Research in
ISSN : P-2409-0603, E-2409-9325
AGRICULTURE, LIVESTOCK and FISHERIES
An Open Access Peer Reviewed Journal

Open Access
Research Article

Res. Agric. Livest. Fish.
Vol. 4, No. 3, December 2017: 237-248.

POPULATION DYNAMICS OF *Sardinella aurita* (Val., 1847) WITHIN GHANA'S COASTAL WATERS

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ARTICLE INFO

Received
02 December, 2017

Accepted
24 December, 2017

Online
31 December, 2017

Key words
Round sardine
Exploitation
Growth
Mortality
Recruitment
Overfishing

ABSTRACT

Following the declining stocks of *Sardinella aurita* within the coastal waters of Ghana, this study aimed at examining some population parameters of *Sardinella aurita* as a guide for managing this important stock sustainably. Length-frequency data of 717 samples were obtained from June, 2014 to January 2015 and measured for total length with the resultant data analyzed using FiSAT II. The asymptotic length ($L\infty$) and growth rate (K) were 21.53 cm SL and 0.25yr^{-1} respectively. The theoretical age at birth (t_0), longevity (t_{max}) and growth performance index (ϕ) were -0.74yr^{-1}, 12 years and 1.849 respectively. Total mortality rate (Z), natural mortality rate (M) and fishing mortality rate (F) were 3.17, 0.76 and 2.41yr^{-1} respectively. The ages at first recruitment and first capture signaled future collapse of the stock, in the absence of proper management interventions. VPA outcome showed that mid- lengths of 11 cm and 12 cm SL experienced the highest harvesting rate with MSY estimated at 7733 tons. The recruitment pattern was continuous with two major recruitment pulses. Exploitation rate (E_{curr}=0.76) was higher than the maximum exploitation rate (E_{max}=0.56), indicating unsustainable exploitation. Further, the fishing regime fell within the overfished stage based on the Quadrant Rule. For sustainable exploitation of this commercial fish species, implementation of relevant biological reference points through reduction in fishing efforts, creation of marine protected areas and mesh size regulation are urgently advocated.

To cite this article: Amponsah SKK, Ofori-Danson PK, Nunoo FKE and Ameyaw GA, 2017. Population dynamics of *Sardinella aurita* (Val., 1847) within Ghana's coastal waters. Res. Agric. Livest. Fish., 4 (3): 237-248.

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INTRODUCTION

Round sardines, *Sardinella aurita* (Pisces, Clupeidae), is a middle-sized pelagic fish with its distribution as tropical and subtropical mostly linked to major upwelling systems (Tsikliras, 2004). In Africa, its range extends from the Mediterranean to Cape Frio (Brainerd, 1991). In terms of adaptation to temperature and salinity, Round sardine is a stenothermic and stenohaline species with fair sensitivity to temperatures beyond the range 18ºC to 25ºC (Binet, 1982; Longhurst and Pauly, 1987; Fréon and Misund, 1999). The fishery for sardinellas in the western Gulf of Guinea is affected by various environmental factors, including coastal upwelling and rainfall (Oren and Ofori-Adu, 1973; Cury and Roy, 1987; Ofori-Adu, 1975; Binet, 1982). Copepods particularly calanoids, form the main diet of *S. aurita* together with a number of phytoplankton including *Cyclotella, Thalassiosira* and *Coscinodiscus*, *Synedra, Nitzschia, Navicula*, *Scenedesmus*, *Anabaena* and *Spirulina spp.* (Madkour, 2012; Tsikliras et al., 2005).

Sardinella aurita fishery is one of the targeted species for the artisanal fishing sector in Ghana (Bard and Koranteng, 1995). Evidently, in the early 1970s, Round sardine stocks were thought to be the greatest potential resources in the whole of the Gulf of Guinea (Ansa-Emmim, 1973). Kwei (1964) noted that the round sardine was the most exploited fish in Ghanaian marine waters during the early 1970s. Nonetheless, landings of Round sardines in Ghana have usually fluctuated from year to year which has sometimes given fishers and fisheries managers the cause to worry. However, since the early 1980s there has been an increasing trend in the landings of sardines, especially of *Sardinella aurita*.

