International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 20, No. 1, p. 1-11, 2022

INNSPUB

RESEARCH PAPER OPEN ACCESS

Population dynamics of 15 fish species in Grand-Lahou lagoon (West Africa, Côte d'Ivoire)

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Key words: Population parameters, Fishes, Grand-Lahou lagoon, Côte d'Ivoire.

http://dx.doi.org/10.12692/ijb/20.1.1-11 Article published on January 04, 2022

Abstract

This study described growth, mortality, recruitment patterns and exploitation rates of 15 fish species in Grand-Lahou lagoon (Côte d'Ivoire). Monthly length-frequency data collected from artisanal fisheries from November 2013 to October 2014 were analyzed with FiSAT software using the ELEFAN package to estimate the population parameters of fishes. Asymptotic values for total length (L∞) ranged from 15.75 cm for *Synodontis schall* to 59.80 cm for *Trachinotus teraia*. Growth rate (k) varied from 0.19 for *Coptodon guineensis* to 0.98 for *Caranx hippos*. The growth performance index estimates were close to the values found by other authors for most of the fish species. The total mortality (Z) high values were recorded for *Synodontis schall* (Z= 4.15 year^{-1}; M = 2.50 year^{-1}) *Schilbe mandibularis* (Z= 2.19 year^{-1}; M=1.33 year^{-1}). Fishing mortality (F) and exploitation rate (E) were found to be less than the optimum levels of exploitation for most fish species. The exploitation rate (E) was higher than the maximum sustainable yield (Emax) for *Caranx hippos* and higher than E0.5 for *Eucinostomus melanopterus, Elops lacerta* and *Synodontis schall*. Recruitment was noted as year-round and bimodal for most studied populations. These results demonstrate that some fish stocks necessitate effective management measures particularly *C. hippos*, *E. melanopterus, E. lacerta* and *S. schall.*

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Introduction

Lagoons systems, together with coastal ecosystems, contribute to a large part of the ecological richness of the biosphere (Costanza *et al.*, 1997). However, they are sensitive to climatic and human impact (Dumay *et al.*, 2004). In West Africa, estuaries and lagoons are sites of an important fishing industry for mollusks, crustaceans and fishes (N'Goran, 1998). In Côte d'Ivoire, the estuarine and coastal environments are subject to heavy human pressure. However, throughout the country lagoon systems, Grand-Lahou lagoon seems to be one of the less stressed. Moreover, studies performed in the Ebrié lagoon (Côte d'Ivoire) showed that fishing pressure could induce important changes in the fish community (Albaret and Laë, 2003). In a fish population dynamics study, the most important task is to estimate population parameters such as growth, mortality rates and recruitment patterns of fish species or a group of fish species. Estimation of population parameters leads towards the prediction of the fish stock assessment from which a clear concept about the present status of specific fishing can be ascertained for management purposes. In Côte d'Ivoire, information available on fish species population parameters for lagoons and estuaries is scarce. Therefore, the study of the main fish population parameters of Grand-Lahou lagoon which support important fisheries activities and seem to be one of the less stressed lagoons in the country, is justified and aims to provide up-to-date information on population parameters of 15 fish species in this lagoon.

Materials and methods

Located between 5° 08'-5° 03'N and 4° 51'-5° 25'W, Grand-Lahou lagoon (Côte d'Ivoire, West Africa) is an elongated open coastal water body. A channel connects the lagoon to the Atlantic Ocean in the eastern part, whereas in the north, it receives freshwater discharged from three connecting rivers (Bandama, Boubo and Gô) (Laë, 1982). This aquatic system is a lagoon complex composed of four lagoons which are from east to west, Tagba (57 km2), Mackey (28 km2), Tadio (90 km2) and Niouzoumou (15 km2) (Laë, 1982). The study zones climate was characterized by four seasons. A long dry season from December to March, a long rainy season from April to July, a short dry season from August to September and a short rainy season from October to November (Durand and Skubich, 1982). For this study, three stations (Tadio, Agoudam and Passagri) were chosen. They constitute the main fish landing sectors of the lagoon (Laë, 1982; Diaby *et al.*, 2012) (Fig. 1).

Fishing activities in Grand-Lahou lagoon were operated by the indigenous inhabitants of the lagoon area. Several fishing gear types such as gillnets, cast nets, hooks, long lines were used. Commercial fishing was carried out predominantly by gillnets and cat nets. Monofilament gillnets of various mesh sizes ranging from 10 to 70 mm were used throughout the year.

