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Population dynamics of *Engraulis encrasicolus* (Linnaeus, 1758) within Ghana's coastal waters

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Abstract
The population dynamics of *Engraulis encrasicolus* (Linnaeus, 1758), from catches landed along the eastern coastline of Ghana, was evaluated based on monthly length-frequency data from July, 2014 to January, 2015. The growth parameters were estimated as; asymptotic length (L_∞) = 11.03 cm standard length, growth rate (K) = 0.58 per year, growth performance index (ɸ) = 1.849, theoretical age at birth (t_o) = - 0.37 and maximum lifespan of 5 years. Using the Powell-Wetherall plot, the Z/K ratio was 3.90, implying that the stock is mortality dominated. Total mortality (Z) was estimated at 3.40 per year, while natural mortality (M) was 1.59 per year and fishing mortality (F) at 1.81 per year. The estimated fishing mortality (F = 1.81) was found to be greater than the optimum fishing mortality (Fopt = 0.64). Further, the current exploitation rate (E) was calculated as 0.53, portraying unhealthy *Engraulis encrasicolus* stock. The length at first maturity (Lm_{50}), length at first recruitment (Lr) and length at first capture (Lc_{50}) were obtained at 7.4 cm, 3.5 cm and 3.71 cm respectively. The yield-per-recruit analysis revealed that the current exploitation rate (E) of the *Engraulis encrasicolus* fishery is very close to the maximum exploitation level (E_{max} =0.58), an indication of unsustainable heavy exploitation. Based on the quadrant rule, the *Engraulis encrasicolus* fishery within the investigated area fell in the overfished category. From the study, it was confirmed that the *Engraulis encrasicolus* stock within Ghana's coastal waters is currently overfished.

Keywords: Mortality, growth, fishing, fish stock assessment, anchovy, Ghana

1. Introduction

Engraulis encrasicolus (Linnaeus, 1758) which belongs to the Engraulidae family, mostly feeds on plankton, chiefly copepods and other small crustaceans. They are mostly found in shallow waters to depths of about 400m and often form large shoals (Fischer *et al*., 1981) [6]. *Engraulis encrasicolus* is eurythermic and euryhaline in nature which means it can tolerate salinities from 5-41 ppt and in some areas, enters estuaries, lagoons and lakes, especially during spawning activity (Arneri *et al*., 2011) [1]. Also known as European anchovy, *Engraulis encrasicolus* is a multiple spawner- a mechanism for ensuring complete use of food and increase in the probability of population survival especially in unstable environmental conditions with high mortality in early stages of ontogeny (Arneri *et al*., 2011) [1]. European anchovy does not only have a substantial role in the economy of fishing industries but also plays a paramount role in the marine ecosystem. For instance, *Engraulis encrasicolus* serves as zooplankton predators as well as preys of many other marine organisms including large pelagic fishes and cetaceans (Arneri *et al*., 2011) [1]. These factors result in high natural mortality rates for stocks of *Engraulis encrasicolus*, reduced number of age classes, and intense inter-annual undulation in biomass due to undulations in recruitment strength, often associated to environmental factors (Cole and McGlade, 1998) [4].

In Ghana, *Engraulis encrasicolus* forms part of commercially important marine fish species (Koranteng, 1993) [13] and serves as an important fish protein for most small scale fishing households in many coastal communities in Ghana. Often, it is harvested by small scale fishermen who deploy small mesh sized purse seine and beach seine fishing gears. However, tuna vessels also harvest European anchovy chiefly as bait for tuna fishing (Koranteng, 1993; Fischer *et al.,* 1981) [13, 6]. Fairly good catches are made during July to September, yearly. Locally, European anchovy is marketed fresh, dried or salted. Nonetheless, the absence of adequate information on its population parameters from the coastal waters of Ghana threatens the exploitation status and sustainability of European anchovy with regards to meeting the needs of future generations without compromising the needs of the present generation.

In view of this, the aim of the study was to estimate the various population parameters of *Engraulis encrasicolus* within Ghana's coastal waters and its exploitation status. Information gained from this study will enhance effective management of this species.

2. Materials and Methods

2.1 Study area

The study focused on the eastern coastline of Ghana which comprises of two coastal regions namely; Greater and Volta Region. From each region, two coastal communities were selected which involved Jamestown and Tema from Greater Accra region; Denu and Vodzah from Volta Region (Figure 1). The selection criteria for the corresponding study sites were based on geographical location, the level and type of fishing activity.