Sardinella aurita stock migrates from the Western region of Ghana and moves eastwards which continues into the Republic of Togo and to a lesser extent the Republic of Benin. Thus, serving as the main candidate which dictates the migration of fishers along the coastline of Ghana (Ansa Emmim, 1976). Huge quantities of Round sardines are harvested during the major and minor upwelling period (Ofori-Adu, 1975; Binet, 1982). Artisanal fishing gears used in the sardinella fishery in Ghana include the ali, Poli and Poli Watsa. The Poli and Poli Watsa nets are used when Round sardines are schooling whereas the ali net is applied when the fish are scattered, mostly at the beginning or towards the end of the sardine season. Further, the beach seine net also harvests some appreciable quantities of sardines, especially juveniles. Purse seine nets which are similar in construction to the Poli nets are used by the inshore vessels. The main part of the *Sardinella aurita* landings is caught by the small-scale fishers (60-80%), while the remaining part is caught by inshore fisheries and bottom trawlers (as bycatch). Nutrition-wise, *Sardinella aurita* contains high amount of white protein, certain essential nutrients necessary for effective development of the human system, particularly within coastal communities (Sikoki and Otobotekere, 1999). Also, Round sardines are good source of Vitamin D, calcium, B_{12} and omega 3 fatty acids which ensures a healthy heart through the reduction in developing Alzheimer's disease and regulation of blood sugar level (Telahigue et al, 2013; Abowei, 2009). In Ghana, harvested *Sardinella aurita* species are mostly processed and consumed in the dried or smoked form (Kwei and Ofori-Adu, 2005). However, smoked Round sardines from the market centers contains higher counts of microbes than from landing sites due to poor handling, packaging, transporting and storage conditions (Nyarko *et al*., 2011). In spite of the huge importance of *Sardinella aurita* to the socioeconomic desires of Ghanaians particularly citizens living within fishing communities, information on population parameters appears to be sporadic.

Therefore, the aim of the present study was to estimate some population parameters pertaining to *Sardinella aurita* stock within the Ghanaian coastal fishing operation. Information acquired from this study will contribute to the already existing management interventions geared towards sustainable *Sardinella* fishery in Ghana's coastal waters.

MATERIALS AND METHODS

Study area

This study focused on the Eastern coastline of Ghana comprising of four sampling stations namely; Jamestown, Tema, Vodzah and Denu (Figure 1). In selecting the sites, a two-stage sampling strategy was adopted which involved geographical location and types of fishing fleet to explore information based on all the levels of fishing in Ghana.

