UNIVERSITY OF CAPE COAST

THE BIOLOGY AND POTENTIAL FOR CULTURE OF GREY MULLETS (PISCES: MUGILIDAE) IN GHANA

BY

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JUNE 2001

CANDIDATE'S DECLARATION

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this University or elsewhere.

Candidate:.. Date 29/6/01.................

(Hederick Roosevelt Dankwa)

SUPERVISORS' DECLARATION

We hereby declare that the preparation and presentation of this thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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DEDICATION

Dedicated to my wife, Boatemaa

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ABSTRACT

Aspects of the biology of grey mullets were studied between February 1997 and July 1998 in the Volta and Pra River estuaries in Ghana and their potential for culture in brackish and fresh water ponds was evaluated. Six species of grey mullets were identified during the study. These were: sickle fin mullet, *Liza falcipinnis* (Valenciennes, 1836), large-scaled mullet, *Liza grandisquamis* (Valenciennes, 1836), grooved mullet, *Liza dumerilii* (Steindachner, 1870) white mullet, *Mugil curema* Valenciennes (1836), banana mullet, *Mugil bananensis* (Pellegrin, 1928), and striped mullet, *Mugil cephalus* Linnaeus (1758). With the exception of *L. grandisquamis*, which was found only in the Pra estuary, all the other species were common to both estuaries. *M. curema* and *L. falcipinnis* were the most abundant species in the Volta and Pra estuaries respectively, while *M. cephalus* was the least abundant species in both places. Specimens of all the species from the Volta estuary were relatively larger than their counterparts in the Pra estuary. With the exception of *L. grandisquamis,* whose growth was isometric, the other species from both estuaries exhibited allometric growth. Monthly changes in gonadosomatic index, occurrence of mature and spent fish in samples as well as oocyte size distribution, suggest that the populations in both estuaries were multiple spawners; those from the Volta estuary spawned between February and August while those from the Pra estuary spawned between March and November. Males of all the species matured at a smaller size than the females in both estuaries but species in the Pra estuary matured at a much smaller size than their counterparts in the Volta estuary. Stomach contents of grey mullets in the two estuaries were quite similar consisting mainly of diatoms, detrital material and sand particles. Their diet did not show any substantial seasonality neither did it change with the size of fish. All the species showed a strong diurnal feeding habit, with the main feeding period occurring between 08.00 h and 12.00 h. Growth performance of fish that were given supplementary feed was better than those cultured under natural pond conditions; that of fish fed on wheat bran was also better than those fed on rice bran. The differences in growth of fish in both treatments were however, not statistically significant. Food conversion ratios between 3.6 and 7.7 and survival rates ranging from 43.4 to 68.8 % were recorded during the culture trial. Within a 270-day culture period, fish production of 336.5 kg ha^{-1} and 287.0 kg ha^{-1} were achieved in ponds with and without feed respectively. The mean final weight of *M. curema* was the highest among the species during the 270-day culture period. Results obtained in this study compare favourably with other published works and indicate a good potential for the culture of grey mullets in Ghana.

INTRODUCTION

Grey mullets are a group of fish belonging to the family Mugilidae, which comprises a relatively large number of closely related species (Stephens and Blaber, 1976). They are successful teleost fishes which make up an important and probably the most widely distributed commercial fishery in the coastal waters of tropical and subtropical regions of the world (Wijeyaratne and Costa, 1986; Koutrakis *et al.*, 1994). Grey mullets are a major source of subsistence protein requirements of the peoples of many countries, especially so for the Pacific Basin, Southeast Asia, India, the Mediterranean and Eastern European countries and in many parts of Central and South America (ICLARM Report, 1980).

Grey mullets tolerate a wide range of salinity, temperature and dissolved oxygen concentrations. These characteristics, together with their ability to grow to a large size, ready availability, acceptance of supplementary feed and the excellent texture and taste of their flesh make the group an excellent choice for culture (Bardach *et al.*, 1972). For a successful culture operation of any species however, a good understanding of the biology of the species is an important pre-requisite. However, a major set-back to successful culture of a number of marine species, including grey mullets has been the difficulty in developing suitable feed for early developmental stages (Shirota, 1970). Larval and juvenile food and feeding habits have therefore, been a major research area of most fishery scientists (Thomson, 1966; Odum, 1970; Zismann *et al.*, 1975; Chan and Chua, 1979; Ferrari and Chieregato, 1981). In all these studies, the importance of zooplankton, especially copepods, in the diet of larval and juvenile mullets was emphasised. According to Zismann *et al.* (1975), Blaber and Whitfield (1977), Chan and Chua (1979), De Silva (1980), Marais (1980), Ferrari and Chieregato (1981) and Blaber (1987), as mullets grow, their feeding habits gradually change from a planktonic filter feeding habit to primarily, benthic grazing. They consume a mixed diet consisting of algae, vegetable detritus, sand, silt, zoobenthos and zooplankton organisms.

Food and feeding habits of grey mullets have also been the subject for studies by fishery scientists from West Africa. From the Elmina lagoon in Ghana, Blay (1995a) reported a similar diet for juveniles of four mullet species comprising mainly bacteria, diatoms, blue-green/green algae, protozoans, detritus and particulate organic matter. Blay (1995a,b) also reported that juvenile grey mullets from the Elmina lagoon as well as *L. falcipinnis* in the Cape Coast lagoon showed a strong diurnal feeding habit.

Six species of mullets in the Lagos lagoon in Nigeria were found to feed mainly on organic detritus, diatoms and green algae (Fagade and Olaniyan, 1973). According to King (1988), fine particulate organic matter, mud and diatoms were the most important food items of *Liza grandisquamis* in the Bonny River (Niger Delta). *Mugil cephalus* in the Kulama Creek (Niger Delta) was reported to feed primarily on algae and detritus and did not show any substantial seasonality in the diet (Ikomi, 1990) while on the Mauritanian coast, diatoms constituted the major food item (Bruhlet, 1975)

The diet of all the grey mullet species from the Johnson estuary in Sierra Leone (Payne, 1976) and the Ébrié lagoon in Côte d'Ivoire (Albaret and Legendre, 1985) was similar comprising mainly diatoms, organic detritus and materials associated with sand grains. Species in the Johnson estuary however, showed seasonal variations in the composition of their food.

Apart from food and feeding habits, studies have also been conducted on the relative abundance and distribution, reproduction, age and growth of grey mullets. From the West African coast, the relative abundance of grey mullets have been reported from Sierra Leone (Payne, 1976), Nigeria (Sivalingam, 1975; King, 1988 and Ikomi, 1990) and from Côte d'Ivoire (Alberet and Lengendere, 1985). In all these studies it was concluded that the various species of grey mullets have different temporal distribution patterns influenced, among other factors, by temperature and salinity gradients.

M. cephalus occurred throughout the year on the southern Texas coast (Moore, 1974) while the seasonal distribution of *M. curema* in the Gulf of Mexico was influenced by temperature and salinity (Aguirre, 1993). Studies on the temporal distribution, abundance and size composition of grey mullet populations in the Severn estuary and Bristol Channel was conducted by Claridge and Potter (1985) while Vieira (1991) studied the occurrence of juvenile mullets in a Brazilian estuary.

Not many studies have been conducted with respect to growth parameters of grey mullets. Koutrakis and Sinis (1994) reported on the growth parameters of three grey mullet species from two Northeastern Greek wetlands while Wijeyaratne and Costa (1987) determined the growth parameters of six species from the Negombo lagoon in Sri Lanka.

The reproductive biology of some mullet species especially, *Mugil cephalus*, has been studied by various workers (Thomson, 1966; Brulhet, 1975; Bok, 1979; Wijeyaratne and Costa, 1986; Aguirre, 1993; Render *et al.*, 1995). The species studied were found to have different spawning periods with most of them spawning during periods of low or declining water temperatures.

In Ghana, grey mullets are important in the lagoon, estuarine and inshore fisheries (Mensah, 1979). Fish provides more than 60% of the animal protein needed in Ghana (FSCBP, 1995). The bulk of this demand is provided by marine fisheries resources which are already being over exploited (Quaatey, 1994). Given the present rate of human population growth in Ghana (3.0%) and the cost involved in importing about 30% of local fish requirement, there is an urgent need to increase fish production to meet the increasing demand.

Fish culture has been identified world-wide as an important option for increasing fish production (Bardach *et al*., 1972). The impact of fish culture on the total fish output of Ghana is however, negligible. As at 1999, fish culture contributed just about 500 tonnes out of the national fish production of about 400,000 tonnes a year (Fishery Dept. unpubl. data). Efforts at increasing fish production in the country through fish culture have so far concentrated on freshwater environments even though the coastline of Ghana has numerous lagoons and estuaries most of which have the potential for brackish water fish culture (Pillay, 1962; Pauly, 1976). However, traditional fish culture known as 'acadja', a form of brush-park culture system, is practised on a small scale in some of the lagoons (Mensah, 1979).

The culture of mullets in brackish and fresh water ponds has been practised for many years in the Indo-Pacific region and Mediterranean countries (Bardach *et al*., 1972; ICLARM Report, 1980). A number of countries have increased the fisheries potential of their inland waters through large-scale mullet stocking (El-Zarka and Kamel, 1965; Bar-Ilan, 1975; Bok, 1984) and mullets now form an important component of the extensive fisheries in these waters.

Trials of intensive grey mullet culture aimed at determining conditions for optimising production are more recent, and the approaches differ from region to region because of traditional needs and practices (ICLARM Report, 1980). As techniques for the large-scale propagation of grey mullets have not been perfected (Nash and Kuo, 1975; Nash and Koningsberger, 1981), the culture of these species has relied, to a large extent, on the capture of wild fry for stocking (Bardach *et al.*, 1972; Chen, 1976; Ben-Yami, 1981). Different mullet species, *M. curema, M. cephalus, L. aurata, L. parvus,* and *L. tade,* have been cultured elsewhere (Yashouv, 1966, 1972; Chervinski, 1975, 1976; Alves de Araújo *et al.*, 1980; Pillai *et al.*, 1984 and Philips *et al.*, 1987).

In recent times, research and development efforts in the culture of grey mullets have focused on induced spawning and rearing of the larvae (Alvarez-Lajonchere *et al.*, 1988; Rajyalakshmi *et al.*, 1991; Kuo, 1995). Artificial spawning has, however, been fraught with problems such as fragility of the species during handling, difficulties in obtaining ripe females as well as developing suitable feed for early developmental stages. Early developmental stages depend on live zooplankton foods, which are difficult to provide (Tucker, 1998).

Mullet culture has not been seriously developed in West Africa. Bardach *et al.* (1972) reported that experiments in brackish water fish culture, which started in 1962 on the Island of Buguma in the Niger river delta (Nigeria), included among other fishes, *L. falcipinnis* and *L. grandisquamis*. Polyculture trials of mullet species were conducted in brackish water ponds in Lagos (Nigeria) by Sivalingam (1975). Albaret and Legendre (1985) reported that *L. falcipinnis* and *Mugil cephalus* showed the highest potential for aquaculture in Côte d'Ivoire and suggested polyculture in association with *Chrysichthys nigrodigitatus* using the 'acadja' (brush park) system. After identifying areas along the Mauritanian coast where culture could be undertaken, Brulhet (1975), recommended *M. cephalus ashenteensis* as the best species for culture.

From the foregoing, it is evident that information on the biology and culture of grey mullets in the West African sub-region is inadequate. In Ghana, the only known studies on mullets are those reported by Blay (1995 a,b) on their food and feeding habits in the Elmina and Cape Coast lagoons. The present study is therefore aimed at enhancing knowledge on the biology of the mullets and evaluating their potential for culture in brackish and fresh water systems in Ghana. It is apparent from the experiences of other countries referred to above that successful intensive and extensive culture of grey mullets in Ghana could enhance fish production in the country.

MATERIALS AND METHODS

Study areas

The study was conducted at the estuaries of River Pra and River Volta, both of which discharge into the Atlantic Ocean in the Gulf of Guinea. The two estuaries were chosen because of their location and the different ecological scenarios they offer (Fig. 1).

River Volta estuary

The River Volta estuary is located between latitudes 5° 30' and 6° N and longitudes 0° 30' and 1° 0' E and lies within a Coastal Savannah zone that has an annual rainfall of between 750 and 1,250 mm (Dickson and Benneh, 1977). The estuary is about 1,200 m wide at the mouth. Beyond the mouth of the estuary, the water body covers an extensive area with a number of islands most of which have human settlements.

Two townships, Ada Foah and Big Ada, are situated on the western bank of the estuary. The eastern bank is covered with *Cyperus articulatus* (mat reed), *Polygonum senegalense* (knotweed) and *Typha domingensis* (cattail), except in some few places where *Rhizophora* spp. (red mangroves) and *Avecinnia* sp. (white/olive mangroves) occur in small patches. Submerged aquatic vegetation, predominantly *Vallisneria aethiopica* (eelgrass) and *Ceratophyllum demersum* (coontail), are common in the estuary.

The major tributaries of the Volta River are the White Volta, the Black Volta, the Oti River and the Pru River. Together they drain an area of about 158,000 km^2 (WRRI Technical Report, 1978). Two dams have been built on the Volta river at Akosombo (to provide hydroelectric power) and further downstream at Kpong (to provide hydroelectric power, potable water and water for irrigation). These dams, to a large extent, influence the quality and quantity of water at the Volta River estuary. In addition to serving as a landing area for catches by local fishermen, the estuary is used for boating.

River Pra estuary

The River Pra estuary is located between latitudes 5° and 5° 3' N and longitudes 1° 30' and 2° W. The banks of the estuary are fringed by red mangroves. (*Rhizophora* spp.) up to about 10 km inland (Obodai *et al.*, 1996). The estuary is approximately 100 m wide at the point of entry into the sea. The major tributaries of the River Pra are the Rivers Birim and Offin; these three rivers together form a basin that drains an area of about 22,960 km^2 (CIFA Report, 1991). The basin lies in the Moist Evergreen Forest zone of Ghana, with an annual rainfall of between 1,500 and 1,750 mm (Dickson and Benneh, 1977). The two tributaries are subjected to impacts of mining activities within their basins.

Apart from the effects of mining activities on the Pra estuary and the effects of the two dams on the Volta estuary, the dry and rainy seasons also affect water quality and quantity in both estuaries to a large extent.

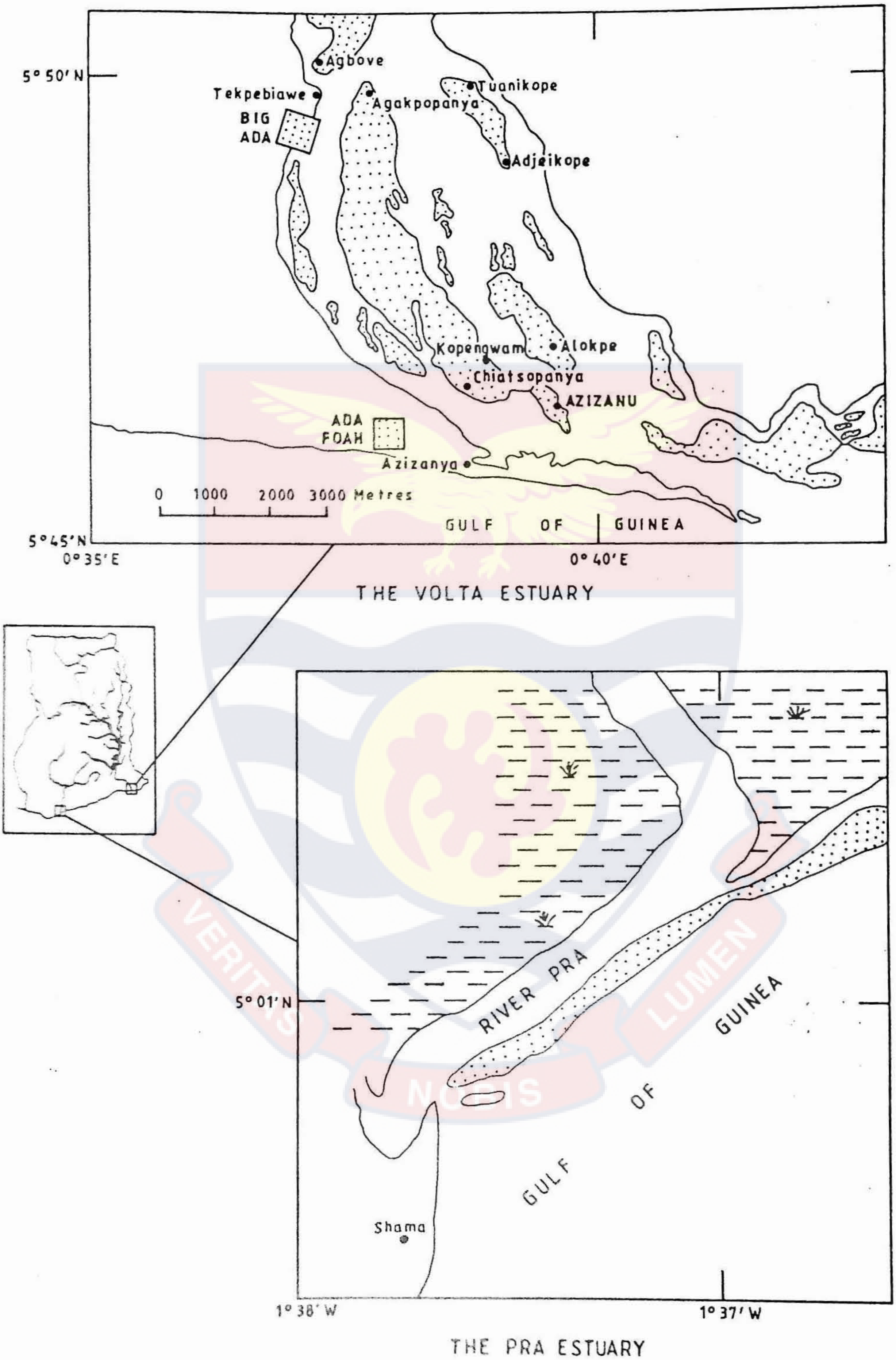

Fig.1 Map of Ghana showing the location of the Volta and Pra estuaries

Hydrographic factors

From February 1997 to July 1998 data on transparency, turbidity, salinity, dissolved oxygen, temperature and hydrogen ion concentration (pH) of the surface waters of the two estuaries were collected monthly to determine their influence on the occurrence, abundance and biology of grey mullets.

Transparency was measured with a 20-cm diameter Secchi disc, and surface water temperature with a hand-held mercury-in-glass thermometer; pH was measured with a portable pH-meter (EIL 7055) and turbidity by 2100P Turbidimeter. Dissolved oxygen was measured by a modification of the Winkler method (FAO, 1975) while salinity was estimated by first determining the chloride concentration by titration with silver nitrate solution using potassium dichromate end point. Salinity was estimated from the formula:

$$S‰ = 0.03 + 1.805 \text{ (g/l cl} \times 1.00045\text{)} \text{ (WHO, 1987)}$$

The relationship between the hydrographic factors and abundance of mullet species at the two estuaries was established using Spearman's rank order correlation analysis.

Fish sampling and identification

Grey mullets were sampled about the middle of each month from February 1997 in the River Volta estuary and March 1997 in the River Pra estuary for studies on their biology. Sampling lasted until July 1998 in both estuaries. The fish were caught with a cast net, a drag net and a battery of mono- and multi-filament gill nets in order to obtain a wide spectrum of sizes of mullet populations in the study area. Three monofilament nets were used each of which measured 50.0 x 2.0 m and consisted of mesh sizes of 50.0, 65.0 and 80.0 mm (stretched mesh). The multifilament nets consisted of eight mesh sizes of 12.5, 15.0, 17.5, 20.0, 22.5, 25.0, 30.0 and 40.0 mm (stretched mesh). Each mesh size was represented by two nets each measuring 25.0 x 2.0 m. The nets were set for one night each month in both estuaries. Samples of grey mullets were also bought from local fishermen to augment those caught from the experimental fishing since the net mesh sizes of local fishermen covered a wider range; they ranged from 15 mm to 115 mm (stretched mesh). This was to ensure that the samples reflected, as much as possible, the population structure of grey mullets in the estuaries.

Two 24-hour samplings were undertaken during the periods 11th - 12th November 1998 and 9th – 10th June 1999, in the Volta estuary to determine the daily feeding periodicity of the grey mullets. Sampling was done at four-hourly intervals with a seine net measuring 120 m long with 15 mm and 10 mm mesh sizes (stretched mesh) for the flanks and bag respectively. Two hauls were made at each sampling time, both of which lasted about 1 h 20 min.

Mullet samples were kept in 10% formalin and taken to the laboratory for further studies. Other samples were kept on ice. In the laboratory, the mullets were sorted out into the various species using the identification keys of Schneider (1990) and Lévêque *et al.* (1992).

Morphometric data

The total length (TL) and standard length (SL) of individuals of the different species of fish were measured to the nearest 1.0 mm and the weight determined to the nearest 0.1 g. Monthly length frequency data were compiled with distribution at 10 mm SL intervals.

Stomach content analysis

The stomach contents of each individual were weighed to the nearest 0.01 g and the total length of the intestine, measured to the nearest 1.0 mm.

Analysis of the stomach contents was carried out using the frequency of occurrence and the 'points' methods (Hynes, 1950). The points method gives the percentage composition or bulk contribution of each food item to the total food composition while the frequency of occurrence method expresses the number of individual stomachs in which each food item occurs as a percentage of all the stomachs examined.

The stomach contents of between five and ten stomachs of each species in each month were each preserved in 5% formalin. Points were awarded each stomach according to its degree of fullness using an arbitrary 4-point scale (20, 15, 10 and 5 points for full, ¾, ½ and ¼ filled stomach, respectively). Some distilled water was added to the sample in each container and shaken vigorously. Two sub-samples were taken and examined under the microscope to identify the items.

The total number of points allotted each stomach was subdivided among the stomach contents present according to their relative contribution to the total stomach content. The points gained by each item were summed up and expressed as a percentage of the total points gained by all the stomachs. The stomach contents were broadly grouped into polychaetes, zooplankton, diatoms, green algae, blue-green algae, detritus and sand particles. For the purpose of this study, protozoans, dinoflagellates and annelid larvae were grouped under zooplankton. Bacteria, nematodes, fish scales and red algae whose composition in the diet was less 1.0% were not included in the analysis. Benthic organisms were therefore made up of only polychaetes.

Using a calibrated eyepiece micrometer, random measurements were made on the longest axis of sand particles in a number of stomachs of all the grey mullet species to compare particle size preference among species and between sites.

The stomach Fullness Index (FI) was used as an indicator of feeding intensity to evaluate seasonal feeding activities as well as diel feeding periodicity of the various species. It was calculated using the equation:

$$FI = (\text{Weight of stomach contents} \times 100) / \text{Fish weight}$$

(Hureau, 1966).

Samples used for the calculation of FI were those captured between 8.00 h and 11.00 h since that was the most active period for feeding.

In order to determine the relationship among the different species, the degree of food niche overlap among the species and different size classes of a given species was calculated using the general (Gô) and the specific (Sô) overlap indices of Petraitis (1979) (quoted in Ludwig and Reynolds, 1988). Both indices were calculated using the computer programme, SPOVRLAP.BAS (Ludwig and Reynolds 1988). The index ranges between 0 and 1 and the closer it is to 1, the greater the overlap.

A cluster analysis was also performed to illustrate similarities among the species based on the frequency of stomach contents. This is an agglomerative type of analysis using group average sorting with the Euclidean measure of distance. The Euclidean linkage distance is simply the geometric distance between the various clusters that is denoted on the horizontal axis.

Calculation of Condition Factor

The Condition Factor (K) of the fish was calculated using the formula:

$$K = W \times 100 / L^3 \quad \text{(Tesch, 1971)}$$

where W = body weight in grams

L = standard length in centimetres

The mean monthly Condition Factor of each species was calculated and plotted to illustrate the fluctuations in the relative 'well-being' or 'fatness' of the species during the study period. Differences in Condition factor of the same species from the different estuaries were determined by Student's *t*-test.

Determination of growth parameters

The growth of all the mullet species from the two estuaries was assumed to conform to the von Bertalanffy growth function (VBGF) which has the basic form:

$$L_t = L_\infty [1 - \exp(-K(t - t_0))]$$

where L_t is the length at age t, $L\infty$ is the asymptotic length, K the growth constant and t_0 the theoretical age at length zero.

The ELEFAN I programme, as incorporated in the FISAT software (Gayanilo *et al.*, 1995), was used to fit growth curves to the restructured length frequency data. This was based on preliminary estimates of the asymptotic length ($L\infty$) obtained using the method of Wetherall (1986), which is also incorporated in the FISAT programme. The value of the growth constant (K) was obtained from the scanning routine in ELEFAN I. In this routine, values of K ranging from 0.1 to 10.0 were scanned in small steps, and the value of K that gave the best 'goodness of fit' was selected.

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

$$\text{Log}_{10}(-t_o) = -0.392 - 0.275\ \text{Log}_{10} L\infty - 1.038\ \text{Log}_{10} K$$

The growth performance index (ϕ') was computed from the equation (Pauly and Munro, 1984):

$$\phi' = \text{Log}_{10} K + 2\ \text{Log}_{10} L\infty$$

Reproductive activities

Each fish was dissected, sexed and the maturity stage determined by visual inspection of the gonads, and whether milt or roe was released upon stripping. A four–point scale was used for the classification of testes while ovaries were assigned on the basis of a five-point scale. Gonads of mature specimens were weighed to the nearest 0.01 g.

Calculation of gonadosomatic index (GSI)

To determine changes in reproductive activities of the mullet species, monthly mean gonadosomatic index was calculated for mature male and female fish. This index is given by Htun-Han (1978) as:

$$GSI = (GW \times 100) / (BW - GW)$$

where, GW = gonad weight in grams

BW = body weight in grams.

Histological preparation of gonads

Histological preparations of gonads of each maturity stage were made to elucidate the microscopic structure of the different gonadal stages. Portions of gonads were stored in 10% formalin and later dehydrated in graded alcohol, cleared in xylene and embedded in paraffin wax. Sections were cut at 5 μm and stained in iron haematoxylin and eosin.

Oocyte diameter measurements

In order to gain further insight into the spawning patterns of the species, oocyte diameters of the different ovarian stages were measured from histological preparations using a compound microscope fitted with a calibrated eye-piece micrometer. Only oocytes with nuclei were considered to ensure that the maximum diameter of the oocytes were measured. The frequency distribution of oocytes was used to determine spawning patterns.

Estimation of fecundity

Fecundity was estimated using the sub-sampling by weight method (Bagenal and Braum, 1971) because of the large number of eggs in the ovaries. Sub-samples of ripe ovaries were weighed after removing excess water on filter papers. Each sub-sample was preserved in Gilson's fluid in labelled sample bottles for one month to ensure that the eggs were hardened enough. Each bottle was vigorously agitated periodically to facilitate separation of the eggs from the ovarian tissues and enhance the hardening process (Bagenal and Braum, 1971). The contents of the bottles were poured into a petri dish and the oocytes separated from the ovarian tissue with a dissecting pin prior to counting. The absolute fecundity of each fish was estimated by multiplying the number of eggs in the sub-sample by the ratio of total ovary weight to the weight of sub-sample of ovary. Relative fecundity was calculated as the number of eggs per gram of fish body weight.

Culture trials in ponds

Preparation of ponds

Mullet culture trials were undertaken in four brackish water and fresh water earthen ponds. The freshwater ponds, each measuring 5.0 m x 10.0 m x 1.0 m were located at the Aquaculture Research and Development Center (ARDEC) of the Water Research Institute (WRI), Akosombo (approximately 160 km from the Volta estuary). The brackish water ponds were located about 400 m from the mouth, and on the eastern shore of the River Volta estuary. They measured 5.7 m x 14.0 m x 0.8m, 5.4 m x 14.0 m x 0.8 m, 5.4

m x 14.0 m x 0.8 m and 5.4 m x 11.5 m x 0.8 m (Plate 1). Different sizes of ponds were constructed because of limited space and uneven terrain. The ponds were fertilised with super phosphate at the rate of 10 g m^{-2} and limed at the rate of 100 g m^{-2}.

In addition to the earthen ponds, two concrete ponds (3.5 m x 7.0 m x 8.0 m each) (Plate 1) at the premises of WRI in Accra were used to evaluate the effect of rice bran and wheat bran feed on growth. Each concrete pond was divided into two compartments with a mosquito proof net, and a thin layer of sand spread at the bottom before filling with tap water. Brackish water condition, close to what prevailed in the Volta estuary, was simulated in the concrete ponds by dissolving commercial salt in the water. The ponds were allowed to stay for one week to allow for algal growth before stocking with fingerlings.

Collection of fingerlings

Fingerlings of grey mullet species were collected at the Volta River estuary with a drag net. The mesh size (stretched mesh) at the wings and pocket of the net were 15.0 and 10.0 mm respectively. With the bag of the net still in the water, a small hand net was used to collect the fish into water-filled containers before transferring them into hapas erected in ponds where they were kept overnight. The fingerlings could not be sorted out into the different species because of their small sizes. Mixed species were therefore stocked in all the ponds. It was however, ensured that sizes of fingerlings stocked were similar.

Plate 1

Top: Brackish water ponds at the Volta estuary
Bottom: A concrete pond used to evaluate effect of wheat bran and rice bran on growth of mullet species.

Transportation, acclimatisation of fingerlings and stocking of ponds

Fingerlings were transported from the estuary to Akosombo and Accra in plastic bags each having a volume of 0.55 m^3. Fifty fingerlings, each weighing 6.0 g on the average, were placed in a bag filled up to about 1/3 of its volume with water from the estuary. Oxygen was bubbled through the water and the bag closed; it was then put into a second bag of similar size and some water containing iced cubes poured in the space between the two bags to keep the temperature low. The bags were then packed in bigger and tougher nylon bags (Plate 2) and transported to the ponds at Akosombo and in Accra.

On arrival at the experimental site, the plastic bags containing the fish were placed in the ponds for 30 minutes for the fingerlings to acclimatise to conditions prevailing in the ponds. This was enhanced by slowly mixing the water in the bags with that from the ponds. They were then released gradually into the ponds. The ponds were flushed daily for a period of one week, until fresh water conditions prevailed. Fingerlings from the tanks at Akosombo were then stocked into the earthen freshwater ponds. The mullets were stocked at a rate of 2 fingerlings m^{-2}. Handling of fish was avoided as much as possible because of their fragility.

Plate 2

Top: Initial size of grey mullets used in stocking ponds.
Middle: Average size of grey mullet after 270 days of culture.
Bottom: Bagging procedure used in transporting live juvenile mullets.

Plate 2

Top: Initial size of grey mullets used in stocking ponds.
Middle: Average size of grey mullet after 270 days of culture.
Bottom: Bagging procedure used in transporting live juvenile mullets.

Management of ponds

Fish in two of the ponds at the Volta estuary, and at Akosombo were fed once a day in the morning between 9.30 h and 10.00 h at 5% body weight. The feed consisted of a mixture of peanut and rice bran, giving a protein level of 9%. Fish in the other two ponds were not fed but depended on the natural productivity of the ponds. In Accra, fish in one of the compartments were fed with rice bran containing 5% protein and those in the other compartment were fed with wheat bran containing 17% protein. The ponds were occasionally fertilised with super phosphate at the rate of 10 g m^{-2}.

Biweekly measurements of water temperature, salinity, dissolved oxygen, pH and transparency were made, usually between 10.0 and 11.0 h. Water samples were taken monthly from the ponds at Ada for algal counts. Algae were counted after sedimentation for 4 hours with an inverted microscope. The average number of cells per filament or colony was determined for 50 individuals and multiplied by the number of filaments and colonies counted to derive an estimate of the cell numbers (Lund *et al.*, 1958).

Growth measurements

A minimum of 50 fish from each pond at Akosombo and the Volta estuary, and 10 from the ponds in Accra, were sampled at 30-day intervals. The average weight recorded was used to monitor growth and to determine the specific growth rate (SGR) using the formula of Ricker (1975) (quoted in Watanabe *et al.*, 1990):

$$SGR = [100(\ln Wf - \ln Wi)] / t$$

where Wf = mean weight at the end of the period

Wi = mean weight at the beginning of the period

t = growth period in days.

The Mean daily weight gain (MDWG, g/day) was calculated from

$$MDWG = (Wf - Wi) / t$$

Differences in the growth performance of fish that received feed and those that did not received feed in the various ponds were evaluated using Analysis of Variance (ANOVA). ANOVA was also used to evaluate differences in growth performance of fish raised during the first and second experiments in brackish water ponds and in freshwater ponds for the first 150 days.

Feed conversion values were determined as the ratio of dry weight (g) of feed given to the fish to the weight gained (g) by the fish at the end of the experiment (Linder *et al.*, 1975)

Fish production in the ponds was calculated using the formula of Linder *et al.* (1975):

Production = Number of fish surviving x (Mean final weight – Mean initial Weight) / Surface area of pond

Survival rate of mullets in each pond was calculated as a percentage of the number of mullets surviving at the end of the experiment to the number of mullets initially stocked.

RESULTS

Fluctuations in hydrographic factors

Fluctuations in hydrographic factors at the two estuaries during the study period are indicated in Fig. 2. The data are based on measurements taken once every month.

Temperature

Temperature variation in the two estuaries showed a similar pattern and ranged from 25.0 to 30.5°C (Fig. 2a). Low temperatures were recorded from June to September and during the dry harmattan season from November to January while high temperatures were recorded from March to May. The drop in temperature in the Pra estuary in March 1997 was due to rainfall that occurred in the night prior to sampling and an overcast weather on the day of sampling.

Dissolved Oxygen Concentration (DO)

Concentration of dissolved oxygen in the Volta estuary decreased from a maximum of 9.2 mg l^{-1} in April 1997 to a minimum of 5.0 mg l^{-1} in December 1997 after which there was an increase until June 1998 (Fig. 2b). In the Pra estuary, DO ranged from a minimum of 4.8 mg l^{-1} to a maximum of 8.8 mg l^{-1} in May 1998 and April 1997, respectively. From May 1997 to January 1998, dissolved oxygen concentration remained consistently higher in the Pra estuary than in the Volta.

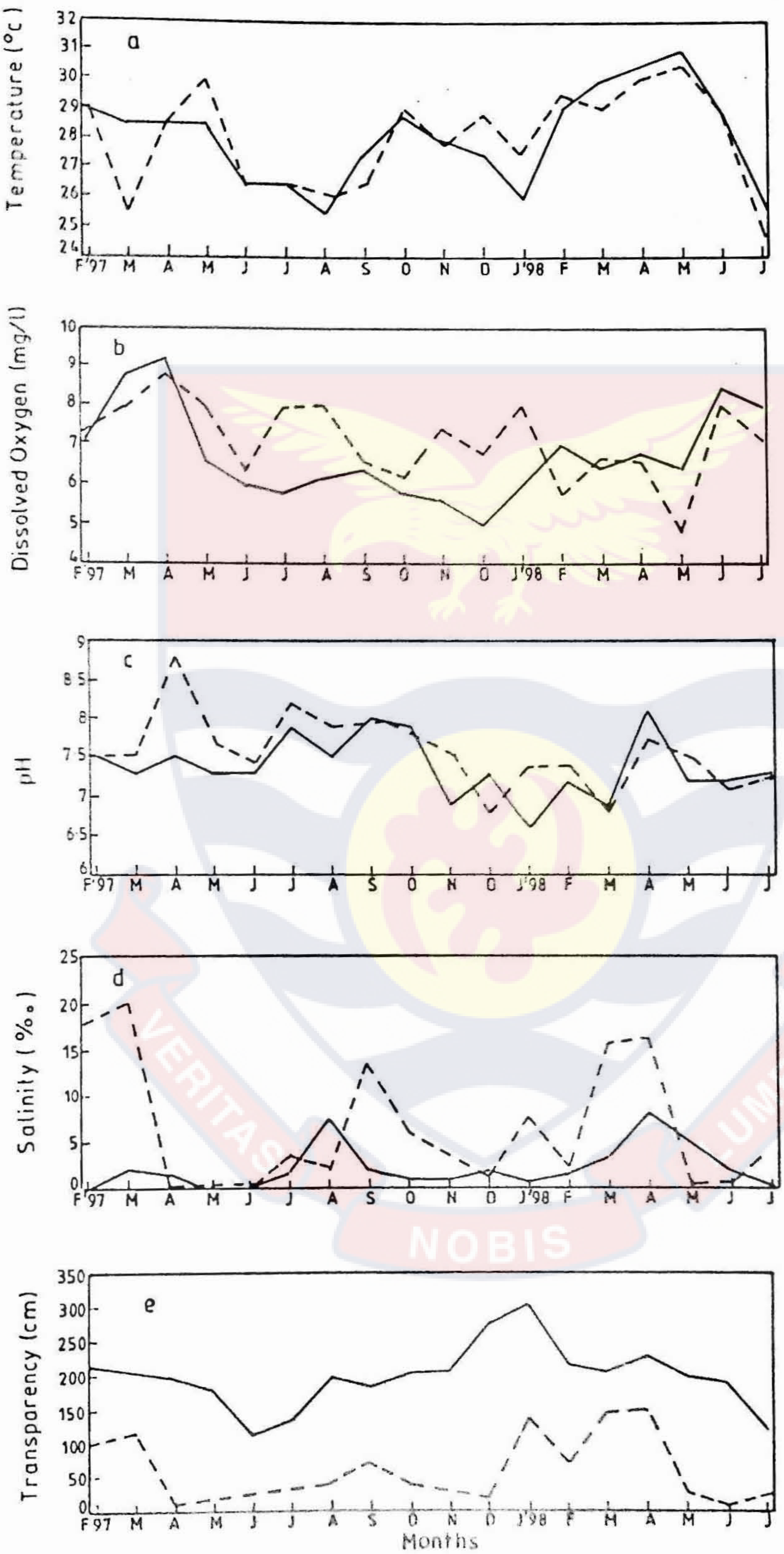

Fig. 2 Fluctuations in hydrographic factors of the Volta (——) and Pra (-----) estuaries.

pH

The pH values ranged from 6.8 to 8.8 and 6.6 to 8.0 in the Pra and the Volta estuaries respectively, with a peak in April in both estuaries (Fig. 2c). The pattern of variations in pH in both estuaries was similar with higher pH values prevailing from April to October and lower values from November to March.

Salinity

Salinities of 0.5-20.0 ‰ and 0.05-8.2 ‰ were recorded in the Pra and Volta estuaries respectively (Fig. 2d). During the study period, the fluctuation in salinity, more or less, followed a similar pattern in both estuaries, with high salinity in March or April and August or September, while low salinities were recorded for the rest of the year.

Transparency

Secchi disk readings (Fig. 2e) indicated that transparency was higher in the Volta estuary than in the Pra estuary. In the Volta estuary transparency ranged from 114 to 306 cm while that in the Pra estuary was from 10 to 152 cm. Generally, transparency was high from January to April when rainfall was low while transparency was low during the rainy season from May to July.

Occurrence and relative abundance of mullets in the estuaries

Six species of grey mullets, comprising three each of the genera *Liza* and *Mugil*, were identified during the study period. These were: the sickle fin mullet, *Liza falcipinnis* (Valenciennes, 1836), the large-scaled mullet, *Liza grandisquamis* (Valenciennes, 1836), grooved mullet, *Liza dumerilii* (Steindachner, 1870), the white mullet, *Mugil curema* Valenciennes (1836), the flathead mullet, *Mugil cephalus* Linnaeus (1758) and the banana mullet, *Mugil bananensis* (Pellegrin, 1928). With the exception of *L. grandisquamis*, which was found only in the Pra estuary, all the other species occurred in both estuaries.

Monthly changes in relative abundance of the different mullet species from the estuaries are illustrated in Fig. 3.

L. falcipinnis: This species was the second most abundant forming 20.7% of the samples in the Volta estuary and was the most abundant species in the Pra estuary where it constituted 56.1% of the samples (Fig. 3a). It was most abundant in the Volta estuary from April to June with a peak in May 1997 while in 1998 the highest peak occurred in March. It dominated samples, for most part of the study period, in the Pra estuary except the period between December 1997 and April 1998. *L. falcipinnis* was present in both estuaries throughout the study period.

L. dumerilii: It constituted 18.7% and 7.8% of grey mullets caught during the study period in the Volta and the Pra estuaries respectively. In both estuaries it was the last but one species in terms of abundance. It was present throughout the study period in the Volta estuary with the highest peak of abundance occurring in November 1997 where it formed 71.6% of the catch for that month (Fig. 3b) whereas in 1998 the highest peak occurred in April. Contrary to the pattern shown in the Volta estuary, the highest peak of abundance in 1997 in the Pra estuary was in May where it constituted 51.3% of the catch for that month. Apart from the peak in May 1997 catches were, generally low in both years with the species being completely absent from the estuary in March and April 1997.

