UNIVERSITY OF CAPE COAST

# ASPECTS OF THE BIOLOGY AND LENGTH-BASED ASSESSMENT OF THE CHUB MACKEREL *SCOMBER COLIAS* (SCOMBRIDAE) STOCK OFF THE COAST OF GHANA

JEMIMAH ETORNAM KASSAH

2020

UNIVERSITY OF CAPE COAST

# ASPECTS OF THE BIOLOGY AND LENGTH-BASED ASSESSMENT OF THE CHUB MACKEREL *SCOMBER COLIAS* (SCOMBRIDAE) STOCK OFF THE COAST OF GHANA

BY

JEMIMAH ETORNAM KASSAH

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

JANUARY 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: Jemimah Etornam Kassah

## 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: Dr. Najih Lazar

## ABSTRACT

The biology and population dynamics of the chub mackerel *Scomber colias* (Gmelin 1789), one of four small pelagic fish of high economic and nutritional value in Ghana waters, were studied from February 2016 to July 2017 to obtain information for management of its fishery. Total length of the fish in the artisanal landings ranged between 13.7 cm and 40.7 cm with two modal length classes. The von Bertalanffy growth parameters estimated using the ELEFAN method were $L_{\infty}$ = 42.5 cm *TL* and $K = 0.28\ yr^{-1}$, and the mortality parameters were $M = 0.70\ yr^{-1}$, $F = 0.52\ yr^{-1}$ and $Z = 1.22\ yr^{-1}$. Monthly analysis of growth marks in the otoliths indicated deposition of an incremental (opaque) zone in August, which happens to be the peak upwelling period in Ghana waters. The species had a maturity size ($L_{m50}$) of 25.6 cm *TL*, maturity age ($t_m$) of 2-3 years, and longevity ($t_{max}$) of 10 years. Asynchronous egg development and batch spawning was suggested by the presence of two distinct size groups (0.4 mm and 0.8 mm) of ova in mature ovaries. A mean (± s. e) absolute fecundity of 48,238 ± 2834 eggs and relative fecundity of 240 ± 10 eggs $g^{-1}$ was estimated for the fish. Spawning was estimated to occur between February and September with peaks in March-April and July-August. Fish were recruited into the stock throughout the year with two peak recruitment periods in April and August. Food of the chub mackerel comprised a wide range of invertebrates with fish, mainly anchovies (*Engraulis encrasicolus*), as the preferred item. Comparison of the current exploitation rate ($E_{curr}$ = 0.43) and optimum exploitation rate ($E_{50}$ = 0.39) suggests that the chub mackerel stock may be overexploited, as generally assessed for the small pelagic fishery in the country. The status of the chub mackerel in trawl by-catch, and proximate analysis of the fish is also discussed.

**KEY WORDS**

Ageing

Exploitation

Growth

Mortality

Nutrient value

Reproduction

*Scomber colias*

## ACKNOWLEDGEMENTS

I wish to sincerely thank my supervisors, Professor John Blay and Dr Najih Lazar of the Department of Fisheries and Aquatic Sciences and the Coastal Resource Center, University of Rhode Island respectively for their guidance and effective supervision. I am also indebted to the staff of the Coastal Resources Center at the University of Rhode Island, the age laboratory of the Rhode Island Department of Environmental Management (RIDEM) at Fort Wetherill, the age laboratory of the Northeast Fisheries Science Center (NEFSC) at the Woods Hole Oceanographic Institution in Massachusetts, as well as Professors Jeremy Collie and Kevin Freidland who gave sufficient technical input and practical training in fisheries oceanography and otolith ageing techniques.

I would like to thank the USAID/UCC Fisheries and Coastal Management Capacity Building Support Project for the full scholarship granted to me for the duration of my studies. Thanks also go the academic as well as non-teaching staff of the Department of Fisheries and Aquatic Sciences for their support in diverse ways. Of particular mention are Mr Armstrong Apprey, Mr Prosper Dordunu and Mr Thomas Robin Davis. Colleague postgraduate students of the Department of Fisheries and Aquatic Sciences especially Michelle N. K. Clottey, Ernest Obeng Chuku, Delali Gamor, Gabriel Gator and Isaac Kofi Osei also deserve a special mention.

I especially thank my husband Francis Kassah, children Setornam and Sedudzi, parents Yvonne and Ralph Avornyo, siblings, other family members and the Clotteys for their invaluable support and contribution during these trying years of study.

# DEDICATION

To the memory of my maternal grandmother, Elizabeth Adakou Afiwa Lawson.

# TABLE OF CONTENTS

Content Page

## LIST OF TABLES

Table Page

## LIST OF FIGURES

Figure Page

# CHAPTER ONE

# INTRODUCTION

This thesis seeks to bridge the knowledge gap on the biology and stock status of Atlantic chub mackerel *Scomber colias* (Gmelin 1789) in the coastal waters of Ghana. Of the four major small pelagic species landed in Ghana, much is known about the biology and stock status of the dominant Sardinellas (*Sardinella aurita* and *Sardinella maderensis*), while there is paucity of information on *Scomber colias*, one of the four main species of small pelagics landed. This study therefore contributes to the literature available on the biology of the species in Ghanaian waters, providing relevant information on the morphometrics, reproductive biology, age, growth, mortality, exploitation levels, nutrient composition and contribution to trawl bycatch. This information will help inform policy makers and stakeholders on the improved management practices to employ for the rational exploitation of the dwindling small pelagics stocks in Ghanaian waters. It also contributes relevant information to broaden understanding on the species for academics, students and interested stakeholders.

## Background to the Study

Atlantic chub mackerel belong to the family Scombridae; which includes the tunas, bonitos, and other true mackerels (Carpenter & De Angelis, 2016c). Scombrids are characterized as having a pointed head, spindle-shaped body, and a powerful caudal fin with pointed lobes which are placed at the end of a narrow caudal peduncle. Usually with small and thin scales; their spinous dorsal fin can be depressed into a dorsal groove to provide a more streamlined effect. Possessing light skeletons, they are active, pelagic, predacious fishes with a temperate and tropical distribution. Many of them grow to a large size with high economic and food values ( Collette & Nauen, 1983).

A review of studies conducted on all 51 known scombrid species revealed that they are among the fastest growing fish species (Juan-Jordá, Mosqueira, Freire, & Dulvy, 2013) . They also have a disproportionately high surface area relative to body weight which permits high rates of oxygen uptake to support the high growth rate. They also appear to mature at about 25.4% of their maximum age. In addition, ovaries of all scombrid species are considered asynchronous, with oocytes of all stages present simultaneously (Juan-Jordá et al., 2013; Murua & Soborido-Rey, 2003). However, reproductive biology is the least studied aspect of scombrid biology and current exploitation rates remain highly uncertain for the majority of scombrids worldwide (Juan-Jordá et al., 2013).

**Description and distribution of *Scomber colias***

The Atlantic chub mackerel is a fast swimming, schooling fish with a fusiform body and narrow caudal peduncle which is classified as a small pelagic fish mostly found in coastal waters (Carpenter & De Angelis, 2016c). It resembles its close relative in the Atlantic Ocean, *Scomber scombrus* which has a more northerly distribution (Carpenter & De Angelis, 2016c), among the taxonomic differences between the two species are the presence of dusky markings/ mottling on the belly and the presence of a swim bladder, which *S. scombrus* does not have (B. B. Collette & Nauen, 1983; Hernández & Ortega, 2000). *S. colias* is widely distributed in both temperate and tropical waters of the Atlantic Ocean (Figure 1), as well as in the Mediterranean and Black Seas; being replaced by the closely related Pacific chub mackerel (*Scomber* *japonicus* Houttuyn 1782) in the Pacific and Indian Oceans (Catanese, Manchado, & Infante, 2010). In the eastern Atlantic, the species has been reported to occur in the Mediterranean and Black Seas, the Bay of Biscay, the Northwest of Africa through to the Cape of Good Hope in South Africa as well as the Canary, Madeira, Azores and Saint Helena Islands (Hernández & Ortega, 2000).


*Figure 1*: Map showing the distribution of resident populations of *Scomber colias* in the world. Image credit: (Collette et al., 2011).

*Scomber colias* was previously believed to have a temperate Atlantic distribution; with *S. japonicus* having a more tropical range. There were however, considerable morphological and genetic differences in samples from various regions which led to further genetic investigations into the subject (Infante, Blanco, Zuasti, Crespo, & Manchado, 2007). Nuclear and mitochondrial DNA sequencing analysis in recent years has proven that chub mackerel from the chub mackerel from the Atlantic, Mediterranean and Black Seas are genetically distinct from those in the Indo- Pacific and should be recognised as separate species (Carpenter & De Angelis, 2016b; Catanese et al., 2010; Infante et al., 2007). As a result, chub mackerel from the Indo-Pacific are now referred to as *Scomber japonicus* (Pacific chub mackerel), while *Scomber colias* refers to those found in the Atlantic Ocean, the Mediterranean and Black Seas.

Previous literature on *Scomber colias* from Atlantic and Mediterranean regions prior to the genetic differentiation explained in the preceding paragraph sometimes refer to the species as *Scomber japonicus*; but due to the recent advances in genetics, it infers that the species in question is actually *Scomber colias*, This work therefore draws on literature that may refer to the species as *S. japonicus* due to the fact that some articles were written before the recent advances in DNA analysis were carried out, some dating back four decades.

Although classified as a pelagic/neritic species (Carpenter & De Angelis, 2016c), Atlantic chub mackerel can be found up to depths of 250 - 300 m below the surface of the sea (Collette & Nauen, 1983). The fish has also been found up to 104 m below the surface of the sea between November and May and at 64 to 62 m below the surface from June to October in Ghanaian waters (Kwei, 1971).  It is migratory and can move across latitudes as well as between inshore and coastal areas for feeding and reproduction (Hernández & Ortega, 2000). The species is known to school with other small pelagic species (Hernández & Ortega, 2000) and in Ghana, they are known to either shoal in size specific schools, or in mixed schools with round sardinellas

(*Sardinella aurita)*, horse mackerels (*Trachurus spp*) and scads (*Decapterus spp*).

The Atlantic chub mackerel has high protein and fat contents with 87% of the polyunsaturated fatty acid profile in its tissue reportely made up of the Omega-3 fatty acids (Celik, 2008), which lower the risk of heart disease, stroke, have oxidative purposes and help in several bodily functions (AHA, 2015). It is therefore seen as a good source of nutrition for human consumption in terms of its proximate chemical composition of proteins and fatty acids (Oliveira, 2014). The species, commonly known in Ghana as "saman" (Ga), "Awukongula" (Fante) and "Ablotsikpokponkuvi" (Ewe) is a food fish of high commercial importance (Kwei & Ofori-Adu, 2005) that is readily available on the local Ghanaian markets in mostly fresh, smoked and frozen forms. There are also various brands of frozen as well as canned, ready-to-eat mackerel available on the market which are imported.

**The importance of fish in human society**

Fisheries (marine, freshwater and brackish) play a very important role in the economies of countries all over the world, with fish and fish related products utilised in the diet of humans, as feed for animals and for various consumer products (FAO, 2018). Over 88% of the world's total fish production in 2016 was meant for human consumption (FAO, 2018), an increase from 67% average production in the 1960's. In recent years, the per capita consumption of food fish has increased, surpassing that of meat consumption from all terrestrial animals combined. According to the FAO (2018) report, marine catches declined drastically from 1974 to 2015. This decline affected 64% of the 25 top fishery producer countries in the world, pointing to a continued decrease of global marine fish stocks. The fraction of the stocks fished at biologically sustainable levels also reduced from 90% in 1974 to about 67% in 2015.

**Overview of Ghana's marine fishery**

Ghana is endowed with a coastline of about 550 km, a continental shelf area of 24,000 square kilometres, an Exclusive Economic Zone (EEZ) of 200 nautical miles and several landing beaches for various marine species (Armah & Amlalo, 1998; FAO, 2016; Tall & Failler, 2012). As at 2016, there were over 186 fishing villages, 292 landing beaches and an estimated 107,518 fishermen actively engaged in the Ghana's marine artisanal industry (Dovlo, Amador, & Nkrumah, 2016). According to the authors, over 10% of the economically active population is directly engaged fishing and fishery related activities

Fish is the preferred source of animal protein in the diet of Ghanaians, accounting for over 60% of the animal protein consumed in the country with (Dovlo et al., 2016). The population consumes about 21.5 kg per capita of fish annually compared to a worldwide average of about 20.3 kg (FAO, 2018; MOFAD, 2018). This suggests a relatively high demand for fish in Ghana.

Marine fishing in Ghana dates back to the pre- and colonial periods, when fishing was artisanal and carried out in small, double-ended and symmetrical dug-out canoes powered by oars and/or sails. These canoes were and are mostly made from the trunk of the "Wawa" (*Triplochyton scleroxylon*) tree. From the use of simple cast nets made from hemp, fishermen in the Gold coast were introduced to the beach-seine, drift net and purse-seine in the mid-nineteenth century (Akyeampong, 2007). When these were first introduced, landings increased due to the size and efficiency of these gears. Motorization of canoes started in 1959, when outboard motors were introduced for the first time (Doyi, 1984).

The modern Ghanaian marine fishery is a characterized by three main types of vessels: the artisanal, inshore (semi-industrial), and the industrial vessels (MOFAD, 2018), with landings from this sector making up 72% (342,427 metric tonnes) of the total fish landings reported for the country in 2017 (MOFAD, 2018). While commonly exploited marine fisheries resources globally include both small pelagic and large pelagic as well as demersal species, the most important small pelagic species exploited in Ghana are the round sardinella (*Sardinella aurita*), flat sardinella (*Sardinella maderensis*), anchovy (*Engraulis encrasicolus*), Atlantic chub mackerel (*Scomber colias*) and horse mackerels (Carangids) (Koranteng, 1995) which are landed in large quantities (Dovlo et al., 2016; Lazar et al., 2018; MOFAD, 2018). Similarly, the most important demersal species exploited in Ghana include sea breams (Sparidae), red snappers (Lutjanidae), groupers (Serranidae), grunts (Haemulidae), croakers (Scianeidae), cephalopods and shrimps (MOFAD, 2018). It is worth noting that these species, together with tunas, contribute significantly to Ghana's foreign exchange earnings (MOFAD, 2018).

Artisanal vessels are mostly small dug-out canoes (up to 20 m in length) made from *Triplocyton scleroxylon* ("wawa") and *Ceiba pentandra* ("silk cotton") trees (Dovlo et al., 2016; Doyi, 1984) which have limited ice storage facilities (Akyeampong, Amador, Nkrumah, & et.al., 2013), with the fishery being open-access and having a multiplicity of gears. The total number of canoes operating in Ghana as at 2016 was estimated at 11,583; with the major gears in the artisanal fishery being local variants of the purse seine ("poli" and "watsa"), beach seine, hook & line, lobster set nets, drifting gill net (DGN), "ali net", "one man canoe" and service canoes, powered by outboard motors of up to 40 hp. The dominant gears used in the artisanal fishery of Ghana are the purse seines and the set nets which make up 28.89 % and 32.20% respectively of the gears used (Dovlo et al., 2016). The fishery mostly targets small pelagic fish, with four small pelagic species, namely *Sardinella aurita, S. maderensis, Engraulis encrasicolus* and *Scomber colias* making up over 80 % of the small pelagic landings in the country, these four species also happen to be the most important small pelagic species landed in the Gulf of Guinea (Koranteng, 1995). The artisanal fishery contributes an average of 71% of the total fish landed from Ghana's marine fishery ( Akyeampong et al., 2013).

Inshore (semi-industrial) vessels are made up of large, wood-hulled vessels which range between 10 to 37 metres in length and use inboard engines of up to between 90 to 400 hp (Dovlo et al., 2016; Koranteng, 1998). They operate in depths ranging from the 10 to 200 m depth contour and mainly employ two gears, using purse seines during the upwelling season to exploit small pelagic species, and switching to trawling during the other months of the year to exploit demersal species (Akyeampong et al., 2013). In addition, these vessels are equipped with fish finders, echo sounders and ice holding facilities to hold fish for several days at a time, with 250 of such vessels currently in operation in Ghana (MOFAD, 2018).

Industrial vessels are made up of large, highly motorized, foreign-built steel hulled vessels with the capacity to hold ice for many months mostly use bottom trawls, tuna pole-and line and purse seines to target commercially valuable fish (Ashitey & Archibald, 2019; FAO, 2016; MOFAD, 2018). These species include tuna, sailfish, marlin and mackerel as well as demersal stocks such as groupers, snappers, soles, threadfins and penaeiid shrimps among others (FAO, 2016; Koranteng, 1998). There are currently 97 trawlers and 33 tuna vessels operating in Ghana, where they are licensed to fish from the 30 m depth contour and beyond into the deeper waters off the continental shelf (FAO, 2016; MOFAD, 2018).

Artisanal fishermen migrate to and from various coastal communities and neighbouring West African countries following migrating fish, mostly small pelagics and sharks (Akyeampong, 2007; Lazar, Yankson, Blay, Ofori-Danson, Markwei, Agbogah, Bannerman, Sotor, Yamoah, et al., 2017). The migrations are seasonal in nature- fishermen usually follow schools of migrating pelagic fish to and from spawning, nursery and/or feeding grounds during the major upwelling season (Akyeampong, 2007; Koranteng, 1995; Lazar et al., 2017).

Currently, Ghana’s fishing industry contributes to about 1.03% of the country’s Gross Domestic Product (GDP), and about 5% to the Agricultural Gross Domestic Product (AGDP) (Lazar, Yankson, Blay, Ofori-Danson, Markwei, Agbogah, Bannerman, Sotor, Yamoah, et al., 2017).

The artisanal fishery which accounts for 67% of the marine fish landed in Ghana is very important to the local Ghanaian economy, directly employing over 107,518 fishermen and 4,241 fish processers in the marine fisheries sub-sector (Lazar, Yankson, Blay, Ofori-Danson, Markwei, Agbogah, Bannerman, Sotor, Yamoah, et al., 2017). Over the years, overcapacity due to increased fishing effort, unsustainable fishing methods and a high demand for small pelagic species have led to excessive pressure on marine fish stocks. The artisanal subsector, which accounts for the most fish produced nationally, has declined steadily for most of the period in recent years, from a production of 230,000 metric tonnes in 2006 to a low of 176,398 metric tonnes in 2017 (MOFAD, 2018).

Due to this, Ghana is currently a net importer of fish as demand far outstrips supply (Atta-Mills, Alder, & Sumaila, 2004; Bank of Ghana, 2008; Lazar, Yankson, Blay, Ofori-Danson, Markwei, Agbogah, Bannerman, Sotor, Yamoa, et al., 2017). There is currently a fish deficit of 46.2%, a situation that led to Ghana importing 197 thousand metric tonnes of seafood valued at 146 million US Dollars in 2017 (MOFAD, 2018).

Despite this deficit in fish supply and intense pressure on the marine fishing industry, Ghana exported an estimated 53 thousand metric tonnes of fish valued at 325 million US Dollars , dominated by high value species (tuna, squid, cuttlefish and flatfish) mainly to the European Union and China in 2017 (Ashitey & Archibald, 2019; MOFAD, 2018).

**Challenges facing the marine fishing industry in Ghana**

Since the 2000's, landings of the four main small pelagic species in Ghana have been reported to have decreased drastically leading to near collapse; with only about 14 % of the maximum landings realized in 1996 (138 thousand tonnes) being landed in 2016 (Lazar et al., 2018). There have been instances when the small pelagic fishery of Ghana faced imminent collapse only to recover (Koranteng, 1989, 1995; Pezennec & Koranteng, 1998). These were mainly linked by the authors to variability in environmental conditions driven by changes in upwelling intensity. The current sustained, steep decline in the total landings of small pelagic species has been exacerbated by a high demand for fish, overcapacity due to increased fishing effort enhanced by the open access nature of the fishery, bad fishing practices and climate induced variability, largely brought on by rising sea surface temperatures (Lazar et al., 2018; Nunoo, Asiedu, Olauson, & Intsiful, 2015; Wiafe, Yaqub, Mensah, & Frid, 2008) .

The drivers of the high levels of fishing effort include an increase in the number of and size of canoes as well as fishing gear and the use of fish finders that have led to the overexploitation of fish stocks. According to Lazar et al. (2018), the average size of a purse seine has increased from a width of 275 m in the 1970's to 800 m currently, while the gross tonnage of canoes has increased 25-fold. The use of more efficient gears and vessels led to an initial increase in catches (Bank of Ghana, 2008), but a current steep decline in recent years as the resource has become over exploited (MOFAD, 2018). The catch per unit effort (CPUE) of vessels has declined considerably due to reduced catches which places additional pressure on the scarce resource and has led to increased poverty in coastal fishing communities (Nunoo et al., 2015).

Illegal, unreported and unregulated (IUU) fishing is also a major problem for Ghana's maritime fishery. It has been estimated that up to one fifth of the global maritime fish catch is obtained through IUU practices (Daniels et al., 2016). This poses a huge threat to the ecology of the marine ecosystem and also on official reports and analyses on fisheries statistics due to under-reporting of numbers. According to Daniels et al. (2016), three types of IUU fishing are of special concern to West African coastal states which includes Ghana. These are: fishing by unlicensed foreign industrial vessels, fishing in prohibited areas, particularly close to shore, using illegal nets and fishing by unlicensed artisanal vessels which fish with illegal nets

In Ghana, industrial fishing trawlers have been at the center of a lucrative trade in transhipped trawl bycatch, locally termed “saiko” fish. Foreign trawlers sell frozen slabs of bycatch, usually made of juvenile small pelagic fish and some low value demersal species to canoes for onward sale at port (Hen Mpoano, 2017).

Saiko fishing contravenes the laws of Ghana and such offences are sanctioned by the Fisheries Act 625, 2002 and Act 880 (Amendment) and the Fisheries Regulation, LI 1968. However, saiko has become prevalent in some major fishing communities in Ghana namely Apam, Elmina, Axim, Tema and Sekondi (Hen Mpoano, 2017; Nunoo, Boateng, Ahulu, Agyekum, & Sumaila, 2009) with no official records being kept of these transactions. Cheap fish floods the market in the face of declining commercial catches, placing more pressure on the dwindling fish stocks. This implies that data used for estimates of stock status may be deficient due to the fact that Saiko activities are largely unreported. There have also been conflicts between industrial trawlers and artisanal fishermen because some trawlers operate within the 30 m depth contour reserved for artisanal fishermen ( Nunoo et al., 2009). There have also been unconfirmed reports of these trawlers deploying midwater trawls to catch small pelagic fishes in a bid to maximise profits in the saiko trade which has led to even more pressure on fish stocks. The reduced landings have led to fishermen employing unorthodox methods to maximise the exploitation of a diminishing resource (MOFAD, 2018).

Among these unorthodox methods are the use of dynamite, carbide, DDT (dichlorodiphenyltrichloroethane), powdered detergent and gari solution, sodium cyanide among others (Afoakwah, Osei, Bonsu, & Effah, 2018). Light bulbs of high wattage (up to 1000 watts) are also placed in the sea as fish attractants in conjunction with the use of the chemicals outlined above. According to the authors, fish landed this way is often flabby with bloodshot eyes, skin lesions, has a peculiar taste, disintegrates upon processing and has a foul odour. The consumption of such fish also has public health implications due the toxic nature of the poisons, while the use of dynamite and other explosives also have adverse effects on aquatic habitats; especially the seabed and coral reef habitats (Durand et al., 1998; Koranteng, 1998). Despite various efforts to curb these practices, weak enforcement of existing laws, overcapacity and the open access nature of the fishery have led to the situation becoming more prevalent as the years go by in the face of dwindling catches, leading to even more pressure on fish stocks (MOFAD, 2018).

Further affecting the dwindling stocks of small pelagics and Ghana's maritime industry has been the issue of climate change. Small pelagic species, which typically feed on plankton are heavily affected by changes in sea surface temperature and upwelling intensity (Cury et al., 2000). Ghana experiences two upwelling seasons; a minor one which occurs for about three weeks anytime from December to March and a major, more sustained event between July and September (Wiafe et al., 2008). In recent years, gradual warming of surface waters has led to a decrease in upwelling intensity as well as a reduction in zooplankton biomass in Ghanaian coastal waters (Wiafe et al., 2008). Sardinella species, especially *S. aurita* which is most abundant during seasonal upwelling periods are greatly affected by the strength of the upwelling (Koranteng, 1989, 1995; MOFAD, 2018; Pezennec & Koranteng, 1998). It is therefore important for the effect of climate on the abundance of fish stocks to be taken into consideration when planning management measures to restore declining fisheries.

**Status of small pelagics in Ghana**

The small pelagics fishery in Ghana is currently said to be overexploited; with a current decline in three of the four main species (Lazar, Yankson, Blay, Ofori-Danson, Markwei, Agbogah, Bannerman, Sotor, Yamoah, et al., 2017; Lazar et al., 2018; USAID, 2015). Landings of the four most important small pelagic species (round and flat sardinellas, chub mackerel and anchovies) have shown a sharp decline in the last decade. Yearly catches of chub mackerel were reported to be less than 10,000 mt from 2002 to date (USAID, 2015). The current fishing pressure (F) on small pelagics has been estimated at 0.74, which is above the acceptable level of fishing pressure of 0.4, a situation caused by excess fishing effort (USAID, 2015). This decline in catches is predicted to lead to an imminent collapse of the small pelagic stocks fishery if urgent steps are not taken to remedy the situation.

A study of the stocks of *Sardinella aurita* and *S. maderensis* have shown that the stocks are mortality dominated and currently overexploited, with more than 50% of the biomass – per recruit exploited before they are sexually mature (Osei, 2015). The recent Fridtjof Nansen research acoustic survey conducted in September 2017 in Ghanaian waters suggested a possible collapse of the sardinella stocks if no interventions actions were taken (Lazar et al., 2018).

The  Fisheries Management Plan of Ghana is a national policy for the management of the marine fisheries of Ghana to span the years 2015-2019 (MOFAD, 2015). It seeks to halt further decline and rebuild the fish stocks of Ghana by addressing key issues which are excessive fishing effort exerted in all fisheries, inadequate information on fisheries biology and stocks, inadequate regulations and weak enforcement of existing regulations, low levels of protection of marine biodiversity and inappropriate procedures in certifying fish for export. Specific measures to address the key issues in the artisanal sector under the plan include efforts to: reduce excessive pressure on fish stocks, ensure fish stocks are exploited within biologically acceptable limits, ensure effective implementation of legislation, sstrengthen participatory decision making and meet regional and international fisheries legislations and finally, meet regional and international obligations in fisheries

As part of measures to curb the drastic decline of small pelagic stocks, the Ministry of Fisheries and Aquaculture Development introduced a closed fishing season for the artisanal, inshore and industrial vessels after a series of deliberations and consultations with scientists, fishermen, fish processors and other key stakeholders in Ghana's fishing industry. After a successful pilot closed fishing season for trawlers in 2016 (Coastal Resources Center, 2016), a proposed closure for the artisanal fleet was to be carried out in August 2018, which was unsuccessful due to agitation from the fishermen. In 2019, a closure was successfully implemented by MOFAD for the artisanal fishery from the 15$^{th}$ of May to the 15$^{th}$ of June 2019. The electronic monitoring of vessels through the use of the Vehicle Monitoring System (VMS) has greatly reduced the incidence of fishing by trawlers in inshore waters, on gas pipelines, oil installations and fishing in third party states without license, with the semi-industrial fleet also being equipped with Automatic Identification System (AIS) beacons for continuous tracking (MOFAD, 2018) .

Literature available on the small pelagic stocks of Ghana has focused on the two dominant sardinella species and anchovies, with emphasis on their distribution, biology and stock status (Castro, Skrobe, Asare, & Kankam, 2017; Koranteng, 1989; Kwei, 1964; Osei, 2015; Pezennec & Koranteng, 1998).

Catches of *Scomber colias* in Ghana are said to fluctuate with no identifiable trends (Koranteng, 1998; Minta, 2003; Pezennec & Koranteng, 1998), although there was a slight increase in landings between 2010-2015. This is in contrast with landings of *Sardinella maderensis*, *S. aurita*; and *Engraulis encrasicolus* which showed trends tied to variability in upwelling periods (Koranteng, 1998) in the years prior to the 2000's. During that period, fishing effort was low, compared to high fishing effort and the rapid decline of stocks recent years. In the canoe fishery of Ghana between 1980 and 2001, chub mackerel contributed to 7% of the total revenue of the canoe fishery, and 5% of total yield within the same period; indicating its high economic importance (Minta, 2003).

**Statement of the Problem**

There is a paucity of information on the fishery biology of *Scomber colias* landed in Ghana, although studies have been carried out on some small pelagic species especially the sardinellas. Most of the data, where available is combined with that of the major small pelagics, or skewed towards the sardinellas. This may lead to inaccuracies in the data being reported as the dynamics of the species may differ from that of the other dominant small pelagics. The few published articles on the species in Ghanaian waters are the works by Kwei (1971) and Amponsah, Ofori-Danson & Nunoo (2016) who dealt with some aspects of reproduction, diet, and stock status of the species based on a short sampling period (one year, and six months respectively). Information on the biology and stock status of the species is inadequate. No information on ageing of the species using hard parts (sagittal otoliths) is also currently available to give an accurate picture of the age structure of the species in Ghanaian waters. In view of the significant contribution of the species to the landings of small pelagics and diet in Ghana; there is the need to assess its fishery and aspects of its biology to generate relevant information for the effective management and exploitation of the stock.

**Main Objectives**

The study therefore sought to investigate various aspects of the biology and stock status of *Scomber colias* in Ghanaian coastal waters to yield updated information on the *Scomber colias* population in our waters.

**Specific objectives**

In line with the main objective, the specific objectives of this study are to:

i. Describe the size distribution of the Atlantic chub mackerel landed
ii. Investigate fluctuations in condition factor and visceral fat for the species

iii. Determine the reproductive capacity and spawning season of the fish

iv. Determine the food and feeding habits of the species

v. Determine the age structure of the species using sagittal otoliths

vi. Assess the growth and mortality parameters as well as determine the exploitation levels of the chub mackerel stock

vii. Investigate the composition of the species in frozen trawl bycatch ("Saiko") landed

viii. Examine the nutritional value via the proximate macronutrient composition of the species landed from Ghanaian coastal waters

**Significance of Study**

The chub mackerel is an economically important food fish in Ghana, but studies on the biology and dynamics of the stock in Ghana to enable assessment of the status of its fishery is very scanty which limits management of this resource on the basis of scientific knowledge. With the current developments in the marine fishery of Ghana, where sardinella stocks are on the brink of collapse, a comprehensive study on *Scomber colias* is needed as it is one of the four major small pelagic species occurring in Ghanaian waters. Data on the size and age structure, growth and mortality parameters, reproductive biology of the population as well as nutrient composition will provide the requisite information for management of the stock. This will ensure the sustainable exploitation of the scombrids and all other small pelagic species landed in Ghana.

There is also the need to factor in the impacts of climate change on the population and explore any trends or changes that have occurred in the timing and/or magnitude of upwelling events that may elicit a phenological response from the species.

The findings of this study will help give current, up-to date scientific information to the general public, academia as well as stakeholders and policy makers (fishermen, fish processers, MoFAD, FC, donor agencies and NGO'S) to help augment current arguments on the immediate need to sustainably exploit the small pelagic stocks found in Ghanaian coastal waters.

**Delimitations of the Study**

The study covered fish landing sites from the Central and Western coastlines of Ghana, where Atlantic chub mackerel are mostly landed. The Eastern coastline was not included due to the relatively low landings of the species along that stretch. Due to practical considerations based on the availability of logistics, five major landing beaches for Atlantic chub mackerel were identified as sampling sites. Field data was obtained from random samples of commercial artisanal fish landings at selected fish landing beaches. The samples were obtained from purse seine landings ("poli/watsa") gears as soon as fishermen offloaded their catches. In order to avoid diffusion of data, field sampling was carried out once a month, at the middle of the month to reduce the possibility of overlaps in the data generated.

**Limitations of the Study**

The lunar cycle affected the landings of small pelagic species. During periods when the moon was full or gibbous, artisanal fishermen did not go often go to sea. They explained that this was because the nets and canoes were more visible to fish at this time and hence evaded capture at this time. This sometimes led to situations where samples were difficult to obtain during some months due to the moon phase during field visits. The reliance on commercial landings also meant that, the researcher had no control over the exact time at which fish were harvested. The lack of a research vessel meant that data was fisheries dependent. However, it gave an accurate reflection of the species as landed commercially.

Due to challenges with equipment, some laboratory analysis was carried out using manual methods. Despite the fact that these limitations were beyond the control of the researcher, they do not undermine the results and inferences made from this study as scientific methods and procedures were followed. They also reflect the major challenges associated with research where external factors such as weather, climate and logistics play an important role in data collection.

**Organisation of Study**

This thesis is organised into six chapters. Chapter One, the Introduction, gives a brief background to the fisheries of Ghana, the problems facing the small pelagics fishery and outlines the knowledge gaps in the biology of Atlantic chub mackerel that need to be addressed. The objectives of the research are also outlined and the significance of the study to academia, policy makers, stakeholders in the fisheries industry and the general public as a whole is outlined.

Chapter Two reviews literature on the various theories and research carried out by other authors that support the objectives of the study. Various articles on fisheries, as well as methods of assessing aspects of the biology of *Scomber colias* are also reviewed and the various methodologies and theories discussed. Gaps in the literature reviewed are also pointed out, and the alternative measures of addressing the problems in the industry are proposed.

Chapter Three details the materials and methods employed in the course of the study. A description of the study sites, field data collection methods, equations and statistical packages used, as well as analyses carried out are outlined. The results of the study based on the procedures outlined in Chapter Three are presented in the forms of relevant graphs and tables in Chapter Four with brief descriptions of trends observed.

Chapter Five is the Discussion chapter which expands the observations made from the results in Chapter Four. The key findings are compared with information reported on the species from earlier studies on the species globally. The trends in the results are discussed into detail and the relevant information that can be gleaned from the study put forward. Chapter Six is the Conclusion and Recommendations Chapter. The main findings of the study are outlined and recommendations based on the outcome of the research are put forward.

**Chapter Summary**

The artisanal fishery is the backbone of the marine fishery in Ghana. In recent years, the stocks of the dominant small pelagic species (Sardinellas, anchovies and Atlantic chub mackerel) are said to be in sharp decline, with the Sardinellas on the verge of collapse. With data gaps on the status and biology of Atlantic chub mackerel landed in the coastal waters of Ghana, this research seeks to make significant input on the biology of the species for effective management of small pelagic stocks. The significance of the study is given, and the organisational structure of the thesis is also laid out.

# CHAPTER TWO

# LITERATURE REVIEW

This chapter examines the relevant literature on selected life history traits of the Atlantic chub mackerel as well as mortality and exploitation relevant to this study. It focuses on physical characteristics, distribution, reproduction, food habits, age, growth parameters, mortality, exploitation and proximate nutrient composition of the species in the context of this study.

## Size and Length-Weight Relationships

The maximum reported size of *Scomber colias* varies due to differences in geographic location, fishing pressure, food availability, selectivity of gear and population structure among others (Daley & Leaf, 2019; Hernández & Ortega, 2000). Various studies on the size of the species indicate that the species is a medium-sized fish. The species is said to have a very fast growth rate in the first year, reaching between 35% and 63% of the maximum length of the species for various geographic areas (Hernández & Ortega, 2000), after which growth slows down and eventually tapers off as the fish nears its maximum length . Maximum lengths of 38.6 cm *TL* have been reported for the Canary Islands (Lorenzo & Pajuelo, 1996), 38.6 cm *TL* in the Northwest Atlantic, 49.0 cm *TL* in Mauritania (Jurado-Ruzafa, Hernandez, & Santamaria, 2017), 46.5 cm *TL* off Portugal (Martins, 2007), 42.7 cm *TL* (Vasconcelos, Dias, & Faria, 2011), 35.1 cm *TL* in the Gulf of Cadiz (Torres, Ramos, & Sobrino, 2012) and 65.0 cm *TL* from Spanish waters (Navarro et al., 2012).

Length-weight relationships are often used to describe the growth of a given species, with growth of species usually expressed as a power function

(Froese, 2006). The value of the intercept (*a*) is the scaling coefficient while the slope (*b*), also known as the allometric constant indicates the state of well-being of the fish (Cadima, 2003). Values of the allometric constant indicate isometry in growth if it is not significantly different from 3. The relationship is also useful for estimating the weight of a specimen given a particular length and vice-versa (Froese, 2006).

This relationship for the species has been studied in the Canary Islands (Lorenzo & Pajuelo, 1996), the Northwest Atlantic (Daley & Leaf, 2019), Mauritania (Jurado-Ruzafa et al., 2017) , and the Azores (Carvalho, Perrotta, & Isidro, 2002) among others, with a trend towards positive allometry for combined sizes (juveniles and adults), and isometry in adult samples.

**Condition Factor and Visceral Fat Index**

The condition factor is an index that gives the state of physiological well-being of a species in an ecosystem. Low values of condition may lower the chances of survival of fish and pose an increased risk of natural mortality as well as affect reproduction. In the event of starvation, disease, depletion of energy reserves due to reproductive activity and migration as well as changes in environmental conditions, the condition of fish may reduce significantly and make organisms more susceptible to predation and disease (ICES, 2017). As a result, condition factor can be used as a reliable indicator of the health of a given stock and its status in the ecosystem, but it is often overlooked.

Commonly used variants of condition index are Fulton's condition factor and the Relative condition index (Le Cren, 1951; Ricker, 1975). Condition factor has been reported on for *Scomber colias* from Madeira Island (Vasconcelos et al., 2011), and Ghana (Kwei, 1971). Closely linked to this is the mesenteric/visceral fat index, a measure of fat attached to the viscera or present in the abdominal cavity of the body which also gives useful information on eating habits and reproductive cycles (Kwei, 1971; Osei, 2015).

**Reproduction**

The overall pattern of reproduction that is common to individuals of a species is termed as the reproductive strategy, with variations in reproductive strategy due to environmental fluctuations termed as reproductive tactics (Murua & Soborido-Rey, 2003). These are reported to be adaptive. The condition of females due to environmental factors tends to affect the quality of eggs and larvae (Leggett & Frank, 2008; Mcbride et al., 2015).

Fish have varied reproductive strategies: in terms of periodicity, most marine fish spawn multiple times in a lifetime (iteroparity), while a few species such as the European eel (*Anguilla anguilla*) and Pacific salmon (*Oncorhynchus* spp.) are semelparous, spawning once in a lifetime after which death usually follows. Fish may also be hermaphroditic or gonochoristic, and spawn in batches (batch spawners) or release all oocytes in one event during a breeding season (total spawners). Other forms of reproductive strategy refer to the type of parental care, place of fertilization of eggs, mode of spawning site preparation, mating system, and secondary sexual characteristics.

To determine whether a species is a total or batch spawner, a frequency distribution of oocyte (ova) diameter of sexually mature females is plotted (Murua & Soborido-Rey, 2003; Newton & Kilambi, 1969). A single bell curve with one peak is indicative of synchronous spawning exhibited by total spawners; another form of synchronous spawning (group synchrony) occurs when a discrete cohort of secondary oocytes advances, resulting in a size hiatus between primary and secondary oocytes. When overlapping size cohorts of primary and secondary oocytes arise and persist throughout the spawning season, this pattern is referred to as asynchronism- manifested by the presence of more than one peak, with a clearly separate stock of hydrated oocytes during the peak spawning in the presence of advance yolked oocytes as well in the frequency distribution. This is indicative of batch spawning (Mcbride et al., 2015; Murua & Soborido-Rey, 2003). Iteroparous species tend to have extended spawning seasons; with oocyte development dependent on food availability, and are usually batch spawners.

**Assessment of ovarian development**

Oocyte recruitment patterns and the leading oocyte developmental stage underlie the various methods used to assess ovarian development (Lowerre-Barbieri, Ganias, Saborido-Rey, Murua, & Hunter, 2011), including macroscopic characteristics, oocyte (ova) size frequency distributions, gonadosomatic indices, and histological assessment. Ova diameter has been used to determine sexual maturity and mode of spawning in *Roccus chrysops* (white bass) (Newton & Kilambi, 1969), *Scomber colias* (Kwei, 1971), and *Sardinella aurita* and *S. maderensis* (Osei, 2015). Histological assessment, a more accurate form of gonadal staging has also been carried out for ovaries of *Scomber colias* (Daley, 2018; ICES, 2015; Keč & Zorica, 2012b) as well as varied species (Lowerre-Barbieri et al., 2011).

Changes in the weight and appearance of gonads have been used to determine spawning season where heavy, ripe and running gonads are indicative of spawning activity. The use of the gonadosomatic index (*GSI*) as well as changes in the proportion of individuals with ripe gonads have been used to establish spawning season in fish (Kwei, 1971; Techetach, Hernando-Casal, Saoul, & Benajiba, 2010; Vasconcelos, Afonso-Dias, & Faria, 2012).

The four most studied reproductive timing characteristics for fish are sexual maturity, spawning seasonality, spawning frequency, and diel periodicity (Johannes, 1978; Lowerre-Barbieri et al., 2011). It is necessary to study these and various aspects of the reproductive strategy of a species to help estimate the fecundity as well as reproductive potential of a species. A knowledge of fecundity enables the researcher to understand the relationship between spawning stock biomass and recruitment, which is dependent not only the length-frequency of spawning adults, but also on the body weight at length (Witthames et al., 2009). This will help enhance stock assessment studies and inform management decisions.

