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Studies on Red Sea Fish

by

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DEDICATION

To My Teacher Mohammed Abu Khalil.

To My Parents.

To my wife Laila and sons Mohammed, Hattan, Rayan,
and to My Mother-in-Law.

To My Brothers Talal, Esam, Esmat and Moatasem.

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ABSTRACT

The study of the morphological and histological characteristics of the alimentary canal of twenty fish species inhabiting the fishing grounds off Jeddah was performed in order to establish the relationship of such characteristics with the feeding habit of the fish. In addition the biological aspects of the life history of *Mulloides flavolineatus* was dealt with in some detail.

Histological sections in the different parts of the alimentary canals of representatives of the different feeding categories revealed that carnivores and omnivores have almost the same structures in the different parts of the gut with the exception of the absence of stomach and pyloric caecae in carnivores.

Food and feeding habits of *M. flavolineatus* showed that this fish consumes mainly small crustacea and invertebrate organisms. It feeds intensively during the winter and summer seasons. Seasonal variations in the preference of different food items seemed to vary according to sex and size of fish.

The length-weight relationship showed that females are slightly heavier than males of the same size. Values of the condition factor were consequently found to decrease with fish size.

Survival rates showed that only 5.2% of males live after their fifth year of life compared to 16.49% of females that live after their sixth year of life. Males were found to be exposed to a higher fishing mortality rate than

females and their rate of exploitation through fishing is over the safe limits for the population to sustain.

It was found evident that this fish is a multiple-spawner that yields two broods at an interval of three months, the first in June and the second in September. The onset of sexual maturity was estimated to be initiated in fishes of 14.4 cm to 21.2 cm in length (SL), i.e. after their second year of life.

CONTENTS

CHAPTER 1

GENERAL INTRODUCTION

Introduction

Tropical waters are paradoxically among the most and least productive of any in the world. Production in warm oceanic waters is very low. Lewis (1977) gave estimates of between 20 and 50 g C $m^{-2}yr^{-1}$ for oceanic waters in the vicinity of reefs. Such low production sustains very small fish yields, although some of the world's most spectacular fish such as marlin, sailfish and tuna occur in such waters. Except for these oceanic giants, tropical fisheries are limited to shelf areas, especially to depths of less than about 30 m, in which reefs and associated communities thrive.

Due to the conditions of temperature and salinity the Red Sea provides a perfect environment for the growth and formation of coral reefs, except for three locations where low temperature and high salinity are not favourable. These are the gulf of Suez, and the South part of Massawa and the Hodeida area (Bemert & Ormond, 1981). According to the work of Mergner (1977), the type of coral reef that occurs in the Red Sea is mostly a fringing reef and, "the longest stretch of reef in the world is the fringing reef that adjoins the shores of the Red Sea. This shore reef, if straightened into a single line, would exceed 2500 miles" (Ladd, 1977). However, it is occasionally interrupted by creeks (sharm) or bays.

A barrier-like reef often lies a few km off shore, mostly as a chain of elongated patch reefs. The "lagoon" thus formed also contains patch reefs of varying size and shape (Mergner, 1977).

In many reef areas in the Red Sea, the total area available for fishing is very small, i.e. between the reefs, and overfishing is a problem that is quite familiar in these areas. The problem is compounded in reef areas by the nature of the environment. To take an example, the Sudan has a total potential fishing area of 9000 km^2 (Sanders and Kedidi, 1981), but has a coastline 700 km long, so the shelf averages only 12.8 km wide. The country has a population of 20.6 million, so the _per capita_ fishing area is only 0.04 hectares, for which Sanders and Kedidi's production potential estimates suggest a potential annual _per capita_ yield of only 305 g. Present production figures are only one sixth of this. Coral reefs and adjoining shelves are morphologically complex, with bottoms of varying depths, and are quite inappropriate for exploitation by large vessels using trawls or nets. Reef areas are ideal for use by one- or two-man boats equipped with sails or outboard engines, fishing with handlines, pots or spearguns. Small boats with shallow draught can safely penetrate deeply into reef systems, and fish in shallow waters. Such small boats are however very restricted by weather and wave conditions, forcing fishermen to concentrate on relatively few safe sites and further restricting the available fishery area during at least part of the year. Heavy fishing pressure on one site can seriously deplete stocks of key species, because many reef fish are territorial and do not disperse rapidly outside a small area (Russell, 1977). This seems particularly characteristic of the groupers (Serranidae), amongst the best eating of reef fish, but is also well marked in the snappers, wrasse and triggerfish. Even apparently pelagic fish such as jacks (Caranx spp.) seem to haunt individual small reefs for long periods rather than dispersing freely over large areas. Heavily fished reefs can often be recognized immediately by experienced divers from the scarcity of large snapper and medium sized grouper (Craik, 1981). If fishing pressure is reduced, individuals of these species will be replaced by juveniles, but the process is relatively slow.

In spite of all this, marine fisheries in Saudi Arabia yield about 26,000 tonnes per year, of which 13,000 MT are fish and the rest Crustaceans, Molluscs or other marine products (FAO, 1986).

Several studies have been made on the ecology of the Red Sea waters off Saudi Arabia, and particularly off Jeddah (Behairy et al., 1981; Shaikh, 1981; Saad and Fahreg, 1984), though little work has been done on the ichthyofauna of the Red Sea coast off Saudi Arabia in general and the district of Jeddah in particular (Al-Kholy, 1972; Krupp, 1983).

The present study examines the predator-prey relationships and morphology of the alimentary canal in relation to feeding habits in the most economically important fish species caught along the coastal waters off

Jeddah. There is a large variety of teleosts living in and around the coral reefs in the vicinity of Jeddah. So far little is known of the anatomy and histology of the Red Sea fishes. Most of the work previously done deals with their systematics. The variety of teleostean forms living in that district seemed to be of much interest not only from the systematic and faunistic angle, but also from a morphological and an ecological point of view. Many contributions have been published on various fishes. The more recent one was that published by Kapoor, Smit and Verighina (1975) who classified fishes according to the diversity of food into (i) euryphags, with a mixed diet, (ii) Stenophags, with a limited assortment of types of food, and (iii) monophags, consuming one sort of food, e.g. crustacea-feeders, mollusca-feeders, etc. According to the feeding conditions some ecological groups are distinguished, for example, pelagic plankton-feeders, benthos-feeders, etc. as reported by Suyehiro (1942); Al-Hussaini (1947a); Gohar and Latif (1959); Das and Moitra (1963) and Nikolsky (1963, 1974). The latter author also reported that some fishes lead a parasitic mode of life. Suyehiro (1942) reported that the feeding habits of fishes are different according to locality, season, age or sex. Emphasis of the influences of some of these factors has been demonstrated by Pillay (1953) and Moitra (1956).

The extent of adaptation of the alimentary tract in fully grown teleost fishes to a particular type of food has been investigated by Ghazzawi (1935); Suyehiro (1942); Al-Hussaini (1945, 1947a,b, 1949a); Angelescu and Gneri (1949); Girgis (1952b); Kapoor (1953, 1957c, 1958a,b); Pillay (1953); Al-Hussaini and Kholy (1953); Khanna (1961); Mohsin (1962); Lal, Bhatnagar and Kaile (1964a); Sehgal (1966a); Lal (1968); Schmitz and Baker (1969); Sehgal and Salaria (1970); Sriwastwa (1970a,b); Bucke (1971); Verma, Tyagi (1974b) and Verma, Tyagi and Dalela (1974c). These authors reported that different species with the same type of food may differ in the structure of the alimentary tract, but the functional adaptations related to the nature of food and feeding habits remain similar, although the degree of relation between alimentary tract and food varies. Angelescu and Gneri (1949) reported multiple specialization of the digestive system in an iliophagus fish, Prochilodus lineatus. Moreover, Greenwood (1964) and Fryer and Iles (1972) found that some species of the family Cichlidae in the African great lakes show wide adaptive radiation so making the best use of every available food. Nikolsky and Verighina (1974) demonstrated some characteristics in the structure of the alimentary tract of some Pleuronectidae living in different ecological niches.

The extensive data about the correlation between the relative length of the alimentary tract and the feeding habits were summarized by Kapoor, Smit and Verighina (1975) who reported that "The longest intestine occurs in microphagous and herbivorous species, the food of which contains a high proportion of indigestible material. The carnivorous species have the shortest gut." It has been suggested that in some cases differences in relative gut-length depend on the presence of a "gizzard" or some other structures in the fore part of the alimentary canal (pharyngeal teeth; pharyngeal or oesophageal sacs) which triturate the food. Al-Hussaini (1949a); Unnithan (1965); Konfal (1966) and Siankowa (1966) have correlated between the surface area of the intestinal mucosa and the feeding habits. In some fishes particularly in microphagous: *Xenocypris macrolepis* (Borutsky, 1950), *Labeo horie* (Girgis, 1952b) *Tilabia mossambica*; *Varicorhynus capaeta savangi* (Verighina, 1967, 1969a respectively) the great length of the gut compensates for poor development of folds which do not hamper the passing of roughage through the intestine. On the other hand, complicated branched folds were found in highly specialized predators, e.g. *Ptychocheilus aregonense* (Weisel, 1962) and *Elopiichthys bambusa* (Verighina, 1963) which have a short intestine. The gut-length depends upon the relationship between the components in the diet of omnivorous fishes. Considerable variability of the intestinal length has been observed in some species which live in conditions of different food supply by Aganovic and Vukovic (1966) in *Aulopige hugelii* and Heckel and Vukovic (1966) in *Barbus meridionalis*. These authors reported that when satisfactory food supply was present the intestinal length and variability were less than when feeding conditions were unsatisfactory.

Al-Hussaini (1947b); Tortones (1952); Girgis (1952b); Gohar and Latif (1959); Khanna (1962); Greenwood (1964); Kazansky (1964); Khanna and Pant (1964); Dalela (1969); Kapoor, Smit and Verighina (1975), and many others reported that the form and position of the mouth, dentition on the jaws and in the bucco-pharynx and the gill rakers are closely related to the mode of feeding and the kind of food. Descriptions of mouth types are given by Suyehiro (1942); Al-Hussaini (1947b) and Nikolsky (1963). The latter author classified fishes according to all the variety of structure and function of mouth into a number of types: (a) Grasping mouth - large, with sharp teeth both on the jaw and often vomerines and the palatine bones. Gill rakers short, few and serving only to protect the gill plates from harm by food. This group includes the predators. (b) Imbibing mouth - in the form of a tube of variable length, sometimes extensible and usually toothless. Such fishes usually feed on bottom invertebrates, less commonly on invertebrates in the water. (c) Crushing mouth - sometimes in the form of a beak (trunkfish), with powerful teeth, sometimes spines (catfish). Such a mouth usually serves for crushing the hard armour of invertebrates such as molluscs, echinoderms, corals. (d) Plantophagic mouth - usually large or of medium size and immobile, teeth small or completely lacking; gill rakers long; acting as a net. (e) Periphyton-eating mouth- feeding on water weeds; placed on the lower side of the head, shaped like a transverse crack, lower lip usually has a sharp cutting edge, sometimes with a horny covering; teeth usually lacking. These basic types of mouth structure are related to each other by a number of transitional types. Kapoor, Smit and Verighana (1975) also reported that "a number of structures may be involved in functioning of the mouth and pharynx as organs for food ingestion: lips, buccal valves, lamellar organs, palatine cushions, the tongue, pharyngeal glands and valves, epibranchial organs, pharyngeal pads and cushions, bucco-pharyngeal teeth, gill rakers, mucous glands and taste buds."

According to Suyehiro (1942), the structure of fish digestive systems is related to their phylogeny, food, and feeding habits. This implies that anatomy is closely associated with feeding specializations, although fish with similar feeding habits do not necessarily have similar digestive systems (Kremetz and Chapman, 1974). Gross anatomy of teleost digestive tracts falls into two main categories, those tracts that have a stomach (i.e. a portion of the digestive tract containing digestive glands) and those that are without a stomach. In the latter the intestine is continuous with the oesophagus and extends to the anal opening. Often the anterior intestine in stomachless fish is swollen to form an intestinal bulb or intestinal swelling which serves as a temporary storage area for ingested food. The term intestinal bulb sometimes implies a sac-like storage area of the intestine while intestinal swelling may imply simply an increase in the diameter of the intestine in the post-oesophageal region.

Fishes of the family Mullidae are among the most economically important fish of the Red Sea coast off Saudi Arabia. They contribute significantly to the fish landings from Jeddah district. However, detailed information pertaining to their biology, in particular reproduction, population dynamics and life history, is lacking. Hobson (1974) working in Hawaii studied the degree of specialization in their feeding habits and feeding behaviour and concluded that while some species are diurnal others are nocturnal. With the exception of several studies on the feeding habits of the goatfish species (Hiatt and Strasburg, 1960 working around the Marshall Is. Pacific and; Ormond, (1980) little is known about the population structure of Mullidae in the Red Sea. Many questions regarding the ideal management strategies for their fisheries still remain unanswered.

This study of the feeding habits of the economically important fish species in this area is vital for better management of the living resources. It also describes the growth patterns and mortality rates of one of the most abundant species of Mullidae in this area, <u>Mulloides flavolineatus</u>, in order to establish the measures necessary for improve-ment of fisheries of this species.

In order to understand biological aspects of the fish living in this area, it is also necessary to describe the area and its hydrography.

CHAPTER 2

MATERIALS AND METHODS

A. Comparative Morphology of the Alimentary Canal

In the present study the main source of data was from commercial fish landings to ports in the district of Jeddah. These ports receive the catch of all fishing fleets that cover the Red Sea coast off Saudi Arabia in the area adjacent to Jeddah (Figure 2.1).

In this study 20 fish species were selected which are regarded as economically important and most abundant in the landed catch. Samples of twelve individuals covering the widest possible size range were taken for each of the chosen species. A list of these species with the length range covered for each of them is presented in Table 2.1.

The gill rakes and viscera of each species were sketched *in situ*. Then the following measurements were made for each individual:

1. Total length (TL), i.e. from tip of nose to tip of tail
2. Length of the whole alimentary tract uncoiled, from lips to anus, Gut length (GL).
3. Length from the lips to the oesophagus (buccal and pharyngeal cavity), Oesophageal length (Oesoph).
4. Length of the stomach from the end of the Oesoph to pyloric valve, Stomach - Cardiac portion (Stom-Car).
5. Length of the stomach from pyloric valve to duodenum, Stomach - Pyloric portion (Stom-Pyl).
6. Length of the duodenum, Intestine (Int).
7. Length from the intestino-rectal valve to the anus, (Rect).

8. Length and number of pyloric caeca, if any (PylCae/L and PylCae/N, respectively).

For each of the sections from 3 to 7, the percentage of the tract occupied by this region has been calculated. The number of pyloric appendices present were also noted.

For each of the above measurements, descriptive statistical analyses were performed and, using the least square method, a regression equation computed relating each measurement to the total fish length.

A qualitative analysis of the stomach contents of sampled fish was carried out in order to place the selected species into categories according to their diet.

B. Descriptive anatomy of the alimentary tract of selected species of Red Sea fish caught off Jeddah

The investigation is based on the study of 20 Red Sea fish species belonging to 17 Families collected from the waters off Jeddah and its immediate neighbourhood.

After collection fresh specimens were either dissected and the gut contents preserved in 70% alcohol or the viscera were first injected with 10% formalin, then preserved in 5% formalin solution to stop decomposition (Gohar and Maher, 1964) and then kept for subsequent examination.

To determine the nature of food and feeding habits, the different regions of the alimentary tract were cut open longitudinally, the contents carefully removed, diluted with

4% formalin (Al-Hussaini, 1947 a&b) and prepared for macro- and microscopic examination.

According to the analysis of their stomach contents, the fish species were divided into plankton feeders (planktivores), herbivores, carnivores, and omnivores. Carnivores were subdivided into four sections depending on the dominant component of the food. The subdivisions were:

1. Invertebrate and fish eaters: in which the main component of the diet was invertebrates, and fish were subsidiary.
2. Fish and invertebrate eaters: in which the main component of the diet was fish with invertebrates of secondary importance.
3. Invertebrate eaters: whose diet was restricted to invertebrate organisms.
4. Fish eaters, or piscivorous fishes: which are predators, attacking other fish.

C. Comparative Histology of the alimentary tract of some Red Sea Fish caught off Jeddah

The investigation studies four species of Red Sea teleosts, i.e., *Tylosurus choram* (Rupell), *Rasteliger Kanagurta* (Forsk), *Siganus rivulatus* (Forsk) and *Iherapon jarbua* (Forsk), which were selected as representatives of carnivores, plankton feeders, herbivores, and omnivores, respectively, which occur commonly in landings from commercial fishing in the vicinity of Jeddah (Figure 1.1).

For histological studies, fresh specimens of each species were dissected, the digestive tract taken out, and washed in a physiological saline solution. The individual parts of the alimentary tracts were then fixed in a range of fixatives including Bouin's fluid, and Zinker's fluid. After fixation, dehydration, clearing and embedding in paraffin wax, serial sections were cut at a thickness of 6-8 Microns and then stained with Mayer's haem-alum and eosin, or Mallory's triple stains. The latter was found particularly useful in demonstrating the presence of cilia.

D. Biological Measurements and Data of *Mulloides flavolineatus*

The total numbers of fish used in the present study were 714 specimens. 126 were males and 255 females, and 333 fish were difficult to determine their sex through external examination and were grouped as "indeterminate sex".

1. Food and feeding habits :

A study of feeding habits was made by examining the gut contents of 705 specimens representing different sizes of fish. 333 were "indeterminate sex", 123 males and 249 females. The intestines were removed immediately and preserved in 4% formalin, in order to prevent the loss of any intestinal contents. Each intestine was placed in a tube and all the necessary information recorded. In the laboratory, the intestines were opened, their contents emptied into a glass dish and the food items were identified.

Feeding was estimated by recording the condition of the guts which were classified as either empty, containing identifiable food, or containing unidentifiable food. This arbitrary estimate of the fullness of the intestine was previously used by Hartley, (1947), Capape, (1975), Hosny, (1981).

The analysis of food of _M. flavolineatus_ was studied using the following standard methods :

a) The fullness coefficient (F.C.), defined as the percentage of stomachs containing food compared with total number of stomachs examined. This coefficient was calculated according to the formula :

$$F.C. = NF \times 100/NE$$

where NF = the number of stomachs containing food, and

NE = the number of examined stomachs.

b) Abundance of the main food groups eaten by the fish, i.e. the percentage frequency of each type of food item in the stomachs examined.

c) Identification of food items, of ingested food items.

d) The frequency index (F.I.) of food items which is the ratio of the number of stomachs containing a certain food item compared to the total number of full stomachs. It was calculated from the following formula:

$$F.I. = n/NF$$

where n = the number of stomachs containing a certain food item, and

NF = the total number of full stomachs.

Fullness coefficient, frequency index and identification of food items are determined in Spring, Summer, Autumn and Winter. Fish were divided into three categories; "indeterminate sex" fish which were not segregated into sexes and mature fish that were separated into males and females, and for each category variations of these indices were studied within different size groups.

2. Length-weight relationship and condition factor :

The length-weight relationship of fish is described by the equation $W=cL^n$, whose logarithmic transformation is :

$$\log W = \log c + n \log L$$

where W = weight in grams,

L = length in cm,

c and n are constants.

The exponent "n" measures the ratio of instantaneous rates of increase in weight and length (Brown, 1957). For an ideal fish which maintains the same shape throughout its length range, its growth is said to be isometric, in this case the exponent $n = 3$ (Le Cren, 1951; Brown, 1957). It was found, however, that the cube law is not obeyed for many fishes studied and the exponent "n" is not equal to 3. Martin (1949) stated that most species change their form or shape as they grow and in such cases the value of the exponent in the formula may considerably alter from the cube "3". The value of the exponent "n" depends on the roundness of fish, being high in fat fish and low in lean ones (Brown, 1957). So the relationship $W=cL^n$ serves best in the study of condition. The value of "c" is changed into a round number and into its reciprocal and expressed as the condition factor which is known as "k" and $k= 100 \times W/L^3$. This equation was proposed by Falton (1902). Where W = weight of fish in grams, L = total length of fish in cm.

A mean condition factor was calculated for each month in order to follow monthly variations in the condition of the fish and correlate it with variations in the gonado-somatic index and fish sexual cycle.

3. Age and growth :

Various investigators contributed to the development of methods for determining the age of fish by studying different parts of the skeleton, i.e., scales, vertebrae, otoliths, fin rays and operculum. In addition, the length frequency method is used for age and growth studies.

Scales are the most widely used of all routines in age and growth studies, and are easily collected. In the present study, the age of M. flavolineatus was determined by examination of scales. The use of scales for age determination was suggested by Hoffbauer (1898) [Quoted from Jobes, 1952] working on carp. Since then scales have been used for the study of age and growth rates in numerous marine and freshwater fish (Van Oosten, 1923, 1929; Hile, 1931, 1936, 1941; Jobes, 1933, 1952; Stroud, 1948; Van Oosten and Hile, 1949; Cable, 1956; June and Roithmayer, 1960).

In the present work, a series of scales of M. flavolineatus were taken from various sized individuals. They were examined to establish the validity of scales for age determination and growth calculations.

The scales used in these determinations were taken from the same position on each fish, midway between the anterior insertion of the first dorsal fin and the lateral line (Lagler, 1956). From each individual 8-10 scales were removed, soaked in a 10% solution of ammonium hydroxide for about 24 hours then washed in water, cleaned, dried and mounted between two glass slides for examination. Annual rings were counted by the aid of a Bausch and Lomb Tri-simplex Micro-Projector at 1.8X magnification. The scale length in millimeters along the dorso-lateral axis from the center of the focus to the margin of the scale and to each annulus was recorded. All scales were examined at least twice, independently. Regenerated scales which are smaller represented about 4% and 3% of the total number of examined scales in males and females, respectively, were discarded. If the independent measurement for a particular specimen did not agree then the data were excluded from growth calculations (Rounsfell and Everhart, 1953). The annulus was identified by crossing-over, and spacing of the circuli, especially on the lateral sides of the scales.

3.1. Body-scale relationship :

The relationship between the body length and the scale radius was studied. The means of the scale radii were plotted against the standard fish length and the regression line was calculated using the least square method, for both males and females and for the sexes combined as well.

3.2. Growth in length :

The estimation of general growth in length is based on the grand average calculated lengths, and successive summations of the grand average increments of calculated lengths.

The back-calculateion of the length at each annulus was done using the formula relating scale length to body length, and applying the equation of Lee (1920), which states that:

$$L_n = a + [((L_t - a)S_n)/S_t]$$

where L_n = length at age n calculated in mm,

L_t = standard length of the fish in mm,

S_t = total scale radius in mm,

S_n = distance from the focus of the scale to the n^{th} annulus in mm, and

a = Y-intercept of body - total scale radius regression.

3.3. Growth in weight :

The growth in weight for each sex was studied from calculated weights corresponding to calculated lengths attained at the end of each year of life, by the substitution of the appropriate length at age in the equations expressing the length-weight relationships.

3.4. Theoretical growth studies :

Theoretical growth studies were made by the calculation of the parameters L_∞, k and t_o of the von Bertalanffy growth equation :

$$L_t = L_\infty[1 - \exp(-k(t-t_o))]$$

The three parameters of the equation were calculated by the regression of L_{t+1} against L_t, which is known as the Ford-Walford Plot (Gulland, 1969, 1983). The slope of the regression is exp(-k). Asymptotic or final length L_∞, is the point where $L_t=L_{t+1}$, and can be calculated from the slope 'b' and the intercept 'a' of the regression, since $L_\infty=a/(1-b)$ (Pauly, 1980).

For the estimation of t_o, the von Bertalanffy equation is rewritten as $\log_e(L_\infty-L_t) = (\log_e L_\infty + kt_o) - kt$

Fitting a regression of $\log_e(L_\infty-L_t)$ against t, we get the Y-intercept as $\log_e(L_\infty+kt_o)$, from which t_o can be determined since we know the other two variables.

4. Mortality of *Mulloides flavolineatus*:

Estimation of total mortality coefficient (Z) was done by the use of the formula derived by Ssentengo and Larkin (1973). From :

$$y=\log(1-L/L_\infty) \qquad \text{and} \qquad y'=\log(1-L'/L_\infty)$$

they derived an unbiased estimate from a sample of 'n' fish as

$$Z/k=[n/(n+1)][1/(\bar{y}-y')]$$

which for large 'n' reduces to

$$Z/k=1/(\bar{y}-y')$$

where L_∞ and k are parameters of the von Bertalanffy growth equation, $\bar{L}$ is the mean length in the catch, and L' is "the smallest length of fishes that are fully represented in catch samples" (Beverton and Holt, 1956).

It is worth mentioning that $\bar{y}$ has to be calculated from individual values of y, and is not equal to $\log(1-\bar{L}/L_\infty)$.

Estimation of the natural mortality coefficient (M) was calculated using the multiple regression equation suggested by Pauly (1978, 1980 and 1984) which relates natural mortality to growth parameters and mean environmental temperature of the stock:

$$\log_{10}M = 0.0066-0.279 \log_{10}L_\infty+0.6543 \log_{10}k+0.4634 \log_{10}T$$

where T is the annual mean temperature (in °C) of the water inhabited by the stock in question, k is expressed on a yearly basis and L_∞ is the asymptotic length in cm. This equation is used for stocks living in temperatures ranging from 5°C to 30°C (Pauly, 1980; 1984).

The fishing mortality coefficient (F) was claculated by the simple subtraction of the value of M from the value of Z since

$$Z = F + M \text{ (Beverton and Holt, 1957)}$$

Estimation of the rate of exploitation was carried out using the formula

$E = (F(1-S)/Z$ (Everhart et al., 1976)

where S = the survival rate and is equal to exp(-Z).

5. Reproduction

At capture, and after a record of the various biological information had been made, the gonads were removed, separated and placed in aqueous Bouins fixative. After dehydration and clearing the material was embedded in Paraffin wax.

Sections, 6-10 Microns thick were cut, stained by Heidenhain's iron alum haematoxylin or azan techniques, mounted in Canada balsam and viewed under a binocular light microscope.

E. Area of Study

The Red Sea is a straight trough, extending in the northern hemisphere from Lat. 30°00' N at Suez to Lat. 12°40'N at Bab el-Mandab, thus exceeding 2000 kms. in length. The coasts are almost parallel to one another, with a maximum distance of some 340 kms. separating them at Masawa, though the average width of the sea is only about 280 kms. The Southern entrance at Bab el-Mandab is only 26 kms. wide. An important feature of the topography of the Red Sea is that in the south its depths are not continuous with those of the Indian ocean, but are separated by a shallow sill-like structure 100 m. deep. This has a profound effect not only on the hydrography of the Red Sea but also on its biology, and may be considered as the oceanic end of the Red Sea.

The city of Jeddah is the largest Red Sea fishing port at Lat. 21°32’N and long 38°52’E. The fishing area associated with this port extends between Eliza shoals to the North (Lat. 21°46’N and Long 38°52’E) seawards to Shib-Al-Kabir and South along the 500m depth contour facing Jazirat Ghorab (Lat. 21°21’N and Long. 39°07’E) (Fig. 2.1).

A report on the environment and fisheries in the coastal area between Jeddah and Yanbu (Red Sea) (Anon, 1984) contains the latest information on the hydrography of this area and can be summarized as follows:

The vertical and horizontal distribution of salinity, temperature and oxygen content suggests the presence of surface water mass moving from South to North, in the opposite direction to the prevailing northerly wind, indicating that the effect of evaporation in this area exceeds that of wind, i.e. water moves in at the open end of the sea, at the surface, to replace that sinking as a result of evaporation. It was also found that during its northerly movement, the surface water mass slides in a serpentine movement towards and away from the shore. The subsurface water masses, however, move in the opposite direction to the surface.

In general, the wind direction in this part of the Red Sea is predominantly from the North (to Lat. 24°N). The annual mean water temperature is about 22°C at depths greater than 200m, while at the surface, it varies between

22.5 and 35°C throughout the year. Salinity values as high as 36.5-40.5%o have been recorded.

Table 2.3 presents data on monthly variations in surface water temperatrue in the vicinity of Jeddah (Sofyani, 1987).

The bottom sediments in the study area are sandy with patches of muddy sand to the north and sand rich in lamellibranch shells to the south (Anon., 1984).

F. General Description of the Red Sea Hydrography and Climate

1. Temperature:

High sea temperatures always occur in tropical seas. Very high surface temperatures coupled with extreme salinities make the Red Sea one of the hottest and saltiest bodies of sea water in the world.

The temperature of the surface water in the Red Sea increases from North to South. The annual mean surface water temperature in the northern part varies from 24.5°C to 25.5°C and in the southern part from 28.4°C to 28.7°C (Vercelli, 1927). Below a depth of between 250 m and 300 m the Red Sea basin is filled by water with a constant temperature of about 21.5 - 21.6°C (Edwards, 1987) except for the hot brine pools, which are more than 2000 m in depth, and the temperature rises to 50.5°C and the salinity 255%o.

2. Salinity:

The salinity of the Red Sea is higher than in open oceans (Morcos, 1970) and increases from South to North. Vercelli (1927), reported that the salinity of surface water ranges from 40‰ in the north, to 36.5‰ in the south near Perim. High salinity in the Red Sea is caused by three factors: evaporation, upwelling (Grasshoff, 1969), and the extreme limit of freshwater influx (Dubach, 1964).

3. Winds:

The Red Sea winds are associated with the monsoon system. Morcos (1970) observed that during the summer months (June, July and August), the winds blow from N and NW throughout the whole length of the Red Sea, while during the winter months (December, January and February), they blow from the same direction, N, NW in the northern half of the Red Sea, but from the opposite direction (S,SE) in the southern part.

G. Red Sea Fisheries

Among the most important of the world's food resources are fisheries. In 1982, the last year for which United Nations Food and Agriculture Organisation (FAO) data are presently available, global fish production had reached 76,772,800 metric tonnes, of which nearly 90% came from marine rather than fresh water fisheries (FAO, 1984a). Fishery production from the Red Sea is small, accounting for only about 0.07% of the world total, although the surface area of the Red Sea (400,000 Km^2 according to Morcos (1970) represents about 0.123% of the total area of the oceans. Historically, fishing has been an important factor in the economy of the countries bordering the Red Sea.

At present the Red Sea fisheries are overwhelmingly artisanal in nature, conducted by individuals or small groups of fishermen who usually own the boats they operate, working in shallow waters close to shore. The boats used range in size up to 24 m. Their methods differ somewhat from those of other countries with similar fishing. The artisanal fishing methods in Saudi Arabia are dominated by hand-lining which is cheap and effective. In addition there are some areas with sandy bottoms and away from reefs which are suitable for fishing by trawling by commercial enterprises as well as by other traditional techniques.

Most of the catch consists of demersal and semi-pelagic fish throughout the Red Sea. In addition the south produces a significant shrimp catch (IUCN, 1987a) and aquaculture is being explored as an additional source of fishery production along the Red Sea coast (Figure 2.2).

Hagl, Al Lith, Wadj Bank and Jizan are all coastal cities in Saudi Arabia.

Many functions combine to determine the methods used to catch particular fish species. Sainsbury (1971) stated that principally the choice depends upon the species being fished, the individual value of the species to the fisherman, the depth of the water and characteristics of the sea bed if the gear is to be used in contact with the bottom. The species fished will have different habits, movements and reactions to stimuli. Some occur near the sea bed or beneath the bottom sediments and are referred to as demersal species. These are usually caught by gear worked on or near the bottom. Other species occur over varying depth ranges in the water column away from the sea bed and are referred to as pelagic species. The movements and behaviour of each species are controlled by factors such as temperature, salinity, available food resources, spawning habits, migration and in the case of pelagic species by thermoclines or other barriers. Some species congregate in numbers and can then be taken in bulk whilst others are taken singly or in small numbers. Thus depending upon this and the way in which a species is processed and marketed, the worth of a species is determined though this may vary in different parts of the world.

Specimens used in the present study were obtained from the fishing area in the vicinity of Jeddah.

H. Boats and gear types used on the Red Sea

The types of fishing can be divided into:-

I Types and boat gear used by artisanal fisheries

A Types of Fishing Boat

There are a number of different boats used by the fishermen:

1. Houri:

The houri varies from 2.5 to 3 m in length. 1-2 persons, using hand-lines or gill nets, work on a houri. One fishing trip usually takes several hours from sunrise until midday. The daily production of one houri is 10 Kg.

Houris usually go out to fish in groups, each group consisting of 3-4 houris (Fig. 2.3.1).

2. Shatya:

The shatya varies from 7 to 8 m in length, from 130-155 cm in width and 90-120 cm in depth. The engine capacity ranges from 15 to 40 horse power. 2-3 fishermen, using hand-lines or gill nets, work on a shatya. One fishing trip usually takes one day. The daily production is 30 Kg. which is 6.3 T/year (Fig. 2.3.2).

3. Khatera:

The khatera varies from 12 to 14 m, from 3 to 4 m in width and from 200 to 250 cm in depth. The engine capacity is up to 55 horse power. 4-6 fishermen work on the khatera. One fishing trip usually takes 7-10 days. The daily production is 500 kg. which is abut 15 T/year. An ice chest is used on the khatera (Fig. 2.3.5).

4. <u>Sambouk</u>:

The sambouk varies from 18-24 m, from 4-5 m in width, and 250-270 cm in depth. The engine capacity is 56-84 horse power. 12-15 fishermen work on the sambouk, using hand-lines and gill nets. One fishing trip takes 15-20 days and there are usually 18-19 trips per year. The mean production of one trip is 1.5 ton. The annual mean production is 28 tons per year (Fig. 2.3.4, 2.3.5 and 2.3.6).

B - Fishing Methods

1 - Lines

There are two types of lines:

a. Hand lines

b. Trolling lines.

(For the types of species caught by these gears and used for catching the samples in this study see Table 2.2.)

2 - Nets

a. Gill nets - where the opening of the mesh size is not less than 2 inch of 5 cm.

b. Trammel nets - where the opening of the intermediate layer of net is not less than 2 inch or 5 cm, and where the opening of two sides layers of the net are not less than 3 inches or 7.6 cm.

c. Beach Seine nets - where the opening is not less than 2.5 inches or 6.4 cm.

d. Stake nets - where the opening is not less than 2 inches or 5 cm.

e. Cast nets - where the opening of the cod-end is not less than 0.6 inch or 1.5 cm.

3 - Fish traps:

There are many types of fish traps:
Fish pots which have different shapes - circular, square or rectangular. The width of these pots ranges from 0.5 to 1 m and the height from 20 to 30 cm.

4 - Spears

The spears range from 0.5 to 1.5 m in length and are made of a hard metal.

II <u>Types of boat and gear used by the commercial fisheries</u>

A. Fishing boats

1. Wooden fishing fleet
2. Fibreglass fishing fleet
3. Metal fishing fleet.

Boats of these classes are few in number, of which Jeddah has the most compared with other coastal cities on the Red Sea of Saudi Arabia (Figs. 2.3.7

and 2.3.8).

B. Fishing methods

1. Trawling - divided into two types

   a. Bottom trawling nets where the opening of the cod-end is not less than 2 inch or 5 cm.

   b. Pelagic trawling nets where the opening of the cod-end is not less than 0.75 inch or 1.9 cm.

2. Ring or Purse Seiners nets:
   These are the best, largest and most modern types and equipment of the fishing fleet used for trawling and purse seining.

In the Saudi Arabian Red Sea, the fisheries represent one of the most economically and culturally valuable resources. For centuries, the Red Sea has supported an active artisanal fishery, and in recent years a commercial fishery has also developed, yielding about 3,000 tonnes/yr. The artisanal fishery, which yields more than 10,000 tonnes/yr. varies from north to south. In the northern Red Sea, the majority of fish caught are found in coral reef areas. While the fishery from Hagl to Al Lith represents 65% of the artisanal fishing areas, it only contributes 33% of the total yield of the Saudi Red Sea fishery. With the exception of the Wadj Bank area, the northern fishery is considered to be fully exploited. The southern area from Al Lith to Jizan supports both artisanal and commercial fisheries (Fig. 2.2).

In Jeddah there are 96 Houri, 69 Shatya, 8 Khatera, and 26 Sambouk. There is no available statistical information regarding fishing boats used by commercial fishermen.

Table 2.1. List of fish species examined for the study of the alimentary canal morphology.

Fish species	Length range (TL)	Mean length cm
Adioryx spinifer (Forsk)	28.2-34.8	31.35±2.3512
Aethaloperca rogaa (Forsk)	24.3-38.0	30.72±4.0249
Caesio suevicus (Klunzinger)	16.3-17.4	16.84±0.3728
Carangoides bajad (Forsk)	43.0-46.5	45.01±1.1309
Caranx ignobilis (Forsk)	22.5-25.8	23.98±1.0582
Gerres oyena (Forsk)	19.7-23.8	21.56±1.3201
Lethrinus lentjan (Forsk)	17.3-29.0	23.23±4.2126
Lutjanus bohar (Forsk)	22.7-38.0	31.30±4.5748
Lutjanus flaviflamma (Forsk)	14.3-21.7	17.52±2.1272
Mulloides flavolineatus (Lacepede)	21.8-24.2	22.88±0.6797
Platycephalus tuberculatus (Linne)	30.5-34.4	32.25±0.7891
Plectorhynchus gaterinus	30.8-38.0	34.70±2.4230
Plectorhynchus schotaf (Forsk)	33.0-48.4	43.34±2.1501
Rastelliger kanagurta (Forsk)	21.3-26.0	24.13±1.3758
Scarus ghabban (Forsk)	22.7-31.2	28.75±2.2597
Scomberomorus lysan (Forsk)	37.8-45.4	41.91±3.0503
Siganus rivulatus (Forsk)	16.7-21.7	19.87±1.5611
Sphyraena genie (Klunzinger)	75.0-82.5	79.78±2.4713
Tylosurus choram (Rupell)	52.0-58.0	54.83±1.8193
Therapon jarbua (Forsk)	20.5-27.0	23.73±2.1398

Table 2.2:

Fish Species	Benthic	Pelagic	Hand line	Gill nets	Fish traps
Adioryx spinifer (Forsk)	✓		✓	✓	
Aethaloperca rogaa (Forsk)	✓		✓		✓
Caesio suevicus (Klunzinger)		✓	✓	✓	
Carangoides bajad (Forsk)		✓	✓		
Caranx ignobilis (Forsk)		✓	✓		
Gerres oyena (Forsk)	✓			✓	
Lethrinus lentjan (Forsk)	✓		✓	✓	✓
Lutjanus bohar (Forsk)	✓		✓	✓	
Lutjanus flaviflamma (Forsk)	✓		✓	✓	
Mulloides flavolineatus (Lacepede)	✓		✓	✓	
Platycephalus tuberculatus (Linne)	✓			✓	
Plectorhynchus gaterinus	✓			✓	
Plectorhynchus schotaf (Forsk)	✓		✓	✓	
Rastelliger kanagurta (Forsk)		✓		✓	
Scarus ghabban (Forsk)	✓			✓	
Scomberomorus lysan (Forsk)		✓	✓		
Siganus rivulatus (Forsk)	✓		✓	✓	✓
Sphyraena genie (Klunzinger)		✓	✓	✓	
Tylosurus choram (Rupell)		✓	✓	✓	
Therapon jarbua (Forsk)	✓			✓	✓

Table 2.3: Monthly values of surface water temperature off Jeddah, Red Sea (After Sofyani, 1987).

Month	Min.°C	Max.°C
January	24.75	25.5
February	22.5	28.0
March	22.5	28.5
April	27.0	31.0
May	24.0	30.0
June	26.0	33.0
July	28.0	35.0
August	28.5	33.0
September	28.75	32.0
October	27.75	31.5
November	27.5	32.0
December	22.5	29.0

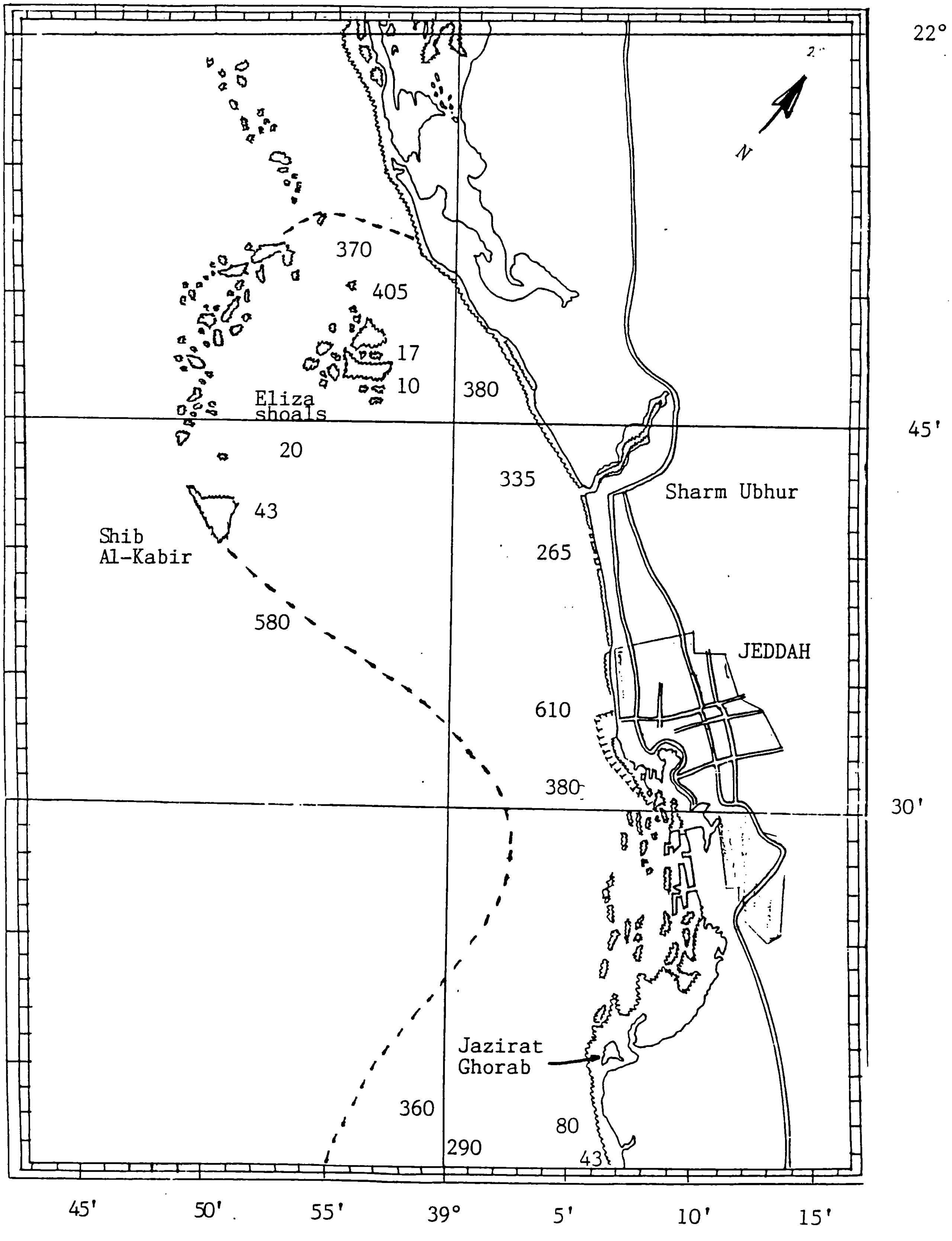
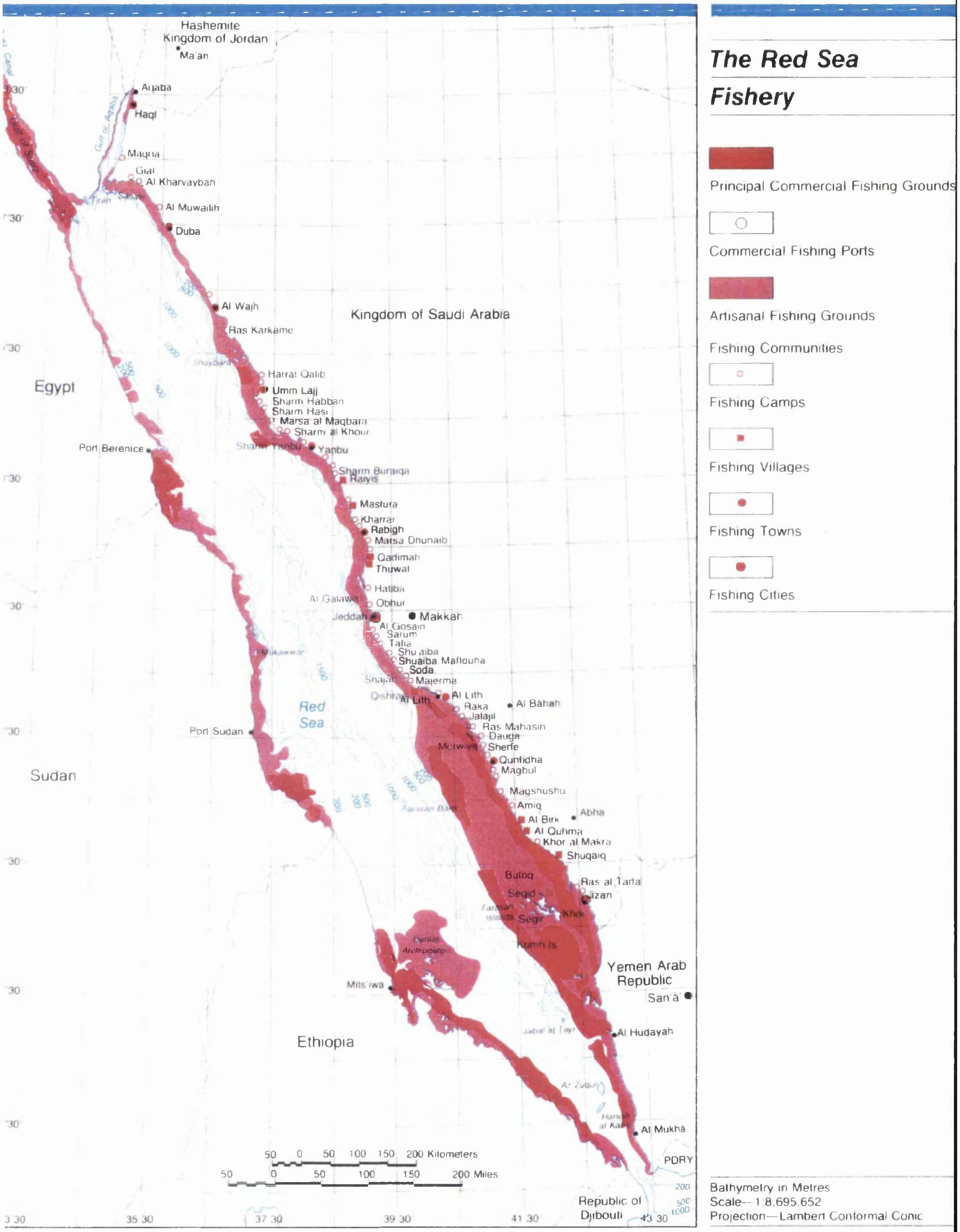


Figure 2.1. Jeddah coast and fishing zones (dotted line marking the 500 m depth contour).

Figure 2.2: The Red Sea Fishery.



From: MEPA Coastal and Marine Management Series, Report No. 7, December, 1987.

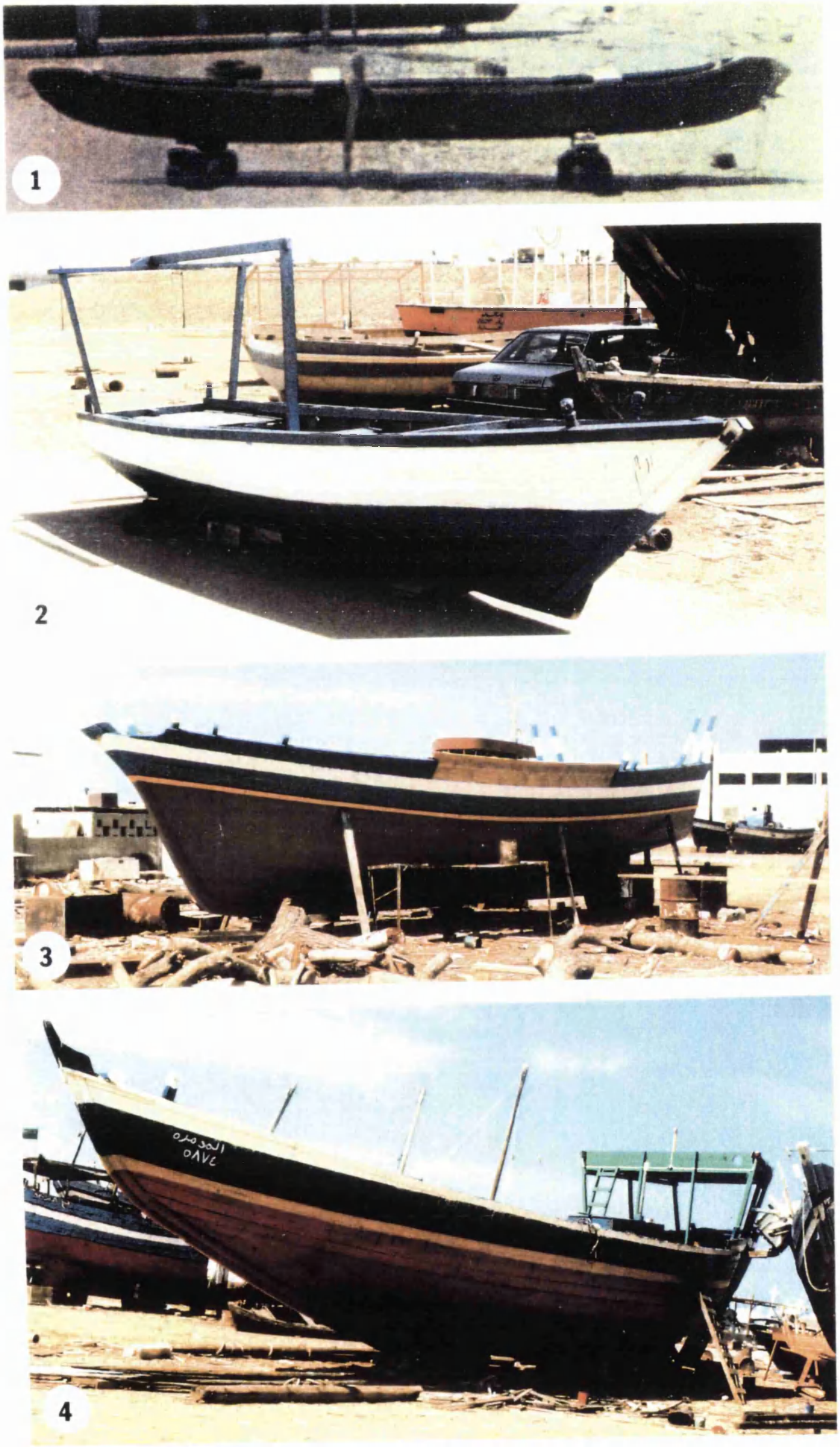


Figure 2.3: Types of Fishing Boat.

Figure 2.3 Contd.

CHAPTER 3

DESCRIPTIVE ANATOMY OF THE ALIMENTARY TRACT

3.1. Introduction

Fish, which represent the most primitive group of vertebrates, show a considerable variation in diet and feeding. Günther (1870) considered fish as either carnivorous or herbivorous, but some were bottom feeders; he also stated that the power of a fish to obtain its food is dependent on the dimensions of its mouth and gullet, and the strength of its teeth and jaws. Payne (1938) considered that fish are either predators, herbivores or plankton feeders. Al-Hussaini (1947a and 1949) divided fish into four groups according to their diet; carnivorous, herbivorous, omnivorous, and plankton feeders. Kapoor et al. (1975) classified fish according to the diversity of their food, into euryphagous, stenophagous and monophagous. According to the feeding conditions some ecological groups may be distinguished, such as, pelagic plankton feeders, benthos feeders, etc., as reported by Suyehiro (1942); Al-Hussaini (1947a), Gohar and Latif (1959), Das and Moitra (1963) and Nikolsky (1963 and 1974). In addition Nikolsky (1963) stated that fish may lead a parasitic mode of life.

Such a variation in the diet of the teleost fish has led to a corresponding variation in their alimentary tract. A considerable volume of work has been published relating to the anatomy and histology of the alimentary tract of fish. Most studies which deal mainly with European and American fish species, have correlated the structure of the gut with feeding in the examined fish species (Blake, 1936; Ghazzawi, 1935; Suyehiro, 1942; Al-Hussaini, 1945; Girgis, 1952 a&b; Kapoor, 1953, 1957, 1958 a&b; Al-Hussaini and Kholy, 1953; Khanna, 1961; Mohsin, 1962; Sehgal, 1966; Schmitz and Baker, 1969; Sehgal and Salaria, 1970; Bucke, 1971; Verma and Tyagi, 1974. However, very few studies were published on fish of the Red Sea (Al-Hussaini, 1947 a&b, 1949; Gohar and Latif, 1959; Abou-Zinadah, 1983; Ismail, 1988).

The present study is a detailed examination of the anatomy of the alimentary tract in as many fish species as possible, inhabiting the waters off Jeddah, because of the paucity of information regarding this subject on Red Sea fish. The main objective of the present investigation is to determine any possible correlation between the anatomy of the digestive tract and the food and feeding habits in these fishes.

3.2. Material and methods

20 Red Sea fish species belonging to 17 Families collected monthly throughout the year from the waters off Jeddah, and the immediate neighbourhood, are examined. The taxonomy of the species under investigation is based on the classification given by Randall (1983). Arabic names refer to common local names adopted by native fishermen in Saudi markets (Table 3.1).

Table 3.1

Family	Species	Arabic Name
Plectrorhynchidae	*Plectrorhynchus schotaf* (Forsk)	Shotaf
	Plectrorhynchus gaterina (Forsk)	Qatranah
Platycephalidae	*Platycephalus tuberculatus* (Linne)	Raqdah
Lutjanidae	*Lutjanus flaviflamma* (Forsk)	Hibr
Lethrinidae	*Lethrinus lentjan* (Forsk)	Sho'our
Gerridae	*Gerres oyena* (Forsk)	Qasa
Lutianidae	*Lutianus bohar* (Forsk)	Bohar
Carangidae	*Scomberomorus lysan* (Forsk)	Lysn
	Carangoide bajad (Forsk)	Biad Oazz
	Caranx ignobilis (Forsk)	Biad
Serranidae	*Aethaloperca rogaa* (Forsk)	Roka
Mullidae	*Mulloides flavolineatus* (Lacépède)	Inbir
Holocentridae	*Adioryx spinifer* (Forsk)	Kahaia
Caesinidae	*Caesio suevicus* (Klunzinger)	Zorgan
Belonidae	*Tylosurus choram* (Rüpell)	Khirm
Sphyraenidae	*Sphyraena genie* (Klunzinger)	Agam
Scombridae	*Rastelliger kanagurta* (Forsk)	Baghah
Scaridae	*Scarus ghabban* (Forsk)	Hyddiah
Siganidae	*Siganus rivulatus* (Forsk)	Sigan
Theraponidae	*Therapon jarbua* (Forsk)	Jarbua

Fresh specimens were prepared as in Chapter 2, Materials and Methods, Section B.

According to the analysis of stomach contents, the fish species were placed in the appropriate feeding categories, either plankton feeders, herbivores, carnivores, or omnivores. Carnivores are further subdivided into four sections depending on the degree of occurrence of a food group over the others.

3.3. Observations

A representative sketch of the mouth, teeth, gill rakers and viscera *in situ* together with their description is provided for each of the species studied. The species are presented according to the categories to which they belong.

3.3.1. Carnivorous Fishes

3.3.1.1. Invertebrate and fish eaters

3.3.1.1.1. *Plectrorhynchus schotaf* (Forsk) (grunt fish)(Fig. 3.1A)

Grunts are nocturnal feeders. They live on coral reefs during the day for shelter until nightfall when they disperse for feeding. They often occur in pairs or small schools of about a dozen in and around reefs. Information on habitats of all fish was obtained from local knowledge and Randall (1983).

The mouth of Plectorhynchus schotaf is rather small and slightly low on the head. The upper jaw projects forward slightly and the lips are thick (Figure 3.1A).

The oesophagus is wide, short and passes indistinguishably into the stomach. Internally, however, the arrangement of the mucosal folds distinguishes the two organs easily. The stomach is of the caecal type. The caecum being conical and when it is full of food may occupy the greater part of the body cavity. The pyloric part of the stomach is large compared with total size of the stomach (Figure 3.1B & C).

There are 8 to 10 long pyloric caeca which are sheathed in fatty tissue. The intestine forms a siphonal one and a half loop. The differentiation of the rectum is not marked externally, but internally it is obvious by the presence of the ileo-rectal valve.

The teeth in the jaws are conical and small, with none developed as canines. There are no teeth on the palate. The gill rakers are short, pointed and thick (Figure 3.2C).

'Grunt fish' is so named because of the sound it makes by grinding its well-developed pharyngeal teeth. The sound is amplified by the gas bladder. The pharyngeal teeth are pointed and arranged above the bulging pharyngobranchials of the second, third and fourth gill-arches and below on the anteriorly coalesced pharyngeals. The pharyngeal teeth resemble those on the gill rakers but are less strong.

These fish feed on a wide variety of benthic invertebrates and small fish.

3.3.1.1.2. *Platycephalus tuberculatus* Linne.

This fish lives on sand flats near to the coral reefs. It is protectively coloured to look like the sand into which it partially or completely buries. The body is wide, depressed anteriorly and sub- cylindrical posteriorly. The head is markedly dorso-ventrally depressed with a large terminal mouth. Its lower jaw is slightly longer than the upper one and the lips are thin. The jaw teeth are villiform and are arranged in several rows on both the upper and lower jaws. The buccal cavity is depressed and widens as it turns backwards to join the wide pharyngeal cavity (Figure 3.3A).

The gill rakers of the first row are slightly long and pointed, they are also covered with small prickly processes, while those of the second row are stout structures with roughened surfaces. In between each of the two rows on one gill arch there are minute villiform teeth (Figure 3.3A).

The pharyngeal teeth are approximately twice as large as the jaw teeth and those on the upper pharyngeal bones and larger than those on the lower ones (Figure 3.3B).

The peritoneal cavity is rather small and slightly depressed. The oesophagus is wide and has a thick muscular wall. The stomach is 9-shaped but akin to Y-shape. The caecum (blind sac) is large, and when full of food, it may occupy the greater of the peritoneal cavity. The pyloric part of the stomach is small compared with the total size of the stomach. The wall of the stomach is thick.

There are ten pyloric caeca which are smaller than those in Plectrorhynchus. The intestine stretches along the right side of the stomach and coils once. The wall of the intestine is rather thick. The ileum and rectum are not distinct externally, but the former, when full of food, is slightly wider (Figure 3.4B & C).

The stomach contents of this fish consist of a mixture of crustacea brittle stars, small sea urchins, chitons, small gastropods, clam, worms and small fish.

3.3.1.1.3. Lethrinus lentjan (Forsk) (Fig. 3.5A)

Lethrinus lentjan are nocturnal feeders. During the day they live on coral reefs for shelter and disperse at nightfall for feeding. They are usually found in pairs or small schools of about a dozen.

The mouth of Lethrinus lentjan is in a terminal position with fairly thick lips. It is of a moderate size and slightly protrusible. The teeth on the jaws vary in shape from conical or canine-like in the anterior region to granular or molariform in the posterior part. Behind the canines there are rows of villiform teeth. This type of dentition was described by Gregory (1933) as durophagous and the jaws as of the crushing type. The tongue is pointed and free at its anterior tip. There are no teeth on the palate (Figure 3.6A).

The gill rakers are short and thick. The pharyngeal teeth are conical shaped but the upper teeth are more developed than the lower ones (Figure 3.6A, B, & C).

The peritoneal cavity is rather large. The oesophagus is very short and passes into the caecal portion of the stomach which lies straight in the body cavity. The size of the caecum is affected by the amount of its contents, when full, it may approach the posterior boundary of the cavity. The short, stout pyloric region of the stomach runs forward in a ventral direction, on the left side, from the very short cardiac region (Fig. 3.5C).

There are three short pyloric caeca, two of which are sinistral, one below the other, while the third one is dextral. The wide intestine forms one and one-half siphonal loops. The differentiation of the rectum is indistinct externally, but internally an ileo-rectal valve is present

(Figure 3.5B & C).

The stomach contents consist of a mixture of crustaceans, sea urchins, brittle stars, small gastropods, and small fish; but crustaceans seem to be their favorite prey.

3.3.1.1.4. *Lutjanus flaviflamma* (Forsk) (Figure 3.7A)

This species is usually bottom-dwelling, and is nocturnal. During the day they form large aggregations near the shelter of reefs.

This snapper fish has a fairly large mouth. The lower jaw projects slightly and the maxilla slips under the edge of the orbital when the mouth is closed. The teeth on the jaws are arranged in several rows, fixed, varying in shape from small conical to large and caniform. The vomerine and palatine teeth are small. The tongue is studded with villiform teeth.

The gill rakers of the first row are long and pointed. They are also covered with small prickly processes, while those of the second row are stout structures with roughened surfaces. In between each of the two rows of gill rakers on one gill arch there are minute villiform teeth. The pharyngeal teeth are well developed and arranged dorsally on the second and fused third and fourth pharyngeobranchials, and below on the separate inferior pharyngeals.

The oesophagus is short and muscular. The stomach is of the caecal type. The short cardiac part passes into a well developed conical caecum. The pyloric region of the stomach is short and slightly stout. There are four wide and short pyloric caeca. The intestine forms one and a half siphonical loop. The rectum is not externally demarcated and has no ileo-rectal value (Figure 3.7B & C).

The contents of the stomach comprise a mixture of invertebrates and small fishes, but the most frequent are crustacea especially crabs and gastropods.

3.3.1.1.5. Gerres oyena (Forsk) (Figure 3.8A)

This fish is often seen over sandy bottoms within or around reefs. It has a moderately deep compressed body and has a distinctive concave ventral profile to the head. The mouth is very protrusible and extends downwards when protruded. The maxilla is broad posteriorly and exposed on the cheek. The teeth on the jaws are small, slender, numerous and close-set, but there are none on the roof of the mouth.

The gill rakers are short, but coarser. The pharyngeal teeth are small, hard, granular and some are conical. They are arranged dorsally on the second, fused third and fourth pharyngeobranchials and below on the coalesced inferior pharyngeals.

The stomach and intestine resemble those in L. lentjan but the differentiation of the rectum is well marked both externally and internally by larger dimensions and by the presence of an ileo-rectal valve (Figure 3.8B & C).

The fish feed on small crustaceans, polychaetes, small fish and other organisms, but its favourite diet seems to be polychaetes which were found in the stomach of several individuals.

3.3.1.2. Fish and invertebrate eaters

3.3.1.2.1. *Lutianus bohar* (Forsk) (Figure 3.9A)

These fish are seen near and around reefs in daytime, and at night the preferred habitat is exposed deep outer reefs, to be closer to their prey.

The alimentary tract of this fish is very similar to that of *L. flaviflamma* but there are five pyloric caeca (Figure 3.9B & C).

The gill rakers of the first row are longer than those of the following rows. All gill rakers are covered with bristles of varying length (Figure 3.10A).

The jaw teeth are well developed canines, and are arranged on the upper and lower jaws in an alternative way, so that, when the mouth is closed, teeth of one jaw are faced with empty space on the other (Figure 3.10B & C).

The upper pharyngeal pad is larger than the lower one, and both bear well developed pharyngeal teeth.

The oesophagus is short and muscular. The cardiac portion of the stomach is much larger than the pyloric. The pyloric caecae are of variable sizes, the short ones covering the cardiac stomach, while the long caecae cover the pyloric portion of the stomach (Figure 3.9B & C). The intestine is divided into two portions, a thick muscular anterior part and a thinner posterior part (Figure 3.9C). The rectum is not demarcated externally from the intestine.

In this species, about three quarters of the stomach contents consisted of fish, and invertebrate organisms, mainly crustaceans, brittle stars and gastropods, constituted the rest of the stomach contents by volume.

3.3.1.2.2. Scomberomorus lysan (Forsk) (Figure 3.11A)

These are mid-water to surface nektonic predators usually found in schools and moving at high speed. None is a reef fish in the sense that they reside in reefs, but some range over reefs to prey upon the fishes there.

The body is elongated but scarcely long, relative to its depth. The snout is conical. The mouth is moderately large and the lower jaw is slightly longer than the upper one which is protrusible. The teeth in the jaws are minute, conical and arranged in several rows. Vomerine and palatine teeth are very small. The tongue is medium sized, triangular, thin, free, armed with very minute teeth and melanin chromatophores are present on its surface (Figure 3.11B & C).

The gill rakers are flat, long 4/5 the length of the corresponding gill filaments, pointed and serrated (Figure 3.12A).

The pharyngeal teeth are similar in shape to those on the jaws; arranged in two sets on the lower pharyngeal bones and four sets on the upper ones (Figure 3.12B & C).

The peritoneal cavity is moderately large. The oesophagus is moderately wide and passes indistinctly into the stomach. The latter is of the caecal type. The conical caecum is large and extends backwards to reach the posterior of the body cavity. The size of the caecum is greatly affected by the amount of its contents. The cardiac and pyloric portions of the stomach are very short (Figure 3.11B).

The intestine is moderately short and winds twice and the anus is slightly anterior compared with normal. The rectum is demarcated both externally and internally, an ileo-rectal valve being well developed. The pyloric caeca are of medium size, and vary between 18 and 24 in number (Figure 3.11C).

The stomach contents consisted of a mixture of small fish and a few crustaceans.

3.3.1.2.3. *Carangoid bajad* (Forsk) (Fig. 3.13A)

This species is identical in habitat to *S. Lysan*. It closely resembles *S. lysan* except that the cardiac portion of the stomach is more clearly demarcated than the cardiac one, the caecum is not so large and the pyloric caeca are much and located on the right side of the stomach (Figure 3.13B).

The food consists mostly of small fish, such as sardines, small crustaceans and small gastropods.

3.3.1.2.4. *Aethaloperca rogaa* (Forsk) (Figure 3.14A)

This red mouthed grouper, usually seen in caves or lurking in their vicinity, and like most members of its Family, Serranidae, has a wide mouth with several rows of teeth on the jaws. Some of these teeth are sharp and point backwards. On the anterior tip of the upper jaw, two pairs of well developed teeth resemble canines. The vomerine and palatine teeth are small and arranged in several rows. The tongue is medium sized, rectangular in shape, thin, free anteriorly and smooth (Figure 3.15B).

The gill rakers are short, thick and carry small spines (Figure 3.15A). The pharyngeal teeth are well developed and arranged dorsally on the bulging pharyngeobranchials of the second, third and fourth gill arches, on the epibranchial of the third arch, and below on the anteriorly coalesced pharyngeals. The pharyngeal cavity is capacious and its internal folds are continued backwards into those of the oesophagus (Figure 3.15B & C).

The peritoneal cavity is large. The stomach is large and of the caecal type. The intestine is moderately long, winds twice and its wall is moderately thick. The rectum is well marked both externally and internally by large dimensions and the presence of an ileo-rectal valve. There are ten pyloric caeca present (Figure 3.14C).

The food of this fish consists mostly of small fish and a mixture of invertebrate organisms, but fish seem to be their favourite prey.

3.3.1.3. Invertebrate eaters

3.3.1.3.1. *Mulloides flavolineatus* (Lacépède) (Fig. 3.16A)

These fish are often seen singly or in small groups swimming close over a sand bottom, probing into it with wriggling barbels, and pouncing sporadically upon some uncovered titbit.

