CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

Ghanaian Fisheries

The Ghanaian fishery is operated in about 24,300 km^2 of marine continental shelf area and approximately 11,000 km^2 inland waters (Bannerman & Cowx, 2002; MOFA, 2012). The marine fishery is the backbone of the fishery sector and has been a significant non-traditional export commodity since the introduction of the Economic Recovery Program in 1984 (Quaatey, 1996). The marine fisheries sector is usually categorized into three main subsectors namely industrial, semi-industrial (inshore) and artisanal (canoe) fisheries (Quaatey, 1997). The artisanal fisheries subsector is the most important with respect to landed weight of fish, contributing about 70 % of the total annual landings of the marine fishery (MOFA, 2012) and employment (Amador, Bannerman, Quartey & Ashong, 2006). FAO (2005) defines artisanal fisheries as traditional fisheries involving fishing households (as opposed to commercial companies) using relatively small amount of capital and energy and relatively small fishing vessels (if any) making short fishing trips close to shore mainly for local consumption. The Ghanaian fishery is characterized by the use of several gears like purse seine net, beach seine net, set net, drifting gillnet and hook and line which are mainly operated from dug-out canoes, powered by outboard motors with engines up to 40 hp (Amador *et al*., 2006). According to MOFA (1995), the artisanal and inshore fisheries provide Ghanaians with fish both for domestic use and export, whilst industrial fishery is export-oriented. The freshwater sector comprises the Volta

Lake, reservoirs and aquaculture systems which include fishponds and cages (MOFA, 2012).

The Sardinella Fishery

Generally, Ghana's marine resources comprise over 300 different species of commercial importance. These include 17 species of cephalopods, 25 species of crustaceans and 3 species of turtles (Anon, 2003). The round and flat sardines are the most important small pelagic fish species in Ghanaian waters and throughout the Western Gulf of Guinea (Koranteng, 1995; Bannerman & Cowx, 2002; Pascual-Alayón *et al*., 2012). They are also exploited by all the three fisheries subsectors (Koranteng, 1995; Minta, 2003). According to the 2013 Agric Sector Annual Progress Report, the total annual fish production for the year was estimated at 434,120.32 metric tons where the marine fisheries accounted for 73 %, inland fisheries 20 % and aquaculture 7 %. In 2011, the total annual fish production for the year was estimated at 440,990 metric tons where the marine fisheries accounted for 74 %; round sardines contributed about 21,011 metric tons (6.4 % of the marine production), whilst flat sardine landings were estimated at 10,718 metric tons (3.3 % of the marine production). The sardine contribution fluctuates and could increase to 30 % or more depending on the environmental factors (Koranteng, 1995). The round sardine (*Sardinella aurita* Valenciennes, 1847) is locally known as 'Eban' or 'Kankama'(Koranteng, 1989; Minta, 2003) and the flat sardine (*Sardinella maderensis* Lowe, 1838) as 'Antebo', 'Adruku' or 'Antar' (Koranteng, 1989; Minta, 2003).

The main types of fishing gears used by artisanal fishermen in the fisheries have different geographical distributions along the coast of Ghana and the dominance of a particular type of gear in a specific area is influenced by the target species (Bannerman & Cowx, 2002). According to the same authors, purse seining is prominent in the Greater Accra and Central Regions where small pelagics are heavily fished, whilst drift nets and set-nets are predominant in the Western and Central Regions.

Sardinella fishery has a long history in Ghana. Before the advent of purse seine gear and motorized fishing in 1958, the fishery which was localized in the coastal waters off Accra and Sekondi-Takoradi was exploited mainly by “ali” (drifting gill net) and beach seine nets (Lawson and Kwei, 1974). The “poli” and “watsa” are both purse seine nets used in the sardinella fishery. However, poli net is the main artisanal fishing gear used in the exploitation of the sardines (Koranteng, 1989; Bannerman & Cowx, 2002). Drifting gill net (ali) is also used mainly during the night and throughout the year, but most particularly before the onset and towards the end of the sardine season when the fish are not shoaling (Koranteng, 1989).

In the Western Gulf of Guinea, the migration pattern of *S. aurita* off Cote d'Ivoire – Ghana, its biological functions and fishery are closely linked with the upwelling cycle (Brainerd, 1991). Before the cold, nutrient-rich water begins to rise up, the adult population winters at depths ranging from 50 to 80 m off central Ghana (Zei, 1969a; Anon, 1976; Koranteng, 1989; Brainerd, 1991). Normally, at the beginning of July when the coastal upwelling starts *S. aurita* population migrates closer to the coastal areas and thus becomes accessible to the local fishing fleets particularly canoes (Zei, 1962a; Brainerd, 1991; Koranteng, 1995). At the commencement of the fishing season, the fish move towards the shores of Cote d'Ivoire and western Ghana. They turn eastward as they approach the coast and continue in this direction to Togo and at times as far as Benin (Anon, 1976; Koranteng, 1989). At the end of this season, normally toward the month of October, the area of distribution of this stock begins to contract and in December the population returns to deep-waters for wintering (Brainerd, 1991). Similar displacements toward the coast are also produced with the minor upwelling observed in about three weeks normally from January to February, but their extent is equally restricted (Koranteng, 1989; Brainerd, 1991). Spawning which could occur more or less throughout the year, is then at its maximum during the upwelling period (Zei, 1969b; Koranteng, 1989). Since migration requires energy to perform, the sardinella stocks take advantage of the upwelling conditions and its attendant abundant food supply to build and store energy. The water current allows the larvae and juveniles to drift in the right directions to ensure overall survival or recruitment success (Koranteng, 1989; Brainerd, 1991). According to Koranteng (1989), there are doubts as to whether one or more separate stocks of *S. aurita* exist off Cote d'Ivoire – Ghana. The above description of the migratory routes of the round sardines off Cote d'Ivoire – Ghana agrees with the single-stock school of thought. The second school of thought maintains that there are two separate and independent stocks, one stock on the eastern side of Cape Three

Points (Ghana stock) and the other on the western side of the Cape Three Points (Koranteng, 1989; Koranteng, 1995).

Off Ghana the migration pattern of flat sardines has not been as well established as that of the round sardines (Koranteng, 1995). According to Cury and Fontana (1988) *S. maderensis* is more of a coastal species and relatively sedentary with limited seasonal migration along the coast. However, Brainerd (1991) reported that the species undertakes extensive movements in the southern sub-tropical area of Congo-Angola.

In the 1960s, the sardinellas contributed about 65 % of Ghana’s total annual catch which was harvested mainly during the main upwelling period (Hammond, 1962). Furthermore, Kwei (1964) reported that *S. aurita* was the most exploited fish in Ghana’s waters accounting for more than 50 % of yearly landings of marine fish. In other words, *S. aurita* was of more commercial importance than *S. maderensis*, which still holds currently.

The sardinella fishery had its first record landing of over 90,000 tonnes in 1972, where almost all landing beaches were choked with the fish. Primarily round sardines contributed about 92 % of the landings (Anon, 1976; Koranteng, 1989). Consequently, the price of the sardinellas crashed within days to the extent fishermen were compelled to dump the fish they had painstakingly caught back into the sea when prices were appalling (Koranteng, 1989). In anticipation of a repetition of the 1972 landings, there was increased capitalization in the fishery by way of addition of new vessels, fishing gears, storage and ice plants (Anon, 1976). However, stakeholders in the fishery were disappointed when *S. aurita* virtually vanished from the catches of Ghanaian, Ivorian and Togolese fishermen in 1973. Subsequently, the fishery collapsed with the industry recording the lowest catches in the following two years (Koranteng, 1989). After the heavy exploitation in 1972, the catches of the sardinellas especially *S. aurita* had been very variable and unpredictable even though there had been good catches from 1985 to 1988 (average of 80,000 tonnes). Again, another record harvest of about 120,000 tonnes was made in 2001 which increased the hope of stakeholders in the fishery (Koranteng, 1989).

Literature Review

Distribution of round sardine and flat sardine in the world

S. aurita is widely distributed throughout the tropical and subtropical seas including the Mediterranean and Black seas (Whitehead, 1985; Bauchot, 1987; Froese & Pauly, 2003). Its range extends to the western and eastern Atlantic Ocean and the Pacific Ocean, (Bauchot, 1987). According to Anon (1976), the *S. aurita* stock off Ivory Coast and Ghana extends from off Jacqueville in Ivory Coast to Port Seguro in Togo. Through a tagging research, it was found out that the stock lives in concentrations in deeper waters of the continental shelf east of Cape Three Points (Anon, 1976; Koranteng, 1995). Vertically, the stocks occur up to about 350 m depth (Whitehead, 1985).

S. maderensis is also known as *Sardinella eba* (Schneider, 1990). According to Whitehead (1985), the species is geographically present in the Mediterranean Sea (southern and eastern parts, also penetrating Suez Canal) and the Eastern Atlantic Ocean (Gilbraltar southward to Angola and a single recorded specimen from Walvis Bay, Namibia). Besides, it occurs between the surface to about 50 m depth (Whitehead, 1985). Cury and Fontana (1988) reported that *S. maderensis* stocks are more widely distributed in the Gulf of Guinea and the whole region of Eastern Central Atlantic than *S. aurita*. Presumably, the largest concentrations are found off Ivory Coast and Sierra Leone (Zei, 1969b).

Stock assessment of sardines

Research on the population dynamics and fishery of the sardinellas particularly *S. aurita* was started in the early 1960s (Koranteng, 1989; Koranteng, 1995). Zei (1962b) indicated that the quest to understand the biology of the sardine stocks was one of the main reasons which led to the establishment of the Fishery Research Unit, now the Fisheries Scientific Survey Division (FSSD) at Tema (formerly Marine Fisheries Research Division, MFRD).

The exploitation rates have been reported on *Sardinella aurita* (El-Sayed, 2009; Salem, El-Aiatt & Ameran, 2010; Mehanna & Salem, 2011) *Sardina pilchardus* (Bedairia & Djebar, 2009; Bouaziz, Kerzabi & Brahmi, 2014) and *Sardinella longiceps* (Aripin & Showers, 2000; Rohit & Bhat, 2003).

The biology, population dynamics and age determination by scales of round sardines have been studied (Muta, 1964; Muta, 1966). Zei (1969b) reported that *S. aurita* is the most abundant of the *sardinella* species off Ghana, partly west and north of Sierra Leone and south of Cape Lopez. Kwei (1988) studied the migratory root of the round sardines. Also, Knudsen (1971) studied the mortalities of sardinella stocks in Ghanaian waters by the approach of length-based data and tagging experiments. Works on the sardinella fishery and the coastal hydrography of Ghana were reported by Ocren & Ofori-Adu (1973).

In Sri Lanka, Dayaratne (1986) compared the primary growth rings of sagittal otolith of *Sardinella* species and *Sprattus sprattus* from Norway. Dayaratne and Gjosaeter (1986) reported on the age and growth of four *Sardinella* spp. using sagittal otolith. In Northwest Africa, Krzeptowski (1981) reported on the growth characteristics of *S. aurita* in Senegal. The method of determining age and growth rate of *S. aurita* population off Senegal-Mauritania was investigated by Chesheva (1998). Age and growth of *S. aurita* was studied by Tsiklirasi, Koutrakis and Stergiou (2005) in northern Mediterranean.

Reproduction

Many authors have worked on the reproductive biology of round sardines in the eastern (Cury & Fontana, 1988; Roy *et al.*, 1989; Brainerd, 1991; Quaatey and Maravelias, 1999) and western Atlantic Ocean (Bakun and Parrish, 1990; Fréon, El-Khattabi, Mendoza & Guzman, 1997) as well as in the Mediterranean Sea (El-Rashidy, 1987; Tsikliras and Antonopoulou, 2006). The sex ratio of *S. aurita* was reported as 1: 1 (Fréon *et al*., 1997; Tsikliras & Antonopoulou, 2006; Lawson & Doseku, 2013). However, Gaamour *et al*. (2001) and Pawson and Giama (1985) observed female preponderance in the species. Although literature on the reproductive biology of *S. maderensis* are relatively few, researchers like Fontana and Pianet (1973), Cury and Fontana (1988), Brainerd (1991) and Gabche and Hockey (1995) reported on the subject. In *S. maderensis,* the sex ratio was given as 1:1 (Gabche & Hockey, 1995) off Kribi, Cameroon.

Sardines and anchovies mature within the first year of growth (Ganias, Somarakis & Nunes, 2014). It has been reported that males of *S. aurita* mature sexually at a smaller size than the females (Quaatey & Maravelias, 1999; Gaamour *et al*., 2001; Tsikliras & Antonopoulou, 2006) as well as in *S. maderensis* (Youmbi, Djama & Gabche, 1991). Pezenne and Koranteng (1998) observed that the size at first maturity of *S. aurita* off Côte d'Ivoire had increased from 15-16 cm in 1969 to 19-20 cm in 1990, which the authors attributed to increasing impact of the minor upwelling on the ecosystem. Similarly, the female population maturity size off Ghana was reported to have increased from 14.5 cm to 17.1 cm (Quaatey and Maravelias, 1999).

Maturation of gonads occurs at the cellular level. However, gross visual examination of gonads has been used to determine the spawning state of the gonads (Potts & Wootton, 1984; Vasconcelos, Afonso-Dias & Faria, 2012). Anon. (1976) reported that both sexes of the sardines attain gonadal maturation synchronously. Several authors (Cury & Fontana, 1988; Koranteng, 1989; Koranteng, 1995) have indicated that *S. aurita* spawns in Ghana waters during the upwelling periods from January to February and a major spawning between July to September. However, some reports noted that *S. aurita* could spawn outside the upwelling season (Pezenne & Koranteng, 1998; Quaatey & Maravelias, 1999). Koranteng (1989) published that eggs and larvae of sardines are found almost year round with higher abundance during the upwelling periods, suggesting that the fish spawns year round. In the Congolese waters, *S. aurita* was observed to reproduce throughout the year (Cury & Fontana, 1988).

Frequency distribution of oocyte diameter has been used to provide evidence of the duration of spawning (Somvanshi, 1980; Shinkafi & Ipinjolu, 2012). According to Ganias *et al*. (2014), some populations of sardines have been reported as multiple spawners with indeterminate fecundity. However, Tsikliras and Antonopoulou (2006) demonstrated that *S. aurita* is a determinate spawner. A similar observation was made for *Ethmalosa fimbriata,* a clupeid (Blay and Eyeson, 1982).

Sardines are highly fecund and the fecundity measurement could be carried out by counting oocytes in tissue fractions and then extrapolating oocyte densities to the whole ovarian weight or volume (Bagenal & Braum, 1978; Ganias *et al.*, 2014). Koranteng (1989) stated that a female *S. aurita* measuring or weighing 45 g is capable of producing about 10,000 eggs at a time off the Ivoro-Ghanaian waters. In the Mediterranean Sea, Aegean waters the species had a reproductive capacity ranging from 9.7 - 72.7 x 10^3 (Tsikliras & Antonopoulou, 2006) and in the Tunisian waters it ranged from 8.3 - 43.2 x 10^3 (Gaamour, Missaoui, Ben-Abdallah & El Ahmed, 2001). Fontana and Pianet (1973) reported on the fecundity of *S. maderensis* in the Congolese waters.

Background to Methodology

Growth

Gayanilo, Sparre and Pauly (2005) define growth as the change over time of the body mass of a fish, being the net result of two processes with opposite tendencies, one the building-up of body substances (anabolism) and the other the breaking-down of these substances (catabolism).

Age and growth studies of bony fish are important bases for stock assessment (Gayanilo *et al*., 2005). Methods such as hard tissue reading, tagging-recapture and length frequency analyses can be used to study age and growth of bony fish (Bagenal & Tesch, 1978). According to Morales-Nin (1992), the international ICLARM/KSIR meeting on the theory and application of stock assessment methods with regards to length-frequency analysis concluded that length-frequency analysis procedures are made much more precise by the addition of data on growth obtained through independent means like otolith studies. In the temperate regions, teleost age and growth have been studied by the analysis of growth rings recorded on calcified structures as well as length-based analysis (Bagenal & Tesch, 1978). However, in the tropics, age determination by the calcified structures is often difficult (Fagade, 1974 as cited in Bagenal & Tesch, 1978) and until recently it was assumed to be almost impossible due to continuous spawning and absence of growth cycles (Mohr, 1921 as cited in Morales-Nin, 1992). Again, there is a challenge with the use of Peterson method (to estimate the age of fish species) because tropical fish generally spawn throughout much of the year and the life cycles are often short, thereby making the younger generations catch up with the older ones in length distributions (Bagenal & Tesch, 1978; King, 1995). Gayanilo *et al.* (2005) explained that the continuous growth of tropical fish could be due to lack of marked seasonal changes in environmental factors and the availability of food throughout the year. However, with the development of the length-based stock assessment methodologies, it is possible to investigate population dynamics using the von Bertalanffy growth function of fish stocks in tropical waters (Pauly, 1984a; Pauly, 1987; Pauly & Morgan, 1987).

Age determination is an important tool in fishery biology which provides information on stock age structure, age at maturity, longevity and mortality (Morales-Nin, 1992). Aging fish through the interpretation and counting of growth checks has been the most frequently used method (Bagenal & Tesch, 1978; Radtke & Dean, 1982). Calcified structures used in aging bony fish include otoliths, scales, operculum, spines and vertebra. Bony fish otoliths are complex polycrystalline structures which act as organs of balance in the inner ear (Morales-Nin, 1992). Otoliths are the preferred calcified structures for aging due to its: early formation ahead of the others (spines, scales, vertebrae etc.), ability to grow throughout the life span of the fish and unlike bones metabolically inert (Campana & Neilson, 1985). Once otoliths are deposited its components are unlikely to be resorbed or altered (Campana, Gagne & McLaren, 1995).

In fisheries science, otolith studies have a wide application for example the microstructural features are of taxonomic significance and ageing of fish (Pannella, 1980; Morales-Nin, 1992). The morphology of the otolith is said to be environmentally determined, hence its usage in identification of different stocks of fish of the same species (Williams & Bedford, 1974). Otolith microstructural analyses have also been used to: document differential growth rates, examine life-history changes, validate other ageing techniques and reconstruct individual growth histories (Pannella, 1980).

Otoliths of bony fish are composed of cyclic deposition of crystallized calcium carbonate in the form of aragonite and a fibrous collagen-like protein (otolin) (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). Based on the size and shape of otoliths, several procedures have been used to reveal the growth rings on the otolith structures. These include sectioning across various planes, burning on low gas or spirit flame, polishing and acid etching of otolith surfaces (Bagenal & Tesch, 1978). The growth rings could be counted to estimate the age of the fish after its deposition has been validated (Pannella, 1980; Morales-Nin, 1992).

Mortality and Exploitation

Mortality assessment of exploited stocks is an important aspect of studies on dynamics of fish populations. It seeks to estimate the total mortality, natural mortality and fishing mortality (Gayanilo, Soriano & Pauly, 1989). There are a number of methods used in estimating total mortality (Sparre & Venema, 1992). The catch curve approach is the most commonly used method in the tropics in estimating total mortality which is based on the assumption of a constant parameter system (Gayanilo *et al.*, 2005). This approach takes two different forms thus, the length-converted catch curve and age-converted catch curve depending on the type of data used. Of the two, the age-converted catch curve is less used in the tropics because of the difficulty in ageing teleost in the region.

Natural Mortality (M) is the loss of fish due to all causes except fishing (example predation, old age, disease and starvation) (King, 1995). Direct estimation of M can therefore be obtained only from completely unexploited stocks (King, 1995). Yet values of this parameter are needed from exploited stocks for most of the models currently used in fish population dynamics (Pauly, 1984a; Pauly, 1984b). Natural mortality is normally calculated from Pauly's (1980) empirical equation.

Fishing mortality (F) is the mortality due to fishing and it is estimated by subtracting natural mortality from total mortality (King, 1995). The ratio of fishing mortality to total mortality is given as the exploitation rate (E) (Sparre & Venema, 1992). This rate determines the level of exploitation of a fishery.

Stock assessment tool (FiSAT)

According to Gayanilo *et al.* (2005), a sub-set of one species having the same growth and mortality parameters, for which the geographical limits can be defined may be considered as a stock. The primary aim of fish stock assessment is to establish the status of the stock and to determine the levels at which it could be exploited sustainably (King, 1995). Research on the population dynamics of fish stocks involves the estimation of stock abundance, determination of growth and mortality parameters, analysis of catch and effort data, determination of yield, reproductive activities and recruitment patterns.

Most tropical teleosts undergo continuous growth and reproduction. In view of this, the application of the conventional stock assessment procedures to tropical fisheries is difficult (Bagenal & Tesch, 1978; Pauly, 1979b; Gayanilo *et* *al*., 2005) However, the development of modified methods of length-based procedures makes it easier and possible to assess tropical fish stocks (Sparre, 1990; Gayanilo, Soriano & Pauly, 1989). Most fish stock assessment procedures are computer-based (including LFSA, ELEFAN and FiSAT) which are used in analysing periodic collection of length or weight-based data (Sparre & Venema, 1992; Pauly & Morgan, 1987). Researchers in Ghana have used length-based data by the use of ELEFAN I (FiSAT) in estimating the exploitation rates and determining suitable levels of exploitation as well as growth and mortality parameters (Blay & Asabere-Ameyaw, 1993; Blay, 1998; Kwafo-Apegyah, Ofori-Danson & Nunoo, 2008; Ofori-Danson & Kwarfo-Apegyah, 2008).

Reproductive biology

Fish species have developed reproductive strategies and traits that ensure their survival under variable and often unfavourable conditions (Potts & Wootton, 1984). The reproductive strategy of fish species is expressed by certain characteristics such as age, fecundity, time duration and frequency of spawning, size at first maturity and reproductive behaviour (Potts & Wootton, 1984). For a rational fisheries management, the reproductive strategies must be investigated to inform management decisions (King, 1995; FAO, 1997; Brander, 2010).).

Researchers have used several methods to investigate the reproductive biology of teleosts by the analysis of sex ratios (Blay & Eyeson, 1982; Tsikliras, Antonopoulou & Stergiou, 2005), the size at first sexual maturity (Blay & Eyeson, 1982; Jurasi & Yamaguti, 1989), the time and duration of the spawning (Kwarfo-Apegyah & Ofori-Danson, 2010; Gupta & Banerjee 2013) and absolute fecundity (Jurasi & Yamaguti, 1989; Okyere, 2012). The spawning activities of fish have been investigated by estimating the monthly gonadosomatic index (GSI), monthly occurrence of gonadal stages as well as establishing the distribution of ova in ripe ovaries (Blay & Eyeson, 1982; Pesic *et al*., 2010; Alam, Ahsan & Parween, 2012).

Other analyses like mesenteric fat index (Marques & Ferreira, 2011; Mustac & Sinovcic, 2009) and condition factor (Gupta & Banerjee, 2013; Tsiklirasi *et al*. (2005) have been used to shed light on fish reproductive biology.

Statement of Research Problem

Although researchers have reported on the sardinella fish stocks in Ghanaian waters, there is a dearth of information on the reproductive biology, population dynamics and exploitation rates of the stocks for the past decade (FSSD, unpublished)

Justification of the Study

The sardinella fishery is the most important fishery in terms of food and employment in Ghana (Koranteng, 1989). The fishery provides relatively cheap source of animal protein and livelihood for many fishers as well as fish processors and traders in coastal areas of Ghana (Mensah & Koranteng, 1988; Koranteng, 1995). The sardinella fishing season is the main fishing period in the Ghanaian waters (Koranteng, 1989; Koranteng, 1995).

Beverton (1990) indicated that fishing mortality is the main cause of the collapse of most pelagic fish stocks. Moreover, small pelagics like sardines have been reported to undergo population crashes and sudden recoveries (Durand *et al*., 1998; Pezenne & Koranteng, 1998; Arnason, 2006). In a classical case, the Peruvian anchovy off the north-west coast of South America which was once the largest pelagic fish resource failed to recover after the stock was overexploited (King, 1995; FAO, WFP & IFAD. 2012; Deutsch *et al*., 2007; MacCall, 2009). In view of this, it is prudent to assess the sardine fish stocks regularly to ensure sustainable utilization of the fishery.

Sex ratio, stages of gonadal development, gonadosomatic index and fecundity are important aspects of fish reproductive biology which provide information necessary for rational fisheries management (King, 1995; FAO, 1997; Adebisi, 2012). Age and growth studies also complement information on reproduction to inform the right management interventions (Bagenal & Tesch, 1978). Moreover, the biology of fish species may change with changes in mortality or environmental conditions (Blaxter & Hunter, 1982; King, 1995). Hence the need to study these aspects of the biology of the sardinella fish stocks regularly for management purposes.

Objectives of the Study

This study seeks to provide complementary information to enhance management strategies for sustainable exploitation of the sardinella stocks.

The specific objectives were to determine the sex-ratio; estimate the size at 50 % sexual maturity; estimate the absolute fecundity; determine the time and duration of the spawning season of the stocks. Also, to estimate the growth and mortality parameters; establish the recruitment patterns and assess the levels of the current exploitation rates on the stocks.

CHAPTER TWO

MATERIALS AND METHOD

Fish sampling and data collection

Samples of sardines were obtained from the landings of purse seine and gill net fisheries at the Elmina fish landing quay (Fig. 1) near Cape Coast (5˚ 06′ N; 1˚ 23′ W) around the middle of each month from October 2013 to September 2014.

The fish were transported to the laboratory for sorting and identification to species level (Appendix A) using fish identification manuals (Fischer *et al*., 1981; Schneider, 1990), after which routine morphometric measurements were carried out. Fish were measured for total length (TL) and fork length (FL) to the nearest 0.1 cm with a measuring board. Total body weight (BW), eviscerated body weight (BW_E) and gonad weight (GW) of the fish were measured to the nearest 0.01 g with an electronic balance. The fish were dissected for sex identification and determination of gonadal development stage. Mesenteric fat of each specimen was examined macroscopically and awarded points based on the coverage of fat on the gut. Sagittal otoliths of the fish obtained from beach seine samples were extracted for examination.

The overall length-frequency distributions for each species and sexes were obtained by pooling the 12 months data. Also, monthly histograms were plotted for each species.

The length and weight data were plotted as scatter diagrams and a regression analysis carried out to determine the relationship between the length and weight of the fish.

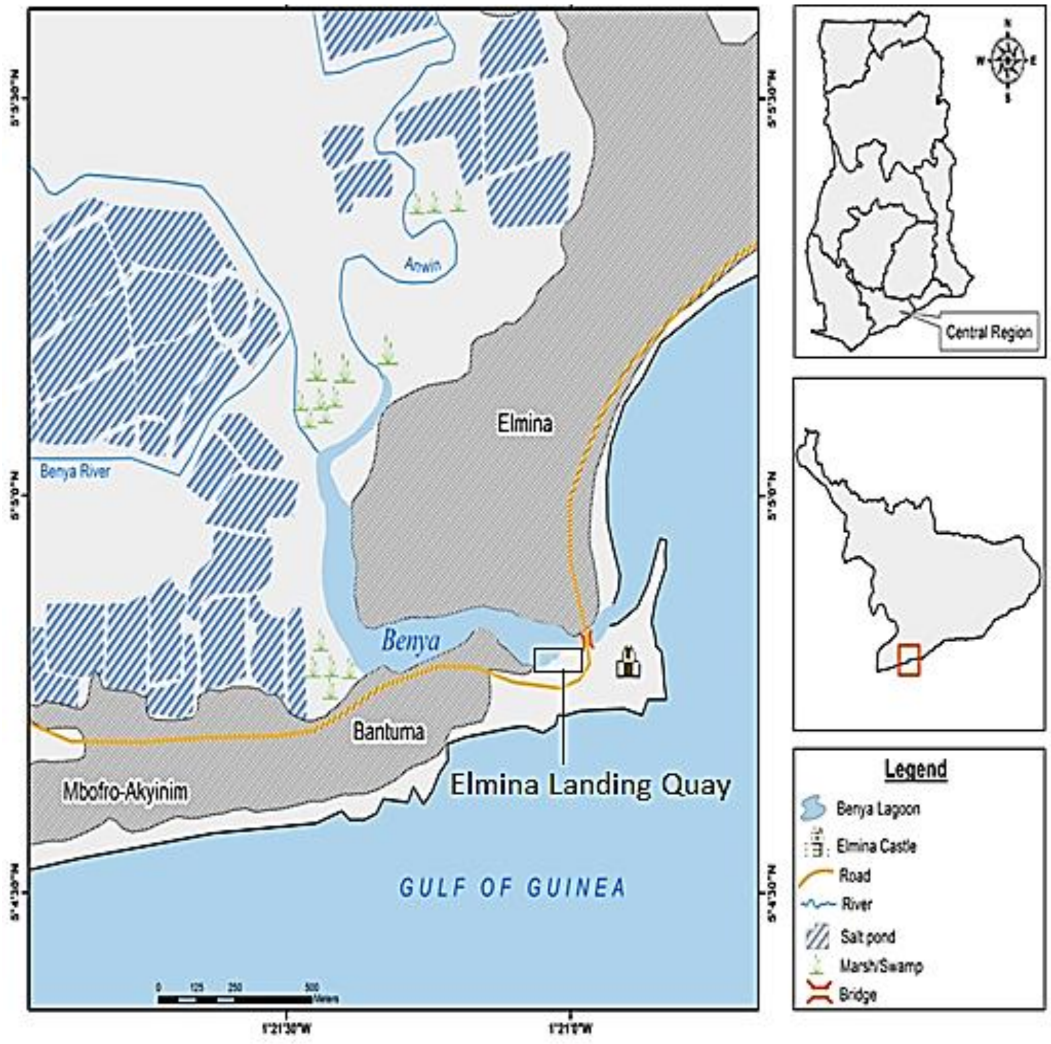


Figure 1: **Map of Ghana, showing Central Region and the Elmina landing quay**

Analyses of monthly length-frequency data

Monthly data were analyzed using FiSAT II software (Gayanilo *et al*., 2005) to determine the growth and mortality parameters as well as obtain information on exploitation of the stocks.