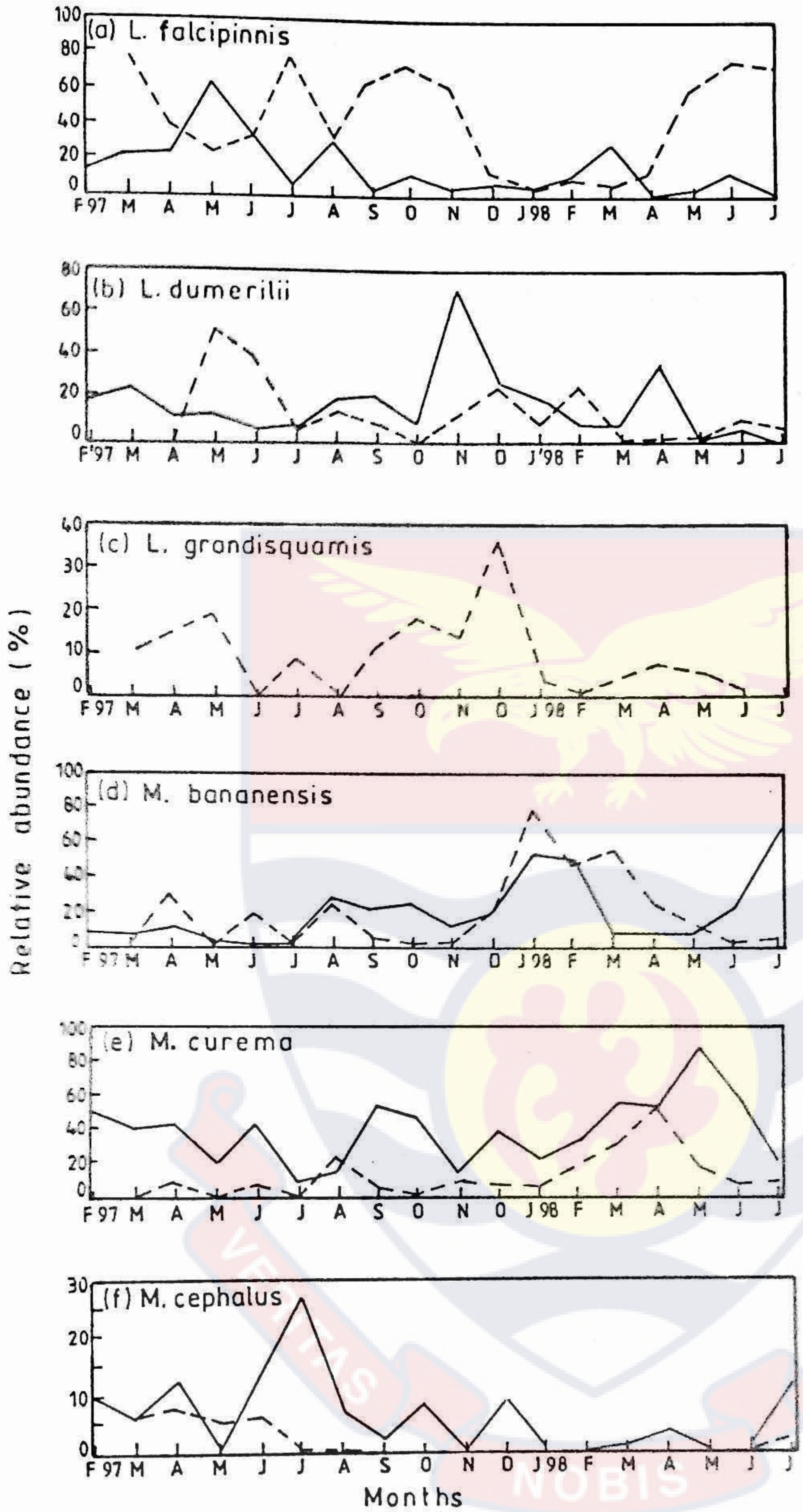

Fig. 3 Changes in the relative abundance of grey mullets in the Volta (—) and Pra (---) estuaries

L. grandisquamis: This species was found in the Pra estuary only and constituted 9.5% of samples during the study period. It showed an increase in abundance from March and peaked in May 1997 (Fig. 3c). After the peak in May 1997 it completely disappeared from samples in June and again in August 1997. It was most abundant in the estuary between October and December 1997 with the highest peak occurring in the latter month. In the following year it occurred in low numbers and was present in June unlike the previous year.

M. bananensis: It constituted 19.0% and 14.3% of the grey mullets sampled from the Volta and Pra estuaries, respectively. The species occurred throughout the study period in the two estuaries, except in May 1997 when it was absent from the Pra estuary (Fig. 3d). The species was the most abundant in the Volta estuary in January, February and July 1998 when it formed 52.7%, 49.2% and 63.4% of the samples in the respective months. In the Pra estuary it dominated from January to March 1998, constituting between 42.4% and 78.0% of the samples, with the highest peak occurring in January 1998.

M. curema: It was the most abundant species in the Volta estuary forming 36.8% of the samples and the third most abundant species constituting 11.8% in the Pra estuary. It occurred throughout the study period in the Volta estuary and dominated catches in 12 out of the 18 samples (Fig. 3e). In 1997 it was most abundant from February to June and September to October while in 1998 it reached the highest peak in May when it constituted 88.6%. In the Pra estuary, the peak abundance of *M. curema* occurred in April 1998 when it constituted 52.5% of the mullets sampled; in 1997, the peak was in August. Even though catches in all the other months, apart from August 1997 and April 1998, remained very low it was always present in samples in the Pra estuary.

M. cephalus: This was the least abundant species in the two estuaries forming only 4.7% and 0.5% of samples in the Volta and the Pra estuaries respectively. *M. cephalus* was present for most part of the study period in the Volta estuary, even though it occurred in very low numbers (Fig. 3f). It was most abundant between June and August with a peak in July in 1997. They were absent from samples in May and November 1997 and January, February, and May 1998. It was mostly caught in the Pra estuary between March and July 1997 and were completely absent from September to December 1997 and from February to May 1998.

Hydrographic factors and relative abundance of grey mullets.

Table 1 shows the correlation between hydrographic factors and relative abundance of the various species in the two estuaries.

L. falcipinnis: Temperature, salinity and transparency correlated negatively with relative abundance of *L. falcipinnis* while pH showed positive correlation with abundance in the two estuaries. The correlation in all cases was not significant.

L. dumerilii: There was no significant correlation between any of the hydrographic factors and abundance of this species in the two estuaries. With the exception of pH, which showed negative correlation with relative abundance in both estuaries, all the other hydrographic factors showed different relationships in the two estuaries.

Table 1 Coefficient of correlation between monthly relative abundance of each grey mullet species and some hydrographic factors in the Volta and Pra estuaries.

Species	Water Temperature	Dissolved Oxygen	pH	Salinity	Transparency
VOLTA EST.					
L. falcipinnis	-0.2063	-0.0514	0.0707	-0.1817	-0.4437
L. dumerilii	-0.0087	-0.2677	-0.0935	0.1186	0.3614
M. curema	0.7302*	0.01939	0.1108	0.2500	0.0966
M. bananensis	-0.4108	0.0878	-0.2770	-0.1281	0.2101
M. cephalus	-0.4482	-0.0134	0.4479	-0.1872	-0.5169*
PRA EST.					
L. falcipinnis	-0.4067	0.1129	0.2773	-0.1076	-0.4266
L. dumerilii	0.1316	0.0076	-0.2015	-0.4689	-0.3588
L. grandisquamis	0.2433	0.0694	0.0016	-0.0953	-0.2271
M. curema	0.3664	-0.3317	-0.1522	0.4495	0.5698*
M. bananensis	0.1613	-0.0424	-0.1934	0.2220	0.5830*
M. cephalus	-0.2515	0.4637	0.3698	-0.0165	-0.1990

* Values in asterisks are significant at the 5% level of probability.

L. grandisquamis: The relative abundance of *L. grandisquamis* correlated negatively with salinity and transparency in contrast to the positive correlation shown with pH, dissolved oxygen concentration and temperature.

M. curema: Transparency in the Pra estuary was the only hydrographic factor that showed positive significant correlation with abundance of *M. curema* ($r=0.5698$, $p<0.05$). Unlike pH and dissolved oxygen concentration which showed conflicting relationship in the two estuaries, temperature and salinity showed positive correlation with relative abundance in both estuaries even though, the correlation was not significant.

M. bananensis: With the exception of transparency which varied significantly with abundance ($r=0.5830$, $p<0.05$) in the Pra estuary, there was no significant correlation between the other hydrographic factors and abundance of *M. bananensis* in both estuaries. The negative correlation between temperature and abundance as well as salinity and abundance in the Volta estuary was in contrast to what pertained in the Pra estuary where there was positive correlation. Dissolved oxygen concentration also showed different relationships with relative abundance in the two estuaries. Correlation with pH was, however, negative in both estuaries.

M. cephalus: The relative abundance of *M. cephalus* correlated negatively with temperature, salinity and transparency in both estuaries. The correlation with transparency in the Volta estuary was significant ($r=-0.5169$, $p<0.05$). On the contrary, the correlation of abundance with pH was positive in both estuaries while that with dissolved oxygen concentration showed different correlation in the two estuaries.

Size frequency distribution of grey mullets in the two estuaries

The size range of the different species in the two estuaries is presented in Table 2. Bigger specimens of each species were caught in the Volta estuary than in the Pra estuary. Figures 4 and 5 show the composite length frequency distribution and their various component cohorts for each species in the Volta and Pra estuaries respectively. The components were separated using the Bhattacharya method in the FISAT programme (Gayanilo *et al.*, 1995). The length frequency distribution for the various species consisted of different cohorts in each estuary.

The length frequency distribution of *L. falcipinnis* from the Volta estuary (Fig. 4a) showed three cohorts with mean lengths of 72.9, 142.5 and 169.3 mm (SL) while those from the Pra estuary (Fig. 5a) showed one cohort with mean length of 82.0 mm (SL). Three cohorts were depicted by the length frequency distribution of *L. dumerilii* from each estuary. The mean lengths in the Volta estuary (Fig. 4b) were 65.6, 94.9 and 130.9 mm (SL). In the Pra estuary (Fig. 5b), the mean lengths were 58.9, 95.3 and 126.8 mm (SL). Only one cohort with a mean length of 115.0 mm (SL) was shown by the length frequency distribution of *L. grandisquamis* (Fig. 5c).

M. bananensis showed one cohort for the length frequency distribution in each of the estuaries with mean length of 111.5 mm (SL) in the Volta estuary (Fig. 4c) and 87.8 mm (SL) in the Pra estuary (Fig. 5d). The length frequency distribution of *M. curema* in the Volta estuary (Fig. 4d) showed two cohorts with 89.0 and 140.4 mm (SL) being the mean lengths. It however, showed one cohort in the Pra estuary (Fig. 5e) with mean length of 86.3 mm (SL).

Table 2 Size range of grey mullets caught in the Volta and Pra estuaries.

Species	Volta estuary		Pra estuary	
	SL(mm)	Wt (g)	SL(mm)	Wt (g)
L. falcipinnis	38-239	1.1-262.3	42-217	1.3-205.6
L. dumerilii	45-233	1.6-216.3	47-230	2.3-238.7
L. grandisquamis	-	-	70-163	7.9-104.8
M. bananensis	54-195	3.6-174.5	47-193	2.1-153.2
M. curema	54-270	3.6-444.1	50-158	3.4-78.4
M. cephalus	77-570	10.2-3300	115-355	34.8-1250

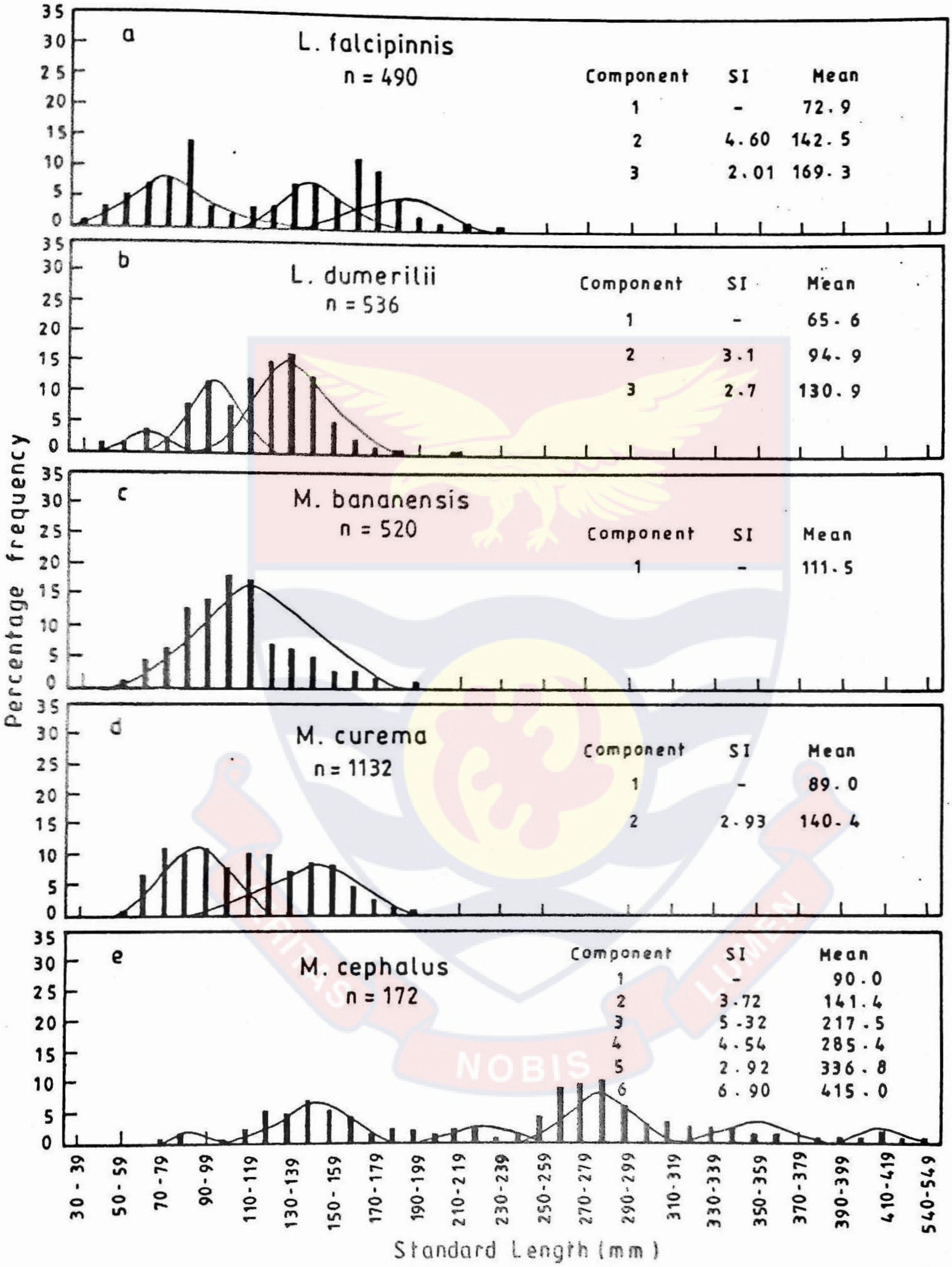

Fig. 4 Length frequency distribution of grey mullets from the Volta estuary. n = sample size, SI = separation index.

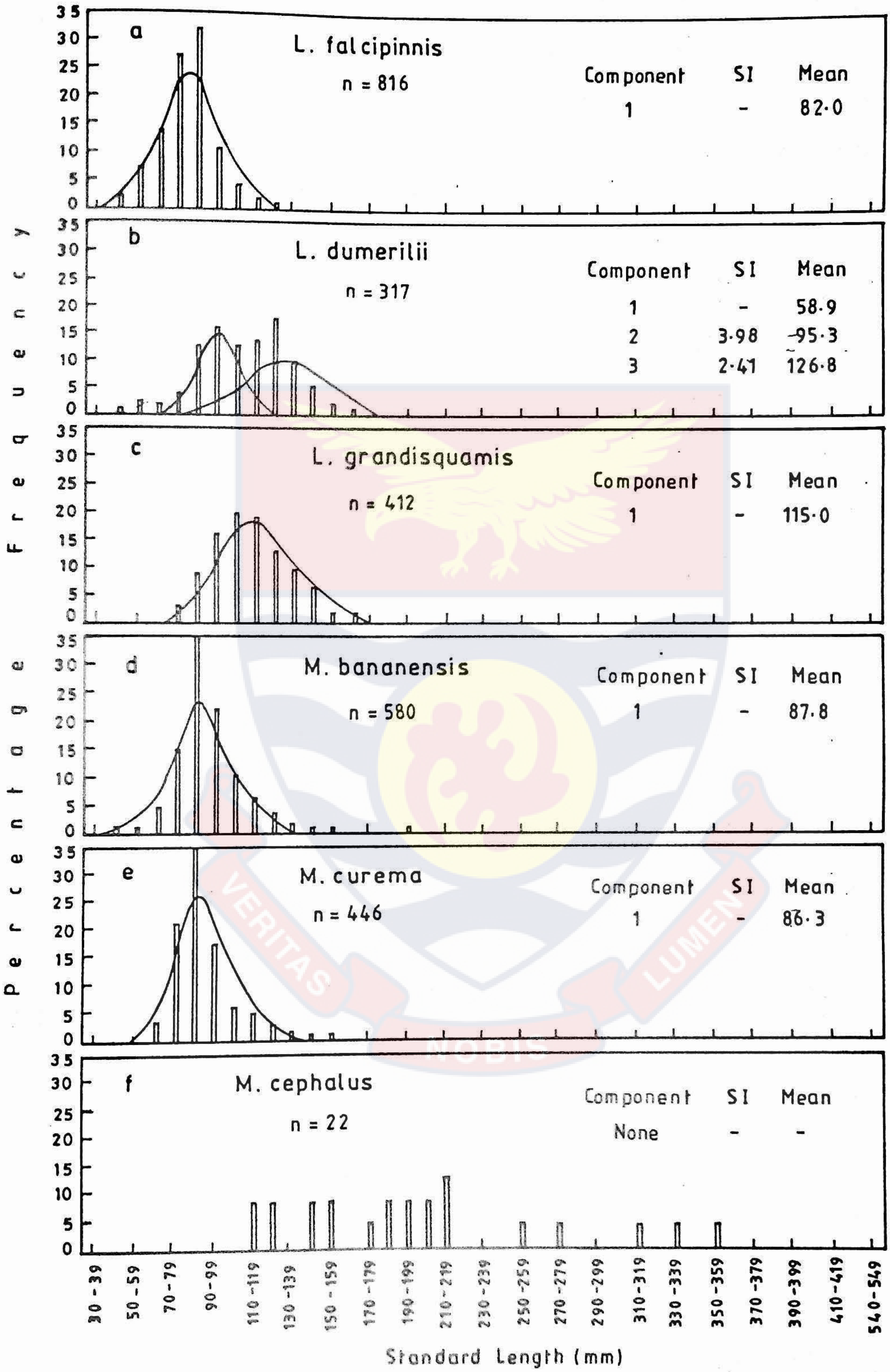

Fig. 5 Length frequency distribution of grey mullets from the Pra estuary. n = sample size, SI = separation index.

In the Volta estuary, the length frequency distribution of *M. cephalus* showed six cohorts (Fig. 4e). The mean lengths were 90.0, 141.4, 217.5, 285.4, 336.8 and 415.0 mm (SL). No composite cohort could be separated from the length frequency distribution of the species in the Pra estuary because of low sample size (Fig. 5f).

The monthly length frequency distributions for each of the species are illustrated in Figures 6-11 except, *M. cephalus* in the Pra estuary because of small sample size.

L. falcipinnis: The size class corresponding to the smallest individuals (30-39 mm SL) occurred in the Volta estuary in March 1997 while in 1998 the smallest size class (50-59 mm SL) was caught in February (Fig. 6). In 1997, adult fishes in the size class of 230-239 mm (SL) were present in the estuary only in April. On the contrary, in 1998 fishes of similar size, occurred in February and June. Progression in the modal class from October to December 1997 indicates an increase in standard length of 80 mm within the three–month period.

In the Pra estuary the smallest size class of 40-49 mm (SL) was found in July, August and September 1997 whereas in 1998 the smallest size class (50-59 mm SL) occurred in June. The maximum size class recorded was 210-219 mm (SL) in March 1998, compared to the maximum size class of 230-239 mm (SL) found in the Volta estuary. Shifts in modes in the Pra estuary were not apparent and therefore not easy to follow the growth pattern.

L. dumerilii: The sizes caught in the Volta and Pra estuaries measured 45-233 and 47-230 mm (SL) respectively (Fig. 7). The smallest individuals belonging to the size class of 40-49 mm (SL) first appeared in the Volta estuary in March 1997. In 1998 however, the size class of 60-69 mm (SL) corresponding to the smallest individuals were caught in January. Between October and December 1997 where the progression in modal class was discernible, a growth increment of 30 mm (SL) was achieved.

The smallest size class of 40-49 mm (SL) occurred in the Pra estuary in July 1997 while in the following year individuals in the smallest size class (70-79 mm SL) appeared in May and June. There was no clear-cut progression in modal class to determine growth in the Pra estuary.

L. grandisquamis: The size of the species ranged from 79 to 163 mm (SL). The size class corresponding to the smallest individuals of 70-79 mm (SL) appeared in the Pra estuary in May, July, September, October and December for 1997 while in 1998 the smallest individuals (80-89 mm SL) were found in January, May, June and July (Fig. 8). Between September and November 1997 where there were clear shifts in modal class, there was a shift from a size of 90-99 to 120-29 mm (SL) - an increase of 30 mm in a period of three months.

M. bananensis: The size of the species ranged from 54 to 195 mm (SL) in the Volta estuary and 47 to 193 mm (SL) in the Pra estuary. Individuals in the smallest size class (50-59 mm SL) were caught in the Volta estuary in March, May and August 1997 while in 1998 the smallest size class of 60-69 mm (SL) occurred in June and July (Fig. 9). Between September and December 1997 where there was an apparent shift in modal class, an increment of 20 mm SL was made over the three-month period.

In the Pra estuary the smallest individuals of 40-49 mm (SL) were caught in July 1997. In 1998 the smallest individuals (60-69 mm SL) appeared in February, March, May and June. From August 1997 the modal class shifted from 60-69 to 110-119 mm (SL) in November 1998, registering an increment of 50 mm in a period of three months.

M. curema: The size of the species caught in the Volta and Pra estuaries ranged from 54 to 270 mm (SL) and 50 to 158 mm (SL) respectively. In 1997, the size class corresponding to the group of smallest individuals (50-59 mm SL) in the Volta estuary appeared for the first time in May. In 1998 the smallest individuals (60-69 mm SL) was present in January and February and again in June and July (Fig. 10). Between August and November 1997, where there was a clear shift in modal class, an increment of 50 mm in size was attained.

In the Pra estuary, the smallest individuals (50-59 mm SL) were caught in July 1997 while in 1998 they first appeared in February and were present in June and July. There were no clear shifts in modal class in the Pra estuary for growth estimation.

M. cephalus: The size of the species ranged from 77 to 570 mm SL in the Volta estuary and 115 to 355 in the Pra estuary. Length frequency distribution on monthly basis is illustrated in Figure 11 for the species from the Volta estuary only since the number of specimens from the Pra estuary was low. The smallest individuals in the size class 60-79 mm (SL) appeared for the first time in the estuary in March 1997. In 1998 the smallest size class, which measured 120-139 mm SL, was caught in June and July. A size increase of 40 mm was attained within three months from February to April 1997 when the modal class shifted from 220-239 in the former month to 260-279 in the latter.

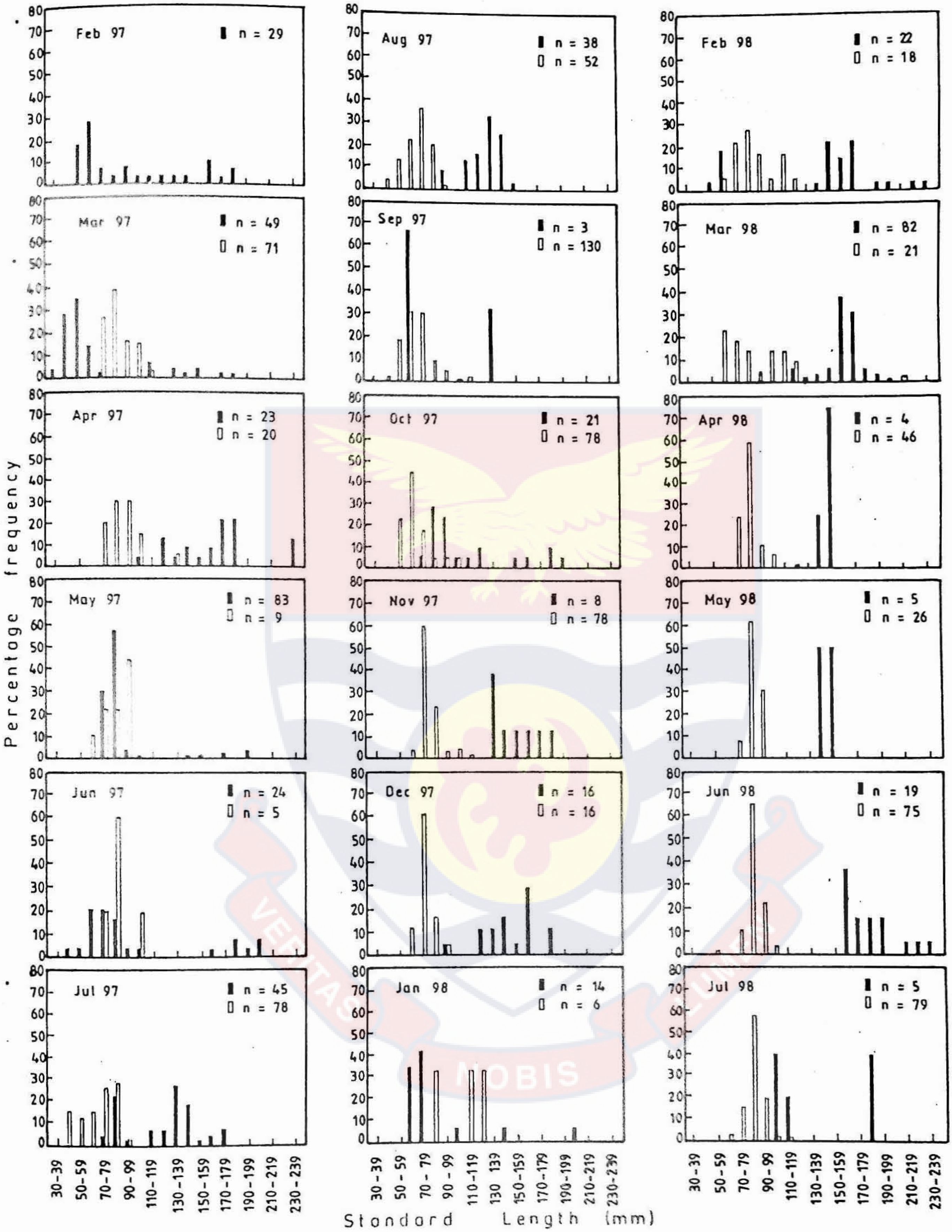

Fig. 6 Monthly length frequency distribution of L. falcipinnis from the Volta (▮) and Pra (▯) estuaries.

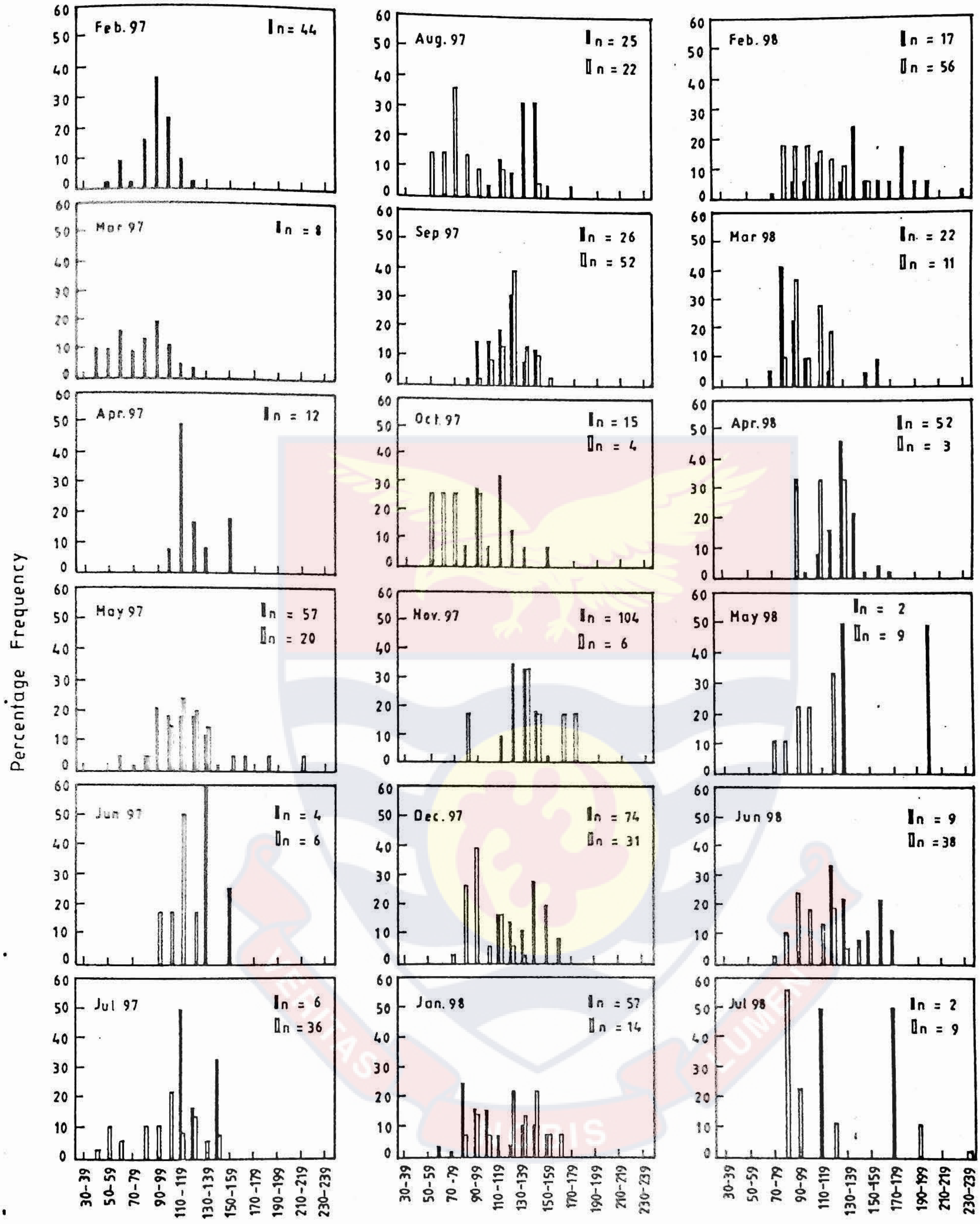

Fig. 7 Monthly length frequency distribution of L. dumerilii from the Volta (▮) and Pra (▯) estuaries

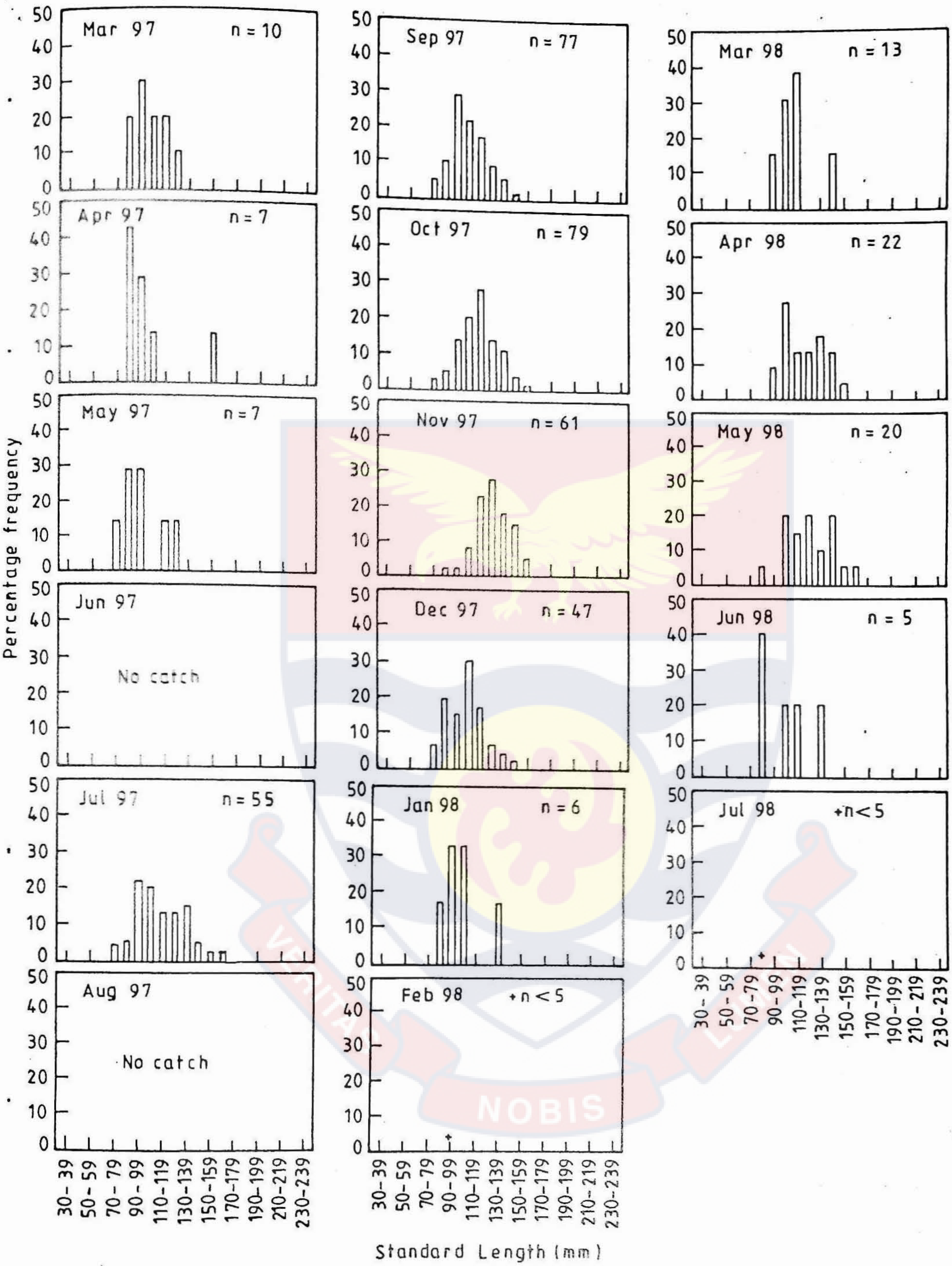

Fig. 8 Monthly length frequency distribution of L. grandisquamis from the Pra estuary

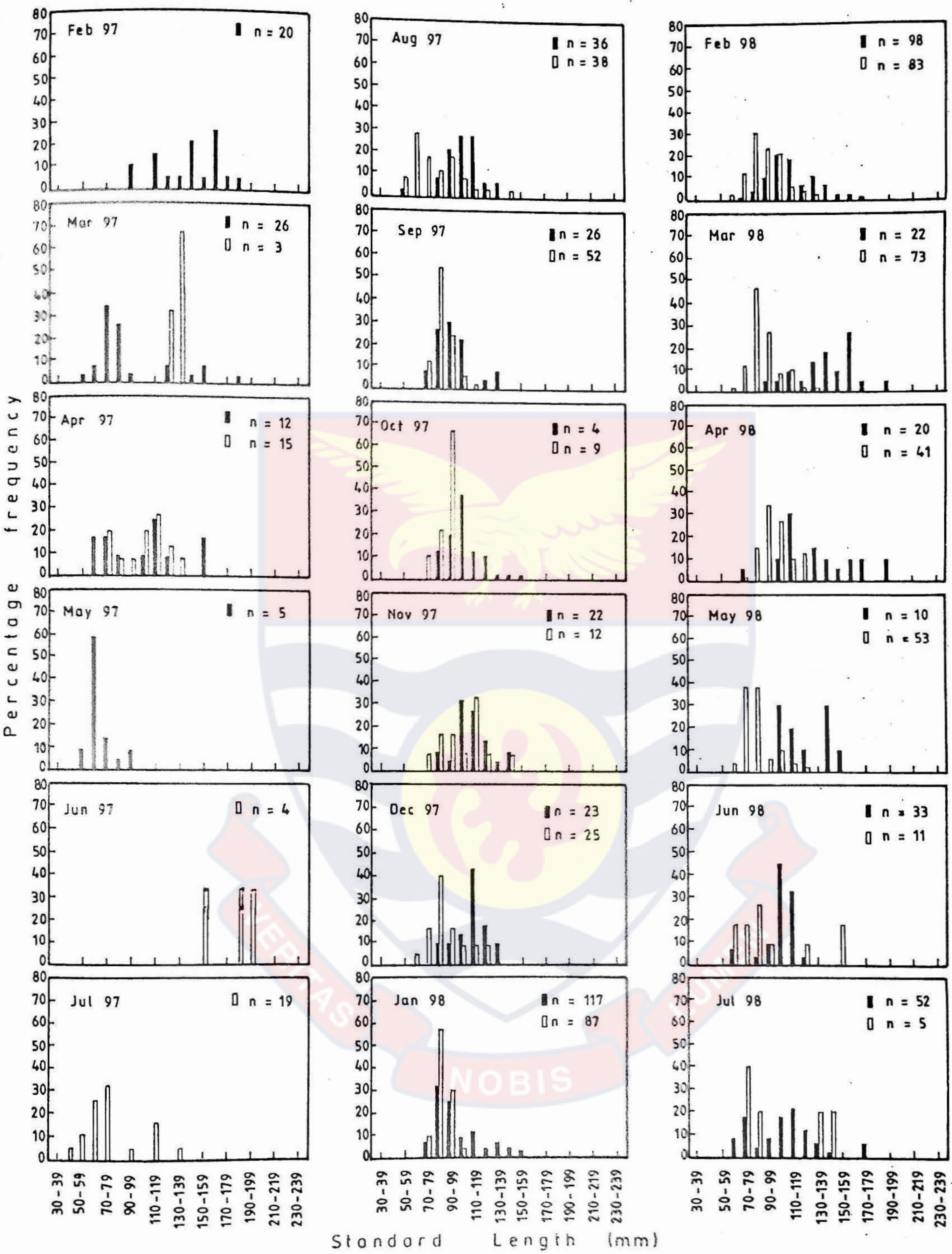

Fig. 9 Monthly length frequency distribution of M. bananensis from the Volta (▮) and Pra (▯) estuaries.

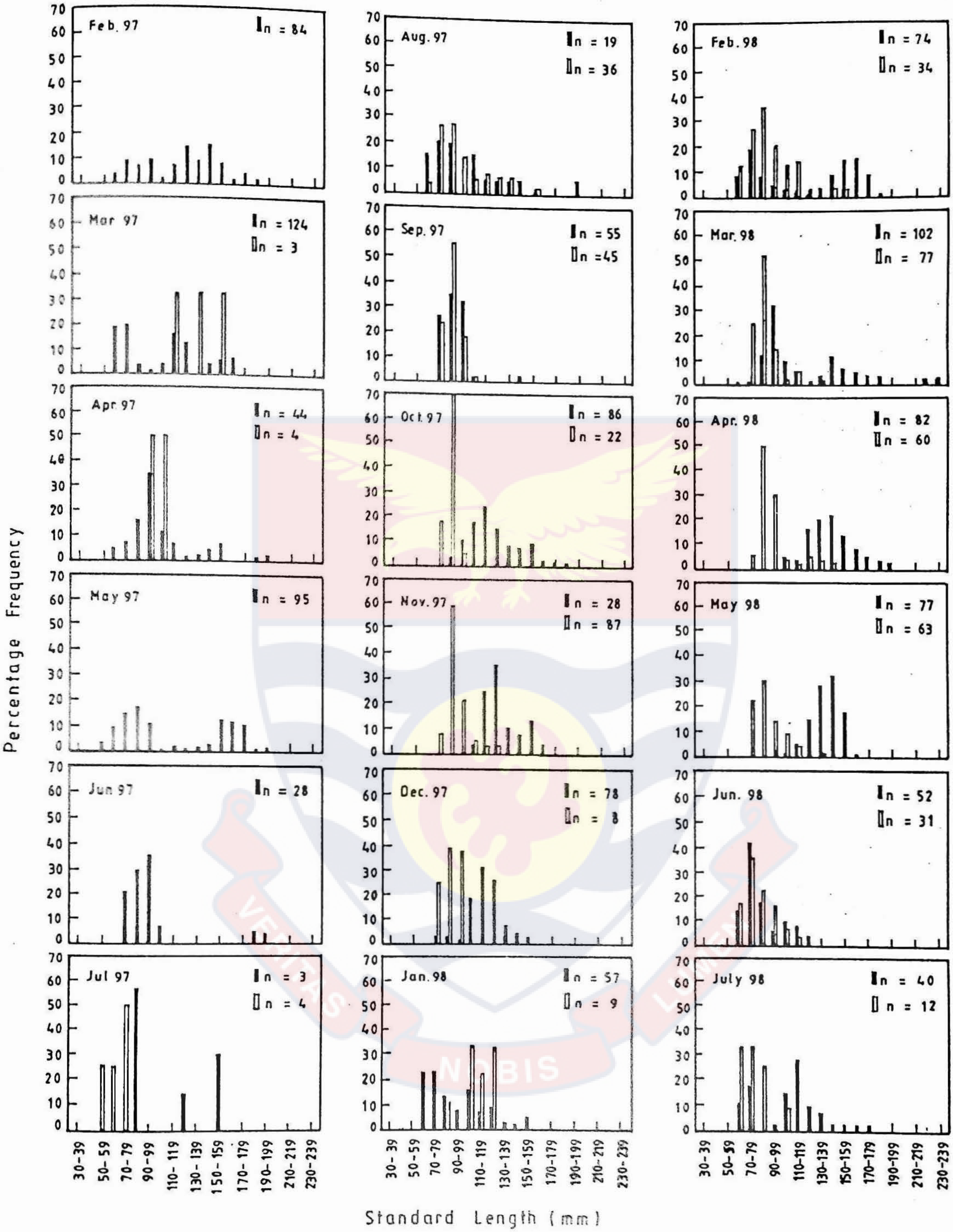

Fig. 10 Monthly length frequency distribution of M. curema from the Volta (▮) and Pra (▯) estuaries

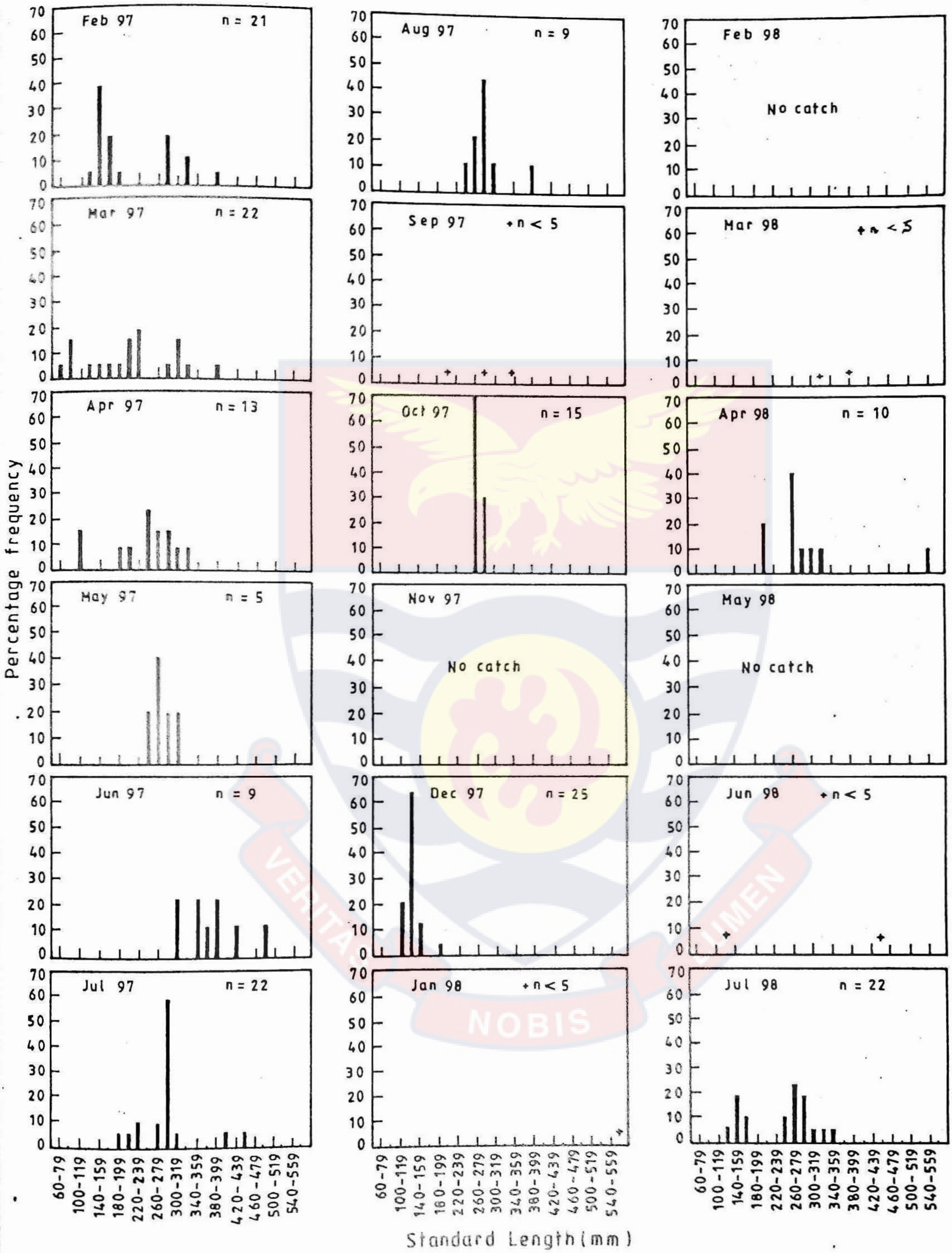

Fig. 11 Monthly length frequency distribution of *M. cephalus* from the Volta estuary

Length-weight relationship

The relationships between length and weight for the different mullet species from the two estuaries are illustrated in Figure 12. For all the species, a relationship of the form $W = a L^b$ was found between body weight and standard length. For each species, the parameters *a* (intercept) and *b* (exponent) of the regression were estimated through base-10 logarithm transformation of length-weight data using least-squares linear regression viz:

$$\log W = \log a + b \log L$$

Differences in the slopes of regressions between same species from the two sites were evaluated using Student's *t*-test (see Appendix 16). The values for the intercept *a* and exponent or regression coefficient *b* in the regression equations, as well as the coefficient of determination (R^2) for the different species are shown in Table 3.