The body of this goatfish is elongated and slightly compressed. The head is rather large and the snout is more or less pointed. The mouth is small and ventral in position. The most distinctive feature of this species is a pair of long barbels just behind the chin (Figure 3.16A). Irregularly two-rowed minute conical teeth grow on the jaws. The buccal cavity is rather small. The roof of the mouth is toothless. The tongue is small and not free (Figure 3.17B).

The gill rakers are short and thick. They are also provided with small prickly processes. Small conical teeth grow coarsely on the pharyngeal bones (Figure 3.17A).

The peritoneal cavity is rather large. The narrow oesophagus is moderately long. The stomach is of the caecal type. The cardiac and pyloric portions of the stomach are rather small. The caecum is voluminous and, when full of food, may occupy the greater part of the body cavity, on account of its high elasticity.

There are 17 pyloric caeca which are moderately long and narrow. The intestine is short and broad, but the duodenum is rather narrow compared with both the ileum and rectum. The latter is poorly differentiated both externally and internally, since the ileo-rectal valve is not well developed (Figure 3.16C).

This species feeds mainly on invertebrates, particularly polychaetes and crustaceans, which live in the sediments. The fish use their barbels, which posses sensory buds to probe into the bottom sediments in search of food organisms.

3.3.1.3.2. *Adioryx* (*Sargocentrum*) *spinifer* (Forsk) (Fig. 3.18A)

This species is a nocturnally active fish found on coral reefs. By day they hide in caves or crevices in reefs. At dusk, however, they slowly emerge from their shelters and disperse across the reef to feed.

The body is relatively deep and laterally compressed. The snout is prolonged forwards and the mouth opens in a horizontal position. The mouth is protrusible and the lips are slender. The tiny villiform teeth are arranged in several rows on the premaxillae and dentries (Figure 3.18A).

There are several rows of villiform teeth on the vomer and on the palatines. The tongue is moderately long, lanceolate and free at its anterior end (Figure 3.19B).

The gill rakers of the first row are well developed and serrated especially those on the ceratobranchials. The rest of the rakers, as well as those of the other rows, are short. Those on the hypobranchials are broad and low and approach each other making, with opposite elements of the other side, roughened V-shaped plates in the floor of the pharynx (when viewed anteriorly) (Figure 3.19A).

The pharyngeal teeth are arranged on the pharyngebranchials of the second, third and fourth arches. They oppose the inferior pharyngeals which do not fuse (Figure 3.19B & C).

The oesophagus is short, muscular and passes without demarcation into the caecal stomach. The broad intestine forms one siphonal loop and one-half which lie in the dextral region of the body cavity. The rectum is marked by larger dimensions, and is separated from the rest of the gut by an ileo-rectal valve. There are 16 to 18 pyloric caeca arranged around the proximal end of the duodenum (Figure 3.18B & C).

The food of this fish consists mainly of crustaceans and polychaetes.

3.3.1.3.3. *Plectrorhynchus gaterina* (Forsk) (Fig. 3.20A)

This species is identical in habitat to *P. schotaf*. The mouth is small, the teeth are similar to those of *Gerres*, but the pharyngeal teeth are sharply pointed. The oesophagus is short, wide and has a thick wall. It passes indistinguishably into the stomach. The stomach is of the caecal type, the caecum being conical and pointed. The pyloric region of the stomach is well developed. There are 6 to 8 pyloric caeca of various lengths (Figure 3.20C). The intestine is one and a half loop. The rectum has a thick wall and it is obvious internally by the presence of the ileo-rectal valve.

This fish feeds on a mixture of crustaceans, especially crabs.

3.3.1.3.4. *Caesio suevicus* (Klunzinger) (Fig. 3.21A)

This species comes readily to cleaning stations on reefs and retire to the shelter of reefs at night to sleep, and it closely resembles *P. gaterina* except that the oesophagus is short and wide, the pyloric part of the stomach is poorly developed and the pyloric caeca are 6 in number (Figure 3.21C). The intestine has a thin wall and winds twice; the rectum is not differentiated.

The fish feeds mostly on crustaceans but also takes in other small invertebrates.

3.3.1.4. *Fish eaters (Piscivorous fishes)*

3.3.1.4.1. *Tylosurus choram* (Rüppell) (Figure 3.22A)

The 'needle fish' lives at the surface and is protectively coloured for this mode of life. When frightened (for example, by light at night), it may leap from the water and skip at the surface. It has a very slender body, being especially adapted for leaping out of the water (Figure 3.22A). The mouth is of the needle-gar type and the jaws are extremely elongated with numerous needle-like teeth. Such teeth belong to a serial set of rows, one of which is modified into well developed canines.

When the mouth is closed, the teeth of the upper jaw fit into depressions in the lower jaw, while those of the lower jaw project upwards. The tongue is lanceolate and free at its anterior end. Its free tip lies posterior to the mandibular valve opposite to a point slightly in front of the mouth angles. It is also provided with small spiny teeth (Figure 3.22C). The gill rakers are rudimentary.

The pharyngeal teeth are well developed, those on the third and fourth pharyngeobranchials are sharply pointed and canine-like. The inferior pharyngeals are completely coalescent.

The peritoneal cavity is elongated. The oesophagus is connected directly to the intestine, since there is no stomach. The bile duct opens into the dextral side of the intestine a short distance behind the oesophagus. The intestine is slightly enlarged posterior to the bile duct and follows a straight course in a backward direction. There is a marked external constriction, at the position of the ileo-rectal valve (Figure 3.22B). The fish feed mainly on small pelagic fish.

3.3.1.4.2. Sphyraena genie (Klunzinger) (Figure 3.23A)

These barracuda are unmistakable top-level predators on a coral reef. It is a very elongated fish, whose body is cylindrical anteriorly, and the head is rather pointed (Figure 3.23). The mouth is typical of predaceous species. This type of mouth has been acquired by the forward growth of both snout and jaws. The formidable teeth are dagger-like, backwardly directed and arranged in a single row in each jaw, on which they are set in sockets. The maxillae and vomer are toothless, while in large specimens the palatines bear teeth slightly smaller than those on the jaws (Figure 3.24B).

The buccal cavity is medium sized. The tongue is elongated and free at its anterior end. On its dorsal surface there are a few melanin chromatophores and small sharp teeth which help in seizure of prey.

The gill rakers are minute and closely set (Figure 3.24A). The pharyngeal teeth are well developed and villiform. The superiors are stronger than the inferiors. The buccal and pharyngeal cavities are beset with armature which renders capturing the prey most efficient (Figure 3.24B & C).

The peritoneal cavity is elongated. The oesophagus is wide, short and passes indistinguishably into the stomach. Internally, however, the mucosal folds distinguish the two organs. The stomach is of the caecal type having a voluminous caecum which, when full of food, may occupy the greater part of the body cavity, on account of its high elasticity. The pyloric portion is small compared with the total size of the stomach (Figure 3.23B & C).

There are numerous, thin pyloric caeca which are arranged around the proximal end of the duodenum. The intestine passes backwards straight to the anus. There is a slight constriction between the ileum and the rectum, the latter is differentiated by larger dimensions and by the presence of an ileo-rectal valve. Baracuda usually feeds on fish.

3.3.1.4.3. Caranx ignobilis (Forsk) (Figure 3.25A)

This species is identical in habitat to S. lysan. The snout is pointed and conical. The mouth is large with minute teeth growing in bands in each jaw. The mouth cavity is large. The vomer and palatines do not carry teeth.

The gill rakers are short and thick, and beset with small prickly processes. On the fourth gill arch the gill rakers fuse in pairs, forming stout structures with roughened surfaces. Between two rows of one gill arch there are minute villiform teeth (Figure 3.26A).

The pharyngeal teeth are well developed and resemble those on the gill rakers and gill arches, but are much stronger (Figure 3.26B & C).

The peritoneal cavity is small. The oesophagus is wide, short and passes insensibly into the stomach. The latter is rather large and consists of a long cardiac region, a short caecum, and a short oval pyloric part. Its wall is generally thick. The pyloric caeca are small, numerous and spread out in all directions. The intestine is moderately wide, with a thick wall. It winds once, describing a circle from the duodenum to the anus. The rectum is not externally demarcated (Figure 3.25B).

This fish was found to feed exclusively on sardines.

3.3.2. Plankton feeders

3.3.2.1. *Rastelliger kanagurta* (Forsk) (Figure 3.27A)

This species is typically found in schools of a few dozen or more individuals in fairly deep water adjacent to coral reefs. The mouth is moderately large. About 60 minute conical teeth grow in a series in each jaw. There are 2 to 3 rows of minute teeth on the vomeral bone, but the palate is void of teeth. Perhaps the smallness of the food organisms does not necessitate their seizure, hence the poorly developed teeth. The tongue is of medium size, triangular, pointed, thin but hard, free and adentulous (Figure 3.28A & B).

The pharyngeal cavity is rather large. The pharyngeal teeth are long but very slender, numerous and resembling closely a scrubbing-brush (Figure 3.29B & C).

The gill rakers of the first row of *R. kanagurta* are extremely long, thick and extend anteriorly to reach the mouth opening, the length being 5/3 that of the corresponding gill filaments. They are closely set, 35-38 in number and the long processes on each gill raker are about 40 in number. The other gill rakers are shorter than those of the first row, but they are longer than corresponding gill filaments. They are also 30 to 40 in number, slender, with pointed tips and have numerous processes which are not so numerous and short (Figure 3.29A). It would seem that these long processes play an important role when the gill rakers sieve and collect planktonic organisms.

The peritoneal cavity is small. The oesophagus is short and has a thick muscular wall. It is considerably narrower than the distended cardiac part of the stomach. The stomach is large, and -shaped (Figure 3.27C). The conical caecum which is externally demarcated is so long that its posterior end, especially when full, reaches to the end of the peritoneal cavity. The pyloric part is well developed and highly muscular. The pyloric caeca are very long and numerous. They are arranged in a circular fashion round the pyloric opening and upper side of the fore-end of the duodenum up to its backwards turning point. Moreover, they are so close together that they look as if they form a massive structure of glandular appearance. The intestine is generally of a small diameter, its proximal part forms three intestinal loops, while its distal part is spirally coiled and leads into a poorly differentiated rectum.

The diet of this fish consists mostly of planktonic crustaceans, the undigested remains of which are detectable in the rectum. In some specimens, however, undigested filamentous algae were observed.

3.3.3. *Herbivorous fishes*

3.3.3.1. *Scarus ghabban* (Forsk) (Figure 3.30A)

The main habitat of this fish is in coastal waters around coral reefs. The mouth is small and nonprotrusible. The upper and lower jaws resemble a parrot's beak. Each jaw carries a dental plate, divided by a median vertical suture. The quadrants thus formed are looked upon as groups of teeth fused together (Rynolds, 1913; Gregory, 1933; Gohar and Latif, 1959). These dental plates have sharp edges which are used to scrape food organisms growing on dead coral and limestone rocks, thus the edges of these plates are always incomplete due to their breakdown while grazing food. The palate is toothless (Figure 3.31A & B).

The pharyngeal valve hangs in the roof of the pharynx marking its beginning and covering a superior pad provided with villiform teeth. It is differentiated into two regions. The anterior one is in the form of two inclined papillated structures joined together by a median, similarly papillated depressed piece. The second region consists of three or four crescentic folds, overlapping each other in a backward direction.

The pharyngeal teeth are well developed. They are located in two areas on the roof of the pharynx (upper pharyngeal teeth) and a single area on the floor of the pharynx (lower pharyngeal teeth). The upper pharyngeal teeth areas carry two rows of teeth, an inner one consisting of large teeth and an outer one of smaller ones, alternating with those of the former (Figure 3.31B). The number of teeth in each row is not constant since they wear out through grinding of coral and limestone pieces. The lower pharyngeal teeth are arranged in rows of teeth of variable number, in a concave tooth plate formed by the fusion of the lower pharyngeals.

The gill rakers are generally fine and closely set, but their degree of development varies in the different gill arches (Figure 3.31C).

The thin walled oesophagus begins as a relatively small tube a little posterior to the pharyngeal teeth. It passes into the intestine with no stomach between them, but there is a pyloric valve. Immediately posterior to this valve, the intestine is swollen sinistrally and dextrally. These lateral extensions are referred to as intestinal bulbs. These two bulbs are unequal, the right being larger (Figure 3.30C). The intestine with a constant diameter extends posteriorly, to the hind end of the abdominal cavity. Two longitudinal lines, on opposite sides, extend along the whole length of the intestine, and closely set constrictions begin at these lines extending from one line to the other causing the wall of the ileum to acquire two series of constrictions. The opposite structures alternate to some extent with each other and hence the food does not follow a straight course while passing in the intestinal lumen (Figure 3.30C). The rectum, representing the posterior region of the gut, is morphologically differentiated from the ileum, by a slight constriction representing an ileo-rectal valve.

The guts of the fish examined contained a white to greenish paste, which liberated carbon dioxide upon treatment with hydrochloric acid. The soft parts remaining after this treatment, were mainly red and green algae, other marine plants and dinoflagellates. Foraminifera, small crustaceans and fragmented polyps were present in some samples and are apparently taken occasionally by fish while feeding.

3.3.3.2. *Siganus rivulatus* (Forsk) (Figure 3.32A)

This is an inshore fish often seen in schools and tend to range over algal flats or seagrass beds. The mouth of this rivulated rabbitfish is small, slightly protrusible and directed slightly downwards with rather broad lips. Each jaw has 25 to 30 small pointed teeth, arranged close to each other forming a continuous serrated edge. Vomeral and palatal teeth are absent (Figure 3.33C). The buccal cavity is large and its roof folds are well developed.

The pharyngeal teeth are well developed and consist of four sets of small conical teeth (Figure 3.33B & C).

The pharynx is slightly capacious, expanded because of the bilateral compression of the body. The gill rakers are short, pointed and diverge (Figure 33.3A).

The body cavity is compressed but large. The oesophagus is long and widens slightly posteriorly in the cardiac region of the stomach. The latter is medium sized and V-shaped, its cardiac part is long, being approximately twice as long as the pyloric part. The caecum is rudimentary and pointed. The stomach which lies in the right side of the body cavity, because of the long oesophagus, can extend almost to the posterior border of this cavity.

There are four pyloric caeca, two of which are short and two long, which are rather thick and round and open into the fore-end of the duodenum. The intestine is long (2.5-3 times the body length). It is spirally coiled and has four loops; the first two in a clockwise direction, and the other two anticlockwise. Two centimetres anterior to the anus, the intestine is slightly dilated and apparently this region corresponds to the rectum. The anus is displaced forwards in such a way that part of the body cavity lies posterior to it (Figure 3.32B & C).

Stomach contents show that fish of about 14 cm in total body length feed chiefly on diatoms and young sea-weeds, while older specimens feed mainly on sea-weeds and to a lesser extent on copepods which are believed to be ingested among the sea-weeds.

3.3.4. Omnivorous fish

3.3.4.1. *Therapon jarbua* (Forsk) (Figure 3.34A)

This species lives in shore waters near muddy bottoms.

The mouth is of a moderate size. The upper jaw is slightly longer than the lower one. The teeth in the jaws are small, conical, and set in many rows on the anterior region of both jaws. The teeth of the outer rows are slightly larger than the rest. The buccal cavity is wide laterally. Vomerine and palatine teeth are absent. The tongue is moderately large, thin, free anteriorly, toothless and a few chromatophores are present on its surface. There is a well developed, pharyngeal valve which limits the beginning of the wide pharyngeal cavity (Figure 3.35B & C).

The gill rakers are short, broad and thick and covered with minute spines. The pharyngeal teeth are small, conical and arranged in several rows (Figure 3.35A). The pharyngeal mucous membrane is markedly folded longitudinally. These folds extend backwards into the oesophagus.

The peritoneal cavity is moderately large. The oesophagus is short, wide and has a thick muscular wall. The stomach is of the caecal type having a voluminous caecum, which, when full of food, may occupy the greater part of the body cavity, on account of its high elasticity. The conical pyloric portion is markedly small as compared with the total size of the stomach. The intestine is moderately long, broad and forms one and one half siphonal loops and its wall is rather thick. The rectum is poorly differentiated externally from the ileum. There are 12 long slender pyloric caeca (Figure 3.34B & C).

This fish is a typical omnivore as it scavenges all sorts of food. It feeds on animals near muddy bottoms where sea-weeds grow.

3.4. Discussion

Complete investigations of food habits and preferences should involve consideration of the functional morphology of the skull, jaws and alimentary tract. From such observations valuable inferences about the nature of dietary items and the limitations of feeding habits can emerge.

Form and position of mouth, dentition in jaws, and bucco-pharyngeal region, and conformation of the gill-rakers are all correlated with food habits in fishes. Thus, Das and Moitra (1956) studied alimentary systems of some Indian fish and found that :

(i) Herbivorous fish lack teeth and possess fine gill-rakers that can sieve phytoplankton from water; they also lack a true stomach (i.e. a highly muscular, acid secreting, distendible, anterior section of the alimentary canal) but do possess a long, coiled, thin-walled intestine.

(ii) Carnivorous fish have well-developed teeth to seize, hold and tear prey organisms, and gill-rakers modified to retain, rasp and crush them. They also possess a true, flask-like stomach, and the intestine is short, thick-walled, and elastic.

(iii) Omnivorous fish have alimentary systems that are intermediate in form between those of herbivorous and carnivorous fish.

Among cyprinids, the common carp *Cyprinus carpio* ingests food by suction with its highly protrusible, subterminal, toothless mouth (Gosline, 1973). This species is an omnivorous, euryphagous, opportunistic feeder, in diverse ecological regions. In place of teeth and stomach there is a well developed pharyngeal masticatory apparatus (Sibbing, 1982). *Therapon jarbua* which is the only omnivorous fish represented in the present study also have a protrusible mouth, though less developed than in *Cyprinus carpio*. In the grass carp *Ctenopharyngodon idella* the pharyngeal teeth interdigitate from left and right sides (which is not the case in the common carp); this reflects one type of adaptation to particular trophic conditions, by means of which grass carp are able to rip pieces from vascular plants by gripping them between their pharyngeal teeth and following this with strong lateral body movements (Cross, 1969).

A relationship also exists between gill-raker morphology and fish trophic status. It is generally assumed that gill-rakers function as a sieve in straining food items from the water, so that we might assume correlations between gill-raker numbers, the spaces between them, their lengths, and fish food habits. There are, however, some exceptions. Galbraith (1967) found that the size of smallest prey did not conform to minimum separation between gill-rakers in rainbow trout, and Kliewer (1970) also found that there was no significant correlation between width of gill-raker separation and ingested prey in lake whitefish *Coregonus clupeaformis*, as also demonstrated by Seghers (1975) in laboratory experiments. Studies such as these indicate that there may not be a close relationship between this spacing and size of food. However, Wright *et al.* (1983) have cautioned against simple attempts to relate gill-raker separation and prey size, suggesting that the degree of buccal cavity expansion must be considered in evaluating the effectivness of gill-raker spacing. Indeed, the general relationship appears dificult to quantify.

ABBREVIATIONS

A	Anus
A.B.	Air bladder
B	Barbels
B.D.	Bile Duct
C.A.	Cardium
C.S.	Cardiac Stomach
F.B.C.	Floor of Buccal Cavity
F.G.R.	Floor of Gill Rakers
Fo.F.B.C.	Folds of Floor of Buccal Cavity
Fo.R.B.C	Folds of Roof of Buccal Cavity
G.A.	Gill Arch
G.B.	Gall Bladder
G.F.	Gill Filament
Go	Gonads
G.R.	Gill Rakers
INT	Intestine
I.RC.	Ileo-Rectal
J.T.	Jaw Teeth
L	Liver
L.INT.B.	Left Intestinal Bulb
L.J.	Lower Jaw
L.L.	Lower Lip
L.PH.CRT.	Lower Pharyngeal Crushing Teeth
L.PH.PA.	Lower Pharyngeal Pads
L.PH.T.	Lower Pharyngeal Teeth
M.T.	Maxillary Teeth

OE	Oesophagus
OE.R.	Oesophageal Roof
P.C.	Pyloric Caecae
PH.PA.	Pharyngeal Pads
PH.T.	Pharyngeal Teeth
PH.VA.	Pharyngeal Valve
P.S.	Pyloric Stomach
R	Rectum
R.B.C.	Roof of Buccal Cavity
R.INT.B.	Right Intestinal Bulb
TO	Tongue
U.J.	Upper Jaw
U.P.	Upper Lip
U.PH.CR.T.	Upper Pharyngeal Crushing Teeth
U.PH.PA.	Upper Pharyngeal Pads
U.PH.T.	Upper Pharyngeal Teeth
V.T.	Vomerine Teeth
VI.T.	Villiform Teeth

Figure 3.1:

Plectrothynchus schotaf, gut morphology.

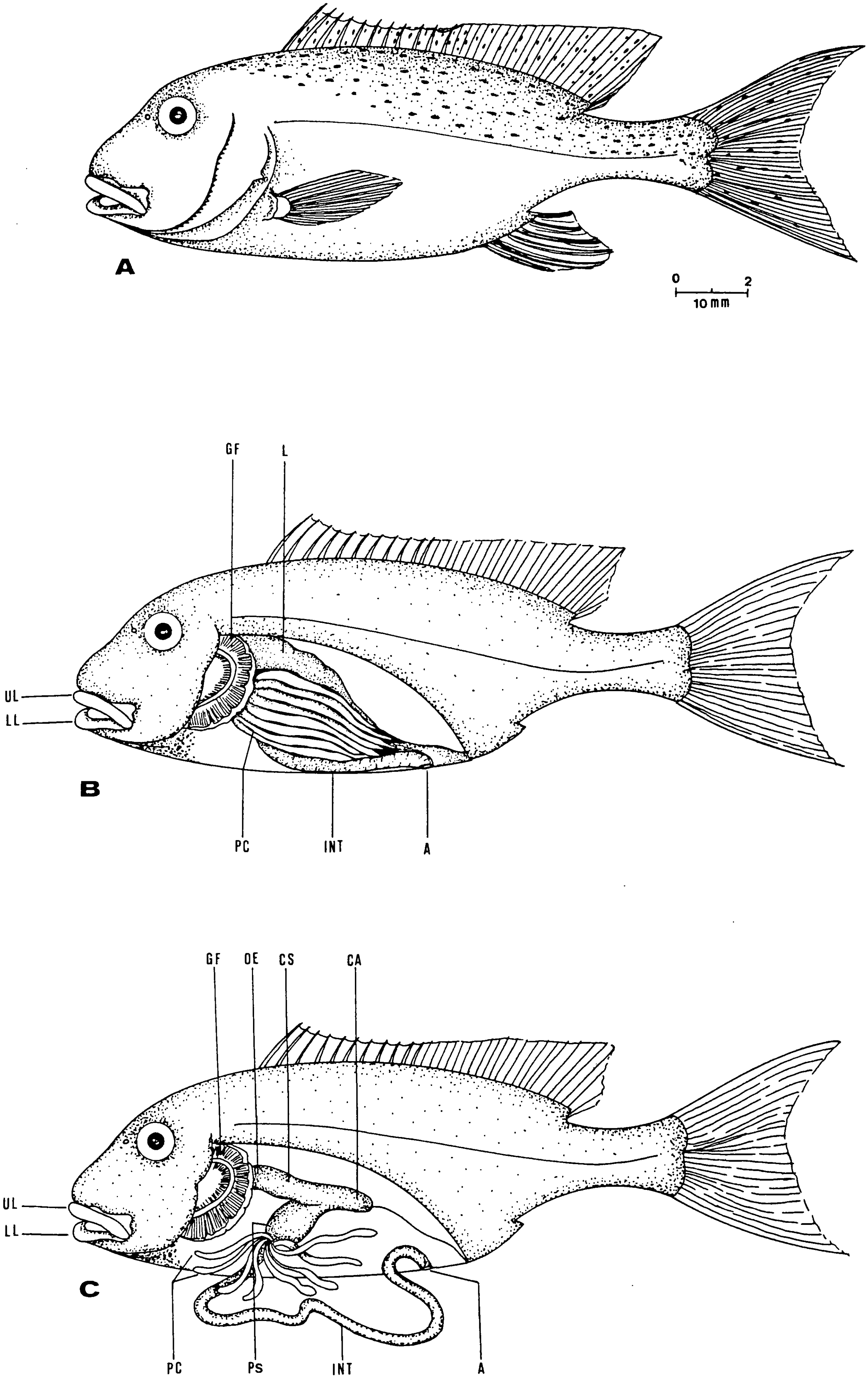

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Figure 3.2:

Plectrorhynchus schotaf, gill-rakers and mouth.

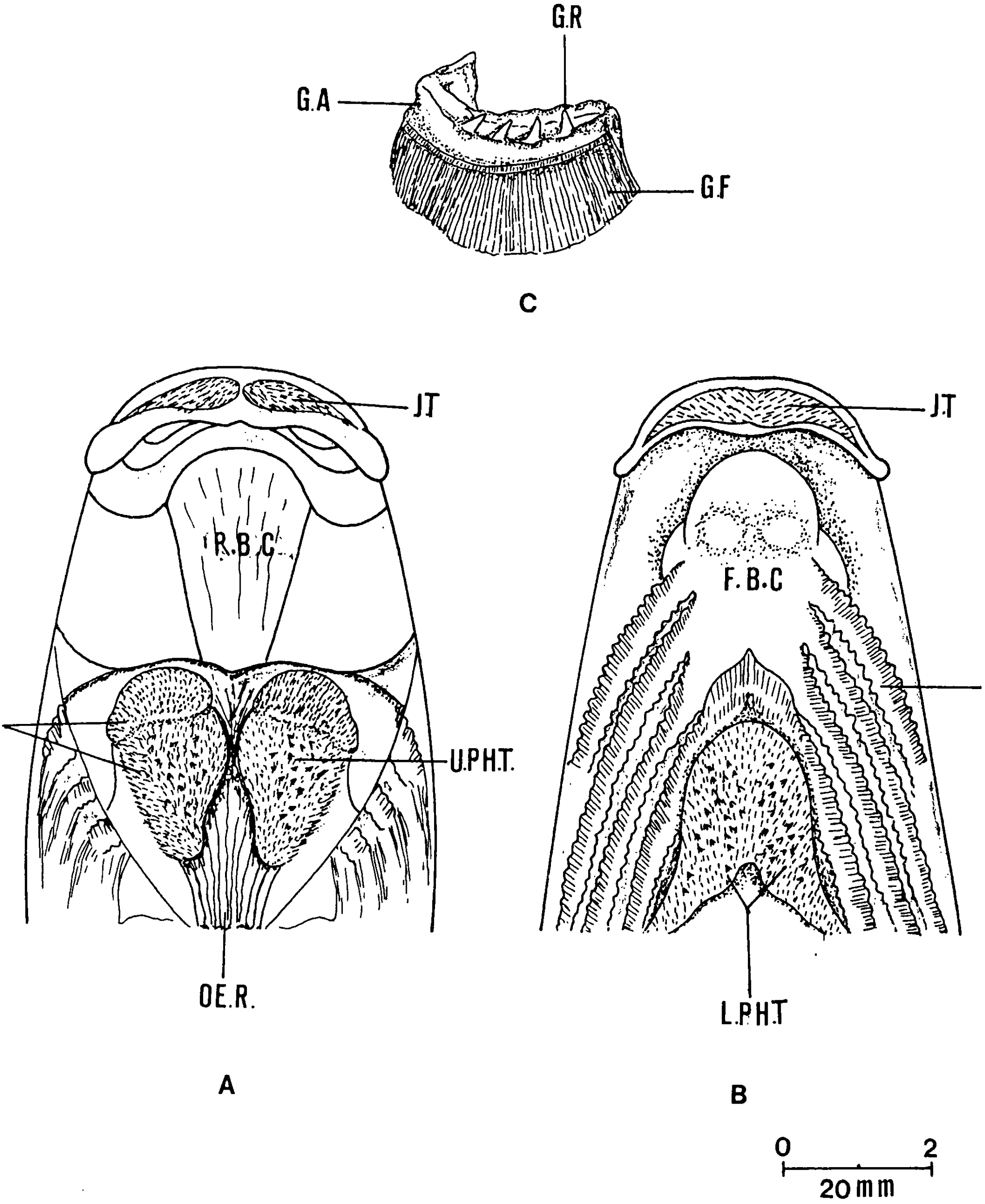
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Figure 3.3:

Platycephalus tuberculatus, gill-rakers and mouth.

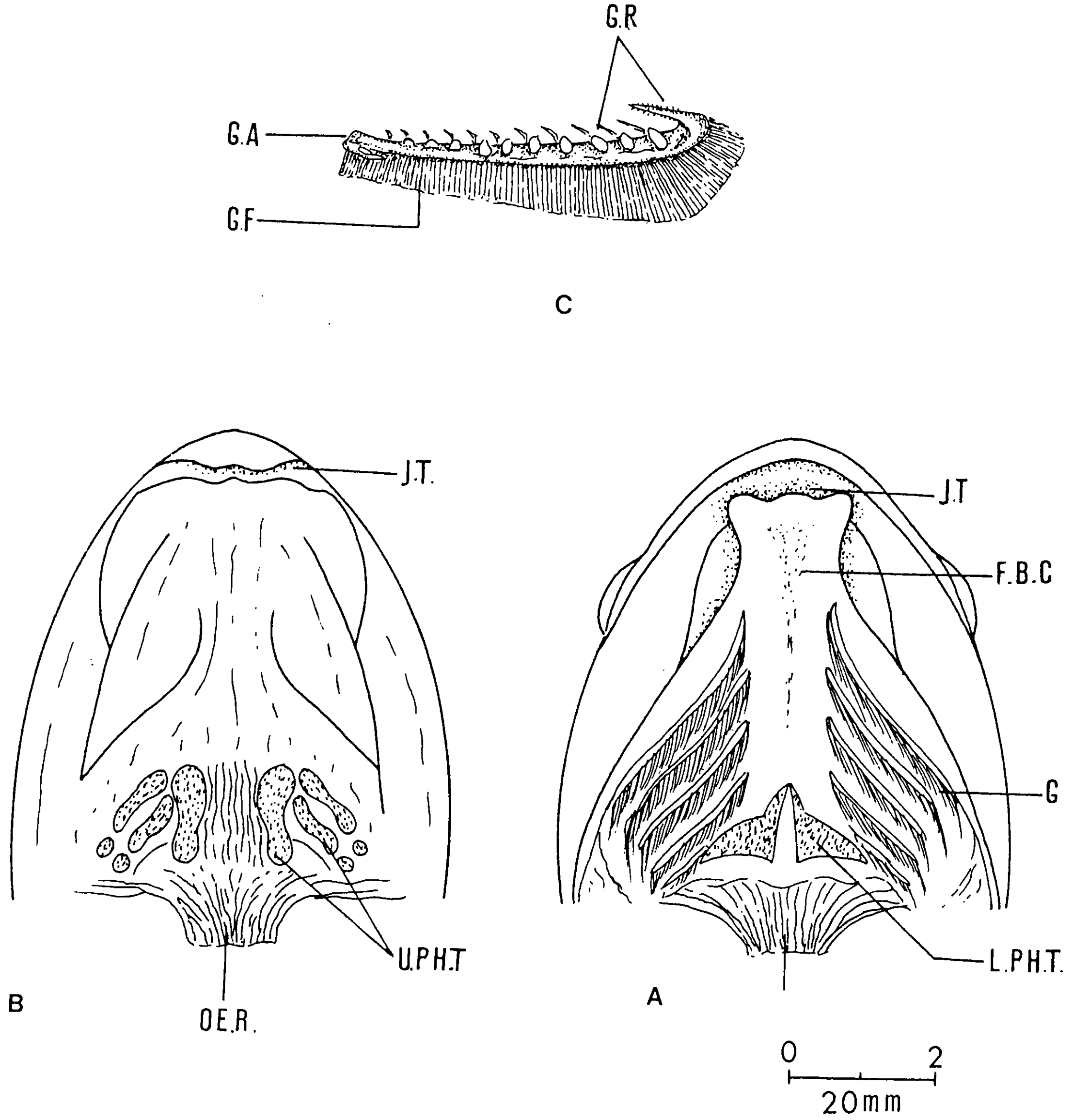
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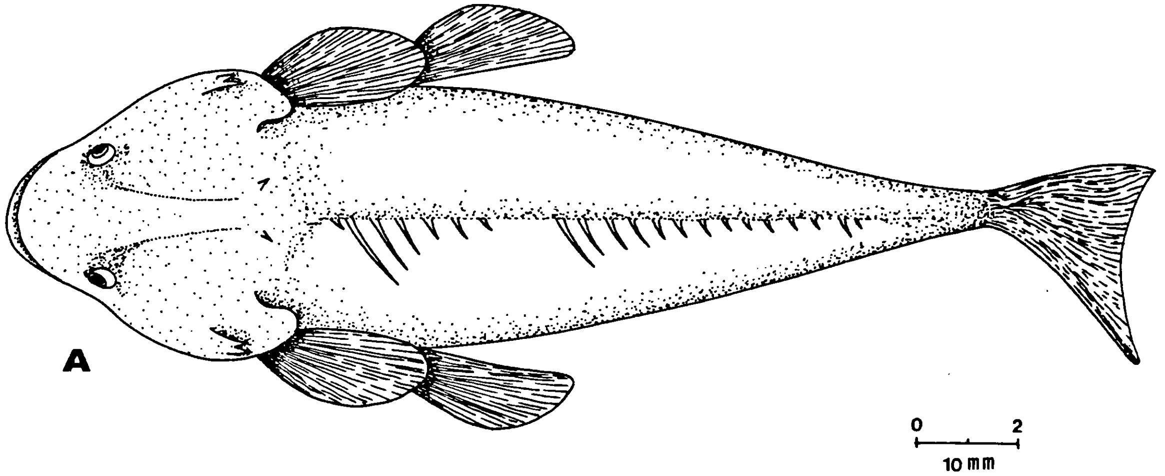
Figure 3.4:

Platycephalus tuberculatus, gut morphology.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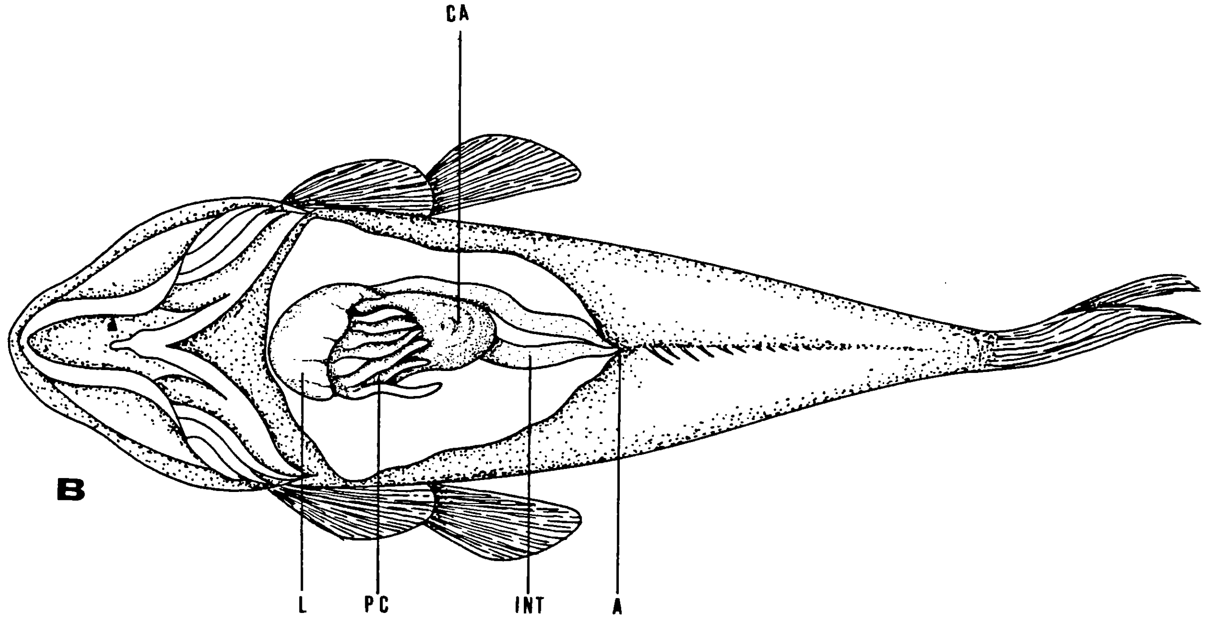
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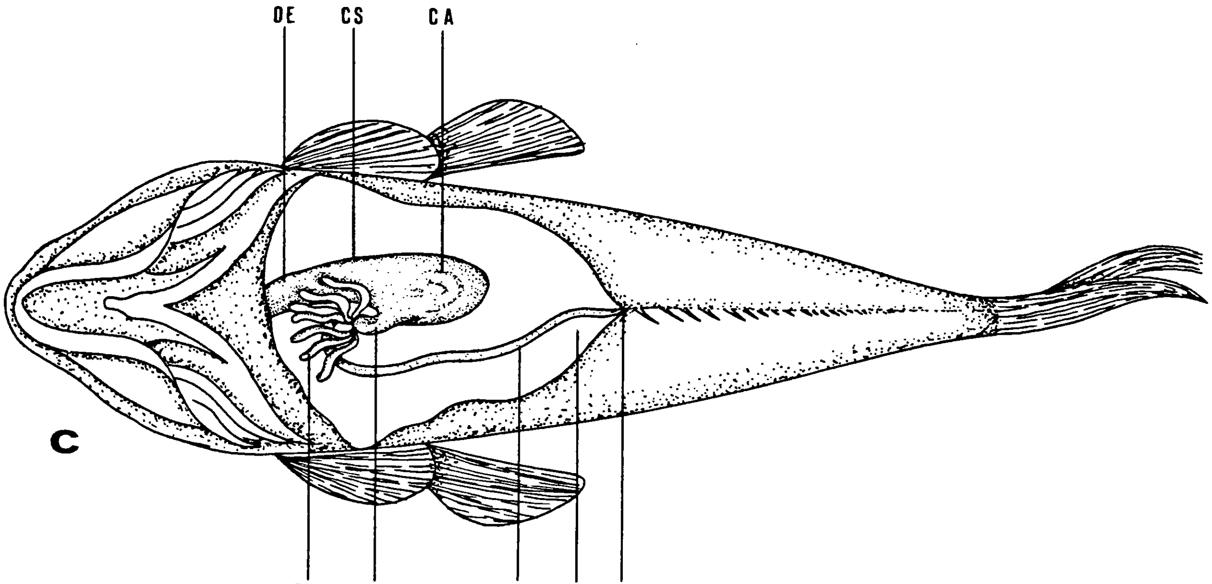
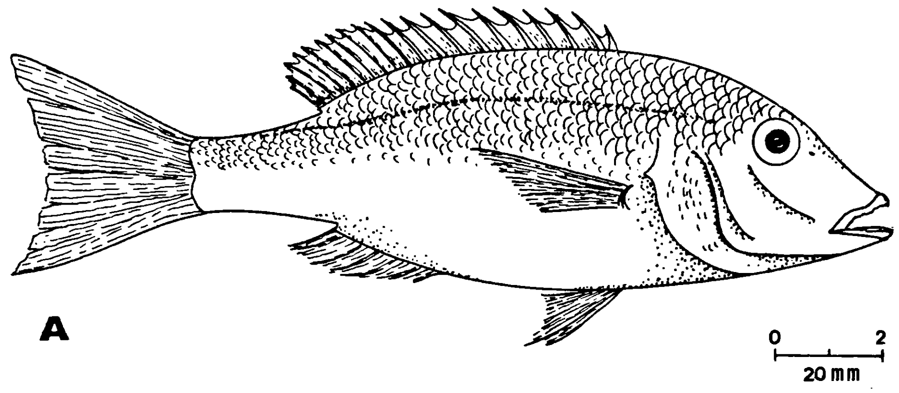
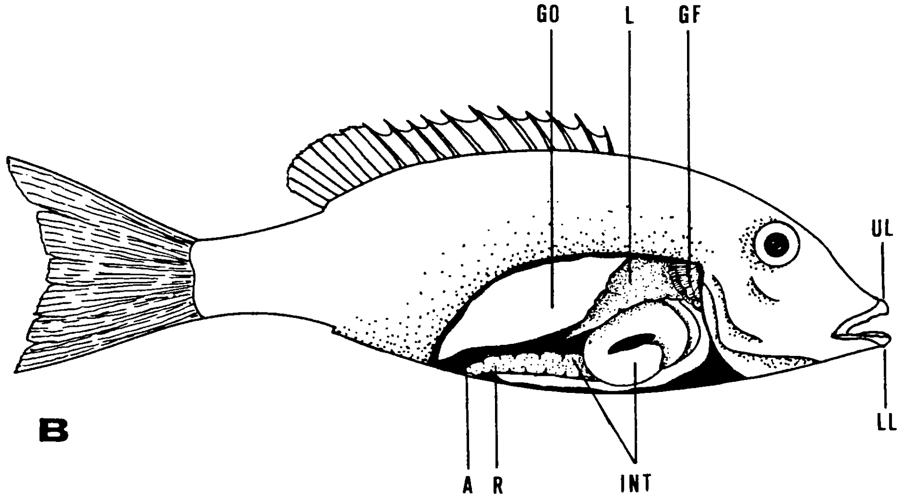

OE
CS
CA
C
PC
PS
IN
R
A

Figure 3.5:

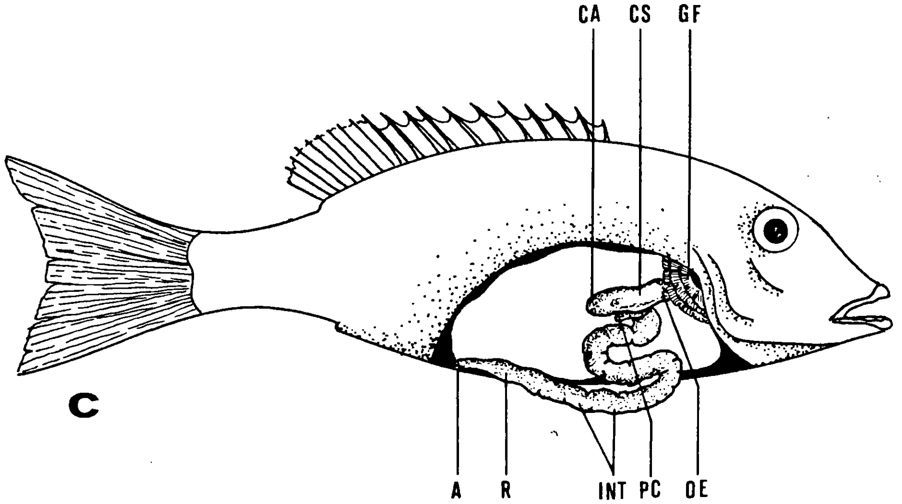
Lethrinus lentjan, body and gut morphology.



A



B



C

Figure 3.6:

Lethrinus lentjan, gill-rakers and mouth.

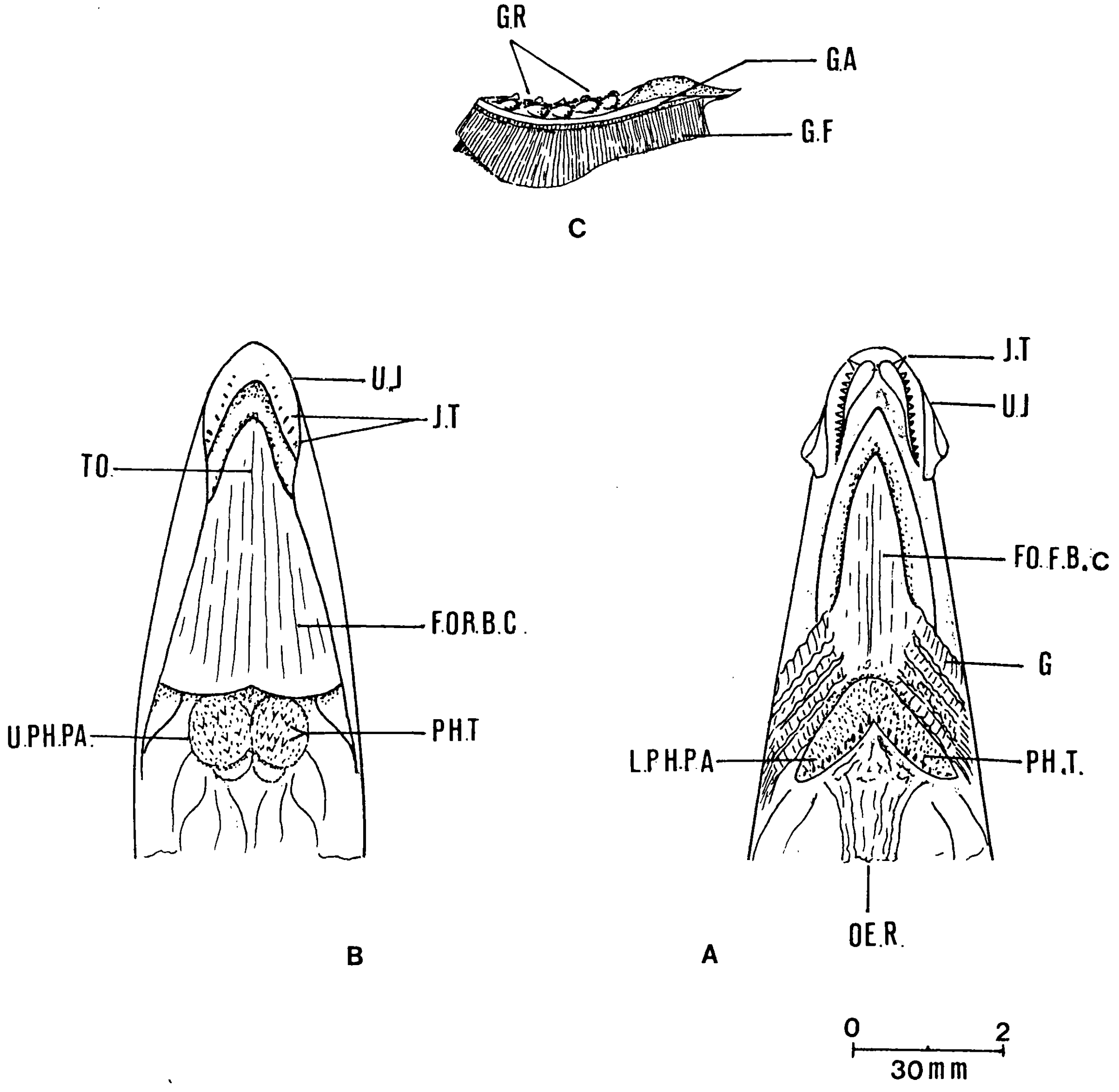
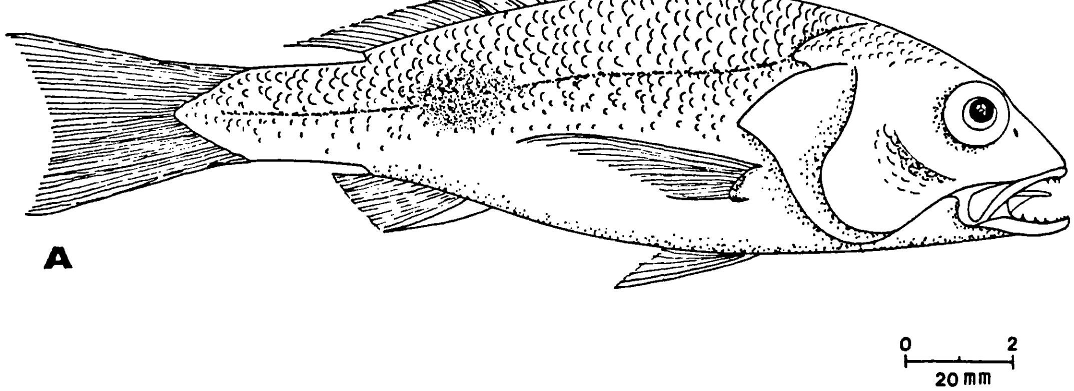
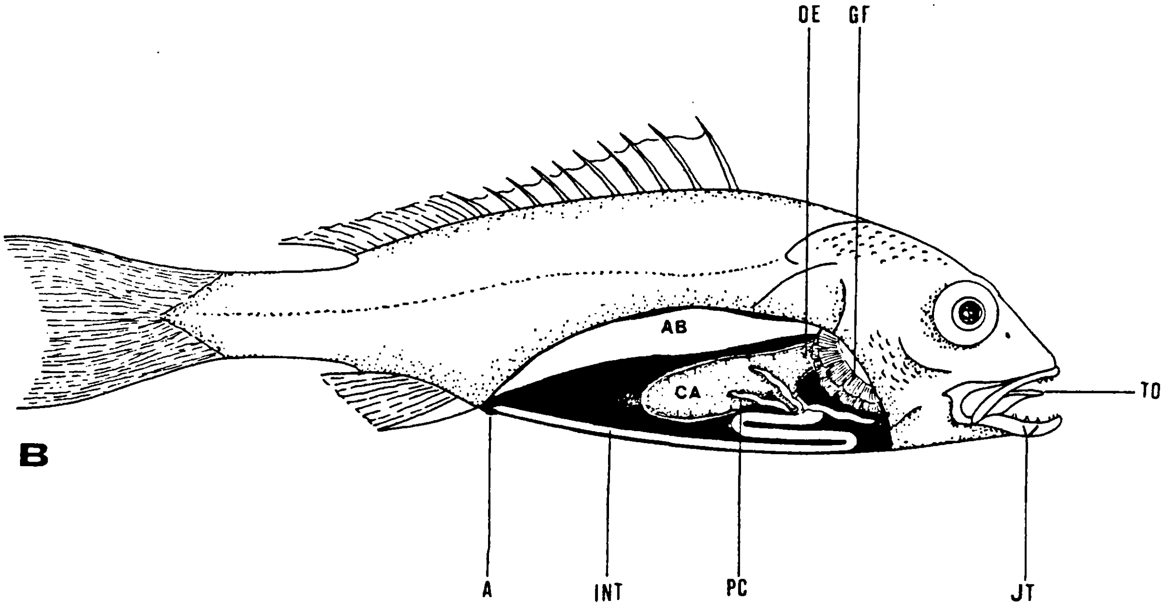

G.R
G.A
G.F
C
U.J
J.T
T.O.
F.O.R.B.C.
U.PH.PA.
PH.T
B
J.T
U.J
F.O.F.B.C
G
L.P.H.P.A
PH.T.
OE.R.
A
0
2
30mm

Figure 3.7:

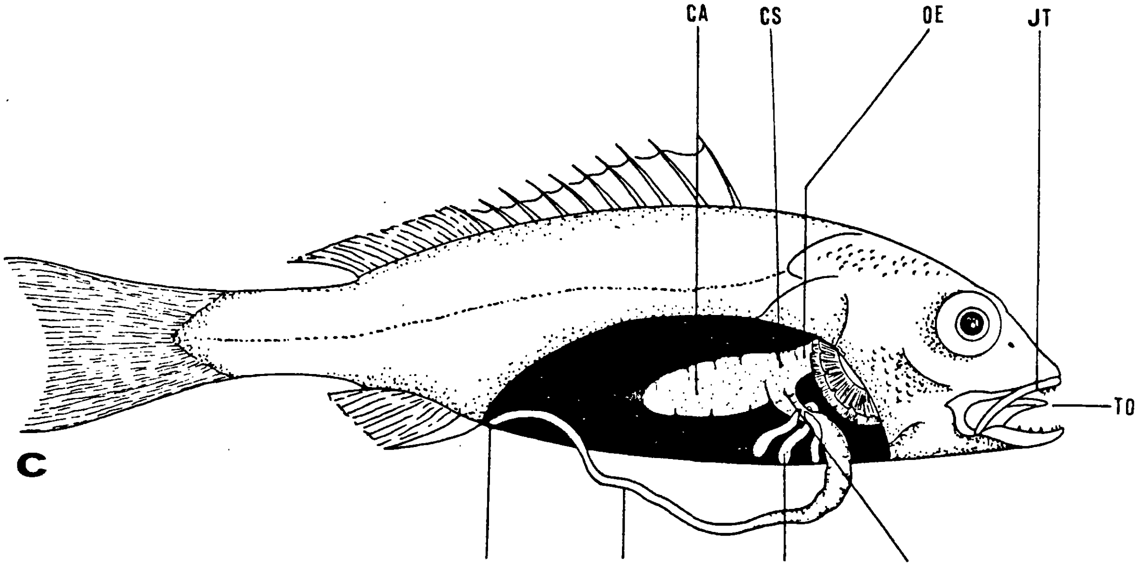
Lutjanus flaviflamma, body and gut morphology.



A



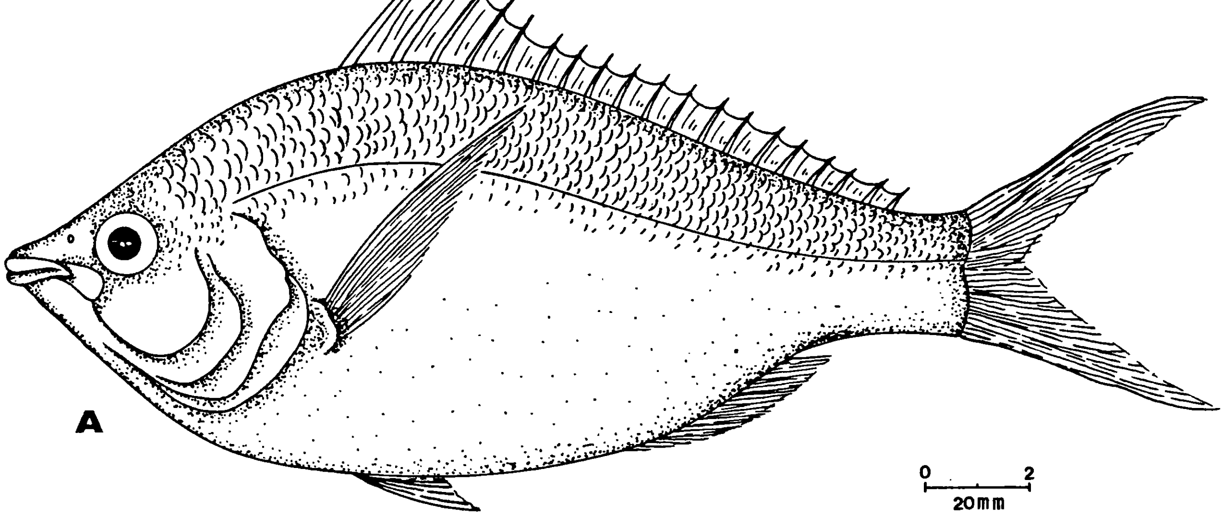
B



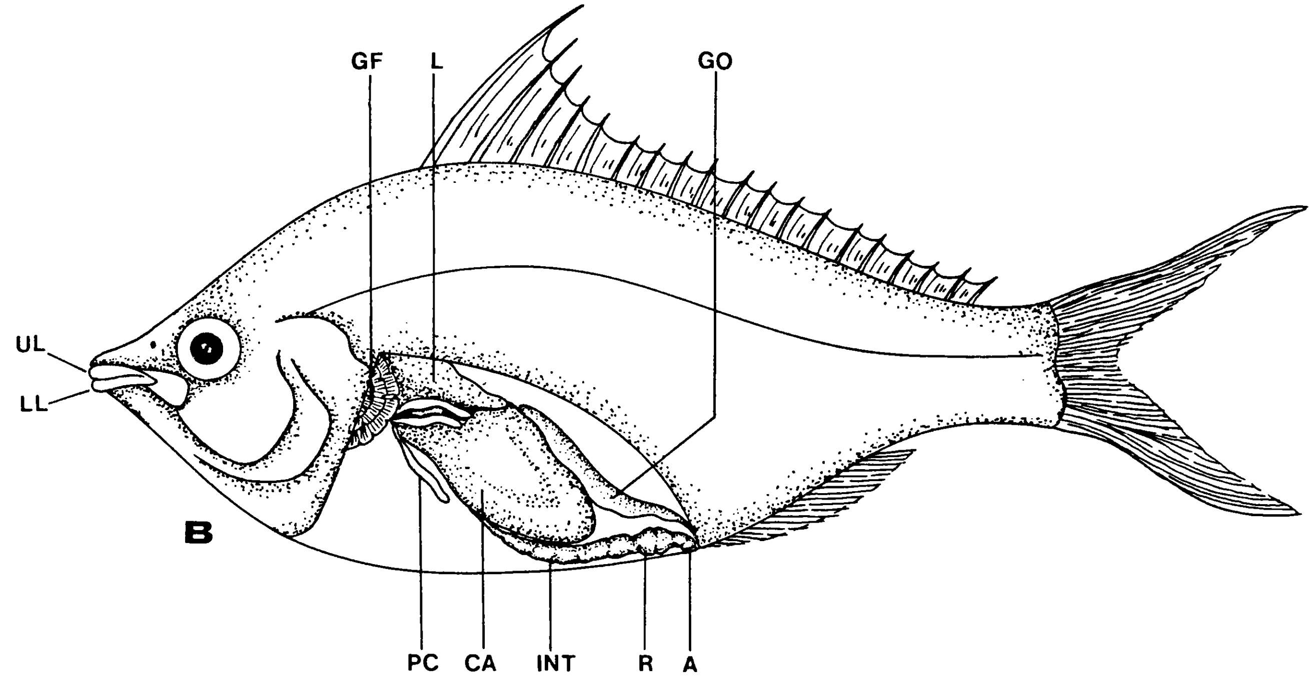
C

Figure 3.8:

Gerres oyena, body and gut morphology.



A



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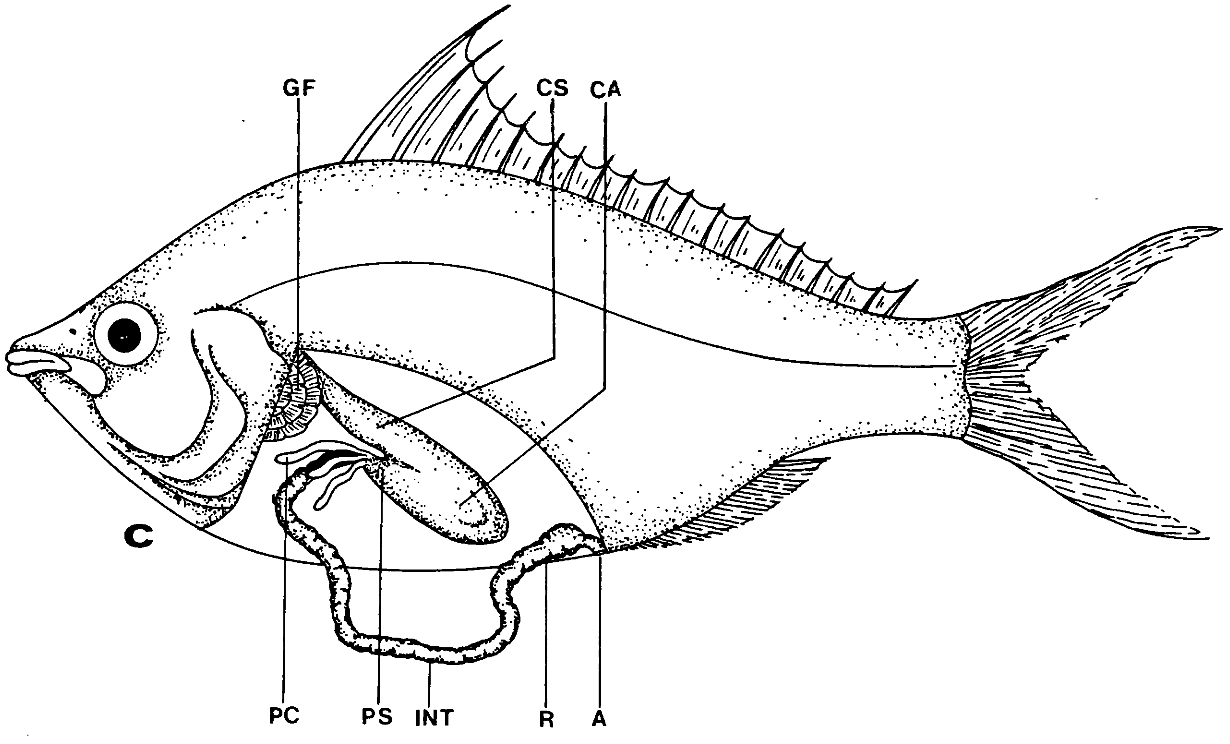


C

Figure 3.9:

Lutianus bohar, body and gut morphology.

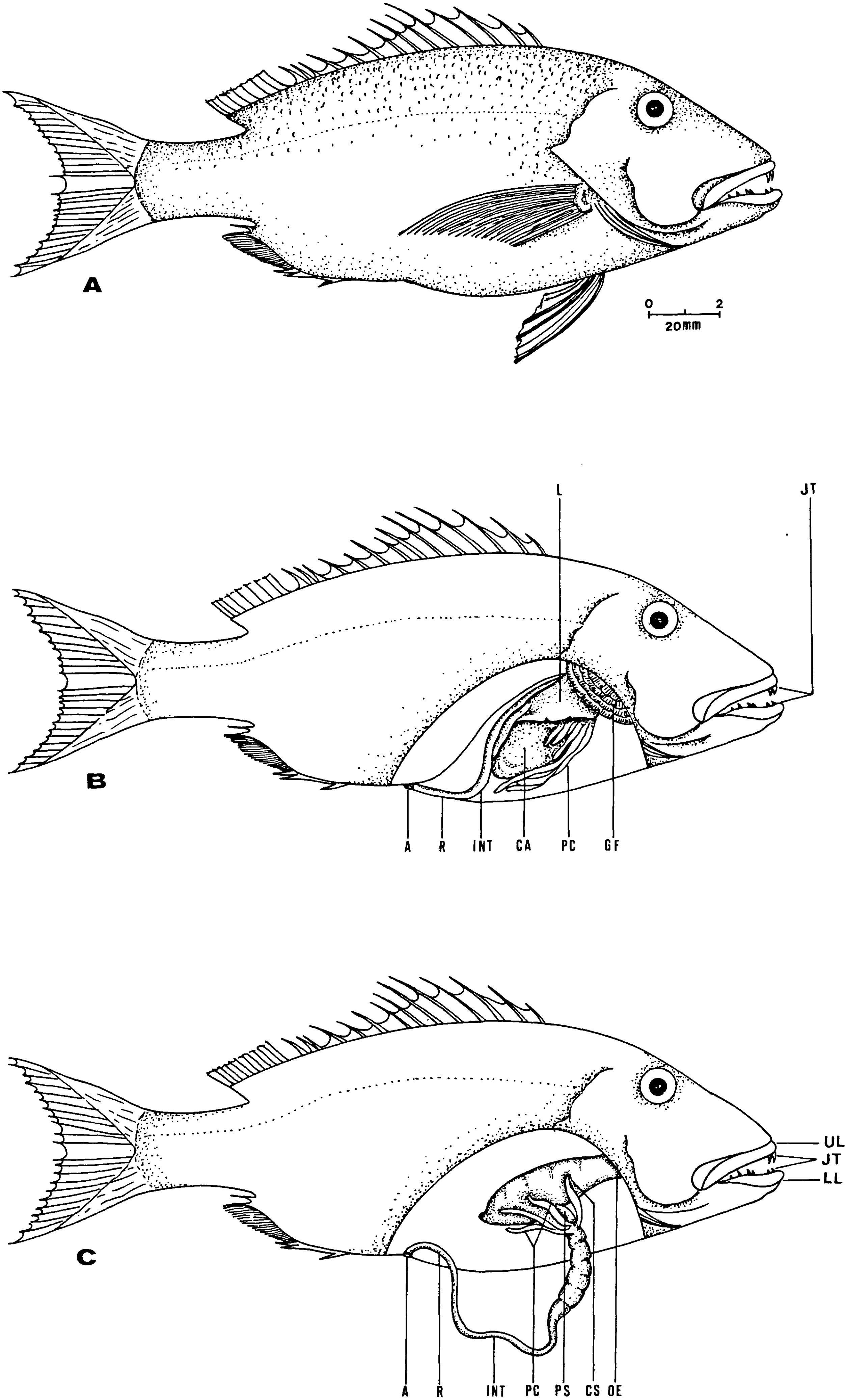

A
0
2
20mm
B
L
JT
A
R
INT
CA
PC
GF
C
UL
JT
LL
A
R
INT
PC
PS
CS
OE

Figure 3.10:

Lutianus bohar, gill-rakers and mouth.

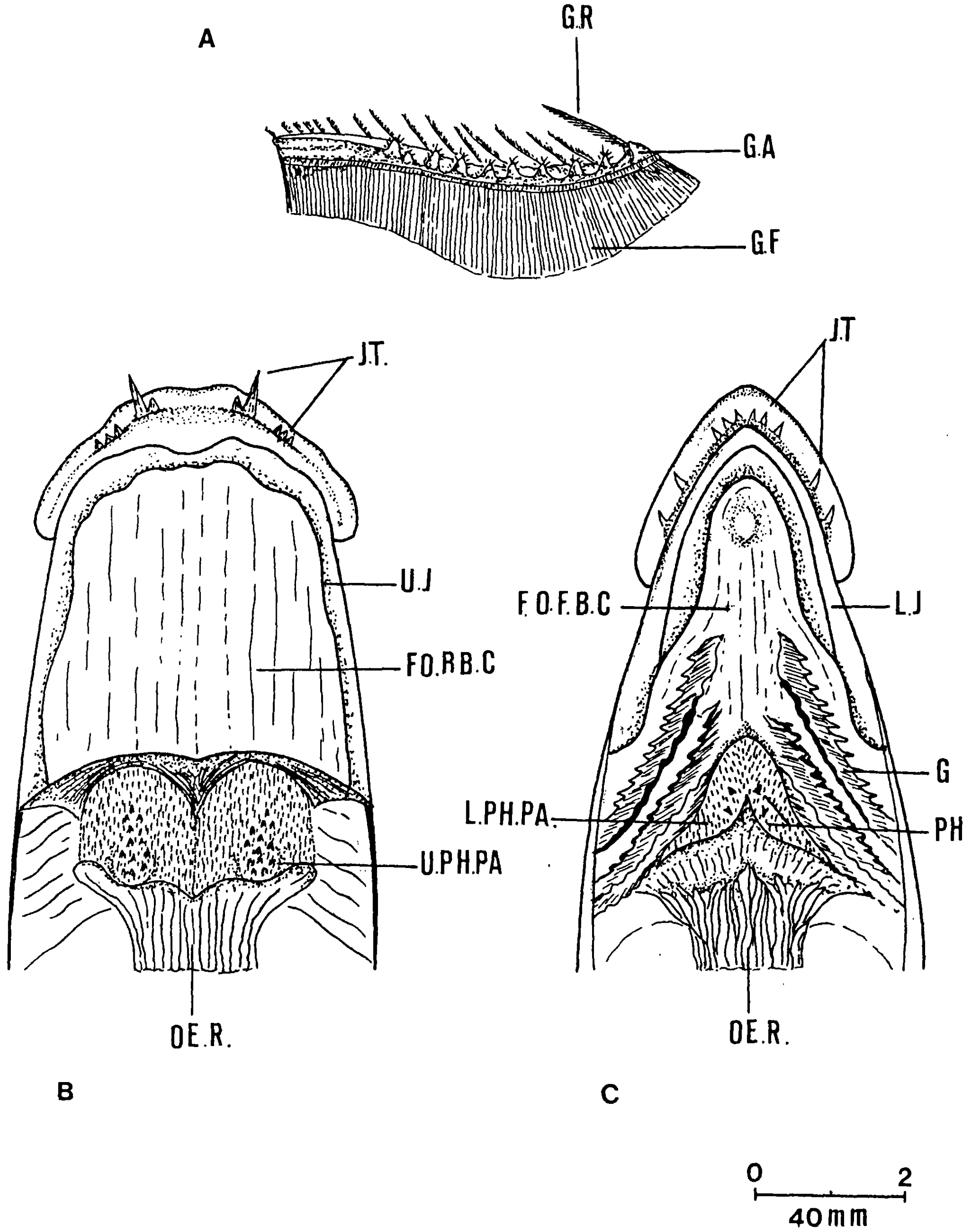

A
G.R
G.A
G.F
J.T.
J.T
U.J
F.O.F.B.C
L.J
FO.RB.C
G
L.PH.PA.
PH.T
U.PH.PA
OE.R.
OE.R.
B
C
0
2
40mm

Figure 3.11:

Schomberomorus lysan, body and gut morphology.