The ELEFAN 1 routine in the FiSAT software was used to estimate the asymptotic length (L_∞) and growth coefficient (K) of the species (Pauly, 1985). The theoretical age at zero length (t_o) was calculated as:

$\text{Log}_{10}(t_o) = 0.392 - 0.275\text{Log}_{10} L_\infty - 1.038 \text{ Log}_{10} K$ (Pauly, 1979a)

and the growth performance index (ϕ') from the equation:

$\Phi' = 2 \log_{10} L_\infty + \log_{10} K$ (Pauly & Munro 1984)

Longevity (t_{max}) of the species was estimated according to the equation:

$t_{max} = 3/K$ (Pauly, 1984a)

The derived growth curves for the various species were obtained from the ELEFAN I routine (FiSAT) using the VBGF (von Bertallanfy Growth Function) and Length Frequency Plot.

The mean length at first capture (L_c) was estimated by procedures of Sparre and Venema, 1992 (Probability of Capture Plot) as incorporated in FiSAT.

The total mortality (Z) of the fish species was estimated from the slope of the descending right arm of the linearized length-converted catch curve (Pauly, 1984a; King, 1995).

The natural mortality (M) was estimated by the empirical formula:

$\text{Log}(M) = -0.0066 - 0.279\log(L_\infty) + 0.6543\log(K) + 0.463\log(T)$

where, M is the natural mortality, K and L_∞ are growth parameters of the von Bertallanfy growth function (VBGF) and T (^{o}C) is the annual mean sea surface temperature of the study period (Pauly, 1980).

The fishing mortality coefficient (F) was estimated as the difference between the total and natural mortality (King, 1995).

Determination of exploitation rates

The level of exploitation (E) of the stocks was determined from equation:

E = F/ Z (Gulland, 1971)

Relative yield per recruit (Y'/R) and the relative biomass per recruit (B'/R) of the stocks were estimated according to Pauly and Soriano (1986) from which E_{max} (exploitation rate producing the maximum yield) and $E_{0.5}$ (exploitation rate at which 50 % of the biomass of recruit is fished) were determined (Gayanilo *et al*., 2005).

Recruitment pattern of each species was constructed using the pooled length-frequency data set. FiSAT generates the pattern by the input of the growth parameters (L_∞, K and t_o).

Sex was determined macroscopically (Holden & Raitt, 1974) thus, without the use of microscope. A Chi-square (χ^2) test (Zar, 1996) was undertaken to compare the male: female ratios per month and size groups with the hypothesized sex-ratio of 1:1.

Analysis of gonadal stages

Classification of maturity stages of the gonads was based on macroscopic sexual maturity scale adapted from Holden and Raitt (1974). Specimens that could not be sexed because of undeveloped gonads were classified as Stage I. The ovaries were staged as follows:

Stage II (Resting / Recovery Spawning) – Translucent, cylindrical shaped, orange or pale yellow coloured ovaries, vascular;

Stage III (Pre-spawning) – Larger and firm ovaries, noticeably thicker and yellow, filling more than half the body cavity and oocytes visible;

Stage IV (Spawning) – Yolky eggs are released under moderate pressure on abdomen, ovaries less firm and completely fills up body cavity;

Stage V (Post-spawning) – Ovaries shrunken with few residual eggs, much slim and often reddish.

The testes were staged as:

Stage II (Resting / Recovering Spawning) – Testes in recovering condition, testes less translucent and light cream colour, vascular;

Stage III (Pre-spawning) – Larger testes, testes more than one half the body cavity length, noticeably thicker and cream colour, vascular;

Stage IV (Spawning) – Milt flows when slight press applied to the abdomen, testes distended almost filling the body cavity and milky;

Stage V (Post-spawning) – Testes elongated, flaccid testes and often reddish; flat, hollow and bloodshot.

Estimation of sexual maturity

The mean length of the fish at sexual maturity (L_m) is defined as the length at which 50 % of individuals in the population are sexually mature (i.e. ovaries and testes in an advanced stage of development). To determine L_m, male and female gonads at pre-spawning and spawning stage were used. The length at which 50 % of the individuals were mature was estimated by fitting frequency data of mature individuals by length class using a cumulative frequency method (King, 1995; Gupta & Banerjee, 2013).

Determination of gonadosomatic index (GSI)

The gonadosomatic index (GSI) of the fish was computed using a modified equation of Marcus and Kusemiju (1984) as follows:

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

where, GW is the gonad weight and BW_E is eviscerated body weight in grams. The monthly mean GSI of the sexes of the various species was determined to ascertain the breeding pattern of the species.

Estimation of absolute fecundity

Absolute fecundity (FA) was estimated using ripe ovaries after the samples had been preserved in 10 % formalin to harden the eggs (Bagenal & Braum, 1978). The ova were teased out of the ovarian tissues, washed and rinsed with water prior to counting. Fecundity was estimated gravimetrically by the sub-sampling method (Bagenal & Braum, 1978). Relationship between fecundity and length of fish were established.

Measurement of ova diameter

Three ripe females (Stage IV) from each species were selected for the determination of ova diameter distribution. Ova from anterior, middle and posterior portions of the ovary from an individual were sampled to give a good representation of all ova sizes (Alam *et al*., 2012) and the diameter of these ova was measured with stage micrometer to the nearest 0.1 mm under a dissecting microscope.

Visceral fat index

The amount of fat deposited in the mesenteries was examined macroscopically and estimated using a five point scale (Kwei, 1970). The five point scale is given as: 1 point – least amount of fat, 2 points – moderate amount of fat, 3 points – considerable amount of fat, 4 points – very high quantity of fat and 5 points – extremely high quantity of fat. The mean visceral fat for each month was then determined as:

$$\text{Mean fat index} = \frac{\sum \mathrm{p}}{\mathrm{n}}$$

where p is the points scored by fish specimens and n is the total number of specimens in the sample.

Determination of condition factor (K)

The condition factor or somatic index (K) of the specimens of each species was calculated by using the equation of Le Cren (1951):

$$\mathrm{K} = \frac{(\mathrm{BW}-\mathrm{GW})}{\mathrm{TL}^3} \times 100$$

where TL (cm) is the total length and BW and GW are the body weight and gonad weight respectively in grams. The mean monthly condition factor for the species was determined to show the fluctuation in the well-being of the fish. A student's t-test was used to ascertain whether the changes in condition factor were significant.

Examination of sagittal otoliths

Both pairs of sagittal otolith were removed by opening up the cranium with scissors and then extracted by using forceps. Pairs of otolith were rubbed between fingers, washed with water and then with alcohol and air dried. The convex or proximal side of the otolith was mounted on microscope slides with DPX mountant. The mounted sagittal otoliths were ground to the core or nucleus on carborundum paper of different coarseness. The radius of otoliths was measured as the distance between the nucleus and posterior margin to the nearest 0.1 mm, which is the longest width. The ground surfaces were polished and etched with 10 % HCl. The etched surface was washed in distilled water, ethanol and air dried. The prepared sagittal otoliths of the two species were viewed under a light microscope to examine their microstructural features to ascertain the possibility of using them for ageing the sardines. In all 98 and 112 otoliths were measured and examined for *S. aurita* and *S. maderensis* respectively.

CHAPTER THREE

RESULTS

Overall length-frequency distribution

Sardinella aurita

A total of 746 specimens were sampled. The fish measured 11.0 to 27.9 cm TL and weighed 9.6 to 141.98 g. Figure 2 illustrates the length-frequency distribution of the fish. The males, females and the total sample showed a unimodal frequency distribution with a modal length of 19.0 – 19.9 cm TL. Males ranged in size from 13.6 to 26.3 cm TL and weighed 22.65 to 125.86 g while females measured 12.0 to 27.9 cm TL and weighed 13.73 to 141.98 g.

Sardinella maderensis

Figure 3 shows the length-frequency distribution of *S. maderensis*. In all 826 specimens measuring 9.8 to 28.2 cm TL and weighing 10.85 to 185.28 g were sampled. The pooled data showed a polymodal length frequency distribution with modes in the 11.0, 15.0, 18.0 and 25.0 cm groups. The males ranged in size from 11.0 to 27.6 cm TL, with a modal class 18.0 – 18.9 cm TL. They weighed 14.41 to 169.57 g. Females ranged in size from 10.0 to 28.2 cm TL and weighed 17.63 to 185.28 g. It showed a trimodal frequency distribution of modal classes 15.0 – 15.9, 18.0 – 18.9 and 25.0 – 25.9 cm TL.

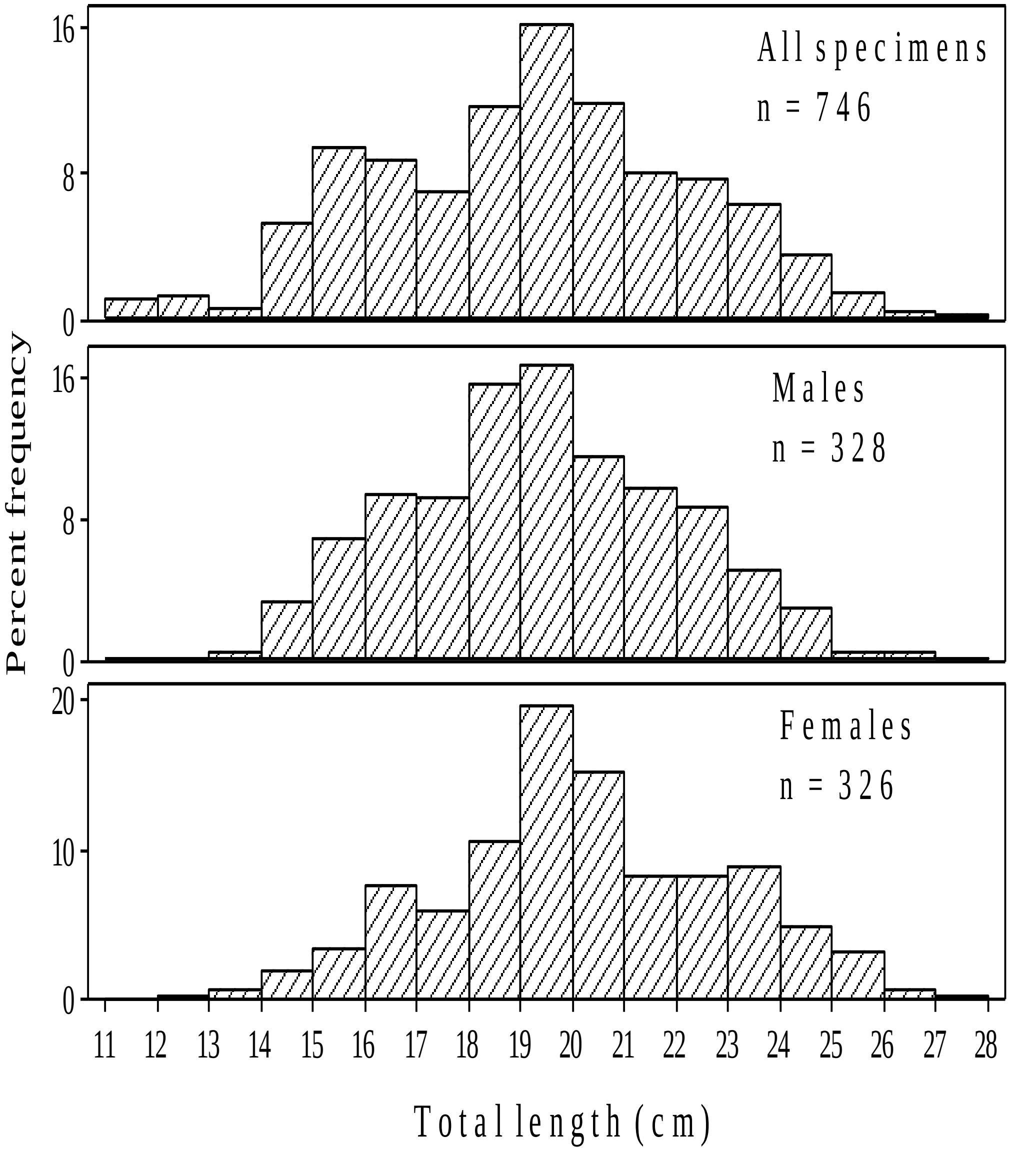


Figure 2: Length-frequency distributions of *Sardinella aurita* samples from commercial landings at Elmina landing quay (n = 746)

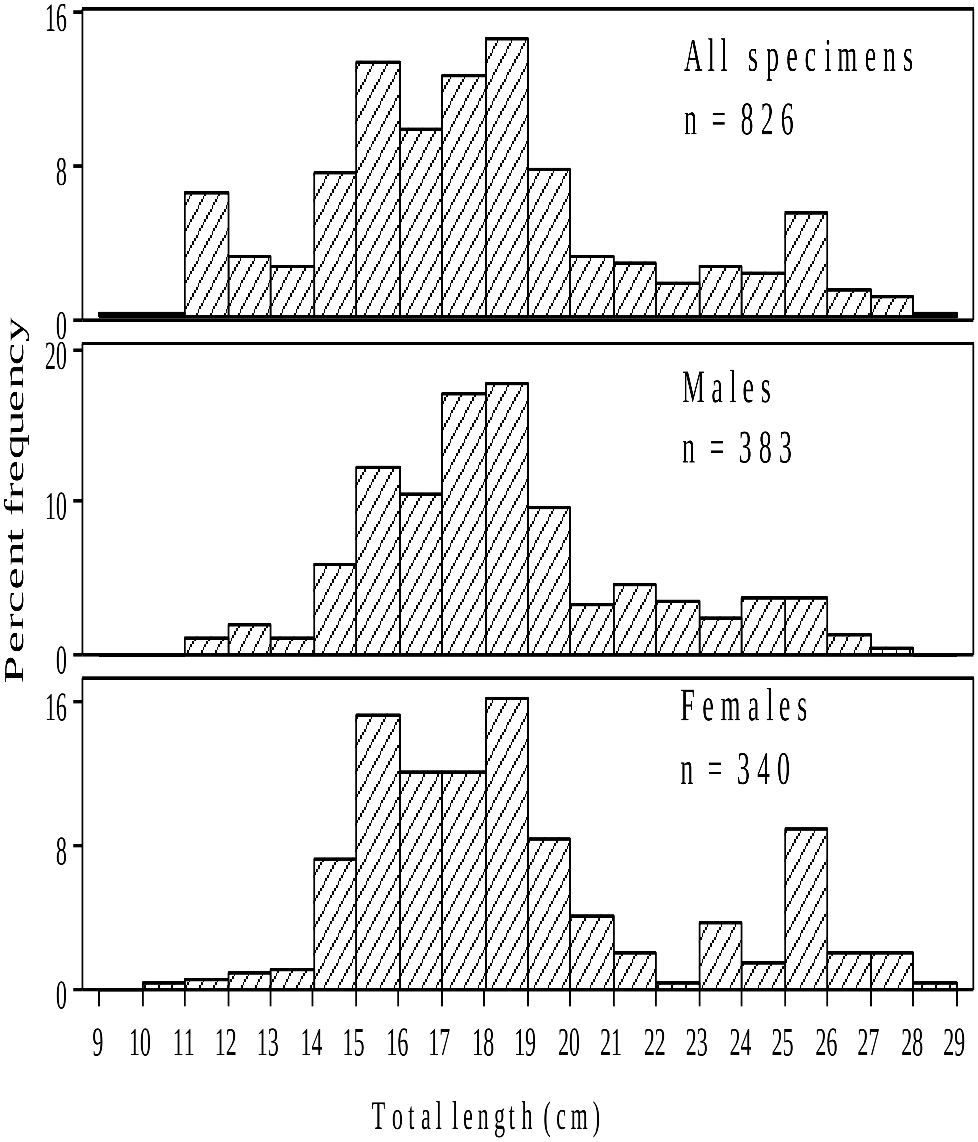


Figure 3: Length-frequency distributions of *Sardinella maderensis* samples from commercial landings at Elmina landing quay (n = 826)

Monthly length-frequency distributions

Sardinella aurita

The monthly length-frequency distributions of *S. aurita* fitted with growth curves are shown in Figure 4. The October 2013 sample appeared to be bimodal with modal class sizes of 16.0 – 16.9 and 18.0 – 18.9 cm TL. November 2013 sample had a unimodal distribution with modal size 15.0 – 15.9 cm TL. The November mode (15.0 – 15.9 cm TL) reoccurred in the December 2013 sample, in addition to the 19.0 – 19.9 cm TL mode. The primary mode (19.0 – 19.9 cm TL) in the December sample was maintained in January and February but was lost in the March sample and later reappeared in the April sample. The May 2014 sample was polymodal with modal classes 11.0 -11.9, 16.0 – 16.9 and 18.0 – 18.9 cm TL. The primary mode (18.0 – 18.9 cm TL) in the May sample was shifted by 1 cm in June 2014 which is secondary to the primary mode 23.0 – 23.9 cm TL. The July, August and September 2014 samples were all unimodal with modal classes 22.0 – 22.5, 19.0 – 19.9 and 21.0 – 21.9 cm TL respectively.

Sardinella maderensis

Figure 5 illustrates the monthly length-frequency distributions of *S. maderensis* superimposed with growth curves. With the exception of the November and August sample, all the monthly distributions were unimodal. The October 2013 sample was unimodal with a modal class of 14.0 – 14.9 cm TL. The November 2013 sample was bimodal with modal classes 15.0 – 15.9 cm TL and 19.0 – 19.9 cm TL. The primary mode (15.0 – 15.9 cm TL) was maintained in the December 2013 sample. The modal class in December increased by 2 cm in

January (17.0 – 17.9 cm TL) and progressed by 1 cm in February 2014 and was maintained in March 2014 sample. The shift in modal classes from December to February 2014 suggests that there was a growth of 3 cm during this period (upwelling season). The April 2014 sample was unimodal with the modal size 14.0 – 14.9 cm TL. May, June and July 2014 samples had a unimodal distribution of modal sizes 11.0 – 11.9, 15.0 – 15.9 and 24.0 – 24.9 cm TL respectively. The August 2014 sample was bimodal, the modal class size in July sample (24.0 – 24.9 cm TL) maintained and a secondary mode of class size 17.0 – 17.5 cm TL. The primary mode in the August sample was shifted by 1 cm in the September 2014 sample.

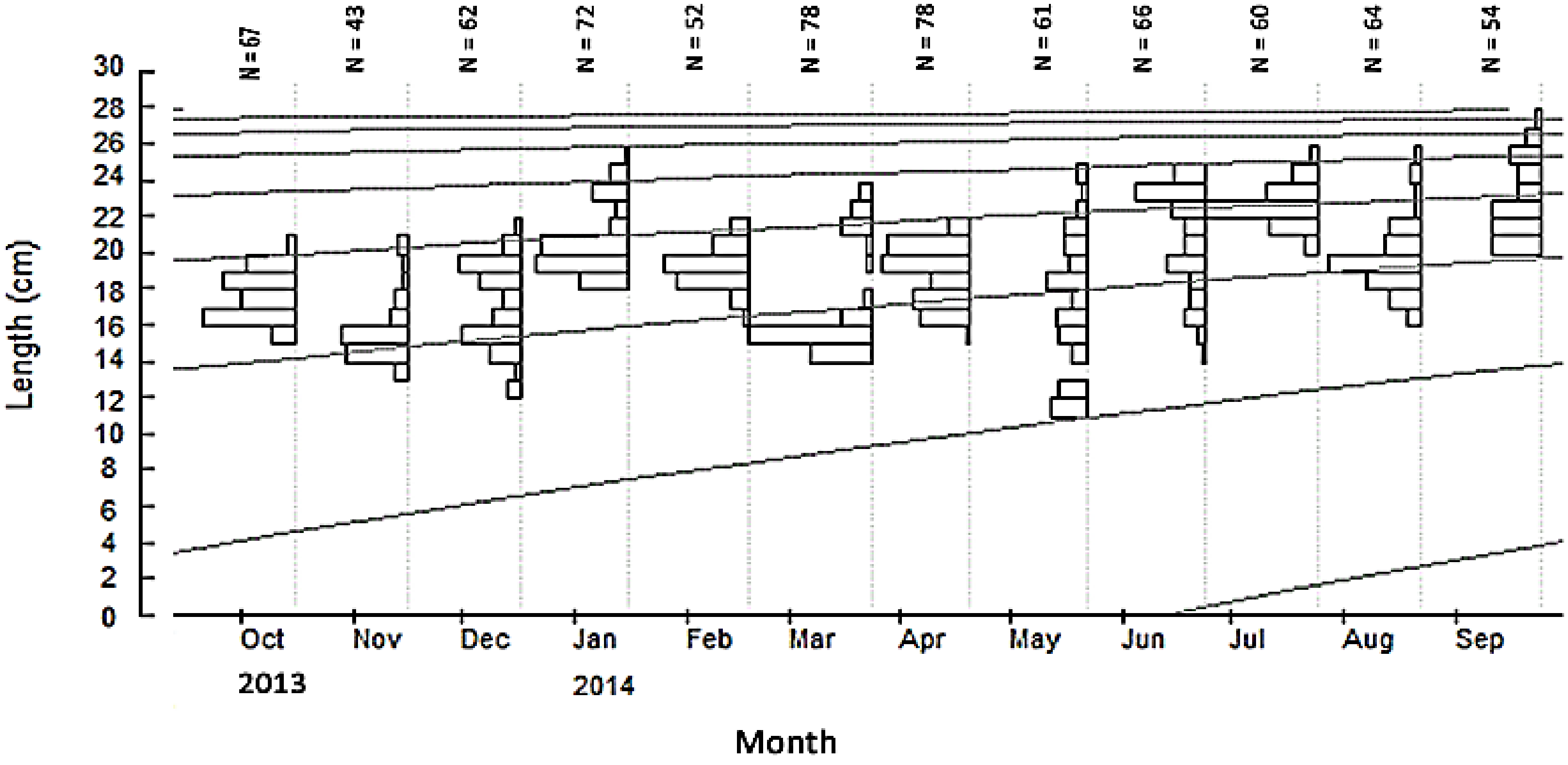


Figure 4: **Monthly length-frequency distributions of *Sardinella aurita* fitted with growth curves obtained by ELEFAN I routine (N = sample size)**

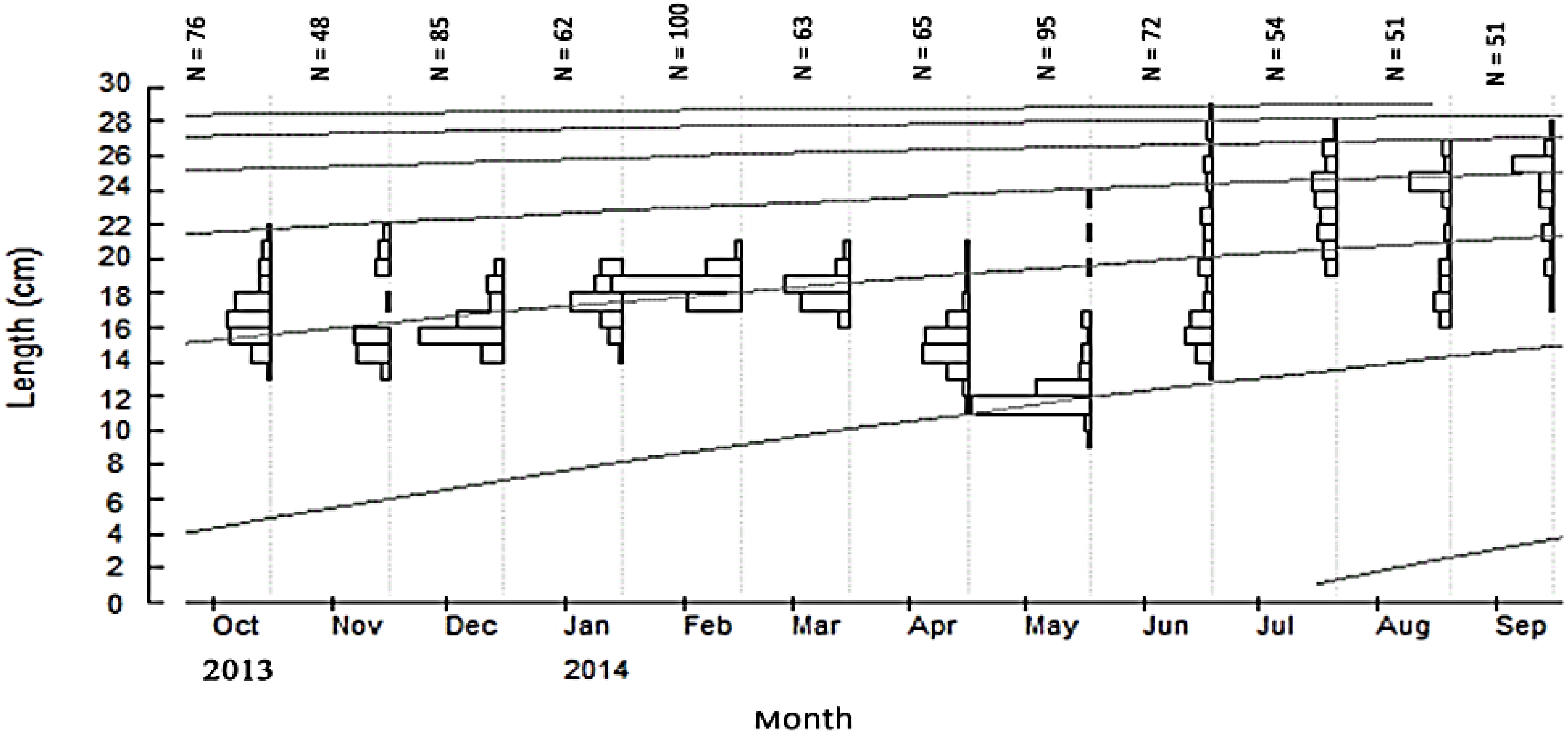


Figure 5: **Monthly length-frequency distributions of *Sardinella maderensis* fitted with growth curves obtained by ELEFAN I routine (N = sample size)**

Otolith radius-total length relationship

Figures 6 and 7 present the relationship between otolith radius and total length of *S. aurita* and *S. maderensis* respectively. Both relationships of sardines were linear with high positive correlations. The equations describing the relationships are:

$TL = 5.58 R + 2.47$ ($r = 0.95$; $P < 0.001$) (*S. aurita*)

$TL = 6.22 R - 1.42$ ($r = 0.96$; $P < 0.001$) (*S. maderensis*)

where TL is the total length of a fish in cm and R is the otolith radius of the sagittal otolith in mm.