With the exception of *M. cephalus* the regression coefficient, *b*, for a given species from the two estuaries were statistically different (Table 3). The regression coefficient *b*, for *L. grandisquamis*, was not significantly different from 3.0 ($p>0.05$), indicating isometric growth while in the other species the exponent was either significantly higher or lower than 3.0 ($p<0.01$) suggesting allometric growth.

Table 3 Parameters of length-weight relationship and coefficient of determination (R^2) for grey mullet species from the Volta and Pra estuaries.

Species	Location	a±se	b±se	R^2
L. falcipinnis	Volta	0.0158±0.002	3.0561±0.02	0.9928
	Pra	0.0255±0.005	2.8507±0.05	0.9500
L. dumerilii	Volta	0.0098±0.003	3.2356±0.03	0.9833
	Pra	0.0223±0.003	2.9175±0.03	0.9771
L. grandisquamis	Volta	-	-	-
	Pra	0.0204±0.004	3.0113±0.03	0.9750
M. bananensis	Volta	0.0191±0.002	3.0296±0.02	0.9894
	Pra	0.0175±0.003	3.1042±0.03	0.9771
M. curema	Volta	0.0311±0.002	2.8456±0.03	0.9728
	Pra	0.0247±0.004	2.9472±0.04	0.9651
M. cephalus	Volta	0.0142±0.002	3.1387±0.02*	0.9944
	Pra	0.0134±0.004	3.1708±0.05*	0.9944

* No significant difference between slopes at the 5% probability level

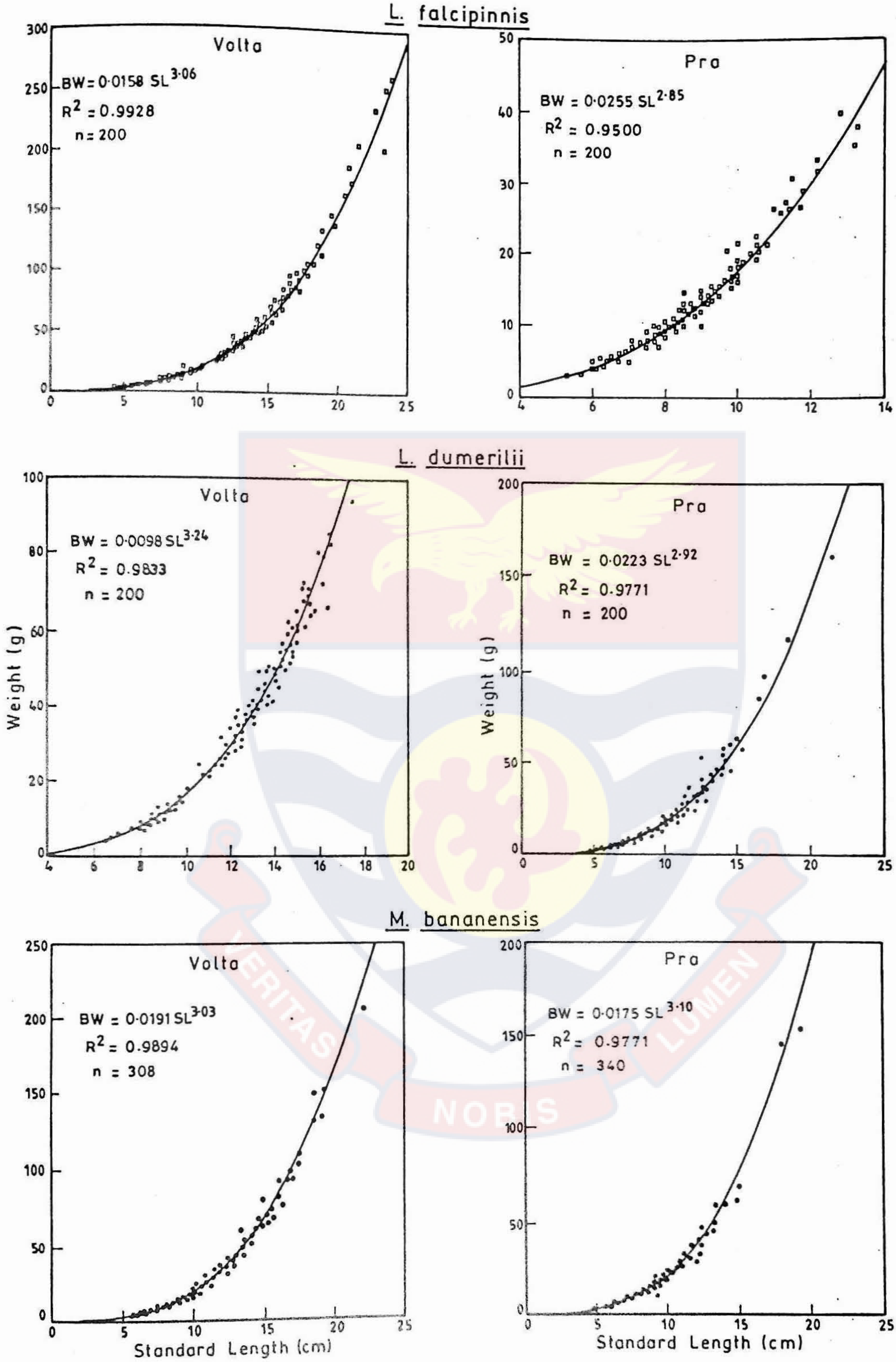

Fig. 12 Length-weight relationship of grey mullets from the Volta and Pra estuaries. n = sample size.

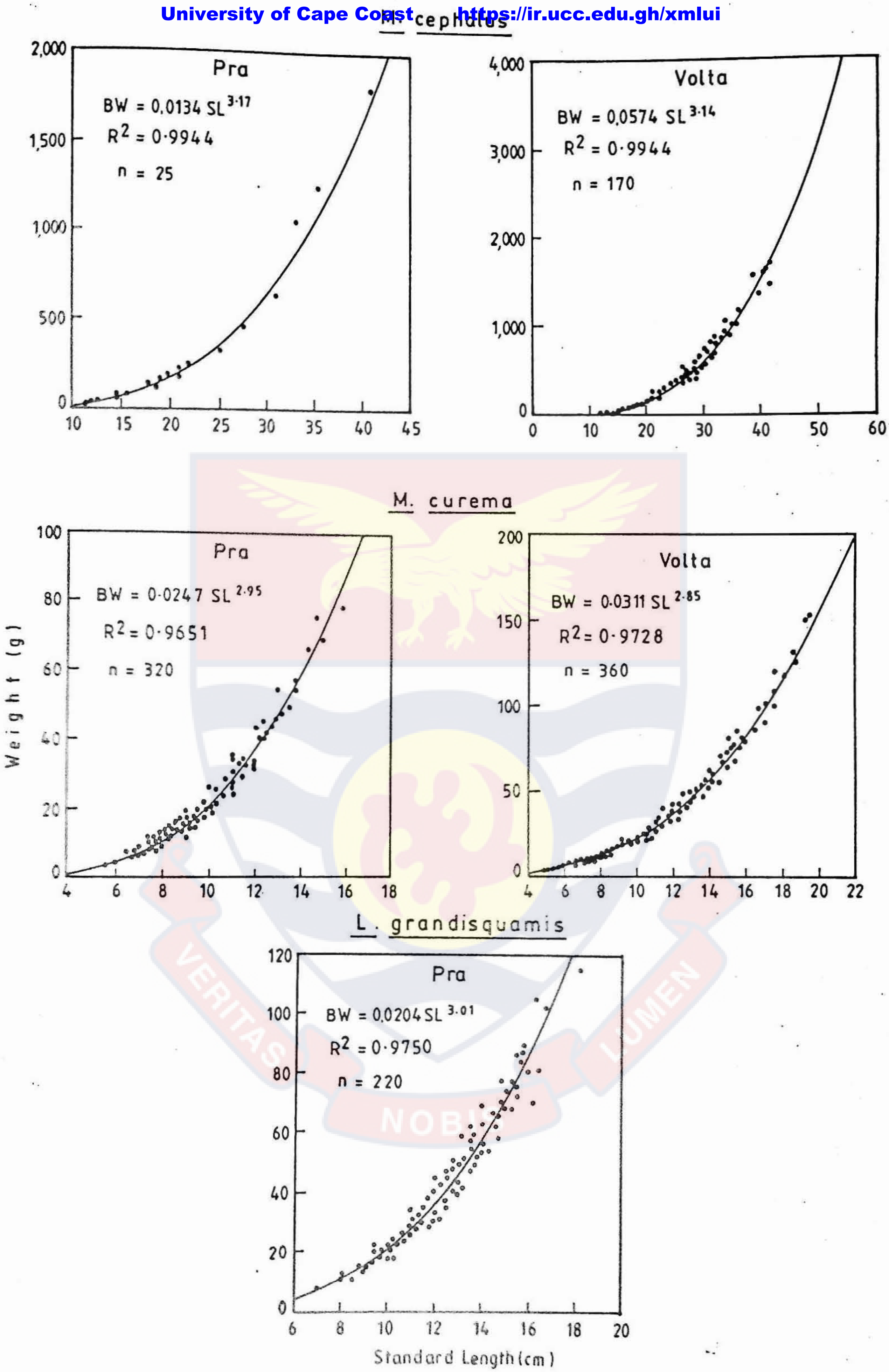

Fig. 12 (contd.) Length-weight relationship of grey mullets from the Volta and Pra estuaries. n = sample size.

Growth parameters

Figure 13a shows a sample of the Wetherall plot for *M. bananensis* from the Volta estuary, providing estimate of $L\infty$ as 206.4 mm SL. The corresponding estimate of K was 0.78 year^{-1} from the scan plot (Fig. 13b), and the growth curve superimposed on the restructured length-frequency data is shown in Fig. 13c. A summary of the growth parameters (K, $L\infty$ and t_o) and growth performance (ϕ') is provided in Table 4 for all the species.

Apart from *L. dumerilii* whose $L\infty$ was similar in both estuaries, the $L\infty$ and K for the other species from each estuary were different. Growth performance (ϕ') for the same species from both estuaries was however similar. The highest $L\infty$ in the Volta estuary was estimated for *M. cephalus*, while in the Pra estuary *L. dumerilii* had the highest estimate. It must be noted that no estimate was made for *M. cephalus* in the Pra estuary because of the small sample size.

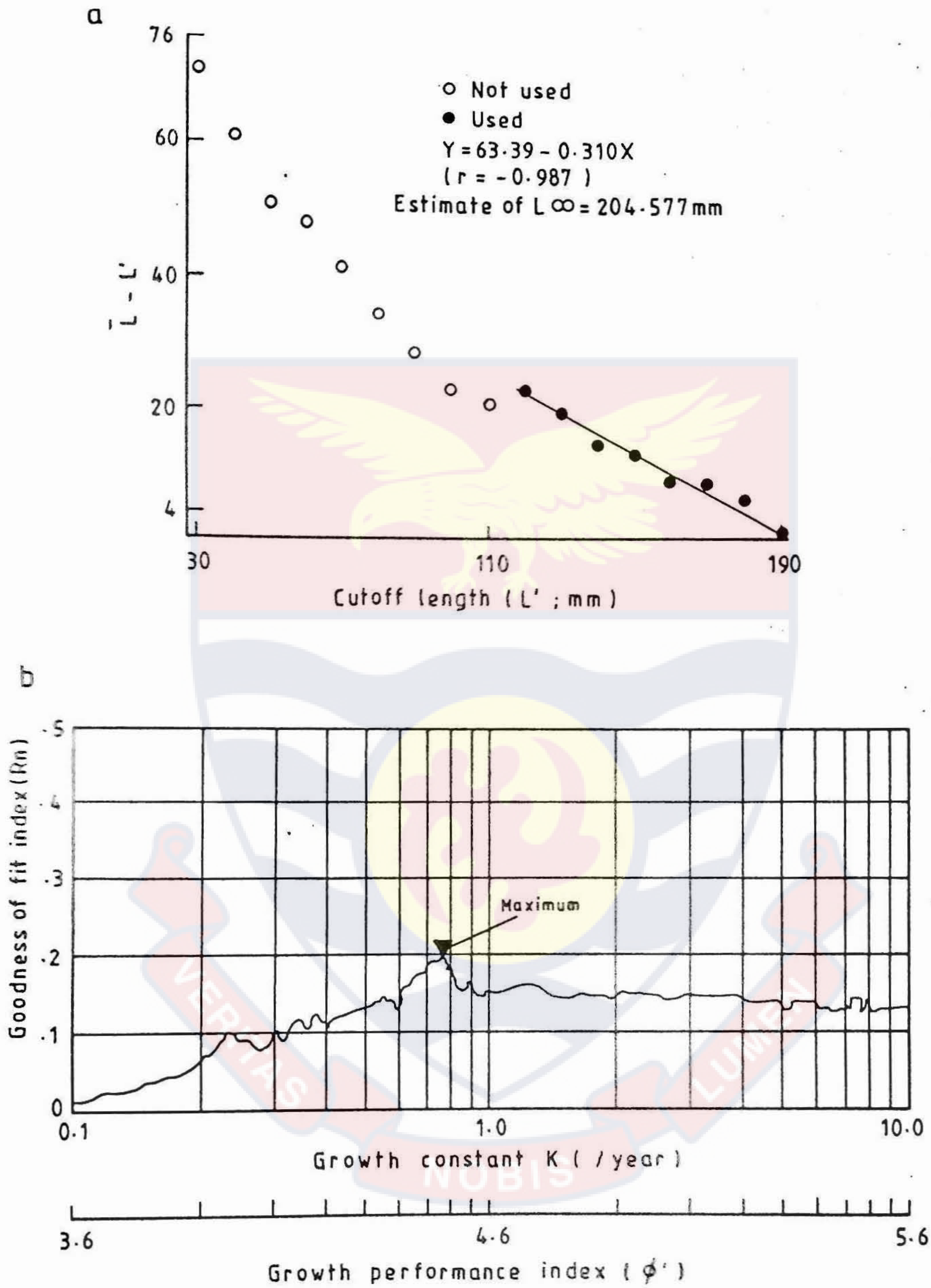

Fig. 13 Estimation of growth parameters for *M. bananensis* from the Volta estuary. (a) $L\infty$ from Wetherall plot. (b) *K* from the scan routine showing the location of 'best' estimate of $K = 0.78$ year-1 (see ϕ' scale below).

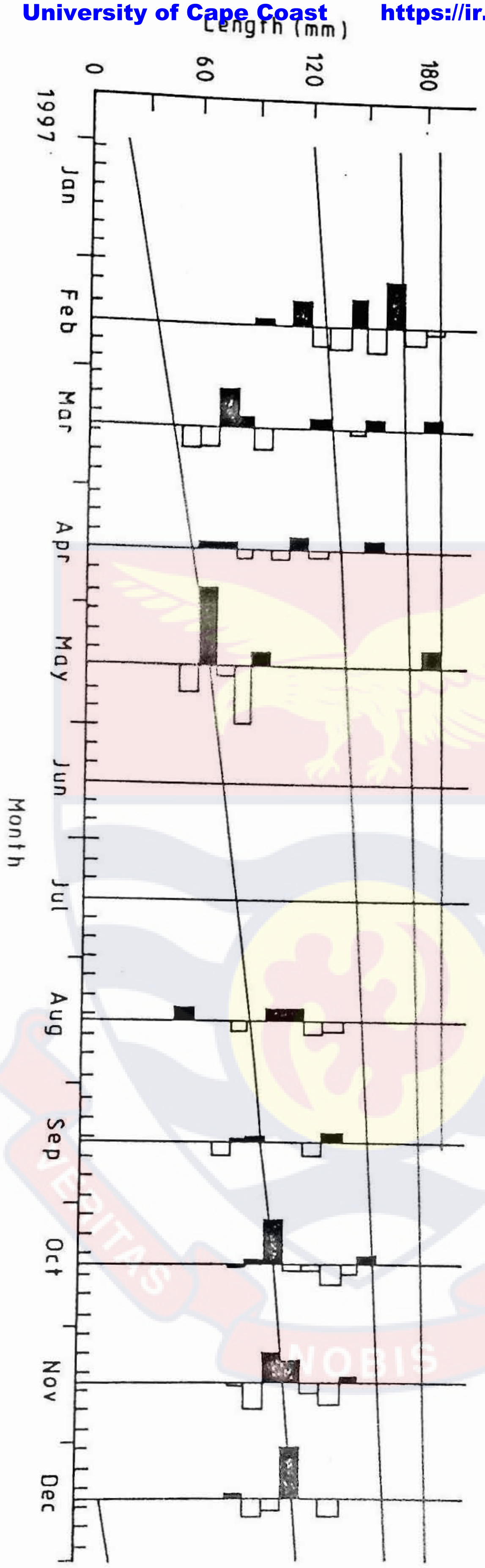

Fig 13c Restructured length-frequency data with superimposed growth curve for *M. bananensis* from the Volta estuary. L_{∞} =204.75 mm SL, K=0.78 year^{-1}, t_0 =- 0.07 and Rn = 0.159.

Table 4 Growth parameters (L_∞, K, t_o) and growth performance index (ϕ') of grey mullets from the Volta and Pra estuaries.

Species	L_∞ (SL, mm)	K (year^{-1})	t_o (years)	ϕ'
Volta estuary				
Liza falcipinnis	247.8	0.41	-0.225	4.41
Liza dumerilii	232.7	0.55	-0.169	4.50
Mugil curema	273.3	0.40	-0.224	4.48
Mugil bananensis	204.8	0.78	-0.122	4.51
Mugil cephalus	565.5	0.31	-0.239	4.99
Pra estuary				
Liza falcipinnis	220.4	0.42	-0.227	4.31
Liza dumerilii	233.4	0.42	-0.223	4.60
Liza grandisquamis	173.9	0.27	-0.382	4.66
Mugil curema	195.8	0.62	-0.156	4.38
Mugil bananensis	201.4	0.32	-0.308	4.09

Food and feeding habits

Composition and frequency of occurrence of stomach contents

The list of stomach contents of grey mullets from the two estuaries is presented in Table 5. Fish scales and eggs were found in the stomachs of *L. falcipinnis* and an unidentified species of red alga was found in a few stomachs of *L. grandisquamis* and *M. bananensis* from the Pra estuary. Apart from these, all the other items were common in the stomachs of all the species from the two estuaries. Twelve species of diatoms, twelve of green algae and 10 species of blue-green algae were identified in the stomachs of the grey mullets. The most common diatoms found in the stomachs were species of *Navicula*, *Surirella*, *Synedra*, *Gyrosigma*, *Nitzschia*, and *Cyclotella*. The blue-green algae consumed consisted mainly of filamentous types e.g., *Lyngbya* spp., *Oscillatoria* spp. and *Anabaena* spp., and unicellular forms e.g., *Merismopedia* sp. while the green algae were mostly species of desmids and filamentous types e.g., *Chaetophora*, and *Ulothrix*. Protozoans were mainly made up of foraminiferans.

Table 5 List of stomach contents of grey mullets from the Volta and Pra estuaries.

Stomach contents	Stomach contents
Bacteria	**Blue-green algae**
Benthic organisms	*Spirulina* sp
Polychaetes	*Chroococcus* sp
Nematodes	*Lyngbya* sp
Zooplankton	*Anabaena* sp
Annelid larvae	*Oscillatoria* sp
Crustacean larvae	*Merismepodia* sp
Protozoans	*Microcystis* sp
Dinoflagellates	*Calothrix* sp
Copepods	*Agmellum* sp
Ostracods	*Gomphosphaeria* sp
Rotifers	**Green algae**
Cladocerans	*Closterium* sp
Diatoms	*Pediastrum* sp
Surirella sp	*Staurastrum* sp
Gyrosigma sp	*Ankistrodesmus* sp
Navicula sp	*Schizomeris* sp
Nitzschia sp	*Chaetophora* sp
Synedra sp	*Spirogyra* sp
Stephanodiscus sp	*Ulothrix* sp
Cyclotella sp	*Microspora* sp
Gomphonema sp	*Prasiola*
Pinnularia sp	*Stichococcus* sp
Diatonia sp	*Scenedesmus* sp
Melosira sp	Unidentified filamentous green algae
Cymbella sp	**Red algae**
Sand particles	**Fish scales**
Detritus	**Fish eggs**

Table 5 List of stomach contents of grey mullets from the Volta and Pra estuaries.

Stomach contents	Stomach contents
Bacteria	**Blue-green algae**
Benthic organisms	*Spirulina* sp
Polychaetes	*Chroococcus* sp
Nematodes	*Lyngbya* sp
Zooplankton	*Anabaena* sp
Annelid larvae	*Oscillatoria* sp
Crustacean larvae	*Merismepodia* sp
Protozoans	*Microcystis* sp
Dinoflagellates	*Calothrix* sp
Copepods	*Agmellum* sp
Ostracods	*Gomphosphaeria* sp
Rotifers	**Green algae**
Cladocerans	*Closterium* sp
Diatoms	*Pediastrum* sp
Surirella sp	*Staurastrum* sp
Gyrosigma sp	*Ankistrodesmus* sp
Navicula sp	*Schizomeris* sp
Nitzschia sp	*Chaetophora* sp
Synedra sp	*Spirogyra* sp
Stephanodiscus sp	*Ulothrix* sp
Cyclotella sp	*Microspora* sp
Gomphonema sp	*Prasiola*
Pinnularia sp	*Stichococcus* sp
Diatonia sp	*Scenedesmus* sp
Melosira sp	Unidentified filamentous green algae
Cymbella sp	**Red algae**
Sand particles	**Fish scales**
Detritus	**Fish eggs**

Data on stomach contents from the monthly samples were pooled to assess their overall composition in the various species (Fig. 14). This was done after it had been ascertained that there was no appreciable change in the stomach contents throughout the seasons and also among the various size groups of a given species. This is illustrated in Figures 15-17 while the general niche overlap indices (*Gô*) among the size groups (Appendices 6 and 7) of the species investigated are shown in Table 6. The general niche overlap indices (*Gô*) among the size groups of the species investigated ranged from 0.785 to 0.978 in the Volta estuary and 0.955 to 0.984 in the Pra estuary. There was a high degree of overlap in the stomach contents among the size groups of *L. falcipinnis*, *L. grandisquamis* and *M. bananensis* investigated in the Pra estuary. In the Volta estuary only *L. dumerilii* showed a high degree of overlap in the stomach contents among the size groups. The percentage frequency of occurrence of the various items is presented in Tables 7 and 8 for the Volta and Pra estuaries respectively. The main components of the stomach contents are described for each species from the two estuaries.

L. falcipinnis: The percentage frequency of items shows that sand particles, diatoms, detritus and green algae in both estuaries, as well as blue-green algae in the Pra estuary, occurred most frequently (50-100 %) in the stomachs of the species. These items, together with diatoms, were also the most important on the basis of their percentage composition in the stomach contents from both estuaries (Fig. 14). Filamentous blue-green algae in the Volta estuary and copepods in both estuaries were fairly frequent (10-45%) items in the stomachs of the fish. Protozoans, rotifers and ostracods, were also fairly frequent in stomachs of fish from the Volta estuary.

Table 6 General niche overlap indices (*Gô*) among size groups of grey mullets from the Volta and Pra estuaries.

Species	*Gô* Volta estuary	*Gô* Pra estuary
L. falcipinnis	0.851	0.984*
L. dumerilii	0.978*	0.955
L. grandisquamis	-	0.971*
M. bananensis	0.930	0.971*
M. curema	0.887	0.957
M. cephalus	0.785	**

* Very high degree of niche overlap

** No estimation made because of few specimens

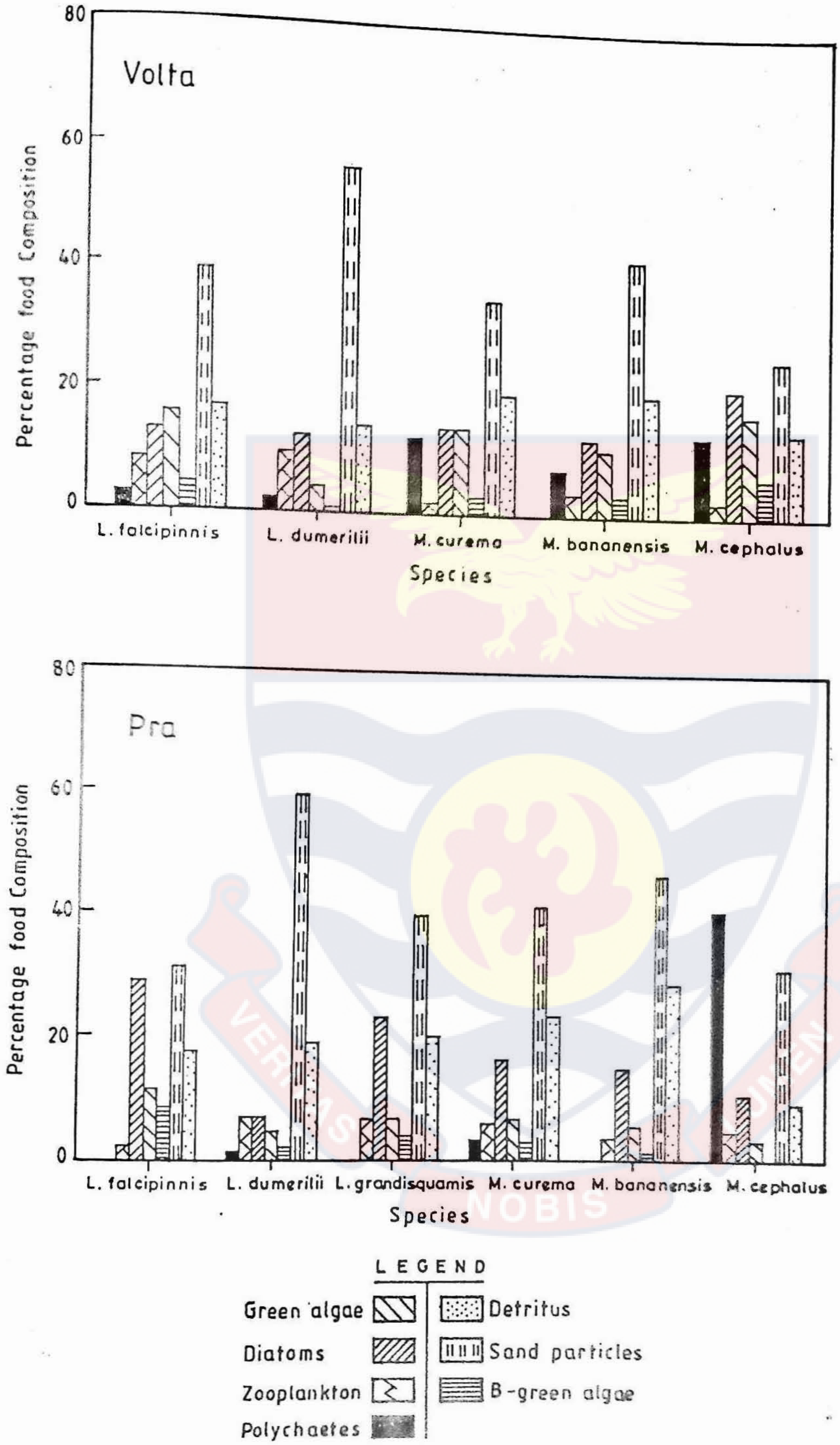

Fig. 14 Composition of stomach contents of grey mullets from the Volta and Pra estuaries

Lower frequency values (< 10 %) were recorded for crustacean larvae, fish scales and eggs, which were found only in fish from the Pra estuary. Low values were also recorded for Dinoflagellates and polychaetes which were present in the stomachs of fish from the Volta estuary only. No seasonal changes occurred in the stomach contents of the species in both estuaries (Fig. 15). The intake of green and blue-green algae as well as zooplankton during the rainy season was however, low.

L. dumerilii: Sand particles constituted about 60% of the stomach contents of *L. dumerilii* from both places (Fig. 14). Detritus, diatoms, green algae and zooplankton were the other important components of the items in the stomachs. Sand particles occurred in all stomachs while detritus and diatoms occurred in more than 50% of the stomachs examined. In both estuaries, blue-green algae, ostracods, copepods and protozoans were fairly frequent (10-50%). Items occurring in less than 10% of the stomachs included polychaetes, annelid larvae, cladocerans and bacteria. Nematodes were absent from the stomachs of *L. dumerilii* from the Volta estuary while crustacean larvae were not found in those from the Pra estuary. The composition of items in the stomachs remained fairy the same throughout the seasons in the two estuaries except that the intake of green and blue-green algae by the species in both estuaries decreased remarkably during the rainy season (Fig. 15). Some polychaetes were eaten by the species from the Pra estuary during the rainy season.

L. grandisquamis: The most important items in the stomachs of this species were sand particles, detritus and diatoms (Fig. 14). These items including green and blue-green algae (Table 8) occurred in more than 50% of stomachs examined. Ostracods, protozoans and cladocerans occurred between 10.5-34.2% of stomachs examined while annelid larvae, nematodes, rotifers and fish scales were noted in less than 10% of stomachs. An unidentified red alga was found in one of the stomachs. The composition of stomach contents did not change over the seasons except an increased in the intake of diatoms and a decrease in the amount of sand particles ingested during the rainy season (Fig. 16).

M. bananensis: Diatoms, sand particles, green algae and detritus occurred in over 50% of stomachs examined in both estuaries. Items that had a fair percentage occurrence (10-50%) in the stomachs of fish from both estuaries were copepods, protozoans and blue-green algae. Included in this group are polychaetes found in the stomachs of species in the Volta estuary and green algae and bacteria found in the stomachs of fish in the Pra estuary. Red algae occurred in a few (< 10%) stomachs in the Pra estuary but were absent from the diet of the species in the Volta estuary. Other items for which lower frequency values were also recorded in both places, were annelid larvae, rotifers and nematodes.

In the Volta estuary polychaetes formed an important component of the stomach contents during the dry season while more zooplankton were consumed during the rainy season. The composition of stomach contents of the species in the Pra estuary was fairly the same during the dry and rainy seasons (Fig. 16).

M. curema: The most important stomach contents in terms of their percentage composition were sand particles, detritus, diatoms and green algae (Fig. 14). Except for green algae in the Volta estuary, these items were found in over 70.5% of stomachs examined. Even though polychaetes were fairly important forming about 12.2% of the stomach contents of the species in the Volta estuary it constituted a small fraction (3.4%) of the stomach contents of the species in the Pra estuary. Other items that were fairly frequently found (10-50%) in the stomachs of *M. curema* from the two places included, protozoans, copepods, and blue-green algae with green algae also being fairly frequent in the stomachs of fish in the Pra estuary. All the other items e.g., bacteria, rotifers, cladocerans and nematodes were frequently low (< 10%) in the stomachs of fish in both estuaries.

During the dry and rainy seasons, polychaetes constituted an important component of the items in the stomachs of the species in the Volta estuary. Comparatively, more diatoms and zooplankton were found in the stomachs of fish in the Volta estuary during the rainy season (Fig. 17). Except for the presence of polychaetes in the stomachs of the species in the Pra estuary during the dry season, there were no changes in the stomach contents in the two seasons in that estuary.

M. cephalus: Sand particles, detritus, green algae, blue-green algae and diatoms were the most frequent items in the stomachs of this species in the Volta estuary while in the Pra estuary polychaetes, diatoms, detritus and sand particles were the most frequent items. These items were also the most important, in terms of percentage composition, in the respective estuaries (Fig. 14). Copepods, rotifers and protozoans occurred fairly frequently in the stomachs of fish from the two estuaries. Polychaetes constituted the major item during the dry season while diatoms and green algae were the major items during the rainy season in the Volta estuary (Fig. 17).

Table 7 Frequency of occurrence of items in the stomachs of different mullet species from the Volta estuary

Stomach contents	Frequency of occurrence (%)				
	Liza falcipinnis (n=60)	*Liza dumerilii* (n=70)	*Mugil curema* (n=65)	*Mugil bananensis* (n=75)	*Mugil cephalus* (n=51)
Bacteria	11.8	9.4	7.4	-	2.0
Dinoflagellates	2.9	-	5.6	-	3.9
Diatoms	79.4	71.7	81.5	70.5	88.2
Blue-green algae	41.2	16.9	31.5	33.3	76.5
Green algae	70.6	43.4	68.5	76.5	100
Red algae	-	-	-	-	-
Polychaetes	5.9	1.9	20.4	11.8	29.4
Annelid larvae	2.9	3.8	-	-	-
Nematodes	2.9	-	5.6	2.0	7.8
Protozoans	23.5	22.6	13.0	17.6	3.9
Rotifers	11.8	18.9	5.6	5.9	13.7
Ostracods	17.6	22.6	9.3	13.7	7.8
Copepods	14.7	41.5	29.6	13.7	15.7
Cladocerans	2.9	9.4	1.9	3.9	15.7
Fish scales	-	-	-	-	-
Fish eggs	-	-	-	-	-
Crustacean larvae	-	3.8	-	-	-
Sand particles	100	100	100	100	100
Detritus	100	100	96.3	100	76.5

n = number of stomachs examined

Table 8 Frequency of occurrence of items in the stomachs of different mullet species from the Pra estuary

Stomach contents	Frequency of occurrence (%)					
	Liza falcipinnis (n 67)	*Liza dumerilii* (n 75)	*Liza grandisquamis* (n 60)	*Mugil curema* (n=72)	*Mugil bananensis* (n=69)	*Mugil cephalus* (n=15)
Bacteria	6.1	3.5	-	5.2	10.0	-
Dinoflagellates	-	-	8.0	-	-	-
Diatoms	93.9	71.9	97.0	96.6	90.0	50.0
Blue-green algae	53.0	33.3	56.2	44.8	23.0	17.0
Green algae	55.0	47.4	60.5	34.5	50.0	33.0
Red algae	-	-	5.3	-	3.0	-
Polychaetes	-	1.8	-	3.4	-	50.0
Annelid larvae	-	3.5	7.9	3.4	-	-
Nematodes	12.2	3.5	5.3	3.4	3.0	-
Protozoans	6.1	36.8	34.2	32.8	20.0	17.0
Rotifers	6.1	7.0	5.3	8.6	-	17.0
Ostracods	6.1	24.6	15.8	15.5	-	-
Copepods	32.7	33.3	18.4	31.0	17.0	17.0
Cladocerans	2.0	3.5	10.5	1.7	-	17.0
Fish scales	2.0	-	2.6	-	-	-
Fish eggs	2.0	-	-	-	-	-
Crustacean larvae	2.0	1.8	-	-	-	-
Sand particles	100	100	100	94.8	100	83.0
Detritus	85.7	96.5	100	87.9	97.0	50.0

n = number of stomachs examined

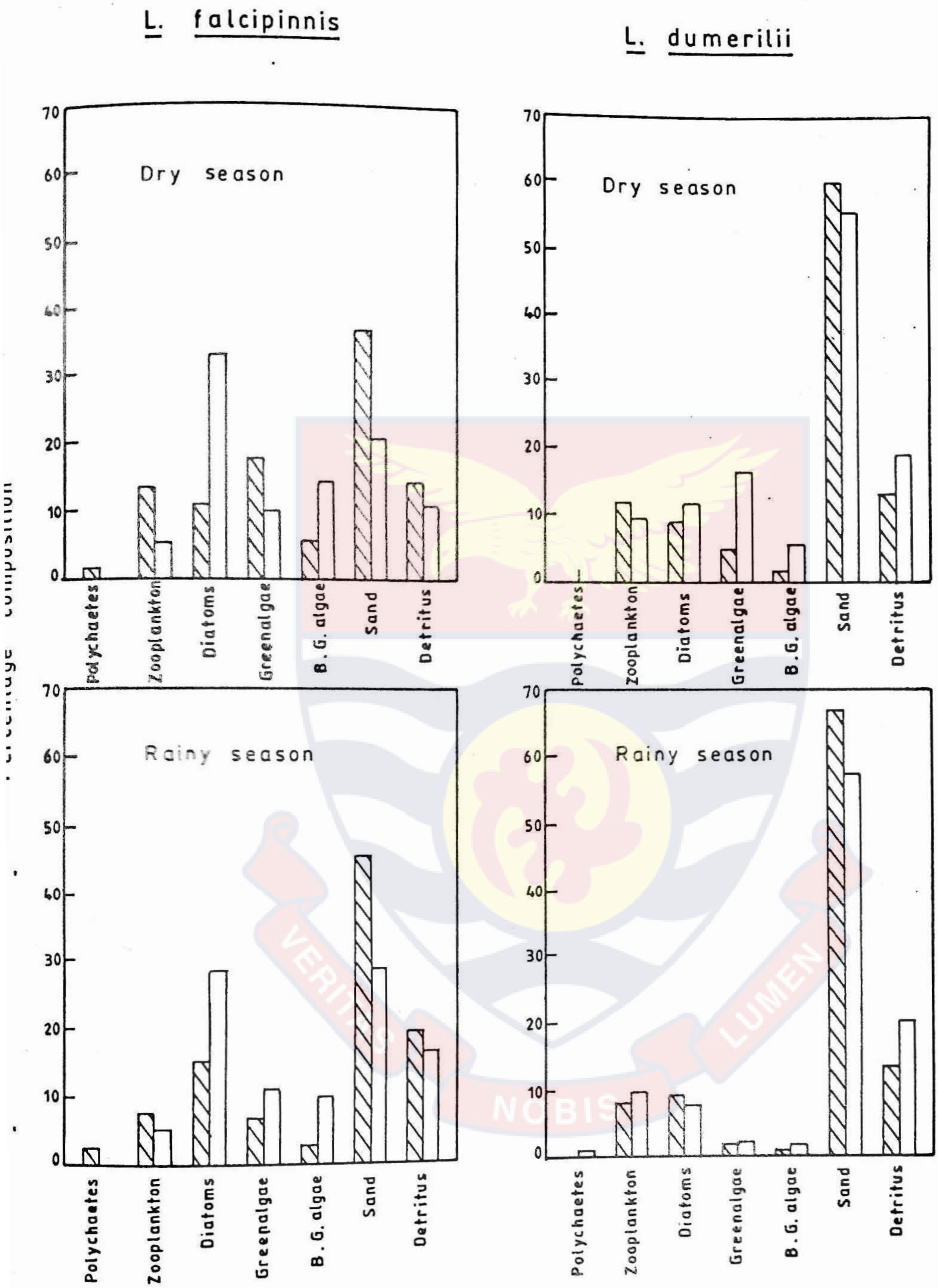

Fig. 15 Seasonal composition of stomach contents of *L. falcipinnis* and *L. dumerilii* from the Volta (▨) and Pra (□) estuaries.

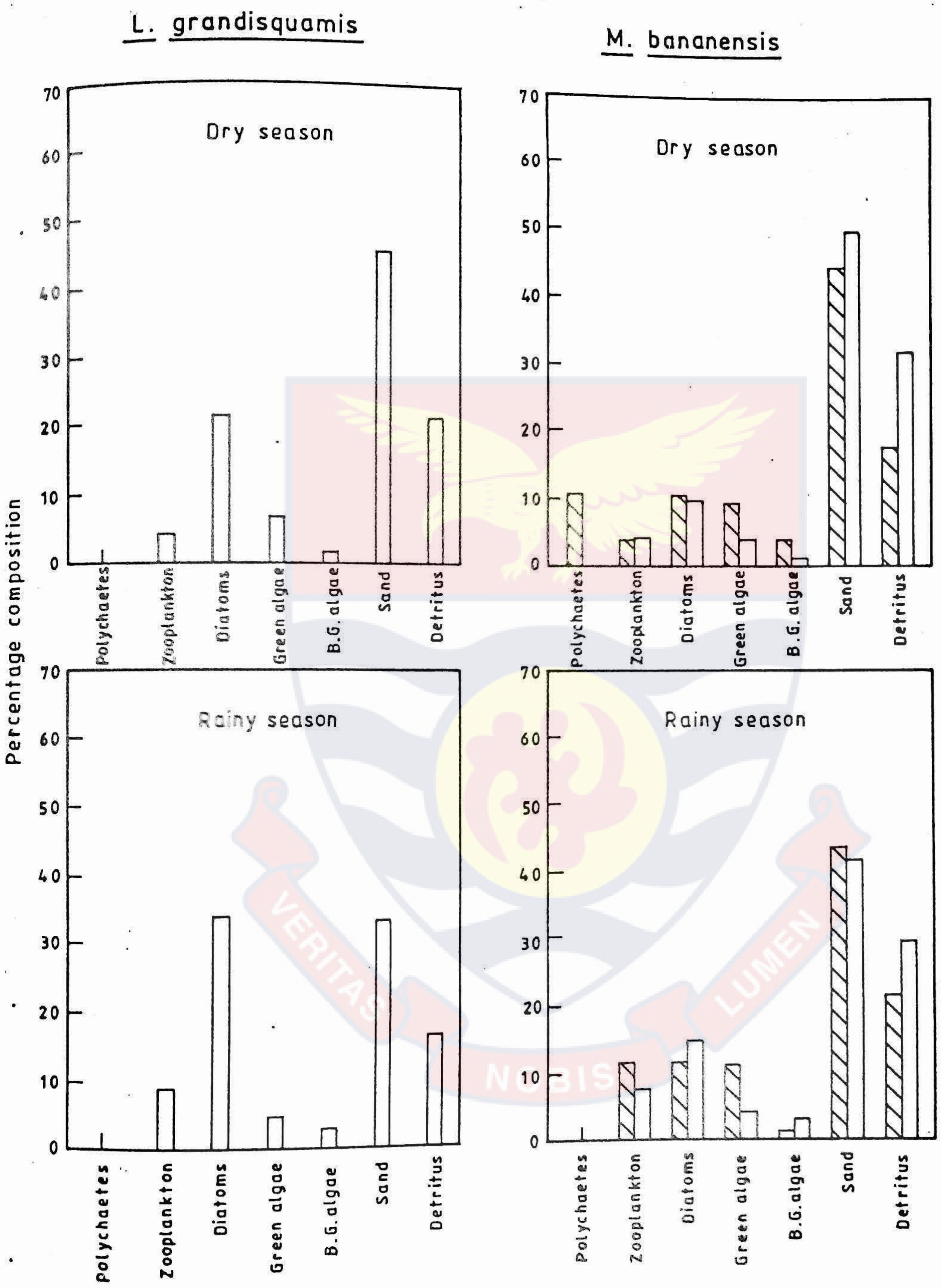

Fig. 16 Seasonal composition of stomach contents of *L. grandisquamis* and *M. bananensis* from the Volta (▨) and Pra (□) estuaries.