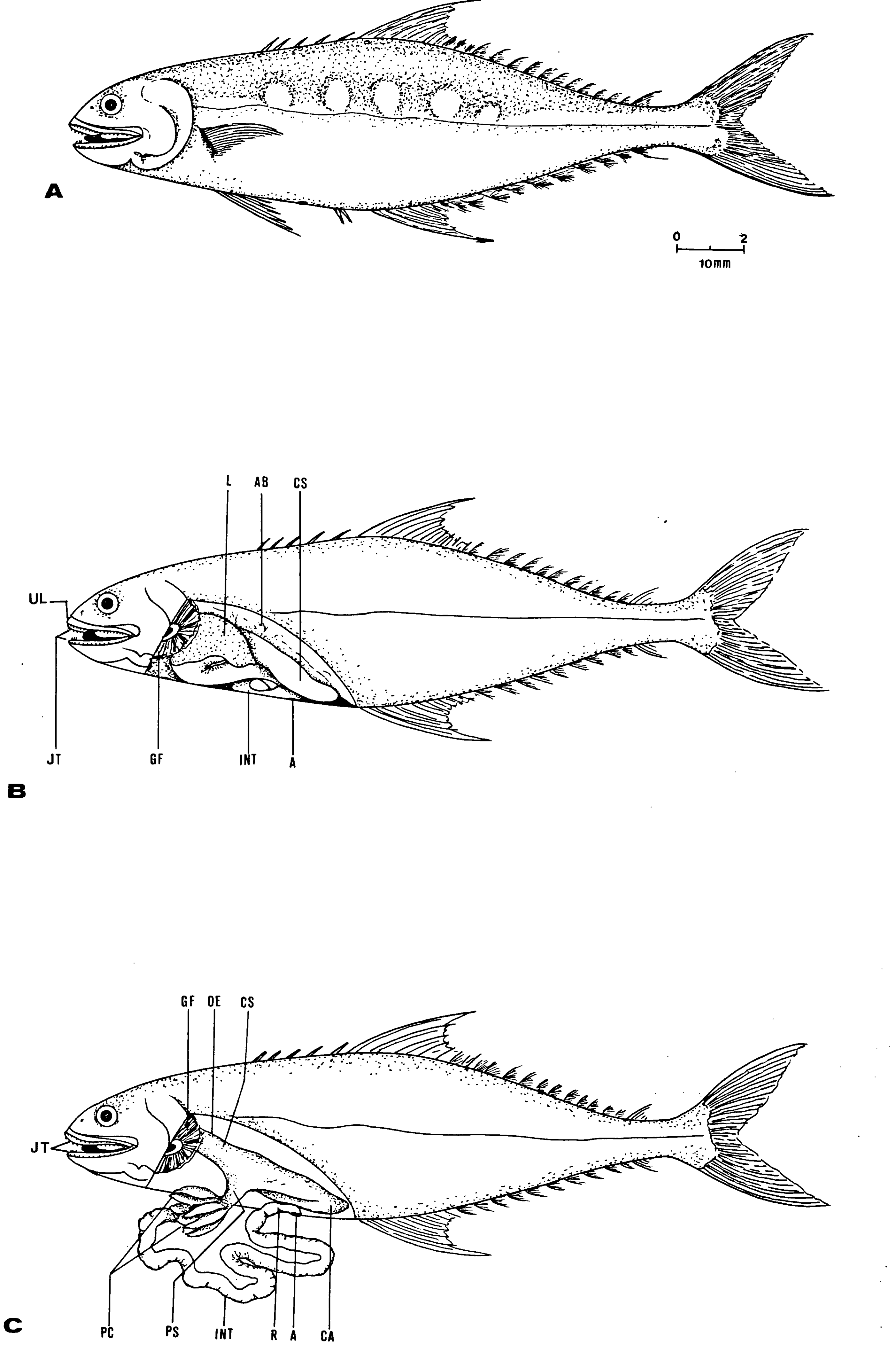

A
0
2
10mm
L
AB
CS
UL
JT
GF
INT
A
B
GF
OE
CS
JT
PC
PS
INT
R
A
CA
C

Figure 3.12:

Schomberomorus lysan, gill-rakers and mouth.

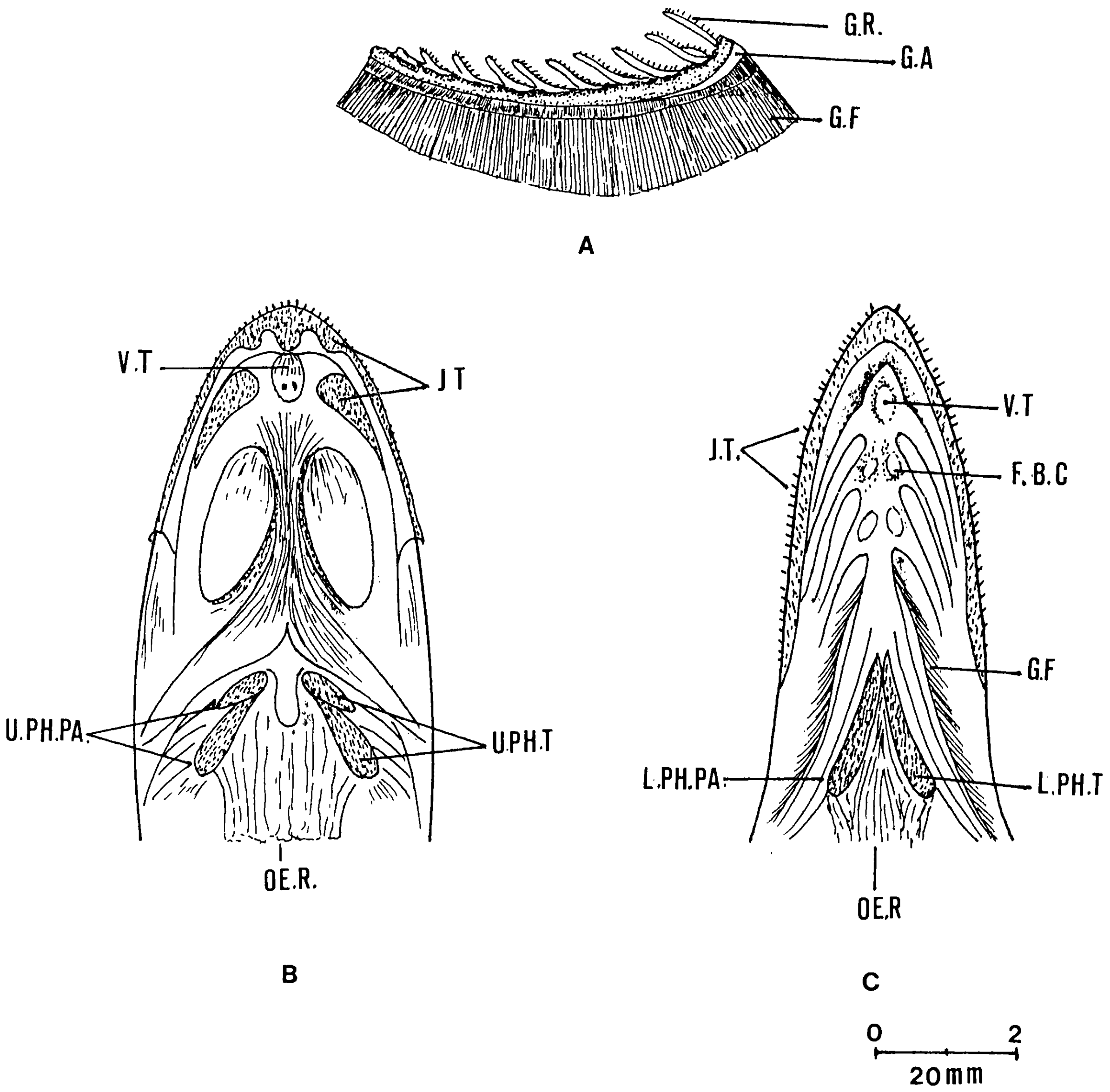
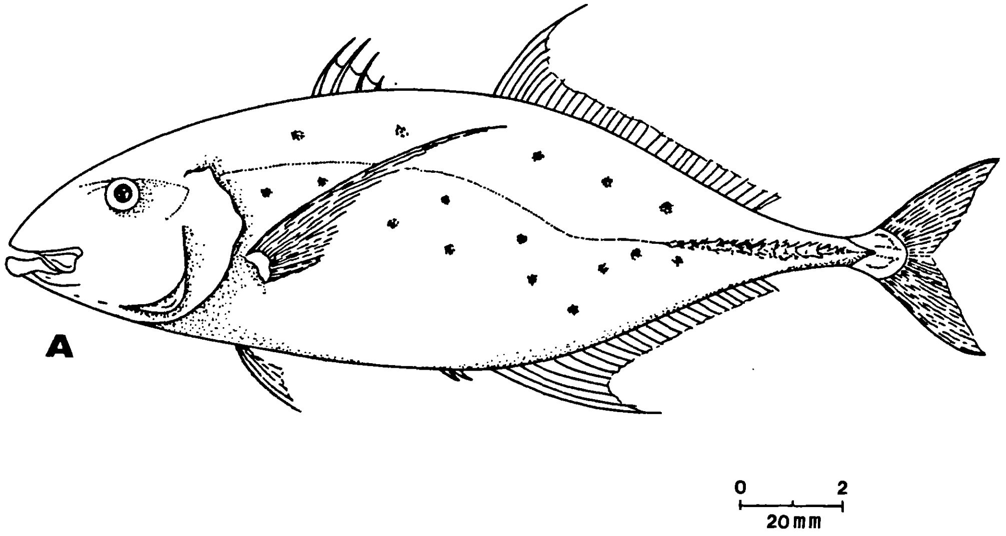
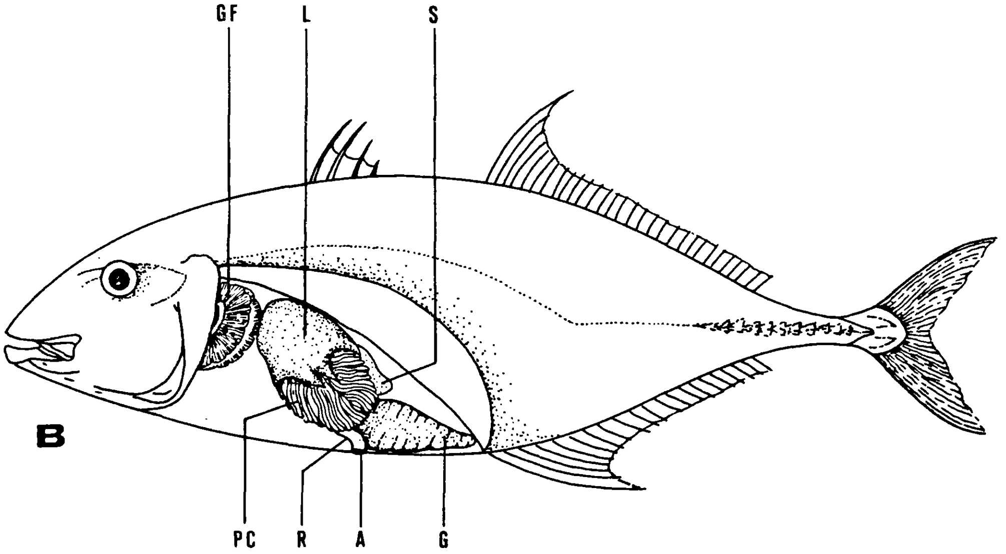

G.R.
G.A
G.F
A
V.T
J T
U.PH.PA
U.PH.T
OE.R.
B
V.T
J.T.
F.B.C
G.F
L.PH.PA
L.PH.T
OE.R
C
0
2
20mm

Figure 3.13:

Carangoid _bajad_, body and gut morphology.


A
0
2
20 mm


GF
L
S
B
PC
R
A
G

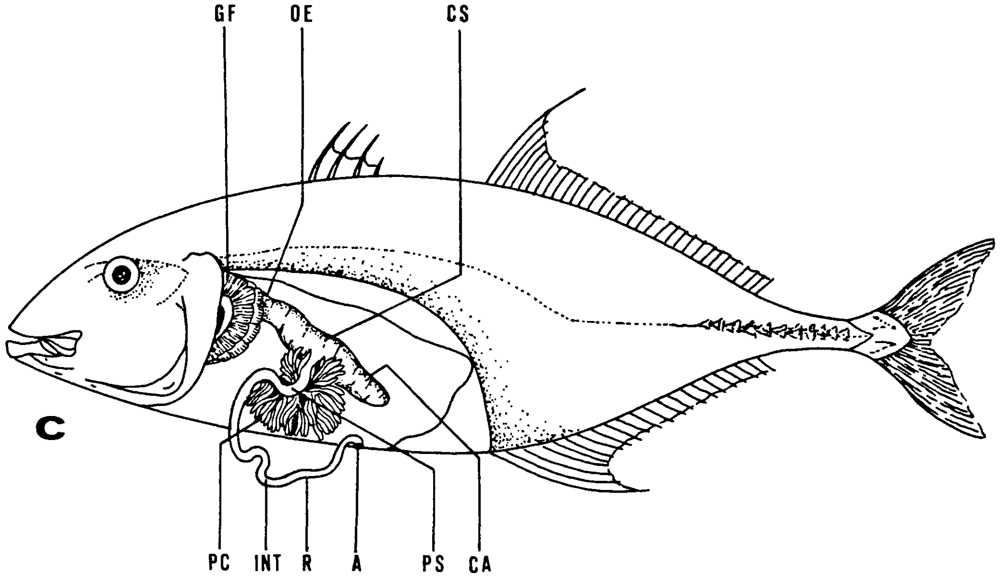

GF
OE
CS
C
PC
INT
R
A
PS
CA

Figure 3.14:

Aethaloperca rogaa, body and gut morphology.

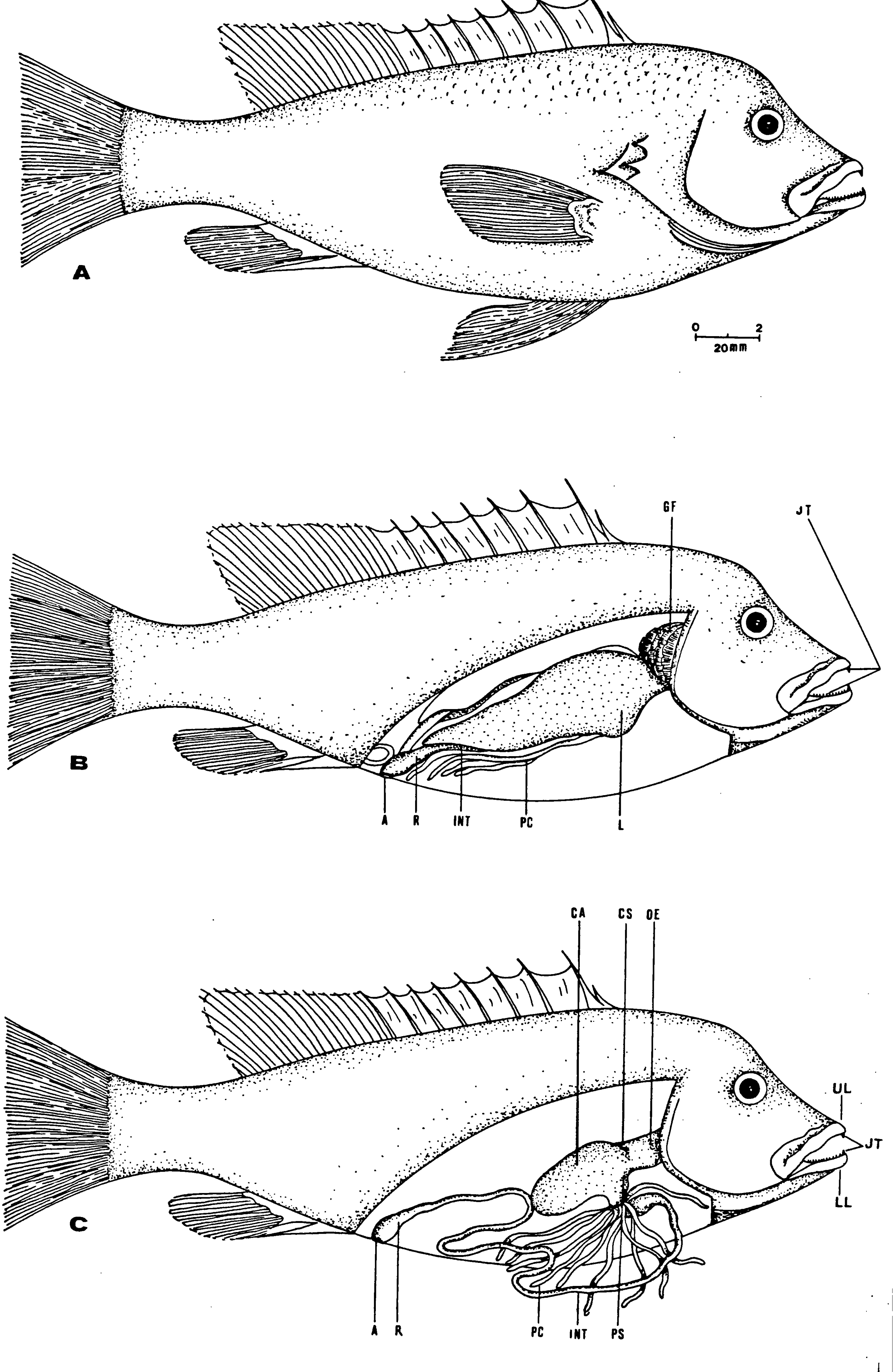

A
0
2
20mm
GF
JT
B
A
R
INT
PC
L
CA
CS
OE
UL
JT
LL
C
A
R
PC
INT
PS

Figure 3.15:

Aethaloperca rogaa, gill-rakers and mouth.

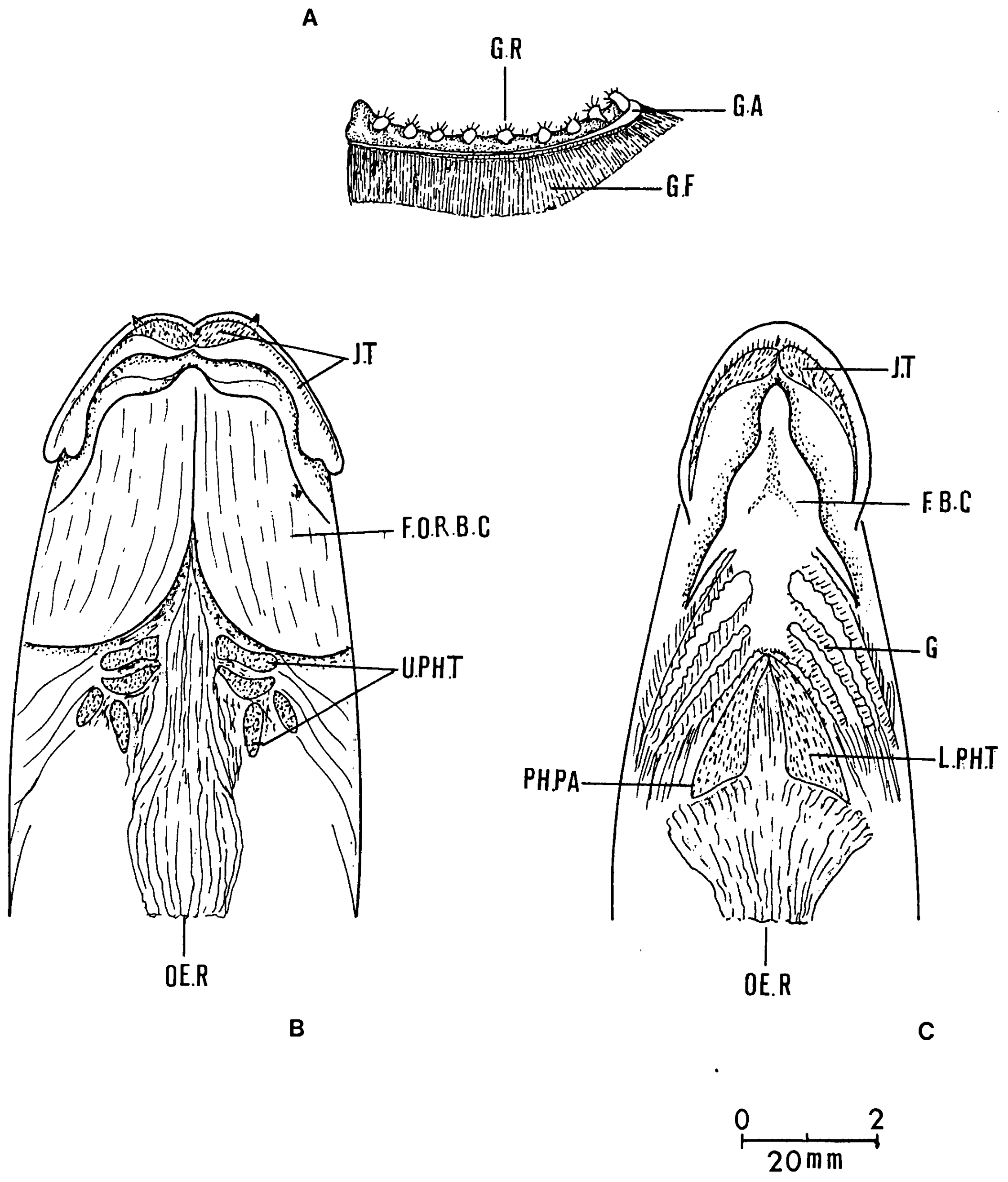
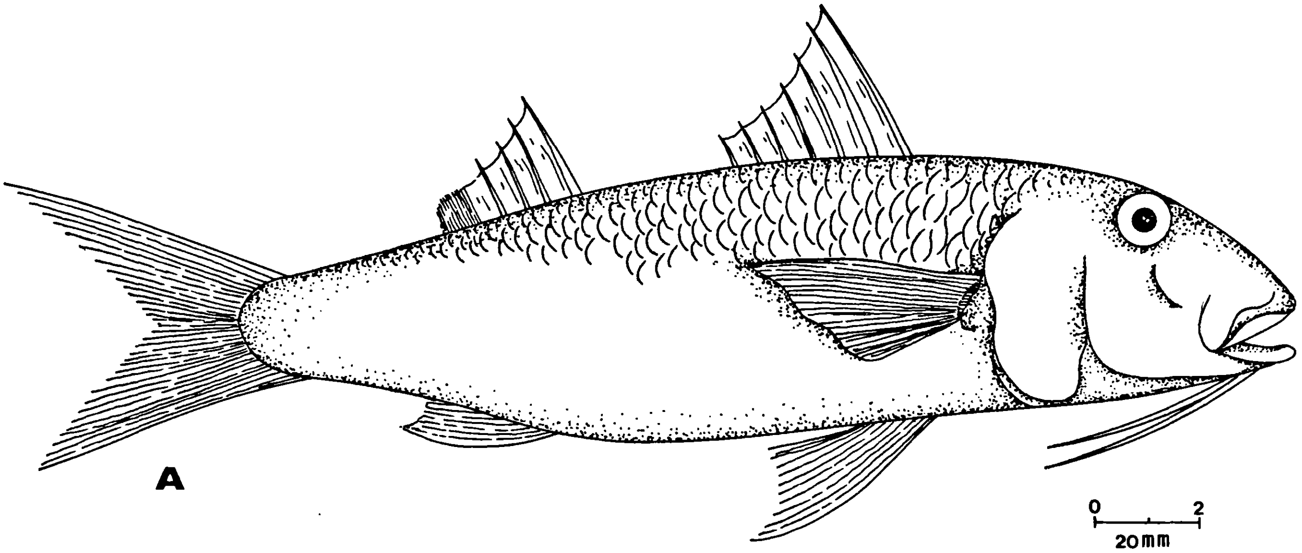
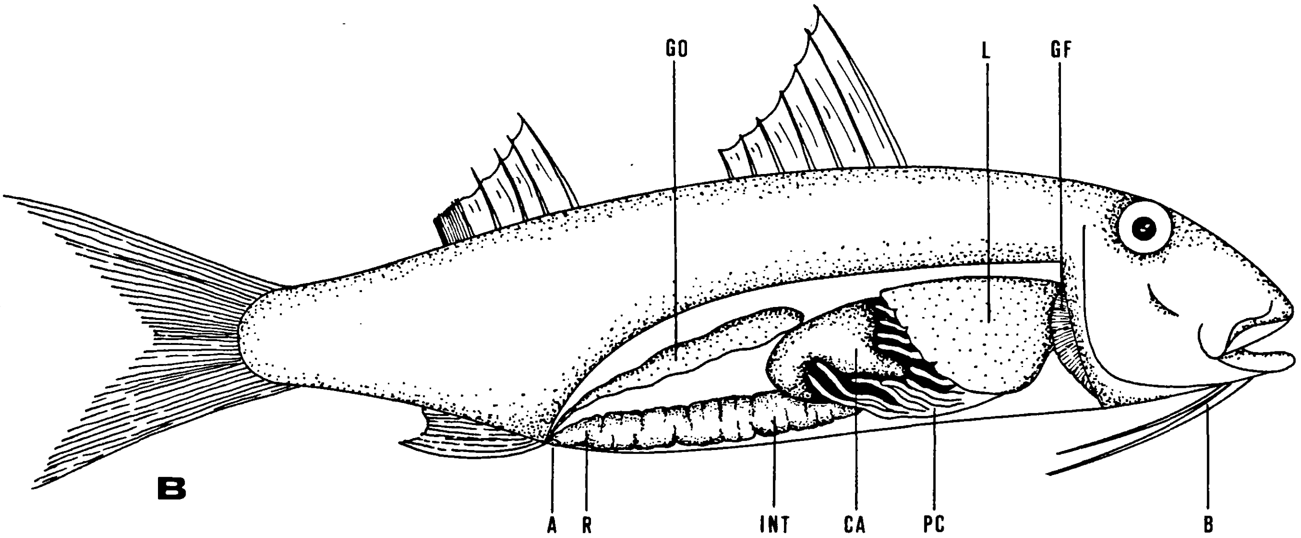

A
G.R
G.A
G.F
J.T
F.O.R.B.C
U.PH.T
OE.R
B
J.T
F.B.C
G
L.PH.T
PH.PA
OE.R
C
0
2
20mm

Figure 3.16:

Mulloides flavolineatus, body and gut morphology.


A
0
2
20mm


GO
L
GF
B
A
R
INT
CA
PC
B

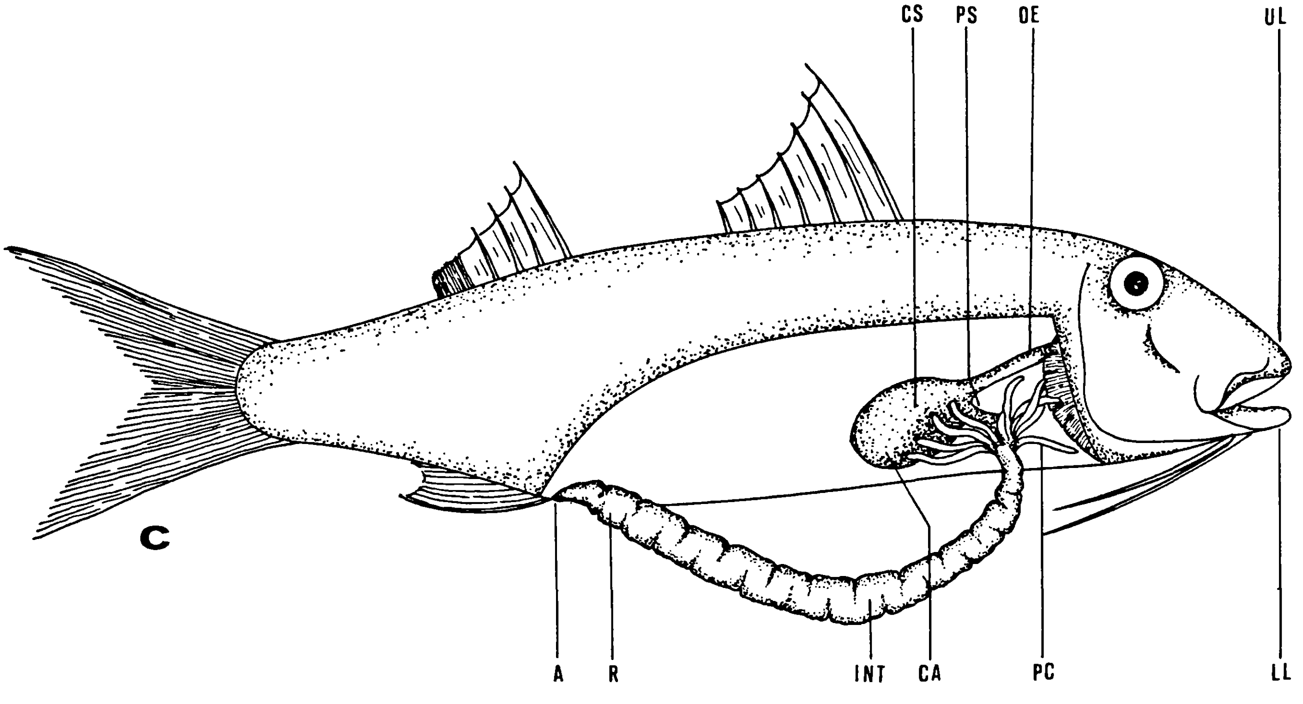

CS
PS
OE
UL
C
A
R
INT
CA
PC
LL

Figure 3.17:

Mulloides flavolineatus, gill-rakers and mouth.

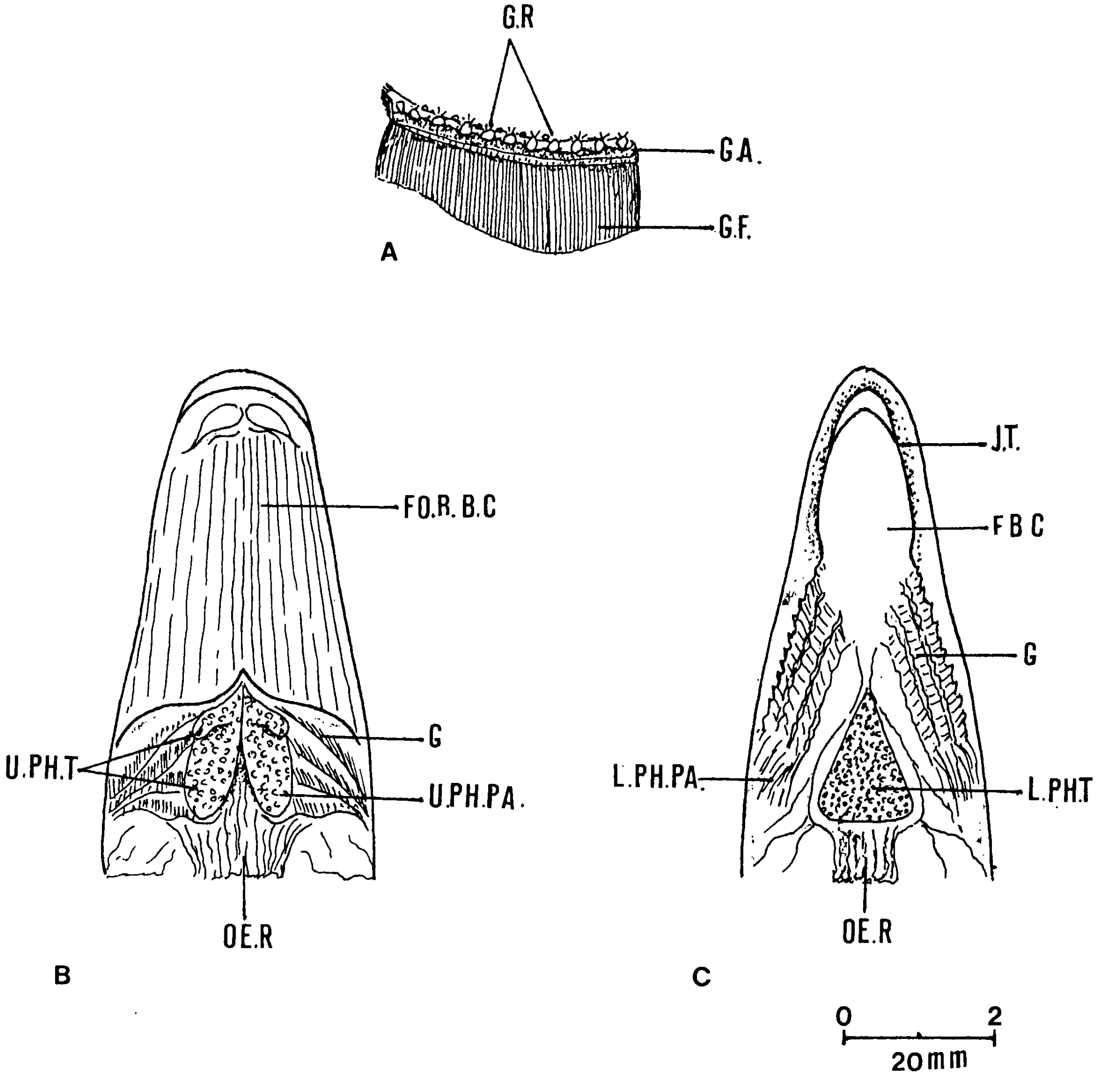
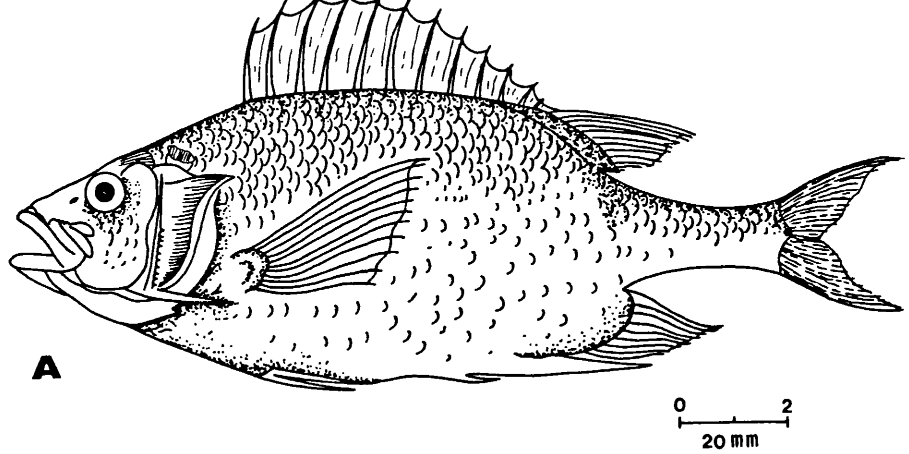
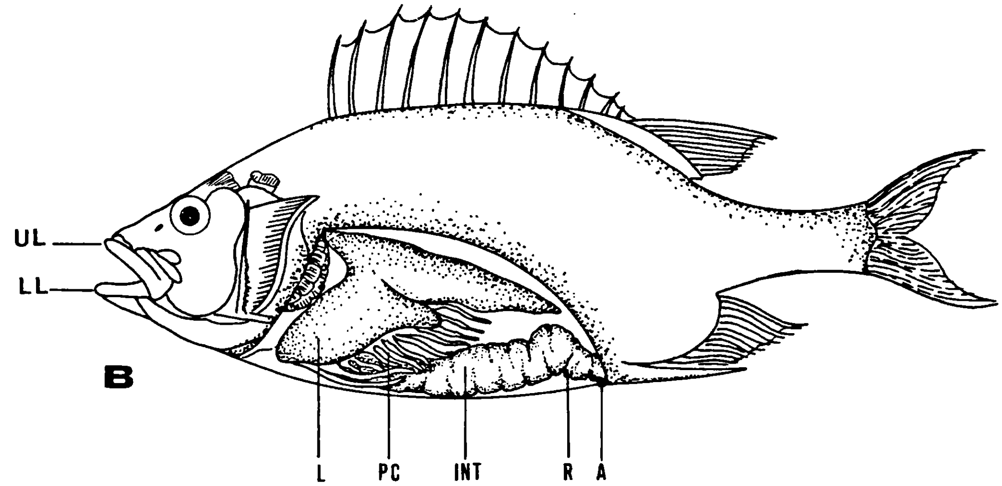

G.R
G.A.
G.F.
A
F.O.R. B.C
G
U.PH.T
U.PH.PA.
OE.R
B
J.T.
F B C
G
L.PH.PA.
L.PH.T
OE.R
C
0
2
20mm

Figure 3.18:

Adioryx spinifer, body and gut morphology.


A
0
2
20 mm


UL
LL
B
L
PC
INT
R
A

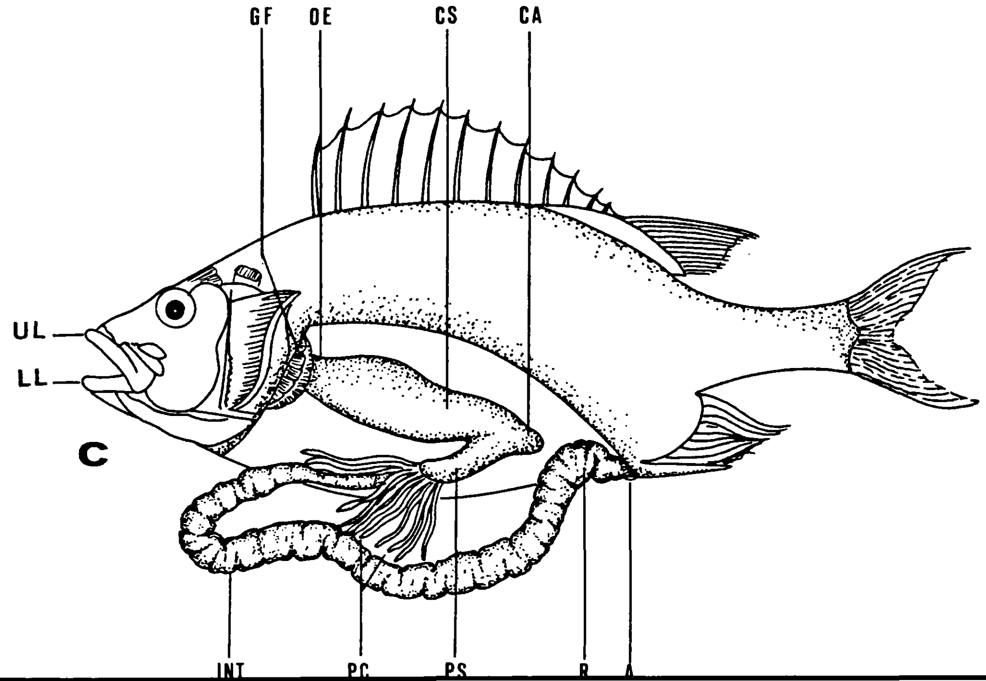

GF
OE
CS
CA
UL
LL
C
INT
PC
PS
R
A

Figure 3.19:

Adioryx spinifer, gill-rakers and mouth.

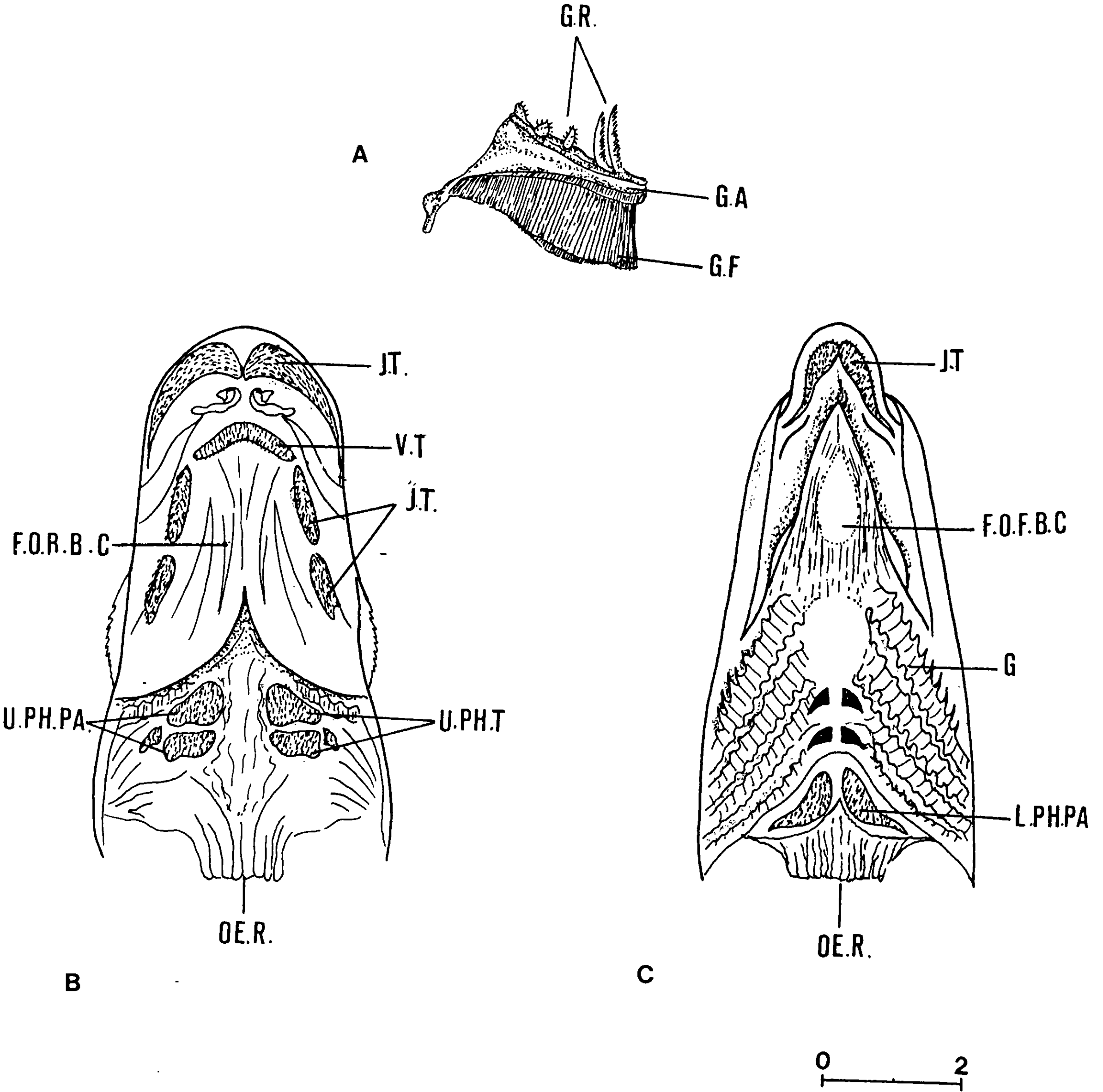

G.R.
A
G.A
G.F
J.T.
V.T
J.T.
F.O.R.B.C
U.PH.PA
U.PH.T
OE.R.
B
J.T
F.O.F.B.C
G
L.PH.PA
OE.R.
C
0
2
40 mm

Figure 3.20:

Plectrorhynchus gaterina, body and gut morphology.

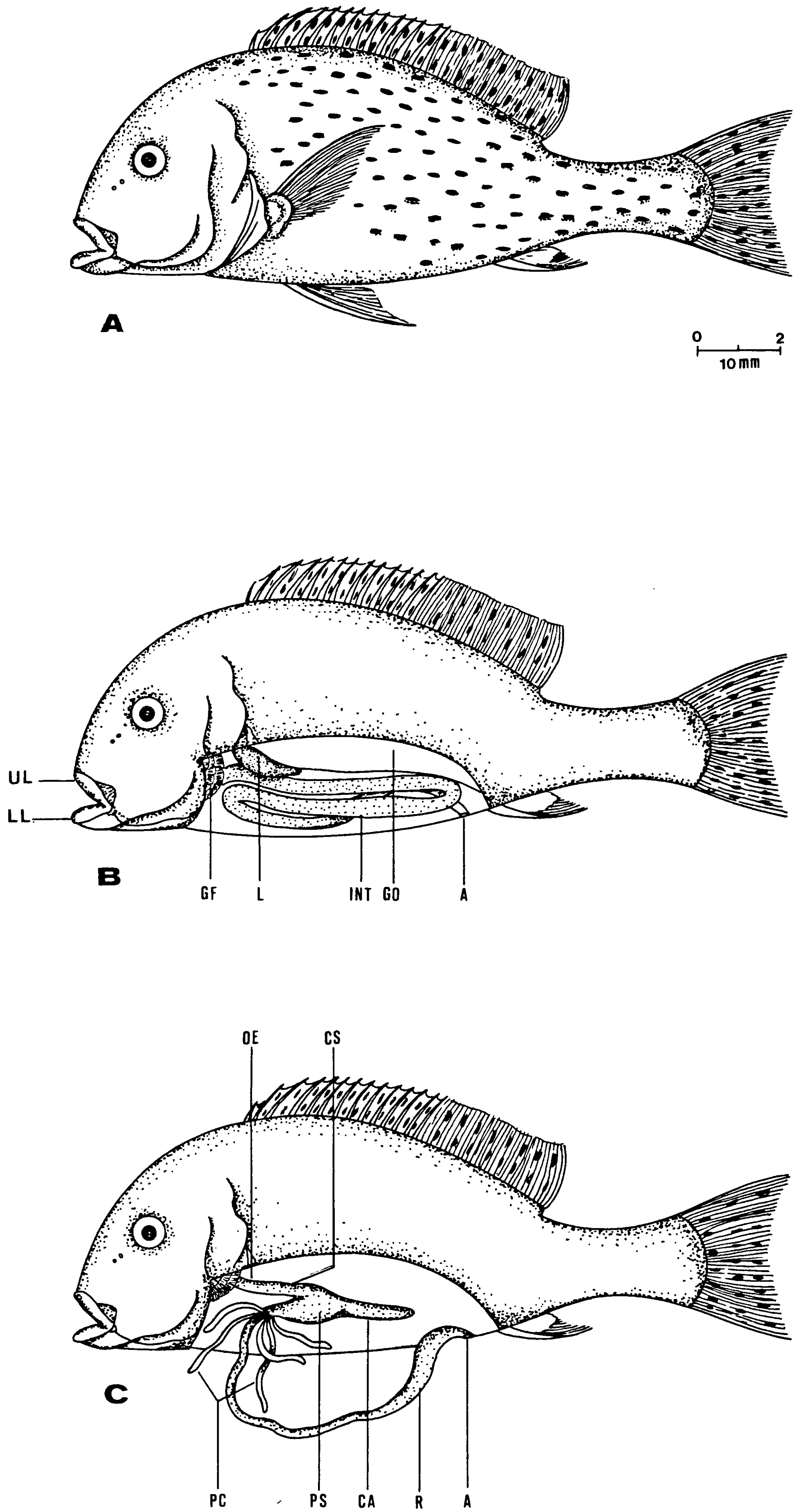
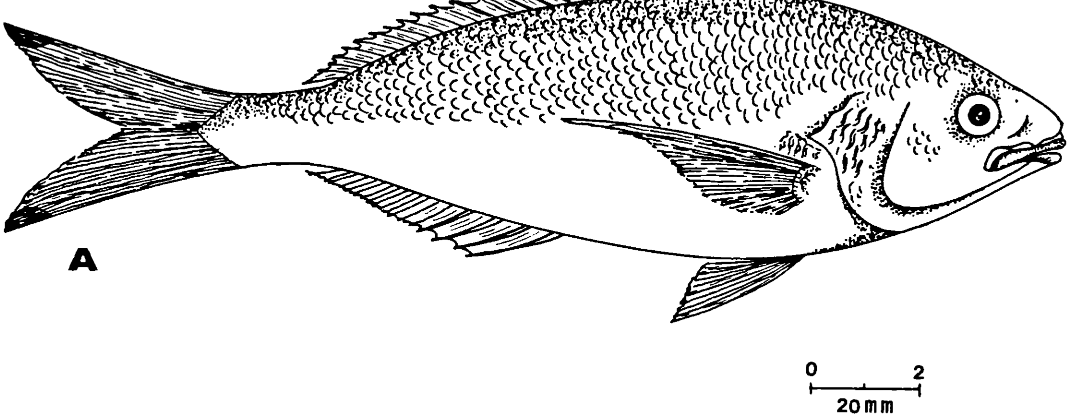
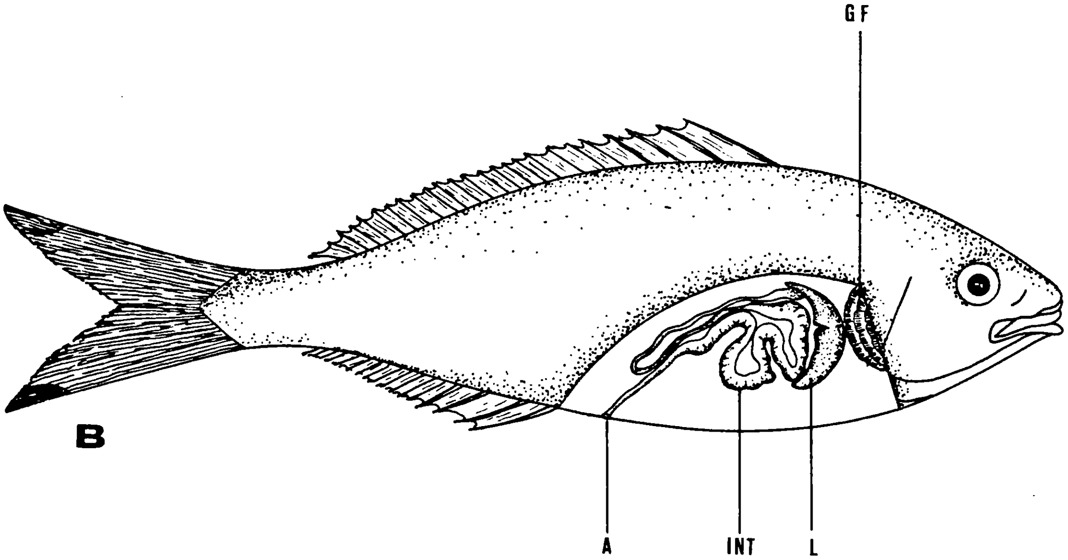

A
0
2
10 mm
UL
LL
B
GF
L
INT
GO
A
OE
CS
C
PC
PS
CA
R
A

Figure 3.21:

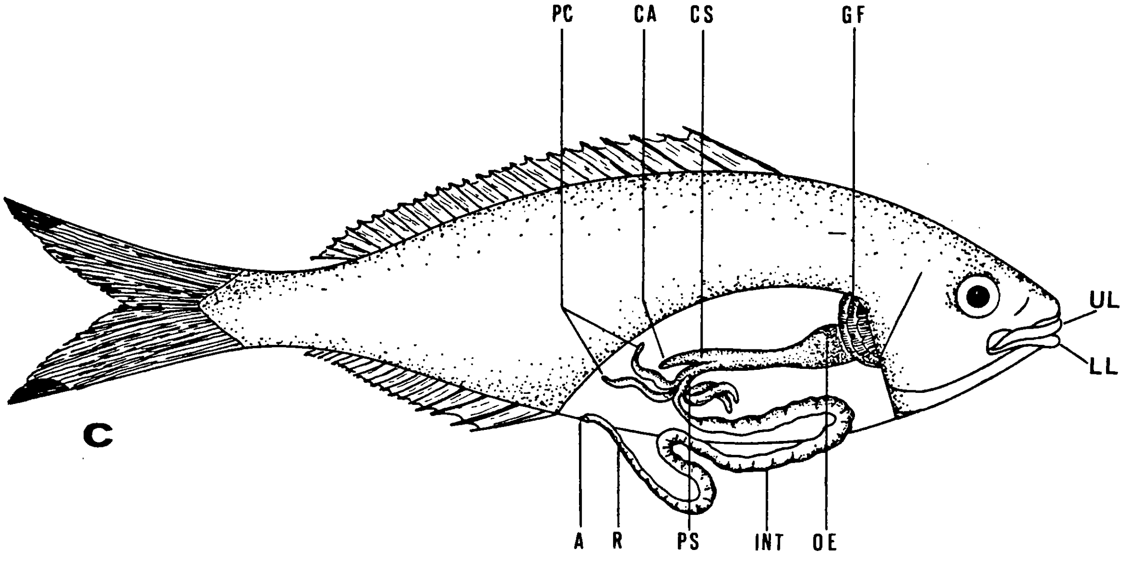
Caesio suevicus, body and gut morphology.



A



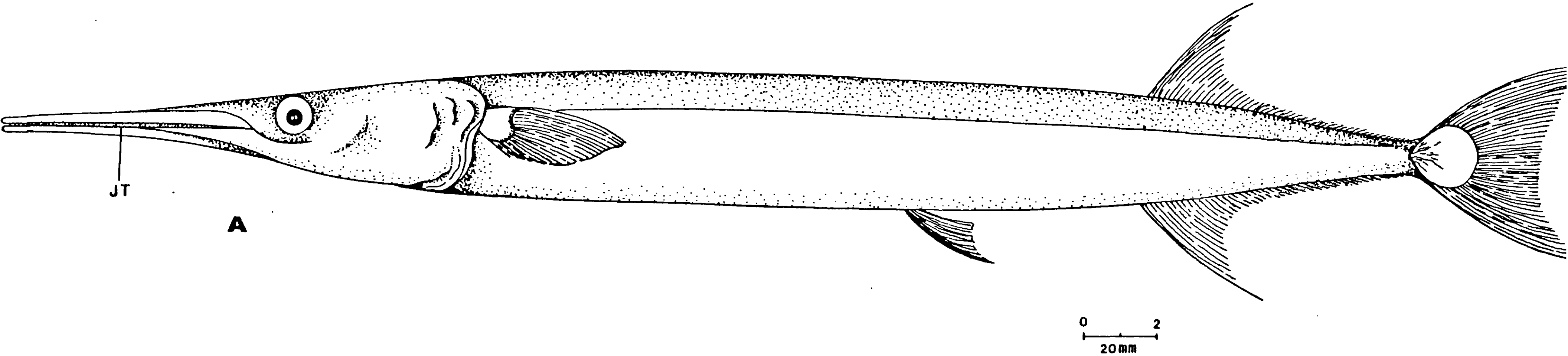
B



C

Figure 3.22:

Tylasurus choram, A) body morphology, B) gut morphololgy.


JT
A
0
2
20mm

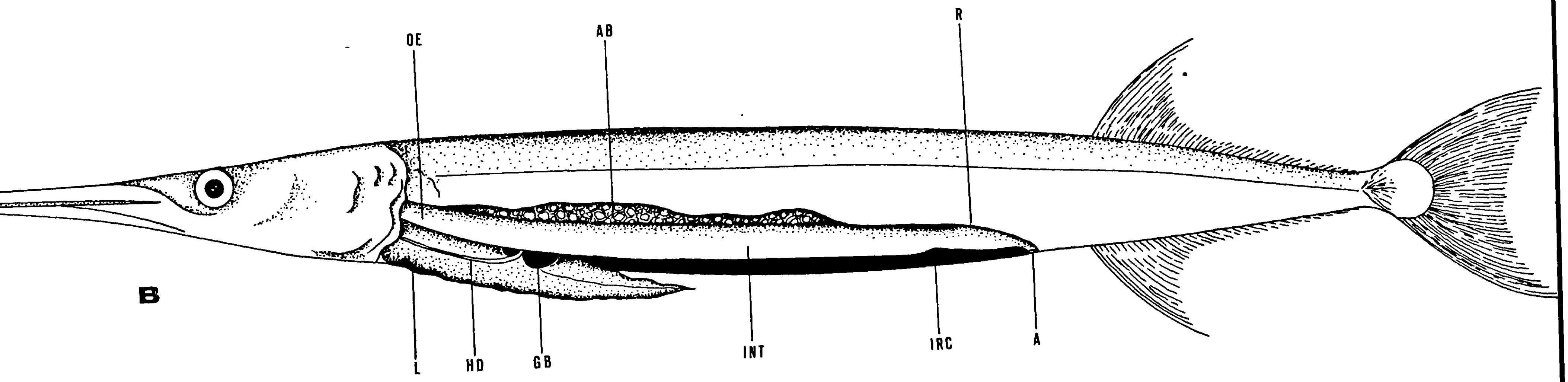
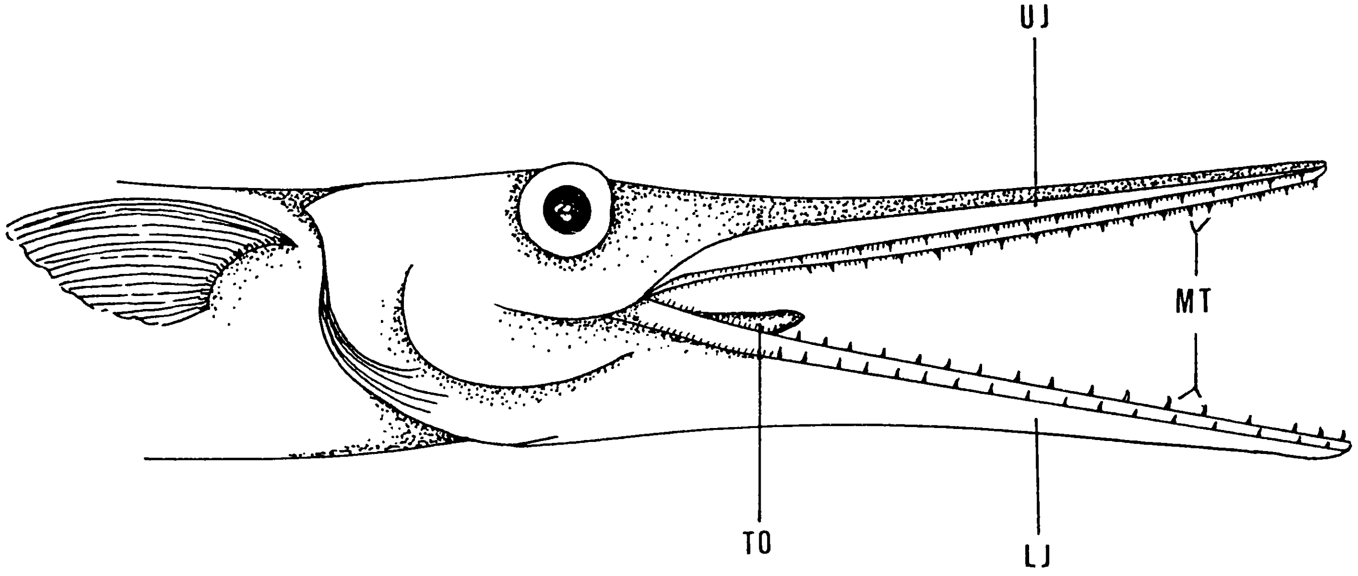

OE
AB
R
B
L
HD
GB
INT
IRC
A

Figure 3.22:

Tylasurus choram, C) Mouth, D) Buccal cavity.



c

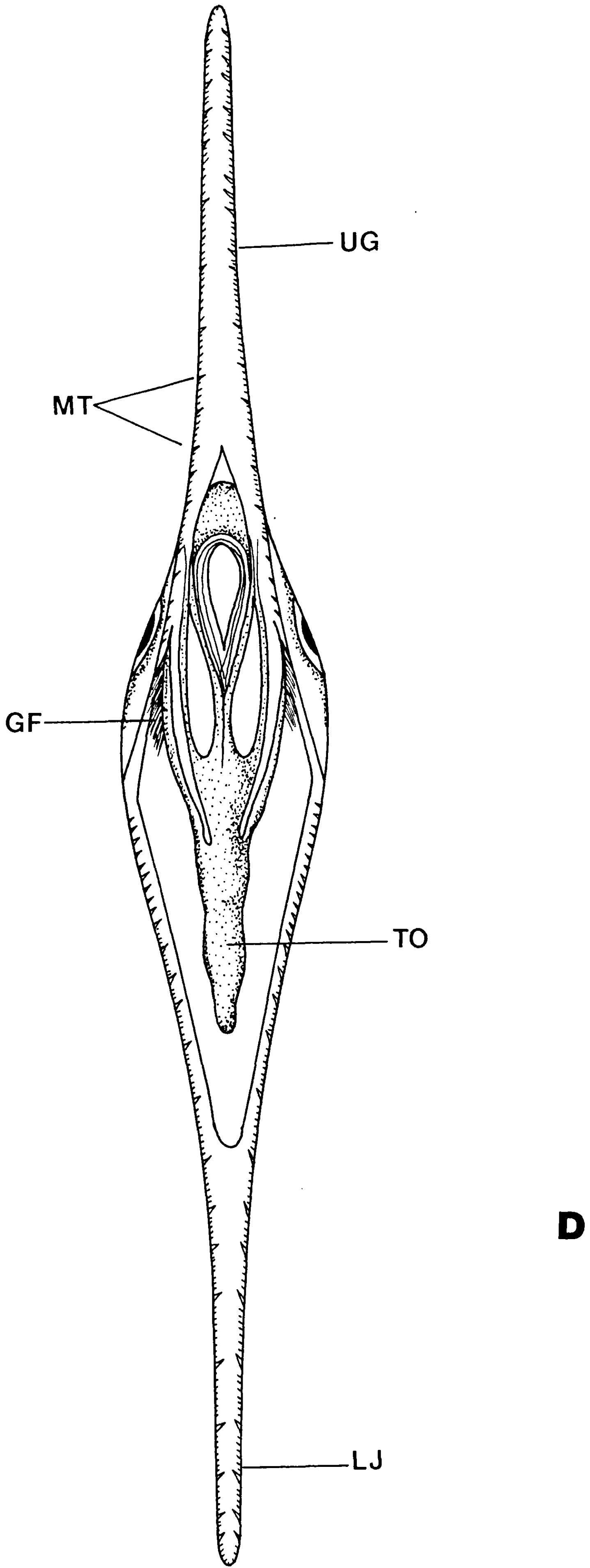
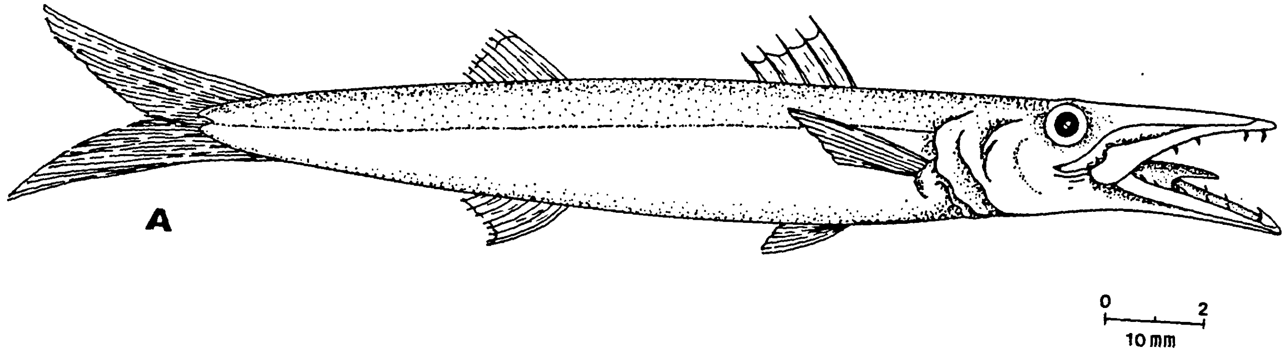
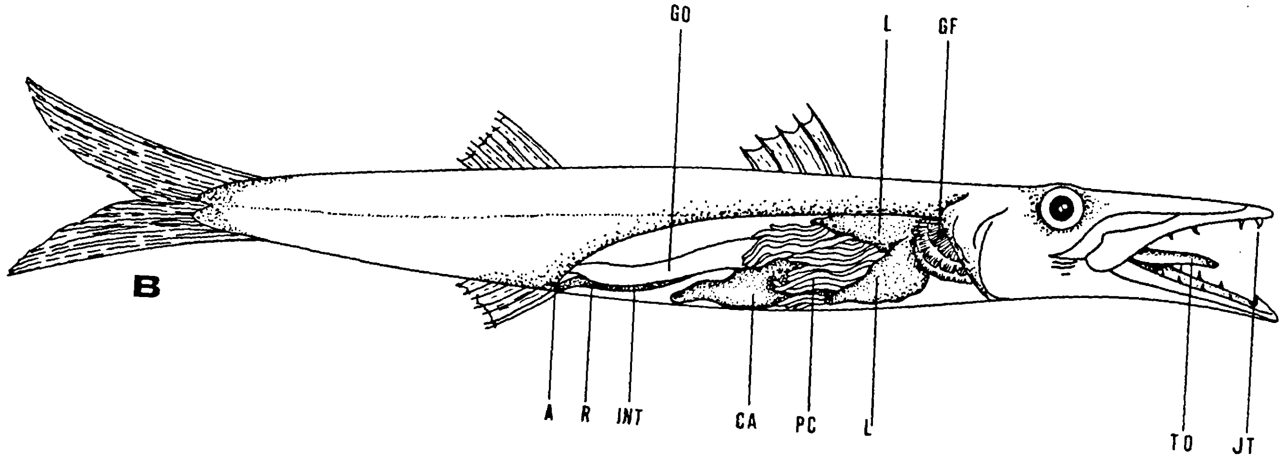

UG
MT
GF
TO
D
LJ

Figure 3.23:

Sphyraena genie, body and gut morphology.


A
0
2
10 mm


GO
L
GF
B
A
R
INT
CA
PC
L
TO
JT

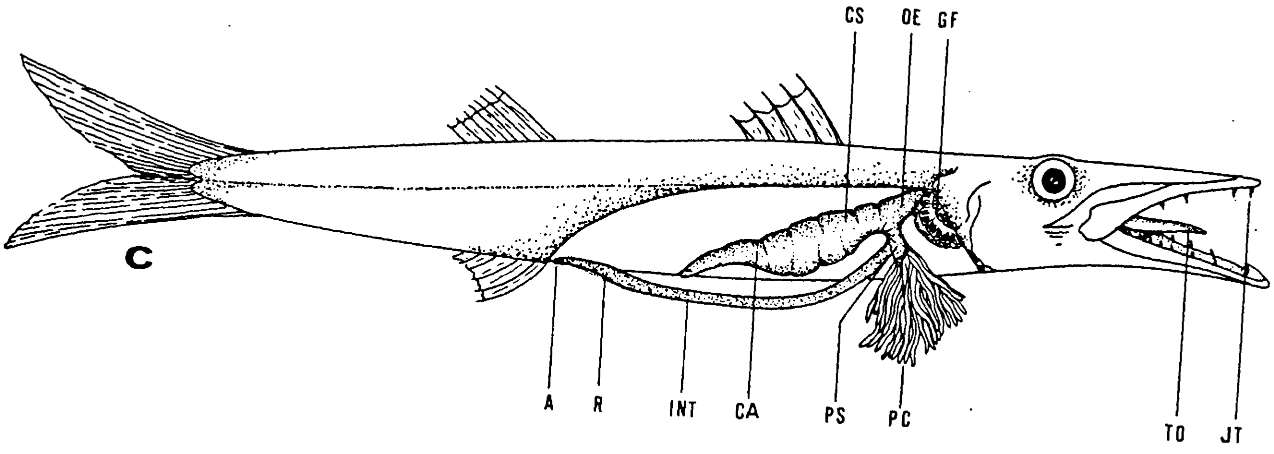

CS
OE
GF
C
A
R
INT
CA
PS
PC
TO
JT

Figure 3.24:

Sphyraena genie, gill-rakers and mouth.