Samples were collected from November 2013 to October 2014 during 3-4 days per month at the three stations in Grand-Lahou lagoon. Moreover, monthly fish samples were collected using a variety of fishing gears such as gillnets with mesh sizes from 10 to 60 mm knock to knock, cast nets with mesh sizes from 15 to 70 mm and hooks in the study area. All these methods were used throughout the year and targ*et al*l fish species indiscriminately. Fishermen were chosen at random and fishes in their catches were analyzed. Each specimen was identified to the species level using Paugy *et al.* (2003 a, b) manual. Then each individual collected was measured for its total length (TL) to the nearest 0.1 cm by using a fish measuring board from the tip of the snout (mouth closed) to the tip of the longest caudal fin. Fish specimens from three localities were grouped into length classes of 1 cm for most of the species. However, 2 cm length class was used for large species. The length-frequency distributions were analyzed using Fisat II (Gayanilo *et al.*, 2002). Monthly length-frequency distribution data were used to estimate the total asymptotic length (TL_∞ cm) and growth coefficient (k $year^{-1}$) of the Von Bertalanffy growth equation $Lt = L_\infty (1- e^{-k(t - t_0)})$, where Lt is the length at age t, L_∞ the asymptotic length, k the body growth coefficient and t_0 the hypothetical age at which a fish would have zero length. The ELEFAN I data are reconstructed to generate peaks and trough and the goodness of fit under (Rn) is defined by Rn = 10 ESP/ASP/10, where the ASP (available sum of peaks) is computed by adding the best values of the available peaks and ESP (Explained sum of peaks) is computed by summing all the peaks and troughs hit by a growth curve (Gayanilo and Pauly, 1997). Rn values range between 0 and 1. L∞ and k with the highest values of Rn were then considered as best estimates.