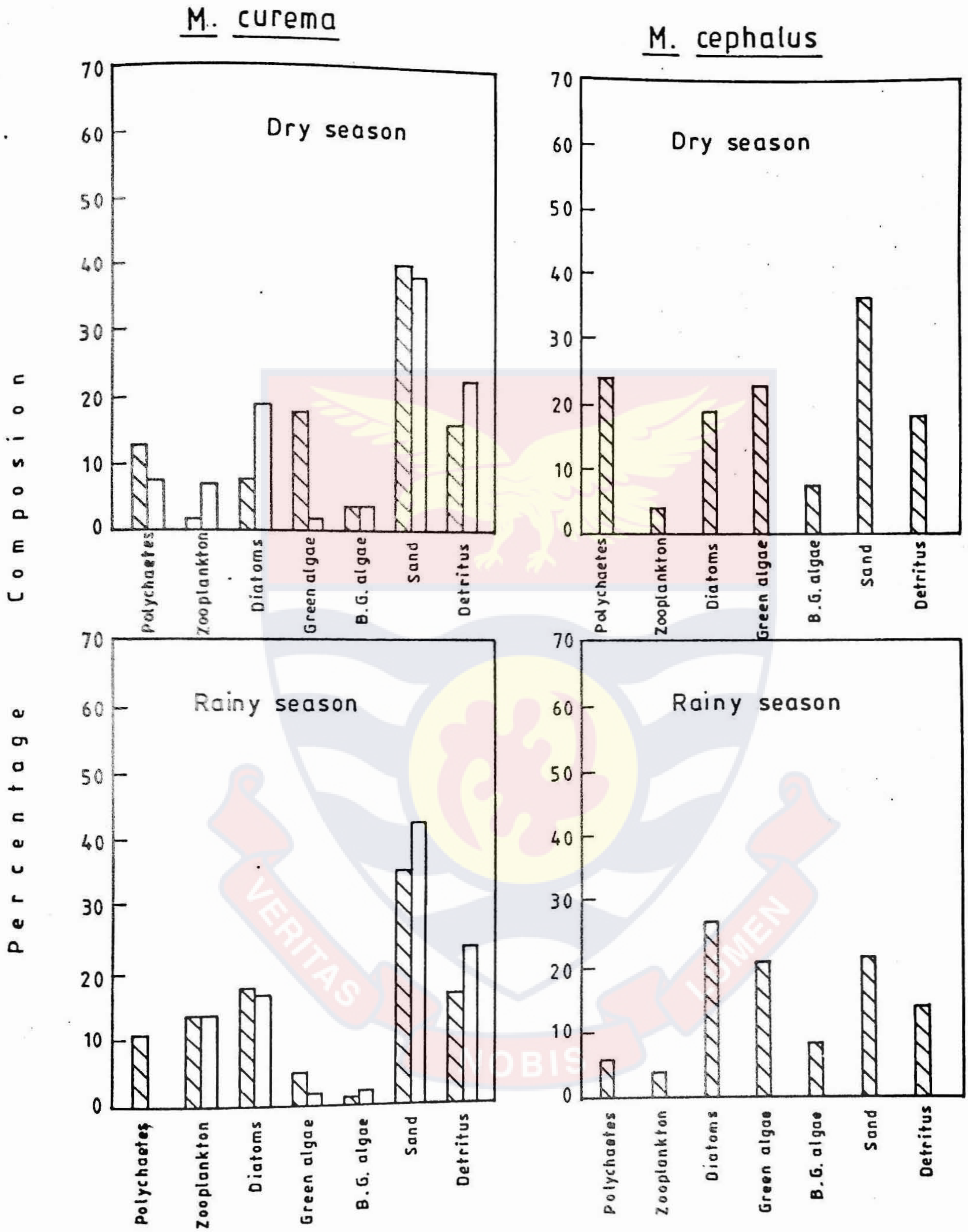

Fig. 17 Seasonal composition of stomach contents of *M. curema* and *M. cephalus* from the Volta (▨) and Pra (□) estuaries.

Among the species themselves, there was a high overlap in the selection of items in each estuary. Even though the overlap was very high in each case, it was higher in the Volta estuary (G$\hat{o}$ = 0.947) than in the Pra estuary (G$\hat{o}$ = 0.904). The cluster dendograms (Fig. 18) based on frequency of items consumed by the different species in each estuary show that *L. falcipinnis* and *M. bananensis* frequently consumed similar items in both estuaries. Also, *L. dumerilii* and *L. grandisquamis* in the Pra estuary preferred similar items. The items found in the stomachs of *M. curema* in the two estuaries were more related to that found in *L. falcipinnis* and *M. bananensis* in both places and also to that found in the stomachs of *L. dumerilii* and *L. grandisquamis* in the Pra estuary. *M. cephalus* in the two estuaries had little interaction with the other species with respect to the items found in their stomachs. This is, most probably, due to the presence of more polychaetes in their stomachs compared to the other species. The low interaction is corroborated by the specific overlap index (S$\hat{o}$), of *M. cephalus* on the other species which was below 0.5.

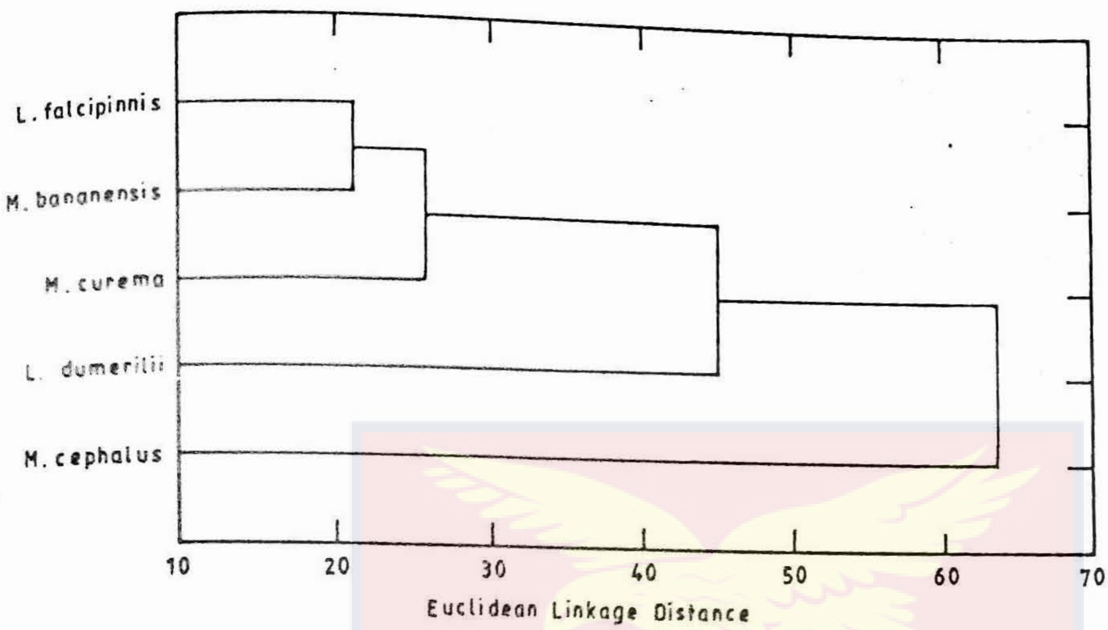

Fig. 18a Cluster diagram based on frequency of stomach contents of grey mullets from the Volta estuary

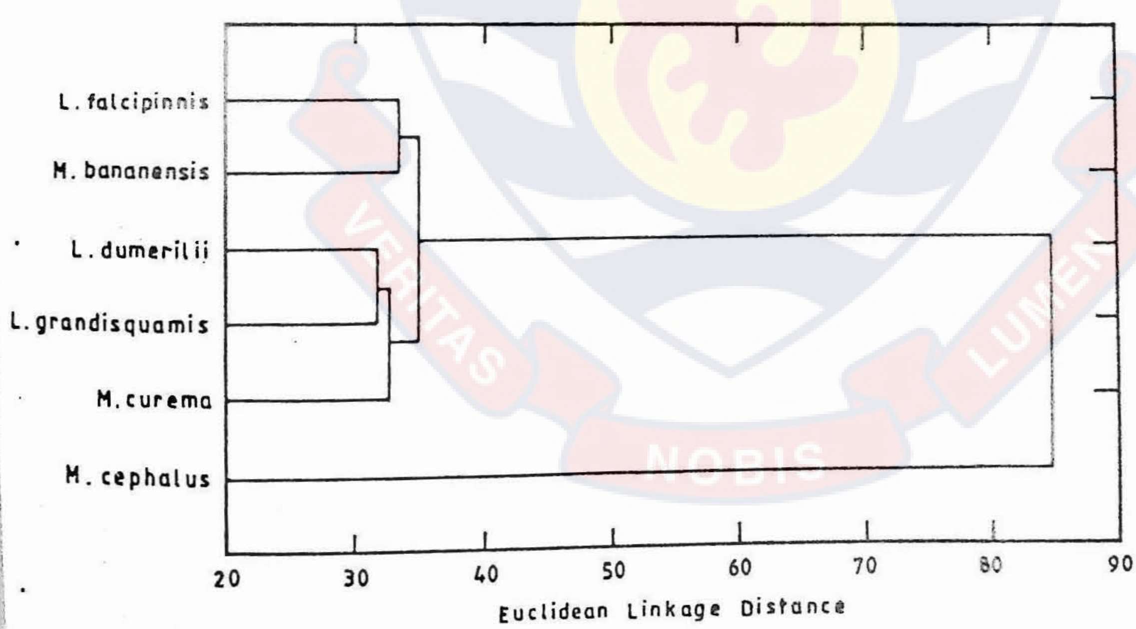

Fig. 18b Cluster diagram based on frequency of stomach contents of grey mullets from the Pra estuary

Particle size selection

Table 9 shows the size of sand particles ingested while their frequency distribution in the different mullet species in both places is illustrated in Figure 19. The species from the Volta estuary generally ingested larger sand particles than their counterparts from the Pra estuary.

In each estuary, *L. dumerilii* ingested the widest range of sand particles from 41.2 to 1195.8 μm with a mean size of 248.8 μm in the Volta estuary and from 33.0 to 1649 μm with a mean size of 194.6 μm in the Pra estuary. The most frequently ingested sand particles by *L. dumerilii*, *M. curema* and *M. cephalus* in the Volta estuary measured 120-139 μm. In the Pra estuary, the most preferred particle size by *L. dumerilii* was 80-99 μm, similar to the commonest size ingested by *L. grandisquamis* in the same estuary. The size of sand particles filtered by the latter species, however, ranged from 31.4 to 270.4μm. The smallest size range of 16.5 – 255.7 μm was ingested by *M. bananensis* in the Pra estuary while in the Volta estuary *L. falcipinnis* filtered the smallest size range, 33.0 – 479.4 μm. The most ingested particle size ranged from 40 to 59 μm for *M. bananensis*, and from 80 to 99 μm for *L. falcipinnis*.

Table 9 Size of sand particles ingested by grey mullets from the Volta and Pra estuaries.

Species	Estuary	Particle size range (μm)	Modal class (μm)	Mean particle diameter (μm)
L. falcipinnis	Volta	33.0 – 479.4	60-79	126.7
	Pra	31.2 – 479.4	40-59	118.3
L. dumerilii	Volta	41.2 – 1195.8	120-139	248.8
	Pra	33.0 – 1649.4	80-99	194.6
L. grandisquamis	Volta	-		-
	Pra	31.2 – 270.4	80-99	99.7
M. bananensis	Volta	41.2 – 494.8	80-99	132.9
	Pra	16.5 – 255.7	40-59	71.9
M. curema	Volta	33.0 – 618.6	120-139	156.5
	Pra	31.2 – 527.8	60-79	123.1
M. cephalus	Volta	41.2 – 783.5	120-139	213.3
	Pra	31.2 – 675.4	100-119	187.3

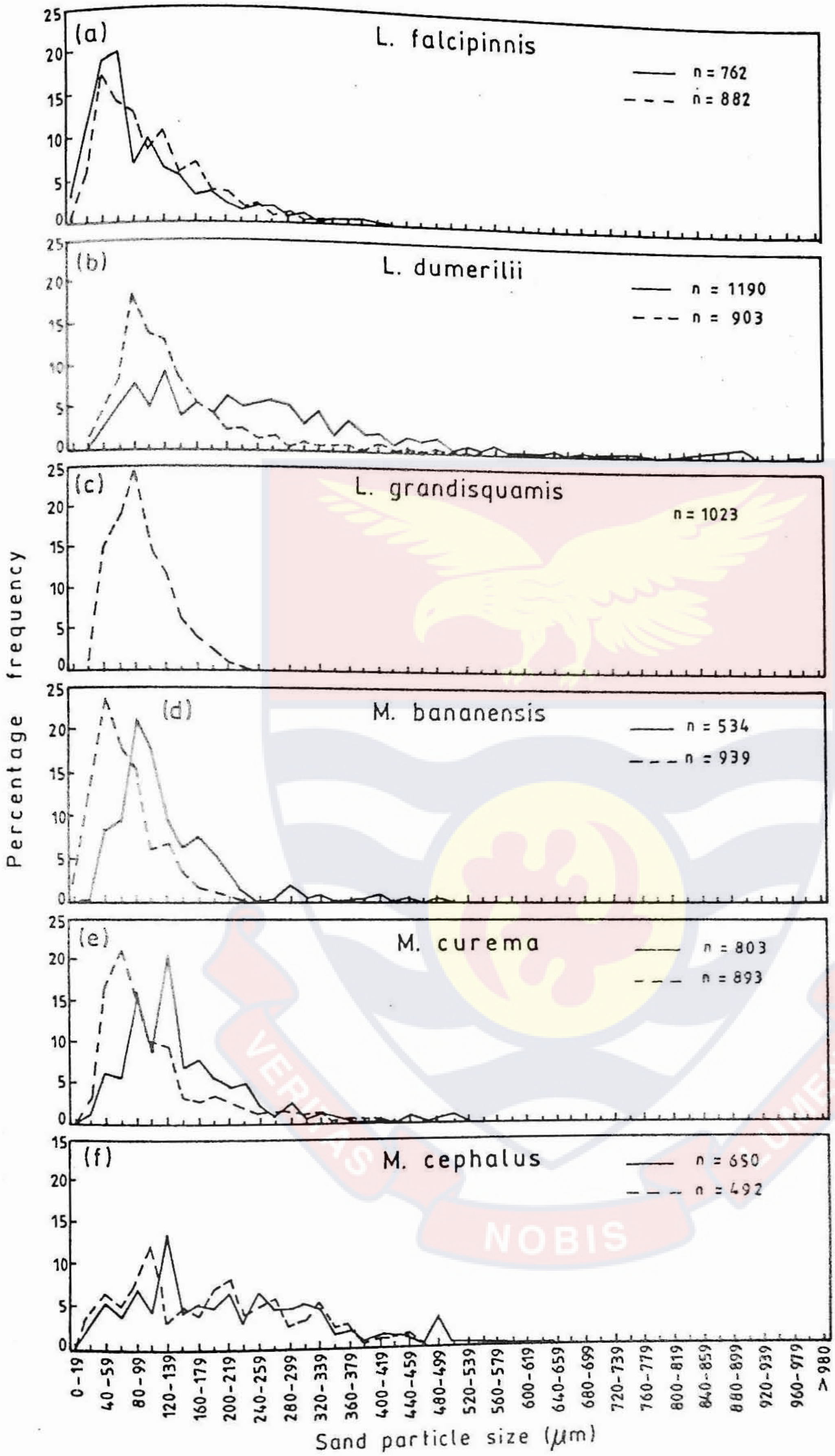

Fig. 19 Size distribution of sand particles in stomachs of mullet species from the Volta (—) and Pra (---) estuaries.
n = number of sand particles counted.

Monthly feeding activity

Changes in monthly feeding activity, measured as changes in the index of stomach fullness (FI), are illustrated in Figure 20 for both estuaries. Feeding activity in both estuaries was erratic during the study period.

Even though erratic, feeding activity was generally low for most of the species in July during the first year in the Volta estuary. This was immediately after the peak of the major rainy season that occurred in June (Appendix 1). Again there was a drop in feeding activity in October for all the species except *M. cephalus* and *L. dumerilii*. The drop in October corresponded with the peak in the minor rainy season. Feeding activity was high in either May or June (major rainy season) and during the low rainfall periods in August, September, November and December 1997. In 1998 the peak of the major rainfall, which occurred in May, corresponded with low feeding activity for most of the species.

Feeding activity of mullets in the Pra estuary was more continuous and higher between March and July 1998 than in the Volta estuary. The high feeding activity during this period coincided with the rainy season. Similarly, in 1997, the feeding activity of *M. bananensis* and *M. curema* was higher between March and June. Higher peaks also occurred during the low rainfall month of January 1998 for most of the species. With the exception of *L. grandisquamis*, the feeding activity of all the species in the Pra estuary was lower during the low rainfall period in August/September and December 1997, and in February 1998.

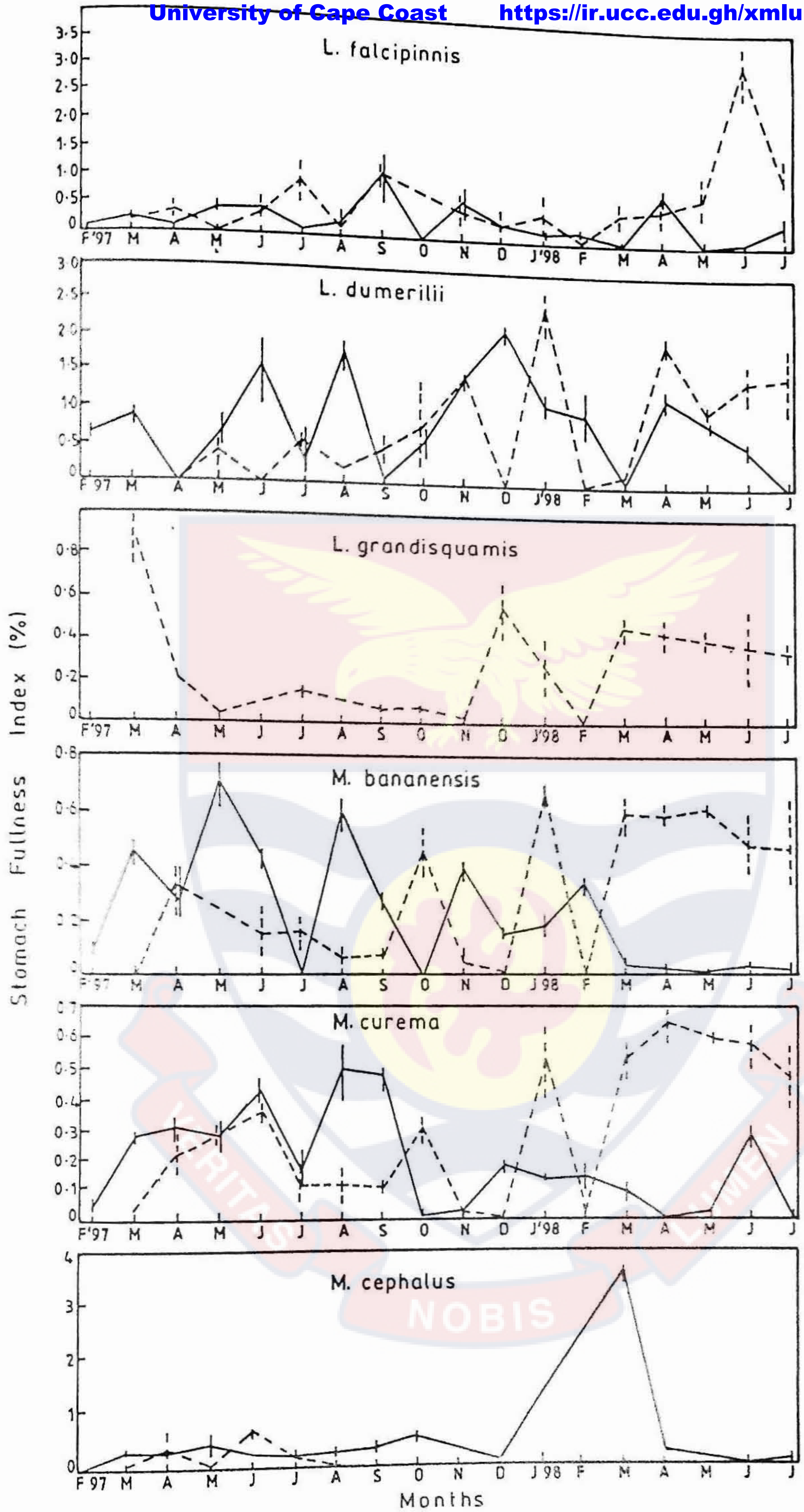

Fig. 20 Changes in stomach fullnes index of grey mullets from the Volta (—) and Pra (----) estuaries. Vertical bars = ± SE

The species that consumed the highest quantity of food with respect to body weight in the Volta estuary were *M. cephalus* followed by *L. dumerilii*. The quantity of food consumed varied from 0.0 to 3.6% and 0.0 to 2.2% of their total body weight respectively. In the Pra estuary *L. falcipinnis* and *L. dumerilii* were the species which consumed the most food. The FI recorded for these species ranged from 0.0 to 3.4% and 0.0 to 2.5% respectively.

Daily feeding cycle

Changes in the mean index of stomach fullness of the mullets in the Volta estuary over two 24-h periods are illustrated in Figure 21 while the fluctuations in environmental parameters measured during the same periods are shown in Figure 22. Conditions in the Pra estuary precluded the use of dragnet, which was the only means of getting enough specimens during each sampling period to follow the daily feeding cycle. The main feeding period in the Volta estuary was during the day between 08.00 and 12.00 h for all the species. There was little or no feeding during the night till dawn, between 20.00 and 04.00 h. The peak in feeding activity for *L. dumerilii* and *L. falcipinnis* occurred at 08.00 h while the peak for *M. bananensis* and *M. curema* occurred at 12.00 h on both sampling occasions. The feeding activity of *M. cephalus* peaked at 20.00 for the first 24-h sampling and at 08.00 h for the second sampling. The highest feeding activity, on both occasions, was shown by *L. dumerilii*, consuming 2.3 and 2.6% of its body weight while *M. cephalus* was the least active feeder.

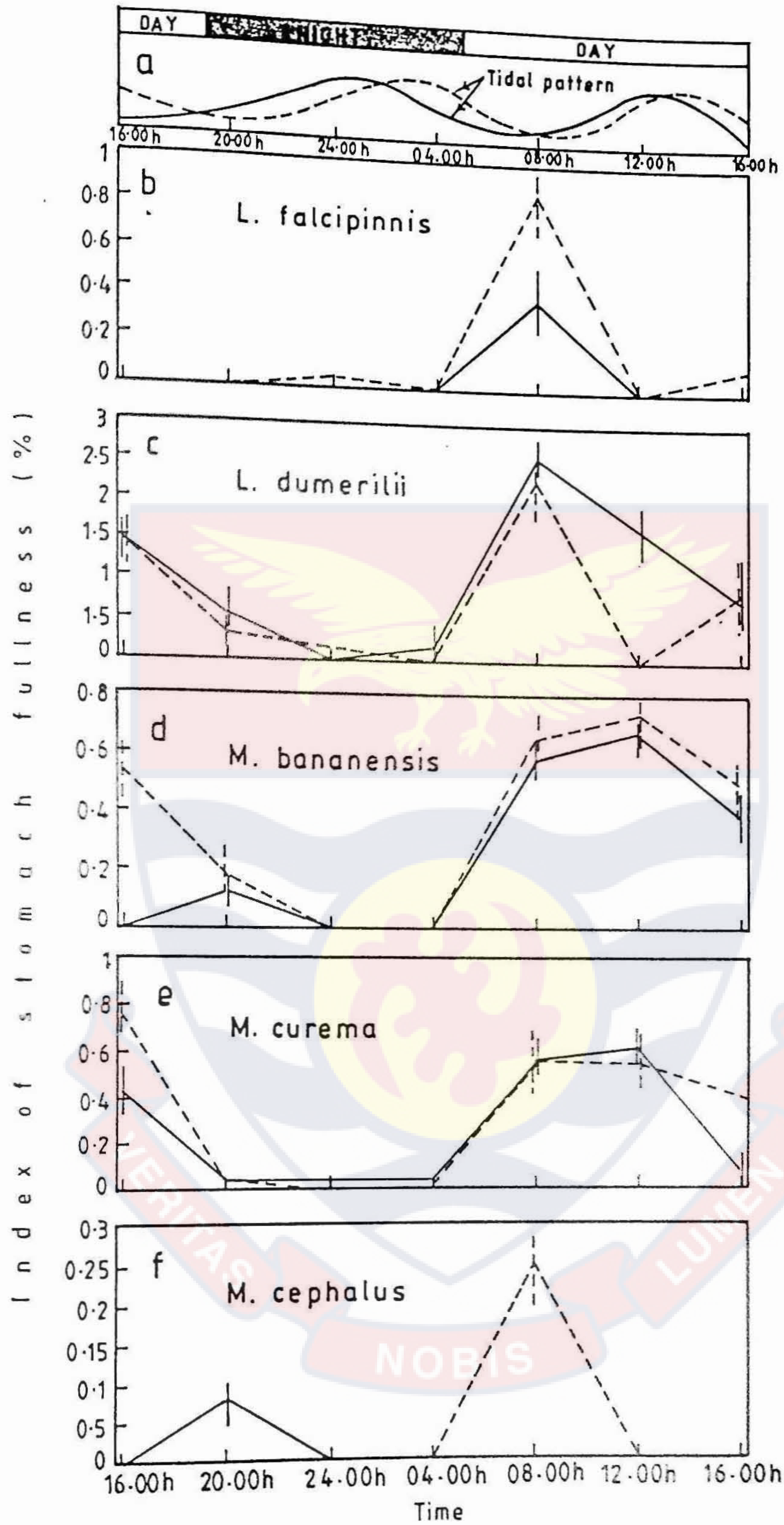

Fig. 21 Tidal patten and feeding periodicity of grey mullets in the Volta estuary on 11-12th November, 1998 (—) and 9-10th June 1999 (-----). Vertical bars = ± SE

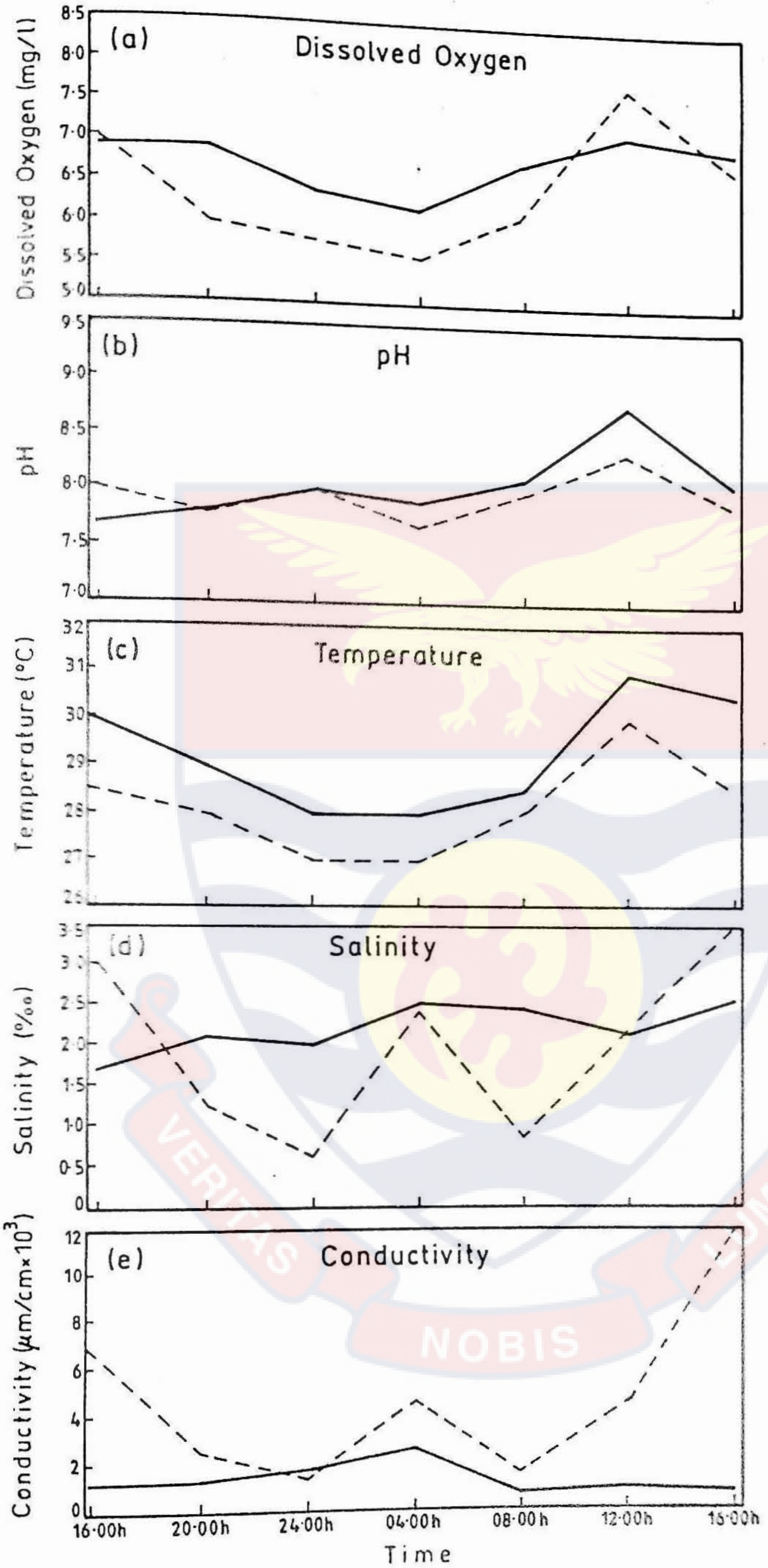

Fig. 22 : Daily changes in environmental parameters in the Volta estuary on 11-12TH November 1998 (—) and 9TH - 10TH June 1999 (- - -)

The pattern shown by dissolved oxygen concentration, pH and temperature during the 24-h study closely related to the feeding activity of *M. bananensis* and *M. curema*, and to some extent, that of *L. dumerilii* and *L. falcipinnis*. Higher feeding activity occurred with increasing pH, temperature and dissolved oxygen concentration. The peak of feeding activity of *L. falcipinnis*, *L. dumerilii* and *M. cephalus* coincided with low tides while that of *M. bananensis* and *M. curema* occurred during both periods of low and high tides in the study area.

There was a significant correlation between pH and feeding activity of *M. bananensis* ($r=0.81$, $p < 0.05$) and *L. falcipinnis* ($r=0.82$, $p < 0.05$) during the first 24-h sampling (Appendix 10a). During the second 24-h sampling, significant correlation was found between dissolved oxygen concentration and feeding activity of *M. bananensis* ($r=0.831$, $p < 0.05$) and *M. curema* ($r=0.767$, $p < 0.05$) (Appendix 10b). Apart from dissolved oxygen concentration, the feeding activity of *M. bananensis* significantly correlated with surface water temperature ($r=0.85$, $p < 0.05$) and again with pH ($r=0.7740$, $p < 0.05$) during the second 24-h sampling.

A positive correlation was found between pH and feeding activity of all the species while salinity showed positive correlation with the feeding activity of *L. dumerilii* and *M. bananensis*.

Intestine length to standard length ratio (Relative Gut Length)

The shortest mean relative gut length, i.e. the ratio between intestine length and standard length, of 1.82 and 1.72 were calculated for *L. dumerilii* in the Volta and Pra estuaries, respectively. The longest mean relative gut length of 4.56 was calculated for *M. cephalus* in the Volta estuary while in the Pra estuary the longest relative gut length of 4.33 was calculated for *L. falcipinnis* (Table 10). The relative gut length of *M. cephalus* in the Pra estuary was not determined because only a few individuals were available. To compare the relative gut lengths of a given species from the two sites, Student's *t*-test was performed. The relative gut length of *L. falcipinnis* and *L. dumerilii* in the Volta estuary was significantly different ($P < 0.05$) from the same species in the Pra estuary. However, those of *M. bananensis* and *M. curema* in the Volta estuary were fairly similar to their counterparts in the Pra estuary.

The relationship between relative gut length and standard length was established by calculating regression lines using the method of least squares. Figure 23 illustrates the relationship for all the species with the regression equations presented in Table 11.

All the species from the Volta estuary showed a positive relationship between relative gut length and standard length with that of *M. curema, M. bananensis* and *M. cephalus* being significant ($p < 0.05$). The relationship for *L. falcipinnis, M. bananensis* and *L. grandisquamis*, in the Pra estuary was however, negative. *L. falcipinnis* and *M. curema* in the Pra estuary showed significant relationship between gut length and standard length. Considering the same species, it was only *M. curema* and *L. dumerilii* whose gut length and standard length showed similar relationship with their counterparts from each estuary. The relationship of gut length and standard length of the other species was different from their counterparts in each estuary.

Table 10 Relative gut length and standard length of grey mullets from the Volta and Pra estuaries.

Species	Number of Specimens Analysed	Range of standard length (mm)	Range of gut length (mm)	Relative gut length	
				Range	Mean ± S.D.
Volta estuary					
L. falcipinnis	106	125-232	270-1054	2.00-4.59	3.89±0.68
L. dumerilii	102	65-200	120-415	1.18-2.57	1.82±0.31
M. bananensis	78	62-190	162-820	2.61-5.07	3.76±0.72
M. curema	124	87-235	265-1475	2.48- 5.59	3.96±0.61
M. cephalus	32	113-375	380-1565	3.36-5.27	4.56±0.54
Pra estuary					
L. falcipinnis	143	70-120	230-580	2.95-5.92	4.33±0.66
L. dumerilii	92	60-168	88-370	1.36-2.50	1.72±0.27
L. grandisquamis	63	80-160	105-390	1.08-2.56	2.00±0.46
M. bananensis	88	75-170	160-600	2.67-4.58	3.81±0.43
M. curema	104	70-113	170-505	2.46-5.05	4.01±0.48

Table 11 Relative gut length (RGL) and standard length (SL mm) relationship of grey mullets from the Volta and Pra estuaries.

Species	Volta	Pra
L. falcipinnis	RGL = 3.1160 + 0.0053 SL r = 0.1793	RGL = 6.5154 – 0.0230 SL r = -0.2582*
L. dumerilii	RGL = 1.9824 + 0.0013 SL r = 0.0994	RGL = 1.6034 + 0.0024 SL r = 0.1435
L. grandisquamis	-	RGL = 2.3818 – 0.0027 SL r = -0.1574
M. curema	RGL = 3.5057 + 0.0034 SL r = 0.1855*	RGL = 3.0600 + 0.0108 SL r = 0.2684*
M. bananensis	RGL = 3.3323 + 0.0065 SL r = 0.2748*	RGL = 4.0346 + 0.0023 SL r = -0.0882
M. cephalus	RGL = 3.0415 + 0.0055 SL r = 0.5324*	-

* *Significant correlation at 5% probability level.*

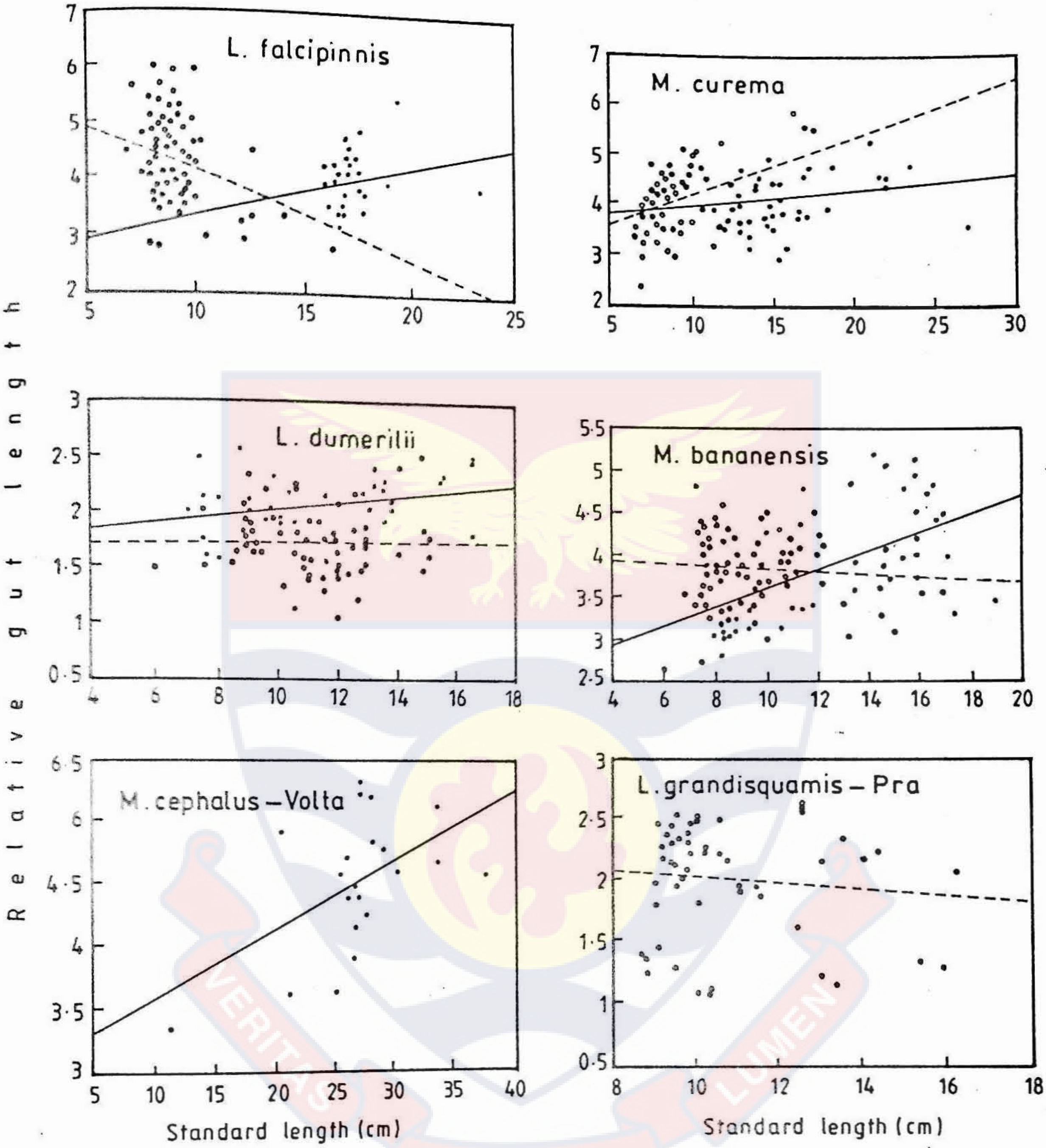

Fig. 23: Relationship between standard length and relative gut length of grey mullets from the Volta and Pra estuaries.(—•—) Volta (-○-) Pra

Changes in Condition Factor (K)

Table 12 presents the overall Condition Factor of the six species from the two estuaries considering individuals measuring between 90 and 150 mm (SL). The differences in the Condition Factor of the species from the Pra and the Volta estuaries were not significant (p>0.05) except that of *L. falcipinnis* and *M. bananensis* in the former which was significantly higher than in the latter estuary. Monthly fluctuations in Condition Factor of the different species are illustrated in Fig. 24. The figure depicts that for all species; higher values of Condition Factor were recorded in the Pra estuary than in the Volta estuary for greater part of the study period.

L. falcipinnis: Generally, similar pattern of fluctuations in Condition Factor was shown by the species in both estuaries except in August and October 1997 and in April 1998 (Fig. 24a). The condition Factor in the Pra ranged from 1.60 to 2.04 and that in the Volta ranged from 1.62 to 1.99. Lower values were recorded in October 1997 and April 1998 in the Volta estuary in contrast to the higher values recorded in the Pra estuary during the same period. Similarly, in August 1997 the lower value recorded in the Pra estuary was in contrast to what was recorded in the Volta estuary.

L. dumerilii: The Condition Factor of *L. dumerilii* in the Volta estuary was fairly stable ranging between 1.70 and 1.90 except in April 1997 and March 1998 when it dropped to about 1.6 (Fig. 24b). Fluctuations in the Condition Factor of the species in the Pra estuary was comparatively, erratic ranging between 1.6 and 2.1 with lower values in June and December 1997 and February 1998.

Table 12 Comparison of Condition Factor (K) of grey mullets from the Volta and Pra estuaries.