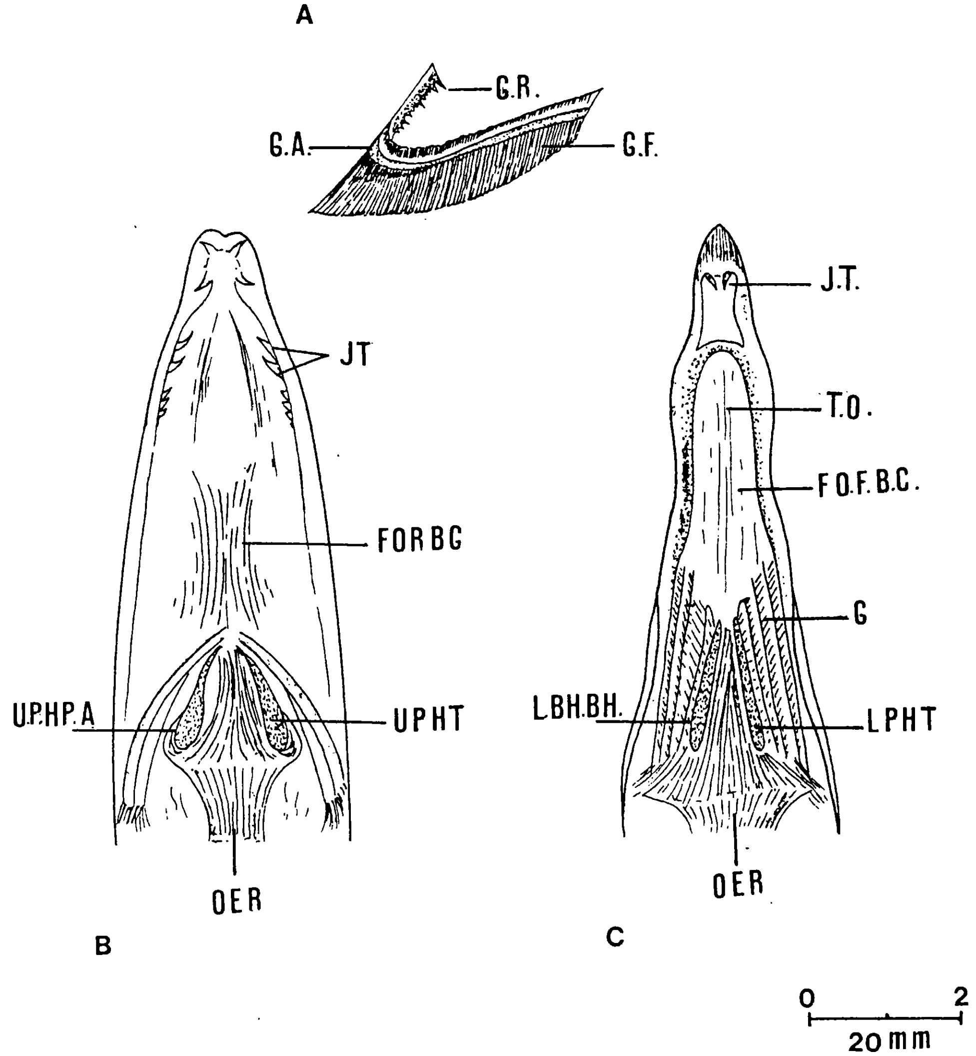
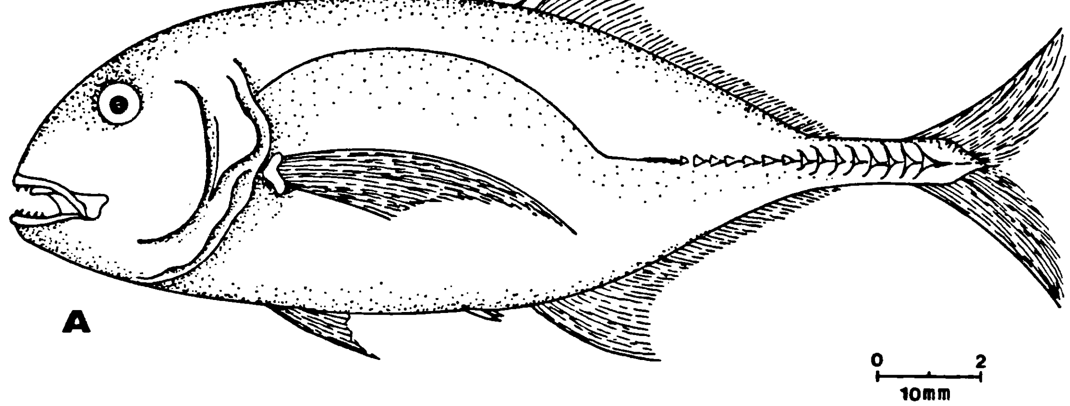
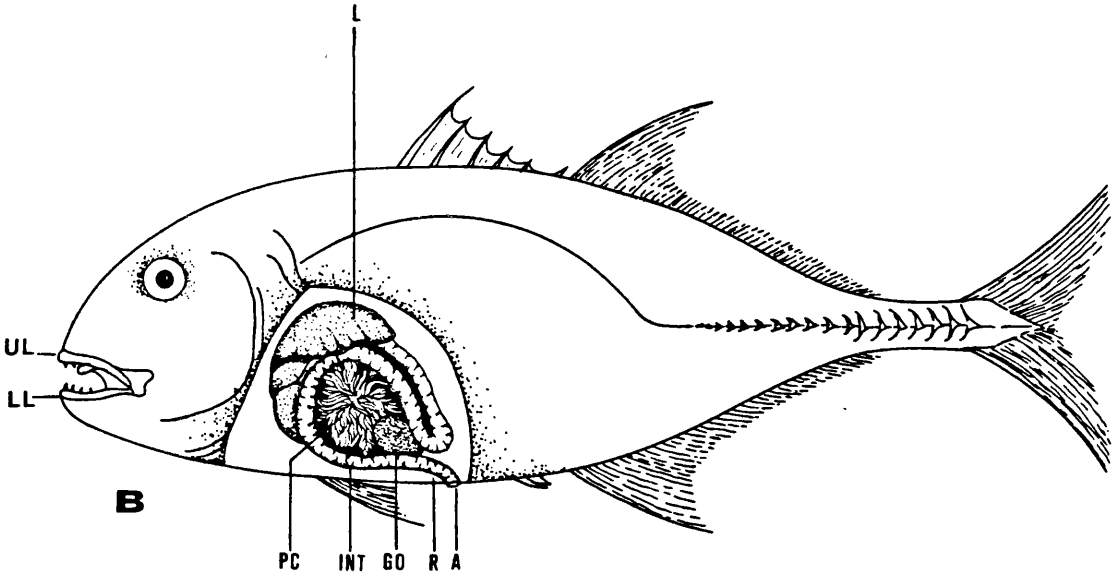

A
G.R.
G.A.
G.F.
JT
FOR BG
U.P.HP.A
UPHT
OER
B
J.T.
T.O.
F.O.F.B.C.
G
LBH.BH.
LPHT
OER
C
0
2
20 mm

Figure 3.25

Caranx ignobilis, body and gut morphology.


A
0
2
10mm


L
UL
LL
B
PC
INT
GO
R
A

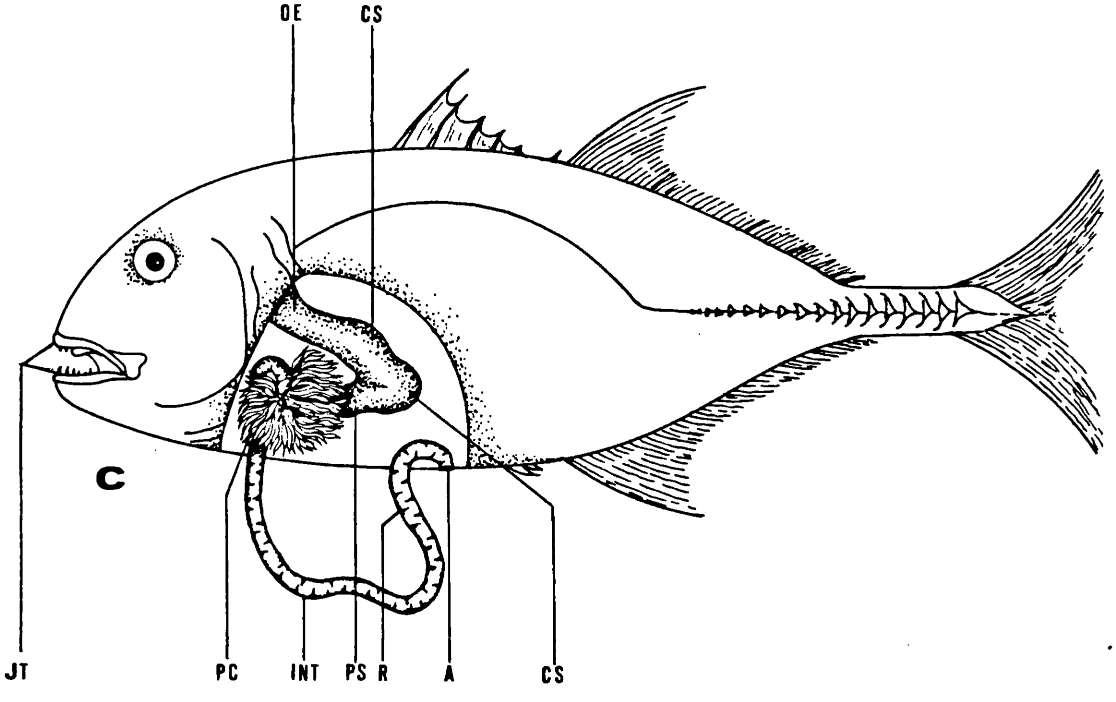

OE
CS
C
JT
PC
INT
PS
R
A
CS

Figure 3.26:

Caranx ignobilis, gill-rakers and mouth.

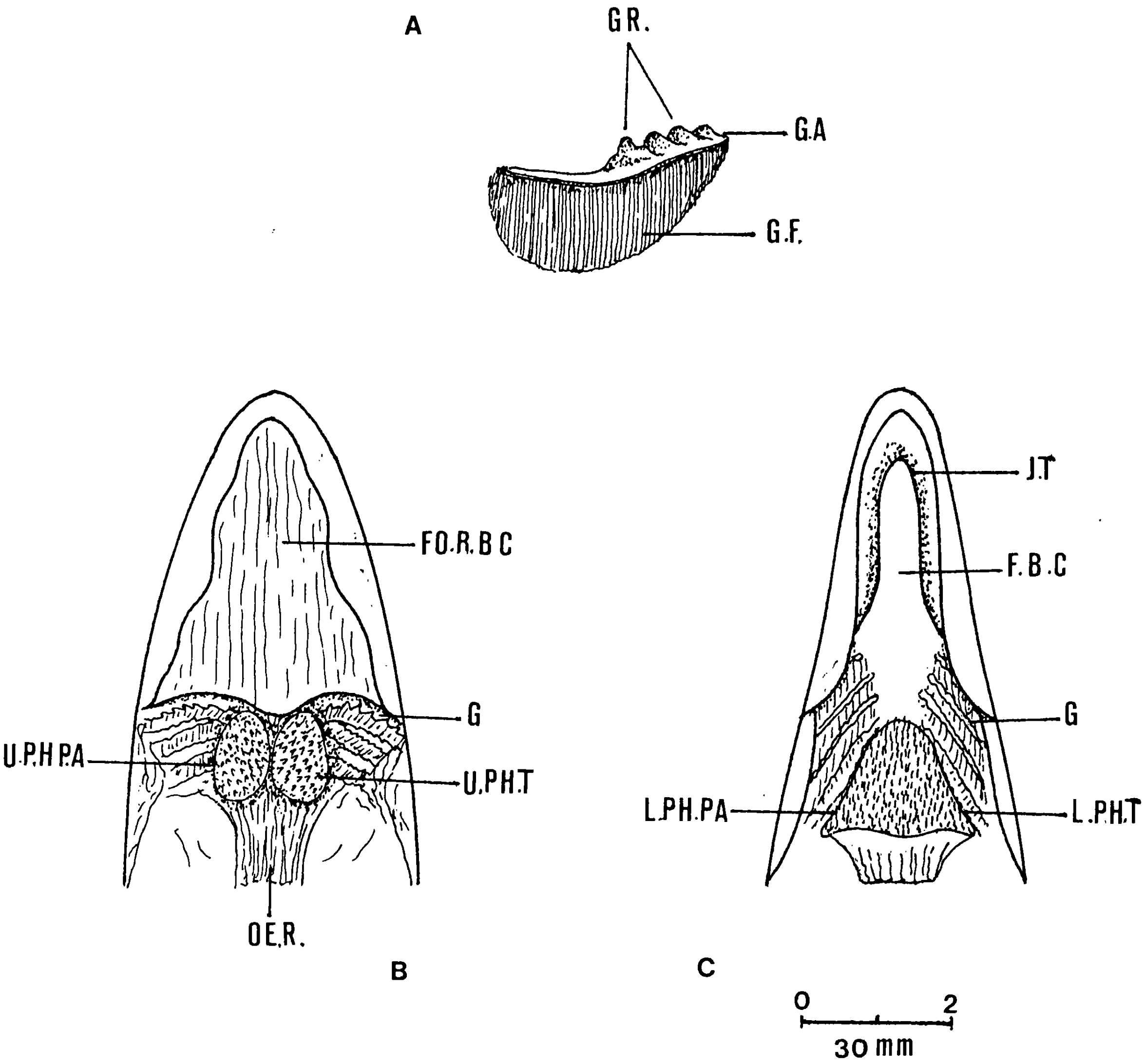

A
GR.
G.A
G.F.
FO.R.B C
G
U.P.H P.A
U.P.H.T
OE.R.
B
J.T
F. B .C
G
L.PH.PA
L.PH.T
C
0
2
30 mm

Figure 3.27:

Rastelliger _kanagurta_, body and gut morphology.

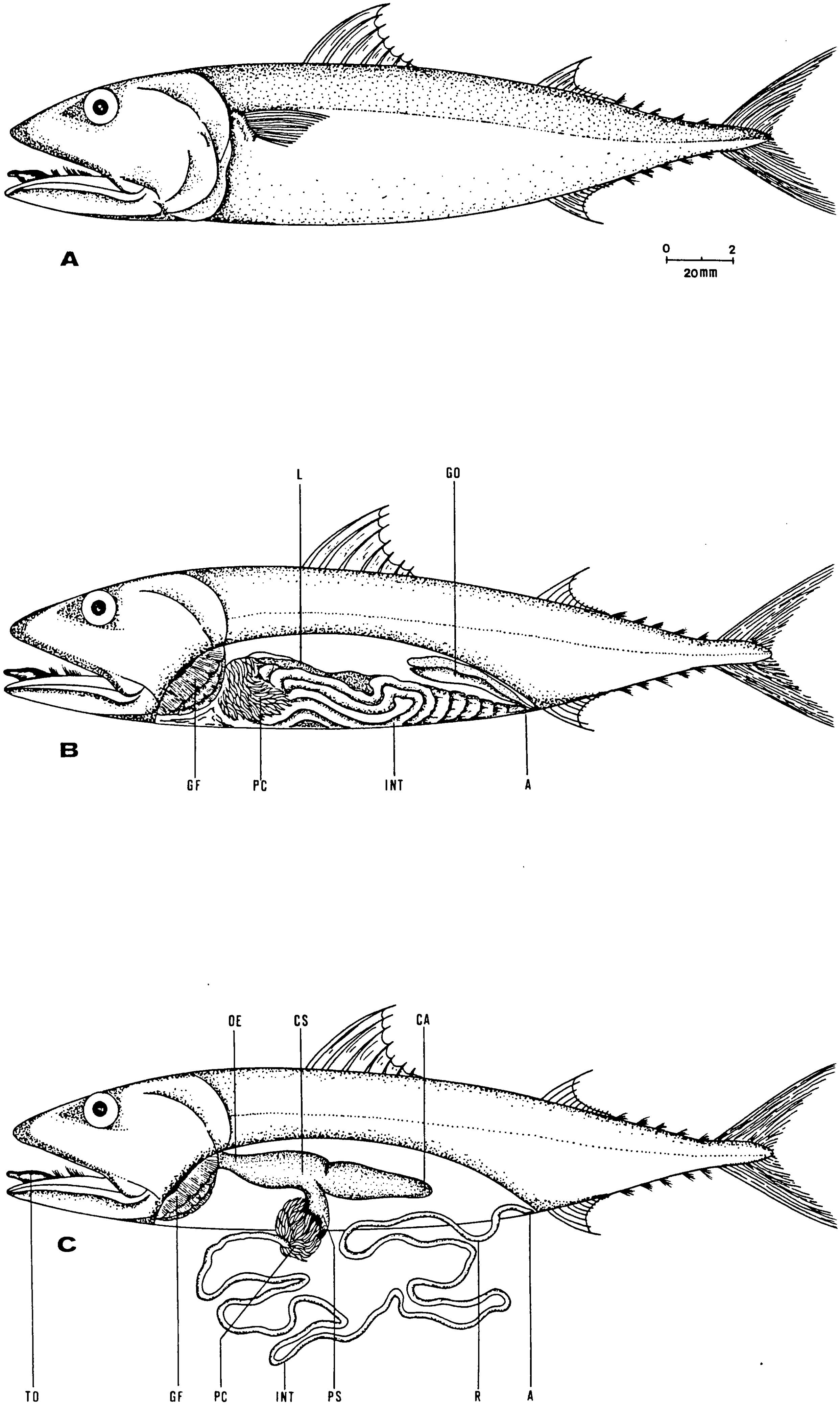

A
0
2
20mm
L
GO
B
GF
PC
INT
A
OE
CS
CA
C
TO
GF
PC
INT
PS
R
A

Figure 3.28:

Rastelliger kanagurta, gill filaments and pharyngeal teeth.

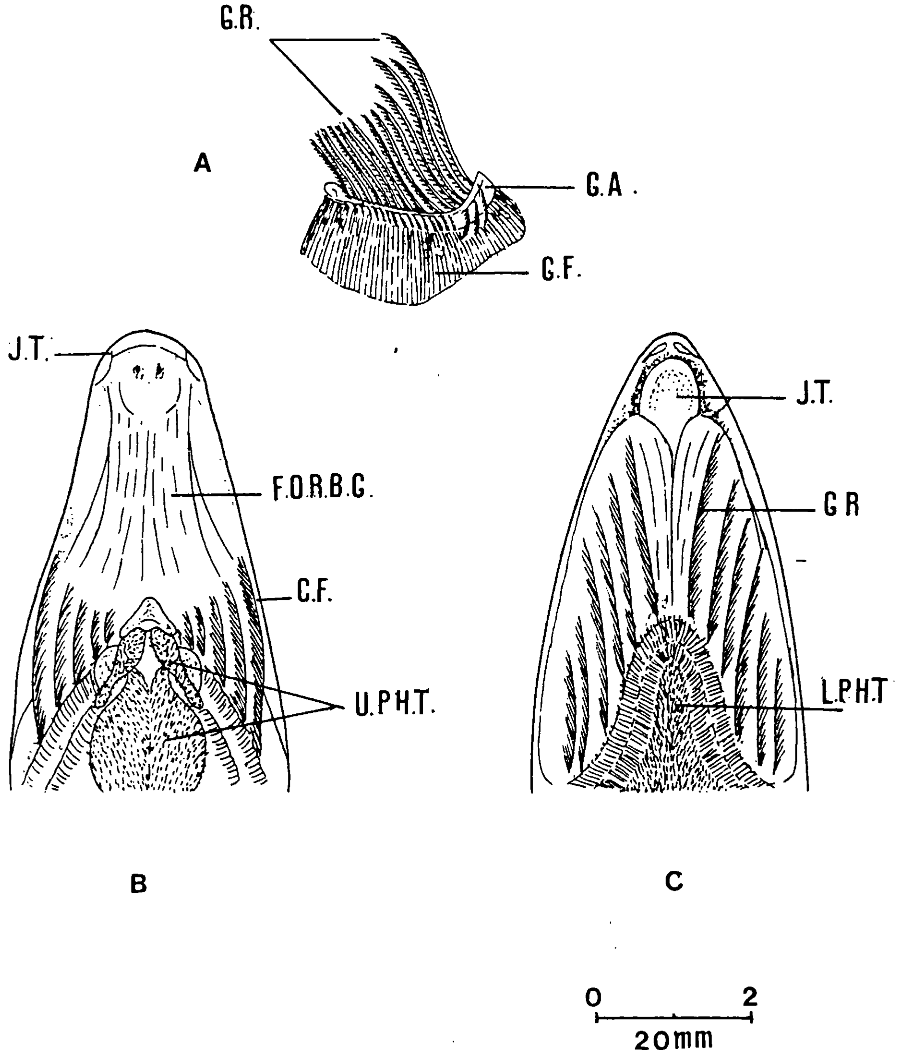

G.R.
A
G.A.
G.F.
J.T.
F.O.R.B.G.
C.F.
U.P.H.T.
J.T.
G.R
L.P.H.T
B
C
0
2
20mm

Figure 3.29:

Rastelliger kanagurta, gill-rakers and mouth.

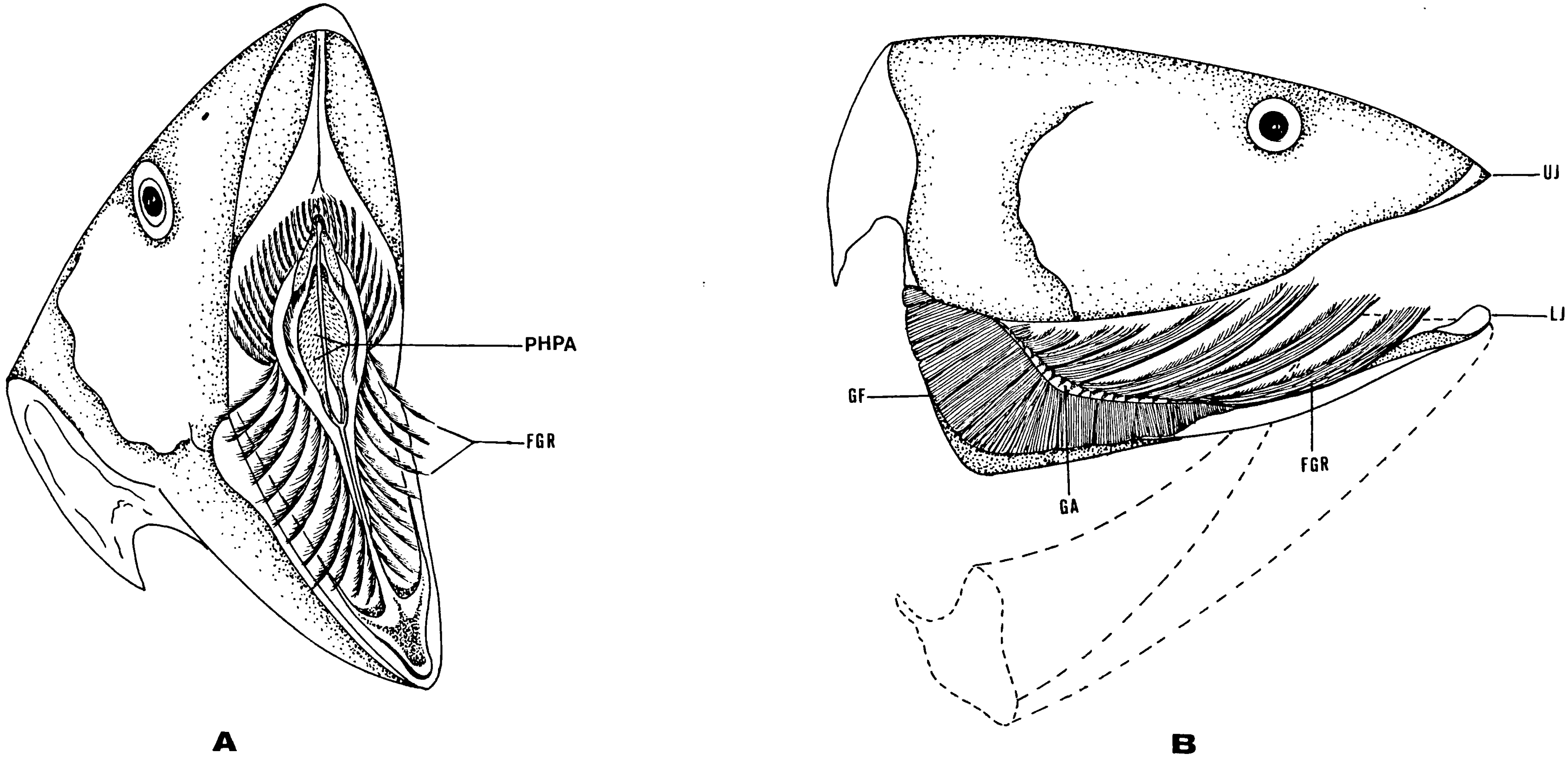
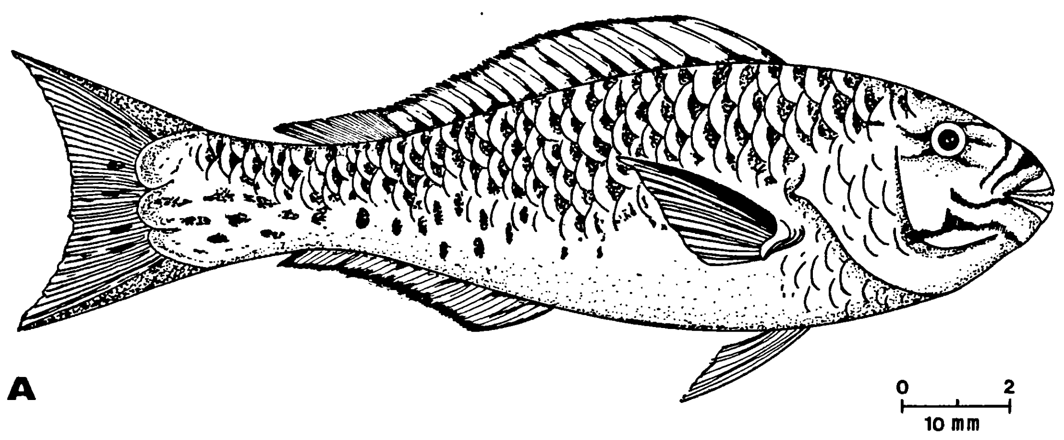
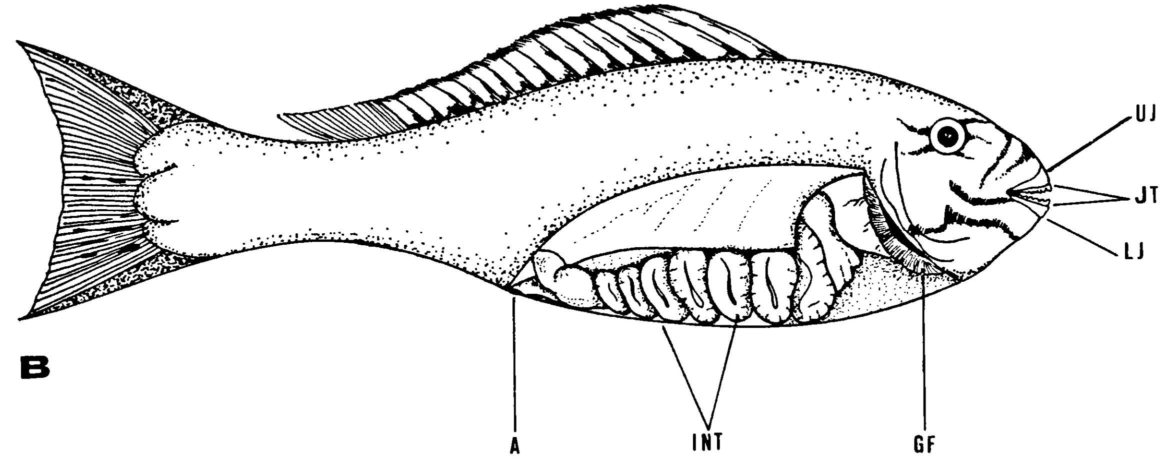

PHPA
FGR
A
UJ
LJ
GF
FGR
GA
B

Figure 3.30:

Scarus ghabban, body and gut morphology.


A
0
2
10 mm


B
UJ
JT
LJ
A
INT
GF

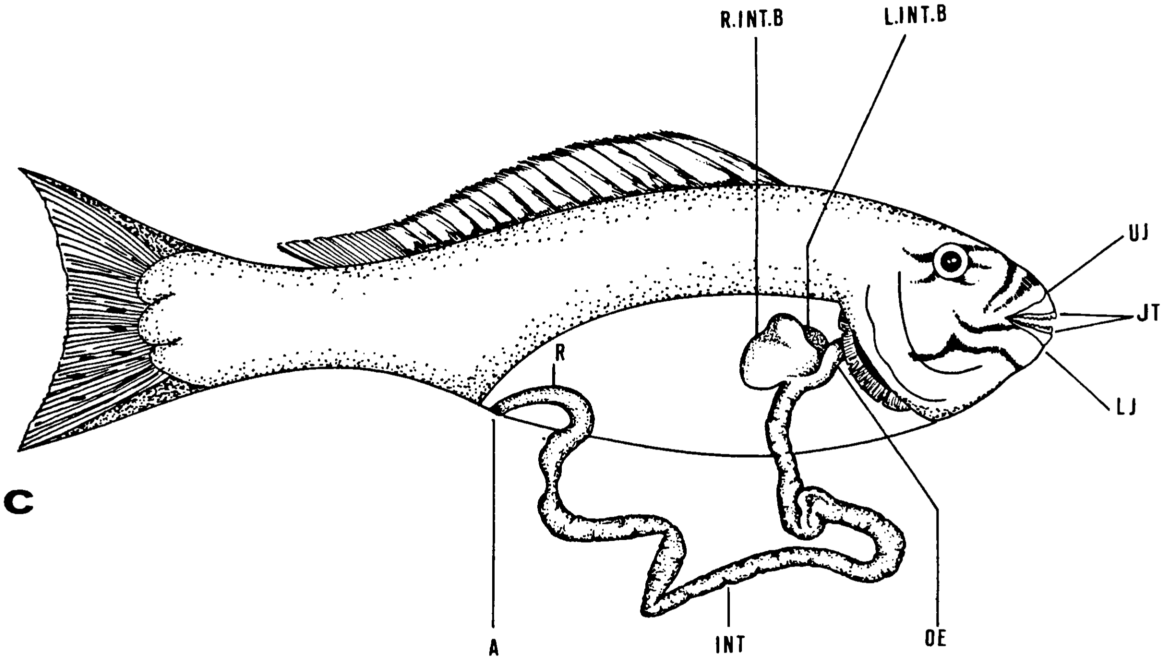
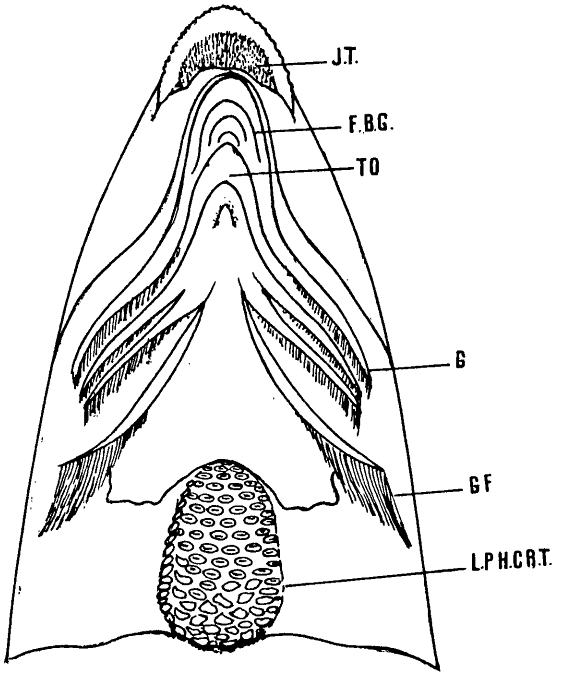
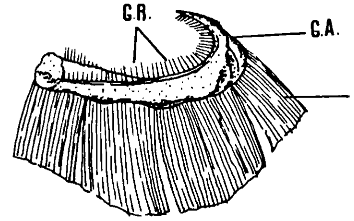

C
R.INT.B
L.INT.B
UJ
JT
LJ
R
A
INT
OE

Figure 3.31:

Scarus ghabban, gill-rakers and mouth.


J.T.
F.B.G.
TO
G
GF
L.PH.CRT.

A


G.R.
G.A.
G.F.

C

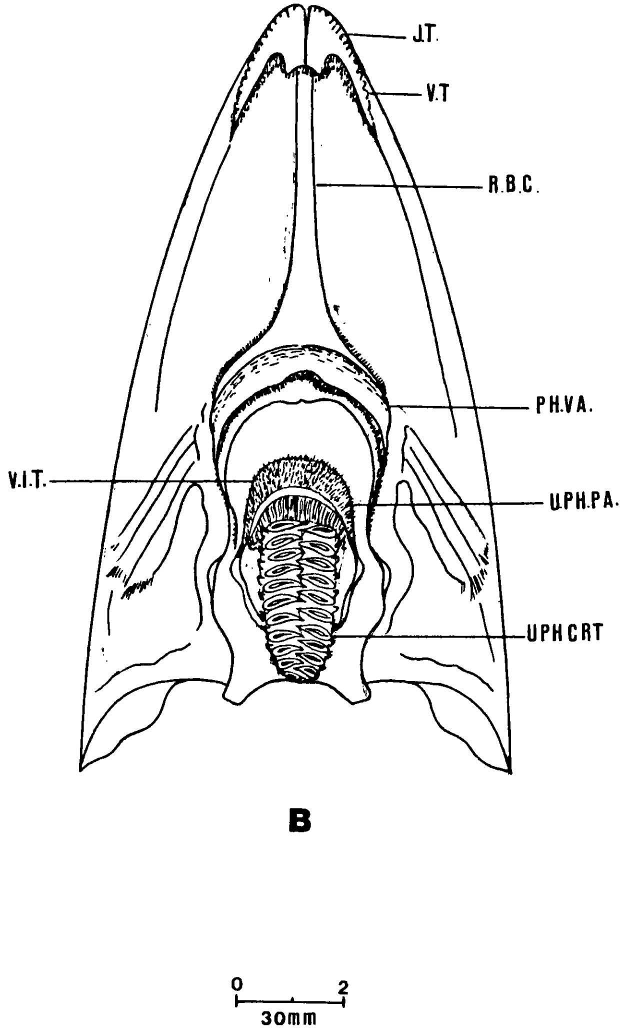

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Figure 3.32:

Siganus rivulatus, body and gut morphology.

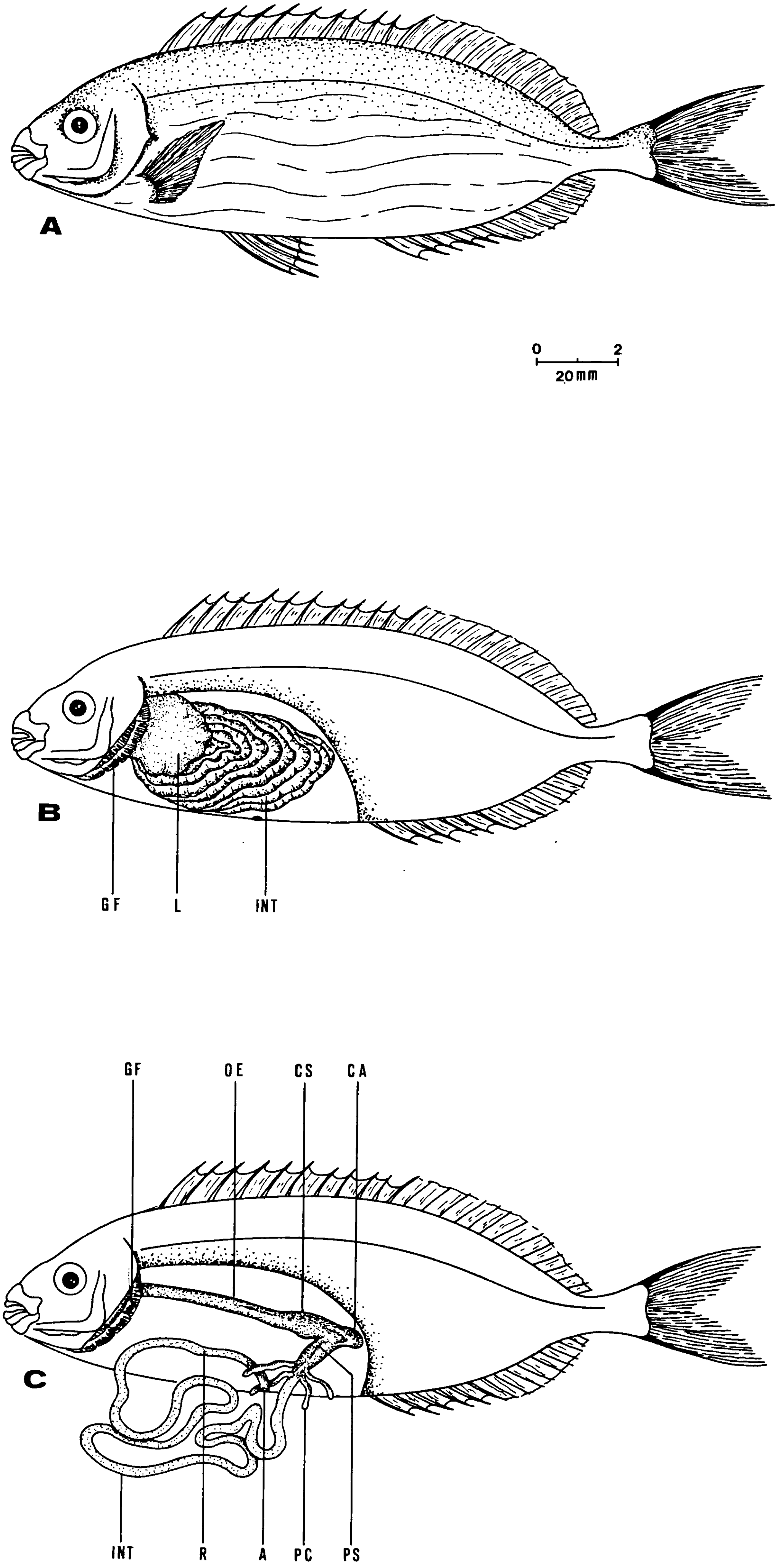
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Figure 3.33:

Siganus rivulatus, gill-rakers and mouth.

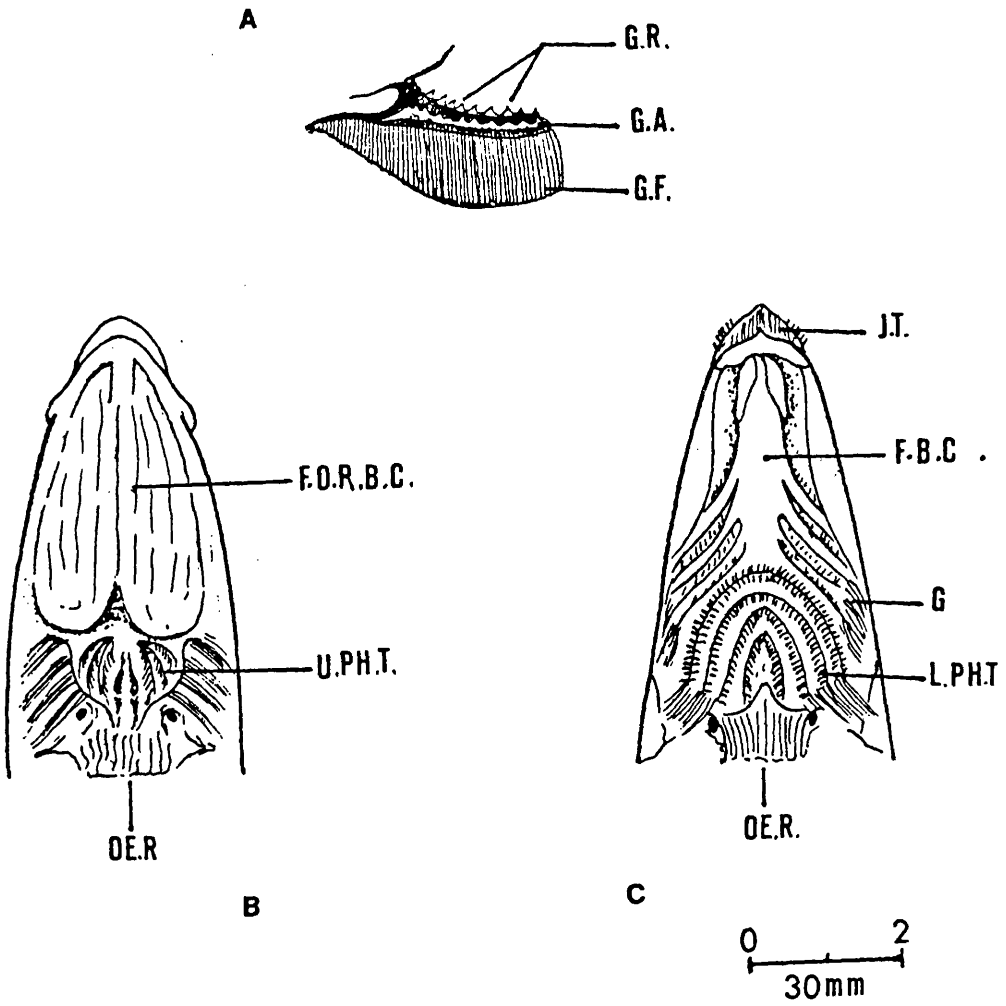
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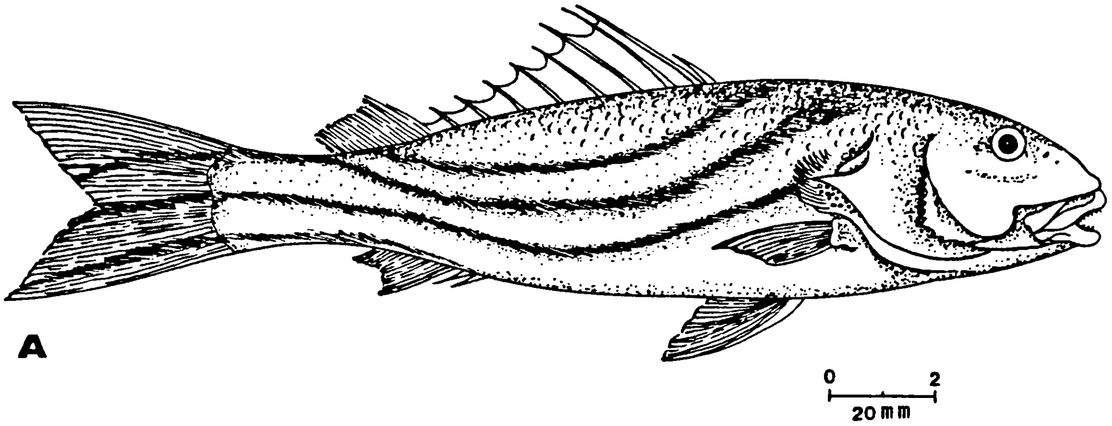
Figure 3.34:

Therapon jarbua, body and gut morphology.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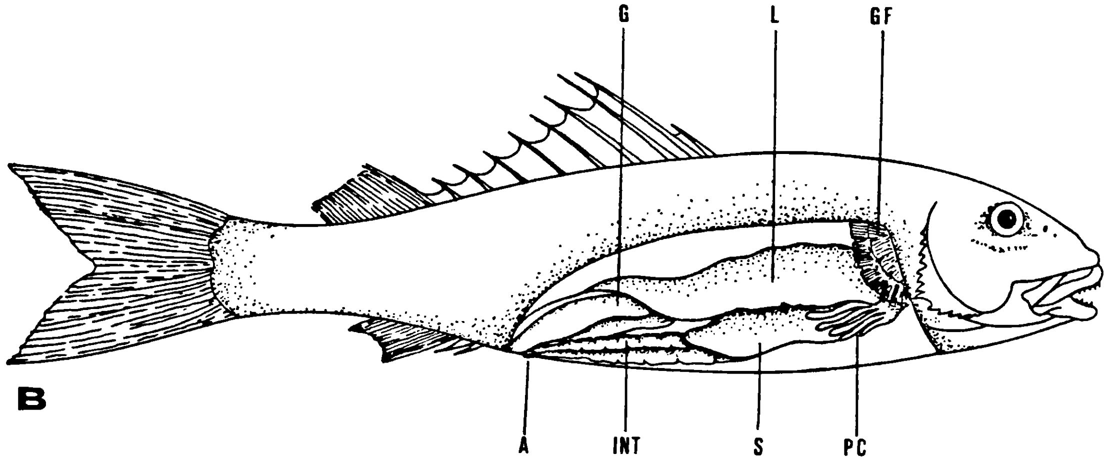
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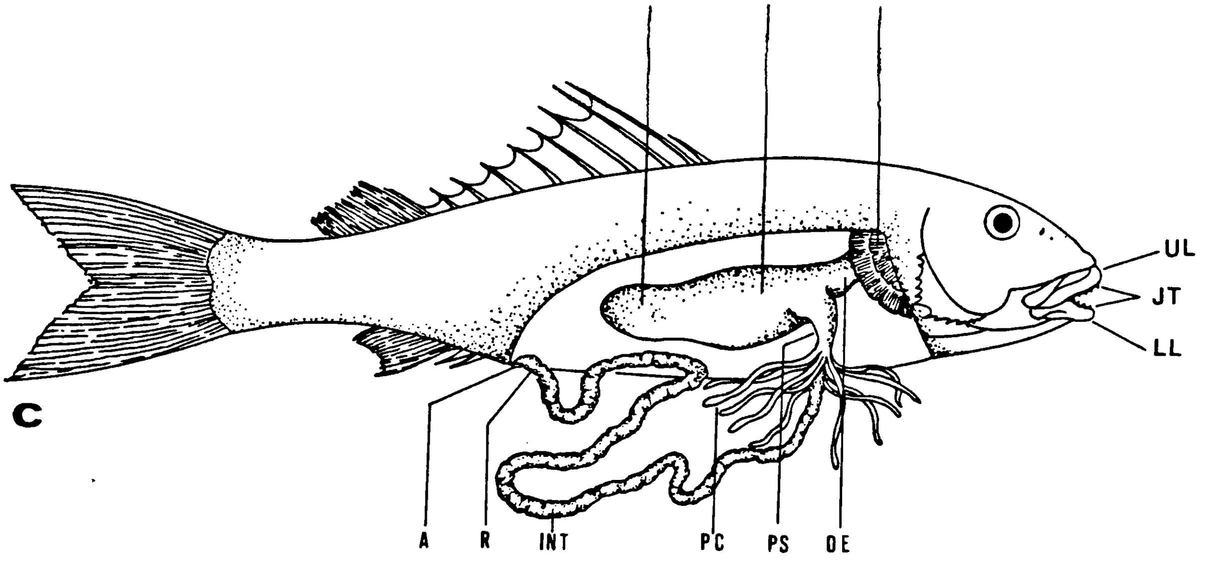
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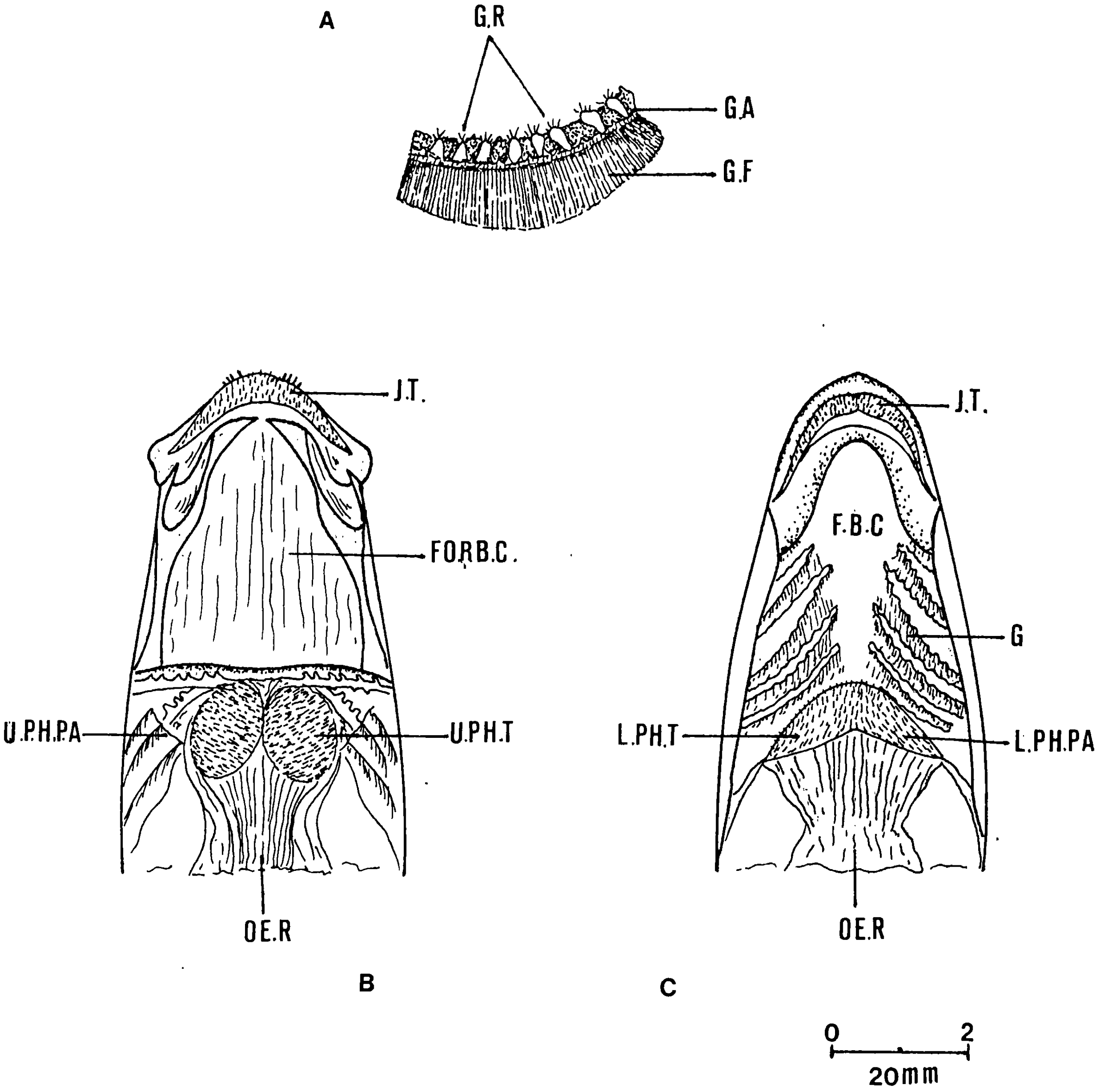
Figure 3.35:

Therapon jarbua, gill-rakers and mouth.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CHAPTER 4

COMPARISON OF THE MORPHOLOGY OF THE ALIMENTARY CANAL WITH FEEDING BEHAVIOUR IN SELECTED FISH SPECIES

4.1 Introduction

Biometric data on fish have been employed widely infish systematics to demonstrate precisely the morphological description of a species. As a result of the adaptation of a fish species to its environment, morphological variations may occur (Gregory, 1928; Nikolsky, 1963). The biometric characters of the alimentary canal of a fish species, on the other hand, are an indication of its feeding habits. In earlier studies it was found that gut proportions are correlated to the type of food ingested (Groot, 1971; Montgomery, 1977). A number of economically important fish in the Jeddah region were examined to determine their gut morphology and diet.

4.2 Materials and Methods

By a qualitative analysis of the stomach contents of sampled fish, 20 fish species inhabiting the region of Jeddah were separated into four major categories (Chapter 2).

From each fish species twelve individuals were sampled covering the widest possible range of the available sizes in the catch. A list of these species along with their individual length ranges is given in Table (2.1) (See Chapter 2).

4.3 Observations

All computations were performed on an IBM PC/XT using the Microstat software package "Microstat".

From the measurements of fish lengths and the lengths of the gut, the ratio of gut length to fish length was computed (R.L.G.). Values of the mean R.L.G.s together with the number of pyloric appendices present were noted for 12 individuals of each of the 20 species under investigation (Table 4.1).

These data show that in carnivores and omnivores, the length of the gut relative to body length is 0.8868±0.2534, while fish which feed planktonic on organisms and on aquatic vegetation have longer alimentary canals compared to their body length, the ratio being 2.2017±0.7494. Among carnivores, fish eaters had shorter alimentary canals than invertebrate eaters, while both categories of fish feeding on both invertebrates and fish, in either proportions, had lengths between these extremes. No relationship was observed between the number of pyloric appendices present and the diet.

Figures 4.1 to 4.7 show the interspecific variations in the gut proportions in the different feeding behavior categories.

Figures 4.1 and 4.2 show that carnivores which feed on both invertebrates and fish have no significant differences in the proportions of their alimentary canals irrespective of the different proportions of invertebrates and fish in their diets.

Data presented in Figure 4.3, shows that invertebrate eaters have larger stomachs than the previous groups, their intestines constitute about 73.69±4.2156% of the length of the alimentary canal. Two species of this group, i.e. *P. galerinus* and *A. spinifer* possessed a rectum that constituted about 6% of the alimentary canal.

Data presented in Figure 4.4 show that in carnivorous fish which feed mainly on fish, the alimentary canal had no fixed trend in its proportions. *C. ignobilis* had the typical alimentary canal of a carnivore, however *S. genie* and *I. choram* showed some unusual features. *S. genie*, which is a voracious fish that engulfs its prey of large fish, has a large cardiac stomach that constitutes about 45% of the alimentary canal, a very small pyloric portion and a relatively short intestine. *I. choram* on the other hand, has no stomach and a long intestine. This is because it feeds on very small pelagic fish which live on coral reefs and are small enough not to need crushing in the stomach and are fragile enough to be easily digested by the intestinal enzymes. This was borne out by analysis of gut contents.

The data presented in Figures 4.5 and 4.6 show that between planktivores and herbivores and among planktivorous species, there are no significant differences between the gut proportions. This is probably because of the great similarity in the variety of food items ingested by both groups of fish. Both species feed on cellulose-rich organisms that need a longer time to be digested by the action of the enzymatic secretions in their intestines. The intestines are proportionately longer in these species. The cardiac portion of the stomach is much larger than the pyloric one in both categories. The former only serves as a storage compartment for food items which are digested mainly in the intestine.

Only one species of omnivorous fish, Iherapon jarbua was represented in the commercial samples collected during the present study. It feeds mainly on small fish, crustacea and small nematodes which live among aquatic algae. The presence of algae in their stomachs may thus be accidental and this species could therefore be classified as invertebrate and fish eating carnivores. In addition its alimentary canal proportions (Figure 4.7) are almost identical to those of that category, in particular L. lentjan and G. oyena (Figure 4.1).

4.4 Morphometric regressions

The observed values of the seven morphometric measurements of the alimentary canal of each of the fish species studied were plotted as a scatter diagram and the regression equation representing each of them was computed. For each equation the statistical significance (from the coefficient of correlation) was determined and the respective equation was then either accepted or rejected. Table (4.2) shows the significant relationships between the morphometric measurements of the alimentary canal and fish length for each of the categories studied.

4.5 Discussion

Based on the functional morphology of the alimentary canals in fish, it is evident that fish consume as food those items that the structural specialization of their skulls, jaws and alimentary tracts enable them to capture, and subsequently digest. Based on their feeding habits, fish are classified as herbivores, omnivores, carnivores, or planktivores. The various degrees of specialization in food habits allow further categorization as monophagous (consuming just one kind of food), stenophagous (a limited range of foods), or euryphagous (mixed diets) species. Most are euryphagous (Weatherley and Gill, 1987). Feeding habits are also frequently associated with particular body form and functional morphology of the skull, jaws and alimentary tract (Barrington, 1957; Keast and Webb, 1966; Keast, 1970, 1977, 1979; Kapoor *et al.*, 1975; Hyatt, 1979). Thus, many herbivorous fish lack the ability to ingest and digest materials other than plants, and are therefore obligatory plant feeders who must ingest large quantities of food of low digestibility from which they can extract nutrients by means of an elongated gut. The long gut evidently functions both in holding a large quantity of food for an extended time and allowing a fuller utilization of materials which are difficult to digest. By contrast, carnivorous fish have shorter, more specialized alimentary tracts. The data presented in Table (4.3) compares the relative gut lengths of several species, and it is clear that gut length may be a major adaptive specialization in the feeding ecology of fish. Even among carnivorous fish gut length is related to the size of prey, being longer in those that consume smaller animals. This is evident from the data presented in Table (4.1). *C. suevicus* feeds mainly on large invertebrates, has the highest relative gut length and possesses only 6 pyloric caecae, while *M. flavolineatus* has the shortest gut length in the same group categories, presumably because it feeds on smaller invertebrates, and it possesses 17 pyloric carcae, the highest number in this category. In the present study it was found that the relative gut length is of intermediate size in omnivorous species and largest in herbivorous species; the relative gut lengths recorded in the present study agree well with the values recorded by Kapoor *et al.*, (1975) and Bond (1979) who worked on a number of different species.

With increased fish size food requirements also increase. Large fish require more food than smaller ones. Ribble and Smith (1983) described the allometric relationships between intestine length (Y) and total fish length (X) for 11 fish species (mostly carnivorous) from seven families by means of a single equation;

$$Y=0.08X^{1.42}.$$

During growth the length of the intestine increases at a relatively higher rate than the length of the fish, thus providing a greater surface area for food absorption as the size of the fish increases and thereby offsetting the consequences of the "cube law". However, Ribble and Smith (1983) pointed out that there is sufficient variation in this relationship to account for major differences in diet between the species studied.

The equations expressing the relationships between fish and gut length for all fish species investigated are presented in Table 4.4. These equations permit the statement that gut length increases more than fish length and that in carnivorous fish which feed on invertebrates, either as the main component, or as part of their diet, the number of pyloric caeca was not correlated with fish length.

Table 4.1: Relative length of gut (R.L.G. in cm) and number of pyloric caeca (P.C.) (mean values) in fish different feeding categories.

Category	Fish species	R.L.G. (cm)	P.C.
CARNIVORES			
Invert. + Fish Eaters	P. Schjotaf	1.0050±0.0258	10
	P. tuberculatus	0.5875±0.0349	10
	L. flaviflamma	0.8942±0.0419	4
	L. lentjan	0.6317±0.0285	3
	G. oyena	0.6858±0.0295	3
Fish + Invert Eaters	L. bohar	0.8508±0.0557	5
	S. lysan	1.2242±0.0350	M
	C. bajad	0.6983±0.0103	M
	A. rogaa	1.2283±0.0262	10
Invert Eaters	M. flavolineatus	0.8567±0.0337	17
	A. spinifer	1.1667±0.0446	17
	P. gaterinus	1.1042±0.0271	8
	C. suevicus	1.2417±0.0164	6
Fish Eaters	T. choram	0.5200±0.0095	-
	S. genie	0.6225±0.0075	M
	C. ignobilis	0.6625±0.0260	M
PLANKTIVORES	R. kanagurta	2.5192±0.0601	M
HERBIVORES	S. ghabban	1.3458±0.0772	-
	S. rivulatus	2.7400±0.0856	4
OMNIVORES	T. jarbua	1.0950±0.0900	10

M = more than 17

Table 4.2: Confidence levels of the regression equations relating various alimentary canal measurements with body length in the different categories.

Category	Fish species	1	2	3	4	5
CARNIVORES Inver.+Fish Eaters	P.schotaf	0.01	NS	0.011	NS	NS
	P.tuberculatus	NS	NS	NS	NS	NS
	L.flaviflamma	0.001	0.01	0.001	0.001	NS
	L.lentjan	0.001	NS	0.001	0.001	0.1
	G.oyena	0.001	NS	0.001	NS	NS
Fish+Invert Eaters	L.bohar	0.001	0.05	0.001	NS	NS
	S.lysan	0.001	0.001	0.05	0.001	0.1
	C.bajad	0.01	NS	0.001	NS	0.1
	A.rogaa	0.001	0.01	0.001	0.1	0.5
Invert. Eaters	P.gaterinus	0.001	0.05	0.02	NS	NS
	A.spinifer	0.001	NS	0.001	NS	NS
	M.flavolineatus	NS	NS	NS	NS	NS
	C.suevicus	0.001	NS	0.001	NS	NS
Fish Eaters	T.choram	0.001	NS	NS	-	-
	S.genie	0.001	0.01	0.001	0.05	NS
	C.ignobilis	0.05	NS	NS	NS	NS
PLANKTIVORES	R.kanagurta	0.001	NS	0.01	-	-
HERBIVORES	S.ghabban	0.01	NS	0.01	-	-
	S.rivulatus	0.001	0.001	0.001	0.001	0.5
OMNIVORES	T.jarbua	0.001	0.05	0.001	0.1	NS

1 = TL vs. GL 2 = TL vs. Oesoph. 3 = TL vs. Int
4 = TL vs. Length of Pyl. App. 5 = Stom-Car vs. Pyl. App.
NS = Statistically not significant

Table 4.3: Relative gut length and feeding habits in some fish species (From Kapoor et al., 1975; Bond, 1979).

Species	Feeding habits	Relative gut length to body length
Labeo hoerie	Detritivorous	15.0 - 21.0
L. niloticus	Detritivorous	16.9
L. calibasu	Herbivorous	3.75 -10.0
Hypophthalmichthys molitrix	Herbivorous	4.6 - 7.1
Ctenopharyngodon idella	Herbivorous	2.5
Gila bicolor	Omnivorous	1.0 - 1.3
Salmo salar	Carnivorous	0.73 - 0.80
Micropterus salmoides	Carnivorous	0.7 - 0.9
Gadus morhua	Carnivorous	1.05 - 1.50

Table 4.4: Regression equations expressing the relationships between gut length (Y) and fish length (X).

Category	Fish species	Regression equation
CARNIVORES		
Invert. + Fish Eaters	P. schotaf	Y=32.8649+0.2667X
	L. flaviflamma	Y= 4.2610+0.6516X
	L. lentjan	Y= 3.2478+0.4813X
	G. oyena	Y=-2.2802+0.7950X
Fish + Invert. Eaters	L. bohar	Y=-6.0988+1.0471X
	S. lysan	Y=14.5359+0.8796X
	C. bajad	Y=10.5900+0.4653X
	A. rogaa	Y= 2.0088+2.6418X
Invert. Eaters	P. gaterinus	Y= 0.1478+1.1019X
	A. spinifer	Y= 1.6023-1.3896X
	C. suevicus	Y= 2.4463+1.0922X
Fish Eaters	T. choram	Y=-4.6623+0.6072X
	S. genie	Y=-6.6856+0.7090X
	C. ignobilis	Y= 0.7122-2.0704X
PLANKTIVORES	R. kanagurta	Y=21.8683+1.6051X
HERBIVORES	S. ghabban	Y= 0.2886+0.0134X
	S. rivulatus	Y=24.0508+2.8677X
OMNIVORES	T. jarbua	Y=-18.5853+1.8895X

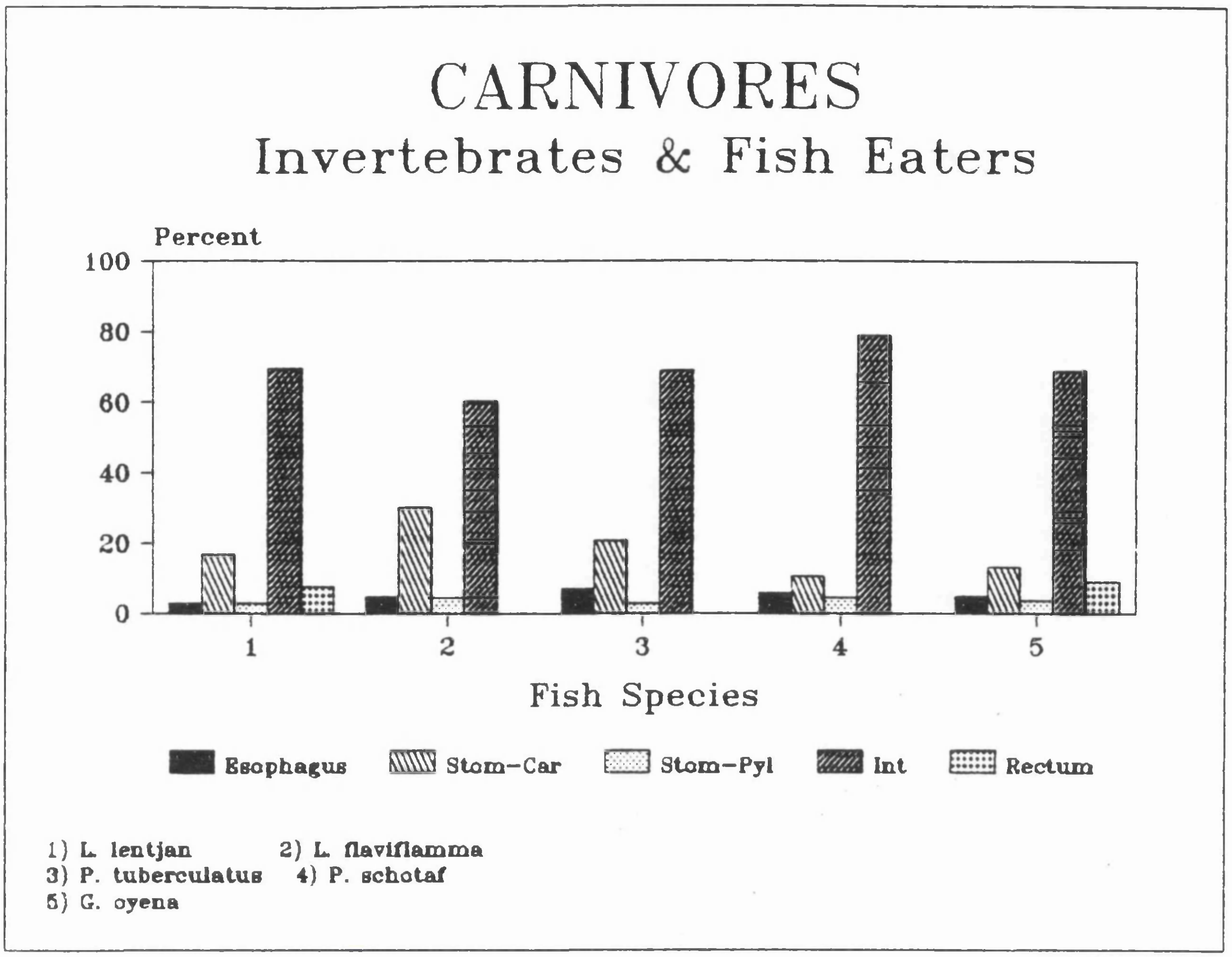


Figure 4.1. Gut proportions of carnivorous fish caught off Jeddah, Red Sea during 1986.

