such as the set-nets, hook and line (“lagas”), beach seines and trawl nets (Koranteng, 2001b; Nunoo, Asiedu, Amador, Belhabib, & Pauly, 2014; RD-BoG, 2008). The artisanal fisheries use the hook and line method which accounts for a greater percentage of the landings due to the inability to conduct trawling in a sizeable part of the continental shelf because of its rocky nature (Ayivi, 2012). They are rated as one of the major commercially important and high-valued demersal fishes that are exploited by the semi-industrial and artisanal fleets, contributing significantly to local fish supply in the country and the national economy by providing livelihood support and poverty reduction, employment, food security,

fishery product exports and foreign exchange earnings, and GDP (Ayivi, 2012; Koranteng, 1998; RD-BoG, 2008).

In the Fridtjof Nansen trawl survey conducted on the demersal fishery resources in 2006 in the Gulf of Guinea in the waters of Benin, Togo, Ghana and Côte d'Ivoire, the seabreams had the highest landing, comprising of a greater percentage of the total catches in Benin, Togo and Ghana (Mehl, Olsen, & Bannerman, 2006). In Ghana, the seabreams recorded comprised over 80 % of the valuable demersal species harvested at 18 000 tonnes (Mehl et al., 2006). Landings of catch comprised of a mean catch of 4 100 tonnes from the artisanal hook and line fishery between the period 2006-2010 for seabreams, as recorded by FAO (2015).

About seven species of seabreams have been identified and recorded from Ghana (Edwards et al., 2001; Kwei & Ofori-Adu, 2005; Mehl et al., 2006). The species are *Boops boops*, *Dentex angolensis*, *Dentex canariensis*, *Dentex congoensis*, *Dentex gibbosus*, *Pagellus bellottii*, and *Pagrus caeruleostictus* (FAO, 2015; Koranteng, 1998; Kwei & Ofori-Adu, 2005; Mehl et al., 2006). These species are noted to be distributed at mean depths of 37 m to 100 m, mean temperatures between 17.5 - 19.8 °C and on sediment types that were of soft to hard bottoms (Figure 1) (Koranteng, 1998). They occur mostly inshore with larger fish preferring deeper waters (Owusu-Boateng, 1994). They are exploited across the entire coast of Ghana, with some skewness towards the western end of the country, due to the narrowness and rocky nature of some parts of the continental shelf (Ayivi, 2012). The artisanal hook and line fishers, thus, account for a greater percentage of the catches of these seabreams in the rocky areas that cannot be trawled (FAO, 2015).

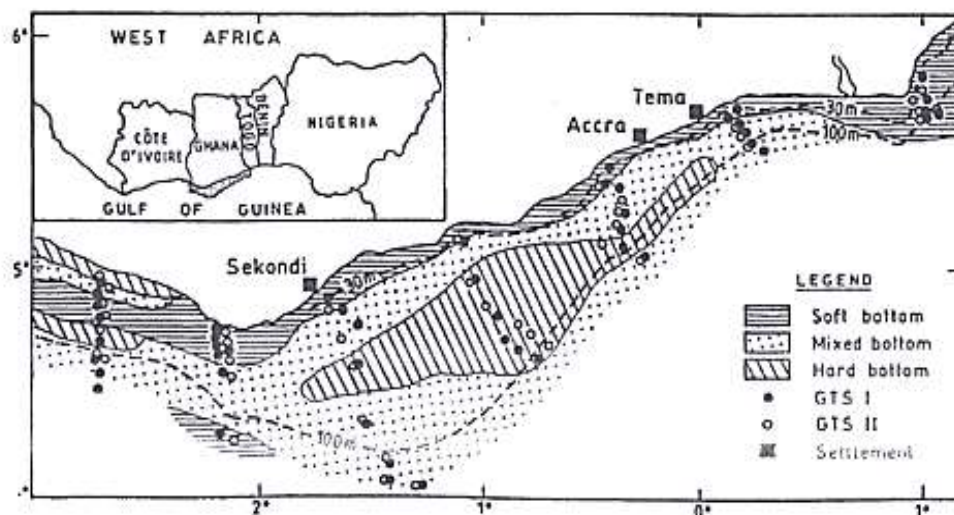


Figure 1: Distribution of bottom types along the coast of Ghana. Source (Koranteng, 2001c).

Biological Research on the Species

The seabreams of importance to this study (*D. canariensis*, *D. gibbosus* and *P. caeruleostictus*) have no exclusive/organised fishery as they are caught together with other seabreams and demersal species (Owusu-Boateng, 1994). Some works have been done on the biology of these species that occur in other parts of the world such as their size distributions, feeding habits and preferences, growth and mortality, and reproduction (Can & Turkmen, 2001; Chakroun-Marzouk & Kartas, 1987b, 1987a; Chen, Liu, & Wu, 2015; FAO, 2019c, 2019b, 2019a; Grubisic et al., 2007; Hamida et al., 2010; Ismail, Mourad, & Farrag, 2018; Otero, Galeote, & Arias, 1998; Pajuelo & Lorenzo, 1995; Russell, 2014; Russell, Carpenter, et al., 2014; Russell, Pollard, & Carpenter, 2014) with a few in Ghana (Owusu-Boateng, 1994; Rijavec, 1973).

The maximum observed length for *D. canariensis* has been reported to be 100 cm, though it is commonly harvested at a length of 35 cm (Edwards et al., 2001; FAO, 2019a). *D. gibbosus* can also grow to a length of 100 cm

(Edwards et al., 2001; Russell, Carpenter, et al., 2014) or 111 cm (FAO, 2019b), but is common to 60 cm (Edwards et al., 2001; FAO, 2019b). Records on *P. caeruleostictus* show that it could grow to a maximum length of 72 cm (Edwards et al., 2001) or 95 cm (FAO, 2019c), though it is commonly caught at 50 cm (Edwards et al., 2001; FAO, 2019c).

For feeding, *P. caeruleostictus*, *D. canariensis* and *D. gibbosus* have been found to be carnivorous species that feed mainly on molluscs, crustaceans and other fish species (K E Carpenter, 2001; Chakroun-Marzouk & Kartas, 1987a; FAO, 2019a, 2019b, 2019c; Hamida et al., 2010; Russell, Carpenter, et al., 2014). In addition, annelids and other organisms such as echinoderms, algae, phanerogams and tunicates have been recorded in the diets of *P. caeruleostictus* from Central Mediterranean (Hamida et al., 2010). *P. caeruleostictus*, though mainly a carnivorous fish, has been considered also to be an opportunistic feeder which feeds across various trophic levels, both on benthic and pelagic organisms, and an extensive variety of prey size and structure (Hamida et al., 2010).

The von Bertalanffy growth parameters documented by Russell, Carpenter, et al. (2014) for *D. gibbosus* were $L_{\infty} = 101.2$ cm, $K = 0.149$ year⁻¹, and $t_0 = -0.111$ years; while the parameters of the length-weight relationship were recorded as $a = 0.01014$ and $b = 3.0812$ (Pajuelo & Lorenzo, 1995). The values of a and b for *P. caeruleostictus* in Turkey were recorded as 0.0172 and 3.139 (Can & Turkmen, 2001). The growth parameter K was found to be 0.1786 in Senegal and 0.240 in Mauritania (Russell, 2014).

Sexual maturity is attained for *Dentex canariensis*, at an age of 2 years and a length of 20 cm, with intermittent spawning during its major spawning

season from July to September, and a minor spawning season in January (FAO, 2019a). For *P. caeruleostictus* also, sexual maturity is attained at the age of 2 years with its spawning migrations being parallel to the coast, and the intermittent activity taking place over soft bottoms in shallower waters (FAO, 2019c; Russell, 2014). In the Gulf of Gables in Tunisia, spawning reportedly takes place from May to October (Tsikliras, Antonopoulou, & Stergiou, 2010), while it occurs from July to November in Egypt (Ismail et al., 2018). It is considered a protogynous hermaphrodite (Chakroun-Marzouk & Kartas, 1987b; Ismail et al., 2018). Fecundity of the species ranged from 19 621 to 1 166 955 in fish with lengths ranging from 15 cm to 42 cm (Chakroun-Marzouk & Kartas, 1987b).

D. gibbosus has been established as a protandric hermaphrodite, though Pajuelo & Lorenzo (1995) classified it as protogynous hermaphrodite, with the males growing up to a length of 50 cm and switching the sex to females thereafter (FAO, 2019b). Hermaphroditic fishes were found ranging from 28.1 cm to 58.3 cm with body weights from 290.3 to 2 850.5 g (Pajuelo & Lorenzo, 1995). Spawning has been noted to take place in the summer months, extending from April to September, with peaks in May-July, and the sexual maturity attained at an age of 4 years (Russell et al., 2014) with sizes of 38.6 cm for males and 34.7 cm for females (Pajuelo & Lorenzo, 1995). In the Adriatic sea in Croatia, spawning takes place from July to October (Tsikliras et al., 2010). The mean absolute fecundity recorded for the species was $1\,672 \times 10^6$ (Russell et al., 2014) with a sex ratio of 1 : 1.45 in favour of females (Pajuelo & Lorenzo, 1995).

Stock Assessment Methods

Fish stock assessments have become important tools in the quest for sustainable management of fishery resources. The goal of fisheries management is “*to obtain the best possible utilization of the resource for the benefit of the community*” (Saetersdal, 1984). Cadima (2003) explained that the “best” could translate into more employment, foreign exchange, bigger profit, yield or catch; the “community” to mean a group of fishermen, consumers, country, or region; and the “possible” is a reminder of how the fisheries resources are self-renewable and need to be conserved. Fisheries stock assessments, therefore, comprise of models that are used to assess various components of the fishing activity or exploitation of the fisheries resources (Cadima, 2003). Some models such as the Lotka-Voterra type models, general production models, growth models, yield-per-recruit models and stock-recruitment models used in fisheries stock assessments are categorised into structural models and production models. These models describe the dynamics of the fisheries which provide parameters such as the biomass, exploitation rate, growth and mortality.

Growth modelling

The modelling of an individual growth of a fish is important to study the evolution of the biomass of that cohort or fish stock. The aged-based and length-based procedures are the main methods used in the modelling of this growth. In the tropics, length-based methods are important and commonly used as it is cheaper and far less work-intensive as compared to age and tagging studies; can be used on species that cannot be aged individually, and has only historical length frequency data available in fisheries laboratories for certain species (Pauly, 1987; Pauly & Greenberg, 2013). As discussed by Schwamborn,

Mildenberger, & Taylor (2019), the length-based stock assessment, since the beginning of fisheries science, has been used to deduce the growth of a fish mostly through modal progression. With modal progression, monthly length frequency (LF) distributions of the fish are plotted with the modes connected to track the growth of each cohort with time (Pauly, 1987; Petersen, 1891; Schwamborn et al., 2019). The von Bertalanffy Growth Function (VBGF) (von Bertalanffy, 1938), adapted by Beverton & Holt (1957), is the recognised growth model used in fisheries biology (Cadima, 2003) to study the growth of a fish and fitted to the monthly LF data (Schwamborn et al., 2019). The basic assumption underlying this VBGF model is that there is an asymptotic length (L_{∞}), which is a maximum that the individual length inclines to, a growth coefficient (K) which describes the curvature of the growth curve, and the theoretical age at length zero (t_0) of the fish (Cadima, 2003).

The modal progression approach, together with the “Petersen method” were combined into an “integrated method” (Pauly, 1983b), which was later incorporated in a computer package known as ‘ELEFAN (Electronic Length Frequency ANalysis) I’ (Pauly, 1987; Pauly & David, 1981; Pauly & Morgan, 1987), ‘COMPLEAT ELEFAN’ (Gayanilo Jr., Soriano, & Pauly, 1988) and ‘FISAT II’ (Gayanilo, Sparre, & Pauly, 2005). Recently, packages such as the ‘ELEFAN in R’ (Pauly & Greenberg, 2013) and ‘TropFishR’ (Mildenberger, Taylor, & Wolff, 2017; Mildenberger, 2019) have incorporated these methods together with some other functions. However, the ‘TropFishR’ appears to be the most improved package over the others as it includes enhanced versions of all the functions in FiSAT II and ELEFAN, in addition to some recent methods

with new optimization procedures (Mildenberger, 2019; Mildenberger et al., 2017; Schwamborn et al., 2019; Taylor & Mildenberger, 2017).

ELEFAN estimates the growth parameters following these steps: (i) “restructuring” of the LF data according to a procedure that grades length bins based on deviations from a moving average (MA) across neighbouring bins (Abobi, Mildenberger, Kolding, & Wolff, 2019; Pauly & David, 1981; Pauly & Morgan, 1987a), (ii) calculation of the scores accumulated (available sum of peaks-ASP) for a given set of VBGF parameters centred on the bin scores that are intersected by resulting growth curves (Abobi et al., 2019; Pauly & David, 1981), and (iii) search for VBGF parameters that result in the largest score value (Mildenberger et al., 2017). ELEFAN-based fit procedure is, therefore, centred on the search for the single best combination of VBGF parameters that yields the finest results, that is, the highest possible R_n value (Schwamborn et al., 2019). The main issue with this procedure is that the asymptotic length (L_∞) and growth coefficient (K) are interrelated such that a high estimate of L_∞ will produce a lower K , and vice versa (Schwamborn et al., 2019). Methods such as the K-Scan (Gayanilo, Sparre, & Pauly, 1996), L_{\max} approach (Sparre & Venema, 1998), and Powell-Wetherall plot were developed to help avoid this issue before ELEFAN I, with Response Surface analysis (RSA) to produce the highest R_n value, was developed .

The TropFishR package, first of all, permits the MA to be determined based on the number of bins selected. It provides an alternative for a square root transformation of the LF data of the larger length class bin scores, but with lesser numbers, to increase their weighting. It also includes an ‘anchor_time’ (t_{anchor} ranges between 0 and 1) which is the fraction of the year where yearly repeating

growth curves cross length zero, and a t_s which is the time of year when growth turns positive (Abobi et al., 2019; Mildenberger et al., 2017; Taylor & Mildenberger, 2017). The inclusion of the simulated annealing (SA) (Xiang, Gubian, & Martin, 1996) and genetic algorithms (GA) (Scrucca, 2013) in the ELEFAN programme to create ELEFAN_SA and ELEFAN_GA respectively in the TropFishR package optimises the search for the growth parameters and helps solve the issues with the previous procedures (Taylor & Mildenberger, 2017). These optimisation procedures (ELEFAN_SA and ELEFAN_GA) also provide significant improvements in the estimates of the parameters of the seasonalised VBGF (soVBGF), concurrently (Mildenberger et al., 2017; Taylor & Mildenberger, 2017). The procedures “find high scoring parameter combinations for the soVBGF” (Taylor & Mildenberger, 2017), though a pitfall with these procedures is the fact that they give just a single optimum combination of the estimated parameters without any confidence intervals (Schwamborn et al., 2019).

The ‘fishboot’ package, which is a bootstrapping method developed to be used together with the ‘TropFishR’ package in R, has proven to be reliable as it does not give only point estimates of the growth parameters but allows for assessment of the uncertainties around the growth estimates (Schwamborn et al., 2019). It also provides confidence intervals of the estimates and is the best to be used in data-poor situations (Schwamborn et al., 2019).

The advancements in modelling with the bootstrap and MCMC approaches have helped tremendously with the demand for reliable and accurate inferences using more realistic complex estimation models (Gavaris & Ianelli, 2002). The bootstrap-based approach (ELEFAN_boot) developed by

Schwamborn et al. (2019) is thus, a robust and reproducible way that provides proper confidence intervals for the VBGF parameter estimates, as well as seasonality. The other direct benefits of the ELEFAN_boot approach are unconstrained search, better reproducibility and accuracy, and the transfer of these confidence intervals into other stock assessments such yield-per-recruit models, virtual population analysis, simulations and bio-economics and mortality estimations (Schwamborn et al., 2019).

Mortality

Mortality is generally separated into two components - natural mortality and fishing mortality (Kilduff, Carmichael, & Latour, 2009). The natural mortality together with the fishing mortality make up the total mortality. The total mortality rate is determined by the length-converted catch curves, given the estimates of the growth parameters (Hoggarth, 2006; Pauly, 1983a, 1984a, 1984b). The length-converted catch curves have proven to be more beneficial than age-structured catch curves though it demands that the data be a good representative of an equilibrium distribution (Pauly & Morgan, 1987).

Fishes die naturally from environmental and density-dependent factors such as: predation, competition, diseases and food availability, which determine the natural mortality rates (M) (Bannerman & Cowx, 2002; Beverton & Holt, 1957). Natural mortality (M) can be divided into three components namely “physiological” mortality, “selective” mortality and “chance” mortality (Pauly, 1980). Physiological mortality (caused solely by disease, or old age, or both, without predation) is thought to be the sole natural mortality occurring in very large fishes that are past their youth while selective mortality (caused by disease, or old age, or both, with susceptibility to predation) is mainly in middle-sized

fishes, and chance mortality (without any physiological mechanisms and is linked to the number of possible encounters with predators) occurring in small-sized fishes (Beverton & Holt, 1957; Pauly, 1980).

The natural mortality rate (M), though an important parameter in stock assessments, is very difficult to estimate with accuracy when tagging and controlled experiments are not accessible, or the estimation cannot be done directly and reliably; thus, the reliance on empirical formulae (Kenchington, 2014; Mildenberger, 2019; Then, Hoenig, Hall, & Hewitt, 2015). There are so many ways of estimating this natural mortality using various empirical formulae (30 different ones), which rely on links with life history parameters together with environmental factors (Kenchington, 2014). The TropFishR package uses a most recent formula and method based on an analysis of 201 fish species (Mildenberger, 2019; Then et al., 2015), together with the Pauly's empirical equation which requires the VBGF growth parameters, in addition to other estimation methods.

The strong relationship between natural mortality (M) and the growth parameters has been established, as M is noted to be partially correlated with L_{∞} and K , with the strongest being with K . Given the value of K and the M/K ratio, the value of M can be computed in situations where M is difficult to obtain (Hordyk, Ono, Sainsbury, Loneragan, & Prince, 2015). This ratio has been noted to be fairly reliable between closely related stocks, provides great understanding into the life history strategy of a fish species, determines the shape of the von Bertalanffy curve, and is widely known as the "Beverton-Holt life history invariant" (Hordyk et al., 2015). Hordyk et al. (2015) explained

further that the M/K ratio is estimated to be within a range of 0.32 to 2.3 with the optimum at 1.5.

Fishing regime

The coefficient of mortality by fishing characterises the outcome of fishing on a stock. This could be further divided into two components known as the fishing level and the exploitation pattern (Cadima, 2003). The fishing level is also known as the fishing mortality and is commonly derived by deducting the natural mortality from the total mortality, which together with the exploitation pattern make up the fishing regime (Cadima, 2003; Mildenberger, 2019). Fishing mortality (F) includes deaths from fishing activities that involve catching and keeping the fish, or fishes that are not caught but die from the fishing activities (Kilduff et al., 2009). It is estimated by deducting the value of the natural mortality from that of the total mortality ($F = Z - M$) (Pauly & Morgan, 1987). The fishing level, thus, comprises of the fishing effort (number of vessels, number of fishing operations in a year, number and efficiency of gears deployed), whereas the exploitation pattern is the susceptibility of the various sizes of individuals available for capture to the selectivity of the fishing gears during the years (Cadima, 2003). Exploitation level is also estimated by determining the ratio of the fishing mortality to the total mortality ($E = F / Z$) (Pauly & Morgan, 1987). The effects of the coefficient of mortality on the resource is analysed by keeping either the fishing level or exploitation pattern constant, or by analysing the combined effect of the two (Cadima, 2003).

Biological reference points for fisheries resources management

In order to achieve the goals for fisheries management, the values of the fishing levels that adversely affect the self-renovation of the stocks or allow

greater yield or biomass and also allows a considerable amount of the biomass to be left behind to replenish the stocks, must be taken into consideration (Cadima, 2003). These fishing level values are referred to as the Biological Reference Points (BRPs). BRPs normally used by fisheries managers are the Target Reference Points (TRPs), Limit Reference Points (LRPs) and Precautionary Reference Points (PRPs). According to Cadima (2003), TRPs, also known as the reference points for management, “are biological reference points defined as the level of fishing mortality or of the biomass, which permits a long-term sustainable exploitation of the stocks, with the *best possible catch*”. It is categorised by fishing levels such as $F_{0.1}$ (fishing mortality at 10 % less of the maximum yield), F_{max} (maximum value of fishing mortality), and F_{MSY} (fishing mortality for maximum sustainable yield). LRPs, also known as the reference points for conservation, represent “maximum values of fishing mortality (F_{lim}) or minimum values of biomass (B_{lim}) which must not be exceeded”. PRPs are used with assumptions in situations where there is lack of information on the parameters of the stocks to avoid overexploitation. They are more restrictive and control the fishing mortality severely than the LRPs, and are characterised by levels such as F_{pa} (maximum values of fishing mortality with precautionary approach) and B_{pa} (minimum values of biomass with precautionary approach) (Cadima, 2003). Since BRPs need to account for periodic changes in the biological parameters or exploitation patterns of the stocks, the TRPs are most commonly used.

Yield and biomass per recruits

For effective fisheries management, TRPs are used and the estimates of fishing mortality that provide maximum sustainable yield are needed. Models

such as the Beverton and Holt model (Beverton & Holt, 1957) and the Thompson and Bell model can be used to predict the effects of management measures on the fisheries, due to changes in fishing mortality and/or the size at first capture (Cadima, 2003). They serve as a direct link between fish stock assessment and fisheries resource management (Mahmoud, Osman, Ezzat, & Saleh, 2010). These yield-per-recruit (Y/R) models are also known as production models and used to evaluate a stock's status in relation to reference levels (Mildenberger et al., 2017). The yield-per-recruit is reliant on the exploitation pattern, growth parameters and natural mortality (Cadima, 2003; Mahmoud et al., 2010). An equilibrium value of the yield-per-recruit could be obtained for a given level of fishing mortality, if its associated exploitation pattern, growth parameters and natural mortality are provided. This Y/R value increases with fishing mortality till a level where the maximum sustainable yield is achieved. Beyond this level of maximum sustainable yield, overfishing occurs and the population collapses (Mahmoud et al., 2010). The fishing mortality (F_{max}) that produces the maximum yield (Y_{max}), gives a corresponding maximum biomass (B_{max}) that can be taken out to allow stock replenishment. However, when the fishing mortality (F) is less than the F_{max} , a greater biomass than B_{max} is produced; while an F greater than F_{max} , will result in a biomass which is less than B_{max} and lead to overfishing (Cadima, 2003).

The 'TropFishR' package allows for the estimation of these reference points using Y/R analysis such as the Thompson and Bell model (Abobi et al., 2019; Mildenberger, 2019; Mildenberger et al., 2017). The selectivity in this model, is denoted by the vector of fishing mortality by length class which is calculated through the cohort analysis, and is described by a "trawl-like

selection ogive which allows for change in selectivity characteristics ('Lc_change') simultaneously with fishing mortality ('FM_change') or exploitation rate ('E_change'), respectively" (Mildenberger, 2019; Mildenberger et al., 2017). The outcome of the analysis is an isopleth graph showing the Y/R isoclines, and the visualisation of the yield and biomass for current fishing patterns based on the exploitation ratios and length-at first-capture, determined from the length-converted catch curve (Mildenberger, 2019; Mildenberger et al., 2017).

Length-weight relationship

Size in fishes is often measured in body length for expediency; yet, for management and conservation purposes, information about the body weight is essential for regulation of catches and estimation of biomass (Froese, Thorson, & Reyes, 2013). The length-weight relationship (LWR) is the most commonly used relationship recognised for the majority of fishes (Karachle & Stergiou, 2012). The weight (W) of a fish can, thus, be calculated from a given length either standard (SL), fork (FL) or total (TL) length with the help of length-weight relationships (Froese et al., 2013; Morato et al., 2001; Schneider, Laarman, & Gowing, 2000). This is due to the fact that length is generally less laborious to measure in field surveys than weight (Maci, Longo, & Basset, 2009). The precise relationship between length and weight varies among species of fish corresponding to their inherited body shape, and within a species according to the state (toughness) of the individual fish (Schneider, Laarman, & Gowing, 2000).

Length-weight relationships are of the power form, that is $W = aL^b$ (Le Cren, 1951). The " a " (a constant which is the intercept of the regression line on

the y-axis) describes the condition as well as the body shape of the fish if $b \sim 3$ (Froese et al., 2013). It is usually around 0.1 for small sized and rounded body shaped fishes, 0.01 for streamlined-shaped fishes and 0.001 for eel-like shaped fishes (Karachle & Stergiou, 2012). The parameter b (regression coefficient) is a measure of the allometric or isometric growth patterns of a fish. It indicates an isometric growth (three-dimensional) in body proportions for a fish, or the retention of the same shape when $b = 3$, and an allometric growth when $b < 3$ (a faster growth in length than in weight, which indicates a lighter fish) and $b > 3$ (a faster growth in weight than in length which corresponds to a heavier fish) (Karachle & Stergiou, 2012; Wootton, 1990). The value of “ b ” generally ranges between 2.5 to 4 (Ecoutin, Albaret, & Trape, 2005; Froese, 2006; Le Cren, 1951).

LWR is an essential formula which has a significant role in fishery biology, physiology, fisheries assessment and ecology; and in biological studies, it enables the monitoring of seasonal variations in fish growth and the computation of condition indices (Sangun, Akamca, & Akar, 2007). It also serves several purposes, such as the differentiation of taxonomic divisions and the comparisons with various developmental events or life histories of a fish, such as metamorphosis and the onset of maturity (Karachle & Stergiou, 2012; Le Cren, 1951; Moutopoulos & Stergiou, 2002). Fishes show their growth in length with its correlates increments in weight, and these developmental activities take place during their lifetime (Wootton, 1990). The LWR can vary considerably under the influence of differences in the number of specimens sampled, the areas sampled from, the type of season and habitat of fishes, the health and general fish condition, the habitat, preservation techniques and the

differences in the range of observed lengths of the individuals sampled (Maci et al., 2009; Moutopoulos & Stergiou, 2002; Schneider et al., 2000). Hence, the growth of a fish, though species specific, can considerably vary among species inhabiting different geographical locations and during different seasons (Wootton, 1990).

Condition index

Condition index, another relationship between the length and weight of a fish, is calculated as a ratio between the observed weight and that of the expected length, that is $K = 100W/L^3$ (Le Cren, 1951). This index, expressed as “coefficient of condition”, “Fulton’s condition factor” or “Ponderal index” and denoted by “K”, is calculated with the intention of describing the “condition”, “fatness” or “well-being” of a particular fish from the relationship drawn between the weight of the fish and its length (Froese, 2006; Le Cren, 1951). Since K is an expression of the relative fatness or heaviness of fish, usually higher values of K or heavier fish of a given length indicate better condition of the fish, and can be used as a means to detect the physiological condition of the fish in relation to its associations with abiotic and biotic factors (Froese, 2006; Le Cren, 1951; Wootton, 1990).

Condition, though variable and dynamic, at times reflects food accessibility and growth within the weeks preceding sampling (Schneider et al., 2000). The dynamism and variability could be attributed to the differences of the individual fishes within the same sample, and also with the seasonal and yearly variations in the average condition of each population (Schneider et al., 2000). Other important variables are sex and gonad development in some species, as K has been found to be correlated with the seasonal changes in

gonadal development, whereas the type of habitat is not a reliable predictor (Le Cren, 1951; Schneider et al., 2000). The index (K), though a simple measurement, can be used to provide important biological information for making better management decisions as it calculates the degree of well-being of the fish and produces information on the specific condition under which the fish is developing (Datta, Kaur, Dhawan, & Jassal, 2013).

Reproductive Biology

Reproductive biology is a fundamental aspect of delivering reliable scientific information for management, and plays a significant part in ascertaining productivity and a population's resiliency to exploitation (Gundersen, Ronneberg, & Boje, 2001). Reproductive biology mostly describes the strategies employed by fishes to replenish stocks that are depleted through harvesting or mortalities, or their additions to future generations (Kilduff et al., 2009). All aspects of the reproductive biology is, therefore, crucial for proper management, assessments and understanding the annual changes in the fish population (Dobroslavic, Mozara, Glamuzina, & Bartulovic, 2017). Reproduction is deemed the most crucial characteristic in the life cycle of a fish population as it determines their survival (Ismail et al., 2018). Studies on reproduction, therefore, generally focus on the reproductive aspects such as the reproductive styles, and the spawning potential and season(s), which aid in understanding the reproductive capability of a fish stock, the recruitment patterns and biological responses to population changes (Bahl, 1990; Dick, 2009).

Reproductive styles of the seabreams

Though fishes usually demonstrate a variety of sexual approaches, the seabreams exhibit some of the most complex and varied manifestations of sexuality (de Mitcheson & Liu, 2008; Ismail et al., 2018; Monteiro et al., 2010). The diversifications exist at the family level and even within the same genus, and they vary between gonochorism, sex reversal, bisexual gonadal progress or hermaphroditism (Buxton & Garratt, 1990; Ismail et al., 2018). Hermaphroditism is thought to be abnormal as it does not follow the normal pattern of separate sexes expected for majority of fishes; and is considered as the occurrence of both male and female features in the gonads of a minor percentage of the population, with its advantage being the maximisation of the lifetime reproductive ability of the fish (Buxton & Garratt, 1990). Hermaphroditism is prevalent in the seabreams (K E Carpenter, 2001), and is expressed in various forms such as protandry, protogyny, rudimentary and sequential hermaphroditism, though Buxton and Garratt (1990) suggest that there are undoubtedly, at least two reproductive styles – protandry and protogyny in addition to gonochorism (de Mitcheson & Liu, 2008).

Protandric hermaphroditism comes about when a number of the seabreams change sex from functional males to functional females, and is evidenced by the females having a lower growth coefficient with a larger asymptotic length in the older classes, while the males dominating the classes in the earliest years of life exhibit a higher growth coefficient (Buxton & Garratt, 1990; Coelho et al., 2005). Another characteristic of protandry is that the males mature at a smaller size than the females (Buxton & Garratt, 1990). Protogynous hermaphroditism also occurs when a number of the species change

sex from functional females to functional males, and is characterised by smaller females than males with an intermediate sizes between them (Buxton & Garratt, 1990).

For rudimentary hermaphrodites, also referred to as “late gonochorists”, the young fishes are known to have an undeveloped intersexual gonad which develops later into either a male or female gonad without any sign of a sex reversal (Buxton & Garratt, 1990). While with sequential hermaphroditism, the fish reproduces best, initially as one sex in a specific time in its life, and then as the other sex at a later time (Buxton & Garratt, 1990; de Mitcheson & Liu, 2008). Though the size or age at which sex reversal occurs is not fixed, it has been documented to occur in response to demographic conditions pertaining at a time (Buxton & Garratt, 1990). De Mitcheson and Liu (2008) noted that the differences in the early maturity and gonadal makeup within the seabreams make the identification of the sexual pattern mostly challenging.

Spawning potential and season(s) of the seabreams

Important methods used to determine and conclude the spawning potential and seasons include the size at first maturity (L_{50}), the gonadosomatic index (GSI), and the fecundity and ova diameter of the species (Tsikliras et al., 2010). Basic knowledge of these parameters is needed to properly manage a species and comprehend how the species react to distresses such as fishing (Laarman & Schneider, 1985). The onset and duration of spawning is vital to the successful management of a species and on their recruitment (Tsikliras et al., 2010). Typically, some tropical marine species have distinct spawning seasons, while others are found in reproductive conditions or spawn throughout

the year with seasonal peaks; though the proportion of ripe individuals at a particular time varies with seasonal variations (Wootton, 1990).

Size-at-first maturity (L_{50})

Size-at-first maturity defines the lifespan of a fish as it represents a critical transition in the life of the species (Wootton, 1990). It is another important population characteristic useful for management, as it is directly associated with the reproductive capability of the population, and ascertains the spawning biomass upon which conservation sizes are generally centred on in exploited populations (Flores, Wiff, & Diaz, 2015; Fontoura, Braun, & Milani, 2009). How long or short a reproductive life span of a fish will be is determined by its size at first maturity, as those who mature early have a shorter life span and vice versa (Wootton, 1990). In determining the maturity, representative samples are taken from the population during their spawning season and their observed matured proportions modelled using the logistic function (Flores et al., 2015). Macroscopic and histological examination of the gonads are crucial in determining the maturation stages of the gonads as slight errors introduced in the staging process would lead to great discrepancies in the estimated parameters for the fitted model (Flores et al., 2015).

Histological examination is the most accurate methodology used in determining the maturity stages of a fish, and it involves examining the features of the ovaries or testis giving an unambiguous interpretation of the maturity (Flores et al., 2015; Fontoura et al., 2009). However, this procedure is quite expensive and laborious, while the macroscopic examination is relatively cheaper and the fastest and commonly used method (Flores et al., 2015). Macroscopic examinations involves the skill of a trained personnel who

examines the gonads with the naked eye and assigns the maturity stages based on the appearance of the gonads (Flores et al., 2015; Fontoura et al., 2009).

Though several approaches have been suggested and are available to estimate the size at first maturity, such as the modified logistic with a variable asymptote using GSI data (Fontoura et al., 2009); and the logistic function fitted to the relationship between proportion matures and size or age using the maximum likelihood method, which is the most commonly used procedure (Militelli, López, Rodrigues, García, & Macchi, 2017).

Gonadosomatic index

Gonadosomatic index (GSI) is an effective tool that could be used to infer the spawning season of a species, as it is a physiological factor extensively applied as an indicator of the reproductive success, and gives understanding into the spawning behaviour of the species (Ismail et al., 2018). It is also a common procedure, expressed in terms of wet or dry weight, used to describe the relative size of the gonads over time (Wootton, 1990). The gonadosomatic index (GSI) is often used to describe the maturity state of the female, and it is traditionally defined as the ratio between the gonad weight (GW) (g) and the total weight (W) (g) of the fish (Gundersen et al., 2001).

GSI is another distinctive character in hermaphrodites, as it is higher in females than in males for protogynous seabreams, and unbiased in rudimentary individuals, with the rudimentary hermaphrodites producing “more gametes than their protogynous counterparts” (Buxton & Garratt, 1990).

Fecundity and Ova diameter

Fecundity is the connection between the spawning stock and the ensuing recruitment (Gundersen et al., 2001). Majority of fishes are oviparous,

discharging their eggs and sperms into the water column to result in external fertilisation and development of the embryos, with majority of these eggs unattended; while a few others are viviparous (internal fertilisation of eggs) (Wootton, 1990). Many are also total spawners who discharge all their matured eggs in a short interval during a particular spawning season, and is evidenced by a high peak in GSI just before spawning, and the fecundity is referred to as breeding season fecundity (Wootton, 1990) while others are batch spawners who have a relatively low GSI, and spawn several times during the spawning season (batch fecundity), and a high rate of egg production with many batches in a season (Wootton, 1990).

Lifetime fecundity is the quantity of eggs that the fish spawns over a definite period which is dependent on the amount of eggs per spawning and the number of spawnings (Wootton, 1990). In addition, fishes are classified into two groups of spawners – indeterminate and determinate (Kennedy, Gundersen, & Boje, 2009). Indeterminate spawners have a fecundity that is unsteady with a continuous supply of pre-vitellogenic oocytes to the developing pool of oocytes even during spawning; whereas the determinate spawners supply a batch to the developing pool and wait to the next maturity cycle (Kennedy et al., 2009). These types of fecundity are, therefore, important to note when describing the fecundity of a fish.

Among individual seabreams and their populations, estimations of fecundity can be immensely variable. Several factors are responsible for this variability which is oftentimes inadequately understood, though some common patterns such as the size of the fish, have been detected (Dick, 2009). For batch fecundity, fecundity is a function of the body size and not the amount of food

consumed prior to breeding, as it is related to the availability of the size of the body cavity to contain the matured ovaries (Wootton, 1990). Though there is a strong correlation between fish size and batch fecundity, the batch fecundities of same-sized fishes can vary between them and within the individual in the same spawning season (Wootton, 1990).

The size and quality of eggs produced by the females is a derivative of the components of the resources deposited in the egg; and the size is restricted ranging between 0.25 mm to about 7 mm (Wootton, 1990). Most fishes, however, have egg sizes in smaller diameters which is due to the predisposition of the fish to minimise egg size in order to maximise fecundity (Wootton, 1990). Nevertheless, the optimal egg size is one that allows the maximum survival of the offspring to become reproductively functional, even though bigger eggs are known to produce bigger larvae (Wootton, 1990).

Egg size has been noted to relate to latitude and the mode of spawning; as demersal egg size increases with increasing latitude and are similar with the size of pelagic eggs at lower latitudes (Albert, Nilssen, Stene, Gundersen, & Nedreaas, 2001; Wootton, 1990). It also varies within a species, interspecifically, at different times in the same year, and from year to year (Albert et al., 2001). Fish populations that spawn in early spring have larger eggs, those that spawn in late spring and summer have small eggs, while those that spawn in late autumn and winter have intermediate sizes of eggs; and this seasonal changes in the sizes could be an adaptation response to variable conditions (Wootton, 1990).

CHAPTER THREE

MATERIALS AND METHODS

This chapter looks at the various materials and methods employed for conducting some aspects of the stock assessment and reproductive studies on the seabreams. The chapter commences with a description of the study sites, followed by the sampling methods, and the type of data collected. Details of how the data collected were analysed have also been outlined.

Study Sites

Three sampling sites on the coast of Ghana were selected based on the active fishing activities that occur in those areas. These were Tema (east coast), Elmina (central coast) and Sekondi (west coast) (Figure 2). Tema is a city located about 25 km from the capital city Accra. It was constructed on the site of a small fishing village and currently called the “harbour city” since it is Ghana’s largest seaport and houses one of the fishing harbours in the country. Tema Fishing harbour (5° 38' 52"N, 0° 01' 29"E) has all the different types of fishing fleets (artisanal, semi-industrial and industrial) operating. Elmina is located about 2 km west from the Central Regional capital Cape Coast (Aheto et al., 2012). It is a fishing community which has a major landing site, the Elmina Fish landing quay (5° 04' 57"N, 1° 21' 01"W), with both the artisanal and semi-industrial fleets operational. Sekondi, one of the twin cities (Sekondi-Takoradi) which happens to be the capital city for Western Region, is a fishing community that houses the other one of the two fishing harbours in Ghana – the Albert Bosumtwi-Sam Fishing harbour (4° 56' 17"N, 1° 42' 26"W). It has the artisanal, semi-industrial and industrial fleets operating there.

