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Stock assessment of the big-eye grunt (*Brachydeuterus auritus*, Val.) fishery in Ghanaian coastal waters

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Abstract

Annual fishery catch statistics and length data series for *Brachydeuterus auritus* (Val.) in coastal waters off Ghana for the periods 1974–1997 and 1990–1991 were used to model the growth, mortality rates, indices of abundance and exploitation patterns. Mean population parameters were $L_\infty = 23.1$ cm (fork length), $L_m = 13.7$ cm, $K = 0.73\ \text{yr}^{-1}$, $Z = 2.67\ \text{yr}^{-1}$, $M = 1.24\ \text{yr}^{-1}$ and $F = 1.43\ \text{yr}^{-1}$. Yield per recruit analysis showed that excessive fishing effort was being exerted on stocks and a very low length at first capture was observed. Corrective measures are recommended with emphasis on co-operation between fishermen and the government in the decision-making process.

Keywords: Big-eye grunt; Fishery management; Ghana; Stock assessment

1. Introduction

Catches of marine fish species in Ghanaian coastal waters have fluctuated widely over the past 20 years, averaging about 300 000 t (Koranteng et al., 1992; FAO, 2001). Sardinellas (*Sardinella aurita*, *Sardinella maderensis*) and chub mackerel (*Scomber japonicus*) are the most important small pelagic fish species, whilst sparids (*Pagellus bellottii* and *Sparus caeruleostictus*), and big-eye grunt (*Brachydeuterus auritus*) are the most important demersal fish species. However, landings of demersal species have declined from 70 000 t in 1990 to the present catch of around 50 000 t. This exceeds the estimated maximum sustainable yield (MSY) (24 000–42 000 t; Fisheries Department, unpublished data) for demersal fisheries resources and indicates the need for immediate management intervention.

The big-eye grunt, *B. auritus* (Val.), a member of the family Pomadysidae, is an extremely valuable component of the fishery, both in terms of abundance and quality, accounting for over 5% of the total marine fish catch. The species inhabits the coastal waters off the West African coast from Mauritania (260°N) to the south of Angola (17°S). Its distribution ranges between 10 and 100 m depth, but it is most commonly found in inshore waters between 30 and 80 m. Despite its importance to the Ghanaian marine fishery sector, understanding of its population dynamics is limited. Furthermore, feedback from local fishermen operating in the coastal waters indicates that size and relative abundance (catch per unit effort) of grunt have decreased in recent years, which suggests that the species is being heavily exploited. This study evaluates the status of the fishery and population dynamics

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of big-eye grunt in Ghanaian coastal waters as a basis for appropriate management polices.

2. Study area

The coastline of Ghana is about 550 km in length with a narrow continental shelf varying in width from a minimum of 20 km off Cape St. Paul to 100 km between Takoradi and Cape Coast (Bernacsek, 1986), and a total EEZ of 24 300 km^2 (Fig. 1). The sea bed is a mixture of soft (i.e. muddy to sandy mud), hard and rocky bottoms in the inshore areas at depths between 10 and 50 m (Buchanan, 1957). The shelf is traversed by a belt of dead madreporarian corals beginning at 75 m, beyond which the bottom falls off sharply suggesting that this marks the approximate transition between the continental shelf and the slope. Soft sediments predominate along the coastline and coral belt, whilst hard bottoms are largely and centrally located between Takoradi and Tema.

The coastal belt of Ghana is part of a central upwelling zone extending from Cape Palmas to about 2°E (Longhurst, 1962; Williams, 1968). This occurs as a result of the southern edge of the Guinean current, which flows along the coast in an eastward direction at the surface, encountering the westward flowing south equatorial current. From July to September each year, a major upwelling occurs on the continental shelf with a minor upwelling occurring in December–January. This period is characterized by low sea surface temperatures (<23 °C), high salinities (>35‰), and the upwelling of cold, nutrient-rich waters to replace the warm surface layers (Ofori-Adu, 1978).