Species	Pra estuary (K ± sd)	Volta estuary (K ± sd)	*t*
L. falcipinnis	1.8760±0.13 (n=300)	1.7407±0.12 (n=300)	4.0611*
L. dumerilii	1.7856±0.22 (n=300)	1.7407±0.14 (n=300)	1.8354
L. grandisquamis	2.1120±0.15 (n=350)	-	-
M.bananensis	2.2651±0.17 (n=300)	2.1230±0.13 (n=300)	7.0301*
M. curema	2.1984±0.23 (n=300)	2.1745±0.16 (n=300)	0.8987
M. cephalus	2.2221±0.25 (n=15)	2.2092±0.19 (n=130)	0.2902

- *L. grandisquamis* did not occur in the Volta estuary
n = number of individuals used in analysis
* Difference is significant at the 5% probability level

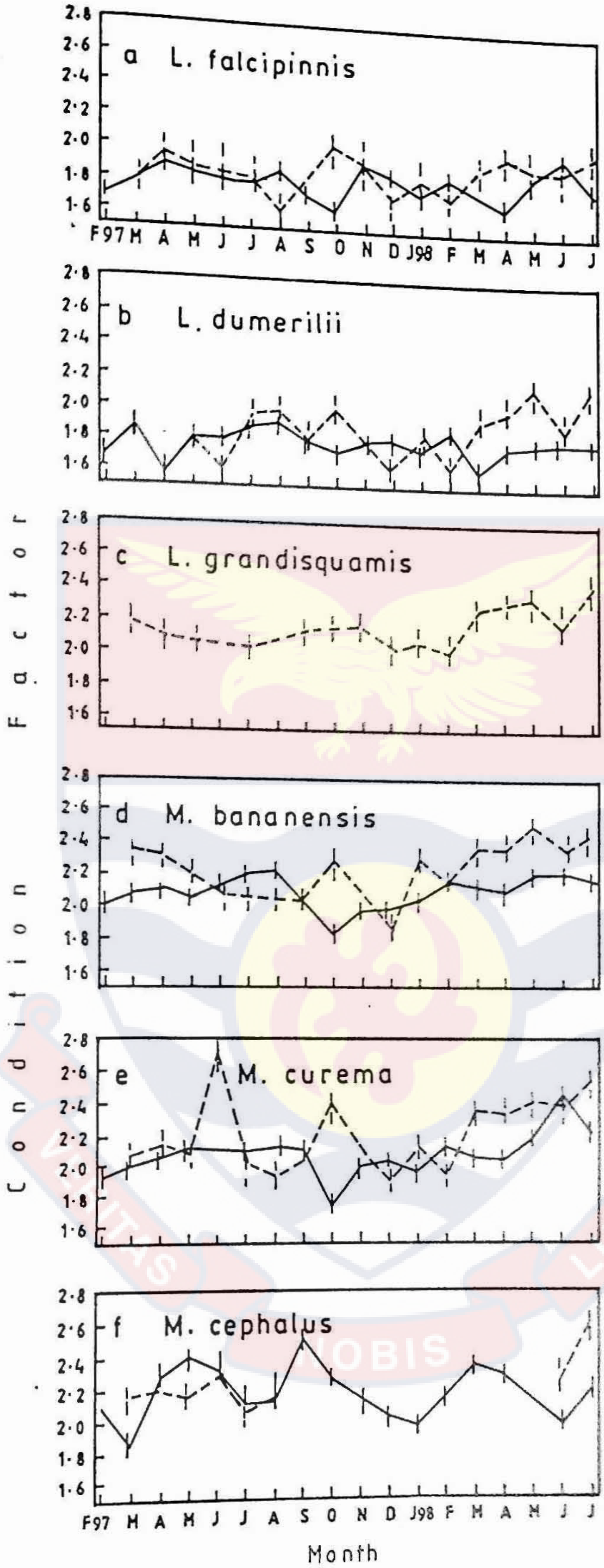

Fig. 24 Variations in Condition Factor of grey mullets in the Volta (——) and Pra (----)estuaries. Vertical bars = ± SE

L. grandisquamis: The species showed a fairly stable Condition Factor ranging between 2.00 and 2.17 from March 1997 to February 1998 (Fig 24c). There was a slight improvement in the Condition Factor from March to July 1998.

M. bananensis: There was a gradual increase in Condition Factor of the species in the Volta estuary from February till August 1997 (Fig. 24d). During the same period, a declining trend was shown by the species in the Pra estuary. Between February and July 1998 while the Condition Factor remained fairly stable in the former estuary it generally, kept increasing in the latter during the same period. The least values occurred in October and December in the Volta and Pra estuaries, respectively. The range of Condition Factor was 1.82-2.21 in the Volta estuary and 1.85-2.48 in the Pra estuary.

M. curema: Apart from the values recorded in June and October 1997, the fluctuations in the Condition Factor of this species were quite similar in both estuaries (Fig. 24e). It ranged from 1.74 to 2.42 in the Volta estuary and from 1.88 to 2.71 in the Pra estuary. Like the previous four species, the values calculated in October 1997 followed the same pattern of low Condition Factor in the Volta estuary and high Condition Factor in the Pra estuary. The Condition Factor between March and July 1998 was fairly high in both estuaries.

M. cephalus: The Condition Factor of the species fluctuated between 1.86 and 2.50 in the Volta estuary. In the Pra estuary, it ranged from 2.28 to 2.06. From April to June 1997, September to October 1997 and March to April 1998, the Condition Factor was high while low values occurred from July to August 1997, December to January 1997 and in June 1998 (Fig. 24f). The Condition Factor of the few specimens that were available from the Pra estuary showed a similar fluctuation as in the Volta estuary for the periods they were available.

Reproductive Biology

Changes in Gonadosomatic Index (GSI)

Gonadosomatic index of *M. cephalus* from the Volta estuary and for all the species in the Pra estuary, with the exception of *L. grandisquamis*, were not calculated because only a few or no mature individuals were encountered in the samples. In the Volta estuary, the maximum GSI of all the species occurred between February and August for both sexes. *M. bananensis*, however, showed another peak in October (Fig. 25). Two peaks were recorded for *L. grandisquamis* from the Pra estuary; one in April and the other in November 1997 for both sexes. In 1998 however, the peak for males occurred in February while that for females occurred in April. The occurrence of more than one peak in the GSI for all the species investigated suggest that they are multiple spawners, spawning more than once during the spawning season.

Individually, the highest gonadosomatic index of 18.16% was recorded for both *M. bananensis* and *L. dumerilii* in the Volta estuary, while in the Pra estuary, the highest value of 20.58% was recorded for *L. dumerilii*. Maximum values obtained for the other species in the Volta estuary are: *M. curema*, 12.43%, *L. falcipinnis*, 10.32%. In the Pra estuary a maximum value of 9.71% was recorded for *L. grandisquamis*.

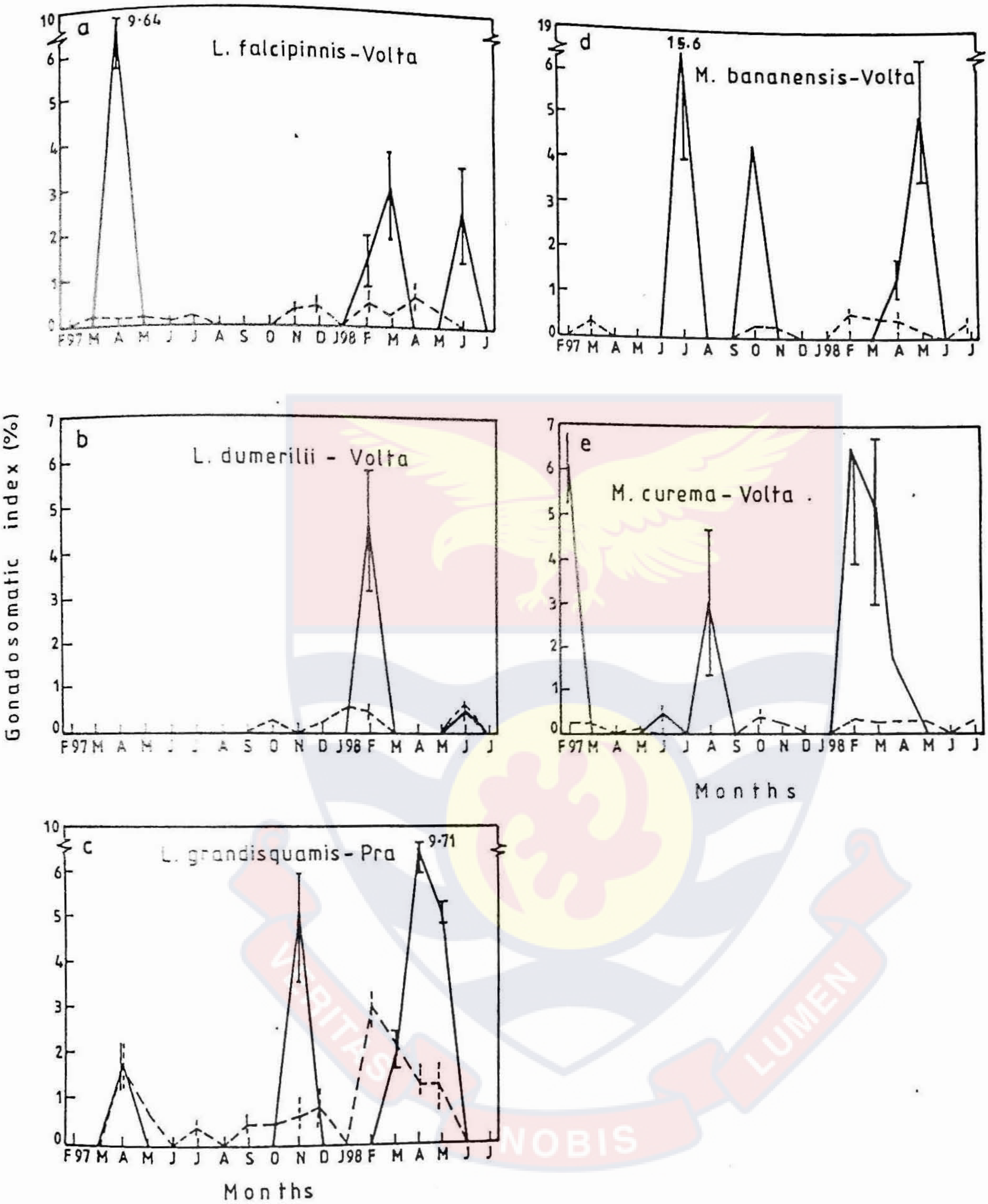

Fig. 25 Changes in gonadosomatic index of grey mullets from the Volta and Pra estuaries (--- males, — females Vertical bars = ± SE)

Description of gonadal stages

The morphological and histological features used to define each of the stages recognised in males and females are presented below. A four-point scale was used for the classification of testes while ovaries were assigned a five-point scale. Histologically, distinction between maturation phases was based on the presence or absence of particular spermatogenic or oogenic cells. Immature specimens whose sex could not be determined were assigned Stage 0.

Male

Stage I (Developing) - Testes were pale rose in colour. Histological sections showed compact seminiferous tubules with a small lumen and contained only groups of spermatogonia and primary spermatocytes (Fig. 26a).

Stage II (Maturing) - Testes were white and swollen with milt but no milt was released when pressure was applied on the sides of the belly of the fish. Testes were clearly organised as tubules with germinal material (Fig. 26b).

Stage III (Mature) - Milt oozed from the genital tract of the fish when sides of the body were pressed. Tubules of testes show predominance of spermatozoa (Fig. 26c).

Stage IV (Spent) - Testes appeared reddish in colour, virtually empty and flabby with some residual sperm. Histologically, lumen of tubules showed virtually empty spaces with germinal material (Fig. 26d).

Female

Stage I (Developing or pre-vitellogenic stage) - Ovaries were translucent, grey-red and round or teardrop shaped. Primary oocytes were the main histological cell types (Fig. 27a). The cytoplasm of the oocytes had no granules. Oocytes had large nuclei. The size of oocytes ranged from 21 to 125 μm with oocytes measuring 78 μm being the most abundant.

Stage II (Maturing or yolk vesicle stage) - Ovaries were yellowish with small and opaque oocytes that were visible to the naked eye (Fig. 27b). Oocytes were characterised by granular cytoplasm. The size range of oocytes was from 21 to 281 μm with the predominant size being 182 μm.

Stage III (Mature or early vitellogenic stage) - Ovaries were yellowish and filled with yolky oocytes with large cytoplasmic vacuoles (Fig. 27c). Diameter of predominant oocyte type was 286 μm but oocytes ranged from 21 to 385 μm.

Stage IV (Running or late vitellogenic stage) - Ovaries were orange-yellowish. Eggs flowed freely upon pressure on the sides of the belly of the fish. The large yolky oocytes had cytoplasm interspersed with cytoplasmic vacuoles (Fig. 27d). Membrane enclosing the egg proper was comparatively thick and oocyte diameter ranged from 21 to 593 μm with oocytes measuring 338 μm being the predominant type.

Stage V (Spent) - Ovaries were wine red in colour and flaccid with some residual oocytes. Atretic oocytes were present with irregular shapes with detached outer membrane (Fig. 27e).

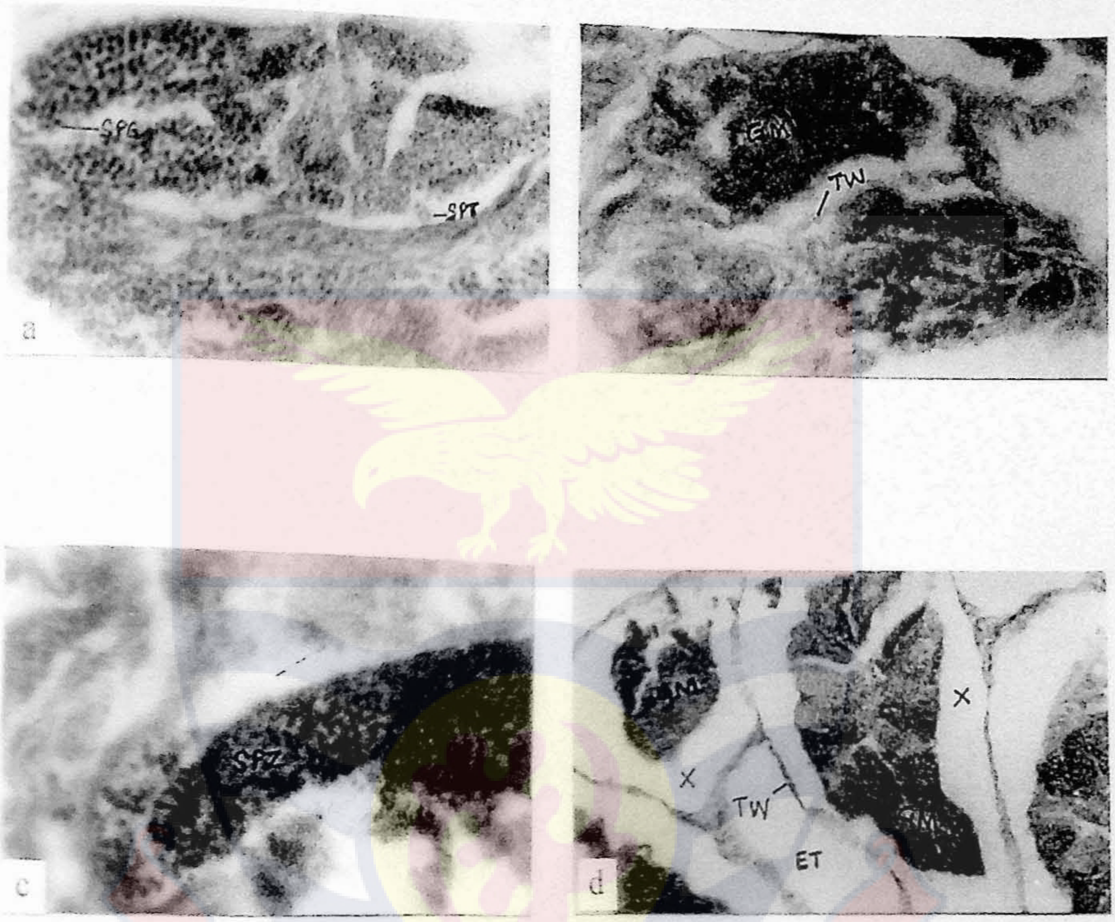

Fig. 26 Photomicrographs of grey mullet testes (a) Stage I testes showing spermatogonia SPG, and spermatocytes SPT x100. (b) Satge II testes showing distinct tubules, TW with germinal material GM, x100 (c) Stage III testes showing spermatozoa SPZ x250. (d) Stage IV testes showing tubules with germinal material, GM (ET empty tuble, X empty portions of tubules, TW tubular wall) x 100.

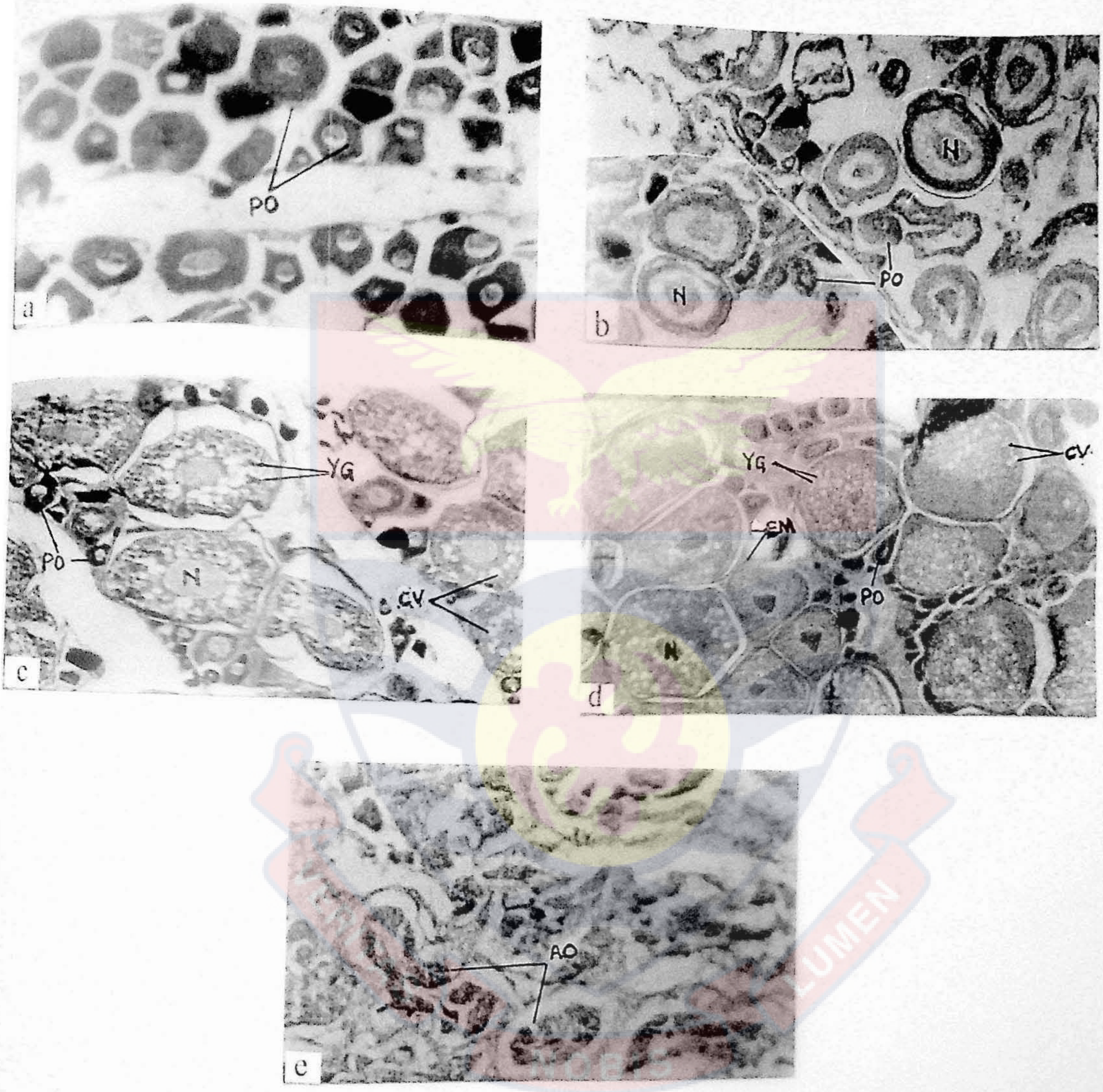

Fig. 27 Photomicrographs of cross sections of grey mullet ovaries. (a) Stage I ovaries showing primary oocyte. PO, x25. (b) Stage II ovaries showing yolk vesicle stage with nucleus N. x25. (c) Satge III ovaries showing yolk granules YG, nucleus N, large cytoplasmic vacuoles CV. x25. (d) Stage IV showing cytoplasmic vacuoles CV, thick egg membrane EM, x25. (e) Stage V showing atretic oocytes AO, x25.

Size frequency distribution of oocytes

The size frequency distribution of oocytes from the various stages of ovaries is shown in Figure 28. Stage I and II ovaries showed unimodal distribution of oocytes. The size of Stage I oocytes ranged from 20.8 to 124.8 μm with a modal class of 52-104 μm while that of Stage II ranged from 20.8 to 280.8 μm with modal classes of 156-208 μm. Two modes were exhibited by Stages III and IV oocytes. Oocytes in Stage III ovaries ranged from 20.8 to 384. 8 μm with the first modal class of 52-104 μm and the second one of 260-312 μm. The size range of oocytes in Stage IV ovaries was from 20.8 to 592.8 μm with 78-130 μm and 312-364 μm as the modal classes.

The mode in Stage I ovaries changed from 52-104 μm to 312-364 μm in Stage IV ovaries with the first mode always present in the Stages III and IV. The presence of two distinct modes in Stages III and IV was an indication that the species were multiple spawners with distinct spawning periods.

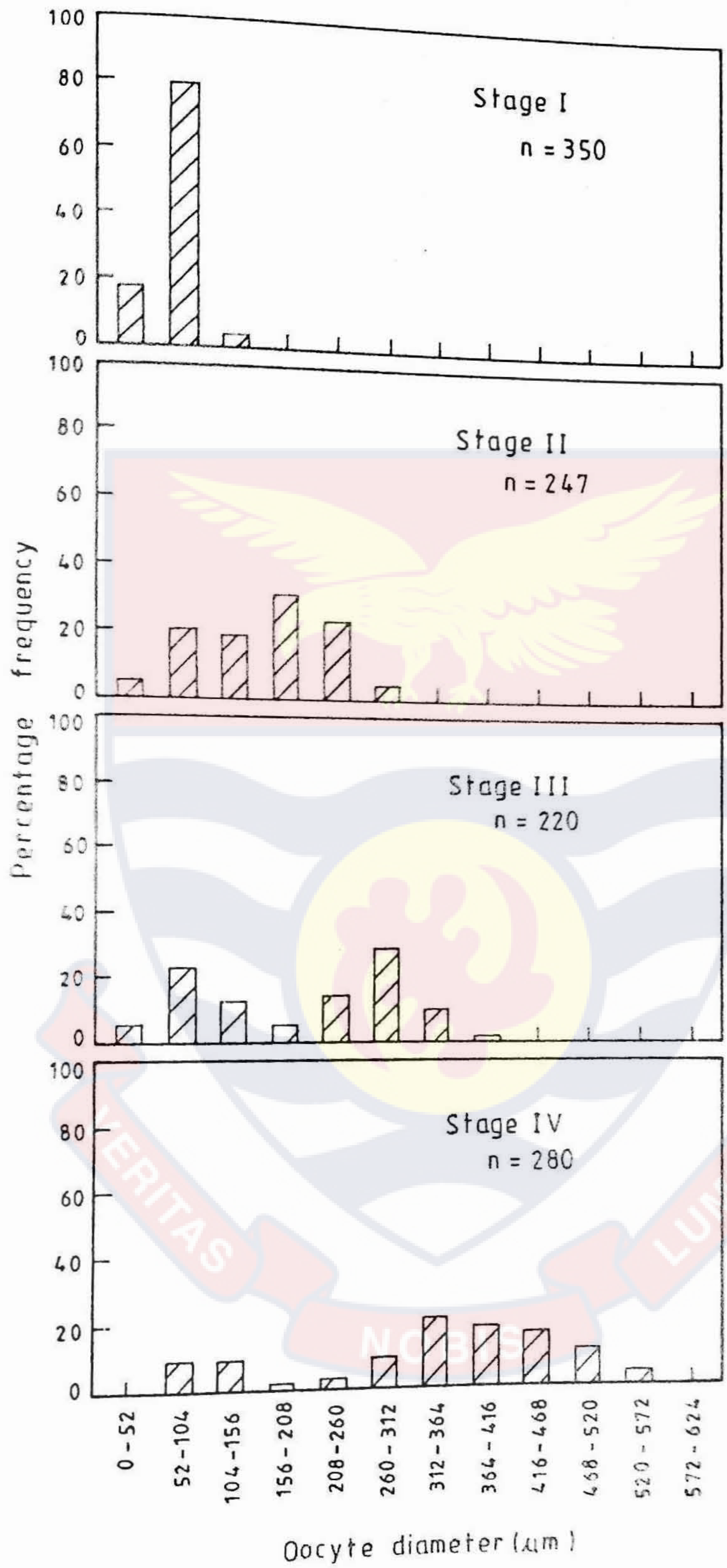

Fig. 28 Size frequency distribution of oocytes in different gonadal stages of grey mullets (n = number of oocytes)

Monthly variations in the occurrence of gonadal stages

Figures 29-32 show monthly variations in the percentage of fish with gonads at different stages of maturation. In the Pra estuary, *L. dumerilii*, *M. bananensis* and *L. grandisquamis* were the species that had some mature individuals unlike the Volta estuary where mature individuals were found for all the species.

L. falcipinnis

Volta estuary: Between October 1997 and January 1998 individuals in Stage I for both sexes were absent from the estuary (Fig. 29). Both sexes in Stage II were present in the estuary for most part of the study period. In contrast to the Stage I counterparts, they predominated from February to July 1997 as well as in November and December 1997. Each of the sexes in that Stage constituted over 20% of all the gonadal stages, for the months in which they occurred. No females in Stage III appeared in the estuary in the first year. They however, occurred in the second year in February, March and June but were less than 20% in each month. Males in Stage III dominated in November 1997 and in April and May 1998 constituting 50% of all the males sexed in each month. Ripe females (Stage IV) were caught in April 1997 and March 1998 and constituted 37.5% and 7.7% of all the females sexed in each month respectively. Both spent males (Stage IV) and females (Stage V) were absent from samples.

L. grandisquamis

Pra estuary: Males in Stage I were present in most of the samples unlike their female counterparts, which were not encountered at all in 1998 (Fig 29). The monthly pattern of occurrence was fairly the same for both males and females in Stage II. Both sexes were also present for most part of the study period. Stage III individuals of both sexes were found in April and from October to December 1997 while in 1998 they occurred from February to May. Ripe females (Stage IV) were found in November 1997 and April 1998 when they constituted 16 and 66.6% respectively. Spent females (Stage V) constituting 33.3 % were caught in May 1998 while spent males (IV) were caught in November and December 1997 and in March and May 1998. Their proportion in May was 28.6% and below 12% for the other months.

L. dumerilii

Volta estuary: Like the two species discussed previously, males and females in Stage I were present in the estuary for greater part of the study period in proportions ranging between 40 and 100% (Fig. 30). Stage II males appeared in samples in October and December forming 50 and 43% respectively during the first year. They were, however, present from the beginning of the following year and attained the highest percentage (60%) in June. Stage II females appeared much earlier than the males from July and appeared again in August, November and December 1997 with the highest proportion of 50% being recorded in July. In 1998 they were found only in February and April and constituted 43 and 33.3% respectively.

No females in Stage III were caught in both years. Their male counterparts were however, present in March, October and November 1997 while in 1998 they appeared in January and June. Ripe females (Stage IV) were found only in the second year in February and June. Both spent females (V) and males (IV) were present in samples during the second year in July and June respectively.

Pra estuary: In the first year Stage I individuals appeared in the samples from May while in the second year they appeared from February. The proportions of both sexes ranged between 20% and 100% (Fig. 30). Both sexes in Stage II were also caught in the estuary between May and November 1997. In 1998 only males were caught. This was in March and May and they constituted 50% in each month. Like their counterparts in the Volta estuary, they were absent from the estuary, at least, for the first three months of the first year. Males in Stage III occurred only in February 1998 when they constituted 50% while females occurred in March and November 1997 with percentage composition of 40 and 33.3 respectively. Ripe females (Stage IV) were found only in November 1977 constituting 33.3%. No spent males or females of *L. dumerilii* were caught in the Pra estuary during the study.

M. bananensis

Volta estuary: Stage I males occurred in only a few samples, March, August and December 1997 and February 1998 while Stage I females occurred in all samples in 1998 and in August 1997 (Fig. 31). Like the Stage I males in 1997, Stage II males occurred only in March 1997 while in 1998 they were present in most of the samples. Females in Stage II in the first year were confined between February and May. They occurred in the second year in January, April and July. In 1997 Stage III males were present only in October. They were however, present during the early part of 1998 and were predominant in March when they constituted 80% of all the males caught. Their female counterparts were caught in February 1997 and April 1998 forming 33.3% and 20% respectively of the females caught. Ripe females (Stage IV) were found in July and October in the first year. In the second year they occurred only in the May sample constituting 50%. Spent females (Stage V) and males (IV) were absent in samples in both years.

Pra estuary: Both sexes in Stage I occurred in only a few samples and appeared in the estuary as late as August in the first year. No Stage I females were found in the following year (Fig. 31). Females beyond Stage I were not found in the rest of the samples. Stages II and III males constituting 33.3% for each stage were found in August 1997.

M. curema

Volta estuary: Stage I individuals of both sexes, like most of the other species, was present in most of the samples constituting more than 20% in most cases (Fig. 32). Individuals in Stage II, like the Stage I counterparts, were found in most samples and were more frequent between February and July each year. Individuals in Stage III appeared in a few samples and, comparatively, in low proportions between 7.1% and 23% for females and 4.5% and 37.5% for males. Ripe females (Stage IV) were present in the estuary in February and August 1997 and from February to March 1998 in low proportions (below 7.1%) except in August 1997 where the highest proportion of 33.3% was attained. Spent females (Stage V) were encountered in February and April 1997 while spent males (Stage IV) were found between March and May in both years with the highest proportion occurring in November 1997.

M. cephalus

Volta estuary: All the maturation stages for males were found in the estuary but they occurred mostly in July 1997 (Fig. 32). Unlike the males, only females in Stages I and II were found in the estuary. Stage II females occurred in June 1997 and April 1998 while females in Stage I were present from February to July and in December 1997. In 1998 they occurred in April and May.

Generally, mature males and females in Stages III & IV, (i.e., those ready to spawn) occurred between March-May and again from October-December in the Pra estuary. They were found in the Volta estuary between February-April and July-August for most of the species.

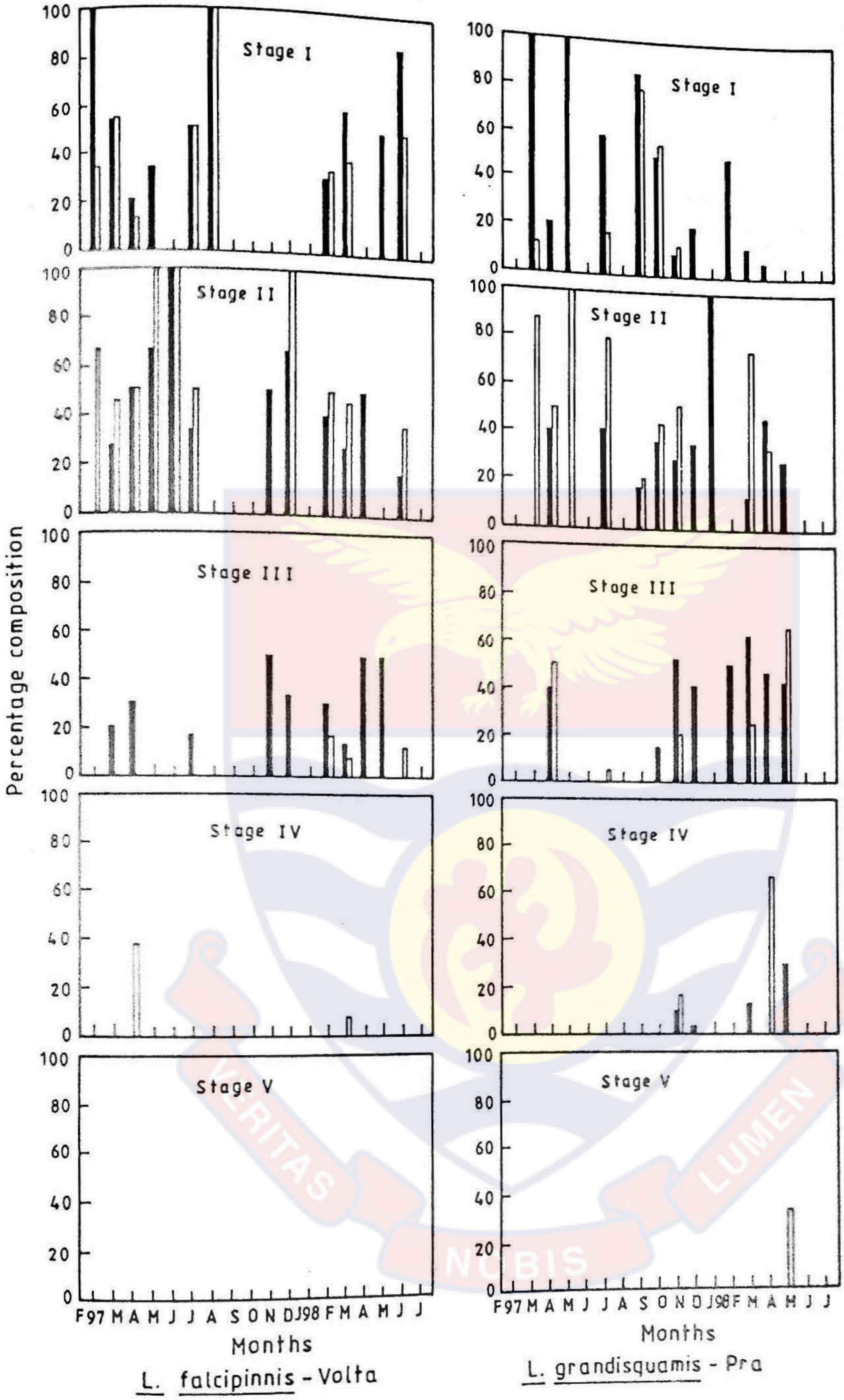

Fig. 29 Monthly variations in the occurrence of gonadal stages of L. falcipinnis from the Volta estuary and L. grandisquamis from the Pra estuary (■ males, □ females)

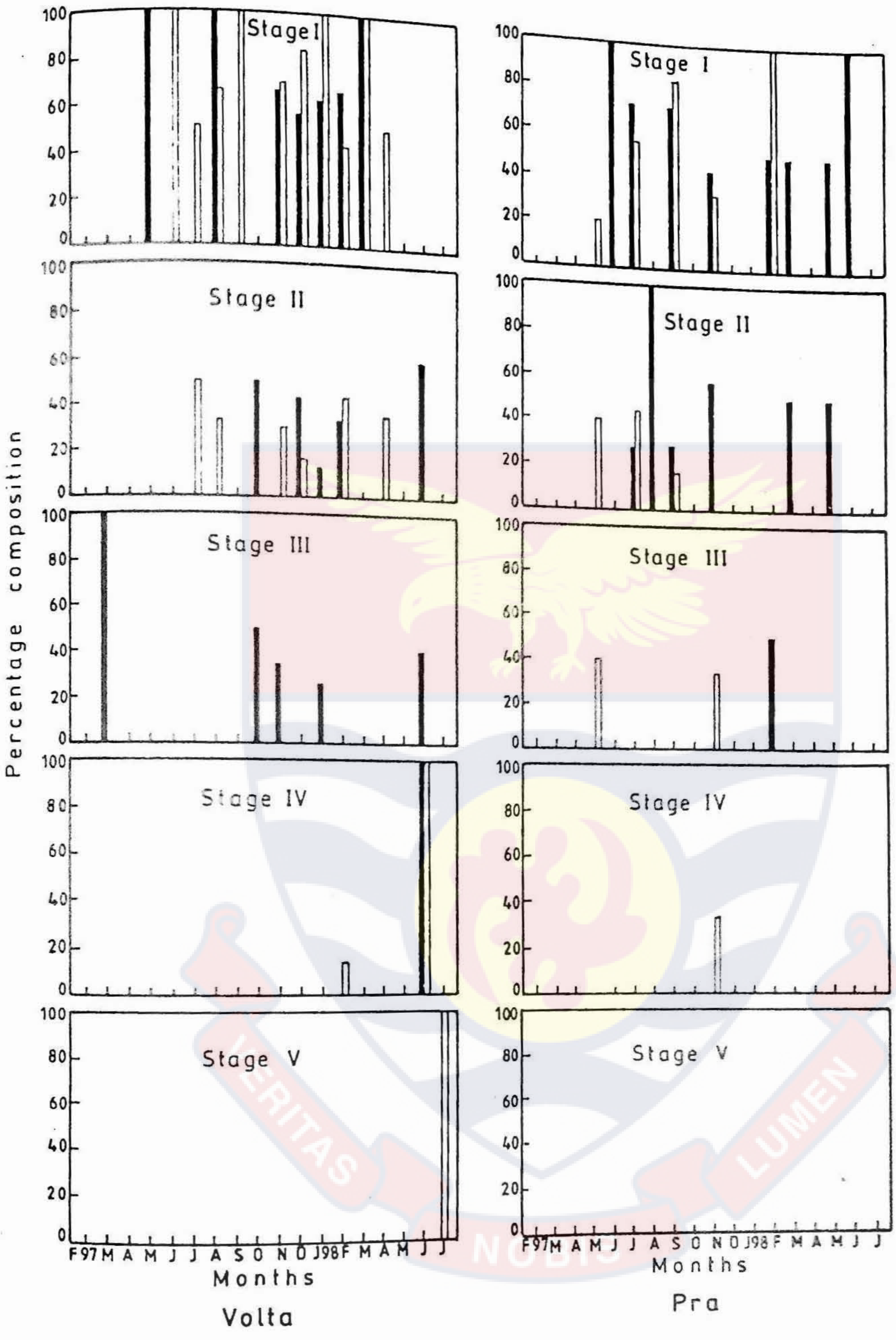

Fig.30 Monthly variations in the occurence of gonadal stages of L. dumerilii from the Volta and Pra estuaries (▮ males, ▯ females).

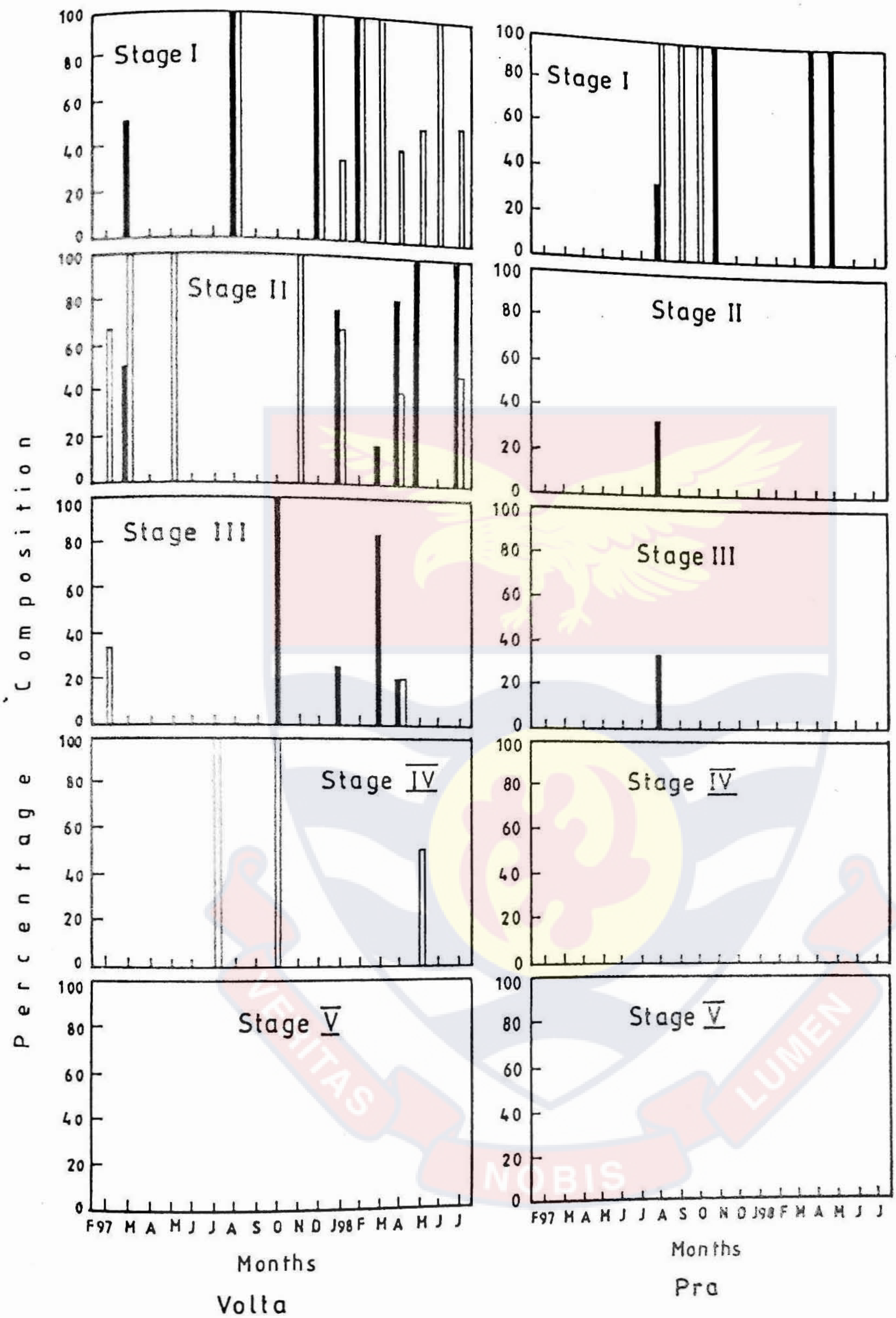

Fig.31 : Monthly variations in the occurrence of gonadal stages of M. bananensis from the Volta and Pra estuaries (▮ males ▯ Females)

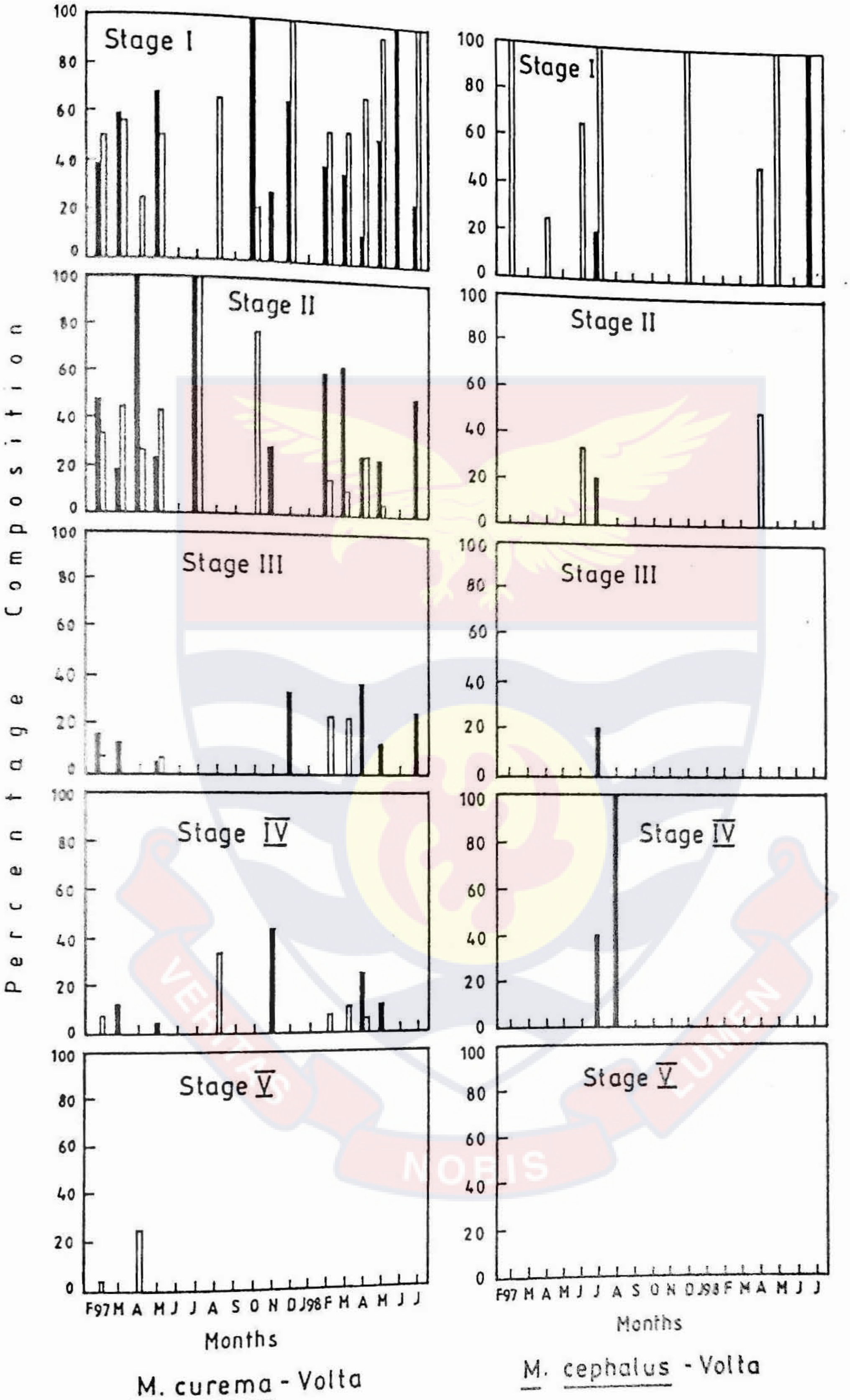

Fig. 32 : Monthly variations in the occurrence of gonadal stages of M. curema and M. cephalus in the Volta estuary (▮ Males, ▯ Females)

Maturity size of the mullets

The cumulative percentage of mature individuals in various length groups was plotted to determine the mean length at first sexual maturity, L_{50} (i.e., the length at which 50% of the population mature, Fig. 33). With the exception of *M. cephalus*, the L_{50} for all the species from the Volta estuary as well as *L. grandisquamis* from the Pra estuary was determined. That of the other species was not determined because only a few or no mature individuals were present in the samples.