The hook and line fishers who were of great importance to the study operated mainly at these three sampling stations. The fishers spent an average of about four days at sea during each fishing trip. The vessels returned to the sites between the hours of 0300 and 0600 GMT, but fish sales started between the hours of 0700 and 1000 GMT during the fish market hours. They land similar sizes of fish across the three sites, which are usually unsorted and comprise of all the three species in crates and preserved on ice.

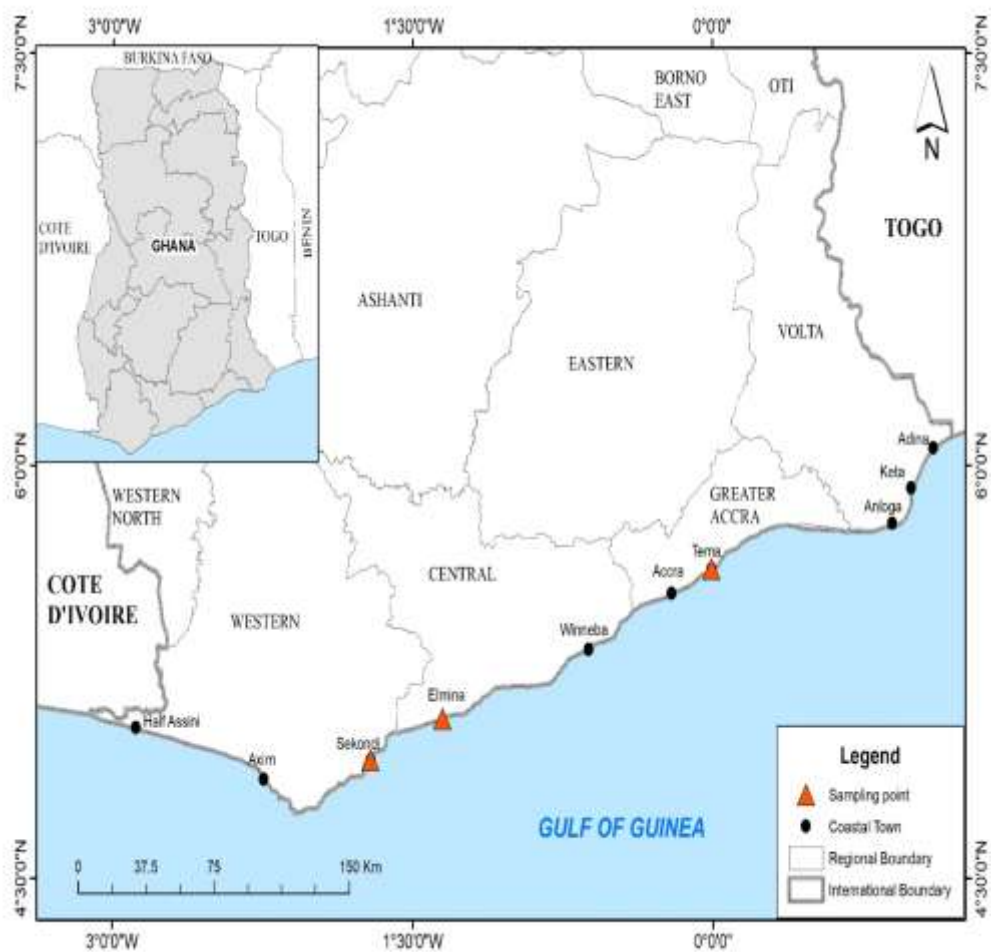


Figure 2: Map of Ghana showing the fish sampling stations.

Sampling Methods and Data Collection

Random samples of the Canary dentex (*Dentex canariensis*), Pink dentex (*Dentex gibbosus*) and the Blue-spotted seabream (*Pagrus caeruleostictus*) (Figure 3), were obtained from landings of fishermen from February 2016 to July 2017 at the three study sites. Each month, fish samples were collected on the second Wednesday from Sekondi, second Saturday from Tema, and third Wednesday from Elmina through a purposive sampling technique. The fish samples, usually in one crate, were collected randomly and sorted. The three species were first obtained from random samples before the start of the study, and identified to the species level with the aid of a fish identification manual (Schneider, 1990). The fish samples were preserved on ice and transported to the laboratory for further analyses. In the laboratory, specimens were measured for total length (TL) to the nearest 0.1 cm with a measuring board, body weight (BW) and gonad weight (GW) to the nearest 0.01 g using a measuring scale. The sex of individuals was determined macroscopically by examining the gonads, and the gonads further assigned maturity stage according to a five-point scale (ICES, 2007), that is, Stage I- Immature, Stage II- Maturing, Stage III- Nearly ripe, Stage IV- Ripe and Stage V- Spent. Fish with thin and translucent gonads were categorized as having indeterminate sex.

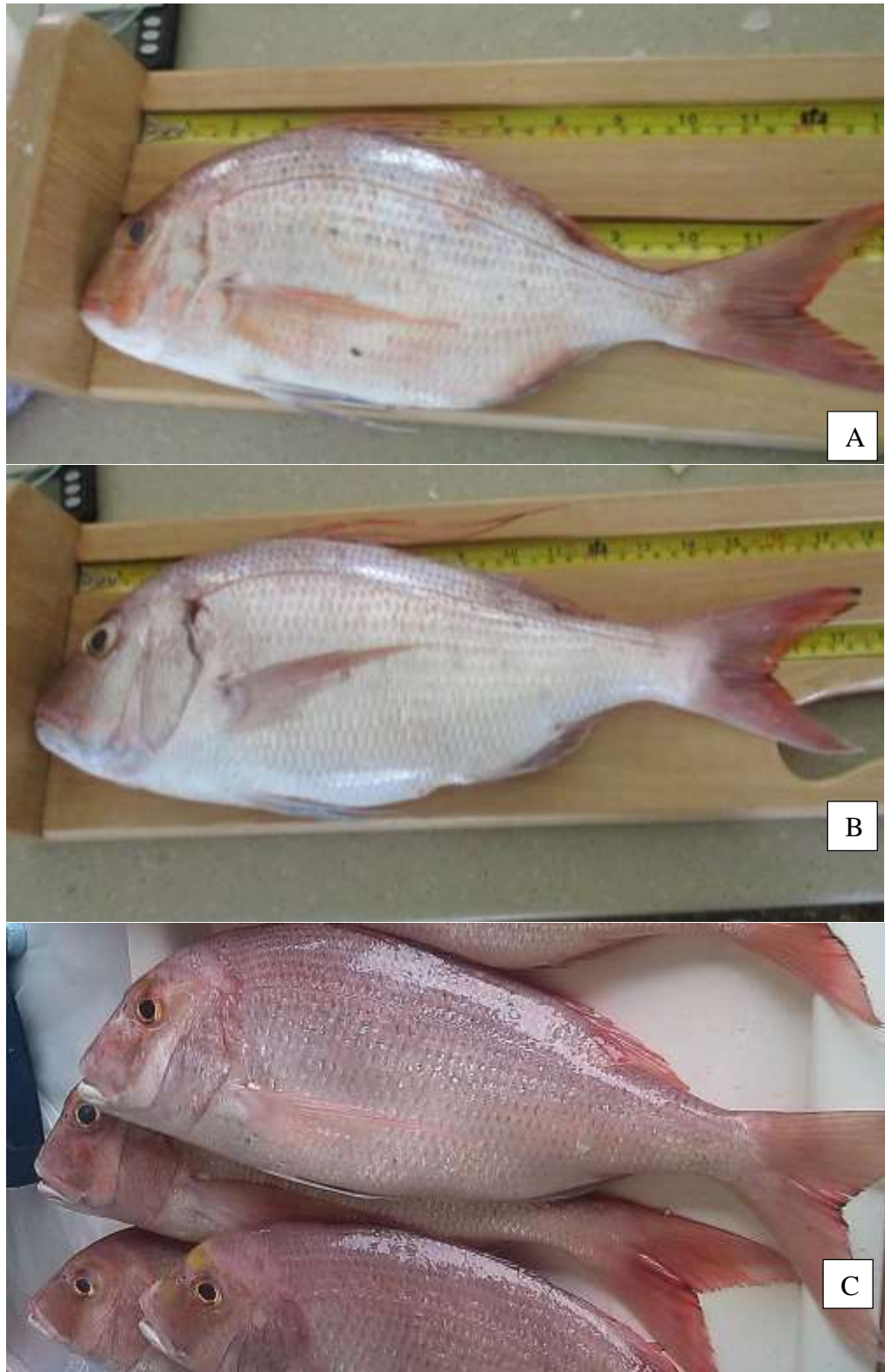


Figure 3: (A) *Pagrus caeruleostictus*, (B) *Dentex gibbosus* and (C) *Dentex canariensis* identified and used in the study.

Additionally, catch and effort data on the sparid species from the artisanal fisheries were obtained from the Fisheries Scientific Survey Division (FSSD) of the Ministry of Fisheries and Aquaculture Development (MoFAD), and from the Fridtjof Nansen 2005 (Mehl, Oslen, & Bannerman, 2005) and 2016 (Toresen, Olsen, Asante, Carocci, & Psomadakis, 2016) cruise reports on the trawl surveys conducted along the coast of Ghana. The data comprised of numbers from catch assessment surveys, data on the fishery, and data on the distribution of the species from transect trawl stations from the shallow to deep waters.

Data Analyses

The relative composition of the three species in the samples obtained during the study period was determined. The length and weight measurements from the three sites were pooled together for the analyses of each species, as the monthly fish sizes from each site were few, similar and with no significant differences between the sites after conducting the Kolmogorov-Smirnoff test. The length measurements were further compiled into 1 cm length classes for the size frequency distributions for each species. All the analyses relating to the growth modelling, natural and fishing mortalities, exploitation ratios and yield-per-recruit were done using the packages “TropFishR” (Taylor & Mildenerger, 2017), “fishboot” (Schwamborn, Mildenerger, & Taylor, 2018), “ks” (Duong, 2019), “devtools” (Wickham, Hester, & Chang, 2018), “fishmethods” (Nelson, 2018), as well as the base packages in the statistical computing software “R” version 3.5 (R Core Team, 2019) (Appendix A). The analyses relating to the length at sexual maturity (Appendix B) and the size frequency distributions of the sexes were done using the packages “sizeMat” (Torrejon-Magallanes,

2016), “FSA” (Ogle, Wheeler, & Dinno, 2019) and the base packages in “R” version 3.5 (R Core Team, 2019). The CPUE, relative composition of the species, size frequency distributions, length-weight relationship (LWR), sex ratios, condition (K) and gonadosomatic (GSI) indices, fecundity, and ova diameter were analysed with MS Excel.

Fish spatial distribution and CPUE estimates

The data from the Fridtjof Nansen cruise reports were used to map out the distributions of the three species in the years 2005 and 2016 using “ArcMap” version 10.5, as well as the determination of the relative abundance in numbers. The catch per unit effort (CPUE) was calculated for *P. caeruleostictus* and *D. gibbosus* from the year 2000 to 2016 with data from the Ghanaian vessels. Data on *D. canariensis* were unavailable.

Determination of length-weight relationships

The relationship between the length and weight parameters of the fishes was calculated using the parabolic equation:

$$BW = aTL^b \text{ (Le Cren, 1951)}$$

The log transformed data gives a least squares linear regression model described by the equation:

$$\ln BW = \ln a + b \ln TL$$

where *BW* is the total body weight in grams and *TL* is the total length in cm.

The parameters *a* and *b* were determined by the least squares linear regression analysis on the log-transformed data (Ecoutin et al., 2005; Sparre & Venema, 1998) using MS Excel. The values of *b* derived from the equations for the species were tested ($\alpha = 0.05$) using the one-sample t-test for significance difference from the isometric value (3) by the function:

$$t_s = \frac{(b - \beta)}{S_b}$$

where b is the regression coefficient of the sample, β is the regression coefficient of the population, and S_b is the standard error of the estimated regression coefficient of the sample.

Estimation of growth parameters

The von Bertalanffy growth equation:

$$TL_t = TL_\infty \times [1 - e^{(-K \times (t - t_0))}] \text{ (von Bertalanffy, 1938)}$$

where TL_t is the total length at-age t , TL_∞ is the asymptotic length, K is the growth rate coefficient and t_0 is the theoretical age at length zero, was used to describe the growth of the three seabreams by fitting the growth curves to the length-frequency data (Gayanilo et al., 2005). The growth parameters (TL_∞ , K , and t_{anchor} (the fraction of year where yearly repeating growth curves cross length equal to zero (Mildenberger, 2019))) were determined by modal progression analysis using the ELEFAN function in the “TropFishR” package. The full bootstrap approach proposed by Schwamborn, Mildenberger, & Taylor (2019) which has been proven to be very robust, replicable and highly accurate, was conducted using the fit algorithm ELEFAN_ GA (Genetic Algorithm (Scrucca, 2013)). This was done due to the small size of the data and to provide confidence intervals for the growth parameter estimates. The settings for the fit algorithms were optimized to ensure maximum precision (Appendix C), with the search space always constant with $t_{\text{anchor}} = 0-1$, $TL_\infty = 40-100$, $K = 0.1-1$, for *P. caeruleostictus*, $t_{\text{anchor}} = 0-1$, $TL_\infty = 50-100$, $K = 0.1-1$, for both *D. canariensis* and *D. gibbosus*, and MA (moving average) = 7 for all three datasets. The growth parameters were then used to model the growth of the species with increasing relative age.

Determination of growth performance index

The growth performance index (ϕ') was calculated by the equation:

$$\phi' = \log_{10} K + 2\log_{10} TL_{\infty} \text{ (Pauly \& Munro, 1983)}$$

Estimation of mortality coefficients

The instantaneous total mortality rate (Z) was estimated from the slope of the descending right arm of the length-converted catch curve, which was derived from the pooled data of the length-frequency samples, together with the VBGF growth parameters (Munro, 1984; Pauly, 1983a, 1984a, 1984b). The growth parameters were also used to estimate the natural instantaneous mortality coefficient (M) from the empirical equation of Pauly (1983b) with M , TL_{∞} , K and $T^{\circ}C$ (mean sea bottom temperature of $19^{\circ}C$ in Ghanaian waters (Torensen et al., 2016)) as follows:

$$\log_{10} M = -0.0066 - 0.279\log_{10} TL_{\infty} + 0.6543\log_{10} K + 0.4634\log_{10} T^{\circ}C$$

(Pauly, 1980)

The fishing mortality rate (F) was calculated from the equation:

$$F = Z - M \text{ (Ricker, 1975)}$$

Determination of exploitation ratio

The exploitation ratio (E) was established by the equation:

$$E = \frac{F}{Z} \text{ (Ricker, 1975)}$$

Estimation of longevity

The longevity or natural lifespan (t_{max}) of the stocks was assessed using the equation:

$$t_{max} \approx \frac{3}{K} \text{ (Pauly, 1983)}$$

where K is the growth coefficient of the species

Relative yield-per-recruit and relative biomass-per-recruit analyses

The estimated growth and mortality parameters were used to determine and model the relative yield per recruit (Y'/R) and the relative biomass per recruit (B'/R) (Sparre & Venema, 1998) at the current fishing mortality rates for the three species. The array of F values per length group needed to predict this model was provided by Virtual Population Analysis (VPA) (Appendix D).

Estimation of length at first capture and age at first capture

The length at first capture (L_c) was estimated from the selectivity function of the length-converted catch curve (Pauly, 1983a, 1984a, 1984b). Its corresponding age at first capture (t_{50}) was obtained by applying the VBGF growth parameters and Z in the equations:

$$t_{50} = t_0 - \left(\frac{-1}{K}\right) \left(\ln \left(1 - \frac{L_c}{TL_\infty}\right)\right) \text{ (Beverton \& Holt, 1957)}$$

where TL_∞ is the mean length of the catch, t_0 , K and TL_∞ are VBGF growth parameters and Z is the instantaneous total mortality rate. The effects of length at first capture on (Y'/R) at the current value of F and at different fishing mortality values of the species were estimated

Estimation of sex ratio

The sex ratios of the sampled species were studied in relation to the months sampled and the size classes of the species. The ratio was ascertained for any dominance of one sex using the Chi-square (χ^2) test by the equation:

$$\chi^2 = \frac{(O_m - E)^2}{E} + \frac{(O_f - E)^2}{E}$$

where O_m is the observed number of males, E is the expected number of male or female, and O_f is the observed number of females.

Determination of condition index of the fish species

The total length and body weight measurements of the fish were used to determine the Fulton's condition index (K) using the equation:

$$K = \frac{BW}{TL^3} \times 100 \text{ (Le Cren, 1951)}$$

Determination of gonadosomatic index

The gonadosomatic index (GSI) of fish was calculated as:

$$GSI = \frac{GW}{BW} \times 100 \text{ (Anderson & Gutreuter, 1983)}$$

Length-at-first-sexual maturity estimates

The lengths at first sexual maturity of males and females were determined separately using logistic ogives in a graphical plot fitted to the proportion of mature fish at length in 2 cm length bins. L_{50} (the length at which 50 % of the individuals mature) was then estimated as the point on the X-axis corresponding to 50% point on the Y-axis. The maturity curve was fitted by the equation:

$$P_L = \frac{1}{1 + e^{-b(L-L_{50})}}$$

where P_L is the proportion of mature individuals in each length class, L is the total length class, and b is the slope.

Estimation of fecundity

The ovaries of the fishes at Stages I and II were classified as immature as the gonads were either thread-like or the ova were not visible to the naked eye. Thus, ovaries which were considered mature (stages III and IV) were used for the fecundity estimation. Mature ovaries were stored in Gilson's fluid to free the ova from ovarian tissue. The ova were washed several times to discard immature ova, and dried before counting. The gravimetric method was

employed to determine fecundity of the fish (Bagenal & Braum, 1978). The total weight of dried ova were first determined and then three subsamples of the ova taken from the samples and each weighed to the nearest 0.001 g. The ova in the subsamples were counted with the help of a dissecting microscope. The total number (N_t) of eggs in ovaries (fecundity) was calculated using the equation:

$$N_t = N_s \frac{DW_t}{W_s}$$

where N_s is the number of ova in the subsample, DW_t is the total weight of dry ova, and W_s is the subsample weight of ova. The relationships between the fecundity and the total length, fecundity and gonad weight, and fecundity and body weight of the three sparids were determined using regression analysis.

Measurements of ova diameter

Three ripe ovaries (Stage IV) were selected from each species to determine the ova diameter distribution, except for *D. gibbosus* where only one ripe ovary could be used. Portions were taken from the anterior, middle and posterior parts of each of the ovaries to give a good representation of all the ova sizes. A stage micrometer was used to measure the ovum diameter to the nearest 0.1 mm under a compound microscope. Frequency polygons were drawn to show the frequency distribution of the sizes of ova.

CHAPTER FOUR

RESULTS

This chapter presents results of the data analyses on the three species relating to their catch trends, relative abundance and distributions, growth and mortality parameters, exploitation patterns, yield and biomass, as well as their reproduction and spawning potentials.

Spatial Distribution, Relative Abundance and Catch-per-unit-effort

Figure 4 shows the spatial distribution of the three species along the coast of Ghana, from shallow to deep waters in the years 2005 and 2016. In 2005, *P. caeruleostictus* was the most widely distributed of the three species and occurred most in shallower waters, while *D. gibbosus* was the least, occurring in deeper waters. *D. canariensis* was sparsely distributed in patchy distributions along the coast, and least in the eastern side. In 2016, *D. canariensis* was more abundant both in shallow and deeper waters. The least abundant was again *D. gibbosus*, and the most abundant *P. caeruleostictus*. *Dentex gibbosus* occurred mainly on the eastern side of the coast in shallower waters.

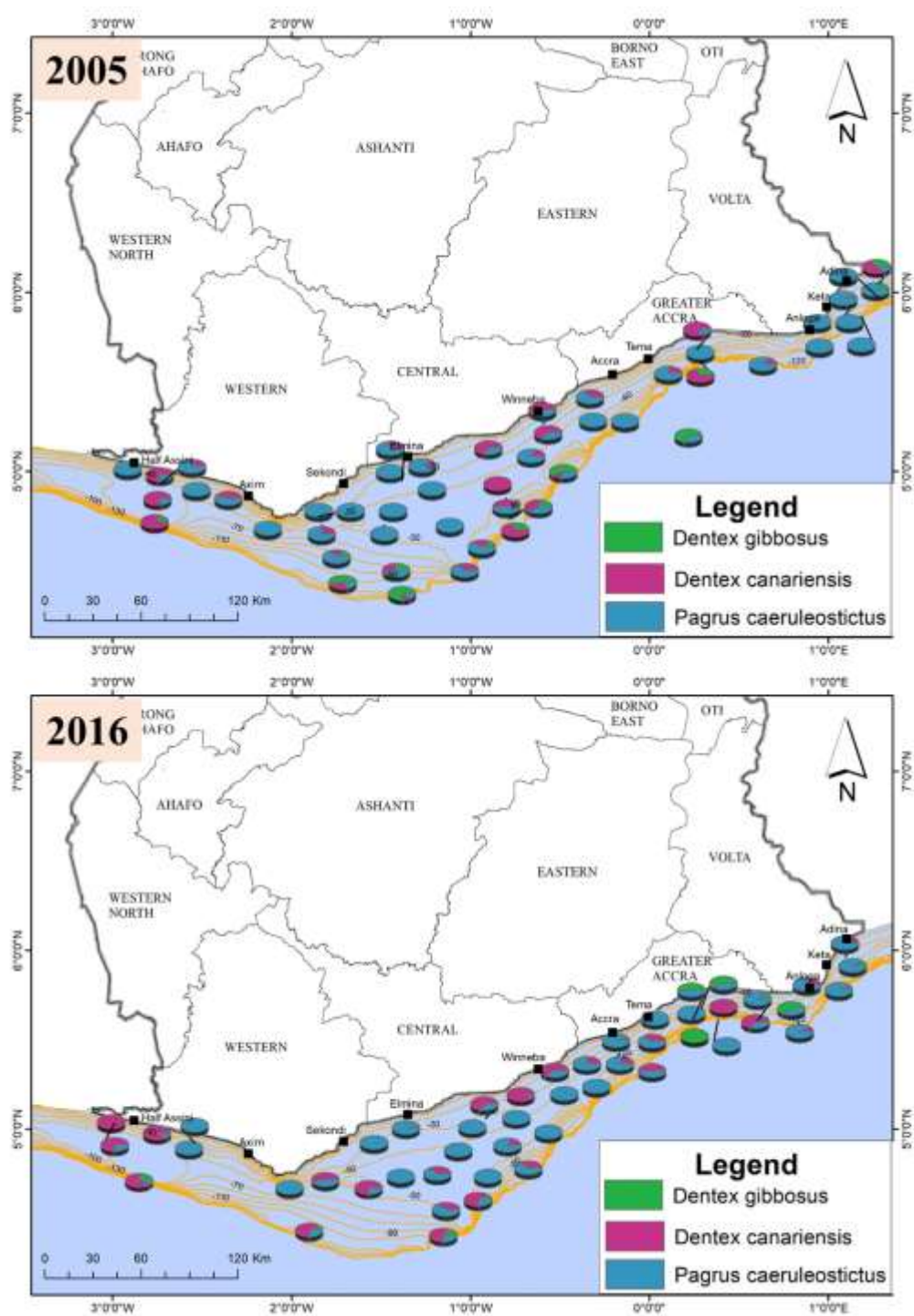


Figure 4: Relative abundance of the three species from shallow to deep waters in the years 2005 and 2016 determined from the Fridtjof Nansen cruise reports of 2005 and 2016.

Figure 5 shows the abundance (in numbers) of *P. caeruleostictus* recorded in 2005 and 2016. Differences were observed in the abundance during the two surveys. *P. caeruleostictus* was more abundant in 2005 than 2016,

though it was sighted in more areas during the latter year. The species was also more abundant in the east basin than the west basin for both years, though more numbers were recorded in 2016 than in 2005.

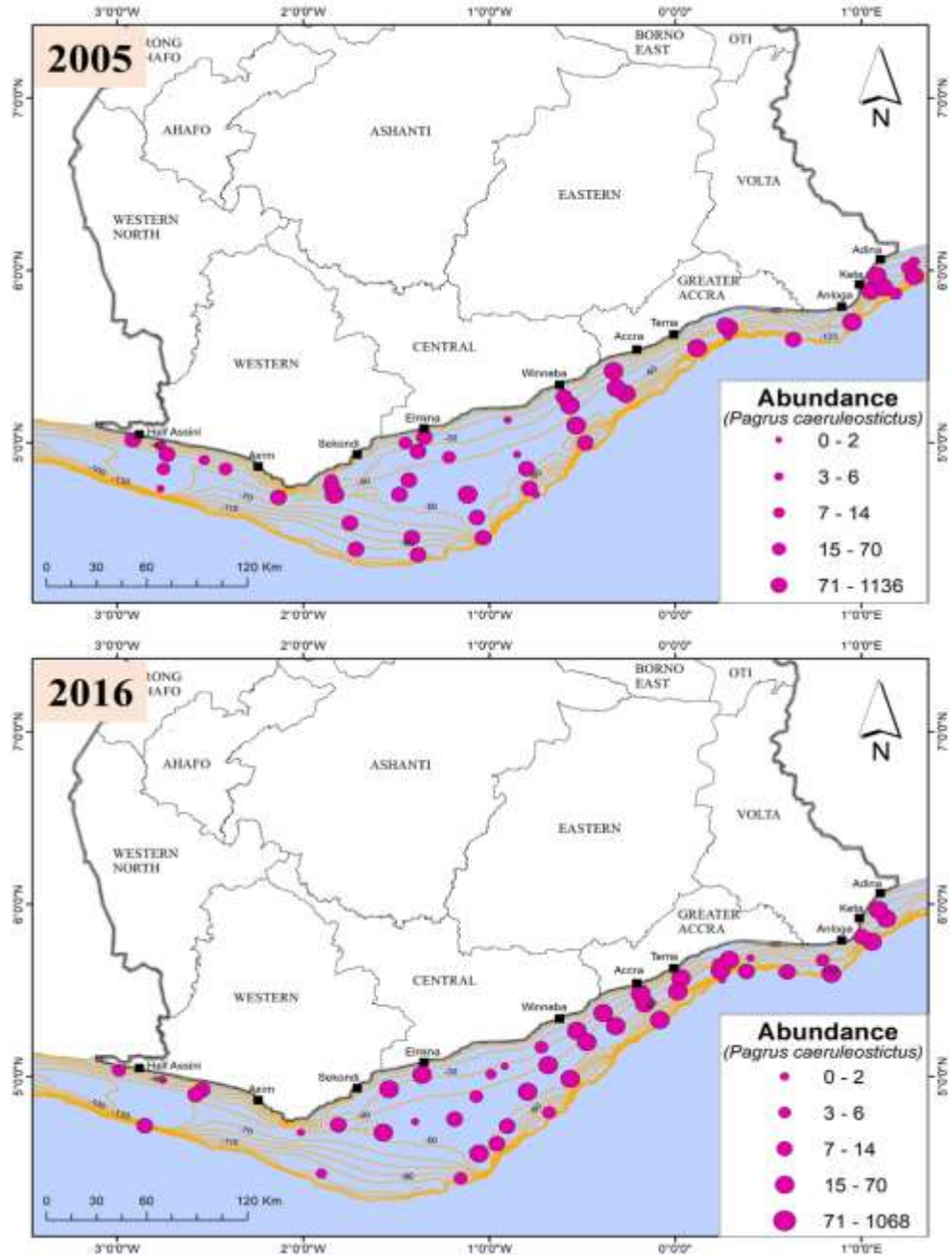


Figure 5: Abundance of *P. caeruleostictus* in the years 2005 and 2016. Data source: Fridtjof Nansen cruise reports of 2005 and 2016.

Figure 6 shows the abundance of *D. canariensis* documented in 2005 and 2016. The dynamics of this species was different from the other two species. *D. canariensis* was less abundant in 2005 than 2016. The species appeared to be concentrated on the east coast and occurred in more areas in 2016 than they did in 2006.

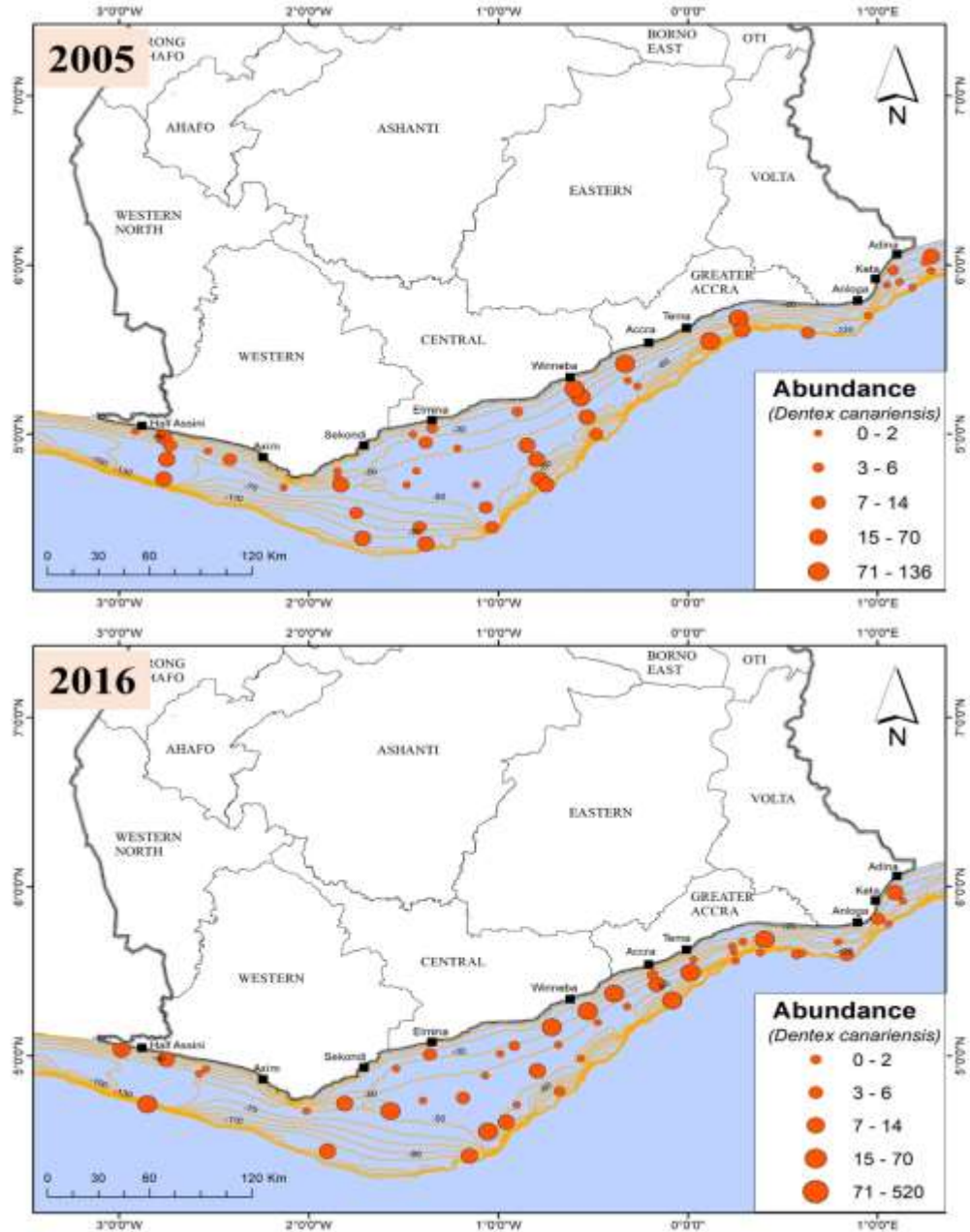


Figure 6: Abundance of *D. canariensis* in the years 2005 and 2016. Data source: Fridtjof Nansen cruise reports of 2005 and 2016.

Figure 7 shows the abundance of *D. gibbosus* in the two years. More numbers of the species were recorded in 2005 than 2016. The species occurred more in deeper waters from the east to west basins. In 2016, the species occurred more in the eastern side of the coast than they did in 2005. However, in 2005, the species occurred less in the eastern side but most in deeper waters.

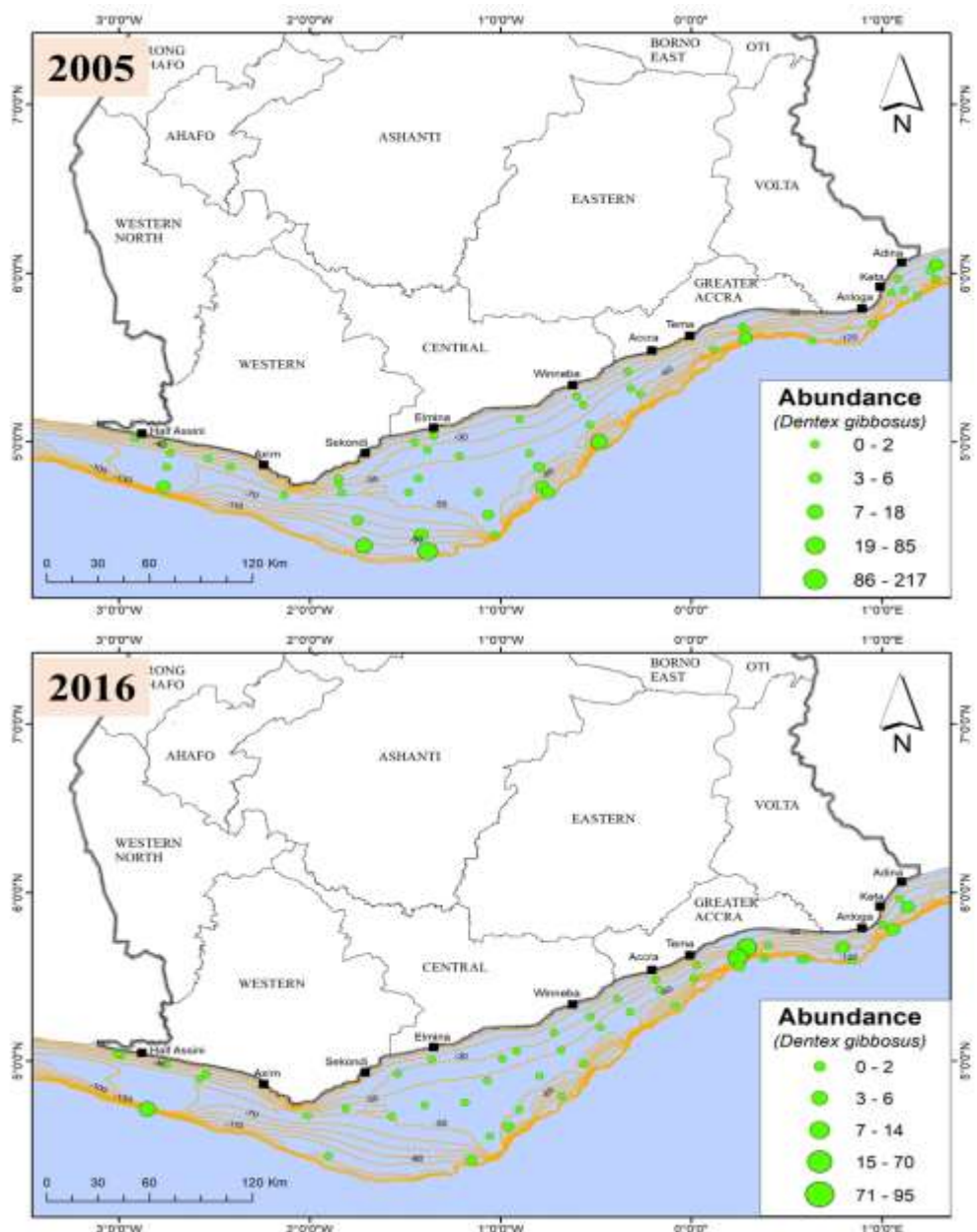


Figure 7: Abundance of *D. gibbosus* in the years 2005 and 2016. Data source: Fridtjof Nansen cruise reports of 2005 and 2016.

Catch trends and catch-per-unit-effort (CPUE)

Figure 8 which shows the catches of *P. caeruleostictus* recorded from the year 2000 to 2016 in the data from FSSD, for the hook and line gear also indicated a higher abundance of *P. caeruleostictus* over the other species. Catches were higher between 2004 and 2008 with a major peak occurring in 2005 and a minor peak in 2008. A sharp decline in abundance occurred in 2009 and remained low until 2016.

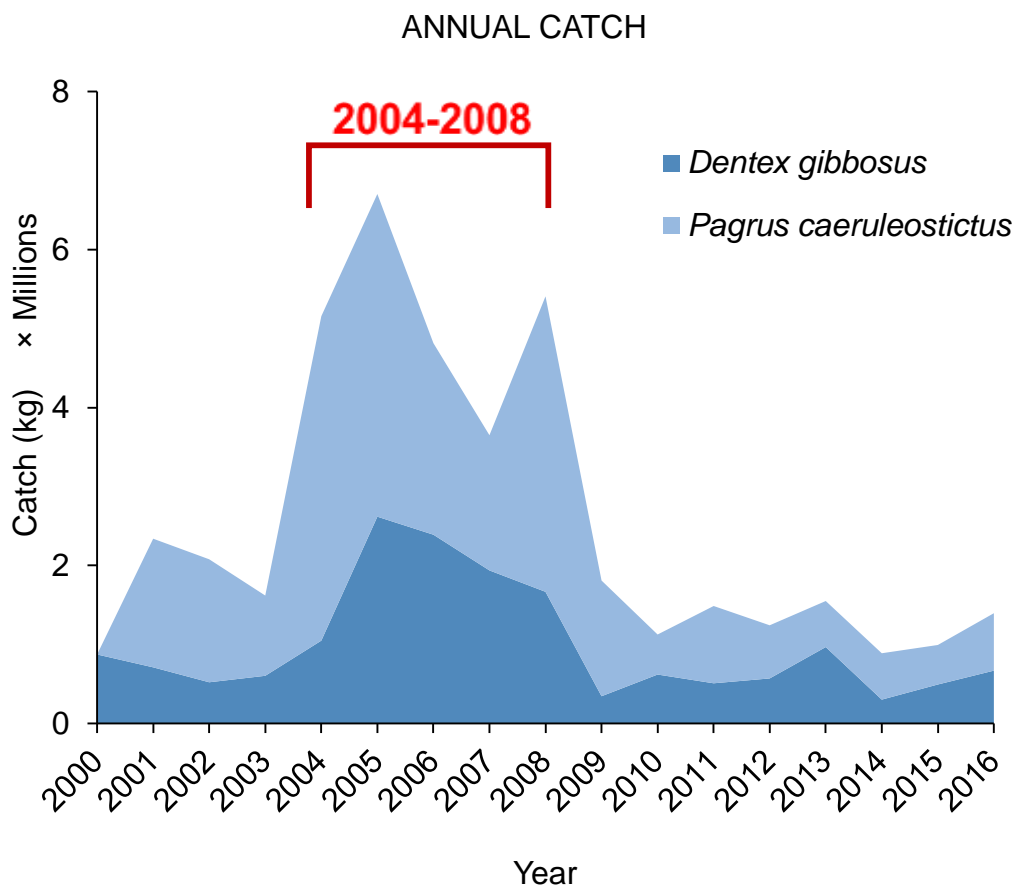


Figure 8: Catches of the seabream species in Ghana from the hook and line gear from 2000 to 2016. Data source: FSSD 2000-2016.