3. Ghanaian coastal fishery

The Ghanaian coastal fishery is made up of artisanal and semi-industrial activities. The artisanal sector dominates, and accounts for over 70% of marine fish production annually (Mensah and Koranteng, 1988). This sector of the economy, with over 8000 canoes, of which approximately half are motorized by out-board engines, has over 100 000 fishermen. The main types of fishing gears used by the artisanal fishermen have different geographical distributions along the coast. The dominance of a particular type of gear in a particular area is influenced by the target species. For example, the beach seine is widely used in the Volta region, particularly around the mouth of the Volta river and other estuarine areas, to exploit mainly juvenile fishes on their nursery grounds. Purse seining is prominent in the Greater Accra and central regions

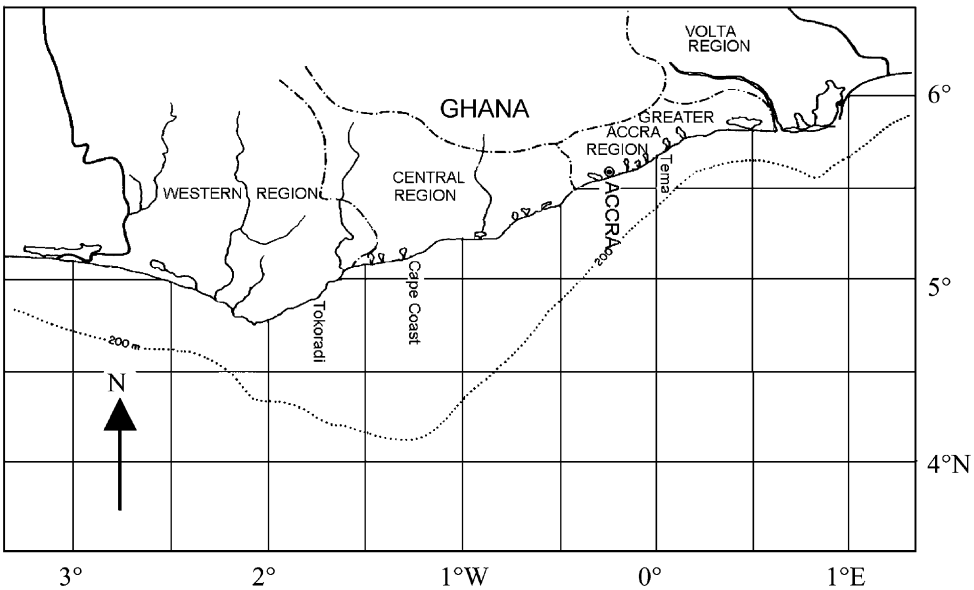

Fig. 1. Coastal map of Ghana showing the 200 m contour line.

where the small pelagics are heavily exploited, whilst drift gill nets and set-nets are predominant in the western and central regions.

The semi-industrial sector comprises approximately 350 medium to large-sized motorized, locally built, wooden vessels of between 8 and 30 m (Bernacsek, 1986). They are dual purpose vessels (purse seine/trawler) and are used for purse seining, mainly during the months of July–September coinciding with the upwelling period, and trawling for the remaining part of the year. Most purse seine nets measure 400–800 m long and 40–70 m deep, and have a knot to knot mesh size of approximately 25–40 mm, whilst bottom trawl gears have a mesh of 40 mm.

4. Materials and methods

Data on the big-eyed grunt were collected from fishery dependent and independent sources. Statistical data on the fishery (i.e. number of gears, fishermen, canoes) were obtained from canoe frame surveys (CFSs) and catch assessment surveys (CASs) conducted by the Marine Fisheries Research Division (MFRD) of the Fisheries Department.

Length (forked, cm) frequency data were collected monthly from stratified random samples taken during trawl surveys conducted by the Ghanaian Fisheries Department's research vessel, R/V Kakadiamaa during the period 1990–1991. A high opening Engel balloon 486 trawl gear with a codend mesh size of 25 mm was used to catch the fish. Individual lengths were grouped by months and raised to indicate the total catch in each month.

The von Bertalanffy (1934) growth model was used to fit growth curves to the length–frequency data. Growth parameters (L_∞ and K) were obtained using the ELEFAN program (Pauly, 1986) and Wetherall's (1986) method.

The growth performance index ($\phi = \log K + 2\log L_\infty$) of Pauly and Munro (1984) was calculated to allow comparison of growth parameters with published values. The modal progression analysis (MPA) (Bhattacharya, 1967) was used to separate length groups (modes) from normal distribution curves. Differences in mean lengths at the age obtained from the different models were tested using Tukey's multiple comparison test.