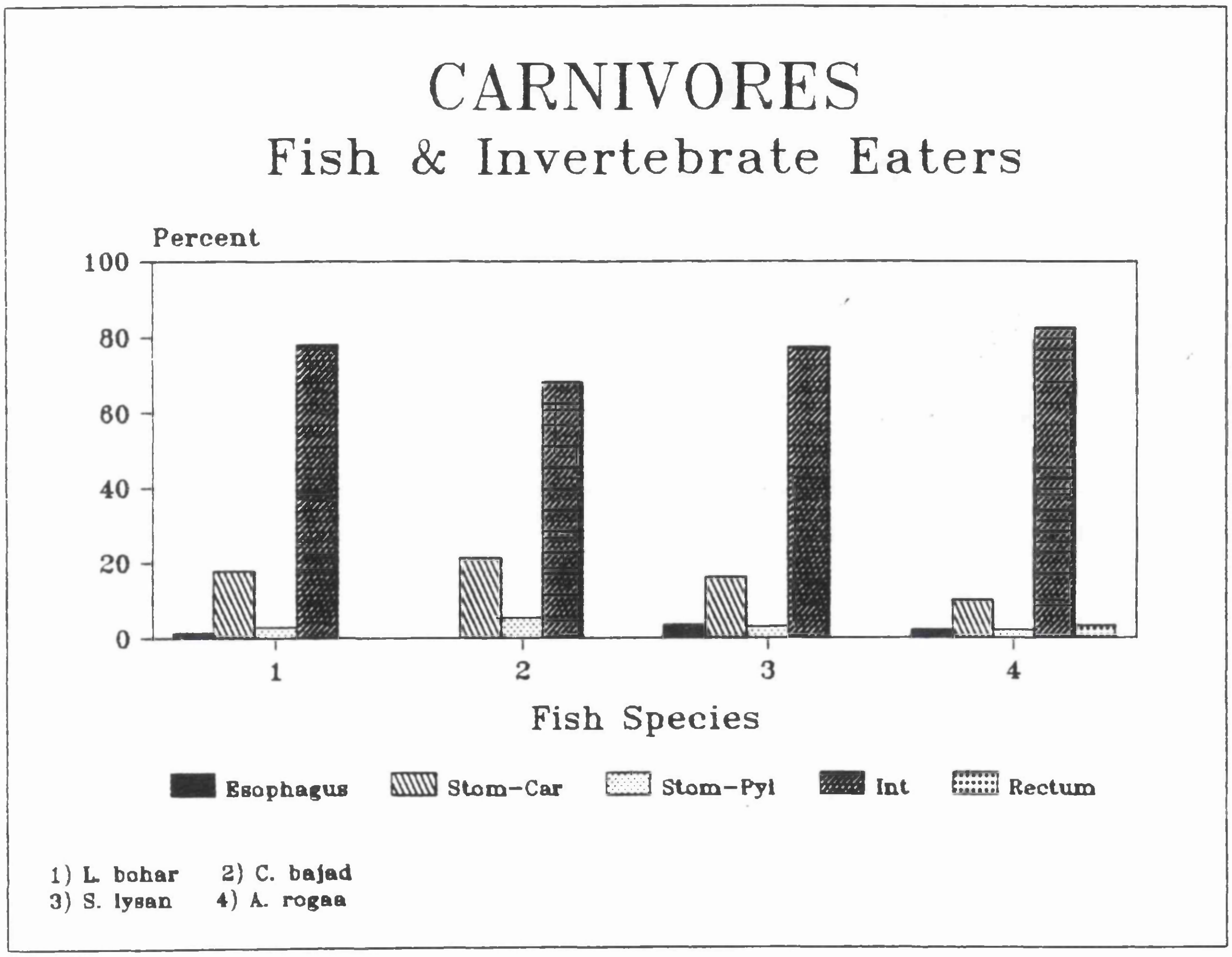


Figure 4.2. Gut proportions of fish-and-invertebrate-eating carnivorous fish caught off Jeddah, Red Sea, 1986.

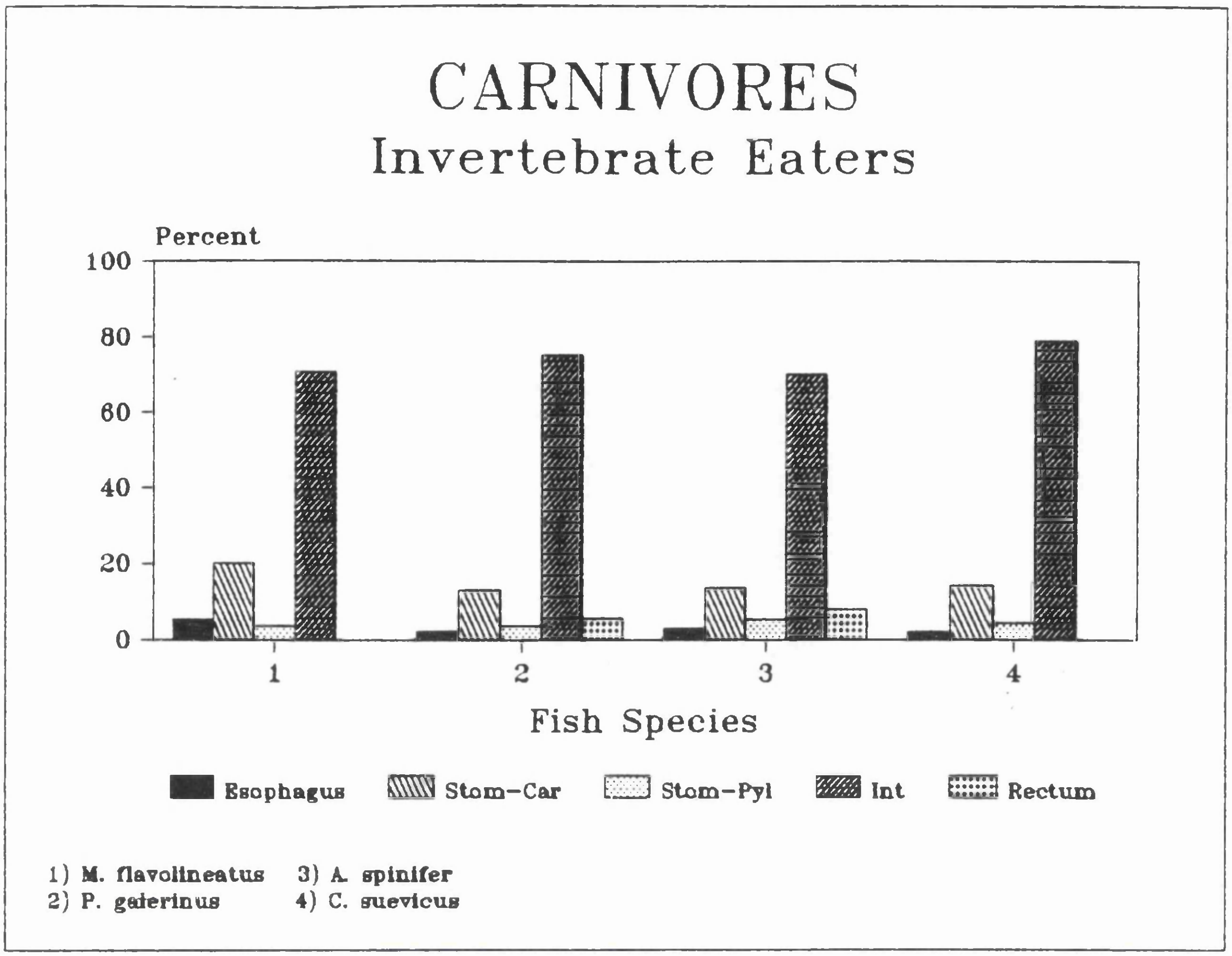


Figure 4.3. Gut proportions of invertebrate-eating carnivorous fish caught off Jeddah, Red Sea, 1986.

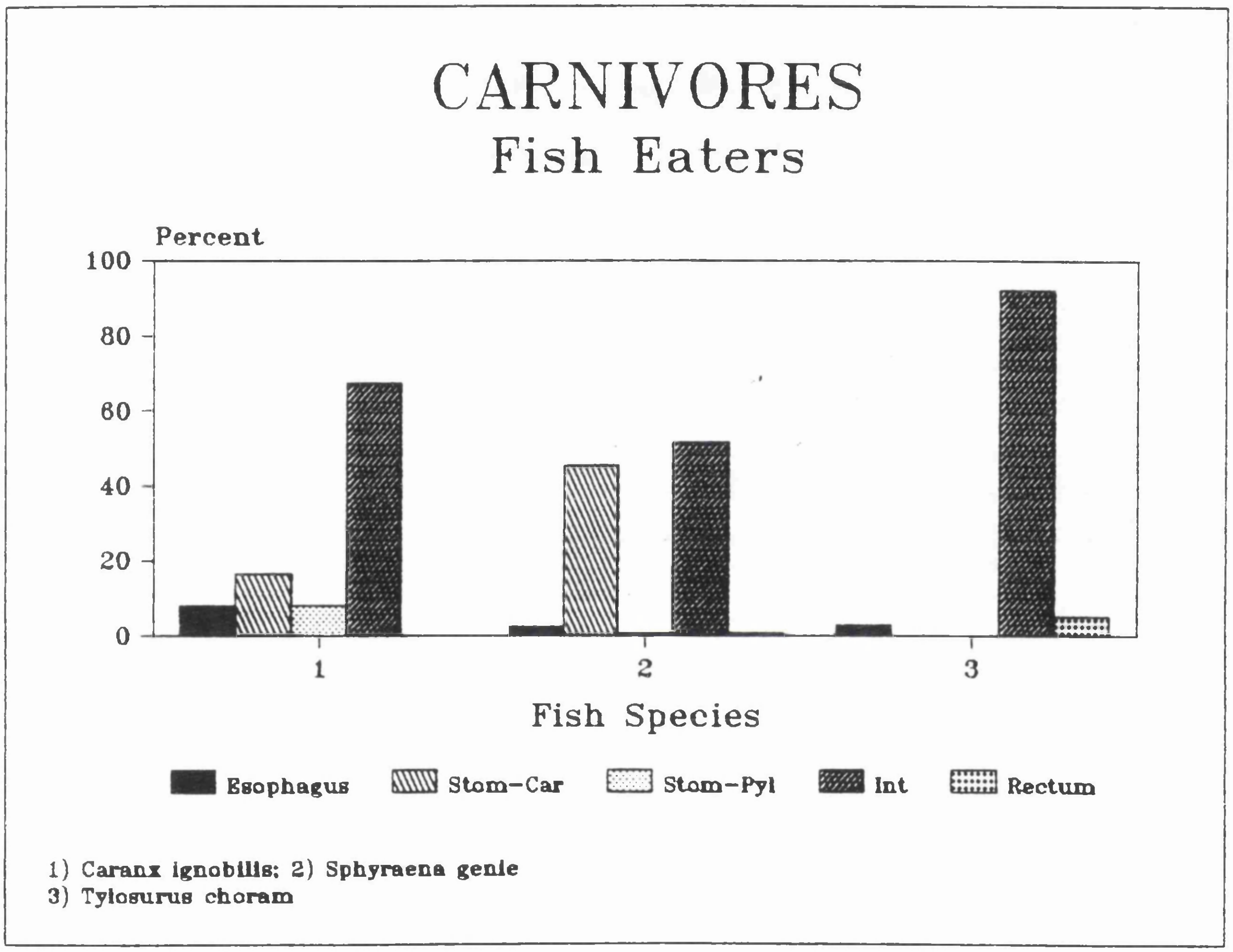


Figure 4.4. Gut proportions of fish-eating carnivorous fish caught off Jeddah, Red Sea, 1986.

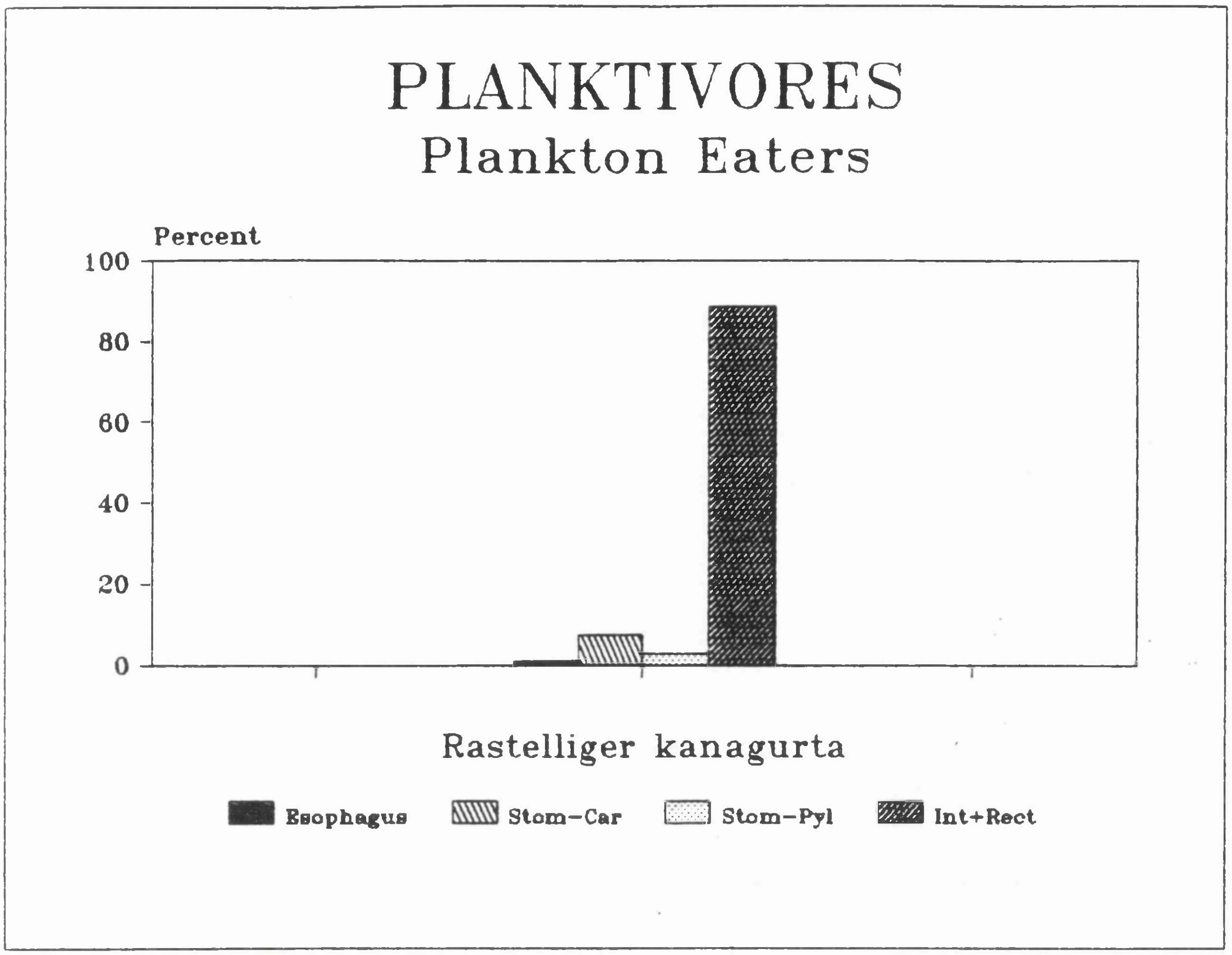


Figure 4.5. Gut proportions of planktivorous fish caught off Jeddah, Red Sea, 1986.

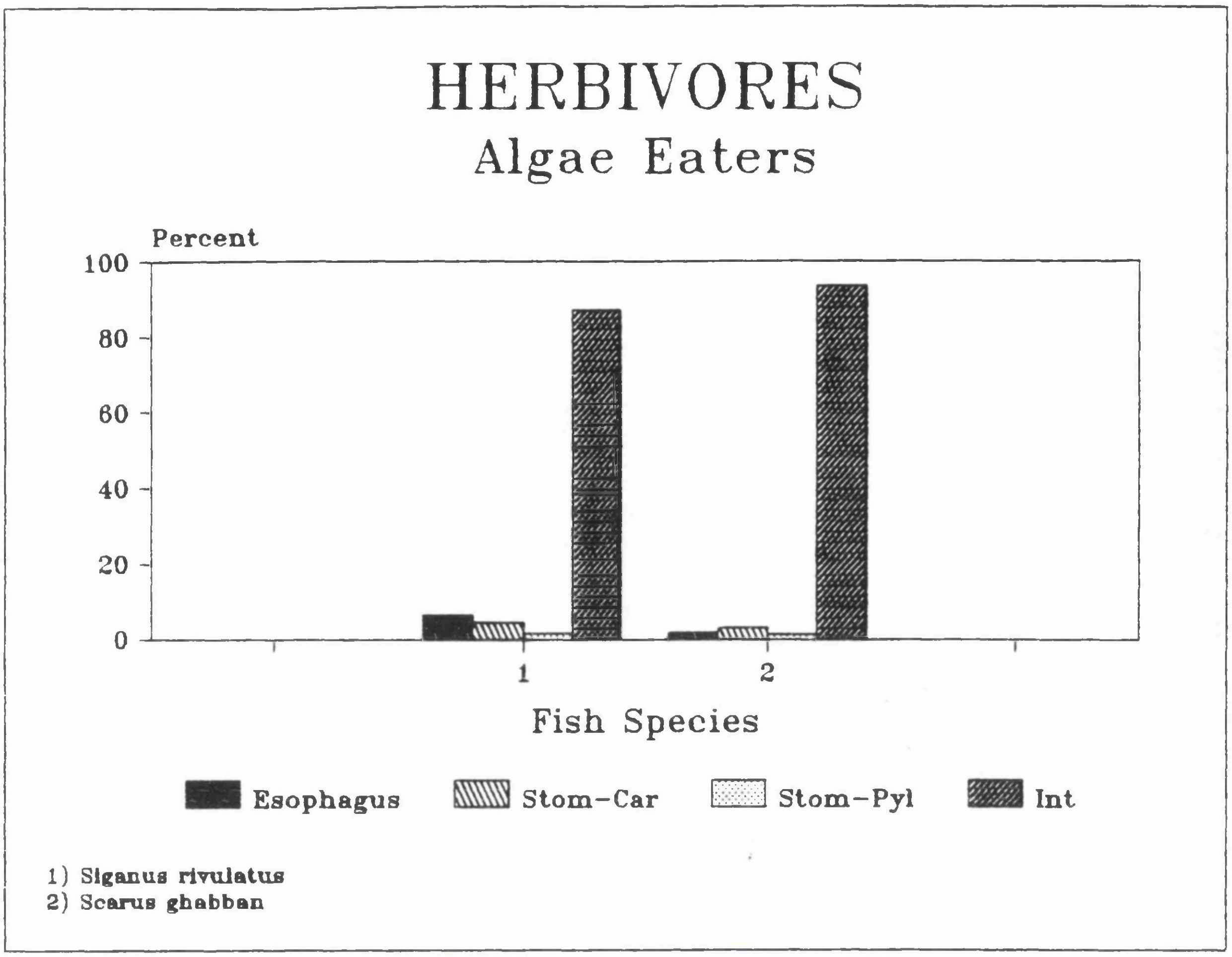


Figure 4.6. Gut proportions of herbivorous fish caught off Jeddah, Red Sea, 1986.

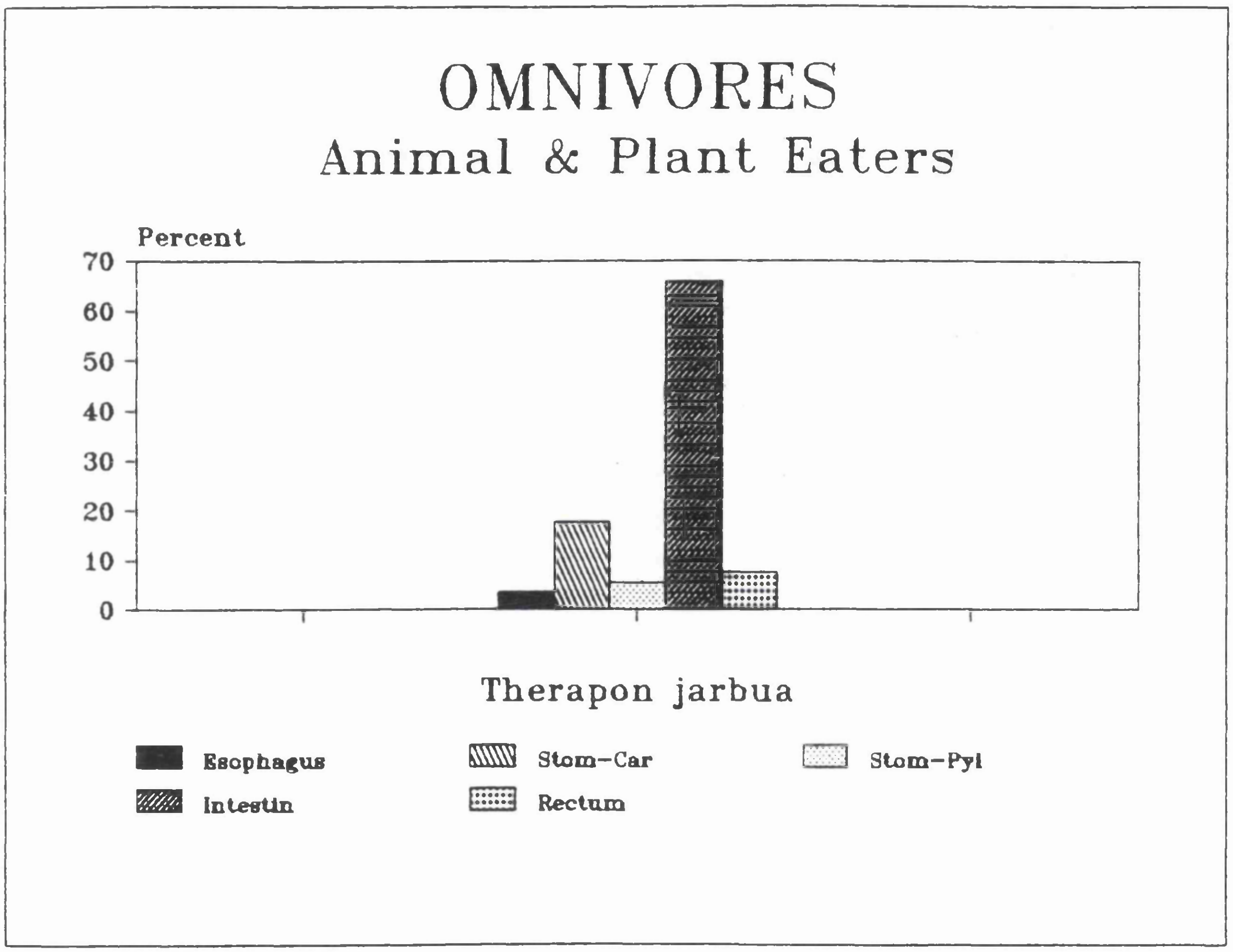


Figure 4.7. Gut proportions of omnivorous fish caught off Jeddah, Red Sea, 1986.

CHAPTR 5

HISTOLOGICAL STUDIES OF THE ALIMENTARY CANALS OF SOME RED SEA FISHES CAUGHT OFF JEDDAH, SAUDI ARABIA

5.1. Introduction

Teleost fish exhibit a wide range of food types and feeding habits. These are reflected in the remarkable morphological diversity of their alimentary tracts (Kapoor et al., 1975). Attempts have been made to correlate the structure of the alimentary tract with the feeding habits of teleost fish species.

The alimentary canal of fish, like those of other vertebrates, can conveniently be regarded as being divided into two regions (Banki, 1936), the "Kopfdarm" comprising the buccal cavity and pharynx, and the "Rumpfdarm" comprising the fore-gut (oesophagus and stomach), mid-gut (intestine), and hind-gut (rectum).

5.1.1 Oesophagus:

The oesphageal lining is provided either with numerous mucous cells (Kapoor, 1958a and Lopez and Carlo, 1959) or it may contain few club-cells and even taste buds (Mehrota and Khanna, 1969). This lining is protected, in some fish, by a cuticular covering (Ghazzawi, 1935) or by a cornified epithelium (Khalilov et al., 1963; Abou-Zinadah, 1983). Oesophageal glands have been reported by Sarbahi (1939); Weinreb and Bilstad (1955); Mohsin (1961 and 1962); Iwai (1962); Verighina and Medani (1968); Schmitz and Baker (1969); Abou-Zinadah (1983) and Ismail (1988). Kapoor et al. (1975) reported that the striated muscular layers vary in disposition in the oesophageal wall; sometimes with only the circular muscle layer present, the longitudinal one being absent or present only as dispersed bundles in the sub-epithelial tissue. A muscularis mucosa has been observed by Kudinsky (1966).

5.1.2. Stomach :

Al-Hussaini and Kholy (1953) and Mohsin (1962) reported that the oesophageal striated muscle may extend into the stomach. Moreover, a distinct muscularis mucosa can be distinguished, in the stomach wall, by Greene (1912); Al-Hussaini (1946); Burnstock (1959); Khanna and Pant (1964) and Bishop and Odense (1966). Kapoor *et al.* (1975) reported that the gastric mucosa varies in thickness in different regions of the stomach due to the development of gastric glands. Digestive glands are mainly restricted in the cardiac portion of the stomach, while those of the mucus-secreting nature are demonstrated in the pyloric stomach (Dawes, 1929; Chan, 1941; Islam, 1951; Sublette, 1956; Verighina, 1967; Vegas-Velez, 1972; Nikolyskaya and Verighina, 1974; Abou-Zinadah, 1983 and Ismail, 1988).

In contrast, Barrington (1957); Smit (1968); Western and Jennings (1970) and Verma and Tyagi (1974) identified only one type of secretory cell in the gastric glands and reported that no physiological division of secretory function exists.

The pyloric stomach in several teleosts is modified to act as a gizzard for trituration and mixing (Ghazzawi, 1935; Al-Hussaini, 1946, 1947 a&b; Wier and Churchil, 1945; Mahadevan, 1954; Thomson, 1954; Swarup, 1959; Castro et al., 1961; Verighina, 1967; Schmitz and Baker, 1969; Verighina and Savvaitova, 1974; Abou-Zinadah, 1983). Moreover, the stomach is either greatly reduced (Al-Hussaini, 1947b; Pasha, 1964 a&b; Verighina, 1967) or completely absent (Al-Hussaini, 1947b, 1949; Girgis, 1952 a&b; Gohar and Latif, 1959; Weisel, 1962; Matthes, 1963; Verighina, 1963; Ismail, 1988). In the stomachless fish, the fore-gut is enlarged in varying degrees and referred to as intestinal bulb, duodenum, swollen part of the intestine, large arm of the intestine and even erroneously as stomach (Kapoor, 1958b; Al-Hussaini, 1947b).

5.1.3. Intestine :

The intestine of fish shows a variety of mucosal ingrowths such as villi and crypts (Jacobshagen, 1937), typhlosole in the ileum (Al-Hussaini, 1945; Ismail, 1988), ileo-rectal valves (Al-Hussaini, 1947b; Maggese, 1967), annulo-spiral septa (Burnstock, 1959; Bullock, 1963; Korovina, 1973), rectal caeca (Agrawal and Singh, 1964; Singh, 1966, 1967 a&b). Intestinal glands have been observed in some Gadidae (Bishop and Odense, 1966) and Macrouridae (Geistdoerfer, 1973; Ismail, 1988).

The small intestine leads into the rectum and externally the difference between the two regions is sometimes well-marked, though internally they can be differentiated on the basis of their histological structure, the main histological differences being : the greater degree of epithelial folding in the rectum, distinguished by a thicker muscular coat and a great abundance of mucous cells in the rectal epithelium as compared with the ileum (Dawes, 1929; Blake, 1936; Young and Fox, 1936; Sarbahi, 1939; Al-Hussaini, 1945, 1946, 1947 a&b; Islam, 1951; Mohsin, 1962; Abou-Zinadah, 1983; Ismail, 1988). In addition, an ileo-rectal valve has been described by many authors such as Dawes (1929), Al-Hussaini (1945, 1946, 1947 a&b) and Ismail (1988).

The pyloric caeca differ in number, form, disposition and communication with the intestine. They are, histologically, almost identical with the intestine (Rahimullah, 1943, 1945; Saddler and Ashley, 1960; Khanna and Mehortra, 1971; Kapoor _et al._, 1975). In some fish such caeca are provided with cilia (Rahimullah, 1945) and even with a sphincter at the base (Blake, 1936; Burnstock, 1959). Khanna (1961) and Mohsin (1962) suggested that the presence or absence of the pyloric caeca has no apparent correlation with the nature of the food. But, Svetovidov (1934) and de Groot (1969) found a correlation between the number of caeca and the kind of food and even an increase in their size with bulk of food.

In the present study, a piscivorous fish, _Tylosurus choram_; a planktivorous, _Rastelliger kanagurta_; a herbivorous fish, _Siganus rivulatus_; and an omnivorous fish, Therapon jarbua, have been described in order to investigate the possible correlation between the histological structure of the alimentary tract and the food and feeding habits of these fish species.

5.2. Material and Methods

Tylosurus choram, Rastelliger Kanagurta, Siganus rivulatus and Therapon jarbua, were selected to represent carnivores, plankton feeders, herbivores, and omnivores, which occur commonly in landings from the commercial fishing area in the vicinity of Jeddah (Figure 1.1).

For histological study, fresh specimens of the four fish species were dissected on board ship as soon as they were caught. The digestive tract was taken out and washed in a physiological saline solution. The different parts of the alimentary tract were then fixed in fixatives such as Bouin's fluid and Zenker's fluid. After fixation, dehydration, clearing and embedding in paraffin wax, a series of transverse sections were cut at 6-8 Microns in thickness and stained with Mayer's haem-alum and eosin, or Mallory's triple stain. The latter was found useful for demonstrating the presence of cilia. Black and white photomicrographs were prepared for various sections to illustrate the text.

5.3. Observations :

5.3.1. Oesophagus :

The oesophageal wall is composed of several layers which are, from the inside (lumen side) out: mucosa, submucosa, muscularis, sub-serosa and serosa.

5.3.1.1. Mucosa : The mucosal epithelium in *Tylosurus choram* is composed mainly of numerous mucous or goblet cells arranged in more than one row. Each mucous cell contains a small nucleus compressed basally by a markedly reticulated cytoplasm. The basal cells, situated deeper, are less compressed and thus appear more circular in form; they are closely packed with relatively larger nuclei and markedly basophilic cytoplasm (Plate 5.I.1). Between the mucous cells lie narrow ciliated columnar cells (Plate 5.I.2). The mucosal epithelium sinks deep into the tunica propria of the mucosal folds which when transversely cut near their bases, circular structures appear, giving a false impression of oesophageal glands ("O.Ep." Plate 5.I.1&2).

The mucosal folds are mainly villiform in *Rastelliger kanagurta* (Plate 5.I.4),while in *Siganus rivulatus* (Plate 5.II.6), the mucosal folds have secondary branches. In the case of *Therapon jarbua* (Plate 5.II.7), there are major and minor mucosal folds which give rise to secondary and sometimes tertiary small branches. The mucous cells, in *R. kanagurta* and *S. rivulatus*, are similar in form to the typical goblet cells, consisting of a simple epithelium, while in *T. jarbua*, the mucosal epithelium is composed of more than three layers, and the typical goblet cells are arranged in groups which are separated by another group of fairly thin columnar cells (Plate 5.II.7). In these three fish, the mucous cells are covered with a cap of flattened cells. In the case of *S. rivulatus* the tips of the mucosal folds which face the oesophageal lumen, are built up of a well developed stratified epithelium which is mostly free of mucous cells (Plate 5.II.5). In *R. kanagurta* (Plate 5.I.3) and *S. rivulatus* (Plate 5.II.5), the mucosal epithelium near the bases of the folds sinks deeply into either the sub-mucosa or tunica propria and gives rise to oesophageal glands. The latter appear in the form of simple alveolar glands. Taste buds have not been observed in the oesophagus of any of the four species studied.

5.3.1.2. *Sub-mucosa* : In *I. choram* this layer is composed of connective tissue fibres which are dense and compact. This tissue is formed mainly of small granular cells, with darkly stained nuclei, blood capillaries and nerve fibres. The sub-mucosal tissue extends into the mucosal folds to form their supporting cores, the tunica propria. The stratum compactum is absent (Plate 5.I.1).

The sub-mucosa and its mucosal projections, the tunica propria, are poorly developed and not compact in either of *R. kanagurta*, *S. rivulatus* or *I. jarbua*. It contains some small granular cells, numerous lymphatic cells, a large number of blood capillaries and lymphatic vessels and spaces. Stratum compactum was also observed in the sub-mucosa of S. rivulatus and I. jarbua, while in R. kanagurta stratum compactum has been observed in the oesophageal sub-mucosa (Plate 5.I.4).

5.3.1.3. Muscularis : In I. choram is composed of striated muscle fibres which are arranged in two layers, the outer being longitudinal, and the inner circular (Plate 5.I Fig. 1). The two layers are highly variable in thickness along the oesophageal wall.

The muscular coat in I. jarbua is markedly thick and the disposition of the longitudinal and circular muscles is on the same pattern as described in I. choram. On the contrary, the arrangement of the two muscular layers is reversed in the oesophagus of both R. kanagurta and S. rivulatus, as the longitudinal muscle fibres form the inner muscular layer, while the circular muscle fibres form the external muscular layer (Plates 5.I.3 and 5.II.5). The muscle fibres are disposed in the form of muscular bundles or fascicles which are separated by loose connective tissue. In the internal longitudinal muscular layer, the fascicles extend into the sub-mucosa, mostly near its periphery, but some of them extend obliquely and penetrate into the connective tissue forming the core of the mucosal folds, tunica propria (Plate 5.I.3 and Plate 5.II.5). The intermediate or mesentric layer is absent in both R. kanagurta and S. rivulatus, while it is well represented in the oesophagus of I. jarbua and more distinct in I. choram.

5.3.1.4. Sub-serosa : This is well developed and consists of more or less loose connective tissue than the muscularis, and is rich in blood capillaries (Plate 5.I.1).

5.3.1.5. Serosa : is the outermost layer and is composed of a single layer of peritoneal cells (Plate 5.I.1).

5.3.2. The stomach :

During the course of examination of the alimentary tract of Tylosurus choram it was observed that this species is stomachless, while in the other three fish species under investrigation, as is often the case in most teleosts, the stomach was curved, with proximal (descending) and distal (ascending) limbs that are commonly referred to in the literature as the "cardiac" and "pyloric" regions of the stomach (Barrington, 1957).

5.3.2.1. Cardiac stomach:

The cardiac stomach has the same histological structures as in the oesophagus and they were found to be clearly defined in the fish species under investigation.

In Siganus rivulatus and Therapon jarbua, in spite of the general form and structure of the stomach, both of the cardiac and pyloric regions are of a similar nature and resemble that of Rastelliger kanagurta in the essential respects, with the exception of a few modifications that have been observed.

5.3.2.1.1. *Mucosa* : In *Rastelliger kanagurta* the gastric epithelium is thrown into a number of folds which have a fan-shaped appearance (Plate 5.III.8). The surface epithelium, towards the tips of the folds, consists of columnar cells which have circular nuclei and a reticulated cytoplasm (Plate 5.III.9). The cells lining the gastric pits are more elongated and of similar form and structure, but their basal nuclei are mostly oval in shape and contain one or two nucleoli. Going deeper in the gastric pits, the epithelial cells become more or less cuboidal and contain rounded nuclei. A few goblet cells also occurred in the epithelium. The mucosa has a well developed glandular region which consists of a large number of branched tubular gastric glands (Plate 5.III.8&9). The glands are separated from each other by a very thin layer of connective tissue, from the tunica propria. It is not easy to show how the glands are connected with the stomach lumen through the gastric pits, as it mostly happened that the section did not pass through this critical part. But some of those glands are seen clearly to open into the pits (Plate 5.III.10). It has been observed, however, that two or three gland ducts open into a single gastric pit. Each gastric gland is composed of large cuboidal or polygonal cells, enclosing a narrow duct, their darkly stained large nuclei are located toward the basal part of the cell and each of them contains a distinct nucleolus (Plate 5.III.9).

One of the differences between the two portions of the stomach is the presence or absence of gastric glands (Kapoor et al., 1975). It has been observed that the gastric glands were abundant in the cardiac region of the stomach of both *S. rivulatus* and *I. jarbua* (Plate 5.IV.12&13 and Plate 5.V.16&17).

Although the cells of the cardiac glands are similar in structure but they vary in shape and size in the different species, yet a variation in the shape and size of these glands was observed during this investigation. Thus, in *R. kanagurta* they are large cuboidal or polygonal in shape, but they are only large cuboidal in *S. rivulatus* (Plate 5.IV.13) and small oval or cuboidal in *I. jarbua* (Plate 5.V.17). The size of such nuclei are, more or less, dependent on the size of the glandular cell. Moreover, it has been observed that all the cells of the cardiac glands in each of the fishes studied are of similar nature, that is, they seemed not differentiated into what is known as the parietal or oxyntic cells and peptic cells described by Barrington (1957).

Another feature of the cardiac mucosa is the rare occurrence of the mucus-secreting cells.

Still another notable aspect of the cardiac stomach structure, is that the muscularis mucosa has been observed only in *Siganus rivulatus* (Plate 5.IV.12), in which a distinct layer lying just below the stratum compactum and formed by the combination of some connective tissue fibres, is derived from the sub-mucosa and a few fine muscle fibres.

5.3.2.1.2. *Sub-mucosa* : In *R. kanagurta* it forms a comparatively wider area than in either *S. rivulatus* or *I. jarbua*. It coats the mucosa and is built up of a highly vascularized and innervated areolar connective tissue in which few granular cells are dispersed (Plates 5.III.9; 5.IV.12; and 5.V.16). It projects into the mucosal folds to form a well developed tunica propria which runs around the gastric epithelial layer, following its curvature. A number of strands from the tunica propria penetrate deep in between the gastric glands, thus separating them. A poorly developed stratum compactum can be seen running parallel to the mucosal epithelium. It is composed of a conspicuous band of loose connective tissue fibres and provides a rigid support for both the tunica and the entire glandular mucosal epithelium (Plate 5.III.8).

5.3.2.1.3. *Muscularis* : In *Rastelliger kanagurta*, *S. rivulatus* and *I. jarbua* this coat is built up of an outer longitudinal and an inner circular muscle layers consisting of smooth muscle fibres. The circular muscular layer consists of a compact mass of circularly arranged muscle fibres made up of spindle-shaped cells with oval nuclei. The longitudinal layer is about half the thickness of the circular one. The two layers are separated by a very thin intermediate layer of areolar connective tissue.

5.3.2.1.4. *Sub-serosa* : In spite of its discontinuity, as a layer, it is well developed and consists of connective tissue fibres, in which blood capillaries and nerve fibres can be observed (Plate 5.III.8).

5.3.2.1.5. Serosa : It is a very thin layer which consists of a single layer of peritoneal cells (Plate 5.III.8).

5.3.2.2. Pyloric stomach :

The pyloric stomach possesses all the coats present in the cardiac stomach, but there are two main differences that must be noticed.

The first is that the lumen is not bordered by a continuous mucosal epithelium. The latter mostly forms six large bunches of simple tubular glands. Between these major folds much finer ones can be observed. Among this folding system, channels of various calibres are observed (Plates 5.III.10&11 and 5.IV.14&15). The granular epithelium consists of a single layer of cuboidal cells with darkly stained small nuclei, mostly located near the base of the cells, and faintly stained cytoplasm. The whole lumen is bordered or lined by a thick layer of protective covering. Microscopically this layer appears mostly laminated parallel to the lumen border. It seems that this lining is secreted by the tubular glands (Plates 5.III.11 and 5.IV.14). This lining certainly acts as a protection for the soft epithelial and sub-epithelial tissues underneath which would, otherwise, be injured or torn away by the hard food material. Moreover, the food of the fish which contain hard substances such as corals, is always found in the lumen surrounded by a heavy matrix which is secreted from the top of the glandular bunches (Patt and Patt, 1969).

The second difference is that the muscularis does not form a compact layer as in the cardiac stomach. It is composed of small bundles or fascicles separated by areolar connective tissue (Plates 5.III.11; 5.IV.14 and 5.V.19). The arrangement of the two muscle layers is the reverse to that in the cardiac portion. Moreover, the thickness of the internal longitudinal muscle layer varies along both the contour of the cross and longitudinal sections. It is well developed just where the large glandular bunches occur.

In the pyloric region of *S. rivulatus* (Plate 5.IV.14&15) the gastric glands are relatively few in number and absent in *I. jarbua* (Plate 5.V.18&19).

The pyloric glands in *S. rivulatus* do not border the whole lumen, only the part which is lined by epithelium. The pyloric glands are in the form of bunches of almost equal depth. These glands are composed of narrow low columnar cells arranged in an oblique parallel position. Their large nuclei lie at their base. The mucoid secretion of this epithelium forms a thick layer lining the lumen of pyloric region. Also it has been observed that desquamated cells, from the surface epithelium, are incorporated internally in this lining which is placed on the internal surface of the soft epithelial tissue underneath, which would otherwise be injured or torn away by hard foods and sand granules during the action of this highly muscular part (Plate 5.IV.14&15). This observation is based on the fact that in none of the studied sections was food found in actual contact with the epithelium. It was always found surrounded by a layer of the mucoid secretion.

In the case of *Therapon jarbua*, the mucosal epithelium of the pyloric stomach is a continuous layer thrown into numerous simple and branched folds of different depth and supported by papillae-like strands of connective tissue (Plate 5.V.18). These epithelial folds are arranged at the base of the grooves in a rosette-like shape radiating on the connective tissue folds. The mucosal epithelium ("Mu.C." in Plate 5.V.18) consists of columnar cells between which numerous goblet cells are situated. The epithelial cells arrange themselves in a parallel position along the pit-like depression and in a fanlike disposition at the tips of the folds. Their nuclei lie at their base, and are large and each has a distinct nucleolus.

Concerning the muscular coat, the peculiarities noticed in the pyloric region of the stomach of *Rastelliger kanagurta* in which the muscularis is comparatively thin and the arrangement of the muscular layers is reversed (the circular layer is outer and the longitudinal one is inner) are the exact opposite of the normal condition as observed in *S. rivulatus* and *T. jarbua* (Plate 5.III.11). In these fish, the muscularis is markedly thick and the layer of circular muscle fibres is sufficiently developed, thick and compact, while the layer of longitudinal muscle fibres is comparatively thin and diminishes gradually going toward the pyloric constriction where it is completely absent (Plates 5.IV.14 and 5.V.18&19).

5.3.3. The pyloric caeca

The pyloric caecum of Rastelliger kanagurta (Plate 5.VI.20&21) differs in its histological details from the structure of the pylorus and resembles, to a great extent, that of the intestine. The histological composition of the pyloric caecum shows the following structures :

5.3.3.1. Mucosa : The caecal epithelium is thrown into a number of major and minor folds which are mostly finger-shaped. This epithelium consists of narrow and long columnar cells with darkly stained nuclei. The basal parts of most of these cells are filamentous and reach even up to the tunica propria (Plate 5.VI.21). Mucus-secreting cells are very few in number and occur mostly towards the inner surface of the epitheium. Few lymphocytes are observed. The apical part of each columnar cell is bordered by a top-plate.

In the case of Siganus rivulatus (Plate 5.VI.22) the mucosal epithelium is thrown into numerous villi which have the same histological structure as in R. Kanagurta, while, the columnar epithelium of the caecal fold of Therapon jarbua (Plate 5.VI.23) is composed of 2-3 layers of cells with rounded nuclei.

5.3.3.2. Sub-mucosa : In *R. kanagurta* it is greatly reduced due to the sinking down of the caecal folds into this layer. In spite of this, the tunica propria is mostly conspicuous. Stratum compactum is absent (Plate 5.VI.21).

The sub-mucosa in *S. rivulatus* and *T. jarbua* is better developed than in *R. kanagurta*, thus the tunica propria is markedly conspicuous. In *S. rivulatus* it has been observed that the sub-mucosa is invaded by numerous large lymphatic spaces and lymphatic cells (Plate 5.VI.22).

5.3.3.3. Muscularis : It consists in *R. kanagurta* of only a continuous thin layer of circular muscle fibres (Plate 5.VI.21), while in *S. rivulatus* and *T. jarbua* the muscularis consists of a comparatively thicker circular layer which is inner and a thin longitudinal layer of muscle fibres which is outer (Plate 5.VI.22&23).

5.3.3.4. Sub-serosa and serosa : The sub-serosa is not distinct while the serosa is very thin (Plate 5.VI.21).

5.3.4. The intestine :

Tylosurus choram has a straight intestine which starts posterior to the oesophageal-intestinal valve and extends to the ileo-rectal valve. It can be divided into two sections; the proximal part, or the duodenum, as it is known, and the distal part which represents the intestine proper, or the ileum. In any of these sections, there are four distinguishable layers in the intestinal wall; i.e., mucosa, sub-mucosa, muscularis, and serosa. The only marked difference between the two sections is that the mucosa is more complex in the distal part than in the proximal one, but generally the intestine has a consistent histological organization throughout its length with minor cytological variations.

5.3.4.1. Mucosa : The epithelial layer of the mucosa consists of simple columnar tissue that, in some places, go deeper into the sub-mucosa (Plate 5.VII.24&25). Two types are found in this layer; i.e. goblet cells and columnar cells, the former type of cells are markedly abundant. The columnar cell is elongated and ciliated, its basal nuclei are large, oval, or slightly rounded and having a distinct deeply stained nucleolus; the cytoplasm is granular (Plate 5.VII.25). The goblet cells are scattered irregularly throughout the epithelium, though they decrease in number towards the tips of the mucosal folds. They are of typical chalice shape, with a slender base and cup-shaped mucigen-containing area open to the lumen. The nuclei of such cells are located in the base of the goblet cells near the basement lamina, and are surrounded by a granular acidophilic cytoplasm. Leucocyte or wandering cells are also seen between the two epithelial elements (Plate 5.VII.25).

The mucosal epithelium of the distal part of the intestine differs histologically from the proximal part. The intestinal folds projecting from the mid-dorsal line of the intestine are much longer, they interdigitate and unite with one another forming a spongy mass seen as a thick mesh-work in transverse sections, this structure is known as the typhlosole (Plate 5.VII.26). The intestinal lumen is very restricted and reduced to a narrow space in between the typhlosole and the low mucosal folds bordering the other sides of the intestinal lumen.

The epithelium consists of two kinds of cells; i.e., ciliated columnar and mucus-secreting cells. The cylindrical columnar cells are more abundant and lower than those of the proximal part. The nucleus is oval in shape and has a distinct nucleolus; it is situated in the basal half of the cell. The cilia, bordering its apical part, are more conspicuous than before (Plate 5.VII.27).

The mucus-secreting cells are different in shape and form. These cells are fewer than in the proximal part of the intestine and are mostly localized along the sides of the folds (Plate 5.VII.27A (inset)). Wandering leucocytes are numerous and invade the epithelium and, in the majority of cases, occur towards the base.

In the other three fish species, the proximal portion of the intestine does not differ in structure from that of the rest of the intestine. The intestinal epithelium possesses the typical structure as described in *Tylosurus choram*, the only difference being in the size and number of the intestinal folds as in *Rastelliger kanagurta* (Plate 5.VIII.28&29) and shape of folds as in *Siganus rivulatus* (Plate 5.VIII.30&31) and *Therapon jarbua* (Plate 5.IX.32&33). The epithelium consists of columnar and goblet cells. The former are very elongated in form in the three fishes, especially in *I. jarbua*. In these cells a thin striated border is continuous along the whole epithelium and is interrupted only where the goblet cells open into the lumen (Plates 5.VIII.29&31; and 5.IX.33). Generally, the goblet cells are not so numerous as in the intestine of *I. choram*, and they also have a typical goblet outline with a filamentous basal portion. The intestinal villi in *R. kanagurta* and folds in *S. rivulatus* are provided, in the tunica propria, with lymphatic vessels of varying size (Plate 5.VIII.29&31).

5.3.4.2. *Sub-mucosa* : This is a well developed compact layer of varying thickness from proximal to distal portions of the intestine. It is composed of a richly areolar connective tissue continuous with that of the tunica propria (Plate 5.VII.25&27). This layer is characterized by the presence of a great number of granular cells. These are small and stained deeply with eosin. They are irregular in shape and their deeply stained nuclei are eccentric. The stratum granulosum is absent. Very few fibres of stratum compactum border the inner surface of the sub-mucosa, and in other places they penetrated radially inside the intestinal folds (Plate 5.VII.27).

The sub-mucosa the intestine of *R. kanagurta*, *S. rivulatus* and *I. jarbua* is similar in structure as found in *I. choram*, excepting that it is poorly developed and contain a fewer number of granular cells (Plates 5.VIII.28&30; and

5.IX.32). In these fish, however, the tunica propria, is more developed than in T. choram.

5.3.4.3. Muscularis : The muscular coat in T. choram consists of two layers; a thicker compact inner layer of circular fibres and a thinner outer one of longitudinal fibres, both of which are unstriated. The intermediate or Myentric layer is not distinct (Plate 5.VII.24).

The circular and longitudinal muscle layers and the intermediate layer between them in both S. rivulatus and T. jarbua are similar to those found in T. choram (Plates 5.VIII.30; and 5.IX.32). But in R. kanagurta these coats are very thin and transparent, thus allowing the fecal material to show through (Plate 5.VIII.28).

5.3.4.4. Serosa : In the four studied fish species is thin and built up of pavement epithelium. Internal to the serosa, in some places, there is a scanty amount of connective tissue (Plate 5.VII.27).

5.3.5. The rectum

The rectum of Tylosurus choram is marked off from the distal part of the intestine by the ileo-rectal valve (Plate 5.IX.34). It differs in structure from the intestine generally in the form and shape of the mucosal folds. The distal part of the intestine in both S. rivulatus (Plate 5.X.39) and T. jarbua (Plate 5.XI.42) passes into the rectum through an ileo-rectal valve which is similar to that in T. choram. In R. kanagurta there is no ileo-rectal valve. In general, the histological composition of the rectum consists of mucosa, sub-mucosa, muscularis, sub-serosa and serosa.

5.3.5.1. Mucosa : The mucosal folds are markedly thicker and more highly branched than that of the intestine (Plates 5.IX.35; and 5.X.36). Small folds are also found, in some places, at the bases of the large ones. The branches unite, so that the folds appear as if completely amalgamated, giving the epithelium a net-like appearance. The rectum of R. kanagurta (Plate 5.X.38), S. rivulatus (Plate 5.X.41) and I. jarbua (Plate 5.XI.43) does not differ much in its histological structure from that of I. choram, but in shape they are less similar. In R. kanagurta, the folds are generally similar in shape and size, they are comparatively fewer, not branching and have a stumpy appearance at their free ends (Plate 5.X.37), while in S. rivulatus and I. jarbua, major and minor folds can be observed (Plate 5.XI.40&42). The mucosal epithelium shows the two common varieties of cells; i.e., columnar and mucus-secreting cells. The two types are as those described in the distal part of the intestine. Small wandering leucocyte invade the epithelium. The granular cells show a remarkable decrease in number (Plate 5.XI.40).

In R. kanagurta and S. rivulatus the mucosal epithelium is simple columnar, while it consists of three to four layers of cells in I. jarbua and a striated border can be seen bordering the epithelium. In general, the goblet cells are less abundant. The leucocyte are few in number in

R. kanagurta and highly represented in the other two species. In the three species lymph spaces also occur, but they are more numerous and voluminous, especially in R. kanagurta than in I. choram (Plate 5.X.38).

5.3.5.2. Sub-mucosa : It is comparatively reduced, enclosing numerous blood capillaries. Lymph spaces are rare. The tunica propria is very voluminous and markedly invaded by numerous small leucocyte and granular cells. The latter, as in the intestine, do not form a stratum granulosum (Plates 5.IX.35; 5.X.37; 5.XI.40 and 5.XI.43).

5.3.5.3. Muscularis : In I. choram this consists of two layers, a thicker inner layer of circular muscle fibres, and a thinner outer layer of longitudinal fibres. The intermediate or Myentric layer is poorly developed (Plate 5.IX.35). In the other three fish species, the musculature as a whole is of the same structure, but thicker.

5.3.5.4. Sub-serosa : It is fairly well developed, consisting of areolar connective tissue which is well vascularized and innervated.

5.3.5.5. Serosa : It is of a usual type and consists of a thin layer of epithelial cells (Plate 5.IX.35).

5.4. Discussion

Histological studies on the alimentary canal of teleosts have demonstrated structural differences which are correlated to the diets of the fish (Kenyon, 1925; Suyehiro, 1934; Ghazzawi, 1935; Imhof, 1935; Ishida

1935b; Al Hussaini, 1947b; Grigis, 1952b; Gohar and Latif, 1959; Khanna, 1962; Greenwood, 1964; Kazansky, 1964; Khanna and Pant, 1964; Kapoor, Smith and Verighina, 1975). These workers reported that the form and position of the mouth, dentition on the jaws and in the bucco-pharynx, pharyngeal pads and cushions, bucco-pharyngeal teeth, mucous glands and taste buds are closely related to the mode of feeding and the kind of food.

Some authors notably Suyehiro (1934), Ghazzawi (1935), Imhof (1935) have also carried out individual studies on a limited number of species and have come to conclusions that illustrate a structural adaptation against the hard material contained in the normal diet in these species. Kenyon (1925) has shown that even the enzymes secreted in the digestive tube differ in their nature and amount according to the kind of food included in the normal diet of the fish. Ishida (1935b) also found similar differences in Mugil cephalus (Linn.).

In contrast, other work has shown that in some fishes there is no correlation between the diet and structure of the alimentary canal (Hartley, 1947; Angelescu and Gneri, 1949; Barrington, 1957; Harder, 1960; Greenwood, 1964; Bishop and Odense, 1966; Fryer and Iles, 1972; Vereghina, 1974). Nikolsky (1963) reported no specialization of the digestive system in an iliophagous fish, Prochilodus lineatus (val). Moreover, Greenwood (1964) found Haplochromis species (Cichlidae) of Lake Victoria showed a wide adaptive range of diets so making the best use of every available food. He grouped them into:

I. a generalized insectivorous species (*H. macrops* (Blgr)),

II. a "winkle-picking" mollusc-eater (*H. sauvagei* (Blgr.)),

III. a species feeding on embryos and larvae obtained from the mouth of brooding females of other Cichlids (*H. parvidens* (Blgr)), and

IV. a piscivorous predator (*H. cavifrons* (Hild)).

Fryer and Iles (1972) also described a range of diets in Cichlidae species of the African Great Lakes. Nikolsky and Verighina (1974) mentioned some characteristics regarding the gut structure of some Pleuronectidae living in different ecological niches.

It is clear, too, that fish can adapt their diet to the circumstances prevailing in the particular community in which they are established. Harder (1960) and Bishop and Odense (1966) questioned the relationship between feeding habits and gut structure. They pointed out that the food of the carnivorous cod *Gadus morhua* L. is not specialized and varies with population, season and size of the individual and Hartley (1947) found that the roach might be predominantly herbivorous or carnivorous as opportunity offered.

In the present study, from the observation of the order of the various layers in the different regions of the alimentary canal, it was found that the basic structure and sequence did not vary clearly from one feeding group to the other. However, minor variations that could be related to the type of food prefered by the fish were observed. In general, it should be mentioned that carnivores and omnivores showed almost the same structures in the different parts of the alimentary canal, with the exception of the absence of the stomach and pyloric caeca in carnivores. The structure of the alimentary canal was very much similar in herbivorous and planktivorous fish.

The oesophagus, besides acting as a transit tube for the food, has been reported as having a variety of functions in different fish. In Salmo salar L., a muscularis mucosa has been found in the oesophageal wall (Kudinsky, 1966). Oesophageal mucosal folds teaming with mucous cells in Chanos chanos (Forsk.) are spirally disposed to aid in rapid movement of food (Chandy, 1956). Ghazzawi (1935) described a perforated cuticular covering protecting against abrasion by hard diatom food on the oesophageal mucosa composed entirely of mucous cells in Mugil capito. Mohsin (1961) described simple mucous glands just below or adjacent to mucous cells in Glossogobius giuris.

In the fish species under investigation, the oesophagus wall was found to be of similar structure in the different layers for fish of similar feeding habits. Thus, as compared to the carnivorous and omnivorous fish, Tylosurus choram and Therapon jarbua, the goblet cells of the mucosa were simple in the planktivorous and herbivorous fish, i.e. Rastelliger kanagurta and Siganus rivulatus. Also, the branching of the mucosal folds was simpler than in the other groups. This may be due to the simple structure of the food items ingested by the herbivore and planktivore fish. Goblet cells were numerous in the carnivorous and omnivorous species. In the muscularis, the arrangement of the muscular layers was reversed and the intermediate layer was absent in the planktivore and herbivore fish. This might be because in these fish the food, i.e. plankton and plants, is easily swallowed, and does not need strong musculature in the oesophagus to push it to the stomach.

The posterior oesophagus has gastric glands in Mugil capito (Ghazzawi, 1935) which increase the effective gastric surface area and may indicate an early form of accessory digestion. The possibility of an absorptive role, on the basis of blood vessels in the tunica propria reaching the columnar epithelium, has been suggested in Mugil crenilabis (Forsk) (Mahadevan, 1954).

The poor development of the tunica propria in R. kanagurta and S. rivulatus compared with that of the carnivorous or omnivorous fish may be because the type of food ingested by the two species do not require accessory digestion at the oesophagus level because of the longer length of their intestines.

The stomach wall consists of a number of layers, which are characteristic for the whole vertebrate series. A distinct muscularis mucosa can be distinguished (Al-Hussaini, 1946; Khanna, 1964). A deviation from the normal (unstriated) nature and disposition of muscles is rare. The striated muscles may extend into the stomach and even a reversed arrangement has been found in which the striated muscles occur in the pyloric region instead of the cardiac region (Al-Hussani and Kholy, 1953; Mohsin, 1962). The reversal of the muscular layer in the two parts of the stomach was also observed in the present investigation in *R. kanagurta*, *S. rivulatus* and *T. jarbua*.

Kapoor et al. (1975) reported that the gastric mucosa varies in thickness in different parts of the stomach due to the degree of development of gastric glands. Al-Hussaini (1949) suggested that the variation in the thickness of the free border in different parts of the intestine of the same fish could be related to the sites of absorption of digested food into the cells. Other common constituents are goblet cells and cellular migrants (lymphocytes and various types of granulocytes). The goblet cells are chiefly mucus producers. It has been suggested that their secretion contains digestive enzymes; and their high water content may facilitate absorption (Siankowa, 1966). In the fish possessing a stomach, this secretion is concerned with the production of zymogen granules. In stomachless fish production of zymogen granules is taken over by the goblet cells of the intestine. The highest concentration of goblet cells occurs in the posterior segment of the intestine.

Mohsin (1962) stated that the extent of development of the gastric glands, ranging from elaborate and complex to simple gland-types, is an adaptation to the digestion times in fish with different feeding habits, and depends on the type of food items. Correlation between the appearance of the gastric glands and feeding behaviour or food could be established, but on the other hand, in the omnivorous fish, I. jarbua, the gastric glands were completely absent; while in the herbivorous fish, S. rivulatus they were very few in number. Their presence or absence could not be correlated with the feeding habits of these fish species.

In some fish species the stomach is absent and, according to Patt and Patt (1969), the presence of a "typical" stomach is as nonessential for fishes as for man from the enzymatic standpoint. Human beings that have undergone surgical procedures for stomach removal need make only minor changes in their mode of living. That this testifies to the role played by the stomach as an enzymatic entity; in most vertebrates its mechanical and lubricating functions can be fulfilled by other structures such as the great length of the gut which occurs in microphagus, in Loriearidae (Siluroidei) and Theutidae (Percoidei). In the stomachless fish, the fore-gut is enlarged in varying degrees and referred to as an intestinal bub, duodenum, swollen part of the intestine, large arm of the intestine, and even erroneously as stomach (Kapoor, 1958b). Hence, the oesophagus of those fish that lack a stomach is well developed and leads directly to the intestine.

Weisel (1962) reported that a macrophagous, toothless cyprinid Ptychocheilus oregonense (Richardson), a predator on small salmon, has inherited the stomachless condition from its suctorial ancestors, the catostomids, but has evolved mechanisms to compensate for ancestral deficiencies, though a stomach and teeth would better equip the species to a piscivorous life.

Therefore, the absence of the stomach in the carnivorous fish Tylosurus choram is not a deficiency in its alimentary system that would not allow it to feed on food of animal origin since, besides its well developed oesophagus, its intestine is highly adapted for such food, as described later. The intestine of Tylosurus choram is differentiated into a complex distal and a simpler proximal portions. The mucosa of the distal part is characterized by the long folds, the abundance of goblet cells, the elongated and ciliated columnar cells, giving a larger surface area in direct contact with the food items. The more intense eosin stain of the cytoplasm of these cells is in fact an indicative of a high concentration of the enzyme "zymogen" that is produced in the goblet cells (Schlottke, 1939). The concentration of this enzyme is higher in the more carnivorous species than in the more herbivorous ones (Barrington, 1957).

In the fish species investigated in the present study, the muscularis of the pyloric stomach was thick and was mostly of the circular type, however, the longitudinal muscle layer was also present, but it was much thinner than the circular one. The pyloric stomach in several members of Clupeodei, Chanoidei, some Characinoidei and Mugiloidei have a characteristic thick muscularis (often a circular muscle layer only), a reduced sub-mucosa, and a special protective inner covering; thus modified to act as a gizzard for trituration and mixing (Schmitz and Baker, 1969).

The stratum compactum is a protective, supporting and strengthening layer, which keeps the distension of the wall within bounds, and is regarded as an adaptive characteristic in many carnivorous fish (Burnstock, 1959a; Bucke, 1971). The stratum compactum is poorly developed in *R. kanagurta*, but well developed in *S. rivulatus* which are planktivorous and herbivorous, respectively. In the omnivorous fish *I. jarbua*, it is absent. Al-Hussaini (1946) observed granular cells with a propensity to wander in various parts of the stomach of *Mulloisdes auriflamma* (Forsk) only during active digestion; he was unable to establish the exact relationship between these cells and the digestive process. Al-Hussaini (1949) thought that they may perform different functions in different species. Mohsin (1962) conjectured that they help in absorption and transport of digested food to the intestine. In the present study, however, a possible correlation could be established between the feeding habits and the stratum compactum.

In the present investigation the structure of the pyloric caeca was found to be similar to that of the intestine. Apart from the difference in the shape of the mucosal folds, the size of the tunica propria and absence of stratum compactum, only in the case of *R. kanagurta*. There were no significant variations in the structure of the pyloric caeca, that could be correlated with the feeding habits of the fish species. The pyloric caeca, or auxilliary appendages in many teleosts, differ in number, form, disposition and communication with the intestine. They are histologically almost identical with the intestine (Khanna and Mehortra, 1971). The presence or absence of pyloric caeca has no apparent correlation with the nature of the food or with feeding habits (Khanna, 1961; Mohsin, 1962). Even the number of caeca is not always constant in a species (Bernard, 1949). On the other hand, the number of pyloric caeca has been used in the identification of species of Mugilidae (Hotta and Nakashima, 1969).

In *I. jarbua*, *R. kanagurta* and *S. rivulatus*, the proximal and distal parts of the intestine do not differ in their structure, this is because they do not need this differentiation that is compensated for by the presence of the stomach. The mucosal folds in the omnivorous fish, *I. jarbua*, is more elongate that in either the herbivourous or planktivorous fish, and this is due to the more complex nature of the food ingested by *I. jarbua*. In addition, its intestinal sub-mucosa is more complex in structure than in the other three fish species.

The intestine, in both gastric and stomachless types of fish, shows a variety of mucosal ingrowths. Typhlosoles in the ileum (Al-Hussaini, 1945), ileorectal valves (Al-Hussaini, 1947b; Maggese, 1967 and many others), rectal caeca absorptive in nature (Singh, 1966, 1967b) have been reported in different teleosts.

In the investigated fish species, typhlosoles were observed in the distal part of the intestine.

The histological structure of the rectum in any of the four studied fish species did not show pronounced differences; except from the absence of an ileo-rectal valve in the planktivorous fish, R. kanagurta. This situation seems to be characteristic of planktivorous fish (Al-Hussaini, 1949).

Such facts suggest that the ecological situation of fish may often favour a generalized rather than a highly specialized digestive system, but the situation cannot be properly evaluated without information as to the growth rate of the particular species under varied conditions of feeding. It is always possible that the organization of the alimentary system of a particular species, as, for example, in the relative concentrations of its digestive enzymes, may be such as to obtain maximum advantage for only a limited part of the range of material which the animal is actually capable of ingesting.

All these considerations imply that attempts to correlate the digestive physiology of fish with their diet must be based upon extensive observations carried out under as wide a range of conditions as possible; and should give due weight to the relevant behaviourial and ecological factors in future investigations.

PLATE 5.I

Fig. 1. Photomicrograph of the T.S. of oesophagus of *Tylosurus choram*, showing its general structure (x50), and the striated muscle fibres.

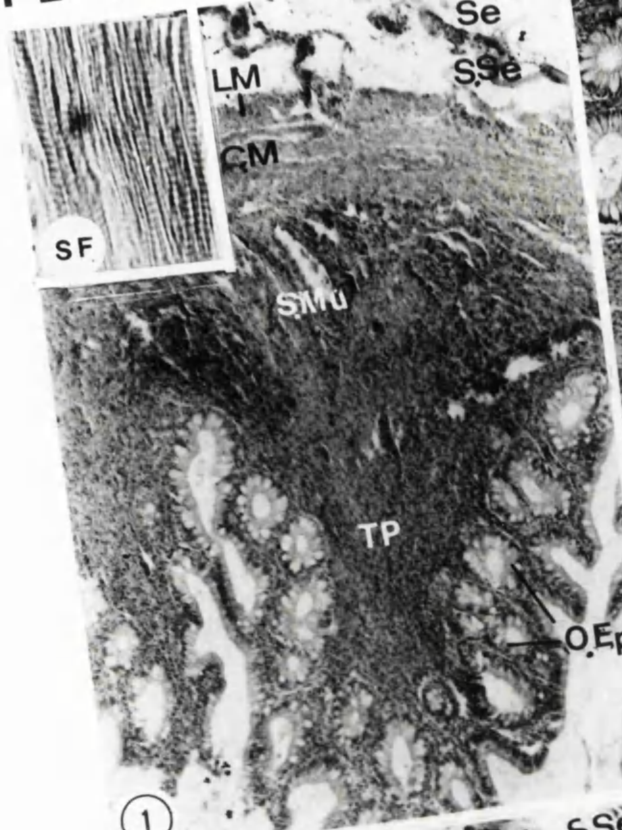
Fig. 2. A part of the above section, showing mainly the glandular mucosal epithelium (x170) and the ciliated columnar cells.

Fig. 3. Photomicrograph a T.S of the oesophagus of *Rastelliger kanagurta*, showing the disposition and the nature of the longitudinal muscle layer in the form of fasciculi (x80).

Fig. 4. A part of the above section, showing the highly folded nature of the mucosa (x180).

