International Journal of Fisheries and Aquatic Research
ISSN: 2456-7248, Impact Factor: RJIF 5.44
www.fishjournals.com
Volume 2; Issue 3; May 2017; Page No. 01-07

Virtual population analysis and estimates of maximum sustainable yield of some commercially important fish species in the coastal waters of Ghana and management implications

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Abstract

Virtual Population Analysis (VPA) was carried out to evaluate maximum sustainable yield (MSY) and the recruitment status for three commercially important fish species, particularly, *Brachydeuterus auritus*, *Scomber japonicus*, and *Engraulis encrasicolus* in response to the alarming rate of decline in annual catches. For this purpose, length frequency data was obtained from fish landing sampling sites along the eastern coast of Ghana from June 2014 to January 2015. Obtained data was measured for standard length and subjected to analysis using FISAT II. The outcome of VPA was applied in the estimation of maximum sustainable yield (MSY) for the three targeted fish species. VPA outcome revealed the strong existence of recruitment within the population of the assessed fish stocks. Further, small-sized fishes experienced higher harvesting rate, a proxy for growth overfishing. Estimated MSY for *Brachydeuterus auritus*, *Scomber japonicus*, and *Engraulis encrasicolus* were 4946.84 tons, 3085.35 tons and 4803.91 tons respectively. The estimated MSY values were lower than annual fish landings for 2014. Results indicated that the assessed fish species were not only plagued with unsustainable fishing pressure and growth overfishing, but vulnerable to recruitment overfishing in the future. In the absence of urgent management measures, the perceived collapse of targeted fish species will worsen food insecurity in vulnerable fishing households in Ghana. To sustainably maintain the fisheries of the assessed fish stocks, mesh sizes should be increased, implemented and enforced.

Keywords: VPA, *brachydeuterus auritus, scomber japonicus, engraulis encrasicolus*, maximum sustainable yield (MSY)

1. Introduction

Globally, sustainable harvest management of commercially important fishes is resident on the comprehension of individual populations' (stocks) dynamics. Particularly, for species with long longevity, delayed maturation process, sexual-sized dimorphism. Therefore, it is imperative to have insights of population size, population age structure and inter-annual recruitment variability (Scarnecchia *et al*., 2014; Bruch, 1999) [1, 2]. Knowledge on the population size of fish species becomes incomplete without insights into Virtual Population Analysis (VPA). Generically referred to as Cohort analysis, Virtual Population Analysis has become a distinguished method of stock assessment since its inception 2-3 decades ago (MacCall, 1986) [3]. Further, information gained from Virtual Population Analysis (VPA) is often used in monitoring fisheries resources as well as providing more information on fish stock status in relation to growth overfishing and recruitment overfishing (Chen *et al*., 2008) [4]. VPA involves a "backward solution" estimation of historical abundances of a cohort based on subsequent catches from a presumed homogeneous stock: where it is assumed that fishes of a certain age are vulnerable to capture (MacCall, 1986) [3]. Scarnecchia *et al*. (2014) [1] added that the rationale behind the Virtual Population Analysis in fisheries stock assessment is to analyze what can be seen and the catch in order to calculate the population that must have been in the water to produce this catch and till date VPA is widely used in making management decisions for marine species.