2.2 Data collection

Fish samples were obtained from local fishers at the selected landing sites for seven months from July, 2014 to January, 2015 operating mostly with purse seine and beach seine multifilament fishing gears. Samples obtained were preserved on ice in ice chest and transported to the laboratory at the Marine and Fisheries Sciences Department, University of Ghana. Identification of the species was done to the species level using identification keys by Fischer *et al.* (1981) [6] and Kwei and Ofori-Adu (2005) [14]. In all a total of 844 individuals of *Engraulis encrasicolus* were sampled. Fish species were weighed using the electronic scale to the nearest 0.01g while the total and standard lengths were measured to the nearest 0.1cm using the 100cm measuring board at the laboratory.

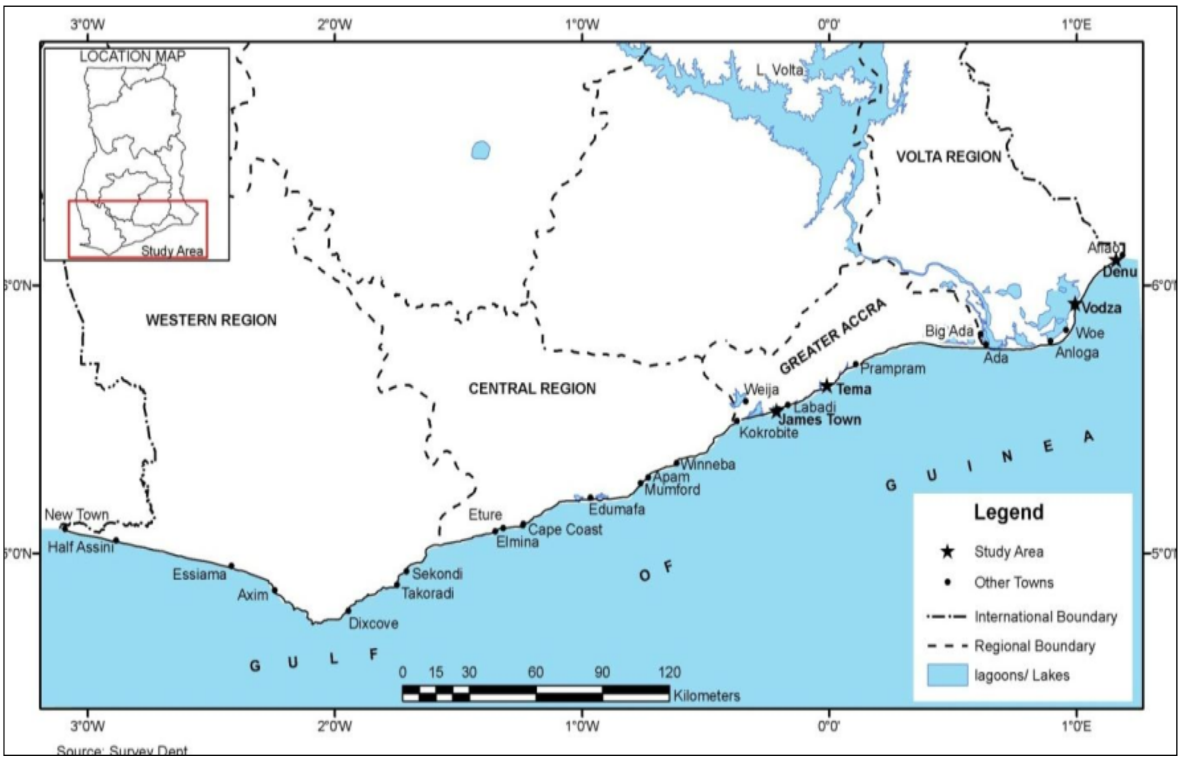

Fig 1: Map showing the sampling sites

2.3 Methods

2.3.1 Growth parameters

To obtain the growth parameters; growth rate (K), asymptotic length (L_∞) and the growth performance index (ϕ), the Von Bertanlaffy Growth Function (VBGF) fitted in FISAT II was used. The Powell-Wetherall Plot fitted in FISAT II was used to obtain the Z/K ratio for the assessed fish species (Pauly, 1984) [20]. The growth of individual fishes on the average towards the asymptotic length at an instantaneous growth rate (K) with length at time (t) was established using the Von Bertanlaffy Growth Function (VBGF): $Lt = L_\infty (1-e^{-k\,(t-t0)})$ (Pauly, 1979) [24]. The theoretical age at birth (t_o) was calculated independently, using the empirical formula: $\log_{10}(-t_o) = -0.3922 - 0.275 * \log_{10}L\infty - 1.038 * \log_{10}K$ (Pauly, 1979) [24]. The longevity of individuals (*Tmax*) was estimated using the following equation: $Tmax = 3/K + t_o$ (Pauly, 1983) [21]. The growth performance index for comparing the growth rate of the fish species with other published values, was generated using the equation: $(\phi) = 2\log L_\infty + \log K$ (Munro & Pauly, 1983) [16].