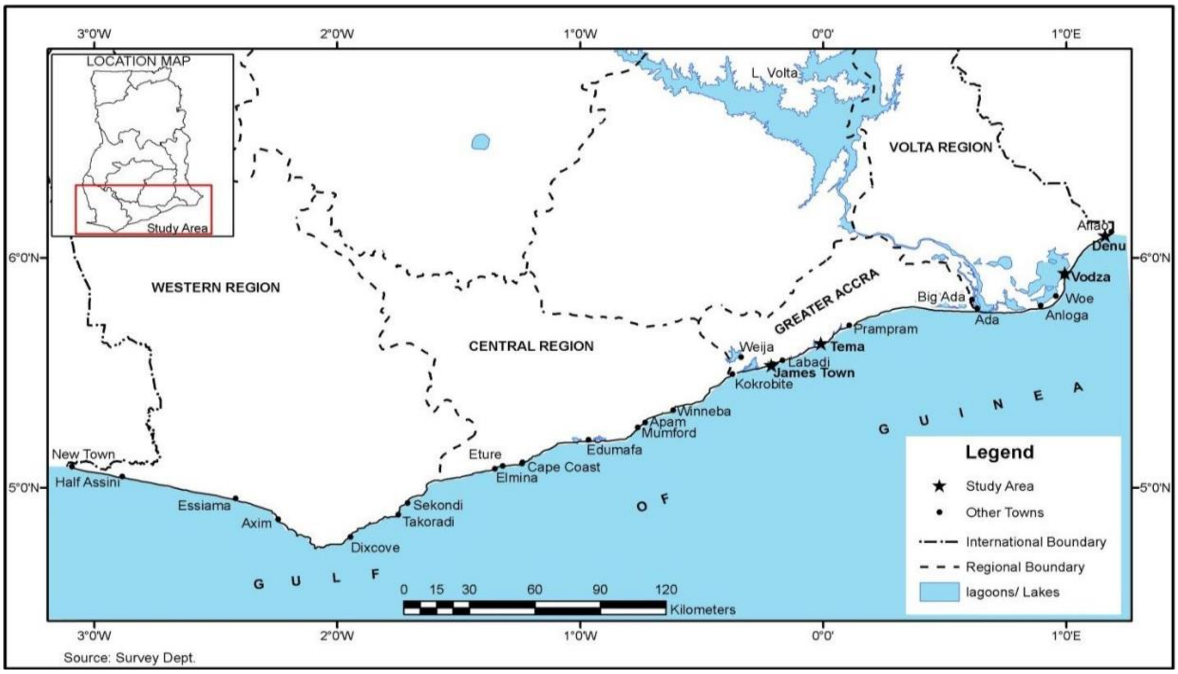

Figure 1. Map showing the sampling sites

Data collection

Fish samples were purchased from local fishers at the selected landing sites operating mostly multifilament fishing gears for eight months (once every month), from July 2014 to January 2015. Purchased specimen were preserved in ice layers and analyzed at the Marine and Fisheries Department, University of Ghana Laboratory. During analysis, fish species were weighed to the nearest 0.01g while the total length was measured to the nearest 0.1cm. Identification of fish species was performed using keys by Fischer et al. (1981) and Kwei and Ofori-Adu (2005). In all a total of 717 samples of *S. aurita* were assessed.

METHODS

Growth parameters

Growth rate (K), asymptotic length (L_∞) and the growth performance index (ϕ) of the Von Bertanlaffy Growth Function (VBGF) was estimated. The Powell-Wetherall Plot was used to compute the Z/K ratio (Pauly, 1984). Theoretical age at birth (t_o) was calculated independently as: $\log_{10}(-t_o) = -0.3922 - 0.275 * \log_{10}L_\infty - 1.038 * \log_{10}K$ (Pauly, 1979). The longevity of individuals (*Tmax*) was estimated using the equation: $Tmax = 3/K + t_o$ (Pauly, 1983). The growth performance index was generated as: $(\phi) = 2\log L_\infty + \log K$ (Munro & Pauly, 1983).

Mortality parameters

Total mortality coefficient (Z) was estimated by using the length-converted catch curve. Natural mortality rate (M) was computed by the empirical equation of Pauly (1980) using a mean surface temperature (T) of 25.7°C: $Log_{10}M = -0.0066 - 0.279\ log_{10} L_\infty + 0.6543\ log_{10} K + 0.4634\ log_{10} T$. Fishing mortality (F) was estimated as: F = Z –M (Gulland, 1971). Optimum fishing mortality was estimated as F_{opt} = 0.4M (Pauly, 1984). Exploitation ratio (E) was computed as: E = F /Z (Gulland, 1971).

Length at first Capture (Lc_{50})) and maturity (Lm_{50})

Probability of capture against mid-length a resultant curve was used to compute the length at first capture (Lc_{50}). Length at first maturity (Lm_{50}) was estimated as: $Lm_{50} = (2 * L\infty)/ 3$ (Hoggarth et al., 2006).

Recruitment pattern

The recruitment pattern was determined by backward projection on the length axis of the set of available length–frequency data (Nurul *et al*., 2009). Input parameters included L∞ and K. The midpoint of the smallest length group in the catch was estimated as the length at first recruitment (Lr) (Gheshlaghi et al., 2012).

Virtual Population Analysis

The estimated length structured VPA was carried out using the inputs L∞, K, M, F, a (constant) and b (exponent) for the species as inputs. The a (constant) and b (exponent) were estimated from the length weight relationship using the expression $W= aL^b$ (LeCren, 1992).

Maximum Sustainable Yield (MSY), Biomass and Yield

An output from the virtual population analysis (VPA) was used to calculate the biomass (tons), the yield (tons) and MSY. MSY was calculated as: 0.5x(Y+MB), where B is the average biomass calculated from cohort analysis in the same year, and M the natural mortality and the Y the annual yield (Sparre and Venema, 1998). The annual yield (Y) was estimated using the expression: $Y = \sum W_{L1,L2} * C_{L1,L2}$, where W is weight and C is the catch.

Exploitation rates (E_{max}, $E_{0.1}$ and $E_{0.5}$)

E_{max} (exploitation rate at maximum yield), $E_{0.1}$ (exploitation rate at 10% of its virgin stock) with $E_{0.5}$ indicating exploitation rate at 50% of its virgin biomass) were estimated using the Knife-edge option.

Yield isopleth

Yield contours which shows the stock status was identified as the interception of the exploitation rate (E) and critical length ratio ($Lc_{50}/L\infty$).

Data Analysis

The length frequency data were pooled into groups with 1cm length intervals. Then the data were analyzed using the FiSAT II (FAO-ICLARM Stock Assessment Tools) software (Gayanilo et al., 2003). The length at age was graphed using the Yield software package (Branch *et al*., 2000).