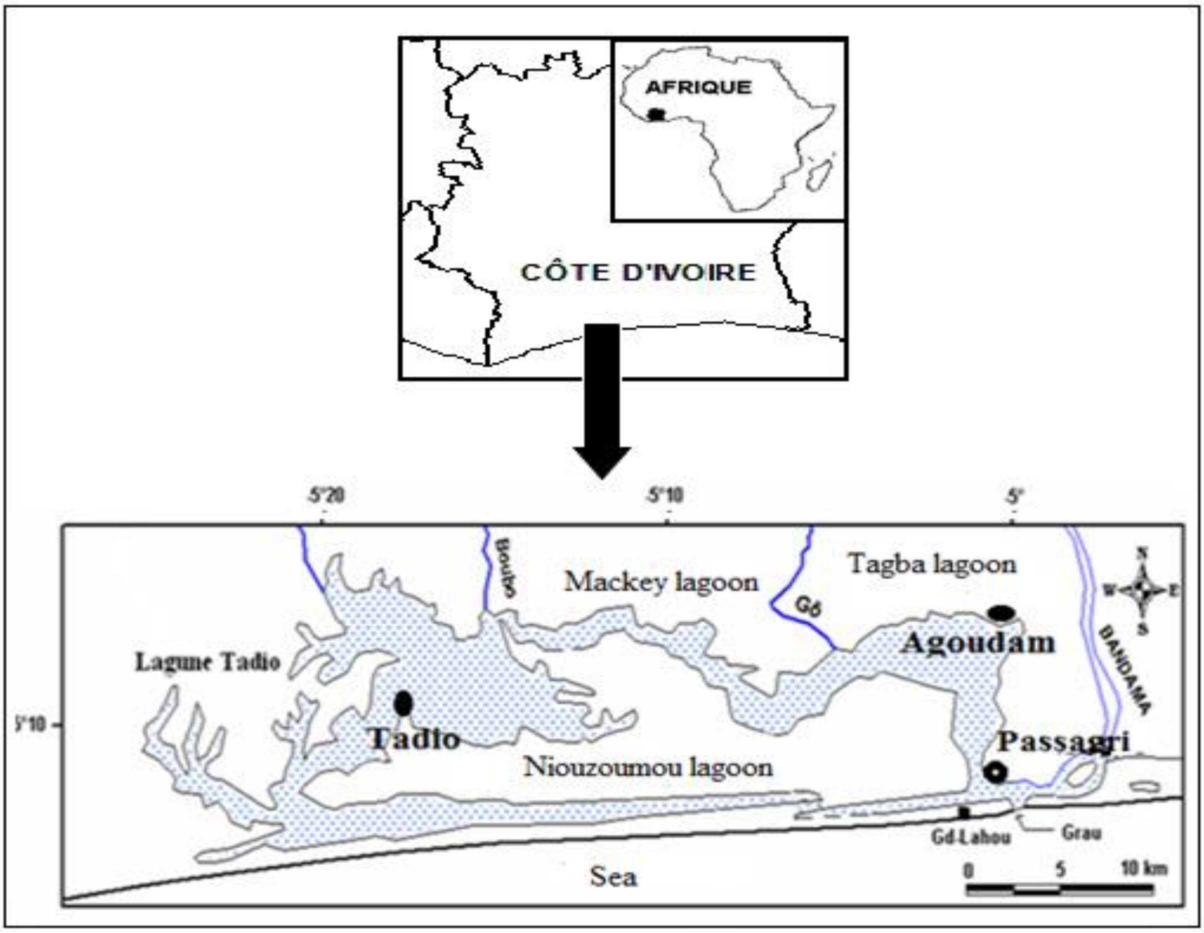

Fig. 1. Map of Grand-Lahou lagoon showing sampling stations (●).

The overall growth performance index (φ') was quantified using the model of Pauly and Munro (1984). The performance index is defined as:

$\varphi' = \log_{10} k + 2 \log_{10} L\infty$.

φ' serves to establish the potential growth of a fish strain under different environmental stress conditions of breeding (Mathews and Samuel 1990). φ' values obtained in the present study were compared with other previous estimates available in the literature.

The theoretical age at length zero (t_0) was obtained from Pauly's (1979) equation:

$\log_{10}(-t_0) = -0.3922 - 0.2752 \log_{10} L\infty - 1.0380 \log_{10} K$.

Total mortality (Z) was estimated using the length-converted catch curve method (Pauly, 1983). The Natural mortality (M) was estimated using the empirical formula of Pauly (1980): Log (M) = 0.0066 Log k + 0.279 Log L∞ + 0.4634 Log T; with T as mean environmental temperature (°C). In this study, T was 27°C. Upon the estimation of (Z) and (M), the fishing mortality (F) was calculated (F = Z-M). The exploitation rate E was computed as E = F/Z. The estimates of length-at-first-capture (Lc or L_{50}) were derived from probabilities of capture generated from the catch curve analysis. The extrapolated points of the length-converted catch curve were used to approximate the probability of capture for each length group using the average running method to estimate the selection parameter L_{50} or Lc through linear interpolation. The recruitment patterns of the stocks were 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.

Input parameters included L∞ and K. Normal distribution of the recruitment pattern was determined by NORMSEP (Separation of the normally distributed components of size-frequency samples) (Pauly and caddy 1985) in FiSAT.

Relative yield per recruit (Y/R)' and relative biomass per recruit (B/R)' were estimated using Beverton and Holt's (1966) model as follows: (Y/R)' = E U M/K [1 – (3U/1 + m) + (3U2 /1 + 2m) - (U3 /1 + 3m)]

(B/R)' = (Y/R)'/F where (Y/R)' is the relative yield per recruit and (B/R)' is the relative biomass per recruit m = (1 - E)/ (M/K) = K/Z U = 1 - (Lc /L∞) Z, M, and F are the total, natural, and fishing mortality coefficients, respectively. E is the exploitation rate. K is the growth parameter.

The optimum exploitation rate which produces maximum yield was found from the yield-per-recruit and biomass-per-recruit model (E max). Also, the exploitation rate at which the marginal increase of Y′/R is 0.1 (E0.1), and that which reduces the biomass to 50% of its unexploited level (E0.5) was estimated.

Results

Growth parameters

The estimated growth parameters (L∞, k, t_0), the longevity (t_{max}), the ELEFAN goodness of fit index (Rn) and the derived growth performance index (φ') are given in Table 1.

Table 1. Growth parameters of exploited fish population in Grand-Lahou lagoon and the mean of (φ') values from previous studies. The authors for the studies were obtained from the literature. TL ∞: asymptotic total length (cm); k: growth coefficient (year $^{-1}$); Rn: ELEFAN I goodness of fit index; φ': growth performance index.

