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Aspects of population dynamics of *Pseudotolithus typus* (Bleeker, 1863) with management implications within the coastal waters of Liberia

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Abstract
This research article seeks to provide information about some aspects of population dynamics of *P. typus* in the Liberia coastal waters for strategic management and sustainability. A total of 1,822 specimens of *P. typus* were collected for six months from April to September 2013. The length frequency data was analyzed using FiSAT II and yield software. The asymptotic length, growth rate, growth performance index and the theoretical age at birth were estimated as: $L\infty$ = 84 cm SL, K = 0.04 yr^{-1}, ø = 2.451 and t_o = -0.276 yr^{-1} respectively, with the maximum age (t_{max}) at 74.75 years. Total instantaneous mortality rate (Z), natural mortality rate (M) and fishing mortality rate (F) were 0.26 yr^{-1}, 0.16 yr^{-1} and 0.10 yr^{-1}. Exploitation rate (Ecurrent) and maximum exploitation rate (Emax) were estimated as 0.40 and 0.671 respectively. Growth overfishing existed in *P. typus* fishery, length at first maturity (L_{m50}= 56 cm) was higher than length at first capture (L_{c50}= 28.48 cm). The recruitment pattern was continuous with two major recruitment pulses. Visual Population Analysis results showed that mid- length 45 cm experienced the highest fishing mortality. The fishing regime of *P. typus* fell in the eumetric stage based on the quadrant rule. Maximum Sustainable Yield (MSY) was 6,621.54 tonnes. From the results growth overfishing was identified within *P. typus* fishery within Liberian waters dovetailed with absence of recruitment overfishing. *P. typus* was underexploited, requiring management interventions to increase exploitation sustainably.

Keywords: Liberia, *Pseudotolithus typus,* Growth, mortality, exploitation rate

1. Introduction

Pseudotolithus typus [1] is widely distributed along the coast of West Africa from Senegal to Angola [2]. Sciaenids constitute a large and varied family of fishes closely related to snappers but differing in that the spinous dorsal fin is short and the adipose tissue is much longer than the anal fin, which has only one or two spines [2]. *P. typus* has long head and body, a compressed body with the top of the head slightly concave, supra-lateral eyes and large mouth with lower jaw projecting [3, 4].

P. typus is among the top commercially fish species that is widely consumed locally by Liberian because of its flesh and abundances on the local market. Pseudotolithus species were among the highest landed catch in 2004 and with a decline in 2005 [5]. And also the total marine landed catch for Liberia was estimated at 1,570.82 tonnes in 2013 excluding artisanal catch and drop speedily to 204 tonnes in 2014. This drastic decline maybe alluded to poor data collection from the artisanal fisheries and limited human resources to cover even half of the 114 artisanal fish landing site [6, 7].

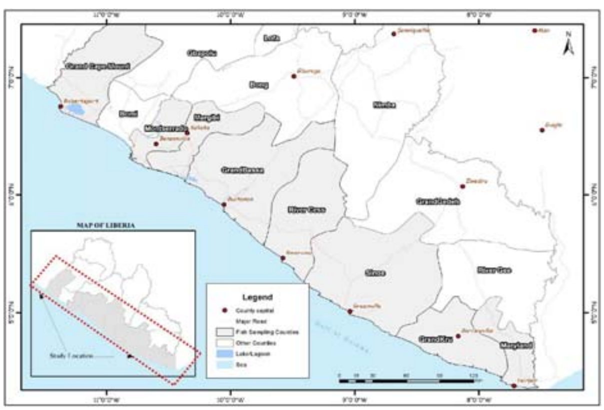
Hughes, S., *et al.* [8] reported that Liberia very vulnerable to a decline in fisheries due to its low adaptive capacity and the importance of fish from a food security perspective. Liberia annual per capita fish consumption is among the lowest in the region and has decreased over time due to damage to fisheries infrastructure during the civil war, over-exploitation of resources in some areas, and a shift from subsistence to trade-based fisheries.