RESULTS

Growth parameters

From ELEFAN I routines, the best estimates of growth parameters obtained were; asymptotic length (L_∞) =21.53 cm standard length and growth rate (K) = 0.25 per year. The restructured Length frequency data superimposed with the estimated growth curve which revealed approximately four cohorts (Figure 2). The estimated theoretical age at birth (t_o) and longevity (t_{max}) were -0.74 and 12 years respectively (Figure 3b). The Von Bertanlaffy Growth Function (VBGF) for *Sardinella aurita* was calculated as $L_t = 21.53(1-e^{-0.25\ (t-(-0.74))})$. The growth performance index (ϕ) of 1.849 was estimated for the *Sardinella aurita.* The estimated Z/K ratio was 4.05, indicating that the *Sardinella aurita* in Ghana is mortality dominated (Figure 3a).

Mortality

From the Jones and van Zalinge Plot (Figure 4), total mortality (Z) was estimated at 3.17 per year, while natural mortality (M) of 0.76 per year was obtained. By subtracting the value of natural mortality from the total mortality, the fishing mortality (F) of 2.41 per year was obtained. The optimum fishing mortality rate was 0.30 per year. The exploitation rate (E) was estimated at 0.76.

Probability of capture and Length at first maturity (Lm_{50})

The probability of capture routine gave an estimate of L_{50}% at 5.99 cm (Figure 5). Further, the estimates for L_{25}% and L_{75}% were 2.78 cm and 9.20 cm respectively. Therefore, the length-at-first capture (Lc_{50}) and age at first capture (tc) for *Sardinella aurita* were estimated at 5.99 cm and 0.56 years respectively. The length at first maturity (Lm_{50}) and age at first maturity (tm) was obtained at 14.4 cm and 3.68 years, respectively.

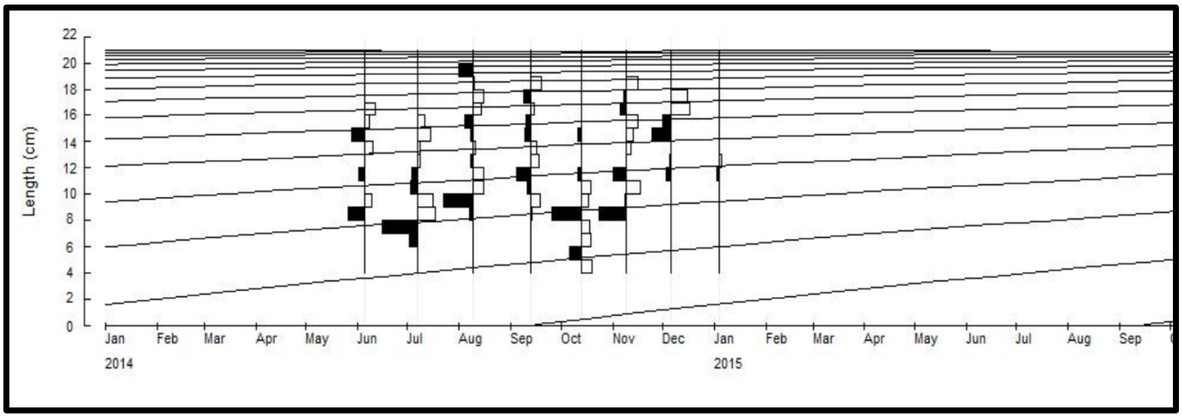

Figure 2. Reconstructed length frequency distribution superimposed with growth curve