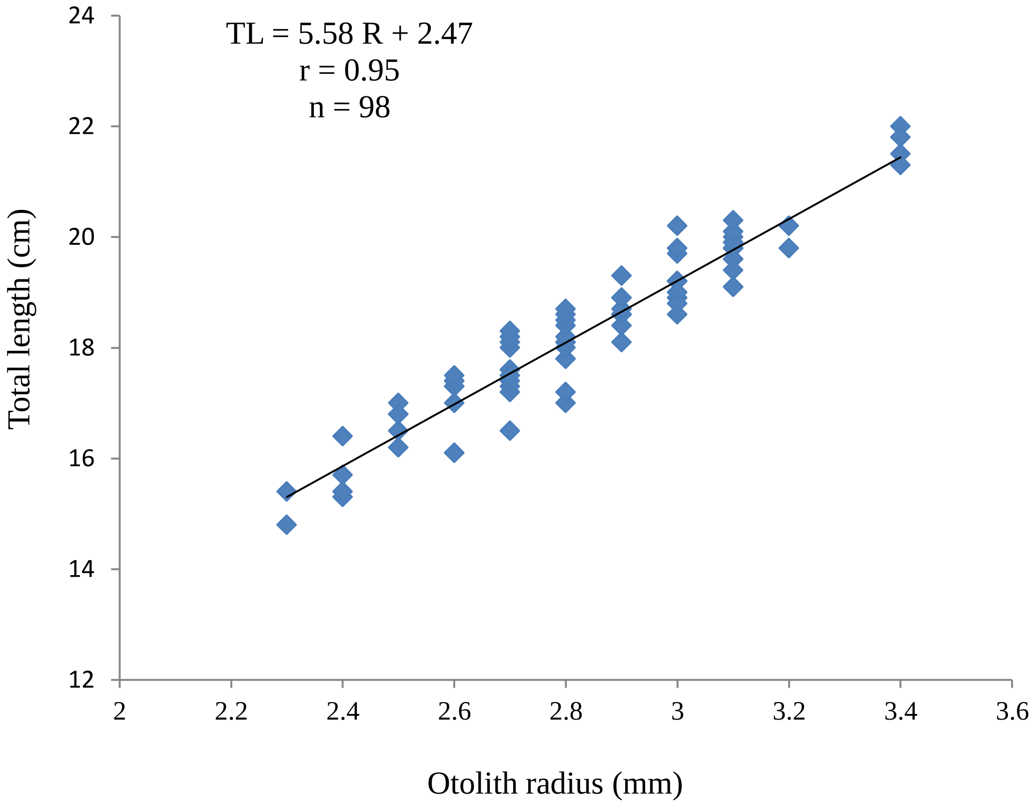


Figure 6: Relationship between otolith radius and total length of *Sardinella aurita* from beach seine landings at Elmina

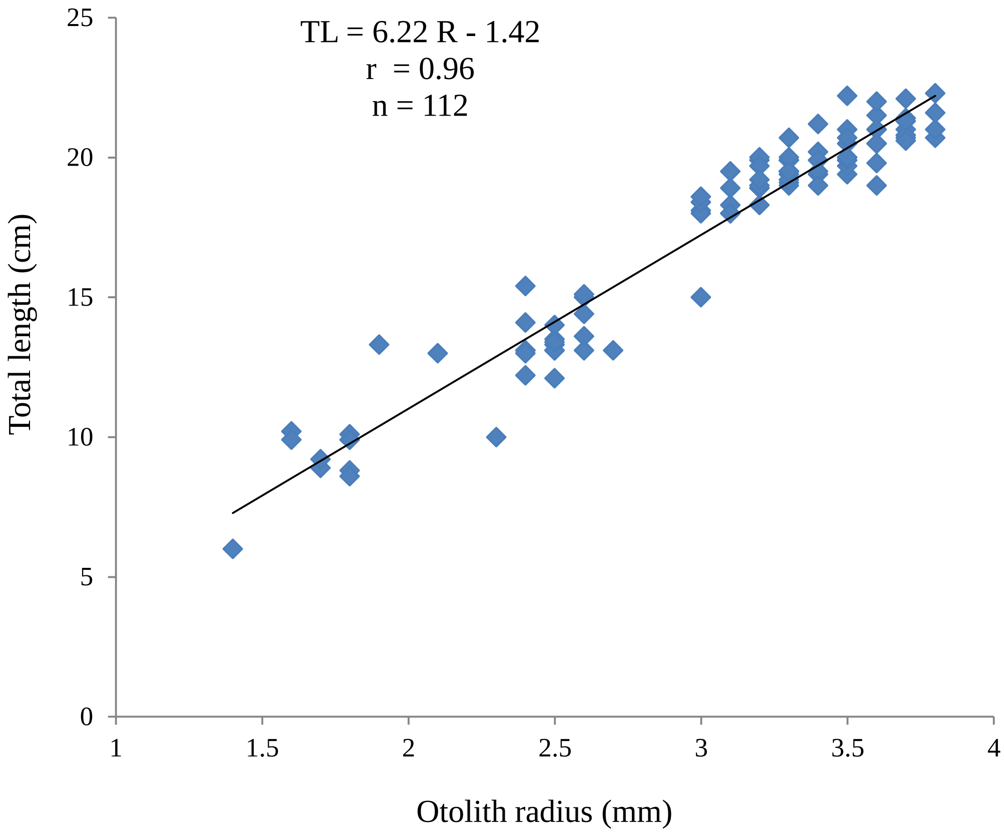


Figure 7: Relationship between otolith radius and total length of *Sardinella maderensis* from beach seine landings at Elmina

Length-weight relationship

Sardinella aurita

Figure 8 shows the relationship between total length (TL) and body weight (BW) of *S. aurita*. A significant exponential relationship ($BW = 0.0115\ TL^{2.90}$, $P < 0.001$) was found between total length and body weight of *S. aurita* stock, showing a strong correlation ($r = 0.98$) between the variables. The regression coefficient '*b*' did not differ statistically (student t-test) from the hypothetical value of 3.0, indicating that the *S. aurita* stock exhibited isometric growth (*b* = 2.90 ± 0.19; P > 0.05).

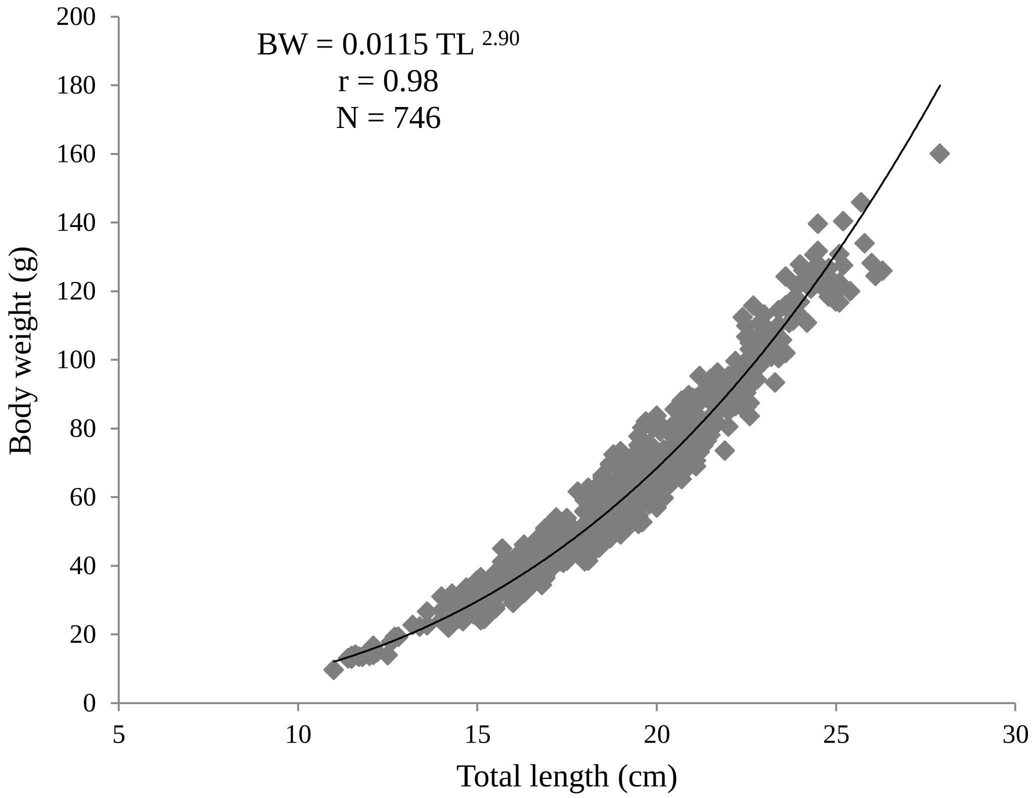


Figure 8: **Length-weight relationship of *Sardinella aurita* from commercial landings at Elmina landing quay**

Sardinella maderensis

The relationship between total length (TL) and body weight (BW) of *S. maderensis* is shown in Figure 9. A significant exponential relationship (BW = 0.0176 TL $^{2.77}$, P < 0.001) was found between total length and body weight. The regression showed a strong correlation (r = 0.99) between the variables. The regression coefficient '*b*' was not significantly different from the hypothetical value of 3.0, indicating that *S. maderensis* stock exhibited isometric growth (*b* = 2.77 ± 0.24; P > 0.05).

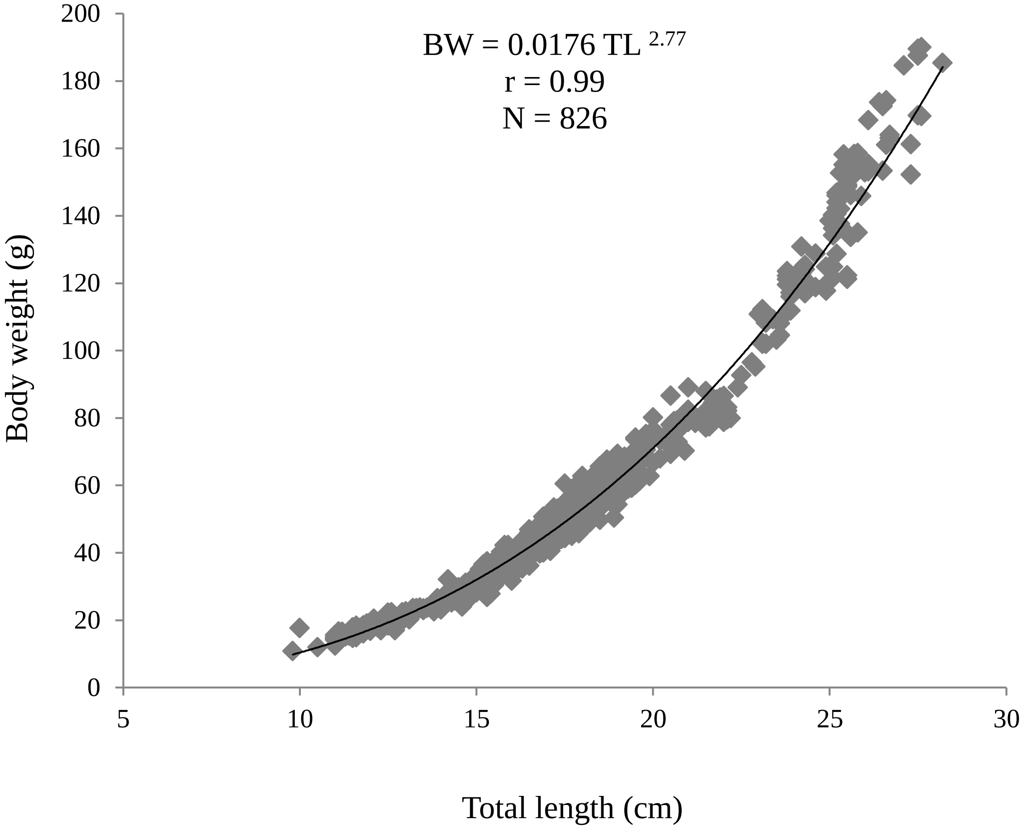


Figure 9: **Length-weight relationship of *Sardinella maderensis* from commercial landings at Elmina landing quay**

Changes in condition factor

Sardinella aurita

Fluctuations in the mean condition factor of *S. aurita* are presented in Figure 10. The pattern of fluctuation in both sexes was similar. The mean monthly condition factor for the males ranged between 0.76 ± 0.001 and 0.98 ± 0.018

whereas that of the females ranged from 0.76 ± 0.007 and 0.97 ± 0.012. The species was relatively in good condition from October 2013 to January 2014 and decreased in February and fluctuated at a lower level up to September 2014.

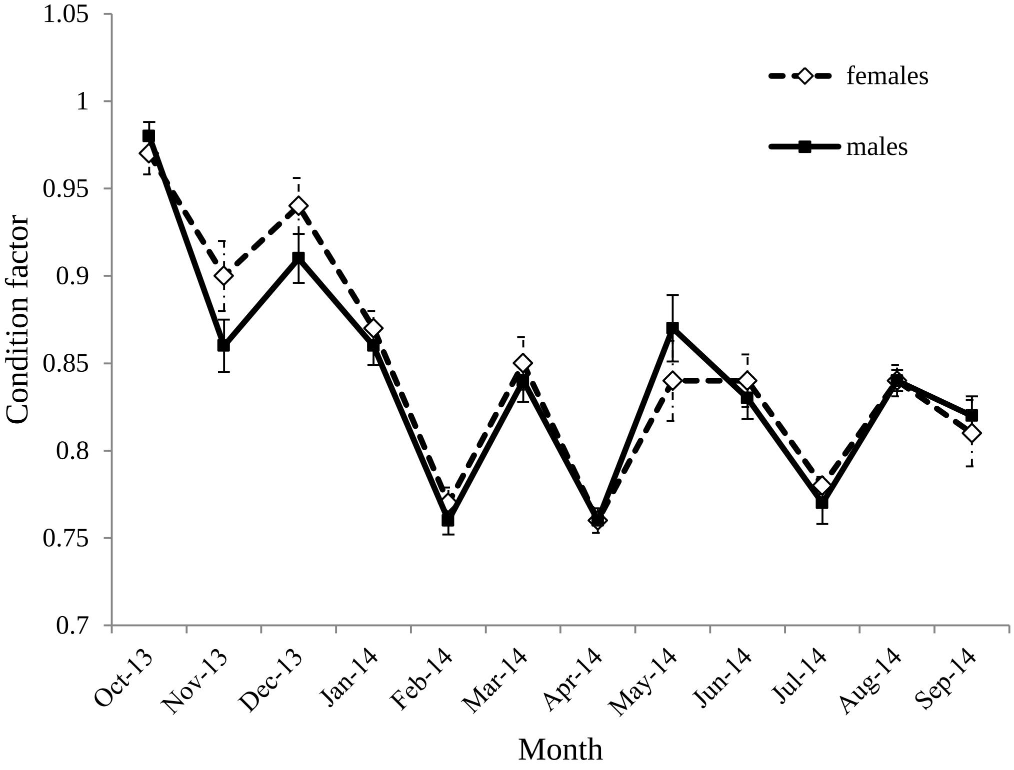


Figure 10: **Mean monthly condition factor of *Sardinella aurita* from commercial landings at Elmina landing quay (vertical bars are 1 standard error)**

Sardinella maderensis

Figure 11 illustrates the fluctuations in the mean condition factor of *S. maderensis*. Generally, the fluctuation patterns were similar for both sexes. The mean monthly condition factor for the males ranged between 0.82 ± 0.010 and 1.01 ± 0.027 whiles that of the females ranged from 0.83 ± 0.010 and 1.08 ± 0.082. Although there was a non-overlap of mean condition of sexes in June 2014, it was not statistically significant (t = 1.82, P > 0.05). *S. maderensis* stock was in poor condition in December 2013, March – April 2014 and June – September 2014. The stock was in peak condition in October 2013, and February and May 2014.

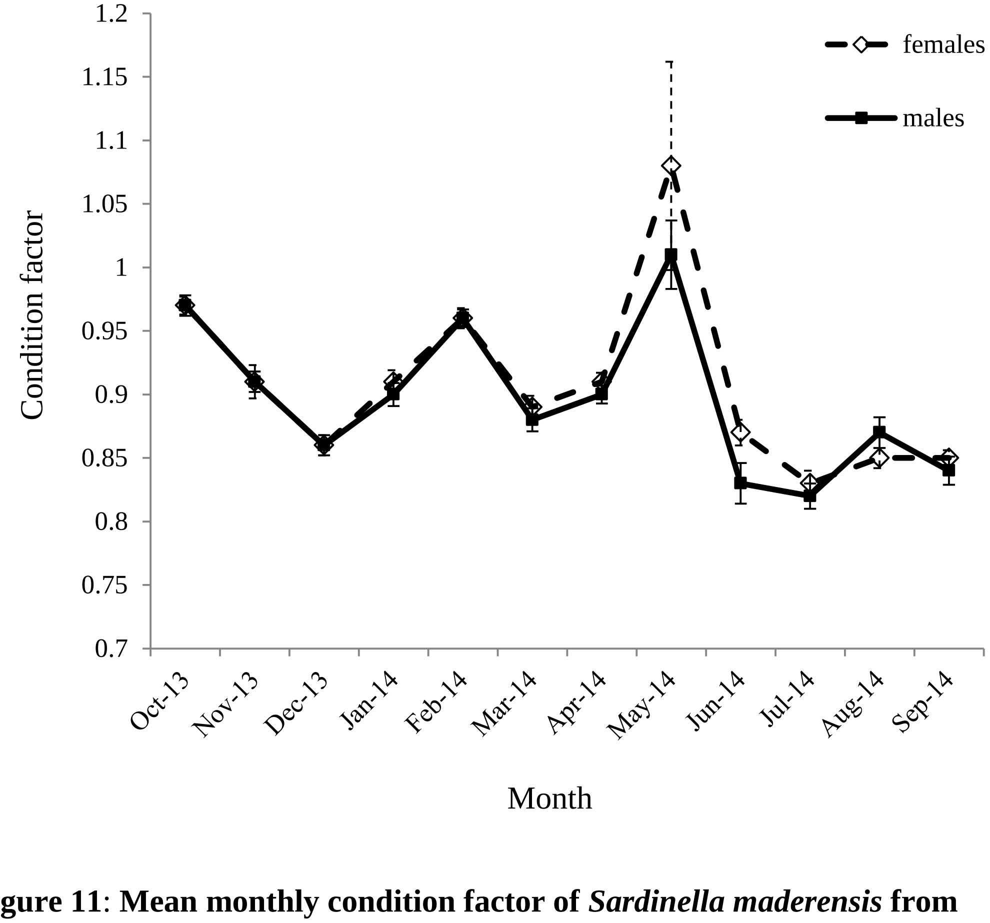


Figure 11: **Mean monthly condition factor of *Sardinella maderensis* from commercial landings at Elmina landing quay (vertical bars are 1 standard error**

Changes in mesenteric fat index

Sardinella aurita

Variations in the mean mesenteric fat index of *S. aurita* are presented in Figure 12. The mean mesenteric fat index of the males ranged from 1.15 ± 0.07 to 3.59 ± 0.21 and that of the females were from 1.37 ± 0.09 to 3.36 ± 0.13. Generally, both sexes had a comparable pattern of fluctuation during the study period. The mean fat index increased from October 2013 to peak in December 2013 followed by a decline in February and remained low until September 2014. The non-overlap in the sexes of *S. aurita* in September 2014 sample was not statistically significant (t = 1.89; P > 0.05).

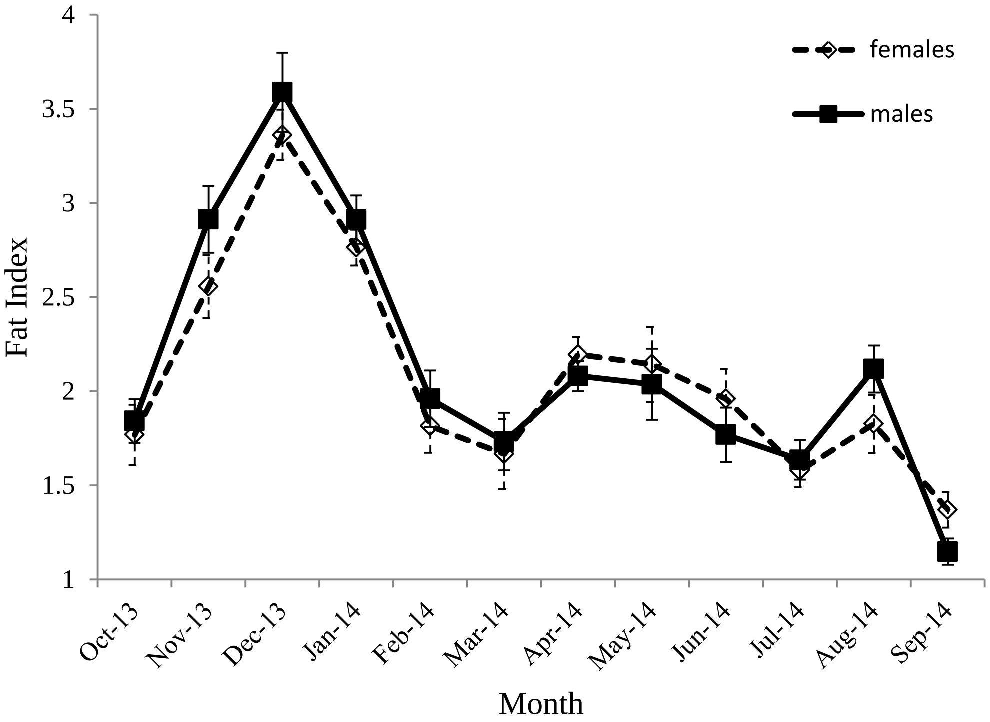


Figure 12: Variations in mean mesenteric fat index of *Sardinella aurita* from commercial landings at Elmina landing quay (vertical bars are 1 standard error)

Sardinella maderensis

Figure 13 illustrates the variations in the mean mesenteric fat index of *S. maderensis*. The fat index of the males ranged from 1.49 ± 0.10 to 3.66 ± 0.15 and that of the females from 1.50 ± 0.13 to 3.39 ± 0.12. Generally, both sexes had a similar pattern of fluctuation in fat. The mean mesenteric fat was high in October 2013 to January 2014 followed by a decline to March 2014. The species accumulated more fat in April 2014 which decreased steadily to September 2014. There was no significant difference in the mean fat index of males and females (t = 1.89; P > 0.05).

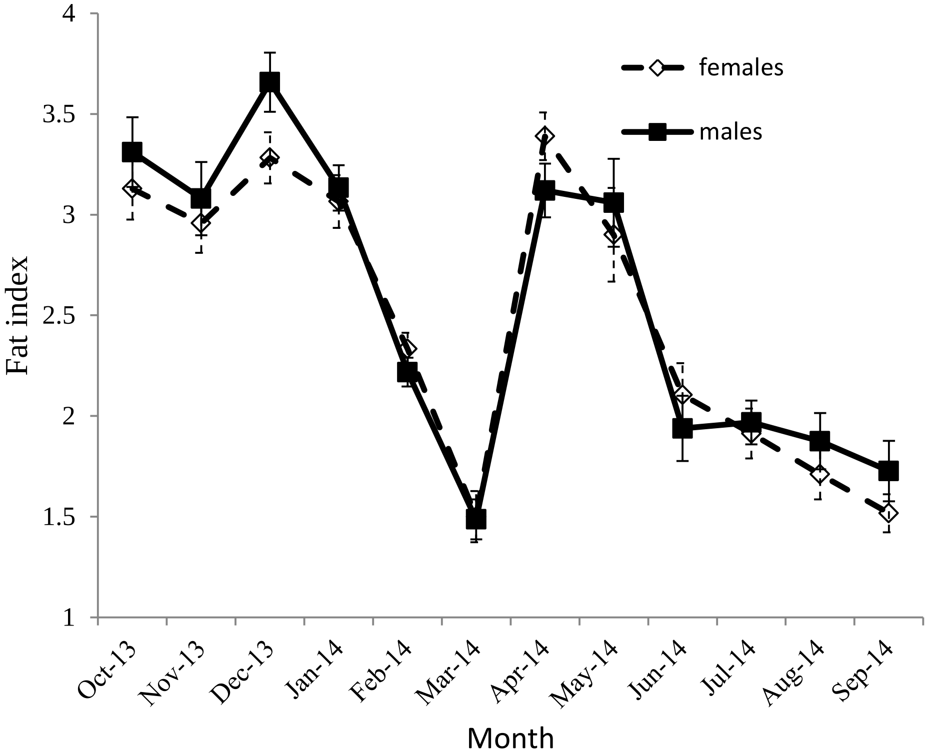


Figure 13: Variations in mean mesenteric fat index of *Sardinella maderensis* from commercial landings at Elmina landing quay (vertical bars are 1 standard error)

Sex ratio

Sardinella aurita

The monthly sex ratios of the species are shown in Table 1. A total of 654 *S. aurita* specimens were sexed, out of which 328 were males and 326 females. Overall, male to female sex ratio was 1:1. No significant changes occurred in the sex ratios except in July when females showed preponderance over males (1: 1.7; $\chi^2 = 4.27$; $P < 0.05$).

Table 2 presents sex ratios of size groups of the species. Size groups below class 19.0 – 19.9 cm TL had more males than females except in 16.0 – 16.9 cm group whiles there were more females from 19.0 – 19.9 cm and above except the 21.0 – 21.9 cm group. However, none of the ratios deviated from 1: 1.

Sardinella maderensis

Of the 723 individuals sexed, 383 were males and 340 females. The overall male to female sex ratio did not deviate from 1: 1 (Table 3). Except for February 2014 when males significantly showed preponderance over females (1: 0.6; $\chi^2 = 4.27$; $P < 0.05$) the monthly sex ratios did not differ from 1:1.

Table 4 shows the sex ratios of size groups of *S. maderensis.* With the exception of size group 22.0 – 22.9 cm TL whose sex ratio significantly went in favour of males (1: 0.1; $\chi^2 = 5.14$; $P < 0.05$), all the other size groups did not differ from 1: 1.

Table 1: **Monthly sex ratios of *Sardinella aurita* from commercial catches at Elmina landing quay**

Month	Number of specimens		Sex ratio	χ^2	$P_{(0.05)}$
	Male	Female	M : F		
October, 2013	38	26	1 : 0.7	2.25	NS
November	23	18	1 : 0.8	0.16	NS
December	17	19	1 : 1.1	0.11	NS
January, 2014	34	38	1 : 1.1	0.22	NS
February	25	27	1 : 1.1	0.07	NS
March	15	15	1 : 1	0.00	NS
April	37	41	1: 1.1	0.10	NS
May	27	21	1 : 0.7	0.75	NS
June	39	25	1 : 0.6	3.06	NS
July	22	38	1 : 1.7	4.27	S
August	24	31	1 : 1.3	0.45	NS
September	27	27	1 : 1	0.00	NS
Total	328	326	1 : 1	0.00	NS

S = Significant; NS = Not Significant; χ^2 = Chi-square; $P_{(0.05)}$ = Probability at 0.05 significant value

Table 2: Sex ratios of size groups of *Sardinella aurita* from commercial catches at Elmina landing quay

Total length (cm)	Number of specimens Male	Female	Sex ratio M : F	χ^2	$P_{(0.05)}$
11.0 – 11.9	1		-	*	-
12.0 – 12.9		1	-	*	-
13.0 – 13.9	1	2	-	*	-
14.0 – 14.9	11	6	1 : 0.5	0.74	NS
15.0 – 15.9	22	12	1 : 0.5	1.47	NS
16.0 – 16.9	31	35	1 : 1.1	0.12	NS
17.0 – 17.9	30	19	1: 0.6	1.23	NS
18.0 – 18.9	51	34	1 : 0.7	1.70	NS
19.0 – 19.9	55	65	1 : 1.2	0.42	NS
20.0 – 20.9	39	49	1 : 1.3	0.57	NS
21.0 – 21.9	32	27	1 : 0.8	0.23	NS
22.0 – 22.9	28	27	1 : 1	0.04	NS
23.0 – 23.9	16	29	1 : 1.8	2.64	NS
24.0 – 24.9	10	16	1 : 1.6	0.69	NS
25.0 – 25.9	1	11	-	*	-
26.0 – 26.9	1	2	-	*	-
27.0 – 27.9		1	-	*	-

* Low numbers, Chi-square values were not determined; NS = Not Significant

Table 3: Monthly sex ratios of *Sardinella maderensis* from commercial catches at Elmina landing quay

Month	Number of specimens		Sex ratio	χ^2	$P_{(0.05)}$
	Male	Female	M : F		
October, 2013	29	39	1 : 1.3	1.47	NS
November	25	23	1 : 0.9	0.08	NS
December	37	39	1 : 1.1	0.05	NS
January, 2014	30	31	1 : 1.0	0.02	NS
February	64	36	1 : 0.6	3.92	S
March	37	26	1 : 0.7	0.96	NS
April	25	18	1 : 0.7	1.14	NS
May	17	10	1 : 0.6	1.81	NS
June	32	38	1 : 1.2	0.51	NS
July	31	23	1 : 0.7	1.19	NS
August	34	28	1 : 0.8	0.29	NS
September	22	29	1 : 1.3	0.48	NS
Total	383	340	1: 0.9	1.27	NS

S = Significant; NS = Not Significant; χ^2 = Chi-square; P $_{(0.05)}$ = Probability at 0.05 significant value

Table 4: **Sex ratios of size groups of *Sardinella maderensis* from commercial catches at Elmina landing quay**

Total length	Number of specimens		Sex ratio	χ^2	$P_{(0.05)}$
(cm)	Male	Female	M : F		
10.0 – 10.9	0	1	-	*	-
11.0 – 11.9	5	2	-	*	-
12.0 – 12.9	8	3	-	*	-
13.0 – 13.9	5	4	-	*	-
14.0 – 14.9	22	25	1 : 1.1	0.09	NS
15.0 – 15.9	46	52	1 : 1.1	0.18	NS
16.0 – 16.9	40	42	1 : 1.1	0.02	NS
17.0 – 17.9	64	42	1: 0.7	0.21	NS
18.0 – 18.9	67	56	1 : 0.8	0.49	NS
19.0 – 19.9	37	28	1 : 0.8	0.62	NS
20.0 – 20.9	13	14	1 : 1.1	0.02	NS
21.0 – 21.9	18	7	1 : 0.4	1.68	NS
22.0 – 22.9	13	1	1 : 0.1	5.14	S
23.0 – 23.9	10	13	1 : 1.3	0.20	NS
24.0 – 24.9	14	5	1 : 0.4	0.47	NS
25.0 – 25.9	14	30	1 : 2.1	2.91	NS
26.0 – 26.9	5	7	-	*	-
27.0 – 27.9	2	7	-	*	-
28.0 – 28.9	0	1	-	*	-

* Low numbers, Chi-square values were not determined

NS = Not Significant; S = Significant

Monthly occurrence of gonadal stages

Specimens in Stage I were immature (thus gonads were undeveloped) therefore Stage II to IV specimens were used for the analysis.

