UNIVERSITY OF CAPE COAST

OBSERVATIONS ON THE BOTTOM-SET GILLNET FISHERY AND FISHERY BIOLOGY OF SELECTED SPECIES AT THREE LOCATIONS OFF THE CENTRAL REGION COAST OF GHANA

MIRIAM YAYRA AMEWORWOR

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BY

MIRIAM YAYRA AMEWORWOR

Thesis submitted to the Department of Fisheries and Aquatic Sciences of the School of Biological Sciences of the College of Agricultural and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Doctor of Philosophy degree in Fisheries Sciences

AUGUST 2020

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: MIRIAM YAYRA AMEWORWOR

Supervisors' 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: PROFESSOR JOHN BLAY

Co-Supervisor's Signature ……………………...….. Date...…………………....

Name: PROFESSOR JOSEPH AGGREY-FYNN

ABSTRACT

Studies were conducted at three coastal stations in the Central Region of Ghana, namely Apam, Egyaa and Cape Coast from February 2017 to July 2018 to assess the characteristics of the bottom-set gillnet fishery, the biology and exploitation of some species of economic importance. Canoe sizes were mainly 7 to 10 m long and mesh sizes were dominated by 7.9 and 8.9 cm. Mean catch per unit effort was 44.59±23.40 kg/day at Apam, 57.97±46.69 kg/day at Egyaa and 36.93±24.55 kg/day at Cape Coast. Landings were dominated by the spotted box crab *Calappa rubroguttata* (Calappidae) at Apam and Egyaa, and by the cassava croaker *Pseudotolithus senegalensis* (Sciaenidae) at Cape Coast. By-catches were mostly corals and crustaceans at Apam and Egyaa and crustaceans at Cape Coast. The asymptotic lengths of *C. rubroguttata*, *P. senegalensis* and *Cynoglossus senegalensis* (Senegalese tonguesole) were 13.13 cm carapace width, 48.83 cm and 60.38 cm total length respectively but were being landed at 7.4 cm carapace width, 27.8 cm and 39.4 cm total length respectively. Mortality in *C. rubroguttata* was largely due to fishing activities and the stock was being exploited above the optimum level. With stocks being exploited below optimal levels, mortality in *P. senegalensis* and *C. senegalensis* was mainly due to natural causes. The operations of the fishery negatively impacted on the marine ecosystem and artisanal fisheries in Ghana. Enforcement of the regulation on the use of monofilament gillnet in the marine waters of Ghana was recommended to minimize its negative ecological impacts. Recommendation was as well made for regular studies on gear specific fisheries to provide and update information critical for their management.

KEY WORDS

Monofilament

Landings

By-catch

Corals

Crustaceans

Mortality

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DEDICATION

To the memory of my dad, the late Mr. Richard Cosmos Atta Ameworwor.

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LIST OF ACRONYMS AND ABBREVIATIONS

CPUE	---	Catch per unit effort
LOA	---	Length overall
CW	---	Carapace width
TL	---	Total length
BW	---	Body weight
CF	---	Condition factor
L_∞	---	Asymptotic length
K	---	Growth coefficient
t_o	---	Age at length zero
ϕ'	---	Growth performance index
Z	---	Total mortality coefficient
M	---	Natural mortality coefficient
F	---	Fishing mortality coefficient
E	---	Exploitation ratio
L_c	----	Length at first capture
L_{m50}	---	Length at maturity
GSI	---	Gonadosomatic index

CHAPTER ONE

INTRODUCTION

Background

Humans have harvested the waters for centuries and the art of fishing continues to change with the motivation for fishing. The art of fishing changed from subsistence fishing, where the fisher only catches fish to meet the daily need, to artisanal fisheries where the motivation goes beyond daily need to targeting special markets. The motivation to expand fish trade by increasing fish supply gave birth to large-scale industrial fisheries (Gabriel, Lange, Dahm, & Wendt, 2005) and all these fisheries are defined by unique characteristics. Even with the introduction of large-scale industrial fishing, artisanal fisheries still play a major role in global fish production employing more than 99% of the world's fishers according to Basurto, Franz, Mills, Virdin, & Westlund, (2017) and contributing to economies.

In Ghana, fish production from aquaculture, inland and marine sectors all together contribute about 1.0% of gross domestic product (GDP) to the economy as at 2018 (Ghana Statistical Service, 2019) and employing about 2.5 million people or 10% of Ghana's population (Ministry of Fisheries and Aquaculture Development, 2015). The marine fisheries sector of Ghana consists of three sub-sectors namely the small-scale or artisanal sector, the semi-industrial and the industrial sector, with the artisanal sector contributing more than 80% of the total annual marine fish catch (Ministry of Fisheries and Aquaculture Development).

The industrial sector involves the use of steel vessels of about 30 m length and targets large pelagics, semi-pelagics and demersal species. The semi-industrial sector makes use of locally constructed wooden vessels ranging in size between 8 m and 30 m and they target both pelagic and demersal species. The artisanal sector is characterized by the use of several gears operated from dugout canoes between 3 m to about 20 m in size which may be motorized or non-motorized (Ministry of Fisheries and Aquaculture Development, 2015; Nunoo et al., 2015; Yamoah, 2012).

According to Aho (2013), the artisanal sector consists of six sub-sectors in terms of gears operated, and they include Ali fishery (gillnet fishery), poli/watsa fishery (purse seine), drift gillnet fishery, set net fishery, hook-and-line fishery and the beach seine fishery. Beach seines are operated on gently-slopping sandy shores and exploit pelagic and demersal fish resources. The hook-and-line gear comprises a long rope with several hooks baited with small low priced fish and the fishery exploits mostly demersal fishes (Akpalu, 2002). Poli/Watsa nets have small mesh sizes of minimum of 1 cm (minimum legal mesh size for the net is however 2.5 cm) which are used to encircle schools of fish in mid-water. Set gillnets are deployed either in mid water, near or at the bottom (Akyeampong, Amador, & Nkrumah, 2013). The "ali net", drift gillnet and the set net all have a component of gillnet, giving gillnet some importance in the gear designs used in the artisanal fisheries sector of Ghana.

Gillnets are rectangular piece of netting fitted to a head line with floats and a foot-rope with weights. The nets are set across the path of the migrating fish with the floats and weights keeping it in a more or less vertical position. By the way in which gillnets are operated, there are free drifting gillnets for surface fish; anchored floating gillnets for mid-water fish; and bottom-set gillnets set on or near the bottom for demersal fish (Gabriel et al., 2005). They may be made from cotton or polyamide (commonly known as nylon) yarns. The synthetic yarns may either be multifilament or monofilament (Appendix A). Multifilament yarns are made from large numbers of very fine fiber of less than 0.07 mm diameter twisted together to form a single yarn. A large number of those are in turn twisted together into the netting yarn. Monofilament nets are made from single filaments with diameter ranging from more than 0.1 mm to more than 0.4 mm. (Potter & Pawson, 1991; Oxvig & Hansen, 2007). The yarn type used for a netting together with its colour has an effect on the efficiency of the netting.

Gillnets are highly selective in terms of species and sizes of fish they catch (Jennings et al., 2001; Faife, 2003). Other researchers have different views on the use of gillnets. According to Hickford, Schiel and Jones (1997), a wide range of species and sizes are caught in a gillnet, and targeting of specific species may be difficult without significant and unpredicted by-catch. Interspecies differences in behavior, morphological characteristics of the species, and even the habitat of a species have been reported (Broadhurst, Gray, Young, & Johnson, 2003) as factors that can override the selectivity of gillnets. By-catch from gillnets has been a subject of growing concern to marine scientists as it often includes endangered species (Faife, 2003). It also impacts the community structure of marine ecosystems (Matsuoka, 2008).

Ghost fishing, which refers to continued fishing of a gear after its control has been lost, is yet another problem associated with gillnets (Ayaz et al., 2006). Active gears only fish when intentionally controlled, however, passive gears not under any intentional control, may continue to fish for several years through a continuous cycle of capture, decay, and attraction. A lost or an abandoned gear may continue to fish as long as the fishing gear stays intact. Lost gillnets cause high fishing mortality compared to other passive gears, with monofilament nets having a higher catch rate than multifilament nets (Pawson, 2003; Ayaz et al., 2006; Akiyama, Saito, & Watanabe, 2007).

The issues of by-catch and ghost fishing associated with the use of gillnets can be greatly reduced through effective management measures. Information on gear design and operation, biology of species caught and fishing area are necessary to making informed management decisions concerning any gillnet fishery.

Statement of the Problem

Gillnets are used extensively in Ghana, and over the years have progressed from cotton nets to multifilament polyamide nets, and currently monofilament polyamide nets (Coastal Resources Center, 2013). The monofilament nets are commonly used in the set gillnet fishery. According to the 2013 Ghana marine canoe frame survey, a total of 4,017 canoes operate set nets but it was not clear how many of these were monofilament nets (Akyeampong, Amador, & Nkrumah, 2013). Its common use could possibly be due to some associated benefits such as comparatively low cost, and high catch efficiency (Coastal Resources Center, 2013). However, the use of monofilament net is prohibited in the marine waters of Ghana, according to Ghana Fisheries Regulation (L.I. 1968, Regulation 8), with culprits facing a fine or imprisonment. A worrying trend is rather observed in the bottom-set gillnet fishery, a vibrant fishery in the Central Region, where the monofilament net is predominantly used.

With the exception of the beach seine fishery (Aggrey-Fynn & Sackey-Mensah, 2012; Kraan, 2006), much have not been reported on the various gear specific fisheries in Ghana, by way of characterizing them. Furthermore, notwithstanding the use of an illegal gear, there have not been much documentation on the bottom-set gillnet fishery. A brief description of set nets used in exploiting demersals by Doyi (1984) stated some characteristics of the gear used in the bottom-set gillnet fishery, and few of the species landed. Marquette *et al. (*2002) also reported on crew in the fishery. There has been no report however on the socio-cultural characteristics of the fishery, the diversity of species exploited, and the impact of their operation on the marine ecosystem and artisanal fisheries in Ghana. An in-depth investigation of the characteristics of the bottom-set gillnet fishery is thus necessary to provide information critical to the sustainable management of the fishery.

Purpose of the study

The purpose of the study was to investigate the characteristics of the bottom-set gillnet fishery, and possible ecological impacts of the fisheries, on the marine ecosystem, at selected fishing communities in the Central Region of Ghana, as well as, examine aspects of the biology of some economic fish species, in the operational area of the fishery.

Research objectives

Specifically, the study sought to:

1. describe the socio-cultural characteristics of the fishery in the study areas.
2. describe the fishing effort employed in the fishery.
3. determine the catch per unit effort (CPUE) and catch composition in the study areas.
4. assess the by-catch obtained in the bottom-set gillnet fishery.
5. examine the growth, mortality and exploitation of some selected economic species in the landings.
6. investigate the reproductive biology of the selected economic species.

Significance of the Study

The findings of the study would provide information critical for management of the bottom-set gillnet fishery in Ghana. The results of the present study would also contribute to scientific knowledge on some commercial species landed in the bottom-set gillnet fishery which will inform management decisions on the fishery of these species. No biological study has been reported on the spotted box crab, *Calappa rubroguttata* (Family Calappidae), which is one of the commercial species. The findings of the study would therefore provide some biological information on the species which will help inform the management of its fishery.

Delimitations

The study focused on Egyaa, Cape Coast and Apam all in the Central Region, noted among the coastal regions of Ghana for set gillnet fisheries. The study covered the following areas of the fishery: socio-cultural characteristics, gears, species exploited, catch trend, by-catch and biology of some commercial species exploited.

Limitations

Two main limitations were encountered in the study. Firstly, access to all the catch from fishermen was not possible at the beginning of the study, specifically in the first two months of the study. This was because "fish mammies" (major female fish buyers) were reluctant to resell fish at the beach. Reaching a favourable agreement therefore took some time resulting in delays in catch and species composition data collection. Data for research objective three and four were therefore collected over a period of 16 months instead of 18 months. However, 16 months data collection was still adequate to produce reliable results. The results of the study were therefore not affected by the delay in commencement of data collection for objectives three and four. Secondly, some fishermen discarded some of the by-catch at sea and were not able to give detailed information on the species and quantities discarded. Though this occurred on few occasions, it could have a possible effect on data collected on the abundance and occurrence of the by-catch species in the landings. To account for this possible error in the data, information given by the fishermen though not detailed, was used to infer what was discarded at sea.

Organization of Study

The thesis is organized into six chapters. The first chapter introduces the study by giving a background, the objectives and the issues that necessitated the study. The significance, delimitations and limitations of the study are also stated in this chapter. Chapter two reviews the literature relevant to the study. Chapter three describes the study area and methods employed to investigate the various objectives. Results of the study are presented in the fourth chapter in tables and figures with descriptions. Chapter five discusses the findings of the study, giving possible interpretations and explanations. The sixth chapter summarizes and concludes the study. Recommendations based on the findings of the study and suggestion for further research are also stated in this chapter. There is also a references section at the end, followed by the appendices and vita.

CHAPTER TWO

LITERATURE REVIEW

Fishing Gears and Techniques in Small-scale Fisheries

Small-scale or artisanal fisheries provides more than half of global fish production, and employs more than 99% of the world's fishers (Basurto et al., 2017). Small-scale fisheries is characterized by vessels less than 15 m long, mechanized or manual fishing gears, low relative catch per vessel, relatively low technology, and limited extent of fishing area (Shester & Micheli, 2011). The fisheries is also characterized by the use of numerous fishing techniques and gear designs (Misund, Kolding, & Fréon, 2002).

In Ghana, artisanal fisheries accounts for about 80% of the total domestic fish production, and carried out within the Inshore Exclusive Zone (IEZ), up to the 30 m depth contour (Ministry of Fisheries and Aquaculture Development, 2015). The most common fishing techniques and gear designs employed include hook and lines, purse seines locally known as poli/watsa, beach seine and gillnets (Afoakwah, Osei, & Effah, 2018). Gillnets may be used as drift nets, or as set nets, with the latter employed either in mid water or at the bottom. Six types of set gillnets are common in the Ghanaian artisanal sector, and these include *toga, ashoo, tengirafo, solu-yaa,* lobster net (*ngaa-yaa*) and *tsile-yaa*. These nets are characterized by their mesh size, net length and depth, the depth at which they are operated and the crew (Doyi, 1984).

The Bottom-Set Gillnet Fishery

Bottom-set gillnets are used in coastal waters to harvest demersal fish resources around the world. At most places where the fishery is well established, the gear is used to target specific species, and several other species may be retained or discarded (Rydell, Lauer, & Forsythe, 2010; Zeng, Tanaka, Chen, Wang, & Zhang, 2018). The use of bottom-set gillnets have been associated with ecological issues, such as by-catch and ghost fishing, and the management of the fisheries has mainly been centered on solving the ecological issues, associated with the use of the gear. Studies on the fishery in most parts of the world has centered on reducing by-catch by investigating properties of the gear.

Studies on the effect of various hanging ratios on catch have been reported (Acosta & Appeldoorn, 1995; Gray, Broadhurst, Johnson, & Young, 2005; Rudershausen, Price, & Buckel, 2015). Also, the selectivity of various mesh sizes has been tested (Broadhurst et al., 2003; Faife, 2003; Gabis, Kibler, Castro, & Parkins, 2013) to inform legal mesh sizes, that ensures the sustainability of the fishery in most parts of the world. The effect of fishing height (net depth), and soak time on catch, have been looked at by other authors (Akiyama et al., 2007; Li, Jiao, & Reid, 2011; Savina, Karlsen, Frandsen, Krag, Kristensen, & Madsen, 2016). Further studies reported on the bottom-set gillnet fishery examined the effect of twine material and diameter, net colour, and abiotic factors, also on catch (Balık, Çubuk, Bahk, & Çubuk, 2001; Gray et al., 2005). Fishing height, twine material and diameter, and net colour are factors relating to the construction of the gear, while soak time is an operational factor.

Reported studies so far have described the characteristics of the bottom-set gillnet fishery based on gear properties. They have as well informed management decision on input controls, which aims at reducing by-catch, and sustainably exploiting targeted species. According to Gabis et al. (2013), combining information on gear properties with biological information, on commercial species caught, would greatly improve harvesting rules and sustainability of the fishery. However, biological information on species caught has not been considered by previous studies, on the bottom-set gillnet fishery. Another factor that can affect the sustainability of the fishery, is the socio-cultural beliefs and practices of the fishers. Fishing according to Acheson (1981) is part of the culture of most fishing communities. The choice of fishing methods are therefore influenced by socio-cultural beliefs and practices, and the management of fisheries cannot be complete without understanding the social and cultural beliefs, and practices that governs these fisheries.

Gear Specific Fisheries in the Ghanaian Artisanal Sector

As reported by Aho (2013), based on gears operated, the Ghanaian artisanal fisheries sector comprised six sub-sectors, namely, poli/watsa fishery (purse seine), drift gillnet fishery, set net fishery, ali fishery, hook-and-line fishery and the beach seine fishery. Not much studies have been reported on most of these fisheries, by way of characterizing them. Kraan (2006) reported on the social and cultural features that characterize the beach seine fishery. Catch composition, species diversity, and abundance of beach seine landings, were also investigated by Aggrey-Fynn & Sackey-Mensah (2012). With the exception of the beach seine fishery, there is paucity of detailed information, on the characteristics of the other gear specific fisheries in the artisanal sector. Conversely, characterizing a fishery should be the first steps towards its effective management. It makes available necessary information for management decisions that ensures the sustainable exploitation of fisheries resources.

Mode of Fish Capture in Gillnets

Gillnets catch fish by gilling, wedging, snagging, and entangling. A fish is gilled when caught with the mesh behind the gill cover, wedged when caught by the maximum girth of the body, snagged when caught by the mouth, teeth, or other part of the head region. Entangled fish is caught by spine, fins or other parts of the body as a result of struggling (He & Pol, 2010). Gilling is reported to be common with monofilament nets, whiles multifilament nets usually entangles the fish (Potter and Pawson, 1991). However, He (2006) reported thinner twines to easily entangle fish due to their softness. Conversely, thin twines have been reported mostly for monofilament (Jensen, 1995) which probably may cause monofilaments to entangle more compared to multifilament (Appendix A) contrary to earlier reports.

Gillnet Fishery and Ecosystem Sustainability

Fisheries impact species interactions directly and indirectly in aquatic systems. Significant removal of aquatic organisms, potentially, causes ecological disturbances in marine ecosystems (Cochrane & Garcia, 2009; Kaiser, Collie, Hall, Jennings, & Poiner, 2010; Küpper & Kamenos, 2017). According to Shester & Micheli (2011), major ecological impacts occur through by-catch, and gillnets are significant contributors due to their poor species selectivity. Erzini et al. (2002) defined by-catch as "incidental capture of species towards which there is no directed effort". This definition suggests that, species considered as by-catch are not targeted, but are caught accidentally. The species, sizes and quantities of organisms discarded from fisheries operations, are largely dependent on the selectivity of the gear used. Bottom-set gillnet fisheries are mixed fisheries, that is, apart from targeted species, other species caught may be retained (Cosgrove et al., 2016). By-catches are common in all gillnet fisheries (He, 2006), and have become a worldwide management issue especially in monofilament gillnet fisheries. This is because, not only do they catch fishes, they also catch crustaceans and endangered species like turtles, birds, and marine mammals (Alverson et al., 1994; Proelss, Krivickaite, Gilles, Herr, & Siebert, 2011). The organisms discarded by fishermen include non-target species, target species of inappropriate sizes, spoilt fish, poisonous fish, and prohibited species. Fish are also discarded when quotas are exceeded, and when the vessel space on board is limited.

According to Armstrong, & Falk-Petersen (2008), many marine habitats are sensitive to fishing activities, and small alterations in habitat characteristics can cause a shift in dominance, within fish assemblages. Gillnets have been reported (Shester & Micheli, 2011) to cause physical disturbance to habitats, by damaging, and removing branched organisms, such as kelps, sponges, and corals.

Another ecological issue with gillnets is ghost fishing, a phenomenon associated with continued fishing by lost or abandoned gillnets (He, 2006; Macfadyen, Huntington & Cappell, 2009). Gears such as gillnets, which are made of synthetic materials, are not biodegradable, and may continue to trap fish for several years. High (1985) estimated that lost salmon nets might take fish for two years and crabs for six years. As lost gillnets become overgrown by algae, they become more visible, and consequently reduce in fishing capacity. Although trawl nets are reportedly more destructive to habitats than static fishing nets, the impact of the latter on habitats increases when they are lost (Brown, Macfadyen, Huntington, Magnus, & Tumilty, 2005). Lost gears may also interfere with fishing, resulting in further loss of gears (Macfadyen, Huntington & Cappell, 2009).

Ecological sustainability can be achieved with the use of gillnets if management options aim at reducing the ecological issues of by-catch, and ghost fishing. Studies have reported various input controls aimed at reducing by-catch in gillnet fisheries. Notable among them is increasing the gillnet selectivity, by constructing the nets with large hanging ratios, combined with large mesh sizes (Acosta & Appeldoorn, 1995). Reducing the probability of individual fishes encountering the fishing net, by reducing the fishing height, has also been reported to effectively reduce by-catch (Broadhurst et al., 2003; Gray et al., 2005). Acoustic by-catch exclusive devices have been deployed on fishing nets in some gillnet fisheries, to alert approaching cetaceans (Jennings et al., 2001). These management options, when well-practiced, are able to reduce the negative ecological impacts of gillnets on marine ecosystems, and thus ensuring the sustainable use of marine resources.

Growth in Fishes

The study of growth in fishes is basically the determination of fish size in relation to age (Sparre & Venema, 1998). Fish increases in length as they grow, and the increment in length per unit time, which is the growth rate, decreases as fish gets old, approaching zero for very old fish. (Cadima, 2003; Pauly & Morgan, 1987). Growth parameters differ among species, and vary among stocks of the same species by sex, and even among successive cohorts, depending on environmental conditions (Blay, 1998; Enberg et al., 2012; Stige et al., 2019).

Growth in finfishes is often described by the Von Bertalanffy Growth Function (VBGF), and the average growth of crustaceans also conforms to VBGF (Pauly & Morgan, 1987). Parameters of the VBGF are L_∞, which is the asymptotic length, or the mean length of very old fish, and K which is the growth coefficient. The parameter K, is related to the metabolic rate, and in effect temperature. Pelagic fishes are more active, and thus have a higher K. Tropical fishes also have a higher K than temperate fishes. K has the tendency to increase with any factor that causes stress, and hence has a direct relation to the longevity of the fish (Pauly, 1980; Montero-Serra, Linares, Doak, Ledoux, & Garrabou, 2018). Conditions such as temperature, population density, and food availability, can cause variations in growth factors in individuals of the same species (Collie & Gislason, 2011; Myrvold & Kennedy, 2015). Most aquatic animals show fast growth rates in the initial stages of growth, slowing down after sexual maturity, as the organism starts diverting energy away from growth into reproduction. Growth in aquatic animals has also been reported to evolve in response to fishing (Enberg et al., 2012).

Data for the estimation of the growth parameters may be assessed from age reading and length measurements, length measurements only, and from mark-recapture experiments. In the tropics where age data is difficult to assess, age composition is obtained from the conversion of length-frequency data (Cadima, 2003). Estimation of growth parameters from these data may be by graphical method, as presented in Gulland and Holt's plot, the Ford-Walford plot, and the Chapman method, where the parameters are derived from the coefficients of the regression equations. L_∞ can also be estimated by the Powell-Wetheral method which also estimates total mortality (Sparre & Venema, 1998). A number of computer programs have been developed for the analysis of length-frequency data, to estimate the growth parameters. Notable among them is the ELEFAN program.

Developed at the International Center for Living Aquatic Resources Management (ICLARM), the ELEFAN (Electronic Length-frequency Analysis) program, was in response to the need for robust methods for analyzing length-frequency data. The ELEFAN system consist of five programs, that is ELEFAN 0 to ELEFAN IV (Pauly & Morgan, 1987). ELEFAN 0 is used to create and modify length-frequency data to feed the other four programs. ELEFAN 1 estimates growth parameters using length-frequency analysis, through a modal progression analysis.

Length-weight relationship and condition factor

According to Le Cren (1951), length-weight data are analyzed to describe the mathematical relationship between length and weight of a fish, and to measure the variation in weight and length, of an individual fish. Historically, the length-weight equation originated from the cube law which states: "in similarly-shaped bodies, the masses, and therefore the weights vary as the cube of the dimensions". A fish therefore increases in weight by eight times, with doubling of its length (Froese, 2006). Fulton (1904) applied the cube law to 5,675 individuals of fish and based on his results, established the conceptual grounds for allometric growth for seasonal, reproductive and spatial variation in fish condition and variation in condition with size. Keys (1928) formulated an equation to describe the relation between the weight and length of a fish, and it was an exponential relationship, with the exponent (denoted by b), indicating the direction and rate of change of form.

For a good estimation of length-weight relationship, it is important for the sampling to be devoid of selection for weight, against length, as in gill-nets, where fatter fish may be selected among short fish, and thinner among long fish. The value of b usually lies between 2.5 and 4.0, with an ideal fish, which maintains the same shape as it grows having $b = 3$ (Le Cren, 1951). In majority of instances, b is not equal to 3, due to fishes changing their shape as they grow. The value of b may differ for fish of the same species, from different localities, different sexes and different growth stanzas, however, it is often constant for fish of similar weight, and length. It also changes with onset of maturity, metamorphosis or other marked events in the life history of the fish. Also, it has been reported to give indications of taxonomic differences (Longo & Mancinelli, 2014). Length-weight relationships, therefore, give life history and morphological comparisons between different fish species, and populations from different habitats (Sangun, Akamca, & Akar, 2007).

As reported by (Froese, 2006), condition factor (*CF*) compares the general well-being of fish, with heavier fish of a given length, being in better condition. Sex, age, maturity, environmental factors, food supply and parasitism can affect the value of *CF*. Condition factor has also been reported to increase prior to the spawning season, and decline after spawning (Longo & Mancinelli, 2014). Temperature changes, which may influence metabolism, and fish behavior, affect the condition of fishes (Murua et al., 2003).

Length frequency distribution

Length frequency distribution describes the size structure of a fish stock, and it reflects differences in various populations, at different geographic locations. It is affected when large numbers of fish are recruited into the fishery, as a result of a strong year class (Pikitch et al., 2012). Fishing pressure causes a reduction in the proportion of large individuals in the population, which in turn impacts on the size distribution of the population. It is though harmful to the survival of the population, as it affects recruitment into the fishery (van Overzee & Rijnsdorp, 2015). As observed by Pope et al. (2010), a population which is characterized by fewer juveniles, relative to adults, has recruitment difficulties.

High fishing mortality is reflected on a fish population by a decline in the average length of fish landed. A decrease in the mean size of landed fish, may also be as a result of size-selective fishing, focused on larger fish. Potentially, it can cause evolutionary change over relatively short time scales, especially for short-lived species (Pikitch et al., 2012). Size distribution of gillnet landings, reflects the selection window of the gear, and the mode of capture of the organisms, either by gilling, wedging, snagging or entangling. Sizes of fish caught in gillnets are therefore not representative of the size structure of finfish populations, unlike crustacean populations (Gabis et al., 2013; Holst et al., 1996).

Mortality and Exploitation of Fish Stocks

The change in numbers in a fish stock is described by the mortality rates of the stock. The coefficient of total mortality (*Z*) accounts for the total number of deaths. *Z* can be split into deaths due to fishing, and deaths due to natural causes. In a stock, small individuals are exposed to greater natural mortality, due to predation, and large or older individuals are exposed to greater fishing mortality (Jørgensen & Holt, 2013). According to Sparre & Venema (1998), *Z* can be estimated from catch per unit effort data (CPUE), from age composition data, and from a linearized catch curve, which is a graphical presentation of logarithm of numbers of fish caught against age. In the tropics, where length data is the easier to obtain, a length-converted catch curve which uses the VBGF to convert length to age is used, to estimate *Z*. Only length groups that are considered to be under full exploitation, are included in the catch curve analysis. ELEFAN II estimates Z, probability of capture, and the mean length at capture, from the length converted catch curve. The Beverton and Holt's Z-equation, and the Powell-Wetheral method also estimates a ratio of *Z/K* (Cadima, 2003; Daniel Pauly & Morgan, 1987; Ricker, 1975).

Natural mortality coefficient is one of the parameters that is most difficult to estimate but really important. Estimates can be obtained from completely unfished stock, where total mortality equals natural mortality, and from *Z*, when *F* is known. *M* can also be estimated through its relation with other parameters, like *K*, L_∞ and temperature of the fish environment (Pauly, 1980). It is expected that, species with a high *K* also have a high *M*, and species with a low *K* have a low *M*, and *M/K* ratio is estimated by Beverton and Holt to lie in the range of 1.5 to 2.5 (Sparre & Venema, 1998). Natural mortality has been linked to L_∞, that is, small fish may have more predators than large fish (Jørgensen & Holt, 2013). Natural mortality has also been linked to GSI, as a fish with high *M* may compensate with early maturity, and production of high numbers of egg. Yet again, natural mortality has been linked to environmental temperature, since biological processes occur at a faster rate at high temperatures. Pauly (1980) thus described *M* as a function of *K*, L_∞ and the environmental temperature (*T*) of the fish.

According to Kenchington (2014), fisheries conservation is aimed at balancing harvests, and the productivity of fisheries resources, making the estimated value of *M* an important consideration, in scientific advice to fishery managers. Species with a low *M* (implying a high *F*) in the adult phase are more susceptible to greater exploitation, than species with high natural mortality in the adult phase (Jørgensen & Holt, 2013).

As defined by Ricker (1975), Pauly (1984) and Cadima (2003), exploitation ratio (*E*) is the ratio of the fishing mortality coefficient to the total mortality coefficient. Fish stocks are considered to be optimally exploited, if their exploitation ratio is 0.5 (E_{opt} = 0.5) (Pauly, 1984). Above this level, they are considered overexploited, and underexploited if below this level. Kolding et al. (2015) found a strong correlation between the mean exploitation ratio and the range of fish sizes exploited (that is the difference between maximum length and median length of fish caught: L_∞ - L_{C50}). Pope et al. (2010) also reported a large juvenile to adult population ratio, to be a possible indication of substantial exploitation. High exploitation ratio, or high fishing mortality, due to size selective fishing, therefore has damaging implications on the size structure, as well the reproductive potential, of a fish stock, since reproductive potential is size related.