Natural mortality M was estimated from Pauly's (1979) empirical relationship. The total mortality rate Z was ascertained from length-converted catch curves (Sparre and Vennema, 1998). Under the assumption of constant rate of mortality, numbers surviving (N_t) will tend to decline exponentially with time or age (t) as shown by the exponential decay expression of $N_t/N_0 = \exp(-Zt)$, where N_0 is the initial number of individuals at time $t = 0$ and N_t the number surviving at time t with Z the total mortality coefficient (Beverton and Holt, 1957; Ricker, 1954). Total mortality, Z, was also estimated by the mean length method (Beverton and Holt, 1956).

Relative indices of abundance were determined from the length structured virtual population analysis (VPA) of the monthly experimental trawl data (Jones, 1984). Relative yield per recruit was estimated according to Beverton and Holt (1956). MSY was also computed from the catch and effort data (1974–1995) using the surplus production model (Schaefer, 1954) and Fox's model (1970).

The FiSAT (FAO-ICLARM Stock Assessment Tools) computerized package of programs (Ganyanilo et al., 1996) incorporating simple analytical tools on growth, mortality and selection parameters, was used to obtain most of the above estimates.

5. Results

Preliminary trawl surveys conducted by the MFRD of the Fisheries Department in Ghana showed the species formed schools, moving near the surface at night and at the bottom by day. Adults of this small demersal fish are mature at approximately 13.7 cm and make a seasonal migration towards the shore to spawn between February and June, with a peak in May. Spawning grounds are usually located between 10 and 30 m depth contour. Recruitment takes place during the upwelling season from June to October when the fish are approximately 4 cm in length, and the fish at this size become vulnerable to the fishing fleets. Following spawning, adults, which are omnivores, move to deeper waters, probably in search of food, feeding on juveniles of other fish such as anchovies, as well as amphipods, diatoms and other fragments of invertebrates (Barro, 1979).

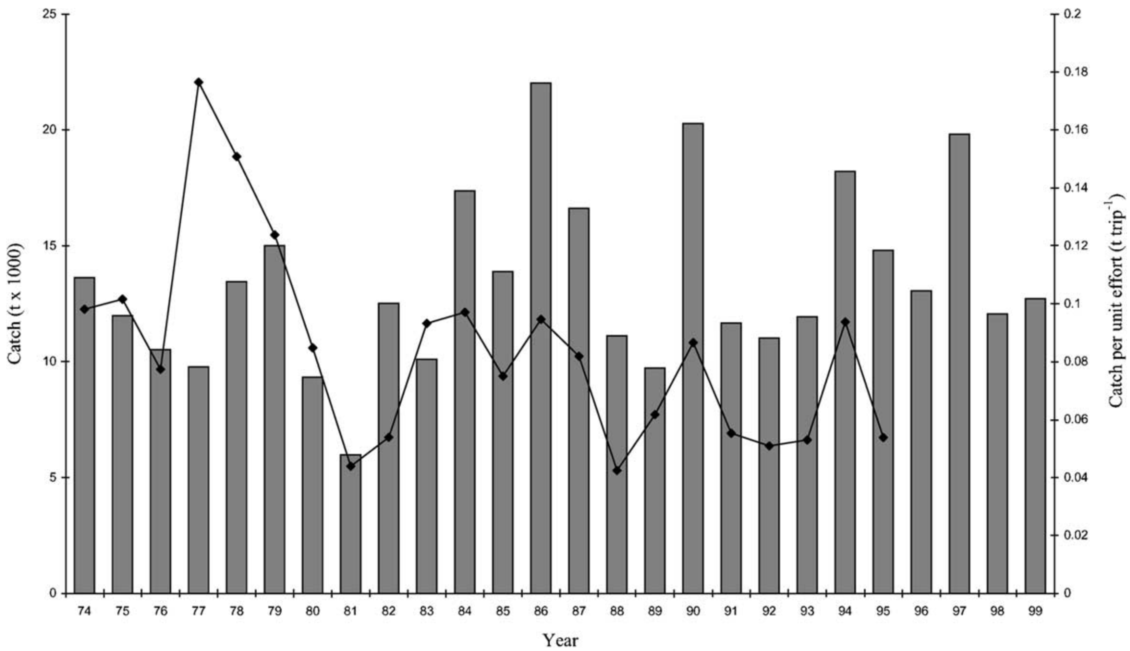

Fig. 2. Total catches of the big-eye grunt fishery and overall CPUE for the artisanal fishery for big-eye grunt (1974–1997) in Ghanaian coastal waters.