Figure 9 shows the fishing effort for the sparid fishery from 2000 to 2016, trend of which was similar to that of the catches. The same number of days was used to exploit the species with the hook and line gear, with the highest

number of days recorded in 2008. The number of days used in exploiting *P. caeruleostictus* and *D. gibbosus* were high between the years 2004 and 2008, after which there was a sharp decline and then slight fluctuations in the numbers.

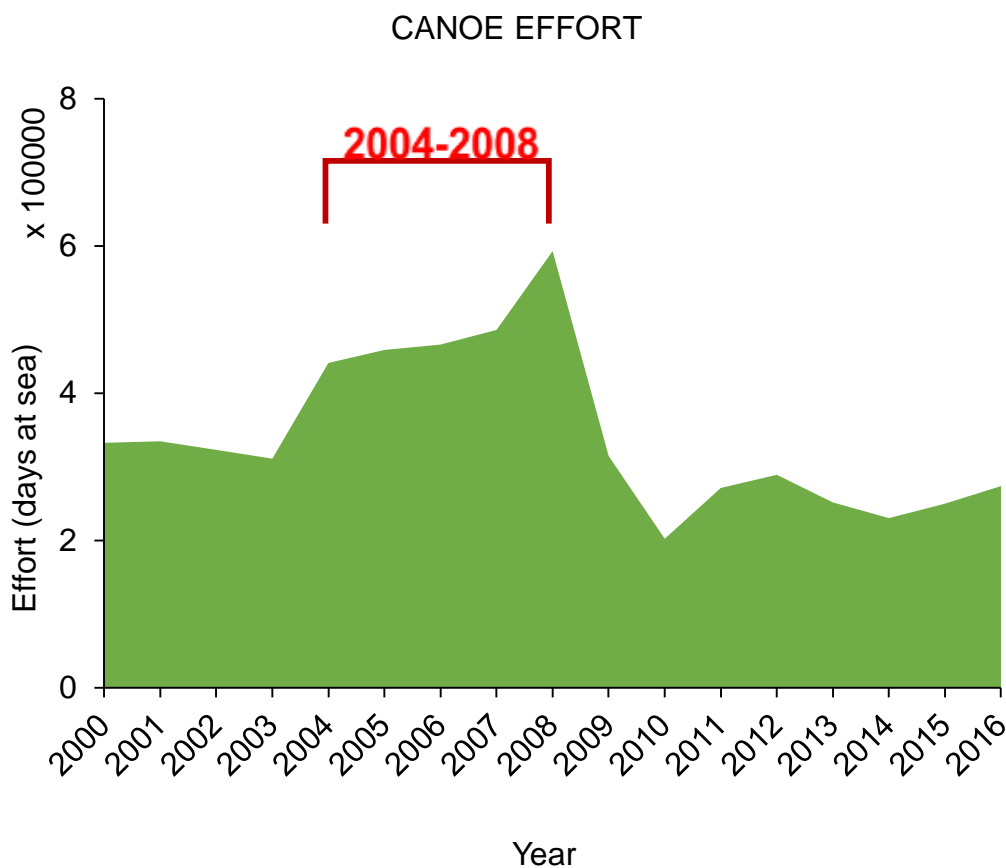


Figure 9: Fishing effort from the hook and line gear employed in exploiting the seabream species from 2000 to 2016. Data source: FSSD 2000-2016.

Trends in the CPUE (kg/hook and line fishing day) for *D. gibbosus* and *P. caeruleostictus* were similar to related catch and effort (Figure 10). Generally, a higher CPUE was observed for *P. caeruleostictus* than that of *D. gibbosus*.

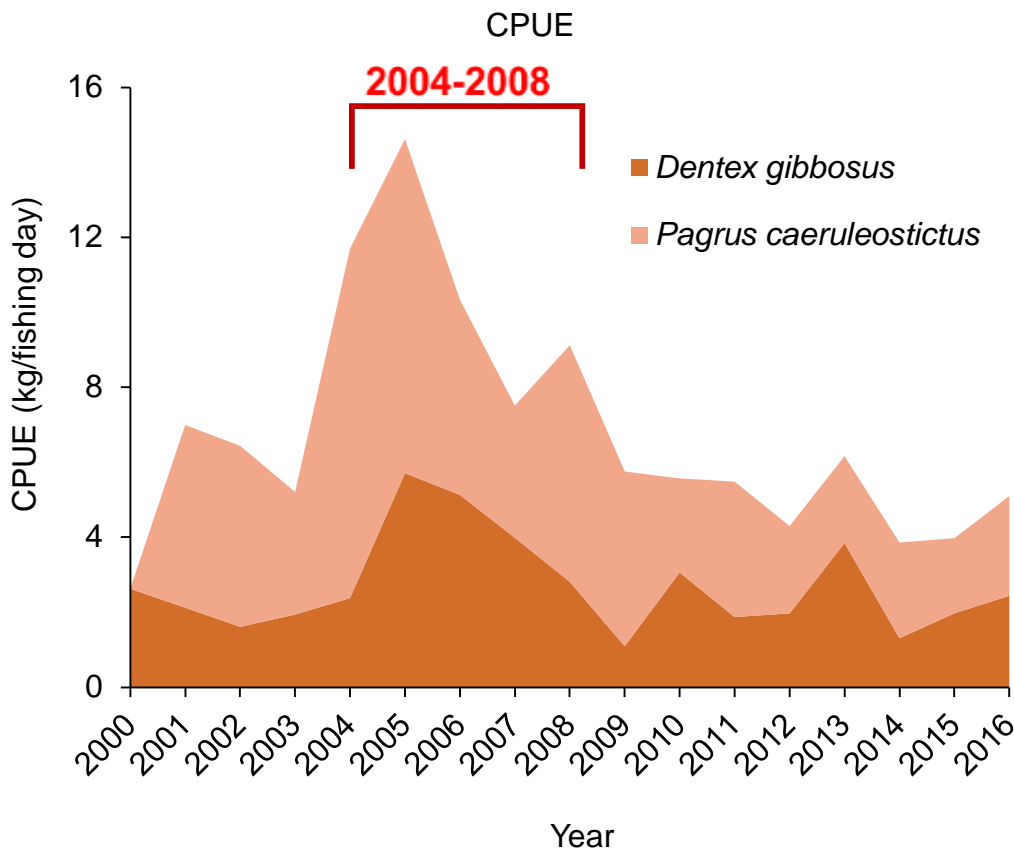


Figure 10: CPUE of the hook and line fishery that exploited the seabream species from 2000 to 2016. Data source: FSSD 2000-2016.

Size Distribution

A total of 1444 individuals of *P. caeruleostictus* were obtained during the 18 months of primary data collection, making up 56% of the total number of samples taken during the study while the specimens of *D. canariensis* were 858 in number, comprising of 33% of the total sample size, and that of *D. gibbosus* were 284, making up 11%.

Figure 11 shows the length frequency distributions of *P. caeruleostictus* comprising of the total number of individuals sampled, the males, females, hermaphrodites and indeterminate sex. The total number of individuals obtained ranged in sizes from 12.6 cm to 46.5 cm TL. The distribution was unimodal with a modal class of 28.0 – 28.9 cm (Figure 11a). The total length of the males

of *P. caeruleostictus* ranged from 17.9 cm to 46.5 cm with body weights ranging from 90.5 g to 1430.0 g. The body weight of the females ranged from 92.7 g to 1404.0 g and total lengths ranged from 17.5 cm to 44.9 cm. The distributions for both males and females were unimodal with the same modal class of 28.0 – 28.9 cm (Figure 11b).

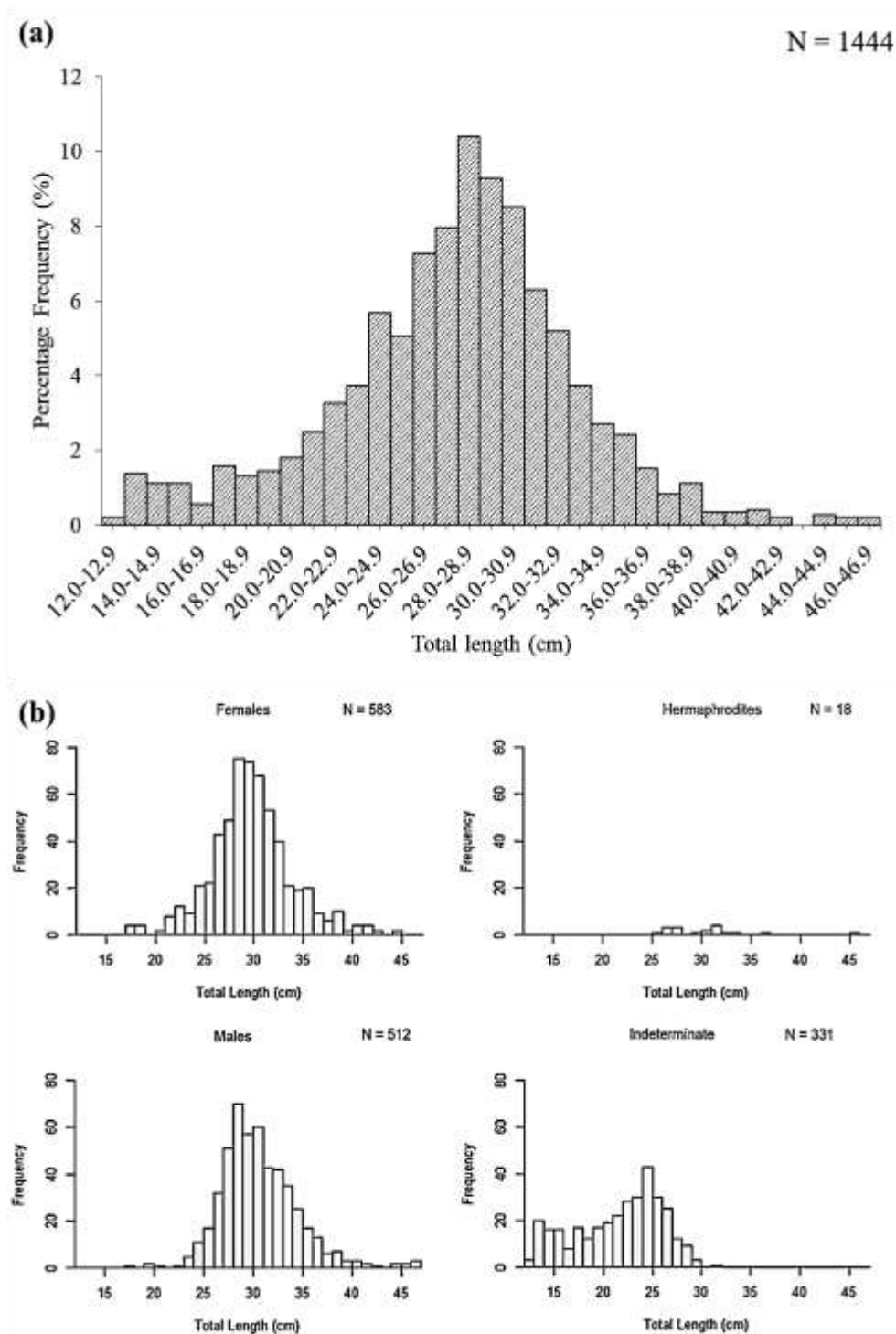


Figure 11: Length frequency distributions of *P. caeruleostictus* indicating (a) the total number of samples and (b) the males, females, hermaphrodites and indeterminate sexes in the samples taken from the catches of hook and line fishers operating in Ghanaian waters from February 2016 to July 2017.

Figure 12 presents the length frequency distributions of *D. canariensis* comprising of the total number of specimens sampled, the males, females, hermaphrodites and indeterminate sex. The total number of specimens ranged from 18.4 cm to 53.6 cm TL. A unimodal distribution was observed with the modal class being 35.0 – 35.9 cm (Figure 12a). The total lengths of the males ranged between 24.6 cm and 53.6 cm, and that of the females ranged from 21.4 cm to 51.5 cm. A unimodal distribution was observed for males, while a bimodal distribution was observed for the females (Figure 12b). The modal classes were 35.0 -35.9 cm for the males, and 28.0 -28.9 cm and 35.0 -35.9 cm for the females. The body weights were between 242.0 g and 2072.0 g for the males and between 132.0 g and 1840 g for the females.

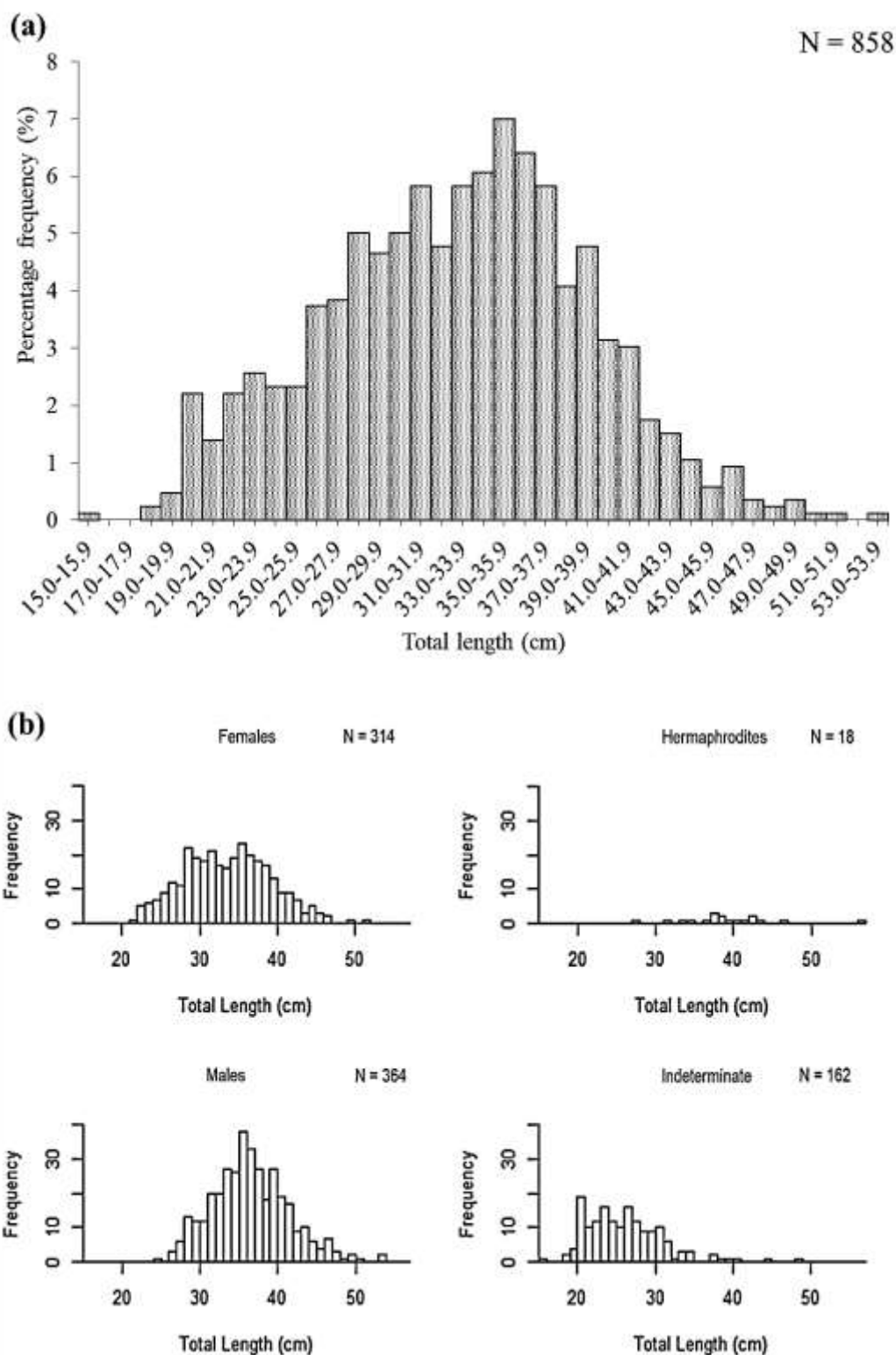


Figure 12: Length frequency distributions of *D. canariensis* indicating (a) the total number of samples and (b) the males, females, hermaphrodites and indeterminate sexes in the samples taken from the catches of hook and line fishers operating in Ghanaian waters from February 2016 to July 2017.

Figure 13 shows the length frequency distributions of *D. gibbosus* comprising of the total number of specimens, the males, females, hermaphrodites and indeterminate sex obtained. The 284 specimens obtained with TL ranges between 18.4 cm and 76.1 cm, showed a bimodal distribution, with modal lengths of 20.0 – 20.9 cm and 40.0 – 40.9 cm (Figure 13a). The total lengths of the males ranged from 23.5 cm to 62.1 cm and the females from 20.3 cm to 58.1 cm. The distributions were unimodal for both males and females (Figure 13b). The modal class of the males was 40.0 – 40.9 cm and the females 39.0 – 39.9 cm. For the body weights, they ranged from 124.6 g to 2028.0 g for the females and from 177.1 g to 2397.0 g for the males.

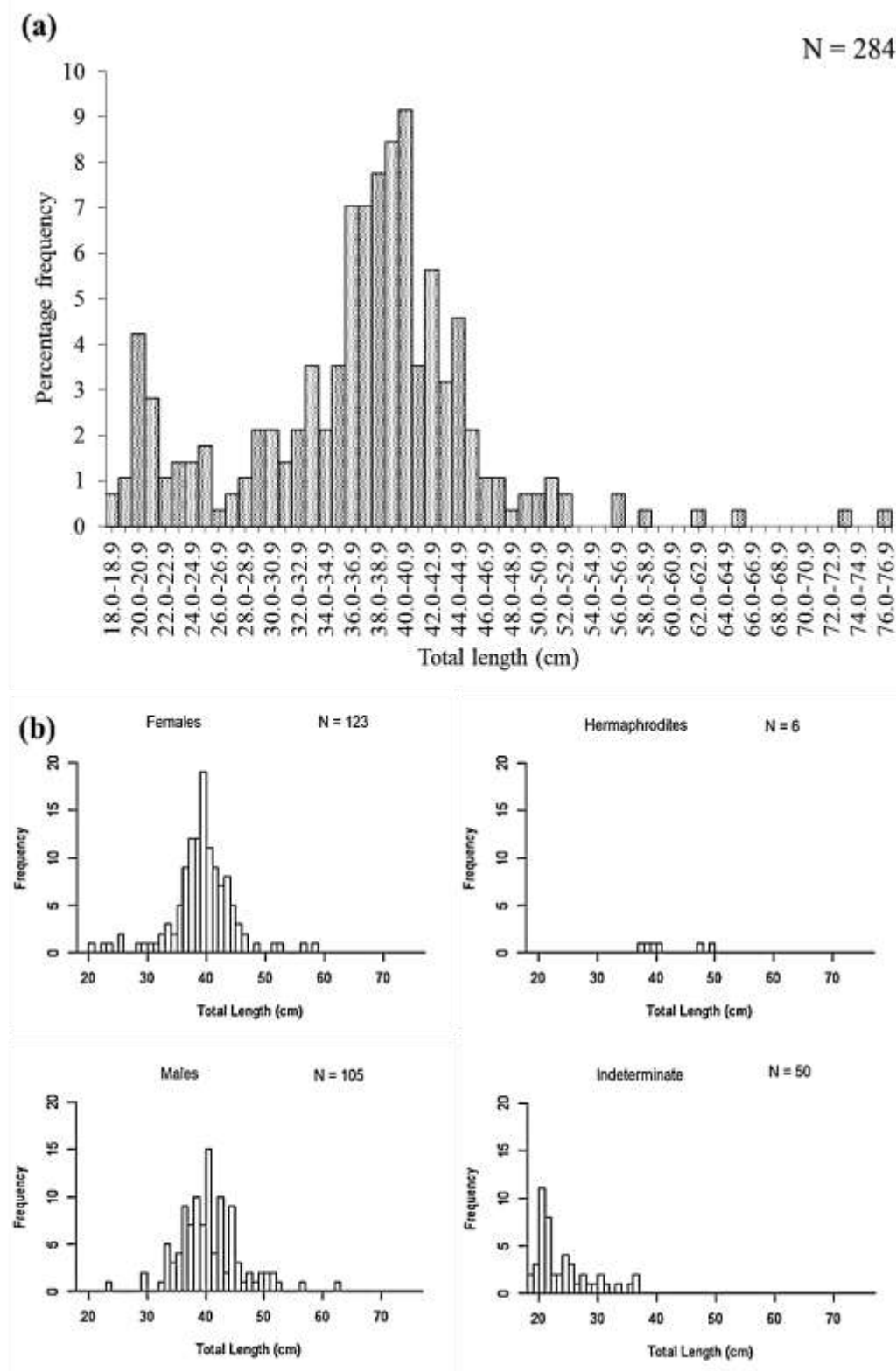


Figure 13: Length frequency distributions of *D. gibbosus* indicating (a) the total number of samples and (b) the males, females, hermaphrodites and indeterminate sexes in the samples taken from the catches of hook and line fishers operating in Ghanaian waters from February 2016 to July 2017.

Population Dynamics

The population dynamics is made up of the population parameters, that is, the length-weight relationships, growth and mortality parameters of the three species.

Length-weight relationship

Figure 14 shows the total length- body weight regression parameters for the three species. The relationships were described by the equations: $BW = 0.020TL^{2.91}$ for *P. caeruleostictus*, $BW=0.018TL^{2.91}$ for *D. canariensis* and $BW=0.030TL^{2.75}$ for *D. gibbosus*. The growth pattern of all three species deviated from isometry as the regression coefficients (*b*) differed significantly from 3 ($p < 0.05$) (Appendix E). The coefficient of determination (R^2) showed strong positive correlation between the length and weight for the three species (Figure 14) as the values were greater than 0.95.

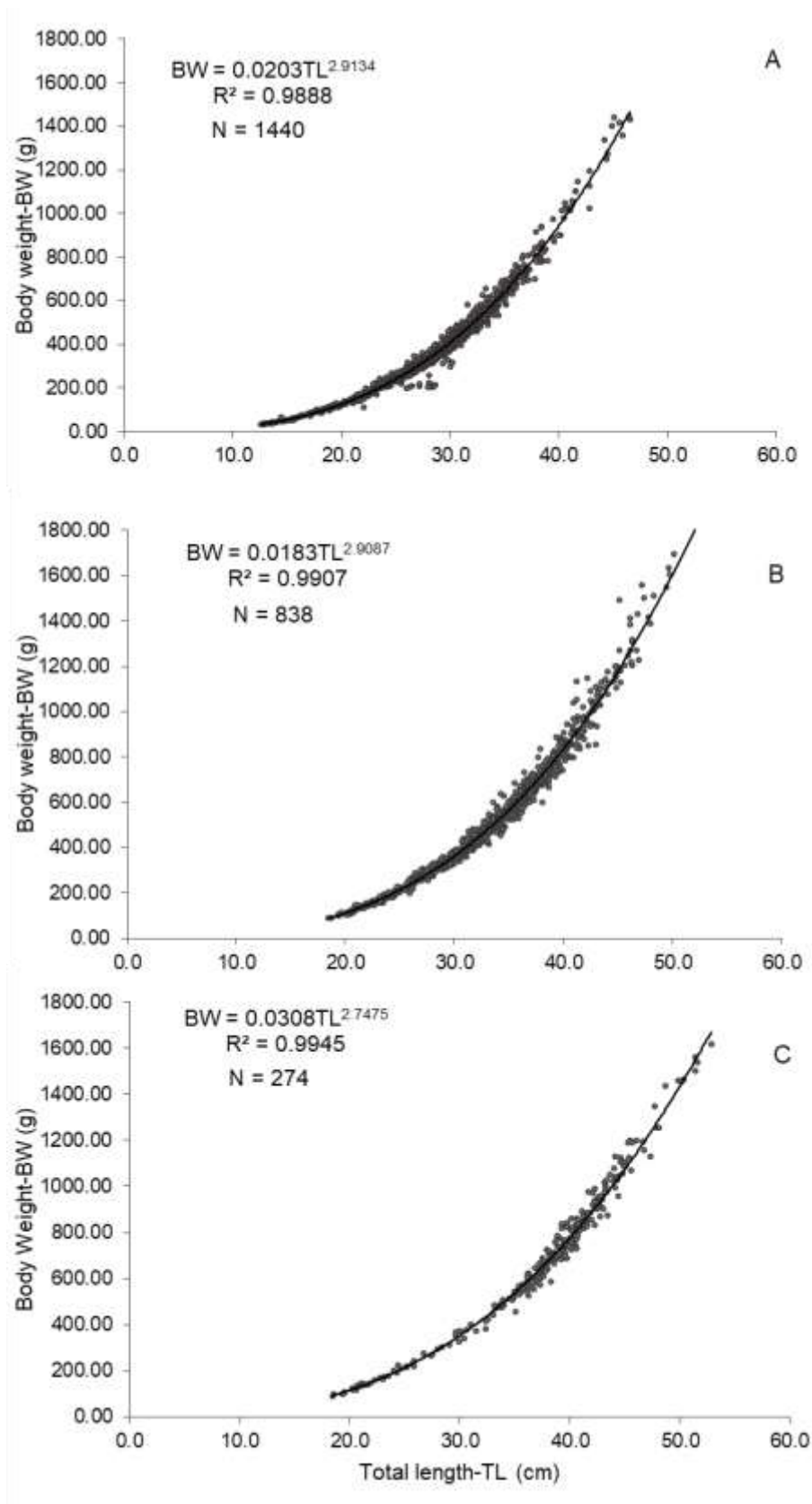


Figure 14: Length-weight relationships of samples of (A) *P. caeruleostictus*, (B) *D. canariensis* and (C) *D. gibbosus* in Ghanaian waters.

Growth parameter estimates

The monthly length-frequency distribution histograms superimposed with the von Bertalanffy growth curves are presented for both catch frequencies and restructured frequencies for the three species in Figures 15, 16 and 17.

Modes of the monthly length-frequency distributions of *P. caeruleostictus*, *D. canariensis* and *D. gibbosus* shifted haphazardly due to the small sample size per month (Figures 15-17). There was no clear-cut modal progression, except for *D. canariensis* where there was some form of a shift in modes from January 2017 to July 2017 (Figure 16). The estimated growth curve fitted through the peaks of these months indicating a modal progression. Appearance of a new cohort of *P. caeruleostictus* in June 2017 might indicate an earlier spawning in the population (Figure 15). A cohort indicating recruitment into the fishery was also observed for *D. gibbosus* in March 2016 (Figure 17). The estimated growth parameters (L_{∞} , K , t_{anchor} , C , t_s , ϕ') with their corresponding confidence intervals (CIs) were obtained by using the 95% quantiles of the posterior distributions (Appendix F). The growth pattern of the three species with respect to relative age and based on the growth parameters are also shown in Figure 18.

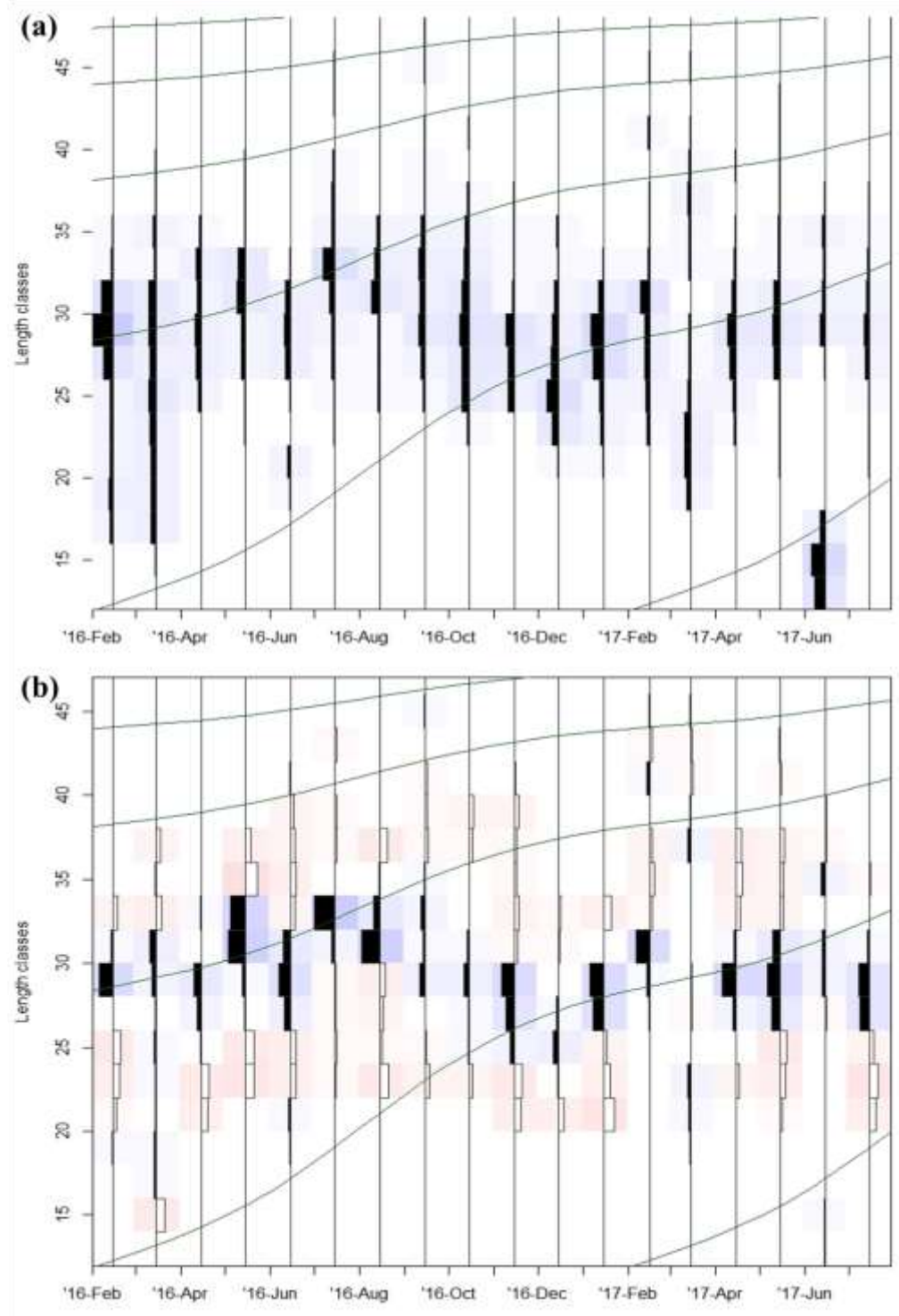


Figure 15: (a) Catch length-frequency and (b) restructured length-frequency distributions of *P. caeruleostictus* fitted with VBGF growth curves obtained through the bootstrap

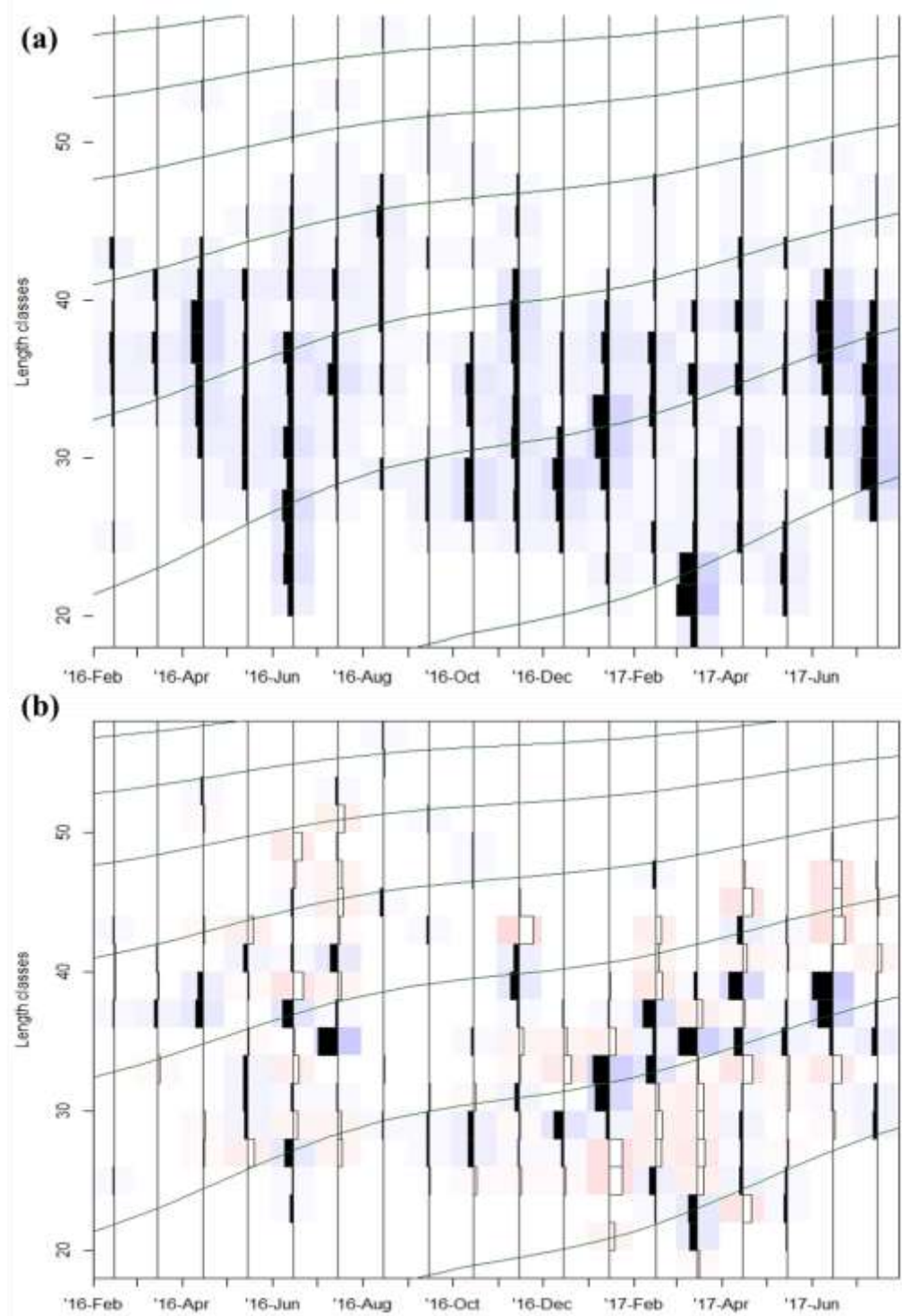


Figure 16: (a) Catch length-frequency and (b) restructured length-frequency distributions of *D. canariensis* fitted with VBGF growth curves obtained through the bootstrap.

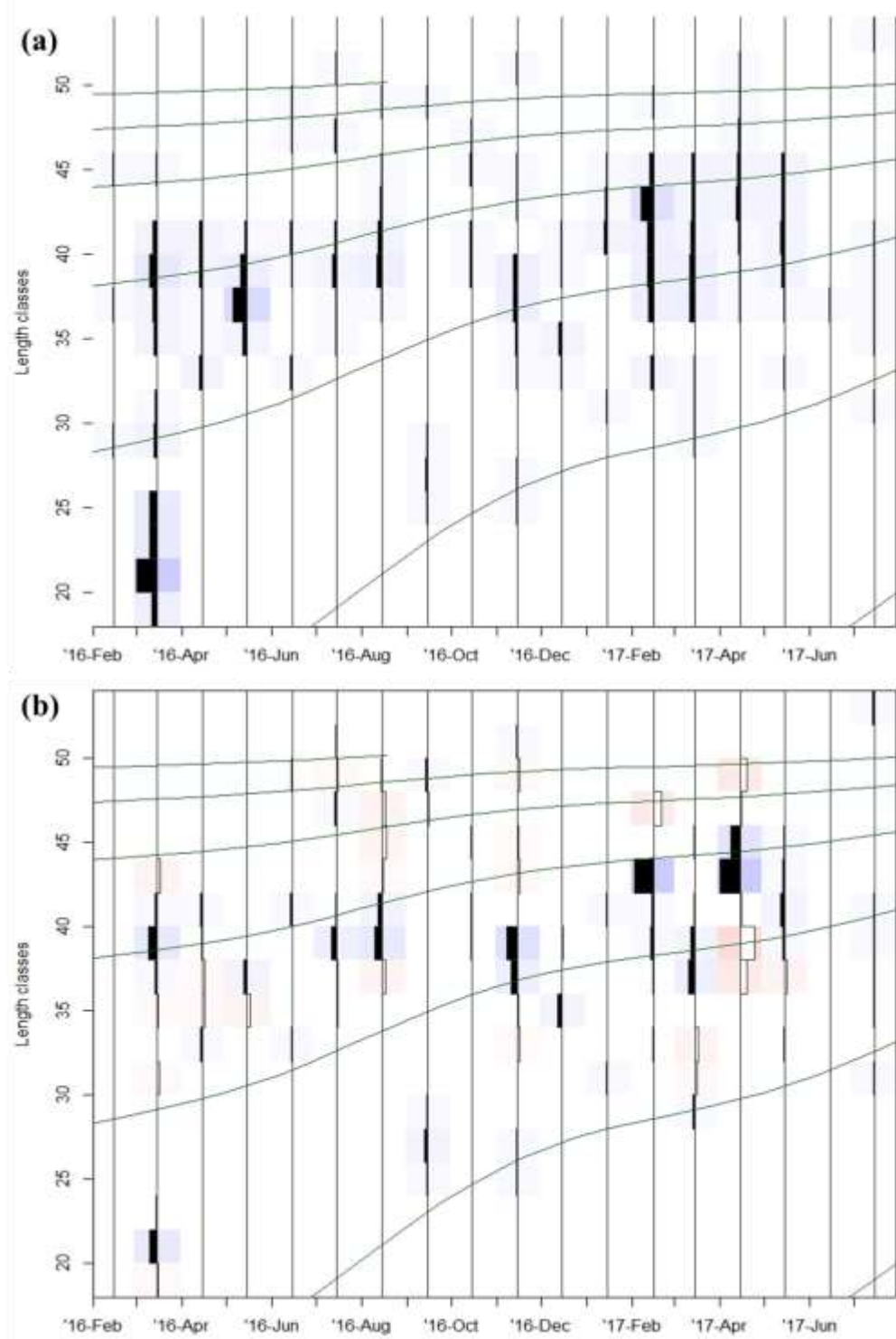


Figure 17: (a) Catch length-frequency and (b) restructured length-frequency distributions of *D. gibbosus* fitted with VBGF growth curves obtained through the bootstrap.