Reproduction in Fishes

Reproductive state of fish can be determined by gonadal staging based on structure of the reproductive organ, calculation of Gonadosomatic Index (GSI) or Egg Mass Ratio (EMR), histological classification of ovaries, and by use of mean egg diameters (Miller & Kendall, 2009). By using structure of the reproductive organ to determine reproductive state, ovaries and testes can be classified as immature, developing, mature, spawning, spent, and recovering depending on the color and size of the gonad (Brandão, Valentim, & Caramaschi, 2003).

Gonadosomatic index (GSI)

The GSI is defined as the gonad weight of a fish relative to its total body weight, expressed as a percentage. It is a good indicator of gonadal development in fish, describing the energy allocation for reproduction by the fish (Khan, Khan, & Hashmi, 2013; Pope et al., 2010). Relatively large GSI values are recorded, when a large amount of energy is directed toward gonad development, and this is usually common in fish populations that are not nutrition limited (Ragheb, 2016). The index has been found to correlate considerably with body weight, and gonad maturation stage. This however has been observed to be more pronounced in females, than in males, because of the heavier weight of ovaries (Shinkafi & Ipinjolu, 2012). Gonadosomatic index is used to predict spawning seasons of fish species, from observed increase in weight of gonads, signifying spawning activity, and a decrease in weight of gonads, indicating absence of spawning activity (Ferreri et al., 2016).

Fecundity

Miller & Kendall (2009) defined fecundity as the number of eggs a female fish produces in a spawning event. It is useful in characterizing fish stocks, populations, and sub-populations of fish. It is also useful in the study of population dynamics, and productivity, as well as fish conditions, as fish in a better condition produces more eggs (Rätz et al., 2000). Fecundity has been found to decrease among species with increasing amount of "care" for offspring. Oviparous fishes have the highest fecundity, followed by ovoviviparous fishes, and viviparous fishes have low fecundity. Among oviparous fishes, pelagic spawners have higher fecundity than nest builders (Jennings et al., 2001; Lambert & Ware, 1984). Marked differences in fecundity may reflect different reproductive strategies among species, and adaptations to habitats, and environmental pressures within species. Annual variations in fecundity have also been reported within stocks, and variability has also been observed among similar-sized individuals in a population (Murua et al., 2003; Pope et al., 2010).

Fecundity has been confirmed to correlate significantly with fish size, with larger fish producing more eggs (Smalås, Amundsen, & Knudsen, 2017). Populations exposed to size selective fishing mortality, where large old fish is targeted, may experience decline in population fecundity, as their numbers reduce. This may result from reduced abundance of spawners, and reduction in the number of highly fecund females beyond appropriate levels (Murua et al., 2003). The physiological condition of a fish can affect its fecundity (Braun, Patterson, & Reynolds, 2013; Pikitch et al., 2012). Maturation of individuals at a younger age, or smaller size, can alter lifetime reproductive output, due to the strong relation between fecundity and size (de Roos, Boukal, & Persson, 2006).

Management regulations that limit harvesting of oldest, and largest fish, can conserve fecundity, whereas regulations that protect the capture of small individuals, will in turn increase fishing mortality of large individuals, leading to a decline in population fecundity (De Leo & Micheli, 2015).

Ovum diameter distribution

Determination of ovum diameter frequency distribution of fish is useful in predicting the spawning strategy of fish species (Miller & Kendall, 2009). Unimodal distribution of ova sizes is indicative of discrete spawners, with synchronous ova development, bimodal distribution of eggs is usually seen for batch spawners, with group-synchronous ova development. A polymodal distribution of ova sizes signifies batch spawners with asynchronous ova development where ova at several stages of development are present in the ovary, and with the most dominant size group, being the most advanced spawning group (Crossland, 1977; Miller & Kendall, 2009; Murua et al., 2003; Plaza, Sakaji, Honda, Hirota, & Nashida, 2007; Hunter, Lo, & Leong, 1985). Protracted spawning activity in a population, may not necessarily be an indication of prolong spawning for individual fish, but rather, an indication of differences in spawning time between age groups, in the population (Saborido-Rey, 2016).

The sizes of ova produced by a fish species is indicative of its reproductive strategy (Duarte & Alcaraz, 1989). Fish species that exhibit extended maternal care, normally produces large eggs, with relatively large yolk, and large initial larval size. Production of large number of eggs, can be a protective measure against high egg and larval mortality, from predation (Christiansen, Fevolden, Karamushko, & Karamushko, 1998; Duarte & Alcaraz, 1989; Lambert & Ware, 1984). Egg size correlates negatively with fecundity, where species with low fecundity, produce larger size eggs and vice visa (Jennings et al., 2001).

Size at maturity

Size at maturity (L_{m50}) is the length at which 50% of individuals are sexually matured and most fishes attain sexual maturity at 65-80% of their L_{∞} (Saborido-Rey & Kjesbu, 2005). It varies among different stocks of the same species, and between sexes. L_{m50} is strongly influenced by genetic adaptation to stress, caused by fishing pressure (Lappalainen et al., 2016). Temperature has also been reported to cause variation in L_{m50} of different stocks, of the same species (O'Brien, 1999). The removal of large matured adult fish from a population, affects the size distribution of the adults, and overtime will result in a decrease in the mean maturity size of the population (Kolding et al., 2015). The reproductive success of a fish population, is affected by the size at which the individuals mature sexually, where larger individuals have different genetic traits than smaller ones (O'Brien, 1999).

Mesh size larger than the maturity size, which allow fish to reach sexual maturity before it is harvested, will ensure a high reproductive success of an exploited stock. This is because, the year class spawning for the first time, contributes greatly, to the reproductive potential of the stock (Wolff, Taylor, & Tesfaye, 2015).

CHAPTER THREE

MATERIALS AND METHODS

Study Area

The study was undertaken in the Central Region of Ghana. Among the four coastal regions of Ghana, Central Region was noted for the use of set gillnet (Ferraris & Koranteng, 1995). Compared with the other three coastal regions, the Central Region recorded the highest number of canoes operating set gillnet, according to the marine canoe frame surveys from 1997 to 2013 (Akyeampong, Amador, & Nkrumah, 2013). Based on the foregoing, the region was selected for the study.

Specifically, the study was carried out at Apam (5º17′05″N, 0º44′13″W) in the Gomoa West district, Egyaa (5º10′60″N, 1º6′0″ W) in the Mfantsiman Municipality and Cape Coast (5º6′19″N, 1º14′47″W) in the Cape Coast Municipality all in the Central Region of Ghana. The three study sites were selected based on two reasons. Firstly, the use of bottom-set gillnet, and secondly, to cover a large stretch of the central coast of Ghana. Apam is a large and busy landing site patronized by migrant fishers. The fishing gears used comprised poli/watsa, drift gillnet, hook-and-line and set gillnet. About 24% of all the canoes at the Apam landing site operated set gillnets. The set gillnets which comprised the bottom and mid-water set gillnets were the main fishing gears used at the *Abrofompoano* landing beach at Cape Coast. The bottom-set gillnet was the sole fishing gear used at Egyaa.

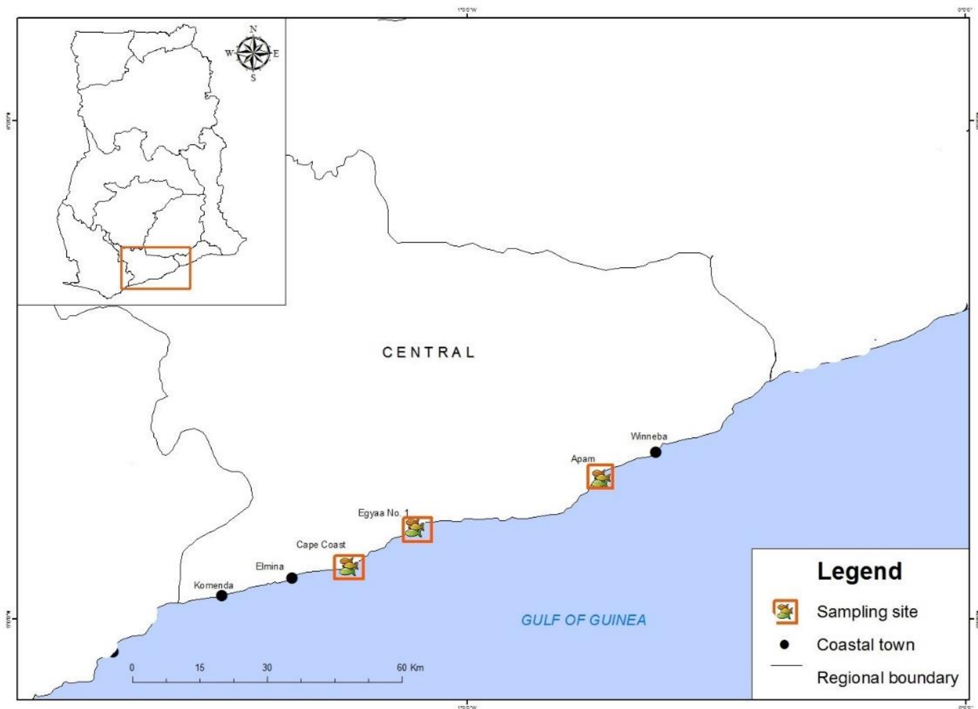


Figure 1: Map of Central Region of Ghana showing location of the sampling sites.

Methods

Description of socio-cultural characteristics

About 60 fishermen in the bottom-set gillnet fishery were interviewed using an interview guide (Appendix B) between February 2017 and July 2017, to elucidate the characteristics of the fishery. The fishermen were sampled purposively based on their activeness in fishing with the bottom-set gillnet. About 20 fishermen were sampled from each study location. Field observations were made, and clarity and understanding of observations made were also achieved through interviews, for which fishermen were selected based on their availability (incidental sampling).

Description of fishing effort employed in the fishery

The total length of fishing net walls (a number of gillnet panels joined together to fish), soak time (referring to the length of time the net remains fishing in water), and crew per canoe, were estimated from the response of the fishermen in the interviews conducted with interview guide (Appendix B). The length and width of 48 canoes used in the fishery were measured to the nearest 0.1 m. The mesh size of about 75 fishing gears were measured to the nearest 0.1 cm from all three study sites. Mesh size of about 25 gears was measured at each study site. Canoes and fishing nets measured were selected by systematic sampling.

Assessment of CPUE and catch composition

The total catch (refers to everything caught in a fishing operation) from three different canoes was recorded monthly at each study site, between April 2017 and July 2018, to estimate the monthly mean catch per day. The catch from each canoe was sorted and the various species weighed using a spring balance with a 0.001 kg accuracy, for determination of species composition by weight in catch. The number of each species was also recorded to determine the numerical abundance of the various species in the catch. The fish species were identified to the species level. With the exception of the coral species, all species were identified using identification guides by Carpenter & De Angelis (2014), (2016) and Schneider (1990). The coral species were identified using the identification guide by Ramos, Blanco & Gonza′lez (2009).

Assessment of by-catch

Species considered to be of value and thus retained and those that were unwanted and thus discarded by the fisherman, were weighed to the nearest 0.001 kg to determine their gravimetric composition. Numerical abundance of each species was determined by direct counts.

Examination of growth, mortality and exploitation of commercial species

Samples of finfish and shellfish were randomly collected from February 2017 to July 2018 for studies on the biology of selected species. Total length (*TL*) which was taken from the tip of the head to the edge of the caudal fin was measured for fin fishes to the nearest 0.1 cm using a fish measuring board. Carapace width (*CW*) which was taken across the lateral margins, at the widest part of the carapace, was measured for crabs using a Vernier caliper. Specimens were weighed with a digital balance (OHAUS RANGER 700) to the nearest 0.1 g.

Reproductive study

The sex of each specimen was determined. Female crabs were identified by their broad, rounded abdomen or occurrence of brood, and males by their triangular abdomen. Data on reproduction of finfishes was collected from October 2017. Finfishes were dissected and the developmental stage of gonads determined using the descriptions of Murua et al. (2003). Gonads of finfish and brood of shellfishes were weighed to the nearest 0.01 g. Matured ovaries of finfish (developmental stage III and IV) and brood of shellfishes were preserved in Gilson's fluid to liberate the ova from the gonadal tissue for the determination of fecundity. Ova were rinsed with tap water and the water drained with filter paper. Fecundity was determined by the gravimetric method. Dry weight of the bulk ova and weight of three subsamples were taken using an OHAUS analytical balance, and ova in each subsample counted with the aid of a dissecting microscope (OPTIKA Microscope; 20× magnification). To determine ova diameter, five ripe gonads of each species were weighed and preserved in formalin. Three samples of ova were taken from different positions (anterior, posterior ends and middle) of each gonad into a Pedri dish, water added, and the ova worked loose using forceps. About 500 ova from each gonad of each species were randomly selected and their diameter measured to the nearest 0.01 mm using a calibrated micrometer under a dissecting microscope with 40× magnification.

Data Analysis

Data collected were analyzed in SPSS version 20, Excel 2013, FiSAT II version 1.2.2. and Primer version 6. Data on socio-cultural characteristics were pooled for all three study sites based on similarity in responses to interviews conducted. Also, biological data for each commercial species were pooled for all sites based on similarities in size distributions which was tested at 95% confidence interval using a one-way ANOVA. Differences and similarities observed in the data were tested for significance with t-test or ANOVA at 95% confidence interval where necessary. Species abundance data were fourth root transformed, and richness, diversity, evenness and similarity of species landed were estimated in Primer version 6.

Determination of species richness

Species richness of the three sampling locations was measured with Margalef's richness index (*D*):

$$D = \frac{S - 1}{\ln N}$$

where *S* is the total number of species in the community, *N* is the total number of individuals in the sample, and *ln* natural log.

Determination of species diversity

Diversity of species was determined using Shannon diversity index (H') calculated from the equation of Shannon & Weaver (1949):

$$H' = -\sum P_i \ln P_i$$

where *Pi* = proportional abundance of species *i* in the sample.

Determination of species evenness

Species evenness of the fish community was determined by Pielous's (1966) index (J′) expressed as:

$$J' = \frac{H'}{H_{max}}$$

where H' is Shannon-Weaver diversity index, and $H_{max} = ln\ S$, where S = total number of species in the community.

The *values* of J' range between 0 and 1. A community is completely even, that is the number of individuals are equally distributed among the species, when the value of J' is 1, and no evenness when J' is 0 (Rozirwan et al., 2014).

Determination of species similarity

Similarity of species among the study sites was determined using Bray Curtis similarity index (BC_{ij}):

$$BC_{ij} = 1 - \frac{2C_{ij}}{S_i + S_j}$$

where C_{ij} is the sum of the lesser values for species common to community *i* and *j*, S*i* is the total number of species in community *i*, and *Sj* is the total number of species in community *j*. BC_{ij} ranges from 0% to 100% with species in two communities being the same when BC_{ij} is 100%.

Fish biological studies

Determination of length-weight relationship and condition factor

Length-weight relationships of selected species were determined using the relationship formulated by Keys (1928):

$$BW = aL^b$$

where *BW* is the weight (g) of fish, *a* is the intercept, *L* is the total length (cm) and *b* is the slope. To determine the type of growth exhibited by the fish, the slope was tested at 95% confidence interval with a one-sample t-test using the equation:

$$t_s = \frac{b - 3}{se(b)}$$

where t_s is the test statistic, b is the slope, and $se(b)$ is the standard error of the slope. The growth is allometric when b is significantly different from *3* and isometric when b is not significantly different from *3*.

Condition factor (*CF*) was calculated for fish specimens from the equation by Fulton (1904):

$$CF = \frac{BW}{L^3} \times 100$$

where *BW* is the body weight of fish and *L* is the total length. Monthly mean condition factor was calculated for the fish species to determine possible seasonal fluctuations.

Determination of sex ratio

The ratio of males to females was determined monthly for the fish species and the deviation of the observed sex ratios from the expected sex ratio of 1:1 was tested using a Chi-square (χ^2) test from the formula:

$$x^2 = \left(\frac{(O_m - E)^2}{E}\right) + \left(\frac{(O_f - E)^2}{E}\right)$$

Where O_m is the observed number of males, O_f is the observed number of females and E is the expected number of males or females.

Determination of gonadosomatic index

Gonadosomatic index (GSI) was calculated by the equation:

$$GSI = \left(\frac{GW}{BW}\right) \times 100$$ (Fontoura, Braun and Milani, 2009)

where GW is the gonad weight and BW is the body weight of the fish. Monthly mean GSI was calculated to determine seasonal fluctuations in the GSI of the fish species.

Estimation of fecundity

Fecundity (F) for individual fish was estimated from the equation of Murua et al. (2003):

$$F = \frac{\left[\sum_i \frac{O_i}{W_i}\right]}{n_i} \times W_{ovary}$$

where O_i is the number of ova in a subsample, W_i is the weight of subsample, n_i is the number of subsamples and W_{ovary} is the weight of the ovary. Subsamples with coefficient of variation (CV) of the number of ova per unit weight not more than 10%, were used in estimating individual fecundities to reduce the error in the estimated fecundity. Fecundity of each fish species was estimated as the mean of individual fecundities. Relationships between fecundity and body length, and fecundity and body weight were established using regression analysis.

Estimation of growth parameters

Fish were grouped into 1 cm length classes. The von Bertalanffy growth function (VBGF) parameters were obtained from analysis of the length frequency data using the ELEFAN I program in Fish Stock Assessment Tool II (FiSAT II version 1.2.2) by the VBGF (Pauly, 1990):

$$L_t = L_\infty \left[1 - e^{(-K\,(t - t_0))}\right]$$

where L_t is the length of fish at age t, L_∞ is the asymptotic length or the average length of very old fish, K is growth coefficient, t_o is the age of fish at length zero. The age of fish at length zero was estimated from the equation of Sparre & Venema (1998):

$$\log_{10}(-t_o) = -0.3922 - 0.275 \times \log_{10} L_\infty - 1.038 \times \log_{10} K$$

Longevity of the species was estimated as *3/K* (Sparre & Venema, 1998) and the growth performance index (ϕ') estimated from the equation:

$$\varphi' = \log_{10} K + 2 \log_{10} L_\infty \quad \text{(Pauly, 1984).}$$

Estimation of length at maturity

The size at which the fish matures was estimated using the formula of Sparre & Venema (1998) in the 'sizeMat' computer package in R (Torrejon-Magallanes, 2019):

$$P = 1 + \left[e^{(-r\,(L_t - L_m))}\right]$$

where P is the proportion of reproductive females, r is the rate of size change from non-reproductive to reproductive status, L_t is the length of the fish and L_m is the size of the fish at sexual maturity.

Mortality and exploitation ratio

Mortality parameters were estimated using ELEFAN II program in FiSAT II. Natural mortality coefficient (*M*) was estimated from the Pauly (1980) empirical equation which is based on asymptotic length (L_∞), growth coefficient (*K*) of the species and mean temperature of its environment (*T*):

$\log M = -0.0066 - 0.279 \times \log L_\infty + 0.6543 \times \log K + 0.463 \times \log T$

The total mortality coefficient (Z) was estimated from the length converted catch curve by the equation:

$$\ln\left(\frac{N}{\Delta t}\right) = a + bt' \quad \text{(Pauly, 1990)}$$

where N is the number of fishes in a given length class, Δt is the time needed for the fish to grow through the length class, a is the intercept of the regression, t' is the relative age of the fishes in that length class and b is the slope of the regression which is an estimate of Z.

Fishing mortality coefficient (F) and exploitation ratio (E) were estimated respectively from the equations:

$F = Z - M$ and $E = \frac{F}{Z}$ (Sparre & Venema, 1998).

Estimation of length at first capture

The size at first capture, which is the size at which 50% of the population is retained by the gear was estimated from the ascending arm of the length converted catch curve.

CHAPTER FOUR

RESULTS

Socio-cultural Characteristics of the Bottom-Set Gillnet Fishery

A total of 58 fishermen were interviewed from all three sampling sites. All fishermen interviewed were active in fishing. The fishery engaged both men and women at all sampling sites. Women were found to be involved with the catch after it has been landed, that is, the sale and processing of the catch. The fishing activity was entirely for men.

Business partnerships in the fishery

Two forms of business partnerships were observed in the bottom-set gillnet fishery, namely sole ownership and partnership, the latter of which was of three types:

Type 1: partnership between two people where one partner owns the canoe and the other owns the gear (fishing net), and both are part of the fishing crew. The catch is shared between the two and the other crew (if any).

Type 2: partnership between a gear owner and someone who has a canoe and a gear. The two partners are part of the crew. Catch from the two gears are not combined, rather, catch from a gear solely belongs to the owner of that particular net.

Type 3: partnership between either two or three people. For a partnership among three people, one partner owns the canoe, another owns the gear and the other does the fishing. If it is between two people, one owns the canoe and gear, and the other does the fishing. The canoe and gear owners usually are not part of the crew and the catch is shared among the three and the other crew.

As a result of these partnerships, there were more net owners than canoe owners in the fishery. This observation was confirmed by the responses from the interviews where 74.10% of respondents owned fishing gears compared to 53.4% owning canoes.

Fishing holidays

Fishing holiday, as practiced in most coastal communities in Ghana, was not strictly observed in the bottom-set gillnet fishery at the three study sites. Fishing was done every day of the week even on fishing holidays. This, however, was determined by the soak time decided on by a fisherman. Soak time that required setting of the net and hauling in of the catch on the same day was not allowed on a fishing holiday.

Problems in the fishery

The main problems facing the fishery, according to 78.6% of the 58 respondents, were the destruction and loss of fishing gear, of which frequent loss of fishing gear, during fishing operations accounted for 96%. These were caused by strong currents, however, most offenders were purse seiners as they either miss or ignore the net markers.

Other socio-cultural characteristics

Fishermen quoted length of net panels in *patch*, a jargon unit of measurement used in the fishery, which refers to the length of a fishing net panel made from a bundle of monofilament net of about 91.4 m length.

Fishing Effort Employed in the Fishery

Canoe and fishing gear characteristics

The measurements of a total of 48 canoes used for bottom-set gillnetting were taken from the three sampling sites. The sizes of canoes used in the gillnet fishery at the three sampling locations ranged from 6 m - 12 m LOA (Length Overall) with a mean width of 1.5±0.28 m. Variation in canoe sizes was not statistically significant between Egyaa and Cape Coast (P = 0.302) and Apam and Cape Coast (P = 0.126). Although, canoe size between Egyaa and Apam varied significantly (P = 0.002). The fishery was dominated by canoe sizes of 7 m to 10 m LOA. The crew per canoe ranged from two to four people, but most canoes had a crew of three people. There was no significant variation in crew among sites (F = 2.35, P = 0.104).

The bottom-set gillnets employed at the three sampling stations were made of monofilament nylon material. Nets panels were joined end to end to form long net walls during fishing. Total length of fishing net walls ranged from 30 m to1097 m (1/3 of a ‘patch’ to 12 ‘patches’) with a mean depth of 2.5±0.57 m.

The mesh size of a total of 69 bottom-set gillnets were measured at the three study locations. Six mesh sizes were encountered: 7.6 cm, 8.9 cm, 10.2 cm, 11.4

cm, 12.7 cm and 15.2 cm. Nets with a mesh size of 8.9 cm (37.7%) were the commonest, followed by 7.6 cm (31.8%) and the least was 15.2 cm (1.4%). From 58 respondents, majority (62.5%) use a single mesh size net to fish, others combined nets with two (25%), three (8.3%) or more (4.2%) mesh sizes.

Soak time

Varying soak times ranging from 5 hours to 72 hours were recorded at the three study sites. From 58 respondents, few of them (4% in each case) set nets for 5-8 hours, 25-48 hours and 49-72 hours. Also, 7% and 19% respectively indicated setting nets for 9-12 hours and 13-17 hours. Nevertheless, majority of respondents (63%) set the nets for 18-24 hours before hauling in the catch. Factors that informed soak time, according to respondents, were quantity of fuel available for the fishing trip, distance to the fishing ground, and mesh size of net, with longer soak time for large mesh sizes. Quality of catch was observed to decrease with an increase in soak time, with about 60% of catch getting spoilt at 72 hours soak time.

Catch per Unit Effort (CPUE) and Catch Composition

Catch per unit effort (CPUE)

Figure 2 shows monthly mean fish catch per day at the three sampling locations. Values of 15.88 kg/day to 99.47 kg/day, 23.76 kg/day to 182.70 kg/day and 9.82 kg/day to 82.10 kg/day were recorded at Apam, Egyaa and Cape Coast respectively.

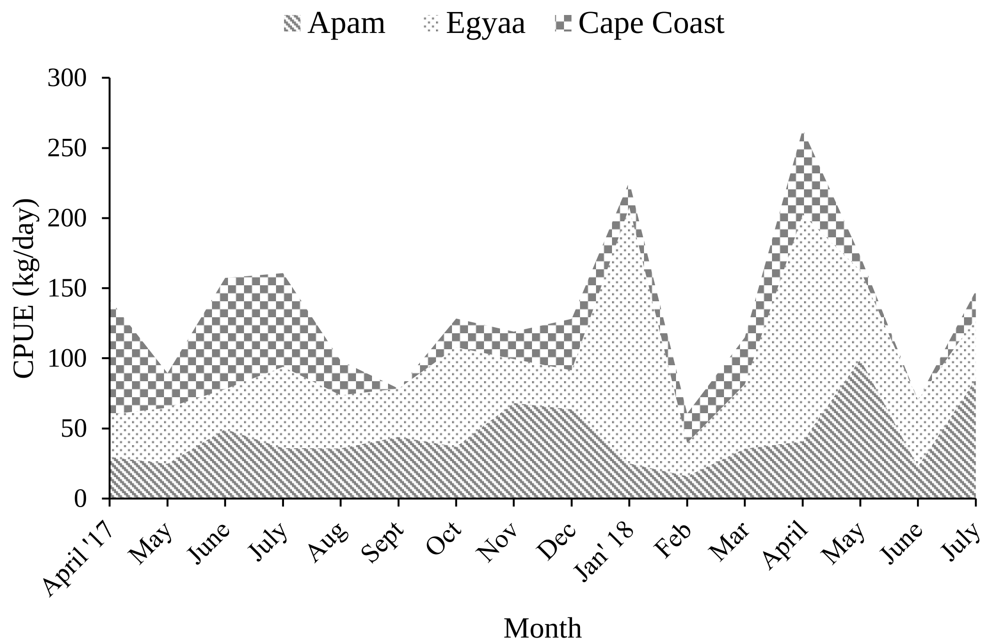


Figure 2: Average CPUE of the bottom-set gillnet fishery at Apam, Egyaa and Cape Coast in the Central Region of Ghana.

The CPUE recorded at Apam was high in November and December 2017 (68.25 kg/day and 63.66 kg/day respectively), May and July 2018 (99.47 kg/day and 85.30 kg/day respectively). At Egyaa, high CPUE was recorded in July and October 2017 (57.93 kg/day and 71.00 kg/day respectively), January, April and May 2018 (182.70 kg/day, 63.45 kg/day and 161.74 kg/day respectively). CPUE was lowest in February at Apam and Egyaa (15.88 kg/day and 23.76 kg/day respectively). At Cape Coast, high CPUE was recorded in April, June and July 2017 (82.10 kg/day, 79.3 kg/day and 66.79 kg/day respectively), and in April 2018 (60.90 kg/day). The lowest CPUE (9.82 kg/day) recorded at Cape Coast was in June 2018. Mean CPUE recorded during the sampling period was 44.59±23.40 kg at Apam, 57.97±46.69 kg at Egyaa and 36.93±24.55 kg at Cape Coast

Low CPUE recorded in February at Apam and Egyaa coincided with very low numbers of the spotted box crab (*Calappa rubroguttata*) in February samples, following the disappearance of the species from the landings at all three study sites in January. The highest CPUE recorded at Egyaa in January was as a result of high landings (81.7% by weight and 59.4% by numerical abundance of total landings) of the cuttlefish (*Sepia hierrada*) which was actually being targeted in that month.

Catch composition and species occurrence in the fishery

Table 1 shows a list of the species recorded in the bottom-set gillnet landings at the three study locations. Catches comprised of bony fishes, elasmobranchs, crustaceans, gastropods, cephalopods, echinoderms and cnidarians. Fifty-two bony fish species from 34 families, 15 crustacean species from 9 families and 9 elasmobranch species from 5 families were encountered at Apam. Also recorded were 12 gastropod species from 4 families, a cephalopod and 4 echinoderm species from 4 families. Ten coral species from 8 families were also encountered at Apam. At Egyaa, bony fishes were the highest recorded with 51 species from 34 families, which was followed by crustaceans with 16 species from 9 families, elasmobranchs with 7 species from 4 families, and gastropods with 11 species from 4 families. Furthermore, 2 cephalopod species from 2 families, 2 echinoderm species from 2 families, and 2 coral species from one family were recorded at Egyaa. At Cape Coast, 55 species of bony fish from 28 families, 9 crustacean species from 6 families, and 5 elasmobranch species from 4 families were encountered. A cephalopod species, 6 gastropod species from one family, and

2 echinoderm species from 2 families were, as well, encountered. Coral species were absent from the landings at Cape Coast.