2.3.2 Mortality parameters

Total mortality coefficient (Z) was estimated by using the length-converted catch curve incorporated in the FISAT II tool. Natural mortality rate, M, was computed by the empirical equation of Pauly (1980) [23] using a mean surface temperature (T) of 25.7°C: $\text{Log}_{10}M = -0.0066 - 0.279\ 1og_{10} L_\infty + 0.6543\ \log_{10} K + 0.4634\ \log_{10} T$, where M is the natural mortality and K refers to the growth rate of the VBGF. Fishing mortality (F) was estimated using the relationship: $F = Z - M$ (Gulland, 1969) [10], where Z is the total mortality, F the fishing mortality and M is the natural mortality. The optimum fishing mortality was estimated as $F_{opt} = 0.4M$ (Pauly, 1984) [20]. The exploitation level (E) was obtained by the relationship: $E = F / Z$ (Gulland, 1969) [10].

2.3.3 Length at first Capture

The ascending left arm of the length-converted catch curve was used to analyze the probability of capture of each length class as fitted in the FISAT II. By plotting the cumulative probability of capture against mid-length a resultant curve was obtained from which the length at first capture (Lc_{50}) was taken as corresponding to the cumulative probability at 50%. Additionally, the length at both 25 and 75 captures were taken as corresponding to the cumulative probability at 25% and 75% respectively.

2.3.4 Recruitment pattern
The recruitment pattern was determined by backward projection on the length axis of the set of available length–frequency data as described in FiSAT. This routine reconstructs the recruitment pulse from a time series of length–frequency data to determine the number of pulses per year and the relative strength of each pulse (Nurul *et al*., 2009) [17]. Input parameters included L∞ and K. Normal distribution of the recruitment pattern was determined by NORMSEP (Pauly and Caddy, 1985) [19] in FiSAT. The midpoint of the smallest length group in the catch was estimated as the length at first recruitment (Lr) (Gheshlaghi *et al*., 2012) [9].

2.3.5 Length at first maturity (Lm_{50})
The length at first maturity (Lm_{50}) is the maiden length at which the fish is capable of contributing to the stock population. The length at first maturity (Lm_{50}) was estimated using the expression: $Lm_{50} = (2 * L\infty)/ 3$ (Hoggarth *et al.,* 2006) [11].

2.3.6 Relative Yield per Recruit (Y'/R) and Relative Biomass per Recruit (B'/R)
The relative biomass per recruit (B'/R) was estimated as B'/R = (Y'/R)/F. E_{max} which implies exploitation rate producing maximum yield, $E_{0.1}$ suggesting exploitation rate at which the marginal increase of Y'/R is 10% of its virgin stock with $E_{0.5}$ indicating exploitation rate under which the stock is reduced to half its virgin biomass were computed using the procedure incorporated in the FiSAT II Tool, using the Knife-edge option.

2.3.7 Yield isopleth
Yield contours which characterize yield isopleth were plotted to identify the impact on yield based on changes in exploitation rate (E_{max}) and critical length ratio ($Lc_{50}/L\infty$) using the FiSAT II Tool.

2.4 Data Analysis
The length frequency data were pooled into groups with 1cm length intervals and analyzed using the FiSAT II (FAO-ICLARM Stock Assessment Tools) software (Gayanilo *et al.,* 2003) [9]. The length at age was graphed using the Yield software package (Branch *et al*., 2000) [2].

3. Results
3.1 Growth parameters
From ELEFAN I routines, the best estimates of growth parameters obtained were; asymptotic length (L_∞) =11.03 cm standard length and growth rate (K) = 0.58 per year. Figure (2) shows the restructured Length frequency data superimposed with the estimated growth curve which revealed approximately four cohorts. The estimated theoretical age at birth (t_o) and longevity (T_{max}) were -0.37 and 5 years respectively (Figure 3b). The Von Bertanlaffy Growth Function (VBGF) for *Engraulis encrasicolus* was calculated as $Lt = 11.03\,(1-e^{-0.58\,(t-(-0.37))})$.