	TL∞ (cm)	k (year^{-1})	t_0	tmax	Rn	(φ')	(φ') from previous studies
Sarotherodon melanotheron	17.85	0.33	-0.24	3.94	0.68	2.33	2.73 (Niyonkuru *et al.* 2003)
Pomadasys jubelini	26.26	0.64	-0.26	4.68	0.69	2.64	(Bodji *et al.* 2015)
Caranx hippos	18.90	0.98	-0.18	3.06	0.50	2.54	6.21 (Segbefia *et al.* 2013)
Eucinostomus melanopterus	23.10	0.31	-0.57	9.67	0.50	2.21	-
Coptodon guineensis	44.10	0.19	-0.12	15.2	0.35	2.56	2.58 (Niyonkuru *et al.* 2003)
Liza falcipinnis	44.10	0.28	-0.53	10.7	0.35	2.73	2.59 (Djadji, 2015)
Chrysichthys nigrodigitatus	36.75	0.90	-0.26	1.82	0.21	3.08	2.95 (Niyonkuru *et al.* 2003)
Chrysichthys maurus	47.25	0.28	-0.52	10.7	0.36	2.79	
Elops lacerta	37.80	0.72	-0.20	4.16	0.15	3.01	2.70 (Niyonkuru *et al.* 2003)
Mugil bananensis	44.10	0.29	-0.51	10.3	0.50	2.75	4.51 (Dankwa 2011)
Synodontis schall	15.75	1.30	-0.07	1.20	1	2.78	2.94 (Akombo *et al.* 2015)
Tylochromis jentinki	23.10	0.54	-0.32	5.55	0.31	2.45	2.62 (Kouadio *et al.* 2015)
Schilbe mandibularis	16.80	0.76	-0.24	3.94	0.68	2.33	2.59 (Tah *et al.* 2009)
M. cephalus	43.05	0.76	-0.18	3.79	0.50	3.16	3.37 (Murugan 2014)
Trachinotus teraia	59.80	0.58	-0.23	5.17	0.20	3.31	3.16 (Sylla *et al.* 2015)

The maximum estimate of asymptotic length L∞ was observed for *Trachinotus teraia* (59.80 cm) and the minimum within the Mochokidae for *Synodontis schall* (15.75 cm). On the whole, the studied species in the Grand-Lahou lagoon present high values of growth rates k with a mean value of more than 0.6 year^{-1}. The smallest values of k were recorded for *Coptodon guineensis* (k= 0.19 year^{-1}), *Chrysichthys maurus* (0.28 year^{-1}) and *Mugil bananensis* (0.29 year^{-1}). Four species, *Synodontis schall*, Caranx hippos, *Chrysichthys nigrodigitatus* and *Liza falcipinnis* presented the highest growth rates (k =

1.30, 0.98, 0.90 and 0.91 respectively). The Rn values obtained in the study ranged from 0.15 (*Elops lacerta*) to 1 (*Synodontis schall*. The maximum growth performance (φ') estimated from the growth parameters was 3.31 (*Trachinotus teraia*) and the minimum value was 2.21 for *Eucinostomus melanopterus*.

Instantaneous mortality and exploitation rates

Instantaneous mortality rates Z, M, F and the exploitation rate E are given in Table 2. Value of (Z) more than 3 was recorded with *Synodontis schall* (4.15 year^{-1}). For most populations, the (Z) values were lower than 3. For most species in Grand-Lahou lagoon, natural mortalities (M) were found to be higher than the fishing mortalities (F) except *Caranx hippos* (M= 1.04 year^{-1}; F= 1.90 year^{-1}), *Eucinostomus melanopterus* (M=0.88 year^{-1}; F= 2.01 year^{-1}) and *Trachinotus teraia* (M=0.53 year^{-1}; F= 1.13 year^{-1}). The exploitation rate E ranged from 0.08 to 0.65.

The highest value was recorded for two Carangidae species, notably *T. teraia* and *C. hippos*. The E values of three species, *T. teraia*, (E=0.65), *C. hippos* (E=0.65) and *E. melanopterus* (E= 0.70), were slightly higher than the assumed optimum value (Eopt = 0.5). These results concern the ranges of age exploited by fishermen in the lagoon (Table 2).

Table 2. Estimates of mortalities and related parameters derived from this study. N: total number of fish sampled; M: number of months sampled; Z: total mortality (year^{-1}); M: natural mortality (year^{-1}); F: fishing mortality (year^{-1}); E: exploitation rate; L50: size of fishes at 50% probabilities of capture (length at first capture).