Table 1: *Species occurring in bottom-set gillnet landings from April 2017 to July 2018 at Apam, Egyaa and Cape Coast*

Family	Species	Apam	Egyaa No.1	Cape Coast
Bony fishes				
Acanthuridae	*Acanthurus monronviae*	+	+	+
Ariidae	*Carlarius latiscutatus*	-	+	-
Balistedae	*Balistes capriscus*	-	+	-
	Balistes punctatus	+	+	+
Batrachoididae	*Halobatrachus conspicillum*	+	+	+
	Halobatrachus didactylus	+	+	-
Bothidae	*Citharichthys stampflii*	-	-	+
	Monolene mertensi	-	-	+
	Syacium guineensis	+	+	+
Carangidae	*Alectis alexandrinus*	+	-	-
	Caranx crysos	+	+	+
	Caranx hippos	+	+	+
	Caranx senegallus	+	-	+
	Chloroscombrus chrysurus	+	+	+
	Selene dorsalis	-	+	+
	Uraspis secunda	+	-	-
	Trachinotus maxillosus	+	+	-
Clupeidae	*Sardinella aurita*	+	+	-
	Sardinella maderensis	+	-	+
Cynoglossidae	*Cynoglossus browni*	-	-	+
	Cynoglossus canariensis	+	+	+
	Cynoglossus monodi	+	+	+
	Cynoglossus senegalensis	+	+	+
Dactylopteridae	*Dactylopterus volitans*	+	+	+
*Diodontidae	*Diodon holocanthus*	+	-	-
Drepanidae	*Drepane africana*	+	+	-
Echeneidae	*Remora brachyptera*	-	+	-
Elopidae	*Elops lacerta*	-	-	+
Ephippidae	*Ephippus goreensis*	+	+	-
Exocoetidae	*Cheilopogon pinnatibarbatus*	-	-	+
	Hirundichthys affinis	-	-	+
Fistularidae	*Fistularia tabacaria*	-	-	+

Gerreidae	*Eucinostomus melanopterus*	-	-	+
Gymnuridae	*Gymnura micrura*	+	-	-
Haemulidae	*Brachydeuterus auritus*	+	-	+
	Parakuhlia macrophthalmus	-	-	+
	Plectorhinchus mediterraneus	+	-	+
	Pomadasys incisus	-	+	+
	Pomadasys jubelini	-	+	+
	Pomadasys rogerri	-	-	+
Labridae	*Bodianus speciosus*	+	-	+
Lethrinidae	*Lethrinus atlanticus*	+	+	+
Lobotidae	*Lobotes surinamensis*	+	-	-
Lutjanidae	*Lutjanus fulgens*	+	-	+
	Lutjanus goreensis	-	+	+
Monacanthidae	*Aluterus monoceros*	-	+	-
	Aluterus scriptus	+	+	+
	Stephanolepis hispidus	+	+	-
Mullidae	*Mullus surmuletus*	+	-	-
	Pseudopeneus prayensis	+	+	+
Muraenesocidae	*Cynoponticus ferox*	-	-	+
Muraenidae	*Channomuraena vittata*	+	+	-
Ophichthidae	*Mystriophis crosnieri*	+	+	+
	Mystriophis rostellatus	-	-	+
	Ophichthus ophis	-	+	-
Ophidiidae	*Brotula barbata*	+	-	-
*Ostraciidae	*Acanthostracion guineensis*	+	+	-
Platycephalidae	*Solitas gruveli*	-	+	-
Polynemidae	*Galeiodes decadactylus*	+	+	+
Psettodidae	*Psettodes belcheri*	+	-	-
Scaridae	*Scarus hoefleri*	+	-	-
	Sparisoma choati	+	+	-
	Nicholsina colletei	-	+	-
	Sparisoma cretense	-	+	-
Sciaenidae	*Pseudotolithus epipercus*	-	-	+
	Pseudotholithus senegalensis	+	+	+
	Pseudotolithus senegallus	+	+	+
	Pseudotolithus typus	+	+	+
	Pteroscion peli	+	-	+
	Sciaena umbra	-	+	-
Scombridae	*Auxis thazard*	+	+	-
Scorpaenidae	*Scorpaena laevis*	+	+	-

Sparidae	*Dentex canariensis*	+	-	-
	Dentex gibbosus	-	-	+
	Pagellus bellotii	+	+	+
	Pagrus auriga	-	-	+
	Pagrus caeruleostictus	+	+	+
	Virididentex acromegalus	-	-	+
Sphyraenidae	*Sphyraena afra*	+	-	+
	Sphyraena guachancho	-	-	+
	Sphyraena sphyraena	-	+	-
Stromateidae	*Stromateus fiatola*	+	+	-
Synodontidae	*Trachinotus maxillosus*	+	-	-
	Synodus synodus	+	-	-
	Trachinocephalus myops	-	+	+
Tetraodontidae	*Ephippion gutiffer*	+	+	-
	Lagocephalus laevigatus	+	+	+
Trachinidae	*Trachinus armatus*	-	+	-
	Trachinus lineolatus	-	-	+
Uranoscopidae	*Uranoscopus polli*	+	+	+
Elasmobranchs				
Dasyatidae	*Dasyatis magarita*	+	+	+
Rajidae	*Raja miraletus*	+	-	+
Rhinobatidae	*Glaucostegus cemiculus*	+	+	-
	Rhinnobatos irvinei	+	+	+
	Rhinobatos rhinobatos	+	+	+
	Rhinobatos albomaculatus	+	-	-
*Torpedinidae	*Torpedo mackayana*	+	+	-
	Torpedo marmorata	-	+	-
	Torpedo torpedo	+	-	-
*Zanobatidae	*Zanobatus maculatus*	+	+	+
Crustaceans				
Calappidae	*Calappa galloides*	+	+	+
	Calappa rubroguttata	+	+	+
*Dromiidae	*Dromiidae sp*	+	+	+
*Majidae	*Maja brachydactyla*	+	+	-
*Paguroidae	*Paguristes cadenati*	+	+	+
Palinuridae	*Panulirius reguis*	+	+	+
Penaeidae	*Marsupenaeus japonicus*	+	+	-
	Melicertus kerathurus	+	+	+
	Parapenaeopsis atlantica	+	+	+
	Penaeus notialis	+	-	-
Portunidae	*Callinectes pallidus*	+	+	+

	**Cronius ruber*	-	+	-
	Sanquerus validus	+	+	+
Scyllaridae	*Scyllarides delfosi*	+	+	-
	Scyllarides latus	+	+	-
*Squillidae	*Squilla calmani*	-	+	-
	Squilla mantis	+	+	-
Gastropods				
Cassidae	*Cassis tessellata*	+	+	-
*Melongenidae	*Pugilina morio*	+	+	-
*Muricidae	*Bolinus cornetus*	+	-	-
	Hexaplex duplex	+	-	-
	Hexaplex megacerus	-	+	-
Volutidae	*Cymbium cucumis*	+	+	+
	Cymbium cymbium	+	+	+
	Cymbium fragile	+	+	+
	Cymbium glans	+	+	+
	Cymbium gracile	+	+	+
	Cymbium marmoratum	+	-	-
	Cymbium patulum	+	-	-
	Cymbuim souliei	+	+	+
Cephalopods				
Amphitretidae	*Amphitretus pelagicus*	-	+	-
Sepiidae	*Sepia hierrada*	+	+	+
Echinodems				
*Cidaroidea (sea urchin)	*Phyllacanthus imperialis*	+	+	-
*Oreasteridae	*Oreaster clavatus*	+	+	+
*Astropectinidae	*Astropecten vappa*	+	-	+
*Clypeasteridae	*Arachnoides placenta*	+	-	-
Cnidarians				
*Gorgoniidae	*Iciligorgia schrammi*	+	-	-
	Gorgonia mariae	+	-	-
	Gorgonia flabellum	+	-	-
*Chrysogorgiidea		+	-	-
*Plexauridae	*Plexaura flexuos*	+	-	-
*Faviidae		+	-	-
Acroporidae	*Montipora sp*	+	-	-
*Poritidae	*Porites profundus*	+	+	-
	Porites sp	+	+	-

***Poriferans**	+	-	-

*By-catch species

Figure 3 shows a summary of composition of organisms landed at the three study locations. Based on taxonomic groups, significant differences were observed in the numeric composition (F = 24.40, $df1$ = 6, $df2$ = 119, p = 1.09E-18) and composition by weight (F = 15.25, $df1$ = 6, $df2$ = 119, p = 6.69E-13) of landings at Apam. Crustaceans dominated numerically (56%) and by weight (33%), Bony fishes, elasmobranchs, gastropods and cnidarians by numeric composition formed 10.0%, 5.0%, 7.0% and 22.0%, respectively, and by weight formed 16.0%, 17.0%, 22.0% and 10.0%, respectively.

A similar observation was made at Egyaa in terms of the composition of landings by weight (F = 5.60, $df1$ = 6, $df2$ = 104, p = 4.59E-05), and by abundance (F = 18.03, $df1$ = 6, $df2$ = 103, p = 3.34E-14), where the crustaceans again dominated (32.3% numerically and 71.5% by weight). Respectively, by numeric and weight compositions, bony fishes (14.6%, 22.2%), elasmobranchs (5.0%, 12.7%), gastropods (3.5%, 21.8%), and cephalopods (9.4%, 2.8%) were also represented in the landings. The spotted box crab *Calappa rubroguttata* (Family: Calappidae) was the main crustacean species at both Apam (81.1% numeric composition and 90% by weight) and Egyaa (52.8% numerically and 78.6% by weight).

Again at Cape Coast, the composition of landings based on taxonomic groups differed greatly by weight (F = 24.49, $df1$ = 5, $df2$ = 65, p = 2.18E-12) and numerically (F = 16.84, $df1$ = 5, $df2$ = 88, p = 1.21E-11). The dominant group recorded by weight (64.3%) and numeric composition (61.0%) was bony fishes, with the dominant species being *Pseudotolithus senegalensis* (Family: Sciaenidae) (37.1% numerically and 44.9% weight composition). Elasmobranchs formed 2.4% numerically and 6.2% by weight of the composition of landings. Likewise, by numerical composition and weight, crustaceans formed 31.8% and 16.3%, and gastropods formed 3.4% and 11.4% respectively. The most landed bony fish species at Apam (25% numeric composition and 23.3% by weight) and Egyaa

(28.7% numerically and 31.4% by weight) was *Cynoglossus senegalensis* (Family: Cynoglossidae). Cnidarians, commonly known as coral species were encountered in the landings at Apam and Egyaa but were absent at Cape Coast.

The spotted box crab was the dominant species by abundance (45%) and by weight (30%) at Apam. *C. senegalensis* formed 2.5% of landings by number and 3.8% by weight, and the cassava croaker *P. senegalensis* formed 1% by abundance and 2% by weight. At Egyaa, *C. rubroguttata* dominated numerically (35%) and by weight (26.8%), *C. senegalensis* formed 4% and 8% by abundance and by weight respectively. *P. senegalensis* formed 1% numerically and 2% by weight of landings at Egyaa. The dominant species by number (22%) and weight (28%) was *P. senegalensis* at Cape Coast. By number and by weight, *C. rubroguttata* formed 16% and 13% respectively and *C. senegalensis* formed 3% and 4% respectively.

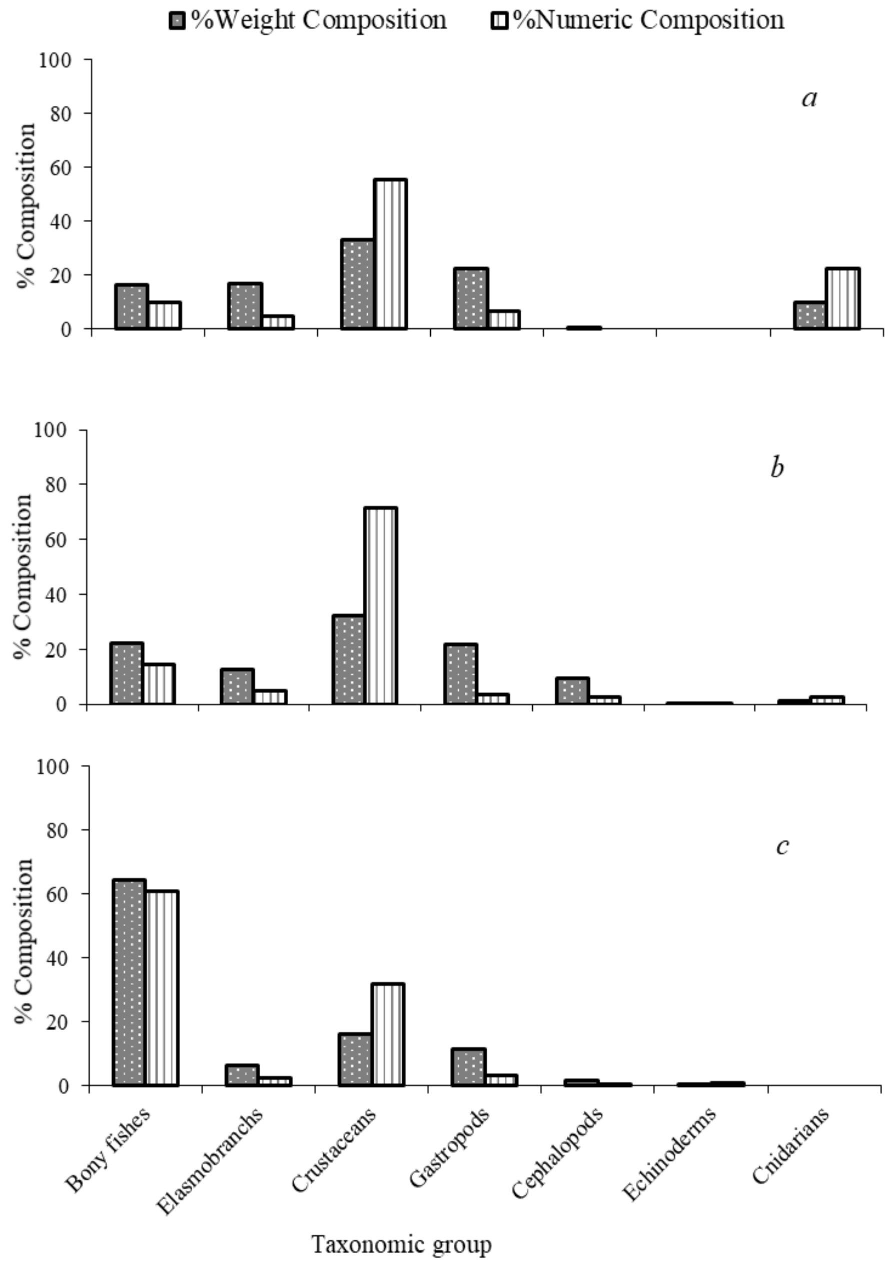


Figure 3: Summary of the composition of organisms landed at Apam (*a*), Egyaa (*b*) and Cape Coast (*c*) from April 2017 to July 2018.

Species diversity and similarity

Table 2 shows the indices of diversity determined from the three study locations. The highest species richness among the three study sites was recorded at Apam, and the least recorded was at Cape Coast. Again, the Shannon-Wiener diversity index estimated for the sites indicated species diversity at Apam was the highest, and Cape Coast was the least. Despite this, the number of individual organisms were most evenly distributed among the species landed at Cape Coast, and species evenness at Apam and Egyaa was observed to be the same. Species evenness was however high at all three sites.

Table 2: *Diversity indices of species caught in the bottom-set gillnets catches at Apam, Egyaa and Cape Coast*

	Study site		
Diversity index	Apam	Egyaa	Cape Coast
Margalef's index	18.32	17.65	15.74
Shannon-Wiener index (*H′*)	4.45	4.41	4.25
Pielous's index (*J′*)	0.97	0.97	0.98

The estimated similarity index pointed out Apam and Egyaa to have the highest resemblance (68.8%) in species landed and the least (54.9%) was recorded at Cape Coast and Egyaa. Species similarity between Apam and Cape Coast was 55.5%. A hierarchical cluster analysis identified two statistically distinct clusters (Appendix C) with Cape Coast forming one cluster and Apam and Egyaa forming the second cluster.

By-catch in the Bottom-set Gillnet Fishery

Retained catch and by-catch

Figure 4 shows variation in retained catch and by-catch in landings at Apam Egyaa and Cape Coast. A significantly high proportion by abundance and by weight respectively of the monthly catch was retained respectively at Egyaa (t = 4.468; p = 0.001, t = 6.194; p = 11E-07) and Cape Coast (t = 5.699; p = 3.25E-06, t = 6.052; p = 1.21E-06). At Apam also, the proportion by weight of the monthly catch retained was significantly high (t = 5.507; p = 5.58E-0.6). Numerically, the proportion was as well high (t = 2.609; p = 0.014), however, the p-value (0.014) indicated a moderately significant difference in proportion by abundance between monthly retained catch and by-catch. The proportion of landings recorded as unwanted (by-catch) differ significantly among the three study locations (F = 9.17, $df1$ = 2, $df2$ = 45, p = 0.005), with the highest recorded at Apam (31.4% numeric composition and 11.5% weight composition) and lowest at Cape Coast (6.9% numeric and 1.5% weight composition). By-catch at Egyaa formed 26% numerical and 6.2% weight composition of all landings during the study period.

By-catch composition and Species occurrence

Composition of by-catch in the landings from the three sampling stations is shown in Figure 5. The occurrence of by-catch organisms among the various taxonomic groups differed significantly at Apam by numeric composition (F = 4.09, $df1$ = 6, $df2$ = 119, p = 0.0009) and by weight (F = 2.34, $df1$ = 6, $df2$ = 119, p = 0.0356). Cnidarians (Figure 7) were the dominant by-catch at Apam by

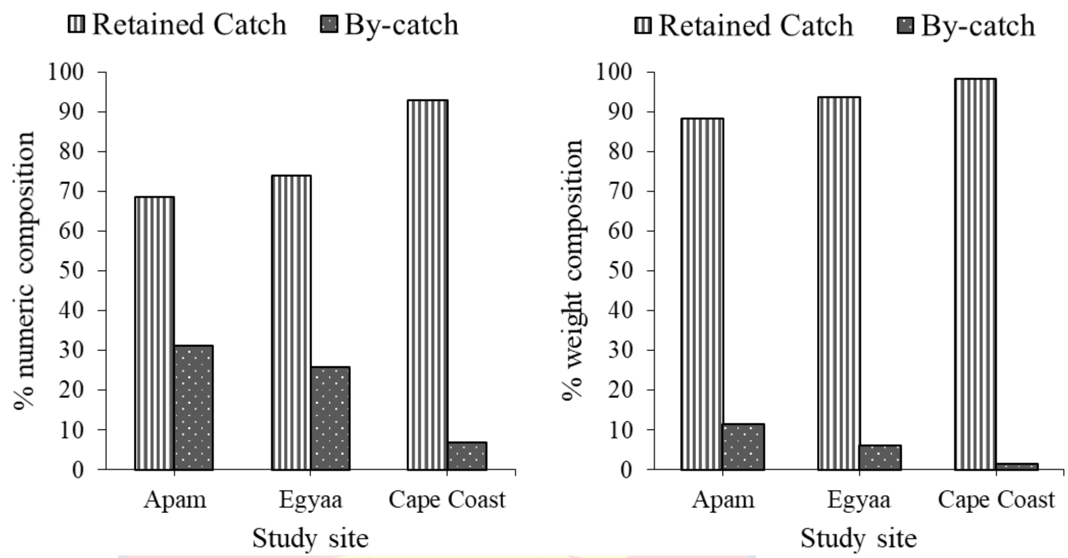


Figure 4: Variation in retained catch and by-catch in the landings of the bottom-set gillnet fishery at Apam, Egyaa and Cape Coast from April 2017 to July 2018.

abundance (71%) and by weight (79%), and 10 species from seven families were encountered (Table 1). Crustaceans formed 21% of the by-catch by numeric composition and 8% weight at Apam of which five species from five families were recorded. The main crustacean species in the by-catch at Apam included the hermit crabs (*Pagurites cadenati),* spiny spider crabs (*Maja brachdactylus*) and sponge crabs (Dromiidea *sp*) (Figure 6), forming 11%, 5% and 4.8%, respectively, by numerical composition. Significant difference was also observed in the numeric occurrence of by-catch species among the taxonomic groups at Egyaa (F = 4.51, $df1$ = 5, $df2$ = 87, p = 0.0011), despite this, no significant difference (F = 1.96, $df1$ = 5, $df2$ = 87, p = 0.923) was observed in the weight composition. Likewise, at Cape Coast, no significant differences were observed in the occurrence of by-catch organisms among the taxonomic groups both by numeric composition (F = 2.57, *df1* = 2, *df2* =12, *p* = 0.1173) and composition by weight (*F* = 2.63, *df1* = 2, *df2* = 12, *p* = 0.1129).

The highest percentage, in numeric and weight compositions respectively, was recorded for crustaceans both at Egyaa (79.8% and 36%) and Cape Coast (86.3% and 82.5%). Five crustacean species from 5 families, and 3 species from 3 families, were observed respectively at Egyaa and Cape Coast (Table 1). Spiny spider crabs dominated the by-catch at Egyaa with a numerical composition of 36.9%, sponge crabs and hermit crabs numerically formed 31.5% and 14.1%, respectively. At Cape Coast, spiny spider crabs, sponge crabs, and hermit crabs had a numerical composition of 51.1%, 24.2% and 10.5%, respectively. Gravimetric composition of elasmobranchs was moderately high at Egyaa (33.8%) and Cape Coast (16.0%), and particularly dominated by the striped panray (*Zanobatos maculatus).* Bony fishes constituted 0.3% by weight and 0.1% numeric composition of by-catch at Apam and Egyaa, respectively. The species recorded at Egyaa was the yellow cowfish *Acanthostracion guineensis* (Family: Ostraciidae), and those encountered at Apam were yellow cowfish and longspinned porcupinefish *Diodon holocanthos* (Family: Diodontidae) (Figure 6). Cnidarians formed 27.6% weight and 13.0% numeric composition of all by-catch recorded at Egyaa.

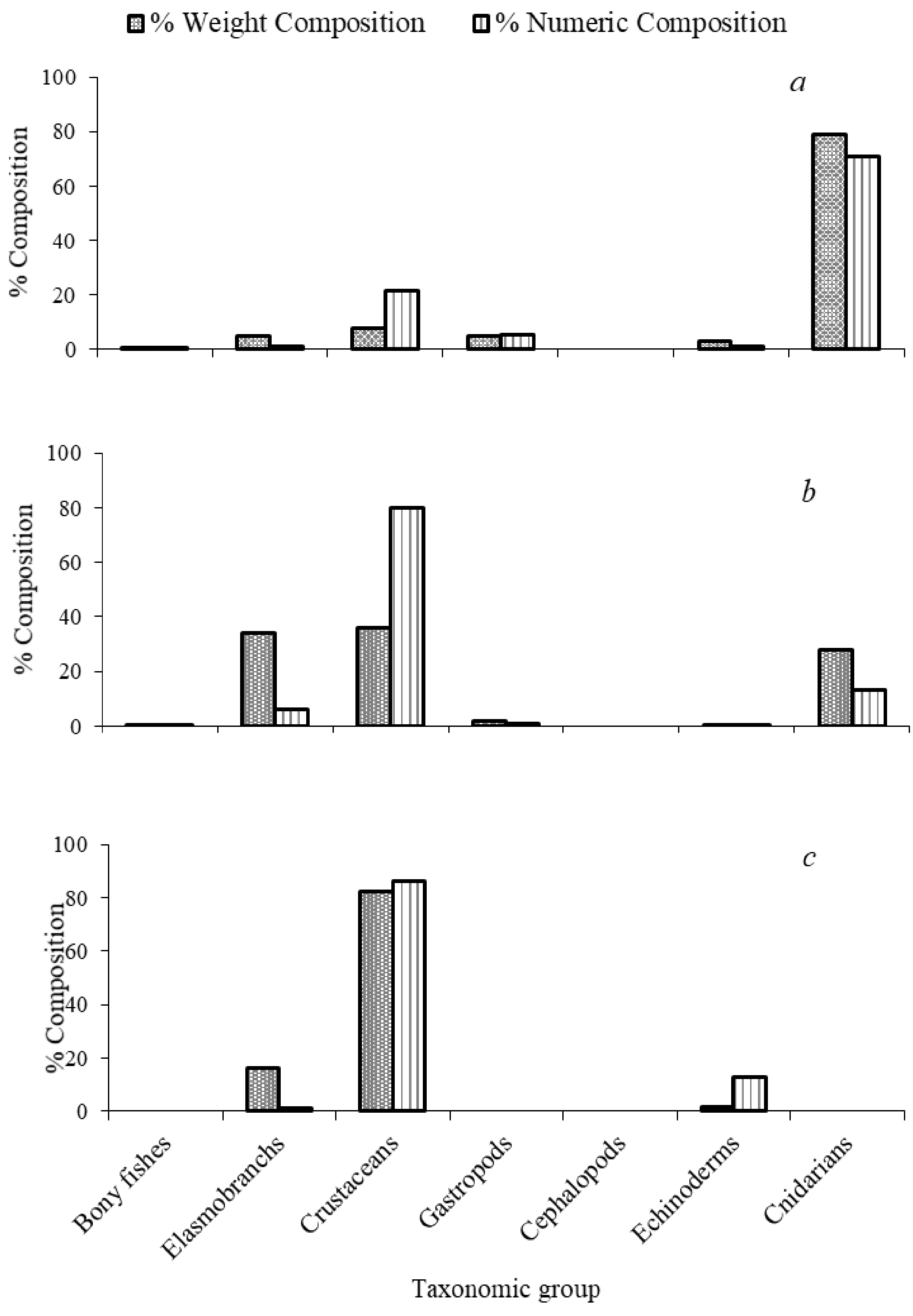


Figure 5: Composition of by-catch in the landings at Apam (*a*), Egyaa (*b*), and Cape Coast (*c*).

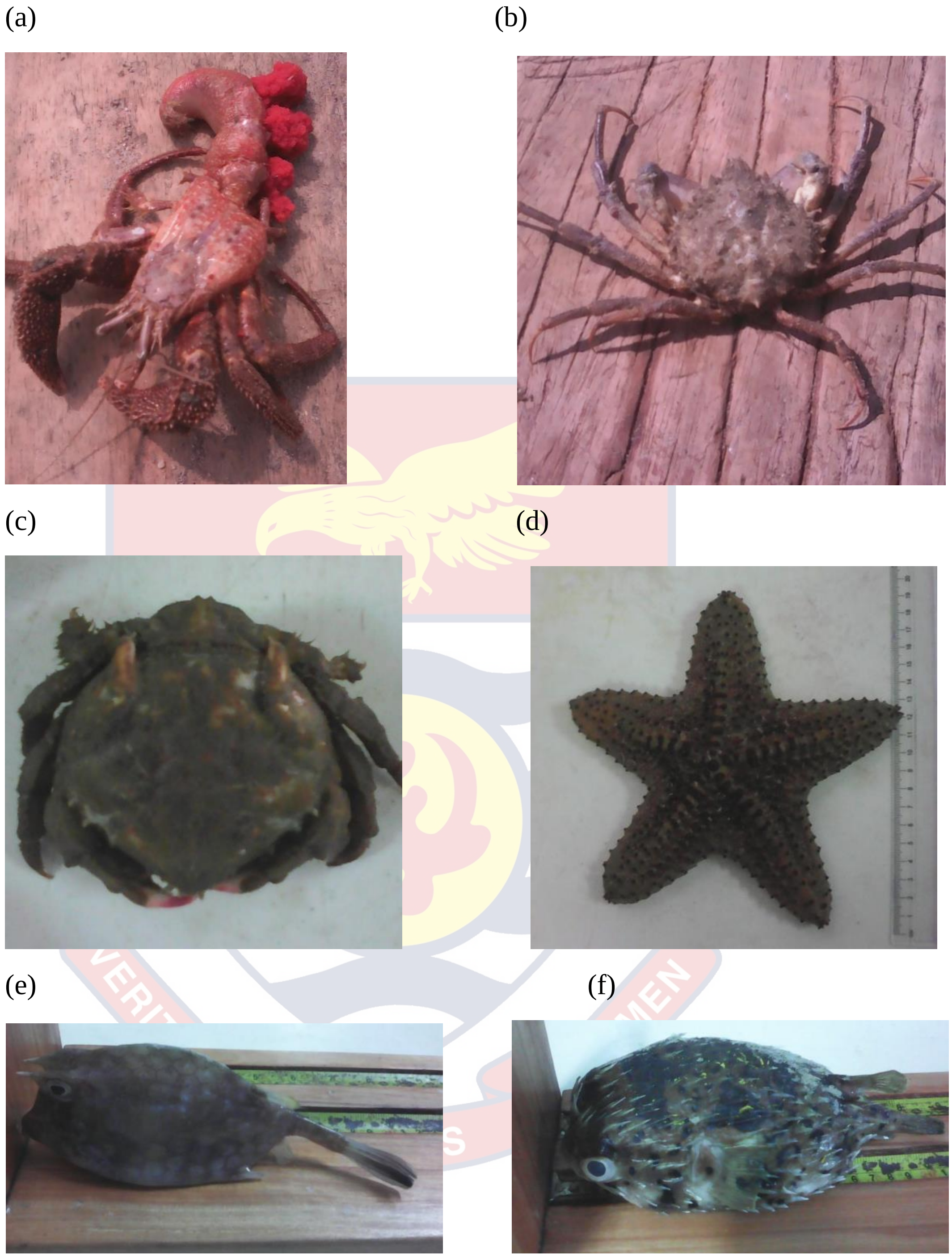


Figure 6: Some by-catch species occurring in the landings of the bottom-set gillnet fishery at Apam, Egyaa and Cape Coast: (a) *Pagurites cadenati*, (b) *Maja brachdactylus*, (c) Dromiidae *sp.*, (d) *Oreaster clavatus*, (e) *Acanthostracion guineensis and* (f) *Diodon halocanthus.*

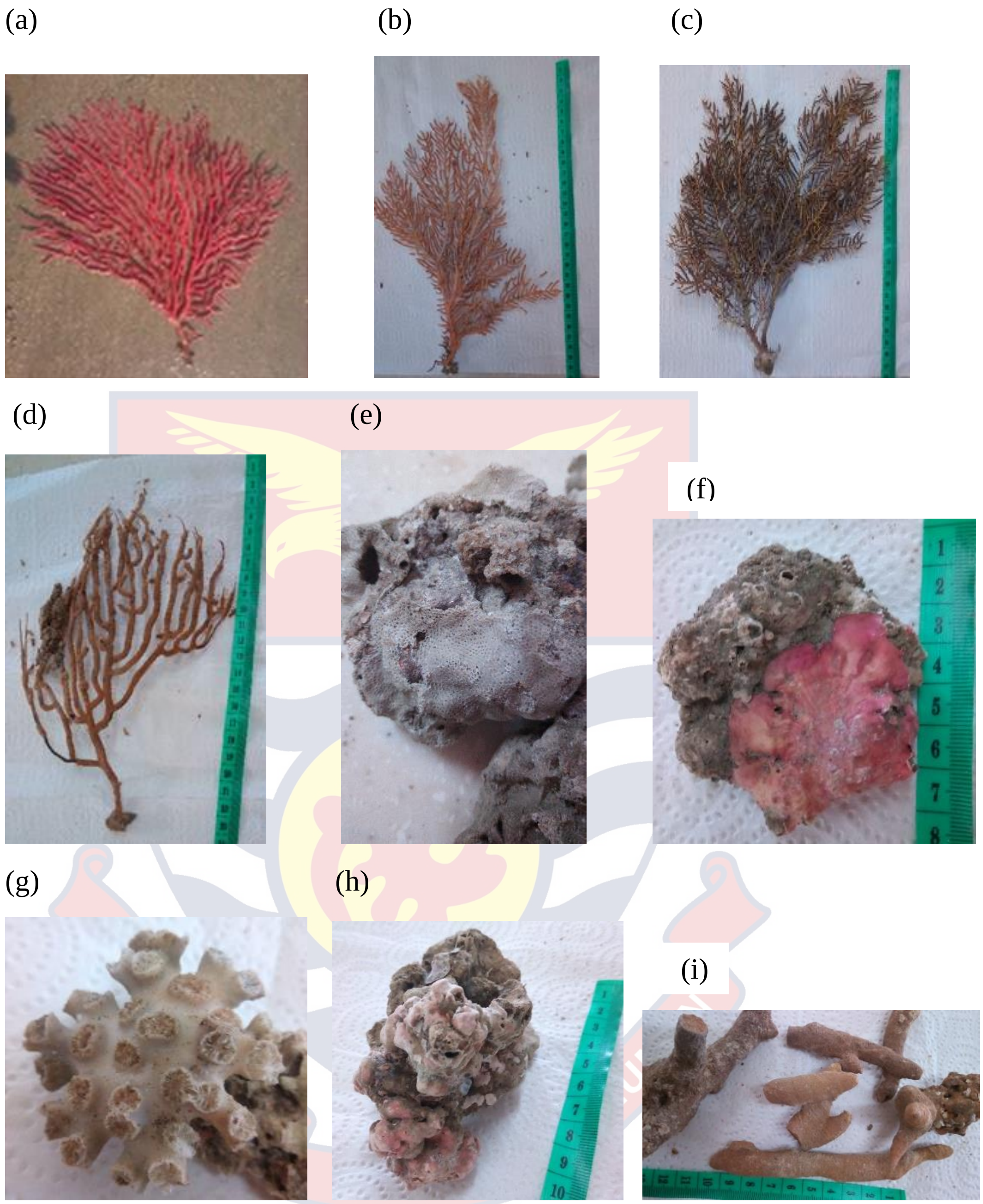


Figure 7: Some coral species occurring in the by-catch of the bottom-set gillnet fishery at Apam and Egyaa: (a) *Iciligorgia schrammi*, (b) *Gorgonia mariae*, (c) *Gorgonia flabellum*, (d) *Plexaura flexuos*, (e) Porifera, (f) Montipora *sp*, (g) Faviidae *sp*, (h) Poritidae *sp* and (i) *Porites profundus*.

