Estimates of Population parameters for *Sardinella maderensis* (Lowe, 1838) in the coastal waters of Ghana

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**ABSTRACT**

This study examined some population parameters of *Sardinella maderensis* landed along the eastern coast of Ghana, based on length-frequency data from June, 2014 to January 2015. Overall, 1401 samples of *S. maderensis* were measured for standard length and resultant data analysed with FiSAT II. The asymptotic length (*L*∞) and growth rate (*K*) were 23.63 cm SL and 0.61 yr⁻¹ respectively. The theoretical age at birth (*t*₀) and growth performance index (ϕ) were -0.284 yr⁻¹ and 2.532 respectively. The recruitment pattern was continuous with two recruitment pulses. Total mortality rate (Z), natural mortality rate (M) and fishing mortality rate (F) were 2.96 yr⁻¹, 1.30 yr⁻¹ and 1.63 yr⁻¹ correspondingly. Fishing mortality rate surpassed the optimum fishing rate which showed that the assessed fish species is under high fishing pressure. The estimated exploitation rate (*E*curr) was 0.55, implying that the stock is over-exploitation. VPA outcome revealed higher harvesting rate on individuals with length between 10 – 11 cm. The spawning biomass which was below the 30% of unexploited biomass indicated future recruitment failure of the stock. As a result, urgent management interventions such as the application of biological reference points and mesh size regulations are urgently recommended for sustainable exploitation of *Sardinella maderensis*. 

**Keywords**: Madeiran sardine, population parameters, Ghana, MSY, VPA, overfishing

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1.0 INTRODUCTION

Fishing is central to the livelihoods of both artisanal coastal and inland fishing households in Ghana (Sarpong et al., 2005). Marine artisanal fisheries are practiced within the EEZ of Ghana and account for 85% of the total fish catches in Ghana (Nunoo et al., 2014). Among these species, 65% are mostly small pelagics (Nunoo et al., 2014). Ansa-Emmim (1973) reported that Sardinella maderensis and other species within the Clupeids family serve as important small pelagics exploited from the Ghanaian coast to fishing households in Ghana. Sardinellas including Sardinella maderensis accounts for more than 40% of the total domestic marine fish contribution. The abundance of these small pelagics is heavily linked to both minor and major upwelling activities in the Ghana-Ivorian marine ecosystem as well as rainfall (Koranteng, 1989; Binet, 1982).

Ecologically, juveniles of Sardinella maderensis are concentrated in the coastal waters from where they gradually move offshore as they grow older. A great majority of the adults remain confined over the shallow half of the continental shelf. Adults of Sardinella maderensis are much more sedentary with limited traveling distances along the coast (Gheno, 1970). They are most abundant in two regions to the north and south of the Gulf of Guinea respectively (FAO, 1971). Throughout the year, Sardinellas (particularly Sardinella maderensis and Sardinella aurita) supply the main part of the catch for the coastal artisanal fleets and they also form part of the catch of the long-distance fishery seiners when they operate sufficiently close to inshore (Brainerd, 1991). Despite having lower catches in the Ghanaian coastal fishery than Sardinella aurita, Sardinella maderensis which is said to be accessible for most months of the year are a very cheap source of animal protein to vulnerable fishing households (Nunoo et al., 2014; Muta 1964). Thus, its continuous occurrence in the coastal waters enhances household nutrition in vulnerable fishing communities. Its fishery also constitutes extreme economic activities of many fishers including fishermen, fish processors and traders in Ghana.

However, its population, together with Sardinella aurita currently suffers from declining catches due to the consistent application of light in fishing - an intervention introduced to ensure all-year-round supply of sardines and other unsustainable fishing practices. These aforementioned threats, as a result, make sustainable management of Sardinella maderensis stocks within Ghana’s coastal waters problematic. As such, this study seeks to address some aspects of population parameters of Sardinella maderensis off the coast of Ghana with the aim of providing a basis for proper management.

2.0 MATERIALS AND METHODS

2.1 Study area

This study was carried out in four fish landing sampling stations, namely Vodzah, Denu, Jamestown and Tema based on two staged sampling criteria (Figure 1).

Figure 1: Map showing the sampling sites
2.2 Data collection

Fish samples were obtained on monthly basis from fishermen within the study areas from June 2014 to January 2015. Obtained samples were kept on ice blocks and sent to the laboratory at the Department of Marine and Fisheries Sciences, University of Ghana for analysis. Weight and standard lengths were obtained using electronic scale and the 100-cm measuring board respectively. Identification of samples was carried out using Fischer et al. (1981) and Kwei & Ofori-Adu (2005). In all, 1401 samples of Sardinella maderensis were assessed.

2.3 Methods

Monthly length frequency data was obtained and standard length (SL) measured throughout the study period to estimate the various population parameters.