The L_{50} for the species from the Volta estuary are: *L. falcipinnis*, 157 mm for males and 175 mm for females; *L. dumerilii*, 148 mm for males and 169 mm for females; *M. bananensis*, 158 mm for males and 171 mm for females; *M. curema*, 151 mm for males and 161 mm for females. In the Pra estuary maturity sizes of *L. grandisquamis* were 115 mm for males and 125 mm for females. Generally, males matured at a smaller size than females.

The smallest mature individuals of the different species observed in the samples are presented in Table 13. Males of all the species were also found to mature at a smaller size than the females. *L. dumerilii* was the only species that had mature individuals in both estuaries. Both sexes of the species matured at a smaller size in the Pra estuary than in the Volta estuary.

Table 13. The smallest size at maturity observed for grey mullets from the Volta and Pra estuaries.

Species	Smallest matured fish (SL mm) Volta estuary		Smallest matured fish (SL mm) Pra estuary	
	Males	Females	Males	Females
L. falcipinnis	140	167	*	*
L. dumerilii	130	170	118	168
L. grandisquamis	-	-	95	102
M. bananensis	140	152	*	*
M. curema	130	150	*	*
M. cephalus	375	*	-	-

* No mature individual present.

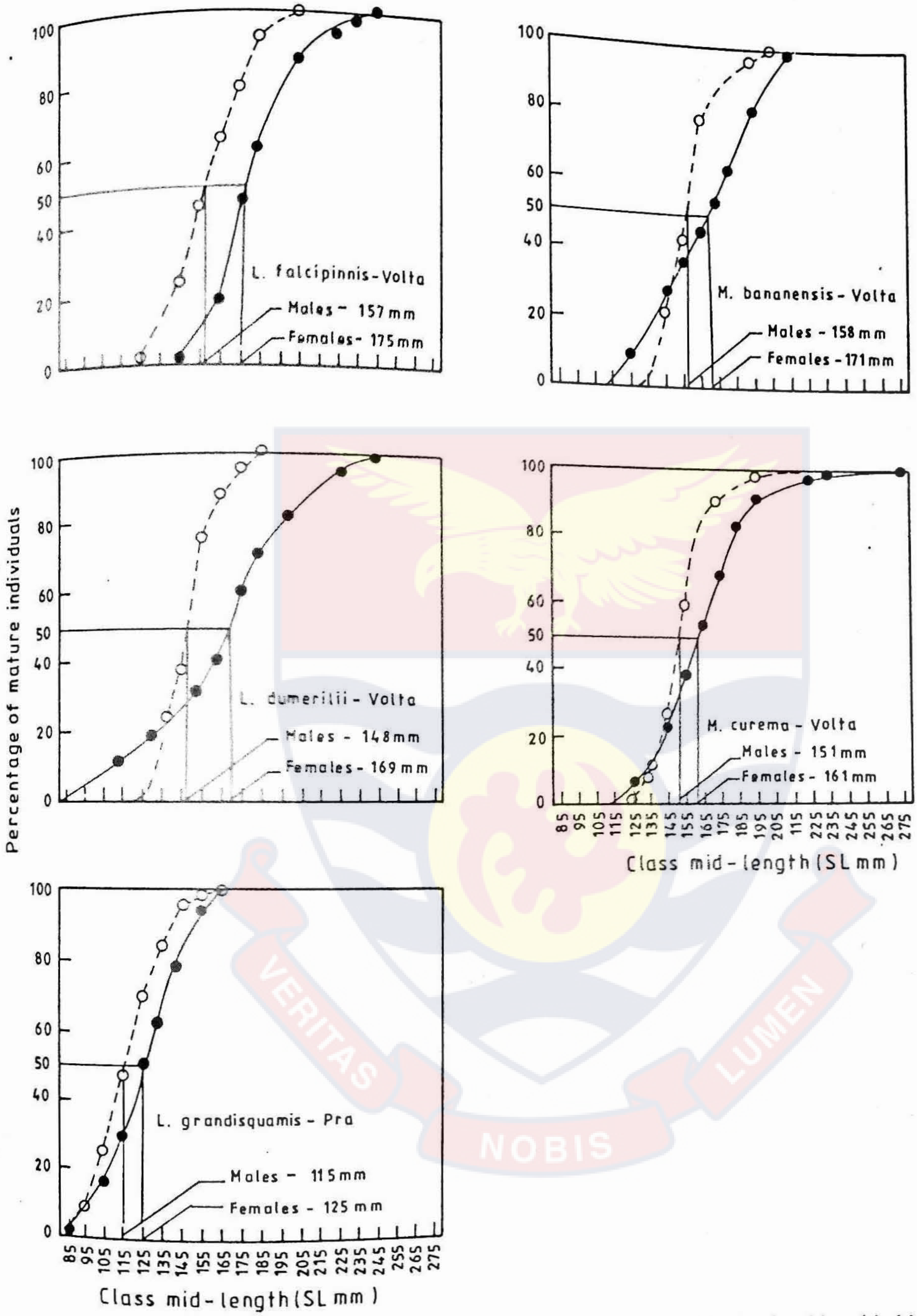

Fig.33 Mean length at first maturity of grey mullets in the Volta and Pra estuaries (-o- males, -●- females)

Fecundity estimates

Very few individuals with mature ovaries were available in samples during the study period for estimation of fecundity. In the Pra estuary only *L. grandisquamis* had mature ovaries. Apart from *M. cephalus*, mature ovaries were obtained for the other species in the Volta estuary. The fecundity estimates for the various species are shown in (Table 14). The relative fecundity of the species in terms of importance are, *M. bananensis* (1183), *M. curema* (712), *L. falcipinnis* (638), *L. grandisquamis* (457) and *L. dumerilii* (318). Thus, *M. bananensis* was the species with the highest reproductive capability.

Table 14 Estimates of fecundity of grey mullet species from the Volta and Pra estuaries

Species	Size range (SL mm)	Absolute Fecundity range	Mean absolute fecundity	Relative fecundity (eggs g^{-1} body weight)	Mean egg diameter (μm)	N
L. falcipinnis	208-240	117,344-143,291	130,418	638	309	8
L. dumerilii	168-230	38,785-51742	45,263	318	305	6
L. grandisquamis	148-164	24,935-66,387	41,125	457	285	12
M. bananensis	175- 209	112,454-282,024	206,255	1,183	336	10
M. curema	170-270	33,340-345,177	132,777	712	273	12

N = number of ovaries

Culture trials in ponds

Growth and production in brackish water ponds

Mean values of water quality parameters measured during the first and second experiments are shown in Tables 15a and 15b for both treatments (i.e., with and without feed). Statistically, there was no significant difference ($p>0.05$) between treatments with respect to water quality in both experiments.

Algal counts made during the second experiment indicated that green algae were the most dominant phytoplankton in all the ponds followed by diatoms and blue-green algae. The most common green algae were the desmids, mostly species of *Ankistrodesmus*, *Closterium*, *Pediastrum*, *Staurastrum* and the flagellates *Euglena* and *Chlamydomonas*. The diatoms comprised mainly *Navicula*, *Cyclotella*, *Gyrosigma*, *Pinnularia*, and *Nitzschia* species, while the blue-green algae were dominated by species of *Merismopedia*, *Oscillatoria*, *Anabaena*, and *Mycrocystis*. No significant difference was observed between treatments with respect to concentration of algae even though the mean algal concentration was comparatively higher in those that received feed than in those that did not receive any feed (Table 15b). Comparatively, higher mean growth was recorded for fish in ponds that had higher concentration of algae than in those that had lower concentration of algae (Fig. 34, second experiment).

Table 15a Mean values of water quality parameters in brackish water ponds during the first experiment.

Water quality parameters	Ponds with feed	Ponds without feed	$t_{(0.05)}$
PH	7.79±0.60	7.72±0.30	0.283531
Temperature (°C)	30.08±1.81	29.99±1.90	0.093147
Dissolved oxygen (mg l^{-1})	10.14±3.54	10.03±3.55	0.050490
Salinity (‰)	1.80±0.89	1.82±0.97	0.037110
Turbidity (NTU)	38.22±10.58	46.10±8.45	0.520558
Transparency (cm)	20.81±7.2	17.22±5.5	0.153601

Table 15b Mean values of water quality parameters and algal concentration in brackish water ponds during the second experiment.

Water quality parameters	Ponds with feed	Ponds without Feed	$t_{(0.05)}$
pH	7.77±0.45	7.90±0.61	0.543716
Temperature (°C)	30.15±1.36	30.10±1.35	0.431249
Dissolved oxygen (mg l^{-1})	8.07±1.53	7.97±1.67	0.146334
Salinity (‰)	1.95±0.78	2.03±1.09	0.193785
Transparency (cm)	19.25±5.0	17.08±4.32	1.002133
Turbidity (NTU)	42.0±15.7	46.56±12.94	0.594482
Green algae (counts/10ml)	213	150	0.799941
Blue- green (counts/10ml)	44	29	0.877079
Diatoms (counts/10ml)	94	61	0.718115

The growth performance of the juvenile mullets during the first and second experiments is shown in Fig. 34. Fish supplied with supplementary feed grew from an initial mean weight of 5.08±0.70 to 28.60±0.90 g while those without feed grew from 4.58±0.55 to 25.20±1.05 g during the 150-day growing period. These represent growth increments of 463.0% and 450.2% for fishes that were fed and those that were not fed respectively. The growth pattern was quite similar during the first 120 days in both treatments, but after the 120th day higher growth increment was recorded for fishes supplied with supplementary feed than for those that were not fed.

For the second experiment, which lasted 270 days, the mean weight of fish that were fed increase from 7.25±0.10 to 41.85±1.06 g (476.7% increment) while those that were not fed rose from 7.17±0.38 to 32.10±0.44 g (347.7% increment). Growth within the first 150 days was similar in both treatments but after the 150th day higher growth was also recorded for fishes that received feed than those without feed. The difference in growth performance between treatments in both experiments was not significant ($p > 0.05$)

The mean daily weight gain and the specific growth rate, taking the average from two replicate ponds, during the first experiment were higher for fish that were fed (0.1568 g/day; 1.1521 %/day) than those without feed (0.1375 g/day; 1.1368 %/day) respectively (Table 16a). An average feed conversion ratio of 3.6 was estimated. The average feed supplied in the two ponds that received feed was 13.733 kg. The first experiment was terminated after 150 days due to flooding of the ponds. It was therefore not possible to estimate production and survival rate.

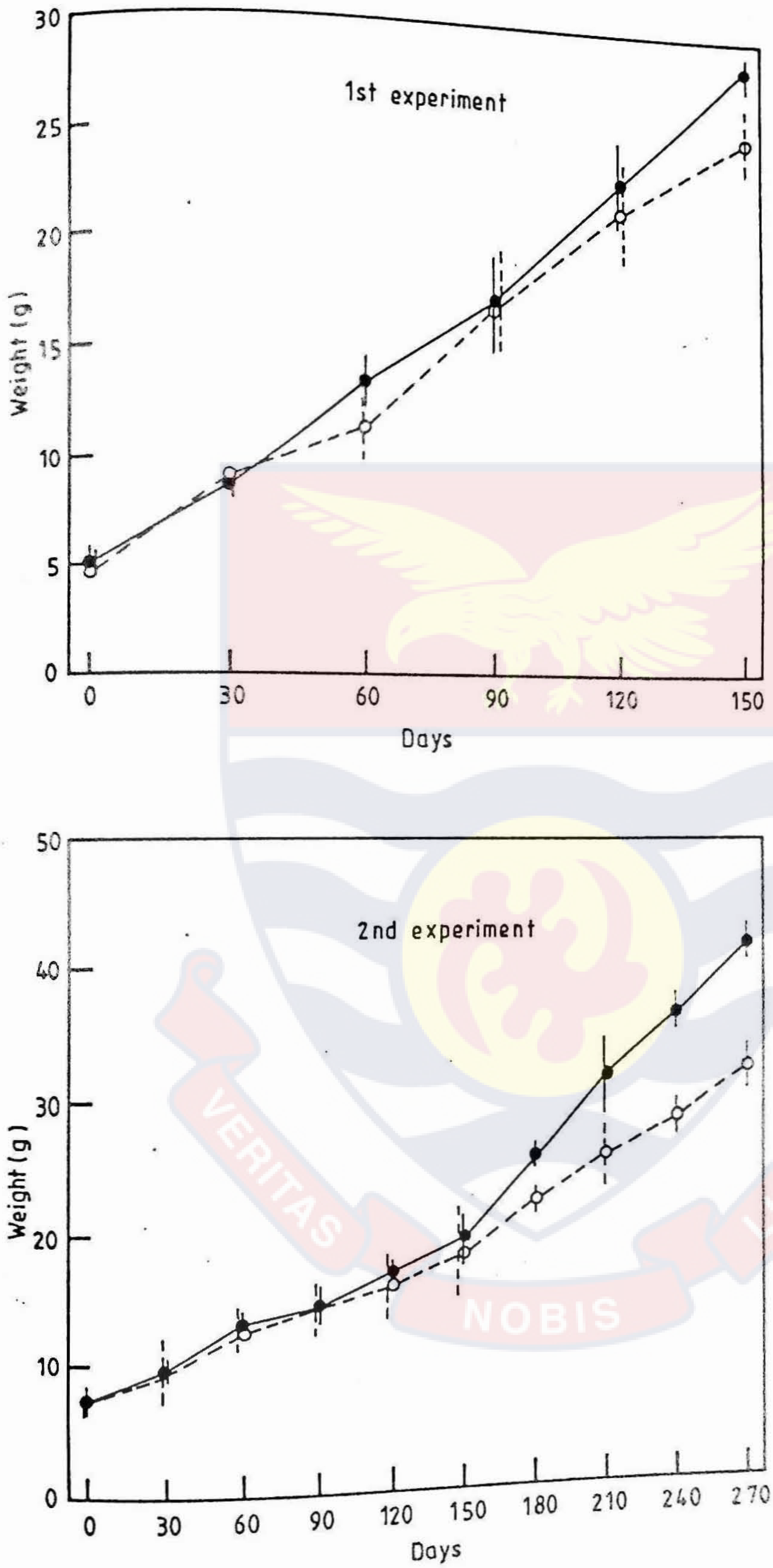

Fig. 34 Growth performance of mullet species in brackish water ponds (—— feed, ----- no feed. Vertical bars = ±1SD).

Table 16a Mean daily weight gain and specific growth rate of grey mullets cultured in brackish water ponds during the first experiment.

Treatment	No. of Days	No. of fingerlings	Mean weight gain daily (g)	Specific growth rate (%/day)	Feed conversion ratio
Feed	150	312	0.1568	1.1521	3.6
No feed	150	276	0.1375	1.1368	-

Table 16b Mean daily weight gain, survival rate, production and feed conversion ratio of grey mullets cultured in brackish water ponds during the second experiment.

Ponds	No. of days	No. of fingerlings (n)	Mean Weight gain/day (g)	Specific growth rate (%/day)	Survival (%)	Production Kg/ha	Feed conversion ratio
1 (no feed)	270	152	0.0948	0.5702	51.88	266	No feed
3 (no feed)	270	124	0.0936	0.5411	68.67	347	No feed
2 (feed)	270	160	0.1306	0.6550	43.42	306	7.1
4 (feed)	270	152	0.1256	0.6449	54.17	367	7.7

The second experiment was carried through to the end. The mean daily weight gain, specific growth rate and production of ponds in which feed was supplied were also higher (0.1281 g/day; 0.6500 %/day; 336.5 kg/ha) than those in which feed was not supplied (0.0923 g/day; 0.5557 %/day; 287 kg/ha) respectively (Table 16b).

Unlike the first experiment, the average feed conversion ratio was higher 7.4, and suggests inefficient utilisation of feed by fish during the second experiment during which an average of 34.629 kg of feed was supplied. This may explain the lower mean daily weight gained and specific growth rate compared to that obtained in the first experiment. The survival rate recorded in ponds in which supplementary feed was supplied was lower (48.49%) than those in which supplementary feed was not supplied (60.28%). More and bigger predators were found in the former ponds than in the latter. On the whole, the average survival in all the ponds was 54.54 %.

At the end of the second experiment, *M. curema* and *M. bananensis* were found to be the most common species in the ponds whereas, *M. cephalus* was not found in any of them. All the other species, *L. dumerilii*, *L. falcipinnis*, *M. bananensis* and *M. curema*, occurred in Ponds 2 and 3 while the last three species occurred in Pond 4 with only the latter two occurring in Pond 1. Comparatively, higher final mean weights were recorded for *M. curema* and *M. bananensis* than the other species in all the ponds. The final mean weight of *M. curema* and *M. bananensis* in ponds that received feed were 49.50±1.34 and 41.80±1.60 while those of *L. dumerilii* and *L. falcipinnis* were 42.64±2.54 and 34.10±2.15 respectively. With respect to ponds that did not receive feed the final mean weights of the various species were: *M. curema*, 37.38±4.41; *M. bananensis*, 31.45±2.59; *L. dumerilii*, 28.50±2.28 and *L. falcipinnis*, 22.89±1.89.

The composition of mullet species in the various ponds at the end of the experiment is shown in Table 17.

Table 17 Number of individuals of grey mullet species in the various ponds at the end of the second experiment in brackish water ponds.

Species	Composition			
	Pond 1	Pond 2	Pond 3	Pond 4
L. falcipinnis	0 (0.0)*	17 (25.8)	19 (18.5)	20 (30.8)
L. dumerilii	0 (0.0)	5 (7.6)	3 (2.9)	0 (0.0)
M. curema	4 (4.8)	15 (22.7)	36 (35.0)	19 (29.2)
M. bananensis	79 (95.2)	29 (43.9)	45 (43.7)	26 (40.0)

*Figures in parenthesis represent percentages

Growth and production in freshwater ponds

Water quality of ponds in which fish were provided with feed and those in which fish were not provided with feed is presented in Table 18. There was no significant difference in the water quality of ponds that received feed and those that did not receive feed.

After the 180-day growth period a higher final mean weight of 28.65±0.78 g was recorded for fishes that were fed than those that were not fed for which 25.56±0.34 g was recorded. The initial weights were 8.34±1.21 g and 7.82±0.88 for the former and latter fishes respectively (Fig. 35). Thus, a percentage increase of 243.5% was recorded for fish that received supplementary feed and 226.8% for those that did not receive supplementary feed. The difference in growth performance between treatments in the fresh water ponds was however, not significant ($p>0.5$). Production and survival rates could not be calculated as a result of premature termination of the experiment after 180 days due to predation by monitor lizards.

Like the brackish water ponds, the average mean daily weight gain and specific growth rate were higher for fish that were fed (0.1128g/day; 0.6856%/day) than those that were not fed (0.0986g/day; 0.6579%/day) (Table 19). The feed conversion ratios in ponds 3 and 4 were 6.2 and 7.2 respectively, with a mean value of 6.7. The total feed supplied in pond 3 was 12.740 kg while pond 4 received 14.343 kg of feed.

Considering the same culture period of 150 days, the mean daily weight gain (MDWG), specific growth rate (SGR), feed conversion ratio and percentage increment in weight were highest for fish raised in brackish water ponds during the first experiment. Results for fish raised in brackish water ponds during the second experiment and for those raised in freshwater ponds were quite similar (Table 20). Growth of fish during the second experiment in brackish water ponds was significantly different from the others ($p < 0.05$).

Table 18 Mean values of water quality parameters in fresh water ponds used for culture of mullets.

Water quality parameters	Ponds with Feed	Ponds without Feed	$t_{(0.05)}$
PH	7.51±0.80	7.64±1.08	0.690610
Temperature (°C)	28.75±0.87	29.19±1.27	0.744302
Dissolved oxygen (mg l^{-1})	6.10±3.49	5.27±2.98	0.437190
Transparency (cm)	18.83±7.02	19.13±6.91	0.068164

Table 19 Mean daily weight gain, specific growth rate and feed conversion ratio of grey mullets cultured in fresh water ponds.

Pond	No. of Days	No. of fish stocked	Mean weight gain/day (g)	Specific growth Rate (%/day)	Feed conversion ratio
1 (No feed)	180	100	0.0973	0.6314	-
2 (No feed)	180	100	0.1000	0.6894	-
3 (Feed)	180	100	0.1147	0.7368	6.2
4 (Feed)	180	100	0.1221	0.6404	7.2

Table 20 Comparison of mean daily weight gain, specific growth rate, percentage increment in weight and feed conversion ratio of fish raised in brackish- and fresh- water ponds for 150 days.

		Fresh water ponds	Brackish water ponds 1st experiment	Brackish water Ponds 2nd experiment
Mean Daily Weight gain	(Feed)	0.1020 g/day	0.1568 g/day	0.0820 g/day
	(No feed)	0.0926 g/day	0.1375 g/day	0.0735 g/day
Specific Growth Rate	(Feed)	0.6963 %/day	1.1521 %/day	0.6613 %/day
	(No feed)	0.6807 %/day	1.1368 %/day	0.6210 %/day
Percentage increment in weight	(Feed)	184.2	463.2	169.7
	(No feed)	177.6	450.2	153.8
Feed Conversion Ratio		6.0	3.6	5.9

Effect of wheat and rice bran on growth of mullets

Evaluation of the effect of wheat and rice bran on growth, which lasted 180 days, was concurrently carried out within two ponds each divided into two compartments with mosquito netting. Water quality in each pond was therefore common to fishes in both compartments. Each compartment was stocked with 20 mixed species of mullets and in each pond, one compartment received wheat bran while the other compartment received rice bran. Water quality with respect to temperature, dissolved oxygen concentration and pH ranged between, 26-28°C, 5.8-8.2 mg l^{-1} and 6.71-8.75 respectively.

Specific growth rate of the fish fed on wheat bran and rice bran was investigated. Fish that received wheat bran grew from an initial mean weight of 46.46±1.21 g to a final mean weight of 94.73±0.95 g representing a percentage increase of 103. Those that were fed on rice bran grew from an initial mean weight of 48.46±1.85 g to a final mean weight of 91.84±1.10 g representing a percentage increase of 89.5. On the average, 12.928 kg of rice bran and 12.826 kg of wheat bran were supplied during the experiment. Figure 36 illustrates the specific growth pattern with higher growth recorded for fish that received wheat bran than those fed on rice bran. Specific growth rates of 0.3958 %/day and 0.3552 %/day were attained by fish supplied with wheat bran and rice bran respectively. The difference in growth was not significant ($p>0.05$).

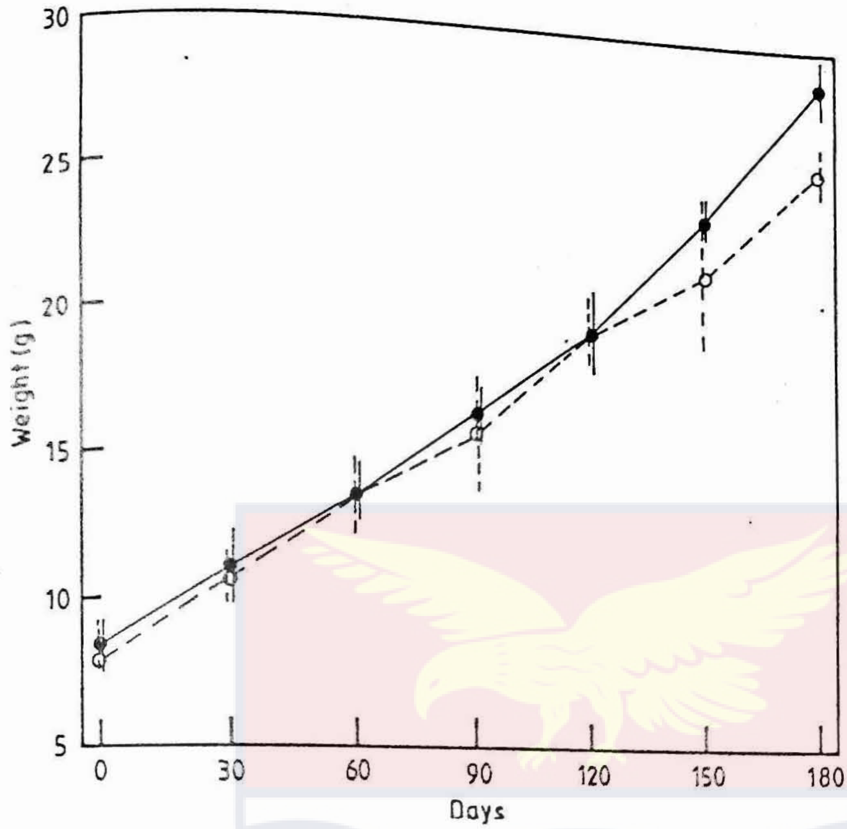

Fig. 35 Growth performance of mullet species in fresh water ponds (——— feed, ------- no feed. Vertical bars = ± 1SD)

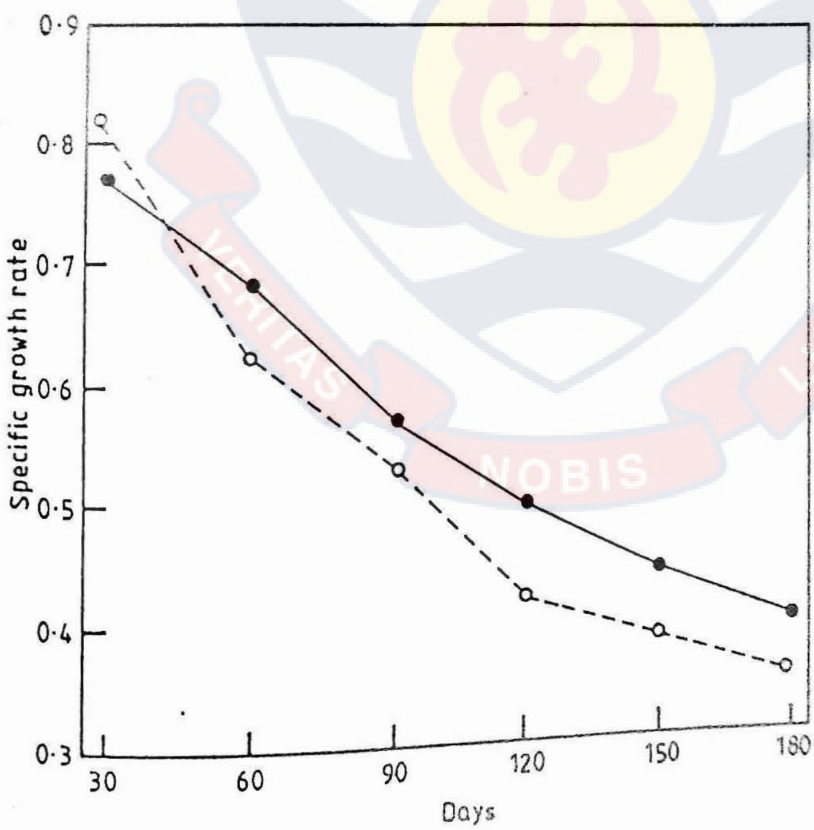

Fig. 36 Effect of rice and wheat bran on growth performance of mullet species in freshwater concrete ponds (-•- wheat bran, -o- rice bran)

DISCUSSION

Species occurrence and abundance

Six species of grey mullets: *L. falcipinnis*, *L. dumerilii*, *L. grandisquamis*, *M. bananensis*, *M. curema* and *M. cephalus* were encountered during the study period. All the six species occurred in the Pra estuary while five of them excluding *L. grandisquamis* occurred in the Volta estuary.

Occurrence and abundance patterns of estuarine fishes are influenced by various biotic and environmental factors such as salinity, temperature, tides and abundance of food (Blaber and Whitfield, 1977; Weistein *et al.*, 1980; Blaber, 1987). It has been emphasised that the most important factor influencing the distribution of mullets is high turbidity at the mouths of river ecosystems since mullet fry are known to avoid bright light and concentrate in areas with little light and high turbidity (Liao, 1975; Blaber, 1987). The remarkable differences between the two estuaries sampled, were the high salinity and turbidity and the presence of dense mangrove vegetation in the Pra estuary. The presence of *L. grandisquamis* in the Pra estuary could possibly be due to their preference for high turbidity and mangrove habitats as indicated by King (1988) in the Bonny River (Niger Delta).

In the Ébrié lagoon in Côte d'Ivoire, *M. curema* and *L. grandisquamis* showed increasing abundance with higher salinity unlike *L. falcipinnis* whose distribution did not seem to be related to any salinity gradients (Albaret and Lengendre, 1985). Other studies on *M. curema* suggest that juveniles and adults are most often found at temperatures above 20°C (Moore, 1974; Vieira, 1991) and at high salinities (Moore, 1974; Weinstein, 1979; Weinstein *et al.*, 1980). Contrary to previous findings, salinity in the

Volta estuary where *M. curema* was the most abundant grey mullet species ranged from 0.06 to 8.17‰. This species has been recorded in the northern part of the Songor lagoon at a salinity of 80 ‰ (Shenker *et al.*, 1998) implying that *M. curema* can tolerate much wider salinity range. In the current study the abundance of *M. curema* in both estuaries showed a positive correlation with water temperature which was significant in the Volta estuary. Apart from temperature, the abundance of *M. curema* is likely to be influenced by transparency since there was a significant correlation between the two in the Pra estuary. This was, however, not the case in the Volta estuary where fluctuations in transparency were not strong enough to have made any impact on the abundance of *M. curema*.

The significant negative and positive correlation of turbidity with the abundance of *M. cephalus* and *M. bananensis* in the Volta and Pra estuaries respectively, confirms the assertion by Blaber (1987) and Liao (1975) that high turbidity or low transparency is a major factor that attracts juvenile mullets into estuaries. The intensity of this factor in attracting the young of the two species may differ as indicated by Koutrakis *et al.* (1994), hence the different magnitude of correlation in the two estuaries.

M. cephalus was most abundant in the Kulama Creek at the Niger Delta in Nigeria from November to January when salinity of the water was 27.5‰ (Ikomi, 1990). This is in contrast with the current findings where the relative abundance of *M. cephalus* in both estuaries rather showed a negative correlation with salinity. Unlike the Kulama creek where the species was found throughout the year, it was not present in both estuaries for most part of the current study. He further noted that *M. cephalus* has a preference for mangrove environments which observation does not conform to what was found in this study. The abundance of *M. cephalus* was lower in the Pra estuary which rather has a dense mangrove cover compared to the Volta estuary, which has virtually no mangrove cover in the study area. It appears that *M. cephalus* prefers less turbid environments as indicated by the significant correlation in the Volta estuary, rather than mangrove habitats.

Of the mullet species encountered, *L. falcipinnis* and *M. curema* were the most abundant in the Pra and Volta estuaries respectively. The former species has been reported as the most abundant mullet species in Nigeria (Fagade and Olaniyan, 1973; Sellappah, 1975), Côte d'Ivoire (Daget and Iltis, 1965), Dahomey (Gras, 1961). Studies in the Black Johnson estuary in Sierra Leone (Payne, 1976), however, indicated that *L. falcipinnis* was the most abundant species after *L. dumerilii hoeferi* while *M. curema* was the least abundant species. *L. falcipinnis* therefore, appears to be widespread and abundant along the West African coast.

M. cephalus, which was the largest of all the species, was the least abundant in both estuaries. Hardly were individuals below 10 cm captured during the study unlike the other species. This implies that fingerlings of *M. cephalus* are less likely to enter the estuaries. It will therefore be more difficult getting their fingerlings from the wild for culture purposes. Similarly, low abundance of *M. cephalus* was recorded from the Negombo Lagoon in Sri Lanka (Wijeyaratne and Costa, 1987a), and the Aegean Sea in Greece (Koutrakis *et al.*, 1994).

The restricted distribution of *L. grandisquamis* and the low abundance of *L. dumerilii* in the current study were also reported by Gras (1961), from Dahomey. *L. grandisquamis* was, however, found by King (1988) to be one of the most common species at the Niger Delta. Daget and Iltis (1965) did not record *L. dumerilii* and *M. cephalus* from the lagoons of Côte d'Ivoire at all.

The different grey mullet species obtained peak abundance at different times of the year during the study. According to Mc Haughton and Wolf (1979), seasonal changes in abundance of sympatric species could be of an adaptive value that may allow them to utilise fully resources at different times, thus reducing overlap for required resources. This strategy could have been applied by the grey mullet species in the Volta and Pra estuaries to allow for their coexistence.

Grey mullets in the Volta estuary were most abundant from November to May i.e., during the dry season and early part of the rainy season while in the Pra estuary they were most abundant between September and November – a period that coincided with the minor rainy season. Abundance of mullets was low during the major rainy season period and just after the rains (June – August) in both estuaries. A similar observation of high abundance was made by Payne (1976), during the period when the rains are subsiding and as the dry season sets in. This was attributed to rising salinity, high organic content in the sediment and the very turbulent conditions that prevailed. On the contrary, catches of all grey mullets in the Negombo Lagoon (Sri Lanka) were high in May, a rainy month (Wijeyaratne and Costa, 1987a). This was attributed to the high efficiency of fishing gears as a result of high turbidity during this period. The low catches during the rainy season in this study is attributed to the swift current, especially in the Pra estuary, which made fishing inefficient in spite of the high turbidity associated with such periods.

For proper management and protection of the fish stocks, knowledge of the seasonal occurrence and abundance of a particular species especially the juveniles in an area is very important. It also indicates when juveniles of a particular species could be exploited for stocking in fishponds or for stock different in terms of their impact on the shape of their fish populations. It is worth noting that the Pra estuary was more saline and turbid than the Volta estuary. The significant difference of the regression coefficient *b* from 3.0 shown by all the species, except *L. grandisquamis* from the Pra estuary indicates that, in general, grey mullets from the two estuaries exhibit allometric growth.

A similar observation of allometric growth was made by King (1996), for *M. curema*, *M. cephalus* and *L. falcipinnis* on the Nigerian coast. *M. cephalus* from both estuaries exhibited positive allometric growth, as reported for the species in the Niger Delta (Ikomi, 1990). Interpretation of the relationship of *M. cephalus* from the Pra estuary should however, be treated with caution in view of the small sample size.

All the species from the Volta estuary were comparatively, larger than their counterparts from the Pra estuary. Fishing activities in and around the two estuaries were observed to be higher in the Pra than in the Volta estuary. The preponderance of small-sized individuals in the samples from the Pra estuary is an indication of overfishing which has, probably led to substantial reduction in the size of the species in that estuary. Apart from high fishing pressure it is also possible that low transparency in the Pra estuary could have adversely affected algal production and eventually growth of mullets.

Growth parameters

Different growth parameters were determined for fish of the same species from the two estuaries. According to Sparre (1985), growth parameters do not only differ from species to species but also among different populations of the same species. This might explain the different values obtained for the same species in each estuary. Apart from *L. dumerilii* from both estuaries whose $L\infty$ was quite similar, estimates for the species from the Volta estuary were relatively higher than those from the Pra estuary. This could be attributed, as pointed out earlier, to higher fishing pressure in the Pra estuary than in the Volta estuary. The growth performance index (ϕ') for the same species from both estuaries and among the various species was quite similar except that of *M. cephalus*. Longhurst and Pauly (1987) reported that the growth performance index (ϕ') is constant for a given species and similar within related groups of species.

The $L\infty$ and K of *M. cephalus* in the Negombo lagoon in Sri Lanka was determined by Wijeyeratne and Costa (1987) to be 897 mm and 0.094 year^{-1} respectively. There are no estimates of growth parameters for the other species dealt with from previous studies, hence no comparisons with populations from other areas could be made. However, specimens measuring 297 mm TL for *L. grandisquamis*, 410 mm TL for *L. falcipinnis* and 394 mm TL for *M. curema* have been reported from the Ébrié lagoon in Côte d'Ivoire (Alberet and Legendre, 1985). The estimated theoretical maximum sizes for these species in the current study suggest that the stocks in the estuaries are relatively small.

The estimated growth parameters for the mullets in the current study must however, be treated with caution and regarded as preliminary since the analysis involved predominantly juvenile fishes.

Food and feeding habits

The diet of all the species in the two estuaries was similar; only slight variations in proportions of food items were noted. The food consisted mostly of diatoms, algae, detrital materials and sand particles. Polychaetes and zooplankton were also prominent in the diet with polychaetes being more important, especially in the diet of *M. cephalus*. Detritus is considered a good source of vitamin B_{12} for mullets (Vallet *et al.*, 1970 quoted in Eggold and Motta, 1992) and also rich in bacterial and protozoa which may be of some nutritional value (Bruslé, 1981).

Even though sand particles occurred in the stomachs of all the species, they were predominant in the stomachs of *L. dumerilii* forming 61 and 57 % of the stomach contents in the Volta and Pra estuaries respectively. Ingested sand particles are supposedly helpful in the grinding of food particles in the thick-walled pyloric stomach, which acts as a gizzard (Thomson, 1966). Apart from the 'grinding' action, sand particles with the associated micro-organisms serve as a source of nutrition (Hickling, 1970; Odum, 1970).

It has been suggested that grey mullets ingest sand particles of a selected range (Odum, 1968). This was evident in this study where it was found that the different species in each estuary selected different size ranges of sand particles with *L. dumerilii* selecting the widest range in both estuaries. The particle size consumed by each species varied according to locality probably, due to the difference in the substrates in each estuary. Ingestion of larger particles by *L. dumerilii* as compared to other mugilids is confirmed by Masson and Marais (1975) from the Zwartkops estuary in Cape Province in South Africa, Payne (1976) from the Black Johnson estuary in Sierra Leone and Blay (1995a) from the Elmina lagoon.

Even though *L. dumerilii* ingested the widest range of sand particles, the size it preferred most was also ingested by *M. curema* and *M. cephalus* in the Volta estuary and *L. grandisquamis* in the Pra estuary. In the former estuary *L. dumerilii* showed a preference for zooplankton and diatoms while

M. cephalus and *M. curema* ingested less zooplankton but more of green algae and polychaetes. In the Pra estuary *L. grandisquamis* ingested more of diatoms while polychaetes and zooplankton were prominent in the diet of *L. dumerilii*. Thus, species that ingested the same modal size of sand particles showed preferences for different food items. This corroborates the findings of Blabber (1976) who noted that *L. dumerilii* and *M. cephalus* selected sand particles in the same range but showed preferences for different food items. It was also noted that species that ingested finer particles consumed more plant material and organic matter while those that ingested coarser particles showed preference for substrates rich in animal material.

According to Nilsson (1967) when two closely related species coexist in one environment, various mechanisms may occur which permit this coexistence. One of these is partitioning of resources. The preference of each grey mullet species in the two estuaries for a particular particle size was a way of partitioning the resource to avoid interspecific competition, thus ensuring their coexistence.

Apart from detritus and sand particles, results on food habits from the current study corroborate the findings of Blay (1995a) who reported on the diet of juveniles of four mullet species (*L. falcipinnis, L. dumerilii, M. curema* and *M. bananensis*) from the Elmina lagoon in Ghana. Comparatively, mullets in the Elmina lagoon utilize a wider range of food items than was found in the current study. According to Blaber (1977) and Juslé (1981), the composition of the diet of grey mullets from different localities differs, depending on the abundance and types of food organisms present. The wide range of food items of mugilids have been noted by Cain and Dean (1976) who explained that such flexibility in feeding ensures the constant energy source required for the sustenance of the population.