Biological Study of Some Economic Species

A shellfish (*Calappa rubroguttata* (Figure 8)) and two finfishes (*Pseudotolithus senegalensis* and *Cynoglossus senegalensis* (Figure 18 and 30 respectively)) were selected, respectively, from the families Calappidae, Sciaenidae and Cynoglossidea for the biological study. Differences in the size distributions of the *Calappa rubroguttata* (F = 2.728; $df1$ = 2; $df2$ = 2197; p = 0.074), *Pseudotolithus senegalensis* (F = 2.874; $df1$ = 2; $df2$ = 426; p = 0.068) and the *Cynoglossus senegalensis* (F = 1.83; $df1$ = 2; $df2$ = 500; p = 0.165) recorded at the three study locations showed no statistical significance.

Growth, mortality and exploitation of the spotted box crab (*Calappa rubrogutatta*)

Figure 8: The spotted box crab *Calappa rubroguttata* Herklots, 1851 (Family: Calappidae).

Crab size distribution

Figure 9 shows the size distribution of spotted box crabs in catches from February 2017 to July 2018. A total of 2100 individuals of the spotted box crab was sampled, and sizes ranged from 4.5 cm to 12.0 cm carapace width. Monthly mean crab size was between 7.2±0.2 cm and 9.0±1.1 cm during the sampling period (Appendix D). The sizes of males ranged from 4.5 cm to 12.0 cm and the females ranged from 4.9 cm to 9.6 cm. The size distribution for all crabs sampled was unimodal with the mode occurring at 7.0 cm to 7.9. Size distribution for males was bimodal with modes at 7.0 cm to 7.9 cm, and 9.0 cm to 9.9 cm. Female size frequency distribution was unimodal with a modal class of 7.0 cm to 7.9 cm carapace width.

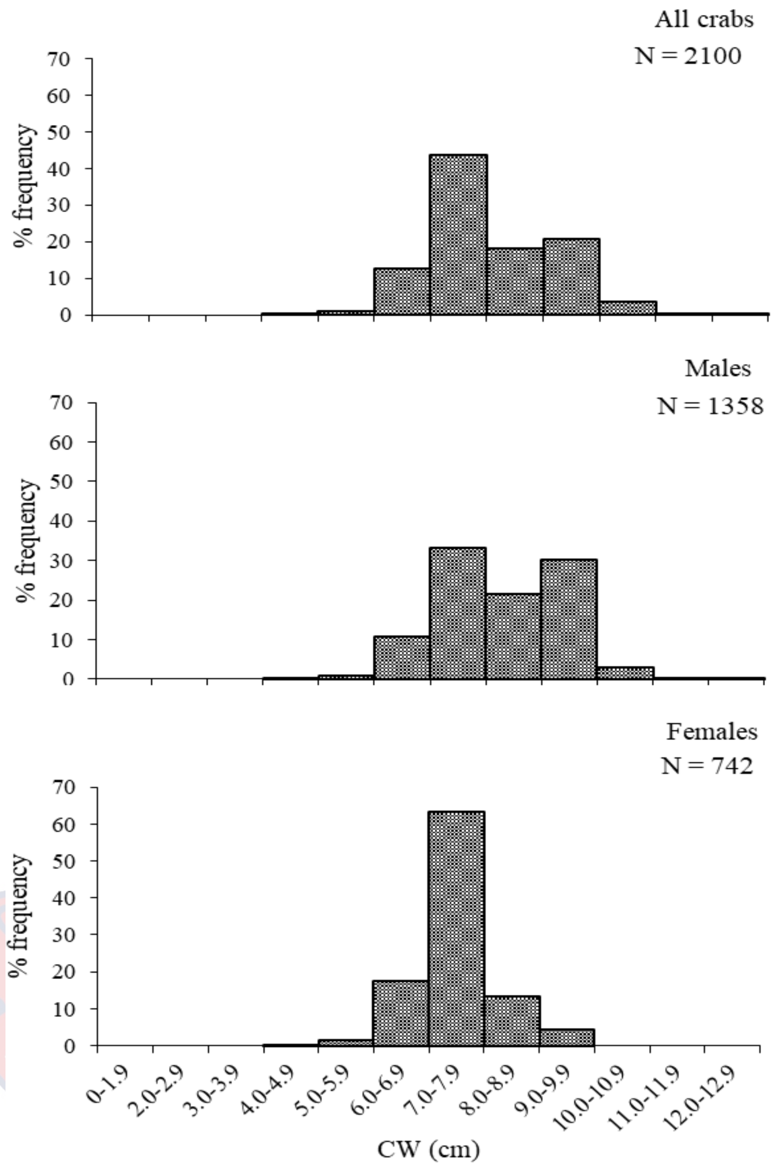


Figure 9: Carapace width frequency distribution of *Calappa rubroguttata*.

Carapace width-body weight relationship

Figure 10 shows the relationship between carapace width (*CW*) and body weight (*BW*) of males and females of *C. rubroguttata*. The relationship for males was described by the power equation:

$BW = 0.7074CW^{2.598}$

The relationship for females was described by the power equation:

$BW = 1.1069CW^{2.386}$

The regression coefficient (*b* = 2.598) for males was significantly less than 3 (t = -7.423; P = 0.00001) indicating a negative allometric growth. With *b* = 2.386 which was significantly less than 3 (t = -28.836; P = 0.00001), the females also showed a negative allometric growth.

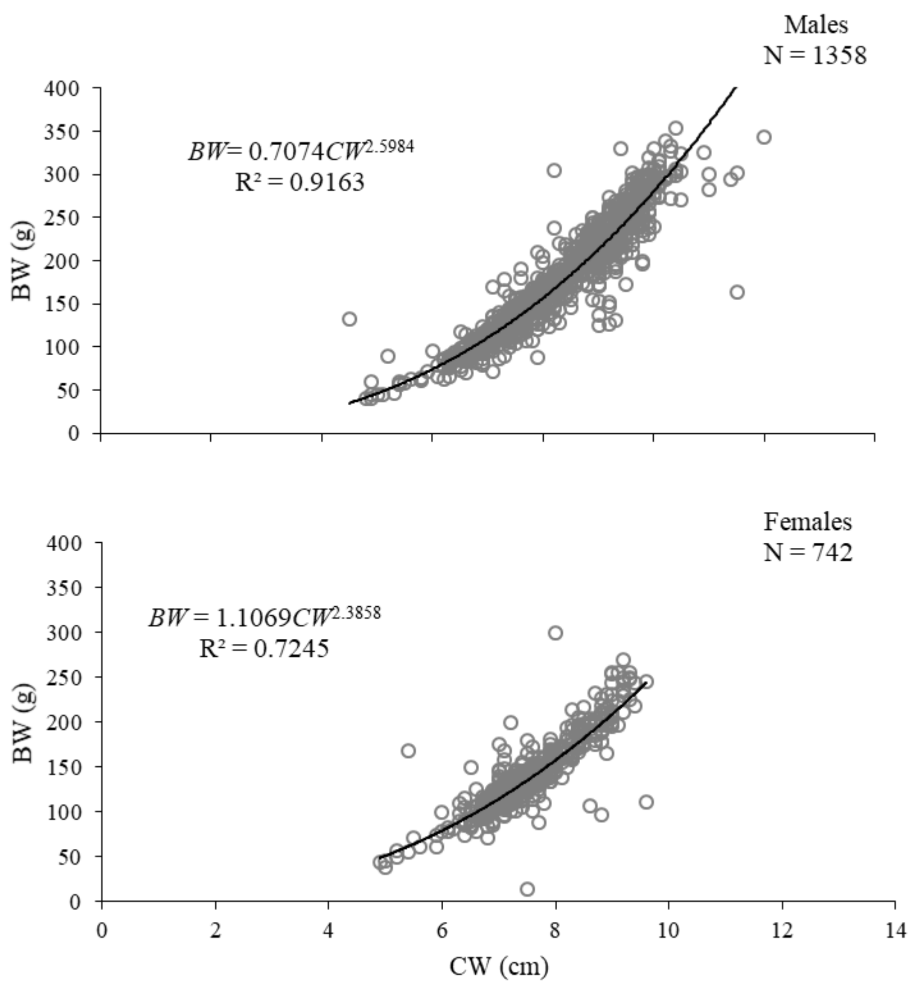


Figure 10: Carapace width and body weight relationship of *Calappa rubroguttata*.

Fluctuations in condition factor

Figure 11 shows the fluctuations in the monthly mean condition factor (*CF*) of the spotted box crab. The values ranged from 0.029±0.002 to 0.033±0.005 for males and 0.030±0.001 to 0.034±0.001 for females during the study period. Monthly mean condition factor differed significantly (t = -5.163, P = 1.24E−05) between males and females. A major peak in condition occurred in September 2017 for both sexes with minor peaks in April and November 2017, March and May-June 2018 for males. Minor peaks were also observed for females in March, May and November 2017 and May 2018. Condition factor was lowest for both sexes in July. No sample was obtained in January due to the absence of the species from landings.

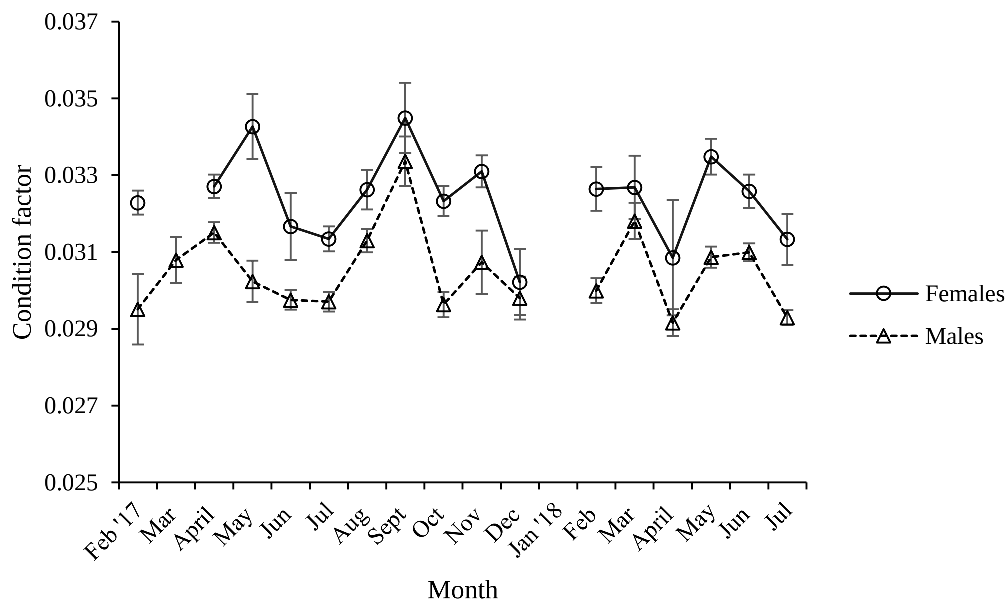


Figure 11: Monthly fluctuation in condition factor of males and females of *Calappa rubroguttata* from February 2017 to July 2018.

Growth parameters

Figure 12 shows ELEFAN I output of the monthly length frequency fitted with growth curves. Modal progression of the monthly length frequencies observed for the species from February 2017 to December 2017, May 2017 to July 2018 and from November 2017 to July 2018 indicated three distinct cohorts. Small individuals observed in November 2017 suggested recruitment into the fishery.

Table 3 shows the growth parameters of *C. rubroguttata*. Growth parameters of the spotted box crab estimated from the length frequency data using the ELEFAN I program gave an asymptotic carapace width (L_∞) of 13.13 cm and growth coefficient (K) of 0.62 yr^{-1}. The theoretical age at which the length of the crab is zero (t_o) was estimated as -0.33. The growth of *C. rubroguttata* was described by the Von Bertalanffy Growth Function (VBGF) as:

$L_t = 13.13 \times [1 - e^{(-0.62\,(t + 0.33))}]$ cm, where L_t is the carapace width of crab at age t.

The life span estimated for the crabs was 4.8 years and growth performance index (ϕ') was 2.03.

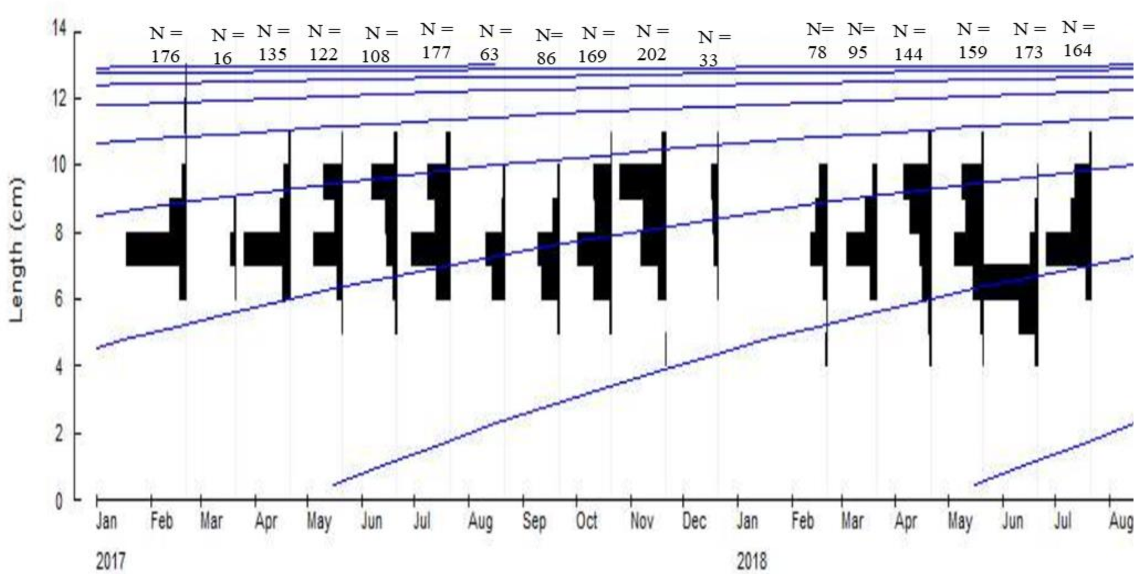


Figure 12: Monthly length frequency distribution of *Calappa rubroguttata* fitted with growth curves.

Table 3: *Estimated growth parameters of Calappa rubroguttata*

Parameter	Estimate
L_∞ (cm)	13.13
K (yr^{-1})	0.62
t_o	-0.33
ϕ'	2.03
Longevity (years)	4.8

Length at first capture

Figure 13 shows the selection curve of the spotted box crab generated from the ascending part of the length converted catch curve. Length at which 50% of the population is retained by the gear was estimated for the spotted box crab as 7.4 cm carapace width.

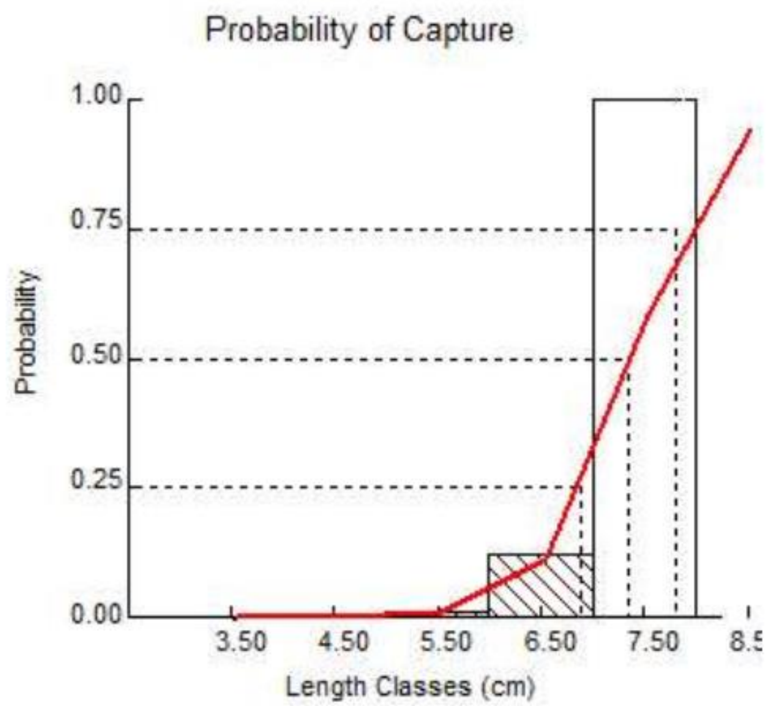


Figure 13: Selection curve of *Calappa rubroguttata*.

Mortality and exploitation ratio estimates

Figure 14 shows ELEFAN II output of the length converted catch curve of *C. rubroguttata*. The slope of the curve gave a total mortality coefficient (*Z*) of 3.50±1.33. Natural mortality coefficient (*M*) estimated from Pauly's empirical equation by substituting L_∞, *K* and a mean temperature of 27°C gave 1.62 yr^{-1}. The fishing mortality coefficient and exploitation ratio were 1.88 yr^{-1} and 0.54, respectively.

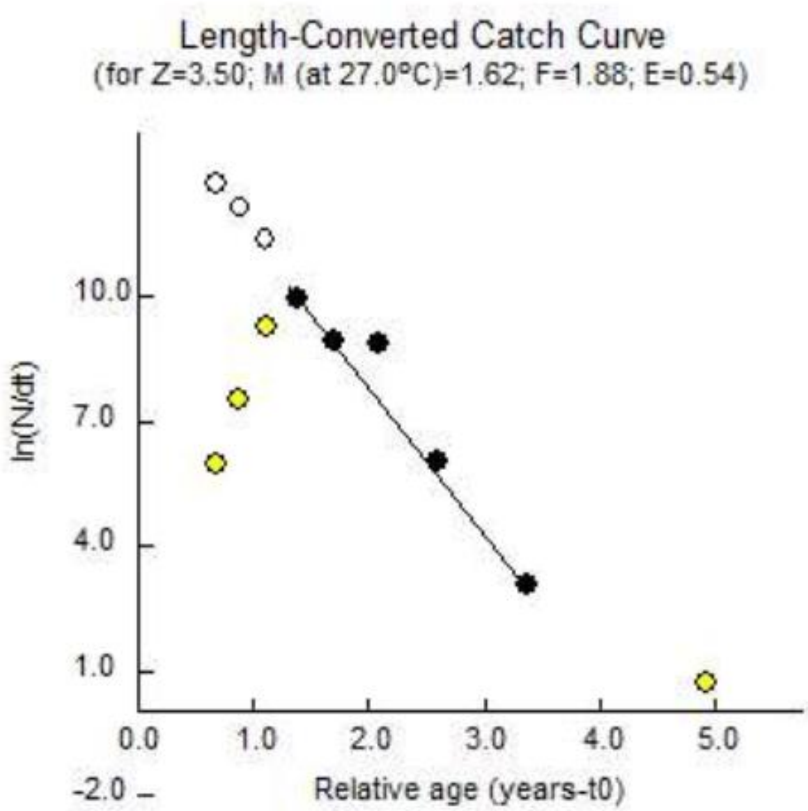


Figure 14: Length converted catch curve of *Calappa rubroguttata.*

Reproductive biology of *C. rubroguttata*

Sex ratio

The sex ratio of the spotted box crab from February 2017 to July 2018 is shown in Table 4. A total of 2,100 individual crabs was sampled, of which 1,358 were males and 742 were females. Males dominated in all months except February and October 2017. The overall ratio of males to females was therefore 1.8:1, which was significant in favor of males.

Table 4: *Sex ratio of spotted box crab (Calappa rubrogutatta) in bottom-set gillnet catches from February 2017 to July 2018*

Month	Number of fish		Sex ratio (M:F)	χ^2	Significant level ($P_{0.05}$)
	Males	Females			
Feb 2017	49	127	1 : 2.6	34.57	S
Mar	16	1	-	-	-
April	100	36	2.8 : 1	30.12	S
May	92	30	3.1 : 1	31.51	S
June	85	23	3.7 : 1	35.59	S
July	90	87	1.03 : 1	0.05	NS
Aug	44	19	2.3 : 1	9.92	S
Sept	47	39	1.2 : 1	0.74	NS
Oct	83	88	1 : 1.1	0.14	NS
Nov	143	59	2.4 : 1	34.39	S
Dec	24	9	2.8 : 1	6.81	S
Jan 2018	-	-	-	-	-
Feb	51	27	1.9 : 1	7.38	S
Mar	57	39	1.5 : 1	3.8	S
April	86	53	1.6 : 1	7.83	S
May	116	42	2.8 : 1	34.7	S
June	132	42	3.1 : 1	46.55	S
July	143	21	6.8 : 1	90.76	S
Overall	1358	742	1.8 : 1	180.69	S

*S = significant, NS = not significant

Monthly percentage occurrence of gravid crabs

Figure 15 shows the monthly percentage of gravid spotted box crabs in the samples during the study period. Gravid crabs occurred from May to December with the highest percentage occurrence in December (44.4%). Occurrence was also high in May (36.6%) and October (32.9%), and the lowest occurrence of gravid crabs (2.4%) was observed in February 2017.

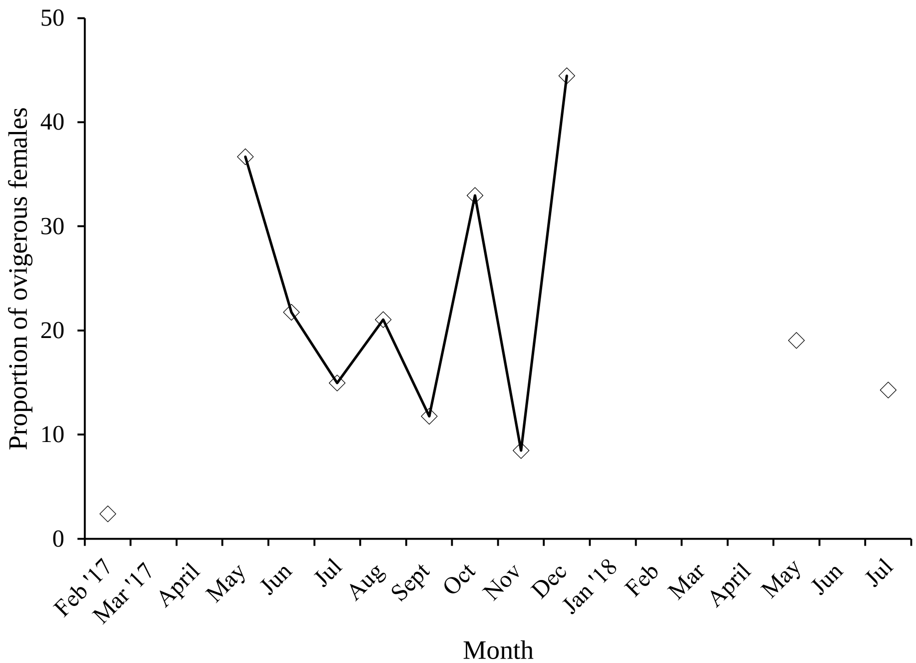


Figure 15: Monthly percentage occurrence of ovigerous crabs in samples from February 2017 to July 2018.

Ovum diameter distribution

Figure 16 shows the ovum diameter distribution of brood from five specimens of *C. rubroguttata*. The distribution of ova was unimodal for all the broods. Ova diameter of one of the specimens ranged from 0.10 mm to 0.24 mm (Appendix E) with a modal diameter at 0.15 mm – 0.19 mm. Ova from all the others had a modal diameter at 0.20 mm – 0.24 mm and a diameter range of 0.15 to 0.29 mm.

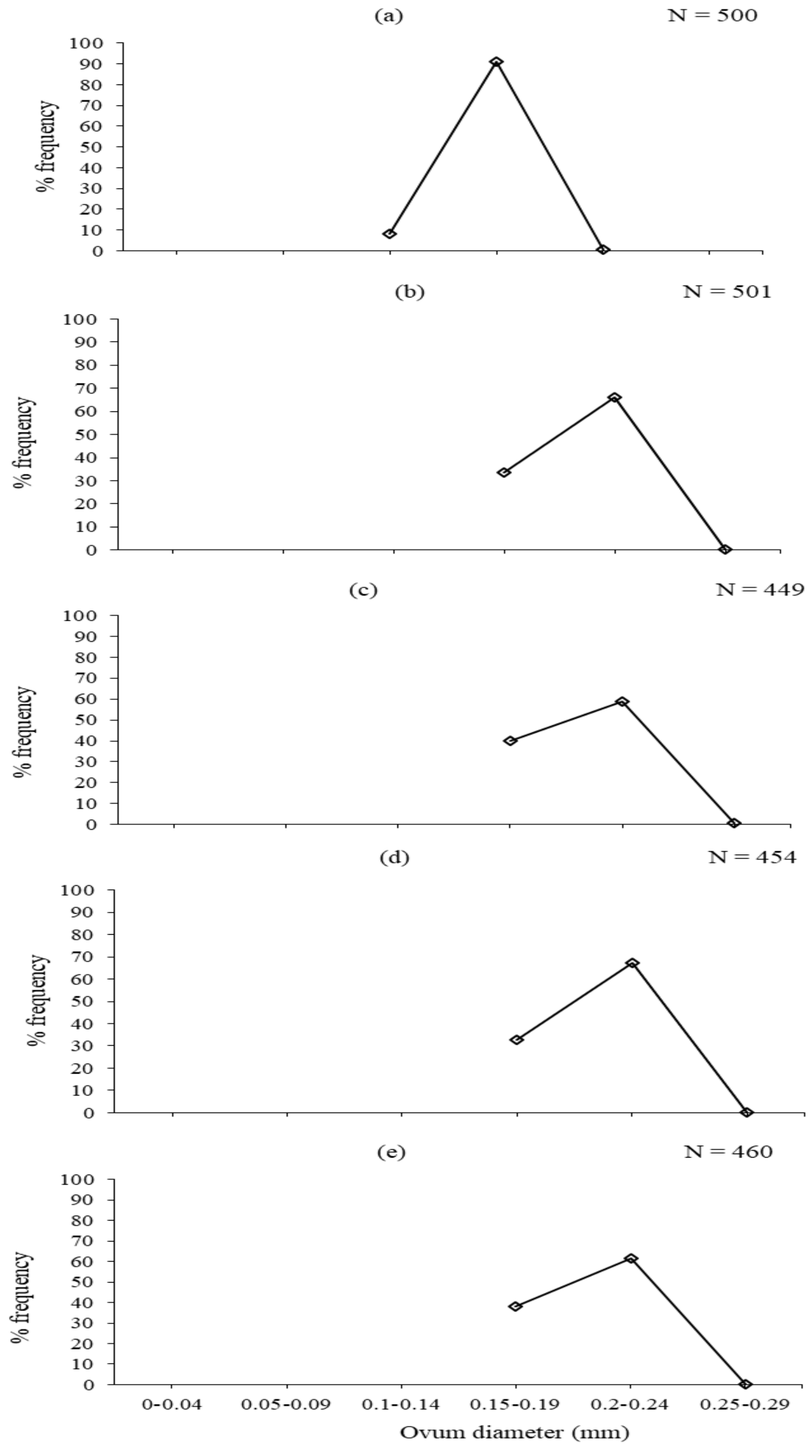


Figure 16: Ovum diameter distribution of *Calappa rubroguttata.*

Fecundity

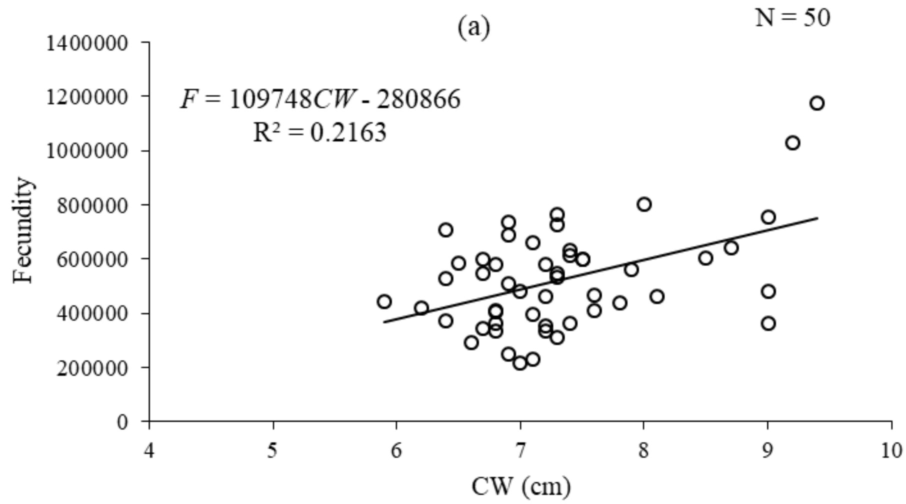
Fecundity was determined for 50 specimens of the spotted box crab. The estimated number of eggs carried by gravid specimens of *C. rubroguttata* ranged from 213,814 (in females with 7.0 cm carapace width and 122.5 g body weight) to 1,173,028 (in females with 9.4 cm carapace width and 244.0 g body weight). Mean fecundity estimated was 523,306±189,149. Figure 17 shows the relationship between fecundity and carapace width, and fecundity and body weight of spotted box crabs. The relationship between fecundity and carapace width was described by the linear equation:

$$F = 109{,}748CW - 284{,}454$$

The relationship between fecundity and body weight was described by the linear equation:

$$F = 1991.4BW + 243{,}821$$

Relationships between fecundity and carapace width (F = 13.52; $df1$ = 1; $df2$ = 49; p = 0.0006), and fecundity and body weight ($F = 14.26$; $df1$ = 1; $df2$ = 49; p = 0.0004) were significant with moderate correlation between fecundity and carapace width (r = 0.47), and fecundity and body weight (r = 0.47) of the crabs.