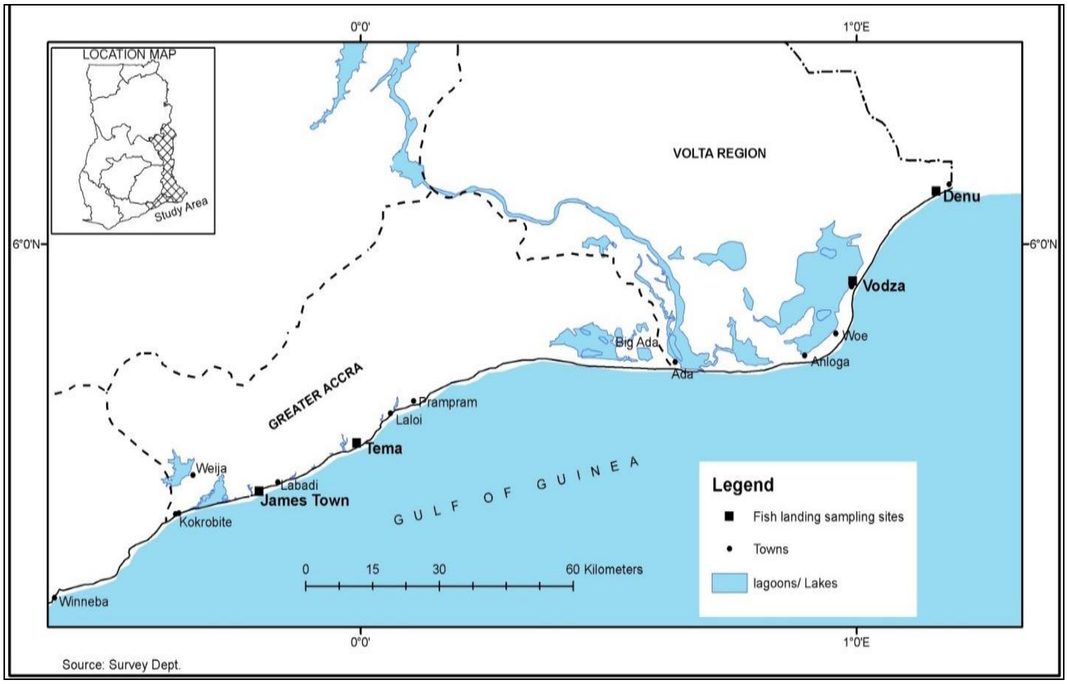
Cohort analysis and its statistical variants are the most widely used methods for estimating the size of fish stocks which rely on the catch in numbers at age (Pope, 1972) [5] or catch in biomass at age (Zhang and Sullivan, 1988) [6]. Application of VPA requires the use of an age or length based data. Sometimes age determination for age based VPA for the stock of interest is difficult or impossible to carry out, and it is often a costly procedure. Also, in data-deficient situations, traditional age-structured stock assessment models cannot be applied, particularly in developing countries (Zhang & Megrey, 2010) [7]. As a result, length based VPA are highly preferred to aged based VPA for stock assessment in developing countries.

Length based VPA provides a medium for estimating fishing pressure on various length groups using fish landings from fishing operations (Anderson, 1978; Neethiselvan and Venkataramani, 2002) [8, 9]. The length based VPA was used in the present study due to the easy access to data needed for its estimation. In spite of the numerous stock assessment studies on various commercially important fish species in Ghana, studies focused VPA and MSY appears to be sparse. In view of this, the aim of the present study was to assess the status of some commercial fish species within Ghana's coastal fishing operations using VPA. Insights gained from the present study will not only aid in effective management of fisheries resources in Ghana but also serve as a springboard for further studies in this area of stock assessment.

2. Materials and Methods

2.1 Study site

This study focused on the eastern coastline of Ghana comprising of Volta and Greater Accra regions (Fig. 1). For each coastal region, two fish landing sampling stations were selected, giving a total of four fish landing sampling stations. These fish landing sampling stations were Jamestown and Tema for Greater Accra Region and Vodzah and Denu for Volta Region (Fig. 1). Denu, the capital of Ketu South Municipal, a district on the south-eastern corner of the Volta region is a coastal community located on coordinates 06^{o}06'0" N 01^{o}08'52" E. Vodzah is located in Keta, Volta region of Ghana, geographically located on coordinates 5^{o}57'0"N 1^{o} 0'0" E. Tema, located 25 kilometers east of the capital city Accra, Ghana is the eleventh most populous settlement in Ghana. Tema is a city constructed on the site of a small fishing village with geographical coordinates as 5^{o}40'N 0^{o}0'W and has the Greenwich Meridian passing directly through it whereas Jamestown, one of the oldest cities in Accra, Ghana is located on 5^{o}32'1N 0^{o}12'49W. Tema and Jamestown fishing community is home to various fishing methods including gill netting, purse seining, hooks, and line as well as drift gill netting by fishers from most coastal communities in Ghana. In all the four fish landing sampling stations, fishing and fishing related activities such as fish processing, fish trading, and fish marketing served as the main source of livelihood for the majority of the inhabitants. However, the minority of indigenes are included alternative livelihoods including trading, farming, driving and others.