C.M. : Circular muscle layer
Ci : Cilia
Go.C. : Goblet cells
L.M. : Longitudinal muscle layer
Ly.V. : Lymphatic vessel
Mu.C. : Mucous cell
Mu.Fo. : Mucosal fold
O.Ep. : Oesophageal epithelium
S.Mu. : Submucosa
S.Se. : Subserosa
Se : Serosa
St.Co. : Stratum compactum
Su.Ep. : Surface epithelium
T.P. : Tunica propria
S.F. : Striated fibres

PLATE 5.1



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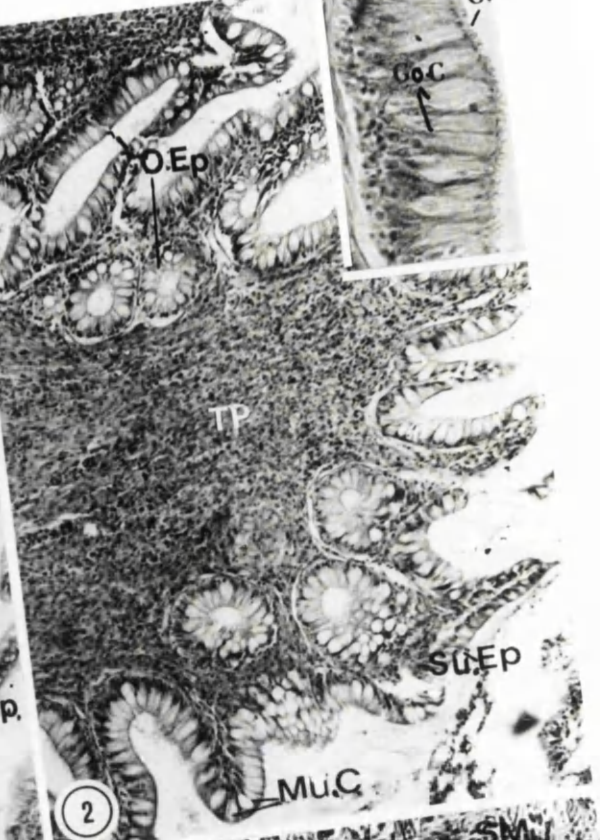

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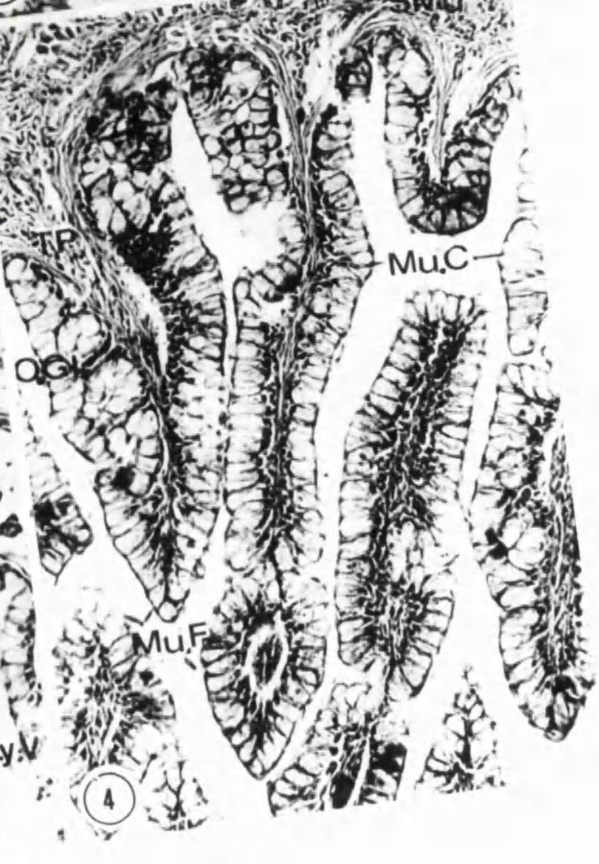


④

PLATE 5.II

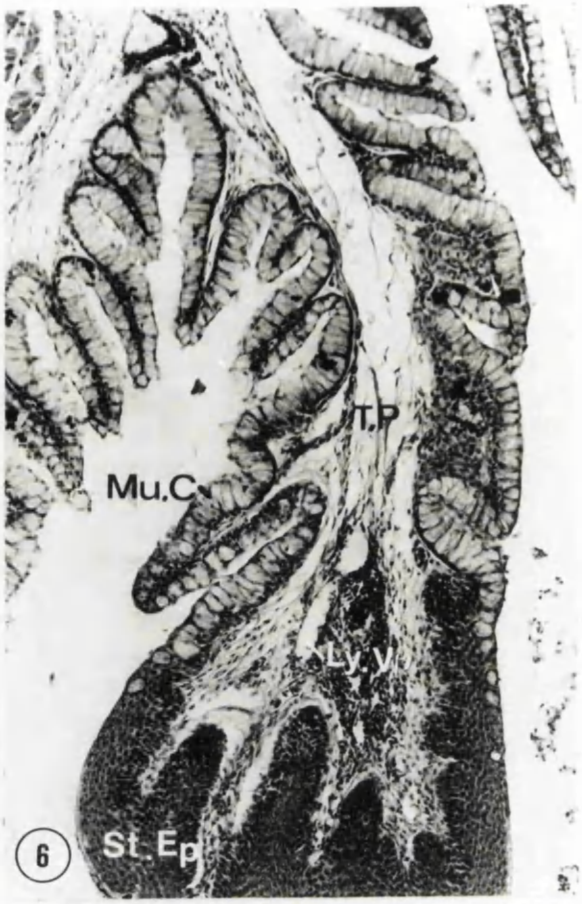
Fig. 5. A photomicrograph of a part of a T.S in the oesophagus of *Siganus rivulatus*, showing the highly branched folds, and the nature of the mucosa at the tips of the folds and the reduced condition of the outer longitudinal muscle layer (arrow) (x40).

Fig. 6. A part of the above section, showing the nature of the oesophageal mucosal epithelium (x150).

Fig. 7. A photomicrograph of a T.S. in the oesophagus of *Therapen jarbua*, notice the branched large fold and the mucous cells together with the reduced longitudinal muscle layer compared with that of the circular one (x360).

B.V. : Blood vessel
C.M. : Circular muscle layer
L.M. : Longitudinal muscle layer
Ly.V. : Lymphatic vessel
Mu.C. : Mucous cell
Mu.Fo. : Mucosal fold
M.L. : Muscular layer
Mu.Gl. : Mucous gland
St.Ep. : Stratified epithelium
T.P. : Tunica propria

PLATE 5.11



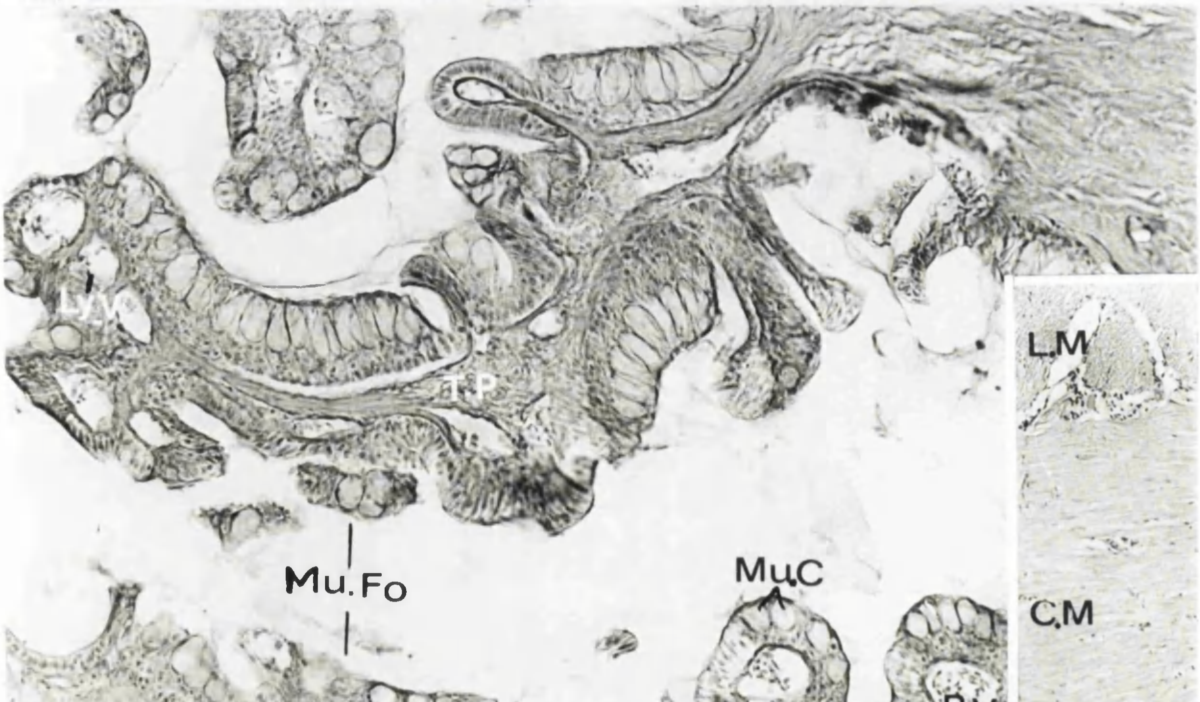


PLATE 5.III

Fig. 8 A photomicrograph of a T.S. in the cardiac stomach of *Rastelliger kanagurta*, showing the general histological structure. Notice the well developed glandular region (x80).

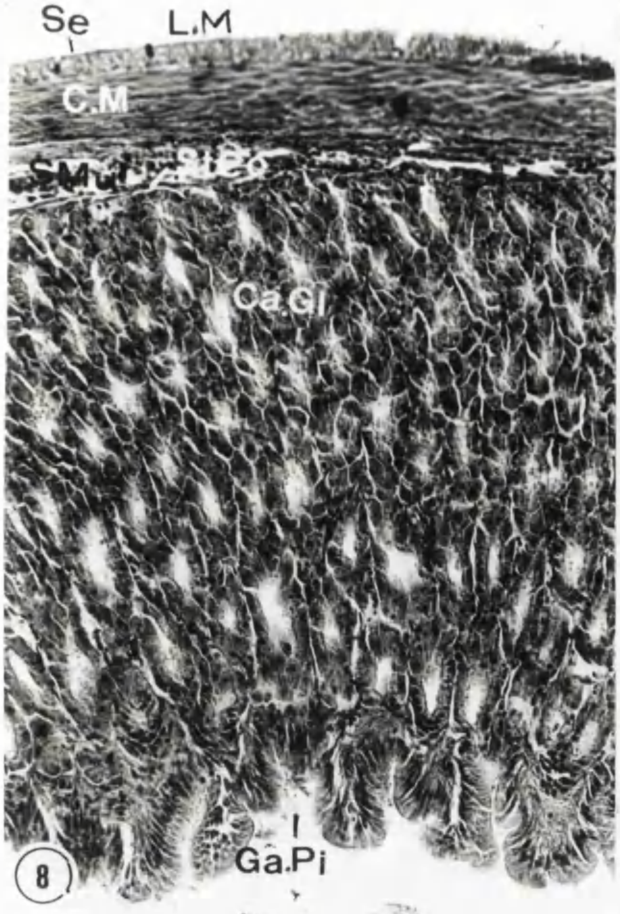
Fig. 9. An enlarged part of the above section, showing the fundic glands (x180).

Fig.10. A photomicrograph of a T.S. in the pyloric stomach of *R. kanagurta*, showing the highly folded mucosa which has a protective inner covering (x40).

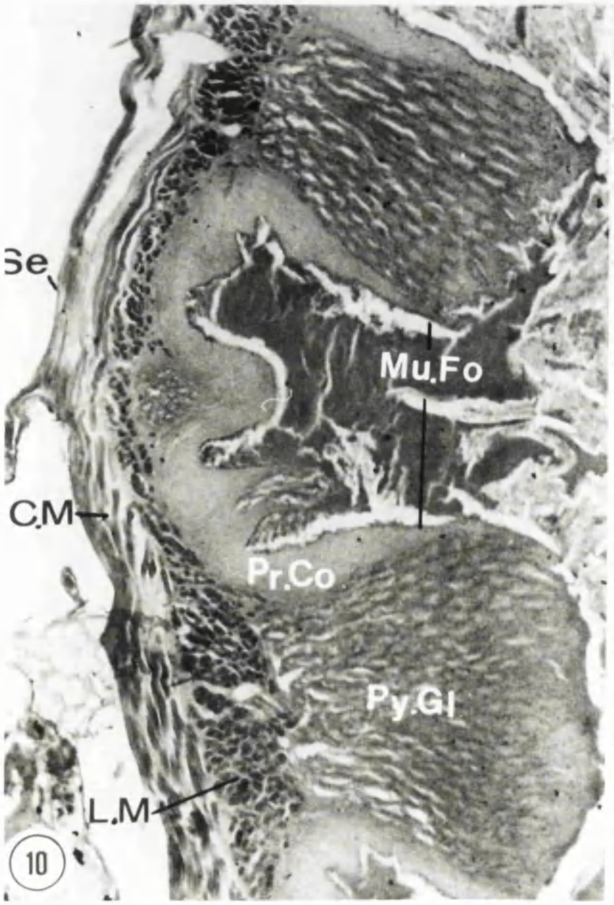
Fig.11. An enlarged part of the above T.S., showing the nature of both the pyloric glands and the protective covering. Notice also the disposition of the longitudinal muscle layer which appears in the form of fasciculi (x90).

C.M. : Circular muscle layer
Ca.Gl. : Cardiac glands
Ca.Gl.C. : Cardiac gland cell
Ga.Pi. : Gastric pit
L.M. : Longitudinal muscle layer
Mu.Fo. : Mucosal folds
Pr.Go. : Protective covering
Py.Gl. : Pyloric glands
Py.Gl.C. : Pyloric glands cells
S.C. : Stratum compactum
S.Mu. : Submucosa
S.Ep. : Surface epithelium
Se : Serosa

PLATE 5.III


Se
L.M
C.M
S.Mu
S.Co
Ca.Gl
Ga.Pi
8


CaGlC
Ga.Pi
S.Ep
9


Se
Mu.Fo
C.M
Pr.Co
Py.Gl
L.M
10

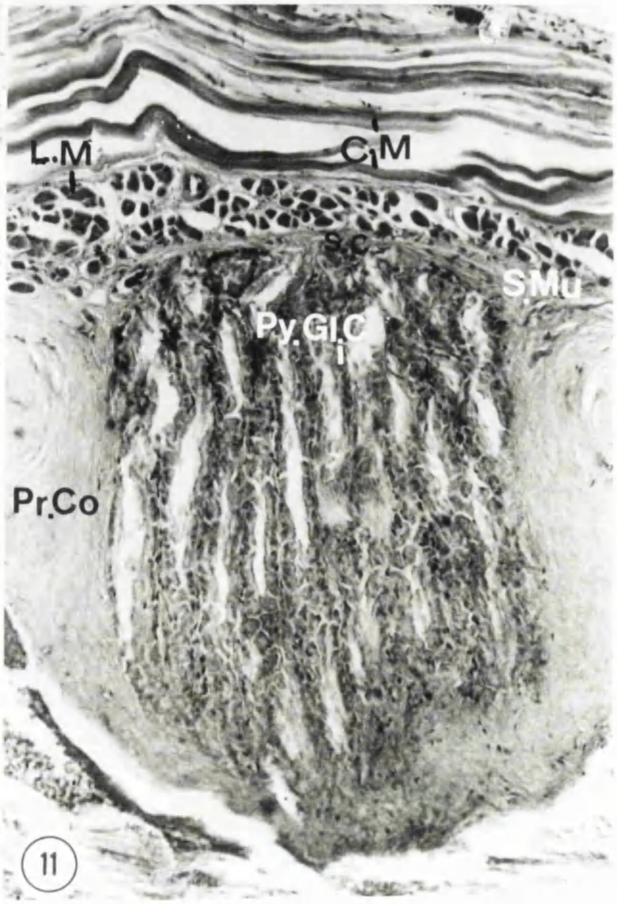

L.M
C.M
S.c
S.Mu
Py.Gl.C
Pr.Co
11

PLATE 5.IV

Fig.12 A photomicrograph of a T.S. in cardiac stomach of *Siganus rivulatus*, showing the general histological details (x40).

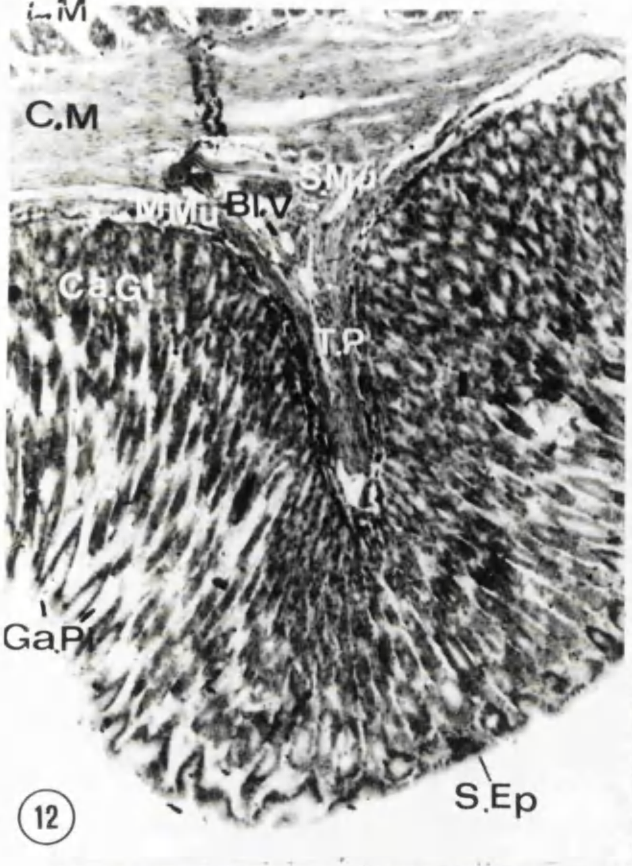
Fig.13 An enlarged part of the above section, showing the nature of the cardiac glands (x180).

Fig.14 A photomicrograph of T.S. in the pyloric stomach of *S. rivulatus*, showing the general histological structure. notice the marked thickness of the circular muscle layer and the protective covering of the mucosal epithelium (x40).

Fig.15 An enlarged part of the above section, showing the nature of the pyloric glands and their protective covering (x160).

Bl.V. : Blood vessel
C.M. : Circular muscle layer
Ca.Gl. : Cardiac gland
Ca.Gl.C. : Cardiac gland cells
D : Duct
Ga.Pi. : Gastric pit
L.M. : Longitudinal muscle layer
M.Mu. : Musculario mucosa
Pr.Co. : Protective covering
Py.Gl. : Pyloric glands
Py.Gl.C. : Pyloric gland cells
S.Mu. : Submucosa
S.Ep. : Surface epithelium
Se : Serosa
T.P. : Tunica propria

PLATE 5.IV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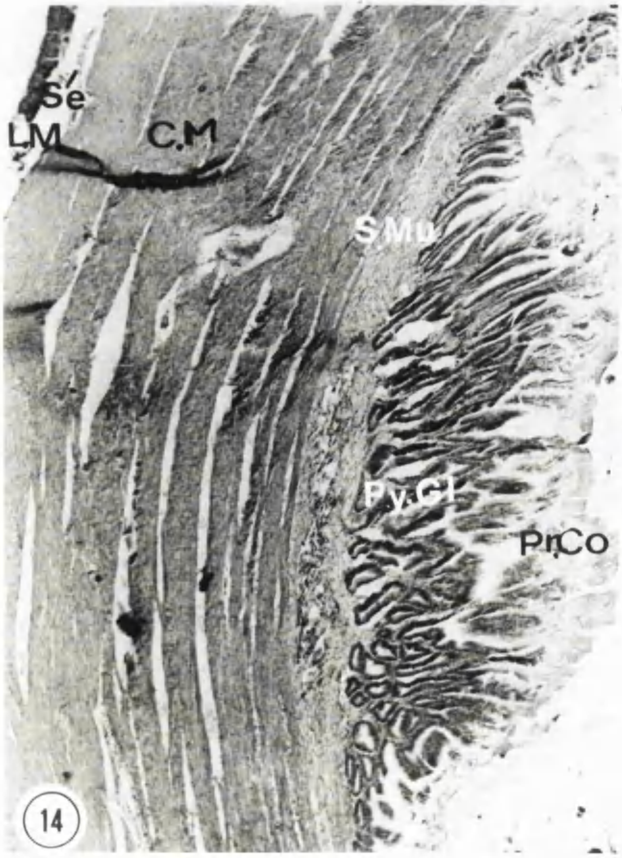
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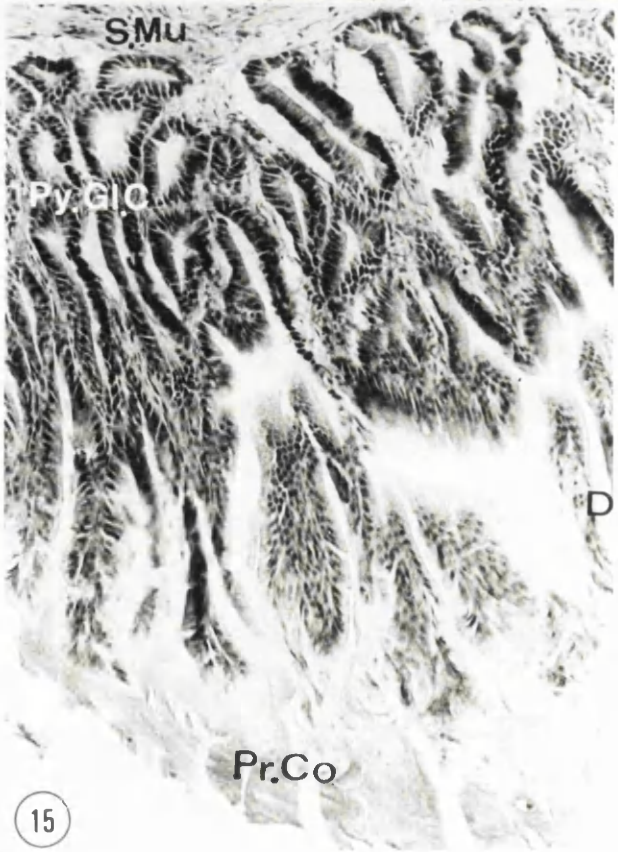

15

PLATE 5.V

Fig.16 A photomicrograph of a part of s T.S. in the cardiac stomach of *Therapen jarbua*, showing a mucosal fold and the simple type of the cardiac glands (x50).

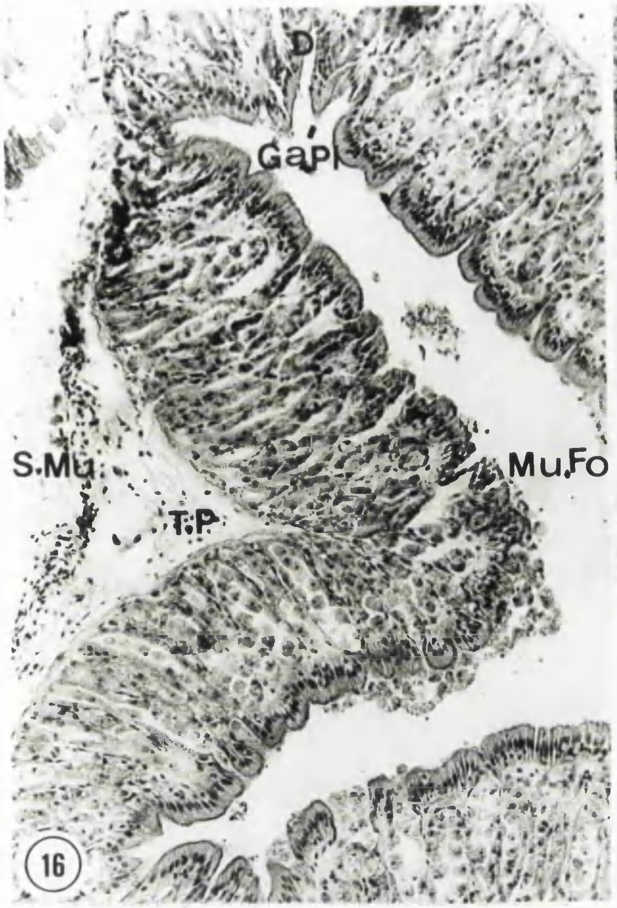
Fig.17 A photomicrograph of an enlarged mucosal fold in the cardiac port of the stomach of *T. jarbua*, showing the simple type of the cardiac glands (x70).

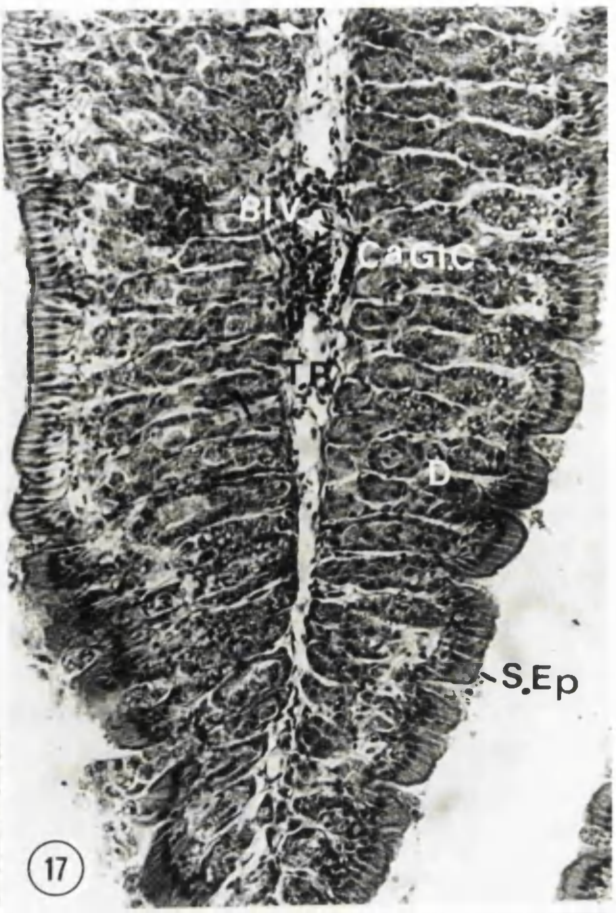
Fig.18 A photomicrograph of a T.S. in the pyloric region of the stomach of *T. jarbua*, showing the nature of the mucosal folds. Notice also the reduced longitudinal muscle layer compared with the circular one (x60).

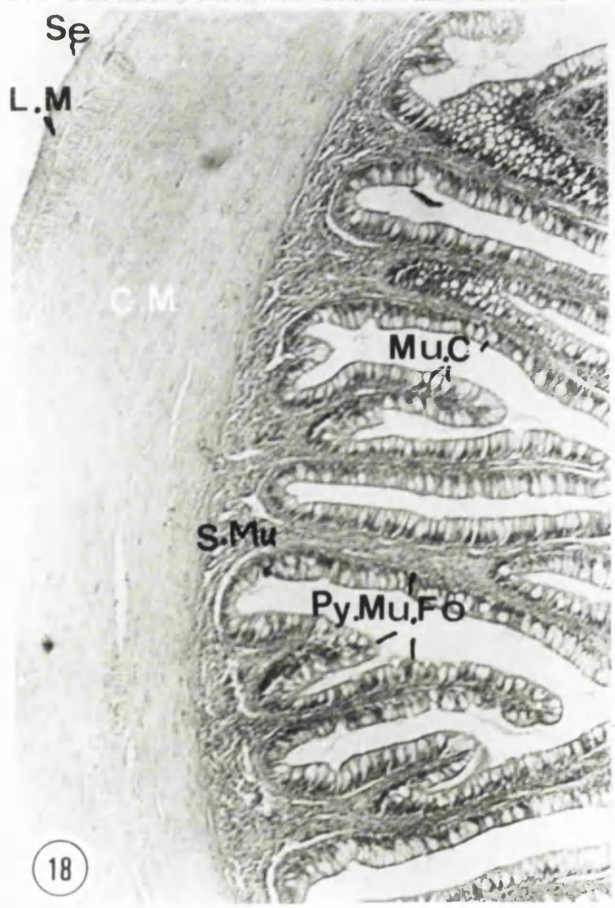
Fig.19 A photomicrograph of L.S. passing through the pyloric constriction of *T. jarbua*, showing its histological details (x40).

Bl.V. : Blood vessel
C.M. : Circular muscle layer
Ca.Gl.C. : Cardiac gland cells
D : Duct
Du : Duodenum
Ga.Pi. : Gastric pit
L.M. : Longitudinal muscle layer
Mu.Fo. : Mucosal folds
Pa.Ti. : Pancreatic tissue
Py : Pylorus
Py.Mu.Fo. : Pyloric mucosal folds
S.Ep. : Surface epithelium
S.Mu. : Submucosa
Se : Serosa
T.P. : Tunica propria

PLATE 5.V


D
Ga.Pl
S.Mu
T.P
Mu.Fo
16


Bl.V
Ca.Gl.C
T.P
D
S.Ep
17


Se
L.M
C.M
Mu.C
S.Mu
Py.Mu.Fo
18

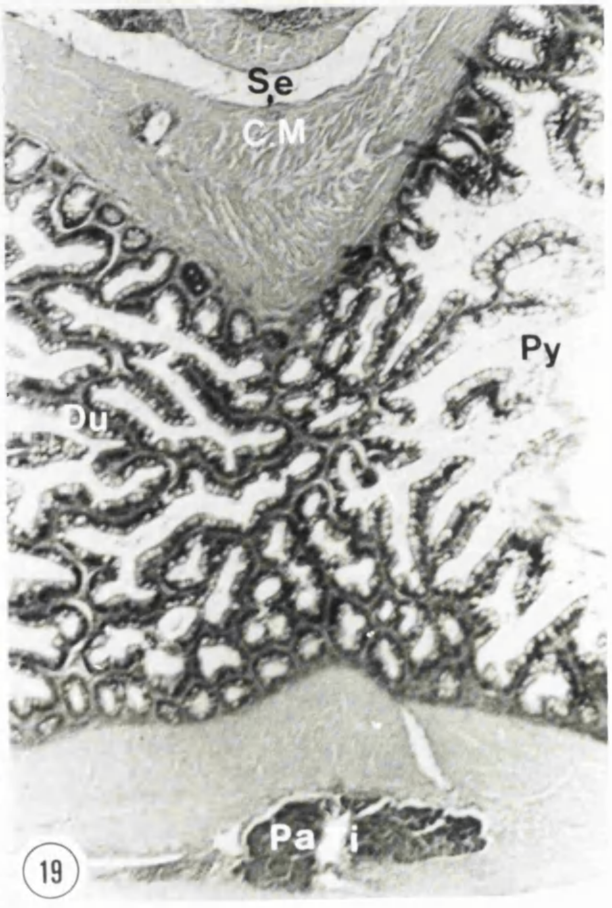

Se
C.M
Py
Du
Pa i
19

PLATE 5.VI

Fig.20 A photomicrograph of a T.S. passing through a pyloric caecum in *Rastelliger kanagurta*, showing the simple type of its mucosal folds (x80).

Fig.21 An enlarged part of the previous section (x100).

Fig.22 A photomicrograph of the L.S. passing through the pyloric caecum of *Siganus revulatus*, showing the nature of the caecal villi.

Fig.23 A photomicrograph of a T.S. in the pyloric caecum of *Therapen jarbua*, showing the simple type of the mucosal fold. Notice the well developed muscular coat (x100).

C.M. : Circular muscle layer
Cae.Fo. : Caecal folds
Cae.Ep. : Caecal epithelium
Cae.Vi. : Caecal villi
L.M. : Longitudinal muscle layer
Ly.Sp. : Lymphatic space
Pa.Ti. : Pancreatic tissue
S.Mu. : Submucosa
Se : Serosa
T.P. : Tunica propria
To.Pl. : Top-plate

PLATE 5.VI

20

21

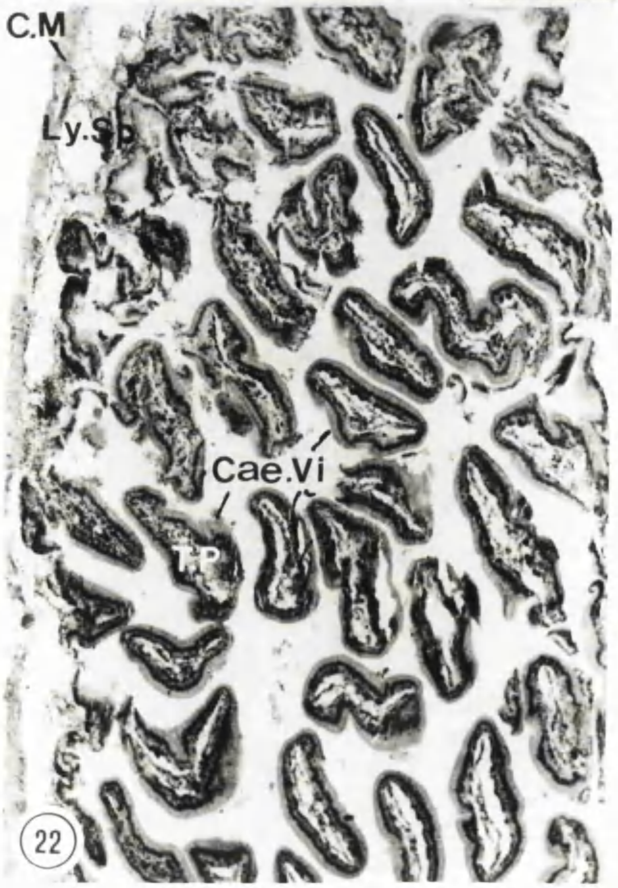


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PLATE 5.VII

Fig.24 A photomicrograph of a T.S. in the proximal part of the intestine of *Tylosurus choram*, showing its general histological details (x80).

Fig.25 A photomicrograph of an enlarged part of the intestine, the large number of mucous cells as well as the presence of cilia along the inner margin of the intestinal mucosal folds.

Fig.26 A photomicrograph of a T.S. in the middle part of the intestine (ileum) of *T. choram*, showing the mucosal ingrowth, the typhlosole (x40).

Fig.27 An enlarged part of another T.S. in the middle part of the intestine showing the presence of cilia along the surface of the mucosal folds (see the highly magnified part F1) (x200 - 340).

C.M. : Circular muscle layer
Ci : Cilia
L.M. : Longitudinal muscle layer
Lu : Lumen
Ly.C. : Lymphatic cell
Mu.C. : Mucous cell
Mu.Ep. : Mucous epithelium
S.Mu. : Submucosa
Se : Serosa
St.Co. : Stratum compactum
T.P. : Tunica propria
Typ : Typhlosole

PLATE 5.VII

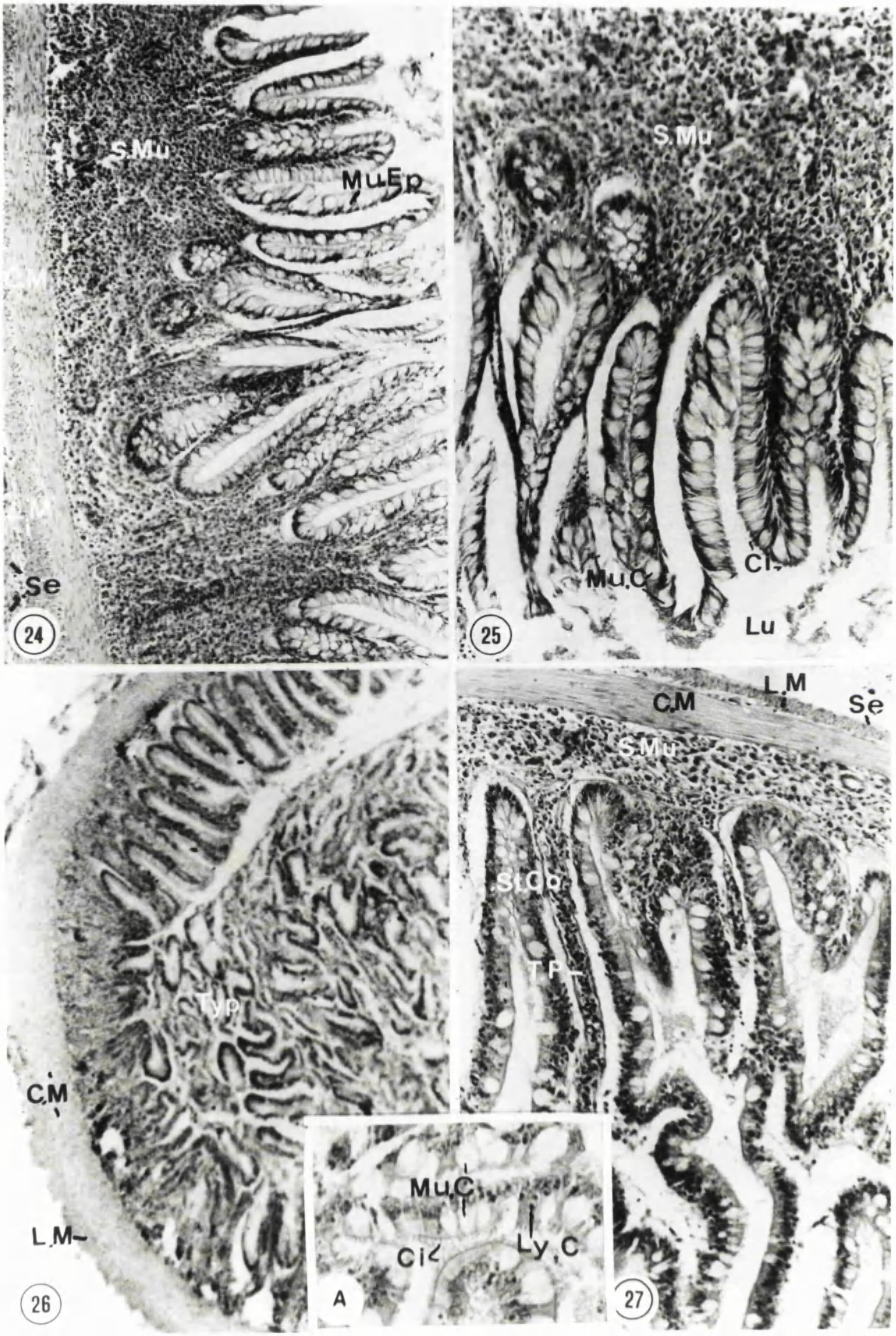

S.Mu
Mu.Ep
C.M
L.M
Se
24
S.Mu
Mu.C
Cl
Lu
25
Typ
C.M
L.M
26
Mu.C
Cl
Ly.C
A
L.M
C.M
Se
S.Mu
St.Co
T.P
27

PLATE 5.V111

Fig. 28 A photomicrograph of a T.S. in the intestine of *Rastelliger kanagurta*, showing the highly folded mucosa and the intestinal villi are digitiform in appearance (x40).

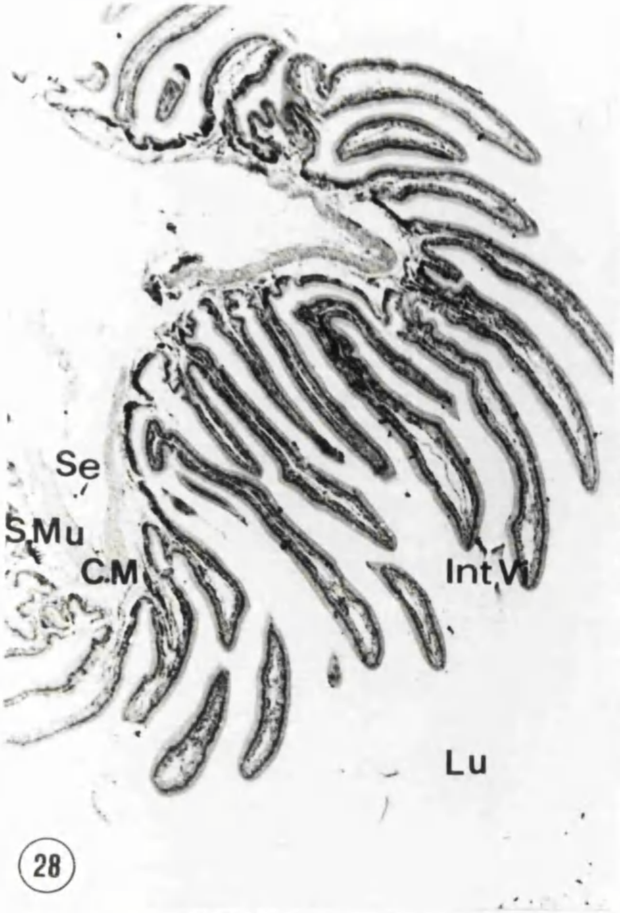
Fig.29 An enlarged part of the previous section (x160).

Fig.30 A photomicrograph of an oblique section in the intestine of *Siganus rivulatus*, showing its general histological details (x60).

Fig.31 An enlarged part of the previous section (x130).

Bl.V. : Blood vessel
C.M. : Circular muscle layer
Int.Ep. : Intestinal Epithelium
Int.Fo. : Intestinal Fold
Int.Vi. : Intestinal Villi
Ly.V. : Lymphatic vessel
Lu : Lumen
M.Co. : Muscular coat
Mu.C. : Mucous cell
Se : Serosa
S.Mu. : Submucosa
St.Bo. : Striated border
T.P. : Tunica propria

PLATE 5.VIII



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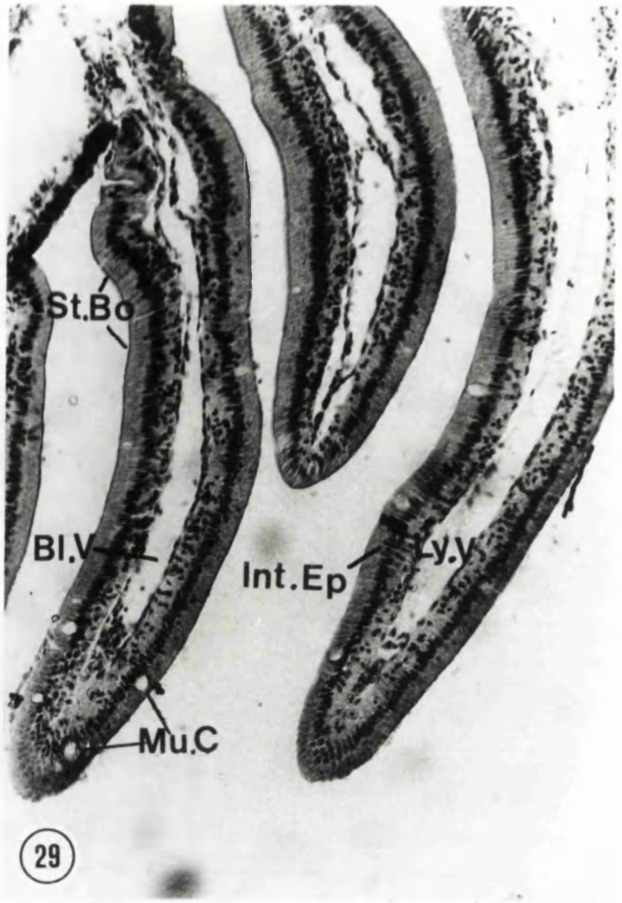

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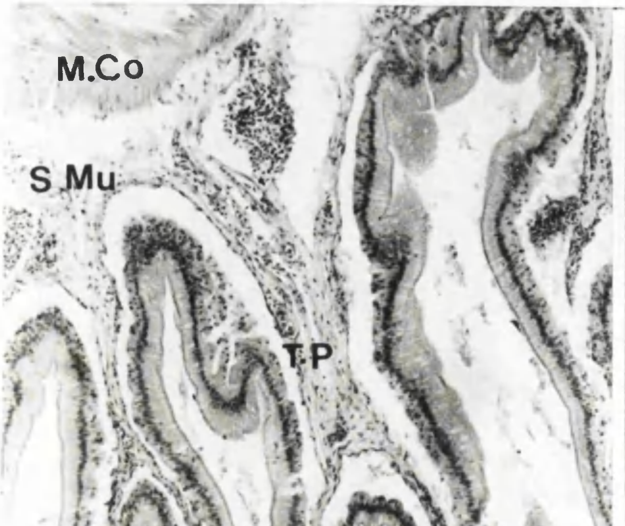

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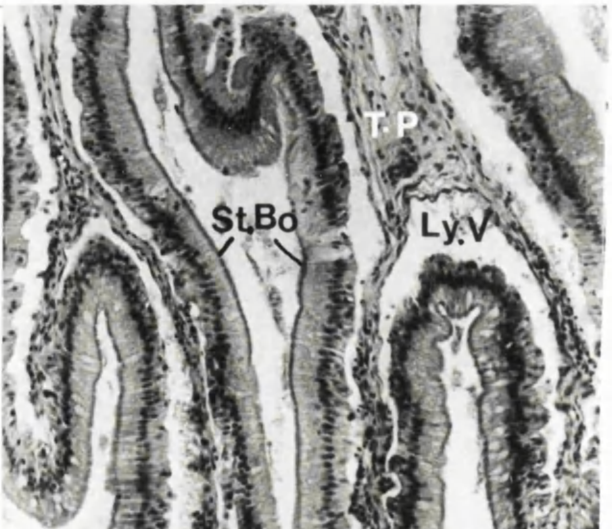


31

PLATE 5.IX

Fig.32 A photomicrograph of a T.S. section passing through the intestine of *Therapen jarbua*, showing its general histological details (x60).

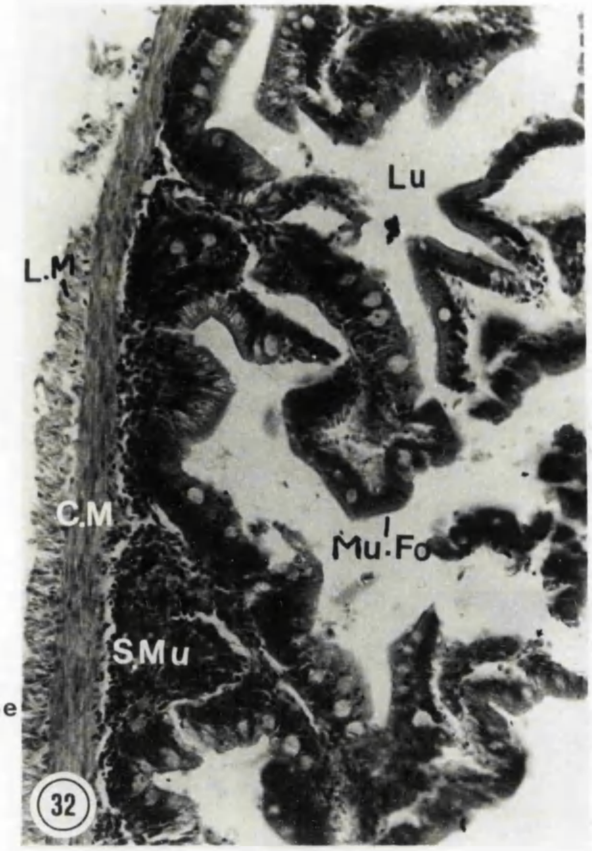
Fig.33 An enlarged part of a section in the intestinal region of *T. jarbua*, showing the disposition of mucosal folds together with very prominent mucous cells (x130).

Fig.34 A photomicrograph of an oblique section passing through the ileo-rectal valve of a small specimen (10 cm) of *Tylosurus choram* (x40).

Fig. 35 A photomicrograph of a T.S. passing through the rectum of *T. choram*, showing mainly the disposition of the mucosal folds (x50).

C.M. : Circular muscle layer
Int.Ep. : Intestinal epithelium
Int.Fo. : Intestinal fold
L.M. : Longitudinal muscle layer
Lu : Lumen
Ly.C. : Lymphatic cell
Mu.C. : Mucosal cell
Mu.Fo. : Mucosal fold
Re.Fo. : Rectal fold
Re.Gl. : Rectal gland
Re.Lu. : Rectal lumen
S.Mu. : Submucosa
Se : Serosa
St.Bo. : Striated boarder
T.P. : Tunica propria

PLATE 5.IX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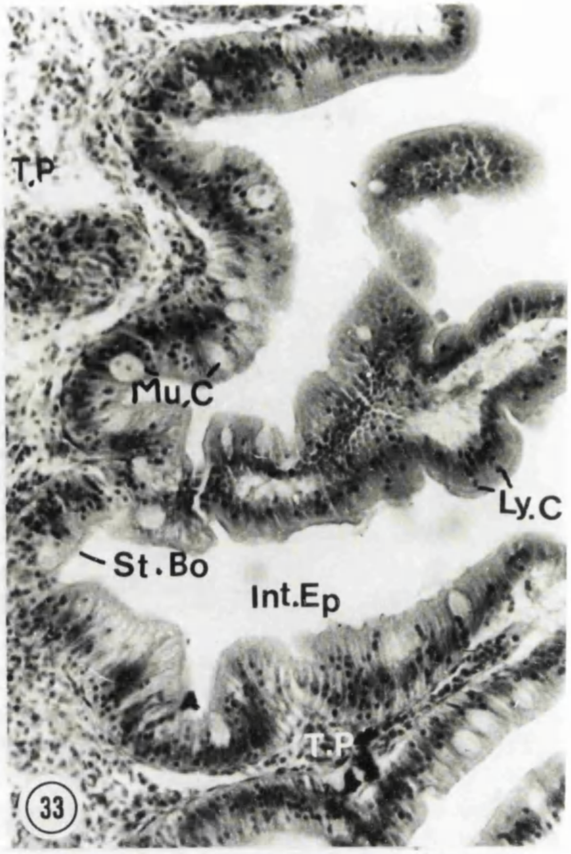
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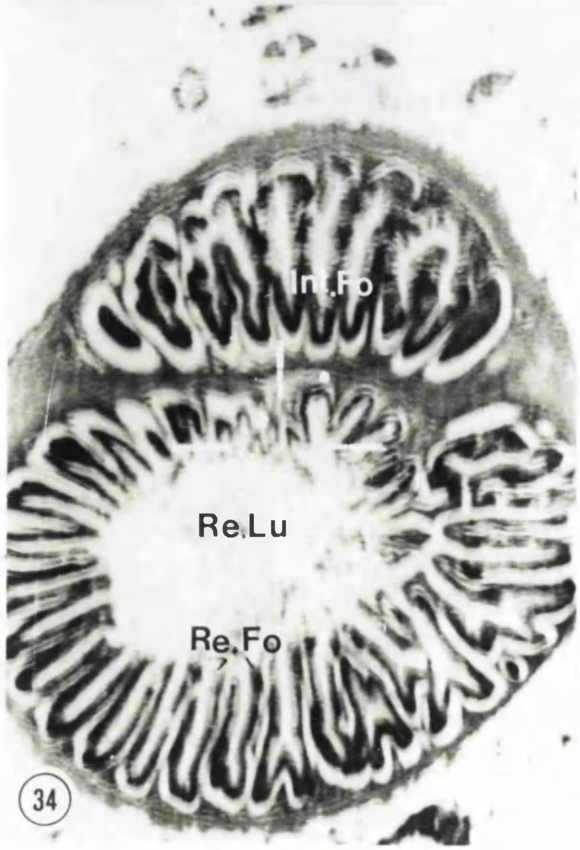
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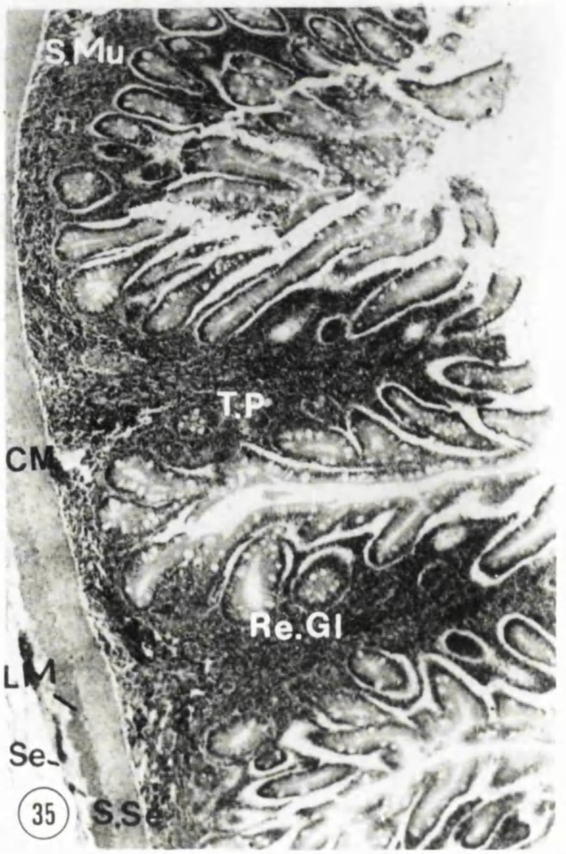

35

PLATE 5.X

Fig.36 An enlarged part of the section shown in Fig. 35. showing the nature and disposition of the epithelial and mucous cells (x160).

Fig.37 A photomicrograph of a T.S. in the rectum of *Rastelliger kanagurta*, showing its histological details (x50).

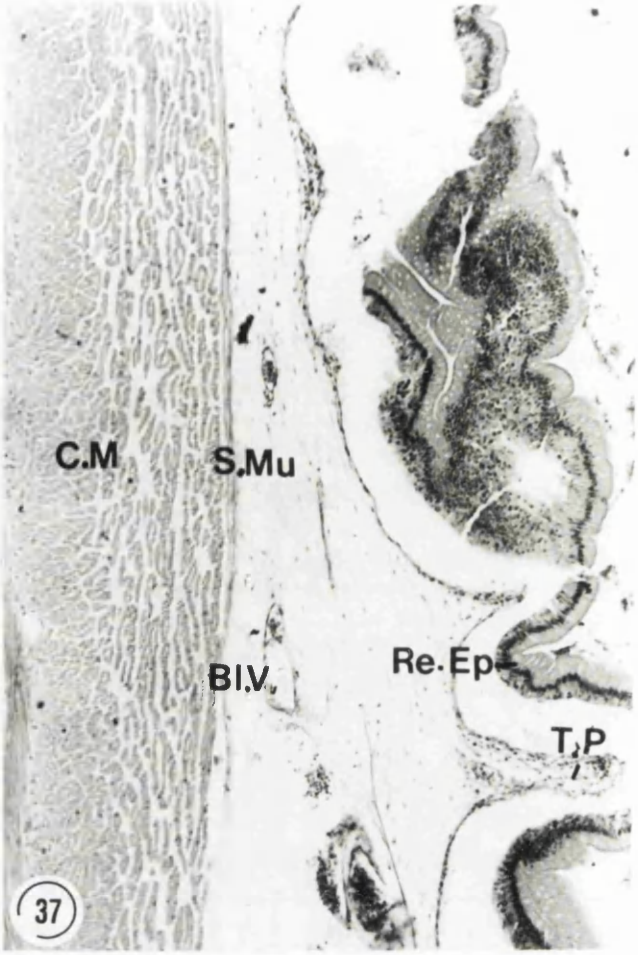
Fig.38 An enlarged part of a T.S. passing through the rectum of *R. kanagurta*, showing the disposition of its mucosal folds together with the nature and disposition of the epithelial and mucous cells (x90).

Fig.39 A photomicrograph of a part of a L.S. passing through the ileo-rectal valve of *Siganus rivulatus*, showing its histological details (x40).

Bl.V. : Blood vessel
C.M. : Circular muscle layer
Con.Ti. : Connective tissue
Ile.Re.Va. : Ileo-rectal valve
Int.Fo. : Intestinal fold
Ly.Sp. : Lymphatic space
Mu.C. : Mucous cell
Re.Ep. : Rectal epithelium
Re.Fo. : Rectal fold
Re.Gl. : Rectal gland
S.Mu. : Submucosa
St.Bo. : Striated boarder
T.P. : Tunica propria

PLATE 5.X

36



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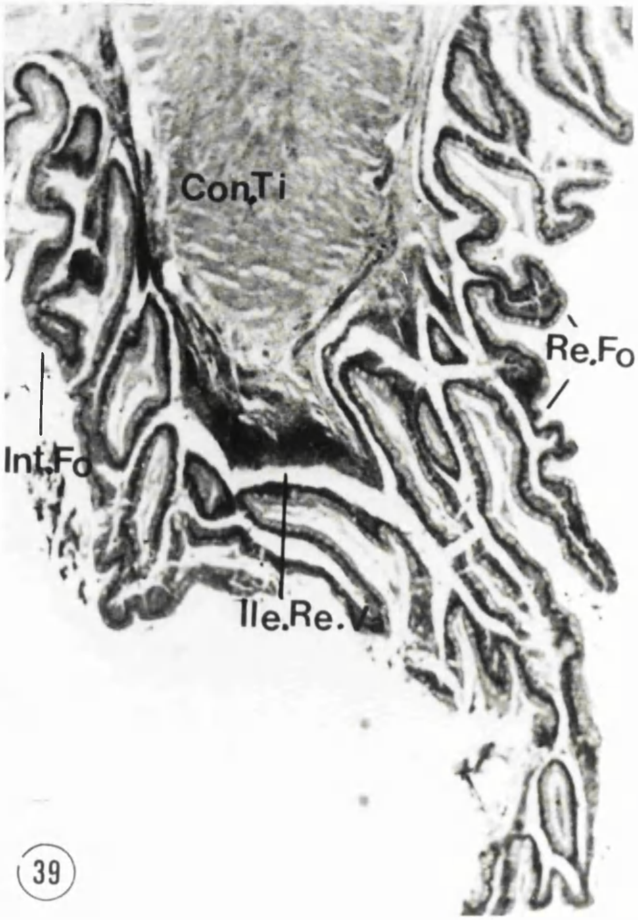

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PLATE 5.XI

Fig.40 A photomicrograph of T.S. passing through the rectum of *Siganus revulatus*, showing its histological details (x60).

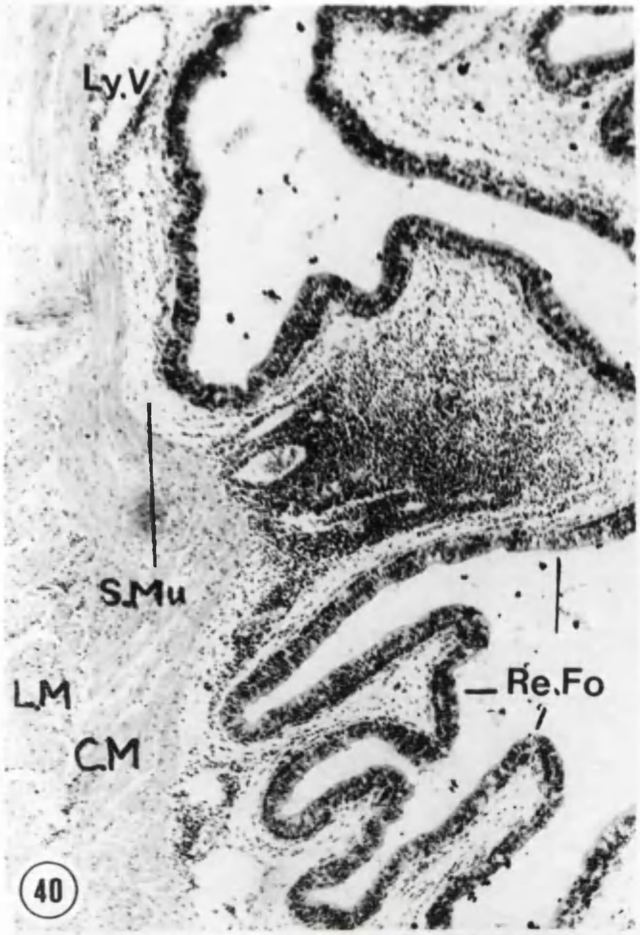
Fig.41 An enlarged mucosal fold of the above section, showing the nature and disposition of both epithelial and mucous cells. Notice the presence of a large number of lymphatic cells (x120).

Fig.42 A photomicrograph of a L.S. passing through the ileo-rectal valve of *Therapen jarbua*, showing the nature of its mucosa (x90).

Fig.43 A photomicrograph of an enlarged part of a T.S. passing through the rectum of *T. jarbua*, showing the nature of its mucosa (x90).

Bl.V. : Blood vessel
C.M. : Circular muscle layer
Con.Ti. : Connective tissue
Ile.Re.Va. : Ileo-rectal valve
Int.Fo. : Intestinal fold
L.M. : Longitudinal muscle layer
Ly.Ti. : Lymphatic tissue
Ly.V. : Lymphatic vessel
Mu.C. : Mucous cell
Re.Ep. : Rectal epithelium
Re.Fo. : Rectal fold
S.Mu. : Submucosa
St.Bo. : Striated boarder
T.P. : Tunica propria

PLATE 5.XI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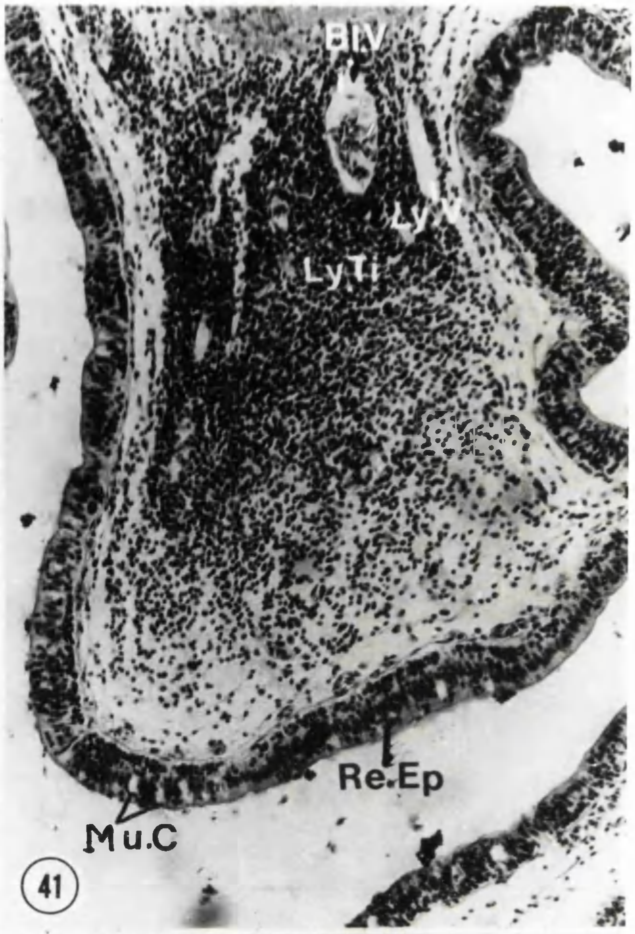
S.Mu
LM
CM
Re.Fo
40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Ly.V
Ly.Ti
Re.Ep
Mu.C
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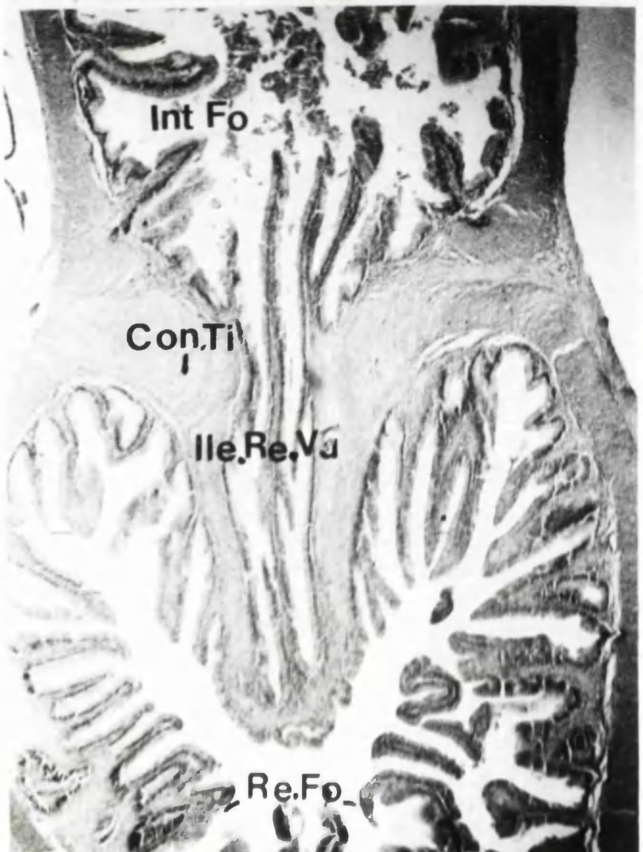
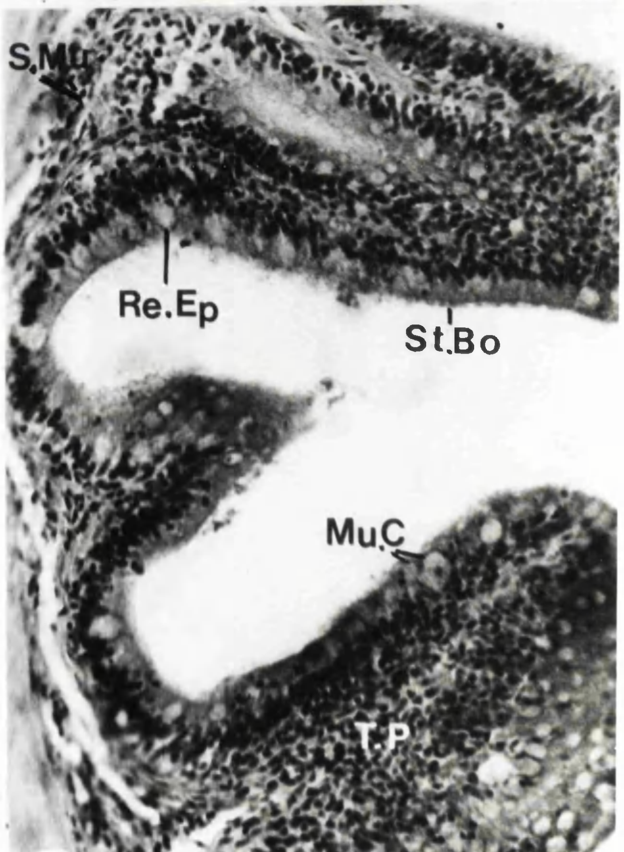

Int Fo
Con.Ti
Ile.Re.Va
Re.Fo
42


S.Mu
Re.Ep
St.Bo
Mu.C
T.P
43

CHAPTER 6

FOOD AND FEEDING HABITS OF *M. FLAVOLINEATUS*

6.1. Introduction

The basic productivity of waters, food organisms present and fish populations are related to each other in an extremely complex way. Food relationships determine population levels, distribution, rate of growth, condition of fish and fertility. Thus food and feeding habits are among the most essential topics in a study of the biology of any fish species.

The present study describes the feeding habits of *Mulloides flavolineatus* with particular emphasis on the feeding intensity in different seasons, and the variations in the diet with sex and size.

6.2. Material and methods

705 specimens of *M. flavolineatus* were examined, of which 333 were "indeterminate sex", 123 were males and 249 were females. These were caught between January 1986 and December 1986. Because digestive enzymes remain active after the death of the fish, the stomach samples were removed as soon as possible after capture. Specimens were either collected on fishing docks as the boats arrived or stomach samples were preserved on board ship as the fish were caught. Both methods produced usable samples.

Stomach analysis was undertaken to obtain the following information:

1) The fullness coefficient (F.C.) defined as the percentage of stomachs containing food. This coefficient was calculated

according to the formula :

$$F.C. = NF \times 100/NE$$

where NF = the number of stomachs containing food, and

NE = the total number of examined stomachs.

2) The percentage frequency of each type of food item in the stomachs examined.

3) Species identification of ingested food items.

4) The frequency index (F.I.) of food items. The number of stomachs containing a certain food item compared with the total number of full stomachs. This was calculated from the formula:

$$F.I. = n/NF$$

where n = the number of stomachs containing a certain food item, and

NF = the total number of full stomachs.

Fullness coefficients, frequency indexes and specific analyses of ingested food items are given in the four seasons:

Spring (March, April and May),
Summer (June, July and August),
Fall (September, October and November), and
Winter (December, January and February).

Fish were divided into three categories; "indeterminate sex" fish (which were not able to be sexed i.e. either immature or spent), males and females. In each category variations of the indices were observed within the different size groups.

Observations -

6.3. Morphology of the alimentary canal of M. flavolineatus

Regarding the alimentary canal of M. flavolineatus, the oesophagus is short, constituting only 1/20th of the total gut length, and is rather thick-walled. The stomach is U-shaped with a thick elastic wall, forming two portions, the cardiac and the pyloric, constituting on the average respectively 84% and 16% of the stomach size. There are usually 17 pyloric caeca covering the stomach; and according to Nikolsky (1963), their main function is the neutralization of the food from an acid to alkaline condition during its passage from the stomach to the intestine. He also stated that absorption takes place in the pyloric caeca which also have an enzymatic function.

6.4. Fullness coefficient

Among 705 stomachs examined, 417 (59.15%) were completely empty. The rest (40.85%) contained food in various degrees of digestion.

6.4.1. Seasonal variation in fullness coefficient :

Variations in the relative numbers of full stomachs were computed in order to determine when heavy feeding occurred in "indeterminate sex", in males and in females.

Table (6.1) and figure (6.1a) show that in the three categories of fish the highest values of fullness coefficient occurred in winter and summer while the lowest values were in spring and fall. "Indeterminate sex" fish had lower fullness coefficient values than males or females in all seasons, except for males in spring. Females had higher values than males during winter and spring and equal in summer but more males had food in their stomach than females during fall. Most *M. flavolineatus* fed heavily during winter and summer (F.C.= 72.22 and 61.54, respectively) rather than in the fall or spring (F.C.= 35.1 and 27.0, respectively).