	N/M	Z	M	F	Age range	E (F/Z)	L50 (cm)
Sarotherodon melanotheron	117/5	1.10	0.98	0.12	0.2-1.99	0.11	13.86
Pomadasys jubelini	159/6	1.71	1.36	0.36	1.5-1.9	0.20	17.62
Caranx hippos	197/7	2.94	1.04	1.9	0.5-5.3	0.65	8.8
Eucinostomus melanopterus	719/11	2.89	0.88	2.01	1.6-4.1	0.70	9.75
Coptodon guineensis	792/6	0.67	0.53	0.14	0.3-0.6	0.21	9.56
Liza falcipinnis	739/11	2.76	1.61	1.15	1.6-3.8	0.47	13.19
Chrysichthys nigrodigitatus	930/11	2.25	1.55	0.70	2-2.51	0.31	10.07
Chrysichthys maurus	205/7	0.76	0.67	0.09	0.5-0.7	0.11	11.21
Elops lacerta	1543/11	2.26	1.33	0.93	2-2.48	0.41	20.83
Mugil bananensis	180/7	0.76	0.70	0.06	0.4-1	0.08	18.09
Synodontis schall	238/4	4.15	2.50	1.65	1.6-6.6	0.40	9.25
Tylochromis jentinki	223/4	1.60	1.26	0.34	1.1-2.01	0.21	11.14
Schilbe mandibularis	329/4	2.19	1.73	0.47	1-3.3	0.21	10.66
M. cephalus	132/6	2.13	1.33	0.80	2.6-6.9	0.38	30.18
Trachinotus teraia	717/11	1.66	0.53	1.13	1.2-2	0.65	30.12

Length at first capture and recruitment patterns

The length at-first-capture or (Lc) (length at 50% capture) values estimated by backward extrapolation of the straight part of the right descending area of the catch curve are given in Table 2.

The highest values were recorded for *T. teraia* and *M. cephalus* (30.12 and 30.18, respectively). L50 less than 10 cm were recorded for four species *C. hippos* (8.8cm), *E. melanopterus* (9.75 cm) *C. guineensis* (9.56 cm) and *S. schall* (9.25 cm). The recruitment patterns (Fig. 2) showed two separate annual pulses (One major and the second minor) of recruitment for most of the studied species. The main recruitments occurred in the earlier part of the year, coinciding with the rainy season. Two populations (*M. Cephalus* and *T. jentinki*) presented only one annual pulse of recruitment.

Relative yield/biomass-per-recruit analysis and reference points

Fig. 3 shows the various exploitation rates based on the Beverton and Holt relative yield per recruit model. Emax which implies exploitation rate producing maximum yield (yellow dashes), E0.1 suggests exploitation rate at which the marginal increase of Y'/R is 10% of its virgin stock (green dashes) and E0.5 indicating exploitation rate under which the stock is reduced to half its virgin biomass (red dashes). The estimated exploitation rates E were higher than the maximum sustainable yield (Emax) for one specie *Caranx hippos*. The exploitation rates E were higher than E0.5 for *Eucinostomus melanopterus, Elops lacerta* and *Synodontis schall*. However the exploitation rate (E) of *Chrysichthys nigrodigitatus* was equal to the exploitation rate which reduces the biomass to 50% of its unexploited level (E0.5) (Table 3).

Table 3. Summary of estimated reference points E0.1, E0.5 and Emax of exploited fish population in Grand-Lahou lagoon N: total number of fish sampled; M: number of months sampled

	N/M	E	E0.1	E0.5	Emax
Sarotherodon melanotheron	117/5	0.11	1	0.43	1
Pomadasys jubelini	159/6	0.20	0.76	0.40	0.84
Caranx hippos	197/7	0.65	0.55	0.50	0.62
Eucinostomus melanopterus	719/11	0.53	1	0.42	1
Coptodon guineensis	792/6	0.21	0.40	0.30	0.47
Liza falcipinnis	739/11	0.02	0.45	0.32	0.53
Chrysichthys nigrodigitatus	930/11	0.31	0.41	0.31	0.50
Chrysichthys maurus	205/7	0.11	0.41	0.30	0.48
Elops lacerta	1543/11	0.41	0.61	0.37	0.71
Mugil bananensis	180/7	0.08	0.51	0.34	0.59
Synodontis schall	238/4	0.40	0.66	0.38	0.74
Tylochromis jentinki	223/4	0.21	0.56	0.36	0.64
Schilbe mandibularis	329/4	0.21	0.72	0.40	0.80
M. cephalus	132/6	0.38	0.82	0.42	0.91
Trachinotus teraia	717/11	0.12	1	0.44	1