Although fisheries contribute about 10% to the country’s Gross Domestic Product (GDP) in Liberia, and the sector provides full- or part-time employment for 37,000 people, its real potential is unknown [9, 10]. This research article seeks to provide information on the status of *P. typus* in the Liberia coastal waters for strategic management plans and sustainability.

2. Materials and Methods

2.1 Study area

Liberia is a relatively small coastal state located in West Africa with geographical coordinates as 6.4281O N, 9.4295 O W. The coastline of Liberia is 570 kilometers comprising of relatively warm waters and low nutrient contents [7]. However, the study focused on eight fish landing sampling stations within eight coastal counties along the coastline of Liberia (Figure 1). These fish landing sampling coastal counties include Maryland, River cess, Sinoe, Margibi, Montserrado, Grand cape Mount, Grand Kru and Grand Bassa. Selection of the eight fish landing sampling sites was based on the level of fishing activity and geographical location. The main source of livelihood for the majority of the inhabitants residing within the selected eight fish landing sampling stations is fishing and its related activities such as fish processing and fish trade. However, a few of the indigenes are engaged in alternative forms of livelihoods including farming, driving, and others.



2.2 Data collection

Fish samples were collected from artisanal fishermen who operated with multifilament gears from the selected fish landing stations by Fisheries Enumerators of the Bureau of National Fisheries (BNF). Fish sample collection was performed from April, 2013 to September, 2013 (six months). Morphometric measurements of the obtained fish samples including total length and weights were recorded on-site. The total length was measured using the 100 cm measuring board to the nearest 0.1cm, whereas the weight was measured using the electronic weighing scale to the nearest 0.01g. Fish samples were identified to the species level using fish identification keys by [11]. In all, a total of 1,822 specimens of *P. typus* were analysed.

2.3.1 Growth parameters

Growth parameters including growth rate (K), asymptotic length (L∞) and the growth performance index (ϕ) were obtained using the Von Bertanlaffy Growth Function (VBGF) fitted in FISAT II. The Powell- Wetherall Plot fitted in FISAT II was applied in estimating the Z/K ratio for the treated fish species [12]. The growth of individual fishes on the average towards the asymptotic length based on instantaneous growth rate (K) and length at any time (t) was identified using the Von Bertanlaffy Growth Function (VBGF): Lt =L∞ (1-e-k (t-t0)) [13]. The theoretical age at birth (to) was estimated independently, using the equation: log10 (−to) = −0.3922 − 0.275 * log10L∞ − 1.038 * log10K [13]. The longevity of individuals (tmax) was estimated using the expression: tmax = 3/K + to [14]. The growth performance index was generated using the formula: (ϕ) =2logL∞ + log K [15].

2.3.2 Mortality parameters

The total instantaneous mortality rate (Z) was estimated using length converted catch curve method as implemented in FiSAT II. Natural mortality rate (M) was estimated using Pauly's empirical relationship using a mean surface temperature (T) of 25.5°C: log10M = - 0.0066 - 0.279 * log10L∞ + 0.6543 * log10K + 0.4634 * log10T [16], where M is the instantaneous natural mortality, L∞ is the asymptotic length, T is the mean surface temperature and K refers to the growth rate coefficient of the VBGF. Instantaneous fishing mortality (F) was estimated as F = Z – M [17], where Z = instantaneous total mortality rate, F = instantaneous fishing mortality rate and M = the instantaneous natural mortality rate. The exploitation level (E) was obtained by the relationship of Gulland [18]: E = F/Z [18]. The maximum fishing effort (Fmax) was estimated using the expression: Fmax = 0.67K/0.67–Lc [19], where Lc=L_{c50}/L∞. The precautionary limit reference point (Flimit) was computed as Flimit = (2/3) * M [20]. The precautionary target reference point (Fopt) was calculated as Fopt = 0.4*M [12].