6.4.2. Variation of fullness coefficient with fish size

The data were divided into four size groups: 10-13 cm, 14-17 cm, 18-21 cm and fish more than 21 cm standard length; these sizes correspond to fish of age groups I, II, III+IV and older than IV years, respectively (see chapter 8). The data are summarized in table (6.2) and figure (6.1b).

Fish belonging to the size range of 14-17 cm (SL) or age group II, had the lowest rate of feeding (F.C.= 26.8) compared with other size groups. No pattern was detected in the variation of the fullness coefficient in either "indeterminate sex" fish, males or females (Figure 6.1b). Males and females had higher rates of feeding than "indeterminate sex" fish in size groups 10-13 and 18-21, while "indeterminate sex" fish had higher values of F.C. than males or females of medium size group (14-17 cm SL). In fish larger than 21 cm (SL) all males and "indeterminate sex" fish fed well, but females fed at low rate (only 20% of the examined fish that contained food).

6.5. Percentage frequency of major food items

Analysis of the data showed that 40.85% (288 stomachs) of the stomachs examined contained food. This may indicate the extent of feeding activity and/or food availability. Among this number, only 82.64% (238 stomachs) contained identifiable food organisms, while the others contained only unidentifiable digested food. Analysis of the identifiable food items showed a wide variety of food organisms; of which crustaceans, molluscs and annelids formed the main categories. These were as follows :

6.5.1. Crustaceans : The most important item represented in 68% of the stomachs containing identifiable food items. Among crustaceans, amphipods were the dominant groups constituting 57.83%; penaeid shrimps and prawns, brachyuran crabs and isopods were almost equally abundant constituting each 15.66%, 15.06% and 11.45%, respectively (Table 6.3).

Most abundant amphipods were *Amphithoe* sp. and *Elasmopus* sp. constituting 43.75% and 38.54%, respectively, while *Cymadusa* sp. were less frequent (in only 17.71% of the stomachs containing amphipods). The shrimp *Solenocera choprai* was the most abundant among penaeids (46.15%)

followed by *Penaeus indicus* (26.92%), other shrimps occurred less frequently. Only two species of isopods were found; *Cirolana* sp. was dominant occurring in 80% of the stomachs and *Cymodocea* sp. was much less important. Brachyuran crab *Scyra acutifrons* was the dominant species within this group (52.63%), the crab *Calappa flammea* and a hermit crab *Pagurus* sp. constituted only 26.32% and 21.05%, respectively.

6.5.2. *Molluscs* : were represented in 42.4% of the stomachs with identifiable items. These were either bivalves or gastropods. The bivalves constituted 73.8% of the molluscs; they were represented by three species, *Tellina* sp. (65.30%), *Trachicardium* sp. (26.55%) and *Mytilus* sp. which was found in relatively fewer stomachs (Table 6.3). Gastropods constituted only 26.2% of the molluscs ingested by *M. flavolineatus* but were represented by a wider variety of species than bivalves. The most important of these gastropods were *Strombus* sp. *Turitella* sp. and *Turbo triarinulatus* which constituted 38.78%, 28.57% and 26.53% of the gastropods, respectively.

6.5.3. *Annelids* : Occurred in 34.03% of the stomachs, and because of the nature of their structure, were in various degrees of digestion. They were thus separated into three groups: the first was the tube worms comprising 43.75% of the total annelids in the diet, the second was that of bristle worms constituting 34.38% and mostly belonging to the genus Lambreconereis; the third group constituted of other annelids which were more digested and not identified. These constituted 21.88% of the examined stomachs.

An unidentified worm occurred in 21% of the examined specimens having identifiable food items in their stomachs. This worm was not included in the list given in table (6.3) because it was found only in the intestines, and never in the stomachs, and was thus considered as parasitic.

6.5.4. Algae : Were found in only 5% of the examined stomachs; they were represented by five species which were almost equally abundant in the stomach contents.

6.5.5. Echinoderms : Occurred less frequently, being present in only 2.9% of the stomachs with identifiable food items. The bristle star Ophiocoma sp. was the most abundant (present in 54.55% of the stomachs containing echinoderms), followed by the sea cucumber Cucumaria sp. (36.36%); and the sea urchin Echinocyamus pusiellus represented in only 9.09%.

6.5.6. Other groups, including sponges and teleosts were represented in 1.7% and 1.3% of the stomachs examined, respectively.

6.6. Specific analysis of ingested food items

Analysis of the stomach contents of 238 stomachs containing identifiable food items showed that, among the overall food bulk (F.B.) ingested by *M. flavolineatus* the dominant groups were amphipods, annelids and bivalves, constituting 25.32%, 21.91% and 20.15%, respectively, to the food bulk (Figure 6.2). All the other groups shown in table (6.4) made a smaller contribution to the food bulk ingested by this fish. However, in term of species, the bivalve *Tellina* sp. was the most frequently ingested item, representing 13.16% of F.B.. This was followed by two amphipods, *Amphithoe* sp. and *Elasmopus* sp., representing respectively, 11.08% and 9.76% of F.B. Annelid tubeworms followed in abundance and represented 9.59% of F.B.

6.7. Frequency index of ingested food items

The frequency index gives a good idea of the degree of preference of the fish to various food items; Three categories of preys were distinguished:

1- Accidental, in which F.I. < 0.10 .

2- Secondary, in which F.I.>0.10-<0.50, and

3- Preferential, in which F.I.>0.50 .

6.7.1. Seasonal variation of F.I.

Table 6.5 shows the seasonal changes in the degree of preference for food items ingested by *M. flavolineatus*. Crustaceans were the most preferred food throughout the year but particularly preferred during the fall.

Molluscs were preferred during spring and summer, but were secondary during winter. In fall, on the other hand, they were accidental (F.I.=0.1).

Annelids were highly preferred as a food items during winter but during the other seasons they were secondary in choice as food items, and during the fall they were of even lesser importance to the diet of this fish.

All other food items, i.e. algae, sponges, teleosts and echinoderms were accidentally ingested whenever present within the reach of the fish.

During winter, "indeterminate sex", males and females had different preferences. "Indeterminate sex" fish preferred crustaceans and annelids, while males preferred annelids and females equally preferred crustaceans, annelids and molluscs. Males and females, however, both fed accidentally on echinoderms but these were not eaten by "indeterminate sex" fish (Figure 6.3). During subsequent seasons, "indeterminate sex" fish took a more diverse range of food items than did males or females, but with a preference for invertebrates, especially Crustaceans (Table 6.6). Males and females, on the other hand, were more selective for Crustaceans and molluscs.

6.7.2. Variation of F.I. with fish size :

Evidence suggest that the diet of *M. flavolineatus* depends greatly upon the size of the feeding fish. From the analysis of food preference by fish of different size groups, it was found that some food items are exclusive to certain sizes of fish. Fish smaller than 14 cm (SL) fed entirely on crustaceans (F.I.= 1.0), while larger fish took a wider range of food items (Table 6.7). However, the degree of preference for one particular food item varied with the size of the fish. Crustaceans were the preferred food item for fish ranging in size between 14 cm and 21 cm (SL), but for larger fish molluscs were preferred (F.I.= 0.86). Annelids were of secondary preference for medium sized fish (14-21 cm SL) but occurred only occasionally in the diet of larger fish. Algae, echinoderms, sponges and teleosts were of minor importance to M. flavolineatus.

Among small size fish (10-13 cm SL), "indeterminate sex" males and females all had the same diet, feeding only on crustaceans. In fish of larger size range (14-17 cm SL), it seems that "indeterminate sex" individuals have the highest variation in their diets; while males and females fed mainly on crustaceans, molluscs, and annelids (Table 6.8, Fig. 6.4). In fish ranging from 18 cm to 21 cm (SL), the diet resembled that of the undetermined, males and females, and with the same degree of preference. For the largest specimens, females had the greatest variety in their diet, with crustaceans prominent. Males and "indeterminate sex" fish fed strictly on crustaceans and molluscs; they were of equal preference in the case of males, while in the case of "indeterminate sex" fishes, molluscs were more preferable and crustaceans were of secondary order of preference.

In general, it may be concluded that at all seasons and for all sizes of fish, M. flavolineatus prefer crustaceans as the major constituent of their diet, while molluscs and annelids are of secondary order of preference, and other food items occur accidentally in the diet of this fish.

6.8. Discussion

The feeding habits of M. flavolineatus were studied in the present analysis in order to determine the types of food items present and its preponderance in the stomach and the degree of preference of the fish to every food item.

Little work has been published regarding the feeding habits of Red Sea and Indo-Pacific goat fish in general and M. flavolineatus in particular, though Mediterranean goatfish species have received considerable attention (Hashem, 1973a,b).

In the present study, M. flavolineatus was found to feed mainly on small Crustaceans and other invertebrates which occur in the reef communities of the Red Sea. Amphithoe and Elasmopus were the most preferred of the amphipods, while Solenocera choprai was the most abundant shrimp in the diet of this fish. Cirolana sp. was the frequent isopod, and the brachyuran Scyra acutifrons was the most dominant. Molluscs were second in order of preference among ingested food items by this goatfish, Tellina sp. and Trachicardium sp. were the most abundant. The annelid, *Lambreconereis* sp. was next in order of preference for this fish.

According to Hobson (1974) the three commonest Red Sea species of goatfish are the ‘yellowsaddle goatfish’ (*Paraeupeneus cyclostomus*) which is typical of rich coral areas, ‘Forskal’s goatfish’ (*P. forskali*) which feeds over bare rock areas of the reef, and the ‘longbarbel goatfish’ (*P. macronema*) which mostly occurs in sandy and lagoon areas. These species feed by day, but the species of *Mulloides*, which spend the day in stationary schools above sandy bottoms, feed by night. The Crustaceans present in the diet are more active during the night, which correlates with the nocturnal feeding of *M. flavolineatus*. According to Hiatt and Strasburg (1960) most goatfish feed on small Crustaceans and polychaetes, and as described by Ormond (1980) usually hunt in small groups, winkling prey out of coral heads with their barbels. This could explain the presence of fragments of coral in their stomachs.

Seasonal variation in food items is observed for several fish species (Nikolsky, 1963). The seasonal rhythm in food consumption has been observed to vary according to abiotic conditions. Feeding intensity also changes in relation to seasonal variation. Thus for immature sheat fish, *Silurus glanis* L. (in Volga river, USSR), feeding is usually more intense during summer time (Fortunatova, 1955).

For the fish under investigation, it was found that feeding intensity was very high in winter and summer with a lower rate of feeding during spring and fall.

Changes in the food spectrum occur in some fish populations throughout the year (Nikolsky, 1963). Usually the period of most intensive feeding occurs at the time of blooming of a food organism which forms the basis of the diet. Thus, for example, in the white fish, Coregonus muksun Pall, the food spectrum consists of 7 basic components, with a fullness index of 58.5 in summer. In winter, which is the main feeding period, the food consists of 3 components. The index of fullness rises to 112 (Pirozhnikev, 1950).

In the present study, it has been shown that, the fish feed mainly on crustaceans and molluscs in fall, spring and summer time , while it feeds heavily on annelids in winter. This change in food prey probably brings about the winter check line (annulus) in the scales. The changes in the composition of the food with fish size are well known among other fish (Nikolsky, 1963; Mittelbach, 1981)

Food provides energy, and fish, as they grow larger, gradually get access to food with a higher relative energy content that enables them to grow to a larger size than might have been if they remained dependent on the same food items all their life, and this is the topic analyzed by the optimum foraging theory (Tricas, 1986). Most studies on the food of fish report ingested prey in the form of individual counts, or as percentage occurrence of stomach contents, and most such studies fail to report absolute changes in the diet of a fish species as it grows in size.

In the present study, M. flavolineatus was found to change their feeding habits with increase of fish size. Thus for small sizes, the fish feeds only on Crustaceans, and as it increases in size, it shifts its feeding preference to be more dependent on molluscs together with Crustaceans which are the most abundant food item in bigger sizes. This phenomenon has been observed in the Mediterranean Goat fish Mullus barabatus , thus Froglia (1988) have shown that as the fish gets older, they become more selective to peracarid Crustaceans and small decapods. However, according to him, Polychate worms and bivalves are more abundant in the stomachs of fish sizes of more than 15 cm in TL.

Constraints in collecting samples, in that the samples were obtained from commercial boats, so that fish could not be collected from all areas considered necessary leave some doubts regarding the firmness of the conclusions which can be made from the data. Samples were not as large in the feeding section as those used in the reproductive section so that results may give indications but must not be taken as necessarily a true picture. However, an examination of them may indicate areas in which further studies could and should be pursued.

Specimens 10-13 cm long which are not mature (Figure 6.5a,b,c,d) had a diet of Crustacea (mostly demersal) whereas the larger sizes had mixed diets of Crustacea, Mollusca, Annelida and to a lesser extent Algae, Echinoderms and Sponges. This extra variety and quantity is necessary for development of the yolk in the eggs (See Ch. 10.3.1.II). Fig. 6.4 shows that as the fish become larger the proportion of indeterminate fish is reduced, i.e. at 14-17 cm it is 64%, at 18-21 cm it is 31% and at >21 cm it is 57%. Unfortunately, because of time and labour constraints the category of "indeterminate sex" was not examined for spent or immature fish but there is an indication that either fish become mature over a varying period of time having attained the minimum size for maturity (14.4 cm) or a higher proportion of larger fish spawn.

Fig. 6.3 indicates that all fish have a higher proportion of Crustacea in their diets during the fall. This may reflect some changes in abundance of the food organism or reflect a movement into deeper water for the winter months when weather is slightly worse inshore.

Although the location of the spawning grounds is unknown data presented in Chapter 10 regarding ovarian indices suggests that fish spawn during June, July and September. It is assumed that the samples are probably obtained from the feeding grounds and whether fish move away to spawn is not known. The limited sized sample taken to examine food types suggests that during the fall only small (10-13 cm) fish and a few larger >21 cm fish were caught. The high proportion of small fish may be those produced by the earlier spawning. In winter only a few of the larger fish were caught, perhaps the smaller ones moved into deeper water for protection. In spring the majority were 14-17 cm but in summer some larger fish were present. These may suggest recruitment of the previous seasons hatch but little can be inferred regarding possible movements. The vague hint is that perhaps the spawning ground or grounds are not far away from the feeding grounds but much more data is needed regarding this point.

ble 6.1: Seasonal variation of the fullness coefficient with sex of *M. flavolineatus* off Jeddah (1986).

	Winter			Spring			Summer			Fall		
	I.S.	males	females	I.S.	males	females	I.S.	males	females	I.S.	males	females
C.	57.1	71.4	86.7	26.4	24.5	29.5	52.6	67.6	67.5	26.9	46.7	39.4
an		72.22			27.00			61.54			35.1	

ble 6.2: Variation of the fullness coefficient of *M. flavolineatus* off Jeddah (1986) of different sex with respect to fish size.

	10 - 13 cm			14 - 17 cm			18 - 31 cm			> 21 cm		
	I.S.	males	females	I.S.	males	females	I.S.	males	females	I.S.	males	females
C.	58.1	92.3	72.0	29.1	20.0	24.2	34.7	50.7	64.9	100.0	100.0	20.0
an		69.86			26.80			52.22			46.70	

S. = "indeterminate sex"

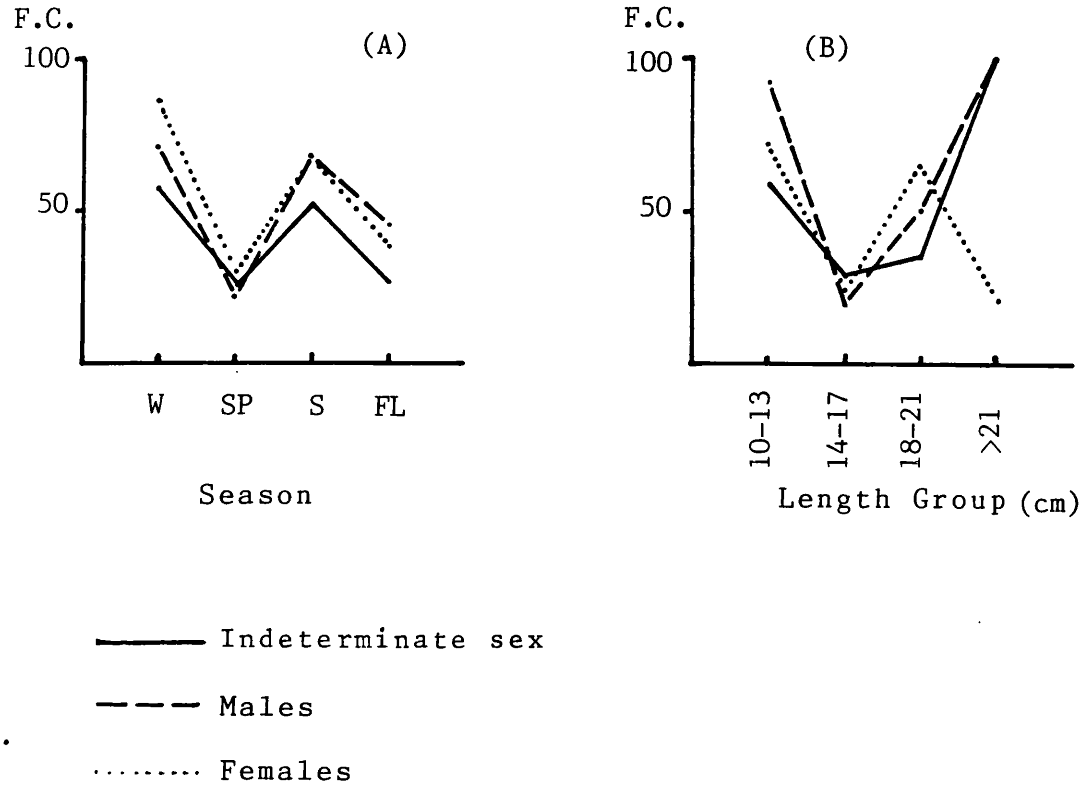


Figure 6.1. Variation in fullness coefficient of "indeterminate sex", males and females of *Mulloides flavolineatus* off Jeddah (1986); (A) with season, (B) with fish size.

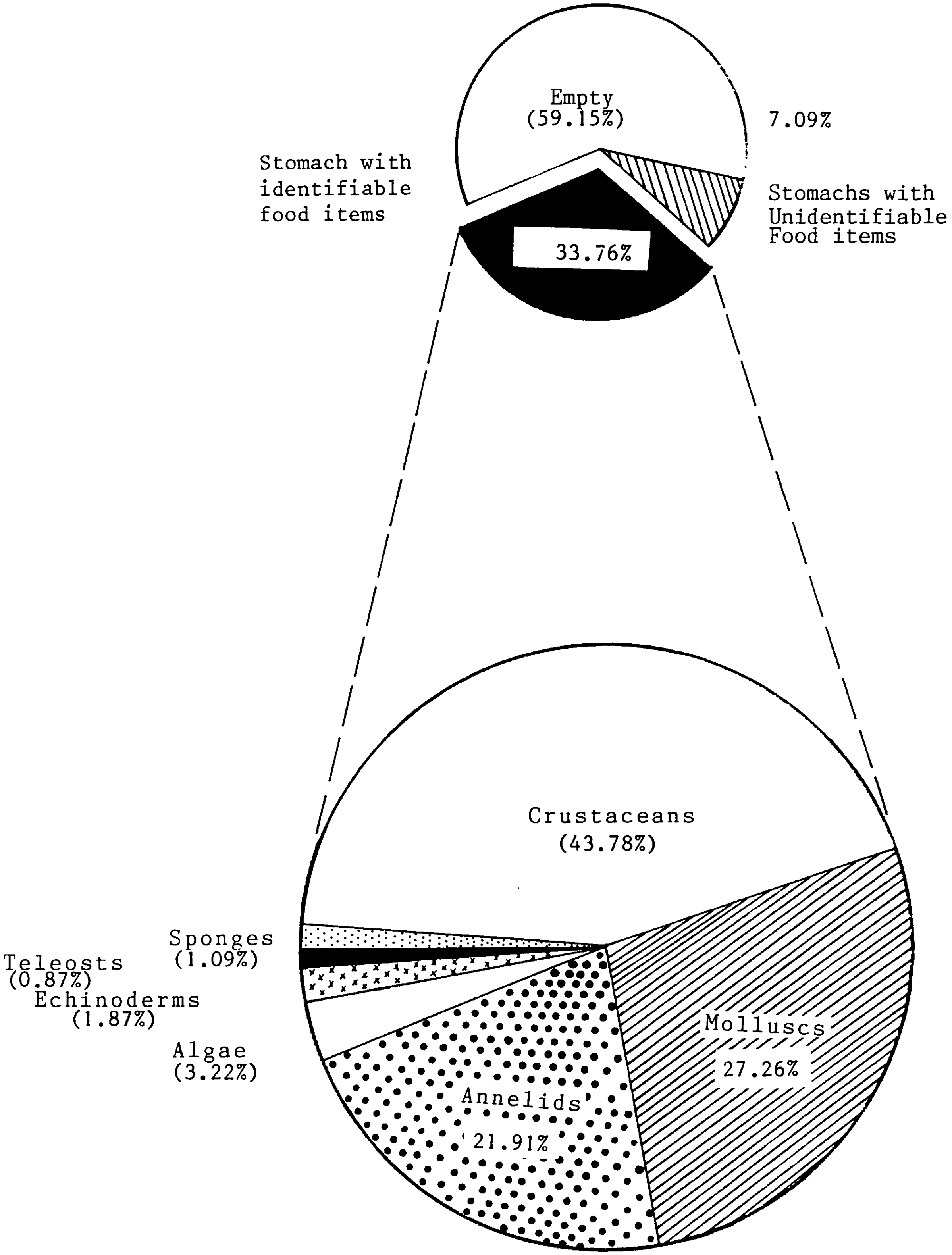


Figure 6.2. Percentage composition of the major food groups ingested by <u>M. flavolineatus</u> off Jeddah (1986).

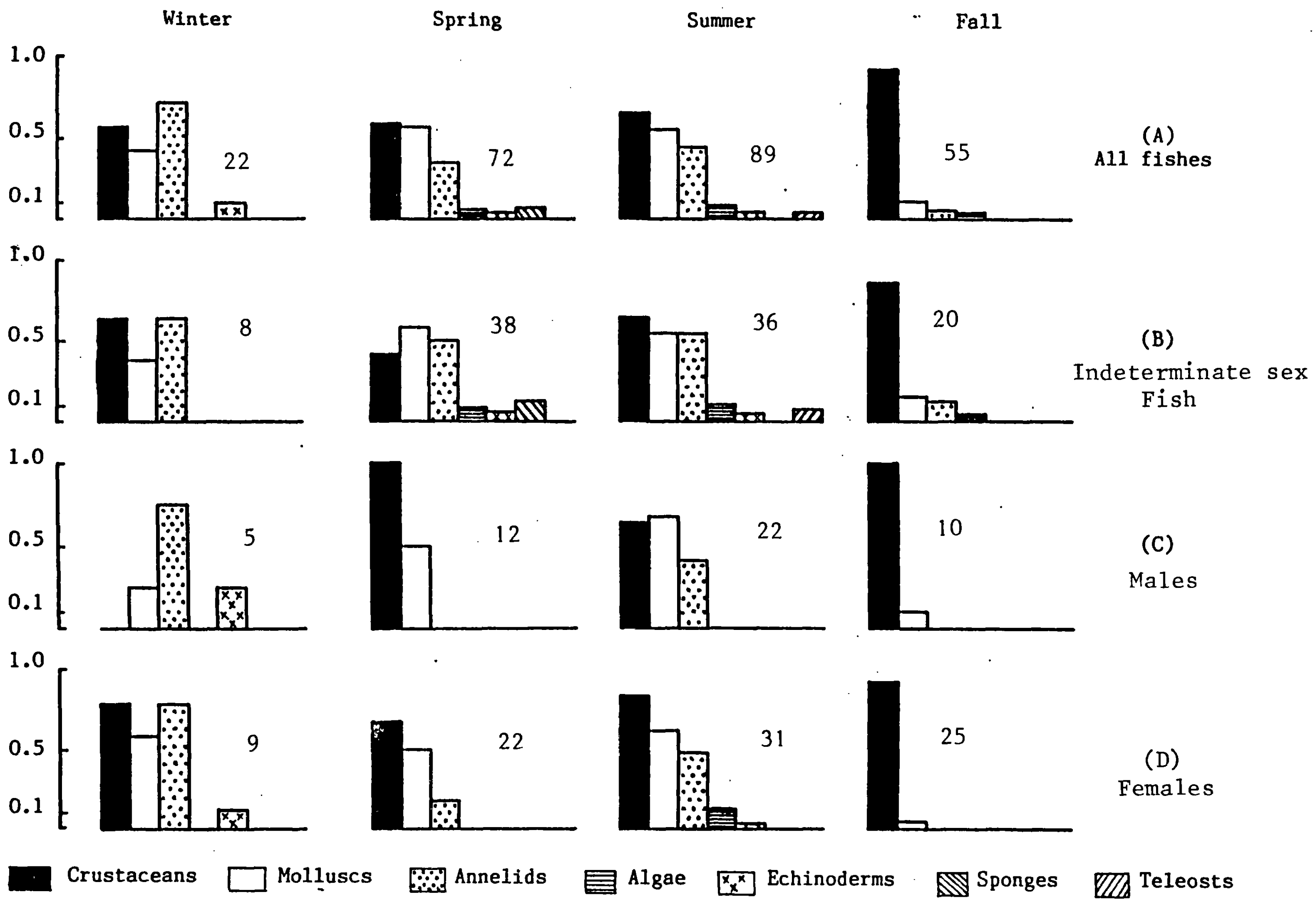


Figure 6.3. Histogram showing seasonal variation in frequency index of different food groups ingested by *Mulloides flavolineatus* off Jeddah (1986).

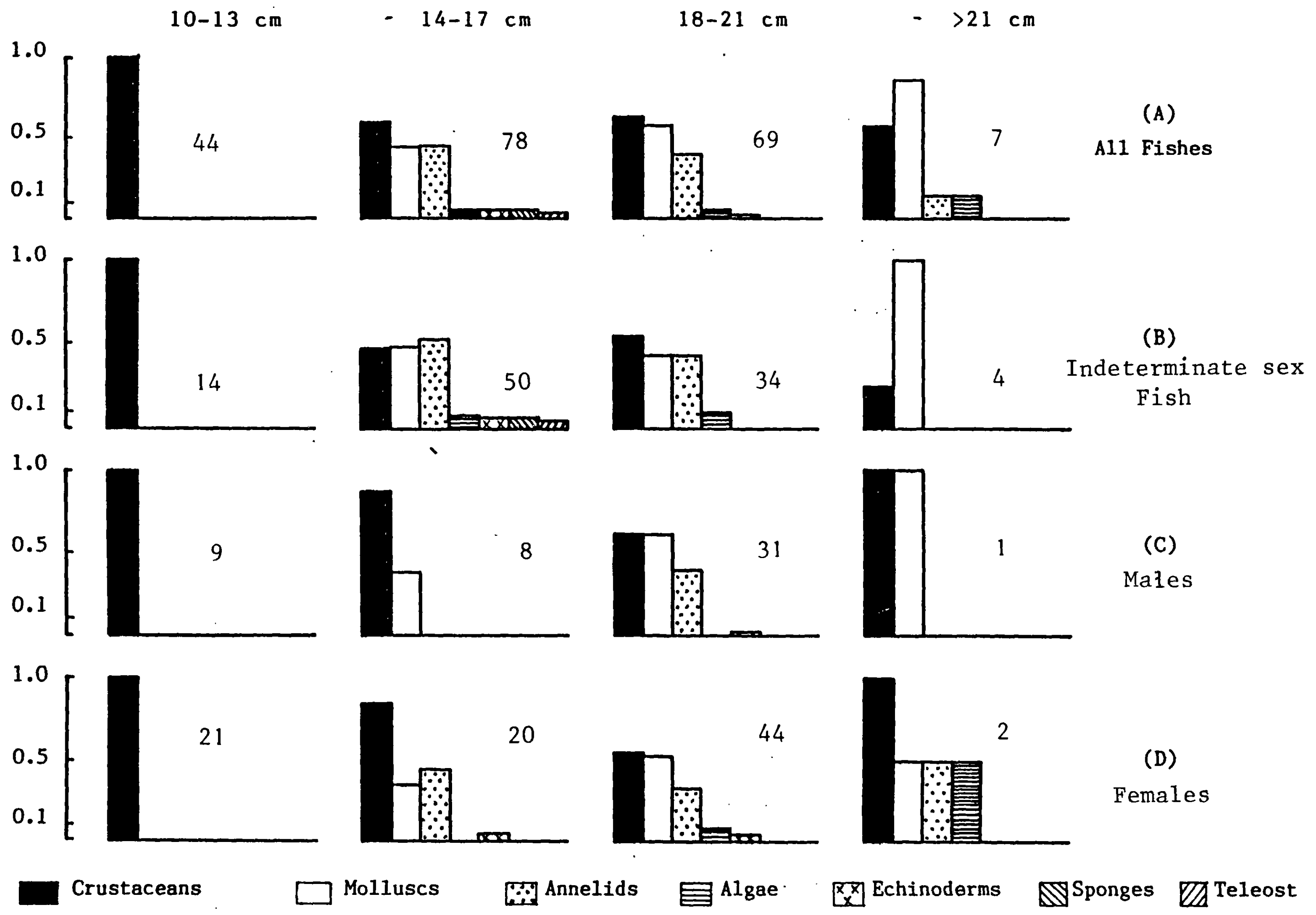


Figure 6.4. Histogram showing variation in frequency index of different food groups ingested by Mulloides flavolineatus off Jeddah (1986) with respect to fish size.

Figure 6.5a: Histogram showing seasonal (winter) and different size group variations in frequency index of different food groups ingested by *Mulloides flavolineatus*.

Size group

A = 10 - 13
B = 14 - 17
C = 18 - 21
D = > 21

Food items

A = Crustacea
M = Mollusc
A = Annelida
AL = Algae
E = Echinoderms
S = Sponges
T = Teleost

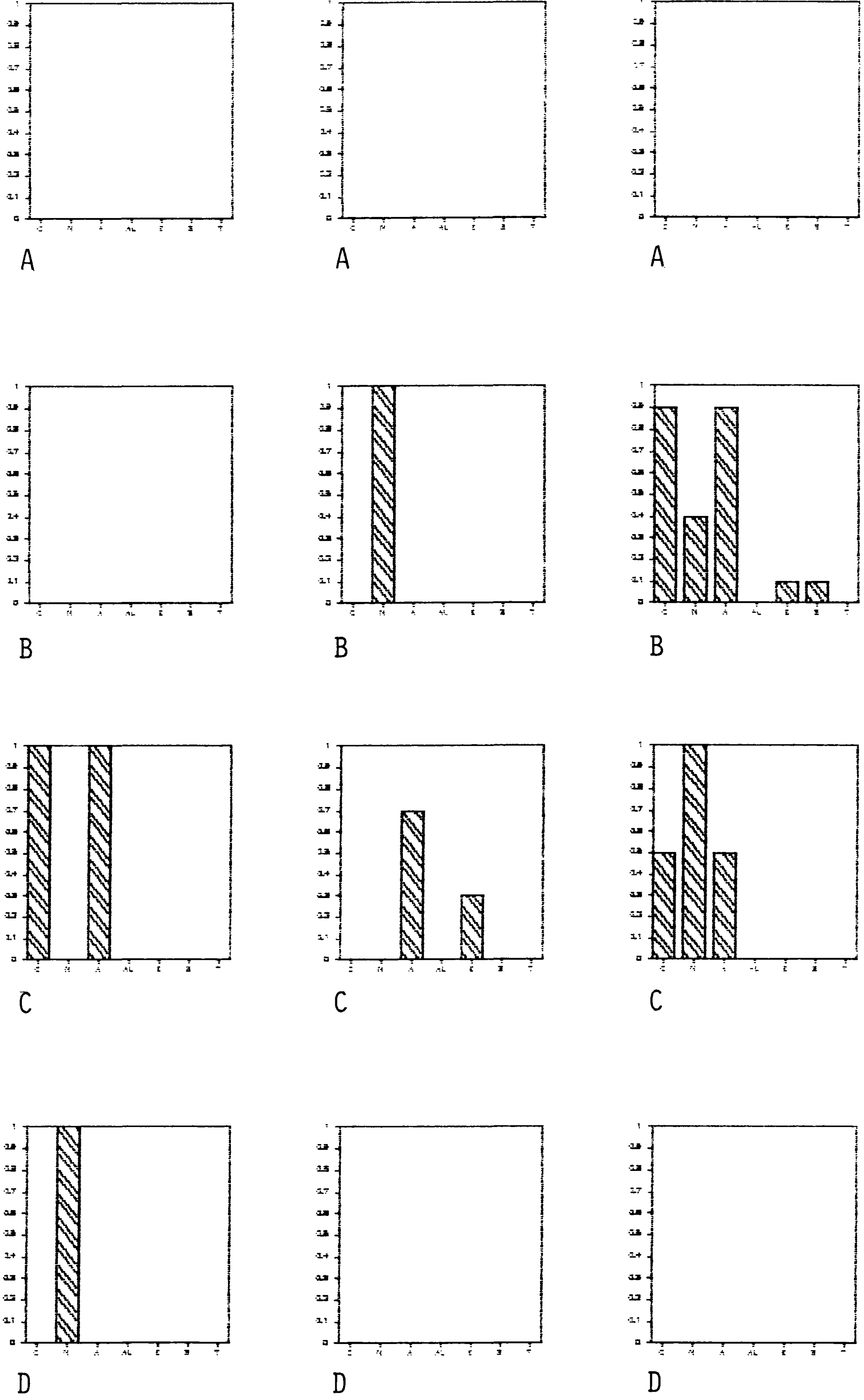


Figure 6.5a

Figure 6.5b: Histogram showing seasonal (spring) and different size group variations in frequency index of different food groups ingested by *Mulloides flavolineatus*.

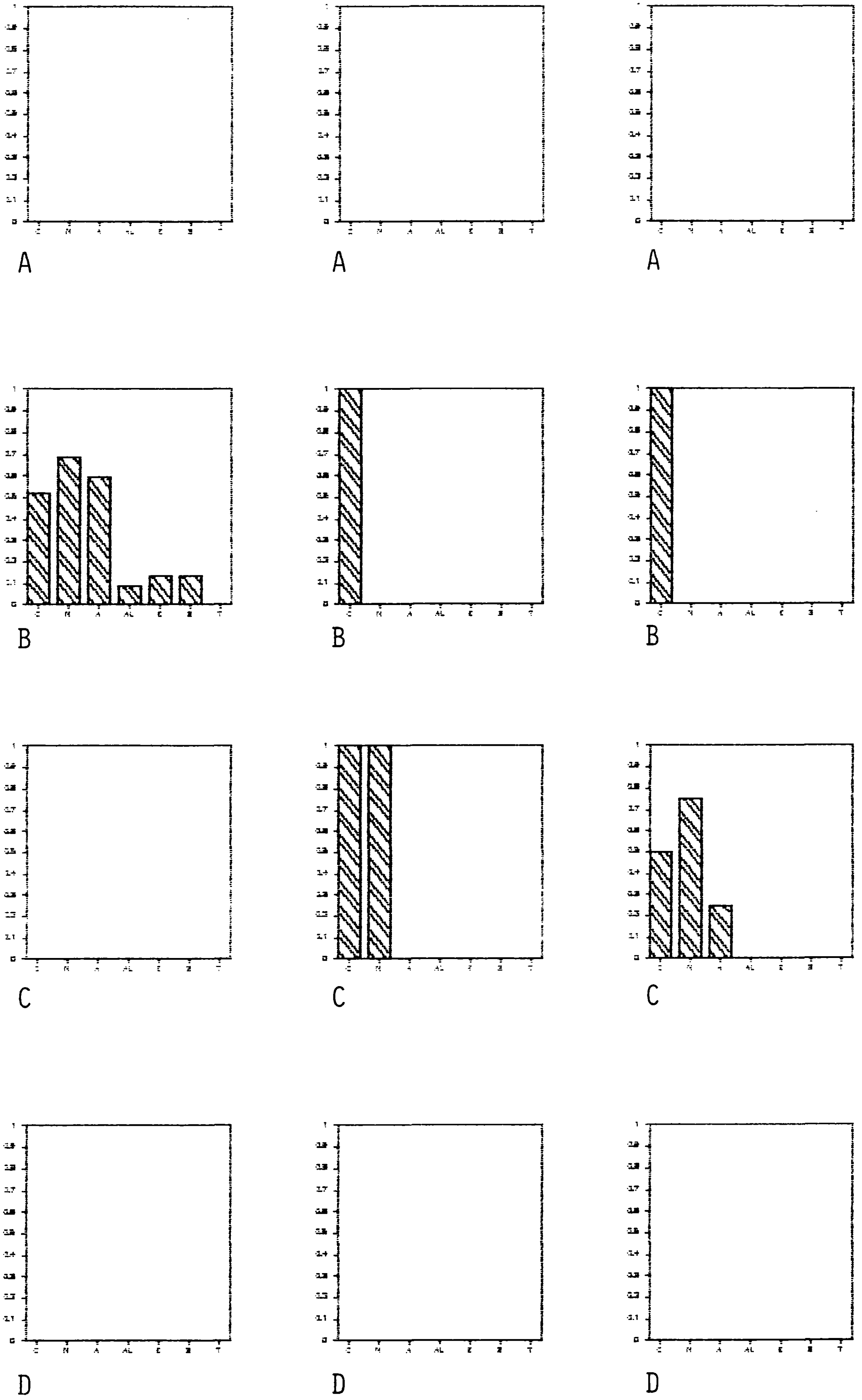


Figure 6.5b

Figure 6.5c: Histogram showing seasonal (summer) and different size group variations in frequency index of different food groups ingested by *Mulloides flavolineatus*.

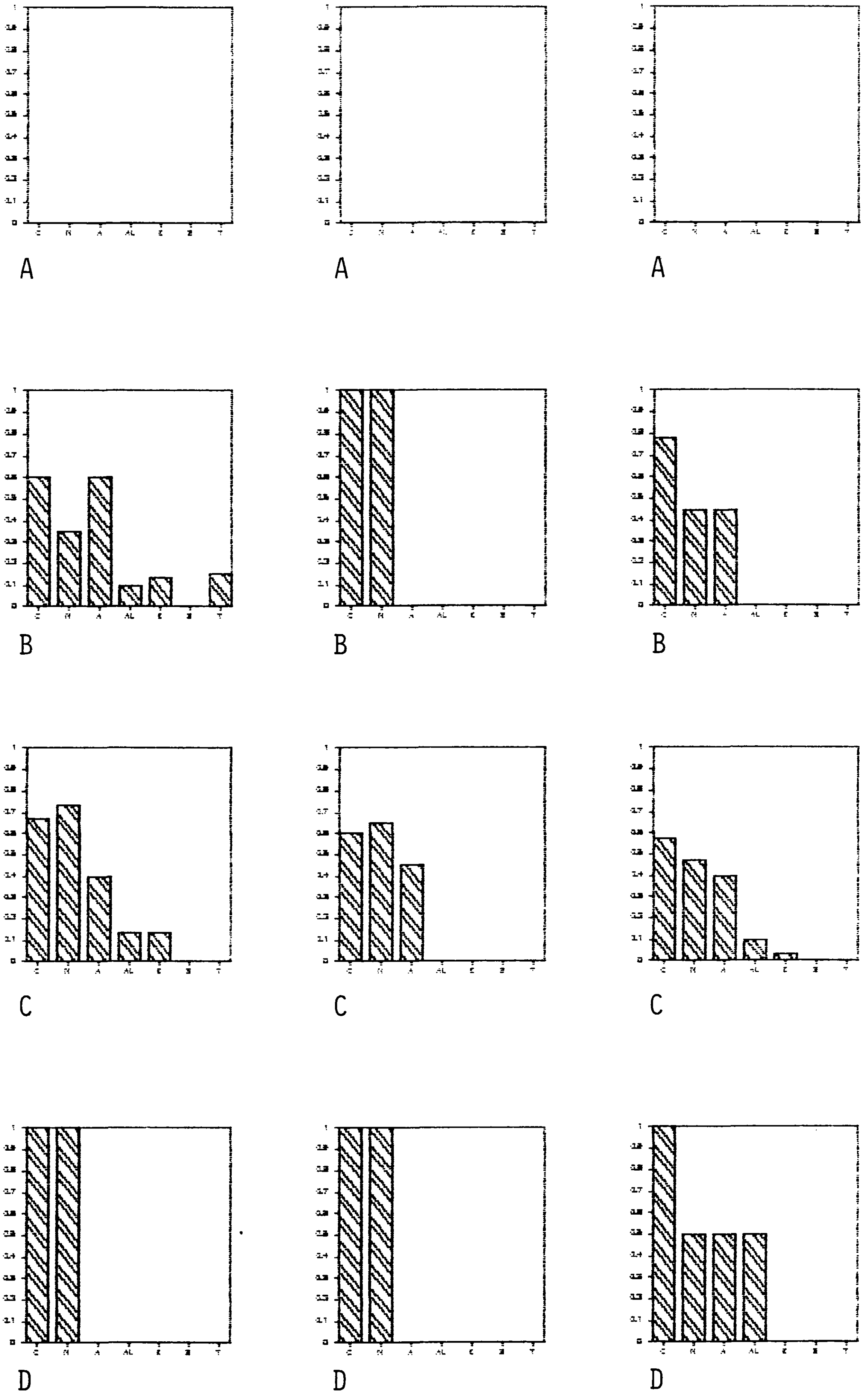


Figure 6.5c

Figure 6.5d: Histogram showing seasonal (fall) and different size group variations in frequency index of different food groups ingested by *Mulloides flavolineatus*.

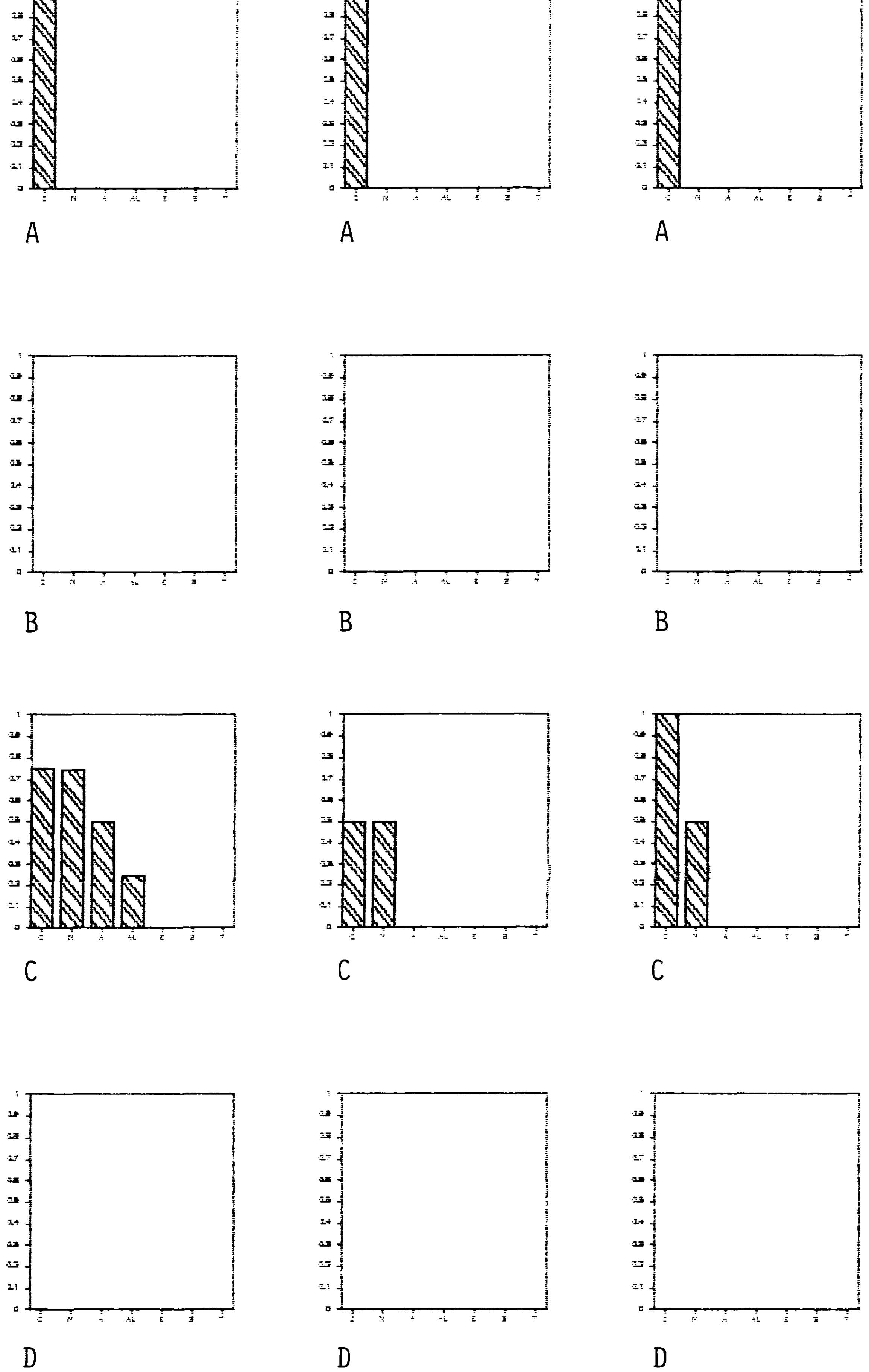


Figure 6.5d

CHAPTER 7

LENGTH-WEIGHT RELATIONSHIP AND CONDITION FACTOR

7.1. Introduction

The length of a fish is often more rapidly and accurately measured than the weight. Moreover, back-calculations of past growth from bony structures, e.g. scales, usually yield data on length alone. Thus it is very convenient to be able to determine a weight when length only is known, and occasionally it may be useful to reverse this process.

It has been found that the length-weight relationship of most fish can adequately be described by a formula of the type: $W=cL^n$, where W= weight, L=length, 'c' is a constant and 'n' an exponent usually lying between 2.5 and 4.0 (Hile, 1936; Martin, 1949). For an "ideal" fish which maintains the same shape as it grows the exponent is equal 3 ($n=3$, cube law), and this has occasionally been observed (Allen, 1938). In the vast majority of instances where length-weight relationships have been calculated, however, it has been found that the cube law is not obeyed and $n\neq3$.. Further, most species of fish do change their shape as they grow (Martin, 1949) and so a cube relationship between length and weight would not be expected.

The study of length-weight relationships of fish has usually been directed towards two objectives, first, to provide a mathematical expression between the two measurements, length and weight, so that one may be converted to the other, and second, to calculate the condition factor (Le Cren, 1951).

The condition factor (K) is a coefficient which is commonly used for measuring variations in fish weight which are not associated with length. For the purpose of comparing the condition of a fish species the cube relationship of length to weight ($K=W\times100/L^3$) is usually used. This formula assumes that growth in length and weight is isometric, otherwise (K) will tend to increase or decrease with fish length (Le Cren, 1951).

In nature, the value of (K) is not constant for a species or population, but is subject to a wide variation. So, the values of (K) can be used as measures of individual or average seasonal and regional differences in the condition or 'degree of well-being' of fishes.

7.2. Materials and methods

7.2.1. Length-weight relationships

Values of 'c' and 'n' can be determined for a species by the following equation (Lagler, 1956):

$$\log c = \frac{\Sigma\log W.\ \Sigma(\log L)^2 - \Sigma\log L.\ \Sigma(\log L.\log W)}{N.\ \Sigma(\log L)^2 - (\Sigma\log L)^2}$$

$$n = \frac{\Sigma\log W - (N.\log c)}{\Sigma\log L}$$

where W= fish weight

L= fish length, and

N= number of fish in the sample.

In the present study, the length-weight relationships were obtained for 380 specimens of *Mulloides flavolineatus* caught from the coastal waters of the Red Sea off Jeddah (Saudi Arabia) covering the length range 10 to 25 cm (Standard Length), and including 126 males and 254 females.

The standard length (SL) was adopted instead of the total length of the fish in order to cancel the possible bias in the computations, that would arise because of the fragility of the caudal fin of this fish.

Generally, the length-weight relationship is affected by various factors such as the availability of food, rate of feeding, stage of gonadal development, and spawning. Consequently, the gutted weight is usually used in length-weight calculations in order to exclude the bias due to variation in weight of the gut and gonads. To check the effect of the weights of the alimentary tract and gonads upon the length-weight relationship, these organs were removed from the fish, and the gutted weights (weight without viscera) of fish covering the range from 10 to 25 cm (Standard Lengths) for males and females were obtained.

7.2.2. Condition Factor

Fulton (1902) was the first to calculate the coefficient of condition by using the formula $K=W\times100/L^3$, where W is the total weight in grams, and L is the fish length in cm, K being the condition factor.

But using the whole body weight, it is impossible to exclude the effect of the gonads and also the weight of the gut contents, which in many fish may account for a considerable portion of the total fish weight. The weight of the gonad and the intestinal contents might often alter the value of the coefficient of condition and mask the true dynamics of the condition of the fish.

In order to exclude the effects of the weight of the gonads and intestinal contents, Clark (1928) suggested calculating the condition factor (K) from the body weight of fish without the internal organs. However, the use of this method has the disadvantage of excluding the internal fat, the amount of which in many fish is subject to great changes, and is to a significant extent connected with the condition of the fish.

Many fishery investigators find it better to calculate both the coefficients of Fulton (1902) and Clark (1928) to express the condition of fish with regard to the degree of well-being, relative robustness, and plumbness, in numerical terms. These coefficients, although naturally giving only a first approximation to the actual condition of the fish, are quite suitable for comparative analyses and practical purposes (Nikolsky, 1963).

7.3. Results and Observations

7.3.1. Length-weight relationships

The examination of the data obtained for the mean total body weights per length group of *M. flavolineatus* (Table 7.1) revealed no significant differences between sexes ($P<0.1$) over the length range studied. However, it showed that in fish less than 17 cm (SL), males tended to be heavier than females, while in larger fish, females had higher weights than males. Statistical tests showed a significant difference between mean weight per length group for each sex among small individuals (<17 cm SL) ($P>0.1$) but no significant difference among large fish ($P<0.1$).

The equations representing the standard length/total weight relationship for each sex were found to be :

For males : $Twt = 0.0656\ SL^{2.5308}$

or $\log W\ (\text{total}) = 2.5308 \log SL - 1.1831$

$n = 126 \quad r = 0.9784$

For females : $Twt = 0.0549\ SL^{2.6003}$

or $\log W\ (\text{total}) = 2.6003 \log SL - 1.2607$

$n = 254 \quad r = 0.9846$

These equations are graphically represented in Figures 7.1 and 7.2.

The values of the exponent "n" show that , although the difference is not significant, females tend to be heavier with respect to length than males.

When data of the two sexes were combined (Figure 7.3), the following general equation was found to be the most useful to describe the length-weight relationship of _M. flavolineatus_, as a function of total weight, within the length range recorded during the present study.

$$Twt = 0.0578\ SL^{2.5797}$$

$$\text{or } \log W\ (\text{total}) = 2.5797 \log SL - 1.2381$$

$n = 380 \qquad r = 0.9828$

Contrary to what was found in the case of the total weight, examination of the data obtained for the gutted weights of males and females (Table 7.2), revealed no significant differences between sexes for all size groups ($P<0.1$), or for any size range ($P<0.05$). This means that, when using total weights, beside the difference which may be present in the food content of the different sexes, the weight of the mature/maturing ovaries are no doubt heavier than those of ripening testes, and this would be responsible for the differences in the total body weight between the sexes in larger (mature) fish.

The general equation of length-gutted weight for the combined sexes of standard lengths ranging from 10 to 25 cm was found to be:

$$\log W\ (\text{gutted}) = 2.6641 \log SL - 1.3811$$

and is graphically represented in Figure 7.4; while the length-total weight equation of the combined sexes and for the same length range (10-25 cm) was found, as shown before, to be:

$$\log W\ (\text{total}) = 2.5797 \log SL - 1.2381$$

In most fish species, after a certain age and size, the fecundity, and hence the weight of the gonads, decrease as the fish grow older and larger (Bagenal, 1978).Therefore, the state of the gonads will have a more pronounced effect on the length-weight relationship. For this reason it is recommended to use the gutted weight in future studies on this species.

The standard length-gutted weight relationships for *M. flavolineatus* were found to be :

For males : $\log W\ (\text{gutted}) = 2.5997 \log SL - 1.3071$

$n = 126$ $r = 0.9770$ for males, and

For females : $\log W\ (\text{gutted}) = 2.6905 \log SL - 1.4107$

$n = 254$ $r = 0.9853$ for females.

7.3.2. Condition factor

The average values of (K), were calculated using both Fulton and Clark methods, for males and females of *M. flavolineatus* at 1 cm intervals of body standard length. Values are listed in Table 7.3. The values of 'K' for males and females, whether calculated by Fulton's or Clark's methods, are significantly different ($P>0.25$). For the same length group, males have "poorer" condition than females. Also, the average values of K for both sexes show a general trend of decrease with increase in length, suggesting a reduction in the growth performance of large individuals of *M. flavolineatus* in Saudi Arabian waters.

7.3.3. Cyclical changes in the condition factor

Changes in the mean values of the condition factor occur throughout the year. These changes were observed in *M. flavolineatus* for both males and females whether the value of 'K' was calculated from total (Fulton's) or gutted weight (Clark's) as shown in Table 7.4. The table also shows that the condition factor of males and females reflects fluctuations in their condition from one month to the other. It shows, however, two distinct peaks, one in November (being 1.9338 and 1.9075 (Clark's formula) for males and females, respectively) and a smaller one in August (1.7089 for males and 1.6455 (Clark's formula) for females). Furthermore, these data show a minimum value of condition for both sexes in June, being 1.3949 and 1.4449 for males and females, respectively.

Whether these fluctuations are related to the spawning cycle of this fish or to environmental conditions needs confirmation by the analysis of the cyclic variations in the gonado-somatic index (See Chapter 10). However, females >21 SL show reduced feeding activity at this time (Chapter 6).

7.4. Discussion

It is known that the weight of fish increases as a function of its length and the relation between length and weight is one of the most important biological parameters considered in fish biology. The use of this relationship has been discussed by Le Cren (1951) and Rounsefell and Everhart

(1953) who concluded that it serves several objectives. It is possible to find out the weight of a fish of known length and vice versa. This is very important especially when a large number of fish has to be examined in a short time, as, for example, it is only possible in most cases to measure the length, but not the weight in the commercial catch. Such a relationship allows one to determine their weight through back calculations. It is also applied to measure the deviations from expected weights for a given length of individual fish so as to indicate fatness, gonad development, and estimate total weight of fish catch when length and number of fish are known.

The relationship between the two variables, viz. length and weight, was determined by several authors using the general formula $W=cL^n$. Hile (1948) demonstrated that the exponent 'n' can vary widely from 1.34 to 3.68 for various fish species. The value of n=3 indicates that the fish grows symmetrically or isometrically, provided that its specific gravity remains constant. Values other than 3 indicate allometric growth.

In the present work, values of the exponent 'n' were found to be 2.5308, 2.6003, and 2.5797 for males, females and combined sexes, respectively, Hashem (1973a) calculated the value of 'n' as 2.7636, 2.8715 and 2.8800, respectively for Mullus barbatus (the Red Goatfish) in the south eastern Mediterranean. The corresponding values of the exponent 'n' for Mullus surmuletus (the Rock Goatfish) were found to be

3.1635, 3.1941 and 3.1924 for males, females and combined sexes, respectively, on the Egyptian Mediterranean coast (Hashem, 1973b). Al-Absy and Ajiad (1988), on the other hand, gave values of 'n' as 3.1748 for *Paraupeneus cinnabarinus* (Cuv. & Valen.) in the Gulf of Aqaba, Red Sea. This shows that due to the fact that the northern part of the Red Sea is of low productivity (Lewis, 1977), *M. flavolineatus* have relatively low values of 'n' indicating that this fish grows slightly lighter for its length as it grows longer. Values of expected weights (total and gutted) as calculated from the length-weight equations are given in Table 7.5.

The coefficient of condition 'K' is another way of comparing the relationship between length and weight. This parameter is widely used as an indicator to give an idea about the degree of well-being of fish and its relative robustness.

In the present study, values of the condition factor, calculated for both the total and gutted weight, i.e. according to Fulton (1902) and Clark (1928), for *M. flavolineatus* were found to be 1.7536 and 1.6028, respectively for males, and 1.8047 and 1.6440, respectively for females. Table (7.6) shows values of the condition factor for different goatfish species as given by several authors. *M. flavolineatus* has the highest values of any goatfish species in any locality, indicating that water quality feeding and substrate in the vicinity of Jeddah are highly suitable for the well being of this fish.

Concerning the monthly variations in the value of the condition factor, Al-Absy and Ajiad (1988) pointed out that nonsignificant variations in the value of 'K' for *Paraupeneus cinnabarinus* throughout the year reflect a relatively stable environment in the Gulf of Aqaba. On the other hand, Hashem (1973b) observed monthly variations in the value of the condition factor of *Mullus surmuletus* in the Mediterranean and attributed these variations to the spawning activity of the fish, 'K' being maximum in the prespawning season and least during the months of spawning.

In the present study, monthly variations in the condition factor for the fish were observed, and these are perhaps correlated with the spawning season (see later section). Fish had the highest condition factor during November and August for both males and females. (See also Chapter 6, Fig. 6.1a).

Considering variation in the condition factor with fish length, in the Gulf of Aqaba *P. cinnabarinus* was found to have a variable condition factor that tends to increase as the fish grew in size (Al-Absy and Ajiad, 1988). In the Mediterranean, *Mullus surmuletus* was found to show a similar trend (Hashem, 1973b). In contrast, however, in the present study, it was found that the condition factor of both males and females *M. flavolineatus* tend to decrease with increasing fish length. This coincides with the fact that this fish gets leaner as it grows in length. The lowest recorded value, however, was much higher than that recorded for goatfish in any other locality. More important, though, it indicates that this fish thrives well in the waters of the Red Sea off Jeddah.

Table 7.1. Length-weight relationship of the sexes of *M. flavolineatus* from the Red Sea off Jeddah.

SL (cm)	Males N	Males Av. Wt. (gm)	Females N	Females Av. Wt. (gm)
10	1	24.46	4	23.7
11	9	28.60	20	27.10
12	3	35.04	10	36.13
13	-		1	46.09
14	5	55.80	10	53.32
15	3	62.50	10	62.52
16	18	70.98	33	70.68
17	22	80.74	45	84.01
18	33	98.17	47	99.88
19	18	115.50	34	111.82
20	18	128.45	22	135.25
21	7	147.85	19	157.67
22	2	175.65	5	180.99
23	1	177.61	4	211.51
24	-		2	229.05
25	-		1	261.07

$t=-1.5148$ $P=0.0779$

N = No. of fish

Table 7.2. Length-Gutted weight relationship of the sexes of *M. flavolineatus* in the Red Sea off Jeddah.

SL (cm)	Males N	Males Av. Wt. (gm)	Females N	Females Av. Wt. (gm)
10	1	21.02	4	20.18
11	9	24.98	20	24.61
12	3	30.39	10	31.08
13	-		1	38.02
14	5	49.93	11	47.65
15	3	59.27	10	57.35
16	18	65.74	33	64.59
17	22	74.38	45	78.04
18	33	91.20	47	92.91
19	18	106.51	34	103.13
20	18	117.60	22	124.66
21	7	135.25	19	145.28
22	2	159.70	5	161.61
23	1	166.55	4	189.63
24	-		2	199.90
25	-		1	229.65

t=-1.4814 P=0.0821

N = No. of fish

Table 7.3. The condition factor (K), by Fulton and Clark, for males and females of *M. flavolineatus* in the Red Sea off Jeddah.

SL (cm)		Males			Females	
	N	KF.	KCl.	N	KF.	KCl.
10	1	2.3049	1.9808	4	2.3222	1.9697
11	9	2.1644	1.8885	20	2.1768	1.8720
12	3	2.1553	1.8719	10	2.1840	1.8724
13	-			1	2.0979	1.7579
14	5	2.0251	1.8136	11	1.9247	1.7519
15	3	1.8866	1.7892	10	1.8730	1.7171
16	18	1.7434	1.6150	33	1.7266	1.5962
17	22	1.6751	1.5422	45	1.7212	1.5977
18	33	1.6884	1.5584	47	1.7044	1.6109
19	18	1.6512	1.5125	22	1.7176	1.5712
21	7	1.6566	1.5153	19	1.7339	1.5404
22	2	1.6050	1.4594	5	1.7120	1.5284
23	1	1.4223	1.3338	4	1.6670	1.5511
24	-			2	1.7094	1.4912
25	-			1	1.7116	1.5056
Average				1.6028		1.6440

KF = Condition factor calculated using Fulton's equation. (Total body weight)
KCl = Condition factor calculated using Clark's equation. (Total body weight)

Table 7.4. Monthly variations of the condition factor for the sexes of *M. flavolineatus* from the Red Sea off Jeddah.

	Males			Females		
Month	N	KF.	KCl.	N	KF.	KCl.
Dec.	5	1.6570	1.5236	15	1.6704	1.5359
Jan.	-			-		
Feb.	2	1.6498	1.5802	-		
Mar.	24	1.7984	1.6703	54	1.7987	1.6886
Apr.	14	1.6614	1.5297	21	1.7262	1.6066
May	18	1.7970	1.6818	25	1.8002	1.6876
Jun.	28	1.5364	1.3949	47	1.5865	1.4449
Jul.	7	1.7296	1.5833	18	1.7301	1.5891
Aug.	7	1.9321	1.7089	13	1.9495	1.6455
Sep.	6	1.6813	1.5387	5	1.7852	1.5979
Oct.	20	1.6822	1.5455	42	1.7013	1.5621
Nov.	9	2.2194	1.9338	28	2.2229	1.9075

KF = Condition factor calculated using Fulton's equation.
KCl = Condition factor calculated using Clark's equation.

Table 7.5. Calculated weights for the different sexes of *M. flavolineatus* off Jeddah, Saudi Arabia.

	Males		Females		Combined Sexes	
SL (cm)	Twt (gm)	Gwt (gm)	Twt (gm)	Gwt (gm)	Twt (gm)	Gwt (gm)
10	21.87	19.61	22.27	19.03	21.96	19.20
15	62.77	56.64	62.14	56.64	62.50	56.54
20	132.63	118.89	128.69	122.82	131.28	121.67
25	236.94	212.36	226.37	223.87	233.45	220.47
30	380.65	341.13	359.09	365.62	373.64	358.34
35	568.35	509.28	530.43	553.54	556.11	540.31
40	804.28	720.65	743.70	792.82	784.81	771.15

Twt = Total weight

Gwt = Gutted weight

Table 7.6 Values of the condition factor given by different authors for goatfish species

Species	Sex	K	Locality and Reference
M. surmuletus	M	1.318	Mediterranean, Hashem
	F	1.313	(1973b)
P. barberinus	c.s.	1.048	Aqaba, Al-Absy (1977)
M. auriflamma	c.s.	0.975	Aqaba, Al-Absy (1977)
P. cinnabarinus	c.s.	1.230	Aqaba, Al-Absy & Ajiad (1988)
M. flavolineatus	M	1.7536	Jeddah (Red Sea),
	F	1.8047	Present study.

c.s.= combined sexes.

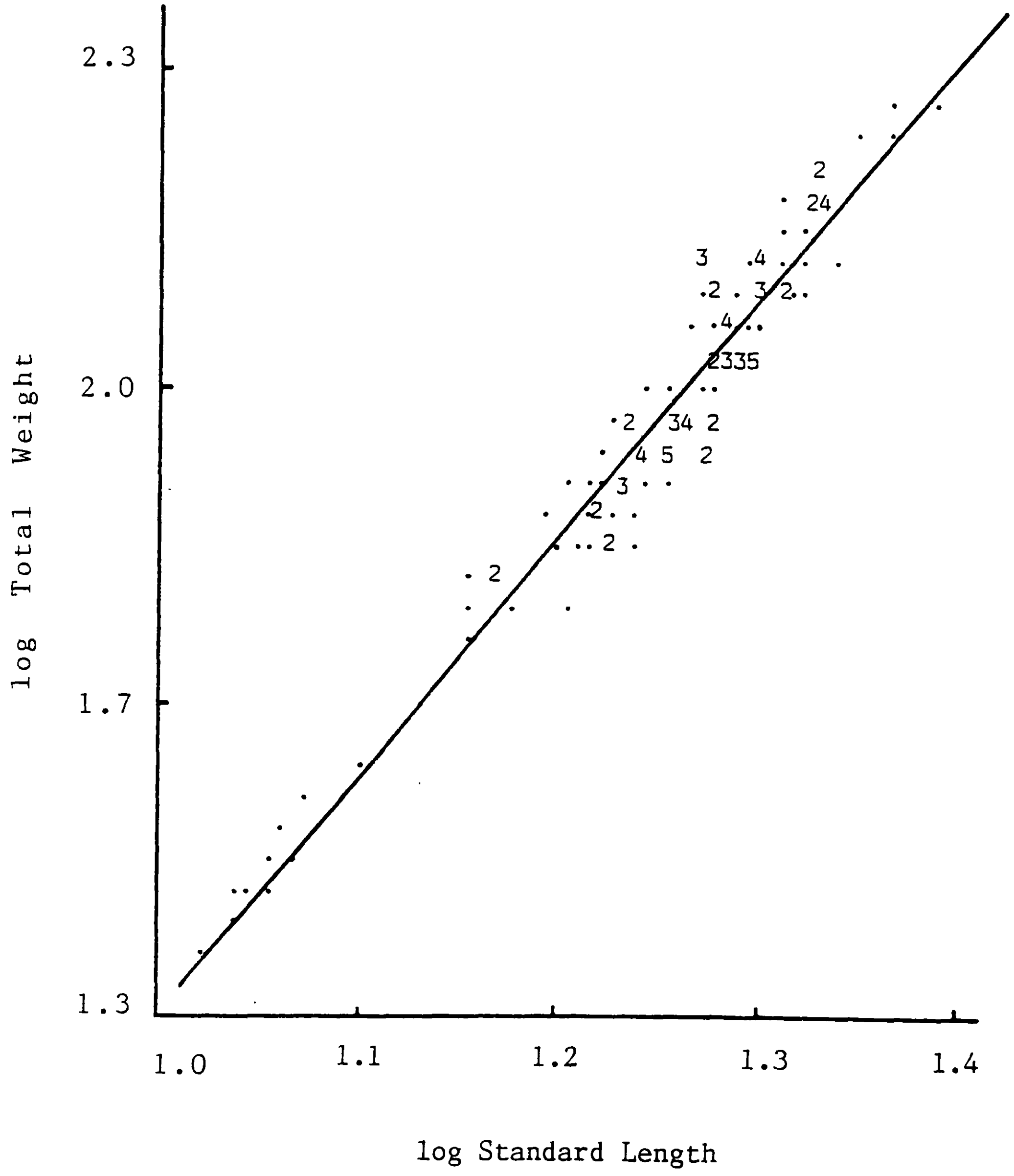


Figure 7.1. Standard length-Total weight relationship of male *M. flavolineatus* off Jeddah (1986).