Source: Survey Dept.

Fig 1: Map showing the four fish landing sampling sites.

2.2 Fish catch data

Monthly fish samples were obtained from local fishers engaged in beach seine, purse seine and set net fishing at the selected fish landing sampling sites for eight months from June 2014 to January 2015. At each of the selected fish landing sampling sites, a minimum of 30 specimens of each fish species were randomly obtained on monthly basis, preserved on ice blocks in an ice chest and transported to the laboratory at the Department of Marine and Fisheries Sciences, University of Ghana. At the laboratory, fish samples were weighed using the electronic weighing balance to the nearest 0.01g, with the standard lengths measured to the nearest 0.1 cm using the 100-cm measuring board. Fish samples were identified to the species level using fish identification keys by Fischer *et al*. (1981) [10] and Kwei & Ofori-Adu (2005) [11]. The fish species treated in this study included *Brachydeuterus auritus*, *Scomber japonicus*, and *Engraulis encrasicolus*. In 2801 samples were assessed, encasing 1675 samples of *Brachydeuterus auritus*, 282 samples of *Scomber japonicus*, and 844 samples of *Engraulis encrasicolus*.

2.3 Virtual population analysis

The inputs for VPA included 'a' and 'b' constants from length weight relationship, fishing mortality (F), natural mortality (M), terminal fishing mortality (Ft) and growth parameters – asymptotic length (L∞) and growth rate (K). This routine modified from Jones and van Zalinge (1981) [16] utilizes basically the same approach as the previous routine (age-structured VPA), but is adapted to accommodate length frequencies. The required file for VPA was Length-frequency data file (representing mean annual catch at length). The required inputs for VPA were L∞ and K. However, it is noteworthy that L∞ must be at least 10% larger than the largest fish in the length frequency distribution. The actual procedure for VPA in FiSAT II was as follows:

The initial step is to estimate the terminal population (N_t) given the inputs, from:

$$\mathbf{N_t = Ct \cdot (M + F_t)/F_t,}$$

where C_t is the terminal catch (i.e. the catch taken from the largest length class).

Then, starting from N_t, successive values of F are estimated, by iteratively solving:

$$\mathbf{Ci = N_{i+t} \cdot (F_i/Z_i) \cdot (EXP\ (Z_{i \cdot ti})\text{-}1),}$$

where $t_i = (t_{i+1} - t_i)$, and $t_i = to - (1/K) \cdot \ln(1-(L_i/L))$, where population sizes (Ni) are computed from:

$$\mathbf{Ni = N_{i+t} \cdot EXP\ (Z_i).}$$

The last two equations were used alternatively, until the population sizes and fishing mortality for all length groups have been computed (Gayanilo *et al.*, 2005) [12].
Growth and mortality rates parameters estimated by Amponsah et al (2016a, 2016b, 2016c) [18-20] were used as inputs for the VPA.