Sardinella aurita

The monthly variations in the occurrence of the different gonadal stages of males and females of *S. aurita* are presented in Figure 14. Generally, both sexes had similar pattern of fluctuations.

a) Males

Stage II (Resting / Recovering Spawning) males occurred throughout the study period with the exception of July and September 2014. High proportions of Stage II males were sampled from October to December 2013, recording its peak in November 2013 (78.26 %) but there was a decrease in proportion from January to August 2014. February and August 2014 samples had the lowest percentages of Stage II males.

Stage III (Pre-spawning) males occurred throughout the sampling period except in July 2014. Males of this stage appeared to have increased in proportion from October 2013 to a peak in February 2014 (92 %) followed by a decline in proportion for the rest of the samples of the study period. The 92 % occurrence of Stage III males in February suggests that Stage II males of the previous months were developing into Stage III. The lowest proportions of Stage III males were in March and September 2014 samples.

Stage IV (Spawning) males were observed from February to September 2014. The proportion of ripe males increased sharply from February (4 %) to

April (48.46 %) but declined to 25.64 % in June and increased in proportion from July to September 2014 with its maximum value of 81.82 % in July 2014.

Stage V (Post-spawning) males occurred sparsely from March to September 2014 samples. The males appeared to have increased from March to a peak in June (20.51 %) followed by a gradual decline in September 2014 (11.11 %).

It appears Stage III males were developing into Stage IV in March - April and July - September 2014 as evidenced by the presence of high percentages in the Stage IV males.

b) Females

Stage II (Resting / Recovering Spawning) females occurred only from October 2013 to June 2014 except in April 2014 of the study period. High proportions of Stage II females occurred from October to December 2013, recording its peak in November 2013 (77.78 %) but relatively there was a decrease in percentages from January to August 2014. The lowest proportions of Stage II females were observed from January to March 2014.

Stage III (Pre-spawning) females occurred throughout the study period. Females of this stage increased in proportion from October 2013 to a maximum in February 2014 (88.88 %) but declined in proportion for the rest of the samples with July 2014 (2.63 %) recording the least proportion. The peak in February 2014 hints that Stage II females of the previous samples may have developed into Stage III.

Stage IV (Spawning) females appeared in the samples from March to September 2014. The females of this stage occurred in March (60 %) and April 2014 (60.98 %) sample but declined by approximately 30 % in May and June followed by an increase in proportion from July to September 2014, with a peak in July (89.47 %).

Stage V (Post-spawning) females were present from March to September 2014 except in May 2014 sample. The females appeared to have increased from March (6.7 %) to a peak in June (16.0 %) but declined gradually to September 2014 (7.1 %).

It seems Stage III females were developing into Stage IV in March and April as evidenced by the presence of high percentages. Also, it appears the remaining Stage III females in the population got matured into Stage IV in July to September 2014.

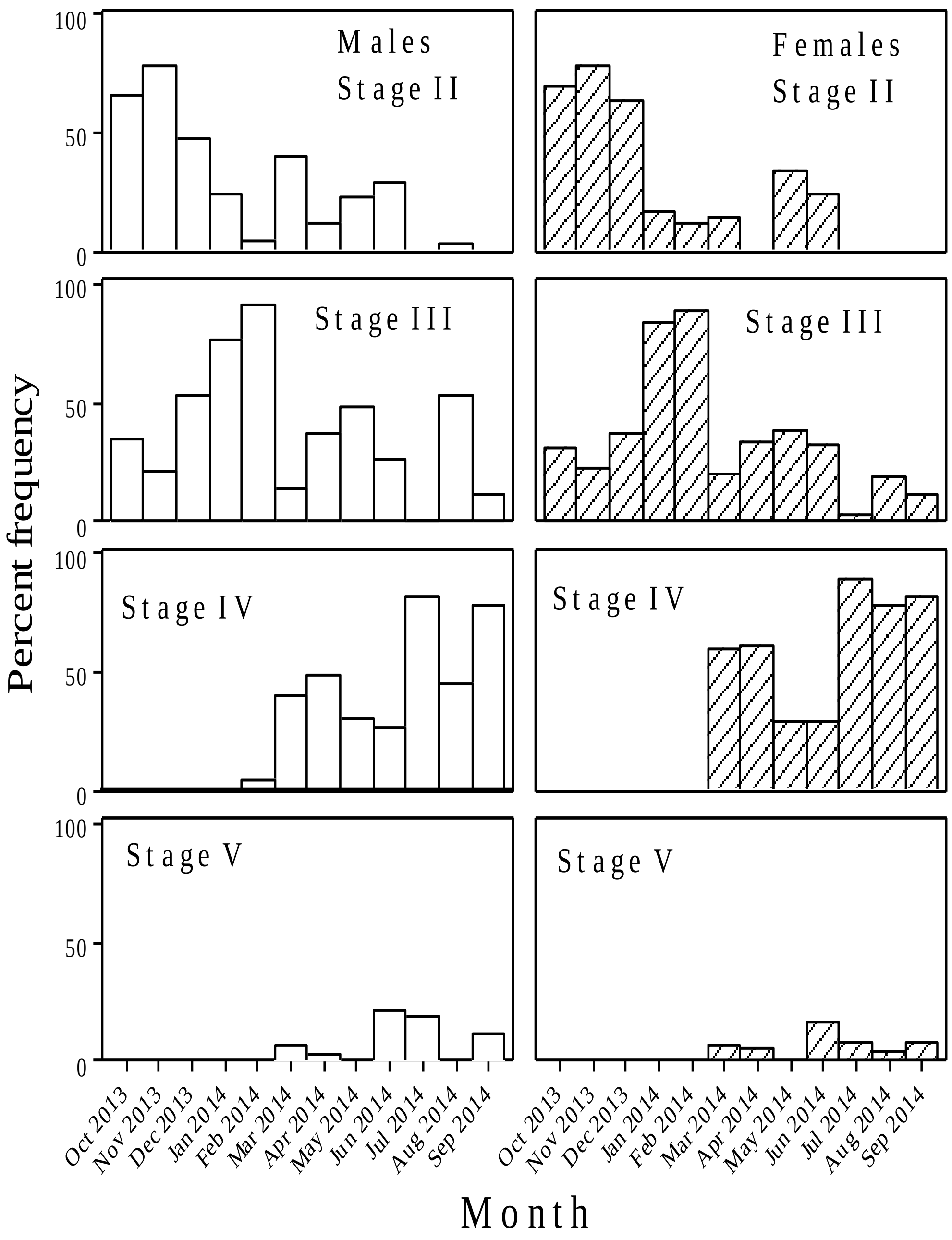


Figure 14: Monthly occurrence frequency of gonadal stages in males and females of *Sardinella aurita* from commercial landings at Elmina landing quay

Sardinella maderensis

Figure 15 illustrates the monthly variations in the occurrence of the different gonadal stages of males and females of *S. maderensis*. Mainly, both sexes had similar pattern of fluctuation.

a) Males

Stage II (Resting / Recovering Spawning) males occurred throughout the study period with the exception of March, July and September 2014. Males at this stage recorded a peak in October 2013 (94.82 %) which appeared to decrease until vanished in the sample in March 2014. The males appeared again in the April (20.0 %) sample and surged to 82.35 % in May but declined in August 2014.

Stage III (Pre-spawning) males occurred throughout the study period. Males of this stage increased gradually from October 2013 to a peak in March 2014 (100 %) but declined sharply in May 2014 and surged to July 2014 (87.10 %) followed by a decrease in September 2014. October 2013 and May 2014 recorded least proportions of Stage III males.

Stage IV (Spawning) males occurred only in February to September 2014 except in March 2014 sample. The males appeared to have increased steadily from February (4.68 %) to a peak in September 2014.

Stage V (Post-spawning) males were present in June and September 2014 samples but of lower proportions 6.25 % and 13.64 % respectively.

The 100 % peak in March suggests that Stage II males of the previous months were developing into Stage III. Moreover, the Stage II males that appeared in the subsequent samples seemed to have developed into Stage III in July 2014.

b) Females

Stage II (Resting / Recovering Spawning) females occurred from October 2013 to August 2014 but not in March and June 2014 samples. High proportions of Stage II females occurred from October to November 2013, with a maximum in October 2013 (94.87 %) but it decreased until it disappeared from the March 2014 sample. The Stage II females surged in the May 2014 (70.0 %) sample after appearing in April 2014 sample and finally declined to low proportion in August 2014 .The lowest proportions of Stage II females were observed in February (2.78 %) to August 2014 (3.20 %).

Stage III (Pre-spawning) females occurred throughout the sampling period. Females of this stage increased in proportion from October 2013 to a maximum in March 2014 (100 %) but declined in proportion for the rest of the samples. October (5.13%), November (12.50 %), May (10.0 %) and September 2014 (13.79 %) recorded the least proportions of stage III females in the study period.

Stage IV (Spawning) females occurred only in April to September 2014 samples. The females of this stage increased from the April sample to a peak in September 2014.

Stage V (Post-spawning) females were present from May to September 2014 but August 2014 sample. The females appeared to have increased from May

(10 %) to a maximum in July (21.74 %) followed by a decline in September 2014 (6.70 %).

The increased proportions in February and March 2014 indicate that Stage II females of the previous samples were developing into Stage III. Also, it seemed Stage III females were developing into Stage IV in August and September 2014 samples as evidenced by the presence of high percentages.

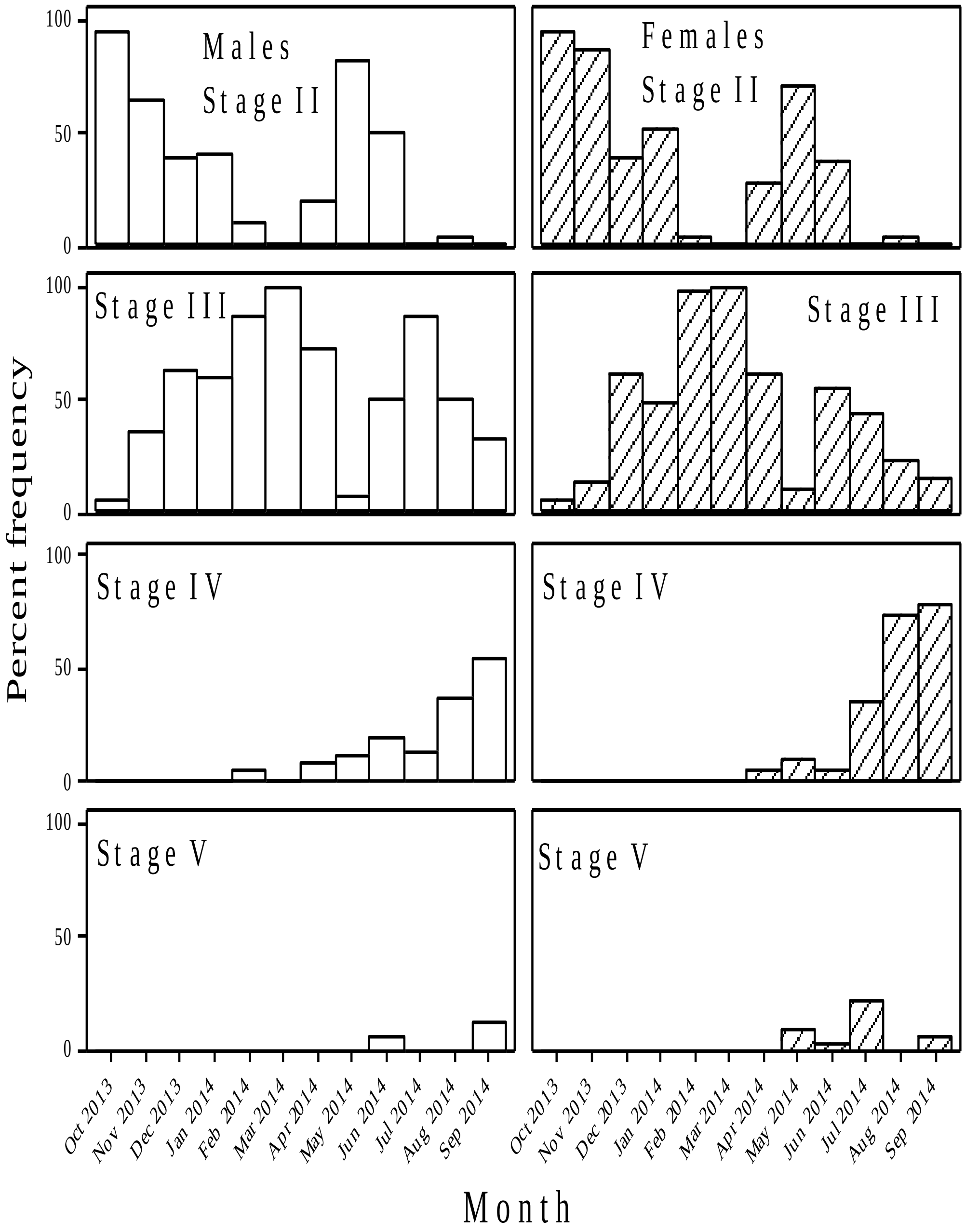


Figure 15: **Monthly occurrence frequency of gonadal stages in males and females of *Sardinella maderensis* from commercial landings at Elmina landing quay**

Maturity size

Sardinella aurita

The length at sexual maturity of the *S. aurita* was 16.40 and 16.74 cm TL for males and females respectively (Fig. 16a and 16b). The smallest mature male (Stage III) was 15.4 cm TL and weighed 30.82 g whilst the smallest mature female in the sample was 16.1 cm TL and weighed 37.82 g. About 23 % of the fish was below the average maturity size of the species.

Sardinella maderensis

The length at sexual maturity of the *S. maderensis* was 15.43 and 15.56 cm TL for males and females respectively (Fig. 17a & 17b). The smallest mature male (Stage III) was 14.3 cm TL and weighed 25.81 g whilst the smallest mature female was 15.0 cm TL and weighed 30.11 g. About 29 % of the fish was below the average maturity size of the species.

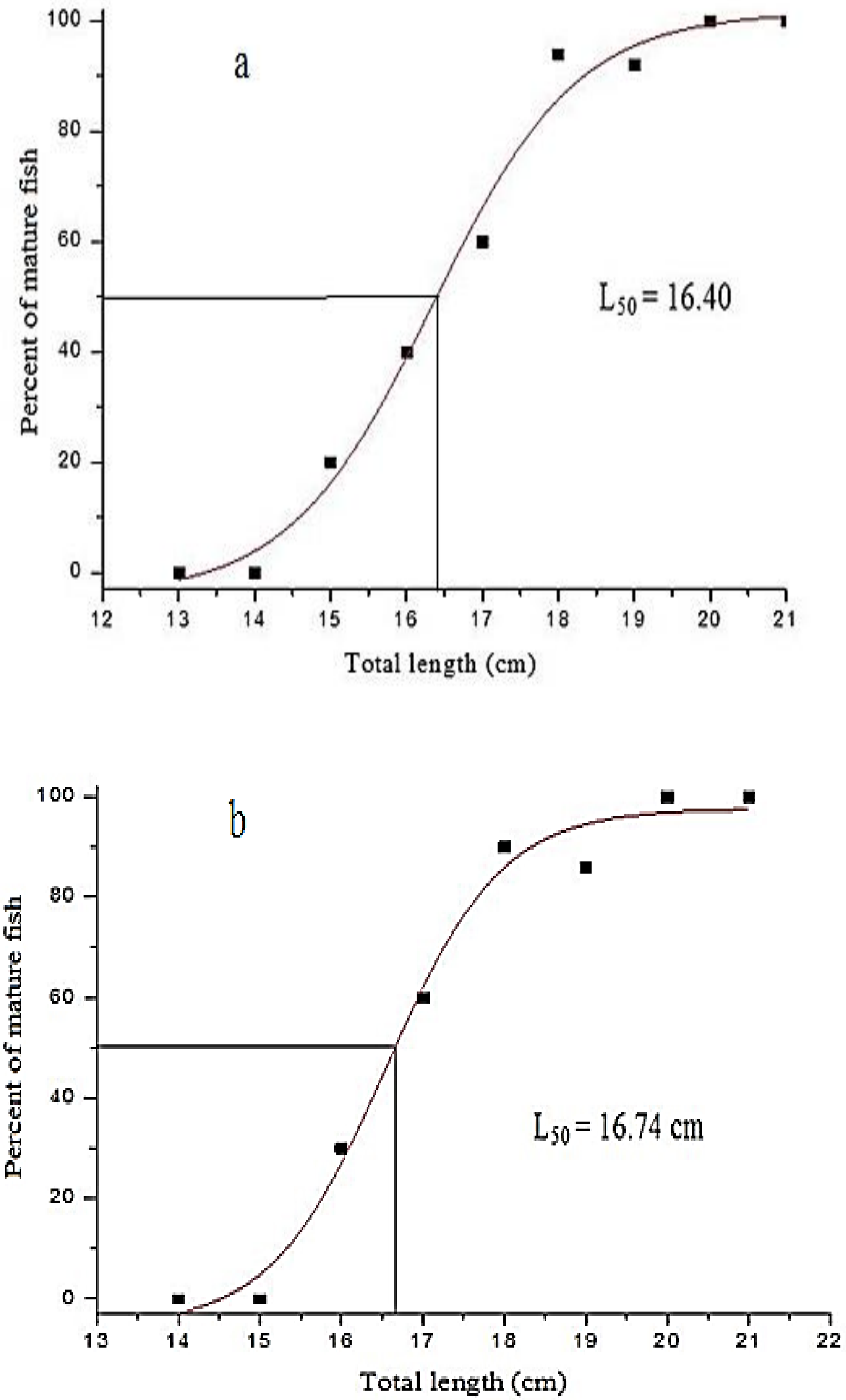


Figure 16: **Length at sexual maturity of (a) male and (b) female *Sardinella aurita* from commercial landings at Elmina landing quay**

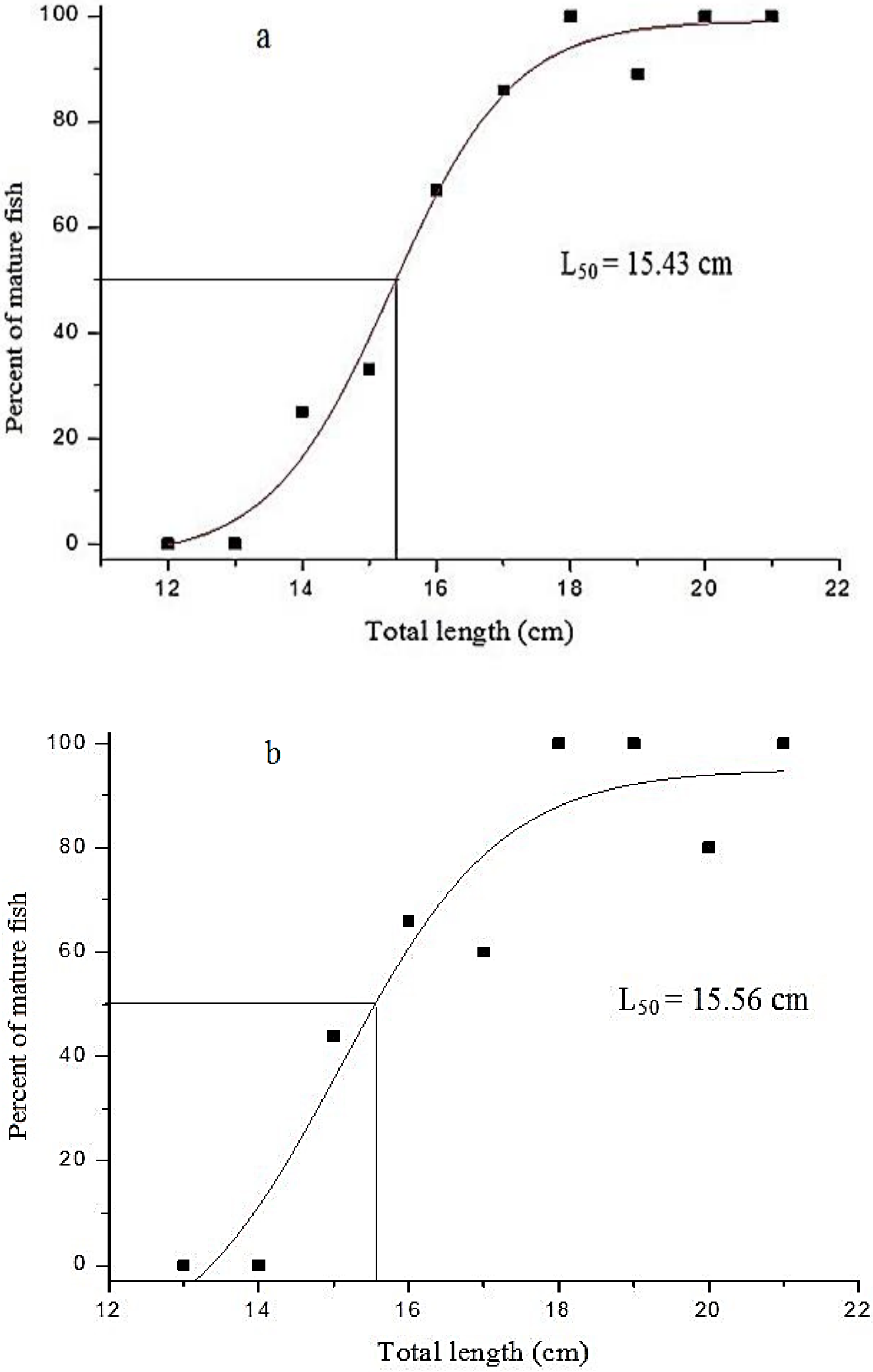


Figure 17: Length at sexual maturity of (a) male and (b) female *Sardinella maderensis* from commercial landings at Elmina landing quay

Frequency distribution of oocyte diameter

Sardinella aurita

Figure 18 shows the frequency distributions of ovum diameter of three ripe ovaries of *S. aurita*. The ovum diameter ranged from 0.1 to 0.8 mm for the ovaries examined. All groups of ova exhibited a bimodal frequency distribution. The modes were 0.1 mm and 0.6 mm for fish measuring 20.5 cm and 22.0 cm TL and 0.1 mm and 0.5 mm for fish measuring 19.9 cm SL.

Sardinella maderensis

The frequency distributions of ovum diameter of three ripe ovaries of *S. maderensis* are illustrated in Figure 19. The ovum diameter ranged from 0.1 to 0.8 mm for the ovaries examined. All groups of ova exhibited a bimodal frequency distribution with modes at 0.1 mm and 0.5 mm.

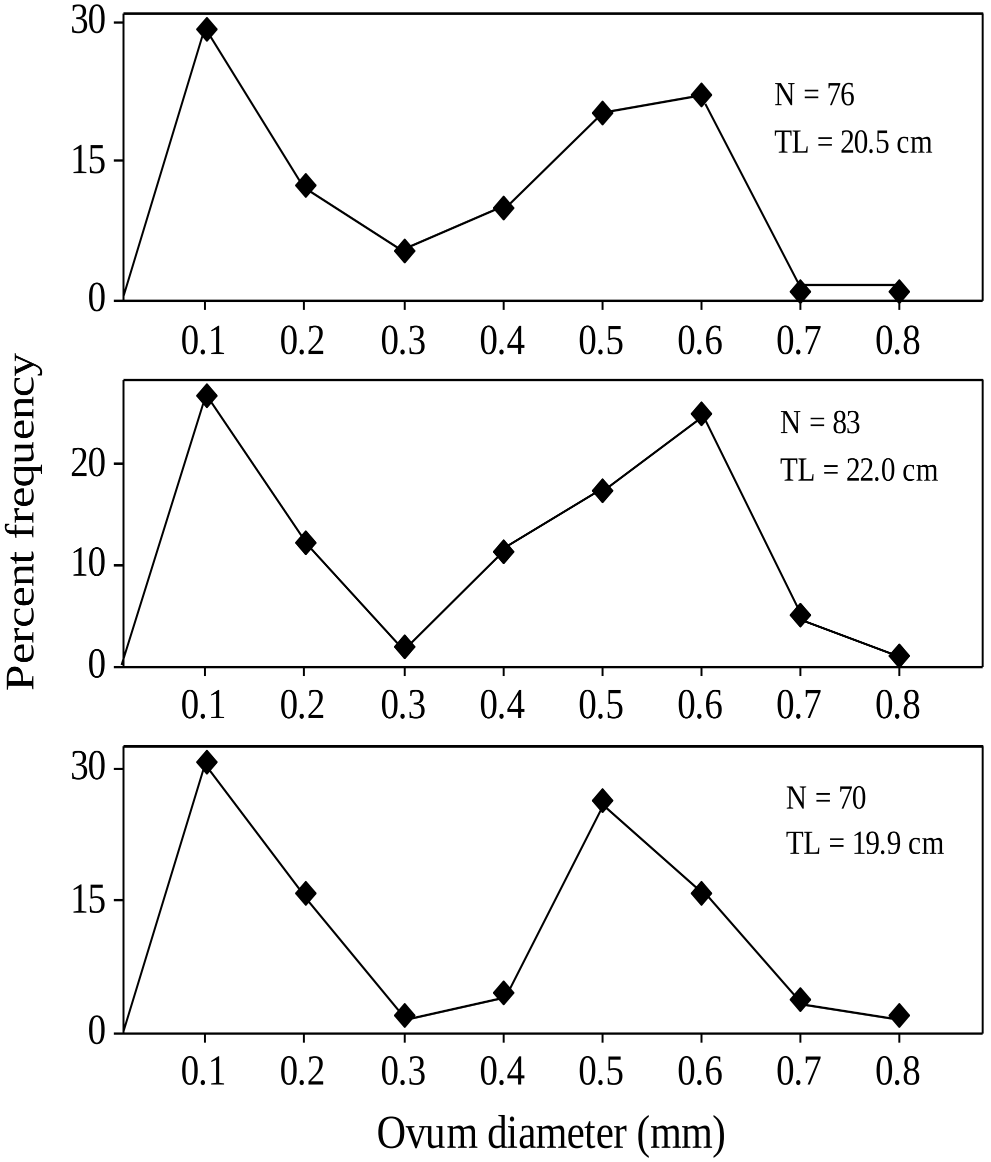


Figure 18: **Frequency distribution of ovum diameter of three ripe ovaries of *Sardinella aurita* from commercial landings at Elmina landing quay**

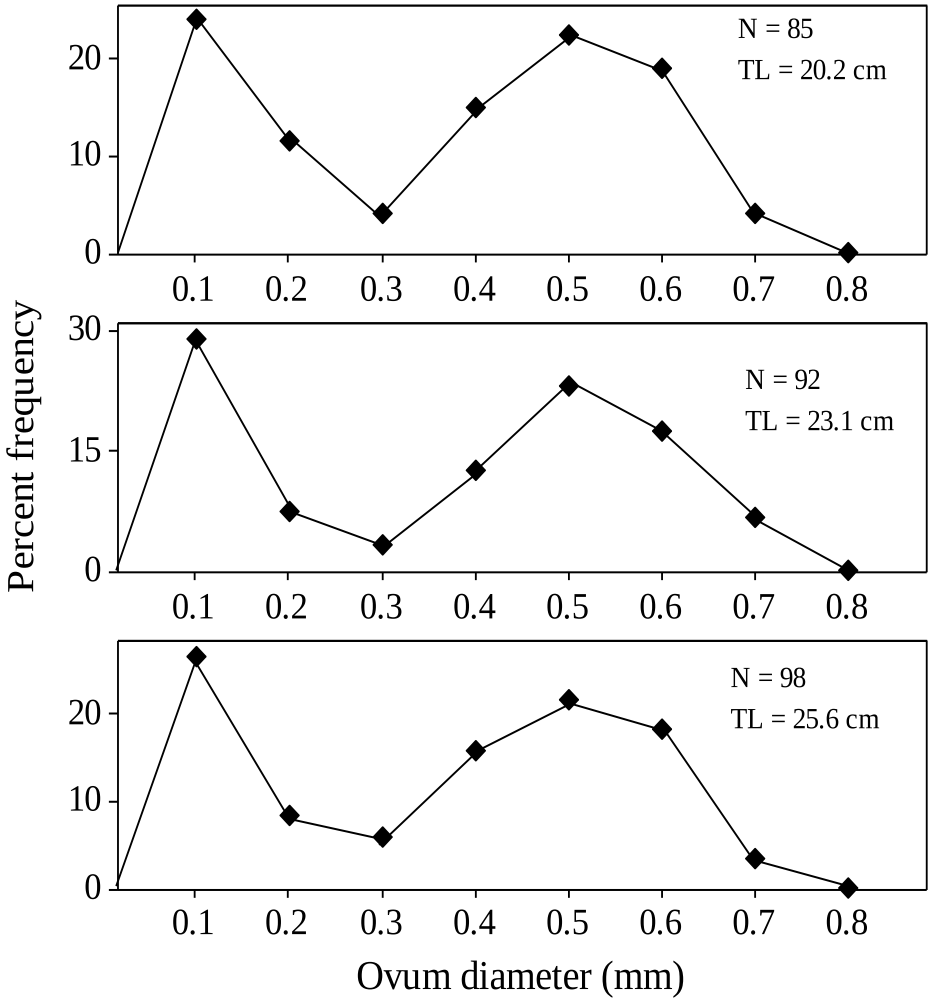


Figure 19: **Frequency distribution of ovum diameter of three ripe ovaries of *Sardinella maderensis* from commercial landings at Elmina landing quay**

Variations in gonadosomatic index (GSI)

Sardinella aurita

The variations in the mean gonadosomatic index of *S. aurita* are presented in Figure 20. The mean GSI of males ranged from 0.23 ± 0.04 to 6.56 ± 0.30 and that of females from 0.24 ± 0.06 to 6.31 ± 0.31. Generally, both sexes of the species exhibited similar pattern of GSI. There was an increase in the mean GSI for both sexes from 0.35 ± 0.06 for males and 0.24 ± 0.04 for females in October 2013 to peak values of 5.60 ± 0.35 and 4.29 ± 0.39 respectively in February 2014. But generally, both declined to May 2014 (males 2.08 ± 0.50; females 1.86 ± 0.47) followed by an increase to a peak in July 2014. The index decreased in August and to another peak in September 2014 (males 6.56 ± 0.30; females 5.11 ± 0.62).