5.1. Catch effort statistics

Catches of big-eye grunt exhibit considerable annual variation (Fig. 2). The artisanal sector contributes about 87% of all landings of big-eye grunt followed by the inshore (8%) and distant water fleets (5%). There was a rise in catches in the late 1970s due to the influx of distant water vessels into the fishery prior to the establishment of a 200 nautical mile EEZ. Catches peaked at about 15 000 t in 1977. From the early 1980s, catches declined to a low around 5000 t, probably due to overfishing caused by increased effort, but again rose to approximately 20 000 t in 1986. Since 1990 catches have fluctuated between 11 000 and 20 000 t with peaks in 1990, 1994 and 1997.

Effort, measured as the number of fishing trips, increased from about 270 000 in 1974 to approximately 520 000 in 1975. From 1975, it fluctuated around a mean of 600 000 trips yr^{-1} until 1984, then it rose to above 900 000 trips. From 1989 to 1991, effort exerted in the fishery rose to a peak of over 1 000 000 trips, then dropped in 1992. Exceptionally high effort was also exerted in 1993 and 1995.

Catch per unit of effort (CPUE) (Fig. 2) decreased from approximately 100 kg trip^{-1} in 1974 to about 60 kg trip^{-1} in 1976. It then rose to approximately 180 kg trip^{-1} in 1977 and fell to a low of 40 kg trip^{-1} in 1981. Since 1982, it has oscillated between 50 and 90 kg trip^{-1}.

On a regional basis, the greatest catches were from the central region, except between 1981 and 1987, followed by the western region. Landings from the Greater Accra and Volta regions were comparatively lower except between 1983 and 1986 when exceptionally high catches were recorded.

Fish sampled during CASs between June and December 1995 were between 6 and 25 cm in length. The beach seines and purse seine nets caught a high proportion of immature fish, whilst the hook and line gears caught mainly mature fish (Fig. 3). By contrast, catches from the trawl gear exhibited a size range 6–24 cm, but with a mode between 12 and 15 cm, with majority of these fish being immature (Fig. 3).

5.2. Growth

Monthly length data samples (raised) were large and considered representative of the population (Fig. 4).