2.4 Maximum sustainable yield

VPA was applied to estimate the biomass (tons), the yield (tons), total mortality (Z), fishing mortality (M) and exploitation ratio (E) using the following equation (Jones 1984) [17]:

$$N_{L2} = N_{L1} * (X_{L1,L2} + C_{L1,L2}) * X_{L1,12},$$

Where, N_{L1} and N_{L2} are the number of animals for the beginning (L_1) and the ending (L_2) length interval, $C_{L1,\ L2}$ is the catch for the length interval, and $X_{L1,\ L2}$ the natural mortality factor for the length interval.
The natural mortality factor for the length interval was computed using the expression:

$$X_{L1,\ L2} = \left(\frac{L\infty - L1}{L\infty - L2}\right)^{M/2K}.$$

The exploitation rate (E) and the fishing mortality (F) for each length interval were calculated as follows;

$$E = \left(\frac{C_{L1,L2}}{N_{L1} - N_{L2}}\right)$$

$$F = \left(\frac{F/Z_{L1,L2}}{1 - F/Z_{L1,L2}}\right)$$

The total mortality (Z) for each length interval was obtained using:

$$Z = \left(\frac{M_{L1,L2}}{1 - F/Z_{L1,L2}}\right).$$

The Maximum Sustainable Yield (MSY) was estimated using Cadima's formula for exploited stocks (Sparre and Venema 1998) [14]:
MSY = 0.5 * (Y+MB), where B = total biomass, Y = annual yield and M = natural mortality rate.
The annual yield (Y) was estimated using the expression:

$$Y = \sum W_{L1,L2} * C_{L1,L2},$$

where W is the weight and C is the catch. The total biomass (B) was calculated following the expression:

$$B = \sum \frac{N_{L1} - N_{L2}}{Z_{L1,L2}} * \textbf{mean body weight.}$$

The body weight for each length interval was calculated as:

$$\textbf{Body weight} = a * \left[\frac{L1+L2}{2}\right]^{b},$$

where, *a* is the intercept and *b* is the slope of the length weight relationship.

2.5 Data analysis

Analysis of information obtained from the study was carried out using the FISAT II statistical tool (Gayanilo *et al.*, 2005) [12].

3. Results

3.1 Virtual Population Analysis (VPA)

Scomber japonicus observed natural loss due to natural mortality at 13cm to 18cm, with the highest loss due to natural mortality observed at 13cm to 15cm (Fig 2a). Catches for *Scomber japonicus* by fishing gears occurred from size 13cm and peaked at 18 cm to 19cm. The highest fishing mortality rate of $4.28 yr^{-1}$ for *Scomber japonicus* corresponded to length interval of 24cm to 25cm. The number of recruits into the *Scomber japonicus* stock was calculated as 74224480.

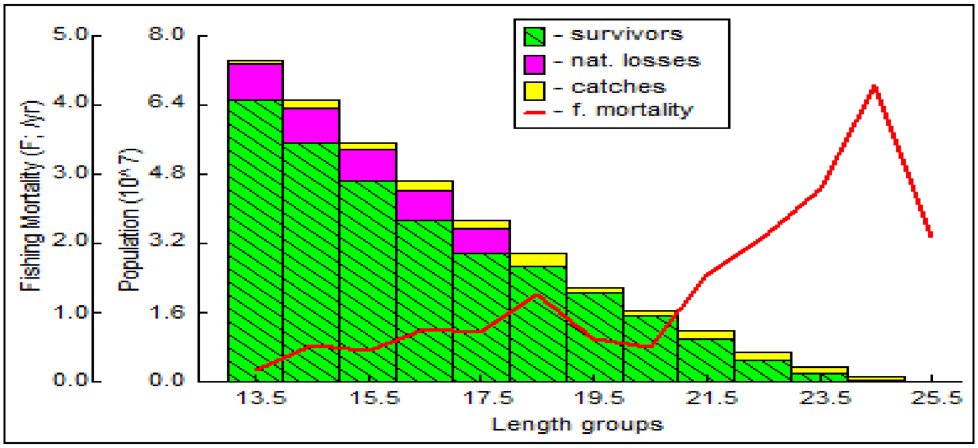


Fig 2a: Virtual Population Analysis for *Scomber japonicus*

Brachydeuterus auritus began to experience natural loss due to natural mortality at length interval of 3cm to 10cm, with the highest rate of natural loss at 3cm – 6cm (Fig 2b). The vulnerability of *Brachydeuterus auritus* to fishing gears began from size 4cm, with the greatest catch occurring at 11cm – 12cm (Fig. 2b). Further, the fishing mortality rate peaked at 3.46yr^{-1} within the length interval of 14cm – 15cm for *Brachydeuterus auritus*. Recruitment into *Brachydeuterus auritus* stock was estimated at 575108544.