Discussion

Comparing with the studies done previously, the asymptotic length (L∞) and curvature parameter (k) were found to be different in most studies. Rudnick *et al.* (1999) reported L∞ of 124 cm for *C. hippos* as compared to the 18.9 cm of the current study, whereas Segbefia *et al.* (2013) reported L∞ of 19.43 cm for this species, close to the result of the current study. The L∞ value (17.85 cm) obtained in the current study for *S. melanotheron* was lower than L∞ (27 cm) recorded in Lake Nokoué by Niyonkuru *et al.* (2003). The low asymptotic length value in the current study could be explained by the use of the Grand-Lahou lagoon as a nursery area by the fish species *S. melanotheron*. According to Sparre *et al.* (1989), growth parameters do not only differ from species to species but also among the different populations of the same species. Similar growth values of (φ') of the present study in comparison with those of other authors were obtained with *Coptodon guineensis* in Lake Nokoué (with φ'= 2.58) by Niyonkuru *et al.* (2003) and *Pomadasys jubelini* in ébrié lagoon (φ'= 2.78) by Bodji *et al.* (2015). For the other species, lower or higher values of φ' were reported. In the case of *T. teraia*, *Chrysichthys nigrodigitatus*, *Liza falcipinnis* and *Elops lacerta* φ'values recorded in the present work were higher than those reported for cited species in Ebrié lagoon (*Trachinotus teraia*: φ'= 3.16; *L. falcipinnis*: φ'= 2.59) and lake Nokoué (*C. nigrodigitatus*: φ'=2.95; *E. lacerta* φ'= 2.70). In comparison with the results of other authors, lowest values of φ' in the present study were obtained with *Sarotherodon melanotheron* (φ'= 2.33) low than φ' (2.73) recorded by Niyonkuru *et al.* (2003). Such values of φ' higher than our results were obtained with *Caranx hippos* (φ'=6.21) and *Mugil bananensis* (φ'= 4.51) in the Volta estuary of Ghana. In the study, φ'mean values estimates of most species such as *P. jubelini, C. nigrodigitatus, C. maurus, E. lacerta, M. Cephalus, T. teraia* fall within range estimated by Baijot *et al.* (1997). Moreover, species such as *S. melanotheron*, *C. hippos*, *E. melanopterus* and *Tylochromis jentinki* values estimates slightly fall below 2.65. These species are regarded as showing a slow growth performance index. The growth performance index of overall the 15 fish species in the current study appeared to be in line with estimates but also among different populations of the same species. This may explain the different values obtained for the same species by several authors.