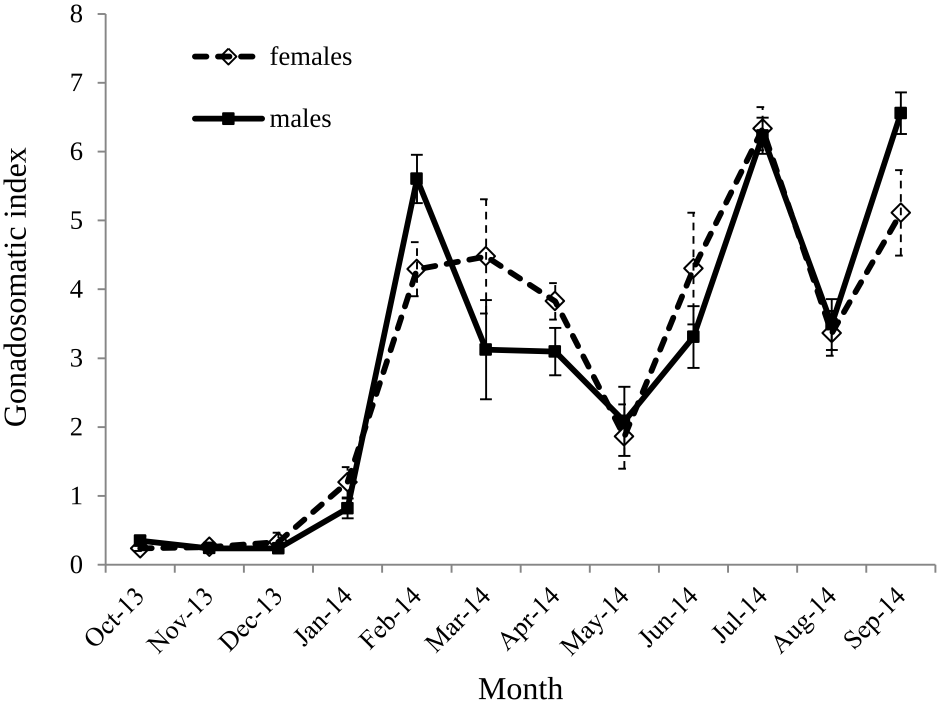


Figure 20: **Mean monthly gonadosomatic index of *Sardinella aurita* from commercial landings at Elmina landing quay (vertical bars are 1 standard error)**

Sardinella maderensis

Figure 21 illustrates the mean variations in the gonadosomatic index of *S. maderensis*. The mean GSI of the males ranged from 0.11 ± 0.01 to 4.43 ± 0.66 and that of the females was from 0.51 ± 0.04 to 3.49 ± 0.33. Mainly, both sexes of the *S. maderensis* exhibited comparable pattern. There was an increase in the mean GSI for both sexes from 0.11 ± 0.01 for males and 0.15 ± 0.04 for females in October 2013 to peak values of 2.03 ± 0.10 and 2.99 ± 0.20 respectively in March 2014. But both sexes declined to May 2014 (males 0.42 ± 0.16; females 0.81 ± 0.33) and followed by an increase to 4.43 ± 0.66 and 3.47 ± 0.33 respectively in September 2014. The mean GSI was not statistically higher in males than females in March samples (t = 1.32; P > 0.05).

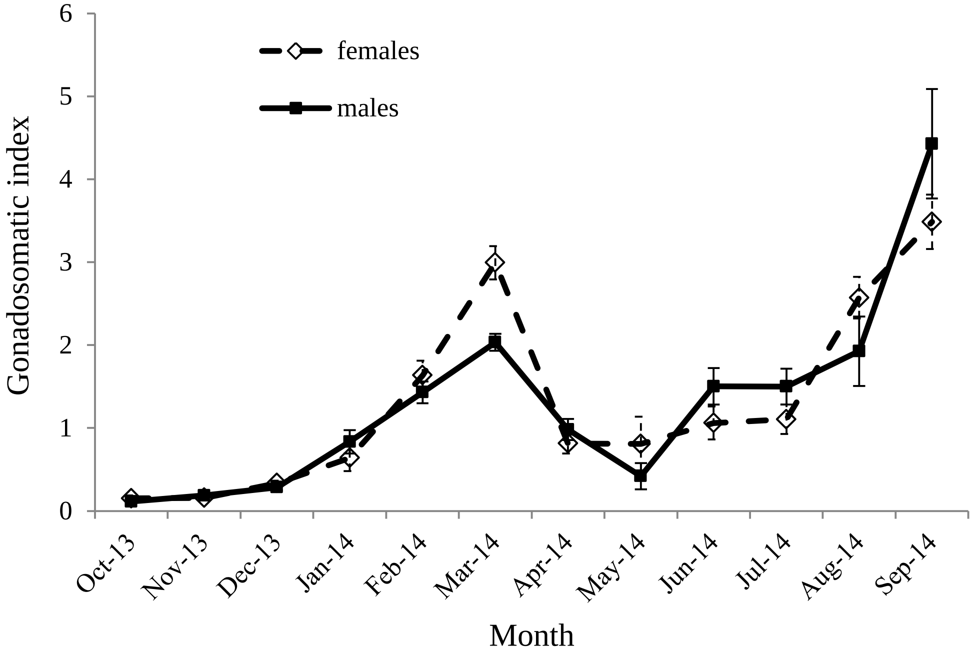


Figure 21: **Mean monthly gonadosomatic index of *Sardinella maderensis* from commercial landings at Elmina landing quay (vertical bars are 1 standard error)**

Fecundity

Sardinella aurita

Figure 22 shows the relationship between fecundity (F) and total length (TL), as well as fecundity and body weight (BW). For the 93 females used in the analysis, fecundity ranged from 4,834 for fish of 19.3 cm TL and weighing 65.92 g to 63,917 for fish of total length 25.7 cm and body weight 145.82 g. The relationships were positive and significant; described by the equations:

$F = 3130.6\ TL - 48817$ ($r = 0.56$; $P < 0.001$)

$F = 274.7\ BW - 5162.6$ ($r = 0.58$; $P < 0.001$)

Sardinella maderensis

Figure 23 illustrates the relationship between fecundity (F) and total length (TL) as well as fecundity and body weight. Fecundity ranged from 7,597 for a fish of 23.6 cm TL weighing 112.51 g to 33,984 for a fish measuring 27.5 cm TL and weighing 187.48 g. The relationships were positive and significant; they are described by the equations:

$F = 1240.9\ TL - 14402$ ($r = 0.58$; $P < 0.001$)

$F = 94.8\ BW + 3407.3$ ($r = 0.55$; $P < 0.001$)

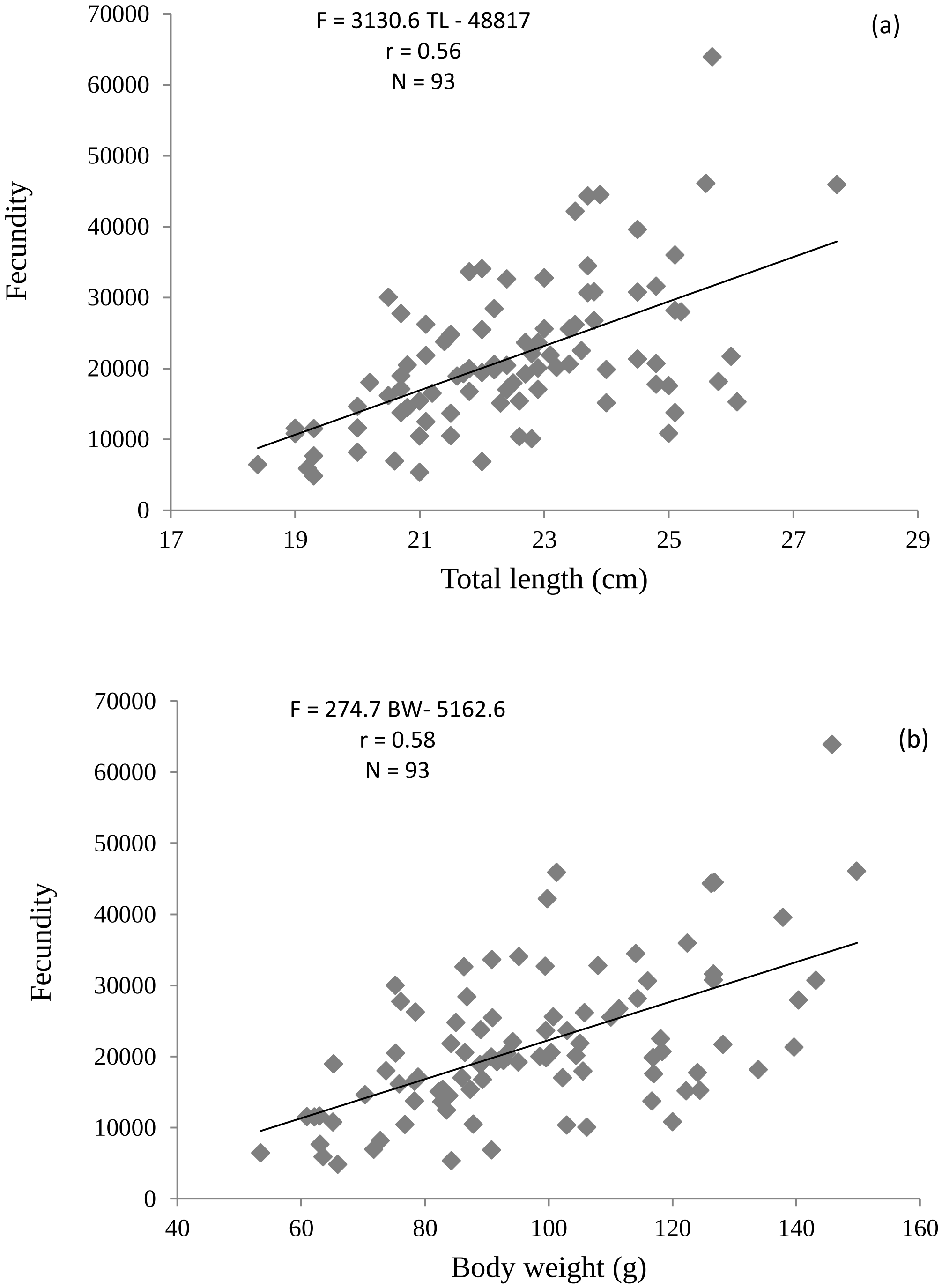


Figure 22: **Relationship between (a) fecundity and total length (b) fecundity and body weight of *Sardinella aurita* from commercial landings at Elmina landing quay**

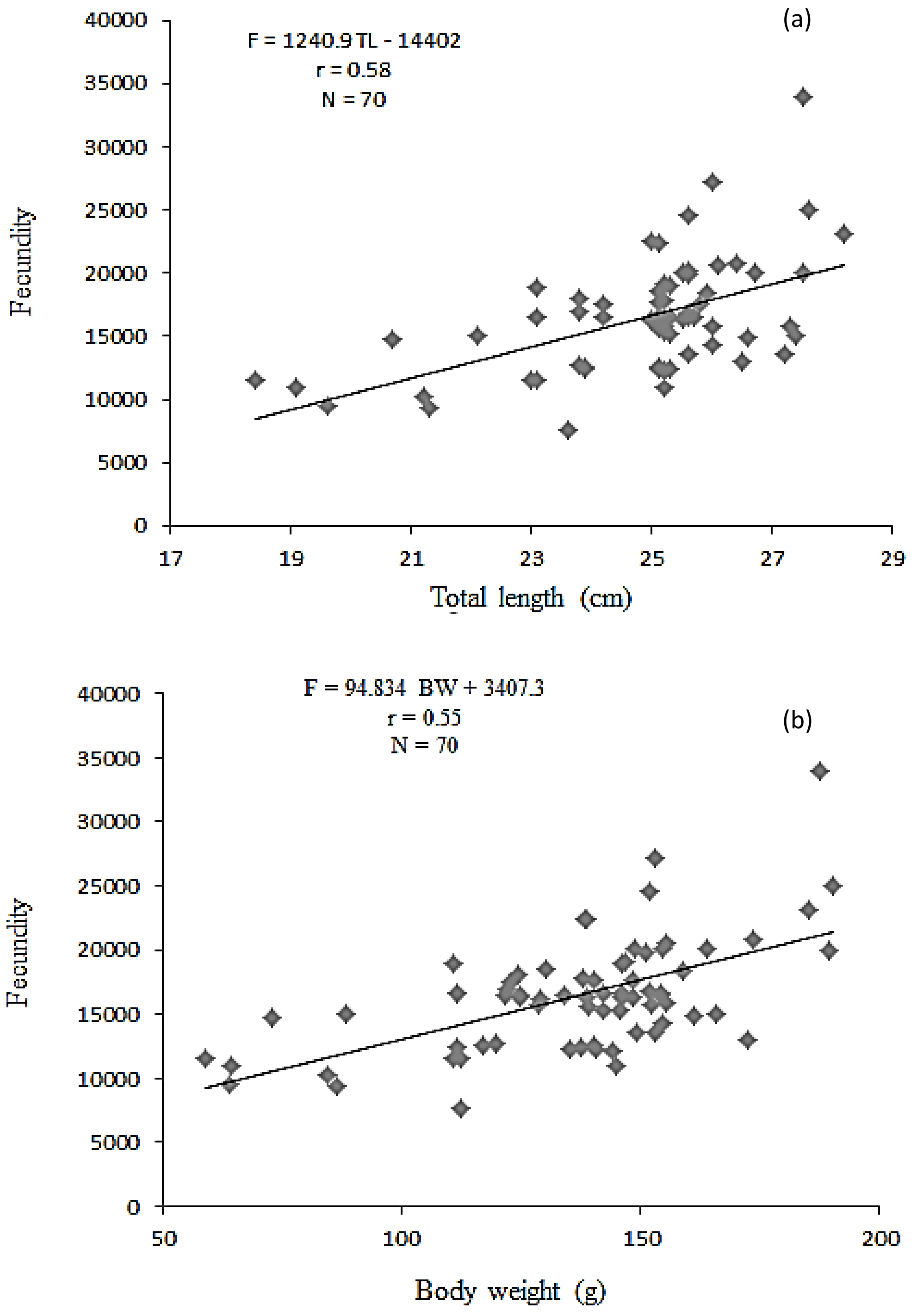


Figure 23: Relationship between (a) fecundity and total length (b) fecundity and body weight of *Sardinella maderensis* from commercial landings at Elmina landing quay

Growth parameter estimates of the *Sardinella* species

Estimates of the growth parameters of the sardines were generated from the monthly length-frequency data collected for the period October 2013 to September 2014. Preliminary estimates were obtained using the Powell-Wetherall Plot to guide the final estimates by the ELEFAN I routine (Sparre and Venema, 1992).

Figure 24a shows the Powell-Wetherall Plot for estimating the asymptotic length (L_∞) and Z/K of *S. aurita*. The selected points (line) represent size group of fish that were fully recruited to the fishery. The fully recruited fish were identified by the assistance of the Pseudo-catch curve routine (FiSAT). The asymptotic length or theoretical maximum length as was estimated at 27.57 cm TL and Z/K was 2.52, where Z is total mortality and K is growth coefficient of the species.

Figure 24b illustrates the Powell-Wetherall Plot for estimating the asymptotic length (L_∞) of *S. maderensis*. The asymptotic length and Z/K of *S. maderensis* were 30.61 cm TL and 2.54 respectively.

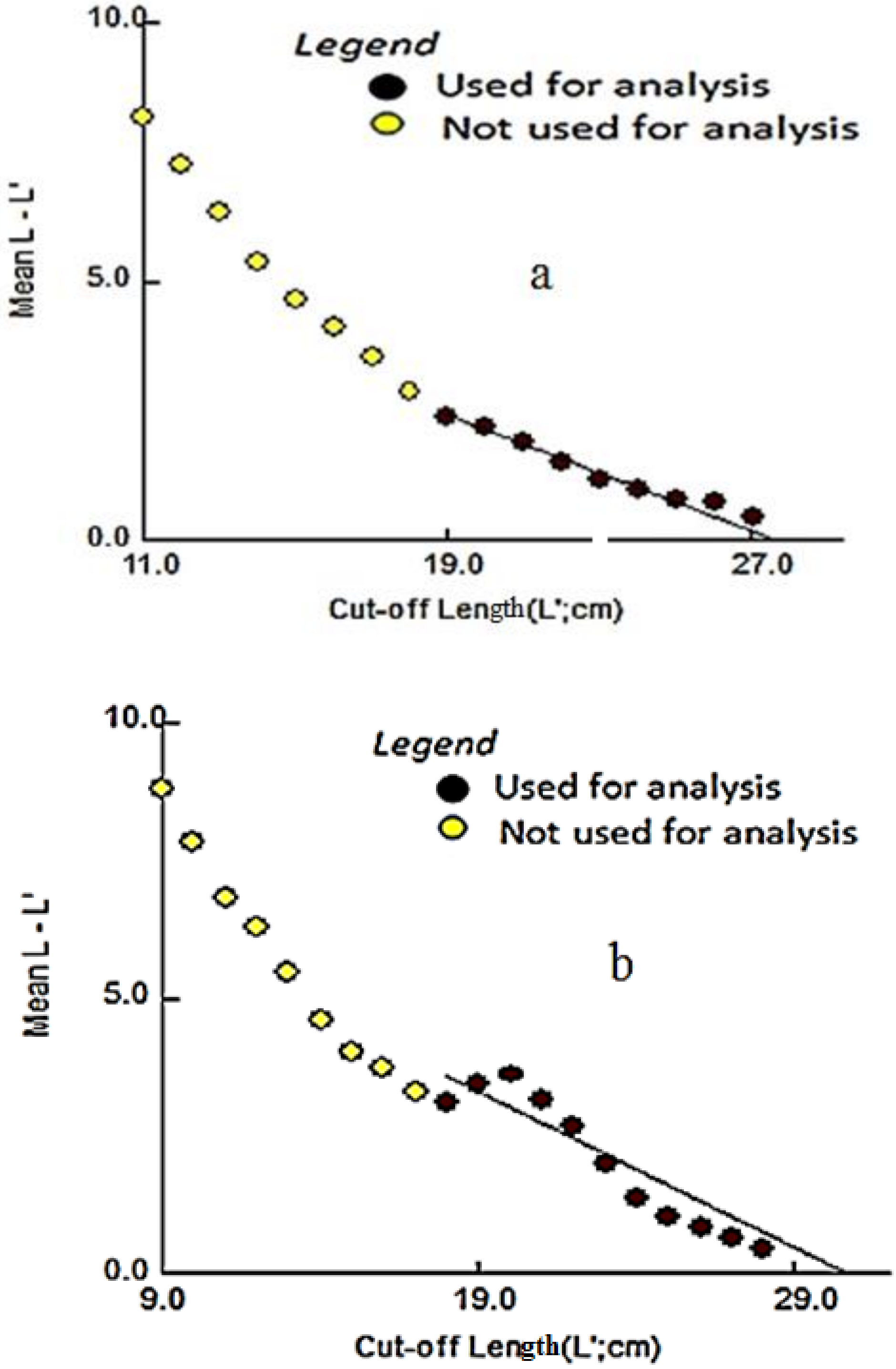


Figure 24: **Powell-Wetherall Plot for estimating the asymptotic length of (a) *Sardinella aurita* and (b) *Sardinella maderensis* populations**

Table 5 shows the final estimates of growth parameters of the sardines using ELEFAN I in addition to other growth parameters from other computations.

The maximum observed length (L_{max}) of *S. aurita* in the samples was 27.6 cm TL which is comparable to the asymptotic length of 28.70 cm TL (Table 5). The stock had a growth rate of 0.51 yr^{-1} and its longevity was estimated at 5.9 year (approximately 6 yr). Moreover, the growth performance index (Φ') and the theoretical age at zero length (t_o) were estimated at 2.63 and -1.97 year respectively. The von Bertalanffy equation describing the growth of *S. aurita* is:

$L_t = 28.70 \{1 – \exp [– 0.51 (t + 1.97)]\}$

where t is the age of the fish in years and L_t is the total length of fish at age t.

The largest *S. maderensis* sampled during the study was 28.2 cm TL while its maximum theoretical length was 29.53 cm TL (Table 5). Individuals are expected to live up to 5 years and their growth rate was estimated at 0.6 yr^{-1}. The growth performance index (Φ') and the theoretical age at zero length (t_o) were estimated at 2.63 and -1.97 year respectively. The von Bertalanffy growth function (VBGF) describing the growth of *S. maderensis* is given as:

$L_t = 29.53 \{1 – \exp [– 0.6 (t + 1.65)]\}$

The derived growth curves of the two species are shown in Figure 25. From the VBGF the lengths of one year old of *S. aurita* and *S. maderensis* are extrapolated as approximately as 22.39 cm TL and 23.39 cm TL respectively. At two years they are estimated as 24.91 cm TL and 26.25 cm TL respectively. At three years they are approximately 26.41 cm TL and 27.73 cm TL respectively. At four years the lengths of *S. aurita* and *S. maderensis* are approximately 27.33 cm

TL and 28.53 cm TL respectively. At five years they are estimated as 27.87 cm TL and 28.99 cm TL respectively. *S. aurita* at six years is approximately 27.89 cm TL

Table 5: **Estimates of growth parameters of the *Sardinella* species**

GROWTH PARAMETERS	SARDINELLAS	
	S. aurita	*S. maderensis*
L_{max}	27.9 cm	28.2 cm
L_∞	28.70 cm	29.53 cm
K	0.51 yr^{-1}	0.6 yr^{-1}
t_{max}	5.88 yr	5.0 yr
t_o	- 1.97 yr	- 1.65 yr
Φ‘	2.63	2.72

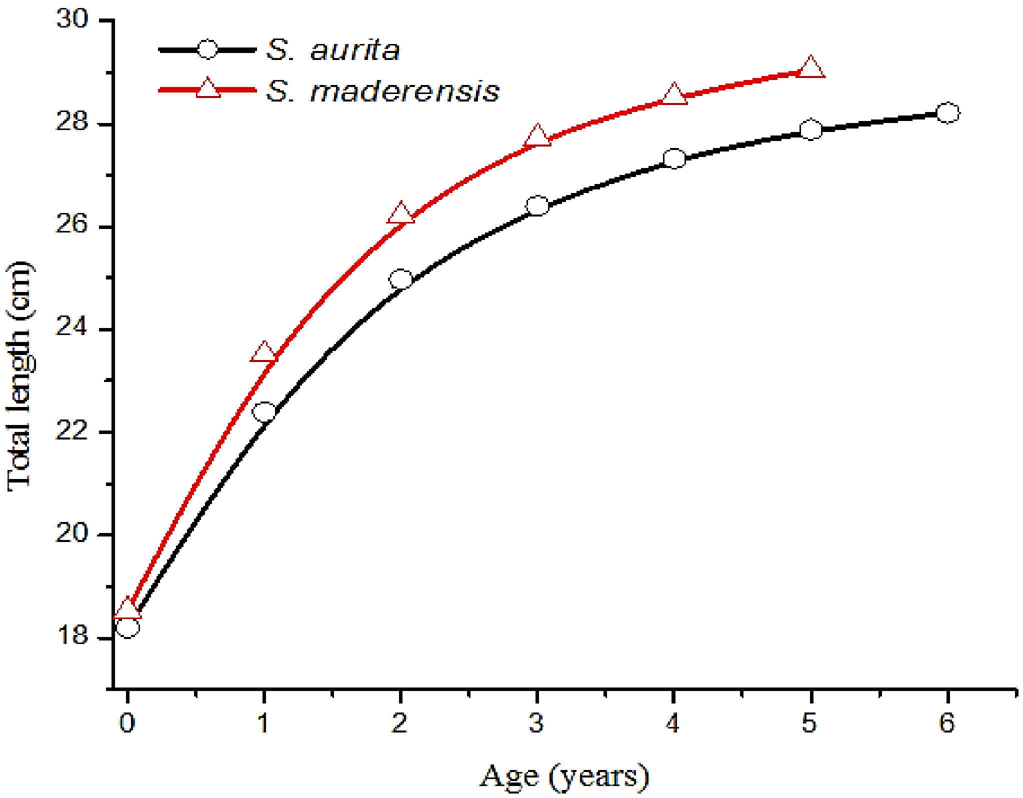


Figure 25: Derived growth curves of *Sardinella aurita* and *Sardinella maderensis*

Mortality parameters of the sardines

Figure 26a and 26b illustrate the length-converted catch curves of *S. aurita* and *S. maderensis* which estimated the total mortality rate (Z) of the populations based on fish that were fully exploited. The annual mean sea surface temperature during the sampling period was 27.2 °C (Fisheries Scientific Survey Division, FSSD, Tema).

The total mortality (Z), natural mortality (M) and fishing mortality (F) of *S. aurita* were estimated as 2.42, 1.22 and 1.20 yr $^{-1}$ respectively (Fig. 26a).

The estimates of total mortality, natural mortality and fishing mortality of *S. maderensis* were 2.72, 1.26 and 1.46 yr $^{-1}$ respectively (Fig. 26b). This might suggest that fishing mortality contributed more to the total mortality of *S. maderensis* stock.