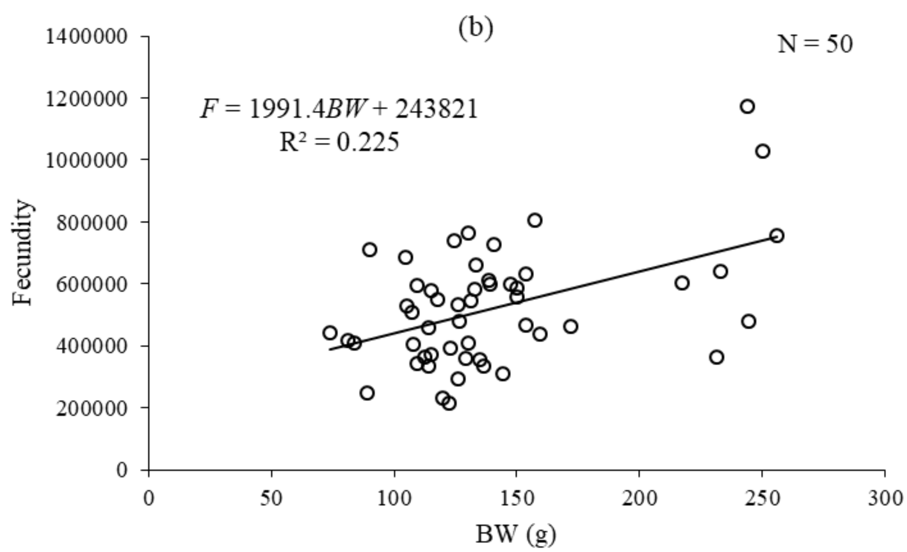


Figure 17: Relationship between (a) fecundity (*F*) and carapace width (*CW*), and (b) fecundity and body weight (*BW*) of spotted box crabs *Calappa rubroguttata*.

Growth, mortality and exploitation of the Cassava croaker (*Pseudotolithus senegalensis*)

Figure 18: Cassava croaker *Pseudotolithus senegalensis* Valencinnes, 1833 (Family: Sciaenidae).

Length frequency distribution

The length frequency distribution of *P. senegalensis* (Figure 18) is presented in Figure 19. A total of 428 individuals of *P. senegalensis* was sampled from February 2017 to July 2018. The lengths observed ranged from 15.2 cm to 46.5 cm total length. Monthly mean length determined ranged between 28.7±2.9 cm and 41.8±4.8 cm (Appendix F). At 1.0 cm class intervals, the distribution was unimodal with a modal class of 27.0 cm to 27.9 cm TL. From October 2017 to July 2018, a total of 143 males with a total length range of 18.2 cm to 42.3 cm, and 139 females with a total length range of 20.3 cm to 44.4 cm were examined. The length distribution of males and females was unimodal with a mode in the 27.0 cm class.

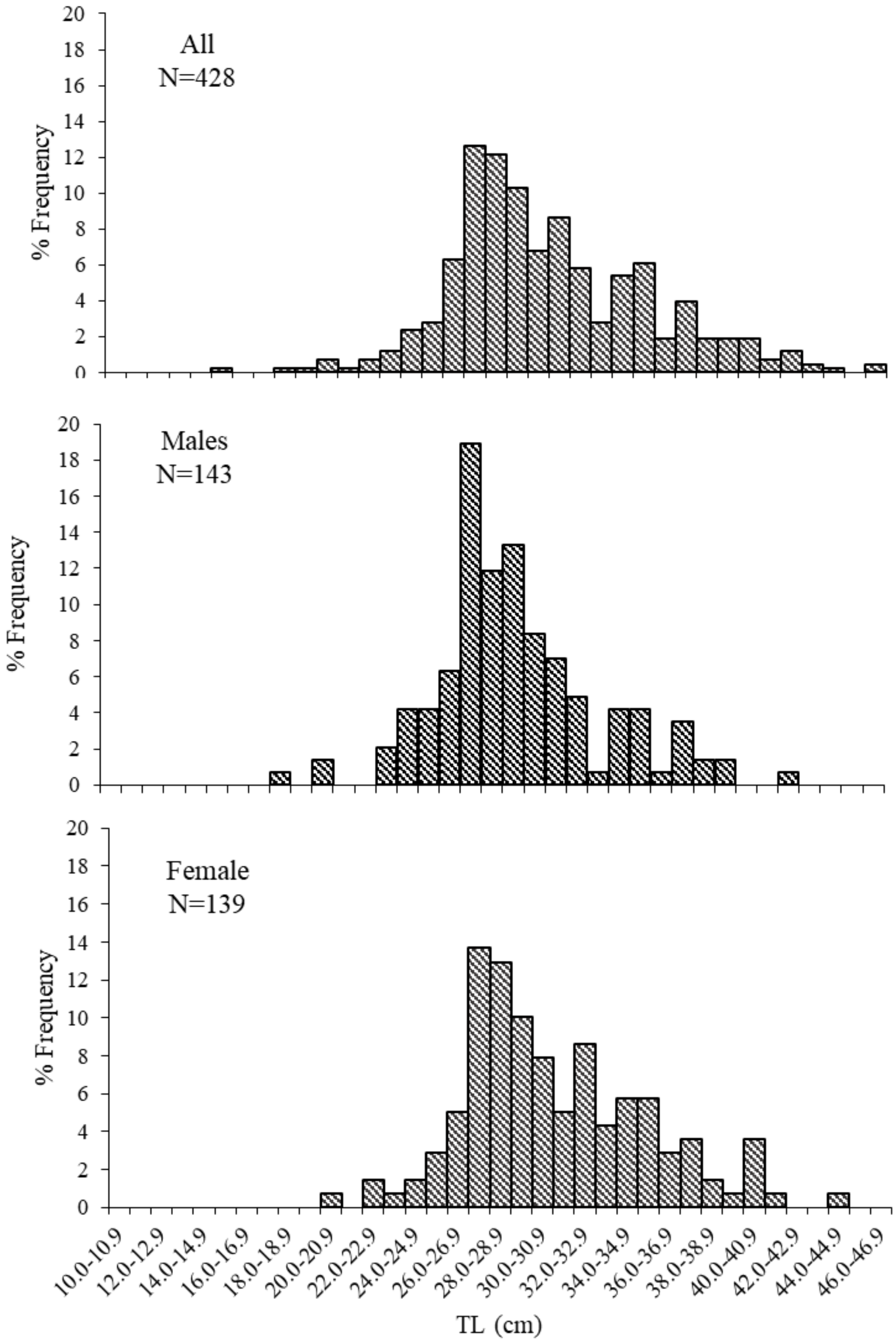


Figure 19: Length frequency distribution of *Pseudotolithus senegalensis.*

Length-weight relationship

The relationship between the total length (*TL*) and body weight (*BW*) of *P. senegalensis* males and females is shown in Figure 20. The relationship for males was described by the power equation:

$$BW = 0.0355TL^{2.762}$$

The relationship for females was described by the power equation:

$$BW = 0.0372TL^{2.757}$$

At 95% confidence level, the regression coefficient of males and females (b = 2.762 and 2.757 respectively) was statistically less than 3 for males (t = -3.167; P = 0.0019) and females (t = -2.817; P = 0.0055) indicating negative allometric growth.

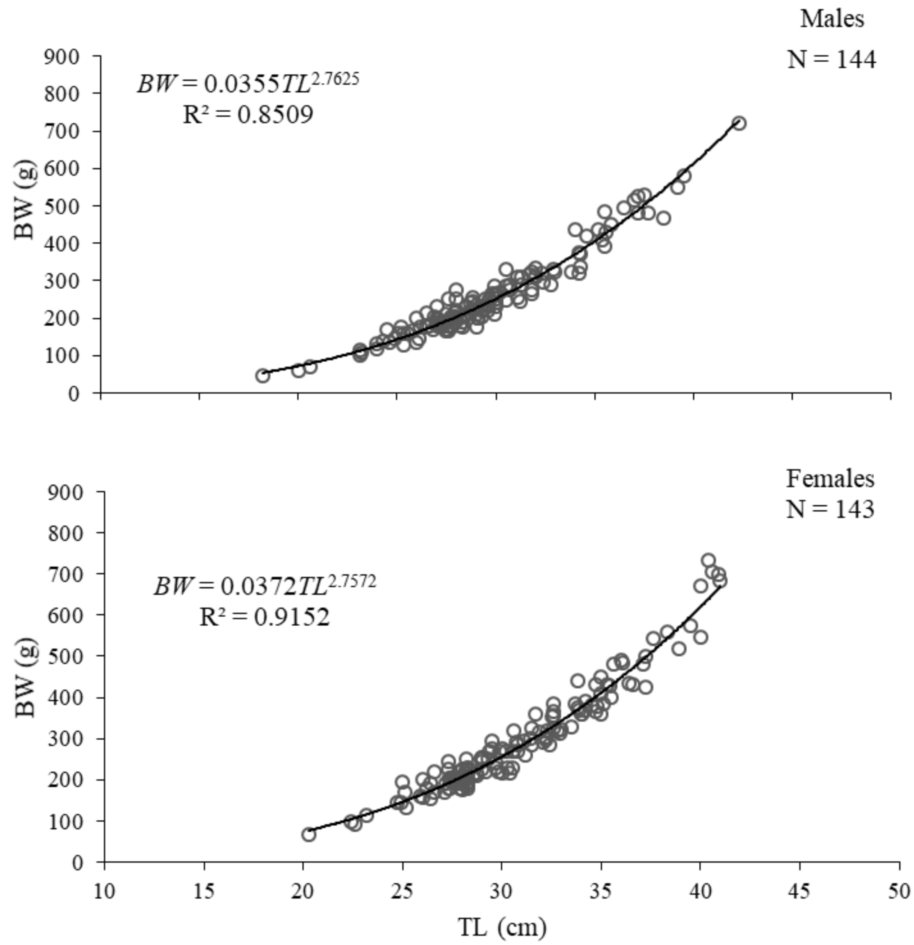


Figure 20: Length-weight relationship of *Pseudotolithus senegalensis.*

Fluctuations in condition factor

Figure 21 shows the monthly fluctuations in the condition of male and female cassava croakers. Monthly mean condition factor for males fluctuated between 0.013±1.013 and 0.247±0.967, and that of females fluctuated between 0.892±0.042 and 1.089±0.110 during the study period. Condition was highest for males in December 2017, and for females in January 2017. Peaks were also recorded for males in October 2017, March and June 2018, and for females in

October 2017, April-May and July 2018. The lowest condition factor recorded for males was in July 2018 and that of females was in February 2018.

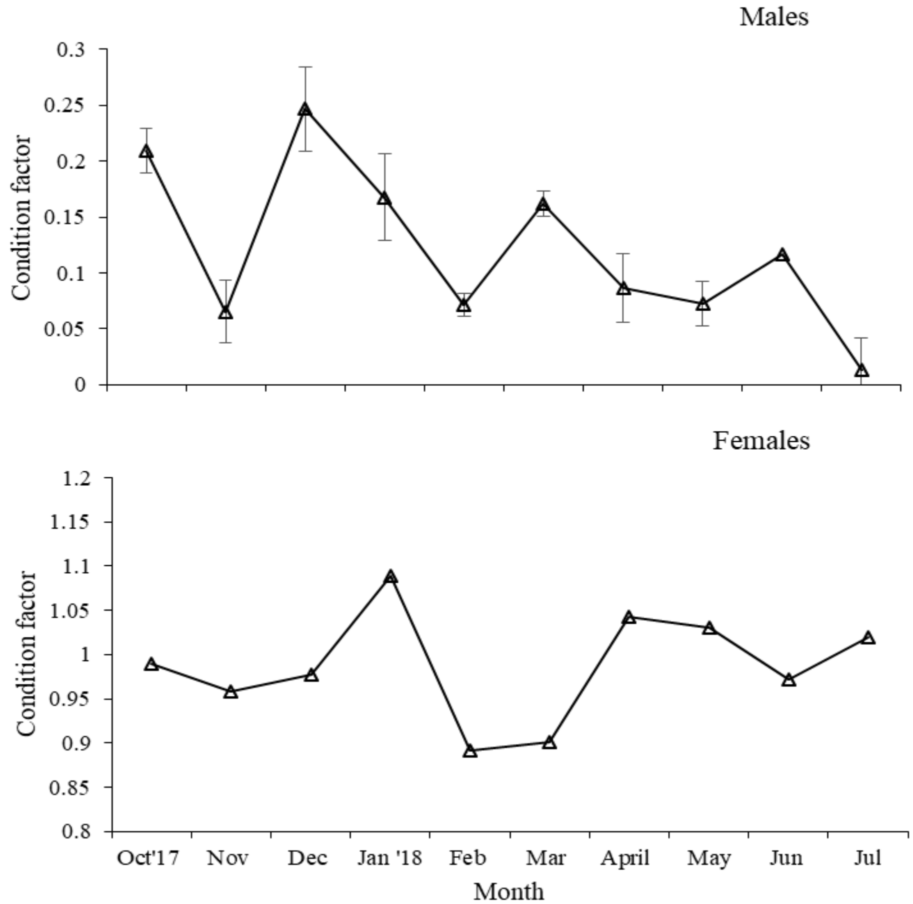


Figure 21: Monthly fluctuation in condition factor of males and females of *Pseudotolithus senegalensis.*

Growth parameters

Figure 22 shows the monthly length frequency data fitted with growth curves generated by ELEFAN I. Progression of modes observed in the restructured monthly length frequency data showed the growth of one cohort from February 2017 to May 2018. Small size individuals observed in February 2017 and December 2017 suggested possible recruitment.

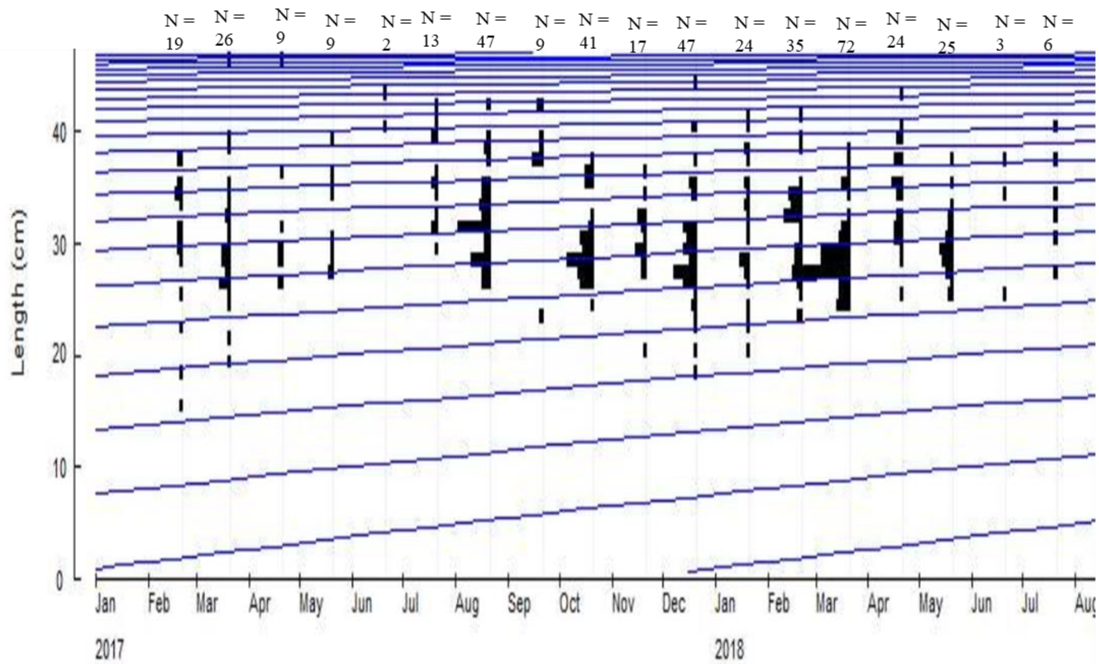


Figure 22: Monthly length frequency distribution of *P. senegalensis* with superimposed growth curves.

Analysis of the length frequency data using the ELEFAN I program estimated the VBGF parameters. Table 5 shows the estimated growth parameters of *P. senegalensis*. L_∞ and K were estimated as 48.83 cm and 0.17yr^{-1} respectively. Substituting L_∞ and K in the respective equations, age at length zero of the species was -1.3 and longevity, which is the number of years the species can live if not caught was estimated as 17.6 years. Growth of *P. senegalensis* was thus described by the Von Bertalanffy Growth Function as:

$L_t = 48.83 \times [1 - e^{(-0.17\,(t + 1.3))}]$ cm, where L_t is the length of the fish at age t.

Growth performance index (ϕ') was estimated as 2.61.

Table 5: *Estimated growth parameters of Pseudotolithus senegalensis*

Parameter	Estimate
L_∞ (cm)	48.83
K (yr-1)	0.17
t_o	-1.3
ϕ'	2.61
Longevity (years)	17.6

Length at first capture

The selection curve of *P. senegalensis,* generated from the ascending part of the length converted catch curve, is shown in Figure 23. The length at first capture (L_C) estimated for *P. senegalensis* was 27.8 cm.

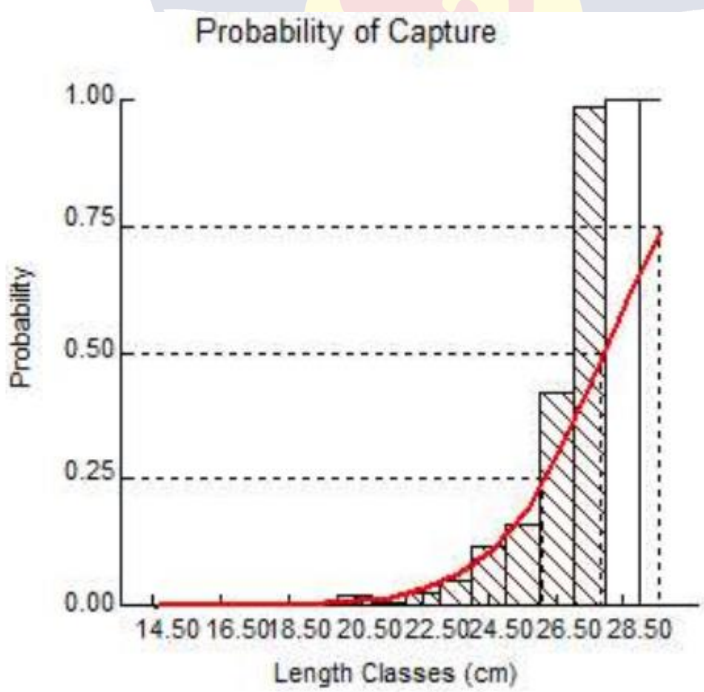


Figure 23: Selection curve of *Pseudotolithus senegalensis.*

Length at first maturity

Maturity ogive of *P. senegalensis* males and females is presented in Figure 24. Length at which 50% of the males reach sexual maturity was 20.9 cm TL and L_{m50} for females was 26.8 cm TL. Majority of individuals (98% males and 87% females) observed have attained the L_{m50}.

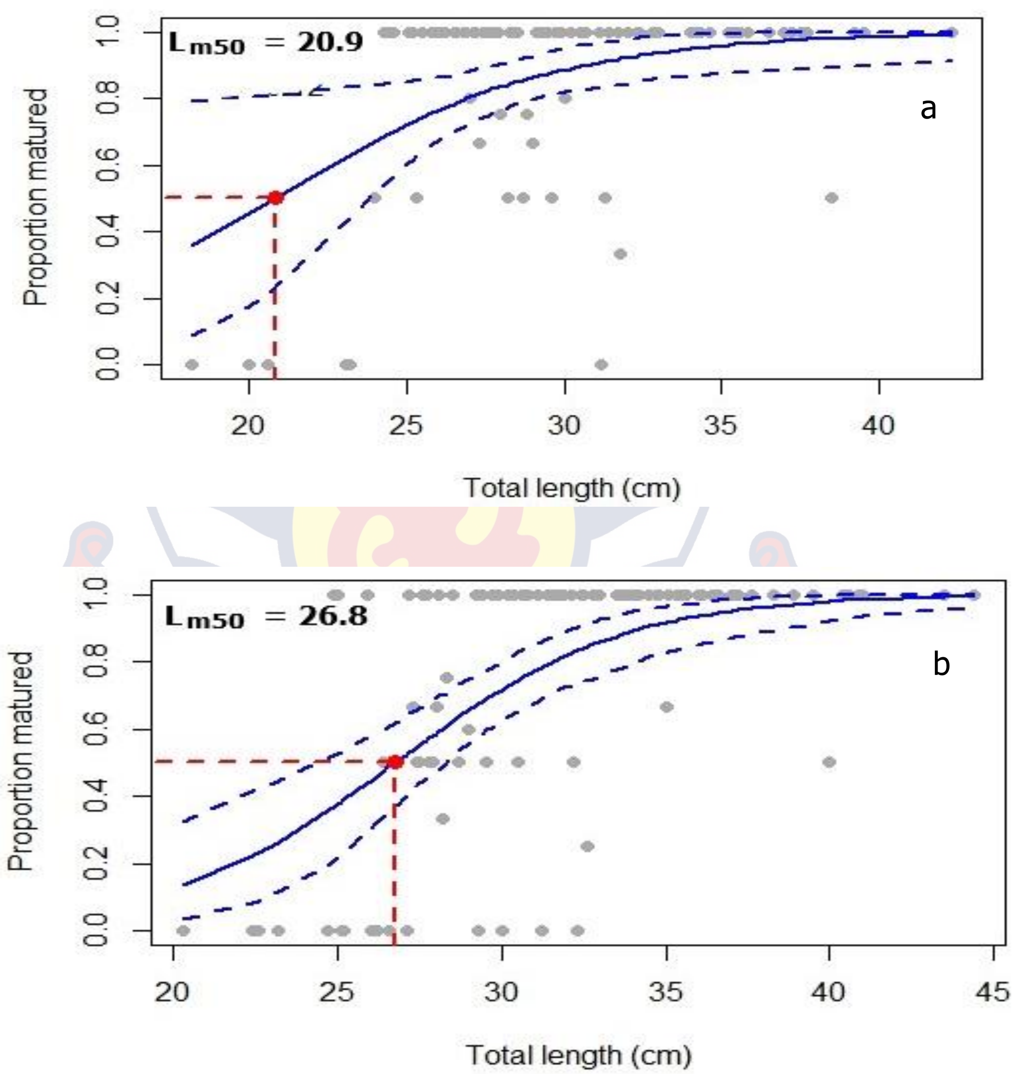


Figure 24: Maturity ogive of *Pseudotolithus senegalensis* males (a) and females (b).

Mortality and exploitation ratio estimates

Figure 25 shows the length converted catch curve of *P. senegalensis* generated by ELEFAN II. The slope of the curve, which is the total mortality coefficient (Z) was estimated as 0.58±0.06 yr^{-1}. Natural mortality coefficient estimated by substituting L_∞, K and a mean water temperature of 27°C in Pauly's empirical equation was 0.48 yr^{-1}. From Z and M, fishing mortality coefficient (F) was estimated as 0.10 yr^{-1}and the exploitation ratio estimated from F and Z was 0.17.

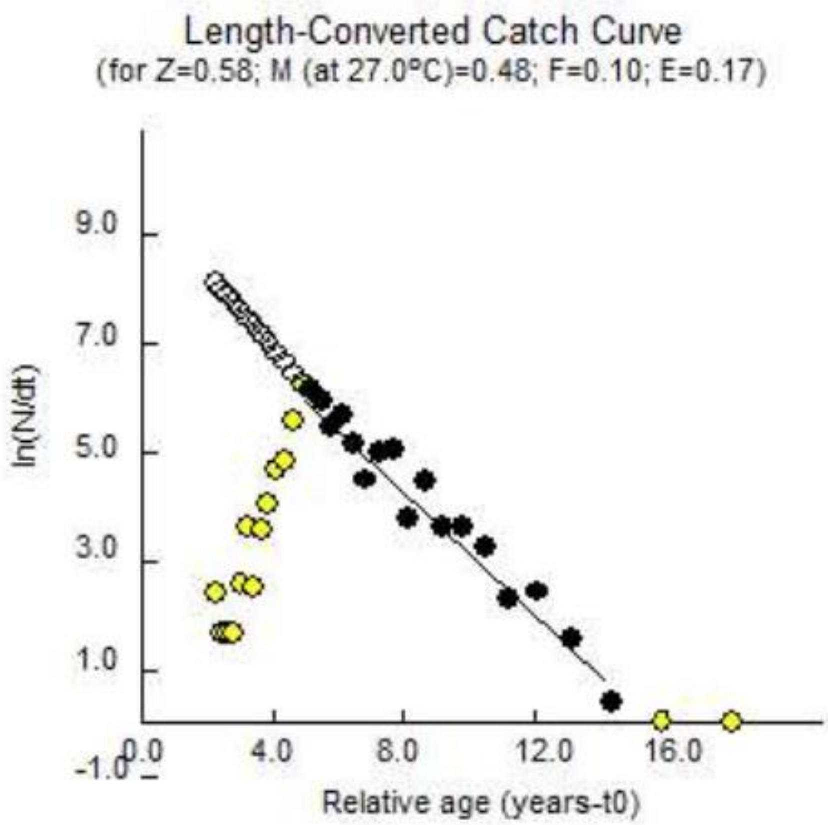


Figure 25: Length converted catch curve of *Pseudotolithus senegalensis*.

Reproductive biology of *Pseudotolithus senegalensis*

Sex ratio

The sex ratio of the cassava croaker in bottom-set gillnet catches is presented in Table 6. A total of 144 males and 143 female cassava croakers were analyzed from October 2017 to July 2018. Significant differences ($P < 0.05$) in the ratio of males to females were observed in November 2017, January and April 2018. The sex ratio in all the other months was not significant and the overall ratio was 1.01:1, which also was not significant.

Table 6: *Sex ratio of Pseudotolithus senegalensis in the bottom-set gillnet catches from October 2017 to July 2018*

Month	Number of fish		Sex ratio (M:F)	χ^2	Significant level ($P_{0.05}$)
	Males	Females			
Oct 2017	20	20	1 : 1	-	-
Nov	7	10	1 : 1.4	0.53	S
Dec	19	22	1 : 1.6	0.22	NS
Jan 2018	12	8	1.5 : 1	0.80	S
Feb	18	17	1.1 : 1	0.03	NS
Mar	37	35	1.1 : 1	0.06	NS
April	14	9	1.6 : 1	1.09	S
May	13	16	1 : 1.2	0.31	NS
June	2	1	2 : 1	-	-
July	2	5	1 : 2.5	-	-
Overall	144	143	1.01 : 1	0.003	NS

*S = significant, NS = not significant

Fluctuations in gonadosomatic index

Figure 26 shows fluctuations in monthly mean gonadosomatic index (GSI) of *P. senegalensis* males and females from October 2017 to July 2018. Monthly mean GSI ranged from 0.21±0.19 to 0.46±0.17 for males, and 0.42±0.41 to 3.91±2.51 for females. GSI was lowest in October 2017 and highest in April 2018 for both sexes.

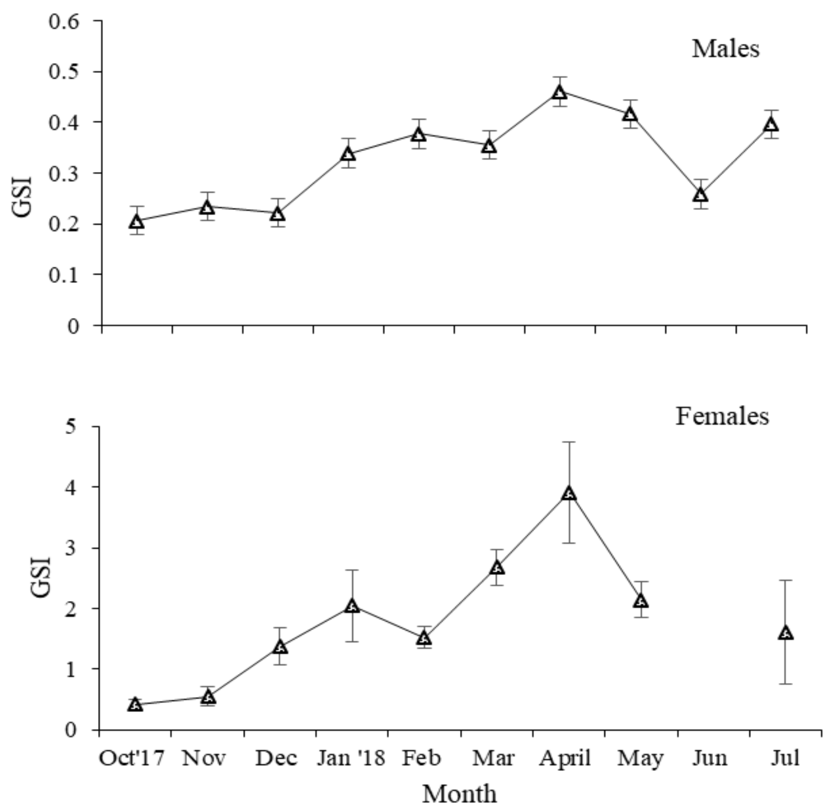


Figure 26: Monthly fluctuation in GSI of *Pseudotolithus senegalensis* males and females.