2.3.3 Length at first maturity

The length at first maturity (L_{m50}) for the assessed species was estimated using the procedure by Hoggarth *et al.* [19] as Length at first maturity (L_{m50}) = 2/3 * (L∞). The input parameters for the model included asymptotic length only (L∞). The age at first maturity (t_{m50}) was calculated using the age at length equation by Goonetileke & Sivasubramania [21]: t_{m50} = - (1/K) Ln (1-L_{m50}/L∞) + to, where L_{m50} is the length at first maturity.

2.3.4 Probability of Capture

The probability of capture was estimated using the procedure outlined in the FISAT II tool [22]. By plotting the cumulative probability of capture against mid-length, a resultant curve was obtained, from which the length at first capture (L_{c50}) was taken as corresponding to the cumulative probability at 50%. Additionally, the lengths at which 25% and 75% of the stock is captured were taken as corresponding to the cumulative probability at 25% and 75% respectively. The age at first capture (t_{c50}) was estimated as t_{c50} = - (1/ K) Ln (1-L_{c50}/L∞) + to [17].

2.3.5 Recruitment pattern

The recruitment pattern was obtained following the procedure described in the FiSAT routine [22]. The length at first recruitment (L_{r50}) was estimated as the mid-length of the smallest length interval [23]. The age at first recruitment (t_{r50}) was estimated as t_{r50} = -(1/K) Ln (1-L_{r50}/L∞) + to [17].

2.3.6 Virtual Population Analysis (VPA)

The estimated length structured VPA was carried out using the FiSAT routine [22]. The values of the L∞, K, M, F, a (constant) and b (exponent) for the species were used as inputs. The t_0 value was approximated to be zero. The constants a and b (exponent) for the species were estimated from the length-weight relationship using the expression W= aL^b, where W is the body weight and Length is the corresponding standard length [12]. The length-based VPA was used to calculate the biomass (tons), the yield (tons), total and fishing mortality and exploitation ratios following the length convert curve procedure fitted in FiSAT II. The maximum sustainable yield (MSY) was calculated following the equation by Sparre and Venema [24]: MSY = 0.5 * (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. The annual yield (Y) was estimated using the expression: Y = ∑⟦W(L1, L2)* C(L1, L2)⟧, where W is weight and C is the catch.

2.3.7 Relative yield per recruit (Y/R) and relative biomass per recruit (B/R)

Relative yield per recruit (Y/R) and relative biomass per recruit (B/R) values as a function of E were determined from the estimated growth parameters and the probability of capture by length [25]. As a result, the maximum exploitation rate (Emax), which implies exploitation rate producing maximum yield, exploitation rate at which the stock is 10% of its virgin stock (E0.1) and E0.5 indicating exploitation rate under which the stock is reduced to half of its virgin biomass were computed using the Knife-edge option incorporated in the FiSAT II Tool.

2.4 Data Analysis

The length frequency data was pooled into groups with 1cm length interval. The resultant data was analyzed using the FiSAT II (FAO- ICLARM Stock Assessment Tools) software as explained in detailed by Gayanilo *et al.* [22]. The length at age graph was carried out using the Yield Software by Branch *et al*. [26].

3. Results

3.1 Growth parameters

Figure 2.1A presents the estimate of Z/K ratio to be 5.38 from the Powell-Wetherall plot implemented in FiSAT II. The length at age plot was used to verify the calculated maximum age (t_{max}) at 74.75 years (Figure 2.1B). Figure 2.3 shows the restructured length frequency with superimposed growth curves. Growth performance index (ø) was estimated as 2.451. The growth parameters of *P. typus* were calculated as L∞ = 84 cm SL and K = 0.04 yr $^{-1}$. The theoretical age at birth (t_o) was obtained at t_o = -0.276 yr $^{-1}$. Therefore, the growth curve for this species based on Von Bertalanffy Growth Function (VBGF) was established as Lt= 84 (1-$e^{-0.04(t-(-0.276)}$)).