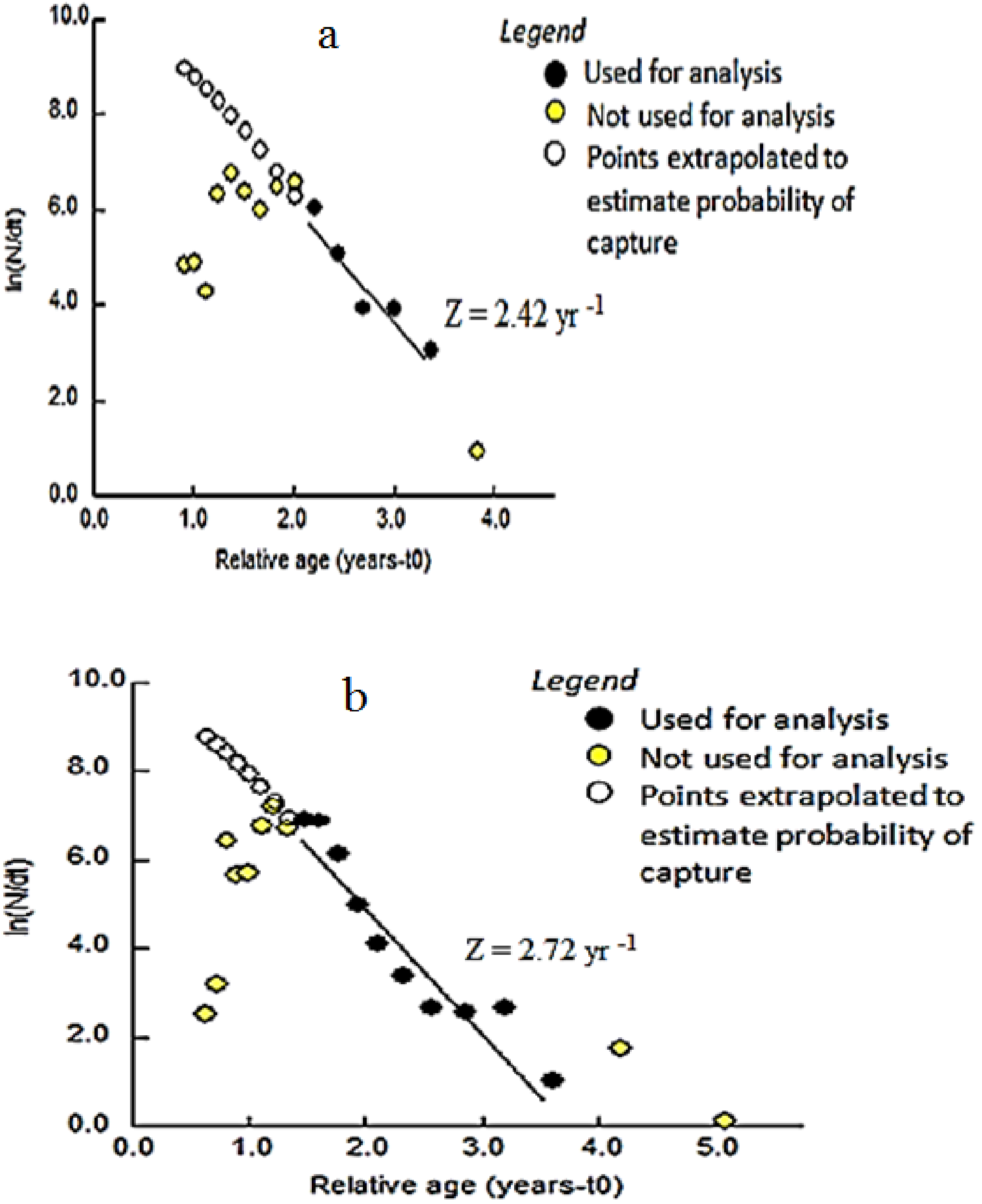


Figure 26: **Length-converted catch curve of (a) *Sardinella aurita* and (b) *Sardinella maderensis* populations**

Mean length at first capture of the *Sardinella* species

The proportions of fish going through the net at every length as a result of gear selection were generated from the ascending arm of the length-converted catch curve (Figure 27a and 27b).

Figure 27a illustrates the probability of capture of *S. aurita*. The mean length at first capture (L_{C50}) of *S. aurita* was determined as 15.83 cm TL.

Figure 27b shows the probability of capture of *S. maderensis*. The mean length at first capture (L_{C50}) of the species was estimated at 14.56 cm TL.

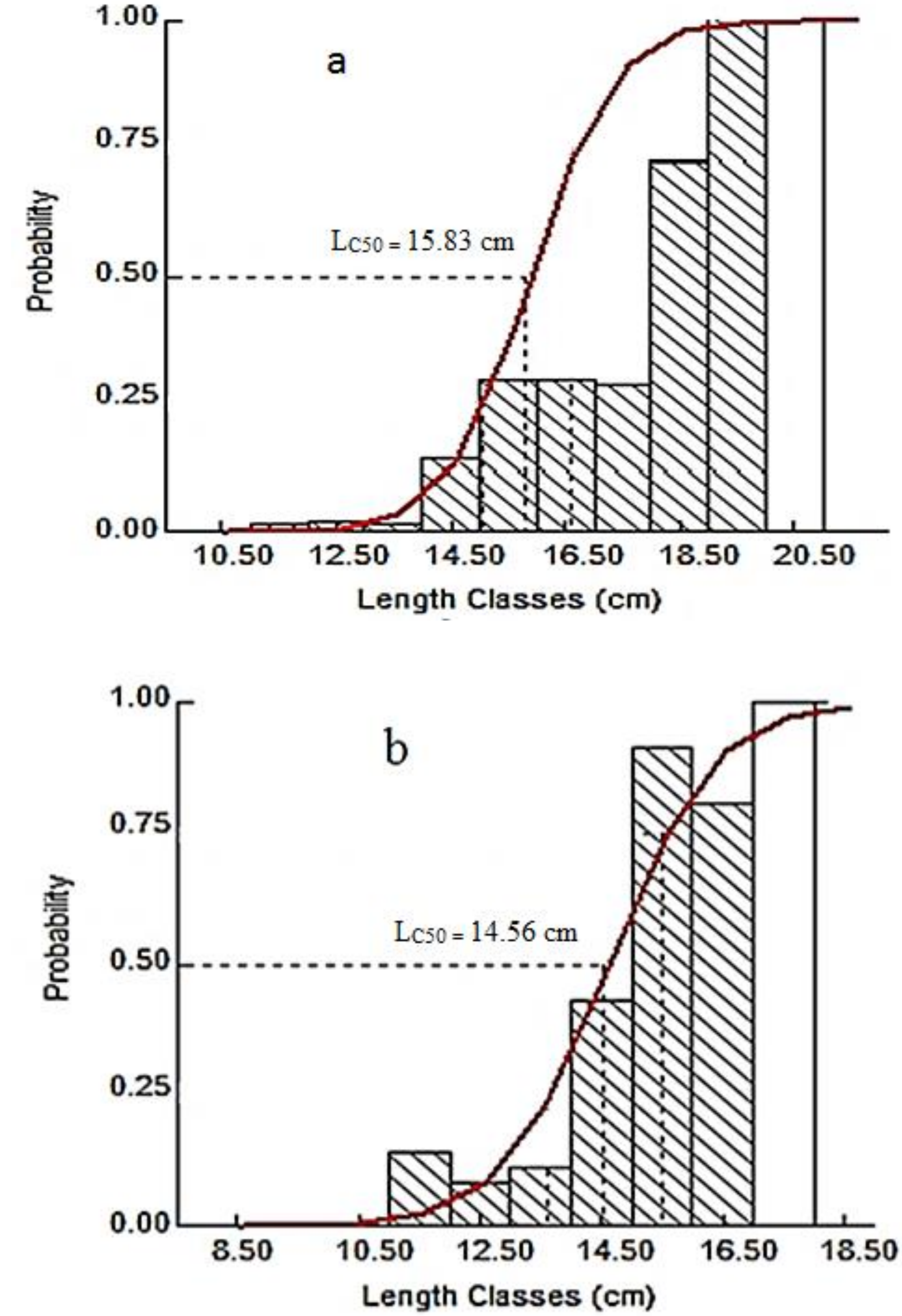


Figure 27: **Probability of Capture of (a)** ***Sardinella aurita*** **and (b)** ***Sardinella maderensis*** **in the fishery**

Exploitation rates of the *Sardinella* species

Figure 28a shows the relative yield-per-recruit and relative biomass-per-recruit of *S. aurita*. The current exploitation rate ($E_{present}$) was estimated at 0.50 and the maximum yield-per-recruit (E_{max}) occurred at an exploitation rate of 0.93. Exploitation level (E_{50}) which results in a reduction of the unexploited biomass by 50 percent was estimated at 0.38.

The relative yield-per-recruit and relative biomass-per-recruit of *S. maderensis* are presented in Figure 28b which shows the present exploitation rate as 0.54 while maximum yield-per-recruit is obtained at an exploitation rate of 0.79. Exploitation level which results in a reduction of the unexploited biomass by 50 percent was estimated at 0.36.

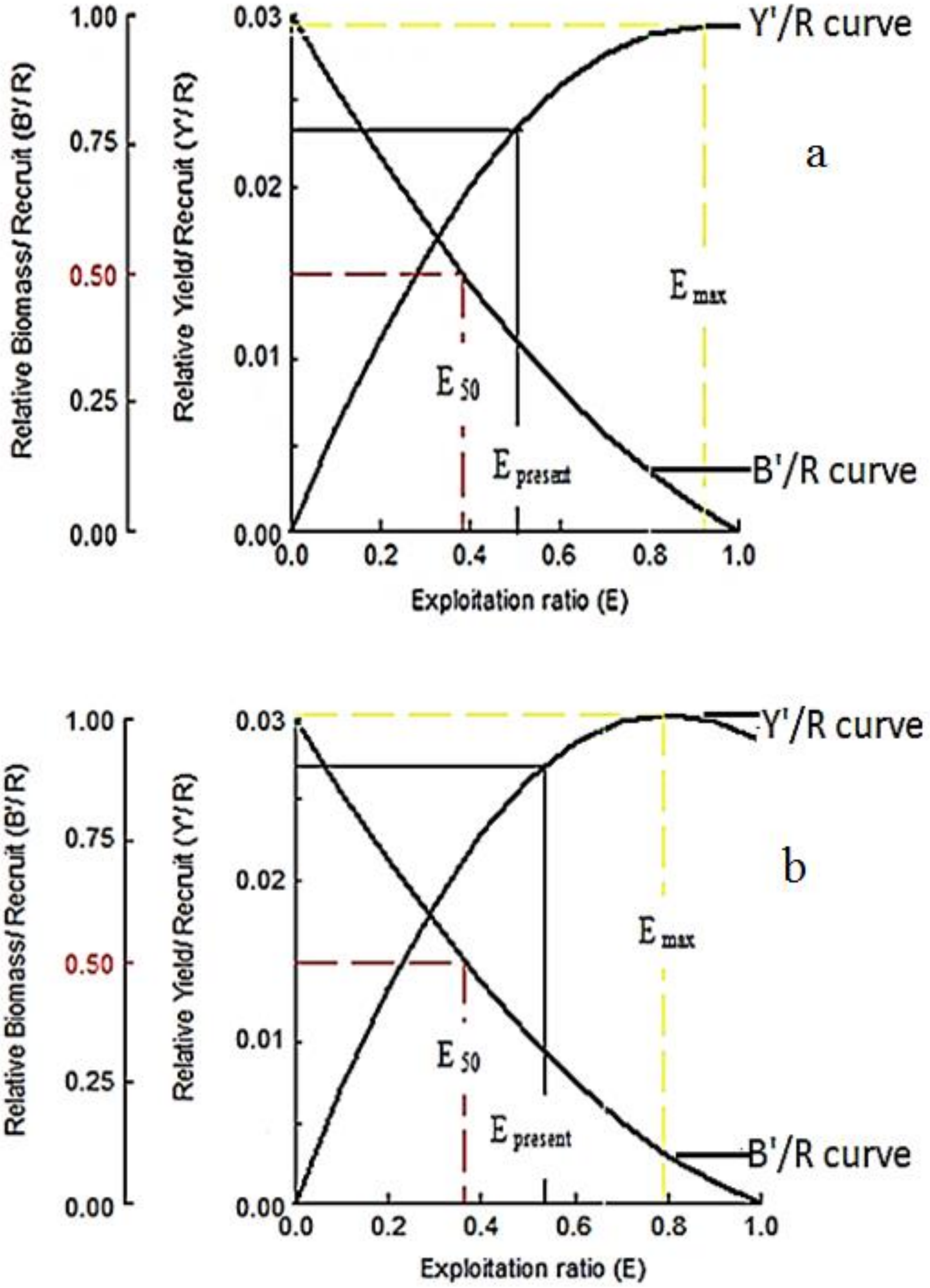


Figure 28: **Y'/R and B'/R (Knife-edge Selection) of (a) *Sardinella aurita* and (b) *Sardinella maderensis***

Recruitment patterns

Gayanilo *et al.* (1989) defined recruitment as a fully metamorphosed young fish whose growth is described adequately by the VBGF and occur at the fishing ground(s) with the instantaneous rate of natural mortality similar to that of the adults.

Sardinella aurita

Figure 29 illustrates the recruitment pattern of *S. aurita.* Recruitment occurred throughout the year showing two pulses (curves) of unequal strengths. The period of high proportions of recruits (major curve) occurred between February and August. September to January appear to record the lowest proportions (minor curve).

Sardinella maderensis

The recruitment pattern of *S. maderensis* is presented in Figure 30. Recruitment occurred throughout the year with two pulses (curves) of unequal strengths. The period of high proportions of recruits (major curve) was between June and September. Lowest proportions (minor curve) appear to have occurred from November to January.

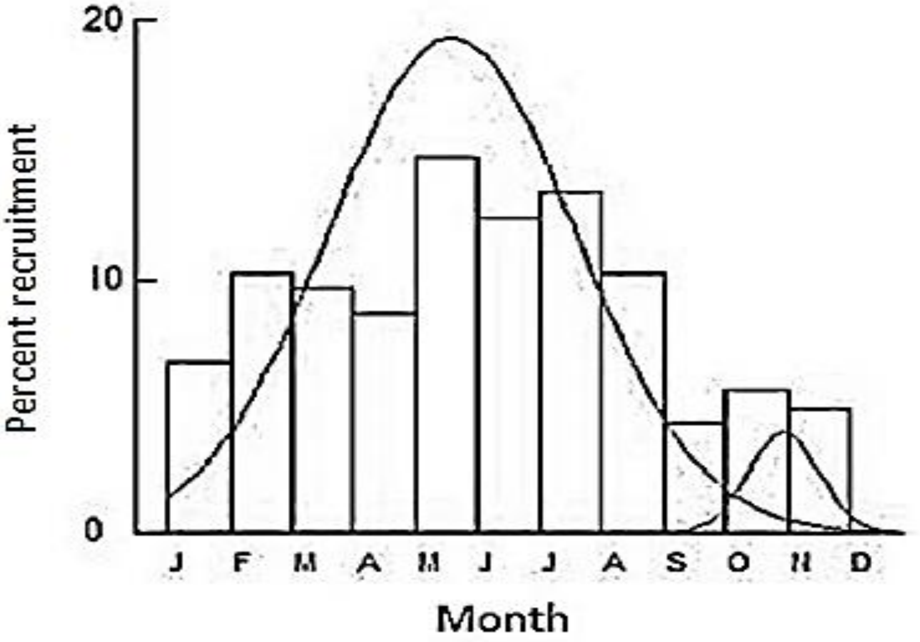


Figure 29: Recruitment pattern of *Sardinella aurita*

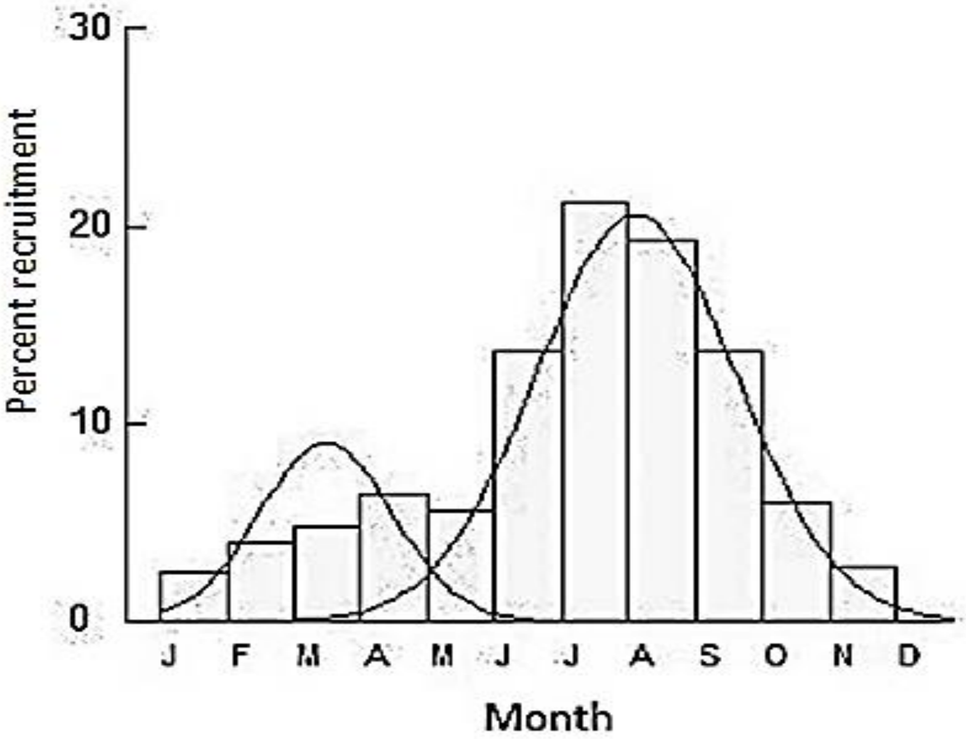


Figure 30: Recruitment pattern of *Sardinella maderensis*

CHAPTER FOUR

DISCUSSION

Growth

Length-weight relationship gives information on the condition and growth pattern of fish (Bagenal & Tesch, 1978; Moutopoulos & Stergiou, 2002). The length-weight relationships for the *Sardinella* species were exponential and described by the relationship:

$$BW = aL^b$$

where BW is the body weight, L is the length, a is a constant and b the exponent. This relationship has been reported in fish (Hart & Abowei, 2007, Abowei, 2010; Salem *et al.*, 2010; Aggrey-Fynn, 2009). Both species had a significant relationship and a strong correlation between total length (TL) and body weight (BW). Moreover, the exponents of both species ($b = 2.90 \pm 0.19$; $P > 0.05$ for *S. aurita* and $b = 2.77 \pm 0.24$; $P > 0.05$ for *S. maderensis*) did not differ significantly from 3.0. Such a fish is said to grow isometrically in other words the same shape is maintained throughout its life (Bagenal & Tesch, 1978).

It has been reported that the *S. aurita* stock in Ivorian and Ghanaian waters exhibit isometric growth (Anon., 1976), which agrees with the current finding. However, in Nigerian waters, the same species was found to exhibit negative allometric growth (Lawson & Doseku, 2013). In Mediterranean Sea, *S. aurita* stocks were reported (Tsikliras, Torre & Stergiou, 2005) to show positive allometric growth while Salem *et al.* (2010) and Mehanna and Salem (2011) reported positive allometric growth. Isometric growth of *S. maderensis* stock was observed in Cameroonian waters (Djama, Gabche & Youmbi-Tiencteu, 1989).

Bagenal and Tesch (1978) indicated that variation in the growth of the same species could come about as a result of difference in sex, maturity stage and season as well as differences in geographical locations and associated environmental conditions (Kraljevic, Dulcic, Pallaoro, Cetinic & Jug-Dujakovic, 1995).

From the current study, *S. aurita* stock condition factor declined between December 2013 and February 2014. However, the stock was expected to have increased in condition during the upwelling period (December/ January – February) when there is high primary production which leads to abundance of zooplankton hence abundant food for the stock. One possible reason for the decline in condition during the upwelling period could be that energy for somatic growth was channeled into gonad maturation. This is evidenced by an increase in GSI during the period. A similar observation was made between May and July 2014.

In *S. maderensis*, the condition index increased from December 2013 to February 2014 during the minor upwelling, perhaps the species made use of the high abundance of food (zooplankton). However, the fat index analysis which also gives an impression on the well-being of the fish declined during this period. Probably, stored fat was used to support gonad development as shown by a decline in fat index analysis and a surge in GSI during the period. Condition factor seemed to stabilize from July to September 2014; once again the stored fat might have been used in gonadal maturation as indicated by a decline in fat index and an increase in GSI of *S. maderensis.*

The monthly length-frequency distributions of *S. aurita* did not show consistent shifts in the modes. Nonetheless, *S. maderensis* seemed to exhibit some progression in the modes. It appeared *S. maderensis* stock grew by 3 cm from December 2013 to February 2014 and 2 cm from July to September 2014 during the upwelling seasons. Bagenal and Tesch (1978) explained that the lack of consistent shifts in modes could be attributed to lack of marked seasonal changes in temperature and availability of food throughout the year which guarantee continuous growth in tropical fish. Furthermore, younger fish catch up with older generations due to the decline in growth rate with increase in age. Consequently, younger fish cohort distributions superimpose on the older ones (King, 1995).

The observed maximum length of *S. aurita* of 27.9 cm TL is greater than the 25 cm maximum size observed in the Ivoro-Ghanaian waters (Brainerd, 1991) but smaller than that recorded for the Congo-Angolan, Senegal and Mauritania populations (>30 cm TL) (Brainerd, 1991). Schneider (1990) reported that the species grows up to 35 cm but commonly up to 18 cm in the Gulf of Guinea.

In this study the asymptotic length of *S. aurita* was estimated at 28.70 cm compared to the Mediterranean Sea off Algeria where the observed maximum length and the asymptotic length was 25.50 cm and 34.96 cm respectively (Bouaziz, Bennoui, Brahm & Semroud, 2001); in Tunisian waters it was 27.35 cm and 29.73 cm respectively (Gaamour *et al*., 2001). Chesheva (1998) recorded a maximum length of 39.10 cm and asymptotic length of 41.63 cm for the Mauritanian stock.

In the current study, *S. maderensis* was observed to have 28.2 cm TL as maximum observed length. However, Schneider (1990) found maximum observed length in the Gulf of Guinea to be 30 cm. The asymptotic length for the stock was estimated at 29.53 cm TL. In Nigerian waters, the asymptotic length has been estimated at 37.5 cm (Marcus, 1984 as cited in Djama, Gabche & Youmbi-Tienctheu, 1989). In Cameroon, asymptotic length of the population was estimated at 32.5 cm (Djama *et al*., 1989) and 24.9 cm in Congolese waters (Gbeno and LeGuen, 1968 as cited in Djama *et al*., 1989).

From the current study, *S. maderensis* had a higher von Bertalanffy growth coefficient (K) (0.6) than *S. aurita* (0.51) which suggests that the former species grows faster than the latter. The current finding endorses Koranteng's (1989) assertion that *S. maderensis* is generally bigger than *S. aurita* of the same age. The faster growth demonstrated by *S. maderensis* could be due to its genetic make-up or the fact that it is more of a coastal species than *S. aurita* (Whitehead, 1985) hence taking advantage of the high productivity associated with coastal waters (King, 1995). This observation could also be attributed to the relatively high mortality experienced by the *S. maderensis* stock (Anon, 1976).

The study shows that *S. aurita* lives relatively longer than *S. maderensis.* With the relatively high growth coefficient in *S. maderensis* (K = 0.6), it could be inferred that the stock approaches its theoretical maximum length at faster rate than *S. aurita* stock (K = 0.51) as illustrated by the derived growth curves of the two species. According to earlier work done in the Ghanaian waters (Ansa-Emmim, 1976 as cited in Koranteng 1989) a 2-year old *S. aurita* measures between 17 to 19 cm and at 3 years it is about 21 cm TL. However, the current study reveals that a 1-year old was about 21.6 cm TL and a 2-year old was 24.4 cm TL, which suggests that the current population of *S. aurita* grows at a faster rate than the one reported by the latter author, whilst that of *S. maderensis* was 22.3 cm TL for 1-year old and 25.8 cm TL for 2-year old. On longevity, *S. aurita* stock in the Mediterranean Sea, off Tunisia was observed to live up to for 7 years (Gaamour *et al*., 2001). However a shorter life span of 4 years has been reported in Algerian waters (Bouaziz *et al*., 2001). Around Northwest Africa, off Senegal, longevity of the species is estimated at 8 years (Krzeptowski, 1981) which is more than that of the Congo population (5 years) (Rossignol, 1955 as cited in Tsikliras *et al*., 2005). The above reports are in conformity with the report of Blaxter and Hunter (1982, as cited in King 1995) that clupeids tend to be relatively fast-growing and short-lived, rarely living beyond 5 – 10 years.

The growth performance index of *S. maderensis* (Φ' = 2.72) was slightly higher than *S. aurita* (Φ' = 2.63). *S. aurita* stocks in the Mediterranean Sea, off Tunisia, had a growth performance index of 2.31 (Gaamour *et al*., 2001) which was lower than that (2.46) observed in Algerian waters (Bouaziz *et al*., 2001). Off Senegal the growth performance index of the species was 2.70 (Krzeptowski, 1981) which was lower than the Congolese population (2.82) (Rossignol, 1955 as cited in Tsikliras *et al*., 2005).

The establishment of otolith radius and body length of the *Sardinella* species was to provide information for derivation of back-calculation formulae.

Attempts were made to examine the sagittal otoliths of both *Sardinella* species, however, the preparations did not show clear growth rings. This is a shortcoming for an accurate estimation of the number of primary growth increments for ageing the fish. This necessitates the use of length-based computer procedures in age and growth studies of the fish stocks rather than otolith studies as the latter could be frustrating.

Reproductive Biology

The overall sex ratio of *S. aurita* in the present study exhibited a statistically significant male to female ratio of 1: 1. This agrees with earlier work done in Nigerian waters (Lawson & Doseku, 2013), Mediterranean Sea (Tsikliras & Antonopoulou, 2006) and Venezuelan waters (Freon, El-Khattabi, Mendoza & Guzman, 1997). However, female *S. aurita* showed preponderance in Senegalese waters (Gaamour *et al*., 2001). According to the current results, females showed a statistically significant dominance in the July sample; perhaps the males leave the breeding grounds soon after spawning (as July happened to be the month in which spawning occurred according to the study). Ganias (2008) demonstrated that sardines form aggregations during spawning which are usually identified by hauls with increased proportions of actively spawning females and skewed sex ratios. The clupeid, *Opisthoperus sp*. was reported to have shown predominance of females in the breeding season (Radhakrishma, 1963 as reported in Asabere-Ameyaw, 1998). The analysis of size group sex ratio showed that none of the size-specific sex ratios statistically deviated from theoretical 1: 1 sex ratio, even though males seemed to outnumber the females below 19 cm TL. Nonetheless, in the Ivoro-Ghanaian waters, differences in sex ratios of size groups of the species have been reported where females dominated size groups above 17 cm whilst males dominated size groups below the stated size (Anon., 1976). Also, Pawson and Giama (1985) reported female preponderance in Libyan waters where it was ascribed to sexual differences in growth, mortality or energy cost of reproduction.

In *S. maderensis*, the overall monthly sex ratio did not deviate from the hypothetical 1:1 ratio. However, a ratio of 1: 1.5 in favour of females was found in Senegalese waters (Gabche & Hockey, 1995). With the exception of February 2014 when males significantly showed preponderance over females, the monthly sex ratios did not differ from unity. It is not clear what might be the reason for this observation. Also, except for size group 22.0 – 22.9 cm TL whose sex ratio went in favour of males, all the other size groups did not differ significantly from 1: 1. The size-specific ratios not deviating from 1:1 is a characteristic of gonochorism (Sadovy & Shapiro, 1987) as seen in the species under study. A clupeid, *Ethmalosa fimbriata* in the Ghanaian waters showed male preponderance over females after spawning and it was attributed to migration of females from the spawning grounds soon after spawning (Blay & Eyeson, 1982).