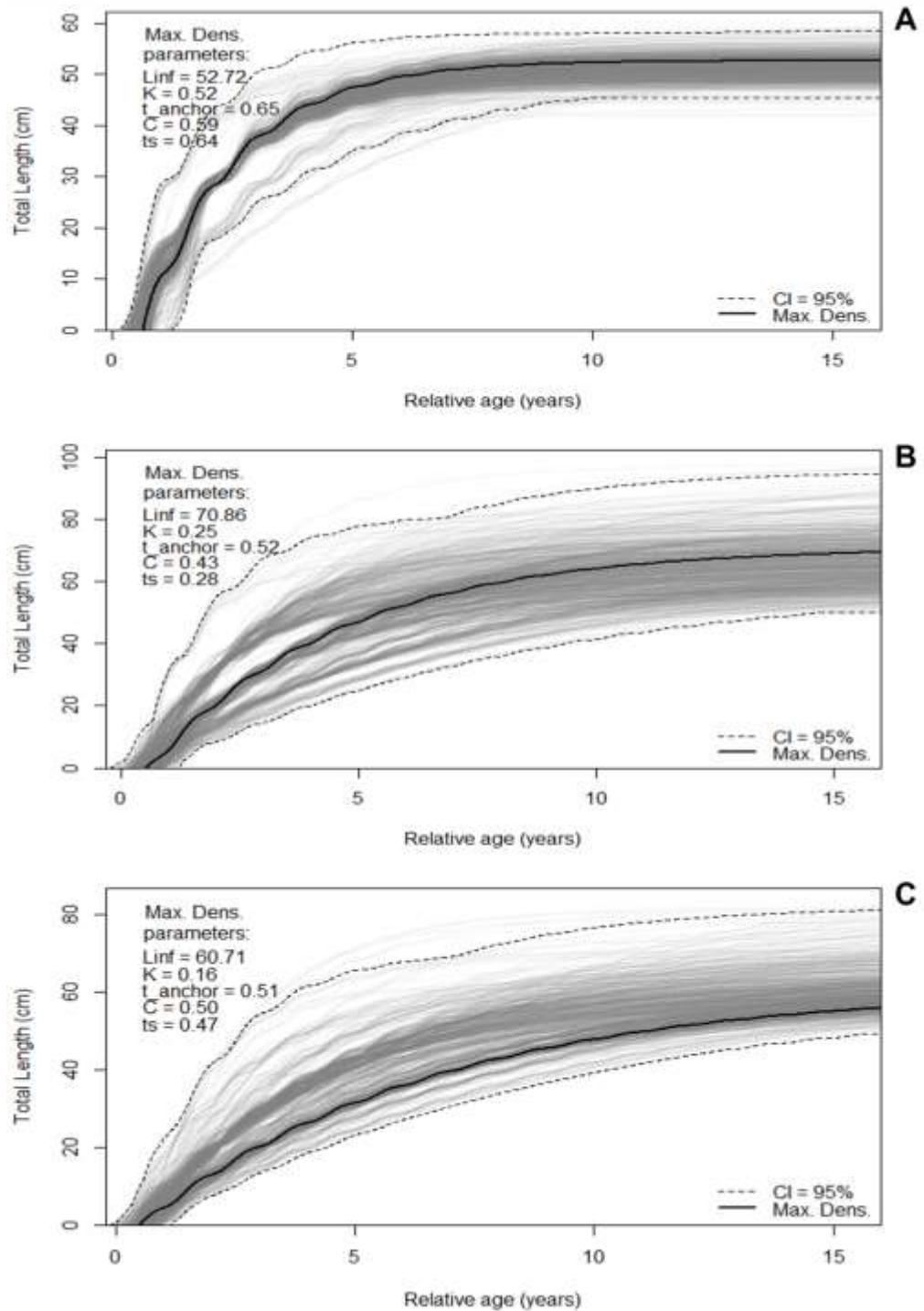


Figure 18: Growth curves representing the growth parameters (shown as the maximum density with thick black line), their 95% confidence intervals (black dashed lines) and curve swarms (grey lines) for (A) *P. caeruleostictus* (B) *D. canariensis* and (C) *D. gibbosus* derived from the fit method ELEFAN_GA_boot.

Estimates of mortality parameters and mean length at first capture

The instantaneous total mortality, Z , and the mean length at first capture estimated from the length-converted catch curves for the three species are shown in Figures 19-21. Fishes that were not fully recruited into the fishery and relatively old fish were excluded from the analysis.

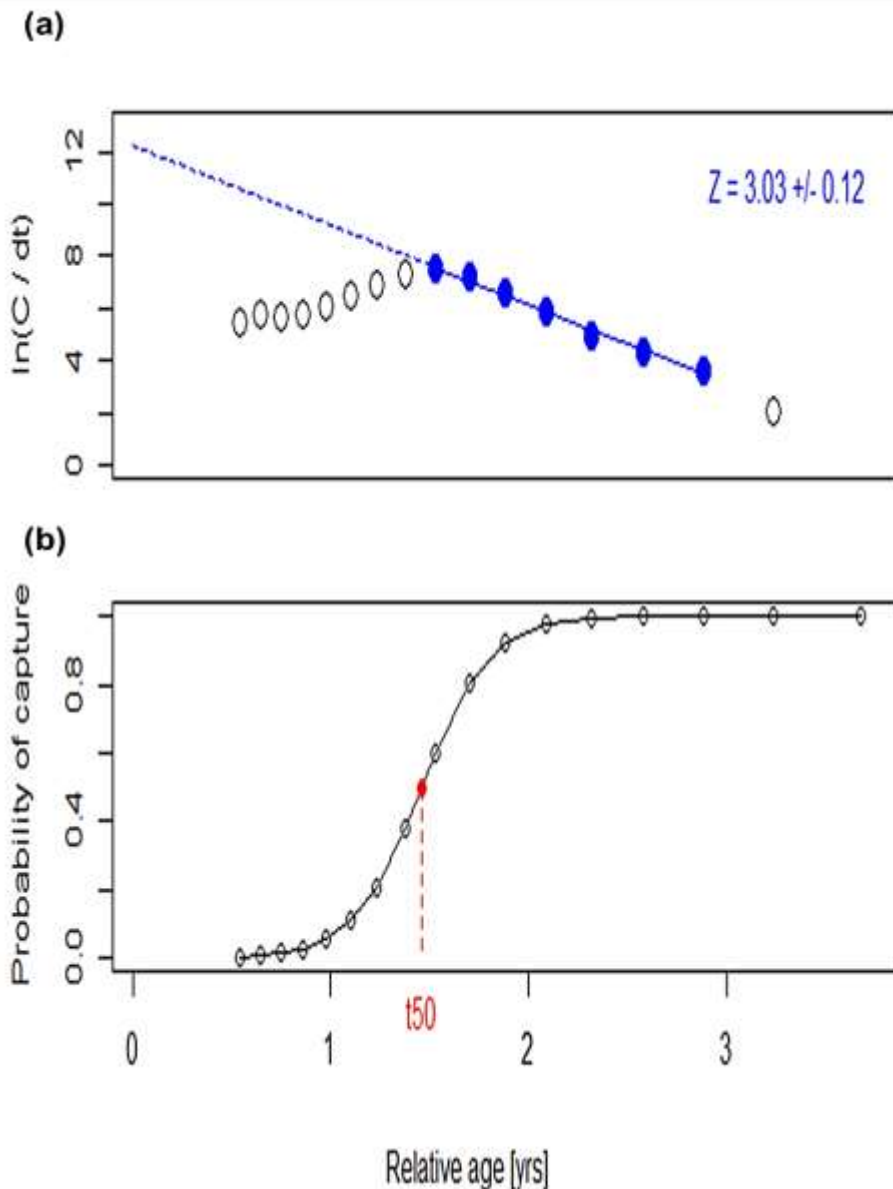


Figure 19: (a) Length-converted catch curve of *P. caeruleostictus* indicating the value of Z with its corresponding standard error, and (b) the relative age (t_{50}) at first capture, based on inputs from ELEFAN_GA_boot. Blue circles indicate data used for the estimation, while the white circles are data not used.

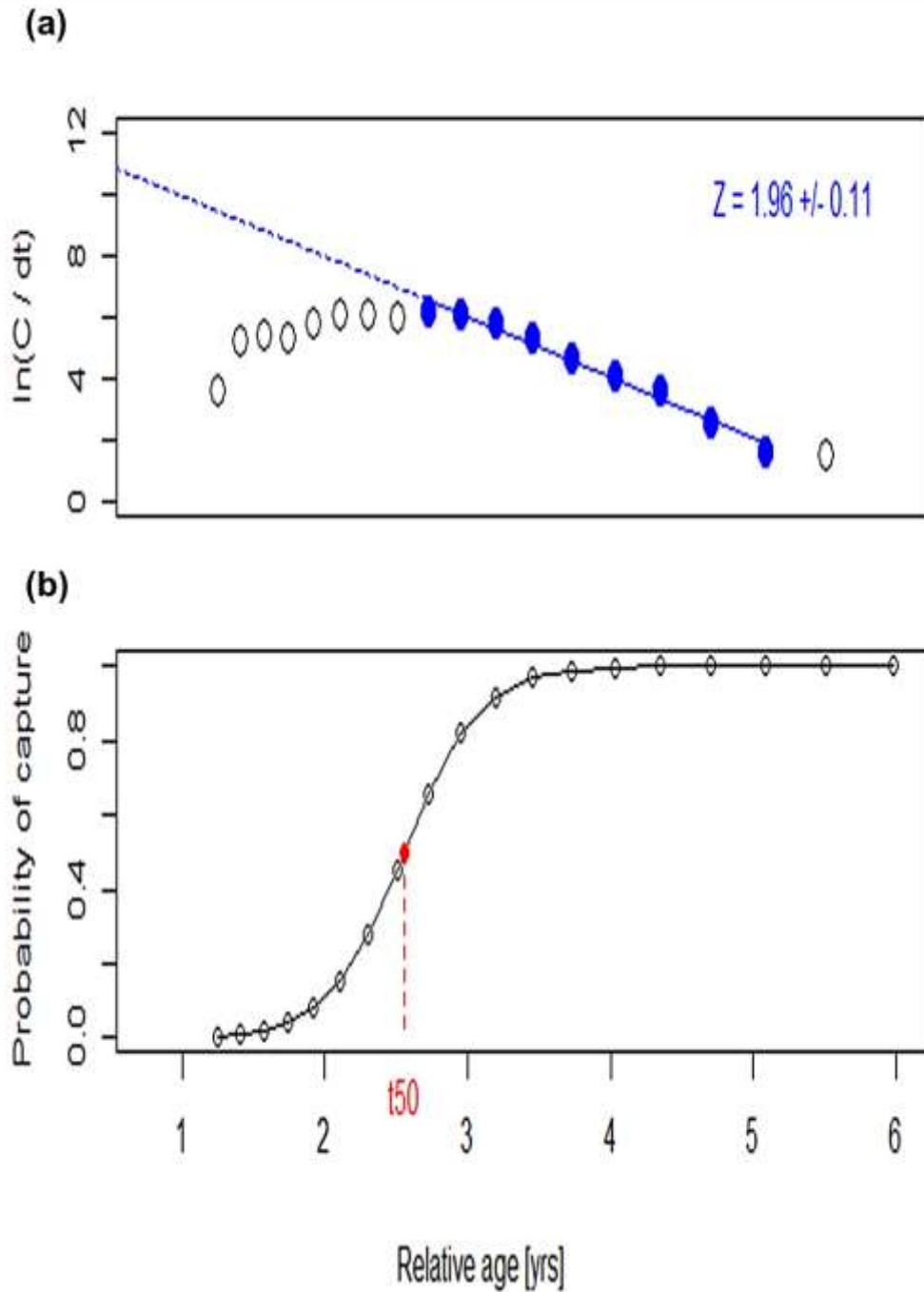


Figure 20: (a) Length-converted catch curve of *D. canariensis* indicating the value of Z with its corresponding standard error, and (b) the relative age (t_{50}) at first capture, based on inputs from ELEFAN_GA_boot. Blue circles indicate data used for the estimation, while the white circles are data not used.

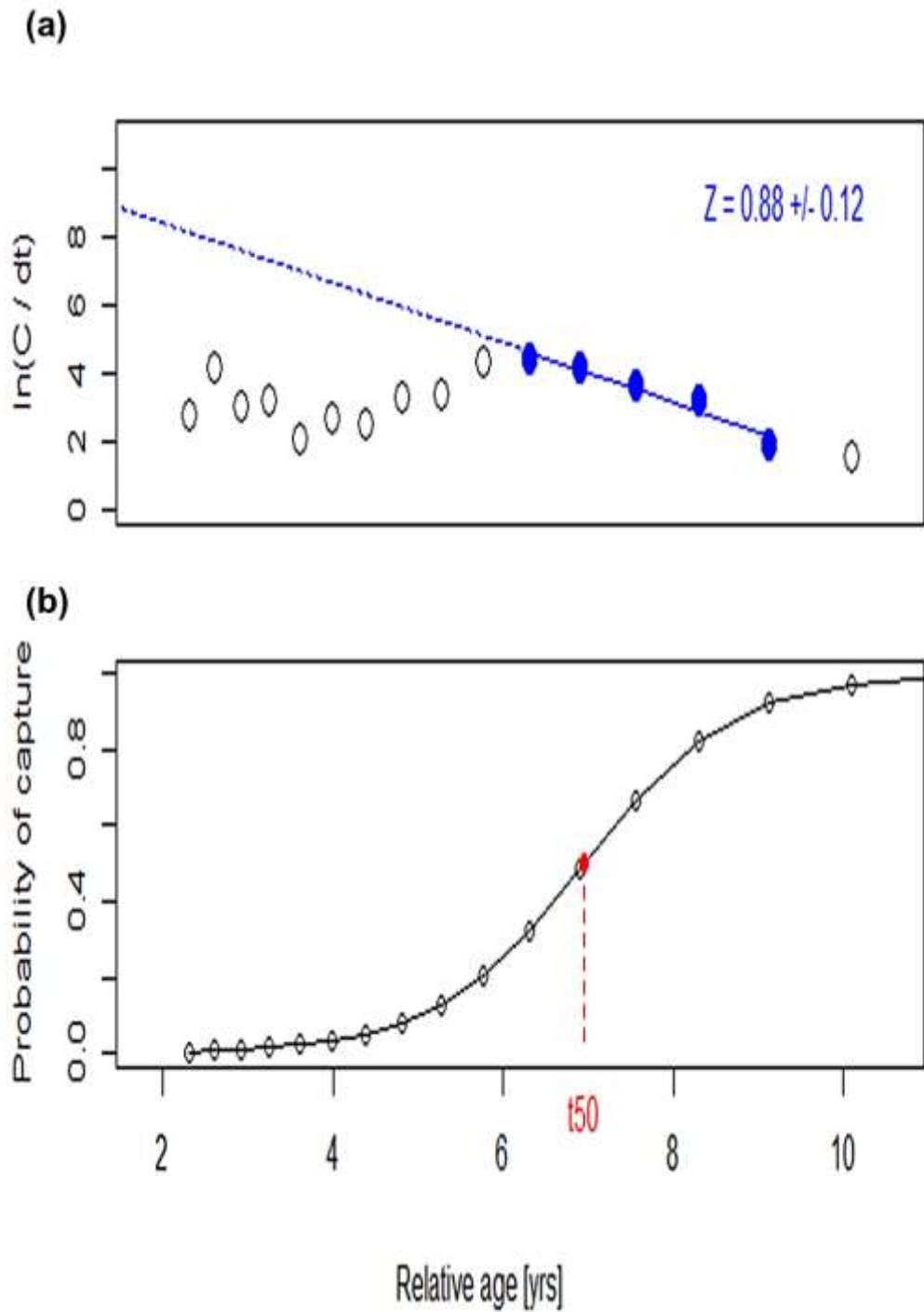


Figure 21: (a) Length-converted catch curve of *D. gibbosus* indicating the value of Z with its corresponding standard error, and (b) the relative age (t_{50}) at first capture, based on inputs from ELEFAN_GA_boot. Blue circles indicate data used for the estimation, while the white circles are data not used.

The results of the calculated instantaneous natural mortality (M), fishing mortality (F), exploitation ratio (E), longevity (t_{max}), as well as the length at first capture (L_c) with its corresponding relative age at first capture (t_{50}) estimated from the selectivity function of the catch curve are presented in Table 1. The M/K ratio is indicated to have a range of 1.12-2.50 for most species with an optimal value of 1.5 (Beverton & Holt, 1957; Hordyk et al., 2015). The values of the ratio for *P. caeruleostictus*, *D. canariensis* and *D. gibbosus* are presented in Table 1. The values for all three species were above the optimal value.

Table 1 – Growth and Mortality Parameter Estimates of Three Sparid Species from the Coastal Waters of Ghana

Parameter	<i>P. caeruleostictus</i>	<i>D. canariensis</i>	<i>D. gibbosus</i>
Z	3.03	1.96	0.88
M (yr ⁻¹)	0.83	0.47	0.37
F (yr ⁻¹)	2.20	1.48	0.50
E	0.73	0.76	0.57
L_c (cm)	28.1	33.5	41.2
t_{50} (yrs.)	1.46	2.55	6.95
t_{max} (yrs.)	5.75	11.99	18.40
M/K ratio	1.60	1.70	2.34

Stock Assessment Indices

The stock assessment indices of the species comprises of the exploitation ratios and the yield- and biomass-per-recruit models.

Exploitation levels, yield-per-recruit and biomass- per- recruit

Figure 22-24 show the Thompson and Bell analysis for predicting effects of the current fishing mortality rates or fishing effort, as well as the L_c , on the yield and biomass per recruit (YPR/BPR) of the three species. The red dashed lines

represent the fishing mortality ($F_{0.5}$) to fish 50% of the virgin biomass, while the yellow lines represent the fishing mortality (F_{msy}) for maximum sustainable yield. The results show that with the exception of *D. gibbosus*, the current fishing mortality rate was well above the levels (F_{msy} and $F_{0.5}$) for ensuring maximum sustainable yield. A summary of the biological reference points extracted from the analyses are presented in Table 2.

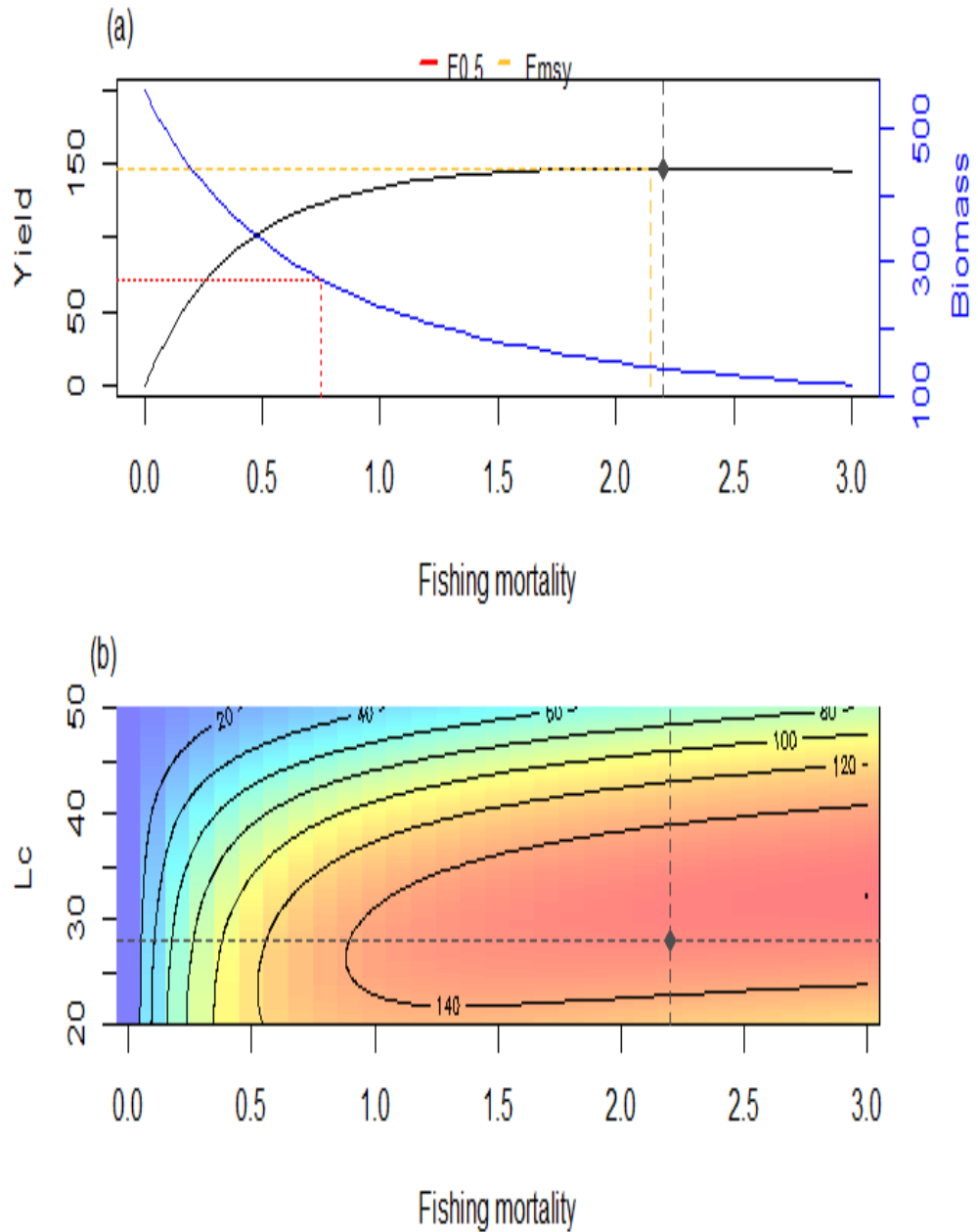


Figure 22: (a) Curves of the YPR and BPR for *P. caeruleostictus* with the black dot representing the yield and biomass in numbers under the current fishing pressure, and (b) Isopleth diagram showing the impact of current L_c and fishing mortality on the YPR.

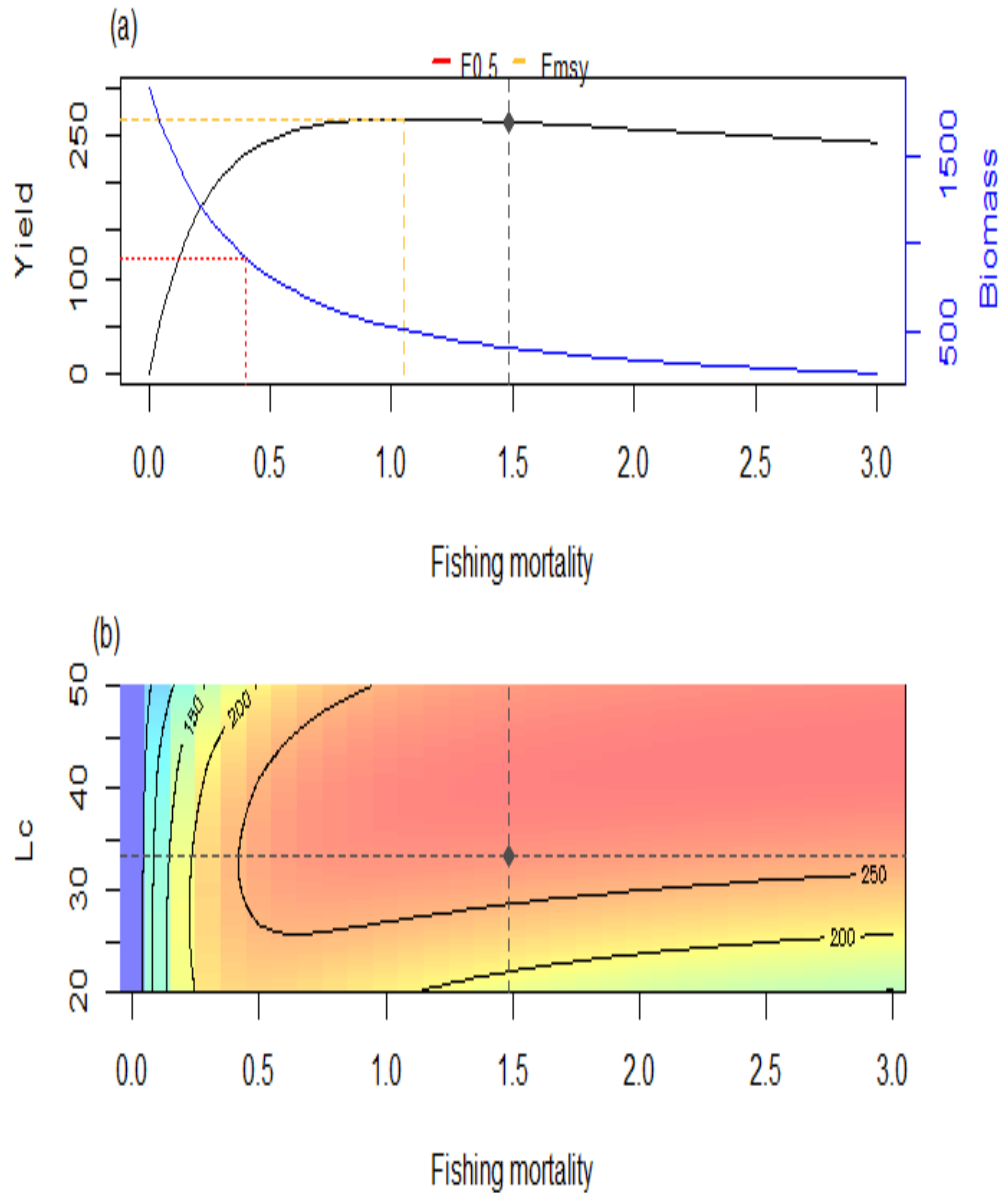


Figure 23: (a) Curves of the YPR and BPR for *D. canariensis* with the black dot representing the yield and biomass in numbers under the current fishing pressure, and (b) Isopleth diagram showing the impact of current L_c and fishing mortality on the YPR.

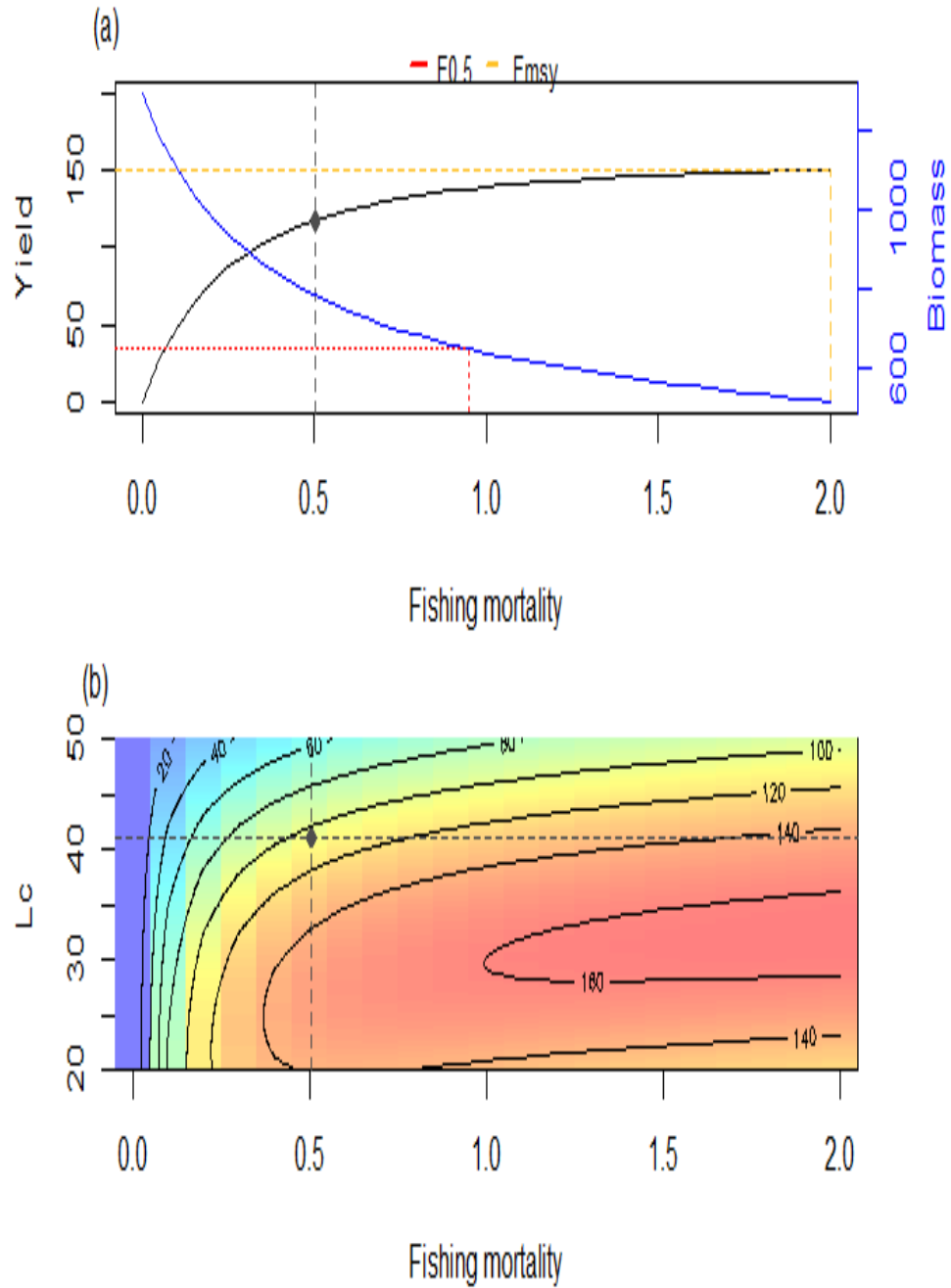


Figure 24: (a) Curves of the YPR and BPR for *D. gibbosus* with the black dot representing the yield and biomass in numbers under the current fishing pressure, and (b) Isoleth diagram showing the impact of current L_c and fishing mortality on the YPR.

Table 2 – *Biological Reference Point Estimates for Three Sparids from the Coastal Waters of Ghana*

Reference point	<i>Pagrus caeruleostictus</i>	<i>Dentex canariensis</i>	<i>Dentex gibbosus</i>
F_{msy}	2.15	1.05	2.00
$F_{0.5}$	0.75	0.40	0.95
F_{cur}	2.20	1.48	0.50
E_{msy}	0.72	0.69	0.84
$E_{0.5}$	0.47	0.46	0.72
E_{cur}	0.73	0.76	0.57
Y_{cur}	147.5	264.9	117.9
B_{cur}	140.8	406.4	778.8

Reproductive Biology

Sex ratio

The results of the χ^2 -test (Table 3) indicated that overall, the females of *P. caeruleostictus* dominated the catches and were significantly more than the males. The values for both *D. canariensis* and *D. gibbosus* indicated that the number of the males were almost equal to that of the females, as there was no significant differences between them.

Table 3 – *Sex Ratio of the Three Species from the Samples Collected From the Commercial Catches of the Hook and Line Fishers*

Species	Males	Females	Sex Ratio M : F	χ^2	($P_{(0.05)}$)
<i>P. caeruleostictus</i>	512	583	1.00 : 1.14	4.60	S
<i>D. canariensis</i>	364	314	1.16 : 1.00	3.69	NS
<i>D. gibbosus</i>	105	123	1.00 : 1.17	1.49	NS

S=Significant; NS=Not Significant

The sex ratio for the lengths favoured the females of *P. caeruleostictus* in the lower lengths < 23 cm (Table 4), though there were no significance differences except at length 22 cm. There were also no differences statistically in the numbers between males and females for the other lengths.

Table 4 – Sex Ratio Variations according To the Lengths of *P. caeruleostictus* from the Coastal Waters of Ghana

Total Length (cm)	Male	Female	M:F	χ^2	Level of Significance (P (0.05))
17	1	4	1.00: 4.00	1.80	NS
18	0	4	-	-	-
19	2	0	-	-	-
20	1	2	1.00: 2.00	0.33	NS
21	0	8	-	-	-
22	1	12	1.00: 12.00	9.31	S
23	5	9	1.00: 1.80	1.14	NS
24	11	21	1.00:1.91	3.13	NS
25	17	22	1.00:1.29	0.64	NS
26	32	43	1.00:1.34	1.61	NS
27	51	49	1.04:1.00	0.04	NS
28	70	75	1.00:1.07	0.17	NS
29	57	74	1.00:1.30	2.21	NS
30	60	68	1.00:1.13	0.50	NS
31	43	53:	1.00:1.23	1.05	NS
32	42	40	1.05:1.00	0.05	NS
33	35	21	1.67:1.00	3.50	NS
34	25	19	1.32:1.00	0.82	NS
35	17	20	1.00: 1.18	0.24	NS
36	13	9	1.44:1.00	0.73	NS
37	6	6	1.00:1.00	0.00	NS
38	7	10	1.00:1.43	0.53	NS
39	3	2	1.50:1.00	0.20	NS
40	3	4	1.00:1.33	0.14	NS
41	2	4	1.00:2.00	0.67	NS
42	1	2	1.00:2.00	0.33	NS
43	0	0	-	-	-
44	2	2	1.00:1.00	0	NS
45	2	0	-	-	-
46	3	0	-	3.00	NS

S=Significant; NS=Not Significant; - = χ^2 test or sex ratio non applicable

The females of *D. canariensis* dominated the length classes below 27 cm, while the males outnumbered the females in the 39 cm length class (Table 5). There were no significant differences between the numbers of males and

females for the rest of the length classes. No significant differences were observed between the numbers of the males and females in the length classes of *D. gibbosus*, except for the 39 cm length class where the females outnumbered the males (Table 6).

Table 5 – Sex Ratio Variations according to the Lengths of *D. canariensis* from the Coastal Waters of Ghana

Total Length (cm)	Male	Female	M:F	χ^2	Level of Significance (P _(0.05))
21	0	1	-	-	-
22	0	5	-	-	-
23	0	6	-	-	-
24	1	7	1.00:7.00	4.50	S
25	0	9	-	-	-
26	3	12	1.00:4.00	5.40	S
27	6	11	1.04:1.83	1.47	NS
28	13	22	1.00:1.69	2.31	NS
29	12	19	1.00:1.58	1.58	NS
30	12	18	1.00:1.50	1.20	NS
31	20	21	1.00:1.05	0.02	NS
32	20	17	1.18:1.00	0.24	NS
33	27	16	1.69:1.00	2.81	NS
34	26	19	1.37:1.00	1.09	NS
35	38	23	1.65: 1.00	3.69	NS
36	33	20	1.65:1.00	3.19	NS
37	16	11	1.45:1.00	0.93	NS
38	18	17	1.06:1.00	0.03	NS
39	27	13	2.08:1.00	4.90	S
40	19	9	2.11:1.00	3.57	NS
41	17	9	1.89:1.00	2.46	NS
42	9	7	1.29:1.00	0.25	NS
43	10	3	3.33:1.00	3.77	NS
44	6	5	1.20:1.00	0.09	NS
45	4	3	1.33:0.00	0.14	NS
46	7	2	3.05:1.00	2.78	NS
47	3	0	-	-	-
48	1	0	-	-	-
49	2	1	2.00:1.00	0.33	NS
50	1	0	-	-	-
51	0	1	-	-	-
52	0	0	-	-	-
53	2	0	-	-	-

S=Significant; NS=Not Significant; - = χ^2 test or sex ratio non applicable

Table 6 – Sex Ratio Variations according to the Lengths of *D. gibbosus* from the Coastal Waters of Ghana

Total Length (cm)	Male	Female	M:F	χ^2	Level of Significance (P _(0.05))
20	0	1	-	-	-
21	0	0	-	-	-
22	0	1	-	-	-
23	1	1	1.00: 1.00	0	NS
24	0	0	-	-	-
25	0	2	-	-	-
26	0	0	-	-	-
27	0	0	-	-	-
28	0	1	-	-	-
29	2	1	2.00:1.00	0.33	NS
30	0	1	-	-	-
31	0	1	-	-	-
32	1	2	1.00:2.00	0.33	NS
33	5	3	1.67:1.00	0.50	NS
34	3	2	1.50:1.00	0.20	NS
35	4	5	1.00: 1.25	0.11	NS
36	9	9	1.00:1.00	0.00	NS
37	7	12	1.00:1.71	1.32	NS
38	10	12	1.00:1.20	0.18	NS
39	7	19	1.00:2.71	5.54	S
40	15	11	1.36:1.00	0.62	NS
41	4	9	1.00:2.25	1.92	NS
42	10	7	1.43:1.00	0.53	NS
43	2	8	1.00:4.00	3.60	NS
44	9	5	1.80:1.00	1.14	NS
45	3	3	1.00:1.00	0.00	NS
46	1	2	1.00:2.00	0.33	NS
47	2	0	-	-	-
48	1	1	1.00:1.00	0.00	NS
49	2	0	-	-	-
50	2	0	-	-	-
51	2	1	2.00:1.00	0.33	NS
52	1	1	1.00:1.00	0.00	NS
53	0	0	-	-	-
54	0	0	-	-	-
55	0	0	-	-	-
56	1	1	1.00:1.00	0.00	NS
57	0	0	-	-	-
58	0	1	-	-	-
59	0	0	-	-	-
60	0	0	-	-	-
61	0	0	-	-	-
62	1	0	-	-	-

S=Significant; NS=Not Significant; - = χ^2 test or sex ratio non applicable

Size at first maturity (L_{50})

Figure 25 shows the cumulative proportions of mature male and female fish of different sizes of *P. caeruleostictus* with their 95% confidence intervals (CI). The length at which 50% of males attain sexual maturity was estimated as 36.2 cm (CI= 34.9 - 37.8 cm), and that of females was 28.0 cm (CI= 27.6 – 28.4 cm).