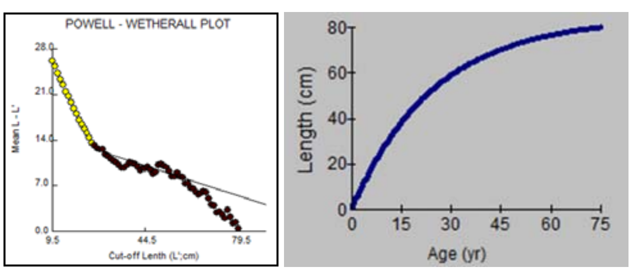


Fig 2.1: A) Powell-Wetherall plot for Z/K ratio; B) Length at age plot

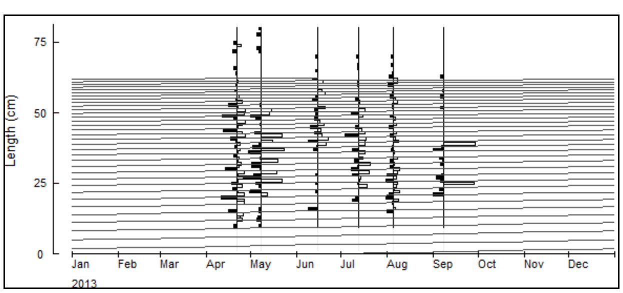


Fig 2.2: Reconstructed length frequency distribution superimposed with growth curve.

3.2 Mortality

Using the length converted curve executed in FiSAT II as shown in Figure 3, the instantaneous total mortality rate, natural mortality and fishing mortality were estimated as Z = 0.26 yr $^{-1}$, M = 0.16 yr $^{-1}$ and F = 0.10 yr $^{-1}$ respectively with the maximum exploitation rate obtained at Ecurrent = 0.40. The optimum fishing rate (F_{opt}), maximum fishing limit (F_{max}) and the precautionary fishing limit (F_{limit}) were 0.064 yr $^{-1}$, 0.081 yr $^{-1}$ and 0.107 yr $^{-1}$ respectively.

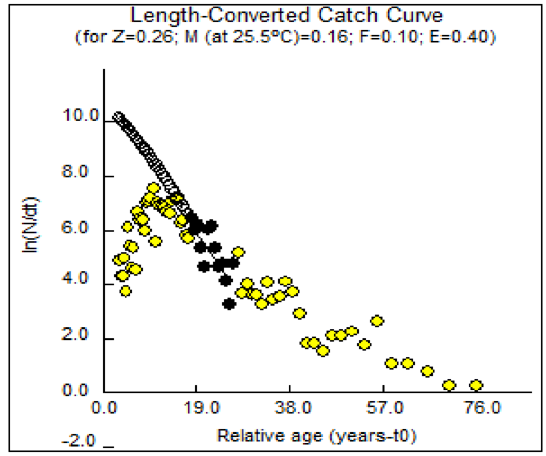


Fig 3: Linearized length-converted catch curve of *P. typus*

3.3 Probability of capture and Length at first maturity (Lm50)

The length at which 50% of the stock biomass is volunrable to capture was estimated at L_{c50}= 28.48 cm with the resultant age at first capture caculated at t_{c50}= 10.08 years. Correspondingly, the lengths at which 25% and 75% of the stock is captured were estimated as L_{c25}= 24.99 cm and L_{c75}= 31.96 cm (Figure 4). The length at maturity was estimated at L_{m50}= 56 cm and it corresponding age at maturity was calculated to be t_{m50}= 27.19 years.