Monthly occurrence of ripe gonads

The monthly occurrence of ripe cassava croaker gonads in samples from October 2017 to July 2018 is shown in Figure 27. The highest occurrence was observed in February-May 2018. A peak was also observed in July 2018.

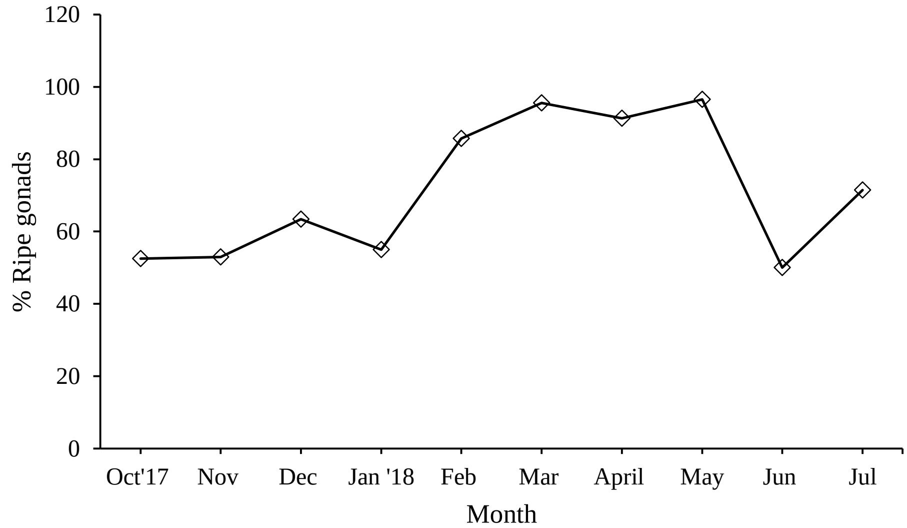


Figure 27: Monthly fluctuation in the occurrence of ripe gonads in *Pseudotolithus senegalensis.*

Ovum diameter distribution

Figure 28 shows the ovum size distribution in five ripe ovaries of *P. senegalensis.* Ova diameter distribution was bimodal for all specimen. Ova diameter ranged from 0.05 mm to 0.03 mm (Appendix E) for two of the specimens with modal classes at 0.12 mm – 0.15 mm and 0.20 mm – 0.23 mm. Modes were observed in 0.12 mm – 0.15 mm size group and 0.24 mm – 0.27 mm size group for two other specimens, with diameter range of 0.10 mm to 0.30 mm. With a size range between 0.05 mm and 0.27, one of the specimens had modal diameter at 0.08 mm – 0.11 mm and 0.20 mm – 0.23 mm.

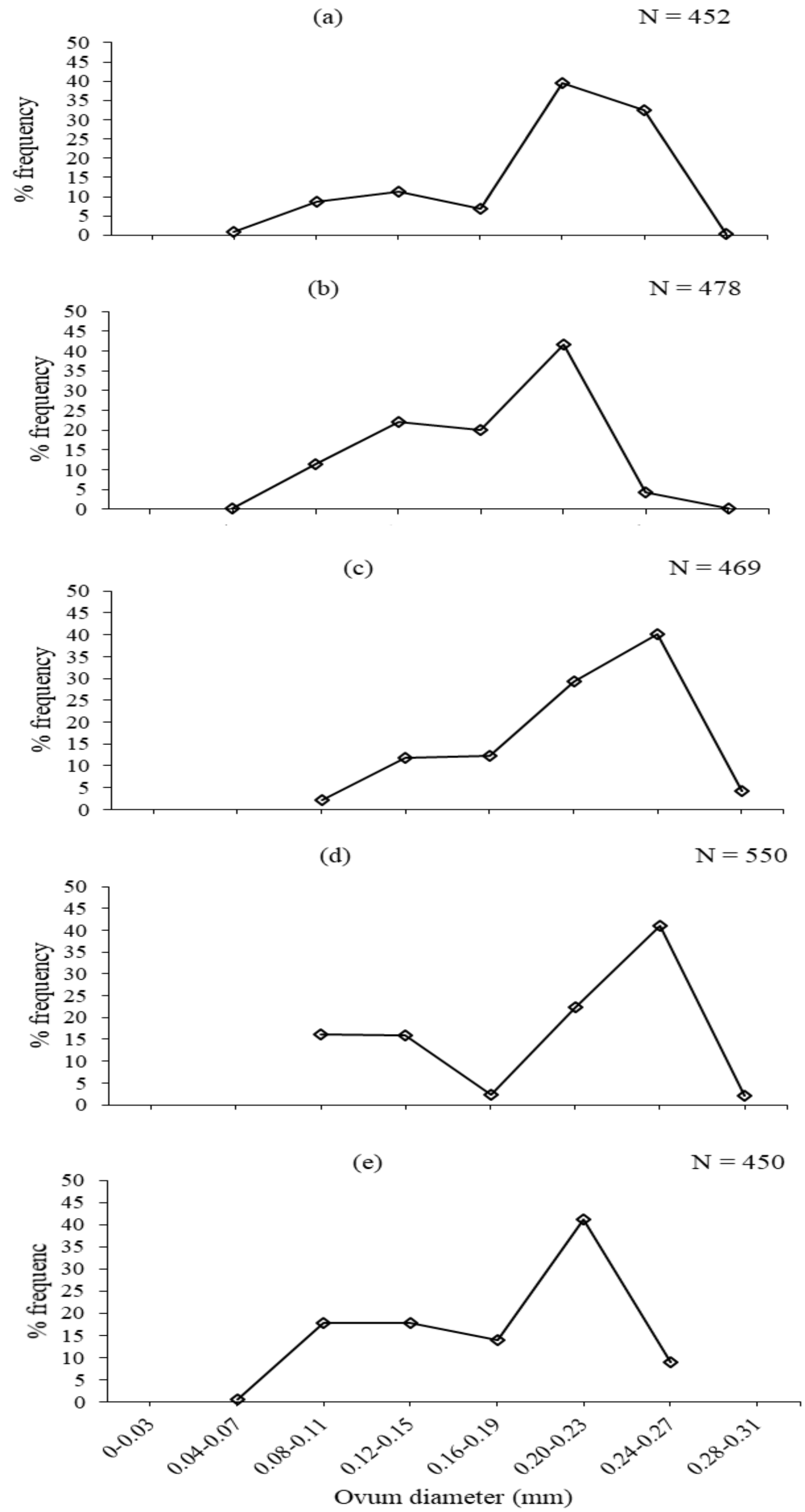


Figure 28: Ovum diameter distribution of *Pseudotolithus senegalensis*.

Fecundity

A total of 29 specimens were selected for the determination of fecundity. Gravid females of *P. senegalensis* were estimated to carry 125,005 eggs to 508,622 eggs in individuals of 28.3 cm total length and 230 g body weight, and 40 cm total length and 670 g body weight respectively. Mean fecundity recorded was 193,690±143,065. Figure 29 shows the relationship between fecundity and body weight, and fecundity and total length of *Pseudotolithus senegalensis*. Fecundity and body weight relationship was described by the linear equation:

$$F = 438.1BW + 105748$$

Fecundity and total length relationship was described by the linear equation:

$$F = 17102TL - 293532$$

The relationship between fecundity and body weight ($F = 24.5$; $df1 = 1$; $df2 = 20$; $p = 7.63E\text{-}05$), and fecundity and total length ($F = 45.8$; $df1 = 1$; $df2 = 20$; $p = 1.39E\text{-}06$) was significant with strong correlations between fecundity and body weight ($r = 0.84$), and fecundity and total length ($r = 0.83$).

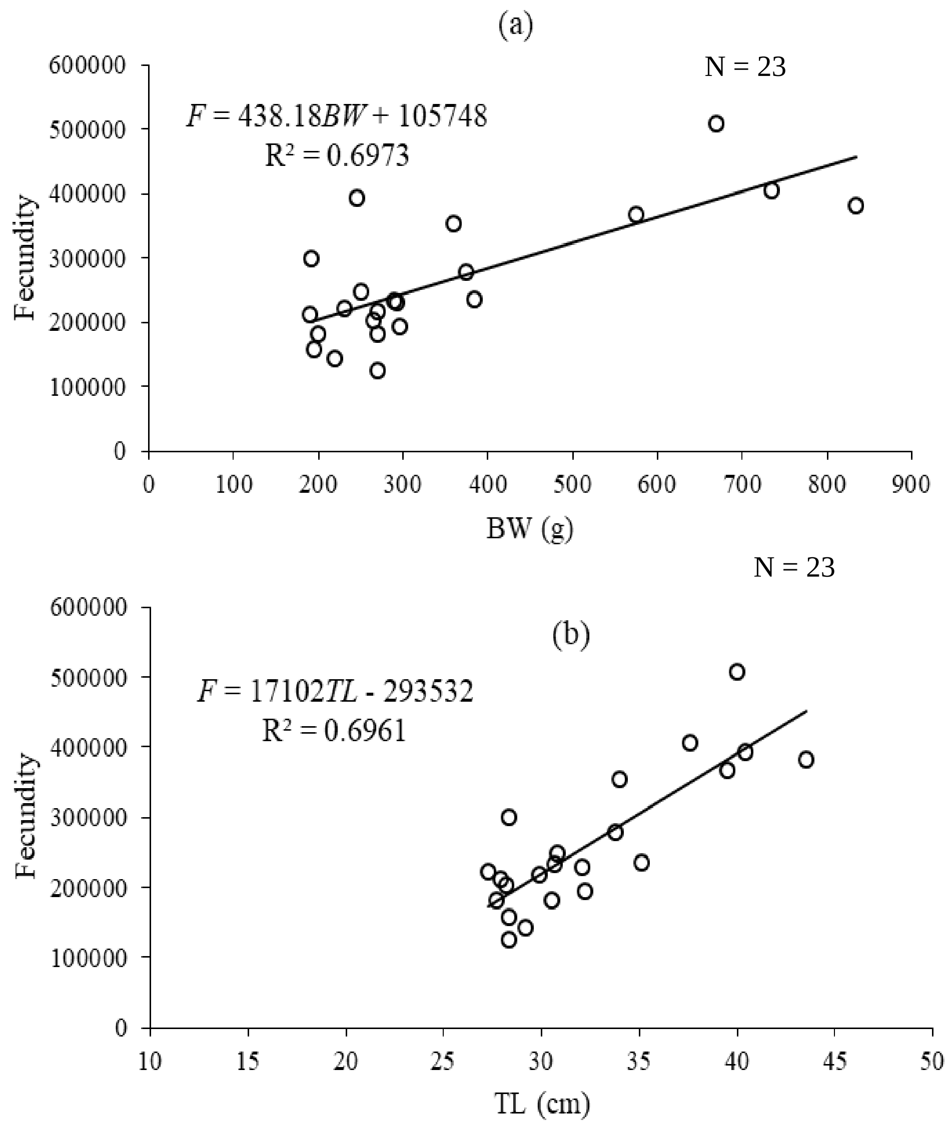


Figure 29: Relationship between (a) fecundity (*F*) and body weight (*BW*), and (b) fecundity and total length (*TL*) of *Pseudotolithus senegalensis.*

Growth, mortality and exploitation of the Senegalese tonguesole (*Cynoglossus senegalensis*)

Figure 30: The Senegalese tonguesole *Cynoglossus senegalensis* Kaup, 1858 (Family: Cynoglossidae)

Length frequency distribution

Figure 31 shows the length frequency distribution of *C. senegalensis* (Figure 30) in samples from February 2017 to July 2018. The lengths ranged from 22.9 cm to 59.0 cm TL, with the monthly mean length ranging between 30.9±6.6 cm and 48.0±4.8 cm (Appendix G). The distribution was unimodal with a mode in the 41 cm group. Males and females in samples from October 2017 to July 2018 were of size ranges of 22.9 cm to 47.8 cm, and 24.6 cm to 55.5 cm, respectively. The length frequency distribution of males was unimodal with a modal class of 39.0 cm to 39.9 cm. Females showed a bimodal length frequency distribution with modes in the 43 cm and 50 cm groups.

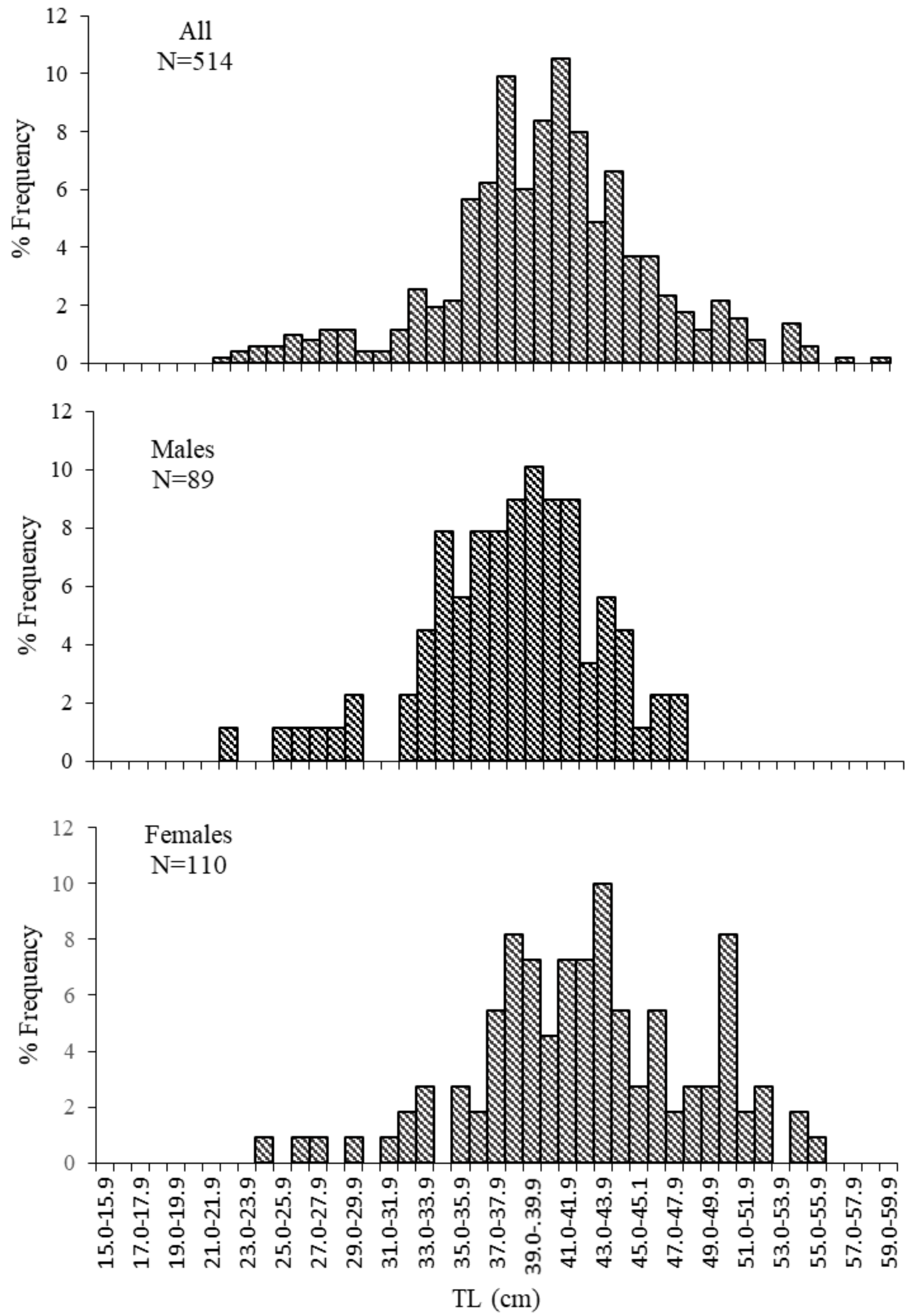


Figure 31: Length frequency distribution of *Cynoglossus senegalensis* from February 2017 to July 2018.

Length-weight relationship

The relationship between the body weight (*BW*) and total length (*TL*) of *C. senegalensis* males and females is illustrated in Figure 32. The relationship for males was described by the power equation:

$BW = 0.0051TL^{3.036}$

The body weight and total length relationship for females was described by the power equation:

$BW = 0.0018TL^{3.322}$

The regression coefficient (b = 3.036 and b = 3.322 respectively) was not statistically different from 3 (t = 0.363; P = 0.717) for males, and significantly greater than 3 for females (t = 4.952; P = 0.00001), indicating isometric growth in males and positive allometric growth in females.

Condition factor

Figure 33 shows fluctuations in mean monthly condition factor of *C. senegalensis* males and females. Fulton's condition factor of *C. senegalensis* fluctuated between 0.431±0.079 and 0.564±0.083 for males, and 0.461±0.051 and 0.548±0.040 for females. Monthly fluctuations observed for the two sexes showed no significant difference (t = -1.007, P = 0.329). Peaks were observed for males in October and December 2017 with a major one in May 2018. Condition for females was highest in July 2017 with other peaks recorded in October 2017 and April 2018. Condition was lowest in January for both sexes.

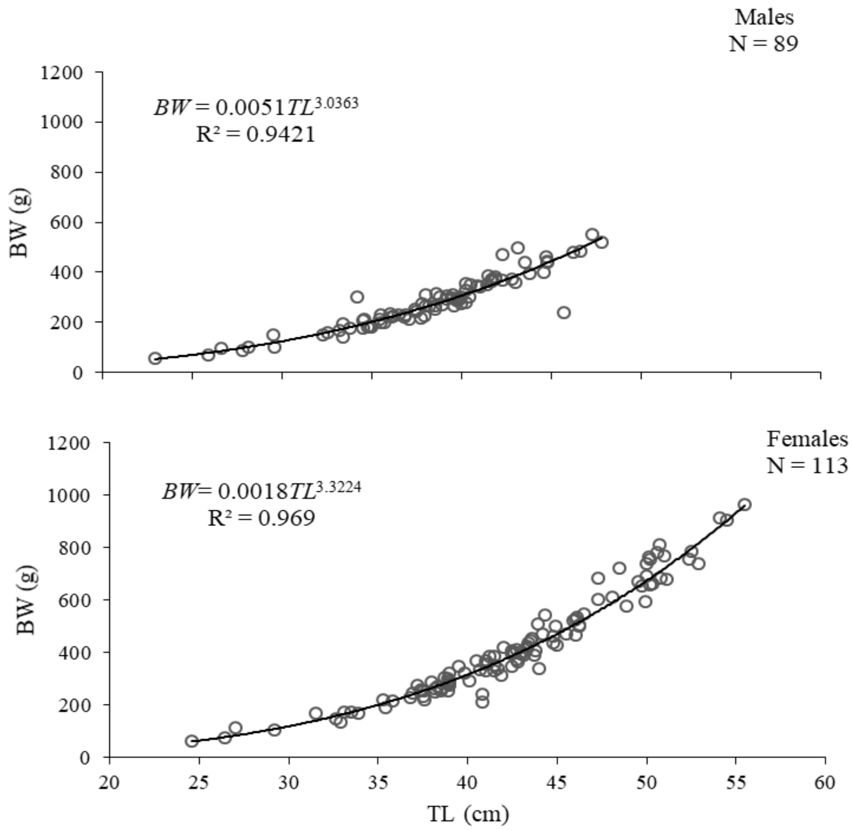


Figure 32: Length-weight relationship of *Cynoglossus senegalensis.*

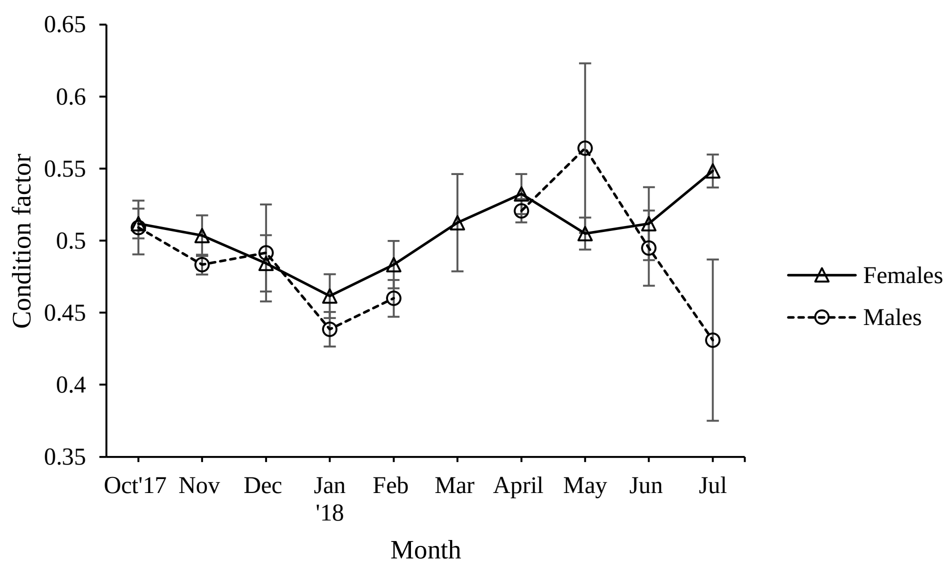


Figure 33: Monthly fluctuation in mean condition factor of *Cynoglossus senegalensis* males and females from October 2017 to July 2018.

Growth parameters

Figure 34 shows ELEFAN I output of the monthly length frequencies of *C. senegalensis* superimposed with growth curves. Progression of modes from February 2017 to February 2018 and also from April 2017 to July 2018 indicated two cohorts.

Analysis of the length frequency data by ELEFAN I estimated the parameters of the Von Bertalanffy Growth Function (VBGF). Table 7 shows the growth parameter determined for *C. senegalensis*. L_∞ and K were determined as 60.38 cm and 0.18 yr^{-1} respectively. Substituting L_∞ and K in the respective equations, the theoretical age at length zero was -0.72 and the maximum number of years the species can live if not caught (longevity) was determined as 16.7 years. From the estimated parameters, growth of *C. senegalensis* was described by the equation:

$L_t = 60.38 \times [1 - e^{(-0.18\,(t + 0.72))}]$ cm TL, where Lt is the length of fish at age t.

Growth performance index was estimated as 2.82.

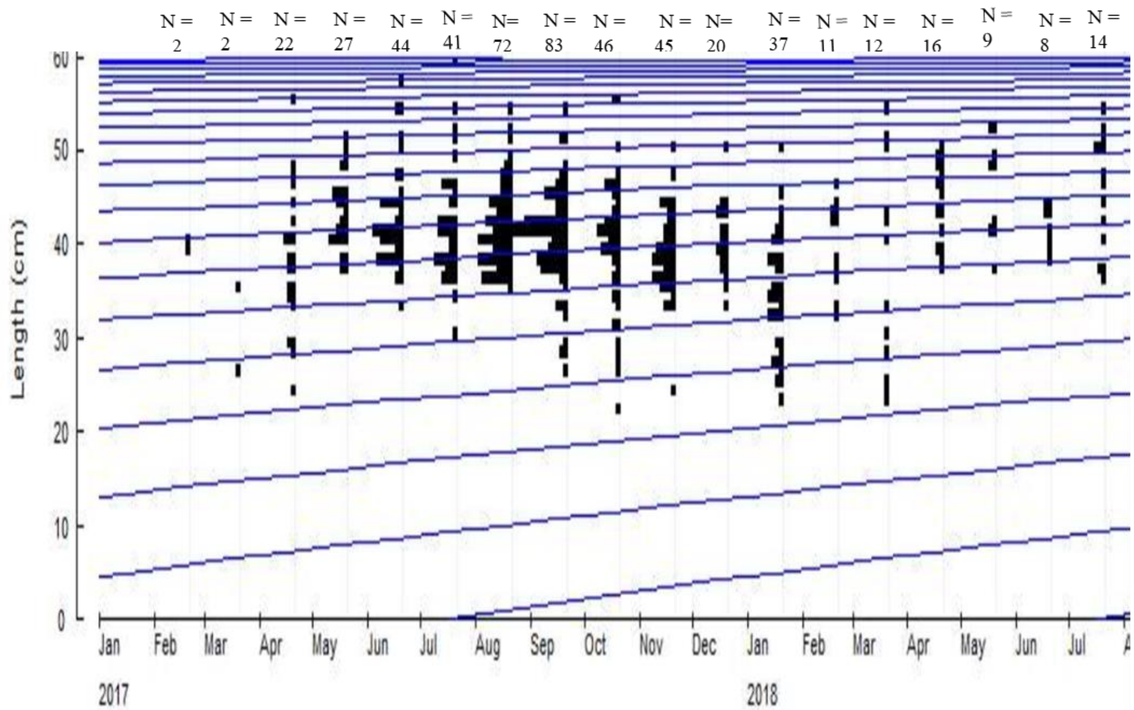


Figure 34: Monthly length frequency distribution of *C. senegalensis* with superimposed growth curve.

Table 7: *Growth parameters of Cynoglossus senegalensis*

Parameter	Estimate
L_∞ (cm)	60.38
$K(yr^{-1})$	0.18
t_o	-0.72
ϕ'	2.82
Longevity (years)	16.7

Length at first capture

The selection curve of *C. senegalensis* generated from the ascending part of the length converted catch curve is presented in Figure 35. Size at first capture (L_c) estimated from the selection curve was 39.42 cm.

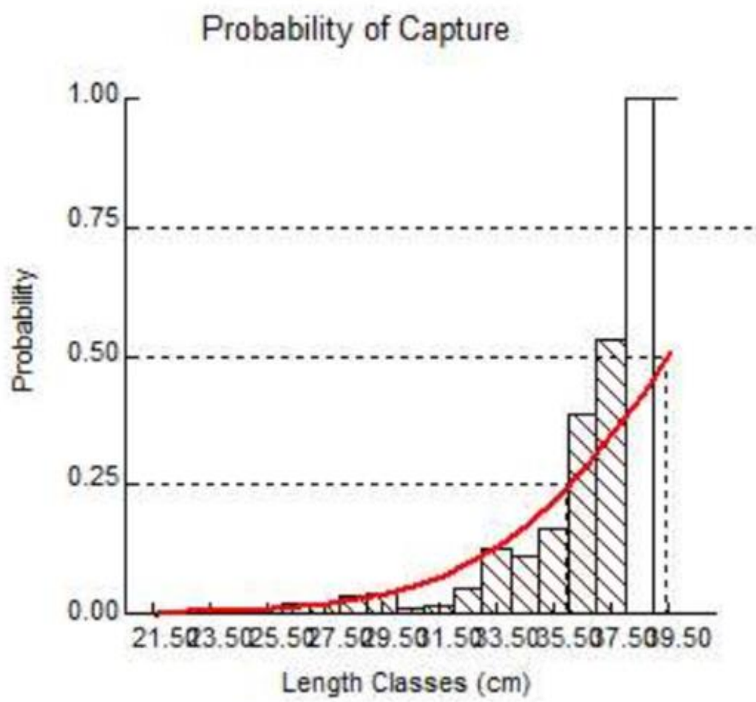


Figure 35: Selection curve of *Cynoglossus senegalensis.*

Length at first maturity

Maturity ogive of the Senegalese tonguesole is presented in Figure 36. L_{m50}, which is the length at which half the population of *C. senegalensis* reach sexual maturity, was 40.6 cm TL for females. The minimum matured length (L_m) observed was on the other hand 35.3 cm TL, and 28% of females encountered have attained the L_{m50} estimated.

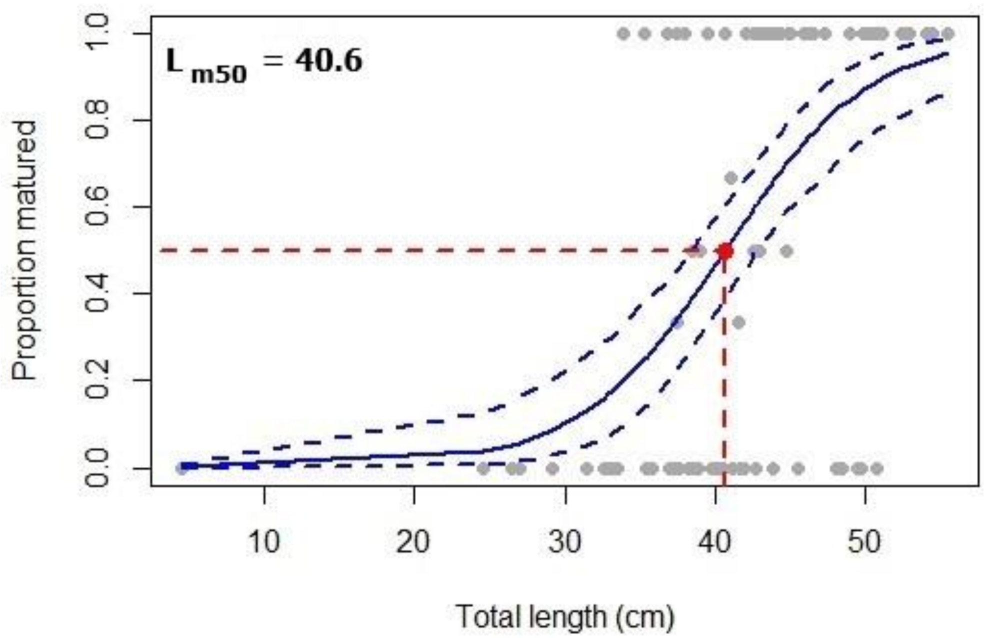


Figure 36: Length at sexual maturity of *Cynoglossus senegalensis* females.

Mortality and exploitation ratio estimates

Figure 37 shows the ELEFAN II output of the length converted catch curve of *C. senegalensis*. Total mortality coefficient (*Z*) estimated from the slope of the length converted catch curve was 0.61±0.05 yr^{-1}. The natural mortality coefficient (*M*) of 0.47 yr^{-1} was determined by substituting L_{∞}, *K* and a mean water temperature of 27^{o}C in Pauly's empirical formula. Fishing mortality coefficient (*F*) of 0.14 yr^{-1} was estimated from *Z* and *M* and exploitation ratio estimated from *Z* and *F* was 0.23.