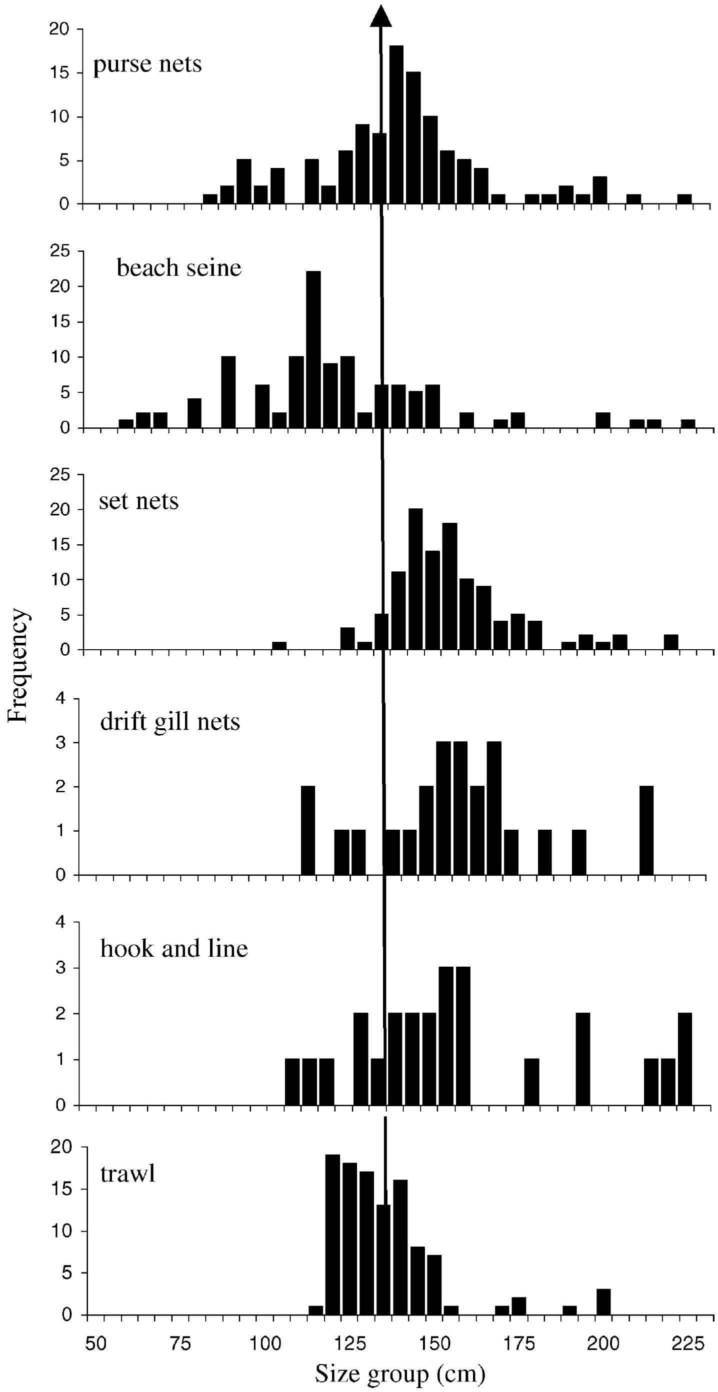

Fig. 3. Size composition of the big-eye grunt caught by the various artisanal gears.

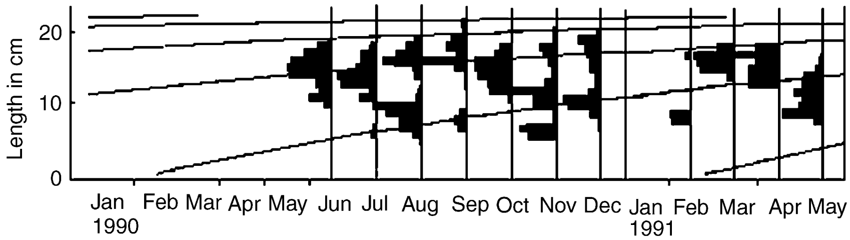

Fig. 4. Growth curves of *B. auritus* estimated by ELEFAN superimposed on length–frequency histograms.

No sample was obtained in January 1991 because the research vessel broke down. Few fish greater than 20 cm were caught. Growth of the fish was assumed to be isometric and length–frequency distribution histograms of the big-eye grunt superimposed with growth curves from ELEFAN showed a polymodal pattern (Fig. 4). Estimates of L_∞ and K obtained from ELEFAN were 23.1 cm and 0.73 yr^{-1}, respectively. Wetherall's (1986) method put the asymptotic length L_∞ at 23.2 cm with a Z/K of 3.82. The growth performance index ϕ estimated in this study (1990/1991) was 2.41, and compares favorably with the value of 2.58 in 1968 (Barro, 1968).

The length at first maturity (13.7 cm) (Barro, 1968) suggests that majority of the fish caught between October and February were immature, whilst the observed length of 4 cm at which fish recruit into the fishery appears rather low (Table 1).

The MPA output indicates four distinct modes or length/age groups were present (Table 2). The predicted lengths for age were estimated from this analysis and compared with the output from FiSAT and the von Bertalanffy's growth model with input parameters of L_∞ (23.1 cm), K (0.73) and t_0 (0) (Table 2). There was no significant difference at the 95% confidence level in mean lengths at age for the different growth models (Tukey's multiple comparison test, $P > 0.05$).

5.3. Mortality rates

The total instantaneous mortality (Z) from the length-converted catch curve was 2.67 (Fig. 5). Very small fish were excluded from the analysis because they were not fully recruited to the fishery. Furthermore, as the very old fish approach the asymptotic

Table 1
Probabilities of capture for big-eyed grunt in the experimental trawl with a 25 mm mesh codend

Mid-length (mm)	Probability
5	0.002
6	0.019
7	0.039
8	0.056
9	0.104
10	0.099
11	0.103
12	0.146
13	0.166
14	0.300
15	0.492
16	1.000
17	1.000
18	1.000
19	1.000
20	1.000
21	1.000
22	1.000