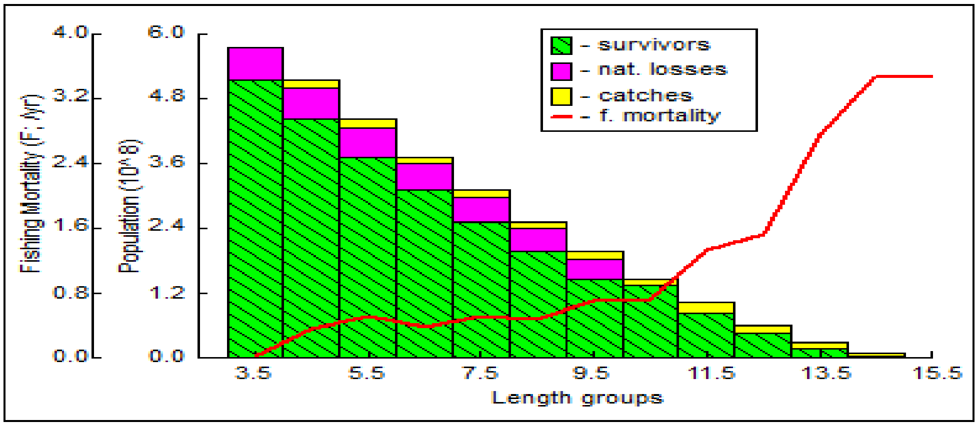


Fig 2b: Virtual Population Analysis for *Brachydeuterus auritus*

Engraulis encrasicolus began to encounter natural loss as a result of natural mortality at length 3cm, with the peak of the natural loss evident at size interval of 3cm to 4cm (Fig 2b). The stock of *Engraulis encrasicolus* became prone to fishing gears from size 4cm, with the greatest catch rate taking place at length interval of 7cm to 8cm (Fig. 2c). The *Engraulis encrasicolus* experienced the highest fishing mortality rate of 1.59yr^{-1} at length interval of 9cm to 10cm. Nonetheless, recruitment into the stock of *Engraulis encrasicolus* was 898573440.

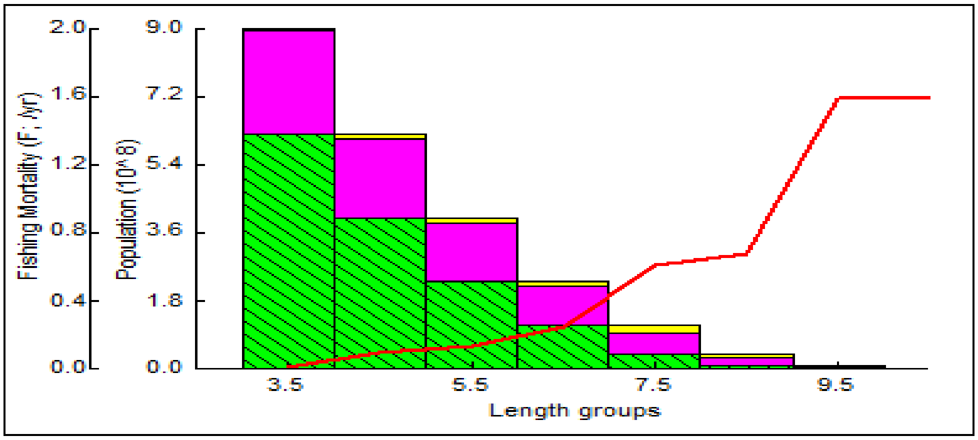


Fig 2c: Virtual Population Analysis for *Engraulis encrasicolus*.