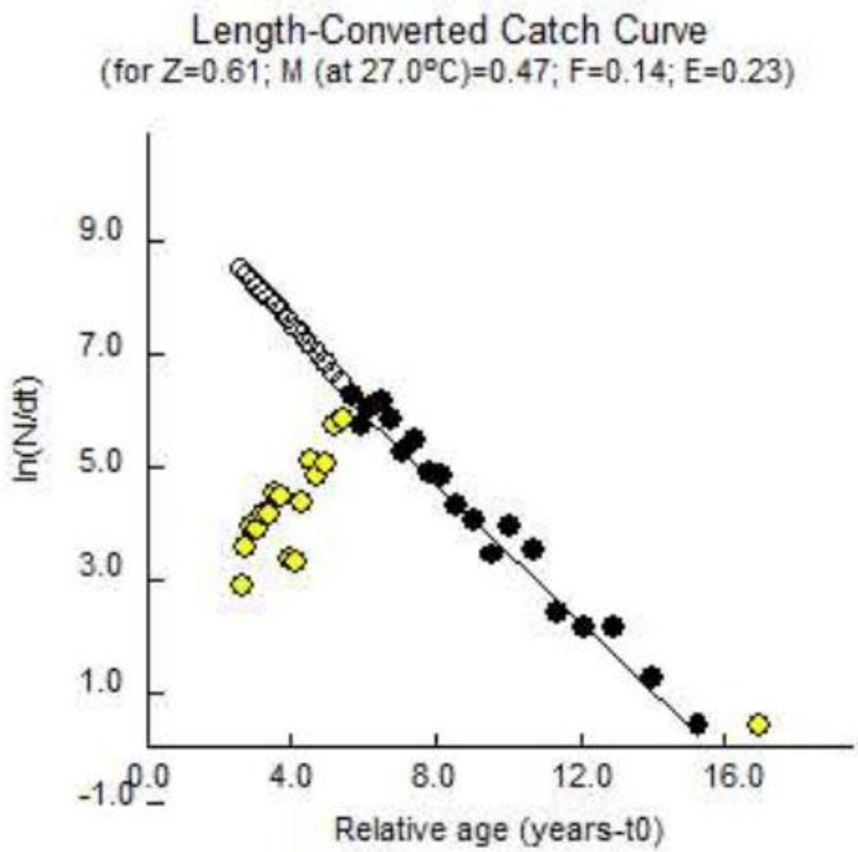


Figure 37: Length converted catch curve of *Cynoglossus senegalensis*.

Reproductive biology of *Cynoglossus senegalensis*

Sex ratio

Table 8 shows the monthly sex ratio of *Senegalese tonguesole* in bottom-set gillnet catches. A total of 89 males and 113 females of *C. senegalensis* was sampled from October 2017 to July 2018. Females dominated in all the months except in November 2017 and January 2018 when males significantly dominated. The overall sex ratio showed female dominance with a ratio of 1:2.7.

Table 8: *Sex ratio of Cynoglossus senegalensis in bottom-set gillnet catches from October 2017 to July 2018*

Month	Number of fish		Sex ratio (M:F)	χ^2	Significant level ($P_{0.05}$)
	Males	Females			
Oct 2017	16	24	1 : 1.5	1.60	S
Nov	32	12	2.7 : 1	9.09	S
Dec	5	15	1 : 3	5.00	S
Jan 2018	21	11	1.9 : 1	3.13	S
Feb	5	9	1 : 1.8	1.14	S
Mar	0	6	-	-	-
April	4	12	1 : 3	4.00	S
May	2	6	1 : 3	2.00	S
June	2	6	1 : 3	2.00	S
July	2	12	1 : 6	7.14	S
Overall	89	113	1 : 2.7	2.85	S

*S = significant, NS = not significant

Gonadosomatic index (GSI)

The monthly fluctuation in GSI of *C. senegalensis* is presented in Figure 38. GSI recorded from October 2017 to July 2018 ranged from 0.05±0.01 to 0.09±0.07 for males and 1.30±0.79 to 3.72±0.86 for females. The highest GSI recorded for males was in October 2018, a peak also was in May 2018. Peaks were recorded for females in October 2017 and March-May 2018, with the highest peak in July 2018. Males were not encountered in the sample in March 2017.

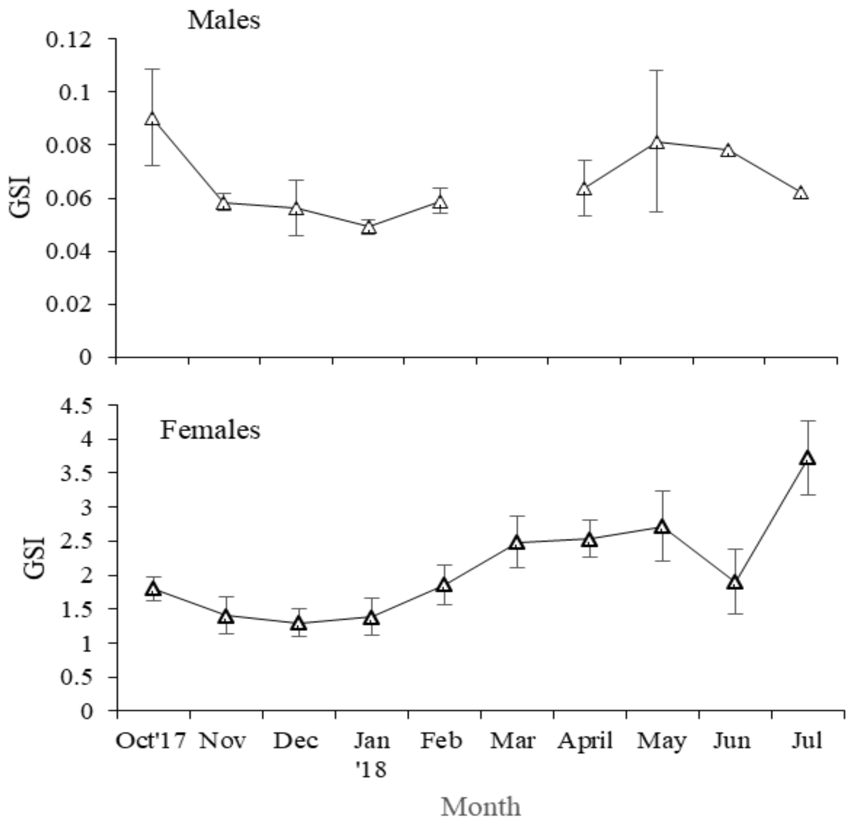


Figure 38: Monthly fluctuation in GSI of *Cynoglossus senegalensis* males and females.

Monthly occurrence of ripe gonads

The monthly percentage occurrence of ripe gonads of *C. senegalensis* in samples is shown in Figure 39. Ripe gonads occurred most in February-March 2018. High occurrences were also observed in October 2017, May and July 2018.

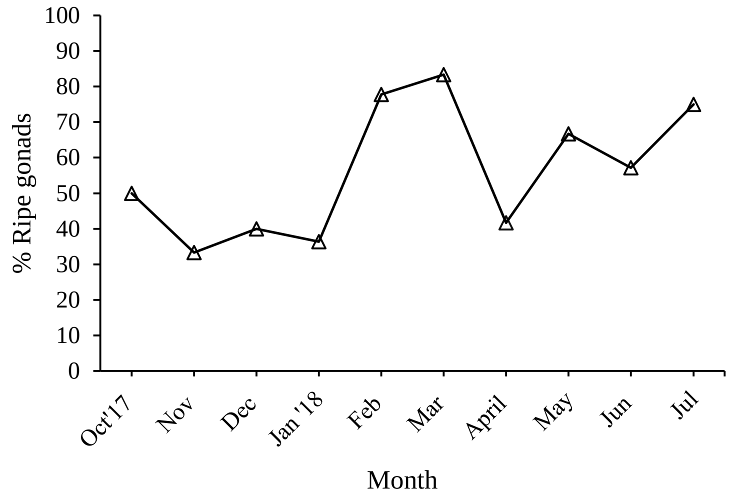


Figure 39: Monthly percentage occurrence of ripe gonads of *Cynoglossus senegalensis.*

Ovum diameter distribution

Figure 40 shows the ovum size distribution of five ripe ovaries of *C. senegalensis*. A unimodal distribution was observed for all five ovaries. Ova diameter ranged between 0.08 mm and 0.30 mm for three specimens with modal diameter at 0.20 mm – 0.23 mm for two of them and 0.24 mm – 0.27 mm for the other. All other specimens have modal diameter in the 0.20 mm – 0.23 mm size group and with ova size ranging from 0.05 mm to 0.30 mm.

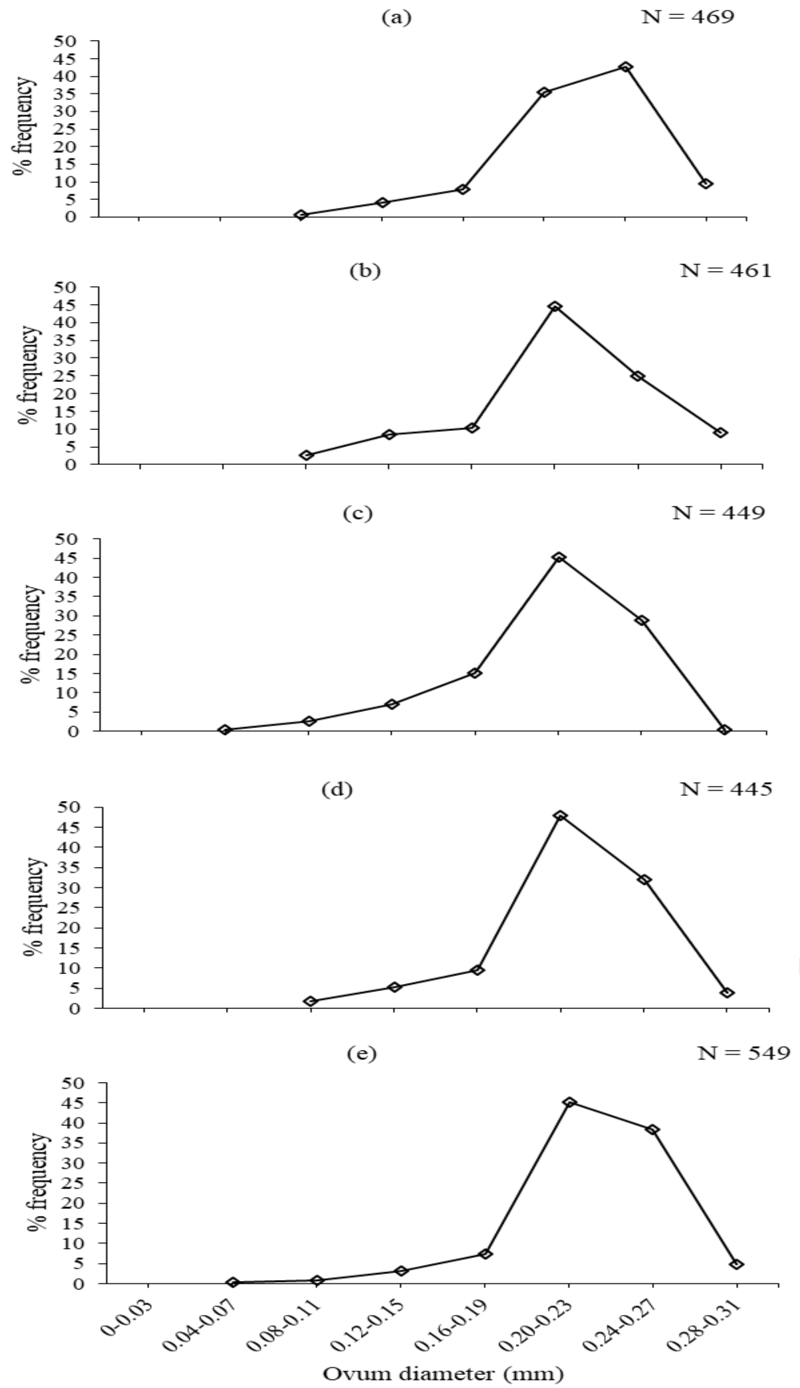


Figure 40: Ovum diameter distribution of *Cynoglossus senegalensis.*

Fecundity

Fecundity was estimated for six specimens. The number of eggs carried by a gravid specimen of *C. senegalensis* was estimated to range from 100,039 eggs for a female of 50.8 cm total length and body weight of 685.0 g, to 352,890 eggs for a female of 55.5 cm total length and 965.0 g body weight. Mean fecundity of the species was 197,817±106,469.

CHAPTER FIVE

DISCUSSION

Socio-cultural Characteristics of the Bottom-set Gillnet Fishery

The business nature of fishing was observed in the current study with unique partnership systems. Sharing of catch as a form of paying the fishing crew (Acheson, 1981) and the involvement of the canoe and/or gear owner in the fishing operation (Marquette et al., 2002), were characteristics of the partnerships observed. According to Marquette et al. (2002), small-scale fishing in West Africa falls within complex international fish marketing systems since it is purely business and not subsistence. The high proportion of gear owners and comparatively less canoe owners, as a result of the form of partnerships practiced, may result in underestimation of effort in the fishery. This is because two gear owners fish simultaneously, using the same canoe. Most of the canoes encountered in the study were embossed with numbers. This implied these canoes have been documented by the fisheries managing body, the Fisheries Commission, as operating the bottom-set gillnet. Reporting effort based on the number of canoes may therefore greatly underestimate effort in this fishery. Effort estimated on number of fishing gears or number of gear owners may give reliable estimate of effort in the bottom-set gillnet fishery. The partnership systems, nonetheless, may be advantageous to the fishermen by lowering their individual production cost, and increasing their profit as premix and extra labor cost are shared among partners.

The taboo of not fishing on Tuesdays, according to Dosu (2017), is the most prevalent among socio-cultural practices among fishers. This and other taboos have been social mechanisms guiding traditional natural resource management which ensures the protection of some threatened species in their habitat. Reasons given by the bottom-set gillnet fishery for flouting the fishing holiday were similar to exceptions to the taboo reported by Abane, Akonor, Ekumah, & Adjei (2013). According to the authors, going to sea before Tuesday and staying at sea or returning to land on Tuesday does not amount to a violation but selling the catch on the Tuesday violates the taboo. This violation has become a normal thing to the bottom-set gillnet fishery at Apam, Egyaa and Cape Coast, possibly due to non-availability of storage facility at these landing sites to safely store their catch for sale the next day. According to Dosu (2017), socio-cultural beliefs have begun facing problems, resulting in the breakdown of fishing holidays and rest periods in some fishing communities due to people disregarding the taboos associated with them. Disregard of fishing taboos, which were once strictly observed, suggests a breakdown of traditional fisheries management systems which further puts the future of the Ghanaian fisheries at risk.

Regular loss of fishing gears at sea, as a major problem in the fishery, is a matter of ecological concern as gillnets lost and not retrieved will continue to fish, contributing to ghost fishing in the Ghanaian marine waters. Ghost fishing is a conservation issue as it has negative effects on aquatic habitats and the organisms living in these habitats (Brown et al., 2005). Lost gears have also been reported to interfere with fishing, resulting in further loss of gears (Macfadyen, Huntington &

Cappell, 2009). Solution to this problem will be the enforcement of regulations on submerged stationary fishing gears, which clearly stated the required surface markers to be used for these gears, as well as compensation for properly marked gears that get destroyed by other vessels (Fisheries Act, 2002, n.d.; Ghana Fisheries Regulations (LI 1968), 2010).

There are jargons for every work type and fishing is no exception. The jargon unit – *patch*, by which net lengths were quoted and used among the fishermen and net traders was unique to this group of people. According to Aggrey (2015), the jargons have a social function as an instrument of social cohesion among fishers, setting them apart from other groups.

Fishing Effort Employed in the Fishery

Catalogue of small-scale fishing gears of Ghana by Doyi (1984) stated and described four types of canoes and six types of set gillnets in Ghana. The canoe types were differentiated by their sizes which were determined by the overall length and the maximum width. The types were small-sized one man canoes, medium-sized canoes, large-sized ali poli canoes and large beach seine canoes. Doyi (1984) described medium-sized canoes to be six to eleven meters long and 0.70 to a meter wide, and large-sized ali poli canoes to be 12 to 18 m long and 1.30 to 1.80 m wide. The canoes encountered in this study were mostly medium-sized canoes with only 3.9% of them being large-sized ali poli canoes. The canoes were however wider (mostly 1.5 m width) than the width documented by the author for medium-sized canoes. The increase in width is probably to create more space for the gear, as the number of net panels used have probably increased in a bid to increase catch. The significant variation in canoe size observed between Apam and Egyaa could be attributed to the use of some of the canoes at Apam for other gears, apart from bottom-set gillnets, as Apam is a multi-gear landing site. Egyaa, on the other hand, is a single-gear landing site, using only the bottom-set gillnet. More than one gear is used at the Cape Coast landing site, explaining why canoe sizes did not differ significantly between Apam and Cape Coast.

The fishing gears encountered were all made of monofilament netting, making these nets illegal. According to section eight of the Fisheries Regulation of Ghana (LI 1968), the use of monofilament net in the marine waters of Ghana is prohibited. This offence is liable on summary conviction to a fine of not more than one hundred and fifty penalty units, or to a term imprisonment of not more than 12 months, or both. The switch to monofilament nets is due to its perceived higher catch efficiency, lower relative cost and ease of use, according to Coastal Resources Center Report of 2013. The large mesh size nets used in the bottom-set gillnet fishery may cause the gear, though made of monofilaments, to be less efficient and hence less damaging to the aquatic environment. As mesh sizes increase, efficiency of monofilament nets decrease and even show no difference in efficiency with multifilament nets (Faife, 2003; Gabis et al., 2013).

Of the six set gillnet types described by Doyi (1984), two of them, the lobster net and the tsile-yaa, were similar to the fishing nets encountered in the current study. The lobster net described by the author was of mesh size of 6 cm – 12 cm, 180 m long, 1.3 m to 1.5 m deep and operated by a crew of three to four.

The tsile-yaa was of 15 cm to 16.5 cm mesh size, 50 m long and 3.0 to 3.5 m deep. Marquette et al. (2002) also described the lobster net as of mesh size of 8.0 cm to 12.5 cm and operated by a crew of three to four. The nets observed in the current study, though of similar mesh size, were deeper (2.5±0.57 m) than the lobster net described by Doyi (1984). The increased depth of the nets may probably increase their efficiency. Also, the short net lengths (91.4 m) observed may be for easy handling of nets. Mesh size combinations observed may be to increase catch and diversity of species landed, as gillnets of different mesh sizes have different selection windows, though some may overlap (Gabis et al., 2013; Mendes et al., 2006; Reis & Pawson, 1999). The crew per canoe observed in this study was in line with the crew reported by Doyi (1984) and Marquette et al. (2002) for lobster nets.

Soak time according to Ateweberhan, Gough, Fennelly, & Frejaville (2012), is referred to the duration of time from deployment of the fishing net to its retrieval from the water. Increased soak time (49 – 72 hours) allowed in the bottom-set gillnet fishery for gears of large mesh sizes (12.7 cm and 15.2 cm) was possibly to maximize catch (Li et al., 2011; Savina et al., 2016), as soak time has been reported to affect the efficiency of gillnets (Acosta & Turingan, 1996; He, 2006; Li, Jiao, & Reid, 2011; Savina et al, 2016). Though increased soak time maximized catch, it also resulted in reduction in catch quality and therefore led to a reduction in market value of the catch. Reduction in the market value of landings reduces the profit of the fishermen as landings were bought at low prices to be processed into fermented fish. Soak time was determined in the fishery by available fuel, mesh size of the fishing gear, and distance to the fishing ground. The available fuel determined whether the fisherman set net and wait at sea to retrieve it before returning to land, resulting in a short soak time, or the fishermen sets and retrieves net in two trips, resulting in a long soak time. Also, long soak time was allowed for large mesh size nets to ensure enough time for net saturation. Furthermore, the further the fishing ground, the shorter the soak time. The quality of landings should however be an important factor in determining soak time if profits are to be optimized in the bottom-set gill net fishery.

Catch per Unit Effort (CPUE) and Catch Composition

Fish production in Ghana is driven by a seasonal coastal upwelling occurring in the Gulf of Guinea. High CPUE recorded at the three study locations in July, as well in December at Apam, and in January at Egyaa, may be as a result of increased fish density due to coastal upwelling. The major upwelling in Ghana occurs from July to September and the minor upwelling, of about three weeks duration, occurs from December to January or February to March (Kwadjosse, 2009). According to Koranteng (2001), coastal upwelling have an effect on the dynamics of demersal assemblages in Ghanaian waters. Koranteng (2002) also reported significant differences in the density of demersal fishes between the upwelling and the lean fishing seasons with the highest demersal biomass recorded during the major upwelling season. Shift in area fished can affect CPUE (Cochrane & Garcia, 2009) and that may explain high CPUE recorded in November and May at Apam, October at Egyaa and April at Cape Coast, which are lean fishing months in Ghana. Shift in area fished may be an effective way of ensuring and sustaining a good catch. However, fluctuations in CPUE recorded may also be attributed to varying soak time and fish accumulation which also affect CPUE estimates from gillnets. Increasing soak time may increase catch, however, the rate of fish accumulation in the gear may override this effect. As fish accumulates in the gear to saturation, no more fish is caught even at a prolong soak time (Li et al., 2011) making CPUE estimates from gillnet catches unreliable as indices of abundance (Acosta & Turingan, 1996).

High landings of cuttlefish (*Sepia hierrada*) at Egyaa in January which resulted in the high CPUE recorded in that month at Egyaa, may be due to the abundance of the species in the coastal waters in that particular month. Sakyi-Djan (2017) also reported high landings of cuttlefish along the central coast of Ghana in January. Targeting of cuttlefish by the bottom-set gillnet fishermen in January may have attributed to the absence of the spotted box crab in that month's samples at all the study locations. However, this does not indicate a complete absence of the species in the landings in January since sampling only covered three days in each month at each study location. The absence of the species in the samples may rather be an indication of very low numbers of the species in that month's landings.

The high number of different species landed at all three study locations indicated the fishery is a multispecies fishery with some of the landed species discarded. As reported by Cosgrove et al., (2016), bottom-set gillnet fisheries are multispecies fisheries, that is, apart from the targeted species, other species caught may be retained and others discarded. The multispecies nature of the bottom-set gillnet fishery may be as a result of the poor species selectivity of gillnets, which resulted in the catching of a wide range of species. According to He (2006), though gillnets are size selective, they are very poor in species selectivity making them to catch various species, hence the species richness observed for the study sites.

The high resemblance in species landed at Apam and Egyaa, making these two sites to be clustered as one, reveals a possibility of the same or similar fish assemblage off the Apam and Egyaa. Differences in species richness, diversity, and evenness among the three study locations may have resulted from the relative abundance of size classes of the various species at the fishing grounds. It has been reported that differences in the number of each species retained in a gillnet may be an indication of the relative abundance of the size classes present in each of the species retained (Acosta & Turingan, 1996; Hickford et al., 1997). Body morphology and feeding behavior of the species could have also contributed to the differences observed in species composition of landings as these factors affect the capture of species in gillnets. The spotted box crab, which was the most abundant species landed, was caught by entangling. Body extensions like claws and modifications in fins may aid the capture of some fish species in gillnets (Broadhurst et al., 2003; Hickford et al., 1997; Mendes et al., 2006; Reis & Pawson, 1999). The mode of capture of the spotted box crab coupled with its possible abundance, could explain its dominance in the landings. According to Faife (2003), gillnets are selective when fish are caught by enmeshing and almost no selectivity when fish are caught by entangling. Most of the by-catch species, dominated by corals and crustaceans were also caught by entangling. As observed in the study, most of the fishermen set their gears during the day and lift it out of the water the next day. A gear set during the day may, first catch day feeders before catching nocturnal feeders later at night. The time of the day the net is set has also been reported to affect species composition and dominance in gillnet catches due to different feeding behaviors in different species (Acosta & Turingan, 1996; Li et al., 2011).

By-catch in the Bottom-set Gillnet Fishery

Though not significant, compared to retained catch, by-catch was recorded at all the three study locations. Major fisheries ecological impacts occur through by-catch (Shester & Micheli, 2011). Target species, non-target species, and branched organisms such as corals and sponges, are all components of the ecosystem that help shape community structure as well as promote fisheries (Shester & Micheli, 2011). The branched organisms and the non-target species component of the aquatic ecosystem make up the by-catch from fishing and are usually discarded. Differences in the level of by-catch associated with catch at Apam, Egyaa, and Cape Coast could be attributed to the level of concentration of target fishes in the respective fishing areas. Low by-catch has been reported for gillnets in areas of high concentration of target fish and high by-catch rates in diverse assemblages (Shester & Micheli, 2011). High quantities of by-catch, as observed at Apam, may negatively affect the community structure of the aquatic ecosystem. The by-catch species are important to the functioning of the aquatic ecosystem as they play specific roles in their habitat. Other species in the aquatic ecosystem may depend on them. According to Cochrane & Garcia (2009), species are not in isolation since they depend on each other through unique relationships as part of the wider aquatic ecosystem. Examples are the corals and hermit crabs.

Corals have been reported to serve as substrata for primary production, provide habitat to a diversity of fishes and invertebrates, as well as protect the coast from wave action (Kaiser et al., 2010). Their removal may result in the loss of these services to the ecosystem. Habitat loss is a possible reason for global dwindling stocks. This is because even slight alterations to habitats causes dominance shifts in species (Armstrong et al., 2008).

The dominance of coral species in the by-catch at Apam with some occurring in the by-catch at Egyaa, and their complete absence at Cape Coast, suggest a possible coral garden off the Apam coast stretching towards the Egyaa coast. A coral garden is a relatively dense aggregation of colonies or individuals of coral species. The relatively high numbers of hermit crabs at Apam, compared to the other sites, also indicates the presence of a coral habitat off the Apam coast. Hermit crabs have been reported to have a great diversity of symbiotic associations and exhibiting the highest number of associates with arthropods, polychaets and corals (De Grave & Barnes, 2001). The same or similar fish assemblage off the Apam and Egyaa coasts, suggested by results of the study, could be possible if the assemblage is being supported by the same or similar habitat. This observation further confirms the presence of a possible coral garden stretching from Apam towards Egyaa. With the exception of one species, all other coral species encountered were gorgonian and sclerectinian corals, which are characteristic species of coral gardens. According to Buhl-Mortensen, Buhl-Mortensen, & Purser (2017), coral gardens are characterized by sclerectinian and gorgonian species. The high species richness observed at Apam may be attributed to the possible coral garden, as corals provide a rich habitat that support several species.

Growth, Mortality and Exploitation of the Economic Species

Length frequency distribution of fish samples taken from a population describes the size structure of the population. However, for gillnets, the length frequency distribution of the catch reflects the selectivity of the mesh size of the fishing net and the mode of capture of the fish (Holst et al., 1996; Gabis et al., 2013). The unimodal distributions observed for both male and female cassava croakers, and the male tonguesoles, suggest fishes were caught by one mode of capture, that is, by wedging (caught at the maximum girth). The female tonguesoles, however, were probably caught by more than one mode of capture hence their bimodal distribution. As reported by Reis & Pawson (1999), fish caught at a body position other than the girth turns to skew the retention curve which may result in two modes of the selection curve. Same modal class of the male and female cassava croakers indicate that both sexes have similar sizes, and hence fell within the same selection window of the mesh sizes used. Female tonguesoles were larger and also had wider size range than the males. Their wider size range suggests the individuals may fall within different selection windows of the mesh sizes used, resulting in the female tonguesoles being caught by more than one mode of capture.

The bimodal distribution observed for the males crabs however was not a reflection of the selectivity of the mesh size, since gillnets lose their selectivity when organisms are caught by entangling. The 7.0 to 7.9 cm modal class may represent males that were yet to undergo their terminal molt with the 9.0 cm to 9.9

cm modal class, representing males that have undergone their terminal molt. Smaller size crabs observed in the monthly length frequencies in November suggests recruitment into the fishery. The larger size males (10.9 cm -12.0 cm CW) with very low abundance observed only in February 2017 suggest few male crabs continue to molt after the pubertal molt. A similar observation was made by Diez and Lovrich (2013) in the males of the crab *Halicarcinus planatus* where they observed morphometric changes in males after the pubertal molt. Based on the size range and the low occurrence of these individuals in the population, the authors concluded not all males undergo this terminal molt. The crabs probably have a brief life span after the terminal molt which may explain the disappearance of this size class in subsequent months.

A *b* range of 2.5 – 3.5 was confirmed for all three species (Froese, 2006), except for the female crabs which recorded a lower *b* possibly due to the amount of energy allocated to reproduction. The value of *b* has been reported to give an indication of life history events such as molting in crustaceans, metamorphosis, and onset of maturity (Le Cren, 1951; Morato et al, 2001; Froese, 2006). As was found for both male and female of *C. rubroguttata* in this study, González, Quiles, & Santana, (2000) also reported negative allometric growth for *C. granulata* in the Canary Islands. Abowei (2009) reported isometric growth (b = 3.066) for combined sexes of tonguesole, and negative allometric growth was reported for the species by Bolarinwa (2014). These differ from what was reported for the separate sexes in this study. Contrary to the current finding, positive allometric growth (b = 3.4) was reported for the cassava croaker by Olapade & Tarawallie (2014) with sampling done with gillnets and traps. The difference in the *b* values estimated for the cassava croaker, and the Senegalese tonguesole in the current study, and that by the other authors, may be attributed to differences in locality, effect of selectivity, or possibly the proportion of different growth stanzas making up the samples (Le Cren, 1951; Froese, 2006; Sangun et al., 2007). Deviation of the estimated *b* values from 3 could be attributed to changing body shape as these species grow. For an ideal fish maintaining body shape, *b* is equal to 3, although, most fishes deviate from this due to changing body shape as they grow (Le Cren, 1951; Froese, 2006).

Condition factor defines the general well-being of a fish. The increase in condition observed for the crabs in September and between March-May may be a possibly indication of molting activities in these months. Crabs are reported to fill their shells with water towards molting which may result in an increase in body weight prior to molting. The shape declines in condition observed after the peaks suggest the presence of post molting crabs which have not fully filled their shells with tissue and therefore recorded low body weight (Hosamani, Reddy, & Reddy, 2017; Ogawa, Hamasaki, Dan, & Kitada, 2011). Accorded to Le Cren (1951) and Froese (2006) various biological features such as fatness, gonadal cycles, environmental suitability and rate of feeding can be measured using condition factor as an indicator.