Table 2
Mean lengths (cm) at age computed by the various methods

Age group	Mean length (cm), MPA (Bhattacharya)	Predicted lengths, FiSAT	Mean length (cm), von Bertalanffy's growth equation
I	7.83	7.19	12.01
II	11.79	16.52	17.74
III	15.68	21.52	20.51
IV	18.56	23.19	21.28
V	–		22.41

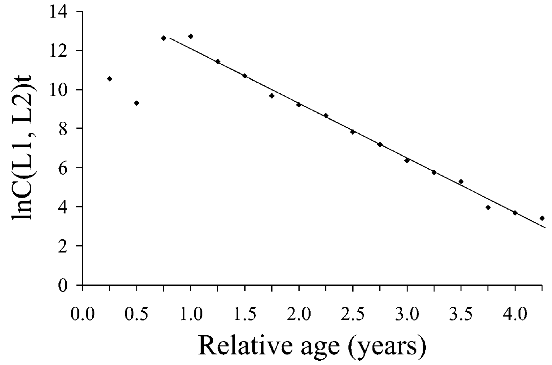

Fig. 5. Catch curve for the estimation of Z (total instantaneous mortality).

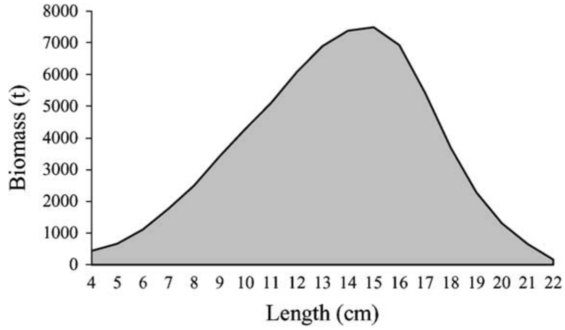

Fig. 7. Biomass estimates by size (length) for the *B. auritus*.

length (L_∞), their growth in length with time becomes uncertain, hence they were also excluded. Estimates of Z from the mean length for age yielded a value of 2.59.

Natural mortality (M) was estimated to be 1.24 based on a mean bottom temperature of 17 °C. Thus fishing mortality (F) was 1.43 yr^{-1}. The exploitation rate ($E = F/Z$) was 0.54.

5.4. Relative index of abundance

Biomass and population estimates from the VPA (Jones, 1984) computed by FiSAT program are shown in Figs. 6 and 7. The fishing mortality on sizes of fish ranging from approximately 16–19 cm (i.e. year 2 + classes) and 21–22 cm (i.e. year 4 + classes) was relatively high compared to other length (sizes) classes. In the absence of commercial fishing, the biomass reached a maximum at about 2 years of age and was estimated at 57 000 t.

5.5. MSY

The MSY computed using the surplus production model of Schaefer (1954) was approximately 12 000 t, with a corresponding level of fishing effort (F_{MSY}) of 860 000 trips. This compares with 15 000 t and 1 000 000 trips based on the Fox model. ANOVA indicated a significant difference in the estimates of MSY and F_{MSY} between the two models ($P < 0.05$).

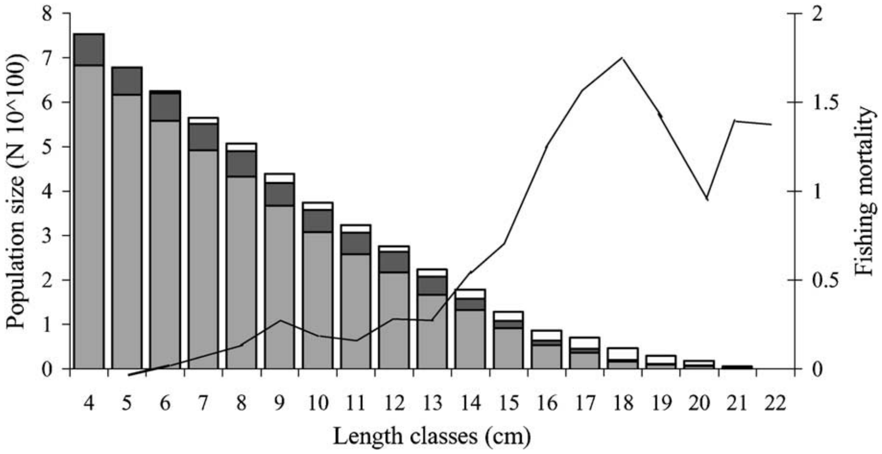

Fig. 6. VPA graph showing catches, survivors and fishing mortality for the various length classes.