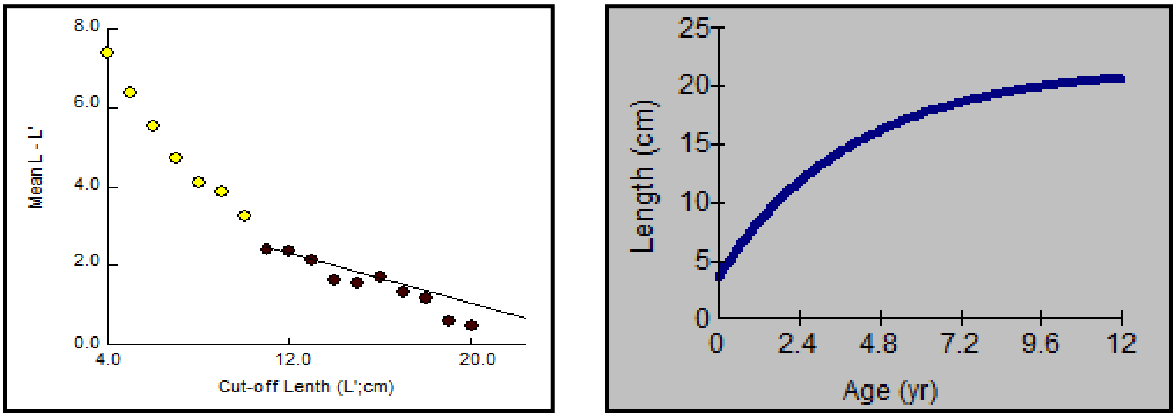

Figure 3. A) Powell-Wetherall plot for Z/K ratio **B)** Length at age plot

Recruitment pattern

The recruitment pattern established in (Figure 6) indicates a year-round recruitment for *Sardinella aurita* but with two peaks of recruitment during one year. From macro inspection, the minor peak occurred from April to May while the major peak took place from July to August. The length at first recruitment (Lr_{50}) and age at first recruitment (tr_{50}) were calculated as 4.5 cm and 0.20 years, respectively.

Virtual population analysis (VPA)

VPA results indicated that maximum number of *Sardinella aurita* harvested were between 11 cm and 12 cm with of fishing mortality (F) at 0.17 yr^{-1} (Figure 7). The highest peak of fishing mortality (F = 1.68 yr^{-1}) occurred within the length range of 20 cm and 21 cm. Increasing fishing mortality (F) translated into declining populations of *Sardinella aurita* (Figure 7). The values of 'a' and 'b' constants from the Length-weight relationship was estimated as '0.0056' and '3.4', respectively. The terminal fishing mortality was 1.52 per year.

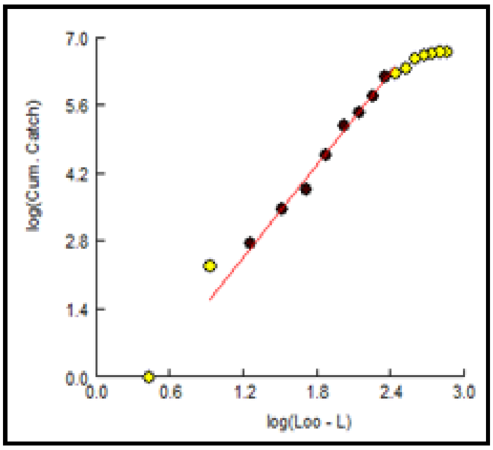

Figure 4. Jones and van Zalinge plot

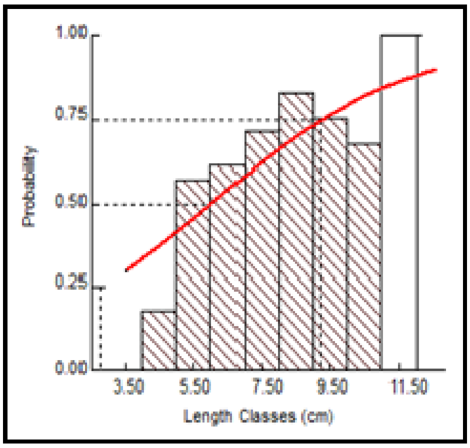

Figure 5. Probability of capture

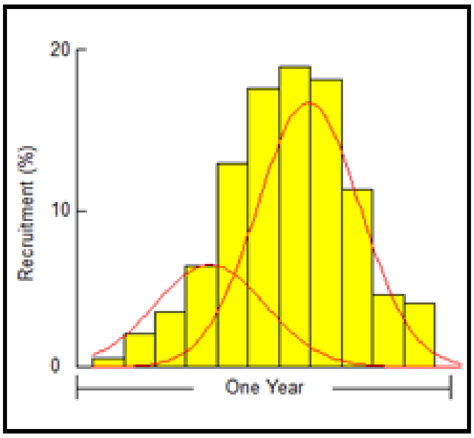

Figure 6. Recruitment pattern

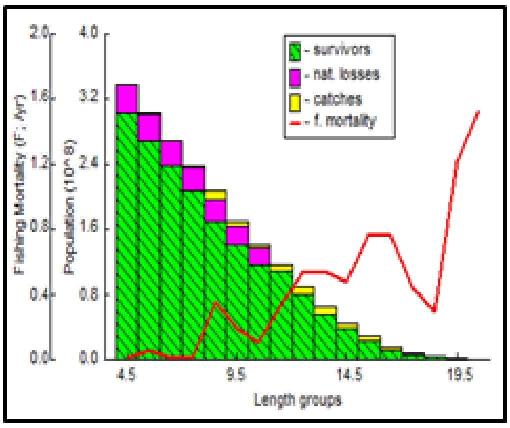

Figure 7. VPA output

Maximum sustainable yield (MSY)

The estimated total biomass and total yield were 17184.62 metric tons and 2405.69 metric tons respectively. The mean body weight was calculated at 0.0491. The maximum sustainable yield (MSY) using the length frequency distribution of *Sardinella aurita* was estimated at 7733 metric tons (Table 1).