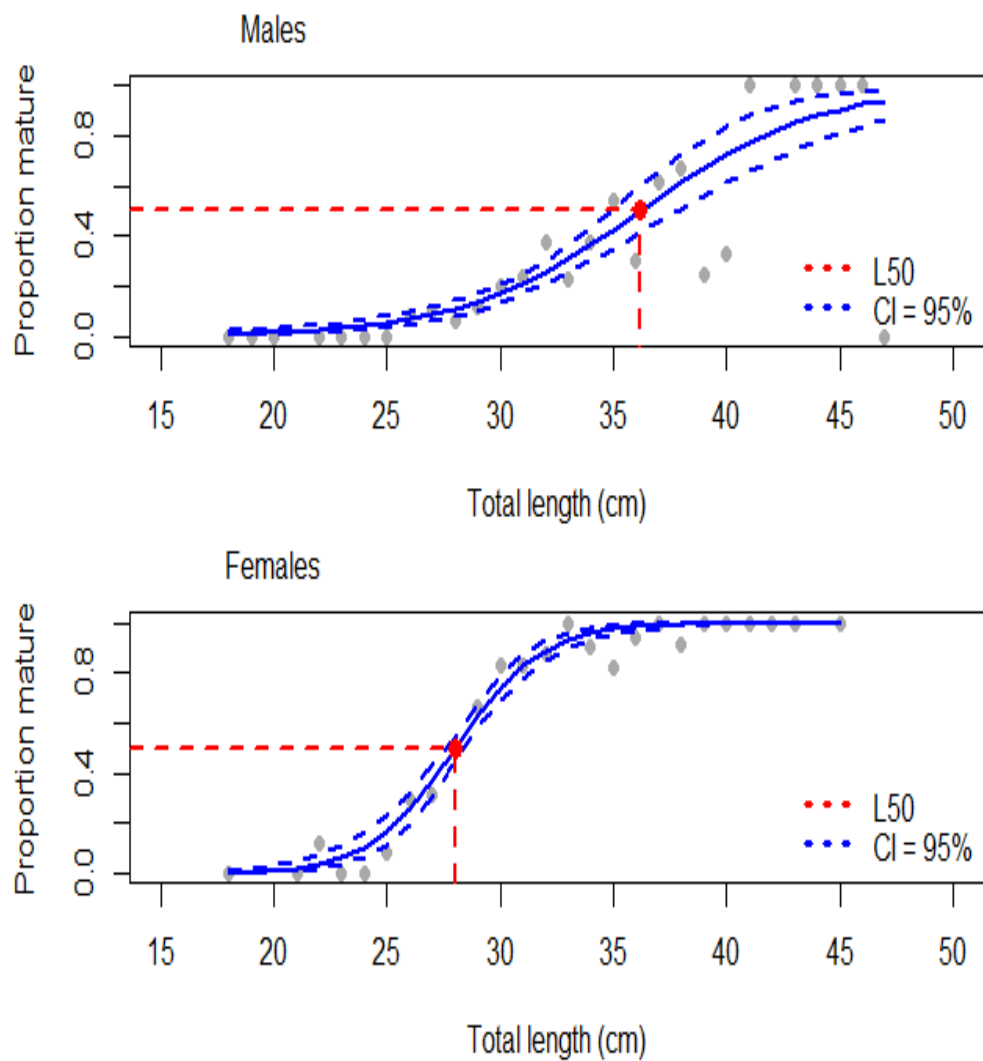


Figure 25: Length at sexual maturity of males and females of *P. caeruleostictus* in the coastal waters of Ghana.

The sexual maturity curves for *D. canariensis* are presented in Figure 26. The total lengths at 50% maturity were 51.7 cm with CIs of 46.7 – 65.8 cm for males, and 31.6 cm with CIs between 30.8 and 32.4 cm for females.

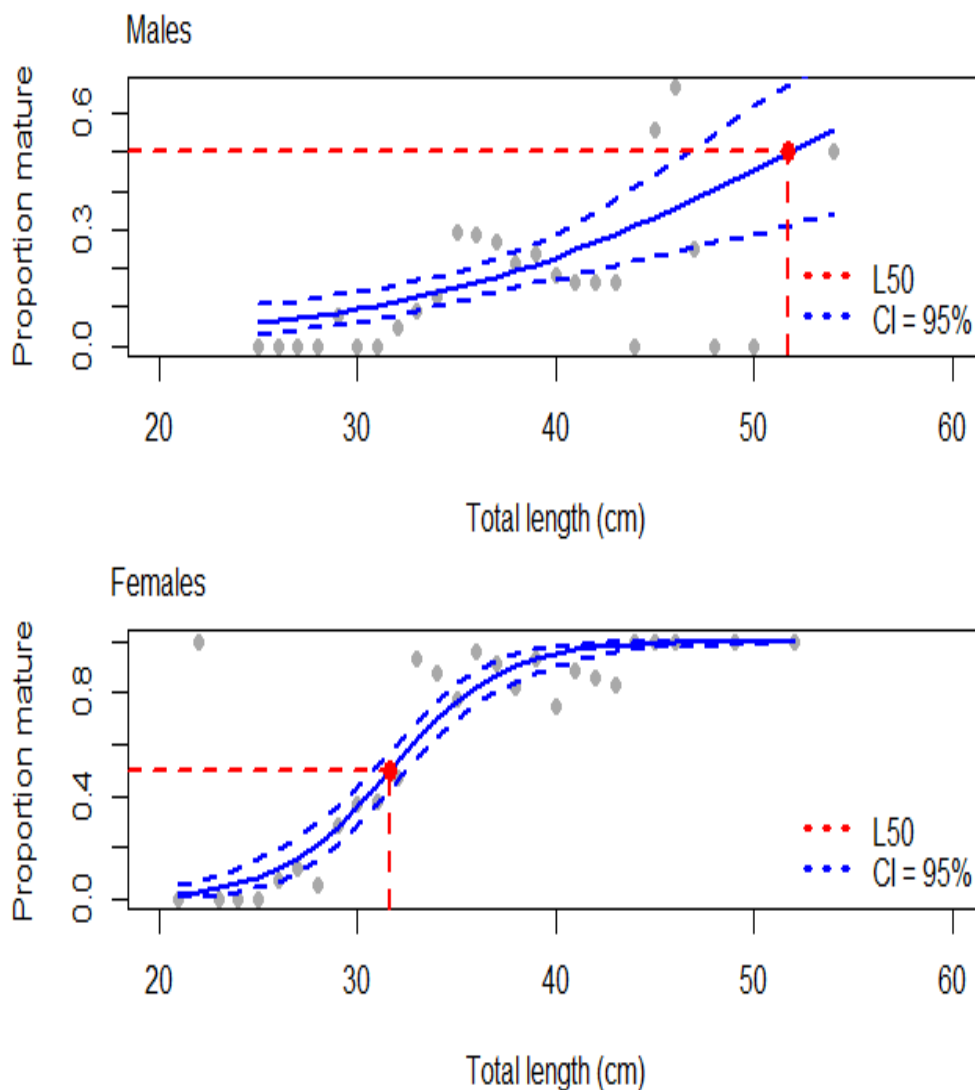


Figure 26: Length at sexual maturity of males and females of *D. canariensis* in the coastal waters of Ghana.

The maturity ogive for *D. gibbosus* showed that 50% of the males were mature at 54.3 cm with CIs of 49.0 – 68.3 cm, and 50 % of the females were mature at 56.4 cm with CIs between 47.2 cm and 77.1 cm (Figure 27).

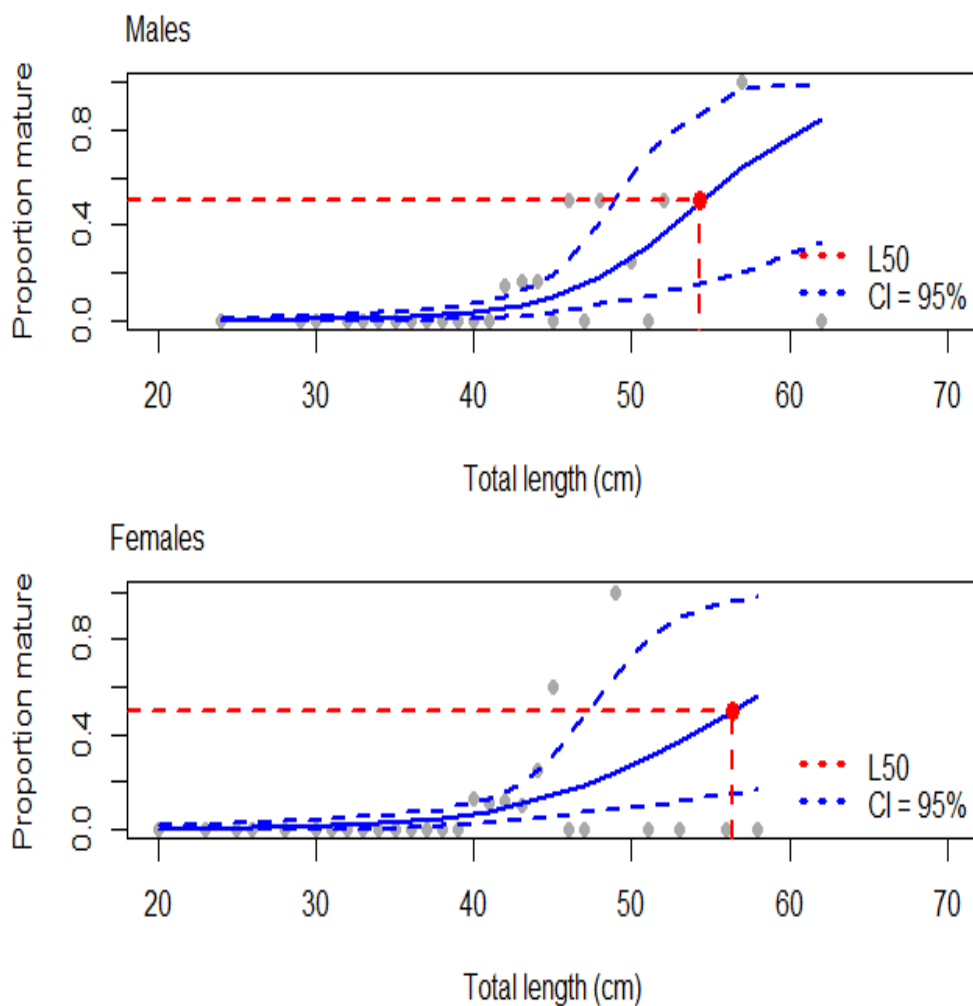


Figure 27: Length at sexual maturity of males and females of *D. gibbosus* in the coastal waters of Ghana.

Monthly fluctuations in Fulton's condition index (K)

Fulton's condition indices for the males and females of *P. caeruleostictus* are presented in Figure 28. The monthly variations show that the maximum value of K for the males was in June 2016 and that of the females in July 2017. The smallest K value was in February 2017 for the males and in March 2017 for the females. Overall, there was no significant difference ($F = 1.532$; $p = 0.224$ at 5% level of significance) between the monthly mean K (K mean = 3.503 ± 0.037 ; $n = 18$) of the males from the monthly mean K (K mean

= 3.476 ± 0.044 ; n = 18) of the females. There was a seasonality observed in the fluctuations which occurred between April and July in 2016 and 2017.

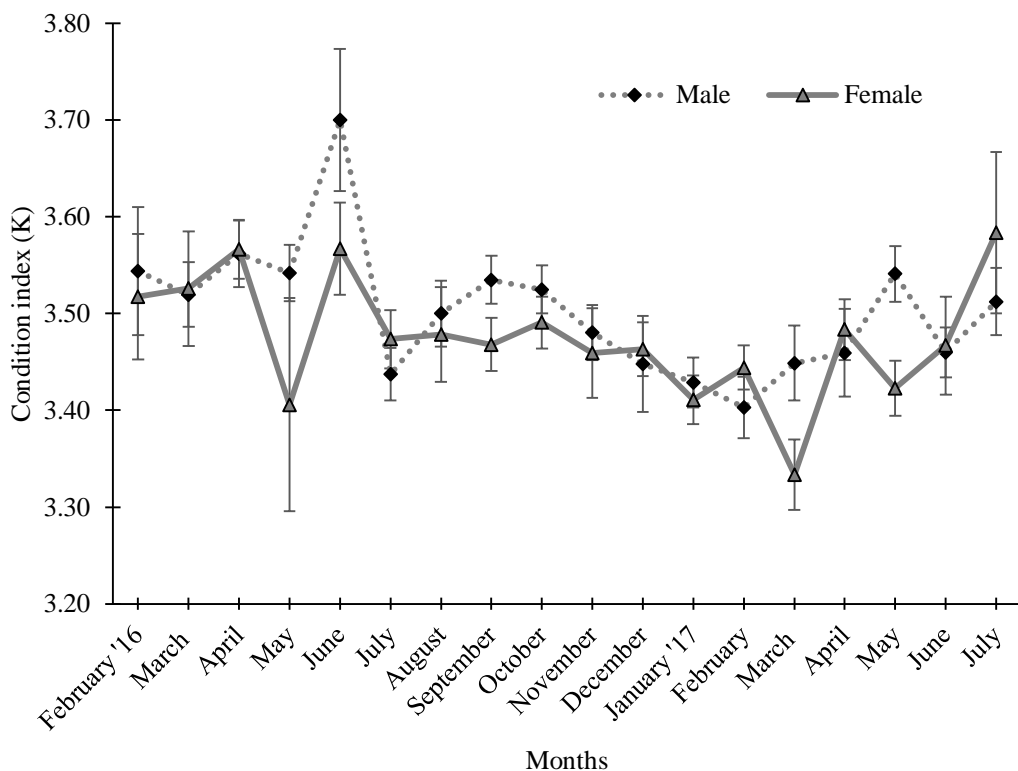


Figure 28: Condition indices (K) of *P. caeruleostictus* from the coastal waters of Ghana.

Monthly variations in Fulton’s condition index for *D. canariensis* were evident in both males and females (Figure 29). The monthly mean K was not significantly higher in one sex than the other (K mean = 2.997 ± 0.082 ; n = 18 for the males versus K mean = 2.948 ± 0.055 ; n = 18 for the females; F = 1.118; p = 0.298 at 5% level of significance). The peak for the males was observed in March 2016 and that of the females in February 2016. The minimum values were observed in July 2016 and June 2017 for males and females, respectively.

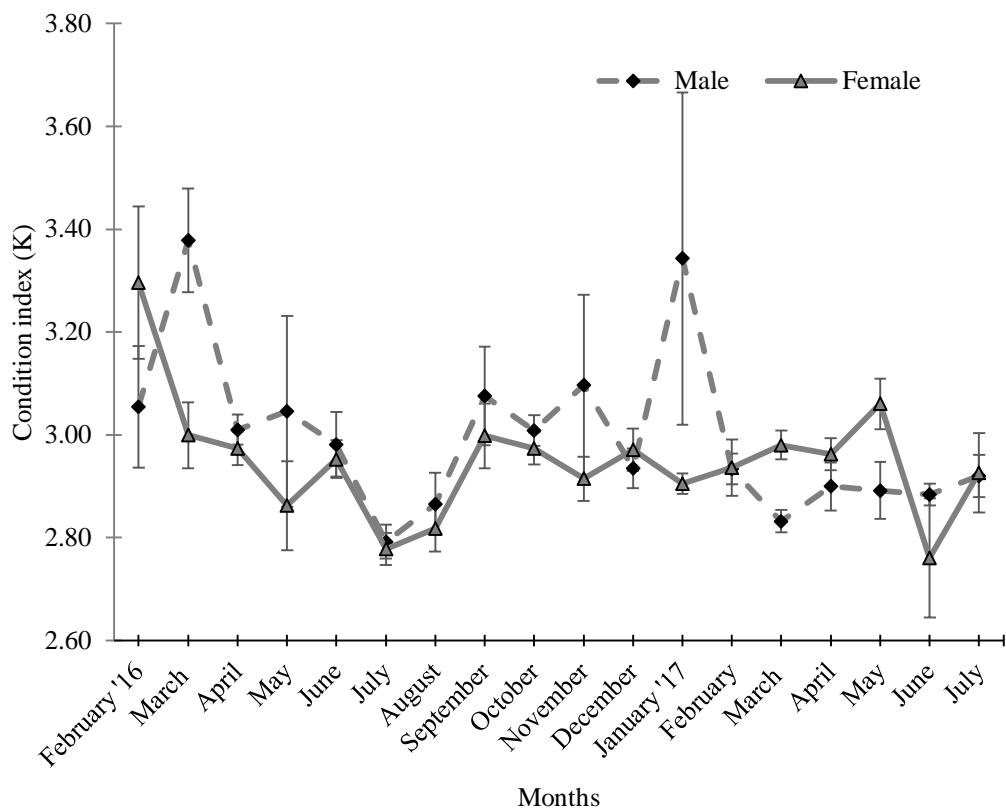


Figure 29: Condition indices (K) of *D. canariensis* from the coastal waters of Ghana.

The graphical representation of the monthly mean Fulton's condition index of *D. gibbosus* shows that K had similar variations in both males and females and variability between the months (Figure 30). The difference is at the peak observed in February 2016 for the males and in March 2016 for the females. The minimum values were also recorded in the months of July 2016 and March 2016 for males and females, respectively. However, overall, there were no significant differences ($F = 2.171$; $p = 0.150$ at 5% level of significance) between the monthly mean K determined for the males ($K \text{ mean} = 2.751 \pm 0.077$; $n = 18$) from that of the females ($K \text{ mean} = 2.645 \pm 0.081$; $n = 18$).

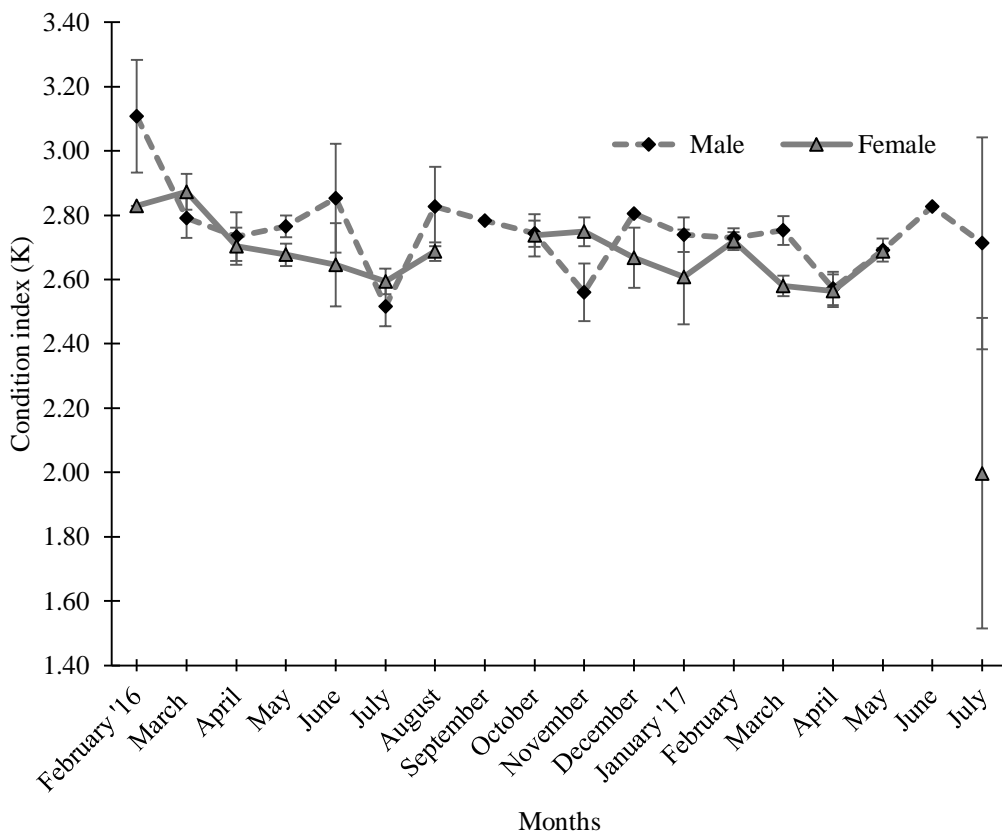


Figure 30: Condition indices (K) of *D. gibbosus* from the coastal waters of Ghana.

Monthly fluctuations in gonadosomatic index (GSI)

The monthly mean GSI for the male and female *P. caeruleostictus* showed similar fluctuation patterns (Figure 31). Peak GSI for females occurred in September 2016 and March 2017. Fluctuations of the GSI of males were not clear except for a distinct peak in March 2017. Generally, the monthly mean GSI was significantly higher for females (GSI mean = 1.501 ± 0.181 ; n = 18) than for males (GSI mean = 0.625 ± 0.086 ; n = 18) ($F = 31.201$; $p = 3E-06$ at 5% level of significance).

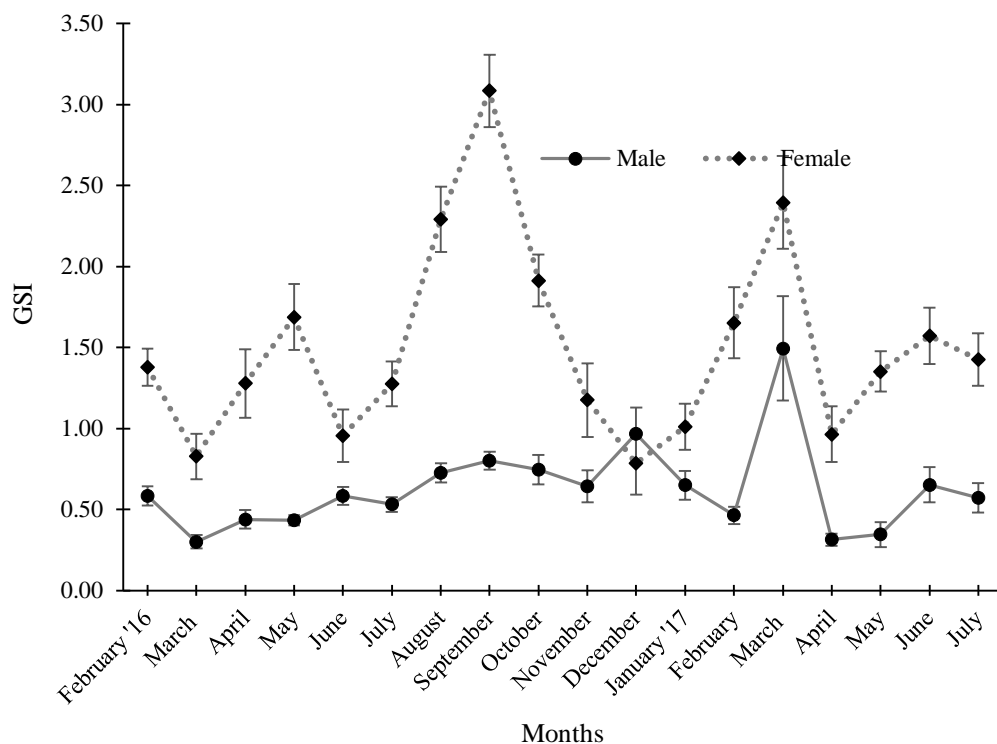


Figure 31: Monthly variations in GSI of *P. caeruleostictus* from the coastal waters of Ghana.

Variations in the monthly mean GSI of *D. canariensis* males and females were similar, as presented in Figure 32. A high GSI was recorded from May to August 2016 and June 2017 while the index was generally low from Oct 2016 to April/May 2017. The high peak periods correspond to the stages of maturation of gonads followed by spawning while the low peak periods correspond to the two stages of post-spawning and sexual rest of the reproductive cycle. Statistically, the monthly mean GSI values showed high significant differences ($F = 71.235$; $p = 7.4E-10$ at 5% level of significance) between the males (GSI mean = 0.447 ± 0.0819 ; $n = 18$) and females (GSI mean = 1.738 ± 0.341 ; $n = 18$).

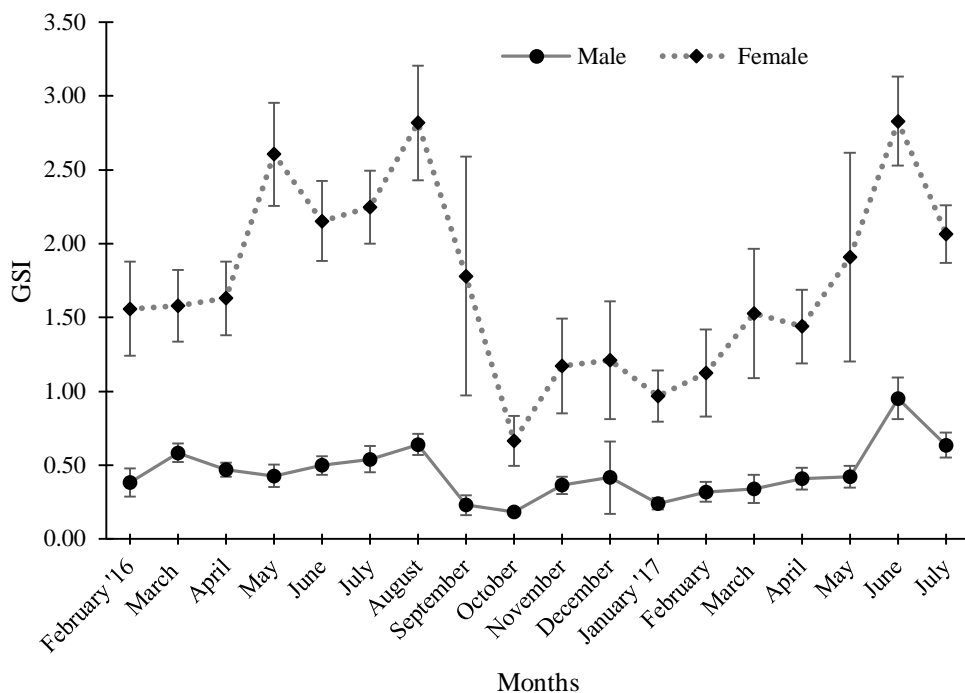


Figure 32: Monthly variations in GSI of *D. canariensis* from the coastal waters of Ghana.

Figure 33 shows the monthly variations in male and female GSI of *D. gibbosus*. For males, the mean GSI was maximised in September 2016 and became minimal in December 2016. The absence of females in September 2016 and June 2017 disrupted the monthly progression of the GSI a bit for the females. There was a gradual increase in GSI from July 2016 and then a decrease from October 2016. Another peak was observed in January 2017, which started decreasing right after to May 2017 and then started increasing again from July 2017. Generally, there was no significant difference between the mean GSI of the males (GSI mean = 0.367 ± 0.084 ; $n = 18$) and that of the females (GSI mean = 0.546 ± 0.104 ; $n = 16$) ($F = 2.171$; $p = 0.150$ at 5% level of significance).

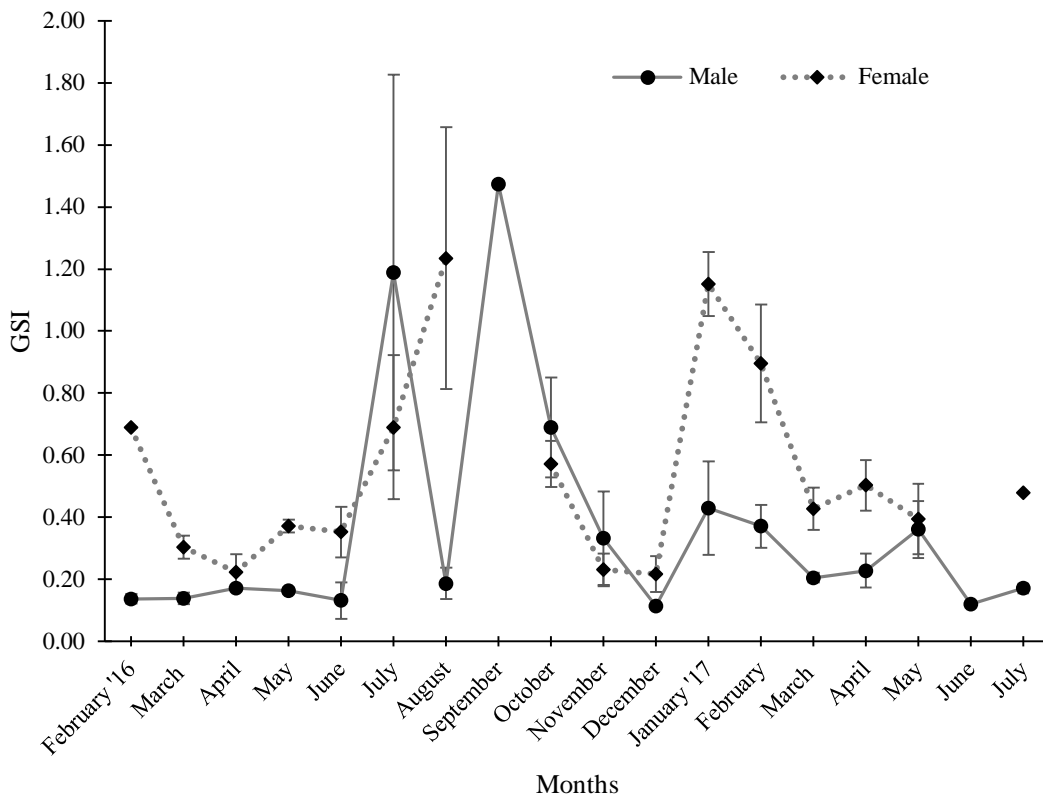


Figure 33: Monthly variations in GSI of *D. gibbosus* from the coastal waters of Ghana.

Monthly changes in the proportion of gonadal stages

The monthly percentages of the different gonadal stages of the males and females of *P. caeruleostictus* are presented in Figure 34. The immature stage (I) was recorded in every monthly sample for both sexes during the study period. The maximum percentage of the immature stage was observed in April 2017 for males (84%) and in December 2016 for females (74%). The maturing stage (II) was identified to be of high percentage in May 2016 (61%) for the males and in June 2016 (36%) for the females. The nearly ripe stage (III) was recorded with a high percentage in December 2016 (47%) for the males and in July 2017 (53%) for the females. Ripe stages (IV) of the female gonads were present throughout the study with the highest occurrence in September 2016

(85%) and March 2017 (75%). Males with ripe testes were present in 10 months only and with the highest representation in March 2017 (50%). No spent individuals were encountered during the study period.

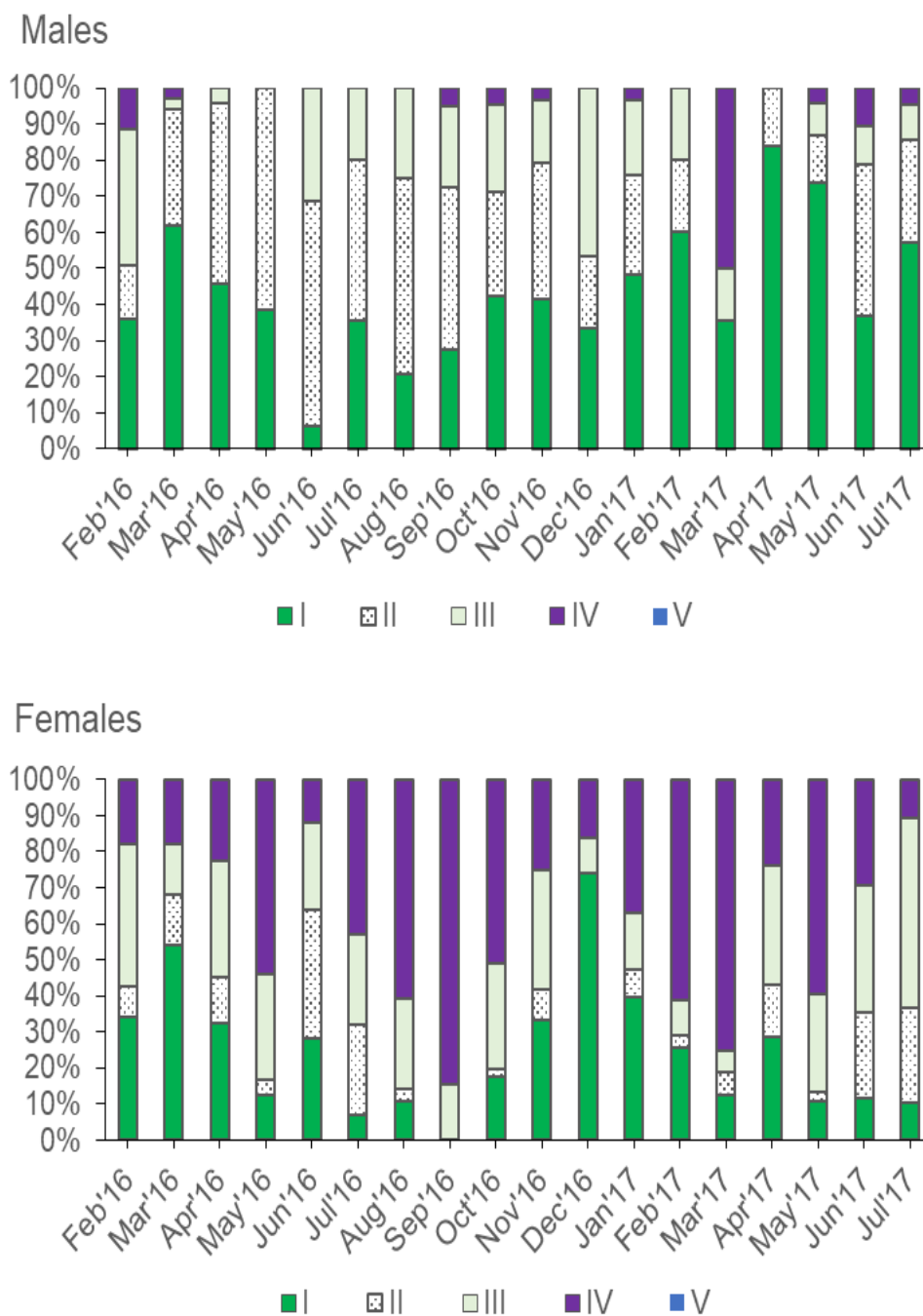


Figure 34: Monthly changes in the percentage of gonad maturity stages of *P. caeruleostictus* from the coastal waters of Ghana.

Figure 35 illustrates the monthly distributions of the different gonadal stages of the male and female gonads of *D. canariensis* over the study period. The immature stage (I) of both sexes was absent in 2 months out of the 18 month sampling period; though the percentage of the males was more than that of the females. It was absent in March 2016 and August 2016 for males and also in March 2016 and June 2017 for females. The maximum percentage of the immature stage was in October 2016 (100%) for males and in December 2016 (65%) for females. The maturing stage (II) displayed a peak in February 2016 (64%) for males and in October 2016 (33%) for females. The nearly ripe (III) peak was distinguished in August 2016 (43%) for males and in March 2016 (67%) for females. The ripe and spawning stage (IV) was observed throughout the study period for females and in 5 months for males. The peaks of the stage were reported from May 2016 (72%) to August 2016 (73%), and then again in June 2017 (76%) for females. For the males, the stage was present in March and June 2016, and in April, June and July 2017, with the maximum percentages being in March 2016 (17%) and June 2017 (16%). Spent (V) males were observed only in February 2017 (10%) and the spent females in February (22%) and March (6%) 2017.

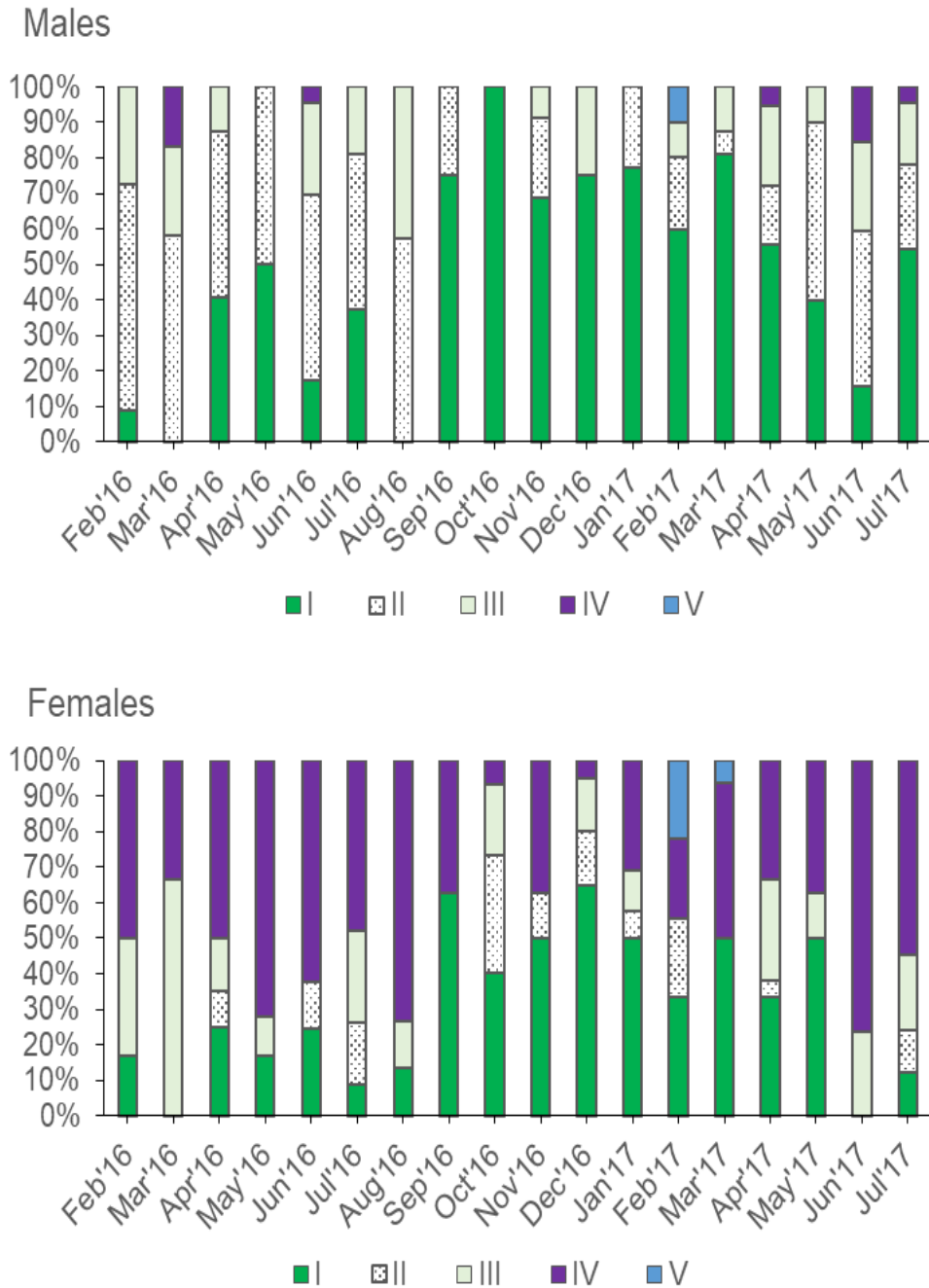


Figure 35: Monthly evolutions of the percentage of gonad maturity stages of *D. canariensis* from the coastal waters of Ghana.