3.2 Maximum sustainable yield

The calculated biomass for *Brachydeuterus auritus*, *Engraulis encrasicolus* and *Scomber japonicus* were 3476.05 tons, 4493.03 tons and 1969.59 tons respectively (Table 1a–1c). The estimated yield for *Brachydeuterus auritus*, *Engraulis encrasicolus* and *Scomber japonicus* were 3880.11 tons, 2463.89 tons and 2034.59 tons respectively (Table 1a–1c). The maximum sustainable yield (MSY) was estimated at 4946.84 tons, 4803.91 tons and 3085.35 tons for *Brachydeuterus auritus*, *Engraulis encrasicolus* and *Scomber japonicus* respectively (Table 1a–1c).

Table 1a: Biomass, yield and Maximum Sustainable Yield (MSY) for *Brachydeuterus auritus*.

Mid-Length	Catch (X 10^5)	XL1, L2	N (X10^6)	E	F	Z	Biomass/kg	Body weight/kg	Yield
3.5	5.0	1.08	575.1	0.00808	0.0141	1.74	34466.07	0.0010	485.97
4.5	124.0	1.08	513.3	0.17512	0.3673	2.10	71513.75	0.0021	26267.00
5.5	164.0	1.09	442.4	0.23183	0.5221	2.25	123949.42	0.0039	64713.99
6.5	109.0	1.10	371.7	0.17840	0.3756	2.11	192203.95	0.0066	72191.80
7.5	139.0	1.11	310.6	0.23220	0.5232	2.25	274199.70	0.0103	143461.28
8.5	114.0	1.13	250.7	0.21577	0.476	2.21	364356.54	0.0152	173433.71
9.5	149.0	1.15	197.9	0.29033	0.7078	2.44	452114.96	0.0215	320006.97
10.5	130.0	1.18	146.6	0.29647	0.729	2.46	522315.18	0.0293	380767.77

11.5	186.0	1.22	102.7	0.43592	1.337	3.07	540225.20	0.0388	722281.09
12.5	145.0	1.29	60.1	0.46911	1.5287	3.26	476976.27	0.0503	729153.62
13.5	133.0	1.41	29.2	0.61393	2.7511	4.48	308609.96	0.0638	849016.87
14.5	50.0	1.73	7.5	0.66667	3.46	5.19	115123.85	0.0797	398328.53
							3476.05 tons	0.0256	3880.11 tons
MSY	4946.84 tons								

Table 1b: Biomass, yield and Maximum Sustainable Yield (MSY) for *Engraulis encrasicolus*.

Mid-Length	Catch ($x10^5$)	XL1, L2	N ($x10^6$)	E	F	Z	Biomass/kg	Body weight/kg	Yield
3.5	15.0	1.20	898.6	0.01	0.01	1.60	1500000.00	0.00	6066.87
4.5	129.0	1.23	622.8	0.06	0.10	1.69	1155818.74	0.01	111449.81
5.5	127.0	1.28	398.6	0.08	0.13	1.72	838315.63	0.02	201134.64
6.5	157.0	1.36	232.7	0.13	0.25	1.84	555921.86	0.03	411799.50
7.5	211.0	1.48	115.4	0.28	0.61	2.20	301626.68	0.04	852619.57
8.5	92.0	1.73	39.1	0.30	0.67	2.26	118912.49	0.06	542526.32
9.5	41.0	2.53	8.2	0.50	1.59	3.18	22434.03	0.08	338297.08
							4493.03 tons	0.0338	2463.89 tons
MSY	4803.91 tons								

Table 1c: Biomass, yield and Maximum Sustainable Yield (MSY) for *Scomber japonicus.*