Table 1. Estimates of the total biomass (tons), the yield (tons) and the MSY (tons) from the length frequency distribution of *Sardinella aurita*

Mid-Length	Catch	XL1, L2	N	E	F	Z	Biomass/kg	Body weight/kg	Yield
4.5	400000	1.09	337401120	0.01	0.0089	0.77	2206741.57	0.0009	372.54
5.5	2300000	1.10	303001088	0.07	0.0542	0.81	2083579.34	0.0018	4237.88
6.5	500000	1.11	268474720	0.02	0.0125	0.77	1964000.00	0.0033	1625.79
7.5	900000	1.11	237540816	0.03	0.0238	0.78	1856722.69	0.0053	4760.35
8.5	12100000	1.12	207942752	0.32	0.3517	1.11	1689252.20	0.0081	97948.49
9.5	5900000	1.13	169697584	0.20	0.1926	0.95	1504101.77	0.0118	69710.84
10.5	2800000	1.15	140521856	0.12	0.1011	0.86	1359841.74	0.0166	46493.23
11.5	8100000	1.16	116671152	0.30	0.3318	1.09	1198643.76	0.0226	183250.73
12.5	10800000	1.18	90015200	0.41	0.5368	1.30	987853.95	0.0300	324418.66
13.5	8600000	1.21	63924376	0.42	0.5467	1.31	772379.73	0.0390	335599.49
14.5	5700000	1.24	43369184	0.38	0.4741	1.23	590318.50	0.0498	283605.14
15.5	6500000	1.29	28532774	0.50	0.767	1.53	416101.69	0.0624	405722.56
16.5	4000000	1.35	15591758	0.50	0.7581	1.52	259068.72	0.0772	308811.47
17.5	1400000	1.46	7581830	0.36	0.4341	1.19	158350.61	0.0943	132021.73
18.5	600000	1.66	3730762	0.28	0.2998	1.06	98265.51	0.1139	68347.58
19.5	900000	2.15	1609826	0.62	1.2218	1.98	36167.95	0.1362	122616.30
20.5	100000	5.01	150000	0.67	1.52	2.28	3230.26	0.1615	16149.21
							17184.62	**0.0491**	**2405.69**
MSY	7733 tons								

Exploitation rates

The exploitation rate giving maximum relative yield-per-recruit (E_{max}) was 0.56 using the knife edge recruitment (Figure 8). The exploitation rate ($E_{0.1}$) at which the marginal increase in relative yield-per recruit is 10% of its value at E = 0, was estimated to be 0.47 (knife-edge recruitment). The exploitation rate ($E_{0.5}$) which corresponds to 50% of the virgin relative biomass-per-recruit was estimated at 0.30 (knife-edge recruitment).

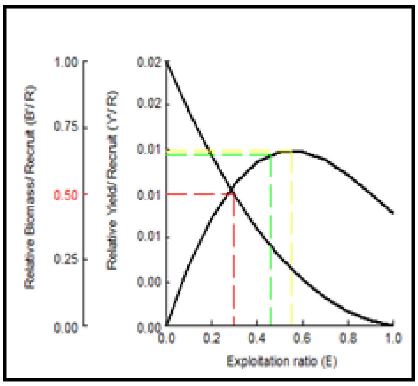

Figure 8. Exploitation rates

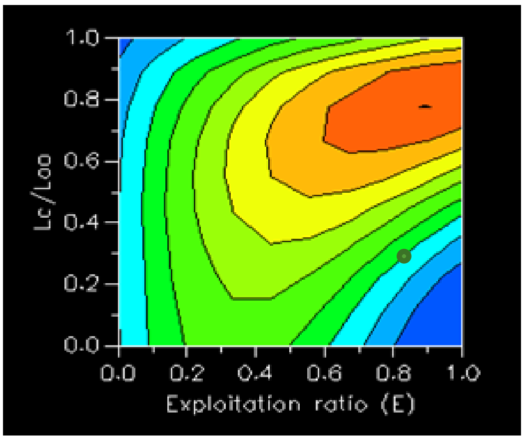

Figure 9. Yield isopleth diagram

Yield isopleth

The yield isopleths placed the fishery of the investigated fish species in quadrant D based on the interception of Lc ($Lc_{50}/L\infty$ = 0.29) and E (0.76) (Figure 9).