Atlantic chub mackerel are dioecious, not sexually dimorphic, and have females reportedly to growing bigger than males. Male and female fish tend to occur in relatively equal proportions in populations, although changes may occur certain periods of the year (Hernández & Ortega, 2000).

The species is said to be a broadcast batch spawner which spawns multiple times within a spawning season, with the annual potential fecundity not fixed before the start of the spawning season, leading to suspected indeterminate fecundity (ICES, 2015; Juan-Jordá et al., 2013). Ovulation is reported to be asynchronous, with various stages of oocyte development at a given time, however, during the spawning periods there is a greater proportion of ripe ova in the ovaries which are hydrated and are extruded upon exertion of slight pressure on the abdomen (Dickerson, Macewicz, & Hunter, 1992; ICES, 2015; Murua & Soborido-Rey, 2003).

It is reported to spawn in water with temperatures of 15°-20°C, leading to different spawning seasons by geographical area (Hernández & Ortega, 2000; Vasconcelos et al., 2012). While it spawns in the Azores from March to August (Carvalho et al., 2002); it spawns in the Canary Islands between November to March (Lorenzo & Pajuelo, 1996), November in Argentina, February to April in Portuguese waters (Martins & Serrano-Gordo, 1984) and July to September in Ghanaian waters (Kwei, 1971).

Fecundity of the species has been determined to be quite high (Hernández & Ortega, 2000), and has been estimated to be between 77,621 to 465,712 oocytes off the Moroccan coast (Techetach et al., 2010); 99,166-394,120 oocytes in the Eastern Adriatic (Keč & Zorica, 2012b), and up to 72,300 oocytes in Ghanaian waters (Kwei, 1971). That of the closely related *Scomber japonicus* has been estimated to range from as low as 101 859 to as high as 1, 859 173 eggs (Hernández & Ortega, 2000).

**Ageing**

An important factor to be considered in age-based fisheries stock assessment is the need to accurately estimate the age of fish species in order to make sound scientific inferences for effective management of fish stocks. In areas where there are distinct seasons or abrupt changes in water temperature, there is often a distinct changes in the growth of fish occur (Lai, Gallucci, & Gunderson, 1996). These lead to different rates of growth of hard parts which can be used to estimate the age of fish if these changes occur regularly on a yearly basis. Various methods are available for the ageing of fish based on the counting of annual marks or checks on the hard parts, known as direct ageing; this includes the use of scales, opercula and other head bones, fin rays and spines, vertebrae, pectoral girdles and otoliths.

The initial technique used for estimating ages of fishes involved following modal progressions of fish lengths as they changed through time, however, marks on the animal's hard parts (calcified structures) were found to be formed on a regular and sometimes annual basis, and so beginning from the 1960's, otoliths began to be one of the most utilised anatomical components for ageing (Rossi- Wongtschowski et al., 2014).

Although ageing using hard parts has mostly been carried out in temperate and boreal waters due to the occurrence of distinct seasons, there is a growing pool of research from tropical countries that points to deposition of annual rings, especially in upwelling areas due to changes in water temperature and chemistry on a yearly basis. This has led to some tropical species being successfully aged (Aggrey-Fynn, 2009; Morales-Nin, 1989; Ofori-Danson, 1989, 1990), with the studies by Aggrey-Fynn (2009) and (Ofori-Danson, 1989) on *Balistes capriscus* in Ghana employing the use of dorsal spines for ageing.

Bony fish otoliths are complex polycrystalline structures which act as organs of balance in the inner ear (Morales-Nin, 1992). Teleost fish have three pairs of otoliths that are present in three otic sacs, the utriculus, sacculus and the lagena. The largest otolith pairs are the sagittae which are found in the sacculus. The other two pairs, the lapillae (found in the utriculus) and the astersci (found in the lagena) are smaller. Due to their relatively large size compared to the other two, the sagittae are the otoliths used for ageing (Lai et al., 1996). Otoliths are the preferred calcified structures for aging due to their early formation ahead of the other hard parts, continuous growth during the life-time of the fish and ease of preparation when compared to other hard parts. Otoliths are mostly made up of an inorganic component (otolin) upon which an organic component (calcium carbonate in the forms of calcite, aragonite, vaterite and calcium carbonate monohydrate is deposited (Lai et al., 1996; Pannella, 1980) The crystallized calcium carbonate and otolin bands laid across the surface of the otolith form the incremental growth zone (primary growth increment) whilst the growth check zone is composed of mainly otolin (Pannella, 1977).

Otolith size and shape vary considerably from species to species, with those of demersal species usually being bigger than that for pelagic species. Differences in thickness also exist for different species (Rossi-Wongtschowski et al., 2014; VanderKooy, 2009). Due to these differences, based on the size and shape of otoliths, several procedures have been used to reveal the growth rings on the otolith structures. These include whole surface reading, sectioning and polishing across various planes, burning on a low gas or spirit flame as well as polishing and acid etching of otolith surfaces (Bagenal & Tesch, 1978; Lai et al., 1996). As with Atlantic mackerel (*Scomber scombrus*), growth rings can be observed on the external face of the otolith, and opaque rings (corresponding to rapid growth) and hyaline or translucent (corresponding to slow growth) rings as seen under reflected light are formed annually.

A succession of one opaque and hyaline band which can be traced throughout the outline of the otolith is taken to represent one year of life

(ICES, 2016; Keč & Zorica, 2013; Martins, 2007), with 1st January fixed as the birthdate of fish as per convention. Otoliths aged this way also may also need to be validated by a qualitative analysis of the evolution of the edge zone or by the use of quantitative methods such as marginal increment analysis (ICES, 2016).

During periods of extreme stress, fish may lay down incomplete rings which may be mistaken for annuli and care must be taken to avoid this error or the age of the fish may be grossly over-estimated with disastrous consequences for management (Daley & Leaf, 2019; ICES, 2016; Lai et al., 1996).

Although sectioned otoliths have also been used for the age determination of *Scomber colias*, the sections are often thin and fragile due to the nature of the otolith and it is difficult to see growth rings using this method (Daley & Leaf, 2019). The use of whole otoliths under reflected light is said to give the best results and is the standardised protocol available for reading otoliths of the species (ICES, 2016). Sagittae of *Scomber colias* have been used successfully for age determination by several authors, for stocks in the Northwest Atlantic (Daley & Leaf, 2019), the Adriatic (Keč & Zorica, 2013), Aegean Sea (Cengiz, 2012), Mauritania (Jurado-Ruzafa et al., 2017), the Azores (Carvalho et al., 2002) and Madeira Island (Vasconcelos et al., 2011). There is currently no comprehensive data on the age composition of the species in the Gulf of Guinea based on otolith analysis in extant literature; and hence a comprehensive study of otoliths of the species is needed to give information on the age structure of the stock for effective management.

**Growth, Mortality and Exploitation**

To effectively assess the status of a fish stock for effective management decisions to be made and implemented, knowledge of the growth parameters of the species in question must be known. Estimates of asymptotic length ($L_\infty$), growth curvature constant ($K$), and theoretical age at zero length ($t_o$) are needed to help inform management decisions as well as determine the growth of the species as per the von Bertalanffy growth equation (Sparre & Venema, 1998). In addition, these parameters help give important information to help determine stock status, age/length at maturity, mortality, recruitment, biomass and yield among others.

. Ideally, data for the determination of these parameters should come from age readings, however, the difficulty of ageing tropical species makes this problematic (Lai et al., 1996). As a result, size-based methods, particularly length-frequency distributions have been devised which make use of weight or length frequency data to estimate the growth parameters in the absence of age data, especially in tropical countries.

Monthly length-frequency-distributions are plotted and the modes are connected to track the growth of each cohort from month to month (Schwamborn, Mildenberger, & Taylor, 2019). Usually, the 'von Bertalanffy Growth Function (VBGF), (von Bertalanffy, 1934, 1938 in Schwamborn et al., 2019) is fitted to such monthly length frequency distribution data. This method became highly popular and has been used in several tropical and data deficient fisheries around the world (Pauly, 1983; Schwamborn et al., 2019; Sparre & Venema, 1998). Various computer based methods to carry out these analyses have been developed such as the 'ELEFAN I' package in FiSAT

(FAO, 2013; Gayanilo, Sparre, & Pauly, 2005), 'ELEFAN in R' (Pauly & Greenberg, 2013) and most recently 'TropFishR', an R package for tropical species (Mildenberger, Taylor, & Wolff, 2017) with the packages in R giving confidence intervals for growth parameters and bootstrapping alternatives for data deficient samples.

Growth parameters have been determined for tropical species via length-based methods using ELEFAN in FiSAT, among which in Ghana include for *Scomber colias* (Amponsah et al., 2016), Sardinella (Osei, 2015), freshwater prawn (Alhassan & Armah, 2015) and cichlids (Ofori-Danson & Kwarfo-Apegyah, 2009). Novel techniques with the use of bootstrapping methods found in TropFishR have recently been carried out for cichlids in the Northern Region of Ghana (Abobi, Mildenberger, Kolding, & Wolff, 2019).

The assessment of mortality rates is a very vital part of stock assessment as it gives valuable information on the key drivers of death in an exploited fishery. The growth parameters derived for the species are also important as they are input data for the determination of instantaneous rates of total mortality (*Z*) rates through catch curves (Gallucci, Amjoun, Hedgepeth, & Lai, 1996). "Instantaneous" in this context refers to rates of mortality per unit of time. The instantaneous rate of fishing mortality (*F*) (fishing mortality coefficient) refers to the relative instantaneous rate of the mortality of the number of individuals that die due to fishing, the instantaneous rate of natural mortality (*M*) refers to the relative instantaneous rate of the mortality of the number of individuals that die due to all causes other than fishing ( predation, disease, while the instantaneous total mortality rate (*Z*) refers to the relative instantaneous rate of the mortality of the number of individuals that die due to all causes. $Z$, $F$ and $M$ are related by the expression: $Z = F + M$, while recruitment to the exploitable phase ($R$) refers to the number of individuals of a stock that enter the fishery for the first time each year (Cadima, 2003).

For exploited stocks, $M$ can be calculated using Pauly's empirical equation (Pauly, 1980), and $Z$ from the descending arm of a linearised length-converted catch curve. $F$ can then be calculated by subtracting $M$ from $Z$. The exploitation rate, ($F/Z$) can then be calculated to give the level of exploitation of a fishery (Gulland, 1971; Ricker, 1975).

Growth, mortality and exploitation has been studied extensively for *Scomber colias* studied from regions outside the Gulf of Guinea. Among these are that for the Adriatic Sea (Keč & Zorica, 2013), the Azores (Carvalho et al., 2002), Mauritania (Jurado-Ruzafa et al., 2017), Aegean Sea (Keč & Zorica, 2013), Northwest Atlantic (Daley & Leaf, 2019), the Mediterranean (Perrotta, Carvalho, & Isidro, 2005) and off Southern Spain (Velasco, Del Arbol, Baro, & Sobrino, 2011) among others.

**Food and Feeding Habits**

A study of the diet of fish species is vital in order to understand the role of the species in the ecosystem, give vital information on factors that may affect growth, food availability, predator growth, competition as well as the response of the ecosystem to a change in prey abundance. Correctly quantifying the importance of prey taxa, as well as the investigation of the contribution of prey items to the overall condition of the species is needed to effectively manage fish stocks. A better understanding of trophic levels and hence the ecological niche of the species in terms of food webs are need for sound management of the resource. Methods for evaluating the stomach contents of fish species range from simple estimates such as the frequency of occurrence of given prey items (frequency of occurrence, expressed as a percentage), and percentage composition by weight, volume and number.

These traditional methods however are unable to depict the true relative value of prey items, especially when there happen to be prey items of unequal sizes or broken body parts (Pinkas, Oliphant, & Iverson, 1971). To avoid this situation, a compound index, the Index of Relative Importance (*IRI*) which integrates the various estimates of abundance to give a value which depicts the true importance of the prey item in the diet of the species is often employed (Hart, Calver, & Dickman, 2002; Liao, Pierce, & Larschild, 2001). As a result, studies which aim to depict an accurate picture of the importance of prey items in diet employ the use of the *IRI.*

The diet of *S. colias* has been studied extensively in the temperate waters of the Atlantic. A synopsis of the biological data available from extant literature on the species points to it being an opportunistic non-selective planktivore that tends to feed mostly on fish (especially anchovies and sardines), decapods, copepods and cephalopods (Hernández & Ortega, 2000), with the adults having a preference for a wide range of organisms ranging from copepods and other crustaceans, mysids, appendicularians, and chaetognaths to fish and squid (Collette & Nauen, 1983).

A study off the Canary Islands identified copepods as the most numerically abundant food item and mysids as the most abundant in terms in weight, while adult fish fed predominantly on fish. (Castro, 1993). In South Africa, the fish is documented as feeding heavily on fish, with a shift in the type and sizes of prey items consumed with age (Crawford & De Villiers, 1984). In Ghanaian waters, the study by Kwei (1971) is currently the only detailed source of information on the prey items of the species. These were determined to be crustaceans, annelids, molluscs, protozoa, fish and cephalopods using indices of frequency of occurrence and percentage occurrence by number but the relative importance of the various prey items was not investigated. He found evidence of diel vertical migration for feeding purposes and intensive feeding occurring between October and May.

Research into the diet of other commercially important marine species landed in Ghana employs the additional use of *IRI* to quantify prey importance. These include studies on the food preference of juveniles of *Pseudotolithus senegalensis* and *Brachydeuterus auritus* (Blay, Awittor, & Agbeko, 2006), as well as *Galeoides decadactylus* and *Sphyraena sphyraena* (Aggrey-Fynn, Fynn-Korsah, & Appiah, 2013).

Most studies on the feeding ecology of *S. colias* have focused heavily on the use of single component indices such as the percentage frequency of occurrence, percentage numerical composition, gravimetric and volumetric compositions in an attempt to describe the prey preferences of the species. A gap therefore exists when it comes to a comprehensive way of determining the relative importance of specific prey items in the diet. It is therefore necessary to include the IRI in estimates of prey items to paint an accurate picture of the important food items the species preys upon for effective management of the nation’s marine fishery resources. This will also contribute to available information on the dietary preferences of the species.

**Proximate Nutrient Composition**

The nutrient composition of fish is of interest to researchers, nutritionists and the general public due to the immense contribution of fish to the diet of humans as a source of high-grade animal protein. As a result of the increased awareness by the general public over what they consume, the use of fish in commercial agricultural feed, and a need to understand the nutritional value of a given species for technological processes (Yeannes & Almandos, 2003), a study of the proximate composition of fish is of prime importance .

The major nutrient components of fish muscle are water, protein and lipids/oil (fat), with carbohydrate, fibre and ash as minor components. These nutrients are usually expressed as a percentage of the total weight of the tissue examined (Murray & Burt, 2001). There is variation in the composition of the various nutrients due to the age of the fish, feeding habits, season, prey items, reproductive cycle and status as well as water temperature among others (Pal et al., 2018). In addition, during starvation periods or of low food availability, the fish uses the energy depots in the form of lipids and also may utilize protein, leading to a general reduction of the biological condition of a given fish (Yeannes & Almandos, 2003).

Carbohydrate, fibre and ash may occur in low quantities but are needed in the diet to fuel metabolic functions, serving as a reliable source of minerals and vitamins for optimum growth, disease prevention and regulation of body functions. The minerals present in fish include iron, calcium, zinc, phosphorus, selenium, fluorine and iodine which have a high bioavailability (Pal et al., 2018).

While proximate analysis has been carried out on various fish species of commercial and ecological interest (Boran & Karaçam, 2011; Jahncke & Gooch, 1997; Ljubojević et al., 2016; Pal et al., 2018; Spitz, Mourocq, Schoen, & Ridoux, 2010) with evidence of seasonality in composition, data on the proximate composition of *Scomber* species tissue is scanty. Seasonal variation related to spawning season has been reported to occur in the proximate composition of *Scomber japonicus* from the coastal waters of Korea (Shim et al., 2017), and *Scomber colias* (reported as *S. japonicus*) from the north eastern Mediterranean Sea (Celik, 2008). However, information on the species from the Gulf of Guinea is data deficient.

The visceral fat content of *S. colias* in Ghanaian waters was studied by Kwei (1971) who found seasonality in fat content directly tied to the spawning season. In addition, proximate analysis of nutrients was also investigated for five commercial fish species in Ghana of which *S. colias* was included, but the samples were obtained from a single batch of specimens for which no seasonality or trends could be determined (Obodai, Abbey, & Maccarthy, 2009). This highlights the need for a comprehensive study of the proximate composition of the species in Ghanaian waters. This will determine trends, if any in seasonal composition of nutrients, aid in the interpretation of linked data and inform academia and the public on the nutrient composition of the species.

# CHAPTER THREE

# MATERIALS AND METHODS

This chapter presents a description of the sites from which samples of chub mackerel, *Scomber colias* were obtained for the study; it also describes the sampling procedures, data collection and the various statistical analytical tools employed.

## Sampling Sites

The target fish samples were collected from five landing sites in Ghana:, three (3) in the Western Region (Half-Assini, Axim and Sekondi), one (1) in the Central Region (Elmina) and one (1) in the Greater-Accra Region (Tema) (Figure 2).

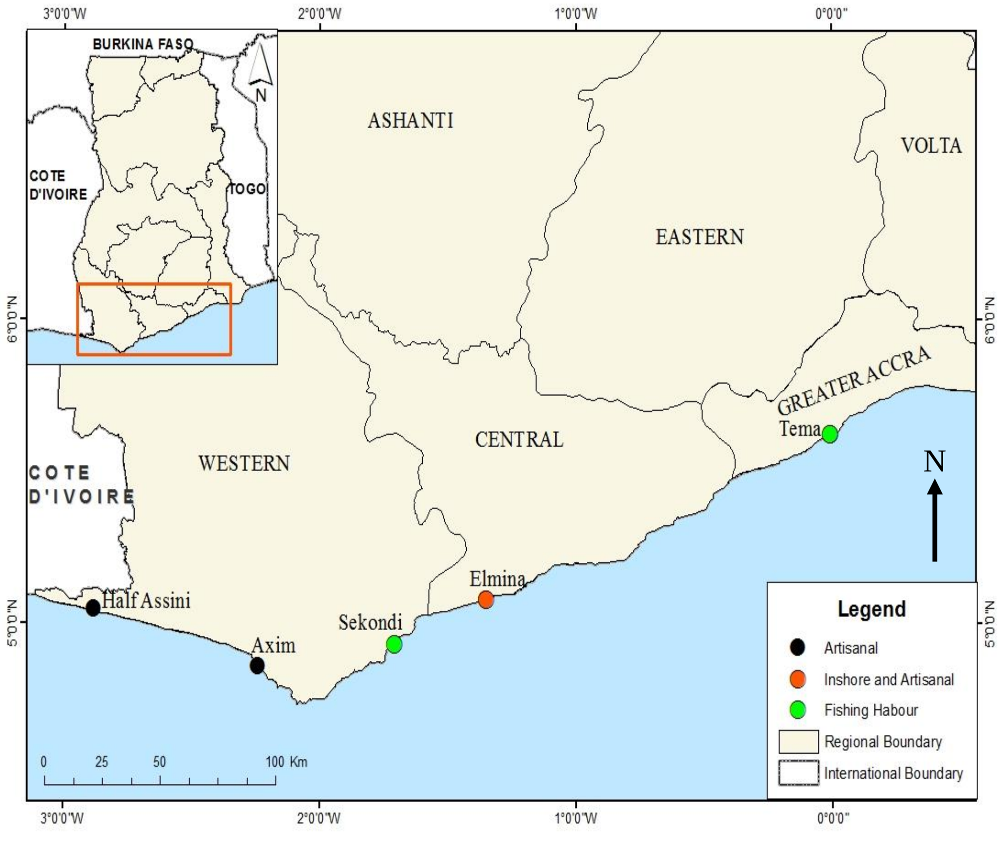



*Figure 2:* Map of Southern Ghana, the study area, showing the locations of the sampling sites for the study. Inset is a map of Ghana in the top left corner.

Tema is located about 25 kilometres east of Accra. It has a fishing harbour subdivided into an inner and outer fishing harbour, and a canoe basin (GPHA, 2016). The harbour has facilities for docking and repair of shrimpers, tuna vessels, trawlers and inshore (semi-industrial) vessels. The harbour is equipped with ice making facilities, cold storage units, fish landing sheds and fish markets. Due to the wide array of vessels that use this port, several species, both demersal and pelagic are landed here. The major species in the landings of the artisanal vessels include the anchovy (*Engraulis encrasicolus*), sardinellas (*Sardinella aurita* and *S. maderensis*), Atlantic bumper (*Chloroscombrus chrysurus*), frigate mackerel (*Caranx hippos*), and Atlantic chub mackerel (*Scomber colias*) (Dovlo et al., 2016).

Elmina, a fishing town near Cape Coast has a fish landing quay locally called "Mpoben") at the southern end of the open Benya lagoon, for both artisanal and inshore vessels. The inshore and artisanal vessels use pursing nets, set nets, gill nets and hook-and-line to exploit small pelagic species (anchovies, sardinellas and Atlantic chub mackerel), semi-pelagics (carangids), demersals (sparids, snappers, croakers, groupers, cuttlefish) and large pelagics (tunas, wahoos, barracudas). Ice-making plants and a cuttlefish processing facility are notable infrastructure located on the shores of Elmina.

In Sekondi, fish is landed at the Albert Bosumtwi-Sam Fishing Harbour. The main pelagic fish species exploited by artisanal vessels as reported by Dovlo et al. (2016) are the sardinellas (*Sardinella aurita* and *S. maderensis*), frigate mackerel (*Auxis thazard*) and long-finned herring (*Ilisha africana*). The main demersal species landed by artisanal vessels include sparids, snappers, groupers, tunas and cuttlefish. Inshore vessels employing large purse seines to exploit small pelagic fish during the upwelling season and trawl for sparids, croakers, groupers and flat fishes during the rest of the year. Infrastructure at the harbour include ice production units and cold stores.

Axim does not have fish landing infrastructure and the fishery there is strictly artisanal. The dominant fishing gears are purse nets (for catching small pelagic fish), drift gill nets (for tunas and bill fishes) and bottom set nets for demersal fish. The main species landed are the sardinellas. Tuna and billfish are also landed in appreciable numbers. The landing beach at Axim is mixed cobble and sand interspersed with rocks.

The landing beach at Half-Assini is sandy. The main gears in use are pursing gears ("ali-poli-watsa") that mostly target small pelagics. Also known as "Fante-line", the long stretch of sandy beach at Half Assini is characterised by fishing hamlets of migrant fishermen from the Central Region of Ghana. A small community of fishermen from the Volta Region are involved in beach seining which exploits small pelagic species and juveniles of other fishes that use the shallow coastal waters and lagoons as nursery and feeding grounds.

**Fish Sampling**

Monthly random samples of freshly-landed *S. colias* (~200 individuals) were obtained from commercial catches over 18 months from February 2016 to July 2017. Due to variations in the numbers of fish caught by the fishermen, actual sample sizes varied considerably from month to month. The fish were kept on ice and transported to the laboratory for measurements and collection of data on the biology of the population. In addition, random slabs (2-3 slabs) of frozen fish from the trawl fisheries bycatch, popularly called "saiko" fish which is transhipped by canoes to landing sites, were also purchased monthly over the 18-month period at the Elmina "Saiko" shed. This was done to assess the occurrence and biological characteristics of chub mackerel in trawl bycatch. Saiko fish were identified using FAO identification manuals (Carpenter & De Angelis, 2014, 2016a, 2016b, 2016c).

## Data Collection

### *Scomber colias* from the artisanal fishery

A total of 2,146 fish obtained from monthly samples were measured (Figure 3) for standard (*SL*), fork length (*FL*) and total length (*TL*) to the nearest 0.1 cm using a measuring board, and weighed to the nearest 0.01 g.

*Figure 3:* Atlantic chub mackerel (*Scomber colias*) on a measuring board.

Each fish was dissected to determine the sex from gonad examination, and fat in the visceral cavity teased out and weighed to the nearest 0.01g with an electronic scale. Gonads of the fish were assigned developmental stages (Table 1) based on a 5-point maturity scale (Holden & Raitt, 1974).

*Table 1*- Description of fish gonads at different developmental stages; adapted from Holden and Raitt (1974)

| Stage | Description | Female | Male |
|---|---|---|---|
| I | Virgin | Very small and translucent, pinkish ovary; threadlike. Ovaries 1/3 length of body cavity. Ova not visible to naked eye. | Very small testes, whitish and threadlike. Testes makes up 1/3 length of body cavity. |
| II | Recovering spent/ maturing virgin | Ovaries pinkish and translucent, small in size, about ½ length of body cavity. | Testes small, whitish. Make up about ½ of the length of the body cavity. |
| III | Maturing (Ripening) | Ovaries about 2/3rds length of body cavity, pinkish-yellow colour with granular appearance of opaque oocytes. | Testes make up about 2/3 length of body cavity, whitish to creamy in appearance. |
| IV | Ripe | Ovaries larger and filling up body cavity, orange-pink in colour, eggs transparent and yellowish orange, released upon application of moderate pressure to abdomen. Conspicuous superficial blood vessels present. | Testes large, whitish-creamy in appearance and filling up body cavity, creamy milt released upon application of moderate pressure to abdomen. |
| V | Spent | Ovary shrunken to about ½ length of body cavity, walls loose with some residual opaque and ripe ova, darkened or translucent. | Testes slack and reduced in size to about ½ the length of the body cavity, reddish in colour and flabby. |

Ovaries in maturing or ripening (Stage III) and ripe (Stage IV) conditions were preserved in modified Gilson's fluid (100 ml 60% absolute alcohol, 800 ml water, 15 ml 80% nitric acid, 18 ml glacial acetic acid, 20 g mercuric chloride) Holden & Raitt, 1974) for fecundity estimation. Each specimen bottle with preserved ovary was coded for specific individual fish. The bottles were vigorously shaken after 48 hours to free the ova from ovarian tissue. Water was added to the sample and decanted several times to eliminate ovarian tissues and immature ova.

Samples of washed ova were strained with a filter paper, and dried in an oven at 105 °C for 3 to 4 hours after which they were placed in a desiccator to cool. The total weight in grams (W) of dried ova from the ovary of each fish was determined. Three subsamples of each batch of ova were weighed to the nearest 0.0001 gram ($w$) and the number ($n$) of ova in a subsample was counted. The total number ($N$) of eggs in an ovary was computed as:

$$N = \frac{nW}{w}$$

and the mean value from the three estimates taken as the absolute fecundity ($F_{abs}$) of the fish.

Diameters of a random sample of wet ova from five ovaries were measured on the longest axis to the nearest 0.1 mm on a stage micrometer under a dissecting microscope (Figure 4). The frequency distribution of the ova was used to predict the spawning pattern of the fish.

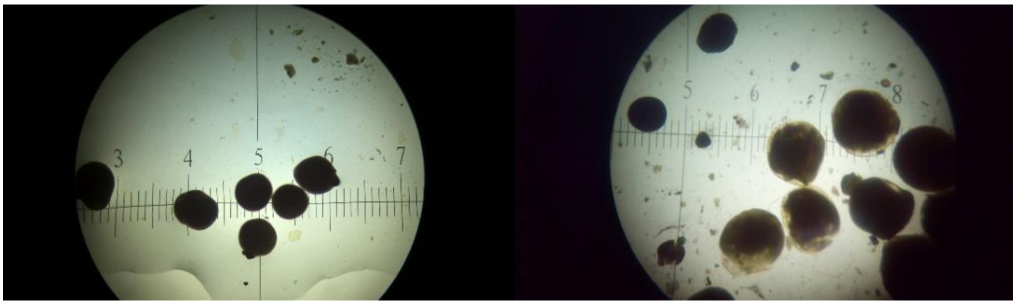


*Figure 4*: Ovum diameter measurement using a graticule under the microscope.

Stomachs of fish specimens were removed (Figure 5) on the day of sample collection and preserved in 4% formaldehyde solution for later examination of their contents after two weeks. Stomach contents were weighed, and prey items identified and sorted into groups; the different items counted and weighed to the nearest 0.01 g.

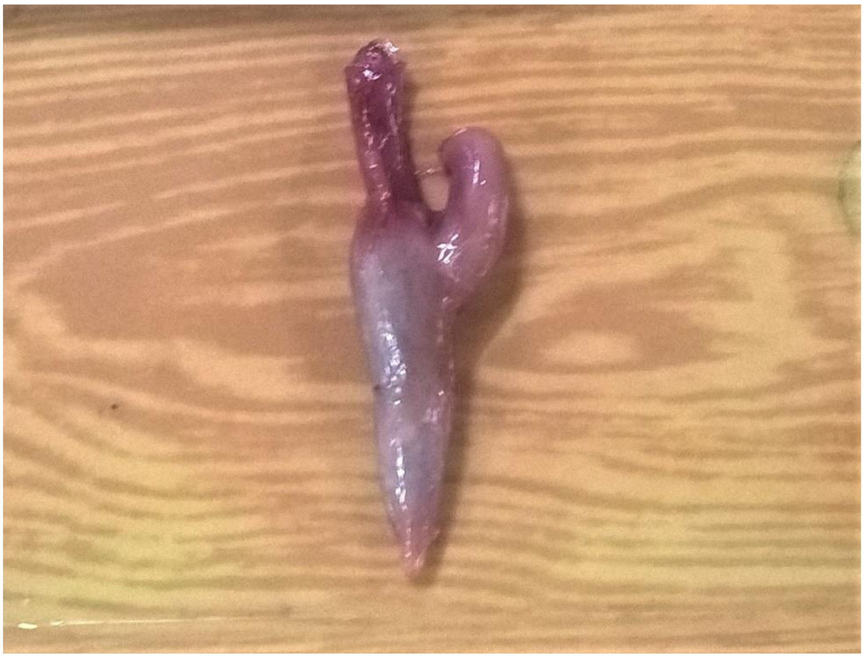


*Figure 5:* Excised stomach of a *Scomber colias* specimen.

The head of the fish was dissected to expose the sagittal otoliths (Figure 6) which were removed with a pair of forceps. Otolith pairs were cleaned in water, dried and stored in Eppendorf vials with labels on the date of sampling, fish length and weight, and sex of the individual. Otoliths were placed on a stage micrometer under a dissecting microscope to measure the otolith diameter (*OD*) as the distance from the posterior edge to the tip of the rostrum, and the otolith radius (*OR*) as the distance from the core of the nucleus to the posterior edge (Figure 7); these measurements were made to the nearest 0.1 mm.

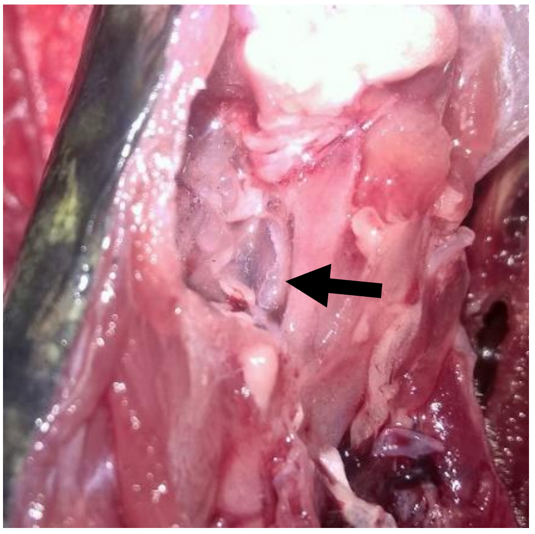


*Figure 6:* Dissected head of *Scomber colias* showing the otoliths (arrowed) in the sacculus.

Otoliths were examined under water in a petri dish with the proximal side down and against a dark background. Growth rings were read with reflected light under a dissecting microscope at a magnification of ×2. Where necessary, a dilute soapy solution or glycerol was used as a medium to enhance the readability of the otoliths (ICES, 2016). Highly calcified or difficult to read otoliths were mounted in thermoplastic resin on a glass slide, etched for 10 - 45 seconds with 1% HCl, and rinsed with distilled water before reading.

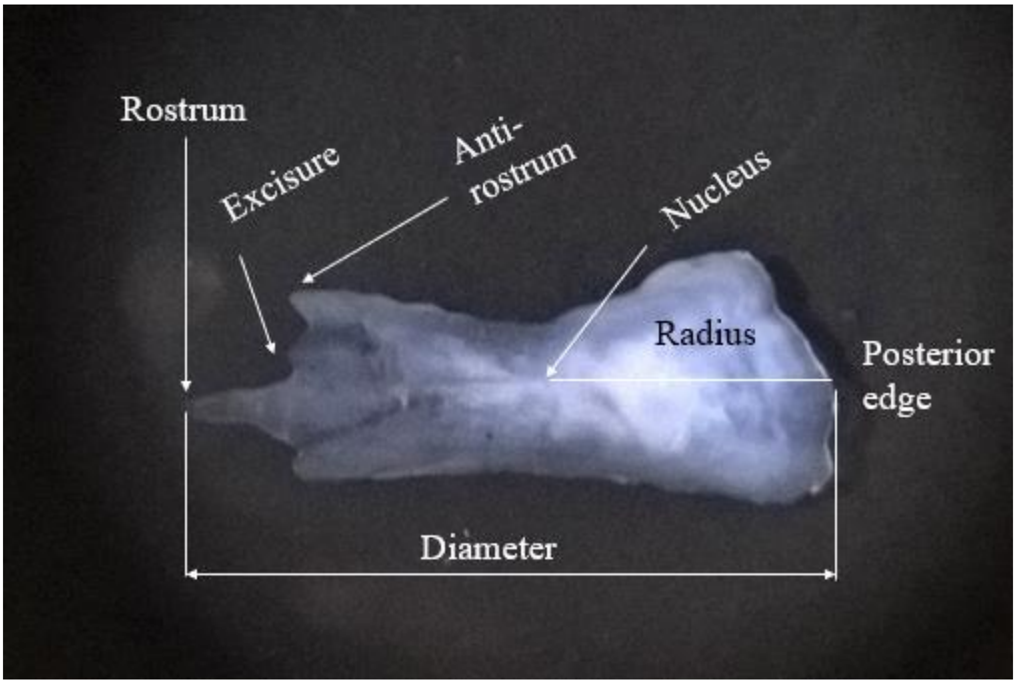



*Figure 7:* Morphological features and axes of measurement of *S. colias* otolith as seen under a microscope with reflected light.

Fish were aged by counting the number of hyaline bands from the nucleus to the posterior edge of the otolith. Bands were considered as true annuli if they could be traced throughout the sagittal plane of the otolith, unlike false rings which are discontinuous (ICES, 2016). Otoliths were read by the author on two different occasions and once by a volunteer. If two or three of the counts matched, the result was accepted as representing the age of the fish.

Records were taken of the occurrence of a hyaline zone at the margin of otoliths, and the marginal increment width, i.e. the distance from the end of the last opaque zone to the margin of the otolith was measured using an image analyser and a camera attached to the microscope (Moticam BTW).

Fillets from twelve fish were sampled for analysis each quarter. A 100 g sample from each fish was flattened with a spatula, spread thinly onto an aluminium foil and dried in an oven at 105 °C for 3 hours. The samples were transferred into a desiccator to cool overnight and then weighed. The relative percentage of water content in tissues was calculated as follows:

$$\text{Relative \% water content} = \frac{W1-W2}{W1}\times 100$$

where $w_1$ is fresh weight (g), and $w_2$ is dry weight (g) of the sample.

The dried samples were crushed and milled into a powdered meal, stored in Ziploc bags and later analysed for the percentage composition of macronutrients in the laboratory of the Department of Soil Science of the School of Agriculture, University of Cape Coast.

Moisture content of the dried muscle sample was determined by further drying a 20 g sub-sample at a temperature of 105° C in a crucible for 24 hours; this was cooled in a desiccator and then the final weight of the sub-sample determined. Total moisture content of the powdered meal was calculated as the ratio of the difference between the initial ($w_1$) and final weights ($w_2$) to the initial weight expressed as a percentage.

$$\text{Moisture content} = \frac{W1-W2}{W1}\times 100$$

The crude protein content of the fish meal was determined using the micro-Kjedahl method (AOAC, 2016). Two grams of fish meal was digested in a 100 ml Kjedahl flask with 4.4 ml of a mixture of 350 ml hydrogen peroxide, 0.42 g selenium powder, 14 g lithium sulphate and 420 ml sulphuric acid at 360 °C for two hours, and cooled to room temperature. The digests were transferred into 50 ml volumetric flasks and filled up to the volume with distilled water. Steam was passed through the digests for about 20 minutes. A 100 ml conical flask containing 5 ml of boric acid indicator solution was placed below the condenser of the distillation apparatus. An aliquot of the sample digest was pipetted to the reaction chamber through the trap funnel.

Ten millilitres of sodium hydroxide were added prior to commencement of distillation; 50 ml of the distillate was measured in a flat-bottomed flask and titrated against 0.0071 M HCl. The amount of nitrogen in the sample (% N) was calculated as:

$$N = \frac{A \times B \times 1.4}{\text{sample weight}} \times 100$$

where $A$ is volume of HCl used in the titration and $B$ is the normality of standard acid used. The percentage crude protein was then calculated for each sample as

Crude protein = % N x 6.25

To determine the percentage carbohydrate content of tissues, 50 mg of dry fish meal was weighed into a 50 ml conical flask. Thirty millilitres of distilled water were added and the solution warmed gently on a hot plate for 2 hours. The solution was topped up to the 30 ml mark periodically, allowed to cool and filtered through a Whatman filter paper (No.44) into a 50 ml volumetric flask and water added to the mark volume when cool. A blank was prepared using the same procedure. For colour development, 2 ml of each standard solution was pipetted into a set of boiling tubes, and 2 ml of the extract and water blank were also pipetted into boiling tubes. Standards and samples were similarly treated. A 10 ml solution of anthrone was added rapidly to each tube and the tubes immersed in an ice bath. Thereafter, the tubes were placed in a beaker of boiling water in a dark fume cupboard, boiled for 10 minutes, and transferred into cold water to cool. The optical density of the samples was measured at 625 nm using water as a reference. A calibration graph was plotted from the standards and used to extrapolate the amount of glucose (in milligrams) in the sample aliquot. The carbohydrate concentration in tissues was calculated as:

$$\text{Soluble carbohydrates} = \frac{\text{C } (mg) \times \text{extract volume } (ml)}{10 \times \text{aliquot } (ml) \times \text{sample weight } (g)} \times 100$$

where C is the carbohydrate concentration extrapolated from the calibration graph.

Crude fat content of tissue samples was determined using the Soxhlet solvent extraction method ( Soxhlet, 1879; AOAC, 2016). Five grams of each sample was weighed into a thimble and inserted into a Soxhlet liquid/solid extractor (Model: Soxhlet Foss, 2020). The Soxhlet extractor was fitted onto a pre-weighed round bottom flask and 80 ml of petroleum-ether (40 - 60 ºC boiling point) introduced into the Soxhlet apparatus with the thimbles and the sample. Extraction involved boiling petroleum ether in the round bottom flask to extract the fat from the sample. Evaporated ether was condensed back into the sample chamber in a continuous cycle for about 6 hours. The extracted lipid plus ether in the round bottom flask was oven dried at 105º C for 1 hour to evaporate the ether. The flask with the lipid was cooled in a desiccator and weighed ($W_2$). The weight of the empty flask ($W_1$) was subtracted from the weight of the flask and the extracted lipid ($W_2$) to obtain the weight of the lipid. Crude fat content was computed as:

$$\text{crude fat} = \frac{(W2 - W1)}{\text{sample weight}} \times 100$$

Fibre content was determined by weighing about 2 g of defatted fish meal from the Soxhlet extraction process into a flask containing 200 ml of 1.25 % $H_2SO_4$ and warmed for 30 minutes, swirling periodically. A Buchner funnel, pre-heated with boiling water, was lined with a sheet of filter paper d for the filtration process. At the end of the boiling period, the flask was removed and allowed to stand for a minute, after which the solution was filtered by connecting a suction pump to the Buchner funnel. The filter paper was washed with boiling water to remove the residue and transferred to a flask containing 200 ml of boiling sodium hydroxide (1.25 %) solution and boiling continued for another 30 minutes.

A filtration crucible, pre-heated with boiling water, was used to carefully filter the hydrolyzed mixture after letting it stand for 1 minute. The residue was washed with boiling water followed by HCI solution, again with boiling water and finished with three washes with of petroleum ether. The filtration crucible was placed in a kiln set at 105°C for 12 hours and cooled in a desiccator. The initial weight of the crucible with the residue (*A*) was determined and placed in the furnace at 600 °C for 12 hours. After cooling in a desiccator, the final weight of the crucible with the ashed sample (B) was determined, and crude fibre determined as:

$$\text{crude fibre} = \frac{A-B}{C} \times 100$$

where *A* is initial weight of crucible with dry residue, *B* is the final weight of crucible with the ash sample, and *C* is weight of the sample, all in grams.