The length at sexual maturity (L_{50}) of *S. aurita* was 16.40 and 16.74 cm TL for males and females respectively. Earlier studies in Ghanaian waters reported that the mean length at first maturity was approximately 16.7 cm TL for males and 17.1 cm TL for females (Quaatey & Maravelias, 1999). Length at maturity has been reported to be liable to alteration in response to changes in population size (Blaxter & Hunter, 1982; Stewart, Ballinger & Ferrell, 2010) and this could explain the slight difference in the estimates made at different times. The maturity sizes of male and female of *S. aurita* are comparable. Anon. (1976) reported 15 cm TL as length at 50 % maturity of *S. aurita* (both sexes) in the Ivoro-Ghanaian waters. In the Mediterranean Sea, Aegean waters L_{50} was 15.5 (Males) and 16.8 (Females) cm TL (Tsikliras & Antonopoulou, 2006), Tunisian waters 14.1 (Males), 15.2 (Females) cm TL (Gaamour *et al*., 2001) and Algerian waters 14.1 (Females) cm TL (Bouaziz *et al*., 2001). Also, off Senegal, length at first maturity of *S. aurita* females was estimated as 16.5 cm TL (Boely, 1979 as cited in Tsikliras & Antonopoulou, 2006) and 18.0 cm (Camarena, 1986 as cited in Tsikliras & Antonopoulou, 2006). Generally, higher length at first maturity values have been reported for Atlantic stocks compared to the Mediterranean stocks. It is known that genetic and environmental factors influence size at first maturity (Potts & Wootton, 1984; Sampson & Al-Jufaily, 1999). Besides, it could also be influenced by long-term fishing pressure which eventually affects the size at maturity (Jennings, Kaiser & Reynolds, 2001; Olsen *et al*., 2004).

The current study estimated the length at sexual maturity as 15.43 and 15.56 cm TL for male and female of *S. maderensis* respectively. Like *S. aurita,* lengths at 50 % maturity of both sexes of *S. maderensis* are comparable. Off Cameroon, *S. maderensis* matured at a longer size (17 cm) for both sexes (Youmbi, *et al*., 1991). According to Fontana and Pianet (1973), 50 % of the females of *S. maderensis* reach stage III (developing) gonadal maturity at 18 cm.

Off Senegal, the maturity size of the species was estimated at 16.5 cm TL (Fréon, 1986).

From the derived growth curves and the length at 50 % sexual maturity of the stocks it can be said that both *Sardinella* species mature within the first year of growth (Koranteng, 1989; Ganias *et al*, 2014).

It has been reported that despite the fact that maturation of the gonads occurs at a cellular level, gross visual examination of gonads can be done to determine the maturation state or the spawning state of the gonads (Potts and Wootton, 1984; Vasconcelos, Afonso-Dias & Faria, 2012). From the present study, the presence of *S. aurita* males at Stage IV (Spawning stage) from February to September 2014 as well as the females in the Spawning stage from March to September 2014 could indicate that the species spawned over a period of 7 – 8 months and a major spawning possibly occurring in July – September 2014 (major upwelling period). Nonetheless, males and females at Post-spawning stage (IV) occurred sparingly, probably individuals at this stage left the spawning grounds soon after breeding or it could be attributed to the shedding of eggs and sperm over a short period of time (Potts & Wootton, 1984). In Congolese waters, Cury & Fontana (1988) reported that *S. aurita* reproduced throughout the year with a maximum at the upwelling season.

Gonadosomatic index increases with developing gonads prior to spawning and its decline suggests spawning (Blay & Eyeson, 1982). In *S. aurita* GSI peaked in February and declined to May 2014 as well the relatively high peak in July declining slightly in August and increasing again in September 2014. Based on the low level of the GSI in October, November and December 2013, it is expected that the mean GSI will drop in October 2014. These observations are indicative of minor but extended spawning activity from February to May as well as a major one probably between July and October. Sardines in general have been reported to exhibit protracted spawning period which are longer at lower latitudes or upwelling areas (Ganias *et al*, 2014). According to Pezenne and Koranteng (1998) spawning activity outside the known main spawning season has intensified in the species. This is in line with the findings of Quaatey and Maravelias (1999) that the species spawned mainly from July to October with a minor spawning activity in March. Moreover, in this study, there was an indication of a time lag between attainment of peak gonad maturation and onset of spawning between July and September, similar to the observation made by Quaatey and Maravelias, (1999) and it was ascribed to unfavorable environmental conditions. However, it was noted that *S. aurita* could spawn outside the upwelling season (Koranteng, 1989; Koranteng, 1995; Pezenne & Koranteng, 1998). The slight difference in the spawning period could be attributed to the annual changes in temperature regimes, as workers have linked gonad maturation and spawning with temperature (Pezenne & Koranteng, 1998; Quaatey & Maravelias, 1999; Ettahiri, Berraho, Vidy, Ramdani & Do Chi, 2003; Tsikliras, 2004). It has been argued that food availability could also be a factor (Roy *et al*., 1989).

Both sexes had similar monthly GSI values except in February and September 2014 where males showed higher GSI. According to Potts and Wootton (1984), when males and females are compared, females invest more energy in gonad maturation than males although in pelagic spawners it may be more comparable since males need to produce a lot of spermatozoa to ensure fertilization.

In *S. maderensis* the presence of males at the spawning stage from February to September 2014 as well as females at this stage from April to September 2014 could suggest that the species spawned over a period of 6 – 7 months. Moreover, higher proportion of *S. maderensis* gonads at stage IV occurred from August to September 2014 suggesting major spawning. The sparse occurrence of males and females at the post-spawning stage may be attributed to individuals at this stage leaving the spawning grounds soon after spawning, or it could be that the eggs and sperm are shed over a short period of time (Potts & Wootton, 1984).

In *S. maderensis,* the GSI of both sexes reached a minor peak in March 2014 and declined in May followed by an increase to a major peak in September 2014. These observations suggest a minor spawning activity from March to April - May and a major one in September. The lower value of the mean GSI in October and November 2013 suggests the possibility of a decline after a spawning activity in September 2013. In Senegal, Cote d' Ivoire and Congo the species have been reported to spawn throughout the year (Brainerd, 1991).

The major spawning periods of both species coincided with the major coastal upwelling off Ghana occurring between July to September (Mensah & Koranteng, 1988; Pezenne & Koranteng, 1998; Bannerman & Cowx, 2002; Ganias, Somarakis & Nunes, 2014). Sardines take advantage of the high primary productivity (abundance of zooplankton) associated with the upwelling period to ensure faster growth and to improve on larval or juvenile survival (Marchal & Picaut, 1977 as cited in Pezenne & Koranteng, 1998; Blaxter & Hunter, 1982). However, it seemed the breeding period of *S. maderensis* lagged behind that of *S. aurita* which is evidenced by a peak in GSI and Stage IV (Spawning) fish in July in the latter and a peak GSI and proportion of Stage IV in September in the former. Palomera and Sabatés (1990) reported that increased antagonism exists among clupeids at certain stages of their life cycle. This has necessitated the evolution of different reproductive strategies to preserve more vulnerable life stages (Wang & Tzeng, 1997). The *Sardinella* species probably adopted this strategy of spawning to ensure optimal utilization of food resources and larval survival. On energy usage, it seemed from the analysis of mesenteric fat that both species utilized mesenteric fat during periods of gonad maturation and that fat was metabolized to provide energy to support spawning activities (Marques & Ferreira, 2011; Mustac & Sinovcic 2009).

Frequency distribution of oocyte diameter has been used to provide evidence of duration of spawning in fish (Somvanshi, 1980; Shinkafi & Ipinjolu, 2012). In the current study, two peaks were observed for both *Sardinella* species, one for undeveloped oocytes and the other for developed oocytes. The bimodal frequency distribution of oocyte diameter of *S. aurita* and *S. maderensis* showed that the two species are determinate spawners producing a single batch of yolky oocytes prior to spawning suggesting a restricted spawning period (Tsikliras & Antonopoulou, 2006). A similar inference was made by Blay and Eyeson (1982) upon observing two peaks in the study of a clupeid, *Ethmalosa fimbriata*. Moreover, the current observation implies that individuals of the two species spawned once during the breeding season (Potts & Wotton, 1984; Gupta & Banerjee, 2013). From the analyses of the mean monthly GSI and monthly occurrence frequency of gonadal stages it could be inferred that the two species spawn twice year. Obviously, the yolky oocytes were spawned in the immediate breeding season as the non-yolky or undeveloped oocytes mature to replace the yolky ones and in turn spawn in the next breeding season (Potts & Wootton, 1984).

Fecundity estimates for this study showed a significant positive correlation between fecundity and total length as well as fecundity and body weight for both species. This is consistent with observations made on fish (Bagenal & Braum, 1978; Blay & Eyeson, 1982). *S. aurita* was more fecund than *S. maderensis*.

From the present study *S. aurita* fecundity ranged from 4,834 to 63,917. Elsewhere in the Mediterranean Sea (Aegean waters) the species had relatively higher reproductive capacity ranging from 9.7 - 72.7 x 10^3 (Tsikliras & Antonopoulou, 2006) and a lower reproductive capacity in Tunisian waters ranging from 8.3 - 43.2 x 10^3 (Gaamour *et al*., 2001).

S. maderensis fecundity ranged from 7,597 to 33,984 (fecundity-body weight relationship was given as F = 94.8 BW + 3407.3) from the current study. In Congolese waters, fecundity and body weight relationship was given as F = 418 W – 18974 (Fontana & Pianet, 1973), this indicates that the Congolese population was more fecund than the Ghanaian stock.

The number of fish is increased by the reproduction of adult fish which eventually results in small fish being recruited or added to the exploitable stock. In a fishery, the stock biomass is increased by growth and recruitment and is reduced by natural mortality and fishing mortality (King, 1995). After each spawning season the new cohort produced often remains in the shallow waters or nursery grounds and grows to attain a certain size before recruiting to the fishery (Brainerd, 1991). Recruitment is a natural way of replenishing the stocks.

S. aurita experienced recruitment throughout the year displaying two pulses of unequal strengths. Between February and August high proportions of young individuals of *S. aurita* were added to the exploitable stock. September to January recorded the lowest proportions of the recruits. Koranteng (1989) reported that stock-recruitment relationship has been examined by many workers in Ghanaian waters but the results have not been conclusive.

The recruitment pattern of *S. maderensis* presented a year round recruitment with two pulses of unequal strengths. The period of high proportions of recruits was between June and September 2014. Lowest proportions occurred from October 2013 to May 2014.

From the recruitment patterns of the *Sardinella* species, it was observed that the stocks recruited their young ones into the fisheries primarily at different periods probably to reduce competition for limiting resources (Cury & Fontana, 1988; Mader, 1996).

Mortalities and Exploitation Rates

Just as in most small pelagic fish stocks, sardinella stocks experience high natural mortalities, probably owing to the fact that the species serve as food for predators (Dutta, Maity, Chanda & Hazra, 2012), coupled with harsh environmental factors (Brainerd, 1991; Barange, 2009; Brander, 2010). Unlike *S. aurita*, fishing mortality contributed more to total mortality in *S. maderensis*. This observation is supported by the sharp decline in sizes greater than the modal class size of the pooled length composition of *S. maderensis* compared to that of *S. aurita* (Gulland & Rosenberg, 1992; King, 1995). A population which is highly exploited or has high natural mortality has scarce large fish (Asabere-Ameyaw, 1998). As a general rule, if Z/K ratio is < 1, the population is growth dominated; if it is > 1, then it is mortality dominated; if it is equal to 1, then the population is in an equilibrium state where mortality balances growth (Barry & Tegner, 1989 as cited in Uneke, Nwani, Okogwu & Okoh, 2010). In the present study, Z/K ratio was estimated at 2.51 for *S. aurita* and 2.54 for *S. maderensis.* This implies that both stocks are mortality dominated.

In Egyptian waters total, natural and fishing mortality estimates of *S. aurita* were 2.53, 0.64 and 1.89 year^{-1}, respectively (Mehanna and Salem, 2011).

The current exploitation rate ($E_{present}$) of *S. aurita* was estimated at 0.50 which is equal to the optimum exploitation level for sustainable fishery (Pauly, 1984b). In other words, the stock is currently exploited at its maximum sustainable level. Also, the maximum exploitation rate (E_{max}) of the relative yield-per-recruit was found to be 0.93 which is higher than the current exploitation level indicating that $E_{present}$ of the stock appeared inadequate for maximal utilization of the stock (Ofori-Danson & Kwarfo-Apegyah, 2008). However, the exploitation rate plots of relative biomass-per-recruit and relative yield-per-recruit showed that $E_{present} > E_{0.5}$ (exploitation rate at which 50 % of the biomass of recruit is fished). This observation suggests that the current exploitation rate could impact adversely on the recruitment into the fishery as more than 50 % of biomass-per-recruit was exploited (Ofori-Danson & Kwarfo-Apegyah, 2008; Uneke, Nwani, Okogwu & Okoh, 2010).

For the *S. maderensis* stock, the maximum exploitation rate (E_{max}) of the relative yield-per-recruit was found to be 0.79, which is higher than the current exploitation level (E = 0.54) indicating that $E_{present}$ of the stock seems inadequate for maximal utilization of stocks (Ofori-Danson & Kwarfo-Apegyah, 2008). However, the present exploitation rate (0.52) of the stock is comparable to the optimum exploitation (E_{opt}) level criterion of 0.5 for a sustainable fishery (Pauly, 1984b). Moreover, the exploitation rate plots of relative biomass-per-recruit and relative yield-per-recruit showed that $E_{present} > E_{0.5,}$ which suggests that the current exploitation rate could adversely affect the fishery as more than 50 % of the stock was exploited (Ofori-Danson & Kwarfo-Apegyah, 2008).

Considering the unstable nature of pelagic fish stocks, *Sardinella* species undergo fluctuations in abundance and distribution (Koranteng, 1989; Koranteng, 1995; Brainerd, 1991; Arnason, 2006). In addition, the species are short lived and fluctuations in recruitment success reflect in the population size (Bakun & Cury, 1999; Ganias *et al.*, 2014). Besides, conservative level of exploitation during years with good recruitment may, during unfavourable years result in overfishing (Cole and McGlade, 1998; Bertrand, Segura, Gutierrez & Vasquez 2004). Hence, it is rational to exploit the stocks below $E_{0.5}$ to give the stocks enough cushioning in case of unfavourable environmental conditions which are normally unpredictable. This is necessary because environmental factors to a large extent determine the abundance and distribution of the stocks (Brainerd, 1991) and could even defeat the purpose of keeping the stock below $E_{0.5}$ should there be a very harsh environmental conditions like weak upwelling seasons.

An increase of the modal size of *S. aurita* was observed for the Ghanaian population from 14-17cm in the early 1960s to 17-21cm fork length in the 1980s (Pezenne & Koranteng, 1998). However, the current study showed a modal length of 16-17 cm fork length (19-20 cm TL), which supports the general notion that the modal length of the landings of the *Sardinella* species has been reducing off Ghana.

The length at first capture (L_c) of *S. aurita* was 15.83 cm TL. In other words, 50 % of fish of total length 15.83 cm going through the fishing net are retained. However, this observation must be treated with caution since the specimens were sampled from both purse-seine and gill net operations. Nonetheless, it is still reasonable to compare L_m and L_c, as this becomes the first point of call to investigate each of these fishing gears. Concerning the above two parameters, it appeared purse-seine or gill netting was injurious to the *S. aurita* fishery as L_C (15.83 cm TL) is smaller than the estimated length at sexual maturity of both males and females (L_m) (16.40 and 16.74 cm TL respectively).

That is, a sizable proportion of the population in the study area is unable to attain sexual maturity before being exploited. The results showed that about 23 % of the fish are immature.

Like the *S. aurita* stock, the exploitation of *S. maderensis* population was harmful to the fishery as lower length at first capture was estimated than the length at which 50 % of the stock matured for both males and females (15.43 and 15.56 cm TL respectively). About 29 % of the specimens were immature.

With the sardinella stocks having the mean length at first capture less than the size at maturity (L_m) coupled with the current exploitation rate especially in *S. maderensis* it could be inferred that one or both fishing gears used in exploiting the stocks were unsuitable for the fisheries. It is therefore prudent to assess these fishing gears (purse seines and gill nets), possibly by revising the mesh sizes of the fishing gears. However, the high reproductive potential and high growth rate of the species could help rebuild the stocks at a faster rate (Anon, 1976; Pezenne & Koranteng, 1998) when favourable conditions set in.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The overall sex ratio of *S. aurita* exhibited a significant male to female ratio of 1: 1. Also the analysis of size group sex ratios showed that none of the size-specific sex ratios statistically deviated from the theoretical 1: 1 sex ratio for the species. Like *S. aurita,* the overall monthly sex ratio of *S. maderensis* did not deviate significantly from 1:1 ratio with the exception of February 2014 when males significantly showed preponderance over females, the reason is not clear. Also, except for size group 22.0 – 22.9 cm TL whose sex ratio went in favour of males, all the other size groups did not differ significantly from 1: 1. It could be inferred that both species exhibited characteristics of gonochorism based on the general 1: 1 sex ratio among the size groups

The lengths at 50 % sexual maturity (L_m) of male and female *S. aurita* were estimated at 16.40 and 16.74 cm and that of *S. maderensis* were 15.43 and 15.56 cm TL respectively. The *Sardinella* species sexually matures within the first year of their growth. *S. maderensis* sexually matured earlier than *S. aurita*. Also both sexes of *S. aurita* and *S. maderensis* matured at comparable sizes.

Fecundity estimates for this study showed a significant and positive correlation between fecundity and total length as well as fecundity and body weight for both species. The fecundity of *S. aurita* ranged from 4,834 to 63,917 whilst *S. maderensis* ranged from 7,597 to 33,984, this implies that *S aurita* is more fecund than *S. maderensis*.

S. aurita species spawned over a period of 7 – 8 months with a minor spawning season from February to May and a major spawning season from July to October. Besides, there was an indication of time lag between attainment of peak gonad maturation and onset of spawning between July and September-October. In *S. maderensis,* the species spawned over a relatively short period of 6 – 7 months with a minor spawning from March to May and a major one from September to October. The study also revealed significant higher GSI in males of *S. aurita* during the breeding seasons. *S. maderensis* lagged behind *S. aurita* during the breeding period. The two species were found to be determinate spawners producing a single batch of yolky oocytes prior to spawning suggesting a restricted spawning period. Thus individuals of the sardines spawn once in a breeding season. Stored mesenteric fat energy was used to support spawning activities.

Both sardines experienced recruitment throughout the year with high proportions at different periods. High proportions of young individuals of *S. aurita* were added to the exploitable stock between March and July whiles September to December recorded low proportions of the recruits. In *S. maderensis*, high proportions of recruits occur between June to September whiles low proportions occurred from October to May.

The *Sardinella* species had a significant relationship and a strong correlation between total length (TL) and body weight (BW). The growth of both stocks were isometric (b = 2.90 ± 0.19; P > 0.05 for *S. aurita* and b = 2.77 ± 0.24; P > 0.05 for *S. maderensis*). Generally, the monthly length-frequency distributions of the *Sardinella* species did not show consistent shifts in the modes. However, *S. maderensis* seemed to exhibit some progression in the modes during the upwelling seasons. In *S. aurita* the observed maximum length and asymptotic length were estimated as 27.9 and 28.70 cm TL respectively. *S. maderensis* had higher estimates of maximum length and asymptotic length (28.2 and 29.53 cm TL respectively). *S. maderensis* (K = 0.6) was found to have a faster growth rate than *S. aurita* (K = 0.51). This corresponds with a longer life span in the latter (6 years) than the former (5 years). The growth performance index of *S. maderensis* (2.72) was slightly higher than *S. aurita* (2.63).

Both sardinella stocks are mortality dominated. Unlike *S. aurita,* fishing mortality contributed more to the total mortality in *S. maderensis*.

A significant otolith radius-total length relationships for the various species were established as $TL = 5.58 R + 2.47$ ($r = 0.95$; $P < 0.001$) for *S. aurita* and $TL = 6.22 R - 1.42$ ($r = 0.96$; $P < 0.001$) for *S. maderensis*.

The main revelation of the current study is that the sardinella stocks are not exploited sustainably, taking into consideration the unstable nature of the pelagic species. The length at first capture (L_C) for *S. aurita* stock (15.83 cm TL) was lower than the estimated length at sexual maturity (L_m) of both males and females (16.40 and 16.74 cm TL respectively). This implies that juveniles are exploited before they become sexually mature. Like the *S. aurita* stock, the exploitation of *S. maderensis* population is harmful to the fishery as length at first capture was lower than the estimated length at which 50 % of the *S. maderensis* stock matured sexually for both males and females (15.43 and 15.56 cm TL respectively). It appeared either the purse-seine or gill net fishing or both gears are injurious to the fishery.

Recommendations

1. The legal minimum mesh sizes of purse seine-net and/or gill net (of the Ghana Fisheries Act 625) should be revised to allow juveniles of the sardinellas to spawn at least once before being caught.
2. Livelihood diversification and alternative livelihood programs should be encouraged among fisher folks to help reduce the fishing pressure on fish stocks.
3. A detailed study on the microstructural features of the otoliths of the *Sardinella* species could advance the existing knowledge on the stocks.

REFERENCES

Abowei, J. F. N. (2010). The Condition Factor, Length – Weight Relationship and Abundance of *Ilisha africana* (Block, 1795) from Nkoro River Niger Delta, Nigeria. *Advance Journal of Food Science and Technology, 2*(1), 6-11.

Anonymous (1976). *Rapport du groupe de travail sur la Sardinelle (S. aurita) des Cotes Ivoiro-Ghaneennes*. Fishery Research Unit Tema.

Anonymous (2003). *"Fish collection of the Royal Ontario Museum".* Royal Ontario Museum.

Adebisi, F. A. (2012). Aspects of reproductive biology of big eye grunt *Brachydeuterus auritus* (Valenciennes, 1832). *Nature and Science*, *10*, 19-24.

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*, 1 -11

Alam, M. M., Ahsan, M. K. & Parween, S. (2012). Ovarian development, fecundity and reproductive cycle in *Securicula gora* (Hamilton, 1822). *DAV International Journal of Science 1*(2).

Amador, K., Bannerman, P., Quartey, R. & Ashong, R. (2006). Ghana Canoe Frame Survey. Information report number 34. Marine Fisheries Research Division, Ministry of Fisheries.

Ansa-Emmim, M. (1976). Tagging experiments in Ghana. (mimeo).

Aripin, I. E. & Showers, P. A. T. (2000). Population Parameters of Small Pelagic Fishes Caught off Tawi-Tawi, Philippines. *Naga*, *The ICLARM Quarterly*, Vol. *23*, No. 4.

Arnason, R. (2006). *Global warming, small pelagic fisheries and risk*. *In*: R. Hanneson, M. Barange and S.J. Herrick (eds.). Climate Change and the Economics of the World's Fisheries. Edwar Elgar Publishing Limited, Cheltenham *328*, 1–32.

Asabere-Ameyaw, A. (1998). *Some population parameters of Pegellus bellotti (Sparidae) and Brachydeuterus auritus (Haemulidae) from Ghana.* PhD. Thesis presented to the Department of Zoology, Faculty of Science, University of Cape Coast, 175 pp.

Bagenal, T. B. & Braum, E. (1978). Eggs and Early Life History. In T. Bagenal (Ed.), *Methods for assessment of fish production in fresh waters*, (3rd ed.). IBP Handbook No. 3, Oxford: Blackwell Science Publications. Pp 165 – 201.

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

Bakun, A. & Parrish, R. H. (1990). Comparative studies of coastal pelagic fish reproductive habitats: the Brazilian sardine (*Sardinella aurita*). *J. Cons. Int. Explor. Mer.*, *46*, 269-283.

Bakun, A., & Cury, P. (1999). The ‘‘school trap’’: a mechanism promoting large-amplitude out-of-phase population oscillations of small pelagic fish species. *Ecology Letters*, *2*(6), 349–351.

Bannerman, P. O. & Cowx, I. G. (2002). Stock Assessment of the big-eye grunt (*Brachydeuterus auritus*) fishery in Ghanaian Coastal Waters. *Fisheries Research 59*, 197-207.

Barange, M., Bernal, M., Cercole, M. C., Cubillos, L., Cunningham, C.L., Daskalov, G.M., De Oliveira, J. A. A., Dickey-Collas, M., Hill, K., Jacobson, L., Koster, F. W., Masse, J., Nishida, H., Niquen, M., Oozeki, Y., Palomera, I., Saccardo, S. A., Santojanni, A., Serra, R., Somarakis, S., Stratoudakis, Y., van der Lingen, C. D., Uriarte, A. & Yatsu, A. (2009). Current trends in the assessment and management of small pelagic fish stocks. In: Checkley, D., Alheit, J., Oozeki, Y. and Roy, C. (eds.). *Climate Change and Small Pelagic Fish Stocks.* Cambridge University Press, Cambridge 382, 191-255.

Barry, J. P. & Tegner, M. J. (1989). Inferring demographic processes from size-frequency distributions: simple models indicate specific patterns of growth and mortality. *Fishery Bulletin, 88*, 13-19.

Bauchot, M. L. (1987). Poissons osseux. In: W. Fischer, Schneider, M. and M.-L. Bauchot (eds.), *Fishes FAO d’ identification des espèces pour les besoins de la pêche: Méditerranée et mer Noire*. Zone de pêche 37. Volume II. Vertèbres., pp. 861-1422. Food and Agricultural Organisation of the United Nations, Rome.

Bedairia, A. & Djebar, A. B. (2009). A preliminary analysis of the state of exploitation of the sardine, *Sardina pilchardus* (Walbaum, 1792), in the gulf of Annaba, East Algerian. *Animal Biodiversity and Conservation*, *32*(2), 89–99.

Bertrand, A., Segura, M., Gutierrez, M. & Vasquez, L. (2004). From Small-scale habitat loopholes to decadal cycles: a habitat-based hypothesis explaining fluctuation in pelagic fish populations off Peru. *Fisheries 5*, 296-316.

Beverton, R. J. H. (1990). Small marine pelagic fish and the threat of fishing; are they endangered*? Journal of Fish Biology, 37* (Supplement A), 5–16.

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

Blay, J. Jr., & Asabere-Ameyaw, A. (1993). Assessment of the fishery of a stunted population of the cichlid, Sarotherodon melanotheron (Rüppel), in a “closed” lagoon in Ghana. *Journal of Applied Ichthyology, 9,* 1 – 11.

Blay, J. Jr. (1998). Growth and mortality parameters of *Sarotherodon melanotheron* (Teleostei: Cichlidae) in two brackish water systems in Ghana. *Ghana Journal of Science*, *38*, 47 – 55.

Blaxter, J. H. S. & Hunter, J. R. (1982). The biology of the clupeoid fishes. *Advance Marine Biology*, *20*, 1-223.

Boely, T. (1979). *Biologie des deux especes de sardinelles (Sardinella aurita Valenciennes 1847 et Sardinella maderensis Lowe 1841) des Cote senegalaises*. These Doctorat d'etat, Universit6 de Paris VI.

Bouaziz, A., Bennoui, A., Brahmi, B. & Semroud, R. (2001). Sur l’estimation de l’état d’exploitation de la sardinelle (*Sardinella aurita* Valenciennes, 1847) de la région centre de la cote algéri- enne. *Rapp. Comm. int. mer Médit*., *36*, 244.

Bouaziz, A., Kerzabi, F. & Brahmi, B. (2014). Impact of the natural mortality (*M*) variability on the evaluation of the exploitable stock of sardine, *Sardina pilchardus* (Actinopterygii: Clupeiformes: Clupeidae) of the central region of the Algerian coast. *Acta Ichthyol. Piscat*., *44*(2), 87–97.

Brainerd, T. R. (1991). *The sardinella fishery off the coast of West Africa: the case of a common property resource*. Paper presented at the Second Annual Conference of the International Association for the Study of Common Property (IASCP), University of Manitoba, Winnipeg, Canada.

Brander, K. (2010). Climate change and fisheries management. *In*: R. Grafton, R. Hilborn, D. Squires, M. Tait and M. Williams (eds.). *Marine Fisheries Conservation and Management.* Oxford University Press, New York. Pp 123-138.

Camarena Luhrs, T. (1986). *Les principales especes de poissons pelagiques cotiers au senegal : biologie et evaluation des ressources*. These de Doctorat Univ. Bretagne Occidentale, France. Pp 187.

Campana, S. E. & Neilson, J. D. (1985). Microstructure of fish otoliths. *Can. Journal of Fish Aquatic Science*, *42*, 1014-1032.

Campana, S. E., Gagne, J. A. & McLaren, J. W. (1995). Elemental fingerprinting of fish otoliths using ID-ICPMS. *Marine Ecology Series*, *122*, 115-120.

Chesheva, Z. A. (1998). The method of determining age and growth rate of gilt sardine (Sardinella) Senegal-Mauritania population. *Journal of Ichthyology, 38,* 814-817.

Cole, J. & McGlade, J. (1998). Clupeoid population variability, the environment and satellite imagery in coastal upwelling. *Reviews in Fish Biology 8*, 445–471.