The growth performance index (Ø') of 1.849 was estimated for the *Engraulis encrasicolus.* The estimated Z/K ratio was 3.90 (Figure 3a).

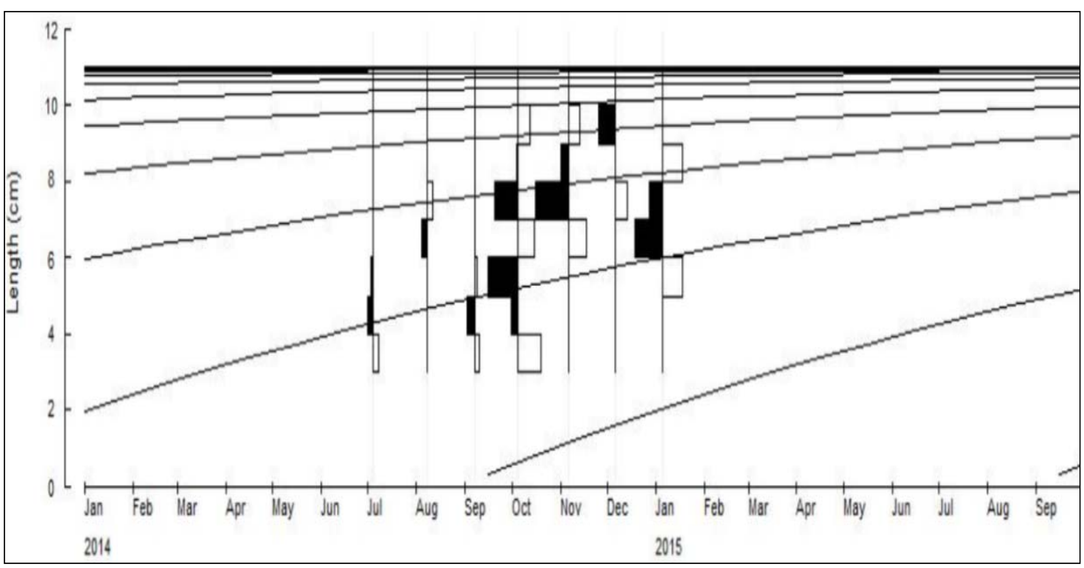

Fig 2: Reconstructed length frequency distribution superimposed with growth curve

3.2 Probability of capture and Length at first maturity (Lm_{50})
The probability of capture routine gave an estimate of L_{50}% at 3.71 cm (Figure 3c). Further, the estimates for L_{25}% and L_{75}% were 2.66 cm and 4.81cm respectively. Therefore, the length-at-first capture (Lc_{50}) was estimated at 3.71 cm for *Engraulis encrasicolus*. The length at first maturity (Lm_{50}) was obtained at 7.4 cm.

3.3 Recruitment pattern
The recruitment pattern established in (Figure 3d) indicated a year-round recruitment for *Engraulis encrasicolus*, but with two peaks of recruitment during one year. The length at first recruitment (Lr) was calculated as 3.5 cm.

3.4 Mortality
From the Jones and van Zalinge Plot (Figure 3e), total mortality (Z) was estimated at 3.40 per year, while natural mortality (M)

of 1.59 per year was obtained. By subtracting the value of natural mortality from the total mortality, the fishing mortality (F) of 1.81 per year was obtained. The optimum fishing mortality rate was 0.64 per year. The exploitation rate (E) was estimated at 0.53.

3.5 Relative Yield per Recruit (Y'/R) and Relative Biomass per Recruit (B'/R)

The exploitation rate giving maximum relative yield-per-recruit (E_{max}) was 0.58 using the knife edge recruitment (Figure 3f). 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 0.45 (knife-edge recruitment). The exploitation rate ($E_{0.5}$) which corresponds to 50% of the virgin relative biomass-per-recruit was estimated at 0.32 (knife-edge recruitment). The yield isopleths are shown in Figure 4, the yield contours predict the response of relative yield-per-recruit of the fish to changes in Lc and E; Lc/L∞ = 0.34 and E_{max} = 0.58.