To determine the ash content of *S. colias* tissue, 1g of the fish meal was placed in a pre-weighed crucible, incinerated for about 12 hours at 600° C in a furnace and allowed to cool in a desiccator. The crucible with ash was weighed afterwards and the difference in weight between the incinerated sample and sample before the incineration represented the ash content of the sample. This was expressed as a percentage of the original sample using the formula:

$$\text{ash} = \frac{a-b}{s} \times 100,$$

where *a* is weight (g) of crucible with sample before incineration, *b* is weight (g) of crucible with sample after incineration and *s* is sample weight (g) before incineration.

***Scomber colias* from "Saiko" samples**

*S. colias* specimens from "Saiko" samples were measured for standard (*SL*), fork (*FL*) and total length (*TL*) to the nearest 0.1 cm and weighed to the nearest 0.01 g. The gonad state of specimens was determined based on the 5-point maturity scale proposed by Holden & Raitt (1974) as seen in Table 1.

**Analysis of *Scomber colias* Data**

**Determination of length-weight relationships**

Scatter plots of data on fish length (*TL*) and weight (*BW*) were made to determine trends in the relationship between the two parameters in males, females and fish for which sex could not be determined. A regression analysis of weight against length using the least squares method was performed to establish a mathematical relationship between the two variables.

**Calculation of condition factor**

Condition factor, which measures the state of well-being or fatness of the fish was calculated for males and females from Fulton's equation:

$$C.F. = \frac{BW}{TL^3} \times 100$$

where *C.F.* is condition factor, *BW* is somatic body weight in grams and *TL* is total length in centimetres. Plots of the monthly *C.F.* values for males and females were presented to describe annual fluctuation patterns of the well-being of the fish.

**Fat index analysis**

The relative visceral fat index of the fish was calculated for individual fish as:

$$\text{Relative fat index} = \frac{\text{Weight of visceral fat (g)}}{\text{Body weight (g)}}$$

Mean values were calculated to determine trends in the fluctuation of fat over time.

**Determination of reproductive parameters**

***Sex ratios and length-at first maturity***

Monthly sex ratios were calculated, and a $\chi^2$ test conducted to determine the occurrence of deviations or otherwise of number of males and females from a 50:50 ratio. The length at first maturity ($L_{m50}$) of males and females was determined from a plot of the cumulative proportions of sexually mature individuals (stages III & IV) in each length class against total length of fish. The $L_{m50}$ was extrapolated from the resultant ogive.

***Fecundity-body size relationship***

A regression analysis was conducted to establish relationships between absolute fecundity and total length (TL), absolute fecundity and body weight (BW), and absolute fecundity and gonad weight (GW). Relative fecundity of gravid females was calculated as: $\frac{\text{Absolute fecundity}}{\text{Body weight (g)}}$

***Gonadosomatic index***

Gonadosomatic index (GSI) was calculated using the formula: GSI= $\frac{\text{GW}}{\text{BW}}$ x 100, where *GW* is gonad weight (g) and *BW* is body weight of the fish (g). Monthly mean values of GSI were computed and the fluctuations used to describe the spawning activity of the fish.

**Stomach content analysis**

The amount of food consumed by the fish was determined by the index of stomach fullness given as:

$$\frac{\text{Weight of stomach content (g)}}{\text{Body weight (g)}} \times 100$$

The mean monthly values of the index were calculated to establish the pattern of changes in feeding activity of the fish. Dietary preference of the species was assessed using the methods of Hyslop (1980):

(i) The frequency of occurrence (% *F*) of food items in samples was determined as the number of stomachs in which each food item occurred expressed as a percentage of fish with stomachs containing food.

(ii) The percentage numerical composition (*NC*) of a food item in samples was computed as:

$NC = (N_i / N_x) \times 100$,

where $N_i$ is the number of a food item in the stomachs of the sample, and $N_x$ is the total number of food items recorded in all the stomachs in the sample.

(iii) The gravimetric composition (*GC*) of each food item in the samples was computed as:

$GC = (W_i/W_x)$ x $100$

where $W_i$ is weight of a food item in the stomachs of the fish sample and $W_x$ is the total weight of all food items in the stomachs.

(iv) The Index of Relative Importance (*IRI*) of the food items consumed by the fish was calculated as:

$IRI = (NC + GC)$ % $F$ (Pinkas et al., 1971).

**Determination of relationship between otolith dimensions and fish length**

Relationships between otolith diameter and fish length, and otolith radius and fish length were determined by regression analysis. Data on the number of annuli in otoliths from fish of different lengths were used to construct a length-at-age key for the population, and the frequency of occurrence of fish in various age groups.

**Validation of growth ring deposition rate**

The periodicity of growth increment formation in otoliths of *S. colias* was determined by interpretation of plots of the monthly percentage occurrence of hyaline zones at the edge of otoliths, and monthly changes in the mean marginal growth increment width of otoliths.

**Monthly length-frequency analysis**

Data from the monthly length-frequency distributions were analysed using the FiSAT II software (FAO, 2013) to estimate the growth and mortality parameters, and exploitation rate of the fish stock. The ELEFAN I routine in the software (FiSAT II) was used to estimate the asymptotic length ($L_\infty$) and growth curvature constant ($K$) of the species. The theoretical age at zero length ($t_o$) was calculated from the equation:

$\text{Log}_{10}(-t_o) = -0.392 - 0.275\text{Log}_{10} L_\infty - 1.038 \text{ Log}_{10} K$ (Froese, Palomares, & Pauly, 2005). The growth parameters, $L_\infty$, $K$ and $t_0$ were substituted in the von Bertalanffy Growth Function to derive the idealized growth curve for the species given as:

$$L_t = L_\infty [1 - \exp(-K(t - t_0))] \text{ cm } TL$$

where $t$ is the age of the fish.

The growth performance index ($\Phi'$) of the population was calculated from the equation, $\Phi' = 2 \log_{10} L_\infty + \log_{10} K$ (Pauly & Munro, 1984) for comparison with the growth performance of the species from other geographical regions. Longevity ($t_{max}$) of the species was estimated according to the equation, $t_{max} = t_0 + 3/K$ (Froese et al., 2005).

**Determination of mortality rates and mean length at first capture**

The total mortality rate ($Z$) of the species was estimated from the slope of the descending right arm of the linearized length-converted catch curve (Pauly, 1984). The natural mortality coefficient ($M$) was estimated by Pauly's (1980) empirical formula:

$$\log (M) = - 0.0066 – 0.279\log (L_\infty) + 0.6543 \log (K) + 0.463 \log (T),$$

where $K$ and $L_\infty$ are the growth parameters of the species, and $T$ is the mean annual sea surface temperature ($^o$ C) of the study area (Pauly, 1980). The fishing mortality coefficient ($F$) was calculated as $F= Z-M$ (King, 2007).

The length of the fish at first capture ($Lc_{50}$) was estimated from the selection curve generated by the FiSAT programme.

**Determination of exploitation rate**

The reference exploitation rate recommended for sustainable exploitation of fish stocks ($E_{0.5}$) (Cadima, 2003; King, 2007) and current exploitation rate ($E_{curr}$) were determined from the relative yield per recruit ($Y'/R$) and relative biomass per recruit ($B'/R$) analysis generated by the FiSAT program.

# CHAPTER FOUR

# RESULTS

The results presented in this chapter are based on 18 months of field sampling from February 2016 to July 2017 from landings in the coastal waters of Ghana, and laboratory analysis to investigate the size structure, reproductive biology, growth and mortality characteristics, and exploitation rate of the Atlantic chub mackerel, *Scomber colias*. This chapter also reports on the food and feeding habits, and proximate nutrient composition of the muscle tissue of the species, as well as the size composition and maturity state of specimens of the chub mackerel from the bycatch of commercial trawlers.

## Length-Frequency Distributions of *S. colias*

The size distributions of *S. colias* samples taken from the canoe fishery of Ghana are shown in Figure 8. The relationship between total length and fork length was positive (Appendix A). The 2,146 specimens ranged from 13.7 cm *TL* to 40.7 cm *TL* with a mean value of 24.61 ± 0.08 cm *TL* (Appendix B) with a bimodal distribution; the modes were in the 17.0-18.9 cm *TL* and 25.0-25.9 cm *TL* classes (Figure 8). Males measured 16.9 to 40.7 cm *TL* with a mean of 26.01 ± 0.09 cm *TL* and females 20.8 to 36.5 cm *TL* with a mean value of 26.24 ± 0.08 cm *TL*. Males and females both had unimodal distributions with the mode in the 24.0-24.9 cm *TL* class for males and 25.0-26.9 cm *TL* class for females. Body weight ranged from 19.95 -695 g for all specimens, with a mean weight of 154.74 ± 1.54 g for all fish.

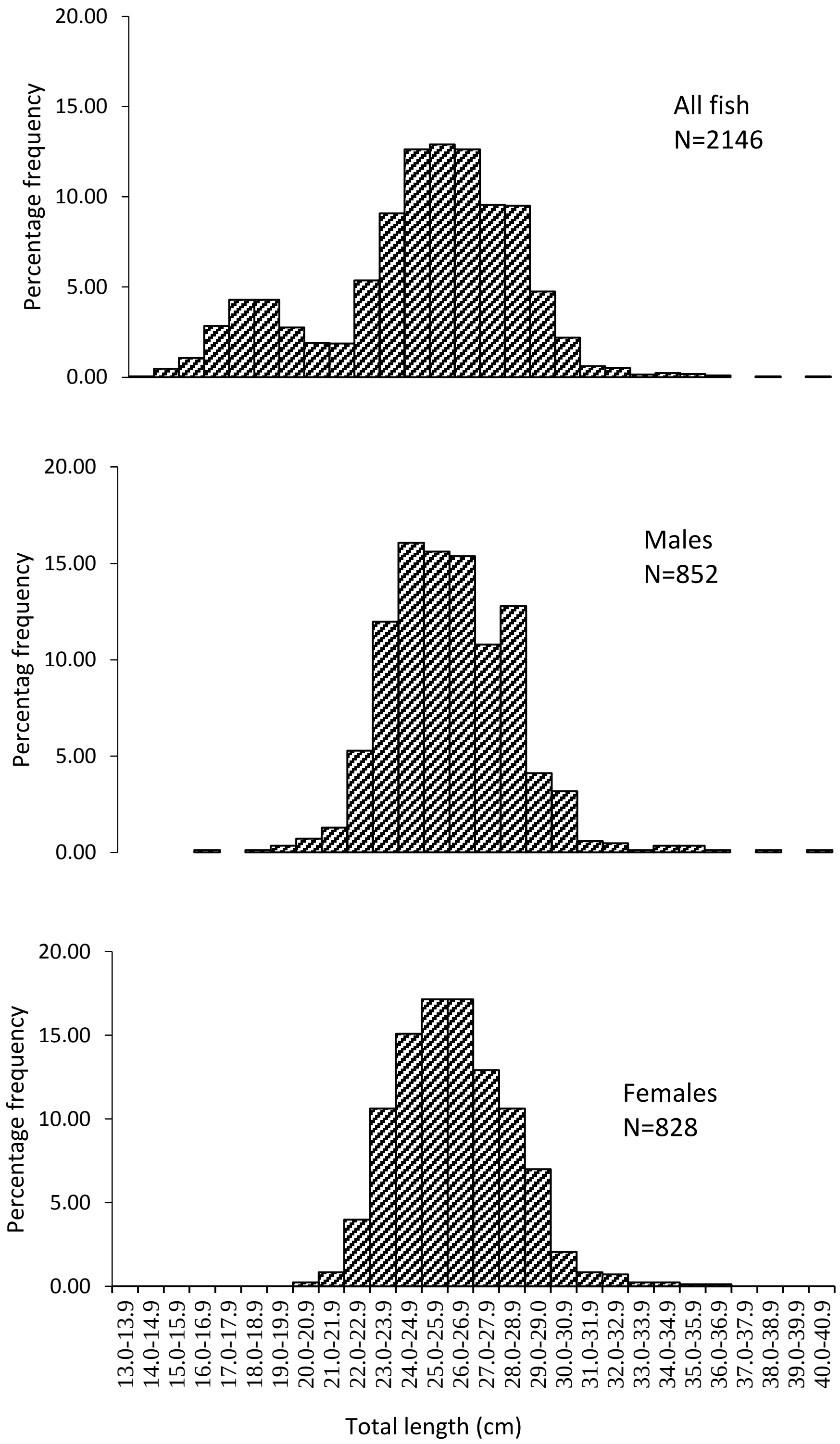



*Figure 8*: Length-frequency distribution of *Scomber colias* in the coastal waters of Ghana (N = sample size).

**Length-Weight Relationships**

Figure 9 shows relationships between total length (*TL*, cm) and body weight (*BW*, g) of all fish combined, and males and females from freshly landed samples. The relationships were described by the power function: $BW = aTL^b$, where $a$ is the antilog of the intercept value on the y-axis of the logarithmic transformed data and $b$ is the regression coefficient. The relationship for all fish was described by the equation:

$$BW = 0.0029TL^{3.37}$$

The exponent ($b$ = 3.37) deviated significantly from 3.0 ($t$ = 24.67, $p$<0.05), indicating positive allometric growth in the population. The relationship for males was described by the equation:

$$BW = 0.0083TL^{3.05}$$

The exponent ($b$ = 3.05) was not significantly different from 3.0 ($t$ = 1.19, $p$>0.05), indicating that male *S. colias* exhibited isometric growth. The relationship between total length (cm) and body weight (g) of females was described by the equation:

$$BW = 0.0119TL^{2.94}$$

which exponent ($b$ = 2.94) did not differ significantly from 3.0 ($t$ = 1.30, $p$>0.05), suggesting isometric growth in females during the study period. It would therefore seem that the positive allometric growth resulting from the pooled length-weight data of the species was due to the fish with the mode in the 17.0-18.9 cm TL class.

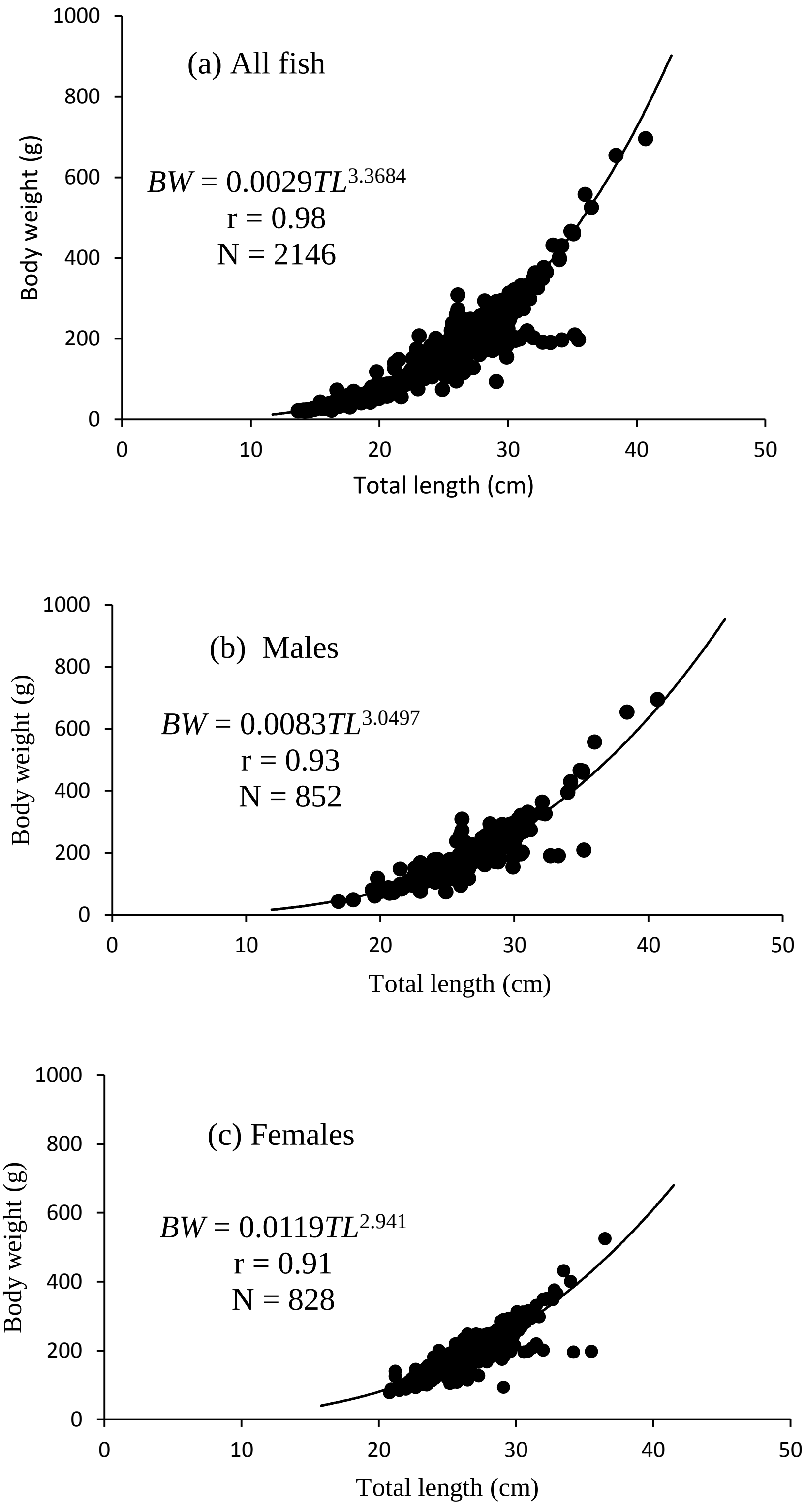



*Figure 9*: Relationship between total length (*TL*) and body weight (*BW*) of (a) all fish, (b) males and (c) female *Scomber colias* in the coastal waters of Ghana (N = sample size).

**Monthly Fluctuations in Condition Factor**

Fluctuations in the condition factor of males and females were similar (Figure 10). High values of the index were recorded from March to May 2016, September 2016, and from December 2016 to March 2017 and low values in February 2016, June to August 2016, October 2016, and in April, June and July 2017 (Figure 10, Appendix D). There was thus no clear seasonal change in the condition factor of the population during the study period. A similar mean condition factor of 0.93 ± 0.03 was computed for males and 0.94 ± 0.00 for females ($t$ = 1.49, $p$>0.05).

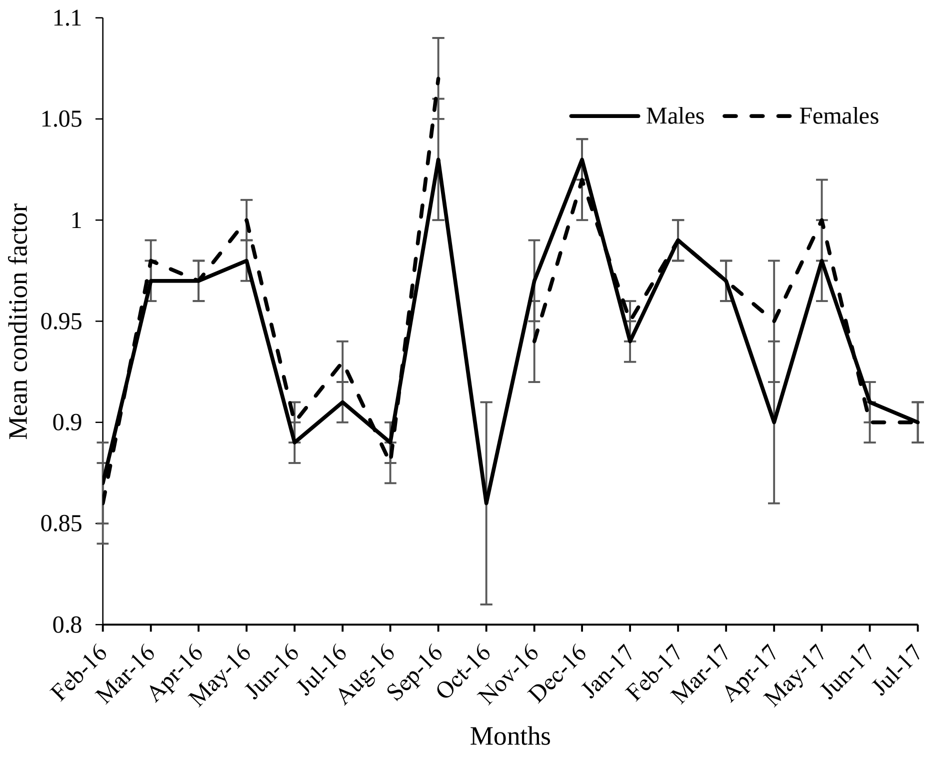



*Figure 10:* Monthly mean condition factor of *Scomber colias* in the coastal waters of Ghana. Vertical bars indicate ± 1 s. e.

## Monthly Fluctuations in Visceral Fat Index

The monthly mean values of visceral fat index were generally low (0 - 0.006) for both male and female chub mackerels sampled during the study period. The mean visceral fat index of females (0.0020 ± 0.0001) was found to be significantly higher than that of males (0.0016 ± 0.0000), ($t$ = 3.258, $p$ < 0.05).

The index however varied from February to August 2016 and increased significantly in September, November (males: 0.05 ± 0.0003, females: 0.06 ± 0.0005) and December of that year. There was a sharp decline in the index in January 2017 (males: 0.002 ± 0.0002, females: 0.003 ± 0.0003) which remained low up to July 2017 (males: 0.001 ± 0, females: 0.01 ± 0.0001). Fluctuations in the mean values of the visceral fat index (weight of fat/body weight) are shown in Figure 11. There were no females present in the samples obtained in October 2016 (Figure 11, Appendix E).

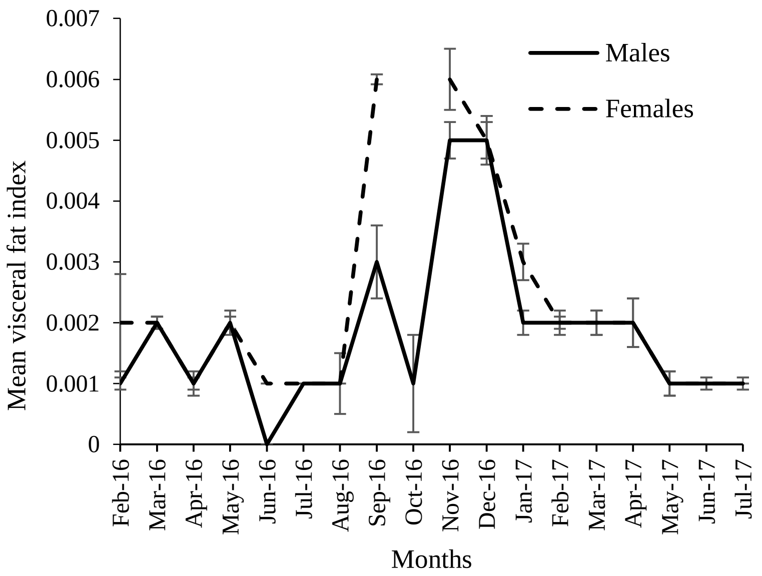



*Figure 11*: Monthly mean visceral fat index in *Scomber colias* in the coastal waters of Ghana. Vertical bars represent ± 1 s. e.

## Reproductive Biology

### Sex ratio

A total of 2,146 fish were sampled during the study period, of which 466 individuals, mostly juveniles (21.7%) were of indeterminate sex, while 852 were males and 828 females. The sex ratio of the population was therefore 1:1 ($\chi^2_{0.05}$ = 0.34). The monthly sex ratio in the population is presented in Table 2. Fish of indeterminate sex occurred from August 2016 to January 2017, majority of which small in size. Males and females occurred in relatively equal proportions in February to June 2016, December 2016 and March to July 2017 but significant differences in the proportions prevailed from July to November 2016 and January to February 2017.

### Length at maturity

The cumulative frequencies of mature male and female *S. colias* indicated indicated a length at 50% maturity ($L_{m50}$) of 25.60 cm *TL* for both males and females (Figure 12).

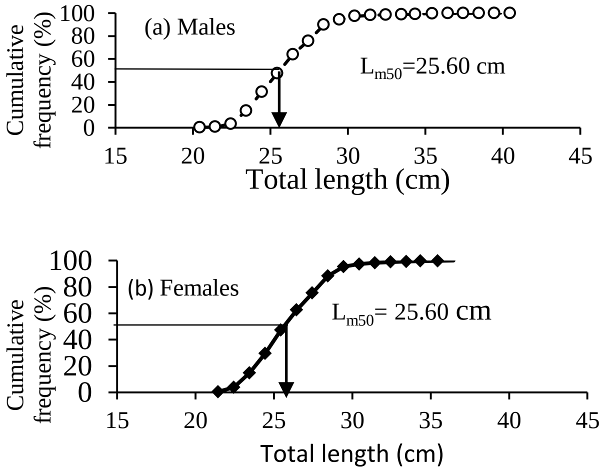



*Figure 12:* Cumulative frequency ogives for estimation of length at 50% maturity of (a) male, and (b) female *Scomber colias* from the coastal waters of Ghana.

The smallest mature male was 20.7 cm *TL* while the smallest mature female was 21.2 cm *TL* (Appendix F).

Table 2- *Monthly sex ratio of Scomber colias in the coastal waters of Ghana (NS-Not Significant, S- Significant at the 5% level of significance)*

| Month | Number of fish | | | | Sex ratio (M: F) | $\chi^2$ | $P_{0.05}$ |
|---|---|---|---|---|---|---|---|
| | Total No. | Males (M) | Females (F) | Indeterminate sex | | | |
| Feb-16 | 163 | 91 | 72 | - | 1.26:1 | 2.22 | NS |
| Mar-16 | 201 | 96 | 105 | - | 1:1.09 | 0.4 | NS |
| Apr-16 | 99 | 56 | 43 | - | 1.30:1 | 1.7 | NS |
| May-16 | 113 | 55 | 58 | - | 1:1.05 | 0.06 | NS |
| Jun-16 | 209 | 106 | 103 | - | 1.03:1 | 0.04 | NS |
| Jul-16 | 74 | 24 | 50 | - | 1:2.08 | 9.14 | S |
| Aug-16 | 160 | 67 | 38 | 55 | 1.76:1 | 8.0 | S |
| Sep-16 | 245 | 18 | 35 | 192 | 1:1.94 | 5.46 | S |
| Oct-16 | 31 | 5 | - | 26 | - | - | - |
| Nov-16 | 222 | 16 | 37 | 169 | 1:2.31 | 8.32 | S |
| Dec-16 | 91 | 38 | 33 | 20 | 1.15:1 | 0.35 | NS |
| Jan-17 | 73 | 48 | 21 | 4 | 2.28:1 | 10.56 | S |
| Feb- 17 | 77 | 48 | 29 | - | 1.66:1 | 4.68 | S |
| Mar-17 | 51 | 26 | 29 | - | 1:1.2 | 0.49 | NS |
| Apr-17 | 25 | 13 | 12 | - | 1.08:1 | 0.04 | NS |
| May-17 | 25 | 11 | 14 | - | 1:1.27 | 0.36 | NS |
| June-17 | 169 | 77 | 92 | - | 1:1.19 | 1.33 | NS |
| July-17 | 118 | 57 | 61 | - | 1:1.07 | 0.14 | NS |
| Overall | 2146 | 852 | 828 | 466 | 1.03:1 | 0.34 | NS |

**Fecundity**

Figure 13 illustrates the relationships between absolute fecundity ($F_{abs}$) and fish length (*TL* cm), body weight (*BW* g), and gonad weight (*GW* g). Estimates of absolute fecundity ranged from 10,220 eggs in fish measuring 24.1 cm *TL*, and weighing 144.32 g, to 155,791 eggs in fish measuring 31.7 cm *TL* and weighing 298.32 g (Appendix G). The mean absolute fecundity was determined to be 48,238 ± 2324 eggs. The positive relationships were described by the equations:

$F_{abs} = 5.28 \text{ x } 10^4 TL - 97009$ ($r = 0.59$, $p < 0.05$)

$F_{abs} = 1.94 \text{ x } 10^2 BW + 8561.4$ ($r = 0.52$, $p < 0.05$)

$F_{abs} = 2.17 \text{ x } 10^3 GW + 17405$ ($r = 0.68$, $p < 0.05$)

The relationship between absolute fecundity and gonad weight showed the highest correlation ($r = 0.68$, $p < 0.05$), followed by that of mean absolute fecundity and total length. The relationship between absolute fecundity and body weight exhibited the lowest correlation among the three relationships studied ($r = 0.52$, $p < 0.05$).

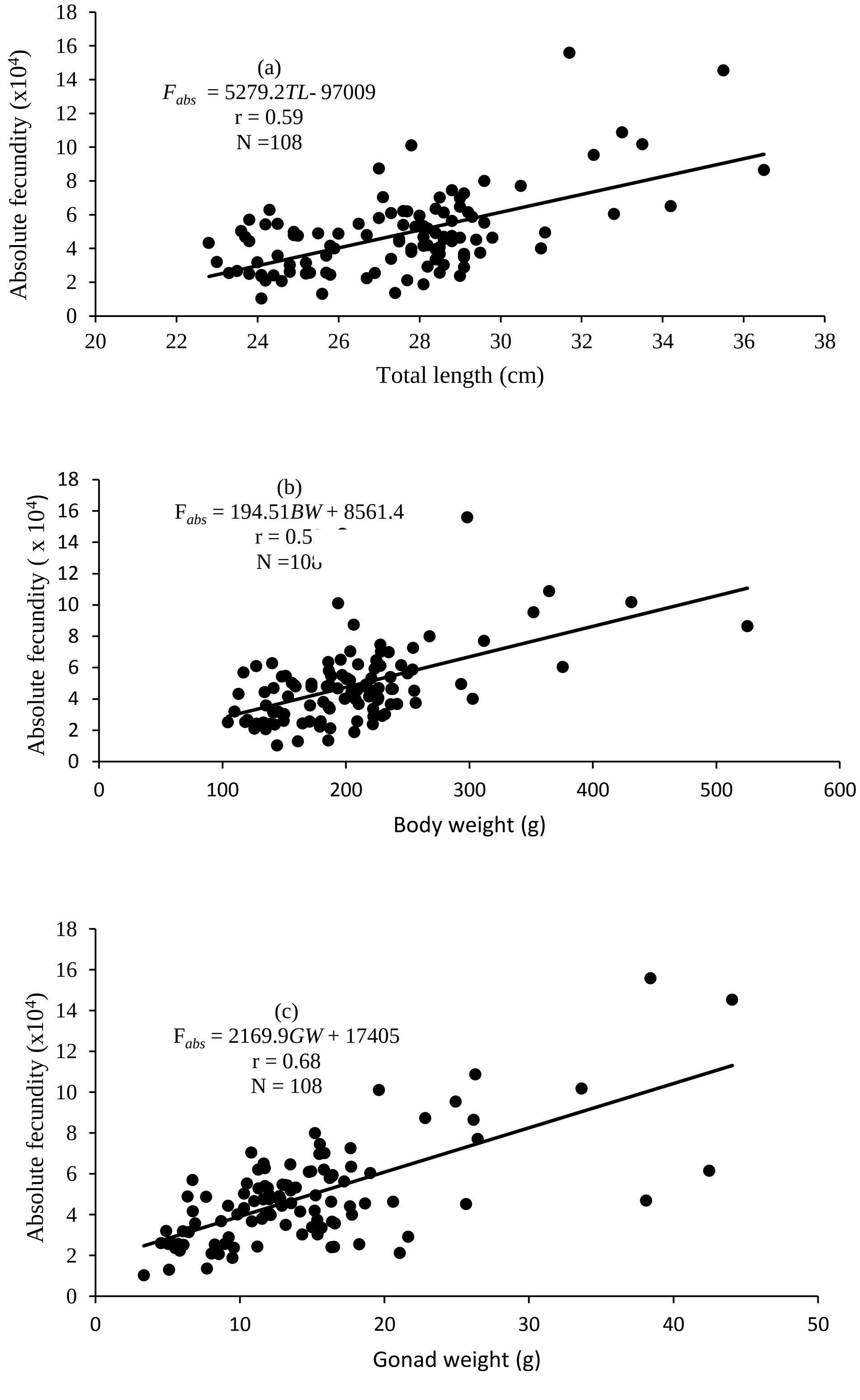



*Figure 13*: Relationship between absolute fecundity ($F_{abs}$) and (a) total length, (b) body weight and (c) gonad weight of *Scomber colias* in the coastal waters of Ghana. N= sample size.

Figure 14 shows the relationship between relative fecundity ($F_{rel}$) and total length of the species which was described by the equation:

$$F_{rel} = 2.094TL + 182.55\ (r = 0.17,\ p > 0.05)$$

Within the size range of the fish samples examined, relative fecundity varied from a range of 71 to 737 eggs $g^{-1}$ body weight (mean = 240 ± 10 eggs $g^{-1}$). The low order of correlation indicates little variation in the relative fecundity with increasing fish size.

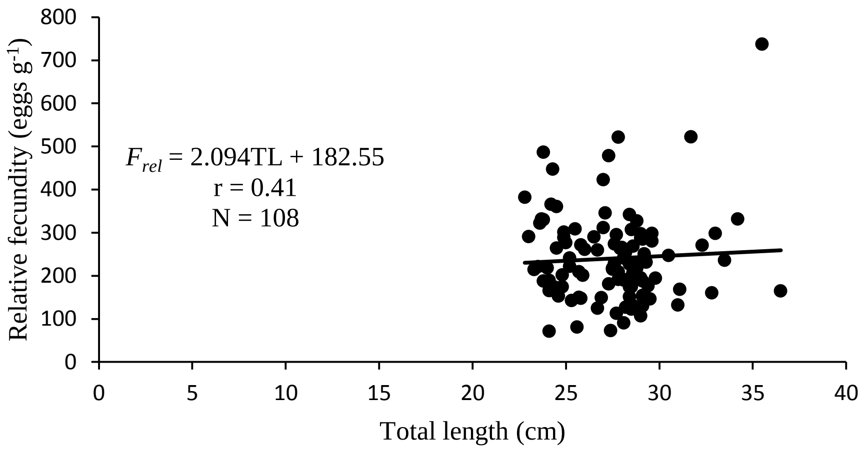



*Figure 14*: Relationship between relative fecundity ($F_{rel}$ = number of eggs $g^{-1}$ body weight) and total length (*TL*, cm) of *Scomber colias* in the coastal waters of Ghana. (N = number of fish).

## Ovum diameter frequency distribution

Figure 15 shows the frequency distribution of ova diameters from five ripe (Stage IV) ovaries of fish sampled in August 2016. The five specimens were in spawning condition. Ova diameters measured 0.1-1.1 mm and their distributions showed two modes at 0.4 mm and 0.8 mm; one of the ovaries had its second mode at 0.7 mm (Figure 15a, Appendix H). A point of inflexion occurred at 0.6 mm in all five ovaries (Figure 15). Ova in the smaller size group were immature and those in the larger groups were mature.

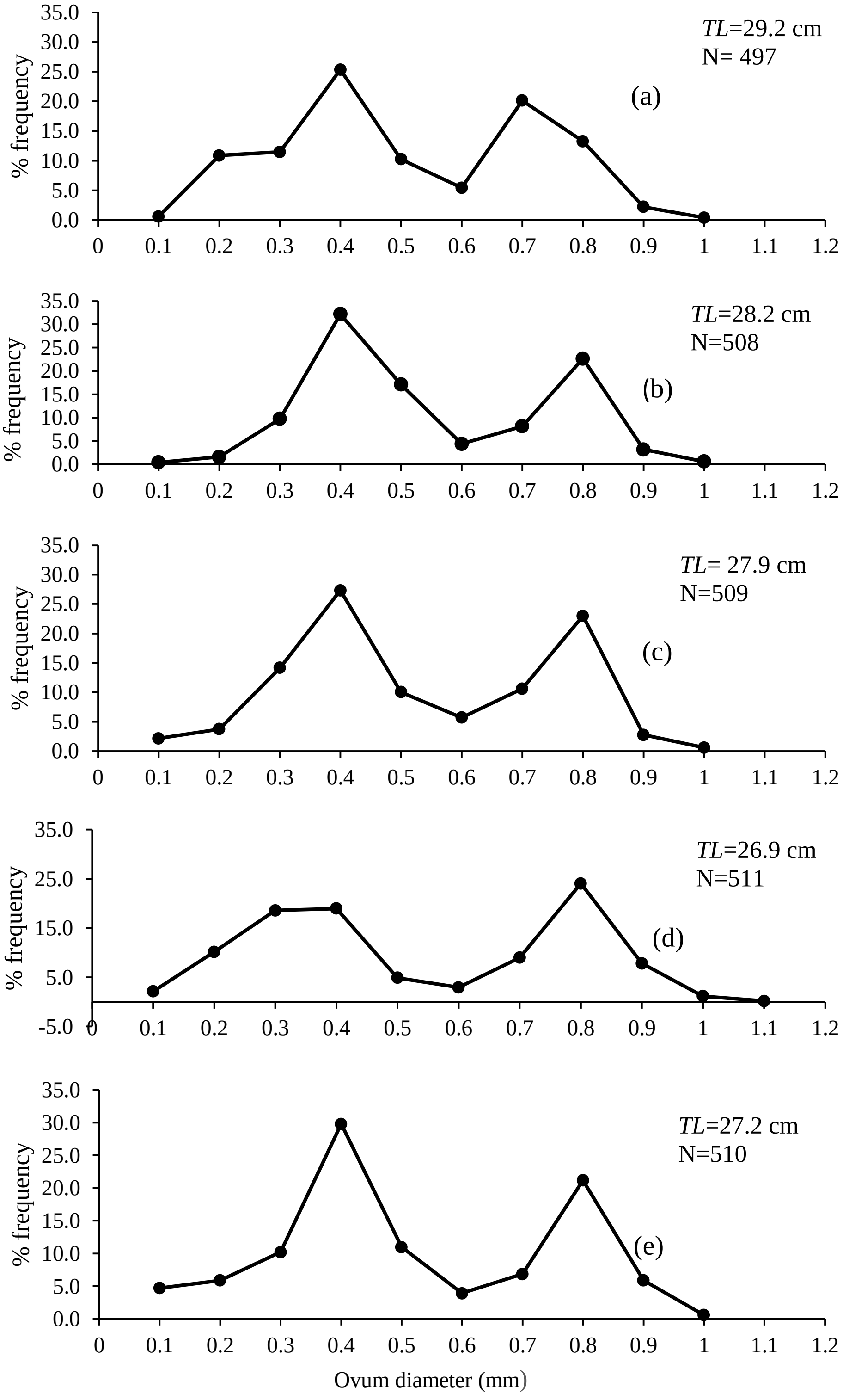



*Figure 15:* Frequency distribution of diameters of ova from *Scomber colias* specimens in the coastal waters of Ghana. *TL* = Total length (cm), N = number of ova measured.

**Monthly representation of gonad maturity stages**

Figure 16 shows the progression of maturity stages of males and females during the study period. Females were not found in the October 2016 samples (Appendix I 2). A high proportion of "virgin" (Stage I) male and females were encountered from September 2016 to January 2017. In October and November 2016, all the males (100%) sampled were in this stage, and in November 2016, 97% of the females were in this stage. Fish in the "recovering spent/maturing virgin" state (Stage II) occurred intermittently with a peak in May 2017 for males (73%) and females (86%). Fish in the "maturing (ripening)" state (Stage III) were absent from October 2016 to January 2017. Peaks for males occurred in August 2016 (57%), March 2017 (69%) and July 2017 (81%). Females in Stage III were dominant in the April 2016 (53%), July 2016 (97%), March 2017 (100%) and in July 2017 (92%) samples.

"Ripe" fish (Stage IV) were not found from September 2016 to January 2017. Male fish in the ripe condition peaked in frequency in April 2016 (36%), July 2016 (83%), April 2017 (38%) and June 2017 (31%). Most females were in ripe condition in June 2016 (62%) and August 2016 (76%). Very few "spent" fish (Stage V) were encountered, and they occurred sporadically. Males at this stage occurred from April to June 2016 and April to June 2017. Peaks in the percentage frequency of "spent" males were recorded in May 2016 (9%) and April 2017 (15%), and females, in September 2016 (6%) and April 2017 (8%).