Mid-Length	Catch ($X10^5$)	XL1, L2	N ($X10^6$)	E	F	Z	Biomass/kg	Body weight/kg	Yield
13.5	7.0	1.06	74.2	0.07639	0.1737	2.27	121299.47	0.0301	21069.72
14.5	19.6	1.07	65.1	0.19891	0.5214	2.62	145050.04	0.0386	75629.09
15.5	15.7	1.07	55.2	0.17793	0.4545	2.55	168063.71	0.0486	76384.96
16.5	23.6	1.08	4.6	0.26406	0.7535	2.85	188822.45	0.0604	142277.72
17.5	20.1	1.09	3.7	0.25661	0.7249	2.82	205174.75	0.0741	148731.18
18.5	29.7	1.10	29.6	0.37424	1.2559	3.36	212616.40	0.0898	267024.94
19.5	12.3	1.12	21.7	0.22764	0.6189	2.72	215013.36	0.1078	133071.77
20.5	8.4	1.14	16.3	0.19047	0.4941	2.59	219241.32	0.1283	108327.14
21.5	20.6	1.17	11.8	0.42299	1.5395	3.64	202787.96	0.1513	312192.07
22.5	18.4	1.21	6.9	0.49863	2.0886	4.19	155929.22	0.1772	325673.77
23.5	12.8	1.28	3.3	0.57081	2.793	4.89	94130.75	0.2060	262907.20
24.5	6.1	1.43	1.02	0.67106	4.2842	6.38	33977.13	0.2381	145564.81
25.5	0.6	1.95	0.01	0.50000	2.10	4.20	7482.29	0.2735	15712.81
							1969.59 tons	0.1249	2034.57 tons
MSY	3085.35 tons								

4. Discussion

Currently, literature on VPA using length frequency distribution for assessing the stock of commercially important fish species within Ghana's coastal is not extant. Therefore, information gained will serve as a springboard for further studies in this area of specialization.

4.1 Virtual Population Analysis (VPA)

Fishing mortality rate (F) for all the assessed fish species were highest at the largest mid-length, depicting that fishing mortality rate is size specific. As such, small sized fish species experience low fishing mortality rate, whereas large-sized fish species encounter high fishing mortality rate. Considering harvesting rate, fish species within the small mid-length groups experienced relatively higher harvesting rate (catches) than fish species contained by large mid-length groups. Possible causes for such stratification in fishing mortality and harvesting rates include small mesh size of fishing gears and the consumer satisfaction – mostly fueled by economic reasons. Consequently, intense harvesting of relatively small-sized fishes (< 10cm) could effectuate growth overfishing. Buttressing this assertion, Amponsah et al. (2016a, 2016b & 2016c) [18-20] documented that the assessed fish species within Ghana's coastal waters are experiencing growth overfishing.

Regarding minimum legal landing lengths of fish stocks, the length intervals that encountered relatively high harvesting rates were lower than the minimum legal landing lengths for *Brachydeuterus auritus* and *Scomber japonicus* enshrined in Ghana's Fishing Regulation (2010) [21]. This reflects the under protection of the assessed fish species by Ghana's Fishing Regulation (Amponsah et al., 2016d) [22]. For *Engraulis encrasicolus*, the detected length interval with the highest harvesting rate was relatively higher than the minimum legal landing size/length enshrined in Ghana's Fishing Regulation (2010) [21]. However, the corresponding fishing mortality was approximately close to the estimated optimum fishing level, illustrating that the stock of *Engraulis encrasicolus* is intensely exploited though within the optimal range. Nevertheless, if fishing effort within Ghana's coastal operations goes unregulated, exploitation of *Engraulis encrasicolus* may fall out of the optimal range, making its fishery overexploited. Therefore, to ensure that fish species with lengths greater than the legal minimum lengths experience higher harvesting rate while safeguarding the fisheries from potential collapse, mesh sizes should be increased. The solid presence of recruitment evidenced by the high number of survivors (recruits) whose length corresponds to the smallest midlength (Lr_{50}) for the assessed fish species exemplifies the absence of recruitment failure. Studies done by Amponsah et al (2016a, 2016b and 2016c) [18-20] also reported that recruitment within the population of the assessed fish stocks within Ghana's coastal waters is functional. Thus, strengthening the earlier assertion that recruitment overfishing is absent from the fisheries of the assessed fish stock. The strong presence of recruitment into the stock of the assessed fish stock could be associated with low fishing mortality rate, mesh size and environmental conditions. Manifestation of functional recruitment within the fisheries of the treated fish species shows that majority of fish juveniles get the opportunity to spawn at least once before becoming prone to capture by any fishing gears (Neethiselvan & Venkataramani, 2002) [9].Conversely, continuous rise in fishing mortality rates from the present study for the assessed fish species consistently translated into a decline in fish population and subsequently, resulting in small numbers of large-sized fish species. The presence of few large sized fish species due to increasing fishing mortality rate could be a premonition of recruitment overfishing in the future.