Cury, P. & Fontana, A. (1988). Compétition et stratégies démo- graphiques compares de deux espèces de sardinelles (*Sardinella aurita* et *Sardinella maderensis*) des cotes ouest- africaines. *Aquatic Living Resources, 1*, 165-180.

Dayaratne, P. (1986). A comparison of primary growth rings in otoliths of *Sprattus sprattus* from Norway and *Sardinella* spp. From Sri Lanka. *Flødevigen rapportser, 1,* 22-264.

Dayaratne, P. & Gjosaeter, J. (1986). Age and growth of four *Sardinella* spp. from Sri Lanka. *Fisheries Research, 4,* 1-33.

Deutsch, L., Graslund, S., Folke, C., Troell, M., Huitric, M., Kautsky, N. & Lebel, L. (2007). Feeding aquaculture growth through globalization: Exploitation of marine ecosystems for fishmeal. *Global Environ. Chang. 17*, 238-249.

Djama, T., Gabche, C. & Youmbi-Tienctheu, J. (1989). Comparisons of the growth of West African Stock of *Sardinella maderensis* with Emphasis on Cameroon. *Fishbyte (ICLARM), 7*(3), 13-14.

Durand, M. H., Cury, P., Mendelssohn, R., Roy, C., Baku, A., & Pauly, D. (eds) (1998). *From local to global changes in upwelling systems*. ORSTOM, Paris. 593 pp.

Dutta, S., Maity, S., Chanda, A. & Hazra, S. (2012). Population Structure, Mortality Rate and Exploitation Rate of Hilsa Shad (*Tenualosa ilisha*) in West Bengal Coast of Northern Bay of Bengal, India. *World Journal of Fish and Marine Sciences, 4*(1), 54-59.

El-Rashidy, H. H. H. (1987). *Icthyoplankton of the south eastern Mediterranean Sea off the Egyptian coast*. M.Sc. Thesis, Fac. Sci., Alexandria.

El-Sayed, H. K. A. (2009). Fisheries of experimental purse seine net using light and population dynamics of *Sardinella aurita* (Family Clupeidae) east of Alexandria, Egypt. *Egypt J. Aquat. Biol. & Fish*., *13*(1) 55 – 77.

Ettahiri, O., Berraho, A., Vidy, G., Ramdani, M. & Do Chi, T. (2003). Observation on the spawning of Sardina and Sardinella off the south Moroccan Atlantic coast (21-26º N). *Fisheries Research, 60,* 207-222.

Fagade, S. O. (1974). Age determination in *Tilapia melanotheron* (Ruppell) in the Lagos Lagoon, Nigeria, with a discussion of the environmental and physiological basis of growth markings in the tropics. In *Ageing of Fish*, pp. 71 – 77 (Ed. T. B. Bagenal). Unwin Brothers, Old Woking. 234 pp.

FAO (1997). Fisheries Management. *FAO Technical Guidelines for Responsible Fisheries, No. 4*. FAO Rome. 82 pp.

FAO (2005). Fisheries and Aquaculture. Small-scale and artisanal fisheries. FAO Fisheries and Aquaculture Department. Fisheries management. *FAO*

Technical Guidelines for Responsible Fisheries, No. 4. FAO, Rome. 82 pp.

FAO, WFP & IFAD. (2012). *The State of Food Insecurity in the World 2012. Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition.* Rome, FAO.

Fischer, W., Bianchi, G. & Scott, W. B. (1981). *FAO Species Identification Sheets for Fishery Purposes. Eastern Central Atlantic; Fishing areas 34, 47 (in part).* FAO, Rome, 7 vols.

Fisheries Commission (2011). Annual Fisheries Report.

Fontana, A. & Pianet, R. (1973). Biologie des sardinelles *Sardinella eba* (Val) et *Sardinella aurita* (Val) des Cotes du Congo au Gabon. Doc. Sci. Cent. Pointe-Noire ORSTOM (Nouv. S6r), (31): 38 pp.

Fréon, P., El Khattabi, M., Mendoza, J. & Guzman, R. (1997). Unexpected reproductive strategy of *Sardinella aurita* off the coast of Venezuela. *Mar. Biol*., *128*, 363-372.

Froese, R. & Pauly, D. (Eds.) (2003). Fishbase, World Wide Web electronic publication, www.fishbase.org.

Gaamour, A., Missaoui, H., Ben-Abdallah, L. & El Ahmed, A. (2001). Paramètres biologiques de la sardinelle ronde (*Sardinella aurita* Valenciennes, 1847) dans la région du Cap Bon (canal siculo-tunisien). GFCM, 26-30 March 2001, Kavala, Greece. (www.faocopemed.org/en/sac/docs.htm).

Gabche, C. E. & Hockey, U. P. (1995). Growth, mortality and reproduction of *Sardinella maderensis* (Lowe, 1841) in the artisanal fisheries off Kribi, Cameroon. *Fisheries Research*, *2*(4). 331-344.

Ganias, K. (2008). Ephemeral spawning aggregations in the Mediterranean sardine, *Sardina pilchardus*: a comparison with other multiple-spawning clupeoids. *Mar. Biol. 155*, 293 - 301.

Ganias, K**.**, Somarakis, S. & Nunes, C. (2014). Reproductive potential. In Ganias K. (ed) *Biology and Ecology of Sardines and Anchovies*. CRC Press, Taylor & Francis Group. 391 pp.

Gayanilo, F. C. Jr., M. Soriano & D. Pauly, (1989). A draft guide to the Compleat ELEFAN. ICLARM Software 2. 70 pp.

Gayanilo, F. C. Jr., Sparre, P. & Pauly, D. (2005). FAO-ICLARM stock assessment tools (FiSAT) user's manual. FAO Comp. Info. Ser. (Fisheries) 8. 126 pp.

Gbeno, Y. & LeGuen, J. C. (1968). Determination de l'age et croissance de Sardinella eba (Val) dans la region de Pointe-Noise, Cah. *ORSTOM (Oceanogr.) 6*(2), 69-82.

Ghana Fisheries Act 625 (2002). *Fisheries Act of the Government of Ghana.*

Gulland, J. A. (1971). *The fish resources of the oceans*. Fishing News (Book) Ltd., West Byfleet, Surrey, 255 pp.

Gulland, J. A. & Rosenberg, A. A. (1992). A review of length-based approaches to assessing fish stocks. *FAO Fisheries Technical Paper*. No. 323. Rome FAO. 100 pp.

Gupta, S. & Banerjee, S. (2013). Studies on some aspects of Reproductive biology of Amblypharyngodon mola (Hamilton-Buchanan, 1822). *International Research Journal of Biological Sciences*, *2*(2), 69-77.

Hammond, D. A. (1962). The Herring season. In *Fisheries Research Report Vol. 1* No. 1. Fisheries Inspectorate Unit Accra, 11-14 pp.

Hart, A. I. & Abowei, J. F. N. (2007). A study of the length-weight relationship, condition factor and age of ten fish species from the lower Nun river. Niger Delta. Afr. *J. Appl. Zool. Environ. Biol*., *9*, 13-19.

Hickling, C. F. & Rutenberg, E. (1963). The ovary as an indicator of spawning period in fishes. *J. Mar. Biol. Ass. U.K*., *21*, 311 – 317.

Holden, M. J. & Raitt, D. F. S. (1974). Manual of fisheries science, Part 2 – Methods of resource investigation and their application.FAO Fish. Tech. Pap.115, Rev.1:255 pp. Available online at http://www.fao.org/DOCREP/003/F0752E/F075 2E00.

Jennings, S., Kaiser, M. J. & Reynolds, J. D. (2001). Marine Fisheries Ecology. Blackwell Science, London.

Jurasi, A. A. & Yamaguti, N. (1989). Sexual maturity, spawning and fecundity of king weakfish *Macrodon ancylodon*, caught off Rio Grande do Sul State (southern coast of Brazil). Bolm Inst. oceanogr., S Paulo, *37*(1), 51-58.

King, M. (1995). *Fisheries biology, assessment and management*. Fishing News Books, Hartnolds Ltd, Bodmin, Cornwall, Great Britain. 341 pp.

Knudsen, H. (1971). Determination of mortalities of Sardinella stocks in Ghanaian waters from tagging experiments and length distributions (mimeo).

Koranteng, A. K. (1989). *The Sardinella (Herring) Fishery in Ghana, The Past, Recent Development and the Years Ahead*. Information Report Number 23, Fisheries Department Research and Utilization branch Tema, Ghana. 38pp.

Koranteng, A. K. (1995). *The Ghanaian Fishery for Sardinellas*. Fisheries Department, Research and Utilization Branch, Tema, Ghana.

Kraljevic, M., Dulcic, J., Pallaoro, A., Cetinic, P. & Jug-Dujakovic, J. (1995). Age, Growth and Mortality of the striped sea bream, *Lithognathus mormyrus* L., in the Northern Adriatic. *Fisheries Research, 28*, 361 – 370.

Krzeptowski, M. (1981). Growth characteristics of gilt sardine (*Sardinella aurita*) from Senegal. *Acta Ichthyol. Piscat, 11*, 27-38.

Kwafo-Apegyah, K., Ofori-Danson, P. K., & Nunoo, F. K. E. (2008). Exploitation rates and management implications for the Fisheries of Bontanga Reservoir in the Northern Region of Ghana. West African *Journal of Applied Ecology*, *14*,1 – 7

Kwarfo-Apegyah, K. & Ofori-Danson P. K. (2010). Spawning and recruitment patterns of major fish species in Bontanga reservoir, Ghana, West Africa. *Lakes & Reservoir: Research and Management, 15*, 3 – 14.

Kwei, E. A. (1964). Migration of *Sardinella aurita* (Val et Cuv.), *Ghana J. Sci. 4*(1), 34 – 43.

Kwei, E. A. (1970). The migration and biology of the Spanish mackerel, *Scomber japonicus* (Houttyn). *Ghana Journal of Science*, *11*(2), 75 – 85.

Kwei, E. A. (1988). Animals with particular reference to fisheries. 29th anniversary lectures; *Ghana Academy of Arts and Sciences*, Accra 21 – 25th November, 1988.

Lawson, E. O. & Doseku, P. A. (2013).Aspects of Biology in Round Sardinella, *Sardinella aurita* (Valenciennes, 1847) from Majidun Creek, Lagos, Nigeria. *World Journal of Fish and Marine Sciences, 5*(5), 575-581.

Lawson, E. O. & Kwei, E. A. (1974). African entrepreneurship and economic growth. A case study of the Fishing Industry of Ghana. Ghana University Press. Accra. 262 pp.

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

MacCall, A. D. (2009). A short scientific history of the fisheries. In: D. Checkley, J. Alheit, Y. Oozeki & C. Roy (eds.). *Climate Change and Small Pelagic Fish Stocks.* Cambridge University Press, Cambridge 382, 6–11.

Mader, S. S. (1996). *Biology*. 5th Edition. Brown, W. C. (Ed), Dubuque.

Marcus, D. (1984). Annual report Nigerian Institute for Oceanography and Marine Research, Lagos, Nigeria.

Marcus, O. & Kusemiju, K. (1984). Some aspects of the biology of the clupeid *Ilisha africana* (Bloch) off the Lagos coast, Nigeria. *Journal of Fish Biology*, *25,* 679 – 689.

Marques, S. & Ferreira, B. P. (2011). Sexual development and reproductive pattern of the Mutton hamlet, *Alphestes afer* (Teleostei: Epinephelidae): a dyandric, hermaphroditic reef fish. *Neotropical Ichthyology.9,* No. 3.

Mehanna, S. F. & Salem, M. (2011). Population Dynamics of round sardine *Sardinella aurita* in El-arish waters, Southeastern Mediterranean, Egypt. *Indian Journal of Fundamental and Applied Life Sciences, 1*(4), 286-294.

Mensah, M. A. & Koranteng, K. A. (1988). A review of the oceanography and fisheries resources in the coastal waters of Ghana, 1981 – 1986. *Marine Fisheries Research Reports* No. 8. Fisheries Department. R and UB. Tema. 35pp.

Minta, O. S. (2003). An Assessment of the Vulnerability of Ghana's coastal artisanal fishery to climate change. Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in International Fisheries Management. University of Ghana, Legon.

MOFA. (1995). Policy on Ghanaian registered fishing vessels operating outside Ghana's 200 mile exclusive economic zone (EEZ) or within Ghana's territorial waters. Facts and Figures.

MOFA. (2012). *Brief Overview of the Ghana Fishing Industry.* Fisheries Commission, Accra.

Mohr, E. (1921). Alterbestimmung bei tropischen Fischen. *Zool Anz.*, *53*, 87-95

Morales-Nin, B. (1992). *Determination of growth in bony fishes from otolith microstructure.* FAO Fisheries Technical Paper. No. 322. Rome, FAO. 51 pp.

Moutopoulos, D. K. & Stergiou, K. I. (2002). Length-weight and length-length relationships of fish species from Aegean sea (Greece). *Journal of Applied Ichthyology*, *18*, 200-203.

Muta, K. (1964). *Report on the biological survey of the sardine* (*Sardinella aurita*). 1. Technical Work (mimeo). 21 pp.

Muta, K. (1966). General bionomics of the sardine in Ghana waters. Symposium on Oceanography and Fisheries Resources of the Tropical Atlantic, Abidjan (mimeo). *Exp. Paper 35*.

Mustac, B. & Sinovcic, G. (2009). Comparison of mesenteric and tissue fat content in relation to sexual cycle of the sardine, *Sardina pilchardus* (Walb. 1792), in the eastern Middle Adriatic fishery grounds (Croatia). *J. Appl. Ichthyol,. 25*, 595-599.

Ocren, O. H. & Ofori-Adu, D. W. (1973). The sardine fishery and the coastal hydrography of Ghana, 1968 – 1969. *Inf. Rep. No. 10,* Fisheries Research Unit, Tema.

Ofori-Danson, P. K. & Kwarfo-Apegyah, K. (2008). An assessment of the cichlid fishery of the Bontanga Reservoir, Northern Ghana. *West African Journal of Applied Ecology, 14,* 88 – 97.

Okyere, I. (2012). Some ambient environmental conditions, food and reproductive habits of the banded lampeye killifish *Aplocheilichthys spilauchen* in the Kakum estuary wetland, Ghana. *Environ Biol. Fish, 94,* 639-647.

Olsen, E. M., Heino, M., Lilly, G. R., Morgan, M. J., Brattey, J., Ernande, B. & Dieckmann, U. (2004). Maturation trends indicative of rapid evolution preceded the collapse of northern cod. *Nature, 428*: 932-935.

Palomera, I. & Sabatés, A. (1990). Co-occurrence of *Engraulis encrasicolus* and *Sardinella aurita* eggs and larvae in the north- western Mediterranean. *Sci. Mar., 54*: 61-67.

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

Pannella, G. (1980). Methods of preparing fish sagittae. In*: skeletal growth in aquatic organisms; biological records of environmental change.* (Eds. D. C. Rohads and R. A. Lutz) Plenum Press. New York. Pp. 619-624.

Pascual-Alayón, P., Sancho, A., Hernández, E., Santamaría, M. T. G, Duque, V., Balguerías, E., Bravo de Laguna, L., López, C. & Presas, C. (2012). Reproductive aspects of sardine (*Sardina pilchardus* Walbaum, 1792), round sardinella (*Sardinella aurita* Valenciennes, 1847), flat sardinella (*Sardinella maderensis* Lowe, 1838) and mackerel (*Scomber colias* Gmelin, 1789) off Mauritanian waters, Northwest Africa. *In* Dans S.

Garcia, M. Tandstad and A.M. Caramelo (eds.). Science and Management of Small Pelagics. Symposium on Science and the Challenge of Managing Small Pelagics. FAO, Rome. pp. 419–423.

Pauly, D. (1979a). Gill size and temperature as governing factors in fish growth: a generalization of von Bertalanffy's growth formula. *Berichte des Instituts für Meereskunde an der* Univ. *Kiel No*. 63. 156 pp.

Pauly, D. (1979b). Theory and management of tropical multispecies stocks: A review, with emphasis on the Southeast Asian demersal fisheries. *ICLARM Stud*. Rev. 1. 35p.

Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *J. Cons. CIEM, 39*(3), 175– 92.

Pauly, D. (1984a). Length-converted catch curves: a powerful tool for fisheries research in the tropics. Part II. *Fishbyte*, *2*, 12-19.

Pauly, D. (1984b). Fish population dynamics in tropical waters: a manual for use with programmable calculators. *ICLARM Stud. Rev. 8*. 325 pp.

Pauly, D. (1985). On improving operation and use of the ELEFAN programs. Part I: avoiding "drift" of K toward low values. ICLARM *Fishbyte*, *3*(3), 13 – 14.

Pauly, D. & Munro, J. L. (1984). Once more on the comparison of growth in fish and invertebrates. *ICLARM Fishbyte, 2*(1), 21.

Pauly, D. & Soriano, M. L. (1986). Some practical extensions to Beverton and Holt's relative yield-per-recruit model. In: Maclean, J. L. Dizon, L. B. & Hosillo, L. V. (eds), *The First Asian Fisheries Forum*. Asian Fisheries Society, Manila, Philippines, 491 pp.

Pauly, D., (1987). A review of the ELEFAN system for analysis of length–frequency data in fish and aquatic invertebrates. In: *Length-based methods in fisheries research*. Pauly and Morgan (eds) *ICLARM Conf. Proc. 13*, 7–34 pp.

Pauly, D. & Morgan, G. R., (Eds.) (1987). Length-based methods in fisheries research. *ICLARM Conf. Proc. 13*, International Centre for Living Aquatic Resources Management, Manila, Philippines.

Pawson, M. G. & Giama, M. S. (1985). A biological sampling problem illustrated by the population structure and growth patterns of *Sardinella aurita* at Tripoli, Libya. *Environ. Biol. Fish. 12*(2), 143-154.

Pesic, A., Durovic, M., Joksimovic A., Regner, S., Simonovic, P. & Glamuzina, B. (2010). Some reproductive patterns of the sardine, *Sardina pilchardus* (Walb, 1792), in Boka Kotorska Bay (Montenegro, southern Adriatic Sea). *Acta Adriatica*, *51*(2), 159 – 168.

Pezenne, 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: Durand, M., Cury, P., Mendelssohn, R. & Pauly, D.

(ed.) *Global versus local changes in upwelling systems*: ORSTOM, 1998. Pp. 329 – 343.

Potts, G. W. & Wootton, R. J. (1984). *Fish Reproduction*: *Strategies and Tactics*. Academic Press, London.

Quaatey, S. N. K. (1996). *Report on the Synthesis of Recent Evaluations Undertaken On the Major Fish Stock in Ghanaian Waters*. Marine Fisheries Research Division, Fisheries Directorate of the Ministry of Food and Agriculture, Tema, Ghana.

Quaatey, S. N. K (1997). *Synthesis of recent evaluation undertaken on the major fish stocks in Ghanaian waters*: A working document for the eleventh session of the CECAF Working Party on Resources Evaluation held in Accra, Ghana. 35pp.

Quaatey, S. N. K. & Maravelias, C. D. (1999). Maturity and spawning pattern of *Sardinella aurita* in relation to water temperature and zooplankton abundance off Ghana, West Africa. *J. Appl.Ichthyol., 15*, 63-69.

Radhakrishman, N. (1963). Notes on maturity and spawning of *Opisthopterus tardoore*. *Indian J. Fish, 10A*, 102 -106.

Radtke, R. L. & Dean, J. M. (1982). Increment formation in the otoliths of embryos, larvae and juveniles of the mummichog, *Fundulus heteroclitus*. *Fish. Bull. U. S., 80*(2): 201-215.

Rohit, P. & Bhat, U. S. (2003). Sardine fishery with notes on the biology and stock assessment of oil sardine off Mangalore-Malpe. *J. Mar. Biol. Ass. India*, *45*(1), 61 – 73.

Rossignol, M. (1955). Premières observations sur la biologie des sardinelles dans la région de Pointe Noire (*Sardinella eba* Val., *S. aurita* Val.). Rapp. Cons. *Intern. Explor. Mer*., *137*, 17-21.

Roy, C., Cury, P., Fontana, A. & Belvese, H. (1989). Spatio-temporal reproductive strategies of the clupeoids in West African upwelling area. *Aquat. Living Resour*., *2,* 21-29.

Sadovy, Y. & Shapiro, D. Y. (1987). Criteria for the diagnosis of hermaphroditism in fishes. *Copeia*, *1,* 136 – 156.

Salem, M., El-Aiatt, A. A. & Ameran, M. (2010). Age, Growth, Mortality and Exploitation Rates of Round Sardinella, *Sardinella aurita* from the East Mediterranean Sea (North Sinai Coast). *Research Journal of Fisheries and Hydrobiology*, *5*(1), 32-38.

Sampson, D. B. & Al-Jufaily, S. M. (1999). Geographic variation in the maturity and growth schedules of English sole along the U.S. West Coast. *J. Fish Biol*., *54*, 1-17.

Schneider, W. (1990). *Field Guide to the Commercial Marine Resources of the Gulf of Guinea.* Marine Resources Service Fishery Resources and Environment Division Fisheries. Department, FAO, Rome.

Shinkafi, B. A. & Ipinjolu, J. K. (2012). Gonadosomatic Index, Fecundity and Egg Size of *Auchenoglanis occidentalis* (Cuvier and Valenciennes) in River Rima, North-Western Nigeria. *Nigerian Journal of Basic and Applied Science, 20*(3), 217-224.

Somvanshi, V. S. (1980). Study on some Aspects of Spawning Biology of a Hill Stream fish *Gara mullya* (Sykes). *Proc. Indian Natn. Sci. Acad. B46 No. 105*, 113 pp.

Sparre, P. (1990). Can we use traditional length-based fish stock assessment when growth is seasonal? *ICLARM Fishbyte, 8*(3), 29–32.

Sparre, P. & Venema, S. C. (1992). *Introduction to tropical fish stock assessment, Part 1 manual*. FAO Fish. Tech. Pap. (306.1) Rev. 1. 376.

Stewart, J., Ballinger, G. & Ferrell, D. (2010). *Review of the biology and fishery for Australian sardines (Sardinops sagax) in New South Wales*. I&I NSW – *Fisheries Research Report Series: No. 26*.

Tsikliras, A. C. (2004). Spawning pattern of round sardinella, Sardinella aurita Valenciennes, 1847, in relation to sea surface temperature (northern Aegean Sea, Greece). *Rapp. Comm. int. Mer Médit., 37*, 449.

Tsikliras, A. C., Antonopoulou, E. & Stergiou, K. I. (2005*).* Reproduction of Mediterranean fishes. In: K. I Stergiou & D. C. Bobori (eds), *Fish and more*, Proc. 3rd FishBase Mini Symp., University Studio Press, Thessaloniki, Greece. 37-40 pp.

Tsikliras, A. C., Koutrakis, E. T. & Stergiou, K. I. (2005). Age and growth of round sardinella (*Sardinella aurita*) in the northeastern Mediterranean. *Journal of Biological Research*, *69*(2), 231–240.

Tsikliras, A. C., Torre, M. & Stergiou, K. I. (2005). Feeding habits and trophic level of round sardinella (*Sardinella aurita*) in the northeastern Mediterranean (Aegean Sea, Greece). *Journal of Biological Research*, *3*, 67–75.

Tsikliras, A. C. & Antonopoulou, E. (2006). Reproductive biology of round sardinella (*Sardinella aurita*) in the north-eastern Mediterranean. *SCI. MAR.*, *70*(2), 281-290.

Uneke, B. I., Nwani, C. D., Okogwu, O. & Okoh, F. (2010). Growth, Mortality, Recruitment and Yield of *Pellonula leonensis* Boulenger, 1917 (Osteichthyes: Clupeidae) in a Tropical Flood River System. *Journal of Fisheries International*, *5*(1), 19-26.

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.

Wang, Y. T. & Tzeng, W. N. (1997). Temporal succession and spatial segregation of clupeoid larvae in the coastal waters off the Tanshui River Estuary, northern Taiwan. *Mar. Biol.*, *129*, 23-32.

Williams, T. & Bedford, B. C. (1974). The use of otoliths for age determination. In: *The ageing of fish* (Ed. T. B. Bagenal) Unwin, Old Working. England. 234 pp.

Whitehead, P. J. P. (1985). *FAO Species catalogue Vol. 7. Clupeoid fishes of the world.* An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, anchovies and wolf-herrings. FAO Fish. Synopsis.

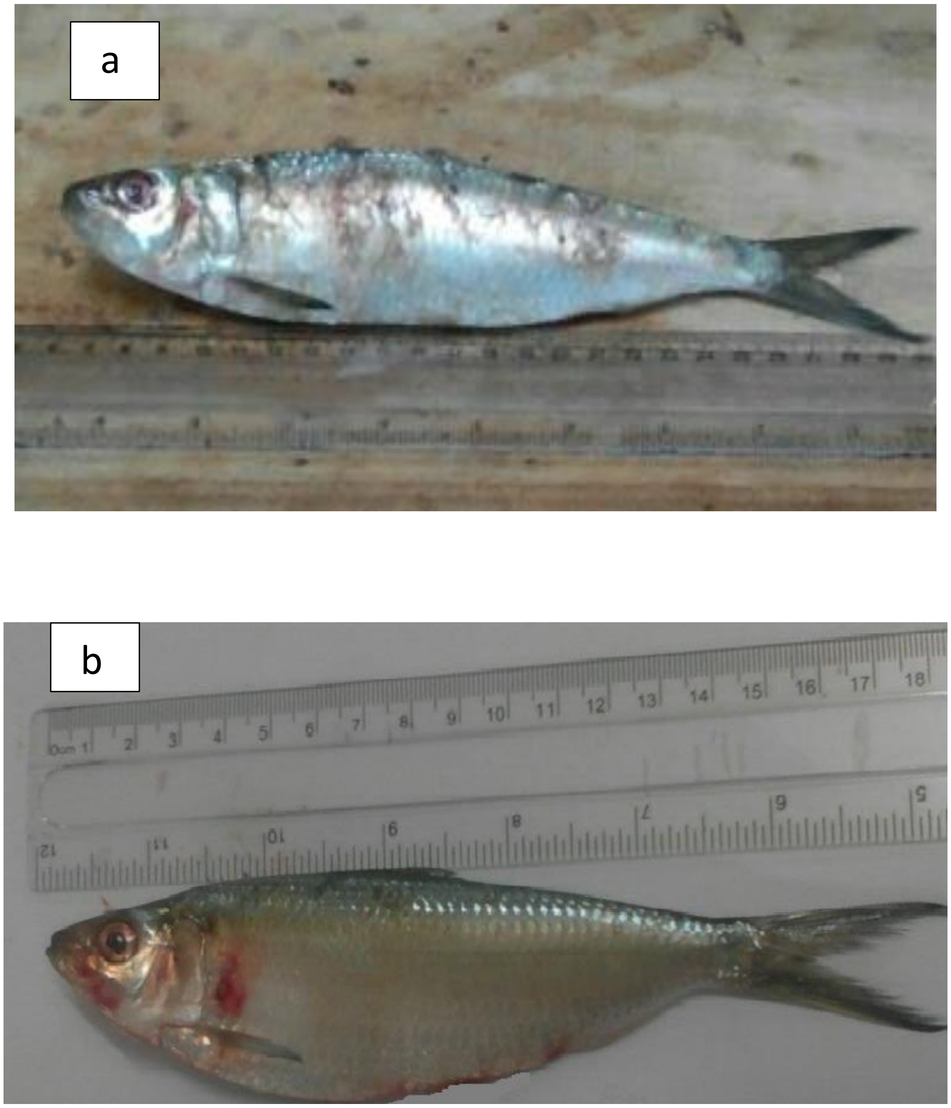
Youmbi, J. T., Djama, T. H. & Gabche, C. (1991). Reproductive patterns of *Sardinella maderensis* (Lowe, 1841) off Cameroon. *Journal of Applied Ichthyology, 7*(1), 60 - 63 pp.

Zar, J. H. (1996). *Biostatistical Analysis*. Prentice-Hall International, 3rd edition, London, 662 pp.

Zei, M. (1962a). Marine fisheries Research Ghana – Its Scope and Development in 1962, pp 1 – 4. In: *Fisheries Research Report vol. 1 No. 1* Fisheries Inspectorate Unit, Accra.

Zei, M. (1962b). *Sardines and related species of the Eastern Tropical Atlantic*. Pro. Symp. On the Oceanography and Fisheries Resources of the Tropical Atlantic, UNESCO, Paris.

APPENDIX



Appendix A: Specimens of (a) *Sardinella aurita* and (b) *Sardinella maderensis* from commercial landings at the Elmina landing quay