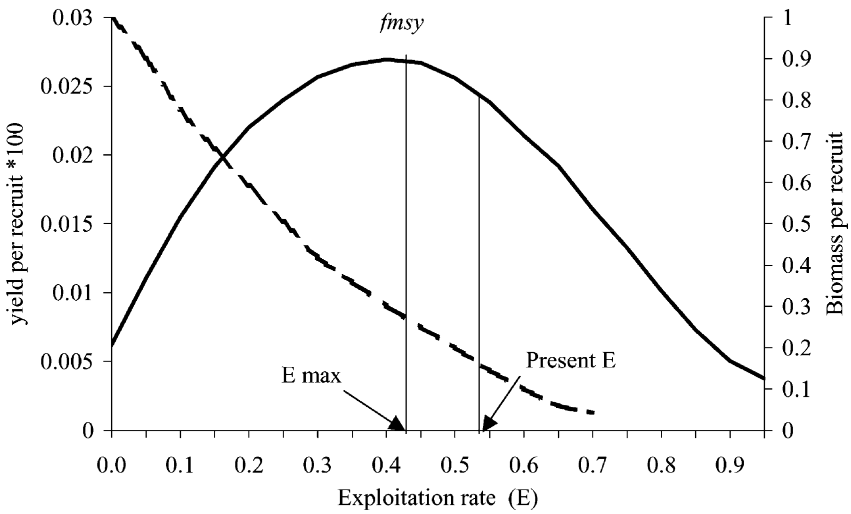

Fig. 8. Yield per recruit and biomass per recruit curves for *B. auritus* according to the exploitation rate and length at recruitment.

Based on the correlation coefficients of the linear regressions of effort vs. catch effort, the Schaefer model ($r = -0.966$) provided a better fit to the big-eye grunt data than the Fox model ($r = -0.897$).

5.6. Yield/biomass per recruit

The yield per recruit model of the big-eye grunt, with input parameters M/K (1.7) and L_c/L_∞ (0.17) (knife edge option), provided an indication of the yield from the fishery in relation to the potential MSY, given constant recruitment (Fig. 8). The Y/R value corresponds to the current rate of fishing mortality $= 1.43\ \text{yr}^{-1}$, the exploitation rate $E = 0.54$ and the length at first capture (4 cm) when fish are recruited into the fishery.

The yield in such conditions seems low and increased overfishing must be occurring, as fishing pressure exceeds the optimum E of 0.43, hence also F_{MSY}. This level of exploitation cannot sustain the resource for long. This output suggests that the fish are caught before they grow large enough to contribute to the stock biomass.

An increase in the first length at capture from 4 cm to about 7.5 cm (FiSAT output) by increasing meshes of the appropriate fishing gears, for instance, will lead, after reaching equilibrium, to an increased yield per recruit, even under the same fishing effort and exploitation rate. This could prevent overfishing and should result in a yield very close to the maximum yield practicable. The biomass per recruit decreases as the exploitation rate increases and relative biomass is reduced to half its level (value) at E (0.25) (Fig. 8).

6. Discussion

6.1. Growth

In the present study, average growth followed the von Bertalanffy curve, and growth parameters were higher than those estimated by Barro (1968) for this species in the CECAF sub-region. In view of the increased pressure on demersals, especially on juveniles, in the region in recent times, it is likely that growth rates have increased over the past 2 decades. The higher growth constant (K) in this study suggests that the species attained the maximum length in the 1990s faster than in the mid-1960s (Barro, 1968).

The majority of fish caught in this study were between 4 and 18 cm in length with a maximum length at 22 cm, smaller than those caught by Barro (1968) and Wolfgang (1990), which were between 4 and 20 cm in length with an asymptotic length of 26 cm. It can thus be inferred that since the 1980s, the maximum size of fish has reduced with a shift towards smaller length groups. This may be due to a shift in the fishing patterns of local fishermen. The most intense fishing period for the artisanal fishermen is between July and September inclusive when the target is small pelagics (mostly sardinellas), but they also catch many small, immature big-eye grunts which are aggregated around the nursery grounds in the shallow waters. The adults are located in deeper water during this period. Following the end of the season, fishermen switch to the demersals, which are caught in substantial quantities for the rest of the year.