4.2 Maximum Sustainable Yield (MSY)

The estimated MSY for the treated fish species was relatively lower than the 2014 annual recorded catches - 4084 tons, 7092.91 tons and 6127.46 tons for *Scomber japonicus*, *Brachydeuterus auritus* and *Engraulis encrasicolus* respectively, corroborating the existence of unsustainable fishing pressure. Nurul-Amin *et al* (2002) [23] highlighted that situations for which the MSY is lower than the annual recorded catch portrays the presence of high fishing pressure on that particular fish stock. WWF (2010) [24] wrote that harvesting of fish slightly beyond the MSY introduces growth overfishing though stock can reproduce to replenish the stock. However, when harvesting of catch (yield) goes highly beyond the MSY, the stock gets subjected to recruitment overfishing; subsequently collapse if effective measures are not implemented (WWF, 2010) [24].

From the study, it was observed that all the three assessed fish species are currently experiencing growth overfishing since estimated values of MSY were below the annual catches. This observation confirms findings by Amponsah et al. (2016a, 2016b and 2016c) [18-20], who reported that the fisheries of *Scomber japonicus*, *Brachydeuterus auritus* and *Engraulis encrasicolus* within Ghana's coastal waters are currently being subjected to growth overfishing. Exploitation of the selected fish species beyond the MSY for the assessed fish species could be linked to increased fishing effort evinced by increased number of fishing canoes, storage capacity as well as geographical reach by fishermen. In support of this assertion, Amponsah et al. (2016a, 2016b and 2016c) [18-20] documented that the treated fish species within Ghana's coastal waters are unsustainably exploited with their respective exploitation rate (E) beyond the optimum level of E = 0.5. Nonetheless, with estimated MSY highly below the annual catches for 2014, *Scomber japonicus* and, *Brachydeuterus auritus* were found to be prone to recruitment overfishing. On the other hand, should annual harvesting of *Engraulis encrasicolus* continue beyond the calculated maximum sustainable yield (MSY), the fishery of *Engraulis encrasicolus* is likely to experience recruitment failure. Consequentially, the fisheries of the assessed fish stocks are likely to be confronted with possible collapse in the future, following the emergence of recruitment failure.

5. Conclusion

Small-sized fish species experienced lower mortality rates, whereas large-sized fish species witnessed higher fishing mortality rate. Harvesting rate in fishing is size specific where small-sized fish species experience higher harvesting rate than the large-sized fishes. Features of growth overfishing were perceived within the fisheries of assessed fish species within Ghana's coastal waters. Recruitment overfishing was relatively nonexistent from the population of the assessed fish species due to the functionality of recruitment. However, MSY estimates in relation to annual catches divulged that the fisheries of *Scomber japonicas and Brachydeuterus auritus* within the coastal waters of Ghana are highly prone to recruitment overfishing with the fishery of *Engraulis encrasicolus* less vulnerable to recruitment overfishing.

6. Acknowledgement

This study is the upshot of concerted 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. Also, the role of Professor Martin Tsamenyi AM and Dr. David Kirby of ANCORS, University of Wollongong, Australia and other colleges who facilitated this collaboration is duly appreciated. Sincere gratitude goes to the technicians at Department of Marine and Fisheries Sciences for assistance provided during both field and laboratory work.

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