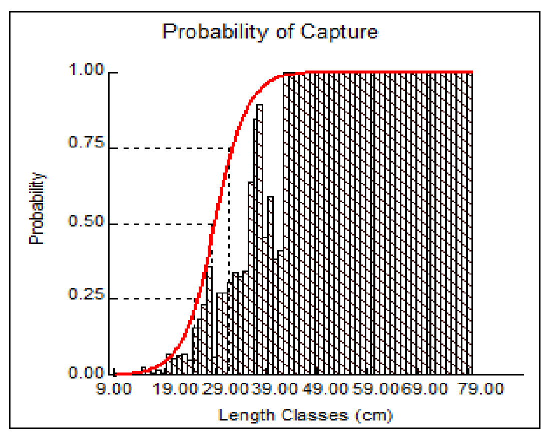


Fig 4: Probability of capture estimation from FiSAT Output

3.4 Recruitment pattern

Figure 5 presents the recruitment pattern from the FISAT II tool based on the size distribution of the catch, which outlined two recruitment peaks (major and minor). By macro inspection, the major recruitment peak occurred in March and April while the minor peak occurred in June and July. The length at first recruitment (L_{r50}) was estimated as 6.82 cm while the age at first recruitment (t_{r50}) was calculated as 1.84 years.

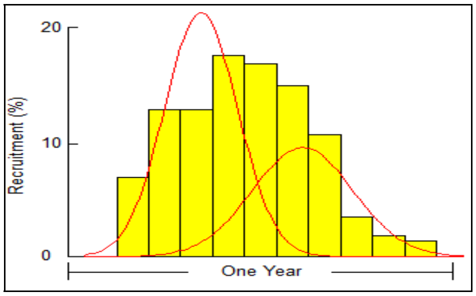


Fig 5: Recruitment pattern from FISAT output for *P. typus*.

3.5 Relative Yield per Recruit (Y'/R)

From Figure 6A, the Beverton and Holt relative yield per recruit model showed that the indices for sustainable yield were 0.342 for optimum sustainable yield ($E_{0.5}$), 0.671 for the maximum sustainable yield (E_{max}) and 0.57 for economic yield target ($E_{0.1}$). From Figure 8, the yield isopleth diagram placed the fishery of *P. typus* in quadrant B (Figure 6B).

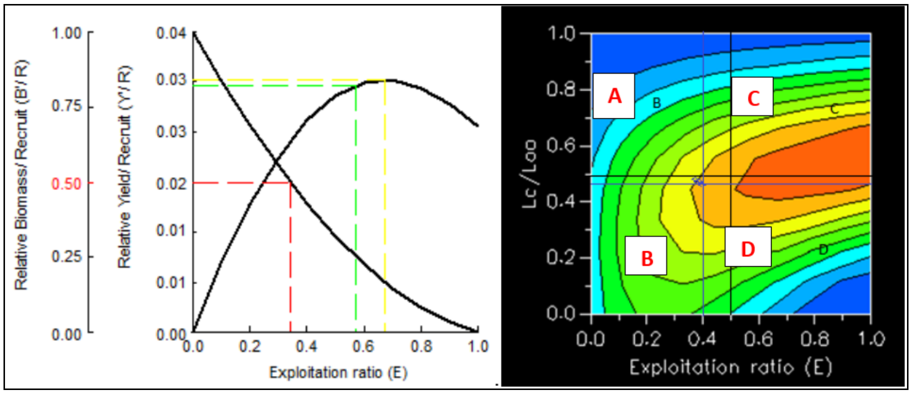


Fig 6: A) Beverton and Holt's relative yield per recruit and average biomass per recruit models from FISAT output and B) Yield isopleth.

3.6 Virtual population analysis (VPA)

Figure 7 presents the graphical portrayal of the VPA analysis with increasing fishing mortality (F) resulting in the decreasing populations of *P. typus*. VPA results revealed that majority of *P. typus* were harvested between 36 cm and 48 cm with values of fishing mortality (F) exceeding 0.157 yr^{-1} (Table 1). The highest peak of fishing mortality (F = 0.43 yr^{-1}) occurred from length 45 cm. The terminal fishing mortality (Ft) was 0.16 yr^{-1}. The maximum sustainable yield (MSY), yield and biomass were calculated to be 6,621.54 tonnes, 4,137.205 tonnes and 9,105.875 tonnes respectively (Table 2).