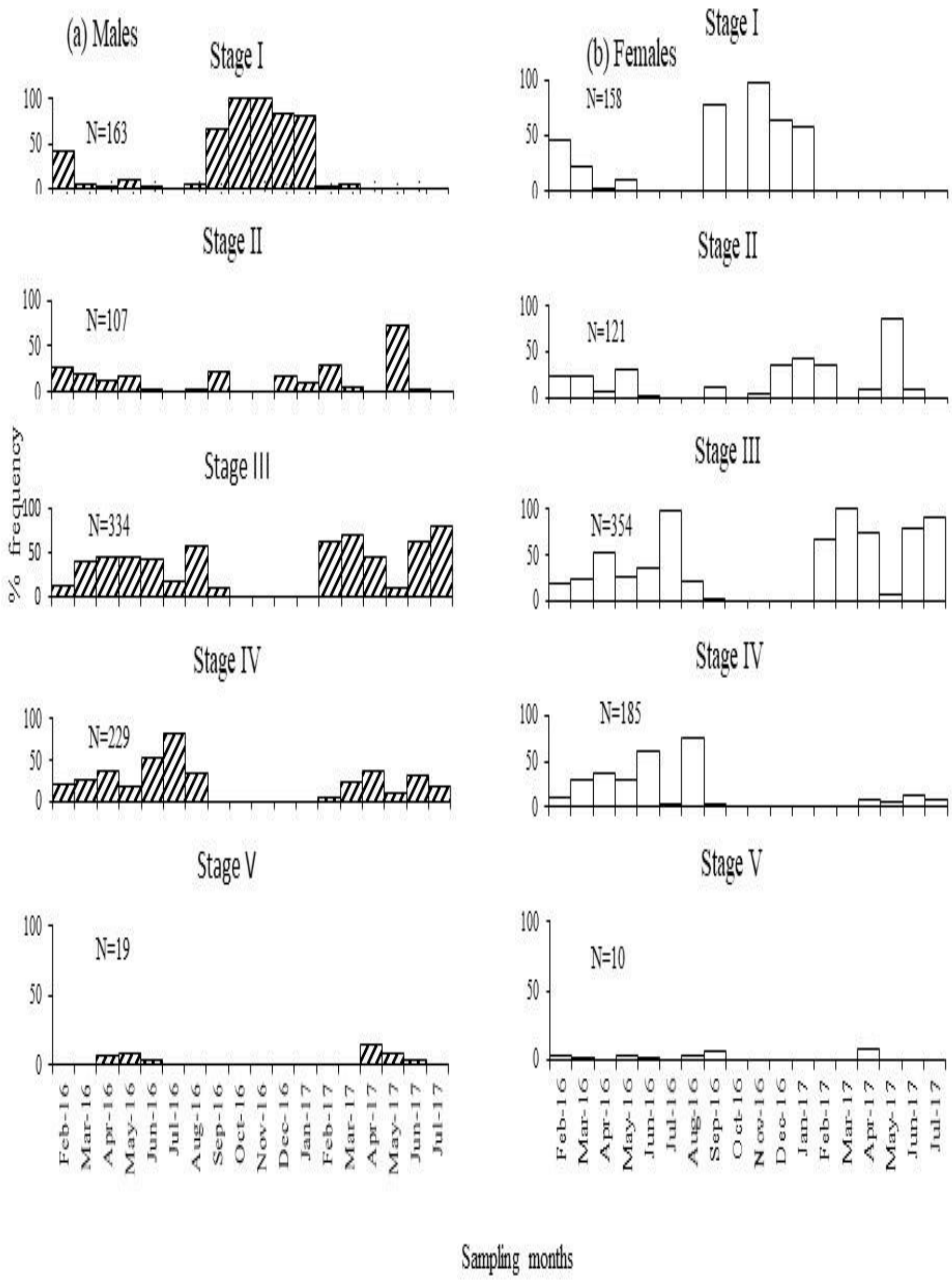



*Figure 16*: Development of sexual maturity stages of (a) male and (b) female *Scomber colias* sampled from February 2016 to July 2017. Stages: I-Virgin, II-Maturing virgin, III-Ripening, IV-Ripe, V-Spent. (Adapted from Holden & Raitt, 1974).

## Monthly changes in the proportion of ripe fish

Figure 17 shows fluctuations in the percentage of fish with ripe gonads (Stages III AND IV) in samples during the study period. The highest proportions (75-100%) occurred in April and June- August 2016, as well as March-April and June- July 2017. Low percentages of mature individuals (0-25%) were recorded for the rest of the year (Appendix J).

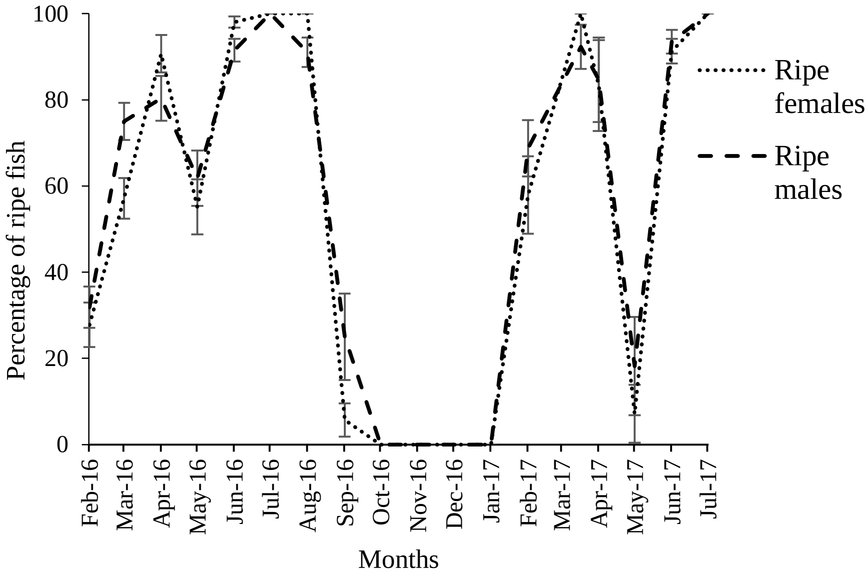



*Figure 17*: Monthly proportions of *Scomber colias* with ripe gonads in Ghanaian waters. Vertical bars represent ± 1 s. e.

## Monthly fluctuations in gonad weight and gonadosomatic index

Changes in the mean weight of testes and ovaries and gonadosomatic index of *S. colias* are shown in Figure 18a. The trends in the fluctuations of gonad weight of males and females indicated peaks in July and April with reduced gonad weights from September 2016 to January 2017 (Appendix K).

A similar pattern was observed in the change in gonadosomatic index for both sexes. (Figure 18b). The index was high from June to August 2016, June to July 2017 and April 2016 and 2017.

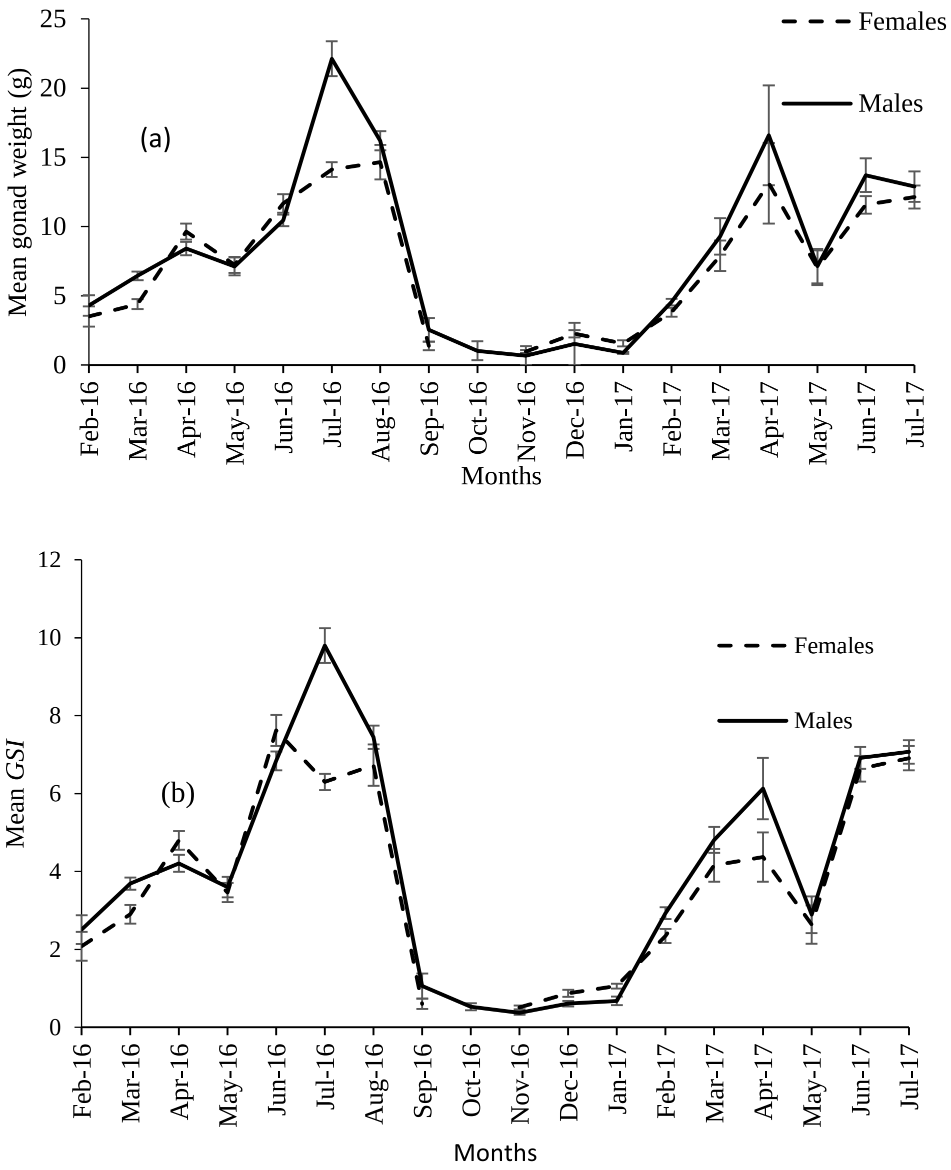



Figure 18: Mean monthly (a) gonad weight, and (b) gonadosomatic index (GSI) of *Scomber colias* in the coastal waters of Ghana. Vertical bars represent ± 1 s. e.

## Food and Feeding Habits

### Stomach contents of *Scomber colias*

The food items found in the stomachs of the fish are presented in Table 3. The species fed on a variety of animals including fish, decapods, cephalopods, bivalves, gastropods, annelids, stomatopod larvae, copepods, amphipods, and chaetognaths. Other items found were sand particles, pieces of coral, and detritus.

Table 3- *Prey items encountered in Scomber colias stomachs during the study period*

| Food item | Species |
|---|---|
| Fish | *Engraulis encrasicolus*, *Sardinella* spp., *Lagocephalus laevigatus*, *Acanthurus monroviae*, larval eels, unidentified fish larvae |
| Decapods | Portunid larvae, crab megalopa, lobster zoea |
| Cephalopods | *Sepia* spp., *Octopus vulgaris* |
| Bivalves | *Donacid clam* |
| Gastropods | Unidentified juveniles |
| Annelids | *Nereis* spp. |
| Stomatopods | *Squilla* spp. larvae |
| Amphipods | Hyperids, gammarids |
| Copepods | *Calanoides carinatus*, Cyclopoid copepods |
| Chaetognaths | *Sagitta spp*. |
| Others | Sand particles, crushed coral, detritus |

### Frequency of occurrence of prey items

The frequency of occurrence of the different food items in the stomachs of *S. colias* is shown in Figure 19. Fish, mainly *Engraulis encrasicolus*, was the most frequently eaten prey item, found in more than

60% of the stomachs each month except in February (54.80%) and June (52.94%) 2016 (Appendix L).

The frequency of decapods fluctuated widely, with peaks in May (61.54%), and August 2016 (42.17%), February 2017 (40%) and the highest peak in June 2017 (94.79%). Stomatopod larvae showed peaks in May (13%) and September 2016 (21.43%), and June (22.96%) 2017. The highest frequency of copepods (19.24%) was recorded in August 2016 which coincided with the upwelling season in Ghanaian waters.

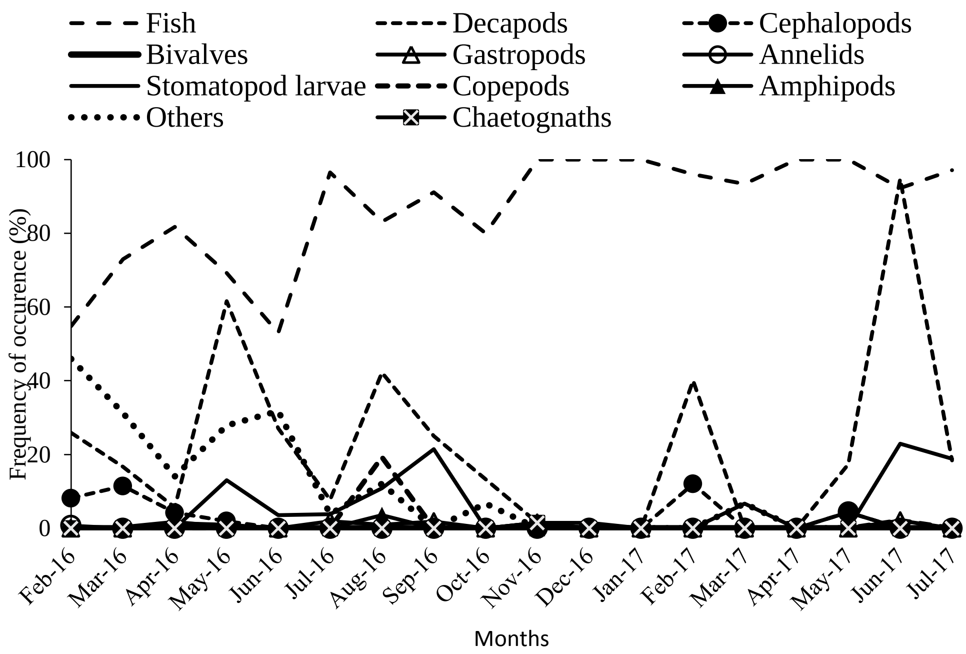



*Figure 19*: Frequency of occurrence of prey items consumed by *Scomber colias* in the coastal waters of Ghana.

**Numerical composition of prey items**

Figure 20 shows the numerical composition of prey items in the stomachs of *S. colias*. Fish were the dominant food throughout the study period except in May 2016 when decapods were the most abundant. Peak fish consumption occurred in April 2016 and 2017, and November 2016 to January 2017 with compositions of 67.35%-100%. Feeding on decapods peaked in May (74.83%) and October (51.85%) 2016 and February 2017 (36.36%). With the exception of stomatopod larvae which comprised 21.95% of the food in June 2017 and copepods with a numerical composition of 33.69% in August 2016, all other food items were less than 20% in numerical composition (Appendix M).

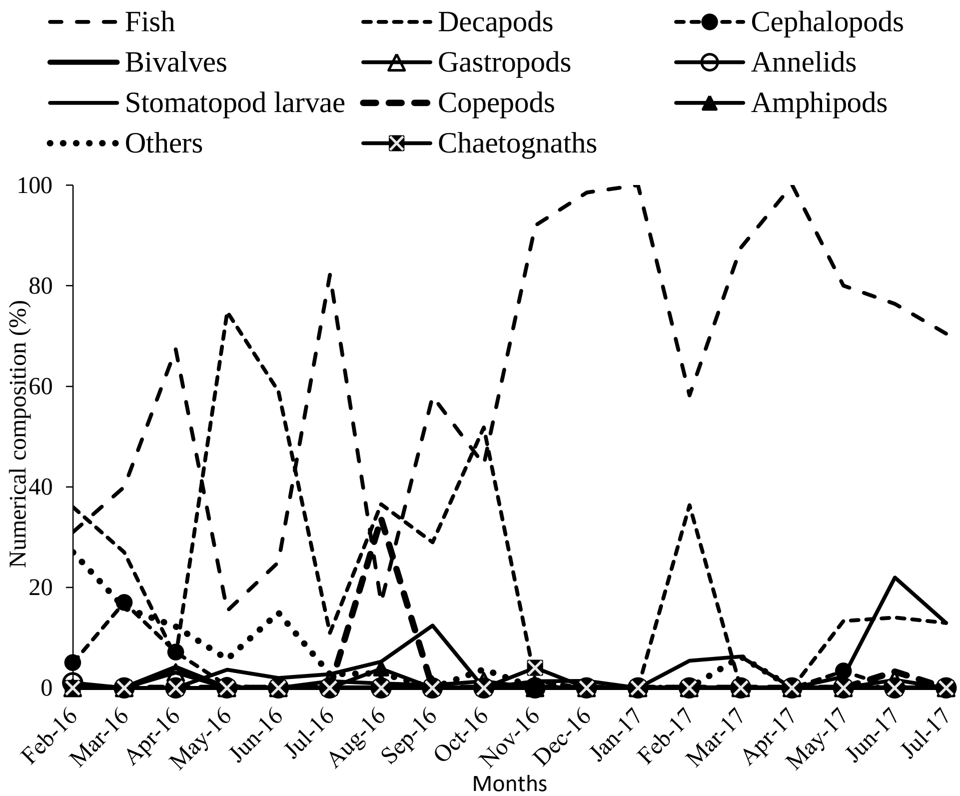



*Figure 20*: Numerical composition of prey items consumed by *Scomber colias* in the coastal waters of Ghana.

## Gravimetric composition of prey items

Figure 21 shows the gravimetric composition of prey items of *S. colias*. Fish comprised 60%-100% by weight of the prey items consumed. Except for the food category designated as “others” with a composition of 26

% in February and 22.07 % in May 2016, the remaining prey items weighed less than 20% of the food consumed each month.

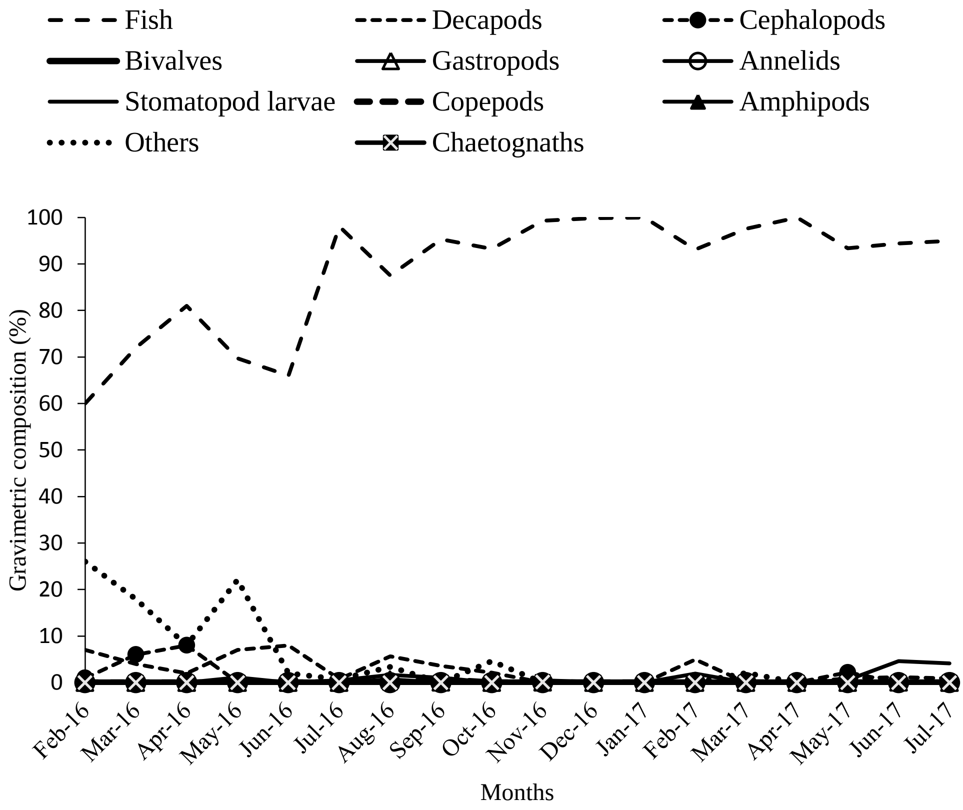



*Figure 21*: Gravimetric composition of prey items consumed by *Scomber colias* in the coastal waters of Ghana.

**Relative importance of food items**

The monthly index of relative importance (IRI) of prey items consumed by *S. colias* is illustrated in Figure 22. Fish were by far the most eaten item in all the months of the study period with IRI values ranging from 4,817.54 to 20,000 with no evidence of seasonality (Figure 22). In the months in which decapods were consumed, their IRI's varied from 1.98 to 5,039.51. The IRI values of sand particles, coral pieces and detritus varied between 284.98 and 2,434.29. All other food items had IRI values below 658 throughout the study period (Appendix O).

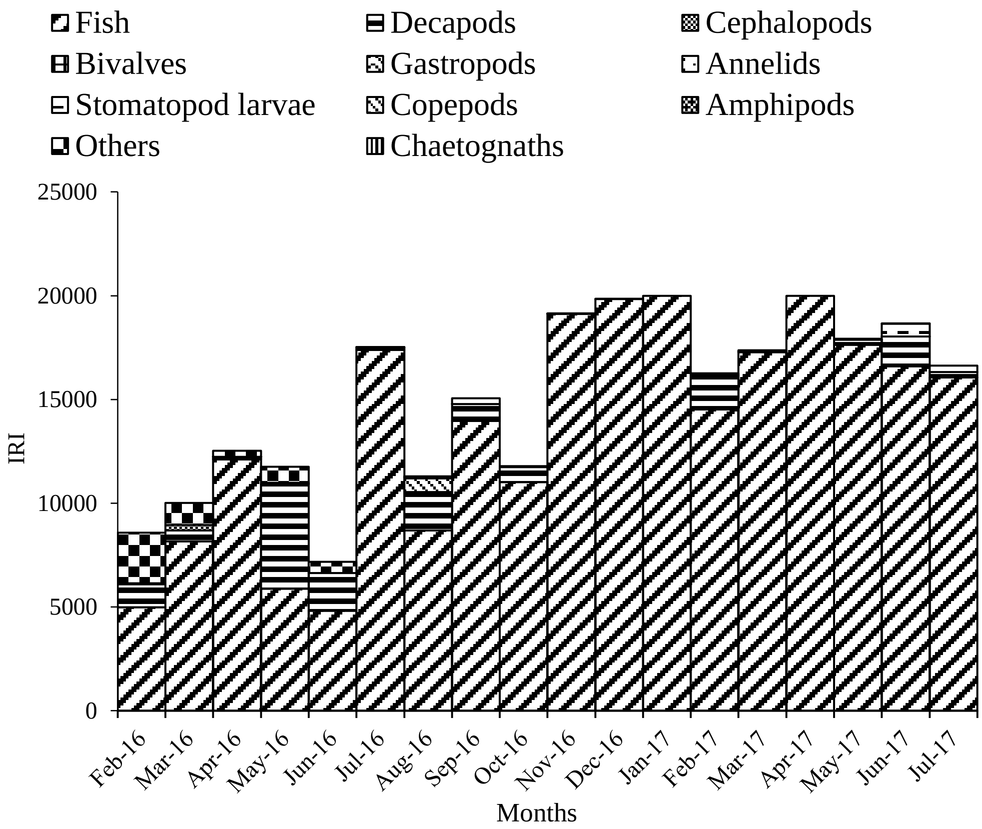



*Figure 22*: Index of Relative Importance (IRI) of prey items in the food of *Scomber colias* in the coastal waters of Ghana.

**Feeding chronology**

Of the 2,146 stomachs examined, 1,080 constituting 50.33% were empty. There was considerable fluctuation in the number of empty stomachs (vacuity index) with no clear trends observed (Figure 23a). However, the highest number of empty stomachs occurred in May of both year 2016 and 2017.

The mean monthly index of stomach fullness during the study ranged from between 0.14 ± 0.03% and 1.57 ± 0.14% with the highest values in February and March 2016. For the remaining period, the index was high from

July 2016 to October 2016, December 2016 and March to May 2017. The lowest values were recorded in November 2016 and February 2017 (Figure 22b, Appendix P).

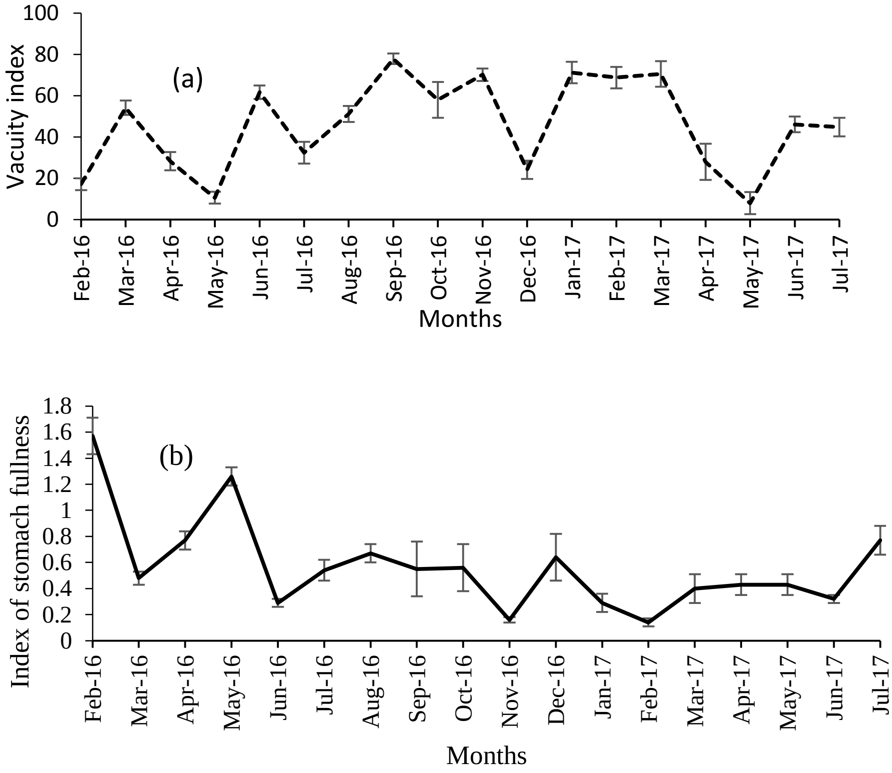



*Figure* 23: Fluctuations in (a) vacuity index and (b) index of stomach fullness of *Scomber colias* in the coastal waters of Ghana. Vertical bars indicate ± 1 s. e.

## Ageing of Fish from Otoliths

### Otolith structure

The saggital otolith of *S. colias* has a concavo-convex shape with a somewhat pointed rostrum and a blunt post-rostrum (Figure 24). Otoliths of juveniles have a less pronounced rostrum. Under reflected light, the otoliths show alternate whitish narrow opaque bands, and wider dark hyaline bands. The former signifies a higher deposition of calcium carbonate and hence represent fast growth zones and the latter, zones of slow growth with less amounts of calcium carbonate.

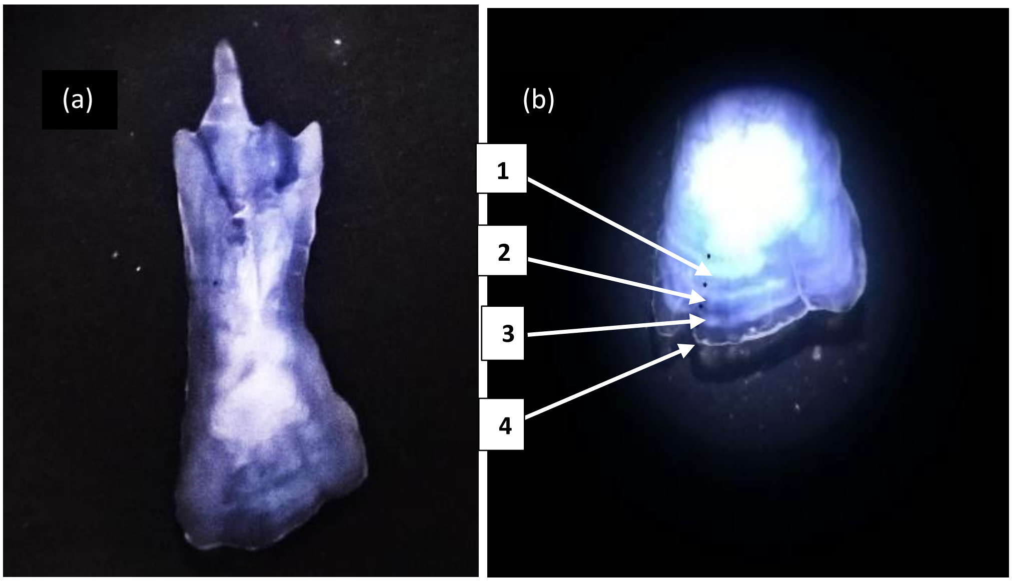



*Figure 24*: (a) Sagittal otolith of *Scomber colias* from Ghana under reflected light, and (b) posterior edge of the otolith from a 4+ year old fish showing alternate translucent and opaque rings.

**Fish length-otolith diameter relationship**

Otoliths of *S. colias* measured 2.4 mm to 4.5 mm in diameter (longest antero-posterior length) for fish of 17.2 cm *TL* and 40.7 cm *TL* respectively. The relationship between otolith diameter (*OD*) and total length (*TL*) of the fish (Figure 25) was linear and described by the equation:

$OD = 0.12TL + 1.15$ ($r = 0.75$, $p<0.05$).

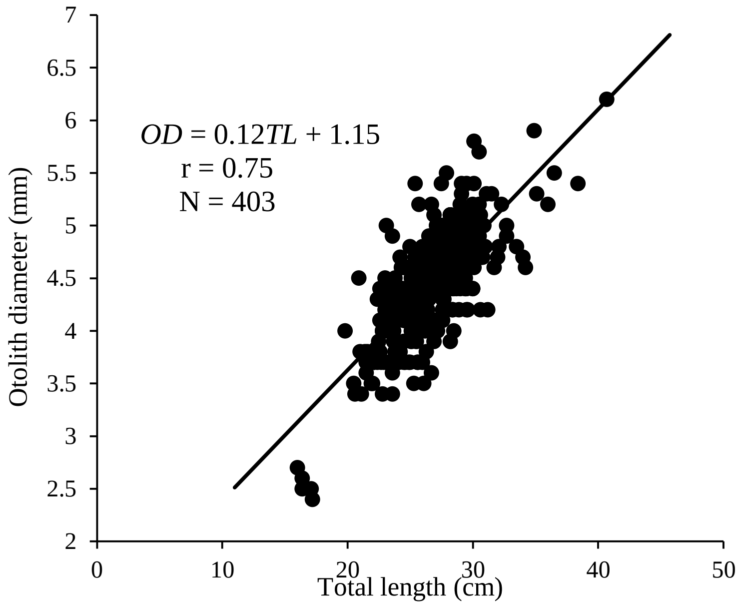



*Figure 25*: Relationship between otolith diameter (OD) and total length (TL) of *Scomber colias* in the coastal waters of Ghana. N=sample size.

**Fish length-otolith radius relationship**

Otolith radius ranged (*OR*) from 1.1 mm for a fish of 17.2 cm *TL* to 2.9 mm for a fish of 40.7 cm *TL*. The relationship between otolith radius and total length of the species (Figure 26) was linear and significant ($r = 0.65$, $p<0.05$). The relationship was described by the equation:

$OR=0.05TL + 0.57$ ($r = 0.65$, $p<0.05$).

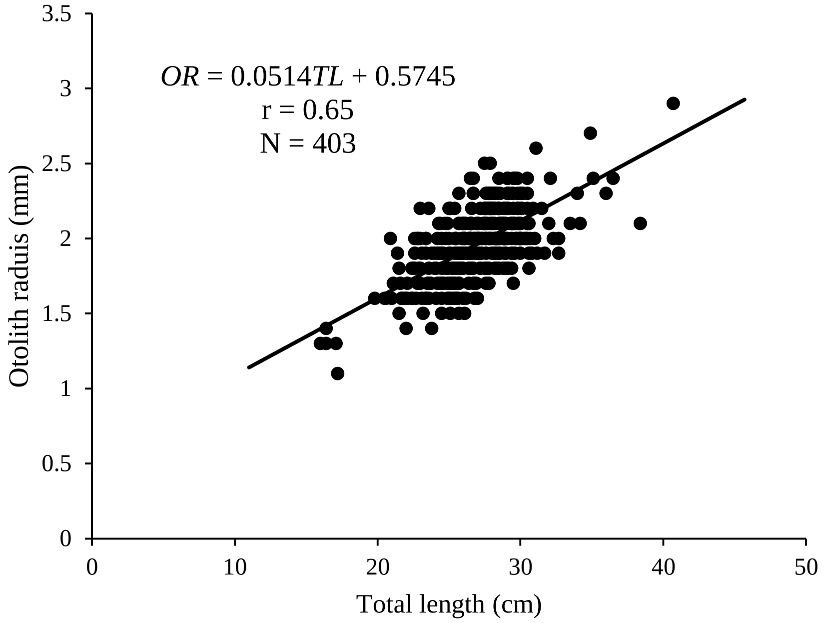



*Figure 26*: Relationship between otolith radius (OR) and total length (TL) of *Scomber colias* in Ghanaian waters. N=sample size.

**Validation of growth ring deposition rate**

Monthly examination of otoliths of *S. colias* showed the occurrence of high proportions (75%-100%) with a hyaline edge between October 2016 and February 2017, and a relatively low proportion (30.77%) with a hyaline edge in August (Figure 27a, Appendix Q). Otoliths with an opaque zone (~15µm) at the edge also occurred in July-August (Figure 27b) suggesting that the growth ring is formed during this month, and thus validating deposition of one ring a year in the fish from Ghana.

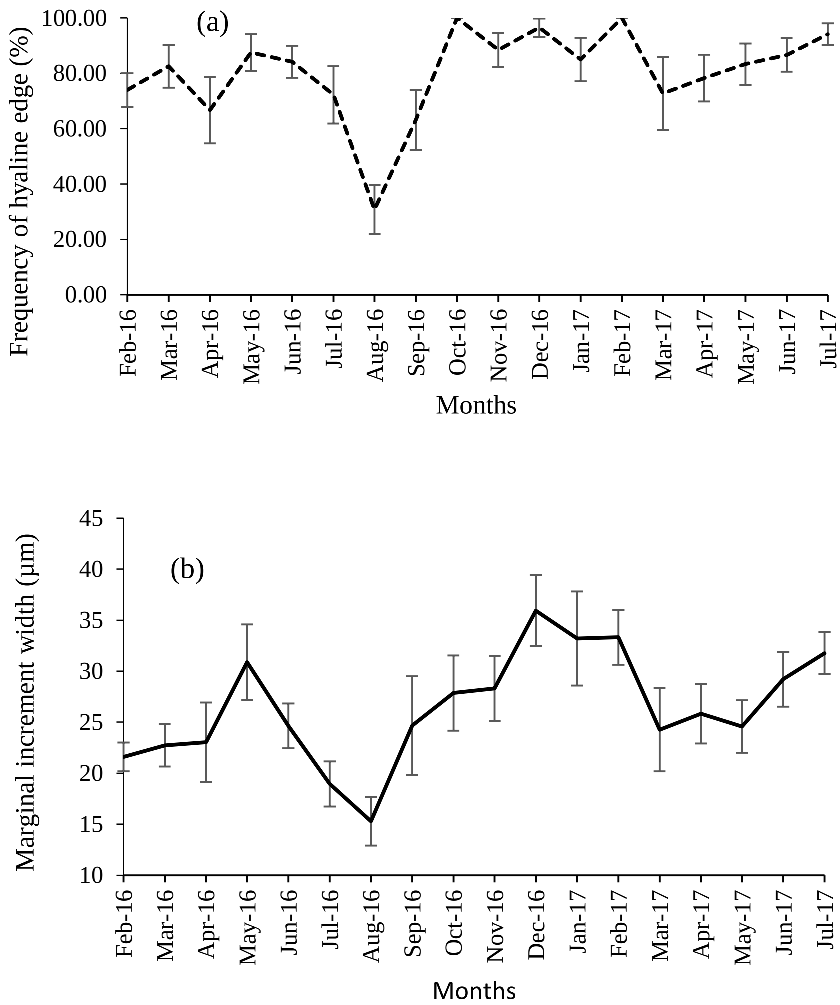



*Figure 27*: (a) Frequency of otoliths with hyaline edge, and (b) mean marginal increment width of otoliths of *Scomber colias* from the coastal waters of Ghana. Vertical bars indicate ± 1 s. e.

**Length-at-age key**

Nine age groups were determined from readings of *S. colias* otoliths. Counts of the annual rings in otoliths from fish of known length were used to develop a length-at-age key which is presented in Table 4. Fish less than a year old (age 0) had an estimated mean length of 19.6 ± 2.5 cm *TL* and 8-year old fish measured 40.5 cm *TL*. However, the estimated lengths of 7- and 8-

year old fish should be treated with caution in view of their small sample sizes.

Table 4- *Mean Length-at-Age Key for Scomber colias from the coastal waters of Ghana; number of fish in the sample in parenthesis*

| Age (years) | Mean length (cm) ± SD |
|---|---|
| 0 | 19.6 ± 2.5 (11) |
| 1 | 22.7 ± 1.5 (28) |
| 2 | 25.4 ±1.8 (94) |
| 3 | 26.7 ± 1.7 (146) |
| 4 | 28.6 ± 2.1 (113) |
| 5 | 30.6 ± 2.4 (34) |
| 6 | 30.5 ±2.3 (6) |
| 7 | 35.8± 0.3 (3) |
| 8 | 40.5 (1) |

Figure 28 shows the size distribution of *S. colias* of different ages. The modal size of fish aged 1, 2, 3, 4, and 5 years was 22.0-22.9 cm *TL*, 24.0-24.9 cm *TL*, 25.0-25.9 cm *TL*, 28.0-28.9 cm *TL* and 29.0-29.9 cm *TL* respectively. The samples were dominated by 2- to 4- year old fish with considerable overlaps in the lengths of fish belonging to different ages (Appendix R).

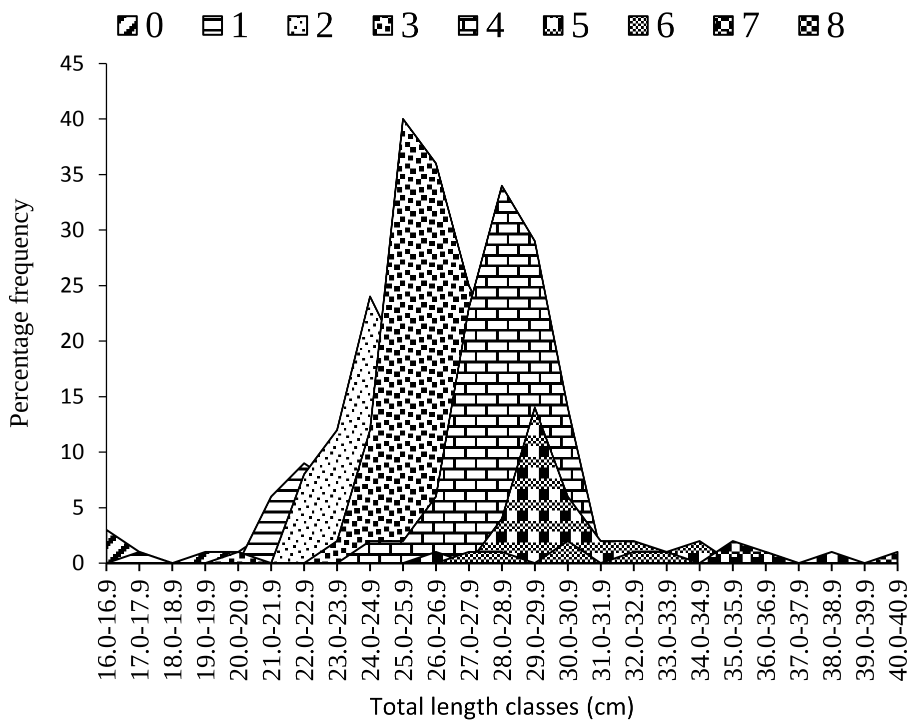



*Figure 28:* Frequency distribution of ages of length groups of *Scomber colias* from the coastal waters of Ghana estimated from otolith readings.

## Growth

### Monthly length-frequency distributions

Figure 29 shows the monthly length distributions of the species in Ghanaian coastal waters. Modal lengths of the fish shifted between the 23.0-23.9 and 28.0-28.9 cm *TL* size classes from February to December 2016. Fish with these modal lengths disappeared from samples thereafter. Recruitment of fish with a modal size class of 16.0-16.9 cm *TL* occurred in August 2016 and grew to a modal class size of 27.0-27.9 cm *TL* along with fish of a modal length of 23.0-23.9 cm *TL* in July 2017. In general, shifts in the modal lengths were irregular (Appendix S).

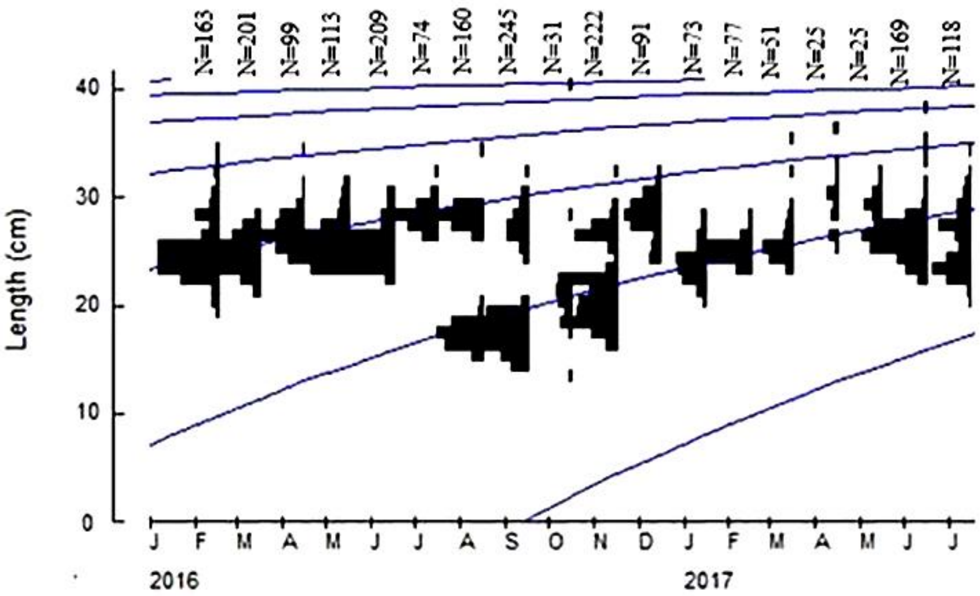



*Figure 29*: Monthly length-frequency distribution of *Scomber colias* from the coastal waters of Ghana fitted with a growth progression curve obtained from ELEFAN I.