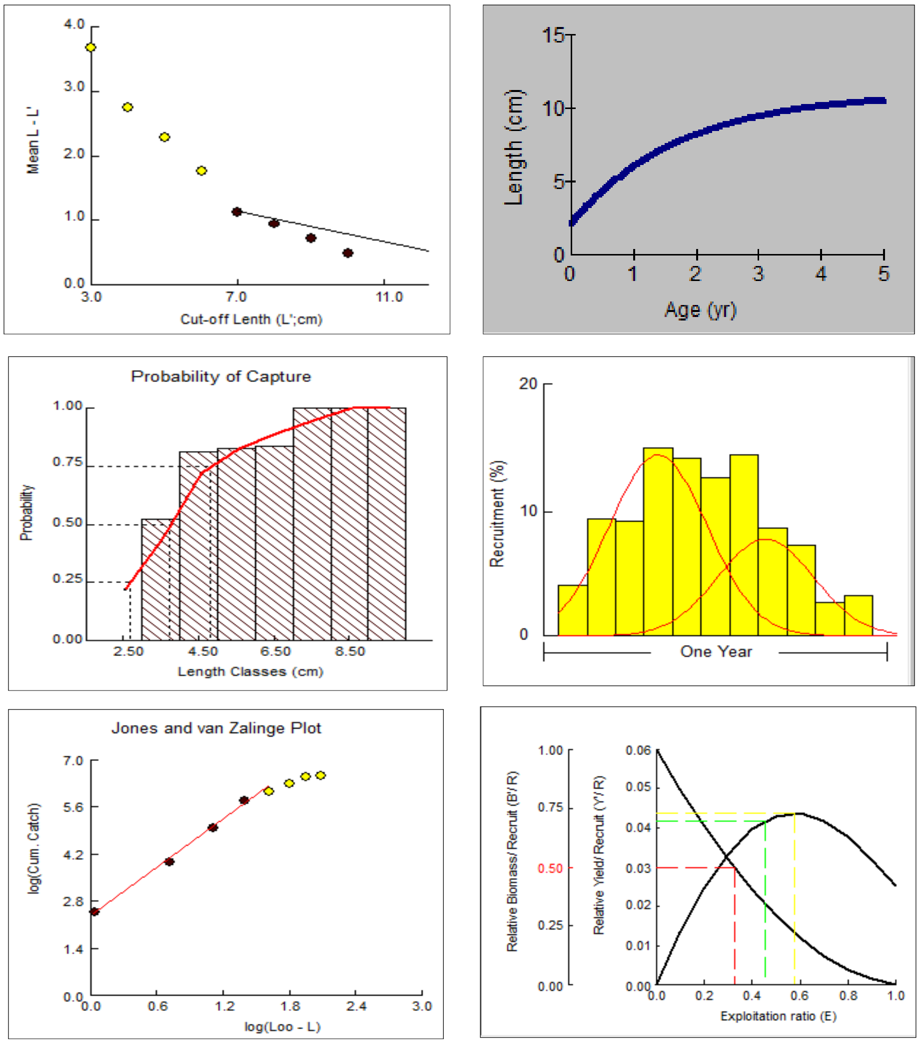

Fig 3: A) Powell-Wetherall plot for Z/K ratio; B) Length at age plot; C) Probability of capture; D) Recruitment pattern; E) Jones and van Zalinge plot and F) Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R).

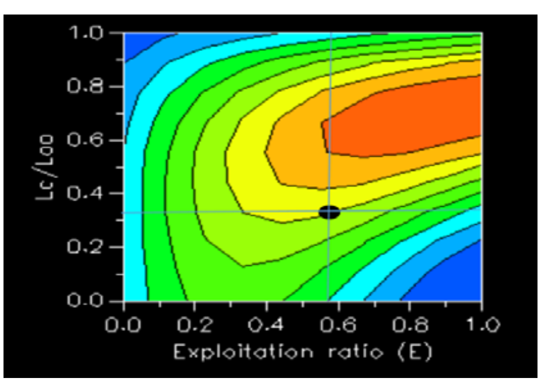

Fig 4: Yield isopleth diagram of *Engraulis encrasicolus*

4. Discussion

The values estimated for asymptotic length, growth rate and growth performance index in this study were lower than estimates from studies done in other locations (e.g: Froese and Pauly, 2000; Monteiro, 2002; Samsun *et al*., 2003) [7, 15, 25]. This variation may be attributed to plethora of factors like sampling procedures, nature of data, computation methods used, and the length frequency (Etim *et al.*, 1998) [5]. Kienzle (2005) [12] has documented that species with growth rate (K) sandwiched between $0.34yr^{-1}$ and $0.67yr^{-1}$ are mostly intermediate growing species. Therefore, with a longevity (T_{max}) of 5 years and growth rate (K) of 0.58, *Engraulis encrasicolus* was found to be an intermediate growing fish species.