The monthly distribution of different stages of maturation of the male and female gonads of *D. gibbosus* is illustrated in Figure 36. Females were absent in the samples of September 2016 and June 2017. The immature stage (I) was present throughout the study except in July 2016 for males and for the

females, February, August and October 2016 and in June 2017. The maximum percentages of this stage were observed in 9 months (100%) out of the 18 for the males, and in March 2017 (86%) for the females. The maturing stage (II) for males was present in only 8 months with the highest percentage occurring in July 2016 (67%). For females, the maximum percentage was reported in February and October 2016 (100%). The nearly ripe stage (III) recorded its maximum peak in September 2016 (100%) for males and January 2017 (100%) for females. The ripe stage (IV) was observed in only two months for both males and females. The months were July and October 2016 for the males, with the maximum percentage recorded in July (33%). For the females, the months were August 2016 and February 2017 with the peak occurring in August (30%). No spent (V) individuals were observed for both sexes.

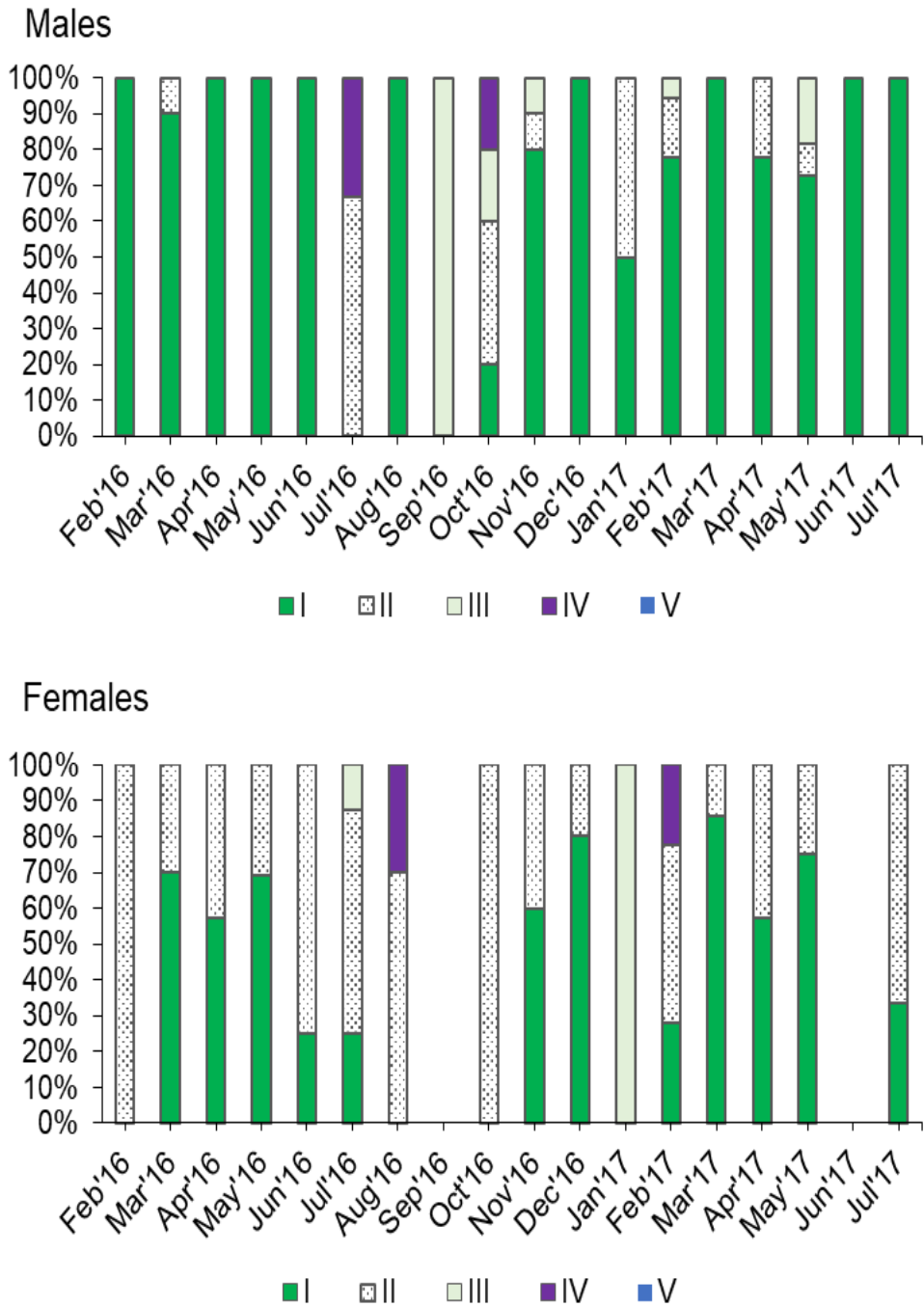


Figure 36: Monthly evolutions of the percentage of gonad maturity stages of *D. gibbosus* from the coastal waters of Ghana.

Fecundity

The fecundity was estimated for females of the three species with gonadal stages III and IV. The absolute fecundity for *P. caeruleostictus* fecundity varied between $264,259 \pm 933$ and $4,100,958 \pm 194,302$ for fish measuring from 25.5 cm to 44.5 cm and weighing 247.00 g to 1,840.00 g. the mean fecundity was $1,606,495 \pm 12,942$. The relationships between fecundity and total length, fecundity and body weight, and fecundity and gonad weight were curvilinear/power and showed that the fecundity increased as the length, body weight and gonad weight increased (as illustrated in Figure 37). There was a little scatter in the data and only 71% of the variation in fecundity could be attributed to the total length. The variation in fecundity was better predicted by the gonad weights which accounted for 92% of the variation.

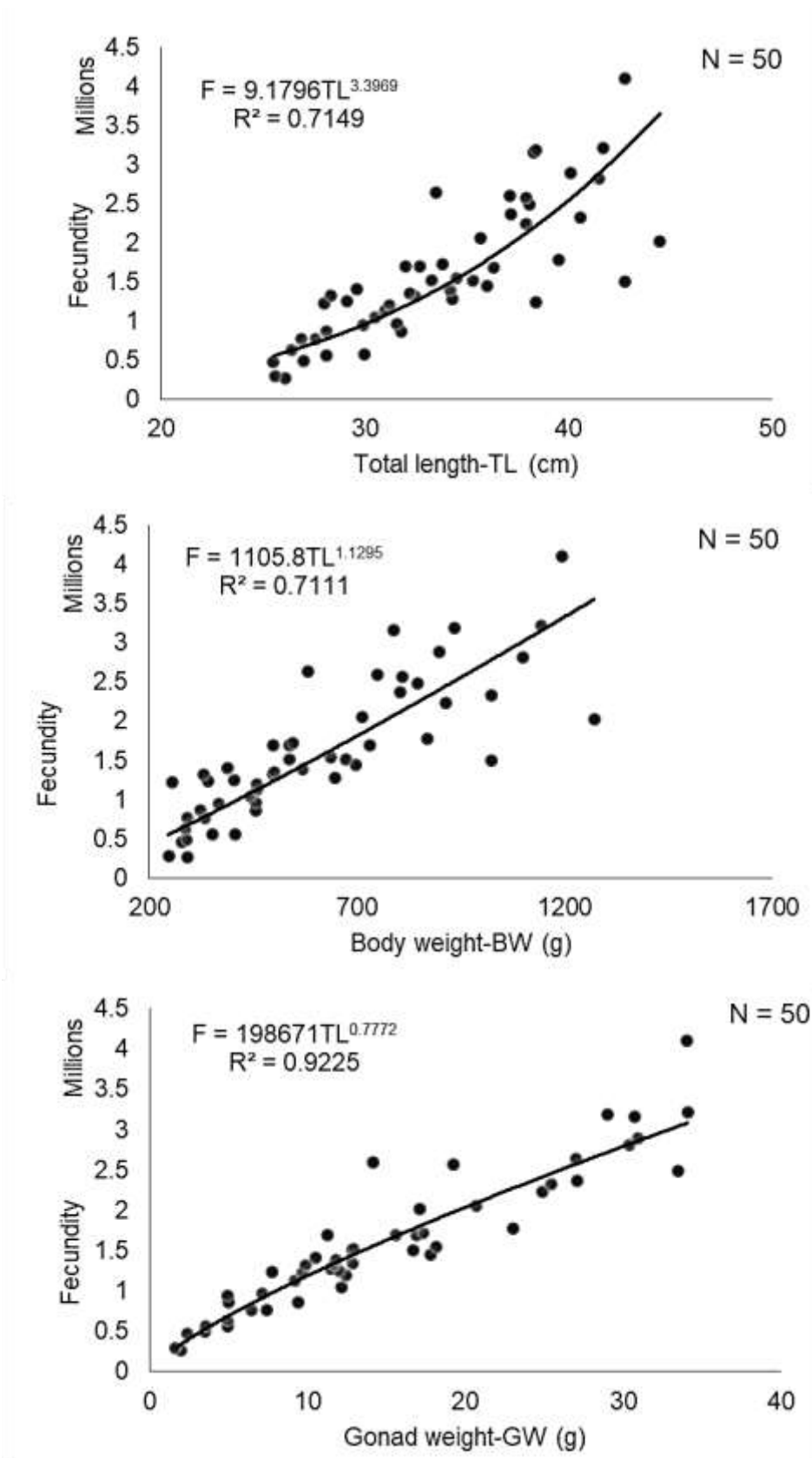


Figure 37: Relationship between fecundity (F) and total length (TL), fecundity and body weight (BW), and fecundity and gonad weight (GW) in *P. caeruleostictus* from the coastal waters of Ghana.

Total length of females of *D. canariensis* used to determine the fecundity ranged from 26.3 cm to 51.5 cm, body weight from 242.0 g to 1840.0 g, and gonad weight from 2.57 g to 48.53 g. Values of the absolute fecundity ranged from $250,902 \pm 9,973$ to $6,761,139 \pm 805,962$. The mean fecundity was estimated at $2,013,315 \pm 23,688$. The relationships between fecundity and total length, fecundity and body weight, and fecundity and gonad weight are presented in Figure 38. All the relationships were curvilinear/ power, and the variation could be attributed greatly to the gonad weight as it accounted for 91% of the variation in fecundity.

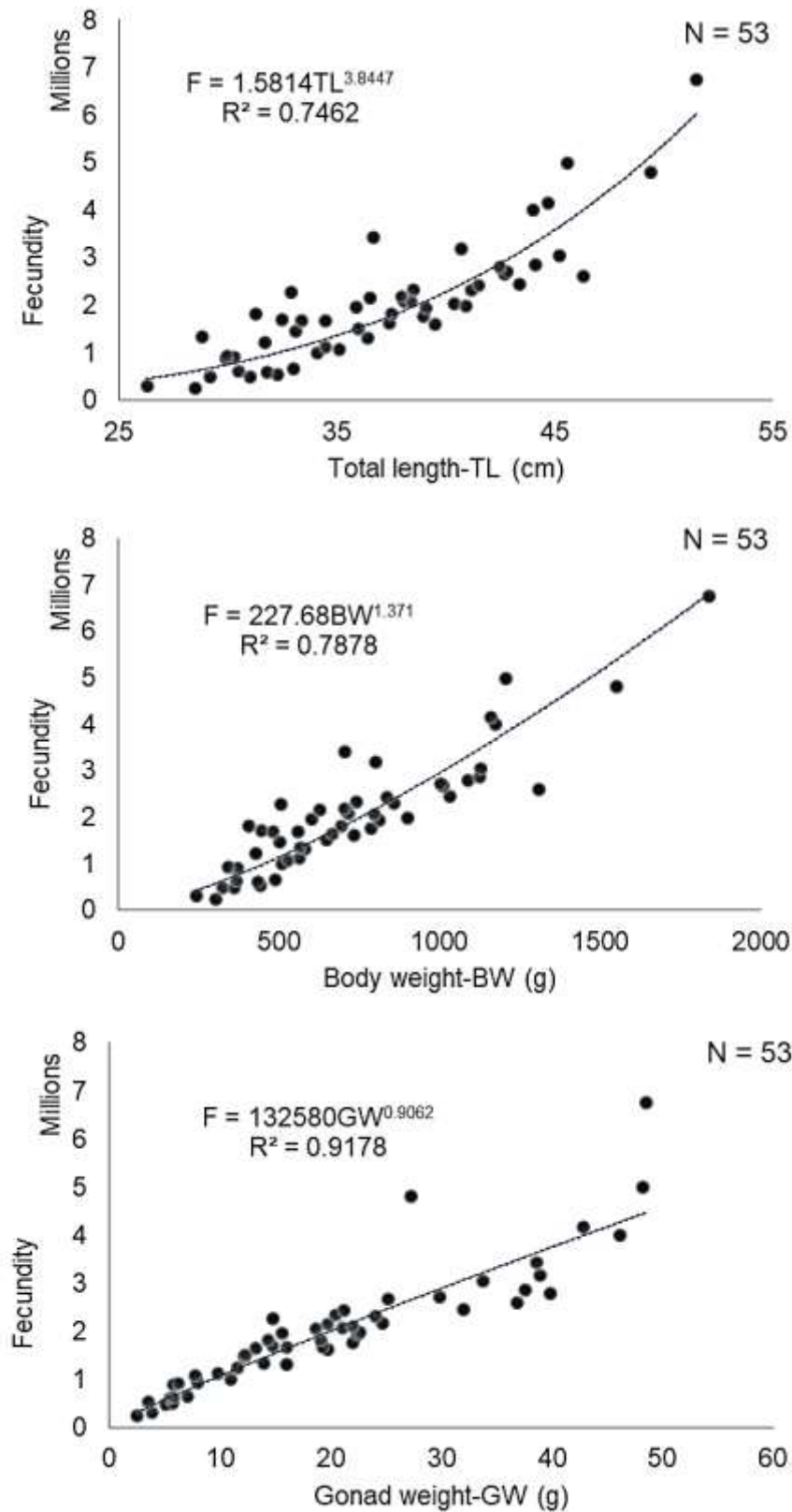


Figure 38: Relationship between fecundity (F) and total length (TL), fecundity and body weight (BW), and fecundity and gonad weight (GW) in *D. canariensis* from the coastal waters of Ghana.

The fecundity of *D. gibbosus* varied between $267,625 \pm 7,983$ and $6,037,543 \pm 430,556$ with the mean as $2,500,750 \pm 25,572$. The females had total length ranging from 39.5 cm to 48.7 cm, body weight ranging from 713.00 g to 1,437.00 g, while the gonad weight ranged from 3.73 g to 63.36 g. The relationships between fecundity and total length, fecundity and body weight, and fecundity and gonad weight illustrated in Figure 39 were all linear. Though there was much scatter in the data, the variation in fecundity was better predicted by the gonad weight (84%).

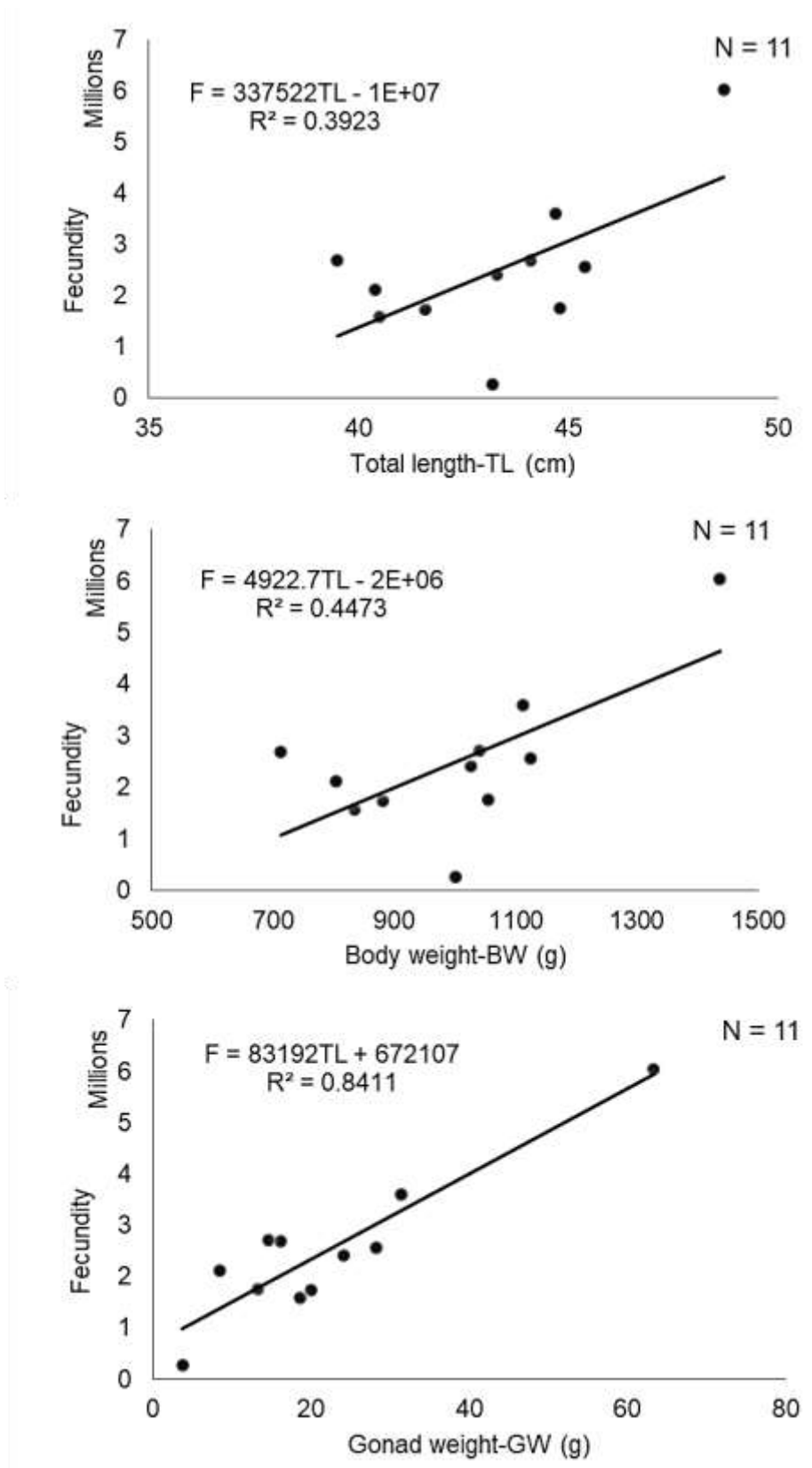


Figure 39: Relationship between fecundity (F) and total length (TL), fecundity and body weight (BW), and fecundity and gonad weight (GW) in *D. gibbosus* from the coastal waters of Ghana.

Ova diameter distribution

The ova diameter of *P. caeruleostictus* varied widely from 0.10 mm to 0.70 mm (Figure 40). The frequency curves showed a single mode of ova in each sample. The mode was either 0.30 mm or 0.20 mm.

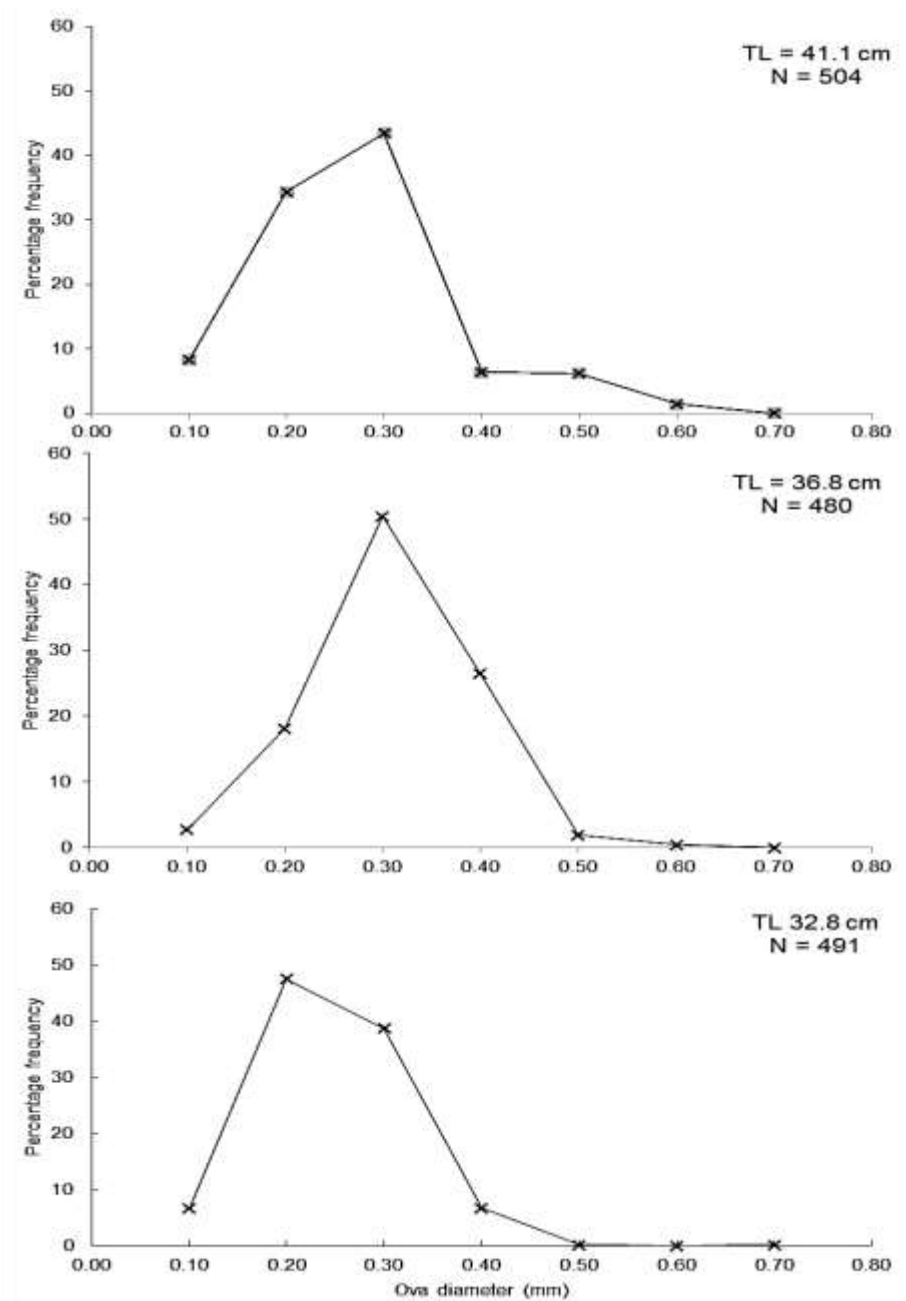


Figure 40: Ova diameter frequency polygons of the ovaries of *P. caeruleostictus* from the coastal waters of Ghana.

The ova diameter of *D. canariensis* was observed to have ranged from 0.10 mm to 0.70 mm (Figure 41). The peak of the frequency for each sample was at 0.20 mm or 0.30 mm. This indicated a single mode of ova for each sample.

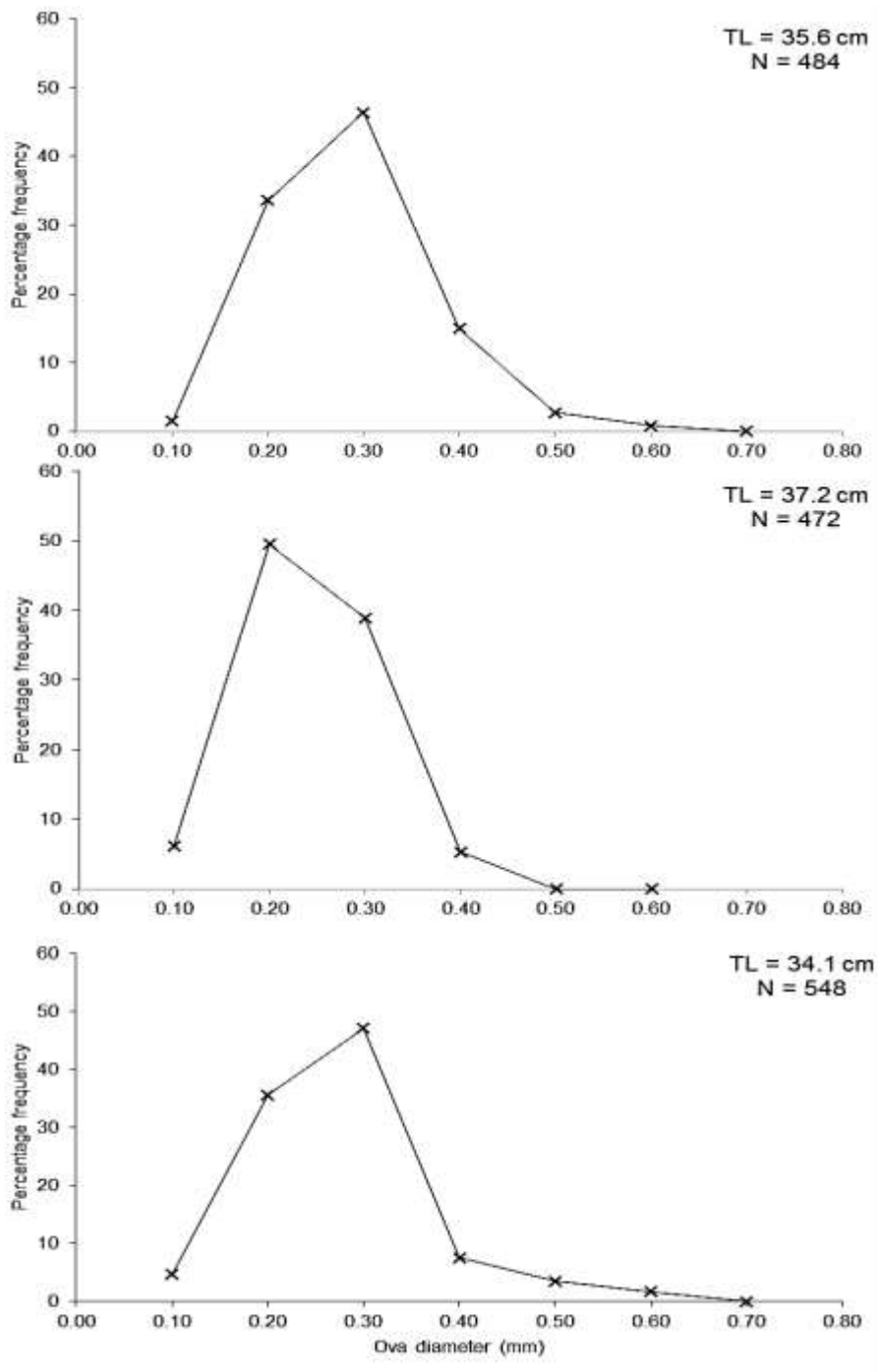


Figure 41: Ova diameter frequency polygons of the ovaries of *D. canariensis* from the coastal waters of Ghana.

For *D. gibbosus*, the ova diameter determined from the one sample varied from 0.10 to 0.70 mm (Figure 42). One clear distinct group with a size of 0.20 mm was identified.

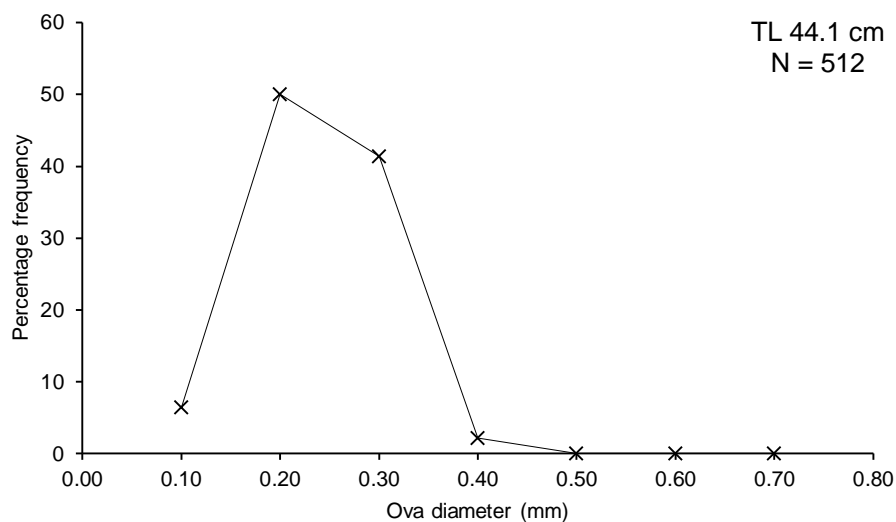


Figure 42: Ova diameter frequency polygons of the ovaries of *D. gibbosus* from the coastal waters of Ghana.

Other Observations Made on the Species

Some parasitic organisms were observed, predominantly in and around the gonads of the three species (Figure 43). The parasitic organisms which penetrated into the gonads resulted in diseased or abnormal gonads. The parasite infested gonads were observed less in the males (Figure 43A) and more in the matured or ripe gonads of the females (Figure 43B). In most cases the gonads would have been destroyed. The number of these parasitic organisms observed ranged from 1 to about 15 per individual fish (Figure 43C). The parasites, observed to belong to the Phylum Nematoda, occurred more in *D. canariensis* and least in *D. gibbosus* (Figure 44). The highest number of parasites was observed in June for *D. canariensis* and in May for both *D. gibbosus* and *P. caeruleostictus* (Figure 45).

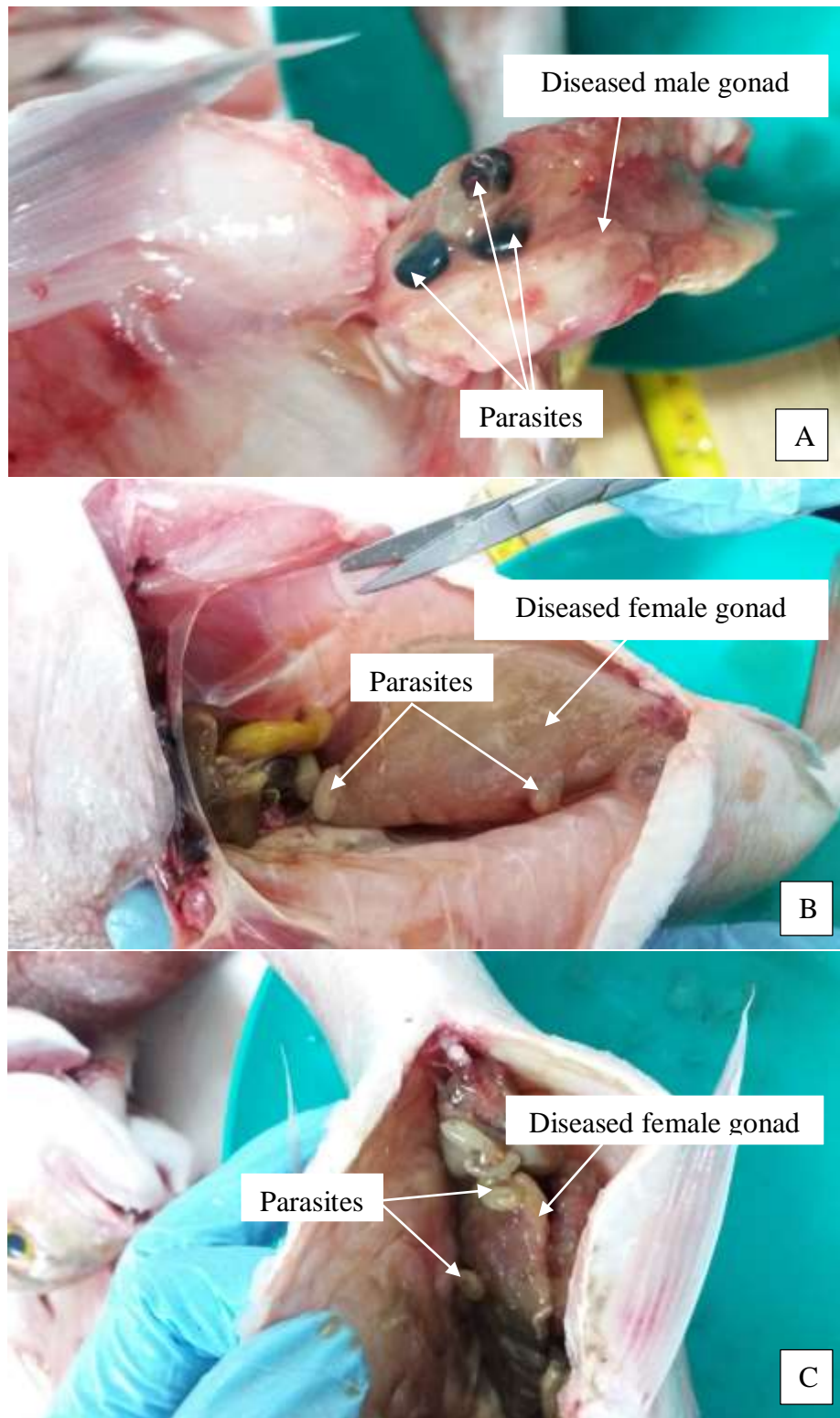


Figure 43: Some parasitic organisms found in and around the gonads of the species, causing diseased gonads. A, B and C show the types of the unidentified parasites.

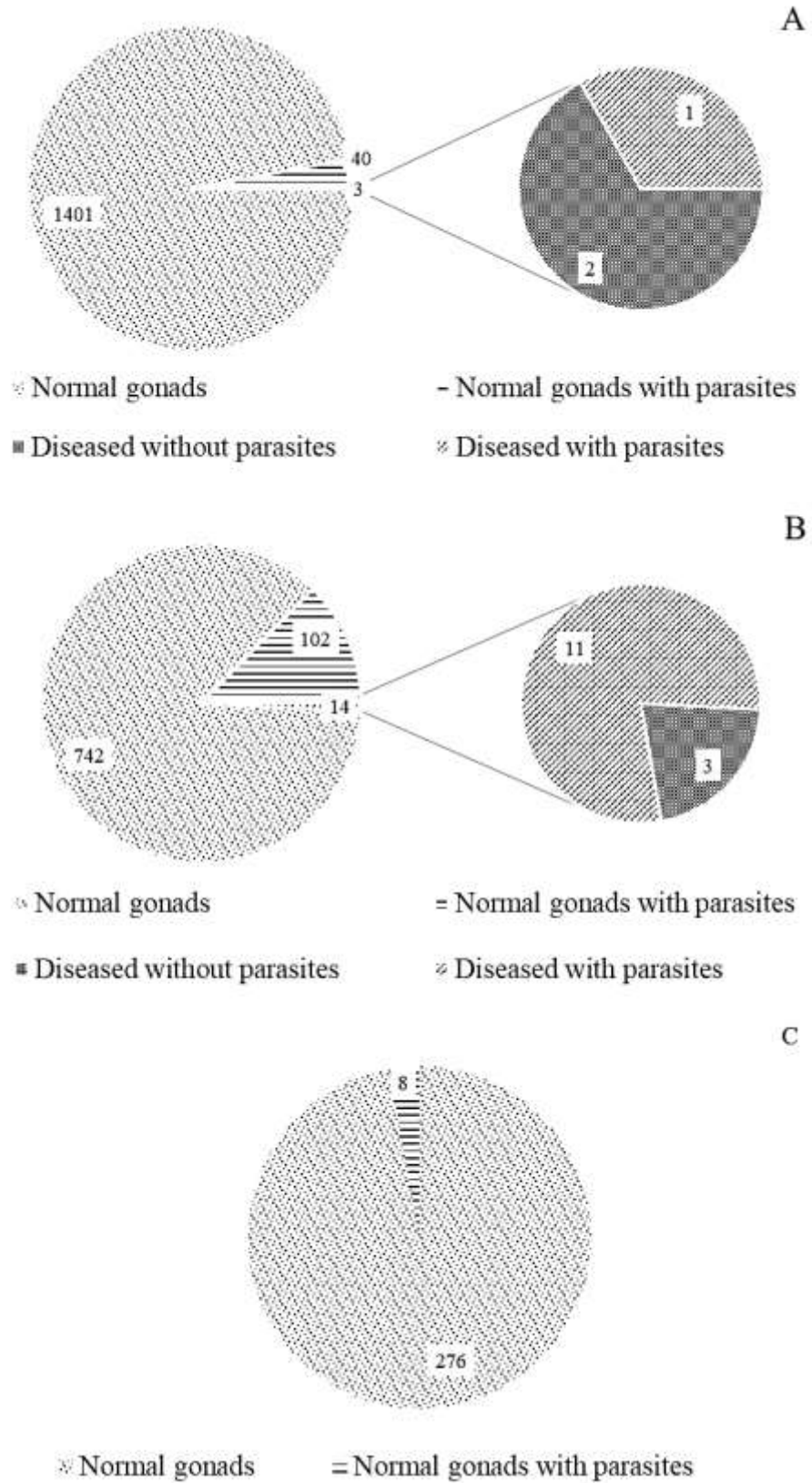


Figure 44: Occurrence of parasites in the gonads of: (A) *P. caeruleostictus*, (B) *D. canariensis* and (C) *D. gibbosus*

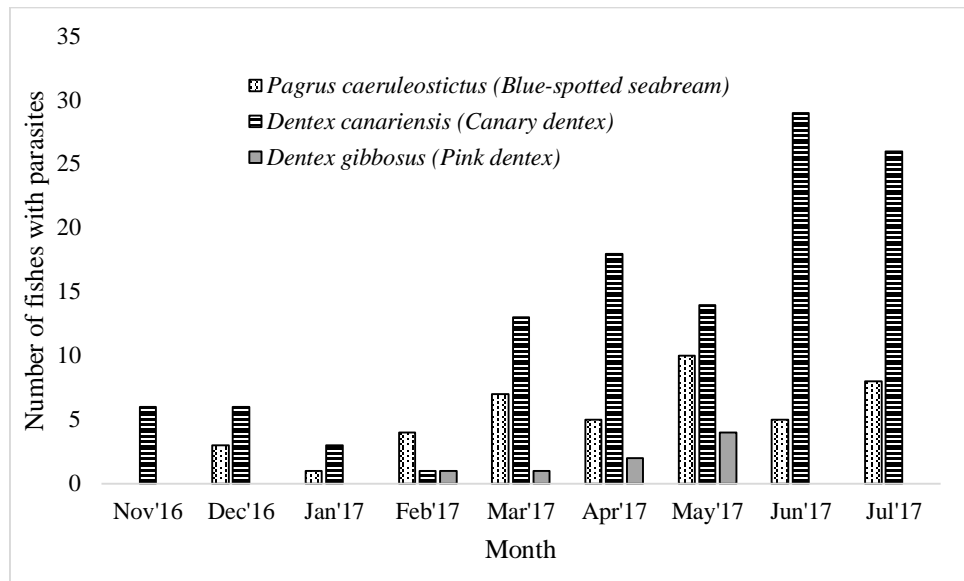


Figure 45: Occurrence of the parasites in the three species over the sampling period

CHAPTER FIVE

DISCUSSION

Distribution, Relative Abundance and CPUE

The sparid fishes *Pagrus caeruleostictus*, *Dentex canariensis*, and *Dentex gibbosus* have a wide distribution in the eastern Atlantic, from Portugal to Angola including the Canary Islands and Sao Tome, and the Mediterranean (Pajuelo & Lorenzo, 1995; Russell, 2014). In Ghanaian waters, the three species were found from the west to the east coast, and inhabited shallow to deep waters, confirming the wide distribution of the species along the coast of Ghana (Koranteng, 2001c). The species are demersal and known to inhabit a depth of up to about 200 m and prefer rocks and rubble bottoms. The adults have been reported to live in deeper waters and the juveniles found in inshore waters (Ayivi, 2012; FAO, 2019c, 2019a, 2019b; Russell, 2014).