2.3.1 Growth parameters

Growth indicators for the assessed fish species was carried out using the Von Bertalanffy Growth Function (VBGF). To ascertain growth or mortality dominated population, the Powell-Wetherell Plot was applied (Pauly, 1984). The equation: \( L_t = L_m \left(1 - e^{-K(t-t_0)}\right) \) (Pauly, 1979) was used in estimating the growth function. Age at birth \((t_0)\), longevity \((T_{\text{max}})\) and growth performance index \((\phi)\) were estimated following procedures outlined by Pauly (1983).

2.3.2 Mortality parameters

Mortality parameters including Total mortality rate \((Z)\), Natural mortality rate \((M)\) and Fishing mortality rate \((F)\) were estimated using Pauly (1980). The mean surface temperature \((T)\) of 25.7°C was applied in estimating natural mortality rate \((M)\). The optimum fishing mortality rate \((F_{\text{opt}})\) and exploitation level \((E)\) were estimated as 0.4M (Pauly, 1984) and \(F/Z\) (Gulland, 1969) respectively. Exploitation rates \((E_{\text{max}}, E_{0.1} \text{ and } E_{0.5})\) were computed following Ahmad et al. (2018). The impact of exploitation on yield was done based on the interrelationship between exploitation rate \((E_{\text{max}})\) and critical length ratio \((L_{50}/L_{\text{∞}})\).

2.3.3 Length at first capture \((L_{c50})\) and maturity \((L_{m50})\)

The length at first capture of the assessed fish species was calculated from the length-converted catch curve. The length at first maturity \((L_{m50})\) was estimated as \(2^{*}(L_{\text{∞}})/3\) (Hoggarth et al., 2006).

2.3.4 Recruitment pattern

Backward projection of the obtained length frequency data was used in establishing the recruitment pattern (Mudoidiong et al., 2017; Nurul-Amin et al., 2008). Midpoint of the smallest length interval was used as length at first recruitment \((L_{r50})\) (Gheshlaghi et al., 2012).

2.3.5 Virtual Population Analysis (VPA)

Length structured VPA was performed using values of \(L_{\text{∞}}, K, F, a\) (constant) and \(b\) (exponent) for the species as inputs (Gayanilo et al., 2005). The \(t_0\) value was approximated to be zero. The direct exponential relationship between the weight \((W)\) and length \((L)\) was used to obtain the values of the constants, \(a\) and \(b\) (exponent) (Pauly, 1984).

2.3.6 Maximum Sustainable Yield (MSY)

MSY was estimated as \(0.5 \times (Y+MB)\), where \(B\) is the average biomass calculated from cohort analysis in the same year, \(M\) is the natural mortality and \(Y\) the annual yield. Annual yield \((Y)\) was calculated as \(\sum W_{t1,t2} \times C_{t1,t2} \times C\), where \(W\) is weight and \(C\) is the catch (Sparre and Venema, 1998).

2.4 Data Analysis

Obtained length frequency data were grouped and fed into FiSAT II (FAO-ICLARM Stock Assessment Tools) software for estimating the population parameters. Yield software package by Branch et al. (2000) was used in plotting length at age.

3.0 RESULTS

3.1 Growth parameters

Estimated growth parameters were 23.63 cm SL and 0.61 per year for asymptotic length \((L_{\text{∞}})\) and growth rate \((K)\) correspondingly. The restructured Length frequency data superimposed with the estimated growth curve exposed three cohorts within the harvest (Figure 2).
The growth function for the assessed species was \( L_t = 23.63 \left(1-e^{-0.61(t+0.284)}\right) \). The growth performance index (\( \phi \)) and Z/K ratio were 2.532 per year and 3.98 respectively (Figure 3a). Age at birth (\( t_0 \)) and longevity (\( T_{\text{max}} \)) were -0.284 and 5 years respectively (Figure 3b).

### 3.2 Probability of capture and Length at first maturity (\( L_{m50} \))

Length-at-first capture (\( L_{c50} \)) and maturity were 5.3 cm and 15.7 cm respectively (Figure 3d). Critical length at first capture (\( L_c \)) was 0.22.

### 3.3 Recruitment pattern

Recruitment pattern was all year-round with minor peak in August-September and major peak took place in May-June (Figure 4a). The length at first recruitment (\( L_{r50} \)) was 5.5 cm SL.

### 3.4 Mortality parameters

From the Jones and van Zalinge plot, Total mortality rate (\( Z \)) was estimated as 2.96 (Figure 3c). Natural and Fishing mortality rates were estimated as 1.33 (M) and 1.63 (F) per year respectively. Optimum fishing mortality rate and exploitation rate (\( E \)) were 0.53 per year and 0.55 respectively. \( E_{\text{max}} \), \( E_{0.1} \) and \( E_{0.5} \) were 0.46, 0.36 and 0.28 respectively (Figure 4b).
3.5 Virtual population analysis (VPA)

Recruits estimated into the population was $6.54 \times 10^7$ with the highest harvesting intensity occurring within lengths, 10 cm and 11 cm with fishing mortality rate (F) of 0.27 yr$^{-1}$ (Table 1). Peak of fishing mortality rate (1.33) ensued within the length range of 22 cm to 23 cm. Values of constants ‘a’ and ‘b’ were calculated as ‘0.0087’ and ‘3.3’.