**Growth parameters**

The growth parameters of *S. colias* in Ghanaian coastal waters estimated with the ELEFAN I routine were $L_\infty$ = 42.5 cm *TL* and $K$ = 0.28 $yr^{-1}$, and the resultant growth curve fitted to the monthly length frequency distributions is illustrated in Figure 29. Substitution of $L_\infty$ in the length-weight relationship equation for the population gave an asymptotic weight ($W_\infty$) of 886.06 g. The maximum observed length ($L_{max}$) and weight ($W_{max}$) of the fish were 40.7 cm *TL* and 695 g respectively. Using Taylor's (1958) equations: $L_\infty \approx L_{max}/0.95$ and $W_\infty \approx W_{max}/0.86$, $L_\infty$ was estimated as 42.8 cm *TL* and $W_\infty$ as 808 g which are similar to the estimates from the ELEFAN programme.

The age at which the length of the fish is zero ($t_0$) calculated from Pauly's (1983) empirical equation was -0.54 yr. Hence on a yearly basis, the growth of the population can be described by the von Bertalanffy equation:

$L_t$=42.5{1-exp[-0.28($t$+0.54)]}cm *TL*.

The von Bertalanffy growth curve derived from the equation is illustrated in Figure 30 together with mean-age at length from otolith readings. It showed that the predicted length from the von Bertalanffy growth function in the first 2 years of growth was lower than the actual mean lengths as obtained from otolith readings. While the predicted length estimated 6 cm *TL* (14% of asymptotic length) in the first year of growth (age 0) alone, actual otolith readings estimated 19.6 cm *TL* (46% of asymptotic length) for age 0 fish. The patterns in the curves were similar for fish aged 3-5 and 7-8 years.

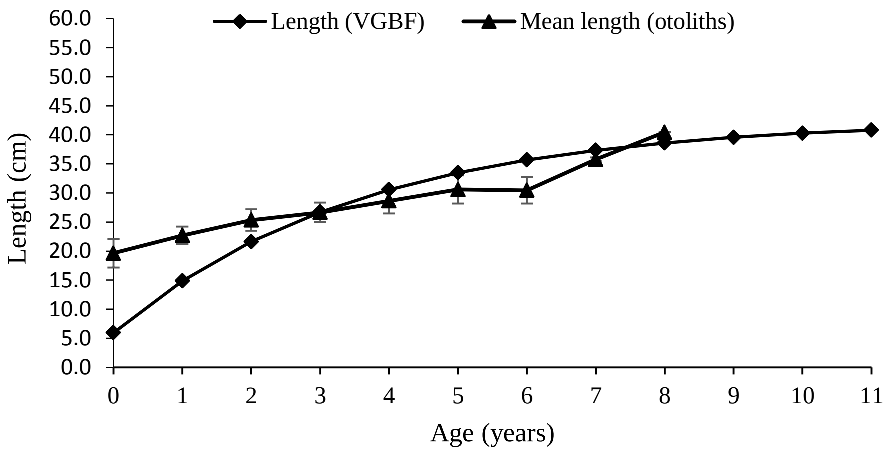



*Figure 30:* The von Bertalanffy growth curve for *Scomber colias* from Ghana illustrated together with mean lengths from length-at-age data derived from otolith readings. Vertical bars indicate ± standard deviation.

. The longevity of *S. colias* in the coastal waters of Ghana as estimated from $t_{max} = t_0 + 3/K$ (Froese et al., 2005) was 10 years. The growth performance index ($ø'$) was calculated to be 2.70.

**Mortality Parameters**

Figure 31 shows the length-converted catch curve of *S. colias* in Ghanaian waters. A total mortality rate (*Z*) of 1.22 $yr^{-1}$ was estimated from the regression line of fish recruited into the fishery. A natural mortality rate (*M*) of

0.70 $yr^{-1}$ was determined by substituting the mean sea surface temperature of Ghana's coastal waters during the study period (27.3ºC), $L_\infty$ (42.5 cm *TL*) and *K* (0.28 $yr^{-1}$) in Pauly's (1983) empirical equation. The fishing mortality rate (*F*) was therefore estimated to be 0.52 $yr^{-1}$.

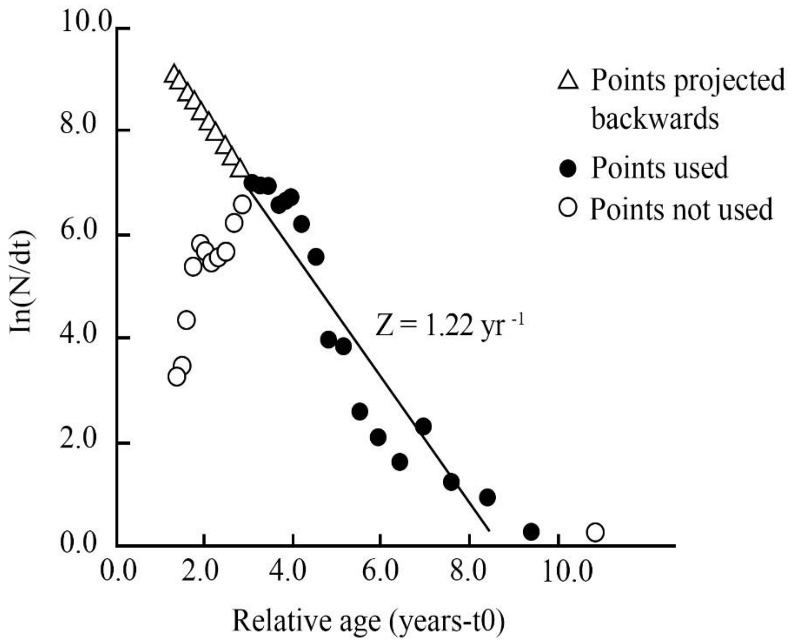



*Figure 31*: Length-converted catch curve for *Scomber colias* in Ghanaian coastal waters.

**Mean length at first capture**

The selection curve generated from the ascending part of the length-converted catch curve for the species is shown in Figure 32. The mean length at first capture ($L_{c50}$) is therefore extrapolated as 24.1 cm *TL* which was close to the mean length (24.6 cm *TL*) and primary modal size (25.0 – 25.9 cm *TL*) of the species.

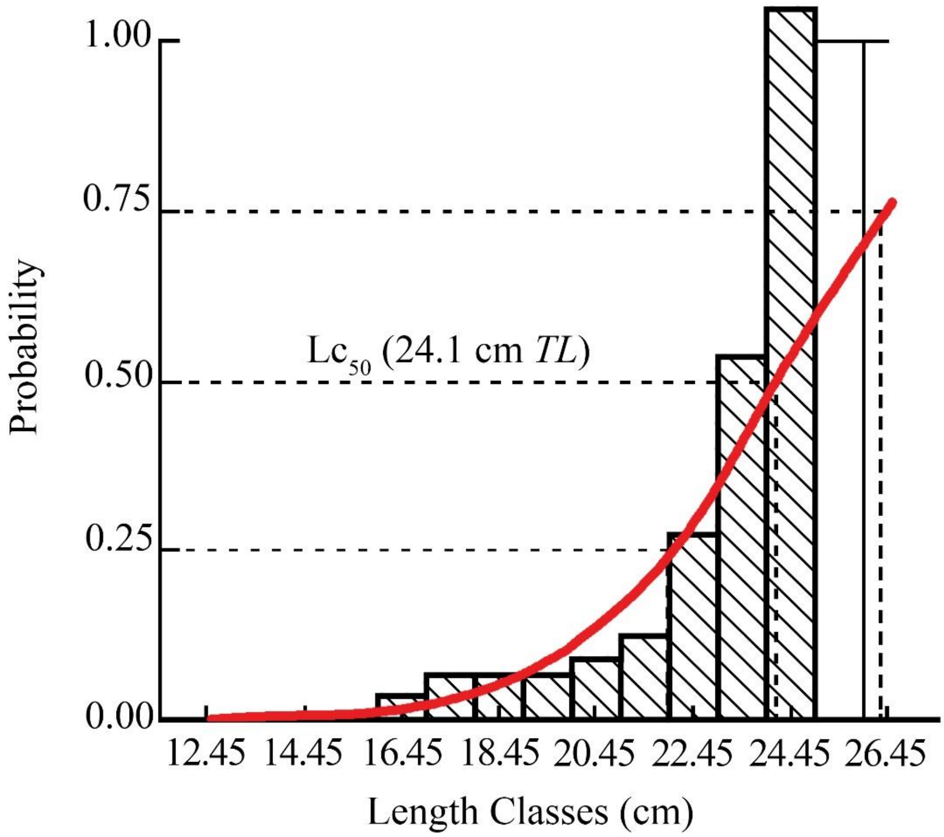



*Figure 32*: Selection curve for estimation the probability of capture of *Scomber colias* in the coastal waters of Ghana.

**Recruitment pattern**

The FiSAT II output of the annual recruitment pattern of *S. colias* in Ghana (Figure 33) shows that fish are recruited into the population throughout the year with a major and a minor peak, possibly in April and August respectively.

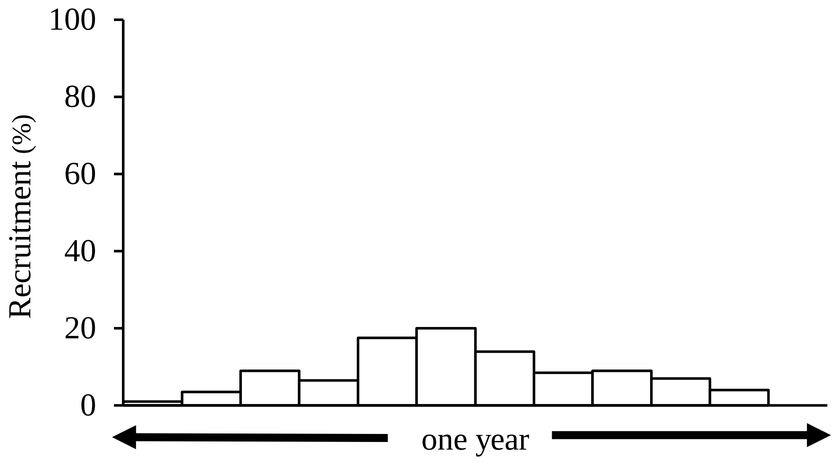



*Figure 33*: Annual recruitment pattern of *Scomber colias* in the coastal waters of Ghana.

**Exploitation Rate**

Figure 34 shows the results of the relative biomass-per-recruit (*B'/R*) and relative yield-per-recruit (*Y'/R*) analysis which indicates the current rate ($E_{curr}$) as 0.43 and optimum rate of exploitation ($E_{50}$) as 0.39, thus suggesting a possible overexploitation of the stock.

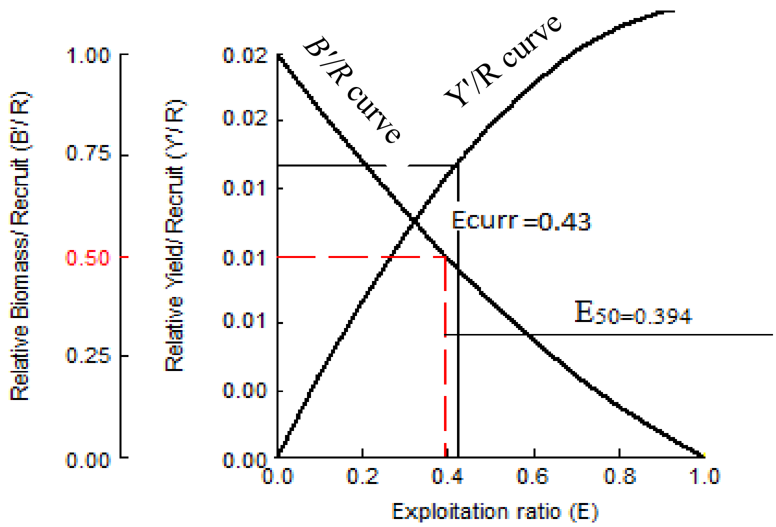



*Figure 34*: Relative biomass per-recruit (B'/R) and yield per-recruit (Y'/R) curves for *Scomber colias* in the coastal waters of Ghana.

## *Scomber colias* Specimens in "Saiko" Samples

### Percentage composition

A total of 5,704 fish specimens belonging to 47 families and 84 species were encountered in frozen fish slabs from the "Saiko" fishery (Appendix U). The fish comprised teleosts, cartilaginous fishes, and cephalopods, with *S. colias* making up 2.3% of the total number, and 3.48% of the total weight (268.31 kg) of fish sampled. Its occurrence in the frozen slabs was sporadic over the months sampled.

### Size distribution and maturity state

The total length of *S. colias* in the frozen fish slabs ranged from 13.4-26.8 cm *TL*, and the mean length was 19.23 ± 0.39 cm *TL*. The fish weighed between 16.23 and 204.30 g, with a mean weight of 71.24 ± 4.48 g. The range of total length and body weight of the specimens was similar to that recorded for juvenile fish of indeterminate sex in the freshly landed samples from the artisanal fishery. Based on information from the mean length-at-age key, most of the specimens in the "saiko" landings were age 0 fish. The length-frequency distribution of *S. colias* in the frozen fish slab samples was polymodal (Figure 35, Appendix V).

Specimens of *S. colias* in the "saiko" fishery were immature upon macroscopic examination of gonads. In addition, the mean length of *S. colias* in the "saiko" fish samples recorded in this study was lower than the length at 50% maturity determined for the species

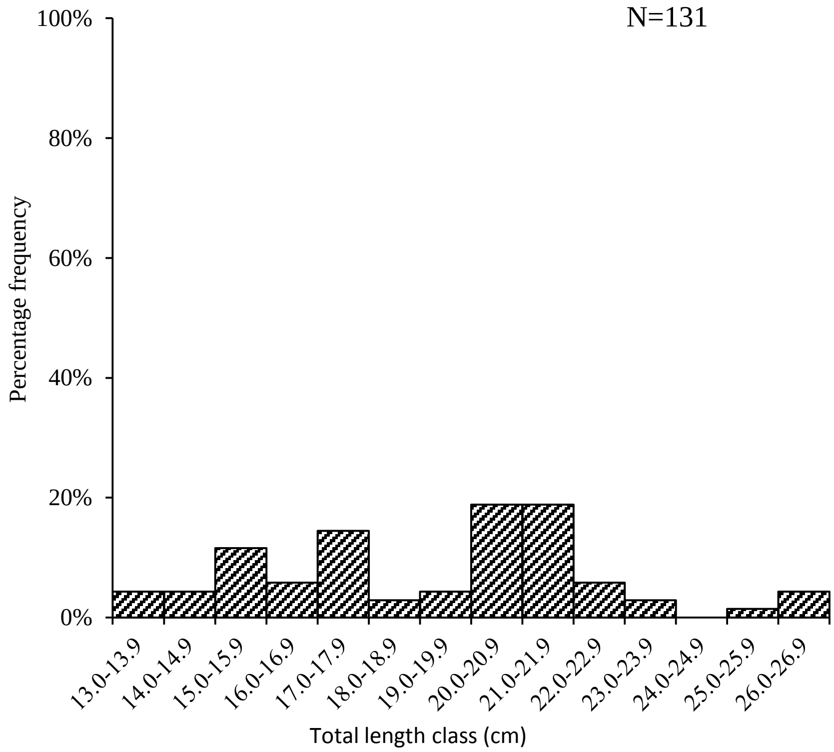



*Figure 35*: Length-frequency distribution of *Scomber colias* from trawl bycatch in Ghana.

## Nutrient Content of Fish Muscle Tissue

### Protein

Proximate nutrient analysis showed protein content varied from 62.27 % to 72.68 ± 0.21 % with an average composition of 70.77 ± 0.85 % during the study period (Figure 36). Higher amounts of tissue protein were recorded in April-June and July-September 2016, and July 2017.

### Fat

Fat varied from 6.55 ± 1.1 % in July 2017 to 24.76 ± 1.69 % in October-December 2016. Low tissue fat content occurred in April-June and July-September 2016, while a peak occurred in October- December 2016 (Figure 36).

### Carbohydrate

Composition of carbohydrate varied between 1.14 ± 0.25% in July-September 2016 and 9.74% in January-March 2016.

### Fibre and ash

Fibre content was low throughout the study period, with the highest value of 2.57% in January-March 2016, and the lowest of 0.12% in July-September of the year. The highest composition of ash (6.96 ± 0.56 %) was recorded in July 2017 and the least (3.13 ± 0.03 %) in October - December 2016 (Figure 36).

### Moisture

The composition of moisture in the dried meal was highest (11.09 ± 0.45%) in January-March 2017 and lowest (4.41 ± 0.19 %) in October-December 2016 (Appendix W).

Figure 36 illustrates quarterly changes in nutrient composition of *Scomber colias*.

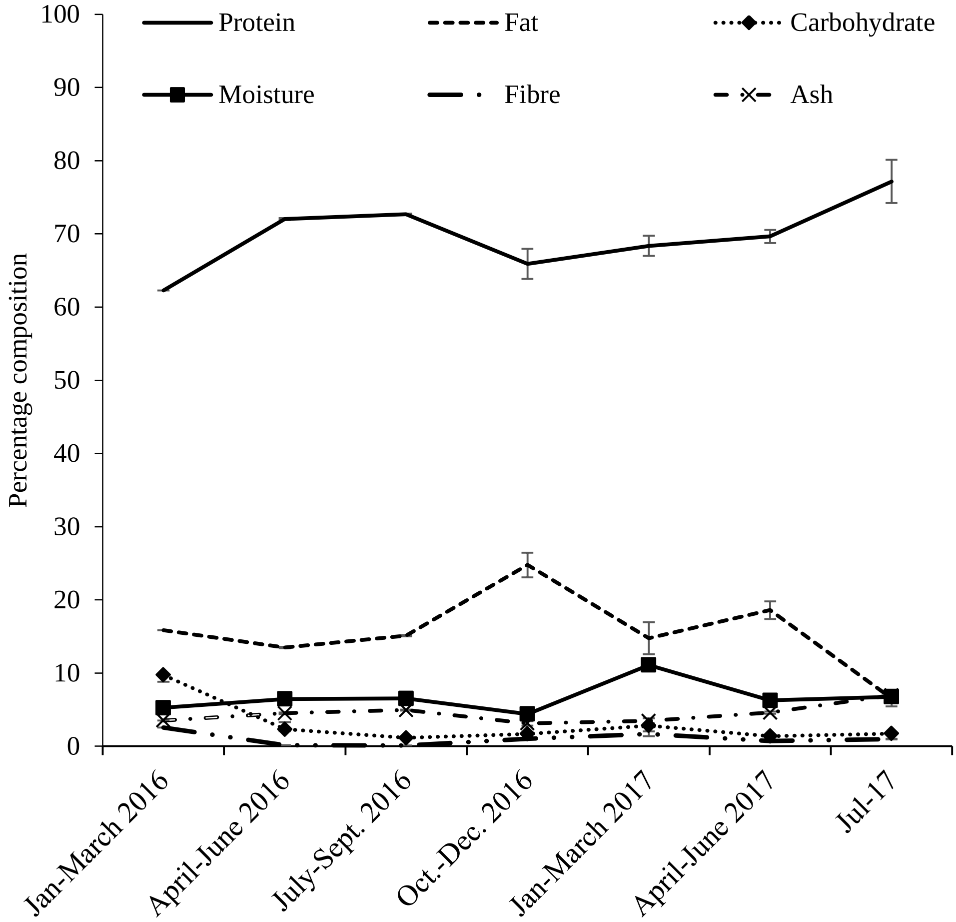



*Figure 36*: Percentage composition of nutrients in *Scomber colias* meal. Vertical bars indicate ± 1 s. e.

# CHAPTER FIVE

# DISCUSSION

This chapter discusses the results obtained from analyses of size distributions, length-weight relationships, otolith readings, growth and mortality parameters, and reproductive characteristics of *Scomber colias* in the coastal waters of Ghana from February 2016 to July 2017. Also discussed are observations on the food and feeding habits, nutrient composition of muscle tissue and status of the species in the illegal "saiko" business.

## Size Structure and Length-Weight Relationship

Specimens of *S. colias* obtained from the artisanal fishery of Ghana measured 13.7 - 40.7 cm *TL* and weighed 42.4 - 695 g. The length distribution was characterized by two groups, whose modal lengths were in the 16.0 - 17.9 cm *TL* and 25.0 - 25.9 cm *TL* classes. The former comprised predominantly juvenile fish possibly caught with undersize mesh nets, as small as 0.7 cm stretched mesh (Arizi, pers comm.). Two modal lengths (21.0 cm *TL* and 30.0 cm *TL*) were also found by Martins, Skagen, Marques, Zwolinski, & Silva (2013) for samples from the artisanal catches off Portugal, while purse seine and trawl samples were represented by a single mode in the 21 cm *TL* and 24-26 cm *TL* classes, respectively. Keč & Zorica (2012) recorded a single mode for the species caught in the Adriatic Sea. Earlier studies on the fish in Ghana (Amponsah et al., 2016; Kwei, 1971) did not report on the size range of the fish. However, it can be deduced from Kwei's (1971) analysis of the length-weight relationship that *S. colias* had a maximum length ($L_{max}$) of 25.0 cm *FL* and weight ($W_{max}$) of ~300 g. Using the equation determined for the fork length-total length relationship of the species in this study (Appendix A), the

$L_{max}$ recorded by Kwei (1971) was 27.4 cm *TL*, indicating that landings in the early 1970s contained fish smaller than the present samples. Similar variations in the size distribution of chub mackerel have been observed in Morocco and Mauritania-Senegal waters (Habashi & Wojciechowski, 1973; quoted in Hernández & Ortega, 2000), and off South Africa (Dietrich & Ritzhaupt, 1979; quoted in Hernández & Ortega, 2000). Lorenzo & Pajuelo (1996) recorded $L_{max}$ of 42.1 cm *TL* and $W_{max}$ of 746.6 g in waters off the Canary Islands, and Jurado-Ruzafa, Hernandez, & Santamaria (2017) reported $L_{max}$ of 49.0 cm *TL* and $W_{max}$ of 1,512 g in Mauritanian waters. An $L_{max}$ of 70 cm *TL* was observed in catches off South Africa in 1984 (Ostapenko, 1988). In the Adriatic Sea, $L_{max}$ of *S. colias* was reported (Keč & Zorica, 2013) to be 38 cm *FL* (= 41.7 cm *TL*). It is therefore apparent that the maximum size of *S. colias* differs among locations perhaps due to differences in the environmental conditions, fishing gears and fishing methods.

In the present study, male and female mackerels exhibited isometric growth while positive allometric growth was determined for the combined samples, including juveniles. This confirmed Kwei's (1971) analysis, which found that chub mackerel also exhibited isometric growth in Ghanaian waters. However, the allometric growth of the combined fish sample was probably due to the juveniles which had a faster growth rate because of their higher metabolic activity. Several reports indicate considerable variations in the growth patterns of chub mackerel populations along the west coast of Africa. Isometric growth of the fish has been reported (Namibia, *b*= 3.1; South Africa, *b*= 3.3; Morocco to Senegal, *b*= 2.88-3.56) (Hernández & Ortega, 2000). Lorenzo & Pajuelo (1996) determined *b* = ~3.3 for male, female and combined specimens of the species off the Canary Islands, and Jurado-Ruzafa, Hernandez & Santamaria (2017) found positive allometric growth for the population in Mauritania. Allometric and isometric growth have similarly been reported for the species in European waters such as the Adriatic Sea (Keč & Zorica, 2013) where males and females were found to exhibit positive allometric growth and isometric growth for all specimens. Isometric growth has also been reported for the species off Turkey (Cengiz, 2012; Sangun, Akamca, & Akar, 2007), while positive allometric growth has been assessed for the fish from other locations (Gluyas-Millan, Castonguay, & Quinonez-Velazquez, 1998; Hwang, Kim, & Lee, 2008; Vasconcelos, Afonso-Dias, & Faria, 2011). Daley & Leaf (2019) found negative allometric growth in the NorthWest Atlantic population. It is evident from these reports that isometric or allometric growth in *S. colias* is not specific to geographical regions.

**Reproductive Biology**

The estimated length at which 50% of the fish matures in Ghana ($L_{m50}$ = 25.6 cm *TL*) was comparable to 27.7 cm *TL* for the population in the Azores (Carvalho, Perrotta, & Isidro, 2002) and 27.39 cm TL for the northwest Atlantic *S. colias* population (Daley, 2018), but slightly larger than 23.0 cm *TL* for females off the Canary Islands (Lorenzo & Pajuelo, 1996), 22.88 cm *TL* for males and 23.01 cm *TL* for females off Morocco (Techetach et al., 2010), and 22.12 cm *TL* for males and 21.55 cm *TL* for females in the waters of Madeira Island (Vasconcelos et al., 2012), and 18.0 cm *TL* for the combined sexes in the coastal waters of Turkey (Cengiz, 2012).

The range of the absolute fecundity of *S. colias* in Ghana (10,220 to 155,791 eggs; mean = 48,238 ± 2324) in fish 24.1 cm *TL* to 31.7 cm *TL* differed from the range (17,000 to 86, 850) found by Kwei (1971) in fish 13.9 cm *FL* (= 15.2 cm *TL*) to 22.6 cm *FL*(= 24.8 cm *TL*). Fecundity of the smallest fish with ripe eggs in this work (24.1 cm *TL*) was about eight times lower than the fecundity of the largest fish (24.8 cm *TL*) reported by (Kwei, 1971). While this study determined partial individual fecundity (Bagenal, 1973), it is possible that Kwei's (1971) work determined the total number of eggs in the ovary.

Nevertheless, fecundity of the Ghana population appeared lower than that the 77,621 - 465,712 ova (mean= 285,704) determined by Techetach et al. (2010) for specimens (20.5 cm *TL* to 31.4 cm *TL*) in Moroccan waters. Furthermore, the fish in Ghana had a much lower relative fecundity (mean = 240 ± 10 eggs $g^{-1}$ body weight) than the Moroccan population (mean = 1,567 $g^{-1}$ body weight) (Techetach et al., 2010). From these observations, ecological conditions, fish size, maturity state of the ovary, and total or partial counts of eggs may explain differences in the fecundity of populations from different geographic zones.

Results of the present study indicated an overall 1:1 sex ratio for *S. colias* in the waters of Ghana, with equal proportions of males and females occurring each month except January-February and July-September. Collette & Nauen (1983), and Hernández & Ortega (2000) reported equal proportions of males and females monthly except during spawning periods. Cengiz (2012) however, found a significantly higher proportion of females in Turkish waters. The aberrant sex ratios in the Ghana population occurred in months overlapping with the spawning period from February to August. Changes in the behaviour of fish during the spawning season resulting in differential capture rates of males and females have similarly been reported for the barracuda, *Sphyraena argentina* (Halliday, 1969), and the West African shad *Ethmalosa fimbriata* (Blay & Eyeson, 1982).

In Ghana, results of this study revealed that, ripe *S. colias* were found from February to August, with peaks occurring in March-April and July-August. This was corroborated by the results on fluctuations in the gonad weight, gonadosomatic index (GSI), and proportion of ripe fish in monthly samples. Kwei (1971) also inferred from changes in the GSI that spawning occurred in July and August. The main spawning period of the fish (July-August) coincided with the major upwelling season in Ghana waters when water temperatures are below 25ºC, and food resources for the chub mackerel and other small pelagic fish (ca. *Sardinella aurita* and *Engraulis encrasicolus*) are abundant (Anang, 1979; Koranteng & McGlade, 2001; Mensah, 1966, 1981; Pezennec & Koranteng, 1998). In Northeast Atlantic waters, chub mackerels spawn when sea surface temperature drops to 15-20º C (Collette & Nauen, 1983). It is however unclear what may have accounted for the substantial spawning activity in March-April in Ghana when temperature was about 29°C. This may be attributed to increased gonad development of the fish in December-January when a minor upwelling is known to occur, resulting in food abundance.

The major spawning period in Ghana (July-August) compliments that for *S. colias* in the Azores (Carvalho et al., 2002) and Turkish waters (Cengiz, 2012). These, however, differ from the spawning periods off Portugal-January-April (Martins & Serrano-Gordo, 1984), February-March and May-June (Correia, 2016), Madeiran waters off Spain: January-April (Vasconcelos et al., 2012) and the Canary Islands (November-March, Lorenzo & Pajuelo, 1996). Techetach et al. (2010) found the species in Moroccan waters to spawn in December-March, and June-July, and in southern Africa, Baird (1977) reported that the fish spawns at least twice a year between June and September. Reports from various studies (Hernández & Ortega, 2000) indicated that spawning occurred in the first half of the year in the northern hemisphere, in the second half of the year in the southern hemisphere, and all-year-round in areas straddling the equator. Obviously, variations in the spawning period of the chub mackerel populations may have been determined by differences in ecological conditions at the different geographic locations.

In the current study, the presence of two distinct groups of ova in ripe ovaries with modal sizes at 0.4 mm and 0.8 mm was indicative of asynchronous egg development and batch spawning in *S. colias*, as observed for other iteroparous fish (Hernández & Ortega; 2000; Murua & Saborido-Rey, 2003). In the anchovy *Engraulis mordax* off California, availability of food in the environment was observed as essential for yolk accumulation and oocyte development (Hunter & Leong, 1981). This might explain the high proportion of females with ripe ovaries in March-April and June-August in Ghana when plankton production is high (Koranteng & McGlade, 2001; Kwei, 1971; Pezennec & Koranteng, 1998). However, Kwei's (1971) observation of a single crop of oocytes in ovaries with the ovum diameter distribution mode at 0.40-0.44 mm is exceptional, as it suggests that the ovaries he analysed contained predominantly immature eggs.

Cycles in the condition factor and fat index have been shown to compliment spawning cycles of fish as fat in the tissues is utilized to provide energy for spawning (Halliday, 1969; Hickling, 1945; Love, 1957). Although there was no clear seasonal variation in condition factor of *S. colias* in Ghana as also observed by Kwei (1971), the low values in June-August 2016 and April 2017 suggests that fat reserves were used for spawning and/or migration during these periods. Kwei (1971) found high fat index values from October to June prior to the spawning season, and low values from July to September during spawning of the fish. In the present study, the high condition factor and fat index in September which occurred during the major upwelling season was probably due to the incidence of high plankton production (Anang, 1979). Low fat reserves and condition index during spawning have similarly been reported in *S. scombrus* in the Northwest Atlantic (Grégoire et al., 1992), *S. colias* in the Canary Islands (Lorenzo & Pajuelo, 1996), the Adriatic Sea (Keč & Zorica, 2012b, 2013), and Madeira waters (Vasconcelos et al. 2012).

**Food and Feeding Habits**

Analysis of the stomach contents revealed wide fluctuations in the vacuity index and index of stomach fullness with no definite trends. This could be attributed to variations in the time from capture to stomach content examination, as samples were obtained from commercial catches. Detailed examination of stomach contents showed that the Ghana population consumed a vast array of organisms as also reported by Kwei (1971) and Wahbi et al. (2015) for the populations off Morocco.

In the present study, the food was dominated by fish, mainly anchovies *Engraulis encrasicolus*. However, previous research in Ghana (Kwei, 1971) showed no presence of anchovies in the stomach contents of chub mackerel. In South African waters the anchovy *E. capensis* was reported (Crawford & De

Villiers, 1984) as the primary food of the species, while Wahbi et al. (2015) found *E. encrasiclus* as the main food item of the chub mackerel in Morocco. (Alegre et al., 2015) found the related *S. japonicus* off the coast of Peru to feed on the anchovy *E. ringens* to some extent. Anchovies therefore seem to be a primary food item for chub mackerels in various geographic zones.

Furthermore, *S. colias* in Ghana waters fed on decapods (crabs and lobster zoea and megalopa larvae), as well as juvenile cephalopods, which occurred seasonally around the upwelling periods during this study. In the present study, lesser consumed prey items such as gastropods, bivalves, annelids and chaetognaths were also found in the diet of the samples examined by Kwei (1971) and Wahbi et al., (2015). In the Canary Current where coastal upwelling is particularly strong and permanent in the area between northern Mauritania and southern Morocco (Braham, Fréon, Laurec, Demarcq, & Bez, 2014; Thiaw et al., 2017), the species reportedly fed on zooplankton mainly copepods, decapods, appendicularians, euphausiids, stomatopod larvae, lamellibranchs and cladocerans ( Castro, 1993).

Ontogenic changes in diet of the species, dictated by distribution of juveniles and adults, have been reported in the Canary Islands (Castro, 1993), with juvenile fishes less than 13.5 cm *TL* selecting copepods, appendicularians, mysids and small sized fish larvae while the adults ate crustaceans and cephalopods (Martins, et al., 2013). The specimens encountered in this study excluded small sized fish (<13.45 cm), hence such ontogeny in food habits could not be established.

**Otolith Macrostructure and Age Structure of the Population**

The gross structure of the otolith of *S. colias* from Ghana was similar to that described by Vasconcelos et al. (2011), Keč and Zorica (2013) and Jurado-Ruzafa et al. (2017) for the fish in European waters, and the related *S. japonicus* (Kang, Jung, & Cha, 2015) in Korean waters. The positive relationship between the length of the fish and diameter /radius of the otolith has similarly been established for the species elsewhere (ICES, 2016); therefore otolith size can be used to predict fish length if the latter cannot be accurately determined, such as in fish with a missing caudal fin.

The hyaline-opaque pattern in the sagittal otoliths of the species from Ghanaian waters matched those interpreted as annual increments in chub mackerels elsewhere (Lorenzo & Pajuelo, 1996; Carvalho, Perrotta, & Isidro, 2002; VanderKooy, 2009; Vasconcelos et al., 2011; Keč & Zorica, 2013; Jurado-Ruzafa et al., 2017; ICES, 2016; Daley, 2018). Deposition of opaque bands over a shorter time period than hyaline bands (Vasconcelos et al., 2011) may explain the narrow widths of the former.

In Ghana, the low percentage of otoliths with a hyaline zone at the edge relative to those with an opaque edge in July-August indicates that this was the period of enhanced deposition of calcium carbonate in the otoliths (ICES, 2016). This period also coincided with the peak upwelling event in Ghanaian waters when temperatures are lowest, and there was increased spawning activity in the mackerel population. In North Atlantic waters, opaque bands are reportedly formed during spring-summer months, and the hyaline bands during autumn-winter months, in various populations (Carvalho et al., 2002; Hernández & Ortega, 2000; Velasco et al., 2011).

The nine age groups (0 to 8 years) identified from the otolith readings of *S. colias* was similar to observations in the Gulf of Cadiz (Velasco et al., 2011). Fish aged 0 to 7 years were found in the Canary Islands (Lorenzo & Pajuelo, 1996) and Mauritania (Jurado-Ruzafa et al., 2017), and 1 to 9 years off the coast of California (Quiñonez-Velázquez & Gluyas-Millán, 1997). Populations with narrower age ranges, e.g. 0-5 years and 0-4 years respectively, have been reported in Turkey (Cengiz, 2012) and the Madeira Island (Vasconcelos et al., 2011). Specimens aged 13 years and 20 years have also been reported elsewhere (Carvalho et al., 2002; Hernández & Ortega, 2000) (Navarro et al., 2012). Presumably, differences in ecological conditions, exploitation levels, sizes of fish specimens examined and genetic variability accounted for the differences in the maximum age determined for the species from the various locations.

Attainment of a mean length of 19.6 cm *TL* in the Ghana population during the first year of life is similar to Martin's (2007) estimate of 20 cm *TL* for the species in Portuguese waters. The mean length of the Ghana specimens during the first year of life was about 46 % of its asymptotic length ($L_\infty$), and within the range (35.4 - 62.6 %) reported for other *S. colias* populations (Hernández & Ortega, 2000; Carvalho et al., 2002; Vasconcelos et al., 2011). The large overlaps in the lengths of fish aged 2 to 6 years may be as a result of slow growth in these groups and the younger fish growing faster to catch up with the lengths of older fish. This might also explain the occurrence of diffuse and unreadable growth increments in the otoliths of older fish (Carvalho et al., 2002; Vasconcelos et al., 2011; Velasco et al., 2011).

Information from the otolith analysis indicated that the fish reached its maturity length ($L_{m50}$= 25.6 cm *TL*) when they are 2 to 3 years old, which compliments the maturity age assessed for the species in the coastal waters of Mauritania (Hernández & Ortega, 2000; Jurado-Ruzafa et al., 2017).

**Growth Characteristics**

Results of the present study show that growth parameters of *S. colias* were $L_{\infty}$= 42.5 cm *TL* and *K*= 0.28 $yr^{-1}$. Amponsah et al. (2016) estimated $L_{\infty}$= 26.8 cm *TL* and *K*= 1.30 $yr^{-1}$ for this species based on limited data from the coastal waters of Ghana during a six-month period, and this could possibly explain the difference in estimates of the growth parameters from these two studies. In Northwest Africa, the species' growth parameters have been reported as $L_{\infty}$ = 48.7 cm *TL* and *K* = 0.20 $yr^{-1}$ in Mauritania-Senegal waters (FAO 1983), $L_{\infty}$ = 51.2 cm *TL* and *K* = 0.20 $yr^{-1}$ off Morocco (Lorenzo & Pajuelo, 1996 a), $L_{\infty}$ = 52.4 cm *TL* and *K* = 0.19 $yr^{-1}$ off the Canary Islands (Lorenzo & Pajuelo, 1996 b), and $L_{\infty}$= 48.4 cm *TL* and *K*= 0.247 $yr^{-1}$ in Mauritania waters (Jurado-Ruzafa et al. (2017). The species in South Africa (Baird, 1977; van der Elst & Adkin, 1991, quoted in Hernandez and Ortega, 2000) have been reported to have growth parameters of $L_{\infty}$= 68 cm *TL* and *K*= 0.207 $yr^{-1}$. It is apparent form these reports that the growth rate for the populations in Ghana is not very different from that of the species in the northwest and southwest coasts of Africa. However, the wide variations in the asymptotic lengths may be due to differences in oceanographic conditions in these areas and the level of fishing activity. Similar growth constants and varying asymptotic lengths have also been reported for *S. colias* in European waters (Cengiz, 2012; Keč & Zorica, 2013; Vasconcelos et al., 2011).

Comparison of the growth parameters of the *S. colias* population in Ghana with those of the fish in the northwest Atlantic region, where $L_\infty$= 33.56 cm *TL* and $K$= 1.75 $yr^{-1}$ (Daley, 2018), indicates that the former grew at a slower rate and attained a longer asymptotic length than the latter population. The maturity-length ratio ($L_{m50}/L_\infty$= 0.60) also indicates that the fish in Ghana matured at a larger size relative to its asymptotic length. This is similar to Iles' (1970) description of lake tilapias with maturity-length ratios ~0.70 as having normal growth.

The maximum age of 8 years and longevity ($t_{max}$) of 10 years determined for the fish in Ghana waters is similar to the age range (8-10 years) described for long-lived chub mackerel (Collette et al., 2011; quoted in Jurado-Ruzafa, 2017); however, specimens aged 20 years have been encountered in Northwest Africa (Navarro et al., 2012). It could be deduced from the low value of the growth constant ($K$ = 0.28 $yr^{-1}$), relatively long asymptotic length ($L_\infty$= 42.5 cm *TL*), long life span ($t_{max}$= 10 years) and high maturity-length ratio ($L_{m50}/L_\infty$= 0.60) that the species in Ghana possesses characteristics of a *K*-strategist (Gunderson, 1980; Pianka, 1970).

The computed value of the growth performance index for the Ghana fish ($ø'$ = 2.70) was within the range ($ø'$ = 2.54 - 2.80) reported for *S. colias* in Northwest Africa (Lorenzo & Pajuelo, 1996; Jurado-Ruzafa et al., 2017), the Canary Islands (Lorenzo & Pajuelo (1996), and parts of Europe (Keč & Zorica, 2013; Vasconcelos, et al. 2011). This is in conformity with Pauly & Munro's (1984) assessment of intraspecific and intrageneric similarity of the growth performance index, and thus suggests reliability of the growth parameter estimates for *S. colias* in Ghana.

**Mortality Parameters and Exploitation Rate**

Estimates of the mortality parameters of *S. colias* in the coastal waters of Ghana show that natural mortality ($M$ = 0.70 $yr^{-1}$) contributed more to the total mortality ($Z$ = 1.22 $yr^{-1}$) than fishing mortality ($F$= 0.52 $yr^{-1}$). Chub mackerels are known to occasionally assume a demersal habit (Hernández & Ortega, 2000; Kwei, 1971; Sousa et al. 2005; quoted in Martins et al., 2013); this change in behaviour of the stock could render the fish less vulnerable to purse seine fishing, and thus limit mortality to demersal predators. Although mortality due to fishing would be expected to increase during the pelagic phase, the fish would also be exposed to high predation levels by birds and larger predatory species like tunas, billfishes and cetaceans, which would result in an overall increase in natural mortality.