Cassava croaker was reported to reach a larger L_∞ (66.6 cm and 51.4 cm respectively) at a slower rate (0.13 yr^{-1} and 0.16 yr^{-1}) in Liberian (Wehye et al., 2017) and Benin waters (Sossoukpe et al., 2013) than estimated in this study. However, the species in Ghanaian waters reached a larger L_∞ at a slower rate compared to the fishes in Ivorian waters (47.9 cm and 0.41 yr^{-1}) as reported by Tia et al. (2017). These differences may be attributed to differences in environmental conditions. The growth performance index estimated by Wehye et al. (2017), Sossoukpe et al. (2013), and Tia et al. (2017), were close to the estimated index in this study, indicating growth parameters estimated for *P. senegalensis* in the current study are in accordance with results from the above studies. Longevity of the cassava croaker (17.6 years) and Senegalese tonguesole (16.7 years) confirm these demersal species to be long-lived species. According to Cochrane and Garcia (2009), demersal species are among exploited species that are long-lived. The low growth coefficient for the cassava croaker and the Senegalese tonguesole confirm the longevity recorded for these species as they take a longer time to reach their L_{∞}.

The estimated length at which 50% of the population was retained by the gear, also referred to as the length at first capture, for the three species was in line with the modes observed in their respective length frequency distributions. Length at first capture of 27.8 cm of the cassava croaker allows the fish to reproduce at 20.9 cm and 26.8 cm respectively for males and females before they are caught. This indicates a healthy stock according to Lappalainen et al. (2016) and van Overzee & Rijnsdorp (2015), as it has the potential to sustain recruitment (Wolff et al., 2015). Wehye et al. (2017) reported a length at first maturity of 44.5 cm for cassava croaker in Liberian waters, suggesting that though the bottom-set gillnet fishery is underexploiting the species, the stock in the Ghanaian waters may be responding to fishing pressure probably from other fisheries by maturing at a smaller size. According to Jørgensen & Holt (2013), the key life history response to increasing fishing mortality is reduction in size and age at sexual maturity. In Ghana, the species is also targeted by purse seiners, beach seiners, and hook and line. L_{m50} of 40.6 cm for females and L_c of 39.42 cm indicate that female tonguesoles are harvested before actually attaining sexual maturity. This may result in a reduction in the reproduction potential of the stock. As reported by Wolff et al. (2015), a year class that survive to spawn in their first year of maturity contributes substantially to reproduction. The situation for the females may not be true for the male tonguesole since the males have a small size compared to females. However, the sex ratio determined showed a female dominated stock, indicating that a stress on the females would have a significant effect on the reproductive potential of the stock. The spotted box crab gets recruited fully into the fishery at 7.4 cm carapace width. The maturity lengths and the length at which the three species were landed, revealed the dominant mesh sizes of 7.6 cm and 8.9 cm to favour a sustainable exploitation of *P. senegalensis* by the bottom-set gillnet fishery. However, the mesh sizes were not so much in favour of the sustainable exploitation of *C. senegalensis*.

Individuals of exploited populations are lost through emigration, fishing mortality and natural mortality (Cochrane & Garcia, 2009). Mortality of the spotted box crab in the bottom-set gillnet fishery was largely caused by fishing, while mortality of cassava croaker and Senegalese tonguesole were attributed largely to natural causes. Tia et al. (2017) also reported high natural mortality for cassava croaker. According to Cochrane & Garcia (2009), at a given level of fishing presure, populations with low natural mortality at the adult phase have a high likelyhood of depletion, compared to one with a high natural mortality in the adult phase. With majority of individual cassava croakers encountered being sexually matured and the high *M* recorded, the stocks may be less susceptible to being overfished by the bottom-set gillnet fishery. The exploitation ratio of 0.17 and 0.23 for the cassava croakers and the tonguesoles, respectively, indicate that the stocks were being exploited below optimal levels by the fishery, and the spotted box crab stock is being exploited above optimum level with an exploitation ratio of 0.70. According to Pauly (1984), exploitation of a stock is optimal if the the exploitation rate is 0.5.

Reproductive Biology of the Economic Species

Sex ratio is an important factor in determining reproductive potential of biological populations, and therefore necessary for their management (Ragheb, 2016). The sex ratio estimated for the spotted box crab, the cassava croaker, and the Senegalese tonguesole all deviated from the Mendelian proportion of 1:1 (Carmona-Suárez, 2008). A sex ratio of 1.8:1 in favor of the males of the spotted box crab indicated a male dominated population. Other studies (Bas, Luppi, & Spivak, 2005; da Silva, da Rocha, & Costa Neto, 2014) also recorded male dominance in populations of other crab species. This could be attributed to differences in growth and mortality rates between sexes (Ragheb, 2016).

Contrary to what was recorded in the current study, other studies recorded sex ratios that indicated female dominance in *P. senegalensis* (Sossoukpe et al., 2013; Olapade, & Tarawallie, 2014) in the Benin and Sierra Leone waters, respectively. Sylla et al. (2016) also observed male dominance for the species in

Ivorian waters. Differences in sex ratio observed in the current study and the other studies may be attributed to difficulty in sex determination of smaller individuals. According to Ragheb (2016), difficulty in sex determination of immature individuals can affect the estimated sex ratio. For the Senegalese tonguesole, the male to female ratio of 1:2.7 observed in favor of females can be attributed to size specific selection by the gear since gillnets are considered to be highly size selective (Broadhurst, Gray, Young, & Johnson, 2003; He, 2006). Larger sizes were recorded for females compared to males. Size specific fishing pressure has been reported to alter the sex ratio of biological populations (Allison, Lubchenco, & Carr, 1998; Garcia, Zerbi, Aliaume, Do Chi, & Lasserre, 2003; Cochrane & Garcia, 2009).

Determination of gonadosomatic index (GSI), fecundity and ova diameter are some of the ways by which the reproductive state of fishes can be studied (Miller & Kendall, 2009). The high GSI recorded for both sexes of the cassava croaker from February to May, and for males in July, and the increased percentage of ripe gonads observed in these months, strongly suggest February to May, and July as the spawning season for the species. GSI is an indicator of gonadal development, with fishes recording high GSI in their spawning seasons (Khan et al., 2013; Olapade & Tarawallie, 2014; Pope et al., 2010; Shinkafi & Ipinjolu, 2012). Increase in condition factor of both sexes of the species in March-May and July for females is a further confirmation of spawning activity in these months. As reported by Le Cren (1951), there is an increase in the condition factor of fishes towards spawning and a decline after spawning. The bimodal ovum diameter distribution also confirm two spawning seasons in a year for the species with the larger size ova to be spawned first, followed by the maturing ova. The peak spawning possibly occurs in April as the highest GSI recorded was in April. Sylla et al. (2016) reported the spawning season for the species to be in April and October. Olapade & Tarawallie (2014) also reported cassava croaker to spawn in April but their study could not capture a second spawning for the species since sampling was done for only six months.

The GSI and percentage ripe gonads observed for the Senegalese tonguesole in this study suggest the species to spawn over a prolonged period in a year from March to July, with a possible peak in July. The increase in condition factor of the species from March to a peak in July, further suggests spawning activity in these months. Ghaffari, Sahafi, Engelhard, & Mekhanik Babaei (2015) confirmed a protracted spawning for *Cynoglossus arel* with the spawning peak occurring in March. The observation of gravid females of the spotted box crab from May to December, with high proportions in May, October, and December, suggest spawning activity for the species from May to December with peaks in May, October, and December. However, the unimodal ovum diameter distribution observed for the tonguesole, and the crabs, suggests a single spawning episode occurring yearly. It therefore indicates that the protracted spawning activity observed for the *C. senegalensis* and *C. rubroguttata* stocks may be due to differences in spawning time between age groups and not a prolong spawning for individuals.

Fecundity in the current study was found to correlate strongly and positively with body weight and length, as have been reported by other authors (Murua et al., 2003; Miller & Kendall, 2009; Pikitch et al., 2012). The fecundity observed for cassava croaker in this study was higher than what was reported by Sylla et al. (2016). This may be attributed to the differences in the size range of the samples since the current study recorded larger individuals as compared to the previous study. Fecundity is found within species to correlate positively with size (Miller & Kendall, 2009). The difference could also be attributed to differences in fish stocks or environmental conditions. Fecundity has also been reported to vary with species, stocks and affected by environmental factors through their effect on condition factor (Murua et al., 2003; Rätz et al., 2000; Pikitch et al., 2012).

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Summary

The study assessed the characteristics of the bottom-set gillnet fishery in three fishing communities in the Central Region, and the possible ecological impacts of the fisheries on the marine ecosystem. Aspects of the biology of some economic species in the landings were also examined. The fishery was assessed through interviews and field observations. Landings were recorded to estimate CPUE, and catch composition was determined by identification, counting and weighing of individuals of various species. Morphometric measurements and body weight were taken for three commercial species to determine their growth, mortality and exploitation. Reproductive study on the species was done by determining GSI, fecundity and ova diameter distribution. Three types of business partnerships practiced in the fishery resulted in 74.1% of the fishermen owning fishing gears and 53.4% owning canoes. Fishing holidays were violated and loss of fishing gear was a major problem in the fishery. Canoe size was dominated by 7 m to 10 m LOA. Total length of net walls ranged from 30 m to 1097 m with mean depth of 2.5±0.6 m. Mesh sizes ranged from 7.6 cm to 15.2 cm and dominated by 7.9 cm and 8.9 cm and soak time in the fishery was mostly 18 to 24 hours. Mean CPUE was 44.59±23.40 kg at Apam, 57.97±46.69 kg at Egyaa and 36.93±24.55 kg at Cape Coast. Landings were dominated by *Calappa rubroguttata* and by-catch recorded was highest (31.4% of landings numerically and 11.5% by weight) at

Apam. Nevertheless, it was not statistically significant compared to the retained catch. By-catch was dominated by corals and crustaceans. *Calappa rubroguttata* could grow to 13.13 cm (L_∞) with a K of 0.62 yr^{-1} and the species could live to 4.8 years. For *P. senegalensis,* L_∞ was 48.83 cm, K was 0.17 yr^{-1}, with the species living up to 17.6 years. Growth parameters estimated for *C. senegalensis* were 60.38 cm, 0.18 yr^{-1} and 16.7 years, respectively, for L_∞, K, and longevity. *Z, M* and *F* for *C. rubroguttata* were 3.50±1.33 yr^{-1}, 1.62 yr^{-1}, and 1.88 yr^{-1}, respectively, and the species was exploited at 0.54. *Z, M and F* of *P. senegalensis* were estimated as 0.58±0.06 yr^{-1}, 0.48 yr^{-1}, and 0.10 yr^{-1}, and exploitation ratio was 0.17. Mortality parameters estimated for *C. senegalensis* were 0.61±0.05 yr^{-1}, 0.47 yr^{-1} and 0.14 yr^{-1}, respectively, for *Z, M,* and *F*. The species was exploited at 0.23. Ovum diameter distribution showed a single spawning episode per year for *C. rubroguttata* and *C. senegalensis* and two spawning episodes per year was observed for *P. senegalensis*. Mean fecundity was estimated for *P. senegalensis* as 193,690±143,065, for *C. senegalensis* as 197,817±106,469 and for *C. rubroguttata* as 523,306±189,149.

Conclusion

From the observations on the bottom-set gillnet fishery at Apam, Egyaa and Cape Coast, the following conclusions were made:

1. The business nature of the bottom-set gillnet fishery was defined by unique partnership systems. Also, the fishery revealed a breakdown of fishing holidays as a traditional fisheries management system, and the major problem faced by fishermen was loss of fishing gears at sea.
2. The bottom-set gillnet fishery was characterized by the use of the lobster net which was mostly made of monofilament polyamide, and operated commonly from medium-sized canoes by crew of about three. Soak time in the fishery was mostly 18 to 24 hours.
3. The fishery was a multispecies fishery and the most dominant species in the landings was the spotted box crab which was caught by entangling. Mean catch per unit effort was 44.59±23.40 at Apam, 57.97±46.69 at Egyaa and 36.93±24.55 at Cape Coast.
4. By-catch in the fishery was dominated by corals and crustaceans. High coral by-catch at Apam revealed a possible occurrence of a coral garden off the Apam coast.
5. The asymptotic lengths of *C. rubroguttata*, *P. senegalensis* and *C. senegalensis* were 13.13 cm carapace width, 48.83 cm and 60.38 cm TL, respectively, but were fully recruited into the fishery at 7.4 cm carapace width, 27.82 cm and 39.42 cm TL, respectively. Mortality was largely caused by fishing activities in *C. rubroguttata* and the stock was being

exploited above the optimum level. Mortality in *P. senegalensis* and *C. senegalensis* was mainly by natural causes, and the stocks were being exploited below optimal levels.

6. Sexual maturity was attained at 20.9 cm and 26.8 cm TL in *P. senegalensis* males and females, respectively, and at 40.6 cm TL in *C. senegalensis* females. *P. senegalensis* spawned from February to May, and in July, with a peak in April. *C. senegalensis* and *C. rubroguttata* showed a single yearly spawning episode occurring between March-July, and May-December, respectively. Mean fecundity for *C. rubroguttata*, *P. senegalensis*, and *C. senegalensis* were 523,306±189,149, 193,690±143,065, and 197,817±106,469, respectively. Fecundity of the three species correlated positively with body weight and length.
7. Species landed suggested a rich demersal resource in the coastal waters of Ghana and operations of the fishery have negative ecological impacts on the marine ecosystem. The negative ecological impacts were as a result of ghost fishing and capture of non-target species which are important as ecosystem components in the sustenance of the marine ecosystem. However, the dominant mesh sizes of 7.6 cm and 8.9 cm supported a sustainable exploitation of *P. senegalensis* by the fishery.

Recommendations

From the findings of the study, the following recommendations were made:

1. Regulation 8 in the Ghana Fisheries Regulations which prohibits the use of monofilament gillnet in the marine waters of Ghana, should be enforced so as to minimize its negative ecological impacts on the marine ecosystem which occurs through ghost fishing.
2. Effort in the bottom-set gillnet fishery should be reported on the basis of number of fishing gear or gear owners, and not number of canoes, to avoid underestimation of effort in this fishery.
3. The possible occurrence of a coral garden off the Apam coast revealed by the study, should be further investigated to ensure its protection if confirmed.
4. As has been done for other commercially important species in the Fisheries Regulations, a minimum landing size should be established for *Cynoglossus senegalensis* as a management measure, since it is one of the commercially important species in Ghana.
5. Studies on gear specific fisheries should be carried out regularly to provide and update information on these fisheries critical for their management.

Suggestions for further research

1. A comparative study should be done on the efficiency of monofilament and multifilament nets of 7.6 cm to 15.2 cm mesh sizes to ascertain the efficiency of monofilament nets of large mesh sizes over multifilament nets.

2. Other properties of gillnets that affect catch efficiency should be investigated towards possibly reducing bycatch and ghost fishing associated with the bottom-set gillnet fishery.
3. Further studies should be done on the biology and stock status of *Calappa rubroguttata* in Ghanaian waters because of its vibrant fishery in the Central Region.
4. The biology and stock status of *Cynoglossus senegalensis* in Ghanaian waters should be further investigated.

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APPENDICES

Appendix A: Gillnet Types

Multifilament gillnet

Monofilament gillnet

Appendix B: Interview Guide

UNIVERSITY OF CAPE COAST

DEPARTMENT OF FISHERIES AND AQUATIC SCIENCES

Interview Guide on the Bottom-set Gillnet Fishery

Target group: Fishermen using bottom-set gillnets.

Dear Respondent,

This interview guide is designed to solicit your views on the bottom-set gillnet fisheries so as to gather information on this fisheries. You have been identified as a fisherman and your assistance is sought to participate in this exercise by answering the following questions as objectively as possible. Note that information obtained will contribute greatly to this study. Your response will be treated with confidentiality and accessed only by those involved in this study.

Personal Information

Date: …………………...

1. Name: ....
2. Age: ……………… Sex: M F
3. Primary occupation:…………………………………………………..
4. Secondary occupation (if any): ………………………………………..
5. Level of education: Primary..... JHS...... Secondary..... Tertiary....... Non…….
6. Marital status: Single...... Married.......
7. Do you have children? .... If yes how many.........................

The Fisheries

8. How did you learn how to fish?

Family trade......... (b) Personal interest...........

9. How long have you been fishing? ....

10. How long have you been in the bottom-set net fishery? ....

11. Do you have your own net? ....

12. Do you have your own canoe? ....

13. What is the size of your canoe? ....length....................width........................

14. What is the size of your fishing net? L=.............................D =........................

15. What is the mesh size of your net? ....

The Fishing Trip

16. State the days you don't fish........................why? ....

17. How many people make up your crew? ....

18. When do you set the nets? ....

19. What is the average soaking time of your net? ....

20. At what depth do you set your net? ....

21. Can you describe the bottom of the fishing environment?

Sandy.......... muddy............ Rocky..................

22. What is your total expenditure per fishing trip? ....

23. What are some of the species you catch? ....

....

24. Which of these species are of economic value to you?..
....

25. Are you able to pay off the cost of your trip from your catch? Yes..... No.....

26. If yes, do you make profit? Yes......... No..........

27. How are you able to increase your catch? ....

28. Do you sometimes lose your nets at sea? Yes........ No..........

29. If yes, how often? Often......... Very often............ Not often.........

30. When is your peak fishing season? ....

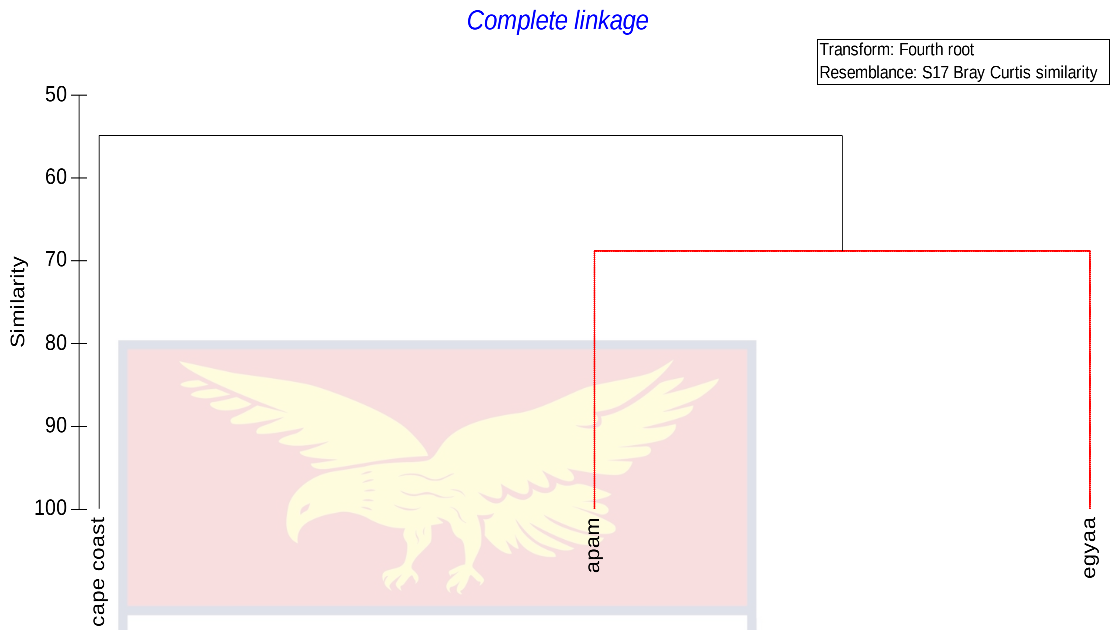
31. Does this fishery have any cultural significance to the people of this area? ....

32. Do you have any constraint in this fishery? Yes............ No............

33. If yes, what are they? ....

....

Appendix C: Hierarchical cluster analysis in Primer v.6



Appendix D: Monthly Mean Size of the Spotted Box Crab

Monthly mean carapace width (CW) and body weight (BW) of Calappa rubroguttata encountered at Apam, Egyaa and Cape Coast from February 2017 to July 2018

Month	Mean CW (cm)	Mean BW (g)
February 2017	7.8±0.1	149.9±47.2
March	7.8±0.5	149.8±24.5
April	7.7±0.8	147.9±41.5
May	8.1±1.0	170.9±60.0
June	8.9±1.1	200.5±64.6
July	9.0±1.1	166.7±63.4
August	7.2±0.6	121.2±35.18
September	7.2±0.7	129.9±39.9
October	7.9±1.6	158.7±54.9
November	8.6±1.0	199.7±58.6
December	8.6±9.0	193.5±52.1
January 2018	-	-
February	8.0±1.8	161.7±56.8
March	7.7±7.0	150.3±41.5
April	8.4±1.2	184.0±62.8
May	8.0±1.1	169.8±61.3
June	7.3±0.7	125.5±34.2
July	8.7±0.9	159.1±51.3

Appendix E: Ovum Diameter Frequency

Ovum diameter frequency of Calappa rubroguttata

Ovum diameter (mm)	Frequency				
	Specimen *a*	Specimen *b*	Specimen *c*	Specimen *d*	Specimen *e*
0-0.04	-	-	-	-	-
0.05-0.09	-	-	-	-	-
0.1-0.14	41	-	-	-	-
0.15-0.19	455	169	180	148	175
0.2-0.24	4	331	265	305	284
0.25-0.29		1	4	1	1

Ovum diameter frequency of Pseudotolithus senegalensis

Ovum diameter (mm)	Frequency				
	Specimen *a*	Specimen *b*	Specimen *c*	Specimen *d*	Specimen *e*
0-0.03	-	-	-	-	-
0.04-0.07	4	1	-	-	2
0.08-0.11	39	55	10	89	80
0.12-0.15	51	105	55	88	80
0.16-0.19	31	96	58	13	63
0.20-0.23	179	199	138	123	185
0.24-0.27	147	21	188	226	40
0.28-0.31	1	1	20	11	-

Ovum diameter frequency of Cynoglossus senegalensis

Ovum diameter (mm)	Frequency				
	Specimen *a*	Specimen *b*	Specimen *c*	Specimen *d*	Specimen *e*
0-0.03	-	-	-	-	-
0.04-0.07	-	-	2	-	2
0.08-0.11	3	12	12	8	4
0.12-0.15	19	39	32	23	17
0.16-0.19	37	48	68	42	41
0.20-0.23	166	205	203	213	248
0.24-0.27	200	115	130	142	211
0.28-0.31	44	42	2	17	26

Appendix F: Monthly Mean Size of the Cassava Croaker

Monthly mean total length (TL) and body weight (BW) of Pseudotolithus senegalensis encountered at Apam, Egyaa and Cape Coast from February 2017 to July 2018

Month	Mean TL (cm)	Mean BW (g)
February 2017	30.2±6.1	202.8±114.4
March	29.9±5.7	201.6±63.8
April	31.3±6.4	313.5±242.5
May	32.1±4.5	315.2±135.1
June	41.8±1.6	756.6±121.6
July	36.2±4.2	530.0±209.4
August	31.7±3.5	311.0±125.2
September	37.2±5.6	525±187.6
October	29.8±3.2	265.6±99.2
November	30.0±3.4	267.8±84.4
December	29.7±5.3	279.9±168.1
January 2018	31.1±5.8	285.0±147.0
February	31.5±4.1	292.3±121.2
March	28.7±2.9	220.7±76.5
April	34.1±4.3	411.8±147.7
May	29.9±3.0	272.8±77.2
June	32.2±6.1	362.5±184.7
July	33.6±4.4	408.3±179.9

Appendix G: Monthly Mean Size of the Senegalese Tongue Sole

Monthly mean total length (TL) and body weight (BW) of Cynoglossus senegalensis encountered at Apam, Egyaa and Cape Coast from February 2017 to July 2018

Month	Mean TL (cm)	Mean BW (g)
February 2017	38.4±0.6	451.7±221.3
March	30.9±6.6	146.1±83.3
April	38.3±7.4	298.6±201.5
May	43.2±3.9	398.7±132.5
June	42.3±4.8	387.5±175.1
July	41.8±5.6	386.2±193.5
August	48.0±4.8	363.6±135.5
September	40.8±4.8	366.7±140.9
October	39.9±6.8	353.9±187.2
November	39.0±4.3	303.1±113.4
December	40.5±3.8	339.3±141.6
January 2018	34.9±6.3	211.5±125.3
February	41.1±4.3	349.2±137.0
March	37.2±11.1	337.0±284.2
April	44.6±4.3	489.4±163.9
May	45.8±5.8	518.0±180.1
June	41.8±2.3	375.6±76.9
July	45.8±6.1	550.6±239.2

VITA

Miriam Yayra Ameworwor

Education and Qualification

August 2016 to March 2021: Pursued and yet to be awarded a Doctor of Philosophy degree in Fisheries Sciences at University of Cape Coast, Ghana. The research was titled: Observations on the bottom-set gillnet fishery and fishery biology of selected species at three locations off the Central Region coast of Ghana. The study was supervised by Prof. John Blay and Prof. Joseph Aggrey-Fynn both of the Fisheries and Aquatic Sciences Department of University of Cape Coast

September - December 2018: University of Rhode Island, USA.

August 2012 - July 2014: Pursued and was awarded a Master of Philosophy degree in Fisheries Science by University of Ghana. The thesis was titled "Impacts of fish cage culture on water quality and selected commercially important fish stocks in Volta Lake (Stratum II)". The thesis was supervised by Prof. Ofori-Danson of Department of Marine and Fisheries Sciences of the University of Ghana and Dr. Ruby Asmah of Water Research Institute of CSIR.

August 2005 - May 2009: Pursued and was awarded a Bachelor of Science degree in Fisheries and Aquatic Sciences with a Second class Honours by University of Cape Coast, Ghana. The dissertation was supervised by Prof. E. Obodai of the Department of Fisheries and Aquatic Sciences of University of Cape Coast and titled comparative study on the condition indices of male and female oysters, *Crassostrea tulipa*, in the Benya lagoon.

January 2001- August 2003: Pursued a Senior Secondary School Science programme in Mawuli School, Ho, Ghana.

Work Experience

- Farm manager at National Fish Farmers Brigade, Juapong from March 2011to May 2012.
- Community Development Assistant (National service) NewEnergy, Tamale, a non-governmental organization from October 2009 to July 2010.
- An intern at Ministry of Agriculture, Department of Fisheries, Cape Coast from June 2008 to August 2008.
- An intern at the Department of Fisheries and Aquatic Sciences, University of Cape Coast from June 2007 to August 2007.

Skills

- IT skills: managing files, Word, Power point.
- Data analysis skills: R, Excel, SPSS, Minitab, Primer.
- Team-working skills: A very good team worker.

Further information

- October – December 2018: Crew member on Amelia Anne, Point Judith, Rhode Island, USA for scientific sampling of lobster at sea for the Southern New England Cooperative Ventless Trap Survey (SNECVTS).
- December 2018: Crew member on Captain Berth of Graduate School of Oceanography University of Rhode Island (GSO-URI) sampling for the GSO Fish Trawl Survey on the Narragansett Bay under Prof. Jeremy Collie.

- Acquired skills in organizing a workshop as a member of logistics and organization team for an outcome mapping workshop.

Publications and Presentations

- **Ameworwor, M. Y**., Asmah, R., Ofori-Danson, P.K. and Clottey, M. N. K., (2019). Enhancing local fish production through cage aquaculture on the Volta Lake: Impacts on capture fisheries. *Journal of Fisheries and Coastal Management* 1 (1), 1–6. DOI: 10.5455/jfcom.20190313031430.
- **Ameworwor, M. Y**., Clottey, M. N. K., Asmah, R. and Ofori-Danson, P.K. (2017). The influence of cage culture on fish relative abundance and species diversity in the Volta Lake Stratum II. A poster presented at the 2017 Coastal and Ocean Environment Summer School held at Regional Maritime University, Accra-Ghana from 31st July- 4th August, 2017.
- Clottey, M.N.K., Asmah, R. Ofori-Danson, P. K., **Ameworwor, M. Y.** and Karikari, A.Y. (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.

Work in Progress

- Characteristics of the bottom-set gillnet fishery in the Central Region of Ghana. Article in progress to be submitted for publication.
- Aspects of the biology of the spotted box crab (*Calappa rubroguttata*) in Ghanaian waters. Article in progress to be submitted for publication.

- Aspects of the biology of the Senegalese Tonguesole (*Cynoglossus senegalensis*) in Ghanaian waters. Article in progress to be submitted for publication.

Conferences and Workshops Attended

- 2nd Conference on Fisheries and Coastal Environment held in Accra, Ghana and organized by Centre for Coastal Management (CCM) and USAID/Ghana Sustainable Fisheries Management Project (SFMP) from 19th to 21st August, 2019.
- SAW/SARC 2018: Stock Assessment Workshop and the Stock Assessment Review Committee organized in Woods Hole, Massachusetts-USA by Northeast Fisheries Science Center (NEFSC), National Oceanic and Atmospheric Administration (NOAA) from 27th to 30th November, 2018.
- Workshop on Plagiarism as a research misconduct: 'what graduate students need to know' organized in Kingston, RI-USA by Carothers Library, URI from 19th to 21st August, 2019.
- Coastal and Ocean Environment Summer School held in Accra, Ghana and organized by University of Michigan in collaboration with University of Ghana from 30th July to 5th August, 2018.
- Conference on Fisheries and Coastal Environment held in Accra, Ghana and organized by Centre for Coastal Management (CCM) and USAID/Ghana Sustainable Fisheries Management Project (SFMP) from 25th to 27th September, 2017.

- Advance Fish Stock Assessment Workshop organized by USAID/Ghana Sustainable Fisheries from 8th – 11th August, 2017 in Accra, Ghana.
- Coastal and Ocean Environment Summer School organized by University of Michigan in collaboration with Regional Maritime University and held in Accra, Ghana from 31st to 4th August, 2017.
- Workshop on Sustainable Cage Aquaculture in Lake Volta organized and held in Accra by Royal Society/Leverhulme Africa Project in March, 2014.
- Workshop on Propagation and hatchery management of the Nile tilapia and mud fish and cage culture of the Nile tilapia organized from 6th – 17th June, 2011 in Akosombo by Aquaculture Research and Development Centre (ARDEC), CSIR.
- Outcome mapping workshop organized and held in Tamale by NewEnergy, a non-governmental organization in March, 2010.