Results obtained by various researchers on the West African coast were quite similar to the current one. *L. grandisquamis* was reported to feed predominantly on detritus, algae and sand (King, 1988) while Fagade and Olaniyan (1973) noted that most of the mullet species found in the Lagos lagoon (Nigeria) fed mainly on organic detritus, diatoms and green algae. Diatoms constituted the major food item in the stomach contents of *M. cephalus ashenteensis* on the Mauritanian coast (Bruhlet, 1975) and all grey mullets occurring in the Black Johnson estuary in Sierra Leone were found to feed principally, on detritus and algae (Payne, 1976). Albaret and Legendre (1985) also reported that the diet of the mullet species identified in the Ébrié lagoon in Côte d'Ivoire was basically the same, consisting mainly of diatoms, organic detritus and sand grains.

The importance of sand particles, algae, and detritus in the diet of mullets has also been emphasized by other workers outside the West African sub-region. The predominant food item of adult *M. cephalus* was reported to be diatoms (De Silva and Wijeyaratne, 1977; Whitfield and Blaber, 1978), while serpulid polychaetes were the main food item of individuals above 10 cm TL (Wijeyaratne and Costa, 1986). Polychaetes were also an important component of the diet of the species in the current study. Almeida *et al.* (1993) indicated that the stomach contents of *L. ramada* consisted, mostly of Bacillariophyceae. The main items in the diet of *Liza subviridis* above 24 mm were algae, detritus and inorganic sediment (Chan and Chua, 1979). From the accounts given above, adult mullets are no doubt herbivorous as has been noted by Blaber (1977), Marais (1980) and Minckley (1982).

The ecological importance of such a diet has been recognized by Odum (1970) who considered mullets as important in providing the herbivore link in the food chain in estuaries and shallow coastal waters. Their low position in the food chain is also an asset in pond culture because their preferred food items can easily be raised in ponds through inexpensive methods of fertilization. Information on the food and feeding behaviour should be useful to aquaculturists who wish to include mullets in ponds where polyculture with other herbivorous species is practiced since grey mullets are mainly benthic feeders. Such a combination with other herbivorous species that do not feed from the bottom of the pond will ensure full utilization of the water column in the pond.

The niche overlap indices for all the species in each estuary indicated that there was no remarkable difference in the diet of all the species with respect to size as well as among the species. Similar observations of a lack of variation in diet with size were made by, Blaber (1977) for *L. macrolepis* and *M. cephalus*. Wijeyaratne and Costa (1986) for *M. cephalus*, and Blay (1995a) for *L. falcipinnis*, *L. dumerilii*, *M. bananensis* and *M. curema*. These observations are, however, at variance with what was reported by Cain and Dean (1976) for *M. cephalus* and *M. curema*, De Silva and Wijeyaratne (1977) for *M. cephalus*, King (1988) for *L. grandisquamis*, and Eggold and Motta (1992) for *M. cephalus*.

Changes in diet with growth, apart from minimising possible intraspecific competition between different cohorts, also offer a wider spectrum of food resources for exploitation by the species and may be important in maintaining large populations of different cohorts of the fish (King, 1988). Competition for a resource occurs when the resource, among other things, is in short supply. The fact that there was a high niche overlap time on both occasions for each species. There were however, differences in the peak feeding time among the species. Marais (1980) and Drake *et al.* (1984) showed that different mugilid species fed at different times while Blay (1995 a,b), indicated that the feeding activity of grey mullets from the Elmina lagoon and *L. falcipinnis* from the Cape Coast lagoon in Ghana, occurred between sunrise (06.00 h) and sunset (18.00 h). He recorded no feeding activity at night (22.00 h - 02.00 h). Studies by other researchers, e.g., Blabber (1976) on *L. macrolepis* from the St. Lucia Lake system in South Africa, De Silva and Wijeyaratne (1977) on *M. cephalus* from the Negombo Lagoon in Sri Lanka and Collins (1981) on *M. cephalus* from Florida showed that these species fed little at night.

Feeding activity of the mullets in this study was, most probably, determined by photoperiodicity, as noted by Keast and Welsh (1968) for many other fishes. Differences in the peak feeding time among the grey mullet species in the Volta estuary could be one of the probable mechanisms for avoiding competition as suggested by Blaber (1976) for sympatric mullets.

Apart from photoperiodicity, other factors, e.g. tides and salinity, have been cited to influence feeding intensity in mugilids. The feeding intensity of *L. richardsoni* and *L. dumerilii* (Marais, 1980) and *L. ramada* (Almeida *et al.*, 1993) have been found to vary according to the tide. It was concluded by Odum (1970) that, in areas that are tidally influenced, there is a definite relationship between feeding intensity and stage of the tide with intensity being highest at high tide. No such relationship was, however, found for species in the Elmina and Cape Coast lagoons (Blay 1995 a,b). According to Blay (1995b), although variations in the daily feeding pattern of *L. falcipinnis* from the Cape Coast lagoon might have been ecologically time on both occasions for each species. There were however, differences in the peak feeding time among the species. Marais (1980) and Drake *et al.* (1984) showed that different mugilid species fed at different times while Blay (1995 a,b), indicated that the feeding activity of grey mullets from the Elmina lagoon and *L. falcipinnis* from the Cape Coast lagoon in Ghana, occurred between sunrise (06.00 h) and sunset (18.00 h). He recorded no feeding activity at night (22.00 h - 02.00 h). Studies by other researchers, e.g., Blabber (1976) on *L. macrolepis* from the St. Lucia Lake system in South Africa, De Silva and Wijeyaratne (1977) on *M. cephalus* from the Negombo Lagoon in Sri Lanka and Collins (1981) on *M. cephalus* from Florida showed that these species fed little at night.

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Increasing salinity was found to decrease food intake in *M. cephalus* measuring 10-50 mm TL (Perera and De Silva 1978) while the reverse trend was found in *L. falcipinnis* (De Silva and Perera, 1976; Blay, 1995a). In the current study, a decrease in feeding activity with increasing salinity was observed for *L. falcipinnis* and *M. curema*. Food intake was also found to increase significantly with increasing pH for the former species and with dissolved oxygen for the latter species. The feeding activity of *M. bananensis* showed a significant correlation with both pH, and surface water temperature while feeding activity of *L. dumerilii* showed a high correlation with both pH and dissolved oxygen concentration. From the various conflicting reports it could be said that various factors, either acting on their own or in conjunction with others, may be responsible for determining peak feeding activity for the different species of grey mullets.

Increase in relative gut length with size is reported to be a characteristic of herbivorous fishes (Blaber and Whitfield, 1977; De Silva, 1980; Marais, 1980; Minckley, 1982; Wijeyaratne and Costa, 1987a,b). This is further supported by Hickling (1970), who observed that larger *Cremugil labrosus* Risso are herbivorous with a high relative gut length while Odum (1970) reported that the intestine to fish length (SL) ratio of 3.2 in *Mugil cephalus* L. from Hawaii (USA) is adequate for assimilating diatoms. Collins (1981) also indicated that striped mullets that consume more plant material have longer standard length-specific intestine length.

In the current study, the relationship between relative gut length and standard length for *M. curema* from both estuaries and *M. bananensis* from the Volta estuary was significantly positive. This is in agreement with what has been reported elsewhere (Blaber and Whitfield, 1977; De Silva, 1980; Marais, 1980; Minckley, 1982; Wijeyaratne and Costa, 1987a,b). However, that of *L. dumerilii* from both estuaries, *M. bananensis* from the Pra estuary and *L. falcipinnis* from the Volta estuary was not significant. Additionally, no significant change was found in diet with size of all the species from both estuaries as similarly observed for mullets from the Elmina lagoon (Blay, 1995a). There was no appreciable variation in the diet of *M. cephalus* from southeast Africa (Blaber, 1976) and *Liza* spp. from Sri Lanka (Wijeyaratne and Costa, 1987a,b) even though, there was a significant change in relative gut length with size. This is confirmed by the results of the current study for *M. curema* from both estuaries and *M. bananensis* from the Volta estuary. Thus, changes in relative gut length with size may not be necessarily accompanied by changes in diet.

Apart from *L. dumerilii* from both estuaries and *L. grandisquamis* which occurred only in the Pra estuary, whose relative gut length ranged from 1.72 to 2.0, all the other species had high relative gut length of between 3.7 and 4.5 which was typical of mugilids. Results of the present study show that populations with a higher relative gut length tended to consume more plant material, as shown by *L. falcipinnis* and *M. curema*. Hickling (1970) noted that the relative gut length of fish that consume high proportion of indigestible matter is fairly high. Longer guts could be an adaptation to increase the digestive area and ensure that such food items are properly digested. *L. dumerilii* and *L. grandisquamis* even though, consumed more zooplankton compared to the other species and may explain their low relative gut length, diatoms were also a major food item. The current results for *L. dumerilii* and *L. granidsquamis* contradict the assertion by Odum (1970) that a relative gut length of 3.2 should be adequate for assimilating diatoms. Relative gut length of as low as 1.72 as calculated for *L. dumerilii* from the Pra estuary was adequate for assimilating diatoms.

Variations in the Stomach Fullness index (FI) indicate that grey mullets from both estuaries do not feed at the same intensity throughout the year. In the Volta estuary, feeding intensity of all the species was generally, low during or immediately after the peak of rainfall and high during the period of low rainfall. In the Pra estuary, even though the pattern of rainfall was quite similar to that in the Volta estuary, except for its magnitude, the fluctuations in feeding intensity were generally, in contrast to those for the Volta estuary. Feeding intensity was generally, low during periods of low rainfall or the dry season and high during periods of high rainfall.

It has been indicated by Welcomme (1985) that there is a rapid increase in food organisms during the flood period, which favours intensive feeding while food resources become limited during the dry season and therefore fish undergo fasting during this period. The Pra estuary has an extensive mangrove cover and the rainfall in its catchment area is much higher than that in the Volta estuary. A more extensive flood plain is therefore created within the mangrove cover at the Pra estuary allowing fishes to be dispersed over an extensive biotope and making it easier for them to access food resources during the rainy period. Feeding intensity is therefore likely to increase during the rainfall period.

On the contrary, there are no extensive flood plains at the Volta estuary as the flow of water is controlled by the two dams upstream. According to Welcomme (1985), in such situations where there is little or no flood plain, the seasonality of feeding may be reversed with more intensive food intake during the dry season. Results from the Volta estuary corroborate this observation. Feeding intensity of most of the species was also low, especially between March and July 1998, which corresponded with the spawning period. Similar observations were made by Odum (1970) from Hawaii (U.S.A) and Brulhet (1975) from Mauritania, for other species of grey mullets.

Changes in Condition Factor based on length-weight data which estimates the general 'well-being' of the individual fish, according to Weatherly (1972) reflect normal seasonal fluctuations in metabolic balance, patterns of maturation, and state and fullness of the alimentary canal. Such changes however, do not include information on nutritional status. In the Pra estuary where all the species except *L. grandisquamis* were mostly juveniles changes in 'Condition' could not have been influenced by maturation processes. There was a corresponding increase in 'Condition' with feeding intensity especially, from March to July 1988 in the Pra estuary. The low 'Condition' recorded by most of the species from the Volta estuary during the same period could be explained by the presence of mature individuals. In Nigeria, Ikomi (1990) attributed the lower 'Condition' for *M. cephalus* during the dry season to breeding activities.

Reproductive biology

Very few individuals in the spawning stage were caught in the two estuaries during this study. Grey mullets have been identified as deep-water spawners (Major, 1978; De Silva, 1980; Vieira, 1991; Koutrakis *et al.*, 1994). After spawning their young, they move into inshore coastal waters, primarily into lagoons and estuaries. Major (1978) argued that offshore spawning probably ensures that fry are not subjected to the wide variations in conditions that prevail in inshore and estuarine waters. This, in addition to the fact that mature or big-sized individuals could not be easily caught due to their habit of jumping out of nets, may explain why few mature individuals were captured in both estuaries. A similar observation was made by Lasiak (1983) for *L. richardsoni* from the Algoa Bay (South Africa), which he attributed to reduced probability of capturing mature fish as well as an indication of spawning further offshore.

Males of all the species investigated matured at a smaller size than the females. This observation agrees with that reported by Albaret and Legendre (1985) for *L. grandisquamis*, *L. falcipinnis* and *M. curema* in the Ébrié lagoon (Côte d'Ivoire). The early maturation of males than females of *M. cephalus* was also reported by Wijeyaratne and Costa (1986), in the Negombo Lagoon (Sri Lanka) and by Collins (1981), in the Seahorse Key and Crystal River in Florida. The difference was attributed to the fact that males have a shorter life span than females due to differential growth rates between the sexes or, the fact that large males may have a different habitat preference than the rest of the population and so were not caught.

Species in the Ébrié lagoon however, matured at larger sizes than those recorded in the present study. Differences in the mean size of maturation of the two sexes of a species at different places has been attributed to difference in latitudes with smaller maturity size at lower latitudes than at higher latitudes (Hickling, 1970; Wijeyaratne and Costa, 1986). The current observation where species in the Ébrié lagoon matured at larger sizes than in the Volta and Pra estuaries cannot be explained by difference in latitudes since Côte d'Ivoire and Ghana are virtually situated within the same latitudes. It is most likely that different fishing pressures could influence the mean size at which these species mature in the different localities. High fishing pressure results in shifts from larger to smaller fishes.

Relative fecundity, which is a way of standardising fecundity with respect to size, varied widely in this study; 638 for *L. falcipinnis*, 318 for *L. dumerilii*, 457 for *L. grandisquamis*, 1,183 for *M. bananensis*, and 712 for *M. curema*. *M. bananensis* had the highest reproductive potential, an asset that could be useful in culture with respect to production of fingerlings through induce spawning. Not much has been reported in literature on fecundity for most of the species studied in this work except for *M. cephalus* (Thomson, 1966; Kuo *et al*., 1973; Wijeyaratne and Costa, 1986; Render *et al*., 1995) which makes it difficult for comparisons to be made. Differences in fecundity can be explained by differences in size as it has been shown for several species that fecundity increases with increasing size (Render *et al*., 1995). It was, however, not possible to find the relationship between length/weight and fecundity due to the few data obtained for the various species.

Spawning activity on an annual basis could be identified by variations in Gonadosomatic index while histological studies give a clearer definition of breeding cycle. Oocyte distribution of a fish with a short and definite spawning period exhibits distinct modes while those of intermittent spawners do not show any distinct modes (Hickling and Rutenberg, 1936). Variations in gonadosomatic index, frequency of occurrence of spawning and spent fish and presence of ova of two size groups, one representing developing oogonia and the other corresponding to mature oocytes indicate that grey mullets in the two estuaries are multiple spawners. In the Volta estuary the spawning period occurred between February-April and June-

August while in the Pra estuary spawning occurred between March-May and October-November. Most mullet species have been found to spawn once during the spawning season (Kuo and Nash 1975; Grant and Spain 1975; Wijeyaratne and Costa 1986).

L. grandisquamis has been reported to reproduce throughout the year in the Ébrié lagoon in Côte d'Ivoire (Alberet and Legendre, 1985) in contrast to what was found in the Pra estuary. According to Van der Horst and Erasmaus (1978), in South Africa *L. dumerilii* spawn during the summer (warmer) period in the Swartkops estuary while in the Natal estuaries it spawns during the winter (colder) and early summer period (Wallace, 1974). In the Volta estuary, *L. dumerilii* spawned between November and February and again from June to July, both periods being cold. Differences in the spawning time conform to the suggestion by Puslé (1981), that spawning period of grey mullets is likely to differ from region to region.

Temperature has been found to play an important role in gonadal development and spawning (Avanesov, 1972). In grey mullets spawning is reported to occur normally, during the cold periods of the year (Wijeyaratne and Costa, 1987b; Kuo, 1995). In this study spawning occurred under various temperature regimes. This is in consonant with findings by Thomson (1966) and Van der Horst and Erasmaus (1978).

Generally, most fish in tropical regions have been found to spawn during the rainy season (Welcomme, 1985). Species from both estuaries in the current study either spawn just before or during the rainy season. The timing of the spawning period to coincide with the rainy season is to enable the young fish to grow in optimal environmental conditions. It is argued that during this period algae and zooplankton are in abundance due to high growth as a result of mixing caused by high wind action that prevail at such periods, high temperature regime and the influx of nutrients from runoffs. This period also coincide with upwelling conditions in coastal waters, which is also associated with high food supply. It is possible that grey mullets in the two estuaries took advantage of the situation prevailing during the rainy season to spawn.

For culture purposes, especially where induced spawning is concerned, knowledge about the spawning periods as well as fecundity for the various species will be useful. This would not only allow for correct timing for the collection of spawners but would also help in estimating egg production capacity as well as progeny survival.

Culture trials in ponds

Survival

Mortalities observed during transportation were usually between 6 and 10%, which is higher than the 2% reported by Bok (1984). This was attributed to physical damage incurred during collection. Most of the fishes that died during transportation and acclimatisation and those which died later after introduction into ponds in the current study were observed to have lesions on their skin. Grey mullets are known to be fragile species that lose their scales very easily even when touched with the hand. It is most likely that lost scales make them more prone to bacterial and fungal infections that could cause mortalities even several days after stocking. Yashouv (1972) concluded that the basic factor in mullet survival in fishponds is their treatment and handling at the time of stocking or when transferred from pond to pond.

To minimise injuries it is advisable to handle them with small scoop or hand nets. The mesh size of the seine net used for the collection of juveniles must be such that debris are not trapped in the net and at the same time prevent fish from being gilled. These could result in the loss of scales. Preferably a small seine net should be used to avoid hauling in too many fish at a go, which could render them weak. Using big nets could catch a lot more fish, many of which could be injured and rendered weak.

Apart from injuries other factors that might have affected survival during transportation, introduction into ponds and acclimatisation were temperature, salinity and pH. Both *Liza falcipinnis* and *M. curema* survived transfer from 32.5 ‰ to freshwater with no mortality (Williams 1962, quoted in Payne, 1976). Salinity in the Volta estuary where juvenile mullets were collected did not exceed 10 ‰ at the time of collection. In spite of this low salinity immediate transfer of mullets from brackish water into freshwater resulted in almost 80% mortality even when temperature and pH were virtually the same with that in the receiving ponds. It was therefore necessary, during the current study, to acclimatise the fish for over a week before transferring them into freshwater ponds. Temperatures between 26-28°C were observed to be suitable during transportation of juveniles. It is possible that other water quality parameters possibly pH, as indicated by Sivalingam (1975), could be equally critical during the acclimatization process and after they have been transferred into ponds. Mullets became stressful whenever pH dropped below 6 in ponds, in such situations lime was applied to raise the level to between 7 and 8.

The average survival of 54.5% from all the ponds compares favourably with what has been reported by Bok (1984). Survival rates of 62-100% were reported for *M. cephalus* stocked at a size of 30 g (Yashouv,

1972) while survival rates of between 50-85% were reported by Linder *et al.* (1975) for the same species stocked at a much smaller size of between 0.37 and 4.81 g. Mortalities were attributed to handling and predation by birds and crabs. In the current study apart from handling, mortalities also occurred as a result of predation by fish, frogs and monitor lizards. The presence of larger and more predatory fishes in ponds that were supplied with feed than those that were not supplied with feed accounts for the low survival rate in the former ponds during the second experiment in brackish water ponds.

Growth and production in ponds

The similarity in growth pattern of fish in ponds supplied with supplementary feed and those in ponds without supplementary feed during the first few months of the experiment could be due to adequate and ready availability of natural food. With time, food could become inadequate if replenishment of natural food through fertilization was not fast enough. In such a situation addition of supplementary feed could enhance the growth of fish receiving such a treatment hence the divergence in growth pattern after a certain culture period with those receiving feed growing faster.

The initial and final weights of fish recorded in the first experiment in brackish water ponds, which lasted for 150 days, were 5.1±0.70-28.6±0.90g for ponds with feed and 4.6±0.55-25.2±1.50 g for ponds without feed representing an increment of 463.0% and 450.2% respectively. In the second experiment, which lasted for 270 days, initial and final weights recorded were 7.3±0.10-41.9±1.06 g an increment of 476.7% and 7.2±0.38-32.1±0.44 g an increment of 347.7% for ponds with feed and without feed respectively. Weights recorded in fresh water ponds with feed increased from an initial increments of 243.5% and 226.8% respectively. These results compare favourably with results of previous studies elsewhere.

After a one-year culture period of *M. curema*, Alves de Araúja *et al.* (1980) reported mean weights of 45.0 g, 33.0 g, and 33.0 g with an initial mean lengths between 20-25 mm (2.0-2.5 g) from three different ponds. Thus, at the end of the experiment the percentage increment, in terms of weight, ranged from 1367 to 1900. The same species was cultured in Costa Rica with an initial total length of 50 mm using supplementary inorganic fertilization and within 5 months, total lengths of between 115 and 145 mm (an increment of 130–190% respectively) were achieved (Philips *et al.*, 1987). Other mullet species, *Mugil cephalus*, *Liza parsia*, and *Liza tade*, showed an increment from initial mean stocking weights of 23.2 g, 9.0 g, and 8.0 g to final mean weights of 514.4 g, 34.9 g and 119.6 g respectively in 374 days (Pillai *et al.*, 1984). These correspond to percentage increments of 2117.2, 287.8 and 1395 respectively. The largest sizes reached by *Myxus capensis* after one, two and three years' growth in various dams in eastern Cape were 31 g, 175 g, and 506 g (Bok, 1984).

Species that were found in the ponds after the second experiment in the brackish water ponds were *L. falcipinnis, L. dumerilii, M. curema* and *M. bananensis*. Conspicuously missing was *M. cephalus*, the species which is acclaimed to be the fastest growing among the mullet species (Bardach *et al.*, 1972; Pruginin *et al.*, 1975; Linder *et al.*, 1975; Alves de Araújo *et al.*, 1980; Bok, 1984). A characteristic, that has made it an obvious choice for culture in most places. From the monthly sampling in the two estuaries it became evident that *M. cephalus* indeed, grows bigger than the other species but was the least common species in both estuaries. Getting their fingerlings from the wild for culture will therefore, be difficult. In the absence of *M.*

cephalus, the highest mean weight was registered for *M. curema* followed by *M. bananensis* during the 270-day culture period.

The other mullet species have however, been shown to have great culture potential. Production of 239 kg ha^{-1} yr^{-1} was achieved without any supplementary feeding in polyculture trials conducted in brackish water ponds in Lagos, Nigeria (Sivalingam, 1975). From Rio Grand do Norte (Brasil), Alves de Araújo *et al.* (1980) have reported production of 276 kg ha^{-1} for *M. curema* after one year of culture in brackish water ponds, also without supplementary feed and fertilisation. Net mullet productions of 217.74 kg ha^{-1} yr^{-1} and 209.76 kg ha^{-1} yr^{-1} have been obtained by Pakrasi *et al.* (1975) while Linder *et al.* (1975) reported of production between 293 kg ha^{-1} and 804 kg ha^{-1} for striped mullet from Texas, USA.

In the current study, where mixed species of grey mullets were cultured for 270 days, production of 336.5 kg ha^{-1} (454.24 kg ha^{-1} yr^{-1}) and 287 kg ha^{-1} (388.0 kg ha^{-1} yr^{-1}) were achieved in ponds with and without supplementary feed respectively. These results compare favourably with those of previous studies, even though production levels attained in those studies were considered to be low. Production from ponds that were supplied with feed was comparatively, higher and confirms the assertion by Sivalingam (1975) that addition of supplementary feed increased both yield and average size of fish.

The low production in the current study is reflected in the low daily growth gain, specific growth rates and feed conversion ratios. In all the investigations in fresh water and brackish water ponds, the daily growth gain ranged from 0.1128 to 0.1568 g/fish/day for fish supplied with feed and from 0.0923 to 0.1375 g/fish/day for fish that were not fed. The specific growth rate ranged from 0.6493 to 1.1521 %/day and from 0.5552 to 1.1368

%/day for fish supplied with feed and for fish without feed respectively. These are low compared to other results reported for some species of grey mullets.

For example, golden grey mullet (*Liza aurata*) raised in saltwater for 150 days attained growth rate of 0.95 g/fish/day (Chervinski, 1975). Growth rate of 0.6-0.95 g/fish/day was recorded for *L. aurata* young of the year while 0.85-1.0 g/fish/day was recorded for fish in their second year of life (Chervinski. 1976). The daily growth rates registered by *M. cephalus, Liza parvus* and *Liza tade* during a culture period of 374 days together with carps, milkfishes and prawns in a low saline pond were 1.313 g, 0.069 g, and 0.298 g respectively (Pillai *et al*., 1984). Linder *et al.* (1975) reported mean daily weight of between 0.36 and 0.71 g from the six ponds they used for *M. cephalus*.

The low production obtained by both Sivalingam (1975) and Alves de Araújo *et al.* (1980) was attributed to the fact that the experiment was conducted without supplementary feed and fertilizers as well as the presence of predators. Apart from the presence of predators, the current study was faced with the problem of *S. melanotheron* and *Oreochromis niloticus* being introduced into the brackish and freshwater ponds respectively, through periodic pumping of water. Both species are known herbivores and also accept supplementary feed. There was the likelihood of these species competing with the grey mullets for the same food resource and also for available space thus, inhibiting their growth and ultimately fish production in ponds.

Yashouv (1972) argued that higher fish density, especially considering the tendency of mullets to school, has a depressing effect on growth. He also asserted that the growth of grey mullets seems to be influenced by its competition for food with other fish groups in ponds. Coupled with this is the fact that, in the current study, feed supplied might also not have been easily available to the fish due to wind action which, most of the time, blew away the feed into the grassy edges of the ponds. It was therefore possible that the supplementary feed was grossly under utilised in the current study. This is confirmed by the feed conversion ratio of between 3.6 and 7.2 which was rather high compared to the range of 2.24 to 3.31 reported for *M. cephalus* (Linder *et al.*, 1975).

Apart from density, which might have resulted in competition, the length of the growing season with respect to initial size of fish stocked was cited by Yashouv (1972) as one of the factors that were likely to have affected growth of grey mullets during his experiment. He noted that as the growing period is increased or the larger the fish are allowed to grow the higher the increase in daily yield. According to Hopkins (1992), small and large fish have low absolute growth rates while fish of intermediate sizes have higher absolute growth rates. Thus, differences in initial stocking size and the length of culture period could affect growth and could make comparison with other studies more difficult. If survival rates could be minimised perhaps, it will be advisable to use juveniles of bigger size (e.g., 20 g) as initial stocking material to achieve better yields.

According to Hora and Nair (1944) (quoted in Pillai *et al.*, 1984) mullets grow faster in freshwaters. Considering a culture period of 150 days, the mean daily weight gain, specific growth rate, percentage growth increment and feed conversion ratio of fish raised in brackish water ponds during the first experiment were higher than those raised in fresh water ponds. Results from the second experiment in brackish water ponds were, however, quite similar to those from the freshwater ponds. The higher growth achieved in the first brackish water experiment than in the freshwater experiment may be due to efficient utilisation of feed by fish as indicated by the feed conversion ratio of 3.6 compared to 6.7 for fish raised in freshwater ponds. Additionally, the fresh water ponds remained turbid for most part of the culture period. As a result plankton production was observed to be very low irrespective of fertilization. The poor growth performance of mullets in the fresh water ponds may also be attributed to the low concentration of natural food. Pillai *et al.* (1984) assigned similar reason for the slow growth of mullet species they cultured in a coastal low saline polyculture pond in West Bengal, in spite of the fact that the fish were given supplementary feed. The turbid nature of the freshwater ponds could have adversely affected the chances of fish to detect supplementary feed supplied hence the poor utilisation of feed in such ponds.

Comparison of the effect of rice bran and wheat bran on growth performance of grey mullets revealed that fish fed on the latter feed attained higher growth than the former one. The different protein content of wheat bran and rice bran, which was 16.8 and 5.23% respectively, could account for the difference in growth performance with the feed containing high protein producing higher growth. Protein-rich food, within certain limits, promotes growth as indicated by Wantanabe *et al.* (1990). They reported of a small but significant improvement in survival and growth for Florida red tilapia fed with 28% protein diet compared to 32% protein diet and suggested that excess dietary protein inhibited growth.

During the second experiment in brackish water ponds where algal counts were made it was noted that ponds that received supplementary feed had higher concentration of algae. Additionally, fish in these ponds recorded comparatively, higher growth. Decomposition of uneaten feed could release nutrients into the ponds and thereby enhance algal growth, which in turn could improve fish growth. A positive correlation has been found between primary productivity and fish biomass (Garg and Bhatnager, 1996; Knud-Hansen and Batterson, 1994).

CONCLUSIONS

A total of six species of grey mullets were identified in the two estuaries studied. These were, *Liza falcipinnis, L. dumerilii, L. grandisquamis, Mugil bananensis, M. curema* and *M. cephalus*. All the six species were found in the Pra estuary while five, excluding *L. grandisquamis*, were encountered in the Volta estuary. The most abundant species in the Volta estuary was *M. curema* while in the Pra estuary *L. falcipinnis* was the dominant species.

Specimens of all the species obtained from the Volta estuary were comparatively larger than their counterparts from the Pra estuary. The situation was attributed to greater fishing pressure exerted on the Pra fish community and the low transparency at the Pra estuary. The growth patterns of the fishes based on length-weight relationships indicated that *L. grandisquamis* exhibited isometric growth while the five other species showed allometric growth pattern.

A study of the food habits of all the six grey mullets species indicated that they were omnivorous with *L. falcipinnis*, *M. curema*, *M. cephalus* and *M. bananensis* having relatively higher proportion of plant material in their diet. These species also had relatively longer guts in relation to standard length of fish. Even though there were no substantial seasonal variations in the diet of all the species, feeding intensity varied throughout the year. Whereas feeding intensity of species from the Pra estuary was high during the peak of the rainy season that of species from the Volta estuary was low during the same period. All the species investigated from the Volta estuary show clear diurnal feeding habit. Although the diet of the species in each estuary was similar there were differences in their feeding periodicity as well estuary ingesting the widest size range of sand particles. These were seen as probable strategies adopted to avert or minimise competition.

Reproductive activities of mullet species studied showed that the mean size at first maturity of males was generally, smaller compared to their female counterparts. Variations in gonadosomatic indices, the presence of mature and spent individuals as well as distribution of oocytes sizes suggest that spawning of grey mullets in the two estuaries occurred twice in a year; March-May and October-November in the Pra estuary, February-April and June-August in the Volta estuary. Among the species studied *M. bananensis* had the highest fecundity. This could be a useful asset for the species with respect to production of fish seed for culture.

A preliminary assessment of culture potential of mullets indicated that supplementary feed enhanced their growth under culture conditions. Wheat bran was also found to enhance their growth better than rice bran. The mean final weight of *M. curema* was the highest among the species during the 270-day culture period. The potential for the culture of grey mullets in Ghana has been demonstrated to be favourable in this study by using inexpensive feed stuffs and even from natural food generated in ponds.

To increase the availability of grey mullets from both capture and culture fisheries it is recommended that,

- fishing pressure in lagoons and estuaries should be controlled to allow for their sustained fisheries
- culture of mullets should be encouraged; however, culture trials must be expanded to generate more local research results.
- for conservation of natural stocks of grey mullets there should be efforts at hatchery production of mullet seed for culture.

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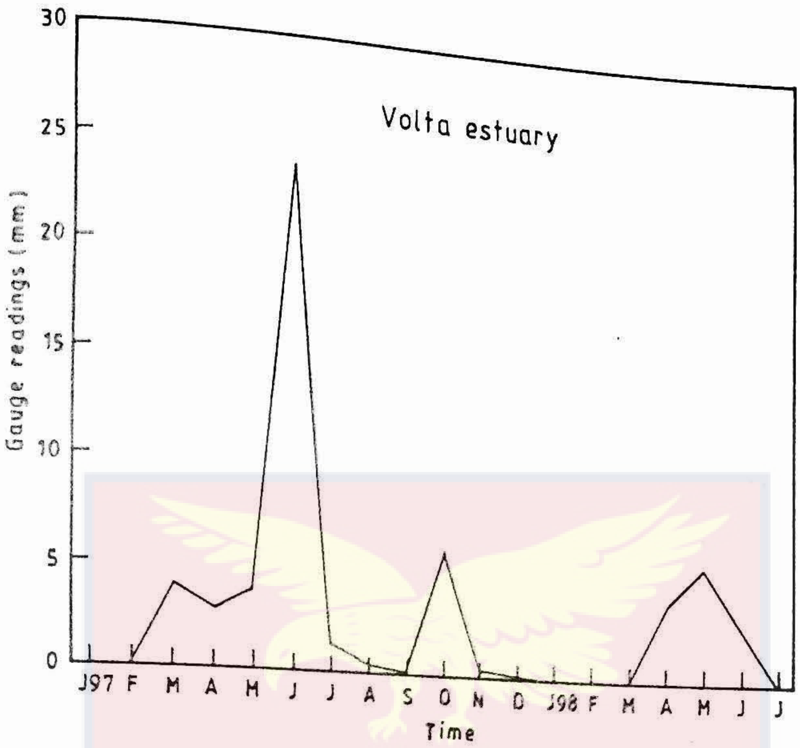

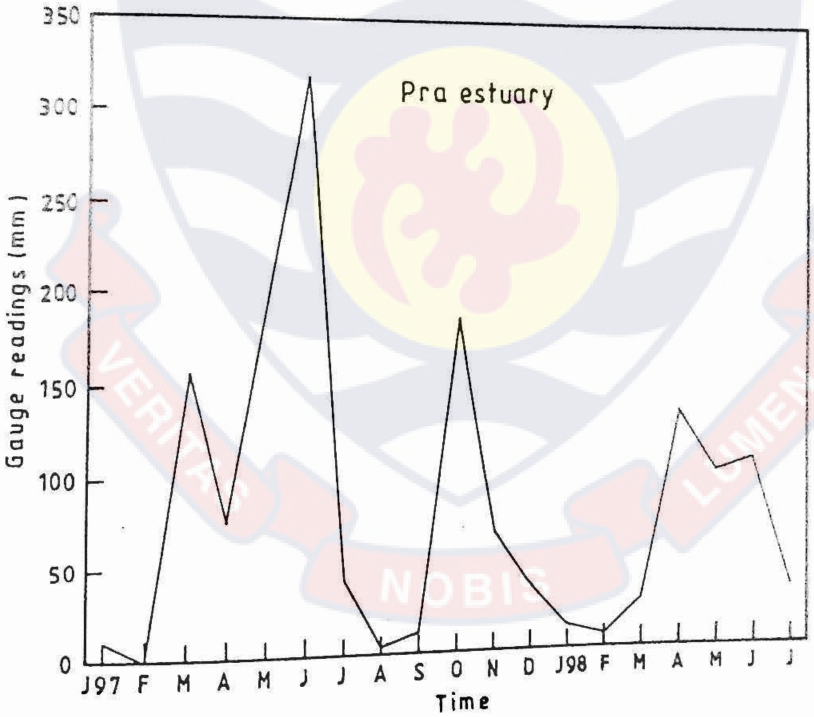

Appendix 1 Rainfall pattern at the lower Volta and Pra estuaries Catchment areas during the study period.

Appendix 2 Variations in hydrograhpic factors in the Volta estuary

Months	pH	DO (mg l^{-1})	Temperature °C	Salinity (‰)	Transparency (cm)
Feb 97	7.5	7.2	29.0	0.06	215
Mar	7.3	8.8	28.5	2.12	207
Apr	7.5	9.2	28.5	1.49	199
May	7.3	6.6	28.5	0.05	181
Jun	7.3	6.0	26.5	0.12	114
Jul	7.9	5.8	26.5	1.81	134
Aug	7.5	6.2	25.5	7.54	199
Sep	8.0	6.4	27.5	2.12	185
Oct	7.9	5.8	28.8	1.08	205
Nov	6.9	5.6	28.0	1.12	206
Dec	7.3	5.0	27.5	1.94	274
Jan 98	6.6	6.0	26.0	0.85	306
Feb	7.2	7.0	29.0	1.76	220
Mar	6.9	6.4	30.0	3.52	210
Apr	8.1	6.8	30.5	8.17	230
May	7.2	6.4	31.0	5.06	200
Jun	7.2	8.4	29.0	2.04	190
Jul	7.3	8.0	26.0	0.51	125

Appendix 3. Variations in hydrograhpic factors in the Pra estuary

Months	pH	DO (mg l^{-1})	Temperature °C	Salinity (‰)	Transparency (cm)
Feb 97	7.5	7.4	29.0	16.00	105
Mar	7.5	8.0	25.5	20.00	119
Apr	8.8	8.8	28.5	0.50	14
May	7.7	8.0	30.0	0.50	19
Jun	7.4	6.4	26.5	0.07	26
Jul	8.2	8.0	26.5	3.50	31
Aug	7.9	8.0	26.0	2.20	40
Sep	8.0	6.6	26.4	1.40	68
Oct	7.8	6.2	29.0	6.10	41
Nov	7.6	7.4	27.8	4.00	30
Dec	6.8	6.8	28.8	1.30	20
Jan 98	7.4	8.0	27.5	7.70	133
Feb	7.4	5.8	29.5	2.30	70
Mar	6.8	6.4	29.0	15.80	146
Apr	7.7	6.6	30.0	16.00	152
May	7.5	4.8	30.5	0.52	28
Jun	7.1	8.0	29.0	0.72	10
Jul	7.2	7.2	25.0	4.06	23

Appendix 4 Relative abundance (%) of grey mullets in the Volta estuary.

Months	*L. falcipinnis*	*L. dumerilii*	*M. curema*	*M. bananensis*	*M. cephalus*
Feb. 97	13.06	19.37	49.55	8.56	9.46
Mar.	21.57	24.65	40.34	7.28	6.16
Apr.	22.12	11.54	42.31	11.54	12.50
May.	63.96	12.61	18.56	3.96	0.90
Jun.	36.36	6.06	42.42	1.52	13.64
Jul.	55.56	7.40	8.64	1.23	27.16
Aug.	29.92	19.69	14.96	28.35	7.09
Sep.	2.44	20.33	53.66	21.14	2.44
Oct.	11.54	8.24	46.70	25.27	8.24
Nov.	3.92	71.57	13.73	10.78	0.0
Dec.	6.02	27.82	37.97	19.17	9.02
Jan. 98	4.98	20.28	21.71	52.66	0.36
Feb.	11.44	8.05	31.36	49.15	0.0
Mar.	29.58	7.39	53.87	8.10	1.06
Apr.	1.42	36.17	51.42	7.45	3.55
May.	3.05	0.76	88.55	7.63	0.0
Jun.	12.42	5.88	58.82	21.57	1.31
Jul.	2.69	1.08	21.50	63.40	11.29

Appendix 5. Relative abundance (%) of grey mullets in the Pra estuary

Months	*L.falcipinnis*	*L. dumerilii*	*L.grandisquamis*	*M.curema*	*M.bananensis*	*M.cephalus*
Mar 97	77.08	0.0	10.42	3.13	3.13	6.25
Apr	40.00	0.0	14.00	8.00	30.00	8.00
May	23.08	51.28	17.95	2.56	0.0	5.13
Jun	31.25	37.50	0.0	6.25	18.75	6.25
Jul	80.99	6.07	8.79	0.64	3.04	0.48
Aug	36.18	14.47	0.0	23.68	25.00	0.66
Sep	68.90	8.25	11.80	5.10	6.0	0.0
Oct	76.51	0.62	18.08	3.40	1.39	0.0
Nov	63.00	12.80	13.40	8.10	2.60	0.0
Dec	12.60	24.41	37.00	6.30	19.69	0.0
Jan 98	3.70	8.50	3.70	5.50	78.00	0.61
Feb	8.10	25.80	0.91	19.90	45.20	0.0
Mar	6.80	3.60	4.20	31.50	53.90	0.0
Apr	14.60	0.90	6.80	52.80	24.80	0.0
May	62.44	2.24	4.98	17.16	13.20	0.0
Jun	78.00	9.60	1.30	7.80	2.80	0.51
Jul	75.60	7.30	0.80	9.80	4.10	2.44

Appendix 6a Percentage composition of stomach contents of different size groups of *L. falcipinnis* from the Volta estuary

Size group (mm)	N	Percentage composition of stomach contents						
		Diatoms	Green algae	Blue green algae	Polychaetes	Zooplankton	Sand particles	Detritus
61 - 80	8	25.0	18.0	4.7	0.0	6.3	31.3	14.8
81 - 100	10	0.0	50.0	9.4	0.0	3.1	25.0	12.5
101 – 120	10	6.7	5.0	0.0	0.0	21.7	53.3	13.3
121 – 140	11	8.3	9.8	0.0	0.0	0.0	51.5	30.3
141 – 160	9	8.3	9.4	2.1	0.0	11.5	64.6	4.2
161 – 180	12	12.2	20.4	6.6	0.0	8.7	25.5	26.5

N number of samples for each size group

Appendix 6b Percentage composition of stomach contents of different size groups of *L. dumerilii* from the Volta estuary

Size group (mm)	N	Percentage composition of stomach contents						
		Diatoms	Green algae	Blue green algae	Polychaetes	Zooplankton	Sand particles	Detritus
81 – 100	18	9.6	1.6	0.4	0.0	14.1	59.9	14.5
101 – 120	12	4.5	4.5	0.0	0.0	10.7	65.7	14.6
121 - 140	16	10.9	1.9	0.3	0.0	11.6	61.6	13.0
141 - 160	14	5.3	4.1	0.0	0.0	4.4	66.7	19.5
161 – 180	10	15.7	5.2	.09	0.0	7.3	56.4	14.5

N – number of samples for each size group

Appendix 6c Percentage composition of stomach contents of different size groups of *M. curema* from the Volta estuary

Size group (mm)	N	Percentage composition of stomach contents: Diatoms	Green algae	Blue green algae	Polychaetes	Zooplankton	Sand particles	Detritus
61 – 80	10	16.7	15.0	5.0	0.0	0.0	41.7	21.7
81 – 100	13	19.8	5.9	1.1	8.6	1.6	44.1	18.8
101 – 120	12	20.2	3.9	0.6	13.8	6.6	33.1	22.4
121 – 140	10	9.3	10.1	2.8	5.6	20.6	42.3	14.9
141 – 160	10	5.7	9.9	2.0	21.3	11.2	33.7	16.1
161 – 180	10	12.5	26.3	4.4	0.0	2.5	36.3	18.1

N- number of samples in each size group

Appendix 6d Percentage composition of stomach contents of different size groups of *M. bananensis* from the Volta estuary

Size group (mm)	N	Percentage composition of stomach contents: Diatoms	Green algae	Blue green algae	Polychaetes	Zooplankton	Sand particles	Detritus
61 – 80	15	8.1	16.7	1.9	0.0	3.9	36.8	32.6
81 – 100	10	10.6	17.3	3.9	0.0	9.1	41.7	17.3
101 – 120	14	11.3	5.9	1.4	12.5	5.7	42.1	21.1
121 – 140	8	11.2	6.7	4.5	3.4	8.1	46.2	19.9
141 – 160	16	7.3	13.2	1.3	0.0	11.3	41.1	25.8
161 – 180	12	23.4	9.2	2.7	0.0	9.8	44.6	10.3

N – number of samples in each size group

Appendix 6e Percentage composition of stomach contents of different size groups of *M. cephalus* from the Volta estuary

Size group (mm)	N	Percentage composition of stomach contents: Diatoms	Green algae	Blue green algae	Polychaetes	Zooplankton	Sand particles	Detritus
61 – 100	6	14.1	7.8	0.0	0.0	6.3	65.7	6.3
101 – 140	6	0.8	3.9	0.4	54.9	8.4	22.3	9.5
141 – 180	6	15.7	4.1	1.1	31.3	2.7	35.7	9.8
181 – 220	6	6.8	19.9	5.3	34.4	7.9	16.8	16.8
221 – 260	6	7.3	42.6	9.1	2.0	1.2	24.4	13.4
261 – 300	6	28.6	24.5	6.9	0.0	1.4	21.4	13.9
301 – 340	6	33.6	18.1	5.6	14.5	5.9	14.8	11.5
341 – 380	6	17.9	10.6	11.5	0.0	4.1	29.4	26.6
381 >	8	20	19.5	7.9	16.8	2.6	34.7	15.3

N – number of samples in each size group

Appendix 7a Percentage composition of stomach contents of different size groups of *L. falcipinnis* from the Pra estuary

Size group (mm)	N	Percentage composition of stomach contents: Diatoms	Green algae	Blue green algae	Polychaetes	Zooplankton	Sand particles	Detritus
61 – 80	18	28.0	14.0	9.6	0.0	13.7	24.4	10.3
81 – 100	24	27.9	14.4	12.9	0.0	6.1	20.4	18.2
101 – 120	25	29.8	8.1	13.3	0.0	13.9	21.4	13.6

N – number of samples in each size group

Appendix 7b Percentage composition of stomach contents of different size groups of *L. dumerilii* from the Pra estuary

Size group (mm)	N	Percentage composition of stomach contents						
		Diatoms	Green algae	Blue green algae	Polychaetes	Zooplankton	Sand particles	Detritus
61 – 80	10	13.4	0.0	0.0	0.0	18.8	48.2	19.6
81 – 100	12	8.6	3.6	0.8	0.0	12.8	56.2	18.0
101 – 120	14	10.8	3.8	2.6	1.6	8.4	48.0	24.5
121 – 140	8	6.6	2.4	1.0	0.0	5.6	70.2	14.3
141 – 160	18	12.7	1.4	1.4	0.0	8.0	73.2	32.9
161 – 180	13	17.3	3.7	3.7	0.0	6.2	39.5	29.6

N – number of samples in each size group

Appendix 7c Percentage composition of stomach contents of different size groups of *L. grandisquamis* from the Pra estuary

Size group (mm)	N	Percentage composition of stomach contents						
		Diatoms	Green algae	Blue green algae	Polychaetes	Zooplankton	Sand particles	Detritus
81 – 100	15	22.3	9.9	1.1	0.0	3.8	40.9	22.0
101 – 120	12	27.3	6.3	5.7	0.0	1.9	36.8	21.9
121 – 140	18	20.4	4.8	3.9	0.0	13.4	39.5	18.0
141 – 160	15	22.6	4.6	1.8	0.0	13.8	41.0	16.3

N – number of samples in each size group

Appendix 7d Percentage composition of stomach contents of different size groups of *M. curema* from the Pra estuary

Size group (mm)	N	Percentage composition of stomach contents						
		Diatoms	Green algae	Blue green algae	Polychaetes	Zooplankton	Sand particles	Detritus
61 – 80	20	15.2	1.5	1.7	0.0	10.7	43.5	27.4
81 – 100	16	16.9	3.0	2.0	0.0	13.4	41.9	23.8
101 – 120	22	18.8	2.2	3.0	4.3	10.6	40.8	20.4
121 – 140	14	16.6	1.6	4.1	12.4	15.5	33.2	17.6

N – number of samples in each size group

Appendix 7e Percentage composition of stomach contents of different size groups of *M. bananensis* from the Pra estuary

Size group (mm)	N	Percentage composition of stomach contents						
		Diatoms	Green algae	Blue green algae	Polychaetes	Zooplankton	Sand particles	Detritus
61 – 80	13	9.4	0.6	1.3	0.0	8.2	42.8	37.7
81 – 100	10	9.4	5.6	2.2	0.0	4.3	48.9	29.6
101 – 120	16	18.4	4.1	0.9	0.0	3.5	43.4	29.7
121 – 140	12	11.8	4.6	7.9	0.0	2.6	40.8	32.2
141 – 160	14	13.0	3.0	1.0	0.0	10.0	40.0	33.0

N – number of samples in each size group

Appendix 8a Stomach fullness index for the first 24-h sampling to determine daily feeding activity of grey mullets from the Volta estuary.