The current exploitation rate ($E_{curr}$ = 0.43) was slightly higher than the optimum exploitation rate ($E_{opt}$ = 0.39) from the relative yield-per-recruit ($Y'/R$) and biomass-per-recruit ($B'/R$) analysis (Froese et al., 2005; Gayanilo et al., 2005) which suggests that *S. colias* may be experiencing overexploitation in Ghana waters, similar to the assessment for the sardinellas (*Sardinella aurita and S. maderensis*) (Lazar et al., 2017, 2018, 2016).

The higher values of the mortality parameters ($M$ = 2.10 $yr^{-1}$, $F$ = 2.92 $yr^{-1}$, $Z$ = 5.02 $yr^{-1}$) and exploitation rate ($E$ = 0.58) estimated by Amponsah et al. (2016) for *S. colias* in Ghana could be attributed to the short study period and small samples analysed. It is therefore possible that these parameters were overestimated in that study.

In Europe, mortality parameters: $M$ = 0.352 $yr^{-1}$, $F$ = 0.56 $yr^{-1}$, $Z$ = 0.91 $yr^{-1}$ were determined for the species in Turkish waters (Cengiz, 2012), and $M$

= 0.352 $yr^{-1}$, $F$ = 0.56 $yr^{-1}$, $Z$ = 0.91 $yr^{-1}$ were estimated the fish in the Adriatic Sea (Keč & Zorica, 2013). The higher fishing than natural mortality parameters, and $E$ = 0.61 for these populations is suggestive of active exploitation of the fish which constitutes a major resource in these areas.

**Nutrient Content of Fish Muscle**

Results of the present study showed an inverse relationship between moisture and fat content in the chub mackerel. This is similar to what has been reported in marine forage species (Boran & Karaçam, 2011; Murray & Burt, 2001; Spitz et al., 2010). Fat content was low during the spawning periods. The high values of tissue fat in October-December of 2016 also coincided with the period of high visceral fat and condition factor of the species. Similar results on seasonality of fat and moisture content have been reported for *S. japonicus* from Korean waters (Shim et al., 2017). October to December was also the period the species preyed heavily on fish, mainly anchovies which are fatty, and this may have boosted the fat reserves in in the chub mackerel prior to the next spawning activity. Fat levels have been documented to be highest about three months following a major spawning activity in fish that undertake extensive spawning migrations (Hernández & Ortega, 2000; Huss, 1995; Keč & Zorica, 2012; Murray & Burt, 2001), similar to the results obtained in this study.

The presence of crude protein levels above 60 % in the dry tissue of *S. colias* suggests that it is suitable as a source of rich protein for humans (Miles & Chapman, 2012). With the exception of January-March 2016, carbohydrate was low and comprised less than 3% of the nutrient composition of the fish.

This is similar to Murray and Burt's (2001) observation that concentration of this nutrient is of little value in fish meal.

It is apparent from these observations that protein and fat were the most important nutrients in *S. colias* as they accounted for greater than 80% of the nutrient content.

**Status of *Scomber colias* in the "Saiko" Fishery**

In recent years, though landings of small pelagic fish have declined (Lazar, Yankson, Blay, Ofori-Danson, Markwei, Agbogah, Bannerman, Sotor, Yamoah, et al., 2017; Lazar et al., 2018, 2016; MOFAD, 2018), fishing effort continues to increase, with an upsurge in illegal fishing practices which include light fishing, use of poisons, dynamite fishing, and unapproved nets (multifilament nets with <2.5 cm stretched mesh, and monofilament nets). Such practices tend to degrade the fishery (Castro et al., 2017; Hen Mpoano, 2017; Nunoo et al., 2009). There have also been reports of foreign trawlers modifying their bottom gears to exploit small pelagics because of the high demand for fish and their quest to enhance profits (pers. comm.).

Assessment of samples from illegally harvested fish, popularly called "saiko fish" in Ghana showed that the chub mackerel constituted a small fraction (i.e. 2.30% by number, and 3.48% by weight) of the fish from "saiko" landings. The mean total length of the fish (19.23 ± 0.39 cm *TL*) indicated that most specimens landed were in their first year of growth and were therefore juveniles.

The 84 species encountered in the "saiko" bycatch was very high compared to the 15 and 10 species reported from Elmina and Apam landed samples, respectively (Nunoo et al., 2009). However, the latter study was based on samples obtained in a single day. The species found included small pelagic, semi-pelagic, and demersal species. In addition, 4 small pelagics species (*Decapterus rhoncus*, *D. punctatus*, *Trachurus trecae*, and *Sardinella aurita*. made up 43.26 % of the total number, and most of the fish encountered were juveniles.

Continued exploitation and transhipment of small pelagics by trawlers would ultimately have a negative effect on the ecosystem due to possible trophic cascades. Rare species with unknown exploitation status e.g. *Psenes sp*. (Nomeidae), *Erythrocles monodi* (Emmelichthyidae) and *Apogon affinis* (Apogonidae) are also at risk, as they were present in the "saiko" samples and may point to trawlers possibly fishing on previously unknown ground.

# CHAPTER SIX

# SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This study was conducted over a period of 18 months and sought to assess the aspects of biology of Atlantic chub mackerel currently exploited in Ghanaian coastal waters to help inform research, management and policy in Ghana's fisheries industry. The parameters studied sought to determine the size distributions (based on length and weight), reproductive characteristics, age determination using otoliths, as well as length-based estimates of growth, mortality and levels of exploitation to establish the current status of the species in the coastal waters of Ghana. A combination of field work involving collection of samples landed from the artisanal fishery across the Central and Western coastlines of Ghana as well as laboratory methods were employed to obtain data which was used to derive estimates of the various parameters. This study was the first of its kind that used otoliths to successfully age *Scomber colias* in Ghanaian waters. The status of the species in commercially sold trawl bycatch was also investigated.

## Summary of Key Findings

The results of the study indicate that two main cohorts of fish in the modal classes of 17.0-18.0 cm *TL* and 25.0-25.9 cm *TL* are the most exploited in Ghanaian waters. The overall length-weight relationship shows that adult fish in Ghanaian waters undergo isometric growth, while all sizes pooled together appear to show positive allometry ($BW = 0.0029TL^{3.37}$). Body weight ranged from 19.95 - 695 g for all freshly landed samples. Condition factor fluctuated during the sampling period, with similar values for male sand females. The overall mean condition factor for male and female fish was 0.93

± 0.03 and 0.94 ± 0.00 respectively, with no significant differences overall for both sexes. Mean visceral fat index was high for the fish between September and December 2016, with females having higher values than males. Overall, males and females occurred in equal proportions, although there were some months during and post-spawning when significant differences in population size were recorded for the two sexes.

Fish of indeterminate sex made up 21.7% of the fish sampled from fresh landings and were sexually immature. Absolute fecundity ranged from 10,220 eggs in fish measuring 24.1 cm *TL*, and weighing 144.32 g to 155,791 eggs in fish measuring 31.7 cm *TL*, body weight 298.32 g. The mean absolute fecundity was determined to be 48, 238 ± 2324 eggs. Ovum diameter distribution ranged from 0.1-1.1 mm, with modes at 0.4, 0.7 and 0.8 mm. The species attains 50% maturity at 25.60 cm *TL*, with a long spawning period (February to September). There was increased spawning activity in April and July-August.

The species fed on a variety of animals including fish, decapods, cephalopods, bivalves, gastropods, annelids, stomatopods larvae, copepods, amphipods and chaetognaths. Values of the Index of Relative Importance of food items from stomach content analysis indicated that fish (mostly anchovies) were the most preferred food item, followed by decapods and cephalopods. This categorises the fish as an opportunistic predator that tends to piscivory. Ageing of otoliths show the highest number of otoliths with opaque margins occurred in August which was validated by marginal increment width analysis. The growth ring is laid down in August. Age groups of fish from otolith readings indicate that fish from age zero to 8 years are exploited in Ghanaian coastal waters. While shifts in modal length of fish in general were irregular, a smaller sized cohort of fish (mostly of indeterminate sex) and modal class 16.0-16.9 cm *TL* was observed to enter the fishery in August 2016.

The growth of the population occurring in Ghanaian coastal waters was described by the von Bertalanffy equation $L_t$=42.5{1-exp[-0.28(t+0.54)]}. Longevity was estimated at 10 years, and growth performance index ($\o'$) to be 2.70. The total (*Z*), natural (*M*) and fishing (*F*) mortality rates were estimated to be 1.22 $yr^{-1}$, 0.70 $yr^{-1}$ and 0.52 $yr^{-1}$ respectively. The species appears to be undergoing moderate overexploitation in Ghanaian coastal waters. The mean length at first capture $L_{c50}$ was extrapolated at 24.1 cm *TL*. Recruitment took place all year round, with two peaks in April and August. The exploitation rate was calculated to be 0.43.

Dry *Scomber colias* meal had high values of protein and fat (over 80%). Protein made up over 60% of the nutrient composition across the study period. An inverse relationship was observed between fat and moisture levels. Fat levels peaked between from October to December 2016, and were low during spawning periods. Values of fibre and ash were very low (less than 7%).

The species made up 2.30% by number in the trawl bycatch sampled, and 3.48% by weight. Length ranged from 13.4-26.8 cm *TL* and body weight from 71.24-204.30 g. These fish were sexually immature.

**Conclusions**

Two main cohorts of the chub mackerel (*Scomber colias)* were exploited by artisanal fishermen. The smaller cohort was made up of immature juveniles possibly caught with undersize mesh nets. Growth in the adult fish was isometric, and that of juveniles allometric. Overall, the sex ratio was 1:1; but differed during months of breeding activity. The length at which 50 % of the fish matured was 25.6 cm *TL*. Absolute fecundity ranged from 10,220 to 155,791 eggs in fish measuring 24.1 cm *TL*, and 31.7 cm *TL* with a mean of 48, 668 ± 2410 eggs. Spawning occurred between February and September, with peaks in April and July-August. Fish, mainly anchovies were the preferred food of the fish.

The fish had a slow growth rate (*K*) of 0.28 $yr^{-1}$, asymptotic length ($L_\infty$) of 42.5 cm *TL* and longevity of 10 years. The maximum age determined from otolith readings was 8 years, and maturity age was between 2 to 3 years when the fish attains a length of 25.6 cm *TL*. The length at first capture (24.1 cm *TL*) was lower than the length at 50 % maturity. Natural mortality contributed more to the total mortality of the fish than fishing mortality. From the relative yield-per-recruit and relative biomass-per-recruit analysis, it would appear that the species is being overexploited but it was lowly represented in landings of the illegal "saiko" activity.

In summary, the results of this study indicated that fishermen exploit two cohorts of the species. It has a protracted spawning period but with peak activity in April and July to August. Sagittal otoliths can be used to successfully age the species in Ghana, which indicate that the exploited groups of fish range from 0-8 years. The species is highly proteinaceous and has a high fat content. It does not contribute significantly to the composition of trawl bycatch.

## Recommendations

Given the fact that the artisanal industry currently exploits two cohorts of the species, one of which was undersized, it is imperative to implement regulations on minimum mesh sizes for the pursing nets which target chub mackerel to allow for the juvenile cohort to spawn at least once before they are harvested.

Stringent fines and punitive measures should be enforced when people are found to flout laws regarding minimum mesh size, the use of monofilament nets, light fishing (in combination with DDT, dynamite, carbide, petrol, omo and gari) and other destructive fishing practices.

The management measures aimed at sustainable exploitation of the species should also take into consideration the role of the major prey item (fish; especially anchovies) and predators in the food web to better mitigate any trophic cascades that may occur due to the overexploitation of chub mackerel. This calls for the need of an ecosystem-based approach to the management of the species.

The results of this study point to overexploitation of the species, and hence the decision to implement a seasonal closure will yield the best results if carried out during the major spawning period (July-August) as part of efforts to revive the small pelagic fisheries of Ghana.

Alternative livelihood training and rewards for good fishing practices should be initiated to encourage sustainable exploitation of the species as these will help to reduce the current intense fishing pressure on the stocks.

Information on the Maximum Sustainable Yield (MSY) for the species and other small pelagics should be obtained in order to set targets of fishing effort and quotas for sustainable exploitation of the stocks.

Results from assessments such as this study should be disseminated to fishermen and other stakeholders such as middlemen, processors to help them appreciate the need for the sustainable exploitation of the small pelagic stocks in Ghana's coastal waters. It will also broaden their knowledge on the biology of the species they exploit.

**Suggestions for Further Research**

Although the mechanism behind the spawning event in April could not be clearly established from this study, it is recommended that research be carried out into the reproductive physiology as well as the prevailing physical oceanographic factors during the minor spawning period to better explain the phenomenon.

The molecular characterisation and stable isotope analysis (using otoliths) of Atlantic chub mackerel in Ghana should be done to determine if there is a single stock or more in Ghanaian waters. This may give information on whether there may be two or more genetically distinct stocks that have may have overlapping distributions.

It is also recommended that further research be carried out into the early life history of the fish to determine otolith microstructure, spawning periodicity, dietary habits of larvae and map out nursery grounds as well as migratory routes. This will augment the information gathered so far on the species in Ghanaian waters which has focused on juvenile and adult fish from commercial catches.

Continuous research into the biology and stock status of the species should also be carried out to generate a dataset that can be used to identify changes in population dynamics and ecology over time, and also allow for time-series analysis to aid in the sustainable exploitation and management of the stocks. This can also be extended to other species of commercial and ecological interest to help manage Ghana's marine fishery as a whole.

Due to the effect of external environmental phenomena (e.g. upwelling) on the species, future studies should also take into consideration aspects of fisheries oceanography for more comprehensive inferences to be made.

For sample collection, it is recommended that fisheries independent surveys be used to obtain specimens to reduce the size bias associated with sampling from commercial landings. It will also enable fish specimens to be obtained in good condition with minimal degradation of internal organs or a decline in quality. The use of imaging techniques to estimate fecundity and oocyte diameter will help give accurate measurements and reduce the time spent on laborious manual methods.

# REFERENCES


Abobi, S. M., Mildenberger, T. K., Kolding, J., & Wolff, M. (2019). Assessing the exploitation status of main fisheries resources in Ghana's reservoirs based on reconstructed catches and a length-based bootstrapping stock assessment method. *Lake and Reservoir Management*, 1–20. https://doi.org/10.1080/10402381.2019.1616340

Afoakwah, R., Osei, D. A. N., Bonsu, M., & Effah, E. (2018). *A Guide on Illegal Fishing Activities in Ghana. USAID/Ghana Sustainable Fisheries Management Project*. Narragansett. Retrieved from https://www.crc.uri.edu/download/GH2014_SCI048_UCC_FIN508.pdf

Aggrey-Fynn, J. (2009). Distribution and growth of grey triggerfish, *Balistes capriscus* (Family: Balistidae), in Western Gulf of Guinea. *West African Journal of Applied Ecology*, *15*. https://doi.org/10.4314/wajae.v15i1.49421

Aggrey-Fynn, J., Fynn-Korsah, S., & Appiah, N. (2013). Length-Weight Relationships and Food Preference of Two Coastal Marine Fishes, *Galeoides decadactylus* (Polynemidae) and *Sphyraena sphyraena* (Sphyraenidae) off Cape Coast, Ghana. *West African Journal of Applied Ecology*, *21*(1), 87–96.

AHA. (2015). Polyunsaturated fat. Retrieved October 28, 2015, from https://www.heart.org/en/healthy-living/healthy-eating/eat-smart/fats/polyunsaturated-fats

Akyeampong, E. (2007). Indigenous Knowledge and Maritime Fishing in West Africa: The Case of Ghana. In *Indigenous Knowledge Systems and Sustainable Development:Relevance for Africa* (pp. 173–182). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.572.7449&rep=rep1&type=pdf

Akyeampong, S., Amador, K., Nkrumah, B., & et.al. (2013). *Fisheries Scientific Survey Division Report on the 2013 Ghana Marine Canoe Frame Survey*. Retrieved from http://rhody.crc.uri.edu/gfa/wp-content/uploads/sites/10/2018/04/Ghana-Marine-Canoe-Frame-Survey-2013.pdf

Alegre, A., Bertrand, A., Espino, M., Espinoza, P., Dioses, T., Ñiquen, M., … Ménard, F. (2015). Diet diversity of jack and chub mackerels and ecosystem changes in the northern Humboldt Current system: A long-term study. *Progress in Oceanography*, *137*, 299–313. https://doi.org/10.1016/j.pocean.2015.07.010

Alhassan, E. H., & Armah, A. K. (2015). Population Dynamics of the African River Prawn, *Macrobrachium vollenhovenii*, in Dawhenya Impoundment. *Turkish Journal of Fisheries and Aquatic Sciences*, *11*, 113–119. https://doi.org/10.4194/trjfas.2010.0115

Amponsah, S. K. K., Ofori-Danson, P. K., & Nunoo, F. K. E. (2016). Fishing regime, growth, mortality and exploitation rates of *Scomber Japonicus* ( Houttuyn, 1782 ) from catches landed along the eastern coastline of Ghana. *International Journal of Fisheries and Aquatic Sciences*, *1*(1), 5–10.

Anang, E. R. (1979). The seasonal cycle of the phytoplankton in the coastal waters of Ghana. *Hydrobiologica*, *62*(1), 33–45. https://doi.org/10.1007/BF00012560

AOAC. (2016). *Official Methods for Analysis of the Association of Official Analytical Chemists*. (G. W. Latimer, Ed.) (20th ed.). Arlington: AOAC.

Armah, A. K., & Amlalo, D. S. (1998). *Coastal zone profile of Ghana*. Accra: Ministry of Environment, Science and Technology.

Ashitey, E., & Archibald, D. (2019). *Ghana Fish and Seafood Report*. Accra. Retrieved from https://gain.fas.usda.gov/Recent GAIN Publications/ Fish and Seafood Report_Accra_Ghana_3-8-2019.pdf

Atta-Mills, J., Alder, J., & Sumaila, U. R. (2004). The decline of a regional fishing nation: The case of Ghana and West Africa. *Natural Resources Forum*, *28*, 13–21. https://doi.org/10.1111/j.0165-0203.2004.00068.x

Bagenal, T. B. (1973). Fish fecundity and its relations with stock and recruitment. *ICES Rapp. Proc.-Verb.*, *164*, 186–198.

Bagenal, T. B., & Tesch, F. W. (1978). Age and growth. In T. B. Bagenal (Ed.), *Methods for assessment of fish production in freshwaters. IBP Handbook No.3.* (3rd ed., pp. 101–136). Oxford: Blackwell Science Publications.

Baird, D. (1977). Age, growth and reproduction of the mackerel *Scomber japonicus* in South African waters (Pisces: Scombridae). *Zool. Afri.*, *12*(2), 347–362.

Bank of Ghana. (2008). *The Fishing Sub-Sector and Ghana's Economy*. Accra, Ghana. Retrieved from http://www.bog.gov.gh/privatecontent /Research/Sector Studies/fisheries_completerpdf.pdf

Blay, J., Awittor, W. K., & Agbeko, D. (2006). Seasonal Variation in Food Preference and Feeding Ecology of Two Juvenile Marine Fishes, *Pseudotolithus senegalensis* (Sciaenidae) and *Brachydeuterus auritus* (Haemulidae) off Cape Coast, Ghana. *West Africa Journal of Applied Ecology*, *9*. Retrieved from www.wajae.org

Blay, J., & Eyeson, K. N. (1982). Observations on the reproductive biology of the shad, *Ethmalosa fimbriata* (Bowdich) in the coastal waters of Cape Coast, Ghana. *Journal of Fish Biology*, *21*, 485–496.

Boran, G., & Karaçam, H. (2011). Seasonal Changes in Proximate Composition of Some Fish Species from the Black Sea. *Turkish Journal of Fisheries and Aquatic Sciences*, *05*, 1–5. https://doi.org/10. 4194/trjfas.2011.0101

Braham, C. B., Fréon, P., Laurec, A., Demarcq, H., & Bez, N. (2014). New insights in the spatial dynamics of sardinella stocks off Mauritania (North-West Africa) based on logbook data analysis. *Fisheries Research*, *154*, 195–204. https://doi.org/10.1016/j.fishres.2014.02.020

Cadima, E. L. (2003). *Fish stock assessment manual* (FAO Fisheries Technical Paper No. 393). *FAO Fisheries Technical Paper* (Vol. 393). Rome. https://doi.org/10.1016/0165-7836(86)90030-5

Carpenter, K. E., & De Angelis, N. (Eds.). (2014). *The living marine resources of the Eastern Central Atlantic. Volume 1: Introduction, crustaceans, chitons and cephalopods*. *FAO Species Identification*

*Guide for Fishery Purposes*. Rome: FAO.

Carpenter, K. E., & De Angelis, N. (Eds.). (2016a). *The living marine resources of the Eastern Central Atlantic. Volume 2: Bivalves, gastropods, hagfishes, sharks, batoid fishes and chimaeras*. *FAO Species Identification Guide for Fishery Purposes*. Rome: FAO.

Carpenter, K. E., & De Angelis, N. (Eds.). (2016b). *The living marine resources of the Eastern Central Atlantic. Volume 3: Bony fishes part 1 (Elopiformes to Scorpaeniformes)*. *FAO Species Identification Guide for Fishery Purposes* (Vol. 3). Rome: FAO.

Carpenter, K. E., & De Angelis, N. (Eds.). (2016c). *The living marine resources of the Eastern Central Atlantic. Volume 4: Bony fishes part 2 (Perciformes to Tetradontiformes) and sea turtles*. *FAO Species Identification Guide for Fishery Purposes*. Rome: FAO.

Carvalho, N., Perrotta, R. G. G., & Isidro, E. (2002). Age, growth and maturity in chub mackerel (*Scomber japonicus* Houttuyn, 1782) from the Azores. *Arquipélago Ciências Biológicas e Marinhas*, *19*, 93–99. https://doi.org/10.4194/1303-2712-v12_4_08

Castro, J. J. (1993). Feeding ecology of chub mackerel *Scomber japonicus* in the Canary islands area. *South African Journal of Marine Science*, *13*(1), 323–328. https://doi.org/10.2989/025776193784287400

Castro, K., Skrobe, L., Asare, C., & Kankam, S. (2017). *Synthesis of Scientific and Local Knowledge on Sardinella species in Ghana.The USAID/Ghana Sustainable Fisheries Management Project (SFMP)*. Narragansett. Retrieved from http://www.crc.uri.edu/download/ GH2014_ACT090_HM_URI_FIN508.pdf

Catanese, G., Manchado, M., & Infante, C. (2010). Evolutionary relatedness of mackerels of the genus Scomber based on complete mitochondrial genomes: Strong support to the recognition of Atlantic *Scomber colias* and Pacific *Scomber japonicus* as distinct species. *Gene*, *452*, 35–43. https://doi.org/10.1016/j.gene.2009.12.004

Celik, M. (2008). Seasonal changes in the proximate chemical compositions and fatty acids of chub mackerel (*Scomber japonicus*) and horse mackerel (*Trachurus trachurus*) from the north eastern Mediterranean Sea. *International Journal of Food Science &Technology*, *43*, 933–938.

Cengiz, Ö. (2012). Age, Growth, Mortality and Reproduction of the Chub Mackerel (*Scomber japonicus* Houttuyn, 1782) from Saros Bay (Northern Aegean Sea, Turkey). *Turkish Journal of Fisheries and Aquatic Sciences*, *12*, 799–809. https://doi.org/10.4194/1303-2712-v12_4_08

Coastal Resources Center. (2016). *Annual Progress Report, October 1, 2015 – September 30, 2016. The USAID/Ghana Sustainable Fisheries Management Project (SFMP)*. Narragansett, RI.

Collette, B., Amorim, A. F., Boustany, A., Carpenter, K. E., de Oliveira Leite Jr, N., Di Natale, A., … Pires Ferreira Travassos, P. E. (2011). *Scomber colias*. https://doi.org/https://dx.doi.org/10.2305/IUCN.UK.2011-2.RLTS.T170357A6767497.en

Collette, B. B., & Nauen, C. E. (1983). *FAO Species Catalogue. Vol . 2. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date.* (FAO

Fish.Synp. No. FIR/S125). *FAO Fisheries Synopsis* (Vol. 2). Rome: FAO. https://doi.org/FAO Fish. Synop. 125(2)

Correia, C. S. da S. (2016). *Study of Atlantic chub mackerel's (Scomber colias, Gmelin, 1789) landings evolution in Portugal: importance for purse seine fleet.* UNIVERSIDADE DE ÉVORA. Retrieved from https://dspace.uevora.pt/rdpc/bitstream/10174/19949/1/Correia%282016%29Study of Atlantic chub mackerels landings evolution in portugal _importance for purse seine fleet.pdf

Crawford, R. J. M., & De Villiers, G. (1984). Chub mackerel *Scomber japonicus* in the South- East Atlantic – its seasonal distribution and evidence of a powerful 1977 year-class. *South African Journal of Marine Science*, *2*(1), 49–61. https://doi.org/10.2989/02577618409504358

Cury, P., Bakun, A., Crawford, R. J. M., Jarre, A., Quiñones, R. A., Shannon, L. J., & Verheye, H. M. (2000). Small pelagics in upwelling systems : patterns of interaction and structural changes in "wasp-waist" ecosystems. *ICES Journal of Marine Science*, *57*, 603–618. https://doi.org/10.1006/jmsc.2000.0712

Daley, T. T. (2018). *Growth and Reproduction of Atlantic Chub Mackerel (Scomber colias) in the Northwest Atlantic*. *Master's thesis*. University of Southern Mississippi. Retrieved from https://aquila.usm.edu/masters_theses/364/

Daley, T. T., & Leaf, R. T. (2019). Age and growth of Atlantic chub mackerel ( *Scomber colias* ) in the Northwest Atlantic. *Journal of Northwest Atlantic Fishery Science*, *50*(Table 2), 1–12. https://doi.org/10.2960/j.

v50.m717

Daniels, A., Gutiérrez, M., Fanjul, G., Guereña, A., Matheson, I., & Watkins, K. (2016). *Western Africa's missing fish: The impacts of illegal, unreported, and unregulated fishing and under-reporting catches by foreign fleets*. *Overseas Development Institute Report*. London. Retrieved from https://www.odi.org/sites/odi.org.uk/files/resource-documents/10665.pdf

Dickerson, T. L., Macewicz, B. J., & Hunter, J. R. (1992). Spawning frequency and batch fecundity of chub mackerel, *Scomber japonicus*, during 1985. *CalCOFI Rep.*, *33*, 130–140.

Dovlo, E. K., Amador, K., & Nkrumah, B. (2016). *Report on the 2016 Ghana Marine Canoe Frame Survey*. Accra.

Doyi, B. A. (1984). *Catalogue of small-scale fishing gear of Ghana* (CECAF/ECAF Series No. 84/31). Rome.

Durand, M.-H., Cury, P., Mendelssohn, R., Roy, C., Bakun, A., & Pauly, D. (Eds.). (1998). *Global versus Local Changes in Upwelling Systems*. *Local And Global Change in Upwelling Systems*. Paris: Orstom Éditions.

FAO. (2013). FiSAT II. FAO-ICLARM Stock Assessment Tools. Rome: FAO. Retrieved from http://www.fao.org/fishery/topic/16072/en

FAO. (2016). Fishery and Aquaculture Country Profiles. Ghana. Retrieved November 7, 2017, from http://www.fao.org/fishery/facp/GHA/en

FAO. (2018). *The State of the World Fisheries and Aquaculture 2018-Meeting the sustainable development goals*. Rome: FAO. Retrieved from http://www.fao.org/3/I9540EN/i9540en.pdf

Froese, R. (2006). Cube law, condition factor and weight-length relationships: History, meta-analysis and recommendations. *Journal of Applied Ichthyology*, *22*(4), 241–253. https://doi.org/10.1111/j.1439-0426.2006.00805.x

Froese, R., Palomares, M. L., & Pauly, D. (2005). Estimation of life-history key facts. Retrieved July 23, 2018, from http://www.fishbase.org/manual/keyfacts.htm

Gallucci, V. F., Amjoun, B., Hedgepeth, J., & Lai, H. L. (1996). Size-Based Methods of Stock Assessment of Small-Scale Fisheries. In V. F. Gallucci, S. B. Saila, D. J. Gustafson, & B. J. Rotschild (Eds.), *Stock assessment: quantative methods and applications for small scale fisheries* (pp. 9–81). Boca Raton: CRC Press, Inc.

Gayanilo, F. C. J., Sparre, P., & Pauly, D. (2005). *FAO-ICLARM stock assessment tools (FiSAT) user's manual* (FAO Comp. Info. Ser. (Fisheries) No. 8). Rome.

Gluyas-Millan, M. G., Castonguay, M., & Quinonez-Velazquez, C. (1998). Growth of juvenile Pacific mackerel, *Scomber japonicus* in the Gulf of California. *Scientia Marina*, *62*(3), 225–231. https://doi.org/10.2989/025776193784287400

GPHA. (2016). Tema Fishing Harbour. Retrieved June 8, 2018, from http://www.ghanaports.gov.gh/page/17/Fishing-Harbour

Grégoire, F., Dionne, H., Lévesque, C., Lamontagne, M., Box, P. O., & Mer, D. (1992). Fat content of Atlantic mackerel ( *Scomber scombrus* L .) in 1991 and 1992 Canadian lndustry Report of Fisheries and Aquatic Sciences 220.

Gulland, J. A. (1971). *The fish resources of the oceans*. Surrey, U.K.: FAO/Fishing News Books, Surrey.

Gunderson, D. R. (1980). Using r-K selection theory to predict natural mortality. *Canadian Journal of Fisheries and Aquatic Science*, *37*, 2266–2271.

Halliday, R. G. (1969). Reproduction and feeding of Argentina sphyraena (Isospondyli) in the Clyde Sea Area. *Journal of the Marine Biological Association, U.K.*, *49*(3), 785–803.

Hart, R. K., Calver, M. C., & Dickman, C. R. (2002). The index of relative importance: An alternative approach to reducing bias in descriptive studies of animal diets. *Wildlife Research*, *29*(5), 415–421. https://doi.org/10.1071/WR02009

Hen Mpoano. (2017). Illegal , Unreported and Unregulated ( IUU ) Fishing The "Saiko" Story. *Issue Brief*. Hen Mpoano. Retrieved from http://henmpoano.org/wp-content/uploads/2017/02/Hen-Mpoano_IUU-ISSUE-BRIEF.pdf

Hernández, J. J. C., & Ortega, A. T. S. (2000). Synopsis of Biological Data on The Chub Mackerel (*Scomber japonicus* Houttuyn, 1782). *FAO Fishery Synopsis*, *39*(157), 1–77.

Hickling, C. . F. (1945). The seasonal cycle in the Cornish pilchard, *Sardina pilchardus* (Walbaum). *J. Mar. Biiol. Ass.*, *26*, 115–138.

Holden, M. J., & Raitt, D. F. S. (1974). *Manual of Fisheries Science Part 2-Methods of resource investigation and their application*. (M. J. Holden & D. F. S. Raitt, Eds.). Rome.

Hunter, J. R., & Leong, R. (1981). The spawning ernergetics of female northern anchovy, *Engraulis mordax*. *Fish. Bull.*, *79*(2), 215–230.

Huss, H. H. (1995). *Quality and quality changes in fresh fish* (FAO Fisheries Technical Paper No. 348). Rome. Retrieved from http://www.fao.org/docrep/V7180E/V7180E00.HTM

Hwang, S.-D., Kim, J.-Y., & Lee, T.-W. (2008). Age, Growth, and Maturity of Chub Mackerel off Korea. *North American Journal of Fisheries Management*, *28*(5), 1414–1425. https://doi.org/10.1577/M07-063.1

Hyslop, E. J. (1980). Stomach content analysis: a review of methods and their applications. *J. Fish Biol.*, *17*.

ICES. (2015). *Report of the Workshop on Maturity Staging of Mackerel and Horse Mackerel (WKMSMAC2), 28 September–2 October 2015, Lisbon, Portugal* (ICES CM 2015/SSGIEOM No. 17). Copenhagen. Retrieved from http://ices.dk/sites/pub/Publication Reports/Expert Group Report/SSGIEOM/2015/01 WKMSMAC2 Report 2015.pdf

ICES. (2016). *Report of the Workshop on Age Reading of Chub mackerel (Scomber colias) (WKARCM ),2-6th November 2015, Lisbon, Portugal.* Lisbon.

ICES. (2017). *Report of the Workshop on Fish condition (WKFICON), 17-18 November 2016, Girona, Spain* (ICES CM 2016/SSGIEOM No. 30). Copenhagen. Retrieved from http://www.ices.dk/sites/pub/Publication Reports/Expert Group Report/SSGIEOM/2016/WKFICON/WKFICON 2016.pdf

Iles, T. D. (1970). Ecological aspects of growth in cichlid fishes. *J. Cons. Int. Explor. Mer*, *33*, 363–385.

Infante, C., Blanco, E., Zuasti, E., Crespo, A., & Manchado, M. (2007). Phylogenetic differentiation between Atlantic *Scomber colias* and Pacific *Scomber japonicus* based on nuclear DNA sequences. *Genetica*, *130*(1), 1–8. https://doi.org/10.1007/s10709-006-0014-5

Jahncke, M. L., & Gooch, J. A. (1997). Sensory and chemical characteristics of selected Gulf of Mexico coastal herring species. *Journal of Food Science*. https://doi.org/10.1111/j.1365-2621.1997.tb04447.x

Johannes, R. E. (1978). Reproductive strategies of coastal marine fishes in the tropics. *Env. Biol. Fish.*, *3*(1), 65–84. https://doi.org/10.1007/BF0000 6309

Juan-Jordá, M. J., Mosqueira, I., Freire, J., & Dulvy, N. K. (2013). The Conservation and Management of Tunas and Their Relatives: Setting Life History Research Priorities. *PLoS ONE*, *8*(8), 18 pp. https://doi.org/10.1371/journal.pone.0070405

Jurado-Ruzafa, A., Hernandez, E., & Santamaria, M. T. . (2017). Age , growth and natural mortality of Atlantic chub mackerel *Scomber colias* Gmelin 1789 (Perciformes : Scombridae), from Mauritania (NW Africa. *Vieraea*, (November), 53–64.

Kang, S., Jung, K., & Cha, H. K. (2015). First Annulus Formation and Age Determination for Otoliths of Chub Mackerel *Scomber japonicus*. *Korean J Fish Aquatic Sci*, *48*(5), 760–767.

Keč, C. V., & Zorica, B. (2012a). Mesenteric fat and condition of chub mackerel, *Scomber colias* in the Adriatic sea. *Ribarstvo*, *70*(1), 19–30.

Keč, C. V., & Zorica, B. (2012b). The reproductive traits of *Scomber japonicus* ( Houttuyn , 1782 ) in the Eastern Adriatic Sea. *J. Appl. Ichthyol.*, *28*, 15–21. https://doi.org/10.1111/j.1439-0426.2011.01893.x

Keč, C. V., & Zorica, B. (2013). Length–weight relationship, age, growth and mortality of Atlantic chub mackerel *Scomber colias* in the Adriatic Sea. *Journal of the Marine Biological Association of the United Kingdom*, *93*(2), 341–349. https://doi.org/doi:10.1017/S0025315412000161

King, M. (2007). *Fisheries biology, assessment and management* (2nd ed.). Glasgow: Blackwell Publishing Ltd. https://doi.org/10.1002/9781118688038

Koranteng, K. A. (1989). *The Sardinella (Herring) Fishery in Ghana, the Past, Recent Development and the Years Ahead* (Information Report No. 23). Tema.

Koranteng, K. A. (1995). *The Ghanaian Fishery for Sardinellas*. Tema. Retrieved from http://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_6/colloques2/42093.pdf

Koranteng, K. A. (1998). *The impacts of environmental forcing on the dynamics of demersal fishery resources of Ghana*. *Unpublished doctoral dissertation*. University of Warwick, Coventry.

Koranteng, K. A., & McGlade, J. M. (2001). Climatic trends in continental shelf waters off Ghana and in the Gulf of Guinea, 1963-1992. *Oceanologica Acta*, *24*(2), 187–198. https://doi.org/10.1016/S0399-1784(01)01140-9

Kwei, E. A. (1964). Migration of *Sardinella aurita* (Val.et Cub.). *Ghana Journal of Science*, *4*(1), 34–43.

Kwei, E. A. (1971). The migration and biology of the Spanish mackerel, *Scomber japonicus* (Houttyn). *Ghana Journal of Science*, *11*(2), 75–86.

Kwei, E. A., & Ofori-Adu, D. (2005). *Fishes in the coastal waters of Ghana*. Tema: Ronna Publishers.

Lai, H. l., Gallucci, V. F., & Gunderson, D. R. (1996). Age Determination in Fisheries: Methods and Applications to Stock Assessment. In V. F. Gallucci, S. B. Saila, D. J. Gustafson, & B. J. Rothschild (Eds.), *Stock assessment: quantative methods and applications for small scale fisheries* (pp. 82–178). Boca Raton: CRC Press, Inc.

Lazar, N., Yankson, K., Blay, J., Ofori-Danson, P. K., Markwei, P., Agbogah, K., … Bilisini, W. B. (2017). *Status of the small pelagic stocks in Ghana-2016. Scientific and Technical Working Group. USAID/Ghana Sustainable Fisheries Management Project (SFMP).* Narragansett.

Lazar, N., Yankson, K., Blay, J., Ofori-Danson, P. K., Markwei, P., Agbogah, K., … Bilisini, W. B. (2017). Status of the small pelagic stocks in Ghana (2015). Scientific and Technical Working Group of USAID/Ghana Sustainable Fisheries Management Project (SFMP). Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island.GH2014_ACT093_, (June), 28.

Lazar, N., Yankson, K., Blay, J., Ofori-Danson, P., Markwei, P., Agbogah, K., … Bilisini, W. B. (2018). *Status of the small pelagic stocks in Ghana and recommendations to achieve sustainable fishing 2017. Scientific* *and Technical Working Group. USAID/Ghana Sustainable Fisheries Management Project (SFMP).* Narragansett.

Lazar, N., Yankson, K., Ofori-Danson, P., Markwei, P., Agbogah, K., Bannerman, P., … Bilisini, W. B. (2016). *Sustainable Fisheries and Coastal Management Project (SFMP). Rebuilding Depleted Small Pelagic Stocks in Ghana. A Closed Fishing Season Proposal to the Ministry of Fisheries and Aquaculture Development.* Narragansett. Retrieved from http://www.crc.uri.edu/download/GH2014_SCI002_CRC_FIN508.pdf

Le Cren, E. D. (1951). The length–weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *Journal of Animal Ecology*, *20*, 201–219.

Leggett, W. C., & Frank, K. T. (2008). Paradigms in fisheries oceanography. *Oceanography and Marine Biology: An Annual Review*, *46*, 331–363. https://doi.org/10.1038/470444a

Liao, H., Pierce, C. L., & Larschild, J. G. (2001). Empirical Assessment of Indices of Prey Importance in the Diets of Predacious Fish. *Transactions of the American Fiisheries Society*, *130*, 583–591.

Ljubojević, D., Radosavljević, V., Pelić, M., Đorđević, V., M, Ž. B., & Ćirković, M. (2016). Fatty acid composition , chemical composition and processing yield of traditional hot smoked common carp (*Cyprinus carpio,* L). *Iranian Journal of Fisheries Sciences*, *15*(4), 1293–1306.

Lorenzo, J. M., & Pajuelo, J. G. (1996). Growth and reproductive biology of chub mackerel *Scomber japonicus* off the Canary Islands. *South African Journal of Marine Science-Suid-Afrikaanse Tydskrif Vir*

*Seewetenskap*, *17*(1991), 275–280. https://doi.org/10.2989/02577619 6784158635

Love, R. (1957). The biochemical compostion of fish. *The Physiology of Fishes*, *1*, 401–418.

Lowerre-Barbieri, S. K., Ganias, K., Saborido-Rey, F., Murua, H., & Hunter, J. R. (2011). Reproductive timing in marine fishes: Variability, temporal scales, and methods. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, *3*, 71–91. https://doi.org/10.1080/19425120.2011.556932

Martins, M. M. (2007). Growth variability in Atlantic mackerel (*Scomber scombrus*) and Spanish mackerel (*Scomber japonicus*) off Portugal. *ICES Journal of Marine Science*, *64*(9), 1785–1790. https://doi.org/10. 1093/icesjms/fsm163

Martins, M. M., & Serrano-Gordo, L. (1984). *On the comparison of Spanish mackerel (Scomber japonicus Houttuyn 1782) from Gorringe Bank and Peniche (Portuguese coast).* (ICES Document No. CM 1984/H: 50). Denmark.

Martins, M. M., Skagen, D., Marques, V., Zwolinski, J., & Silva, A. (2013). Changes in the abundance and spatial distribution of the Atlantic chub mackerel ( *Scomber colias* ) in the pelagic ecosystem and fisheries off Portugal. *Scientia Marina*, *77*(4), 13. https://doi.org/10.3989/scimar. 03861.07B

Mcbride, R. S., Somarakis, S., Fitzhugh, G. R., Albert, A., Yaragina, N. A., Wuenschel, M. J., … Basilone, G. (2015). Energy acquisition and allocation to egg production in relation to fish reproductive strategies.

*Fish and Fisheries*, *16*(1), 23–57. https://doi.org/10.1111/faf.12043

Mensah, M. A. (1966). Zooplankton occurence over the shelf of Ghana. *Proceedings from the symposuim on the oceanography and fisheries resourcs of the tropical Atlantic.* Abidjan , Ivory Coast: UNESCO.