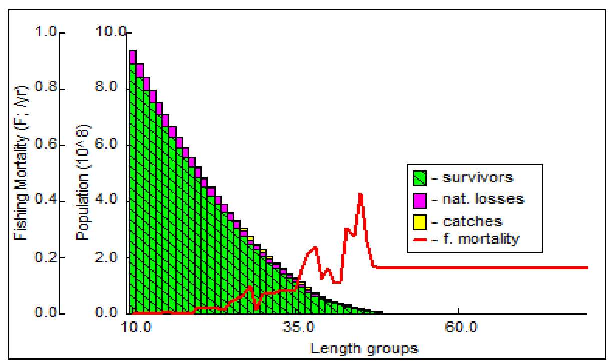


Fig 7: Population estimation using VPA from FiSAT output.

Table 1: Catches, population and steady-state biomass of *P. typus* from VPA out in FISAT II

Mid-Length	Catch (in numbers)	Population (N)	Fishing mortality (F)	Steady-state Biomass (tonnes)
10	800000	938614336	0.0026	30.93
11	0	888446016	0	39.49
12	600000	841073024	0.0021	49.16
13	700000	795036800	0.0026	59.87
14	200000	750803200	0.0008	71.6
15	2200000	708907904	0.0088	84.18
16	1100000	666842816	0.0046	97.54
17	500000	627679552	0.0022	111.75
18	1100000	590816960	0.0051	126.62
19	500000	555005696	0.0024	142.04
20	4300000	521395744	0.0219	157.38
21	3200000	485638496	0.0172	172.44
22	3600000	452662784	0.0204	187.55
23	3400000	420895296	0.0204	202.41
24	2300000	390890848	0.0146	217.26
25	6500000	363456416	0.0441	230.62
26	7200000	333349952	0.0524	241.42
27	8200000	304180864	0.0645	250.17
28	11400000	275651680	0.0981	255.25
29	1700000	245653536	0.0158	261.82

30	7100000	226782688	0.0713	268.91
31	6400000	203751632	0.0703	271.4
32	6500000	182779344	0.0783	272.14
33	6400000	162994352	0.085	270.63
34	5500000	144547840	0.0808	267.7
35	5200000	128152504	0.0846	263.61
36	8500000	113117072	0.1565	253.47
37	9900000	95926280	0.214	234.42
38	9200000	78622760	0.2395	210.8
39	4100000	63277068	0.1261	192.84
40	4600000	53976524	0.1642	179.3
41	2600000	44894836	0.1076	166.63
42	2400000	38427020	0.1137	156.41
43	5300000	32649716	0.3058	137.82
44	3700000	24576646	0.2751	114.58
45	4300000	18724698	0.4303	91.08
46	1900000	12825652	0.2575	71.83
47	1000000	9745057	0.1694	61.3
48	3900242	7800484	0.16	27238.6

Table 2: Yield and biomass estimate from Thompson & Bell yield stock prediction model.

f-factor	Yield	Biomass	Value
0	0	291.673	0
0.1	7.963	286.36	7.963
0.2	15.569	281.27	15.569
0.3	22.841	276.39	22.841
0.4	29.799	271.707	29.799
0.5	36.462	267.209	36.462
0.6	42.847	262.886	42.847
0.7	48.971	258.727	48.971
0.8	54.848	254.723	54.848
0.9	60.493	250.865	60.493
1	65.917	247.146	65.917
1.1	71.132	243.559	71.132
1.2	76.15	240.095	76.15
1.3	80.981	236.749	80.981
1.4	85.635	233.515	85.635
1.5	90.12	230.388	90.12
1.6	94.444	227.361	94.444
1.7	98.616	224.431	98.616
1.8	102.643	221.592	102.643
1.9	106.531	218.841	106.531
2	110.288	216.173	110.288
2.1	113.918	213.584	113.918
2.2	117.429	211.071	117.429
2.3	120.824	208.632	120.824
2.4	124.11	206.261	124.11
2.5	127.29	203.957	127.29
2.6	130.37	201.717	130.37
2.7	133.353	199.538	133.353
2.8	136.244	197.417	136.244
2.9	139.047	195.353	139.047
3	141.764	193.343	141.764
3.1	144.4	191.384	144.4
3.2	146.957	189.476	146.957
3.3	149.439	187.615	149.439
3.4	151.848	185.8	151.848
3.5	154.188	184.03	154.188
3.6	156.461	182.302	156.461
3.7	158.669	180.616	158.669
3.8	160.815	178.969	160.815
3.9	162.901	177.361	162.901
4	164.928	175.789	164.928
	4137.205	9105.875	