The length at first capture (3.71 cm) was found to be lower than the length at first maturity (7.4 cm), potraying the presence of growth overfishing. The ratio of the length at first capture to the asymptotic length ($Lc/L\infty$) provides an insight into whether juvenile or matured fishes are mostly harvested by fishermen. Thus if the ($Lc/L\infty$) ratio is less than 0.5, it indicates that majority of the catch constituted juvenile fish species (Pauly and Soriano, 1986) [18]. The ($Lc/L\infty$) ratio estimated from the present study was 0.34, relatively far below 0.5, showing that juveniles made most of the catch with regards to *Engraulis encrasicolus* fishery. This observation could be due to the use of small mesh sizes, mostly by beach seiners which has the propensity of causing truncation in length at first maturity. However, the calculated length at first maturity (7.4 cm) was relatively higher than the estimates reported by Koranteng (1993) [13] for both males (5.6 cm) and females (5.7 cm). This finding could be linked to the size class obtained and the computational procedures applied.

The double recruitment pattern in the study conformed to the assertion by Pauly (1982) [22] that the double recruitment pulses per year is nearly a general feature of tropical fish species. By macro-inspection, the minor peak which spans from August to September while the major peak was observed in April to May. The strong presence of all year recruitment may be an indication that the *Engraulis encrasicolus* fishery in Ghana is currently not suffering from recruitment failure. This assertion is further supported by the fact that the length at first capture (Lc_{50} = 3.71 cm) was relatively higher than the length at first recruitment (Lr = 3.5 cm), showing that most of the juveniles get recruited into the *Engraulis encrasicolus* stock before being harvested by fishing gears of various types and mesh sizes.

The ratio of Z/K quantifies the interplay between mortality and growth within any fish population whether exploited or unexploited. As a rule, the Z/K ratio of 1.0 indicates that mortality balances growth in the population. However, if the ratio is more than 1, then it is supposed to be mortality dominated and when less than 1, then it is growth dominated (Etim *et al*., 1998) [5]. In this study, the estimated Z/K ratio from Wetherall Plot was 3.90; an indication that the *Engraulis encrasicolus* population is mortality dominated.

The estimated total, natural and fishing mortality rates in this study were relatively higher than estimates reported by other authors (e.g. Samsun *et al.,* 2003) [25]. This observation could be dependent on the density of predators and competitors as well as the intensity of fishing pressures and the mesh sizes of fishing gears (Sparre and Venema, 1992) [26]. Alternatively, Pauly (1984) [20], proposed that optimum fishing mortality (Fopt) should be approximately 40% of the natural mortality or Fopt. = 0.4 M. However, if fishing mortality exceeds the optimum fishing mortality (Fopt), then the fishery is heavily exploited. From the study, fishing mortality appeared to be comparatively greater than the Fopt (0.64 per year), implying that the *Engraulis encrasicolus* fishery is heavily exploited.

The current exploitation rate ($E_{current}$ = 0.53) was found to be greater than optimum exploitation rate (E = 0.50), revealing the *Engraulis encrasicolus* fishery within Ghana's coastal waters is not in a heathy state. Furthermore, the present level of exploitation rate ($E_{current}$ = 0.53) was slightly lower than the maximum allowable limit based on the yield-per-recruit calculation (E_{max}= 0.58), depicting heavy unsustainable exploitation. Also, such observation shows that exploitation of *Engraulis encrasicolus* within Ghana's coastal waters is currently close to the maximum allowable limit (E_{max} = 0.58) which could be a catalyst for collapse of this commercially important fish species.

The yield isopleths diagram in this study regarding Pauly and Soriano (1986) [18] quadrant rule, the $Lc/L\infty$ of 0.34 and exploitation rate (E_{max}) of 0.58 fell within quadrant D. This implied that the *Engraulis encrasicolus* fishery is under the regime of 'catching smaller fishes at high effort level'. Further, using the same quadrant rule as an assessment of a fishery, the *Engraulis encrasicolus* fishery appeared to be in the overfished stage. Therefore, as management intervention, fishing effort level must be reduced and mesh sizes increased to allow small sized *Engraulis encrasicolus* to spawn at least once before they are harvested.

5. Conclusion

The study has argued that the fishery of *Engraulis encrasicolus* is facing excessive fishing pressure and subsequently, its fishery within Ghana's coastal waters is overfished. Hence, to reverse the current situation, routine monitoring by fisheries managers is needed to enhance adherence to the minimum legal mesh size of fishing gears and also, ensure that fishing effort does not increase.

6. Acknowledgment

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