DISCUSSION

The calculated length at infinity ($L\infty$) and growth rates from the current study was relatively different from estimates by other researchers (e.g.: Al-beak, 2016; Mehanna and Salam, 2011). Such variation in growth coefficient may be due to estimation protocol, length classes obtained, the geographical locations and the level of fishing pressure (Amponsah et al., 2016a). The estimated growth rate was lower than the 0.34 yr^{-1}, depicting that *Sardinella aurita* is a slow-growing fish species (Kienzle, 2005), evidenced by its longevity of 12 years and a growth performance index outside the usual range of 2.65-3.32 demarcated for fast growing fish species (Baijot *et al.,* 1997; Montchowui et al., 2011). The slow growth performance of *Sardinella aurita* could be due to reduced nutritional value of the available feed digested (Montchowui et al., 2011). The length at first capture (Lc_{50}) estimated from this study was highly lower than estimates by Al-beak (2016). Furthermore, the critical length at first capture was far below 0.5 (Soriano and Pauly, 1986), suggesting that most of the juveniles were captured before reproduction - a prerequisite for growth overfishing. These observations could be linked to the use of small mesh size by the artisanal fishers. Thus, as a management measure, fishing gears with small mesh sizes should be prohibited.

The estimated length at first maturity (Lc_{50}) was lower than the range documented by Quaatey and Maravelias (1999). Potential causes for the observed variation in estimates include environmental factors, long term fishing pressure and a rapid response to natural selection (Tsikliras and Anthonopoulou, 2006). The estimated ratio of Lm_{50}/L_∞ depicted that *Sardinella aurita* stocks within the coastal waters of Ghana invest more energy into growth than reproduction, potentially due to geographical locations, genetic makeup and environmental factors (Amponsah et al*.,* 2016b). Furthermore, the relatively higher estimated Lm_{50}/L_∞ ratio indicated that *Sardinella aurita* is a small-sized fish species (Tsikliras and Anthonopoulou, 2006). Again, Lm_{50}/L_∞ ratio was within the range postulated for clupeids (0.62 – 0.80) as well as favorable with the value established for *Sardinella spp.* (Beverton, 1963). The computed age at first capture (tc_{50}) showed that *Sardinella aurita* juveniles become vulnerable to capture approximately six months after recruitment into the stock. The calculated age at first capture (tc) was relatively lower than estimated by Al-beak (2006) and Salam and Mehanna (2011), possibly due to the mesh size and type of fishing gears deployed in Ghanaian coastal waters. Additionally, the intensity of fishing over long period could also be a factor, which has the tendency of truncating the length structure of the species to avert collapse in the future.

The estimated age at first maturity (tm_{50}) suggested that juveniles of the *Sardinella aurita* stock become matured three and half years after birth. Beverton (1963) highlighted that, in short lived species, maturation occurs at the end of the first year. However, from the study, maturation began at the third to fourth year, buttressing the earlier assumption that *Sardinella aurita* stock within Ghana's coastal wasters is a long-lived species. The age and length at first maturity were observed to be relatively higher than the age and length at first capture, portraying the presence of growth overfishing within the *Sardinella aurita* stock. In support of this assertion, about 67% of the catch which experienced higher harvest rate had lengths lower than the length at first maturity (Lm_{50}). The estimated age at fist recruitment (tr_{50}) indicated that juveniles of *Sardinella aurita* enter into the stock shortly after birth, approximately two months after birth. The estimated age at first recruitment (tr_{50}) was highly lower than estimate by Al-beak (2016), possibly due to differences in length at first recruitment, the class size of sample used and the mesh size of fishing gears used. Comparatively, the early recruitment into the stock could be a strategy adopted by *Sardinella aurita* in response to the existing high fishing pressure in order to avoid collapse of its species. However, the closeness of the age at recruitment (tr_{50}) to age at capture (tc_{50}) may result in recruitment failure in the future if fishing pressure is not regulated. The two observed recruitment peaks from the study agreed with the suggestion by Pauly (1980) that tropical fish species exhibit two recruitment peaks. The exhibited peaks of recruitment could be due to favorable environmental conditions, availability of feed as well as the presence of higher percentage of matured *Sardinella aurita* species (Madkour, 2012; Tsikliras and Anthonopoulou, 2006). The presence of continuous recruitment may be linked to the presence of more females than males as well as the geographical location (Deekae and Abowei, 2010). Further, the strong presence of recruits evinced by the recruitment pattern implied that recruitment within *Sardinella aurita* stock is still functional (Amponsah et al., 2016c).