4. Discussion

The estimated growth parameters were lower than estimates by Sossoukpe *et al.* [27] and Sidibe [28] (Table 3). The differences observed with values from other researchers could be affixed to a number of factors including the largest fish size obtained, the pattern of the size distribution, period of sampling, the geographical location of fishing ground and certain environmental factors [29]. The estimated growth constant was lower than 0.34 yr^{-1}, showing that *P. typus* is a slowly growing organism. Further, the growth performance index was outside the range set for fishes with fast growth performance, indicating that *P. typus* is a slow growing organism. Studies by Sossoukpe *et al.* [27] within the coastal waters of Benin documented that *P. typus* is slow growing organism, attributing the slow growth performance to the chemical composition of the marine environment. The growth performance index estimated for the assessed fish species was relatively favourable with Sossoukpe *et al.* [27], which portrays that assessed fish species – *P. typus* are of the same family.

The length at first capture (Lc_{50}) was greater than estimates by Sossoukpe *et al.* [30] in Benin coastal waters (Table 5). The variation in figures could be due to the presence of relatively large size fish species and the mesh size of fishing gears deployed by fishermen within Liberia's coastal fishing industry. The critical length at capture revealed that the catch was made up of juveniles as well as reaching 33% of the asymptotic length before being captured [25]. The presence of juvenile fishes within the harvested catch could be as a result of the non-selectivity of gears used as well as the kind of fishing grounds exploited [27]. The length at first maturity (L_{m50}) was greater than values obtained by other researchers (Table 5). This shows the relatively stable fishing environment within Liberia which enables these fish species to mature faster than *P. typus* from other waters. The proportion of the asymptotic length at which *P. typus* attained maturity was found to be 0.66 twice of the estimated percentage for length at first capture (0.33). Therefore, it is obvious that *P. typus* within Liberian coastal waters becomes vulnerable to capture before spawning, a feature of growth overfishing [31]. Age wise, the estimated age at first maturity revealed that *P. typus* species within Liberia's water mature within the early part of their life. Further the estimated age at first capture also signified that *P. typus* becomes vulnerable to fishing gear once they enter into the stock 29 years after birth. The length at first recruitment (Lr_{50}) was found to be lower than the length at first capture, suggesting that juveniles get recruited into the stock before being captured with an estimated number of 44,871404 recruits surviving into stock [29]. Further, the recruitment pattern was characterised by two major peaks. The presence of all year-round recruitment observed in the current study maybe due to the abundance of the stock and favorable environmental conditions [31]. Further, continuous recruitment could be a reproductive strategy by *P. typus* to ensure non-extinction of its population [29]. The presence of the two peaks in recruitment validates the opinion by Pauly [12]; who opined that tropical fish species exhibit continuous recruitment with two major peaks. The strong presence of recruitment within the *P. typus* could be linked to the reduced number of large fish sizes [32].