Studies on *D. canariensis* off the coast of Cádiz (Spain) (Otero et al., 1998) reported the species to be benthopelagic inhabiting depths from 15 to 150 m and on various substrates with preference for rocky grounds or sandy bottoms. In the Canary Islands, *D. gibbosus* has been found to occur at depths of 12 – 204 m (Pajuelo & Lorenzo, 1995), while *D. canariensis* inhabits depths of 20 m to 100 m (Jones & Jones, 1988). Koranteng (2001a) observed an assemblage of sparid species that inhabited both shallow (between 15 and 70 m) and deep (down to 200 m) parts of the shores of Ghana, though the species were prominent between the depths of 10 to 100 m. Thus, there were two sparid assemblages in Ghanaian waters, occurring within the thermocline depth in shallow to the deeper waters (Koranteng, 1998, 2001c). The shallow areas are mostly soft bottom while the deep parts are of mixed bottoms to hard bottom

(Figure 1). The bottom type therefore played a key role in the distribution of the species, and is considered to be an important factor in determining the structure of demersal assemblages (Koranteng, 1998, 2001c). *D. gibbosus* were found more in the mixed bottom and hard bottom zones than they did in the soft bottom in 2005, though their numbers decreased in 2016, and were more towards the eastern coast. Both *P. caeruleostictus* and *D. canariensis* were distributed in all the bottom types, similar to the observation made by Koranteng (2001a). However, *D. canariensis* occurred more in the mixed bottom and hard bottom, as they have been known to have an affinity for all bottom types on the continental shelf (Koranteng, 1998).

As shown in the results, the abundance of all three species has declined over the decade. The higher numbers of the species recorded in the trawl survey by the Fridtjof Nansen in 2005 coincided with the period (2004-2008) within which the highest catch was recorded by the FSSD. This led to a high record of CPUE in those years, and was confirmed by the significant increase in CPUE in that same period by FAO (2015). The lower numbers of fish observed in 2016 was also a confirmation of the low catches recorded by the FSSD. Reports indicate that, generally, Ghana's fisheries have been experiencing a downward trend in catches over some periods now (Ayivi, 2012; Nunoo, Asiedu, Amador, Belhabib, & Pauly, 2014). Koranteng (2001b) observed a consistent reduction in the catches of the seabreams during the periods 1972 – 1982 (depth range of 10 – 30 m), 1964 – 1990 (depths of 30 to 50 m) and 1977 and 1990 (50 – 100 m depth), which he attributed to fishing pressure. An increase in the number of active vessels, over the years, in the Ghanaian waters has contributed to the high fishing pressure on the species (FAO, 2015).

Thus, the decline in abundance of the seabream species could be attributed to overcapacity- the high effort that was allowed in exploiting the fish stocks. Atta-Mills et al. (2004) purported that though the number of canoes might decrease in certain years, the number of fishers on board the vessels increases as well as the time spent at sea, thereby increasing the effort exploiting the stocks, even though the resources are declining and cannot withstand any more increase in effort. The overcapacity in the fishing industry is attributed to unemployment of uneducated Ghanaian fishers who see fishing as source of daily livelihood and income generation (Atta-Mills et al., 2004; Nunoo, Asiedu, Amador, Belhabib, & Pauly, 2014). Though there was a slight decrease in the fishing effort from the year 2009 (Figure 9), this did not lead to a reduction in fishing mortality or exploitation ratio, which could only iterate an increase in fishing efficiency. Alternative livelihood or employment opportunities when made available to these fishers will go a long way in taking some pressure off the fishery resources.

Population Dynamics and Stock Assessment Indices

Length-weight relationship in biological studies is an important management tool for tracing seasonal variations in fish condition (Mahmoud, Osman, Ezzat, & Saleh, 2010; Ndiaye et al., 2015), that also supports the monitoring of the state of well-being in fish populations (Ecoutin et al., 2005; Ndiaye et al., 2015). The allometric coefficient b is predicted to fall between 2.5 and 4 and a value equal to 3 is said to be isometric (Ecoutin et al., 2005), while Froese, Thorson, & Reyes (2013) suggest that b falls between 2.5 and 3.5, with fishes that “do not change shape having an approximated value of 3”. The regression parameters a and b determined from catches from the Guinea ‘90

trawl survey off Sierra Leone, Liberia, Cote d'Ivoire and Ghana, ranged between 2.897-3.013 for b and between 0.0216-0.0304 for a for *P. caeruleostictus*, while that of *D. canariensis* was between 3.039-3.111 for b and between 0.0136-0.0169 for a (Showers, 1993). *P. caeruleostictus* caught from Iskenderun Bay had b values ranging from 2.95-3.188 with a mean value of 3.073, which indicated a positive allometric growth when tested (Can & Turkmen, 2001). The b -value obtained for *P. caeruleostictus* from Benin waters was 2.82 (sd = \pm 0.031) and a was 0.0222 (sd = \pm 0.041), with no test conducted to determine its allometry (Fiogbé, Sohoun, Gbaguidi, Hounkpe, & Dégbé, 2003). The values obtained from this study, however, were comparable to the range of values recorded in these previous studies. The LWR described for *D. gibbosus* off the Canary Islands gave an ' a ' of 0.01014 and ' b ' of 3.0812 ($r = 0.997$) indicating a growth trend of positive allometry (Pajuelo & Lorenzo, 1995). A negative allometric growth pattern, however, was observed for all three species in this study, indicating that the fish species were growing longer than they were growing plumper. This could be due to conditions in their habitats, the size, age and sexual maturity of the fish, the degree of general wellbeing and stomach fullness of the fish, and the size range of the observed lengths of the fishes sampled (Maci et al., 2009; Moutopoulos & Stergiou, 2002). Also, increment in size of fish is influenced by elements such as, physico-chemical parameters of both soil and water, ecological niche, and the number of fish using similar food sources, which could have an effect on the value of the estimates (Katzenmeyer, 2010; Wootton, 1990).

The monthly length-frequency analysis needed to be treated with caution as the monthly samples were considered not large enough, and therefore

not a good representative of the population. Nevertheless, the full bootstrapping approach with the fit algorithm (Schwamborn et al., 2018) addressed this limitation to estimate the VBGF curve. A relatively slower growth was observed for all three species based on the growth coefficient (K) (Figure 18). This trend compared favourably with similar observations on *D. gibbosus* off the Canary Islands (Pajuelo & Lorenzo, 1995), though the age-based method was applied and the maximum observed length (95.2 cm) and asymptotic length (101.2 cm) were higher than those derived from this study. Pauly (1978) determined from earlier studies on the three species, the following growth parameters: L_{∞} of 44.8 cm and K of 0.49 yr⁻¹ off Ghana and L_{∞} of 41.2 and K of 0.501 yr⁻¹ off Togo for *P. caeruleostictus*; L_{∞} of 70.0 cm and K of 0.173 yr⁻¹ off Ghana for *D. canariensis* and an L_{∞} of 107.0 cm and K of 0.124 yr⁻¹ for *D. gibbosus*. The point estimates of the L_{∞} of *P. caeruleostictus* from these earlier studies were of different values and lower than the range estimated in this study. Smaller sized samples could have attributed to this observation (Pajuelo & Lorenzo, 1995) as well as differences in oceanographic conditions affecting the species from different regions, and the mode of data acquisition or analysis (Mahmoud et al., 2010), since the maximum observed length in this study was 46.5 cm. Schwamborn et al. (2019) recommends assessing a few more large individuals monthly to address this problem, since they “have stronger positive effect on the accuracy and growth estimates than hundreds of small individuals”. The K from previous studies, however, fell within the range of values obtained in this study, though the estimate in this study indicated a slightly higher value and thus, a faster growth of the species now than some years ago. Owusu-Boateng (1994) also recorded L_{∞} of 44.3 cm and K of 0.48 yr⁻¹ for *P. caeruleostictus*

from Ghanaian waters over two decades ago, which estimates were lower than those obtained from this study. The higher K value of *P. caeruleostictus* in this study (Figure 18) is an indication of increased pressure on the fish, especially the juveniles, which forces them to attain their maximum lengths faster than previous decades (Bannerman & Cowx, 2002).

Again, the growth performance index recorded by Pajuelo and Lorenzo (1995) was 3.15 for *D. gibbosus*. This point estimate compared favourably with the range observed in this study, which indicates that the fish were growing as they should. The slight difference between the estimates, however, could be due to oceanographic conditions which would apparently affect the growth rates of different stocks (Pajuelo & Lorenzo, 1995). The earlier studies conducted on the species (especially for *P. caeruleostictus* and *D. canariensis*) did not report on the growth performance index (ϕ') which made it difficult to relate how the species are growing in relation to those from other waters. Nevertheless, the ϕ' values for all the three species of sparids were around 3 and ϕ' is normally ascertained to be approximately distributed around 3 and similar within related taxa (Pauly & Munro, 1983).

The component of natural mortality occurring in a particular species determines the rate of the mortality (Pauly, 1980). Short-lived fish species (t_{max} =1 year) have higher M values than long-lived ones (Hordyk et al., 2015). The M and t_{max} values from this study indicate that the three seabreams are relatively long-lived species. The estimates of the t_{max} were all above 5 years suggesting that the species could live for a relatively long time before dying.

M correlates with the size of fish (negatively), the value of K , and the environmental temperature (directly), with the highest partial correlation being

with K (Hordyk et al., 2015; Pauly, 1980). The growth parameters and the temperature, therefore, go a long way to determine the value of M . However, the M/K ratio does not depend solely on the absolute values of either M or K , but determines the shape of the VBGF curve (Hordyk et al., 2015). Also, the VBGF equation describes the average growth curve of the stock, which means that some fish might have their maximum lengths or weights higher than the asymptotic lengths or weights even for fish with a higher ratio (Hordyk et al., 2015), as observed in this study in comparison with other studies. The ratios, which are higher than the optimal ratio, indicate that the species will reach about 95% of their asymptotic lengths at a slower rate and later age, especially for *D. gibbosus*.

Fishing mortality rates are determined by the susceptibility of the fishes to the fishing gear as they reach a certain size. This rate increases as the fishing pressure on the stocks also increase. The total mortality (Z) of the species with values of $3.03 \pm 0.12 \text{ yr}^{-1}$, $1.96 \pm 0.11 \text{ yr}^{-1}$ and $0.88 \pm 0.12 \text{ yr}^{-1}$ for *P. caeruleostictus*, *D. canriensis* and *D. gibbosus*, respectively, was largely accounted for by the fishing mortality. Of the three species, *P. caeruleostictus* had the highest fishing mortality coefficient while the least was recorded for *D. gibbosus*. The mortalities of the three species compared to another seabream species, *Pagellus bellotii*, in Ghanaian waters, were lower than the M of 1.12 yr^{-1} , Z of 3.74 yr^{-1} and F of 2.61 yr^{-1} recorded for this species (Asabere-Ameyaw & Blay, 1999).

In the present study, the F calculated for the three species was greater than M , the E higher than 0.50 (Table 1) which suggests that the fish stocks are being exploited beyond their optimal levels of the yield-per-recruit (Pajuelo &

Lorenzo, 1995). The current exploitation ratios (E_{cur}) calculated were also higher than the exploitation ratios for maximum sustainable yield (E_{msy}) except for *D. gibbosus*. Furthermore, E_{cur} estimates were higher than the ratios for exploiting 50% of the virgin biomass except, again, for *D. gibbosus*.

This implies that a lower percentage of the virgin stocks were being left behind to replenish the exploited stocks. Also, more yield than biomass was produced for the species at the current exploitation ratios, with the exception of *D. gibbosus* which had appreciable numbers of both yield and biomass being produced. Again, looking at the exploitation ratio of the species, over 70 % of the total mortality of *P. caeruleostictus* and *D. canariensis* was due to fishing mortality, while that of *D. gibbosus* was over 50%, suggesting that it is by far over the optimal exploitation. Combining these results with that of the abundance from the Fridtjof Nansen and FSSD throughout the years, the species are being heavily exploited which calls for management intervention. Apart from *D. gibbosus*, the current L_c at the current fishing mortality rate is low. This could lead to a possible growth overfishing as the corresponding t_{50} (Table 1) for both *P. caeruleostictus* and *D. canariensis* was below 2 and 3 years (less than one-third of their t_{max}), respectively, while that of *D. gibbosus* was above 6 years. A way to combat this growth overfishing in exploited stocks is to delay the catching of juveniles (Carlucci, Capezzuto, Maiorano, Sion, & D'Onghia, 2009). Increasing the L_c and maintaining the F_{cur} or preventing growth overfishing, will provide more biomass than is being harvested currently. The exploitation ratios for *D. gibbosus* imply that the stocks are underexploited, which is inconsistent with comparable studies for the same species conducted off the Canary Islands, which suggests that the species were heavily exploited

(Pajuelo & Lorenzo, 1995). Though YPR analysis is a useful tool that is employed to help manage a fishery, it forms just a part of a fishery management strategy and must be applied together with eggs-per-recruit and spawning stock biomass per recruit models in order to comprehensively manage a fishery (Barbieri, Chittenden, & Jones, 1997). Comparing the exploitation ratios of these seabreams with other demersal species in Ghanaian waters, *Balistes capriscus* was found to be underexploited with $E = 0.27$ (Aggrey-Fynn, 2007), while that of *Pagellus bellottii* was found to be overexploited in Ghanaian waters with an exploitation ratio of 0.63 (Asabere-Ameyaw & Blay, 1999).

Reproductive Biology

Sparids have been noted to exhibit protogynous, protandric, simultaneous and rudimentary hermaphroditism, together with gonochorism (Buxton & Garratt, 1990; Manooch III & Hassler, 1978). Protogynous hermaphrodites start out as functional females and then change to functional males later on, while protandric hermaphrodites do the reverse. Rudimentary hermaphrodites also referred to as “late gonochorists”, however, are mostly young fishes that possess immature intersexual gonads which mature later into male or female gonads; whereas true gonochorists have no hermaphroditic tissue in their gonads (Buxton & Garratt, 1990a; Morato, Afonso, Lourinho, Nash, & Santos, 2003).

The sex change in species affects the size range or length-frequency distribution, mean size and mean gonadosomatic indices of both sexes (Morato et al., 2003). For protogynous species, the females should be smaller than the males, and vice versa for protandric species, whereas there are similar sizes in rudimentary hermaphroditic species. In this study, *P. caeruleostictus* and *D.*

canariensis were found to show protogynous hermaphroditism (Chakroun-Marzouk & Kartas, 1987b; Ismail et al., 2018) as the females of these species dominated in smaller sizes and the males in larger sizes. This type of hermaphroditism may show the males having a slower growth and higher asymptotic length, which is the reverse in their earlier stages of life (Coelho et al., 2005). However, though *D. gibbosus* has been reported to exhibit protandric hermaphroditism (Buxton & Garratt, 1990a; FAO, 2019), the data suggest otherwise, as there was no dominance of a particular sex in all the length classes except the 39 cm size class where the females were significantly dominant. Studies conducted in the Canary Islands suggest the hermaphroditic behaviour to be protogynous, as the females dominated the smaller sized classes and the males the larger ones, and this difference is attributed to the nature of sexual succession which varies in diverse populations (Pajuelo & Lorenzo, 1995). The largest sizes of males observed for all three species suggests that sex reversal may possibly not be crucial for all fish and probably an alternative reproductive style that differs geographically, and may depend on environmental conditions and not individual determination (Buxton & Garratt, 1990; Hadj Taieb, Ghorbel, Ben Hadj Hamida, & Jarboui, 2012; Monteiro et al., 2010). The larger sizes observed as part of the indeterminate sex in this study could be those individuals that have switched sex and are waiting for the next reproduction period, which was also reported in *Diplodus bellottii* in the same family by Ndiaye (2015). However, the confirmation of the type of hermaphroditism exhibited by the *P. caeruleostictus*, *D. canariensis* and *D. gibbosus* needs to be determined with a detailed histological examination of the gonadal development.

The sex ratio of *P. caeruleostictus* was in favour of the females as with similar observations made in Egypt (Ismail et al., 2018), while that of *D. canariensis* and *D. gibbosus* indicated equal numbers of both males and females in the population. However, for the sex ratio according to the length classes, there was a dominance of males at length 39 cm for *D. canariensis*, whereas there was a dominance of females at that same length for *D. gibbosus*. Though the females of *D. gibbosus* were more in the small length classes, there was no significant difference, until the length 39 cm when the males dominated.

Size at first sexual maturity is of great significance when determining the optimum mesh size for a fishery (Mehanna, 2007). Taking into account the size at first sexual maturity (L_{50}) of the species, there seem to be a very small number of spawners in the population, as the size at first capture (L_c) was smaller than the L_{50} . The fishes are mostly caught before they are allowed to spawn at least once in their lifetime. The females of *Pagrus caeruleostictus* and *Dentex canariensis* reaching sexual maturity at a smaller size than the males is explained by their protogynous behaviour, and the variances in different populations could be attributed to growth differences which are influenced by food quality and availability, as well as environmental conditions (Saoudi, Saoudi, Mimar, & Aoun, 2017; Zarrad, Cherif, Gharbi, Jarboui, & Missaoui, 2010). The males of *Dentex gibbosus* reached their maturity at a smaller size than the females. This could be a possible indication of its protandric nature. The differences in the sexual maturity of the sexes could also be attributed to their hermaphroditic behaviour (Hadj Taieb et al., 2012). Unfortunately, the L_{50} of the species from Ghanaian waters or the Gulf of Guinea has not been well documented. The only study on *P. caeruleostictus* conducted by Owusu-

Boateng (1994) reported that 50% of the males mature at 18.4 cm and the females at 17.2 cm, which are sizes smaller than those reported in this study and could be due to the difference in sample size and the sizes of the individuals used. However, the females also attained their L_{50} at a smaller size than the males (Owusu-Boateng, 1994), thus, validating the observation in this study.

The condition index of a fish is an expression of its general well-being, and a small value shows that the fish is not in good condition and is probably starving and elongated (Alhassan, Abobi, Mensah, & Boti, 2014). The males and females were generally in similar conditions except for the months of June 2016, September 2016, March 2017 and May 2017, where the males of *P. caeruleostictus* were significantly higher than the females. There were significant differences between conditions of the males and females of *D. canariensis* only in the months of March 2016 and January 2017 when the males were in a better condition, and in March and May 2017 when the females were better. For *D. gibbosus*, the males were in a better condition than the females February 2016 and March 2017, whereas the females were better than the males in November 2016.

The monthly study of the condition factor, monthly changes in the frequency of gonadal maturity, and the peaks of the GSI of the three species gives an indication of their spawning seasons and the type of hermaphroditism exhibited. GSI in protogynous species is higher in the females than the males (Buxton & Garratt, 1990) and this was evident in both *P. caeruleostictus* and *D. canariensis*. The presence of different gonadal stages throughout the study, suggests that the species spawned throughout the year but had peak spawning seasons as observed in Egypt (Ismail et al., 2018) and in Turkey (Chakroun-

Marzouk & Kartas, 1987b). The spawning seasons of *P. caeruleostictus* notably occurs twice in a year with the major one in September as also witnessed in Egyptian waters (Ismail et al., 2018), which happens to be the month with the highest record of ripe stage gonads, after which there is a sexual resting phase, followed by the minor one in March with high proportions of ripe stage gonads in both males and females. Owusu-Boateng (1994) made similar observations in a study conducted over two decades ago for *P. caeruleostictus* in Ghanaian waters, where he documented two spawning periods in a year, occurring between September and October for the main spawning period and a minor one between January and February. Again for *D. canariensis*, the ripe and spawning stage gonads were present throughout the study with major importance in May-August and that of the males in March-July. *D. canariensis* clearly has one extended spawning season in a year which likely occurs between May and September, with the resting phase in between. The spawning season of *D. gibbosus* appears to occur twice in a year in January-February and July-October. This period coincided with the highest record of ripe stage gonads of males in July-October, and that of females in August and February, though the other stages were present throughout the study, suggesting continuous spawning. Pajuelo & Lorenzo (1995) observed the spawning season of *D. gibbosus* in the Canary Islands as an extended period occurring between April and September. Ndiaye (2015) noted that not all the seabreams have two spawning or reproduction seasons and the length of the seasons varies widely. The extended spawning season observed for some of the species could be an indication of favourable environmental conditions that support the hatching and larval

development for longer periods (El-Sayed & Abdel-Bary, 1993; Hadj Taieb et al., 2012).

The estimates of the fecundity confirmed that the sparid species are highly fecund fish species (Alam, Ahsan, & Parween, 2012). The fecundity showed a strong relationship with the total lengths and body weights of the species except for that of *D. gibbosus*. However, there was a strong relationship between the fecundity and the gonad weights for all three species. The relationships were curvilinear/power and also positively correlated, except for that of *D. gibbosus* where the relationships were linear – which suggested that the total length, body weight and gonad weight could be used to predict the fecundity of the species. This implied that the number of eggs increased linearly with the body parameters (Jan, Jan, & Shah, 2014). Owusu-Boateng (1994) observed the fecundity of *P. caeruleostictus* to range between 45,204 and 360,128 for fish length ranging from 17.5 cm to 24.8 cm, and the relationship between fecundity and fork length was nonlinear. The danger for highly fecund fish is the assumption by fisheries biologists that a small portion of the population that is left behind would be sufficient to replenish the stocks that become available to the fishery (Pauly, 1983b). However, highly fecund fish have very small ova diameters because there is a tendency to minimise egg size since fecundity and egg size are inversely correlated. This leads to a decrease in juvenile survival since bigger eggs produce bigger larvae which are able to withstand adverse conditions (Wootton, 1990).

Though the progression of oocyte to maturity could not be followed through the various stages, the species are likely to spawn continuously over a period of time due to the presence of a single group of ova with high modes in

addition to the immature oocyte. The smaller diameter of the egg size recorded for the three species is also an indication of the high fecundity of these seabreams, as fecundity is highest in species that possess smallest eggs (Wootton, 1990). The time of year the fish spawns also plays a key role in the size of egg that would be released, as species that spawn during early spring and summer have been noted to possess the smallest eggs (Wootton, 1990). The presence of the various stages of maturity of the ovaries in some months also suggests that some individual species could probably spawn more than once or over an extended period (Ismail et al., 2018; James, Gupta Chandrasekhara, & Shanbhogue, 1978). Ismail et al. (2018) suggested that *P. caeruleostictus* possessed an asynchronous oocyte development and is a fractional spawner due to the ova frequency size distributions and the different stages of the oocyte in the studies conducted in Egypt.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The study was conducted to establish the current exploitation status and reproductive potential of the stock of each of the three sparid species landed from the coastal waters of Ghana. This was done by assessing the catch trends in their landings by the artisanal fleets (hook and line fishery), through the use of length-based stock assessment methods and some reproductive studies, to serve as an indicator for the sustainable management of the fisheries. Primary data were obtained monthly from catches of the hook and line fishers operating from Tema, Elmina and Sekondi; as well as secondary data from the FSSD and Fridtjof Nansen cruise reports. The results indicated that the catches of *P. caeruleostictus*, *D. canariensis* and *D. gibbosus* had declined over the past decade, with the effort being fairly stable after a short decline. *P. caeruleostictus*, distributed along the entire coast, is the most abundant species in the coastal waters of Ghana, while *D. gibbosus*, occurring more in deeper waters, is the least abundant species. The growth patterns of all three species deviated from an isometric growth. The growths of the species were also faster than previous years, and the species were dying more from fishing than from natural causes. Apart from *D. gibbosus*, *P. caeruleostictus* and *D. canariensis* were overexploited and producing less yield and biomass at their current fishing rates. The females of *P. caeruleostictus* and *D. canariensis* matured faster than the males, while the males of *D. gibbosus* matured faster than the females. The species are also highly fecund species which spawn all year through but have

peak seasons once or twice a year. However, the presence of parasitic organisms that target their gonads could be a serious threat to their successful recruitment.

Conclusions

Despite the importance and distribution of these three seabreams, there is limiting information on its management. Fisheries management requires data of catches that provide maximum yield over a long period of time (Mahmoud et al., 2010). The following conclusions were made:

1. Though limitations in models exist, this study has shown that two out of the three sparid species exploited currently in Ghanaian waters, need management interventions. The catch trends of the species have shown a decline over the past decade, thereby decreasing the CPUE. *P. caeruleostictus*, the most abundant species, occurs from shallow to deeper waters and inhabits all the bottom types of the continental shelf, as well as *D. canariensis*, while *D. gibbosus* prefers deeper waters, mixed and hard bottoms, and is the least abundant species.
2. The three species had faster growths and were reaching their asymptotic lengths faster than they did some decades ago and in other waters. *P. caeruleostictus* and *D. canariensis* appeared to be exploited heavily as a result of the increase in fishing pressure (fishing mortality), as the current fishing mortality was above that for a maximum sustainable yield, while *D. gibbosus* was underexploited.
3. Though the sparid species are highly fecund fishes that have peak spawning seasons once (in the case of *D. canariensis*) or twice (for *P. caeruleostictus* and *D. gibbosus*) in a year, the yield per recruit and biomass per recruit

analyses show that the amount of biomass that was being left behind to replenish the exploited stocks was extremely low.

4. The females of *P. caeruleostictus* and *D. canariensis* attained their sexual maturity at smaller sizes than their males due to their protogynous hermaphroditic behaviour, while the reverse is true for *D. gibbosus*.
5. The presence of parasitic organisms which target the ripe or matured gonads of the species could be a major threat to recruitment.

Recommendations

Based on the findings of this study, it is recommended that some management measures are adopted for the sustainable exploitation of the demersal resources, in order to prevent the seabream fishery from a possible collapse. These measures include:

1. The education of the fishers on the effects of their activities leading to overexploitation and depletion of fish stocks, and possible measures they could adopt to mitigate them through community-based fisheries management;
2. The establishment of MPAs or no-take zones, in addition to closed seasons, to reduce fishing mortality and protect the feeding or nursery grounds of juveniles;
3. The reduction in the amount of fishing through a gradual phased reduction approach to the current level of fishing effort, and the provision of alternative livelihood or employment options; and
4. The adoption and enforcements of minimum hook size and landing sizes for the hook and line fishery, and a minimum mesh size in the trawl cod-

ends for the trawl fishery, to help reduce fishing effort and eliminate the catching of juveniles.

Suggestions for Further Research

1. Histological evidence of the sex changes in the species should be investigated.
2. Investigations into the parasitic attack on the matured gonads and their effect on fish recruitment should be made.
3. Since the estimates of growth with ELEFAN must be used with caution, ageing of the species using their otoliths (reading of daily rings) should be conducted to supplement and verify the estimates of the growth parameters.
4. Studies on other aspects of the fishery that can help calibrate the CPUE should be conducted.