Barry and Tegner (1989) documented that a Z/K ratio < 1 indicates that the population is growth dominated whereas a Z/K ratio > 1 is an indication that the population is mortality dominated. However, when the Z/K ratio = 1, then the growth and mortality of the population are in equilibrium. From the present study, the calculated Z/K ratio was greater than 1, suggesting that the stock is mortality dominated. King and Etim (2004) highlighted that for a mortality dominated stock, Z/K ratio ≈ 2 denotes a lightly-exploited stock while values greater than 2 shows heavy exploitation. With the estimated Z/K ratio highly greater than 2, it showed that *Sardinella aurita* stock in Ghana's coastal waters is heavily exploited. The difference in natural mortalities in relation to other studies could be due to the intensity of predators and competitors whose population dwell heavily on the abundance fish species (Al-beak, 2016). The observed fishing mortality was relatively higher than the natural mortality, revealing that *Sardinella aurita* stock is fishing mortality dominated, hence are more vulnerable to fishing gears than natural marine casualties, particularly environmental conditions (Amponsah *et al.,* 2016d). Again, fishing mortality was found to be higher than the optimum fishing level, suggesting the presence of heavy exploitation on the *Sardinella aurita* stock. Consequent to the intense fishing pressure, the survival rate by natural mortality was 0.47, depicting that only 47% will get recruited into the stock next year. Though similar survival rate of 42% was established by Al-beak (2016) within the Mediterranean waters, total mortality was applied in his estimation. The estimated M/K ratio (3.04) was outside the range 1.5 – 2.5 for fishes indicating the presence of poor environmental state, particularly intensive fishing pressure (Abowei et al., 2009; Beverton and Holt, 1957). The poor state of Ghana's marine environment may be compensated for by the continuous recruitment pattern exhibited by *Sardinella aurita*. The exploitation ratio which was highly greater than the optimum level of 0.5 indicated that *Sardinella aurita* stock is unsustainably over-exploited (Pauly, 1984). The estimated exploitation rate was highly greater than the exploitation ratio at the MEY ($E_{0.1}$), biological conservation level ($E_{0.5}$) and the MSY (E_{max}), supporting the earlier assertion that exploitation on *Sardinella aurita* stock is severely unsustainable and could approach zero if the necessary interventions are not implemented. The interception of the Lc (proportion of the length at first capture to the length at infinity) and the maximum exploitation rate (E=0.76) fell in quadrant D, implying that the *Sardinella aurita* stock is overfished (Pauly and Soriano, 1986). Therefore, as management intervention, fishing effort should be reduced, accompanied with increase in mesh size.

The annual catch for 2014 was found to be higher than the estimated MSY with artisanal sector accounting for over 79% of the annual catch. This finding agreed with the earlier claim that current exploitation rate (E_{curr}) has surpassed the maximum exploitation rate (E_{max}). Fishing highly beyond the MSY for a long period of time could be a precursor for recruitment overfishing (Amponsah et al*.,* 2016e).

CONCLUSION

Sardinella aurita possess slow growth rate, small maximum size, long lifespan, late sexual maturation, year-round recruitment pattern and high natural mortality to asymptotic length ratio (M/K > 1). Growth overfishing was found to be present due to the harvesting of relatively small-sized species. Recruitment overfishing did not occur coupled with continuous recruitment pattern and huge number of survivors. However, *Sardinella aurita* stock is heavily and unsustainably exploited. Furthermore, the intersection of critical length at capture and the exploitation rate revealed that the investigated stock is overfished hence the need to provide stringent management measures to avert possibly collapse in the future.

ACKNOWLEDGEMENT

This study is the outcome of joint investigation between the Department of Marine and Fisheries Sciences, University of Ghana, Legon and the Australian National Centre for Ocean Resources and Security (ANCORS), University of Wollongong, Australia with resources from AusAID. The role of Professor Martin Tsamenyi AM and Dr. David Kirby of ANCORS, University of Wollongong, Australia and other colleges whose efforts facilitated this collaboration is duly valued. Further, this study is the product of supervisory work for the thesis M. Phil (Fisheries Science) degree at the Department of Marine and Fisheries Sciences, University of Ghana, of the corresponding author. Earnest appreciation goes to the technicians from Marine and Fisheries Department, University of Ghana for providing assistance during both field and laboratory work.

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