Mensah, M. A. (1981). *Report for the triennium, 1977-1979, on the Fishery Research Unit.* Tema, Ghana.

Mildenberger, T. K., Taylor, M. H., & Wolff, M. (2017). TropFishR: an R package for fisheries analysis with length-frequency data. *Methods Ecol. Evol*, 97. https://doi.org/10 1111/2041-210X 12791

Miles, R. D., & Chapman, F. A. (2012). *The Benefits of Fish Meal in Aquaculture Diets* (IFAS Extension No. FA 122). Retrieved from http://agrilife.org/fisheries/files/2013/09/The-Benefits-of-Fish-Meal-in-Aquaculture-Diets.pdf

Minta, S. O. (2003). *An assessment of the vulnerability of Ghana's coastal artisanal fishery to climate change*. *Masters' thesis*. University of Tromsø, Tromsø.

MOFAD. (2015). Fisheries Management Plan of Ghana. A National Policy for the Management of the Marine Fisheries Sector 2015-2019. Accra: Government of Ghana.

MOFAD. (2018). *2017 Annual Report*. Accra. https://doi.org/10.1002/ejoc.201200111

Morales-Nin, B. (1989). Growth determination of tropical marine fishes by means of otolith interpretation and length frequency analysis. *Aquatic Living Resources*, *2*, 241–253.

Morales-Nin, B. (1992). *Determination of growth in bony fish from otolith microstructure* (FAO Fish. Tech. Pap. No. 322). Rome.

Murray, J., & Burt, J. . (2001). *The composition of fish* (Tory Advisory Note No. 38). Retrieved from http://www.fao.org/wairdocs/tan/x5916e/x5916e01.htm

Murua, H., & Soborido-Rey, F. (2003). Female reproductive strategies of marine fish species of the North Atlantic. *J. Northw. Atl. Fish. Sci.*, *33*, 23–31. Retrieved from http://digital.csic.es/bitstream/10261/26868/1/murua.pdf

Navarro, M. R., Villamor, B., Myklevoll, S., Gil, J., Abaunza, P., & Canoura, J. (2012). Maximum size of Atlantic mackerel (*Scomber scombrus*) and Atlantic chub mackerel (*Scomber colias*) in the Northeast Atlantic. *Cybuim*, *36*(2), 406–408.

Newton, S. H., & Kilambi, R. V. (1969). Determination of sexual maturity of White Bass from ovum diameters. *The Southwestern Naturalist*, *14*(2), 213–220.

Nunoo, F. K. E., Asiedu, B., Olauson, J., & Intsiful, G. (2015). Achieving sustainable fisheries management: A critical look at traditional fisheries management in the marine artisanal fisheries of Ghana, West Africa. *JENRM*, *2*(1), 15–23.

Nunoo, F. K. E., Boateng, J. O., Ahulu, A. M., Agyekum, K. A., & Sumaila, U. R. (2009). When trash fish is treasure: The case of Ghana in West Africa. *Fisheries Research*, *96*(2–3), 167–172. https://doi.org/10.1016/j.fishres.2008.10.010

Obodai, E. A., Abbey, L. D., & Maccarthy, C. (2009). Biochemical composition of some marine fish species of Ghana. *International Journal of Biological and Chemical Sciences*, *3*(2), 406–409.

Ofori-Danson, P. K. (1989). Growth of the grey triggerfish, *Balistes capriscus*, based on growth checks of the dorsal spine. *Fishbyte 7*, *3*, 11–12.

Ofori-Danson, P. K. (1990). Reproductive ecology of the triggerfish, *Balistes capriscus* from Ghanaian coastal waters. *Journal of Tropical Ecology*, *31*(1), 1–11.

Ofori-Danson, P. K., & Kwarfo-Apegyah, K. (2009). An assessment of the cichlid fishery of Bontanga reservoir, Northern Ghana. *West African Journal of Applied Ecology*, *14*, 1–17.

Oliveira, R. F. (2014). *Benefits and risks of chub mackerel (Scomber japonicus) after culinary treatment.* (44th WEFTA Meeting: SEAFood Science for a changing demand). Bilbao, Spain.

Osei, I. (2015). *Aspects of the biology of Sardinella aurita and Sardinella maderensis (Clupeidae) in the coastal waters of the central region, Ghana. Unpublished master's thesis*. University of Cape Coast, Cape Coast.

Ostapenko, A. T. (1988). Age, croissance et caracteristiques morphologiques du maquereau espagnol (*Scomber japonicus* Houtt.) de L'Atlantique Sud-Est. *Colln Scient. Pap. in Commn SE. Atl. Fish.*, *15*, 161–174.

Pal, J., Shukla, B. N., Maurya, A. K., Verma, H. O., Pandey, G., & Amitha. (2018). A review on role of fish in human nutrition with special emphasis to essential fatty acid. *International Journal of Fisheries and Aquatic Studies*, *6*(2), 427–430.

Pannella, G. (1977). Fish otoliths: daily growth layers and periodal patterns. *Science*, *173*, 124–127.

Pannella, G. (1980). Methods of preparing fish sagittae. In D. C. Rohads & R. A. Lutz (Eds.), *Skeletal growth in aquatic organisms; biological records of environmnetal change.* (pp. 619–624). New York: Plenum Press.

Pauly, D. (1980). On the interrelationship between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *J.Cons.Int. Explor. Mer*, *3(a)*(179–192).

Pauly, D. (1983). *Some simple methods for the assessment of tropical fish stocks* (FAO Fish.Tech. Pap. No. 234). Rome.

Pauly, D. (1984). *Fish population dynamics in tropical waters: a manual for use with programmable calculators* (ICLARM Stud.Rev No. 8).

Pauly, D., & Greenberg, A. (2013). *ELEFAN in R: a new tool for length-frequency analysis*. *Univ. Br. Columbia Fish CentrE Res. Rep.*

Pauly, D., & Munro, J. L. (1984). *Once more on the comparison of growth in fish and invertebrates*. *ICLARM Fishbyte* (Vol. 2).

Perrotta, R. G., Carvalho, N., & Isidro, E. (2005). Comparative study on growth of chub mackerel (*Scomber japonicus* Houttuyn, 1782) from three different regions: NW Mediterranean, NE and SW Atlantic. Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP). Argentina. *Revista de Investigaciones En Desarrollo Pesquero*, *17*, 67–79.

Pezennec, O., & Koranteng, K. A. (1998). Changes in the dynamics and biology of small pelagic fisheries off Côte-d'Ivoire and Ghana : an ecological puzzle. In M. Durand, P. Cury, R. Mendelssohn, C. Roy, A. Bakun, & D. Pauly (Eds.), *Global versus local changes in upwelling systems* (pp. 329–343). Paris: Orstom Éditions. Retrieved from http://www.documentation.ird.fr/hor/fdi:010015318

Pianka, E. R. (1970). On r-and-K selection. *The American Naturalist*, *104*(940), 592–597.

Pinkas, L., Oliphant, M. S., & Iverson, I. L. K. (1971). Food Habits of Albacore, Bluefin Tuna, and Bonito in California Waters. *California Department of Fish and Game Fish Bulletin*, *152*, 1–105. Retrieved from https://oac.cdlib.org/view?docId=kt8290062w&brand=oac4&doc.view=entire_text

Quiñonez-Velázquez, C., & Gluyas-Millán, M. G. (1997). Age, growth and reproduction of Pacific mackerel *Scomber japonicus* in the Gulf of California. *Bulletin of Marine Science*, *61*(3), 837–847.

Ricker, W. E. (1975). Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada*, *191*, 1–382.

Rossi-Wongtschowski, C. L. D. B., Siliprandi, C. C., Brenha, M. R., Gonsales, S. A., Santificetur, C., Vaz-dos-Santos, A. M., & Vaz-dos-Santos, A. M. (2014). Atlas of Marine Bony Fish Otoliths (Sagittae) of Southeastern-Southern Brazil Part I: Gadiformes (Macrouridae, Moridae, Bregmacerotidae, Phycidae and Merlucciidae); Part I : Perciformes (Carangidae, Sciaenidae, Scombridae and Serranidae).

*Brazilian Journal of Oceanography*, *62*, 1–103.

Sangun, L., Akamca, E., & Akar, M. (2007). Weight-Length Relationships for 39 Fish Species from the North-Eastern Mediterranean Coast of Turkey. *Turkish Journal of Fisheries and Aquatic Sciences*, *40*, 37–40.

Schwamborn, R., Mildenberger, T. K., & Taylor, M. H. (2019). Assessing sources of uncertainty in length-based estimates of body growth in populations of fishes and macroinvertebrates with bootstrapped ELEFAN. *Ecological Modelling*, *393*(October 2018), 37–51. https://doi.org/10.1016/j.ecolmodel.2018.12.001

Shim, K., Yoon, N., Lim, C., Kim, M., Kang, S., & Choi, K. (2017). Relationship between Seasonal Variations in Body and Proximate Compositions of Chub Mackerel *Scomber japonicus* from the Korean Coast. *Turkish Journal of Fisheries and Aquatic Sciences*, *744*, 735–744. https://doi.org/10.4194/1303-2712-v17

Soxhlet, F. (1879). Die gewichtsanalytische Bestimmung des Milchfettes. *Dingler's Polytechnisches Journal*, *232*, 461–465.

Sparre, P., & Venema, S. C. (1998). *Introduction to tropical fish stock assessment, Part 1 manual* (FAO Fish. Tech. Pap. No. (306.1) Rev. 1. 376). Rome.

Spitz, J., Mourocq, E., Schoen, V., & Ridoux, V. (2010). Proximate composition and energy content of forage species from the Bay of Biscay: High- or low-quality food? *ICES Journal of Marine Science*, *67*(5), 909–915. https://doi.org/10.1093/icesjms/fsq008

Tall, A., & Failler, P. (2012). Fishery and aquaculture industry in Ghana. *Series Report N°1 of the Review of the Fishery and Aquaculture Industry in the 22 ATLAFCO Member States*, (October 2012), 44. https://doi.org/10.13140/RG.2.1.1624.3362

Taylor, C. C. (1958). Cod growth and temperature. *J. Cons. Int. Explor. Mer*, *23*, 366–370.

Techetach, M., Hernando-Casal, J. A., Saoul, Y., & Benajiba, M. H. (2010). Reproductive biology of chub mackerel *Scomber japonicus* in Larache area, Moroccan North Atlantic coast. *Cybium*, *34*(2), 159–165.

Thiaw, M., Auger, P.-A., Ngom, F., Brochier, T., Faye, S., Diankha, O., & Brehmer, P. (2017). Effect of environmental conditions on the seasonal and inter-annual variability of small pelagic fish abundance off North-West Africa : The case of both Senegalese sardinella. *Fisheries Oceanography*, *26*, 583–601. https://doi.org/10.1111/fog.12218

Torres, M. A., Ramos, F., & Sobrino, I. (2012). Length-weight relationships of 76 fish species from the Gulf of Cadiz (SW Spain). *Fisheries Research*, *127–128*(April 2016), 171–175. https://doi.org/10.1016/j.fishres.2012.02.001

USAID. (2015). Ghana's small pelagic fishery in crisis: National food security at risk. Accra, Ghana.

VanderKooy, S. (2009). A Practical Handbook for Determining the Ages of Gulf of Mexico Fishes. *Gulf States Marine Fisheries Commission*, (167), 157. Retrieved from www.gsmfc.org

Vasconcelos, J., Afonso-Dias, M., & Faria, G. (2012). Atlantic chub mackerel (*Scomber colias*) spawning season, size and age at first maturity in Madeira waters. *Arquipelago. Life and Marine Sciences*, *29*, 43–51.

Vasconcelos, J., Dias, M. A., & Faria, G. (2011). Age and growth of the Atlantic chub mackerel *Scomber colias* Gmelin, 1789 off Madeira Island. *Revista de Biología Marinay Oceanografía*, *1*, 27–34. Retrieved from http://repositorio.uac.pt/handle/10400.3/1228

Velasco, E. M., Del Arbol, J., Baro, J., & Sobrino, I. (2011). Age and growth of the Spanish chub mackerel *Scomber colias* off southern Spain: a comparison between samples from the NE Atlantic and the SW Mediterranean. *Revista de Biología Marina y Oceanografía*, *46*(January), 27–34. https://doi.org/10.4067/S0718-19572011000100004

Wahbi, F., Errhif, A., & Ettahiri, O. (2012). Cycle de reproduction et variabilité du régime alimentaire du maquereau, *Scomber japonicus* (Houttuyn, 1782) débarqué au port de Casablanca/ Reproduction cycle and diet variability of the chub mackerel, *Scomber japonicus* (Houttuyn, 1782) landed at Casablan. In S. Garcia, M. Tandstad, & A. M. Caramelo (Eds.), *Science and Management of small pelagics. Symposium on Science and the Challenge of Managing Small Pelagic Fisheries on Shared Stocks in Northwest Africa, 11–14 March 2008, Casablanca, Morocco/Science et aménagement des petits pélagiques. Symposium sur la* (18th ed., pp. 127–138). Rome: FAO.

Wahbi, F., Tojo, N., Ramzi, A., Somoue, L., Manchih, K., & Errhif, A. (2015). Seasonal and size-dependent variability in diet of *Scomber colias* (Gmelin, 1789) of the Atlantic Coast of the Northwest Africa. *International Journal of Advanced Research*, *3*(12), 485–497.

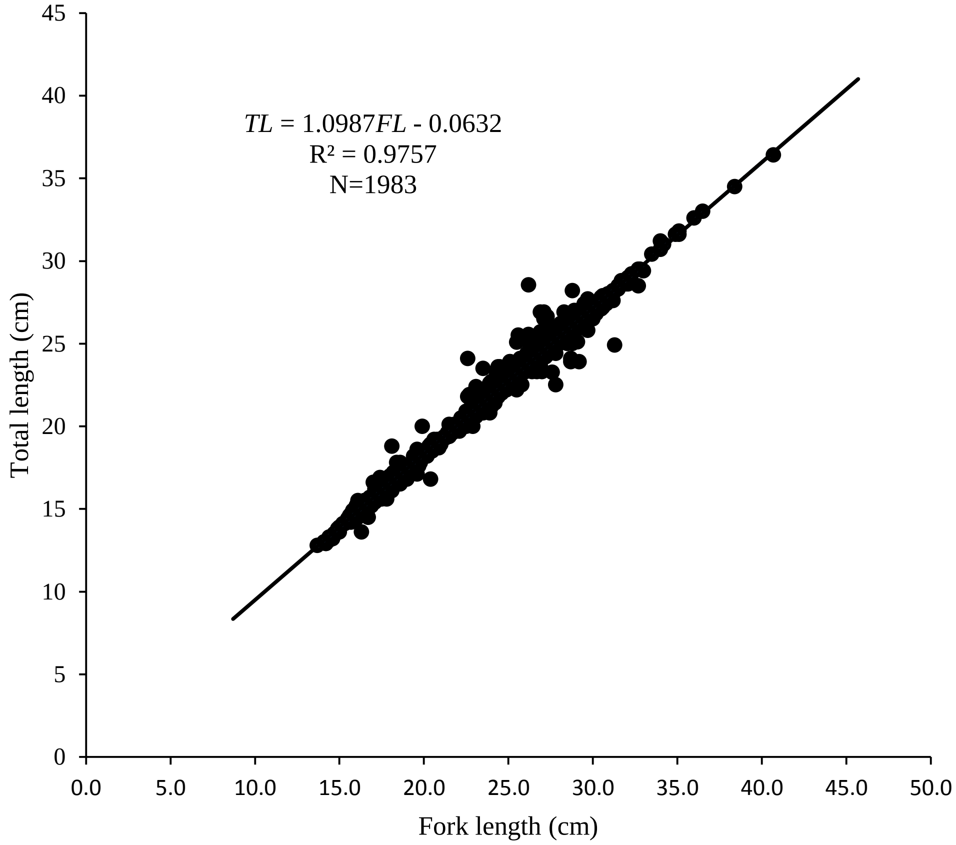
Wiafe, G., Yaqub, H. B., Mensah, M. a, & Frid, C. L. J. (2008). Impact of climate change on long-term zooplankton biomass in the upwelling region of the Gulf of Guinea. *ICES Journal of Marine Science: Journal Du Conseil*, *65*(3), 318–324. https://doi.org/10.1093/icesjms/fsn042

Witthames, P. R., Thorsen, A., Murua, H., Soborido-Rey, F., Greenwood, L. N., Dominguez, R., … Kjesbu, O. S. (2009). Advances in methods for determining fecundity: application of the new methods to some marine fishes. *Fish. Bull.*, *107*(2), 148–164.

Yeannes, M. I., & Almandos, M. E. (2003). Estimation of fish proximate composition starting from water content. *Journal of Food Composition and Analysis*, *16*(1), 81–92. https://doi.org/10.1016/S0889-1575(02)00168-0

# APPENDICES

**Appendix A: Relationship between total length (*TL*) and fork length (*FL*) of *Scomber colias* sampled from the coastal waters of Ghana from February 2016-July 2017**



**Appendix B: Descriptive statistics of total length (*TL*) and body weight (*BW*) for *Scomber colias* sampled from February 2016 - July 2017 in Ghanaian coastal waters**

| Sex | N | Mean TL ± s. e (cm) | TL range (cm) | Mean BW ± s. e. (g) | BW range (g) |
|---|---|---|---|---|---|
| Males | 852 | 26.01 ± 0.09 | 16.9-40.7 | 177.20 ± 2.06 | 42.4-695 |
| Females | 828 | 26.24 ± 0.08 | 20.8-36.5 | 181.73 ± 1.79 | 77.15-525.15 |
| Indeterminate sex | 466 | 19.16 ± 0.13 | 13.7-30.2 | 65.70 ± 2.04 | 19.95-286.40 |
| All sexes | 2146 | 24.61 ± 0.08 | 13.7-40.7 | 154.74 ± 1.54 | 19.95-695 |

**Appendix C 1: Overall length-frequency distributions for *Scomber colias* in Ghanaian coastal waters**

| Class size | Percentage frequency | Number |
|---|---|---|
| 13.0-13.9 | 0.05 | 1 |
| 14.0-14.9 | 0.47 | 10 |
| 15.0-15.9 | 1.07 | 23 |
| 16.0-16.9 | 2.84 | 61 |
| 17.0-17.9 | 4.29 | 92 |
| 18.0-18.9 | 4.29 | 92 |
| 19.0-19.9 | 2.75 | 59 |
| 20.0-20.9 | 1.91 | 41 |
| 21.0-21.9 | 1.86 | 40 |
| 22.0-22.9 | 5.36 | 115 |
| 23.0-23.9 | 9.09 | 195 |
| 24.0-24.9 | 12.63 | 271 |
| 25.0-25.9 | 12.91 | 277 |
| 26.0-26.9 | 12.63 | 271 |
| 27.0-27.9 | 9.55 | 205 |
| 28.0-28.9 | 9.51 | 204 |
| 29.0-29.0 | 4.75 | 102 |
| 30.0-30.9 | 2.19 | 47 |
| 31.0-31.9 | 0.61 | 13 |
| 32.0-32.9 | 0.51 | 11 |
| 33.0-33.9 | 0.14 | 3 |
| 34.0-34.9 | 0.23 | 5 |
| 35.0-35.9 | 0.19 | 4 |
| 36.0-36.9 | 0.09 | 2 |
| 37.0-37.9 | 0.00 | 0 |
| 38.0-38.9 | 0.05 | 1 |
| 39.0-39.9 | 0.00 | 0 |
| 40.0-40.9 | 0.05 | 1 |

**Appendix C 2: Length- frequency distributions for male *Scomber colias* in Ghanaian coastal waters**

| Class size | Percentage frequency | Number |
|---|---|---|
| 13.0-13.9 | 0.00 | 0 |
| 14.0-14.9 | 0.00 | 0 |
| 15.0-15.9 | 0.00 | 0 |
| 16.0-16.9 | 0.12 | 1 |
| 17.0-17.9 | 0.00 | 0 |
| 18.0-18.9 | 0.12 | 1 |
| 19.0-19.9 | 0.35 | 3 |
| 20.0-20.9 | 0.70 | 6 |
| 21.0-21.9 | 1.29 | 11 |
| 22.0-22.9 | 5.28 | 45 |
| 23.0-23.9 | 11.97 | 102 |
| 24.0-24.9 | 16.08 | 137 |
| 25.0-25.9 | 15.61 | 133 |
| 26.0-26.9 | 15.38 | 131 |
| 27.0-27.9 | 10.80 | 92 |
| 28.0-28.9 | 12.79 | 109 |
| 29.0-29.0 | 4.11 | 35 |
| 30.0-30.9 | 3.17 | 27 |
| 31.0-31.9 | 0.59 | 5 |
| 32.0-32.9 | 0.47 | 4 |
| 33.0-33.9 | 0.12 | 1 |
| 34.0-34.9 | 0.35 | 3 |
| 35.0-35.9 | 0.35 | 3 |
| 36.0-36.9 | 0.12 | 1 |
| 37.0-37.9 | 0.00 | 0 |
| 38.0-38.9 | 0.12 | 1 |
| 39.0-39.9 | 0.00 | 0 |
| 40.0-40.9 | 0.12 | 1 |

**Appendix C 3: Length- frequency distributions for female *Scomber colias* in Ghanaian coastal waters**

| Class size | Percentage frequency | Number |
|---|---|---|
| 13.0-13.9 | 0.00 | 0 |
| 14.0-14.9 | 0.00 | 0 |
| 15.0-15.9 | 0.00 | 0 |
| 16.0-16.9 | 0.00 | 0 |
| 17.0-17.9 | 0.00 | 0 |
| 18.0-18.9 | 0.00 | 0 |
| 19.0-19.9 | 0.00 | 0 |
| 20.0-20.9 | 0.24 | 2 |
| 21.0-21.9 | 0.85 | 7 |
| 22.0-22.9 | 3.99 | 33 |
| 23.0-23.9 | 10.63 | 88 |
| 24.0-24.9 | 15.10 | 125 |
| 25.0-25.9 | 17.15 | 142 |
| 26.0-26.9 | 17.15 | 142 |
| 27.0-27.9 | 12.92 | 107 |
| 28.0-28.9 | 10.63 | 88 |
| 29.0-29.0 | 7.00 | 58 |
| 30.0-30.9 | 2.05 | 17 |
| 31.0-31.9 | 0.85 | 7 |
| 32.0-32.9 | 0.72 | 6 |
| 33.0-33.9 | 0.24 | 2 |
| 34.0-34.9 | 0.24 | 2 |
| 35.0-35.9 | 0.12 | 1 |
| 36.0-36.9 | 0.12 | 1 |
| 37.0-37.9 | 0.00 | 0 |
| 38.0-38.9 | 0.00 | 0 |
| 39.0-39.9 | 0.00 | 0 |
| 40.0-40.9 | 0.00 | 0 |

**Appendix C 4: Length- frequency distributions for *Scomber colias* of indeterminate sex in Ghanaian coastal waters**

| Class size | Percentage frequency | Number |
|---|---|---|
| 13.0-13.9 | 0.21 | 1 |
| 14.0-14.9 | 2.15 | 10 |
| 15.0-15.9 | 4.94 | 23 |
| 16.0-16.9 | 12.88 | 60 |
| 17.0-17.9 | 19.74 | 92 |
| 18.0-18.9 | 19.53 | 91 |
| 19.0-19.9 | 12.02 | 56 |
| 20.0-20.9 | 7.08 | 33 |
| 21.0-21.9 | 4.72 | 22 |
| 22.0-22.9 | 7.94 | 37 |
| 23.0-23.9 | 1.07 | 5 |
| 24.0-24.9 | 2.15 | 10 |
| 25.0-25.9 | 0.64 | 3 |
| 26.0-26.9 | 1.29 | 6 |
| 27.0-27.9 | 1.50 | 7 |
| 28.0-28.9 | 1.50 | 7 |
| 29.0-29.0 | 0.43 | 2 |
| 30.0-30.9 | 0.21 | 1 |
| 31.0-31.9 | 0.00 | 0 |
| 32.0-32.9 | 0.00 | 0 |
| 33.0-33.9 | 0.00 | 0 |
| 34.0-34.9 | 0.00 | 0 |
| 35.0-35.9 | 0.00 | 0 |
| 36.0-36.9 | 0.00 | 0 |
| 37.0-37.9 | 0.00 | 0 |
| 38.0-38.9 | 0.00 | 0 |
| 39.0-39.9 | 0.00 | 0 |
| 40.0-40.9 | 0.00 | 0 |

**Appendix D: Condition factor of *Scomber colias* landed in Ghanaian coastal waters from February 2016-July 2017**

| Months | Males | Females | s. e males | s. e females |
|---|---|---|---|---|
| Feb-16 | 0.87 | 0.86 | 0.02 | 0.02 |
| Mar-16 | 0.97 | 0.98 | 0.01 | 0.01 |
| Apr-16 | 0.97 | 0.97 | 0.01 | 0.01 |
| May-16 | 0.98 | 1 | 0.01 | 0.01 |
| Jun-16 | 0.89 | 0.9 | 0.01 | 0.01 |
| Jul-16 | 0.91 | 0.93 | 0.01 | 0.01 |
| Aug-16 | 0.89 | 0.88 | 0.01 | 0.01 |
| Sep-16 | 1.03 | 1.07 | 0.03 | 0.02 |
| Oct-16 | 0.86 | - | 0.05 | - |
| Nov-16 | 0.97 | 0.94 | 0.02 | 0.02 |
| Dec-16 | 1.03 | 1.02 | 0.01 | 0.02 |
| Jan-17 | 0.94 | 0.95 | 0.01 | 0.01 |
| Feb-17 | 0.99 | 0.99 | 0.01 | 0.01 |
| Mar-17 | 0.97 | 0.97 | 0.01 | 0.01 |
| Apr-17 | 0.9 | 0.95 | 0.04 | 0.03 |
| May-17 | 0.98 | 1 | 0.02 | 0.02 |
| Jun-17 | 0.91 | 0.9 | 0.01 | 0.01 |
| Jul-17 | 0.9 | 0.9 | 0.01 | 0.01 |

**Appendix E 1: Visceral fat index of *Scomber colias* from the coastal waters of Ghana. Females were not present in the samples for October 2016**

| Months | Males | Females | s. e Males | s. e Females |
|---|---|---|---|---|
| Feb-16 | 0.001 | 0.002 | 0.0001 | 0.0008 |
| Mar-16 | 0.002 | 0.002 | 0.0001 | 0.0001 |
| Apr-16 | 0.001 | 0.001 | 0.0002 | 0.0001 |
| May-16 | 0.002 | 0.002 | 0.0002 | 0.0001 |
| Jun-16 | 0 | 0.001 | 0 | 0 |
| Jul-16 | 0.001 | 0.001 | 0 | 0 |
| Aug-16 | 0.001 | 0.001 | 0.0005 | 0 |
| Sep-16 | 0.003 | 0.006 | 0.0006 | 0.00008 |
| Oct-16 | 0.001 | | 0.0008 | |
| Nov-16 | 0.005 | 0.006 | 0.0003 | 0.0005 |
| Dec-16 | 0.005 | 0.005 | 0.0004 | 0.0003 |
| Jan-17 | 0.002 | 0.003 | 0.0002 | 0.0003 |
| Feb-17 | 0.002 | 0.002 | 0.0001 | 0.0002 |
| Mar-17 | 0.002 | 0.002 | 0.0002 | 0.0002 |
| Apr-17 | 0.002 | 0.002 | 0.0004 | 0.0004 |
| May-17 | 0.001 | 0.001 | 0.0002 | 0.0002 |
| Jun-17 | 0.001 | 0.001 | 0.0001 | 0 |
| Jul-17 | 0.001 | 0.001 | 0 | 0.0001 |

**Appendix E 2: Inferential statistics on visceral fat index**

| | *males* | *females* |
|---|---|---|
| Mean | 0.001558463 | 0.001959158 |
| Variance | 3.90823E-06 | 8.72635E-06 |
| Observations | 852 | 828 |
| Hypothesized Mean Difference | 0 | |
| df | 1439 | |
| t Stat | -3.257982203 | |
| P(T<=t) one-tail | 0.000574123 | |
| t Critical one-tail | 1.645913222 | |
| P(T<=t) two-tail | 0.001148246 | |
| t Critical two-tail | 1.961613904 | |

**Appendix F: Cumulative percentage proportions of sexually mature *Scomber colias***

| Class midpoint (TL, cm) | Cumulative frequency (males) | Cumulative frequency (females) |
|---|---|---|
| 20.45 | 0.18 | 0.00 |
| 21.45 | 0.71 | 0.37 |
| 22.45 | 3.38 | 3.88 |
| 23.45 | 14.59 | 14.79 |
| 24.45 | 31.32 | 29.58 |
| 25.45 | 47.51 | 47.32 |
| 26.45 | 63.88 | 62.48 |
| 27.45 | 75.62 | 75.42 |
| 28.45 | 89.86 | 88.36 |
| 29.45 | 94.31 | 95.38 |
| 30.45 | 97.33 | 97.41 |
| 31.45 | 98.22 | 98.34 |
| 32.45 | 98.58 | 98.89 |
| 33.45 | 98.75 | 99.26 |
| 34.35 | 99.11 | 99.63 |
| 35.45 | 99.64 | 99.82 |
| 36.45 | 99.82 | 100.00 |
| 37.45 | 99.82 | |
| 38.45 | 100.00 | |
| 39.45 | 100.00 | |
| 40.45 | 100.00 | |

**Appendix G: Absolute ($F_{abs}$) and relative ($F_{rel}$) fecundity of *Scomber colias* from the coastal waters of Ghana-*C.V. = coefficient of variation**

| Specimen | TL (cm) | BW (g) | GW (g) | Sub-sample based estimates ($F_{abs}$) 1 | 2 | 3 | Mean $F_{abs}$ | C. V ($F_{abs}$) | $F_{rel}$(eggs $g^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 29.6 | 197.04 | 10.5 | 55681 | 56145 | 53830 | 55219 | 2.22 | 280 |
| 2 | 34.2 | 195.85 | 11.65 | 62716 | 65575 | 66576 | 64955 | 3.08 | 332 |
| 3 | 35.5 | 197.2 | 44.07 | 147439 | 144651 | 143857 | 145316 | 1.29 | 737 |
| 4 | 28.4 | 185.66 | 17.7 | 62641 | 64107 | 63443 | 63397 | 1.16 | 341 |
| 5 | 25.7 | 170.79 | 5.05 | 24735 | 25907 | 26028 | 25556 | 2.80 | 150 |
| 6 | 24.8 | 149.66 | 4.55 | 26220 | 24833 | 27065 | 26040 | 4.33 | 174 |
| 7 | 23.6 | 156.11 | 10.29 | 50347 | 51046 | 49360 | 50251 | 1.69 | 322 |
| 8 | 25.2 | 104.28 | 6.11 | 24178 | 24712 | 26425 | 25105 | 4.68 | 241 |
| 9 | 27.6 | 236.19 | 11.73 | 55817 | 52133 | 53695 | 53882 | 3.43 | 228 |
| 10 | 27.3 | 127.3 | 14.77 | 62098 | 62122 | 58309 | 60843 | 3.61 | 478 |
| 11 | 25.6 | 161.14 | 5.11 | 13284 | 12082 | 13531 | 12966 | 5.98 | 80 |
| 12 | 24.1 | 144.32 | 3.35 | 10153 | 10115 | 10393 | 10220 | 1.48 | 71 |
| 13 | 24.2 | 148.11 | 13.29 | 54065 | 54463 | 54060 | 54196 | 0.43 | 366 |
| 14 | 25.5 | 158.07 | 6.39 | 48543 | 51749 | 46134 | 48808 | 5.77 | 309 |
| 15 | 25.8 | 153.1 | 6.75 | 41207 | 42017 | 41388 | 41537 | 1.02 | 271 |
| 16 | 25.7 | 171.01 | 6.91 | 35049 | 32925 | 39109 | 35694 | 8.80 | 209 |
| 17 | 25.9 | 199.2 | 9.82 | 39129 | 38730 | 42153 | 40004 | 4.68 | 201 |
| 18 | 26.7 | 178.95 | 5.85 | 21418 | 24114 | 21390 | 22308 | 7.01 | 125 |
| 19 | 25.3 | 179.66 | 5.74 | 26843 | 26463 | 23342 | 25549 | 7.52 | 142 |
| 20 | 24.9 | 172.14 | 12.01 | 47011 | 49841 | 52209 | 49687 | 5.24 | 289 |
| 21 | 24.1 | 142.24 | 5.52 | 23735 | 23905 | 22984 | 23541 | 2.08 | 166 |

**Appendix G continued**.

| Specimen | TL (cm) | BW (g) | GW (g) | Sub-sample based estimates ($F_{abs}$) 1 | 2 | 3 | Mean $F_{abs}$ | C. V ($F_{abs}$) | $F_{rel}$(eggs $g^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 22 | 25 | 172.04 | 12.04 | 48272 | 48896 | 45382 | 47517 | 3.95 | 276 |
| 23 | 23.5 | 120.23 | 5.2 | 27794 | 25377 | 26606 | 26592 | 4.54 | 221 |
| 24 | 26.5 | 188.16 | 12.95 | 55237 | 54949 | 53556 | 54581 | 1.65 | 290 |
| 25 | 23.8 | 133.16 | 5.96 | 26160 | 24954 | 23727 | 24947 | 4.88 | 187 |
| 26 | 24 | 145.5 | 6.07 | 33410 | 32027 | 29827 | 31755 | 5.69 | 218 |
| 27 | 23.7 | 141.48 | 12.77 | 46223 | 47845 | 46608 | 46892 | 1.81 | 331 |
| 28 | 28.5 | 228.51 | 15.85 | 69731 | 70411 | 70049 | 70063 | 0.49 | 307 |
| 29 | 24.2 | 126 | 8.05 | 20532 | 21198 | 21149 | 20959 | 1.77 | 166 |
| 30 | 24.6 | 135.18 | 8.55 | 22427 | 20792 | 18585 | 20601 | 9.36 | 152 |
| 31 | 24.5 | 135.43 | 16.58 | 33920 | 36617 | 36589 | 35709 | 4.34 | 264 |
| 32 | 24.1 | 127.52 | 16.51 | 24374 | 25601 | 22451 | 24142 | 6.58 | 189 |
| 33 | 26.9 | 170.44 | 18.27 | 26318 | 24785 | 25052 | 25385 | 3.23 | 149 |
| 34 | 24.8 | 150.14 | 15.38 | 29436 | 29869 | 31451 | 30252 | 3.51 | 201 |
| 35 | 28.8 | 227.95 | 15.53 | 75858 | 75021 | 72617 | 74499 | 2.26 | 327 |
| 36 | 28.5 | 210.3 | 10.83 | 36925 | 36493 | 36559 | 36659 | 0.63 | 174 |
| 37 | 28.8 | 220.42 | 12.92 | 42975 | 43886 | 46080 | 44314 | 3.60 | 201 |
| 38 | 27.9 | 200.31 | 11.29 | 51322 | 52956 | 53977 | 52752 | 2.54 | 263 |
| 39 | 29 | 224.66 | 13.5 | 63821 | 62974 | 66950 | 64582 | 3.24 | 287 |
| 40 | 28.6 | 227.92 | 14.94 | 62892 | 61560 | 58983 | 61145 | 3.25 | 268 |
| 41 | 27.7 | 209.84 | 11.28 | 62954 | 62782 | 60231 | 61989 | 2.46 | 295 |
| 42 | 29 | 234.73 | 15.5 | 68689 | 71134 | 69301 | 69708 | 1.83 | 297 |

**Appendix G continued**

| Specimen | TL (cm) | BW (g) | GW (g) | Sub-sample based estimates ($F_{abs}$) 1 | 2 | 3 | Mean $F_{abs}$ | C. V ($F_{abs}$) | $F_{rel}$(eggs $g^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 43 | 28.4 | 216.21 | 12.74 | 49550 | 46586 | 50846 | 48994 | 4.46 | 227 |
| 44 | 28.1 | 220.79 | 13.88 | 54105 | 54919 | 50487 | 53170 | 4.44 | 241 |
| 45 | 29.5 | 256.44 | 15.36 | 38320 | 37931 | 35882 | 37378 | 3.50 | 146 |
| 46 | 26.7 | 184.64 | 11.93 | 47448 | 49008 | 47308 | 47921 | 1.97 | 260 |
| 47 | 29.1 | 185.98 | 13.17 | 36488 | 34087 | 34084 | 34887 | 3.98 | 188 |
| 48 | 29.8 | 238.13 | 20.6 | 46201 | 45701 | 47093 | 46331 | 1.52 | 195 |
| 49 | 29.2 | 244.91 | 42.48 | 62259 | 63160 | 58932 | 61450 | 3.62 | 251 |
| 50 | 29.4 | 255.43 | 25.65 | 46442 | 44834 | 44188 | 45155 | 2.57 | 177 |
| 51 | 27.3 | 186.81 | 15 | 35780 | 33488 | 32096 | 33788 | 5.50 | 181 |
| 52 | 27.5 | 204.46 | 17.63 | 45804 | 42973 | 43297 | 44025 | 3.52 | 215 |
| 53 | 27.8 | 181.66 | 11.54 | 39945 | 35948 | 38014 | 37969 | 5.26 | 209 |
| 54 | 28 | 201.23 | 11.93 | 52637 | 51086 | 55356 | 53026 | 4.08 | 264 |
| 55 | 28.6 | 226.6 | 38.11 | 47184 | 47546 | 45901 | 46877 | 1.84 | 207 |
| 56 | 28.6 | 231.77 | 14.32 | 29868 | 29366 | 31500 | 30245 | 3.69 | 130 |
| 57 | 27.4 | 185.77 | 7.73 | 14600 | 13569 | 12295 | 13488 | 8.56 | 73 |
| 58 | 29.1 | 222.36 | 9.22 | 26940 | 29677 | 29844 | 28820 | 5.66 | 130 |
| 59 | 29 | 221.85 | 9.58 | 24439 | 24030 | 22629 | 23699 | 4.01 | 107 |
| 60 | 28.2 | 219.74 | 15.18 | 41465 | 43529 | 40641 | 41879 | 3.55 | 191 |
| 61 | 27.7 | 187.27 | 21.07 | 22346 | 20679 | 20346 | 21124 | 5.07 | 113 |
| 62 | 28.8 | 216.96 | 11.62 | 49711 | 45339 | 47028 | 47359 | 4.66 | 218 |
| 63 | 28.6 | 220.25 | 18.67 | 46698 | 43398 | 46243 | 45446 | 3.93 | 206 |

**Appendix G continued.**

| Specimen | TL (cm) | BW (g) | GW (g) | Sub-sample based estimates ($F_{abs}$) 1 | 2 | 3 | Mean $F_{abs}$ | C. V ($F_{abs}$) | $F_{rel}$(eggs $g^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 64 | 29.1 | 236.3 | 16.37 | 36987 | 38020 | 34413 | 36473 | 5.09 | 154 |
| 65 | 28.4 | 222.09 | 15.66 | 30226 | 34696 | 35609 | 33510 | 8.60 | 151 |
| 66 | 28.1 | 206.93 | 9.49 | 18207 | 20605 | 17520 | 18777 | 8.63 | 91 |
| 67 | 28.5 | 209.3 | 8.94 | 25467 | 23939 | 27431 | 25612 | 6.83 | 122 |
| 68 | 28.1 | 193.42 | 10.99 | 47302 | 45784 | 46726 | 46604 | 1.64 | 241 |
| 69 | 29.1 | 241.51 | 8.7 | 34495 | 36916 | 38937 | 36782 | 6.05 | 152 |
| 70 | 29.3 | 254 | 16.38 | 59411 | 56139 | 60596 | 58715 | 3.93 | 231 |
| 71 | 32.8 | 375.75 | 19.03 | 59104 | 58208 | 63547 | 60286 | 4.74 | 160 |
| 72 | 33.5 | 431.37 | 33.65 | 105971 | 92701 | 106602 | 101758 | 7.71 | 236 |
| 73 | 36.5 | 525.25 | 26.18 | 86807 | 88926 | 83473 | 86402 | 3.18 | 164 |
| 74 | 32.3 | 352 | 24.94 | 96943 | 93814 | 95215 | 95324 | 1.64 | 271 |
| 75 | 31 | 302.72 | 17.76 | 40320 | 40617 | 38881 | 39939 | 2.32 | 132 |
| 76 | 26 | 186.59 | 7.67 | 47127 | 49584 | 49305 | 48672 | 2.76 | 261 |
| 77 | 25.8 | 164.91 | 11.21 | 25356 | 25284 | 22395 | 24345 | 6.94 | 148 |
| 78 | 31.7 | 298.32 | 38.42 | 154133 | 148393 | 164848 | 155791 | 5.36 | 522 |
| 79 | 33 | 364.6 | 26.29 | 101115 | 119811 | 105187 | 108704 | 9.04 | 298 |
| 80 | 23.3 | 118.33 | 8.27 | 23462 | 26786 | 25756 | 25335 | 6.72 | 214 |
| 81 | 25.2 | 141.13 | 6.46 | 29162 | 32155 | 32656 | 31325 | 6.03 | 222 |
| 82 | 28.5 | 226.31 | 12.03 | 39114 | 40775 | 42016 | 40635 | 3.58 | 180 |
| 83 | 30.5 | 311.81 | 26.45 | 76798 | 77867 | 76476 | 77047 | 0.94 | 247 |
| 84 | 31.1 | 293.33 | 15.23 | 46638 | 51073 | 50591 | 49434 | 4.92 | 169 |