Time	*L. dumerilii*	*L. falcipinnis*	*M. curema*	*M. bananensis*	*M. cephalus*
16.00	1.4356±0.41 (n=11)	0.0 (n=0)	0.4331±0.19 (n=6)	0.0013±0.001 (n=19)	0.0 (n=0)
20.00	0.5765±0.30 (n=8)	0.0 (n=0)	0.0373±0.01 (n=32)	0.1293±0.03 (n=114)	0.0820±0.02 (n=8)
24.00	0.0 (n=14)	0.0 (n=0)	0.0417±0.01 (n=57)	0.0 (n=25)	0.0 (n=0)
04.00	0.1609±0.14 (n=12)	0.0 (n=2)	0.0262±0.01 (n=19)	0.0 (n=7)	0.0 (n=0)
08.00	2.5822±0.24 (n=26)	0.4013±0.11 (n=10)	0.5686±0.02 (n=78)	0.5929±0.04 (n=33)	0.0 (n=0)
12.00	1.7109±0.21 (n=22)	0.0 (n=0)	0.6123±0.07 (n=6)	0.6874±0.02 (n=19)	0.0 (n=0)
16.00	0.7786±0.39 (n=6)	0.0 (n=0)	0.0620±0.02 (n=5)	0.3879±0.12 (n=8)	0.0 (n=0)

N- number of samples for each species

Appendix 8b Stomach fullness index for the second 24-h sampling to determine daily feeding activity of grey mullets from the Volta estuary.

Time	*L. dumerilii*	*L. falcipinnis*	*M. curema*	*M. bananensis*	*M. cephalus*
16.00	1.4645±0.25	0.0	0.7705±0.13	0.5366±0.14	0.0
	(n=10)	(n=4)	(n=34)	(n=15)	(n=0)
20.00	0.3223±0.08	0.0	0.0384±0.01	0.1777±0.04	0.0
	(n=36)	(n=0)	(n=19)	(n=28)	(n=2)
24.00	0.1342±0.02	0.0458±0.01	0.0	0.0	0.0
	(n=12)	(n=3)	(n=51)	(n=49)	(n=0)
04.00	0.0	0.0	0.0	0.0	0.0
	(n=18)	(n=13)	(n=36)	(n=6)	(n=0)
08.00	2.2916±0.36	0.8698±0.33	0.5569±0.08	0.6648±0.09	0.2549±0.19
	(n=21)	(n=14)	(n=79)	(n=75)	(n=8)
12.00	0.0	0.0	0.5527±0.08	0.7490±0.10	0.0
	(n=0)	(n=0)	(n=75)	(n=50)	(n=0)
16.00	0.8962±0.37	0.1000±0.001	0.5871±0.03	0.5366±0.05	0.0
	(n=10)	(n=6)	(n=66)	(n=54)	(n=0)

N = number of samples for each species

Appendix 9a Hydrographic factors measured during the first 24-h sampling to determine daily feeding activity of grey mullets from the Volta estuary

Time	pH	Water Temperature (°C)	Conductivity (µs/cm)	DO (mg l^{-1})	Salinity (‰)
16.00	7.69	30.0	1200	6.9	1.86
20.00	7.83	29.0	1242	6.9	2.07
24.00	8.01	28.0	1780	6.4	1.95
04.00	7.91	28.0	2540	6.2	2.46
08.00	8.12	28.5	696	6.8	2.43
12.00	8.81	31.0	828	7.2	2.13
16.00	8.10	30.5	724	7.0	2.34

Appendix 9b Hydrographic factors measured during the second 24-h sampling to determine daily feeding activity of grey mullets from the Volta estuary

Time	pH	Water Temperature (°C)	Conductivity (µs/cm)	DO (mg l^{-1})	Salinity (‰)
16.00	8.0	28.5	6720	7.0	3.00
20.00	8.0	28.0	2480	6.0	1.24
24.00	7.7	27.0	1367	5.8	0.62
04.00	8.0	27.0	4620	5.6	2.39
08.00	8.3	28.0	1533	6.2	0.84
12.00	8.4	30.0	4360	7.8	2.2
16.00	8.0	28.5	11880	6.8	3.52

Appendix 10a Relationship between environmental parameters and daily feeding activity of grey mullets from the Volta estuary during the first 24-h sampling

Species	Dissolved oxygen	pH	Temperature	Salinity	Coductivity
L. falcipinnis	0.6485 p=0.115	0.8177* p=0.025	0.4828 p=0.272	0.3527 p=0.438	-0.7110 p=0.073
L. dumerilii	0.5939 p=0.160	0.3645 p=0.421	0.3702 p=0.414	0.1463 p=0.754	-0.7261 p=0.065
M. bananensis	0.6691 p=0.100	0.8140* p=0.026	0.5280 p=0.223	0.4067 p=0.365	-0.7452 p=0.055
M. curema	0.5663 p=0.185	0.5259 p=0.225	0.4485 p=0.313	-0.0705 p=0.881	-0.5845 p=0.168
M. cephalus	0.1621 p=0.529	-0.2896 p=0.529	-0.1033 p=0.826	-0.1733 p=0.710	-0.0297 p=0.529

* *Correlation is significant at 5% probability level*

Appendix 10b Relationship between environmental parameters and daily feeding activity of grey mullets from the Volta estuary during the second 24-h sampling

Species	Dissolved oxygen	pH	Temperature	Salinity	Coductivity
L. falcipinnis	-0.1660 p=0.722	0.6585 p=0.108	-0.0876 p=0.852	-0.4093 p=0.362	-0.4052 p=0.370
L. dumerilii	0.1250 p=0.789	0.7178 p=0.069	0.1034 p=0.825	0.2889 p=0.530	0.3218 p=0.482
M. bananensis	0.8313* p=0.020	0.1904 p=0.683	0.8503* p=0.015	0.2824 p=0.539	0.2794 p=0.544
M. curema	0.7673* p=0.044	0.2272 p=0.624	0.6956 p=0.083	0.3413 p=0.454	0.3495 p=0.442
M. cephalus	-0.1452 p=0.756	0.428 p=0.341	-0.0612 p=0.896	-0.3829 p=0.397	-0.3792 p=0.402

* *Correlation is significant at 5% probability level*

Appendix 11a Monthly data on Condition Factor, stomach fullness index and gonadosomatic index of *L. falcipinnis* from the Volta estuary

Month	Condition Factor (±se)	Stomach Fullness index (±se)	GSI (±se)	
			males	females
Feb 97	1.69±0.03	0.01±0.04	0.0	0.0
Mar	1.77±0.02	0.25±0.07	0.1899±0.09	0.0
Apr	1.89±0.02	0.11±0.03	0.1675±0.08	9.6400±0.61
May	1.84±0.01	0.43±0.03	0.1823±0.05	0.0
Jun	1.80±0.03	0.46±0.09	0.0830±0.03	0.0
Jul	1.79±0.02	0.11±0.03	0.2730±0.10	0.0
Aug	1.87±0.01	0.23±0.06	0.0	0.0
Sep	1.71±0.05	1.15±0.48	0.0	0.0
Oct	1.62±0.03	0.0	0.0	0.0
Nov	1.93±0.05	0.69±0.35	0.3300±0.15	0.0
Dec	1.85±0.04	0.32±0.17	0.4115±0.12	0.0
Jan 98	1.74±0.06	0.19±0.08	0.0	0.0
Feb	1.85±0.03	0.20±0.07	0.5478±0.17	1.4614±0.76
Mar	1.75±0.01	0.03±0.02	0.3040±0.14	3.0800±2.56
Apr	1.66±0.13	0.91±0.92	0.6496±0.21	0.0
May	1.86±0.06	0.02±0.02	0.4140±0.01	0.0
Jun	1.99±0.02	0.06±0.03	0.2277±0.02	2.5665±1.20
Jul	1.80±0.04	0.39±0.39	0.0	0.0

Appendix 11b Monthly data on Condition Factor, stomach fullness index and gonadosomatic index of *L. dumerilii* from the Volta estuary

Month	Condition Factor (±se)	Stomach Fullness index (±se)	GSI (±se)	
			males	females
Feb 97	1.68±0.03	0.67±0.12	0.0	0.0
Mar	1.87±0.02	0.91±0.10	0.0	0.0
Apr	1.57±0.07	0.0	0.0	0.0
May	1.80±0.02	0.65±0.15	0.0	0.0
Jun	1.79±0.05	1.61±0.43	0.0	0.0
Jul	1.87±0.04	0.31±0.31	0.0	0.0
Aug	1.89±0.05	1.82±0.18	0.0	0.0
Sep	1.77±0.02	0.08±0.04	0.0	0.0
Oct	1.71±0.05	0.62±0.22	0.2655±0.13	0.0
Nov	1.78±0.01	1.49±0.14	0.0	0.0
Dec	1.79±0.02	2.16±0.11	0.2137±0.04	0.0
Jan 98	1.72±0.02	1.13±0.17	0.5510±0.11	0.0
Feb	1.85±0.03	1.00±0.26	0.5249±0.08	4.6672±1.60
Mar	1.59±0.02	0.08±0.08	0.0	0.0
Apr	1.74±0.02	1.27±0.15	0.0	0.0
May	1.77±0.0	0.0	0.0	0.0
Jun	1.78±0.06	0.58±0.13	0.5398±0.21	0.4827±0.0
Jul	1.77±0.01	0.0	0.7470±0.02	0.0

Appendix 11c Monthly data on Condition Factor, stomach fullness index and gonadosomatic index of *M. curema* from the Volta estuary

Month	Condition Factor (±se)	Stomach Fullness index (±se)	GSI (±se)	
			males	females
Feb 97	1.93±0.01	0.04±0.01	0.2470±0.08	6.1290±3.00
Mar	2.00±0.02	0.28±0.01	0.2300±0.08	0.0
Apr	2.05±0.03	0.31±0.03	0.0	9.6370±0.0
May	2.12±0.01	0.28±0.04	0.1460±0.04	0.0
Jun	2.11±0.03	0.43±0.03	0.0	0.4430±0.11
Jul	2.08±0.06	0.16±0.06	0.3195±0.09	0.0
Aug	2.11±0.03	0.50±0.09	0.0	3.1300±1.82
Sep	2.09±0.02	0.48±0.03	0.0	0.0
Oct	1.74±0.02	0.01±0.01	0.3774±0.22	0.0
Nov	1.99±0.02	0.03±0.01	0.2665±0.03	0.0
Dec	2.01±0.01	0.18±0.02	0.0	0.0
Jan 98	1.94±0.02	0.13±0.03	0.0	0.0
Feb	2.11±0.01	0.15±0.03	0.3106±0.06	6.9846±2.10
Mar	2.02±0.01	0.09±0.02	0.2494±0.07	5.2330±4.23
Apr	2.01±0.01	0.0	0.2838±0.09	1.8292±0.07
May	2.14±0.02	0.02±0.01	0.2743±0.11	0.0
Jun	2.42±0.03	0.29±0.03	0.0	0.0
Jul	2.18±0.03	0.02±0.01	0.2930±0.09	0.0

Appendix 11d Monthly data on Condition Factor, stomach fullness index and gonadosomatic index of *M. bananensis* from the Volta estuary.

Month	Condition Factor (±se)	Stomach Fullness index (±se)	GSI (±se)	
			males	Females
Feb 97	2.00±0.04	0.08±0.02	0.0	0.0
Mar	2.07±0.04	0.46±0.06	0.3230±0.06	0.0
Apr	2.10±0.04	0.28±0.10	0.0	0.0
May	2.04±0.03	0.71±0.16	0.0	0.0
Jun	2.11±0.0	0.45±0.0	0.0	0.0
Jul	2.20±0.0	0.0	0.0	15.6590±2.50
Aug	2.21±0.04	0.61±0.05	0.0	0.0
Sep	2.01±0.03	0.27±0.05	0.0	0.0
Oct	1.82±0.03	0.0	0.2980±0.00	4.3500±0.00
Nov	1.96±0.04	0.40±0.07	0.2410±0.00	0.0
Dec	1.97±0.02	0.15±0.03	0.0	0.0
Jan 98	2.02±0.01	0.18±0.03	0.0	0.0
Feb	2.15±0.01	0.34±0.03	0.5515±0.00	0.0
Mar	2.10±0.03	0.03±0.02	0.4969±0.18	0.0
Apr	2.07±0.03	0.02±0.2	0.3920±0.09	1.3762±0.50
May	2.18±0.05	0.01±0.0	0.1640±0.00	5.0880±1.85
Jun	2.19±0.02	0.03±0.01	0.0	0.0
Jul	2.13±0.02	0.02±0.01	0.3795±0.23	0.0

Appendix 11e Monthly data on Condition Factor, stomach fullness index and gonadosomatic index of *M. cephalus* from the Volta estuary.

Month	Condition Factor (±se)	Stomach Fullness index (±se)	GSI (±se)	
			males	females
Feb 97	2.10± 0.05	0.02±0.04		
Mar	1.86±0.11	0.29±0.06	0.0	0.0
Apr	2.28±0.06	0.28±0.06	0.0	0.0
May	2.40±0.08	0.42±0.02	0.0	0.0
Jun	2.33±0.12	0.23±0.04	0.0	0.0
Jul	2.10±0.05	0.19±0.04	0.0	0.0
Aug	2.11±0.05	0.25±0.04	0.0506±0.03	0.0
Sep	2.50±0.09	0.30±0.01	0.1712±0.17	0.0
Oct	2.26±0.03	0.51±0.04	0.0	0.0
Nov	-	-	0.0	0.0
Dec	2.01±0.02	0.08±0.02	-	-
Jan 98	1.95±0.0	0.0	0.0	0.0
Feb	-	-	0.0	0.0
Mar	2.33±0.10	3.63±0.04	-	-
Apr	2.27±0.05	0.22±0.17	0.0	0.0
May	-	-	0.0	1.0
Jun	1.95±0.02	0.0	-	-
Jul	2.17±0.04	0.09±0.03	0.0	0.0
			0.0	0.0

Appendix 12a Monthly data on Condition Factor, stomach fullness index and gonadosomatic index of *L. falcipinnis* from the Pra estuary.

Month	Condition Factor (±se)	Stomach Fullness index (±se)	GSI males (±se)	GSI females (±se)
Mar 97	1.79±0.02	0.20±0.04	0.0	0.0
Apr	1.95±0.03	0.37±0.08	0.0	0.0
May	1.86±0.05	0.02±0.01	0.0	0.0
Jun	1.85±0.03	0.34±0.09	0.0	0.0
Jul	1.82±0.02	0.96±0.19	0.0	0.0
Aug	1.61±0.02	0.12±0.09	0.0	0.0
Sep	1.82±0.01	1.13±0.16	0.0	0.0
Oct	2.04±0.02	0.82±0.20	0.0341±0.02	0.0
Nov	1.91±0.01	0.49±0.13	0.0	0.0
Dec	1.71±0.04	0.31±0.08	0.0	0.0
Jan 98	1.84±0.14	0.48±0.29	0.0	0.0
Feb	1.71±0.04	0.06±0.04	0.0	0.0
Mar	1.90±0.03	0.50±0.06	0.0	0.0
Apr	2.00±0.02	0.63±0.10	0.0	0.0
May	1.91±0.02	0.84±0.15	0.0	0.0
Jun	1.89±0.01	3.36±0.44	0.0	0.0
Jul	1.99±0.02	1.16±0.25	0.0	0.0

Appendix 12b Monthly data on Condition Factor, stomach fullness index and gonadosomatic index of *L. dumerilii* from the Pra estuary.

Month	Condition Factor (±se)	Stomach Fullness index (±se)	GSI (±se)	
			males	females
Mar 97	-	-	-	-
Apr	-	-	-	-
May	1.81±0.03	0.44±0.18	0.0	0.4246±0.17
Jun	1.58±0.08	0.0	0.0	0.0
Jul	1.95±0.04	0.61±0.05	0.1523±0.07	0.0
Aug	1.97±0.03	0.22±0.12	0.0	0.0
Sep	1.78±0.02	0.49±0.10	0.0	0.0
Oct	2.01±0.08	0.82±0.44	0.0	0.0
Nov	1.78±0.02	1.52±0.13	0.201±0.10	20.5790±0.00
Dec	1.59±0.03	0.0	0.0	0.0
Jan 98	1.81±0.04	2.54±0.28	0.0	0.0
Feb	1.61±0.01	0.0	0.0	0.0
Mar	1.92±0.04	0.17±0.04	0.0	0.0
Apr	1.98±0.06	2.06±0.06	0.0	0.0
May	2.14±0.13	1.06±0.30	0.0	0.0
Jun	1.84±0.04	1.48±0.19	0.0	0.0
Jul	2.14±0.03	1.56±0.33	0.0	0.0

Appendix 12c Monthly data on Condition Factor, stomach fullness index and gonadosomatic index of *L. grandisquamis* from the Pra estuary.

Month	Condition Factor (±se)	Stomach Fullness index (±se)	GSI (±se)	
			males	females
Mar 97	2.17±0.03	0.91±0.29	0.0	0.0
Apr	2.09±0.06	0.21±0.11	1.8048±0.60	1.8340±0.80
May	2.06±0.06	0.04±0.03	0.7460±0.00	0.0
Jun	-	-	-	-
Jul	2.02±0.02	0.15±0.03	0.4150±0.09	0.0
Aug	-	-	-	-
Sep	2.12±0.02	0.07±0.02	0.4923±0.29	0.0
Oct	2.14±0.02	0.07±0.03	0.4176±0.20	0.0
Nov	2.16±0.02	0.03±0.01	0.6179±0.29	5.1064±2.36
Dec	2.00±0.02	0.57±0.13	0.8519±0.48	0.0
Jan 98	2.04±0.04	0.28±0.04	0.0	0.0
Feb	2.00±0.13	0.0	3.0250±0.28	0.0
Mar	2.24±0.03	0.47±0.04	2.1172±0.84	1.8655±0.47
Apr	2.27±0.03	0.44±0.06	1.3415±0.39	9.7095±0.08
May	2.32±0.03	0.41±0.04	1.2591±0.55	5.0358±0.35
Jun	2.13±0.08	0.38±0.20	0.0	0.0
Jul	2.38±0.0	0.0	0.0	0.0

Appendix 12d Monthly data on Condition Factor, stomach fullness index and gonadosomatic index of *M. curema* from the Pra estuary.

Month	Condition Factor (±se)	Stomach Fullness index (±se)	GSI (±se)	
			males	females
Mar 97	2.07±0.01	0.03±0.01	0.0	0.0
Apr	2.14±0.05	0.23±0.07	0.0	0.0
May	2.08±0.0	0.0	0.0	0.0
Jun	2.71±0.0	0.38±0.0	0.0	0.0
Jul	2.02±0.05	0.11±0.06	0.0	0.0
Aug	1.92±0.02	0.11±0.06	0.0	0.0
Sep	2.02±0.02	0.10±0.02	0.0	0.0
Oct	2.37±0.04	0.30±0.02	0.0	0.0
Nov	2.09±0.03	0.02±0.01	0.0	0.0
Dec	1.88±0.07	0.0	0.0	0.0
Jan 98	2.10±0.03	0.54±0.12	0.0	0.0
Feb	1.92±0.02	0.02±0.01	0.0	0.0
Mar	2.34±0.02	0.54±0.03	0.0	0.0
Apr	2.29±0.02	0.65±0.03	0.0	0.0
May	2.37±0.02	0.60±0.03	0.0	0.0
Jun	2.34±0.04	0.58±0.06	0.0	0.0
Jul	2.52±0.05	0.47±0.07	0.0	0.0

Appendix 12e Monthly data on Condition Factor, stomach fullness index and gonadosomatic index of *M. bananensis* from the Pra estuary.

Month	Condition Factor (±se)	Stomach Fullness index (±se)	GSI (±se)	
			males	females
Mar 97	2.35±0.08	0.0	0.0	0.0
Apr	2.30±0.04	0.33±0.06	0.0	0.0
May	-	-	-	-
Jun	2.06±0.03	0.15±0.09	0.0	0.0
Jul	2.06±0.03	0.16±0.05	0.0	0.0
Aug	2.03±0.03	0.06±0.03	0.2030±0.10	0.0
Sep	2.02±0.02	0.07±0.01	0.0	0.0
Oct	2.29±0.06	0.46±0.07	0.0	0.2270±0.0
Nov	2.07±0.03	0.04±0.03	0.0	0.0
Dec	1.85±0.02	0.0	0.0	0.0
Jan 98	2.28±0.02	0.69±0.02	0.0	0.0
Feb	2.12±0.02	0.0	0.0	0.0
Mar	2.34±0.01	0.60±0.02	0.0	0.0
Apr	2.32±0.02	0.59±0.03	0.0	0.0
May	2.48±0.02	0.62±0.02	0.0	0.0
Jun	2.34±0.10	0.48±0.08	0.0	0.0
Jul	2.41±0.11	0.47±0.15	0.0	0.0

Appendix 12f Monthly data on Condition Factor, stomach fullness index and gonadosomatic index of *M. cephalus* from the Pra estuary.

Month	Condition Factor (±se)	Stomach Fullness index (±se)	GSI (±se)	
			males	females
Mar 97	2.16±0.04	0.07±0.02	0.0	0.0
Apr	2.20±0.05	0.35±0.16	0.0	0.0
May	2.16±0.13	0.06±0.01	0.0	0.0
Jun	2.28±0.0	0.63±0.0	0.0	0.0
Jul	2.06±0.01	0.15±0.03	0.0	0.0
Aug	2.15±0.0	0.0	0.0	0.0
Sep	-	-	-	-
Oct	-	-	-	-
Nov	-	-	-	-
Dec	-	-	-	-
Jan 98	2.20±0.0	0.05±0.0	0.0	0.0
Feb	-	-	-	-
Mar	-	-	-	-
Apr	-	-	-	-
May	-	-	-	-
Jun	2.25±0.37	0.03±0.03	0.0	0.0
Jul	2.62±0.24	0.0	0.0	0.0

Appendix 13a Monthly frequency of occurrence of gonadal stages of *L. falcipinnis* from the Volta estuary.

Month	Maturity stages								
	Testes				Ovaries				
	I	II	III	IV	I	II	III	IV	V
F97	100 (2)				33.3 (1)	66.7 (2)			
M	53.3 (8)	26.7 (4)	20 (3)		54.5 (6)	45.5 (5)			
A	20 (2)*	50 (5)	30 (3)		12.5 (1)	50 (4)		37.5 (3)	
M	33.2 (1)	66.7 (2)				100 (2)			
J		100 (3)				100 (3)			
J	50 (3)	33.3 (2)	16.7 (1)		50 (2)	50 (2)			
A	100 (3)				100 (6)				
S									
O									
N		50 (1)	50 (1)						
D		66.7 (4)	33.3 (2)			100 (3)			
J98									
F	30 (3)	40 (4)	30 (3)		33.3 (2)	50 (3)	16.7 (1)		
M	60 (9)	26.7 (4)	13.3 (2)		38.5 (5)	46.2 (6)	7.7 (1)	7.7 (1)	
A		50 (1)	50 (1)						
M	50 (1)		50 (1)						
J	83.3 (5)	16.7 (1)			50 (6)	37.5 (5)	12.5 (2)		
J									

Appendix 13b Monthly frequency occurrence of gonadal stages of *L. grandisquamis* from the Pra estuary.

Maturity stages Month	Testes I	Testes II	Testes III	Testes IV	Ovaries I	Ovaries II	Ovaries III	Ovaries IV	Ovaries V
F97									
M	100 (2)								
A	20 (1)*	40 (2)	40 (2)		12.5(1)	87.5(7)			
M	100 (1)					50 (1)	50 (1)		
J						100 (3)			
J	58.8 (10)	41.1 (7)							
A					16.8(4)	79 (19)	4.2 (1)		
S	86.2 (25)	16 (4)							
O	50 (14)	35.7 (10)	14.3 (4)		80 (12)	20 (3)			
N	9.4 (3)	28.1 (9)	53.1 (17)	9.4 (3)	56 (19)	44 (15)			
D	20.6 (7)	35.3 (12)	41.2 (14)	2.9 (1)	12 (3)	52 (13)	20 (5)	16 (4)	
J98		100 (1)							
F	50 (3)		50 (3)						
M	12.5 (1)	12.5 (1)	62.5 (5)	13 (1)					
A	5.8 (1)	47.1 (8)	47.1 (8)			75 (3)	25 (1)		
M		28.6 (4)	66.6 (2)	29 (4)		33.3(1)		67 (2)	
J							66.6(2)		33.3(1)
J									

* *Absolute numbers in parenthesis*

Appendix 13c Monthly frequency of occurrence of gonadal stages of *L. dumerilii* from the Volta estuary.

Month	Maturity stages Testes I	Testes II	Testes III	Testes IV	Ovaries I	Ovaries II	Ovaries III	Ovaries IV	Ovaries V
F97									
M			100 (1)						
A									
M	100 (4)								
J					100 (3)				
J					50 (4)	50 (4)			
A	100 (1)				66.7 (4)	33.3 (2)			
S					100 (3)				
O		50 (1)*	50 (1)						
N	66.7 (4)		33.3 (2)		70 (7)	30 (3)			
D	57.1 (4)	42.9 (3)			84.2 (16)	15.8 (3)			
J98	62.5 (5)	12.5 (1)	25 (2)		42.9 (3)	42.9 (3)		14.3 (1)	
F	66.7 (4)	33.3 (2)			100 (1)				
M	33.3 (1)		66.6 (2)		66.6 (2)	33.3 (1)			
A	100 (1)								
M								100 (1)	
J		60 (3)	40 (2)						
J									

Appendix 13d Monthly frequency of occurrence of gonadal stages of *L. dumerilii* from the Pra estuary.

Month	Testes I	Testes II	Testes III	Testes IV	Ovaries I	Ovaries II	Ovaries III	Ovaries IV	Ovaries V
F97									
M									
A									
M									
J	100 (1)				20 (1)	40 (2)	40 (2)		
J	72.7 (8)	27.3 (3)							
A		100 (1)			55.5 (5)	44.4 (4)			
S	71.1 (5)	28.6 (2)							
O					83.3 (10)	16.7 (2)			
N	42.9 (3)	57.1 (4)							
D					33.3 (1)		33.3 (1)	33.3 (1)	
J98									
F	50 (1)*		50 (1)		100 (1)				
M	50 (1)	50 (1)							
A									
M	50(1)	50(1)							
J	100 (3)								
J				100 (1)					

* *Absolute numbers in parenthesis*

Appendix 13e Monthly frequency of occurrence of gonadal stages of *M. bananensis* from the Volta estuary.

Month	Testes I	Testes II	Testes III	Testes IV	Ovaries I	Ovaries II	Ovaries III	Ovaries IV	Ovaries V
F97	-	-				66.7 (2)	33.3 (1)		
M	50 (2)*	50 (2)				100 (1)			
A	-	-				-			
M	-	-				100 (1)			
J	-	-							
J	-	-						100 (3)	
A	100 (3)				100 (5)				
S	-							100(1)	
O	-		100 (1)						
N	-					100 (1)			
D	100 (3)				100 (6)	-			
J98	-	75 (3)	25 (1)		33.3 (1)	66.7 (2)			
F	100 (1)		-		100 (1)	-			
M	-	16.7 (1)	83.3 (5)		100 (1)				
A	-	80 (4)	20 (1)		40 (2)	40 (2)	20 (1)		
M	-	100 (4)			50 (4)			50 (4)	
J	-	-			100 (1)				
J	-	100 (1)			50 (2)	50 (2)			

Appendix 13f Monthly frequency of occurrence of gonadal stages of *M. bananensis* from the Pra estuary.

Month	Testes I	Testes II	Testes III	Testes IV	Ovaries I	Ovaries II	Ovaries III	Ovaries IV	Ovaries V
F97									
M									
A									
M									
J									
J									
A	33.3 (1)	33.3 (1)	33.3 (1)*						
S					100 (1)				
O					100 (1)				
N	100 (1)				100 (1)				
D									
J98									
F									
M									
A	100 (2)								
M	100 (1)								
J									
J									

* *Absolute numbers in parenthesis*

Appendix 13g Monthly frequency of occurrence of gonadal stages of *M. curema* from the Volta estuary.

Month	Testes I	Testes II	Testes III	Testes IV	Ovaries I	Ovaries II	Ovaries III	Ovaries IV	Ovaries V
F97	38.5(10)	46.2 (12)	15.4 (4)		50 (14)	32.1 (9)	7.1 (2)	7.1 (2)	3.6
M	50.0(14)	17.6 (3)	11.8 (2)	11.8 (2)	55.6 (15)	44.4 (12)			
A		100 (1)			25 (1)	25 (1)			50
M	68.2(15)	22.7 (5)	4.5 (1)	4.5 (1)	50 (7)	42.9 (6)	7.1 (1)		
J									
J		100 (2)				100 (1)			
A					66.7 (6)			33 (3)	
S									
O	100 (4)				22.2 (2)	77.8 (7)			
N	28.6 (2)	28.6 (2)		42.9 (3)					
D	66.7 (2)		33.3 (1)		100 (11)				
J98									
F	40 (4)*	60 (6)			53.9 (8)	15.4 (4)	23.1 (5)	7.7 (2)	
M	37.5 (3)	62.5 (5)			55.6 (5)	11.1 (1)	22.2 (2)	11 (1)	
A	12.5 (1)	25 (2)	37.5 (3)	25 (2)	68.8 (11)	25 (4)		6.3 (1)	
M	52.9 (9)	23.5 (4)	11.8 (2)	11.8 (2)	95.8 (23)	4.2 (1)			
J	100 (1)				100 (2)				
J	25 (1)	50 (2)	25 (1)						

Appendix 13h Monthly frequency occurrence of gonadal stages of *M. cephalus* from the Volta estuary.

Month	Maturity stages								
	Testes				Ovaries				
	I	II	III	IV	I	II	III	IV	V
F97					100 (1)				
M									
A									
M									
J									
J	20 (1)*	20 (1)	20 (1)	40 (2)	66.7 (2)	33.3 (1)			
A				100 (1)	100 (4)				
S									
O									
N					100 (3)				
D									
J98									
F									
M									
A					50 (1)	50 (1)			
M					100 (1)				
J									
J	100 (1)								

* *Absolute numbers in parenthesis*

Appendix 14a Data for the determination of the length at which 50% of *L. falcipinnis* in the Volta estuary matures.

Standard length (mm)	Male Percentage mature	Male CF(%)	Female Percentage mature	Female CF(%)
120-129	2.4 (1)*	2.4		
130-139	0.0 (0)	0.0		
140-149	21.4 (9)	23.8	1.9 (1)	1.9
150-159	21.4 (9)	45.2	0.0	0.0
160-169	19.0 (8)	64.3	17.3 (9)	18.9
170-179	14.0 (6)	78.6	28.8 (15)	47.2
180-189	14.0 (6)	92.9	15.4 (8)	62.3
190-199	4.8 (2)	97.6	15.4 (8)	77.4
200-209	2.4 (1)	100	9.6 (5)	86.8
210-219			1.9 (1)	88.7
220-229			5.8 (3)	94.3
230-239			3.8 (2)	98.1
240-249			1.9 (1)	100

* *Absolute numbers in parenthesis*

Appendix 14b Data for the determination of the length at which 50% of *L. dumerilii* in the Volta estuary matures.

	Male		Female	
Standard length (mm)	Percentage mature	CF(%)	Percentage mature	CF(%)
110-119			10 (1)	10
120-129			10 (1)	20
130-139	18.8 (3)*	18.8		
140-149	18.8 (3)	37.5		
150-159	37.5 (6)	75.0	10 (1)	30
160-169	12.5 (2)	87.5	10 (1)	40
170-179	12.5 (2)	100.0	20 (2)	60
180-189			10 (1)	70
190-199				
200-209			10 (1)	80
210-219				
220-229				
230-239			20 (2)	100

* *Absolute numbers in parenthesis*

Appendix 14c Data for the determination of the length at which 50% of *L. grandisquamis* in the Pra estuary matures.

	Male		Female	
Standard length (mm)	Percentage mature	CF(%)	Percentage mature	CF(%)
80-89	1.7 (2)*	1.7		
90-99	6.8 (8)	8.5	8.1 (3)	8.1
100-109	17.1 (20)	25.6	8.1 (3)	16.2
110-119	22.2 (26)	47.9	13.5 (5)	29.7
120-129	22.2 (26)	70.1	21.6 (8)	51.4
130-139	14.5 (17)	84.6	10.8 (4)	62.2
140-149	11.1 (13)	95.7	16.2 (6)	78.4
150-159	3.4 (4)	99.1	16.2 (6)	94.6
160-169	0.9 (1)	100	5.4 (2)	100

Appendix 14d Data for the determination of the length at which 50% of *M. bananensis* in the Volta estuary matures.

	Male		Female	
Standard length (mm)	Percentage mature	CF(%)	Percentage mature	CF(%)
120-129			9.1 (1)	9.1
130-139				
140-149	18.8 (3)*	21.4	18.2 (1)	27.3
150-159	18.8 (3)	42.9	9.1 (1)	36.4
160-169	31.3 (5)	78.6	9.1 (1)	45.5
170-179	31.3 (5)	100.0	9.1 (1)	54.5
180-189			9.1 (1)	63.6
190-199			18.2 (2)	81.8
200-209			18.2 (2)	100.0

Appendix 14e Data for the determination of the length at which 50% of *M. curema* in the Volta estuary matures.

Standard length (mm)	Male		Female	
	Percentage mature	CF(%)	Percentage mature	CF(%)
120-129				
130-139	1.6 (1)*	1.6	5.9 (2)	5.9
140-149	25.0 (16)	26.6	2.9 (1)	8.8
150-159	32.8 (21)	59.4	14.7 (5)	23.5
160-169	31.3 (20)	90.6	14.7 (5)	38.2
170-179	9.4 (6)	100	14.7 (5)	52.9
180-189			14.7 (5)	67.6
190-199			14.7 (5)	82.4
200-209			8.8 (3)	91.2
210-219				
220-229			2.9 (1)	94.1
230-239			2.9 (1)	97.1
240-249				
250-259				
260-269			2.9 (1)	100

* *Absolute numbers in parenthesis*

Appendix 15a Data on growth during the first experiment in brackish water ponds

No. of Days	Fish supplied with feed		Fish without feed	
	Wt. (g)	SGR (%/day)	Wt. (g)	SGR (%/day)
0	5.08±0.70		4.58±0.55	
30	8.75±0.40	1.8125	9.00±1.41	2.2518
60	13.50±1.40	1.6290	11.50±1.41	1.5344
90	17.30±1.80	1.3616	16.90±1.70	1.4507
120	23.10±2.10	1.2621	21.6±1.40	1.2925
150	28.60±0.90	1.1521	25.2±1.50	1.1368

Appendix 15b Data on growth during the second experiment in brackish water ponds

No. of Days	Fish supplied with feed		Fish without feed	
	Wt. (g)	SGR (%/day)	Wt. (g)	SGR (%/day)
0	7.25±0.10		7.17±0.38	
30	9.54±0.06	0.9150	9.32±1.68	0.8724
60	13.15±0.92	0.9924	12.50±0.71	0.9264
90	14.50±0.71	0.7702	14.35±1.20	0.7709
120	16.90±0.85	0.7053	15.90±1.98	0.6637
150	19.55±1.34	0.6613	18.20±2.40	0.6210
180	25.7±0.99	0.7030	22.30±0.14	0.6304
210	31.65±2.33	0.7018	25.70±0.14	0.6079
240	36.36±1.61	0.6719	28.35±0.21	0.5728
270	41.85±1.06	0.6498	32.10±0.44	0.5552

Appendix 15c Data on growth during experiment in freshwater ponds

No. of	Fish supplied with feed		Fish without feed	
Days	Wt. (g)	SGR (%/day)	Wt. (g)	SGR (%/day)
0	8.34±1.21		7.82±0.88	
30	11.05±1.88	0.9379	10.63±0.57	1.0200
60	13.35±1.59	0.7841	13.60±2.12	0.9223
90	16.40±1.27	0.7514	15.71±0.82	0.7751
120	19.45±1.34	0.7075	19.35±1.20	0.7550
150	23.70±0.28	0.6963	21.71±1.92	0.6807
180	28.65±0.78	0.6856	25.56±0.34	0.6580

Appendix 15d Data on effect of wheat bran and rice bran on growth

No. of	Wheat bran		Rice bran	
Days	Wt. (g)	SGR (%/day)	Wt. (g)	SGR (%/day)
0	46.46±1.21		48.46±1.85	
30	58.50±0.83	0.7681	62.94±0.65	0.8415
60	70.00±1.10	0.6832	71.01±0.85	0.6368
90	78.22±0.75	0.5701	79.01±1.21	0.5432
120	84.40±0.61	0.4975	82.11±1.10	0.4394
150	89.93±1.15	0.4403	87.43±0.68	0.3934
180	94.73±0.95	0.3958	91.84±1.10	0.3552

Appendix 16 Sample calculation of difference in slopes of regression of length-weight relationship for *L. falcipinnis* in the Volta and Pra estuaries.

Samples from the Volta estuary

$\Sigma x^2 = 142.3954$

$\Sigma xy = 200.1613$

$\Sigma y^2 = 286.1973$

$n = 120$

$b = 200.1613/142.3954 = 1.4057$

residual SS $= 286.1973-(200.1613^2/142.3954)$

$= 4.8355$

residual DF $= 120-2 = 118$

Samples from the Pra estuary

$\Sigma x^2 = 105.51865$

$\Sigma xy = 123.2044$

$\Sigma y^2 = 145.5112$

$n = 120$

$b = 123.2044/105.5185 = 1.1676$

SS $= 145.5112-(123.2044^2/105.5185)$

$= 1.6566$

residual DF $= 120-2 = 118$

$(S^2_{yx})p = (4.8355 + 1.6566)/(118+118) = 0.0275$

$S_{b1-b2} = \sqrt{((0.0275/142.3954) + (0.0275/105.5185))}$

$= 0.0224$

$t = (1.4057 - 1.1676) / 0.0224$

$= 10.6295$

$\nu = 118 + 118 = 236$

$t\alpha\,(2), 236 = 1.969$

Therefore the two slopes are significantly different from each other at $P < 0.001$