6.2. Mortality

Most marine species produce large numbers of small eggs and larvae, for which mortality rates are extremely high. Wootton (1990) suggested that a critical period in the early life history of fish occurs at a time when larvae have exhausted their yolk sac reserves, and their survival then depends on the availability of exogenous food. For the grunt, this critical period falls within the upwelling period when there is plenty of food for larvae, despite other factors contributing to high mortality rates. For example, the relatively small size of the grunt makes it subject to intense natural predation. However, the effects of competitive interactions (interspecific and intraspecific), diseases, and other density-dependent factors on the natural mortality rates of the grunt are unknown.

As individual fish reach a certain size (age of first capture), they become susceptible to fishing gear, thereby the instantaneous rate of fishing mortality (F) rises according to the fishing pressure on stocks. Fishing mortality ($F = 1.43$) appears to be high for the grunt population, and inappropriate to the life history strategy of the species. This high mortality arises from the intense fishing effort and small mesh size of the purse seines.

6.3. Stock abundance

Detailed knowledge on the stock/recruitment patterns and intra- and inter-annual variations in stocks levels are important when using predicted biomass levels with confidence for management purposes. Thus, when considering present catches and relatively low CPUE (Fig. 7), the estimated biomass of 57 000 t is vulnerable if no action is taken to reduce pressure on stocks.

Yield per recruit analysis of the big-eye grunt provided evidence that the stock is being overexploited. Although it has been suggested that the Beverton and Holt yield model is not suitable for managing a tropical multi-species fishery where complex interactions among species are largely unknown (Pauly, 1979), present indices of abundance indicate low yields and high exploitation. Similarly, length at first capture is small leading to low production. Excessive effort in the fishery from 1990 to 1995 (mostly from the artisanal fleet) has also contributed to the present low yield. The optimum exploitation rate, to prevent overexploitation (Fig. 8) is 0.43, hence a fishing mortality lower than the present level of 1.43 is required.

In the light of excessive fishing effort on the grunt, estimates of the MSY must be utilized despite the various criticisms of the model (e.g. Larkin, 1977), i.e. its uncertainties in fish community interactions, the problems of by-catches, as well as the susceptibility of stock assessment techniques (Kesteven, 1997). The MSY of about 12 000 t (Schaefer model) suggests that in the years 1984–1987, 1990–1991 and 1993 onwards, annual catches of the grunt were excessive, potentially leading to an unsteady state in the fishery. Thus, to maintain the potential yield at optimal levels for the sustainability of the fishery, appropriate management measures are needed.

A reduction in fishing effort in an artisanal or subsistence fishery, to reduce yields to sustainable levels, is difficult to implement due to various socio-economic implications. Before such a scheme can be implemented, if at all, basic and pertinent questions must be addressed, including:

- Who is going to be affected?
- How is it (reduction in effort) going to be achieved?
- What alternatives are there in place for displaced fishermen?
- Where do the extra fish to come from?

If such a decision to reduce excess fishing pressure on stocks is taken, a careful examination of the implications from a holistic point of view must be considered, especially where economic problems ‘plague’ a developing nation.

Virtually all fishermen in coastal fishing villages of Ghana have been complaining that catches are declining due to too many people fishing. Some of the landing beaches which had only a handful of canoes (i.e. 30–40 canoes) in the 1992 frame census, now have double that number. Old canoes have been planked increasing fishing capacity whilst fishermen are all targeting the same fishing grounds. Like all natural resources, coastal artisanal fisheries suffer from the explosion of the human population and the need to meet growing demand. Reduction in fishing effort may, therefore, be difficult to implement, and can probably only be considered if management of the fishery is devolved to the local communities (Jentoft, 1989). Thus, it is recommended that co-management initiatives are implemented to support the sustainable development of the resources. Such an institutional arrangement has proved successful for management of coastal fisheries in, e.g. Fiji (Fong, 1994) and Japan (Kalland, 1996).

Alternatively, according to the yield per recruit model, for the same level of recruitment, an increase in length at first capture to 7.5 cm will lead to increased yields after attaining a new equilibrium. Thus, perhaps the better solution to the problem would be an increase in length at first capture of the grunt achieved through an increase in mesh size and possibly discarding juveniles that are still alive.

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