**Appendix G continued**

| Specimen | TL (cm) | BW (g) | GW (g) | Sub-sample based estimates ($F_{abs}$) 1 | 2 | 3 | Mean $F_{abs}$ | C. V ($F_{abs}$) | $F_{rel}$(eggs $g^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 85 | 27 | 206.42 | 22.83 | 86719 | 87113 | 87975 | 87269 | 0.74 | 423 |
| 86 | 28.2 | 229.44 | 21.65 | 29713 | 28922 | 28757 | 29131 | 1.75 | 127 |
| 87 | 29.6 | 267.91 | 15.19 | 78192 | 80933 | 80399 | 79841 | 1.82 | 298 |
| 88 | 29.1 | 254.41 | 17.66 | 73416 | 70643 | 73328 | 72462 | 2.18 | 285 |
| 89 | 28 | 223.3 | 16.42 | 59113 | 58531 | 60127 | 59257 | 1.36 | 265 |
| 90 | 27.1 | 203.66 | 10.79 | 71351 | 70987 | 68814 | 70384 | 1.95 | 346 |
| 91 | 24.9 | 159.24 | 12.79 | 49267 | 47394 | 47065 | 47908 | 2.48 | 301 |
| 92 | 23 | 109.8 | 4.91 | 32991 | 31318 | 31355 | 31888 | 3.00 | 290 |
| 93 | 23.8 | 116.92 | 6.73 | 55709 | 58306 | 56536 | 56851 | 2.33 | 486 |
| 94 | 27.8 | 193.7 | 19.63 | 103197 | 103339 | 96509 | 101015 | 3.86 | 522 |
| 95 | 24.5 | 151.27 | 13.12 | 54657 | 52448 | 56512 | 54539 | 3.73 | 361 |
| 96 | 24.3 | 140.25 | 11.74 | 66336 | 64214 | 57678 | 62743 | 7.19 | 447 |
| 97 | 27 | 186.1 | 16.21 | 55607 | 58485 | 59570 | 57887 | 3.54 | 311 |
| 98 | 22.8 | 113.09 | 10.28 | 43666 | 42884 | 42932 | 43160 | 1.02 | 382 |
| 99 | 28.2 | 203.28 | 13.51 | 48844 | 53587 | 52846 | 51759 | 4.93 | 255 |
| 100 | 28.1 | 218.71 | 14.18 | 39514 | 38961 | 45873 | 41449 | 9.27 | 190 |
| 101 | 23.8 | 134.07 | 9.19 | 47508 | 43941 | 41324 | 44257 | 7.01 | 330 |
| 102 | 27.5 | 209.18 | 13.55 | 47125 | 42354 | 47070 | 45516 | 6.02 | 218 |
| 103 | 27.8 | 207.82 | 12.13 | 38669 | 39878 | 40828 | 39792 | 2.72 | 191 |
| 104 | 29 | 236.95 | 16.31 | 46282 | 44485 | 47957 | 46241 | 3.75 | 195 |
| 105 | 24.4 | 138.31 | 16.34 | 25119 | 23357 | 23442 | 23973 | 4.15 | 173 |

**Appendix G continued**

| Specimen | TL (cm) | BW (g) | GW (g) | Sub-sample based estimates ($F_{abs}$) 1 | 2 | 3 | Mean $F_{abs}$ | C. V ($F_{abs}$) | $F_{rel}$(eggs $g^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 106 | 28.4 | 225.93 | 11.73 | 37136 | 40844 | 40312 | 39431 | 5.08 | 175 |
| 107 | 27.6 | 226.6 | 15.82 | 65231 | 60617 | 60316 | 62054 | 4.44 | 274 |
| 108 | 28.8 | 250 | 17.23 | 56436 | 56132 | 56122 | 56230 | 0.32 | 225 |

**Appendix H: Percentage frequency of ovum diameter of *Scomber colias***

| Ovum diameter | Percentage frequency of specimens | | | | |
|---|---|---|---|---|---|
| | a | b | c | d | e |
| 0.1 | 0.60 | 0.40 | 2.16 | 2.15 | 4.71 |
| 0.2 | 10.87 | 1.59 | 3.73 | 10.18 | 5.88 |
| 0.3 | 11.47 | 9.74 | 14.15 | 18.59 | 10.20 |
| 0.4 | 25.35 | 32.21 | 27.31 | 18.98 | 29.80 |
| 0.5 | 10.26 | 17.10 | 10.02 | 4.89 | 10.98 |
| 0.6 | 5.43 | 4.37 | 5.70 | 2.94 | 3.92 |
| 0.7 | 20.12 | 8.15 | 10.61 | 9.00 | 6.86 |
| 0.8 | 13.28 | 22.66 | 22.99 | 24.07 | 21.18 |
| 0.9 | 2.21 | 3.18 | 2.75 | 7.83 | 5.88 |
| 1 | 0.40 | 0.60 | 0.59 | 1.17 | 0.59 |
| 1.1 | | | | 0.20 | |

**Appendix I 1: Numbers of male fish of various maturity stages during the study period**

| Stage | Feb-16 | Mar-16 | Apr-16 | May-16 | Jun-16 | Jul-16 | Aug-16 | Sep-16 | Oct-16 | Nov-16 | Dec-16 | Jan-17 | Feb-17 | Mar-17 | Apr-17 | May-17 | Jun-17 | Jul-17 | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | 38 | 6 | 1 | 6 | 2 | 0 | 4 | 12 | 5 | 16 | 32 | 39 | 1 | 1 | 0 | 0 | 0 | 0 | 163 |
| II | 24 | 18 | 6 | 10 | 3 | 0 | 2 | 4 | 0 | 0 | 6 | 9 | 14 | 1 | 0 | 8 | 2 | 0 | 107 |
| III | 11 | 39 | 25 | 24 | 42 | 4 | 38 | 2 | 0 | 0 | 0 | 0 | 30 | 18 | 6 | 1 | 48 | 46 | 334 |
| IV | 18 | 33 | 20 | 10 | 55 | 20 | 23 | 0 | 0 | 0 | 0 | 0 | 3 | 6 | 5 | 1 | 24 | 11 | 229 |
| V | 0 | 0 | 4 | 5 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 3 | 0 | 19 |

**Appendix I 2: Numbers of female fish of various maturity stages during the study period**

| Stage | Feb-16 | Mar-16 | Apr-16 | May-16 | Jun-16 | Jul-16 | Aug-16 | Sep-16 | Oct-16 | Nov-16 | Dec-16 | Jan-17 | Feb-17 | Mar-17 | Apr-17 | May-17 | Jun-17 | Jul-17 | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | 33 | 22 | 1 | 6 | 0 | 0 | 0 | 27 | 0 | 36 | 21 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 158 |
| II | 17 | 25 | 3 | 18 | 1 | 0 | 0 | 4 | 0 | 1 | 12 | 9 | 10 | 0 | 1 | 12 | 8 | 0 | 121 |
| III | 13 | 25 | 23 | 15 | 37 | 49 | 8 | 1 | 0 | 0 | 0 | 0 | 19 | 25 | 9 | 1 | 73 | 56 | 354 |
| IV | 7 | 32 | 16 | 17 | 64 | 1 | 29 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 11 | 5 | 185 |
| V | 2 | 1 | 0 | 2 | 1 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 10 |

**Appendix J: Monthly changes in the percentage proportions of ripe *Scomber colias* during the study period**

| Month | Ripe females | Ripe males |
|---|---|---|
| Feb-16 | 27.77 | 31.87 |
| Mar-16 | 57.14 | 75 |
| Apr-16 | 90.7 | 80.36 |
| May-16 | 55.17 | 61.82 |
| Jun-16 | 98.06 | 91.51 |
| Jul-16 | 100 | 100 |
| Aug-16 | 100 | 91.04 |
| Sep-16 | 5.7 | 25 |
| Oct-16 | 0 | 0 |
| Nov-16 | 0 | 0 |
| Dec-16 | 0 | 0 |
| Jan-17 | 0 | 0 |
| Feb-17 | 57.88 | 68.75 |
| Mar-17 | 100 | 92.31 |
| Apr-17 | 83.33 | 84.62 |
| May-17 | 7.14 | 18.18 |
| Jun-17 | 91.3 | 93.51 |
| Jul-17 | 100 | 100 |

**Appendix K 1: Mean gonad weight (GW, g) of *Scomber colias* during the study period. s. e. = standard error**

| Month | Mean GW (Females) | Mean GW (Males) | s. e. Females | s. e. Males |
|---|---|---|---|---|
| Feb-16 | 3.51 | 4.3 | 0.73 | 0.73 |
| Mar-16 | 4.4 | 6.44 | 0.36 | 0.32 |
| Apr-16 | 9.63 | 8.41 | 0.58 | 0.49 |
| May-16 | 7.24 | 7.12 | 0.58 | 0.65 |
| Jun-16 | 11.68 | 10.44 | 0.67 | 0.42 |
| Jul-16 | 14.13 | 22.12 | 0.53 | 1.26 |
| Aug-16 | 14.65 | 16.2 | 1.24 | 0.7 |
| Sep-16 | 1.38 | 2.55 | 0.31 | 0.85 |
| Oct-16 | - | 1.03 | - | 0.69 |
| Nov-16 | 0.98 | 0.68 | 0.1 | 0.68 |
| Dec-16 | 2.26 | 1.53 | 0.26 | 1.53 |
| Jan-17 | 1.56 | 0.87 | 0.22 | 0.07 |
| Feb-17 | 3.81 | 4.55 | 0.33 | 0.24 |
| Mar-17 | 7.89 | 9.29 | 1.09 | 1.31 |
| Apr-17 | 13.13 | 16.59 | 2.92 | 3.6 |
| May-17 | 7.03 | 7.14 | 1.24 | 1.25 |
| Jun-17 | 11.57 | 13.71 | 0.64 | 1.21 |
| Jul-17 | 12.14 | 12.89 | 0.83 | 1.1 |

**Appendix K 2: Mean gonadosomatic index (GSI) of *Scomber colias* during the study period. s. e. = standard error.**

| Months | Mean GSI (Females) | Mean GSI (Males) | s. e. Females | s. e. Males |
|---|---|---|---|---|
| Feb-16 | 2.08 | 2.51 | 0.37 | 0.37 |
| Mar-16 | 2.9 | 3.69 | 0.24 | 0.16 |
| Apr-16 | 4.8 | 4.21 | 0.24 | 0.22 |
| May-16 | 3.46 | 3.6 | 0.25 | 0.26 |
| Jun-16 | 7.62 | 6.84 | 0.4 | 0.24 |
| Jul-16 | 6.3 | 9.8 | 0.21 | 0.44 |
| Aug-16 | 6.73 | 7.45 | 0.53 | 0.3 |
| Sep-16 | 0.6 | 1.06 | 0.13 | 0.32 |
| Oct-16 | - | 0.53 | - | 0.09 |
| Nov-16 | 0.51 | 0.37 | 0.05 | 0.05 |
| Dec-16 | 0.87 | 0.61 | 0.09 | 0.07 |
| Jan-17 | 1.06 | 0.68 | 0.06 | 0.11 |
| Feb-17 | 2.34 | 2.93 | 0.18 | 0.15 |
| Mar-17 | 4.16 | 4.81 | 0.42 | 0.33 |
| Apr-17 | 4.37 | 6.13 | 0.63 | 0.79 |
| May-17 | 2.64 | 2.89 | 0.49 | 0.47 |
| Jun-17 | 6.64 | 6.92 | 0.33 | 0.28 |
| Jul-17 | 6.91 | 7.07 | 0.31 | 0.3 |

**Appendix L: Percentage frequency of occurrence of prey items in the diet of *Scomber colias***

| Prey item | Feb-16 | Mar-16 | Apr-16 | May-16 | Jun-16 | Jul-16 | Aug-16 | Sep-16 | Oct-16 | Nov-16 | Dec-16 | Jan-17 | Feb-17 | Mar-17 | Apr-17 | May-17 | Jun-17 | Jul-17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fish | 54.8 | 72.92 | 81.69 | 69.23 | 52.94 | 96.45 | 83.12 | 91.07 | 80 | 100 | 100 | 100 | 96 | 93.33 | 100 | 100 | 92.2 | 97.1 |
| Decapods | 25.92 | 16.67 | 5.63 | 61.54 | 27.06 | 7.69 | 42.17 | 25 | 13.33 | 1.47 | 0 | 0 | 40 | 0 | 0 | 17.39 | 94.79 | 18.4 |
| Cephalopods | 8.15 | 11.45 | 4.23 | 1.92 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 4.35 | 0 | 0 |
| Bivalves | 0 | 0 | 1.41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gastropods | 0 | 0 | 1.41 | 0.96 | 0 | 1.92 | 0.93 | 1.79 | 0 | 1.47 | 0 | 0 | 0 | 0 | 0 | 0 | 2.08 | 0 |
| Annelids | 0.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.35 | 0 | 0 |
| Stomatopod larvae | 0 | 0 | 0 | 13 | 3.53 | 3.85 | 10.84 | 21.43 | 0 | 1.47 | 1.45 | 0 | 0 | 6.67 | 0 | 0 | 22.96 | 18.84 |
| Copepods | 0 | 0 | 0 | 0 | 0 | 0 | 19.24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.08 | 0 |
| Amphipods | 0 | 0 | 0 | 0 | 0 | 0 | 3.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Others | 45.93 | 31.25 | 14.08 | 27.88 | 31.76 | 3.85 | 12.05 | 0 | 6.67 | 0 | 0 | 0 | 0 | 6.67 | 0 | 0 | 0 | 0 |
| Chaetognaths | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.47 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Appendix M: Percentage numerical composition of prey items in the diet of *Scomber colias***

| Prey item | Feb-16 | Mar-16 | Apr-16 | May-16 | Jun-16 | Jul-16 | Aug-16 | Sep-16 | Oct-16 | Nov-16 | Dec-16 | Jan-17 | Feb-17 | Mar-17 | Apr-17 | May-17 | Jun-17 | Jul-17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fish | 31 | 40 | 67.35 | 15.33 | 25 | 82.19 | 17 | 57.99 | 44.47 | 92 | 98.57 | 100 | 58.18 | 87.5 | 100 | 80 | 76.4 | 70.45 |
| Decapods | 36 | 27 | 6.12 | 74.83 | 59 | 10.96 | 36.52 | 28.99 | 51.85 | 1.33 | 0 | 0 | 36.36 | 0 | 0 | 13.33 | 14 | 12.96 |
| Cephalopods | 5 | 17 | 7.14 | 0.46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.33 | 0 | 0 |
| Bivalves | 0 | 0 | 4.08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gastropods | 0 | 0 | 3.06 | 0 | 0 | 1.37 | 0.93 | 0.59 | 1.33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.63 | 0 |
| Annelids | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Stomatopod larvae | 0 | 0 | 0 | 3.66 | 2 | 2.74 | 5.26 | 12.42 | 0 | 1.33 | 1.43 | 0 | 5.45 | 6.25 | 0 | 2.21 | 21.95 | 12.96 |
| Copepods | 0 | 0 | 0 | 0 | 0 | 0 | 33.69 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.25 | 0 |
| Amphipods | 0 | 0 | 0 | 0 | 0 | 0 | 3.86 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Others | 27 | 16 | 12.24 | 5.72 | 15 | 2.74 | 2.94 | 0 | 3.7 | 0 | 0 | 0 | 0 | 6.25 | 0 | 0 | 0 | 0 |
| Chaetognaths | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Appendix N: Percentage gravimetric composition of prey items in the diet of *Scomber colias***

| Prey item | Feb-16 | Mar-16 | Apr-16 | May-16 | Jun-16 | Jul-16 | Aug-16 | Sep-16 | Oct-16 | Nov-16 | Dec-16 | Jan-17 | Feb-17 | Mar-17 | Apr-17 | May-17 | Jun-17 | Jul-17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fish | 60 | 72 | 81 | 69.7 | 66 | 98.09 | 87.56 | 95.31 | 93.27 | 99.29 | 99.86 | 100 | 93.09 | 97.61 | 100 | 93.35 | 94.38 | 94.96 |
| Decapods | 7 | 4 | 2 | 7.06 | 8 | 0.76 | 5.67 | 3.61 | 2.15 | 0.02 | 0 | 0 | 4.97 | 0 | 0 | 0.9 | 1.16 | 0.9 |
| Cephalopods | 1 | 6 | 8 | 0.05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.21 | 0 | 0 |
| Bivalves | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gastropods | 0 | 0 | 0 | 0 | 0 | 0 | 0.59 | 0.04 | 0 | 0.02 | 0 | 0 | 0 | 0 | 0 | 0 | 0.02 | 0 |
| Annelids | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Stomatopod larvae | 0 | 0 | 0 | 1.11 | 0 | 0.48 | 1.63 | 1.02 | 0 | 0.52 | 0.14 | 0 | 1.94 | 0.01 | 0 | 0.57 | 4.65 | 4.14 |
| Copepods | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Amphipods | 0 | 0 | 0 | 0 | 0 | 0 | 0.72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Others | 26 | 18 | 8 | 22.07 | 2 | 0.67 | 3.4 | 0 | 4.61 | 0 | 0 | 0 | 0 | 2.08 | 0 | 0 | 0 | 0 |
| Chaetognaths | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Appendix O**: **Index of Relative Importance of prey items in the diet of *Scomber colias***

| Prey item | Feb-16 | Mar-16 | Apr-16 | May-16 | Jun-16 | Jul-16 | Aug-16 | Sep-16 | Oct-16 | Nov-16 | Dec-16 | Jan-17 | Feb-17 | Mar-17 | Apr-17 | May-17 | Jun-17 | Jul-17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fish | 4987.71 | 8167.04 | 12118.71 | 5886.63 | 4817.54 | 17388 | 8692.07 | 13961 | 11019.2 | 19129 | 19843 | 20000 | 14521.9 | 17276.3 | 20000 | 17635 | 16599.8 | 16061.3 |
| Decapods | 1114.56 | 516.77 | 45.72 | 5039.51 | 1813.2 | 90.13 | 1770.72 | 815 | 719.82 | 1.98 | 0 | 0 | 1653.2 | 0 | 0 | 247.46 | 1437.02 | 255.02 |
| Cephalopods | 48.9 | 263.58 | 64.04 | 0.98 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24.1 | 0 | 0 |
| Bivalves | 0 | 0 | 5.75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gastropods | 0 | 0 | 5.72 | 0 | 0 | 26.3 | 9.15 | 1.13 | 0 | 1.98 | 0 | 0 | 0 | 0 | 0 | 0 | 3.43 | 0 |
| Annelids | 0.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Stomatopod larvae | 0 | 0 | 0 | 62 | 7.06 | 12.4 | 74.69 | 288.02 | 0 | 2.72 | 2.28 | 0 | 88.68 | 42.35 | 0 | 16.83 | 610.74 | 322.16 |
| Copepods | 0 | 0 | 0 | 0 | 0 | 0 | 657.49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.24 | 0 |
| Amphipods | 0 | 0 | 0 | 0 | 0 | 0 | 16.49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Others | 2434.29 | 1062.5 | 284.98 | 774.79 | 539.92 | 13.13 | 76.4 | 0 | 55.43 | 0 | 0 | 0 | 0 | 55.56 | 0 | 0 | 0 | 0 |
| Chaetognaths | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.09 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Appendix P: Vacuity index and Index of Stomach Fullness (ISF) of *Scomber colias* during the study period. s. e. = standard error**

| Month | Vacuity index | s. e. (vacuity index) | ISF | s. e. (ISF) |
|---|---|---|---|---|
| Feb-16 | 17 | 2.90 | 1.57 | 0.14 |
| Mar-16 | 54 | 3.44 | 0.48 | 0.05 |
| Apr-16 | 28 | 4.44 | 0.77 | 0.07 |
| May-16 | 11 | 2.84 | 1.26 | 0.07 |
| Jun-16 | 62 | 3.29 | 0.29 | 0.03 |
| Jul-16 | 32 | 5.33 | 0.54 | 0.08 |
| Aug-16 | 51 | 3.87 | 0.67 | 0.07 |
| Sep-16 | 78 | 2.60 | 0.55 | 0.21 |
| Oct-16 | 58 | 8.69 | 0.56 | 0.18 |
| Nov-16 | 70 | 3.01 | 0.16 | 0.02 |
| Dec-16 | 24 | 4.40 | 0.64 | 0.18 |
| Jan-17 | 71 | 5.19 | 0.29 | 0.07 |
| Feb-17 | 69 | 5.17 | 0.14 | 0.03 |
| Mar-17 | 71 | 6.25 | 0.4 | 0.11 |
| Apr-17 | 28 | 8.80 | 0.43 | 0.08 |
| May-17 | 8 | 5.32 | 0.43 | 0.08 |
| Jun-17 | 46 | 3.76 | 0.32 | 0.03 |
| Jul-17 | 45 | 4.49 | 0.77 | 0.11 |

**Appendix Q: Percentage of otoliths with a hyaline edge, and mean marginal increment width of *Scomber colias* otoliths from off the coast of Ghana. s. e = standard error**

| Month | Total number of otoliths | % Hyaline edge | s. e. (% Hyaline edge) | Mean marginal increment width (µm) | s. e. |
|---|---|---|---|---|---|
| Feb-16 | 50 | 74.00 | 6.08 | 21.59 | 1.42 |
| Mar-16 | 23 | 82.61 | 7.75 | 22.73 | 2.09 |
| Apr-16 | 15 | 66.67 | 11.93 | 23.03 | 3.91 |
| May-16 | 24 | 87.50 | 6.62 | 30.88 | 3.7 |
| Jun-16 | 38 | 84.21 | 5.80 | 24.63 | 2.19 |
| Jul-16 | 18 | 72.22 | 10.35 | 18.96 | 2.21 |
| Aug-16 | 26 | 30.77 | 8.87 | 15.29 | 2.39 |
| Sep-16 | 19 | 63.16 | 10.85 | 24.66 | 4.83 |
| Oct-16 | 10 | 100.00 | 0.00 | 27.86 | 3.68 |
| Nov-16 | 26 | 88.46 | 6.14 | 28.31 | 3.19 |
| Dec-16 | 29 | 96.55 | 3.32 | 35.93 | 3.5 |
| Jan-17 | 20 | 85.00 | 7.82 | 33.2 | 4.62 |
| Feb-17 | 18 | 100.00 | 0.00 | 33.31 | 2.69 |
| Mar-17 | 11 | 72.73 | 13.16 | 24.27 | 4.09 |
| Apr-17 | 23 | 78.26 | 8.43 | 25.82 | 2.92 |
| May-17 | 24 | 83.33 | 7.46 | 24.57 | 2.58 |
| Jun-17 | 30 | 86.67 | 6.08 | 29.2 | 2.67 |
| Jul-17 | 34 | 94.12 | 3.95 | 31.77 | 2.06 |

**Appendix R: Age distribution of *Scomber colias* from off the coast of Ghana**

| | Number of fish at age | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Length classes (*TL*, cm) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 16.0-16.9 | 3 | | | | | | | | |
| 17.0-17.9 | 1 | 1 | | | | | | | |
| 18.0-18.9 | | | | | | | | | |
| 19.0-19.9 | 1 | | | | | | | | |
| 20.0-20.9 | 1 | | | 1 | | | | | |
| 21.0-21.9 | 3 | 6 | | | | | | | |
| 22.0-22.9 | 2 | 9 | 8 | | | | | | |
| 23.0-23.9 | | 7 | 12 | 2 | | | | | |
| 24.0-24.9 | | 4 | 24 | 12 | 2 | | | | |
| 25.0-25.9 | | 1 | 18 | 40 | 2 | | | | |
| 26.0-26.9 | | | 13 | 36 | 6 | 1 | | | |
| 27.0-27.9 | | | 12 | 25 | 23 | | 1 | | |
| 28.0-28.9 | | | 4 | 19 | 34 | 4 | 1 | | |
| 29.0-29.9 | | | 2 | 6 | 29 | 14 | | | |
| 30.0-30.9 | | | | 2 | 14 | 6 | 2 | | |
| 31.0-31.9 | | | 1 | 2 | 1 | 2 | | | |
| 32.0-32.9 | | | | 1 | 1 | 2 | 1 | | |
| 33.0-33.9 | | | | | | 1 | 1 | | |
| 34.0-34.9 | | | | | 1 | 2 | | | |
| 35.0-35.9 | | | | | | | | 2 | |
| 36.0-36.9 | | | | | | 1 | | 1 | |
| 37.0-37.9 | | | | | | | | | |
| 38.0-38.9 | | | | | | 1 | | | |
| 39.0-39.9 | | | | | | | | | |
| 40.0-40.9 | | | | | | | | | 1 |
| Total number | 11 | 28 | 94 | 146 | 113 | 34 | 6 | 3 | 1 |
| Mean length | 19.6 | 22.7 | 25.4 | 26.7 | 28.6 | 30.6 | 30.5 | 35.8 | 40.5 |
| Standard deviation | 2.5 | 1.5 | 1.8 | 1.7 | 2.1 | 2.4 | 2.3 | 0.3 | 0.0 |

**Appendix S: Monthly length-frequency distributions *of Scomber colias***

| Midpoints | Totals | Feb-16 | Mar-16 | Apr-16 | May-16 | Jun-16 | Jul-16 | Aug-16 | Sep-16 | Oct-16 | Nov-16 | Dec-16 | Jan-17 | Feb-17 | Mar-17 | Apr-17 | May-17 | Jun-17 | Jul-17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13.45 | 1 | | | | | | | | | 1 | | | | | | | | | |
| 14.45 | 10 | | | | | | | | 10 | | | | | | | | | | |
| 15.45 | 23 | | | | | | | 6 | 17 | | | | | | | | | | |
| 16.45 | 61 | | | | | | | 24 | 30 | | 7 | | | | | | | | |
| 17.45 | 92 | | | | | | | 16 | 58 | 2 | 16 | | | | | | | | |
| 18.45 | 92 | | | | | | | 8 | 48 | 1 | 35 | | | | | | | | |
| 19.45 | 59 | 1 | | | | | | 3 | 26 | 4 | 25 | | | | | | | | |
| 20.45 | 41 | 3 | | | | | | 1 | 4 | 8 | 23 | | 1 | | | | | | 1 |
| 21.45 | 40 | 4 | 3 | | | | | | | 9 | 17 | | 5 | | | | | | 2 |
| 22.45 | 115 | 23 | 11 | | | 5 | | | | 4 | 37 | | 15 | | | | | 5 | 15 |
| 23.45 | 195 | 38 | 32 | | | 52 | | | | | 6 | | 17 | 9 | 4 | | | 13 | 24 |
| 24.45 | 271 | 30 | 63 | 10 | 4 | 58 | | | 2 | | 1 | 7 | 18 | 30 | 14 | | | 19 | 15 |
| 25.45 | 277 | 20 | 63 | 17 | 27 | 40 | | | 5 | | 5 | 6 | 5 | 28 | 18 | 1 | | 35 | 7 |
| 26.45 | 271 | 10 | 17 | 32 | 49 | 32 | 9 | 6 | 13 | | 26 | 4 | 6 | 7 | 5 | 5 | | 41 | 9 |
| 27.45 | 205 | 5 | 10 | 17 | 17 | 8 | 18 | 19 | 13 | | 16 | 18 | 3 | 2 | 4 | | 2 | 33 | 20 |

**Appendix S continued**

| Midpoints | Totals | Feb-16 | Mar-16 | Apr-16 | May-16 | Jun-16 | Jul-16 | Aug-16 | Sep-16 | Oct-16 | Nov-16 | Dec-16 | Jan-17 | Feb-17 | Mar-17 | Apr-17 | May-17 | Jun-17 | Jul-17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28.45 | 204 | 14 | 2 | 15 | 6 | 7 | 29 | 58 | 9 | 1 | 4 | 22 | 3 | 1 | 3 | 4 | 5 | 13 | 8 |
| 29.45 | 102 | 5 | | 5 | 5 | 4 | 13 | 18 | 5 | | 3 | 18 | | | 1 | 3 | 11 | 3 | 8 |
| 30.45 | 47 | 3 | | 1 | 3 | 3 | 4 | | 4 | | | 11 | | | | 7 | 5 | 2 | 4 |
| 31.45 | 13 | 1 | | 1 | 2 | | | | | | | 3 | | | | 1 | 1 | 1 | 3 |
| 32.45 | 11 | 2 | | | | | 1 | | 1 | | 1 | 2 | | | 1 | 1 | 1 | | 1 |
| 33.45 | 3 | 1 | | | | | | | | | | | | | | 1 | | 1 | |
| 34.35 | 5 | 1 | | 1 | | | | 1 | | | | | | | | | | 1 | 1 |
| 35.45 | 4 | 2 | | | | | | | | | | | | | 1 | | | 1 | |
| 36.45 | 2 | | | | | | | | | | | | | | | 2 | | | |
| 37.45 | 0 | | | | | | | | | | | | | | | | | | |
| 38.45 | 1 | | | | | | | | | | | | | | | | | 1 | |
| 39.45 | 0 | | | | | | | | | | | | | | | | | | |
| 40.45 | 1 | | | | | | | | | 1 | | | | | | | | | |

**Appendix T: Estimated lengths-at-age from the von Bertalanffy growth curve**

| Age | Length (VGBF) |
| --- | --- |
| 0 | 6.0 |
| 1 | 14.9 |
| 2 | 21.6 |
| 3 | 26.7 |
| 4 | 30.6 |
| 5 | 33.5 |
| 6 | 35.7 |
| 7 | 37.3 |
| 8 | 38.6 |
| 9 | 39.5 |
| 10 | 40.2 |
| 11 | 40.8 |

**Appendix U: Distribution of species in "saiko" slabs from February 2016-January 2017. *BD- Bathydemersal, BP-Bathypelagic, D-Demersal, P-Pelagic, RA-Reef associated.**

| Family | Species | Common name | Habitat | % by number | % by weight |
|---|---|---|---|---|---|
| Acanthuridae | *Acanthurus monroviae* | Surgeonfish | D | 0.04% | 0.35% |
| Apogonidae | *Apogon affinis* | Bigtooth cardinalfish | D | 0.11% | 0.01% |
| Ariommatidae | *Ariomma bondi* | Silver-rag driftfish | BP | 2.79% | 1.78% |
| | *Ariomma melanum* | Brown driftfish | P | 3.33% | 3.53% |
| Balistidae | *Balistes capriscus* | Grey triggerfish | D | 0.28% | 1.15% |
| | *Balistes punctatus* | Bluepotted triggerfish | D | 0.05% | 0.27% |
| Bathysauridae | *Bathysaurus ferox* | Deep-sea lizardfish | BD | 0.09% | 0.06% |
| Batrachoididae | *Halobatrachus didactylus* | Lusitanean toadfish | D | 0.02% | 0.02% |
| Bothidae | *Bothus guibei* | Guinean flounder | D | 0.04% | 0.03% |
| | *Bothus podas* | Wide-eyed flounder | D | 0.14% | 0.08% |
| | *Arnoglossus imperialis* | Imperial scaldfish | D | 0.07% | 0.01% |
| Branchiostegidae | *Branchiostegus semifasciatus* | Zebra tilefish | D | 0.11% | 0.19% |
| Carangidae | *Decapterus rhoncus* | Mackerel scad | P | 10.59% | 6.16% |
| | *Trachurus trecae* | Cunene horse mackerel | BP | 12.18% | 7.53% |
| | *Chloroscombrus chrysurus* | Atlantic bumper | BP | 0.72% | 0.69% |
| | *Decapterus punctatus* | Round scad | RA | 14.60% | 8.92% |
| | *Trachinotus ovatus* | Pompano | BP | 0.02% | 0.02% |
| | *Selar crumenophthalmus* | Bigeye scad | P | 1.96% | 2.28% |
| | *Trachurus trachurus* | Horse mackerel | BP | 0.12% | 0.09% |
| | *Caranx crysos* | Blue runner | BP | 0.04% | 0.02% |
| | *Selene dorsalis* | African lookdown | P | 0.02% | 0.01% |

**Appendix U continued**

| Family | Species | Common name | Habitat | % by number | % by weight |
|---|---|---|---|---|---|
| Chaetodontidae | *Chaetodon hoefleri* | Butterflyfish | D | 0.07% | 0.07% |
| Citharidae | *Citharus linguatula* | Spotted flounder | D | 0.42% | 0.34% |
| Clupeidae | *Sardinella maderensis* | Flat sardine | P | 1.16% | 0.61% |
| | *Sardinella aurita* | Round sardine | P | 5.89% | 4.29% |
| Cynoglossidae | *Cynoglossus sp.* | Tongue sole | D | 0.14% | 0.17% |
| Dactylopteridae | *Dactylopterus volitans* | Flying gurnard | RA | 1.72% | 7.70% |
| Elopidae | *Elops lacerta* | Lady fish | P | 0.11% | 0.01% |
| Engraulidae | *Engraulis encrasicolus* | European anchovy | P | 0.77% | 0.18% |
| Emmelichthyidae | *Erythrocles monodi* | Atlantic rubyfish | D | 0.09% | 0.13% |
| Fistulariidae | *Fistularia spp* | Cornetfish | D | 0.04% | 0.01% |
| Haemulidae | *Brachydeuterus auritus* | Bigeye grunt | D | 6.28% | 7.89% |
| | *Parakuhlia macrophthalmus* | Dara | P | 0.05% | 0.09% |
| Holocentridae | *Sargocentron hastatus* | Red squirrelfish | P | 0.02% | 0.04% |
| Labridae | *Xyrichthys novacula* | Pearly razorfish | D | 0.05% | 0.07% |
| Loliginidae | *Alloteuthis africana* | African squid | D | 0.05% | 0.11% |
| Lutjanidae | *Apsilus fuscus* | African forktail snapper | D | 0.46% | 0.30% |
| | *Lutjanus fulgens* | Golden african snapper | D | 0.02% | 0.01% |
| | *Lutjanus endecacanthus* | Guinea snapper | D | 0.02% | 0.03% |
| Monacanthidae | *Stephalenolepis hispidus* | Planehead filefish | D | 0.02% | 0.04% |
| | *Aluterus heudelotii* | Dotterel filefish | D | 0.09% | 0.23% |

**Appendix U continued**

| Family | Species | Common name | Habitat | % by number | % by weight |
|---|---|---|---|---|---|
| Mullidae | *Pseudupeneus prayensis* | Goatfish | D | 0.42% | 0.29% |
| Muraenesocidae | *Cynoponticus ferox* | Guinean pike conger | D | 0.12% | 1.51% |
| Nomeidae | *Psenes spp* | Driftfish | BP | 0.02% | 0.02% |
| Ommastrephidae | *Sthenoteuthis pteropus* | Orangeback squid | D | 0.04% | 0.04% |
| Ophichthidae | *Echelus myrus* | Painted eel | D | 0.04% | 0.33% |
| Paralichthyidae | *Syacium micrurum* | Papillose flounder | D | 1.30% | 1.46% |
| Polynemidae | *Galeoides decadactylus* | Threadfin | D | 0.09% | 0.08% |
| Pomacentridae | *Chromis cadenati* | Damselfish | RA | 1.79% | 2.29% |
| Priacanthidae | *Priacanthus arenatus* | Atlantic bigeye | RA | 2.42% | 3.30% |
| Rajidae | *Rhinobatos albomaculatus* | Whitespotted guitarfish | D | 0.02% | 0.31% |
| | *Raja miraletus* | Brown ray | D | 0.23% | 1.06% |
| Sciaenidae | *Pteroscion peli* | Boe drum | D | 0.02% | 0.02% |
| Scombridae | *Acanthocybuim solandri* | Wahoo | P | 0.02% | 0.03% |
| | *Scomber colias* | Atlantic chub mackerel | P | 2.30% | 3.48% |
| | *Scomberomorus tritor* | West African Spanish Mackerel | P | 0.02% | 0.03% |
| Sepiidae | *Sepia bertheloti* | Cuttlefish | D | 0.04% | 0.03% |
| | *Sepia ornata* | Cuttlefish | D | 0.09% | 0.05% |
| | *Sepia hierreda* | Cuttlefish | D | 0.19% | 0.13% |
| Serranidae | *Rypticus saponaceus* | Greater soapfish | D | 0.02% | 0.05% |
| | *Serranus accraensis* | Ghanaian comber | D | 0.98% | 0.69% |

**Appendix U continued**

| Family | Species | Common name | Habitat | % by number | % by weight |
|---|---|---|---|---|---|
| Soleidae | *Bathysolea profundicola* | Deep-water sole | D | 0.02% | 0.04% |
| | *Bathysolea albida* | Sole | D | 0.04% | 0.05% |
| | *Microchirus hexophthalma* | Ocellated wedge sole | D | 0.02% | 0.03% |
| | *Microchirus frechkopi* | Frechkop's sole | D | 0.23% | 0.16% |
| | *Microchirus ocellatus* | Four-eyed sole | D | 0.02% | 0.02% |
| | *Pegusa lascaris* | Sand sole | D | 0.05% | 0.13% |
| | *Dicologlossa cuneata* | Wedge sole | D | 0.05% | 0.09% |
| Sparidae | *Boops boops* | Bogue | D | 2.49% | 2.36% |
| | *Pagrus caeruleostictus* | Blue-spotted sea bream | D | 0.25% | 0.12% |
| | *Pagellus bellottii* | Red pandora | D | 12.96% | 6.60% |
| | *Dentex congoensis* | Congo dentex | D | 0.49% | 0.26% |
| | *Spicara alta* | Bigeye picarel | D | 0.18% | 0.16% |
| | *Dentex macrophthalmus* | Large-eye dentex | D | 0.02% | 0.01% |
| | *Dentex angolensis* | Angola dentex | D | 0.74% | 0.36% |
| Synodontidae | *Synodus saurus* | Atlantic lizardfish | D | 0.04% | 0.03% |
| | *Trachinocephalus myops* | Lizard fish | RA | 0.68% | 1.62% |
| Tetraodontidae | *Sphoeroides marmoratus* | Guinean puffer | P | 0.05% | 0.03% |
| | *Lagocephalus laevigatus* | Smooth puffer | P | 0.88% | 7.65% |
| Trachinidae | *Trachinus lineolatus* | Striped weever | D | 0.02% | 0.03% |
| Triakidae | *Mustelus mustelus* | Smooth-hound | D | 0.02% | 0.04% |
| Trichiuridae | *Trichiurus lepturus* | Largehead hairtail | BP | 3.73% | 6.24% |

**Appendix U continued**

| Family | Species | Common name | Habitat | % by number | % by weight |
|---|---|---|---|---|---|
| Triglidae | *Lepidotrigla carolae* | Sea robin | BD | 2.02% | 2.78% |
| Uranoscopidae | *Uranoscopus polli* | White-spotted stargazer | D | 0.16% | 0.41% |

**Appendix V: Length- frequency of *Scomber colias* in trawl bycatch**

| Class midpoint | Frequency |
|---|---|
| 13.0-13.9 | 4.3% |
| 14.0-14.9 | 4.3% |
| 15.0-15.9 | 11.6% |
| 16.0-16.9 | 5.8% |
| 17.0-17.9 | 14.5% |
| 18.0-18.9 | 2.9% |
| 19.0-19.9 | 4.3% |
| 20.0-20.9 | 18.8% |
| 21.0-21.9 | 18.8% |
| 22.0-22.9 | 5.8% |
| 23.0-23.9 | 2.9% |
| 24.0-24.9 | 0.0% |
| 25.0-25.9 | 1.4% |
| 26.0-26.9 | 4.3% |

**Appendix W: Percentage nutrient composition of dry *Scomber colias* tissue during the sampling period (quarters) ; s. e.= standard error, q indicates quarter**

| Nutrient | Jan-March 2016 | April-June 2016 | July-Sept. 2016 | Oct.-Dec. 2016 | Jan-March 2017 | April-June 2017 | Jul-17 | s. e 1q | s. e 2q | s. e. 3 q | s. e. 4q | s. e. q5 | s. e. q6 | s. e. .q7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Protein | 62.27 | 72.03 | 72.68 | 65.91 | 68.37 | 69.66 | 77.17 | 0 | 0.12 | 0.08 | 2.05 | 1.39 | 0.89 | 2.95 |
| Fat | 15.85 | 13.49 | 15.12 | 24.76 | 14.77 | 18.59 | 6.55 | 0 | 0.09 | 0.08 | 1.69 | 2.18 | 1.2 | 1.1 |
| Carbohydrate | 9.74 | 2.33 | 1.14 | 1.69 | 2.83 | 1.38 | 1.74 | 0 | 0.95 | 0.25 | 0.07 | 0.1 | 0.08 | 0.11 |
| Moisture | 5.25 | 6.46 | 6.53 | 4.41 | 11.09 | 6.26 | 6.76 | 0 | 0.21 | 0.17 | 0.19 | 0.45 | 0.18 | 0.62 |
| Fibre | 2.57 | 0.13 | 0.12 | 1.02 | 1.69 | 0.73 | 0.98 | 0 | 0 | 0 | 0.05 | 0.33 | 0.03 | 0.04 |
| Ash | 3.53 | 4.51 | 4.94 | 3.13 | 3.47 | 4.59 | 6.96 | 0 | 0.12 | 0.08 | 0.3 | 0.35 | 0.17 | 0.56 |