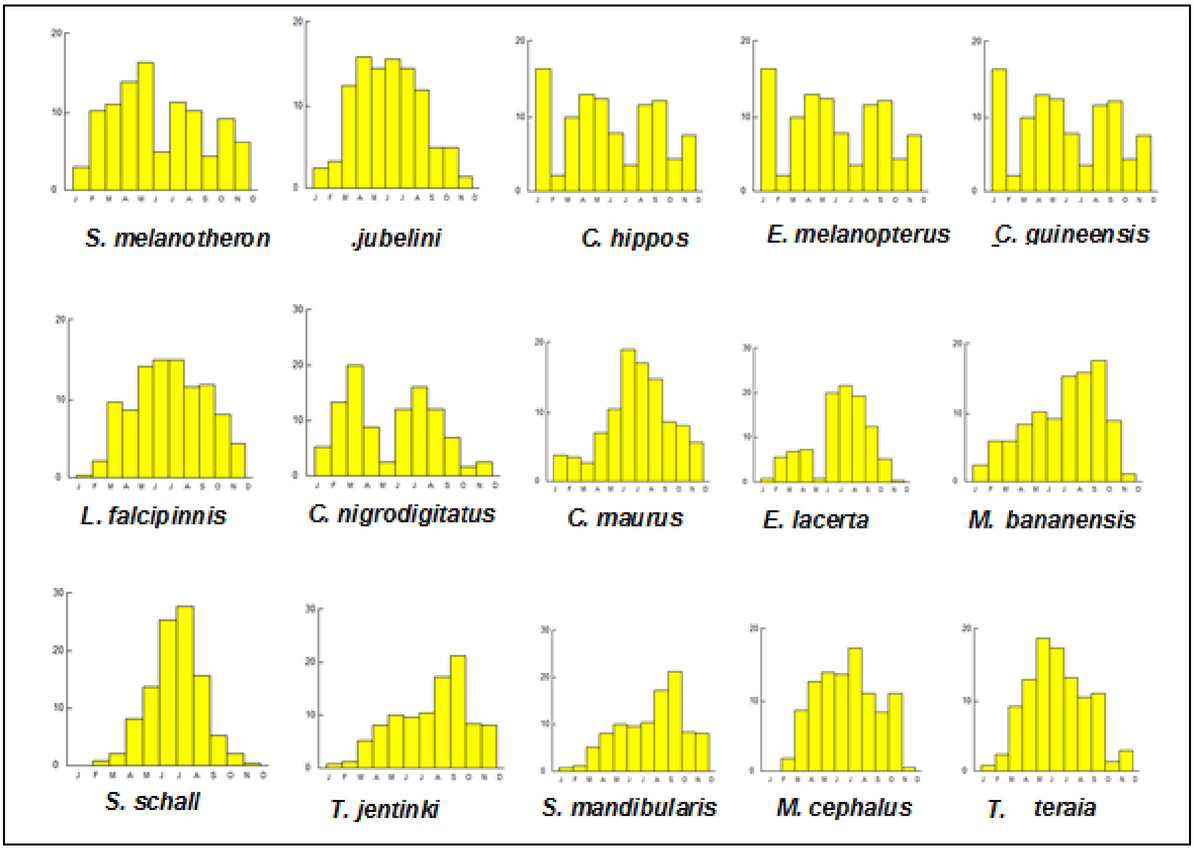

Fig. 2. Recruitment patterns Backwards projection along a trajectory defined by the von Bertalanffy growth function of the length frequency data.

The estimated longevity (tmax) ranged from 1.2 years for *Synodontis schall* to 15.2 years for *C. guineensis* indicating that *S. schall* is a short-lived species in the Grand-Lahou lagoon. The longevity value found in this study is not similar to others (Niyonkuru *et al.*, 2003). According to Cha *et al.* (2004), differences in longevity of species between areas are attributed to environmental factors. Bedsides' longevity of most the exploited fish species was more than 2.5 years indicating that those species were relatively old. For all except three species *Caranx hippos, Eucinostomus melanopterus* and *Trachinotus teraia* in Grand-Lahou lagoon, natural mortality (M) was higher than fishing mortality (F). A similar result was also observed by Villanueva (2004) in the Ebrié lagoon. These results suggest that the maximum level of exploitation has not been reached for most species in the Grand-Lahou lagoon, except *C. hippos* and *E. melanopterus* which appear to be fully exploited. The analysis of mortality rates allowed to show high value for small fish species, particularly *Synodontis schall*. According to Aripin and showers (2000), the level of exploitation is already high for virtually all of the small-sized species such as *S. schall*. In many cases, E values obtained in this study were under the expected optimal exploitation level Eopt = 0.5. According to Gulland (1971), a stock is optimally exploited when fishing mortality (F) equals natural mortality (M), or E = F/Z = 0.5. Thus Gulland (1971) suggested that a fish is optimally exploited at a level of fishing mortality that generates E = 0.5 indicating there is a reasonable exploitation rate recorded in Grand-Lahou lagoon. This result could be explained by the fact that seines were forbidden throughout the lagoon area. Recruitment has been described as a year-round phenomenon for tropical fish species (Qasim, 1973; Weber, 1976). The recruitment pattern of the exploited species was bimodal indicating probably two spawning periods for these species per year. The presence of two recruitments peaks (one major and one minor) from the study was in line with the description of the recruitment patterns for tropical fishes put forward by Pauly (1982). The presence of recruits throughout the year indicated that recruitment within the exploited species is continuous (Abowei *et al.*, 2010). Thus this observation suggests the absence of recruitment overfishing within the fishery of the exploited species.