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APPENDICES

Appendix A: The R codes used for the analyses on the population dynamics and stock assessment indices

```
library(devtools)
library(parallel)
library(TropFishR)
library(fishboot)
library(ks)
library(fishmethods)
----- 1.0 INITIAL SETTINGS -----

# Loading data and specifying species =====

setwd("C:/Users/MICHY/Dropbox (Personal)/PhD/Data/R analysis/Growth-thesis")

lfq1 = read.csv("lfq1.csv")

lfq1$date = as.Date(lfq1$Month, format = "%d.%m.%Y")

species = levels(lfq1$Species)

Cana = lfq1[lfq1$Species== species[1],]
Gibb = lfq1[lfq1$Species== species[2],]
Pag = lfq1[lfq1$Species== species[3],]

# 1.2 Changing the date format to that of R =====

Pag$date = as.Date(Pag$Month, format = "%d.%m.%Y")
Cana$date = as.Date(Cana$Month, format = "%d.%m.%Y")
Gibb$date = as.Date(Gibb$Month, format = "%d.%m.%Y")

# 1.3 Creating a length frequency data =====

lfq1Pag <- lfqCreate(data = Pag, Lname = "TL.cm.", Dname = "date")
lfq1Cana <- lfqCreate(data = Cana, Lname = "TL.cm.", Dname = "date" )
lfq1Gibb <- lfqCreate(data = Gibb, Lname = "TL.cm.", Dname = "date")
```

```
# 1.4 Adjusting bin size =====
lfq1Pag1 <- lfqModify(lfq1Pag, bin_size = 2)
lfq1Cana1 <- lfqModify(lfq1Cana, bin_size = 2)
lfq1Gibb1 <- lfqModify(lfq1Gibb, bin_size = 2)

# 1.5 Restructure data =====
lfq1Pagbin <- lfqRestructure(lfq1Pag1, MA = 7, addl.sqrt = FALSE)
lfq1Canabin <- lfqRestructure(lfq1Cana1, MA = 7, addl.sqrt = FALSE)
lfq1Gibbbin <- lfqRestructure(lfq1Gibb1, MA = 7, addl.sqrt = FALSE)

# 1.6 Plot raw and restructured LFQ data =====
opar <- par(mfrow = c(2,1), mar = c(2,5,2,3), oma = c(2,0,0,0))

plot(lfq1Pagbin, Fname = "catch", date.axis = "modern", labels("Pagrus
caeruleostictus"))

plot(lfq1Pagbin, Fname = "rcounts", date.axis = "modern")

plot(lfq1Canabin, Fname = "catch", date.axis = "modern", head("Dentex
canariensis"))

plot(lfq1Canabin, Fname = "rcounts", date.axis = "modern")

plot(lfq1Gibbbin, Fname = "catch", date.axis = "modern", head("Dentex
gibbosus"))

plot(lfq1Gibbbin, Fname = "rcounts", date.axis = "modern")

par(opar)

##### 2.0 GROWTH ESTIMATES -----
##### ELEFAN_GA =====
# 2.1 full bootstrap =====
t1 <- Sys.time()

PagGAbout <- ELEFAN_GA_boot(lfq=lfq1Pag1, MA = 7, seasonalised =
TRUE, up_par = list(Linf = 60, K = 1, t_anchor = 1, C = 1, ts = 1),
low_par = list(Linf = 40, K = 0.1, t_anchor = 0, C = 0, ts = 0),
popSize = 100, maxiter = 50, run = 10, pmutation = 0.2, nresamp = 1000,
parallel = TRUE, no_cores = detectCores()-1, seed = NULL, resample = TRUE)
```

```
t2 <- Sys.time()

t2 - t1

t1 <- Sys.time()

CanaGAbboot <- ELEFAN_GA_boot(lfq=lfq1Cana1, MA = 7, seasonalised =
TRUE, up_par = list(Linf = 100, K = 1, t_anchor = 1, C = 1, ts = 1),
low_par = list(Linf = 50, K = 0.1, t_anchor = 0, C = 0, ts = 0),
popSize = 100, maxiter = 50, run = 10, pmutation = 0.2, nresamp = 1000,
parallel = TRUE, no_cores = detectCores()-1, seed = NULL, resample = TRUE)

t2 <- Sys.time()

t2 - t1

t1 <- Sys.time()

GibbGAbboot <- ELEFAN_GA_boot(lfq=lfq1Gibb1, MA = 7, seasonalised =
TRUE, up_par = list(Linf = 100, K = 1, t_anchor = 1, C = 1, ts = 1),
low_par = list(Linf = 50, K = 0.1, t_anchor = 0, C = 0, ts = 0),
popSize = 100, maxiter = 50, run = 10, pmutation = 0.2, nresamp = 1000,
parallel = TRUE, no_cores = detectCores()-1, seed = NULL, resample = TRUE)

t2 <- Sys.time()

t2 - t1

# plot results

# univariate density plot of bootstrapped pars

univariate_density(PagGAbboot)

univariate_density(CanaGAbboot)

univariate_density(GibbGAbboot)

# VBGF by time growth curve plot

CIinfo_PagGAbboot <- vbgfCI_time(res = PagGAbboot, agemax = 15, CI = 95,
xlab = "Relative age (years)",ylab= "Total Length (cm)",perm.col =
adjustcolor("grey50",0.1), perm.lwd = 1,ci.col = 1, ci.lty = 2, ci.lwd = 1,
maxd.col = 1, maxd.lty = 1, maxd.lwd = 2)

CIinfo_CanaGAbboot <- vbgfCI_time(res = CanaGAbboot, agemax = 15, CI =
95,xlab = "Relative age (years)",ylab= "Total Length (cm)",perm.col =
adjustcolor("grey50",0.1), perm.lwd = 1,ci.col = 1, ci.lty = 2, ci.lwd = 1,
maxd.col = 1, maxd.lty = 1, maxd.lwd = 2)

CIinfo_GibbGAbboot <- vbgfCI_time(res = GibbGAbboot, agemax = 15, CI = 95,
xlab = "Relative age (years)",ylab= "Total Length (cm)",perm.col =
```



```
adjustcolor("grey50",0.1), perm.lwd = 1,ci.col = 1, ci.lty = 2, ci.lwd = 1,  
maxd.col = 1, maxd.lty = 1, maxd.lwd = 2)
```

```
# Plot raw and restructured LFQ data with growth curves =====
```

```
plot(lfq1Pagbin, Fname = "catch", date.axis = "modern", labels("Pagrus  
caeruleostictus"))
```

```
lt <- lfqFitCurves(lfq1Pag1, par = CInfo_PagGAbboot$max_dens,  
draw = TRUE, col = "darkgreen", lty = 1, lwd=1.5)
```

```
plot(lfq1Pagbin, Fname = "rcounts",date.axis = "modern", ylim=c(10,60))
```

```
lt <- lfqFitCurves(lfq1Pag1, par = CInfo_PagGAbboot$max_dens,  
draw = TRUE, col = "darkgreen", lty = 1, lwd=1.5)
```

```
plot(lfq1Canabin, Fname = "catch", date.axis = "modern", head("Dentex  
canariensis"))
```

```
lt <- lfqFitCurves(lfq1Cana1, par = CInfo_CanaGAbboot$max_dens,  
draw = TRUE, col = "darkgreen", lty = 1, lwd=1.5)
```

```
plot(lfq1Canabin, Fname = "rcounts",date.axis = "modern", ylim=c(10,60))
```

```
lt <- lfqFitCurves(lfq1Cana1, par = CInfo_CanaGAbboot$max_dens,  
draw = TRUE, col = "darkgreen", lty = 1, lwd=1.5)
```

```
plot(lfq1Gibbbin, Fname = "catch", date.axis = "modern", head("Dentex  
gibbosus"))
```

```
lt <- lfqFitCurves(lfq1Pag1, par = CInfo_PagGAbboot$max_dens,  
draw = TRUE, col = "darkgreen", lty = 1, lwd=1.5)
```

```
plot(lfq1Gibbbin, Fname = "rcounts",date.axis = "modern", ylim=c(10,60))
```

```
lt <- lfqFitCurves(lfq1Pag1, par = CInfo_PagGAbboot$max_dens,  
draw = TRUE, col = "darkgreen", lty = 1, lwd=1.5)
```

```
# 2.3 estimate longevity (tmax)
```

```
3/CInfo_PagGAbboot$max_dens$K
```

```
3/CInfo_CanaGAbboot$max_dens$K
```

```
3/CInfo_GibbGAbboot$max_dens$K
```

```
##### 3.0 MORTALITY ESTIMATION WITH ELEFAN_GA  
PARAMETERS
```

```
# 3.1 Natural mortality
```

```
Mort_PagGA <- M_empirical(Linf = CInfo_PagGAbboot$max_dens$Linf, K_1  
= CInfo_PagGAbboot$max_dens$K, temp = 19, method = "Pauly_Linf")
```

```
Mort_CanaGA <- M_empirical(Linf = CInfo_CanaGAbboot$max_dens$Linf,  
K_1 = CInfo_CanaGAbboot$max_dens$K, temp = 19, method = "Pauly_Linf")
```

```
Mort_GibbGA <- M_empirical(Linf = CInfo_GibbGAbboot$max_dens$Linf,  
K_1 = CInfo_GibbGAbboot$max_dens$K, temp = 19, method = "Pauly_Linf")
```

```
# show results
```

```
paste("M =", as.numeric(Mort_PagGA))
```

```
paste("M =", as.numeric(Mort_CanaGA))
```

```
paste("M =", as.numeric(Mort_GibbGA))
```

```
# add to data
```

```
lfq1Pag1$M <- as.numeric(Mort_PagGA)
```

```
lfq1Pag1$Linf <- as.numeric(CInfo_PagGAbboot$max_dens$Linf)
```

```
lfq1Pag1$K <- as.numeric(CInfo_PagGAbboot$max_dens$K)
```

```
lfq1Cana1$M <- as.numeric(Mort_CanaGA)
```

```
lfq1Cana1$Linf <- as.numeric(CInfo_CanaGAbboot$max_dens$Linf)
```

```
lfq1Cana1$K <- as.numeric(CInfo_CanaGAbboot$max_dens$K)
```

```
lfq1Gibb1$M <- as.numeric(Mort_GibbGA)
```

```
lfq1Gibb1$Linf <- as.numeric(CInfo_GibbGAbboot$max_dens$Linf)
```

```
lfq1Gibb1$K <- as.numeric(CInfo_GibbGAbboot$max_dens$K)
```

```
# summarise catch matrix into vector and add plus group which is smaller than  
Linf
```

```
lfq1Pag2 <- lfqModify(lfq1Pag1, vectorise_catch = TRUE, plus_group = 45)
```

```
lfq1Cana2 <- lfqModify(lfq1Cana1, vectorise_catch = TRUE, plus_group = 55)
```

```
lfq1Gibb2 <- lfqModify(lfq1Gibb1, vectorise_catch = TRUE, plus_group = 51)
```

```
# 3.2 run catch curve for FM, E and Z estimates
```

```
CC_PagGA <- catchCurve(lfq1Pag2, catch_columns = 1:ncol(lfq1Pag2$catch),  
calc_ogive = TRUE, plot = TRUE)
```

```
CC_CanaGA <- catchCurve(lfq1Cana2, catch_columns =  
1:ncol(lfq1Cana2$catch), calc_ogive = TRUE, plot = TRUE)
```

```
CC_GibbGA <- catchCurve(lfq1Gibb2, catch_columns =  
1:ncol(lfq1Gibb2$catch), calc_ogive = TRUE, plot = TRUE)
```

```
# 3.3 assign estimates to the data list
```

```
lfq1Pag2$Z <- CC_PagGA$Z
```

```
lfq1Pag2$FM <- as.numeric(lfq1Pag2$Z - lfq1Pag2$M)
```

```
lfq1Pag2$E <- lfq1Pag2$FM/lfq1Pag2$Z
```

```
lfq1Cana2$Z <- CC_CanaGA$Z
```

```
lfq1Cana2$FM <- as.numeric(lfq1Cana2$Z - lfq1Cana2$M)
```

```
lfq1Cana2$E <- lfq1Cana2$FM/lfq1Cana2$Z
```

```
lfq1Gibb2$Z <- CC_GibbGA$Z
```

```
lfq1Gibb2$FM <- as.numeric(lfq1Gibb2$Z - lfq1Gibb2$M)
```

```
lfq1Gibb2$E <- lfq1Gibb2$FM/lfq1Gibb2$Z
```

```
# Show results
```

```
paste("Z =", as.numeric(lfq1Pag2$Z))
```

```
paste("F =", as.numeric(lfq1Pag2$FM))
```

```
paste("E =", as.numeric(lfq1Pag2$E))
```

```
paste("Lc =", as.numeric(CC_PagGA$L50))
```

```
paste("tc =", as.numeric(CC_PagGA$t50))
```

```
paste("Z =", as.numeric(lfq1Cana2$Z))
```

```
paste("F =", as.numeric(lfq1Cana2$FM))
```

```
paste("E =", as.numeric(lfq1Cana2$E))
```

```
paste("Lc =", as.numeric(CC_CanaGA$L50))
```

```
paste("tc =", as.numeric(CC_CanaGA$t50))
```

```
paste("Z =", as.numeric(lfq1Gibb2$Z))
```

```
paste("F =", as.numeric(lfq1Gibb2$FM))
```

```
paste("E =", as.numeric(lfq1Gibb2$E))
```

```
paste("Lc =", as.numeric(CC_GibbGA$L50))
```

```
paste("tc =", as.numeric(CC_GibbGA$t50))
```

```
# 3.4 estimation of M/K ratio
```

```
Mort_PagGA/CIinfo_PagGAboot$max_dens$K
```

```
Mort_CanaGA/CIinfo_CanaGAboot$max_dens$K
```

```
Mort_GibbGA/CIinfo_GibbGAboot$max_dens$K
```

```
##### 4.0 STOCK SIZE AND STATUS
```

```
# 4.1 Assign LWR parameters
```

```
lfq1Pag3 <- lfq1Pag2
```

```
lfq1Pag3$b <- 2.9134
```

```
lfq1Pag3$a <- 0.0203
```

```
lfq1Cana3 <- lfq1Cana2
```

```
lfq1Cana3$b <- 2.9087
```

```
lfq1Cana3$a <- 0.0183
```

```
lfq1Gibb3 <- lfq1Gibb2
```

```
lfq1Gibb3$b <- 2.7475
```

```
lfq1Gibb3$a <- 0.0308
```

```
# 4.2 run CA
```

```
vpa_PagGA <- VPA(param=lfq1Pag3,terminalF = lfq1Pag3$FM,
  catch_columns = 1:ncol(lfq1Pag3$catch),
  analysis_type = "CA",plot=TRUE,
  catch_corFac = (NA))

vpa_CanaGA <- VPA(param=lfq1Cana3,terminalF = lfq1Cana3$FM,
  catch_columns = 1:ncol(lfq1Cana3$catch),
  analysis_type = "CA",plot=TRUE,
  catch_corFac = (NA))

vpa_GibbGA <- VPA(param=lfq1Gibb3,terminalF = lfq1Gibb3$FM,
  catch_columns = 1:ncol(lfq1Gibb3$catch),
  analysis_type = "CA",plot=TRUE,
  catch_corFac = (NA))

#Stock size
sum(vpa_PagGA$annualMeanNr, na.rm = TRUE)/1e3
sum(vpa_CanaGA$annualMeanNr, na.rm = TRUE)/1e3
sum(vpa_GibbGA$annualMeanNr, na.rm = TRUE)/1e3

#sStock biomass
sum(vpa_PagGA$meanBiomassTon, na.rm = TRUE)
sum(vpa_CanaGA$meanBiomassTon, na.rm = TRUE)
sum(vpa_GibbGA$meanBiomassTon, na.rm = TRUE)

#Assigning F per length class
lfq1Pag3$FM <- vpa_PagGA$FM_calc
lfq1Cana3$FM <- vpa_CanaGA$FM_calc
lfq1Gibb3$FM <- vpa_GibbGA$FM_calc

##### 5.0 YIELD PER RECRUIT
```

```
# 5.1 Thompson and Bell model with changes in F
```

```
TB1_PagGA <- predict_mod(lfq1Pag3,type = "ThompBell", FM_change =  
seq(0,3,0.05), stock_size_1 = 1, curr.E = lfq1Pag3$E, plot = TRUE)
```

```
TB1_CanaGA <- predict_mod(lfq1Cana3,type = "ThompBell", FM_change =  
seq(0,3,0.05), stock_size_1 = 1, curr.E = lfq1Cana3$E, plot = TRUE)
```

```
TB1_GibbGA <- predict_mod(lfq1Gibb3,type = "ThompBell", FM_change =  
seq(0,2,0.05), stock_size_1 = 1, curr.E = lfq1Gibb3$E, plot = TRUE)
```

```
# 5.2 Thompson and Bell model with changes in F and Lc
```

```
TB2_PagGA <- predict_mod(lfq1Pag3,type = "ThompBell", Lc_change =  
seq(20,50,0.1), FM_change = seq(0,3,0.1), stock_size_1 = 1, curr.E =  
lfq1Pag3$E, curr.Lc = CC_PagGA$L50,s_list = list(selectType = "trawl_ogive",  
L50 = CC_PagGA$L50, L75 = CC_PagGA$L75), plot = TRUE,  
hide.progressbar = TRUE)
```

```
TB2_CanaGA <- predict_mod(lfq1Cana3,type = "ThompBell", Lc_change =  
seq(20,50,0.1), FM_change = seq(0,3,0.1), stock_size_1 = 1, curr.E =  
lfq1Cana3$E, curr.Lc = CC_CanaGA$L50,s_list = list(selectType =  
"trawl_ogive",L50 = CC_CanaGA$L50, L75 = CC_CanaGA$L75), plot =  
TRUE, hide.progressbar = TRUE)
```

```
TB2_GibbGA <- predict_mod(lfq1Gibb3,type = "ThompBell", Lc_change =  
seq(20,50,0.1), FM_change = seq(0,2,0.1), stock_size_1 = 1, curr.E =  
lfq1Gibb3$E, curr.Lc = CC_GibbGA$L50,s_list = list(selectType =  
"trawl_ogive", L50 = CC_GibbGA$L50, L75 = CC_GibbGA$L75), plot =  
TRUE, hide.progressbar = TRUE)
```

```
# plot results
```

```
par<- par(mfrow = c(2,1), mar = c(4,5,2,4.5), oma = c(1,0,0,0))
```

```
plot(TB1_PagGA, mark = TRUE)
```

```
mtext("(a)", side = 3, at = -0.1, line = 0.6)
```

```
plot(TB2_PagGA, type = "Isopleth", xaxis1 = "FM", mark = TRUE, contour =  
6)
```

```
mtext("(b)", side = 3, at = -0.1, line = 0.6)
```

```
plot(TB1_CanaGA, mark = TRUE)
```

```
mtext("(a)", side = 3, at = -0.1, line = 0.6)
plot(TB2_CanaGA, type = "Isopleth", xaxis1 = "FM", mark = TRUE, contour
= 6)
mtext("(b)", side = 3, at = -0.1, line = 0.6)

plot(TB1_GibbGA, mark = TRUE)
mtext("(a)", side = 3, at = -0.1, line = 0.6)
plot(TB2_GibbGA, type = "Isopleth", xaxis1 = "FM", mark = TRUE, contour
= 6)
mtext("(b)", side = 3, at = -0.1, line = 0.6)
par(par)

# Biological reference levels
TB1_PagGA$df_Es
TB1_CanaGA$df_Es
TB1_GibbGA$df_Es

# Current yield and biomass levels
TB1_PagGA$currents
TB1_CanaGA$currents
TB1_GibbGA$currents
```

Appendix B: The R codes used for analyses performed on the size at first sexual maturity

```
----- 1.0 INITIAL SETTINGS -----  
  
# Loading data and specifying species =====  
setwd("C:/Users/MICHY/Dropbox(Personal)/PhD/Data/Ranalysis/Reproducti  
on")  
  
Mat_Sparids = read.csv("Mat_Sparids.csv")  
  
Mat_Sparids$date = as.Date(Mat_Sparids$Month, format = "%d.%m.%Y")  
  
species = levels(Mat_Sparids$Species)  
  
Cana = Mat_Sparids[Mat_Sparids$Species== species[1],]  
Gibb = Mat_Sparids[Mat_Sparids$Species== species[2],]  
Pag = Mat_Sparids[Mat_Sparids$Species== species[3],]  
  
# Changing the date format to that of R =====  
  
Pag$date = as.Date(Pag$Month, format = "%d.%m.%Y")  
Cana$date = as.Date(Cana$Month, format = "%d.%m.%Y")  
Gibb$date = as.Date(Gibb$Month, format = "%d.%m.%Y")  
  
# specifying sex  
  
sex = levels(Pag$Sex)  
  
PagM = Pag[Pag$Sex== sex[5],]  
PagF = Pag[Pag$Sex== sex[2],]  
  
sex = levels(Cana$Sex)  
  
CanaM = Cana[Cana$Sex== sex[5],]  
CanaF = Cana[Cana$Sex== sex[2],]  
  
sex = levels(Gibb$Sex)  
  
GibbM = Gibb[Gibb$Sex== sex[5],]  
GibbF = Gibb[Gibb$Sex== sex[2],]  
  
library(sizeMat)  
  
library(FSA)
```



```
##### sizeMat - SIZE AT GONAD MATURITY #####  
  
# Bayesian regression  
  
PagM_ogive_bayes = gonad_mature(PagM, varNames = c("TL.cm.",  
"Ripeness"), inmName = "Immature", matName = "Mature", method = "bayes",  
niter = 999)  
  
print(PagM_ogive_bayes)  
  
plot(PagM_ogive_bayes, xlab = "Total length (cm)", ylab = "Proportion  
mature", col = c("blue", "red"), xlim=c(15,50),onlyOgive = TRUE)  
  
legend("bottomright",c("L50","CI = 95%"), lwd=3, col=c("red","blue"), lty=3,  
bty="n")  
  
mtext("Males", side = 3, at = 20, line = 0.6)  
  
PagF_ogive_bayes = gonad_mature(PagF, varNames = c("TL.cm.",  
"Ripeness"), inmName = "Immature", matName = "Mature", method = "bayes",  
niter = 999)  
  
print(PagF_ogive_bayes)  
  
plot(PagF_ogive_bayes, xlab = "Total length (cm)", ylab = "Proportion  
mature", col = c("blue", "red"), xlim=c(15,50),onlyOgive = TRUE)  
  
legend("bottomright",c("L50","CI = 95%"), lwd=3, col=c("red","blue"), lty=3,  
bty="n")  
  
mtext("Females", side = 3, at = 20, line = 0.6)  
  
  
CanaM_ogive_bayes = gonad_mature(CanaM, varNames = c("TL.cm.",  
"Ripeness"), inmName = "Immature", matName = "Mature", method = "bayes",  
niter = 999)  
  
print(CanaM_ogive_bayes)  
  
plot(CanaM_ogive_bayes, xlab = "Total length (cm)", ylab = "Proportion  
mature", col = c("blue", "red"), xlim=c(20,60),ylim=c(0.0,1.0),onlyOgive =  
TRUE)  
  
legend("bottomright",c("L50","CI = 95%"), lwd=3, col=c("red","blue"), lty=3,  
bty="n")  
  
mtext("Males", side = 3, at = 20, line = 0.6)  
  
CanaF_ogive_bayes = gonad_mature(CanaF, varNames = c("TL.cm.",  
"Ripeness"), inmName = "Immature", matName = "Mature", method = "bayes",  
niter = 999)  
  
print(CanaF_ogive_bayes)
```

```
plot(CanaF_ogive_bayes, xlab = "Total length (cm)", ylab = "Proportion  
mature", col = c("blue", "red"), xlim=c(20,60),onlyOgive = TRUE)
```

```
legend("bottomright",c("L50","CI = 95%"), lwd=3, col=c("red","blue"), lty=3,  
bty="n")
```

```
mtext("Females", side = 3, at = 20, line = 0.6)
```

```
GibbM_ogive_bayes = gonad_mature(GibbM, varNames = c("TL.cm",  
"Ripeness"), inmName = "Immature", matName = "Mature", method = "bayes",  
niter = 999)
```

```
print(GibbM_ogive_bayes)
```

```
plot(GibbM_ogive_bayes, xlab = "Total length (cm)", ylab = "Proportion  
mature", col = c("blue", "red"), xlim=c(20,70),onlyOgive = TRUE)
```

```
legend("bottomright",c("L50","CI = 95%"), lwd=3, col=c("red","blue"), lty=3,  
bty="n")
```

```
mtext("Males", side = 3, at = 20, line = 0.6)
```

```
GibbF_ogive_bayes = gonad_mature(GibbF, varNames = c("TL.cm",  
"Ripeness"), inmName = "Immature", matName = "Mature", method = "bayes",  
niter = 999)
```

```
print(GibbF_ogive_bayes)
```

```
plot(GibbF_ogive_bayes, xlab = "Total length (cm)", ylab = "Proportion  
mature", col = c("blue", "red"),xlim=c(20,70), onlyOgive = TRUE)
```

```
legend("bottomright",c("L50","CI = 95%"), lwd=3, col=c("red","blue"), lty=3,  
bty="n")
```

```
mtext("Females", side = 3, at = 20, line = 0.6)
```

```
par()
```

Appendix C: The test settings for the optimisation of the fit algorithm

Table 7 – *Settings for the Fit Algorithm on a Server with an Intel CORE I5 Processor*

Search settings for the fit algorithm	
Fit algorithm	(<i>P. caeruleostictus</i> / <i>D. canariensis</i> / <i>D. gibbosus</i>)
ELEFAN_GA_boot	
popSize	100
maxiter	50
run	30
pmutation	0.2
Bootstrap runs/ nresamp	1000
Bootstrap.time (min.)	163 / 211 / 259

Appendix D: Results of the Jones' Cohort Analysis (CA) for the three seabreams

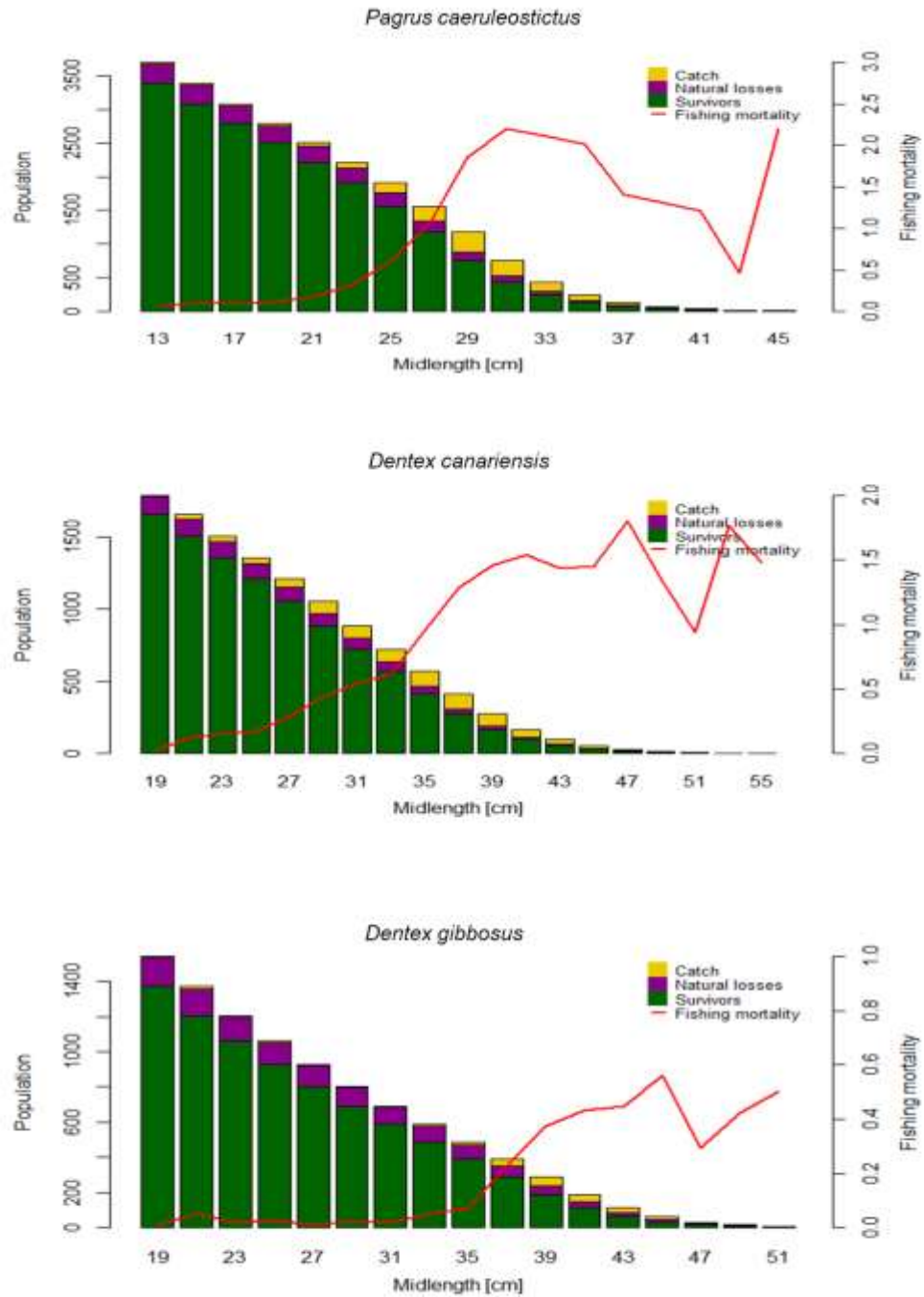


Figure 46: Cohort Analysis (CA) plots for the three species showing the logistic shaped fishing pattern across the length classes.

Appendix E: Regression parameters of the length-weight relationships

Table 8 – *Linear Regression Parameters of the Relationship between Log-Transformed Total Length and Body Weight Measurements for P. caeruleostictus, D. canariensis and D. gibbosus, respectively, with their Corresponding Standard Errors and P-Values*

Species	Parameter	Value	Standard Error	test Statistic	$P_{0.05}$
<i>P. caeruleostictus</i>	<i>a</i>	0.0203	0.0272		
	<i>b</i>	2.9134	0.0082	-10.561	0.00363
<i>D. canariensis</i>	<i>a</i>	0.0183	0.0341		
	<i>b</i>	2.9087	0.0098	-9.316	0.00373
<i>D. gibbosus</i>	<i>a</i>	0.0308	0.0443		
	<i>b</i>	2.7475	0.0123	-20.529	0.00641

Appendix F: Growth parameter estimates of the species indicating the 95 % confidence intervals

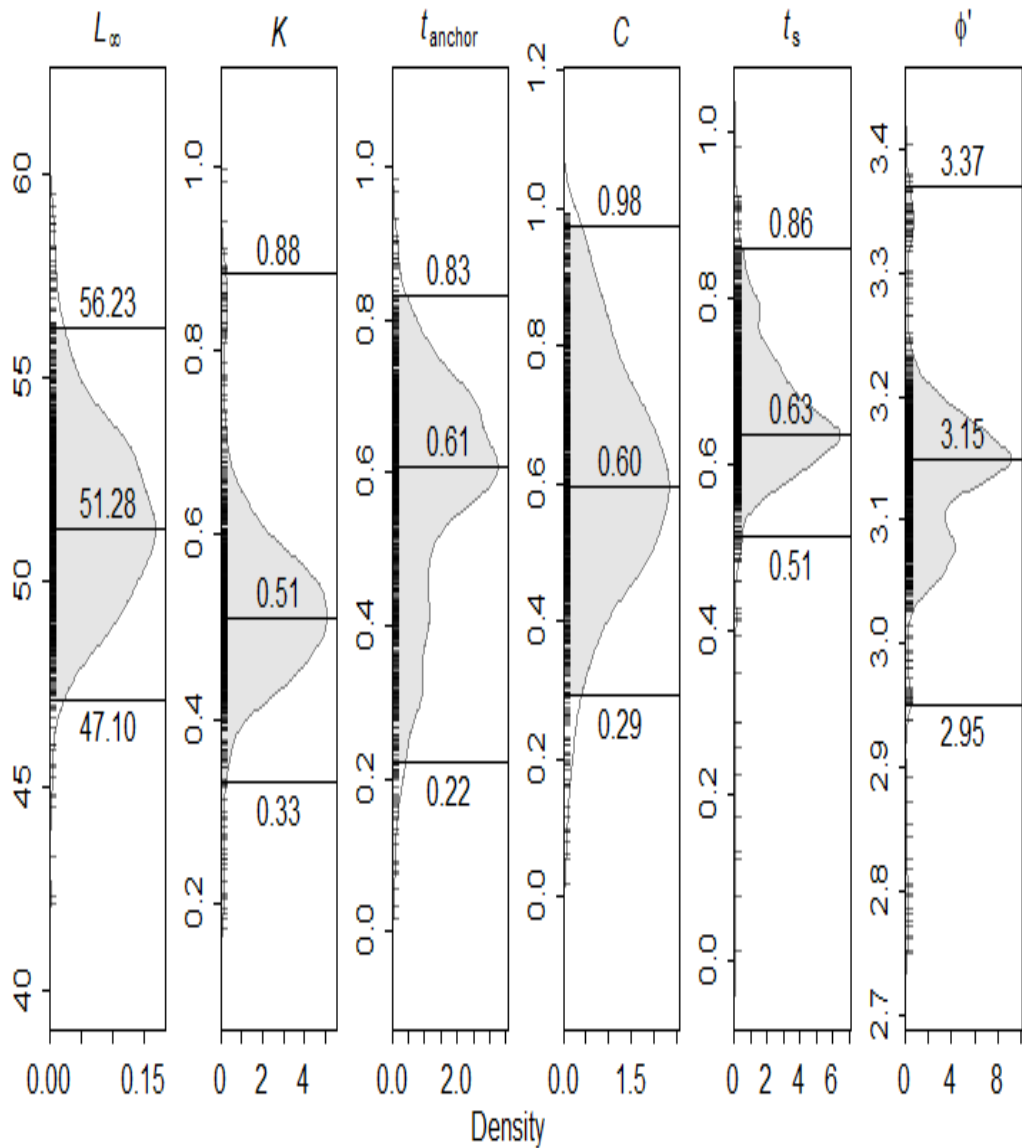


Figure 47: Growth parameter estimates for *P. caeruleostictus* showing the upper and lower 95% quantiles.

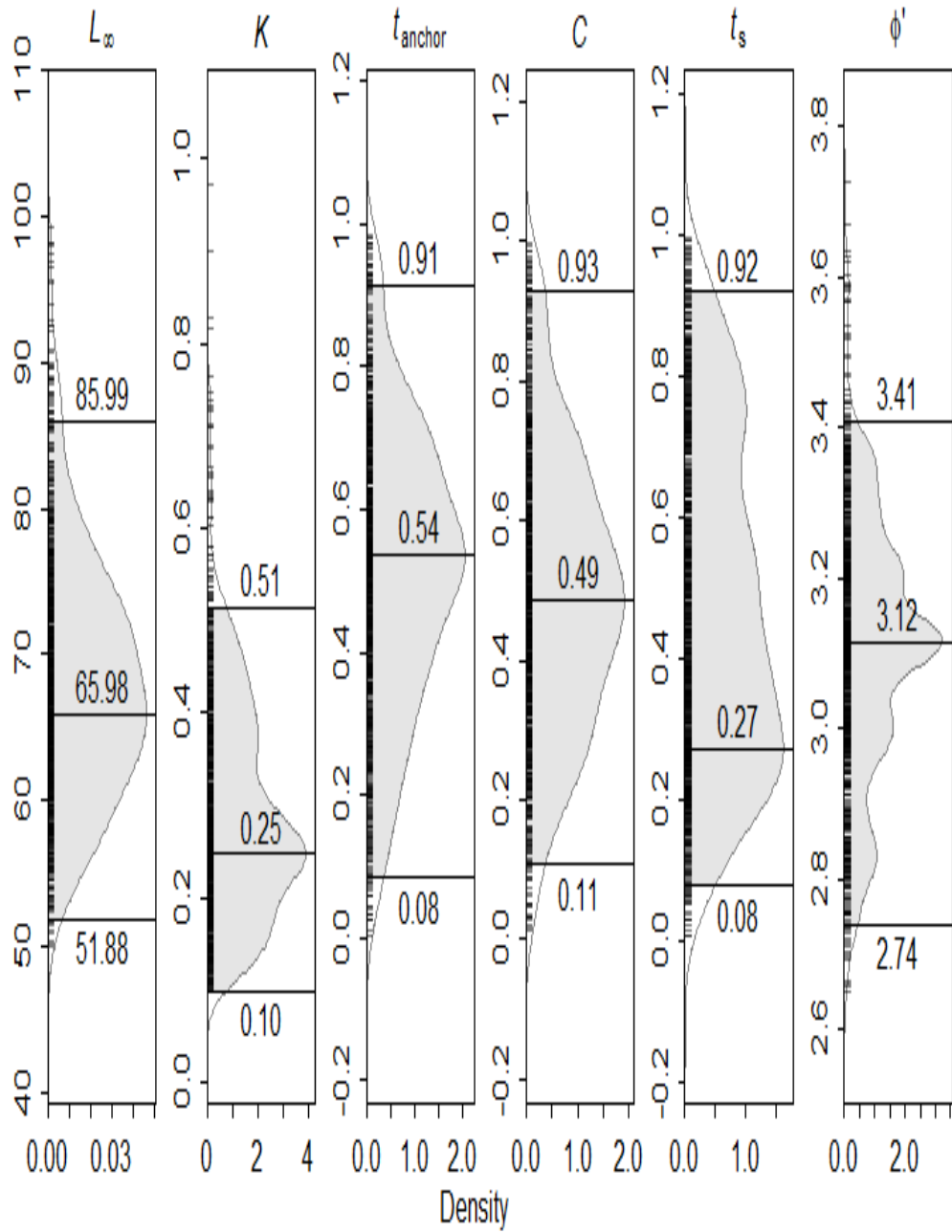


Figure 48: Growth parameter estimates for *D. canariensis* showing the upper and lower 95% quantiles.

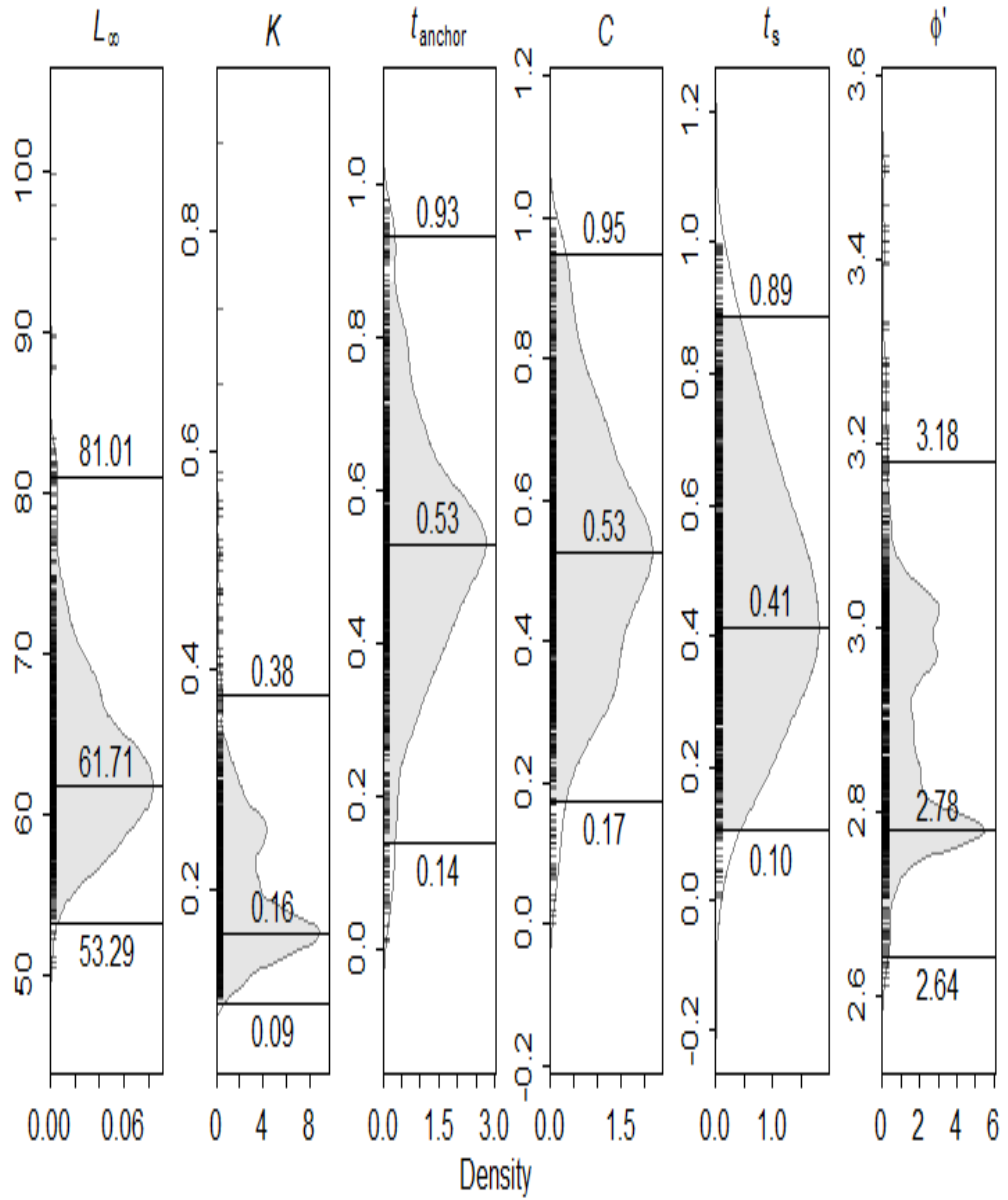


Figure 49: Growth parameter estimates for *D. gibbosus* showing the upper and lower 95% quantiles.

VITA

Michelle Naa Kordei Clottey

EDUCATION

- University of Cape Coast** Doctor of Philosophy in Fisheries Science
2015 – 2019. Thesis title: *“Population dynamics and reproductive studies of three commercially important Sparid species from Ghanaian waters.”*
- University of Ghana** Master of Philosophy in Fisheries Science
2012 – 2014. Thesis title: *“Effects of Microbial Loads on the Physiological Condition and Fecundity of Some Selected Fishes in the Volta Lake (Stratum II).”*
- University of Ghana** Bachelor of Science in Oceanography and Fisheries. **2007 – 2011**. Dissertation title: *“Studies on the Use of Aloe vera (L.) As A Food Additive in the Formulated Feed for Farmed Nile Tilapia (Oreochromis niloticus, Linnaeus, 1758).”*
- Accra Girls’ Sec. Sch.** West Africa Senior Secondary Certificate Examination (WASSCE) in General Science
2003 – 2006
- Prince of Peace of Int. Sch.** Basic Education Certificate Examination (B.E.C.E)
1993 – 2003

WORK EXPERIENCE

August 2014 – September 2015: Teaching Assistant, Department of Marine and Fisheries Sciences, University of Ghana, Legon. Duties included:

- Conducting practical sessions for levels 200, 300 and 400
- Assisting lecturers with their teaching
- Helping supervise the project work of undergraduate students
- Conducting Interim Assessments (I.A) for the students
- Report writing

August 2011 - July 2012: National Service Personnel, Institute of Environment and Sanitation Studies (IESS), University of Ghana, Legon. Duties included:

- Helping with laboratory analyses
- Preparation of Environmental posters
- Assisting with Administrative work
- Assisting M.Phil. and PhD students with their laboratory works
- Assisting with field/research work of the Research Fellows of the Institute
- Taking of minutes at meetings of the Fellows
- Report writing

June 2010-July 2010: Internship Programme, Aquaculture Research and Development Centre (ARDEC), Council for Scientific and Industrial Research-Water Research Institute (CSIR-WRI), Akosombo. Duties included:

- Helping with general farm work
- Harvesting of *Oreochromis niloticus* eggs and fry
- Investigating the effect of feed variations on fry production in *O. niloticus*
- Tagging of fish for easy identification in cross breeding of *O. niloticus*
- Preparation of formulated fish feed for *O. niloticus*

VOLUNTEER EXPERIENCE

June 2017: Participant- World Ocean Acidification Day celebration at the University of Cape Coast

July - December 2006: Voluntary counsellor- Provision of pre- and post-counselling for HIV patients at the Fevers Unit of the Korle-Bu Teaching Hospital, Accra

SEMINAR / WORKSHOP / TRAINING

- August 2019 - The Conference on Fisheries and Coastal Environment, organised by USAID/SFMP (Sustainable Fisheries Management Project), Centre for Coastal Management (CCM) and Ministry of Fisheries and Aquaculture Development (MoFAD)
- July 2019 – 31st Biennial Conference: Promoting Science, Technology and Innovation for Sustainable Growth and Development, organised by the Ghana Science Association (GSA)

- September 2017 - December 2017 – Exchange student at the University of Rhode Island (URI) with training in Fisheries Stock Assessment and the use of R for Ecological Statistics
- November 2017 – 24th Biennial Conference: Coastal Science Inflection Point: Celebrating Successes, Learning From Challenges, organised by the Coastal Estuarine Research Federation
- March 2017 – Project Development and Implementation: Intra-Africa Academic Mobility Scheme Call 2017, organised by the Department of Fisheries and Aquatic Sciences
- August 2016 – Ghana Summer School on the Coastal Ocean Environment, organised by University of Ghana in collaboration with University of Michigan.
- June 2016 – Workshop on Coastal Community Vulnerabilities, Hazards and the need for Coastal Resilience, Hazard and Spatial Planning, organised by Hen Mpoano in collaboration with Centre for Coastal Management (CCM).
- June 2015 – Training Workshop on Hydrodynamic and Ecological Modelling of large Lakes, organised by CSIR Water Research Institute (Ghana) and Institute of Bioscience, Aarhus University (Denmark).
- March 2014 – Sustainable Cage Aquaculture in Lake Volta, Ghana, organised by Royal Society/ Leverhulme Africa Project.
- August 2013 – Knowledge and Skill Enhancement Workshop on Thesis Writing organized by School of Graduate Studies, University of Ghana, in collaboration with UG-Carnegie Next Generation of Academics in Africa Project.

PUBLICATION

- MNK Clotley, R Asmah, PK Ofori-Danson, MY Ameworwor & AY Karikari (2016) Impacts Of Cage Culture on Physico-Chemical and Bacteriological Water Quality in Lake Volta, Ghana, African Journal of Aquatic Science, 41:4, 473-480, DOI:10.2989/16085914.2016.1255587
- M.Y. Ameworwor, R. Asmah, P.K. Ofori-Danson, & M.N.K. Clotley (2019) Enhancing local fish production through cage aquaculture on the Volta Lake: Impacts on capture fisheries, Journal of Fisheries and Coastal Management 1, 1–6, DOI: 10.5455/jfcom.20190313031430

WORKS IN PROGRESS

- “Stock assessment and aspects of the reproductive biology of *Pagrus caeruleostictus* in Ghanaian waters” with J. Aggrey-Fynn. Article manuscript under review
- “Aspects of the reproductive biology and population dynamics of *Dentex canariensis* from the coastal waters of Ghana” with J. Aggrey-Fynn and J. Blay. Article manuscript in progress, to be submitted for publication in Jul 2020
- “Distribution, relative abundance and CPUE of three seabreams from Ghanaian waters”. Article manuscript in progress, to be submitted for publication in April 2020