The Z/K ratio was found to be greater than 1, suggesting that the population of *P. typus* is mortality dominated. Etim *et al.* [33] highlighted that when Z/K is equal to 2, then the mortality dominated stock is lightly exploited while a Z/K ratio greater than 2 is an indication of heavily exploited mortality-dominated stock. From the studies, the Z/K was highly greater than 2, depicting that the *P. typus* is a heavily exploited mortality-dominated stock. The estimated mortality rates were found to be lower than estimates from other scientific studies carried out within West African waters by Sossoukpe *at al.* [27] and Sidibe [28] possibly due to the sampling strategy, environmental conditions and the level of fishing pressure [27]. The estimated natural mortality was slightly higher than the fishing mortality, thus suggesting that *P. typus* is natural mortality dominated with vulnerability to natural mortality related situations [29]. Fishing mortality was relatively higher than the optimum and maximum fishing rate, revealing the presence of intense fishing pressure. However, the fishing mortality rate was lower than the biological reference point (F_{limit}), thus suggesting that the intense fishing pressure on *P. typus* is within the sustainable range. The estimated exploitation rate was relatively lower than estimates by Sossoukpe *et al.* [27] and Sidibe [28] (Table 4). Potential causes include the pressure of fishing effort, type of fishing grounds as well the abundance of the stock. Pauly [16] wrote that optimum categorization of exploitation rate for healthy fish stocks is taken as 0.5 with values lower or greater than E = 0.5 interpreted as underexploited or overexploited stock respectively. From the study, the estimated exploitation rate was less than 0.5, suggesting that *P. typus* is underexploited, hence fishing effort should be increased to ensure the full utilization of the stock. Further, the current exploitation rate (E) was highly lower than the maximum exploitation rate (E_{max}), which supports the earlier assertion that the *P. typus* is not heavily exploited.

Using the quadrant rule by Pauly& Soriano [25], the interplay of the critical length at capture and the current exploitation rate resulted in placing the population of *P. typus* in category B. Using the quadrant rule as an assessment tool, the fishery of *P. typus* was found to be at the developing or eumetric stage. This observation could be due to the low number of fishers engaged in *P. typus* fishery within the coastal fishing operations in Liberia. Meanwhile, this finding supports the earlier assertion that population of *P. typus* is underexploited. As an intervention for the eumetric state of fishing, Pauly & Soriano [25] suggested that 'nothing should be done, however mesh size should be increased as fishing efforts increases.

Table 3: Comparison of the estimated growth parameters with those from other coastal waters in West Africa

Authors	Country	TL∞	K	φ'	t_0
[28]	Guinea	73.8	0.35	3.280	-0.149
[27]	Benin (Site 1)	56.2	0.19	2.652	-0.73
[27]	Benin (site 2)	56.2	0.15	2.549	-0.92
Current study	Liberia	84 (SL∞)	0.04	2.451	-0.267

Table 4: Estimated mortality parameters compared to those off other regions.

Authors	Country	Z (yr^{-1})	M (yr^{-1})	F (yr^{-1})	E
[28]	Guinea	1.26	0.66	0.60	0.65
[27]	Benin (Site 1)	2.65	0.52	2.13	0.80
[27]	Benin (site 2)	1.60	0.45	1.15	0.72
Current study	Liberia	0.26	0.16	0.10	0.40

Table 5: Estimated length at first capture and length at first maturity compared to those off other regions.

TL_{m50} (cm)	TL_{c50} (cm)	Authors	Localities
56 (SL)	28.48(SL)	Current study	Liberia
30.1	22.76	[30]	Benin
40.0	-	[28]	Guinea
37.0	-	[34]	Guinea
26.5	-	[35]	Cameroon
33.0	-	[36]	Congo

Conclusion

P. typus within Liberian coastal exhibited a slowing growing performance with longevity of 75 years. Growth overfishing was identified within *P. typus* fishery within Liberian waters dovetailed with absence of recruitment overfishing. Exploitatively, *P. typus* was underexploited, requiring management interventions to increase exploitation sustainably. Liberian *P. typus* fishery was placed at the developing stage with mesh size and effort regulation as fishing effort increases.

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