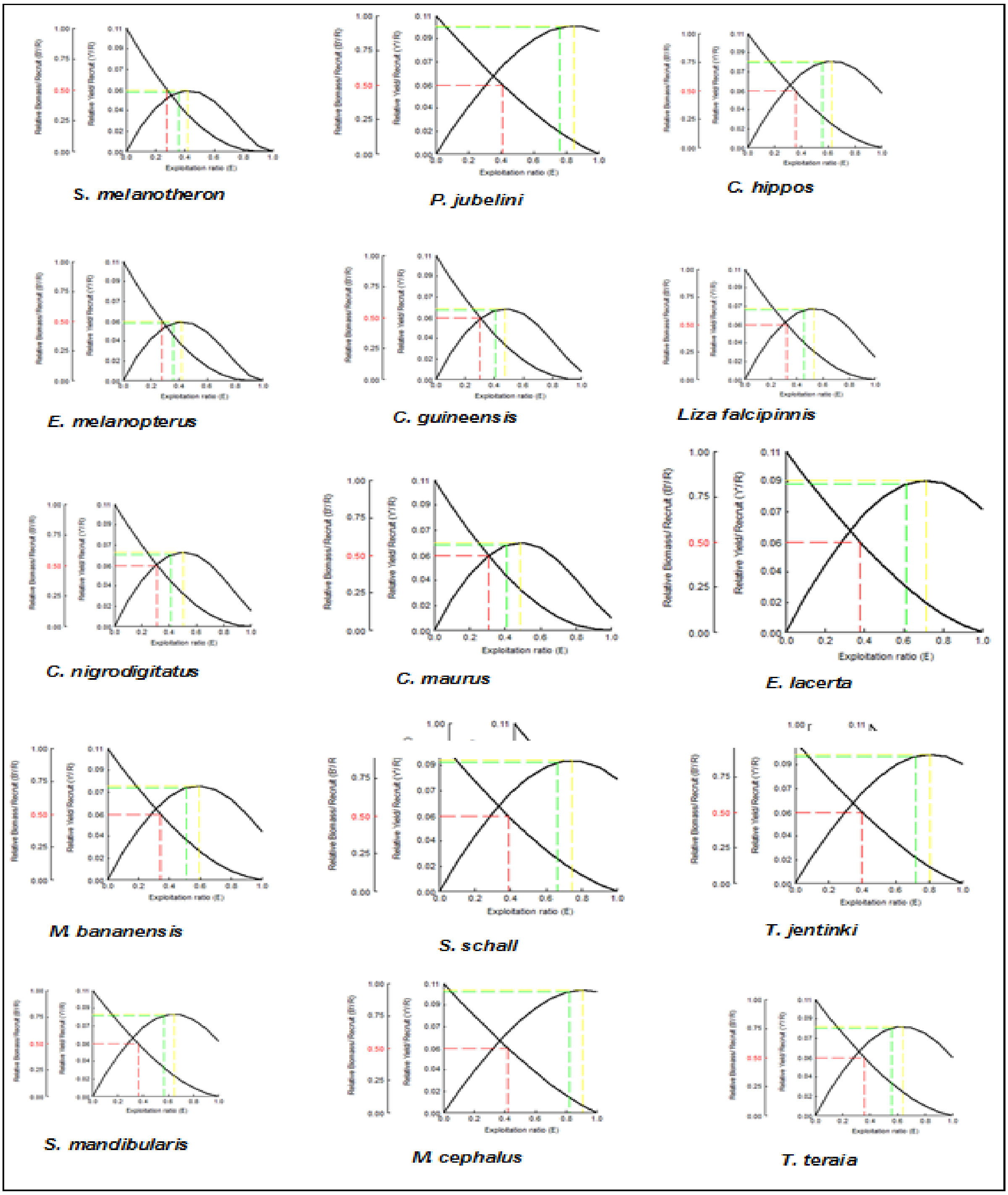

Fig. 3. Beverton and Holt's models, showing relative yield and average biomass per recruit for 15 exploited fish species in Grand-Lahou lagoon from November 2013 to October 2014.

The major peak of recruitment for most studied species was in the earlier part of the year, which coincides with the rainy season. This was reported by many authors who have investigated the spawning periods for tropical fish populations in Africa (Welcomme and De Merona, 1988). The length-at-first-capture (Lc) in the present study for *S. schall* was higher than the value (2.43 cm) recorded in the Ouémé River by Chikou (2006). However, the Lc value of the present study for the same species was less than (15 cm) recorded in pendjari River by Moncho (2011).

The length-at-first-capture serves as a biological index and vital parameter that indicates the health status of the resource and should be considered along with length at first maturity in the management of fisheries resource.

The ratio of length-at-first-capture (Lc) to asymptotic length (L∞) for four species *Chrysichthys nigrodigitatus*, *C. maurus*, *Coptodon guineensis* and *Liza falcipinnis* was closed to 0.3 indicating that (Lc) is quite low for these species. From the management point of view, this is not a healthy trend for the resource and it is important to call for a management strategy that will allow the escape of such sizes from the gear used in the resource exploitation.

Conclusion

In conclusion, this study of population parameters of the main fish populations in Grand-Lahou lagoon based on the samples collected from artisanal catches shows that the growth performance index values φ' were in the range of most previous studies. The analysis of mortality rates showed high values for some small fish species such as *Synodontis schall*. E-values obtained in this study were under the expected optimal exploitation level Eopt =0.5 except for two species, notably *E. melanopterus* (E= 0.53) and *C. hippos* (E= 0.65). Low values of length at first capture (Lc) were recorded for *Chrysichthys nigrodigitatus*, *C. maurus*, *Coptodon guineensis* and *Liza falcipinnis*. Most of the exploited species showed two peaks of recruitment.

Acknowledgements

The authors acknowledge Diplo Patrice, KOUAME Emmanuel and the fishermen of Tadio and Agoudam villages for their support during field sampling. We thank the journal reviewers for their relevant comments, which allowed us to improve this document. Also, sincere gratitude goes to Sizongui Arouna COULIBALY for his contribution.

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