![Figure 4: A) Recruitment pattern; B) Relative yield and relative biomass per recruit (B’/R)](image)

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3.6 Maximum Sustainable Yield (MSY)

Total biomass and yield were estimated as 3404.38 tons and 225.55 tons respectively. Using a mean body weight of 0.0745g, MSY was calculated as 2377 tons (Table 2).
Table 2: Estimates of the total biomass (tons), the yield (tons) and the MSY (tons) for Sardinella maderensis

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**MSY:** 2377 tons

**Yield:** 3404.38 tons

**Body weight/kg:** 0.0745 tons

**Biomass/kg:** 225.55 tons

### 4.0 DISCUSSION

The estimated growth rate was lower than 0.67 yr⁻¹ with a short longevity period indicating that this species is a fast-growing organism that attains maximum length of 22.5 cm in less than 5 years (Kienzle, 2005). Mathews and Samuel (1990) documented that for short-lived species, maximum length (Lₘₐₓ) is lower than the asymptotic length (Lₐ). A similar finding was observed from this study (Lₘₐₓ < Lₐ). The fast growth rate of the assessed fish species points to the equilibrium between fish density and food resources. The relative mortality-growth rate ratio (M/K = 2.18) was within the range for conducive marine environment (i.e. M/K = 1.5 – 2.5) as reported by Abowei et al. (2009). The estimated growth performance index from the study was slightly lower than estimates provided by other researchers (e.g. Sossoukpe et al., 2016). Potential reasons include computation procedure and the nature of the marine environment.

The lower length at first capture obtained from the study may be assigned to the use of small mesh sized fishing gears (Wehaye and Amponsah, 2017a) as well as constant fishing within the nearshore areas of the Ghanaian coast which are areas noted to be active fish nursery grounds. Further to this, the estimated critical length at capture (Lc) fell below 0.5, showing that majority of the catch are juveniles (Paul and Soriano, 1986). This finding signals the occurrence of the growth overfishing as they are not permitted to grow to the socially optimal size. The length at first capture was also found to be lower than lengths at first maturity and first recruitment - implying potential recruitment failure in the future. Diekert (2011) documented that recruitment overfishing largely involves capturing too any small sized fishes before they have matured. Hence, there is the need to implement and enforce mesh size regulations as this intervention will allow individuals of fish species to mature and spawn at least once before harvested.

Length of individuals experiencing high fishing intensity (10 cm – 11 cm) was found to be lower than the minimum legal landing size (18 cm) enshrined in Ghana’s Fishing Regulation (2010). This practice by fishermen fueled by consumer acceptance demonstrates poor enforcement of the fisheries law in Ghana by relevant authorities.

The observed continuous recruitment pattern was in agreement with findings by Pauly (1980) for tropical species, possibly due to the manifestation of more matured females (Deekae and Abowei, 2010). The presence of continuous recruitment pattern and a high number of survivors of individuals at the length at first recruitment (Lₕₒ) as shown in Table 1 indicate proper functioning of recruitment within the Sardinella maderensis stock. This finding shows that recruitment overfishing within the stock of the assessed fish species may be a critical issue in the future.

The higher Z/K ratio (>2) depicts intense exploitation (King and Etim, 2004). Comparatively, the lower natural mortality rate (M) estimated from the study confirms high fishing pressure on S. maderensis in Ghanaian coastal waters. Furthermore, fishing mortality rate (F) was found to be higher than the optimum fishing limit (Fₒₘᵢₙ), which re-echoes the incidence of intense fishing pressure on S. maderensis (Amponsah et al., 2016b).

The exploitation rate (E) was higher than the optimum level of E = 0.5. This illustrates the existence of over-exploitation within the fishery of S. maderensis (Pauly, 1980). The relative biomass per recruit at Eₕₑₐₓ and Eₜₐₓ were all lower than 30%, espousing the possible existence of recruitment failure in the future. Furthermore, the annual catch for Sardinella maderensis in 2014 (4895.76 tons) was found to be higher than the
estimated MSY, reiterating the occurrence of overfishing within the fishery of the assessed stock.

5.0 CONCLUSION

*S. maderensis* within the coastal waters of Ghana is a fast-growing species with short doubling time, thus consequences of overfishing will be economic related than biological. Growth overfishing was found to be present due to the harvesting of small-sized individuals of the species. Recruitment within the stock was observed as active. However, recruitment overfishing within the stock was found to be a precarious issue in the future, especially with relative biomass per recruit below the threshold of 30%. Therefore, stringent management measures such as the use of biological reference points are urgently required for sustainable management.

ACKNOWLEDGEMENT

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