(dot = 1 observation)

(numerical = number of observations)

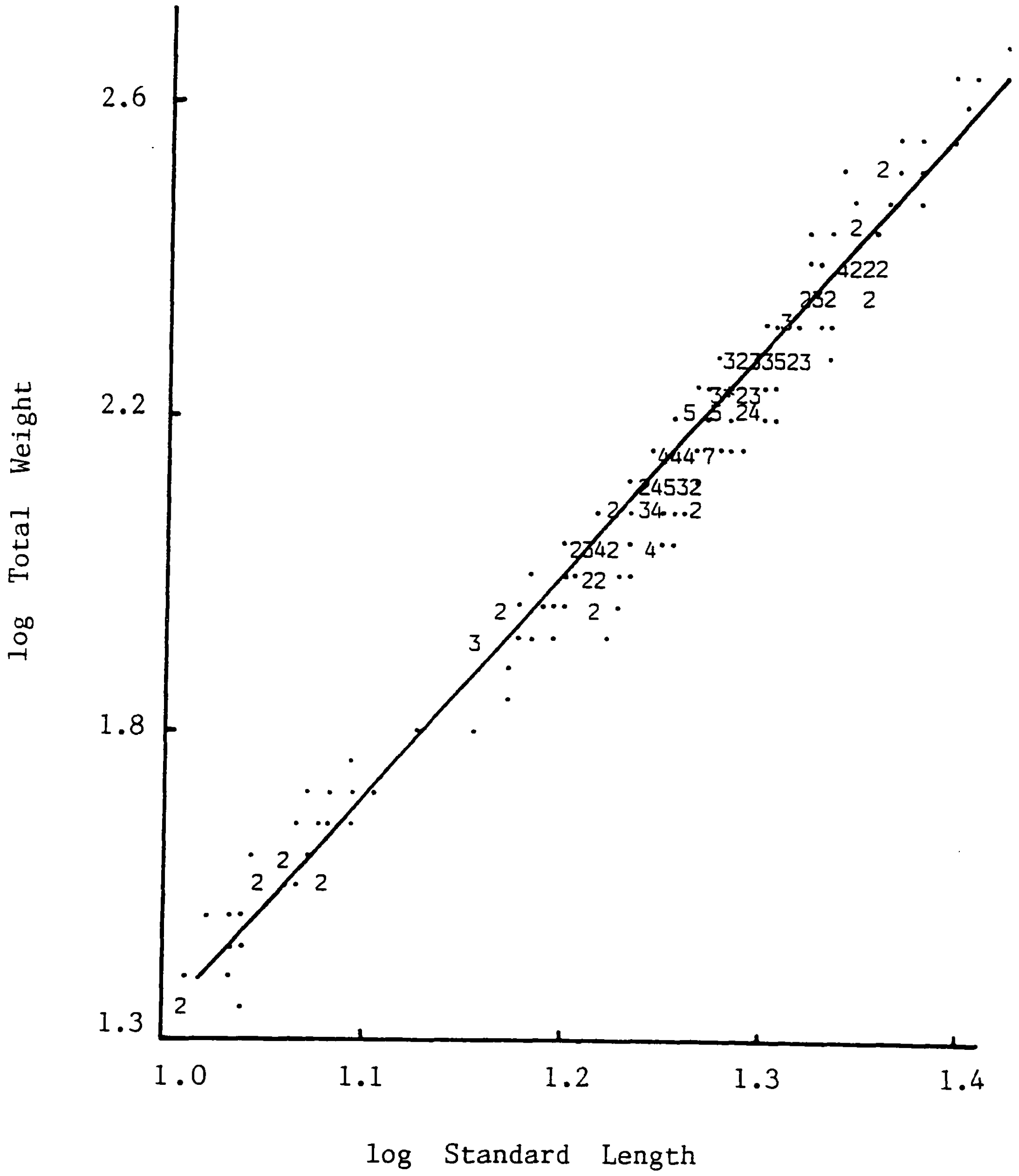


Figure 7.2. Standard length-Total weight relationship of Female M. flavolineatus off Jeddah (1986).

(dot = 1 observation)

(numerical = number of observations)

(* = 10 observations)

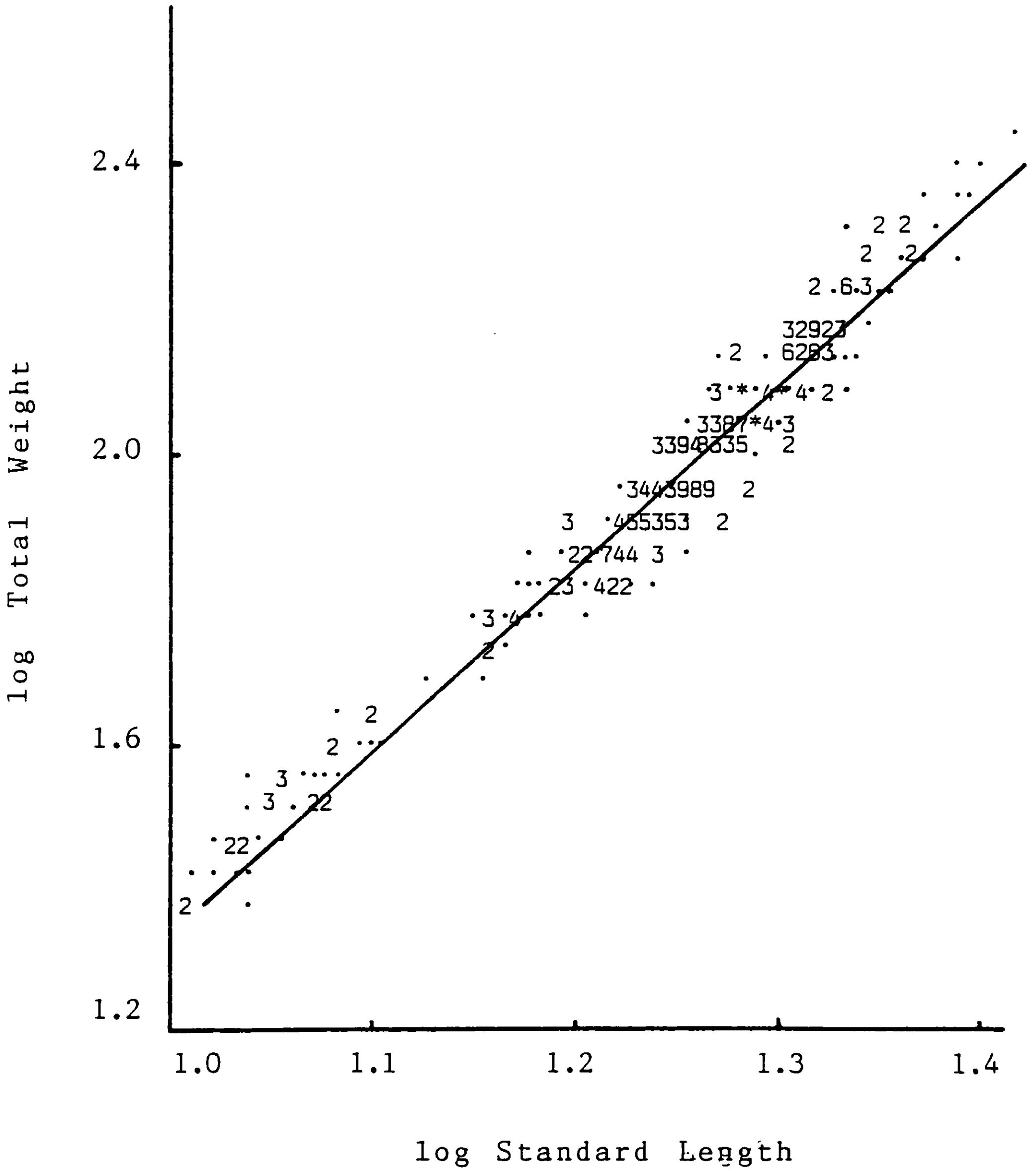


Figure 7.3. Standard length-Total weight relationship for combined sexes of M. flavolineatus off Jeddah (1986) .

(dot = 1 observation)
(numerical = number of observations)
(* = 10 observations)

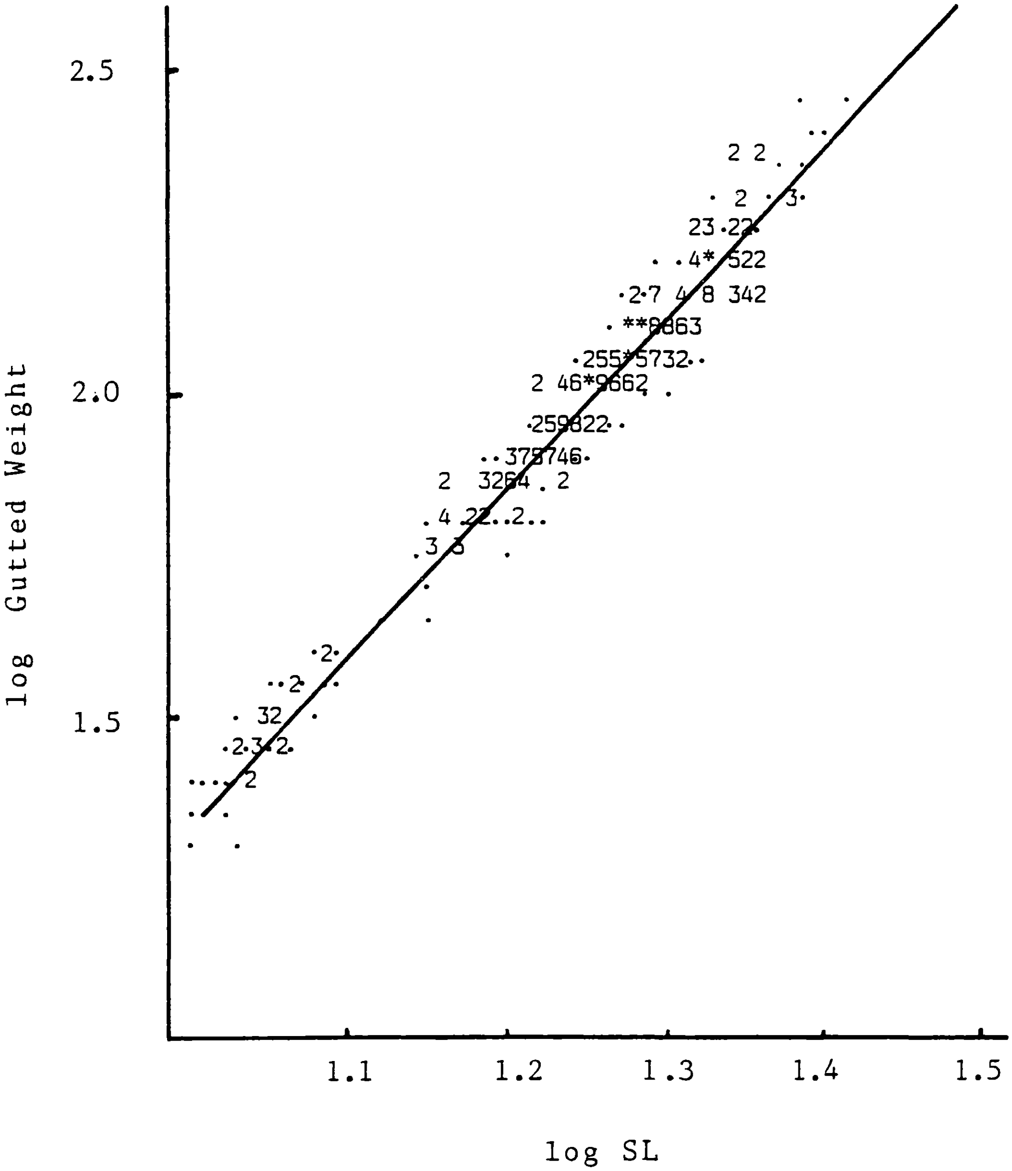


Figure 7.4. Standard length-gutted weight relationship for males and females combined.

(dot = 1 observation)
(numerical = number of observations)
(* = 10 observations)

CHAPTER 8

AGE AND GROWTH

8.1. Introduction

A knowledge of age and rate of growth are essential to fishery biologists, before a clear picture of the status of a fish species can be drawn. Age data are correlated with sexual maturity data, to furnish age at maturity and provide information which is important in establishing minimum size limits for the fishery. From age and growth data, it can be determined what year classes of fish are being taken by the fishery (catchable size), the degree to which dominant year classes are contributing to the catch, and whether fish are being replaced as fast as they are removed by fishing.

8.1.1. Interpretation of layers laid down on hard parts of fish

Age in fish is determined by various methods but the interpretation of annual layers developed on hard parts of fish is the most generally accepted method for determining age. By far the most important structure so far employed is the scale, with otoliths or ear stones, spines and bony structures such as the vertebrae, the dentary bone, and cross sections of other bony structures such as opercular cover and pectoral fin spine, following in that order. These methods depend on changes in the rate of growth or metabolism during certain periods of the year as evidenced in these hard parts. Accuracy in determining age depends on the ability to interpret year marks correctly. Clarity of the layers varies with species and with structure examined.

8.1.2. Ring formation

Factors governing the formation of narrow (reduced growth) and wide (rapid growth) growth rings on hard structures of fish have been discussed by many investigators (Thompson, 1923; Dannevig, 1925; Graham, 1929). There is a marked correlation between width of these rings and growth rate. The wide rings being formed during summer and the narrow ones during winter. The controlling factor might either be temperature (Cutler, 1919), or food (Thompson, 1923).

Van Oosten (1929) also discussed the factors responsible for the difference between winter and summer growth rings, and listed the conditions under which the annual marks or annuli may be considered as true year mark as follows:

1. Constancy in number and identity of the number of annuli.
2. Correlation between the growth of the body and the formation of the scales.
3. Variation in width may be dependent on an inherent rhythm upon which external factors may exert little or no control, or may be due to variations in the external environment of the fish.
4. Frequency and time of formation of the annuli.

Various investigators have shown that temperature affects the annual mark formation on fish scales (Beckman, 1943; Brown, 1945; Le Cren, 1958; and others). Coble (1967) reported that environmental factors which may affect the growth of the fish are; temperature, quantity and quality of food, space limitations, light cycles, oxygen content, diseases, parasites and pollution. These factors may interact altering the effects of each other, and their effects may not be the same on fish of different ages. He also pointed out that attempts to interpret the relationship between growth and any single factor are not successful.

8.1.3. Effect of temperature on ring formation in tropical fish:

Nikolsky (1963) stated that changes in the metabolic rate of fish are most closely connected with changes in the temperature of the surrounding water. Thus, in cold and temperate regions the difference between summer and winter monthly temperature of air may vary respectively from -20 to 15°C, or from 4 to 18°C. This acts as one of the main factors which help in the formation of wide summer and narrow winter rings.

The summer rings correspond to the rapid growth, while the winter rings appear to be due to either slow or cessation of growth during winter and autumn (Van Oosten, 1923; Joseph, 1962). Garrod (1957) showed that in the tropical lake Victoria, environmental fluctuations are slight and do not appear to be sufficient to cause reduction in growth rate, which in temperate waters allow fish to be aged accurately by annual rings laid down on hard parts.

However, Chugonova (1959) pointed out that in tropical regions where the winter is warm, the annuli develop as a result of cessation of growth during the period of seasonal deterioration of food conditions and in connection with gonad maturation. Later, Lagler *et al.* (1962) stated that certain freshwater fish of the monsoon tropics also show seasonal growth marks that correspond to the onset of the dry season. Moreover Nikolsky (1963) stressed that there is strong evidence for the existence of the annual marks on the scales and bones of tropical fish.

8.2. Materials and Methods

8.2.1. Age determination of *Mulloides flavolineatus*:

To determine the rate of growth for *M. flavolineatus* off Jeddah, Saudi Arabia, scales taken from 126 males and 255 females ranging in size between 10 and 25 cm (SL) were examined for age determination. The sampling, treatment and handling of the scales are described in detail in Chapter 2.

Annual rings were best identified on the lateral side of the scales and were followed up to the anterior part of the scale for measurement of their radius. However, a number of scales were rejected because of defects in their structure due to their regeneration, but these did not exceed 4% and 3% of the total number of specimens in males and in females, respectively.

The annual rings laid down on the scale of *M. flavolineatus* had the following criteria:

For the true annulus, the phenomena of "cutting-over" of sclerites, described by Everhart et al. (1976) and later by Bagenal (1978), was the most important characteristic for its identification. The degree of cutting-over varied according to its location on the scale. Sometimes it was complete along the whole length of the annual ring and more pronounced on the lateral sides of the scale. In some scales, the cutting over is not complete in the median region of the scale and only some parts of the rings show this cutting-over.

The well known dark and light zones, or narrow and wide zones, on the scales of temperate spp. were not clearly demarcated on the scales of *M. flavolineatus*, and this might be attributed to the slight differences in temperature between summer and winter in the Red Sea.

8.2.2. Body-sacale relationship:

In order to study the growth in length of *M. flavolineatus* it was necessary to back-calculate the length at previous ages from the relative position of annual rings on the scales. This method was widely adopted on a large number of fish species (Ricker, 1975; Bagenal, 1978).

In the present study, length of fish at previous years of life (L_n) were calculated using the formula :

$$L_n = (S_n/S_t)\,(L_t-a)+a \qquad \text{(Lee, 1920)}$$

where L_n = length at any given age "n" (in cm),

L_t = Fish length at capture,

S_n = scale radius measured to the nth annulus (in cm),

S_t = total scale radius (in cm), and

a = correction factor from the body-scale relationship.

Back-calculated length at the end of each year was calculated for each fish using Lee's equation using the value of the correction factor "a" as deduced from the length-scale relationship as described above. The mean length at age for each age group was then computed. The values of annual increments in length were then calculated by simple subtractions.

Growth in weight was estimated by simple substitution of the values of length at each year of life in the length-weight relationship deduced in Chapter 7. The annual rate of change of weight relative to length was then calculated and expressed as "dW/dL", and the annual increment of this factor was expressed as "Δ".

Because of sampling errors, data on sizes or instantaneous growth rates at age may yield the most useful information when they are combined into growth curves or models. The best known growth model used in fisheries assessment is that of von Bertalanffy (1938), who based his information on physiological considerations. According to von Bertalanffy, the size of fish L_t at any age t is given by

$$L_t = L_\infty \, [1 - \exp(-k(t-t_o))]$$

where L_∞ is the asymptotic length or the value of L for which the rate of growth is zero,

k is the growth constant, and

t_o is the theoretical age of the fish when its size is zero.

It may be noted that the von Bertalanffy equation contains three parameters, L_∞, k and t_o which can be estimated from data on length at age.

An alternative from the von Bertalanffy growth equation is

$$L_{t+1} = L_\infty (1 - \exp(-kT)) + L_t \exp(-kT)$$

which, for T=1, is the well-known Ford-Walford plot. Plotting L_{t+1} against L_t, gives a straight line, the slope of which is equal to exp(-k) and the Y-intercept gives $L_\infty(1 - \exp(-k))$ from which L_∞ can be calculated. The asymptotic length L_∞ is also the length at which the fitted line cuts the 45° diagonal line from the origin (Gulland, 1969).

For estimating t_o, the von Bertalanffy growth equation is rewritten as

$$\log_e(L_\infty - L_t) = (\log_e L_\infty + kt_o) - kt$$

Fitting a regression of $\log_e(L_\infty - L_t)$ against t, we get the Y-intercept as $(\log_e L_\infty + kt_o)$, from which t_o can be estimated, since we know the other two variables (FAO, 1981; Gulland, 1969, 1983).

8.3. Results

8.3.1. Body-scale relationship

For *M. flavolineatus*, standard fish length and scale radius of males and females were found to be related by straight lines whose equations are :

For males : $SL = 0.5435 + 14.4642\ SR$

$n= 121 \quad r= 0.9637$

For females : $SL = 0.9063 + 13.3987\ SR$

$n= 247 \quad r= 0.9741$

The straight lines representing these equations are shown in Figure 8.1.

These linear relationships between scale radius and standard length for males and females indicate that the scales grow in linear proportionality to that of the standard length, in the range of lengths studied in this work.

8.3.2. Growth in length :

The correction factor 'a' was equal to 0.5435 for males and 0.9063 for females.

Tables 8.1 and 8.2 show the back-calculated lengths (SL) at different years of life for males and females *M. flavolineatus*.

From these tables it is seen that, in the water off Jeddah, males were represented by five age groups having back-calculated standard lengths 11.12, 14.11, 18.61, 21.14 and 22.30 cm. On the other hand, females were represented by six age groups having back-calculated standard lengths of 11.03, 15.69, 17.77, 22.06, 23.12 and 24.72 cm, respectively. These lengths show that at the same age, females are larger than males.

These tables also show the annual increment in length for each sex, the percentage increment being highest during the first year for both sexes. The next highest increment was in the second year for females after which it declined then increased again during the fourth year then decreased again afterwards, while in males the next highest increase occurred in the third year after which it decreased progressively (Figure 8.2).

8.3.3. Growth in weight

The back-calculated weights at age of *M. flavolineatus* were determined by applying the back-calculated lengths from scale readings to the length-gutted weight relationships of males and females previously described in Chapter 7. Tables 8.3 and 8.4 show the weights at the end of each year of life as well as the average annual increment in weight.

Except for fish of age group I, females were heavier for each age class than males. The average maximum back-calculated weight reached at the age of five years was 157.79 g and 181.64 g for males and females, respectively (Figure 8.3).

The rate of increase in back-calculated weight for males was highest during the third year of life, reaching

32.05% of the maximum size at age. In females, on the other hand, the maximum annual increase in weight occurred during the fourth year of their life, and was 32.51% of the maximum size at age.

The increment index, i.e. the increment in gutted weight divided by the increment in the standard length for the same age group, was calculated and was found to be as follows:

Age	1		2		3		4		5		6
Males											
dW/dL	2.32		7.43		11.24		15.30		17.63		--
Δ		5.11		3.81		4.06		2.33			
Females:											
dW/dL	2.25		8.41		12.24		16.48		20.31		22.36
Δ		6.16		3.83		4.24		3.83		2.05	

This shows that the highest rate of putting on weight relative to corresponding rate of growth in length, occurred during the second year of life; the next highest index occurred during the fourth year for both sexes. This would suggest that, for management of this species, the best age for capture would be after the second year of age corresponding to a standard length of about 16 cm, which would allow fish to reach age at first maturity (Chapter 10), i.e. allow fish to spawn once before recruitment to the fishery.

8.3.4. Theoretical growth rates of M. flavolineatus

For population analysis, the growth pattern of the fish species under study is an important characteristic, and it is usually desirable to express the growth of fish as a mathematical expression, or simply as a growth model. The basic requirement for such a model is an expression which will give the size (in terms of length or weight) at any given age which agrees with the observed data of size at age, and which is expressed in a mathematical form that can be incorporated reasonably easily in an expression of yield (Gulland, 1983).

There exists a considerable and growing literature on growth equations especially those of Taylor, 1958; Beverton and Holt, 1959; Holt, 1960; Beverton, 1963; Ursin, 1967; Ricker, 1975; Pauly, 1979, 1981 and 1984; Pauly and Ingles, 1981; Munro, 1982 and others which cover a wide range of possible equations none of which seems to be entirely satisfactory in all situations.

The von Bertalanffy growth formula (VBGF) (1938), is one of the convenient growth models, usually used to describe the growth pattern of a fish because it satisfies the two important criteria, i.e. it fits most of the observed data on fish growth, and can be incorporated readily into stock assessment models.

8.3.5. Theoretical growth in length

The mean lengths at age obtained from back-calculation (Tables 8.1 and 8.2) were used for the computation of the parameters of the von Bertalanffy growth equation, namely L_∞, k and t_o, and the results are given in Table 8.5.

This table also shows values of t_{max} for males and females, which is a measure of the longevity of the fish species in question. This last parameter was calculated according to the relation demonstrated by various authors, i.e. that the value of the parameter k is closely linked with longevity (Taylor, 1962; Beverton, 1963; Pauly, 1983). According to these authors

$$t_{max} = (3/k) + t_o$$

From table 8.5 it can be seen that the value of the k indicates a higher growth rate in females than in males corresponding to a shorter life span, since they both have almost the same asymptotic length. The maximum expected age is about 10 years for females and 12 years for males.

The von Bertalanffy equations for growth in length for *M. flavolineatus* would be in the form :

$$L_t = 28.96 \, [\, 1 - e^{-0.2482\,(t-0.8423)}] \quad \text{for males, and}$$

$$L_t = 28.57 \, [\, 1 - e^{-0.2975\,(t-0.5449)}] \quad \text{for females}$$

Comparison of the back-calculated length at age with that calculated from the von Bertalanffy growth formula (VBGF) are shown in Table 8.6. The Student-*t* test was performed on the values obtained with both methods and showed that there is no significant differences between them

($P<0.001$). This proves the fitness of the von Bertalanffy growth model for this fish. Moreover, the calculated length at age by the VBGF also showed the size superiority of females over males of the same age, but starting from age group four.

The question of whether or not there is a size dimorphism between males and females still remains questionable; this might lead to a near constancy of the growth performance parameter ø', defined by

$$\text{ø}' = \log_{10} k + 2 \log_{10} L_\infty \quad \text{(Pauly, 1979)}$$

The computation of this parameter showed that females have slightly higher growth performance than males, ø' being 2.385 and 2.318 for females and males, respectively.

8.3.6. Theoretical growth in weight

The weight of a fish is usually closely proportional to the cube of its length, so that from the von Bertalanffy equation

$$W_t = W_\infty[1 - \exp(-k(t-t_o))]^3$$

where W_∞ is the asymptotic weight corresponding to the asymptotic length L_∞.

Similarly, if weight is proportional to the nth power of the length, then

$$W_t = W_\infty[1 - \exp(-k(t-t_o))]^n \quad \text{(Gulland, 1969).}$$

Values of W_∞ for male and female *M. flavolineatus* were calculated by substituting the value of L in the length-weight relationship by the corresponding value of L_∞, the resulting weight is the asymptotic weight of each sex.

The von Bertalanffy equations for growth in weight for males and females were thus found to be :

$W_t=311.27\ [1 - e^{-0.2482(t-0.8423)}]^{2.5997}$ for males

$W_t=320.94\ [1 - e^{-0.2482(t-0.5449)}]^{2.6905}$ for females

8.4. Discussion

One of the earliest scientific contributions on the age and growth of tropical fishes (Mohr, 1921) rationalized such studies in the following words:

"In modern fisheries research, ageing of fishes is very important because ... through age determination we have the means to identify the age composition of our fish population, and so it can be determined to what degree the various age classes are on the appropriateness or the need for management measures such as closed seasons or minimum sizes ..."

Mohr then went on to describe what she perceived as the major problem of biological studies on tropical fish, namely "the suggestion, and later the dogma, that the scales of tropical fish should have no annual rings." This myth persisted widely among fishery biologists until the 1960s, and although conditions do occur where tropical fishes do not seem to generate annual rings on their hard parts, such rings are now known to occur in scales, otoliths, and vertebrae of tropical fish under too wide a range of conditions to be dismissed as exceptions that prove the rule

(Longhurst and Pauly, 1987). Moreover, Fagade (1974) pointed out that annual environmental changes in the tropics could sometimes lead to "growth rings".

In the present study, Mulloides flavolineatus caught in the vicinity of Jeddah, Red Sea, was found to have annual marks on its scales that were used for the back-calculation of length at age. The annual mark is probably a consequence of diet change (Chapter 6). Males were found to be represented by five age groups, while six age groups of females were found in the area of study.

Attempts have been made to interpret the length of the intercept 'a', in the length-scale relationship, as the theoretical length at which scales first appear on the fish (Lee, 1920). In some species this interpretation may be approximately correct, but it cannot be accepted as a generalization, since the intercept is negative in certain species (Monastyrsky, 1930; Lagler, 1956). Furthermore, Lea (1933) and later Weese (1950) calculated regressions by the Lee method for each age group separately. They found that values for 'a' increased successively with age. Thus age and length distribution of the sample must influence estimation of the constant. In other words, the values of 'a' given in this study are true for the fish species studied only in the range of lengths considered. On the other hand, the concept that the intercept is best represented by the size of the fish at the time the scale was first formed has been a popular one (Lee, 1920; Merriman, 1941; Carlander and Smith, 1944). However, Schuck (1949) concluded, after a detailed discussion of this topic, that the significance of intercept 'a' obtained by extrapolating the straight line relationship between fish and scale sizes for fish one-year-old and older need not be interpreted; it is enough merely that the intercept has value for calculating past lengths at ages.

The calculated length at age for both sexes is compared with results obtained by various authors in different localities and are presented in Table (8.~~7~~6). All the results agree upon the fact that, no matter where the goatfish lives, it seems to have one thing in common, i.e., the annual increment decreases through the first three years of life then increases temporarily in the fourth year and drops again afterwards. The annual increment ranging between 1 and 11 cm for *M. flavolineatus*, while it fell between 3 and 8 cm for *Parupeneus cinnabarinus* in the Gulf of Aqaba (Al-Absy and Ajiad, 1988), and varied between 1.5 and 12 cm for *Mullus surmuletus* in the Mediterranean (Hashem, 1973a).

As was demonstrated, earlier in this study, *M. flavolineatus* becomes lighter, relative to its length, as it grows older, the annual increment in weight for females and males showed a fluctuation in its value throughout the size range studied, and it is during their fourth year of life that they reach the highest rate of increase in weight. These results seem in agreement with the findings of Al-Absy and Ajiad for *P. cinnabarinus* in the Gulf of Aqaba. However, Hashem (1973a) showed no such fluctuations in the annual increment in length or weight for M. surmuletus in the Mediterranean. This last author mentioned that the fish tends to decrease its rate of putting on weight as it grows older.

As information accumulated about the growth rates of various species, it became apparent that usually either the males and females of a given species grow at the same rate and have a similar maximum size - the reverse of the usual situation in mammals. In some families, such as Clupeids, however, sexual dimorphism in size, which the second alternative represents, is relatively uncommon; in other families, such as the Gadidae, the female is often the larger sex. In extreme cases such as the deep sea Angler fish, the disparity in size is often very great, the male being minute and parasitic on the female. Accounts of the incidence of male growth superiority, however, was recorded in some Cichlidae in African freshwater systems, but this reveals no systematic pattern (Fryer and Iles, 1972).
In the present study female superiority in size was only observed in fish of the age group two and older. This dimorphism in size was, however, very slight.

Information on the availability of previous works on the theoretical growth of M. flavolineatus is uncertain. From the present study the von Bertalanffy growth parameters were found to be as follows:
L_∞=28.57 and 28.96 cm; k=0.2975 and 0.2482 cm.yr^{-1}; t_o=0.5449 and 0.8423 yr; W_∞=320.94 and 311.27 gm for females

and males, respectively.

This may lead to the conclusion that, although sex dimorphism in size is probable in _M. flavolineatus_, yet the difference in size between sexes is very slight. The differences in the condition factor and relative weight per length group between sexes could be attributed to the differences in their feeding habits and performance as discussed in previous chapters.

Table 8.1. The back-calculated lengths (SL) at the end of each year of life of male *M. flavolineatus* in the Red Sea off Jeddah.

Age group	N of fish	Max. Length at capture (cm)	Length at the end of each year of life				
			SL_1	SL_2	SL_3	SL_4	SL_5
I	10	12.74	11.38	-	-	-	-
II	7	16.58	11.21	14.28	-	-	-
III	53	19.31	11.04	14.02	18.65	-	-
IV	51	21.53	11.16	14.19	18.58	21.19	-
V	5	22.56	10.79	14.12	18.55	20.62	22.30
Average			11.12	14.11	18.61	21.14	22.30
Increment			11.12	2.99	4.50	2.53	1.16
% increment relative to maximum length			49.87	13.41	20.18	11.34	5.20
% increment relative to previous year				26.98	31.89	13.59	5.49

Table 8.2. The back-calculated lengths at the end of each year of life of female *M. flavolineatus* in the Red Sea off Jeddah.

Age group	N of fish	Length at capture (cm)	SL_1	Length at the end of each year of life SL_2	SL_3	SL_4	SL_5	SL_6
I	24	12.67	11.42	-	-	-	-	-
II	28	16.86	11.34	15.69	-	-	-	-
III	58	19.45	11.25	15.60	17.52	-	-	-
IV	116	22.46	10.75	15.77	17.78	22.16	-	-
V	23	23.63	11.00	15.52	18.28	21.62	23.14	-
VI	5	24.97	11.25	15.60	17.94	21.79	23.04	24.72
Average			11.03	15.69	17.77	22.06	23.12	24.72
Increment			11.03	4.66	2.08	4.29	1.06	1.60
% increment relative to maximum length			44.6	18.85	8.41	17.35	4.29	6.47
% increment relative to previous year				42.25	13.26	24.14	4.81	6.92

Table 8.3. The back-calculated weights at the end of each year of life of males *M. flavolineatus* in the Red Sea off Jeddah.

Age group	N of fish	Weight at capture (g)	Weight at the end of each year of life Gwt_1	Gwt_2	Gwt_3	Gwt_4	Gwt_5
I	10	36.81	27.45	-	-	-	-
II	7	73.02	26.40	49.53	-	-	-
III	53	108.53	25.37	47.22	99.15	-	-
IV	51	144.02	26.09	48.72	98.18	138.18	-
V	5	162.62	23.90	48.10	97.77	128.72	157.79
Average			25.83	48.06	98.63	137.34	157.79
Increment			25.83	22.23	50.57	38.71	20.45
% increment relative to maximum weight			16.37	14.09	32.05	24.53	12.96
% increment relative to previous year				86.06	105.22	39.25	14.89

Table 8.4. The back-calculated weights at the end of each year of life of females *M. flavolineatus* in the Red Sea off Jeddah.

Age group	N of fish	Weight at capture (g)	Weight at the end of each year of life					
			Gwt_1	Gwt_2	Gwt_3	Gwt_4	Gwt_5	Gwt_6
I	24	36.00	27.22	-	-	-	-	-
II	28	77.65	26.71	63.99	-	-	-	-
III	58	114.06	26.15	63.01	86.11	-	-	-
IV	116	167.98	23.14	64.87	89.59	162.02	-	-
V	23	192.58	24.61	62.14	96.53	151.61	182.02	-
VI	5	223.39	26.15	63.01	91.77	154.84	179.91	217.42
Average			24.80	63.98	89.43	160.11	181.64	217.42
Increment			24.80	39.18	25.45	70.68	21.53	35.78
% increment relative to maximum weight			11.4	18.02	11.71	32.51	9.90	16.46
% increment relative to previous year				157.98	39.78	79.03	13.45	19.70

Table 8.5. The von Bertalanffy growth parameters of *M. flavolineatus* in the Red Sea off Saudi Arabia.

	Females	Males
L_∞	28.57 cm (SL)	28.96 cm (SL)
k	0.2975 cm.yr^{-1}	0.2482 cm.yr^{-1}
t_o	0.5449 yr	0.8423 yr
t_{max}	10.08 yr	12.09 yr

Table 8.6. The average back-calculated length at age values and Von Bertalanffy Growth Formula (VBGF) for Mulloides flavolineatus off Jeddah, Red Sea.

Age group	Females		Males	
	Back calculated (cm)	VBGF (cm)	Back calculated (cm)	VBGF (cm)
I	11.03	10.04	11.12	12.01
II	15.69	14.80	14.11	15.73
III	17.77	18.35	18.61	18.64
IV	22.06	21.00	21.41	20.91
V	23.12	22.90	22.30	22.68
VI	24.72	24.40	-	-

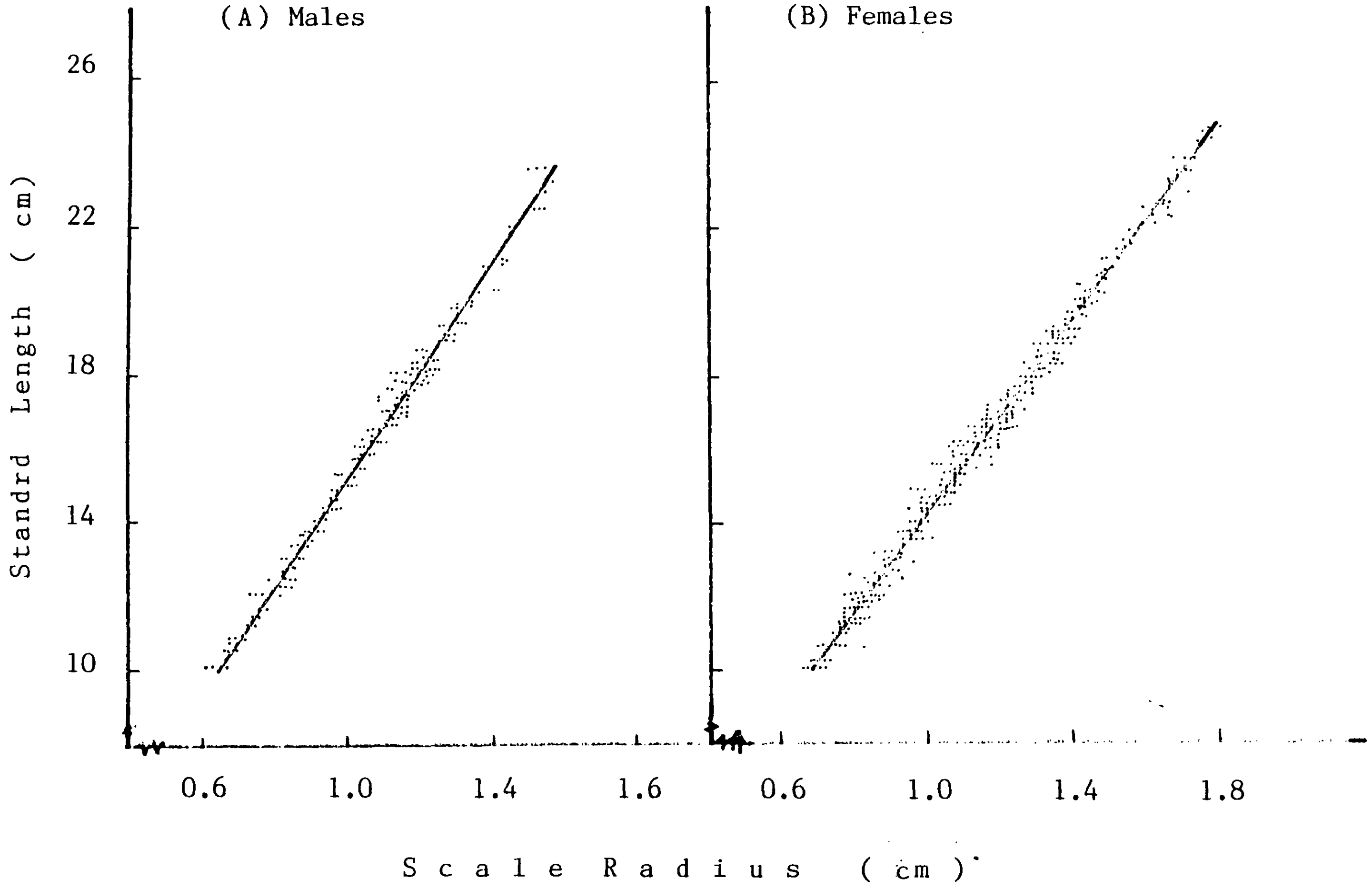


Figure 8.1 Standard body length/ scale rdius regression lines of males and females M. flavolineatus off Jeddah (1986).

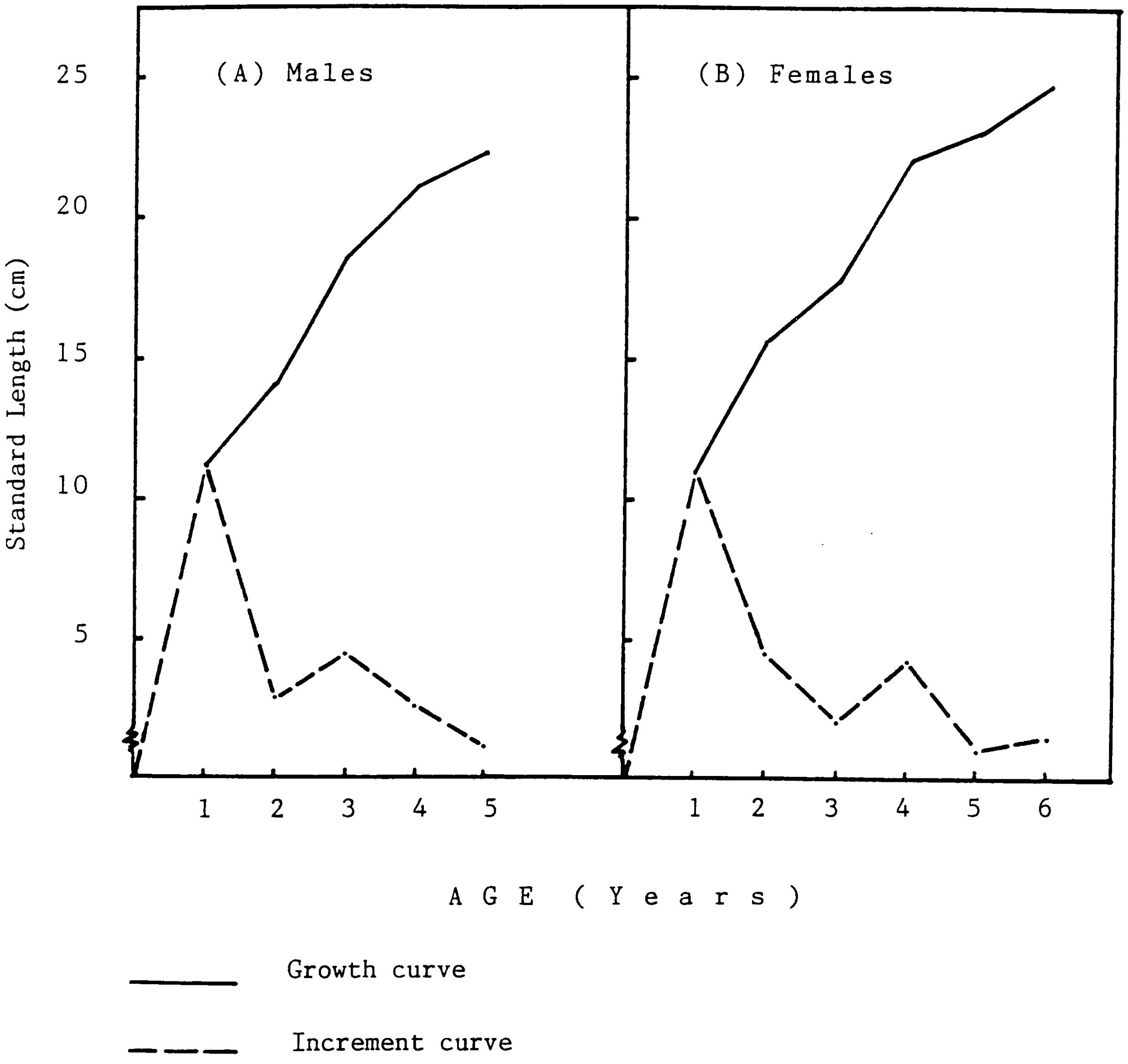


Figure 8.2.Growth and increment curves in length of M. flavolineatus.

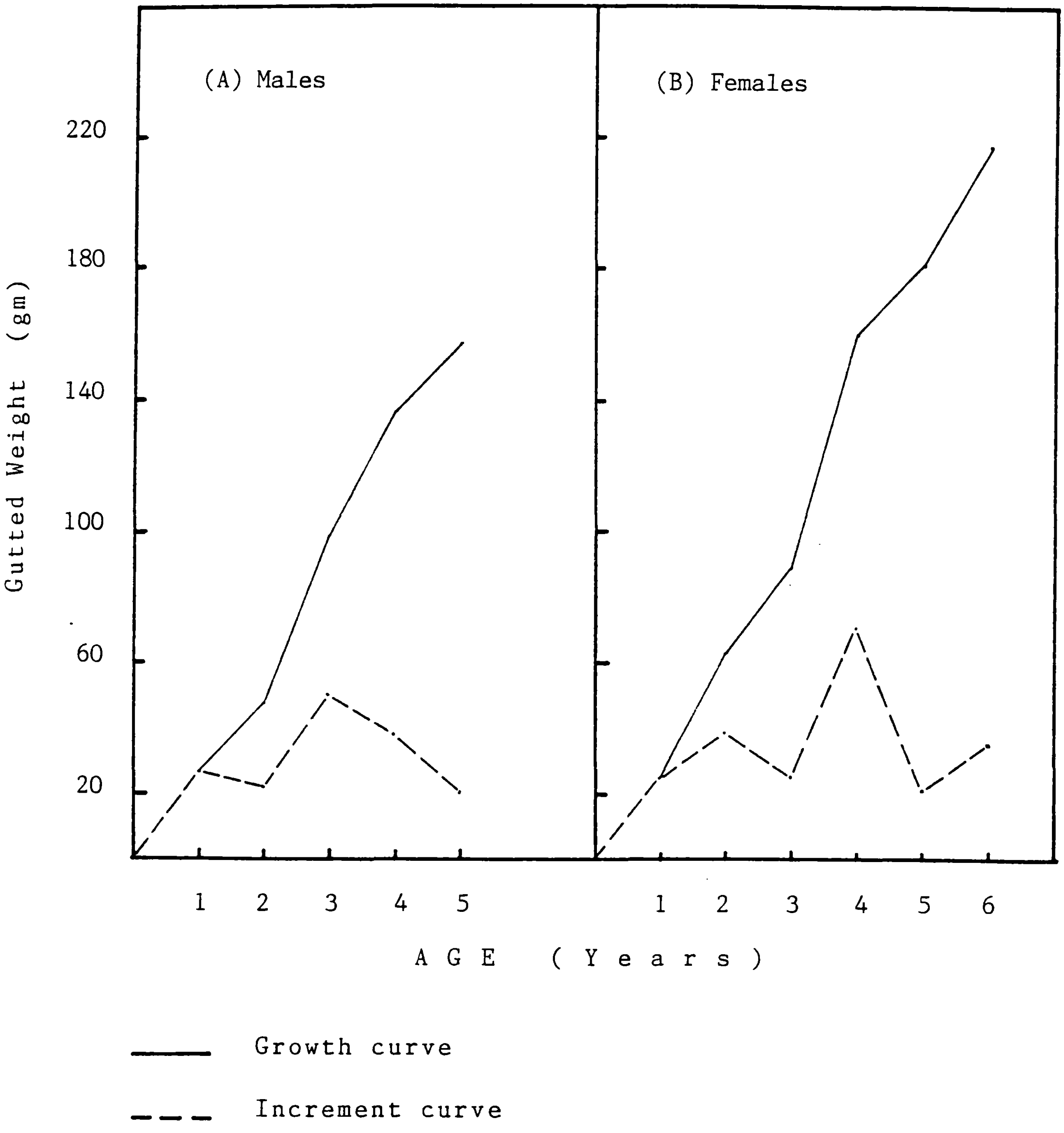
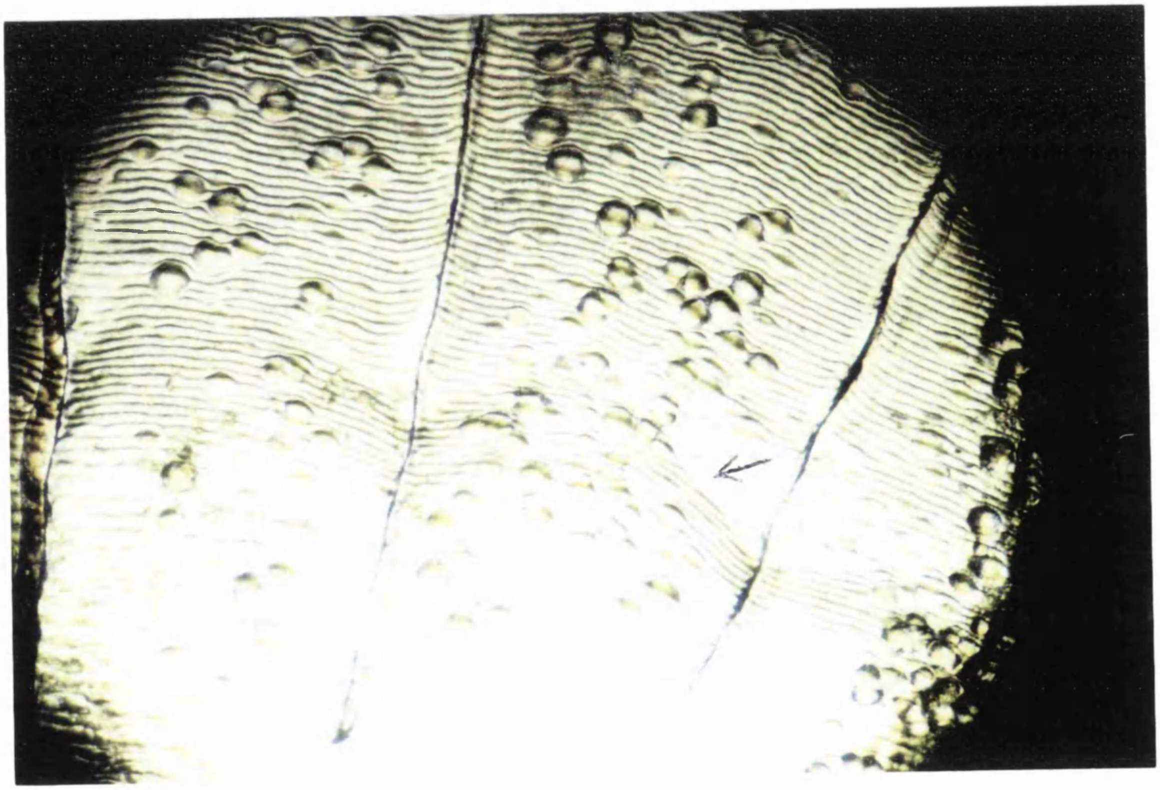


Figure 8.3. Growth and increment curves in weight of M. flavolineatus.

(a)



(b)

Plate 8.1(a) Scale of M. flavolineatus.

(b) Magnified portion of scale showing annulus (arrowed).

CHAPTER 9

MORTALITIES OF *MULLOIDES FLAVOLINEATUS*

9.1. Introduction

Knowledge of mortality is essential for the management of a fish species. It may be estimated by means of catch curves (Ricker, 1975), cohort analysis (virtual population analysis) (Jones, 1964; Gulland, 1965), and by the use of length at age data (Gulland, 1983; Pauly, 1983). In the present study, mortality was estimated by means of length at age data.

The size composition of a population is clearly related to the total mortality; the lower the mortality, the more old and therefore large, fish there will be (Gulland, 1983).

9.2. Materials and Methods

According to Pauly (1983), when a large number of length data have been obtained from a given population, the total mortality coefficient (Z) can be estimated from the mean length ($\bar{L}$) in the catch taken from this population by means of the relationship.

$Z = [k(L_\infty - \bar{L})]/(\bar{L} - L')$ (Beverton and Holt, 1956)

where L_∞ and k are parameters of the von Bertalanffy equation, $\bar{L}$ is the mean length in the catch, and L' is the smallest length of animals that are represented in the catch samples. Although this last expression is widely used for the estimation of the total mortality, yet it yields biased results due to the length distribution of the sampled populations (Bagenal, 1978). A slightly different expression obtained by Ssentengo and Larkin (1973) was found to be more pertinent to the available data on Mulloides flavolineatus caught off Jeddah.

They derived an unbiased estimate from a sample of 'n' fish as:

$$Z/K=[n/(n+1)][1/(\bar{y}-y')]$$

where

$$y=\log(1-L/L\infty) \quad \text{and} \quad y'=\log(1-L'/L\infty)$$

where L' and $L\infty$ are as defined in previous chapters, and L is the fish length.

For large values of 'n' this expression reduces to:

$$Z/K=1/(y - y')$$

It is worth mentioning that y has to be calculated from the individual values of y, and is not equal to $\log(1-L/L\infty)$.

According to Pauly (1983), natural mortality in fishes should be correlated with longevity, hence with k, and also with size, since large fish should have, as a rule, fewer predators than small fish, in addition, natural mortality in fish is correlated with mean environmental temperature (Pauly, 1978 and 1980). These various interrelationships are expressed for length-growth data by multiple regression as follows (Pauly, 1983):

$$\log M= -0.0066 - 0.179 \log L\infty + 0.6543 \log k + 0.4634 \log T$$

where M is the natural mortality in a given stock, $L\infty$ being the asymptotic length of the fishes of that stock (in cm), k their growth coefficient, and T is the annual mean temperature (in °C) of the water in which the stock in question lives.

Total mortality is the sum of all fish that died from natural and fishing mortalities; the total deaths will be proportional to the instantaneous natural mortality coefficient M, and the instantaneous fishing mortality coefficient F. In the present study, the instantaneous total mortality coefficient Z was calculated by the formula:

$Z = F + M$ (Beverton and Holt, 1957)

with the values of Z and M available, the coefficient of fishing mortality F could be calculated by simple subtraction.

The rate of exploitation or expectation of death from fishing during some specified time period when all causes of death are working on the population (Everhart *et al.*, 1976) is calculated according to the following relation :

$E = [F(1 - S)]/Z$ (Everhart et al., 1976)

where E = rate of exploitation,

F = instantaneous coefficient of fishing mortality,

Z = instantaneous coefficient of total mortality,

and

S = rate of survival which is equal to exp (-Z).

Holt *et al.* (1959) defined this relationship as the exploitation rate or unconditional fishing mortality rate or expectation of death by capture. Everhart *et al.* (1976) stated that "the above relationship is considered on an annual basis. However, any time period may be used.". Cadima (1978) gave a different relationship, being E = F/Z and defined it as the 'exploitation ratio'; in the same work he said that "although this term should be reserved for the quantity $F(1-\exp(-Z))^T/Z$. The two quantities are of course, equal for $T=\infty$.". However, for T=1, this expression is equal to that of Everhart et al. (1976).

Pauly (1983) used the term 'exploitation ratio (E)' and computed it from $E = F/(F+M)$. However, Gulland (1983) called the expression F/Z as 'amount of fishing', at the same time he defined the annual rate of exploitation as being equal to $F(1-\exp(-Z)/Z$. This is equal to the relationship given by Holt et al. (1959); Everhart et al. (1976); and Cadima (1978) (for T=1).

9.3. Results and Discussion

9.3.1. Estimation of Total Mortality Coefficient (Z)

In the present study, the von Bertalanffy parameters are given in table 8.5, the smallest fish caught for males and females was 10.2 and 10.0 cm (SL), respectively, corresponding to fish of age group 0. The corresponding value of the total mortality coefficient (Z), as calculated using the Ssentengo and Larkin equation, were found to be 2.9561 for males and 1.8022 for females.

According to Everhart et al. (1976), the structure of a population would stay the same, on an annual basis, if the survival rate 'S' (=exp(-Z)) was always 50%.

The values of the total mortality coefficient (Z) obtained for M. flavolineatus off Jeddah correspond to survival rates of 0.0520 and 0.1649 for males and females, respectively. This signifies that only 5.2% of the males survive after age 5, while in females 16.49% of the population survive to become older than 6 years. This means that this fish species is subjected to high mortality and that the conditions are not quite propitious for the procreation and development of fishes in the size range of 10 to 25 cm (SL). However, these high mortality rates could be due to either environmental and density-dependent causes or to high levels of fishing exploitation. Therefore a splitting to its components, i.e. natural and fishing mortalities was found to be a necessity.

9.3.2. Estimation of Natural Mortality Coefficient (M)

According to Sofyani (1987), the annual mean water temperature at the district of Jeddah is 28.26°C. Upon replacement of this value, along with those of k and L_∞ for each sex, as given in Table 8.5, in Pauly's equation (1983), values of the coefficient of natural mortality (M) were found to be 1.0191 and 1.1502 for males and females, respectively.

These values indicate that both sexes, over the size/age range sampled are almost equally affected by environmental conditions in the fishing region off Jeddah.

9.3.3. Estimation of Fishing Mortality Coefficient (F)

By subtracting values of the natural mortality coefficient from those of total mortality, values of the fishing mortality rate for males and females of *M. flavolineatus*, within the size/age range sampled, would be 1.9370 and 0.6520, respectively.

This clearly shows that males are exposed to a relatively unreasonably high rate of fishing mortality, compared to females of the same species in the same fishing grounds. This might be due to the greater availability of males to the commercial gear. Males and females have different food preferences and this could make males more vulnerable to netting (Chapter 6, Fig. 6.4).

9.3.4. Estimation of the Rate of Exploitation (E)

As computed from the results given above, and using the expression of Everhart *et al.* (1976), values of the annual rate of exploitation for males and females *M. flavolineatus* were found to be 0.6212 and 0.3021, respectively. This clearly proves that males are twice as heavily exploited through fishing as females (See Chapter 6).

All of the above results could be summarized as follows:

Parameter	Males	Females
L_∞	28.96 cm (SL)	28.57 cm (SL)
k	0.2482 $cm.yr^{-1}$	0.2975 $cm.yr^{-1}$
t_o	0.8423 yr	0.5449 yr

t_{max}	12.93 yr	10.63 yr
Z	2.9561	1.8022
M	1.0191	1.1502
F	1.9370	0.6520
S	0.0520	0.1649
E	0.6212	0.3021

These results show a difference in the growth rate between the two sexes. Since, for the same age group females were always bigger than males both in length and weight (Tables 8.1-8.3). In spite of the fact that both sexes have almost the same values of L_∞, females had a higher rate of growth per year (k) than males and this was reflected on their shorter life span (t_{max}) (because they reach the same asymptotic length at a higher rate).

Values of the average condition factor for both sexes (Table 7.3), indicate that females had a slightly higher coefficient of condition than males, this superiority of females parallels the low value of their natural mortality, relative to males, since the condition factor expresses the nutritional conditions in the environment and the availability of the preferred food items for each sex (See Chapter 6).

Males seem to be more active than females and are thus more available to the fishing gear. This may explain the high values of their fishing mortality coefficient, relative to females.

In a stable fishery the rate of exploitation (E) is commonly taken as equal to 0.5 or 50% of the total mortality coefficient (Z) (Gulland, 1971; Pauly, 1983). This shows that in the area of study males are slightly over exploited by commercial gear. Females, on the other hand, are slightly under exploited, this might be because of biological superiority of females both in condition and growth rates and their different food preference, which enable them to be out of reach of the commercial fishing gear.

Finally, one might say that, in spite of the fact that both males and females of M. flavolineatus have equal natural mortality coefficients, females are more affected by density independent causes of mortality, while males are more affected by fishing mortality. This necessitates a complementary study on the relationship between the length of the fish and its girth, this would permit fishery biologists to issue the proper recommendations concerning mesh size regulations necessary to lower the impact of the fishing gear on males for a better propagation of the species.

CHAPTER 10

REPRODUCTION IN NULLOIDES FLAVOLINEATUS

10.1. Introduction

Reproduction in teleost fishes is diverse. The teleosts are predominantly dioecious, but hermaphroditism, including juvenile hermaphroditism, and gynogenesis occur in some species (e.g., Hoar, 1969; Dodd, 1977; Lepori, 1980). Although this complexity of reproduction in teleosts is reflected in their wide range of gonadal structures, their fundamental structures (i.e., the morphology of germ cells and various somatic cell elements constituting the gonadal tissue) are similar (Nagahama, 1983).

The female reproductive system of teleosts, unlike that of mammals, is highly variable, reflecting the wide range of reproductive patterns, including viviparity. Most teleosts are oviparous and the ovary varies greatly in appearance at different times in the cycle. Three ovarian types have been classified according to the pattern of oocyte development (e.g., Wallace and Selma, 1981; de Valming, 1982). The synchronous ovary contains oocytes all at the same stage of development; this type is found in teleosts which spawn only once and then die, such as anadromous Oncorhynchus species or catadromous eels. The group synchronous ovary consists of at least two populations of oocytes at different developmental stages; teleosts with this type of the ovary, such as the flounder, Liposetta obscura and the rainbow trout, Salmo gairdneri, generally spawn once a year and have a relatively short breeding season. The asynchronous ovary contains oocytes at all stages of development; this type occurs in those species (e.g., the gold fish, Carassius auratus) which spawn many times during a prolonged breeding season.

Very little information is available on the reproductive cycles of the commercial fish inhabiting the coastal waters of Saudi Arabia. The present investigation deals with a morpho-histological study of the ovaries of Mulloides flavolineatus which is an important commercial fish species caught off Jeddah, in order to reveal the nature of its spawning habits and to follow its reproductive cycle in order to add to the biological information that would help in the better management of its fisheries. M. flavolineatus is oviparous. The spawned eggs are demersal and, following fertilisation, are guarded by both parents through to the larval stages (Al Kholy, 1966).

10.2. Material and Methods

372 specimens of M. flavolineatus, ranging is size between 10 and 25 cm standard length, were collected at monthly intervals from the commercial catch in the vicinity of Jeddah fishing zone. These consisted of 123 males and 249 females. At capture, and after the record of the various biological information (see earlier chapters for details), a full description of the gonads was recorded, this included colour, size relative to body cavity, and size of oocytes whenever they were easily seen by the naked eye. The gonads were then removed, fixed immediately in aqueous Bouin.

Paraffin embedding was carried out after dehydration and clearing in an alcohol series.

Sections ranging between 6-10 Microns in thickness were stained by using Heidenhain's iron alum haematoxylin technique. The resulting films were examined under a binocular microscope

10.3. Results and Discussion

10.3.1. Morphological observations on ovarian development

In the present study, after morphological examinations, the gonads of Mulloides flavolineatus have been placed in one of 5 stages. These stages are :

I. Immature ovary (Stage I): This occurs in virgin fish, i.e., that were never engaged in sexual activity before (first time spawners). In this stage, the ovaries lie close to the dorsal surface of the body cavity, and in gross appearance, they are small, threadlike, translucent, and occupy less than one third of the body cavity (Plate 10.I.1). This stage occurs throughout the year and includes fish of size range between 10 and 14 cm Standard Length.

II. Intermediate ovary (Stage II): The ovaries occupy one third of the body cavity and have a light pink colour. Developing oocytes are seen through the ovarian membrane (Plate 10.I.2). This stage occurs throughout the year among fish of 10 to 22.0 cm in length (SL). The gonado-somatic index (GSI) is equal to 0.8247±0.1814.

III. Maturing ovary (Stage III): The ovaries are yellowish in colour and occupy half of the body cavity (Plate 10.I.3). This stage occurred in fish of an average length of 18.46±1.2568 cm and ranging between 14.4 and 21.2 cm (SL). They occurred in the Saudi Arabian coastal waters during the period from March to November, during the present investigation. The GSI was equal to 1.4523±0.5171.

IV. Ripe ovary (Stage IV): The ovaries occupy the whole body cavity and are turgid in appearance resembling an inflated balloon, full with eggs of a reddish colour which are easily released by pressure on the ovaries (Plate 10.I.4). Blood vessels appear over the surface of the ovarian membrane. This stage is present in fish of average length of 21.27±2.1502 cm, ranging between 15.6 and 24.8 cm (SL). Fish in this stage occurred only during June, July and September. The GSI was equal to 3.3200±2.0499.

V. Spent ovary (Stage V): This stage was represented in very few samples during the present study. This may be attributed to the post-spawning parental care of this species which is known to spawn, in the Red Sea, along the Egyptian coasts of the Gulf of Aqaba (Al-Kholy, 1966).

From the gonadal examination of the population in the vicinity of Jeddah, it seems that by the time the mothers return to their feeding grounds they are already either in the intermediate or maturing stage (i.e., stage II or III). The ovaries have the appearance of a deflated balloon. Fish in this stage of ovarian development were present during September and December.

10.3.2. Histological obsrvations on oocyte development

Stage I: In histological sections, the immature ovary consists of ovarian lamellae loaded with clusters of oogonia and spherical oocytes (Plate 10.II.1). The premeiotic oocytes (=oogonia) (15 - 50 µ) are mostly polygonal in appearance and are characterized by large spherical nucleus (5 - 15 µ), occupying the whole bulk of the cell and surrounded by a thin layer of cytoplasm. Basophilic nucleoli are present near the central region of the nucleus (Plate 10.II.2).

Stage II (Intermediate): During this stage, the oocytes are characterized by being of larger size than in the immature ovary (cell (C)= 100 - 150 µ, nucleus (N)= 50 - 100 µ). The cytoplasm is not highly basophilic because of the presence of scattered vacuoles. Some oocytes with vacuolized cytoplasm are present and a large number of previtellogenic oocytes are present in this stage (Plate 10.II.3&4).

Stage III (Maturing ovary): The ovary is filled with maturing oocytes in different stages. The deposition of yolk spheres starts in the peripheral layer of maturing oocytes, and extend centripetally till the entire cytoplasm (C= 190 - 300 µ, N = 100 - 150 µ) is full of yolk spheres. Empty vacuoles lie between the yolk spheres (Plate 10.III.5&6). The nucleus becomes irregular in shape. The zona radiata is formed and increases in thickness (Plate 10.III.7&8). The oocyte is surrounded by two layers; an inner layer, the zona radiata, and an outer layer of follicular epithelium (Plate 10.III.7).

Stage IV: This stage was found in ripe fish, in sections, the ovaries are full of ripe eggs and oocytes in different stages of development (Plate 10.IV.9&10). The zona radiata is relatively thin. The nucleus has an irregular shape (Plate 10.IV. 11). The ovary at this stage is not markedly different from those in the previous stage of maturity, except in the presence of relatively larger oocytes (C= 650 - 900 µ) (Plate 10.IV.9,10&11). The maturing oocytes are mostly characterised by the absence of a distinguishable nuclear envelope.

Stage V (Spent): Histologically, the ovaries consists mainly of premeiotic oocytes, and resemble the ovaries in Stage II, but they also show atretic follicles that remain after spawning (Plate 10.IV.12).

10.3.3. Spawning season

Knowledge of the spawning season is important in studying the effect of various environmental factors on the onset of the spawning, and the survival of eggs and larvae, since success or failure of year classes is usually determined during the very early stages of development. Information concerning the spawning season also helps to show the exact age of fish or at least the time when an age group is transferred to the next. Moreover, the time of fishing and the mesh size of the fishing gear is regulated according to the time of sampling and the size of fish at its first sexual maturity. It is also important to know the frequency of spawning of the fish during its spawning period, and within the same year in order to estimate the reproductive potential of the fish.

Lagler et al. (1962), in his study on the breeding of fish, pointed out that most fish species have a definite spawning season, and are generally grouped as follows:

1. Mid water fish, are summer spawners;
2. Cold water fish, are autumn and winter spawners;
3. Fish tolerating intermediate temperatures are generally spring spawners; and
4. Some tropical fish spawn all the year round.

However, Longhurst and Pauly (1987) showed that, while the spawning of tropical fish is often more protracted than that of temperate fish, it is usually concentrated in one or two periods each year.

The gonado-somatic index (GSI), which is an indicator of spawning in most fish species, was calculated for each fish and the mean obtained for each month of the study period and was computed by the formula :

$$GSI = \frac{\text{gonad weight} \times 100}{\text{gutted weight of fish}} \quad \text{(Meien, 1972)}$$

Table 10.1 shows two maximum values of GSI for males and females, indicating that M. flavolineatus is a fractional spawner that yields two broods at an interval of three months, the first in June (GSI = 3.3879 for males and 4.3069 for females) and the second in September (GSI = 3.7060 and 6.6127 for males and females, respectively). After the second spawning wave there is a long resting period of almost no spawning activity, starting from October through April, after which the gonadal activity increases and gonads gain weight by the increased development of the sex products during May and starts spawning again in June.

Obviously both males and females have the same timing in their gonadal cycle ($P<0.01$) and both are together on the spawning grounds, since their reproductive cycle was shown to coincide in timing.

10.3.4. Reproductive cycle

Changes in the mean values of GSI in females occurred throughout the year (Figure 10.2, from Table 10.1). The increase in the values of GSI is highest in June/July and in

September, which indicates that this species is, possibly, a fractional spawner, laying two batches of eggs, the first in mid summer and the second in early autumn. This seems to be a common spawning pattern among goat fishes, since Al-Kholy (1966) mentioned that *Mulloidichthys auriflamma* (presently *Upeneus moluccensis* (Ben-Tuvia, 1973)) spawns along the Red Sea coasts of Egypt during this period. He said that they move from deep water to shallow coastal areas for spawning. They reach the coasts off Geftoon, Shedwan, Senafer, Tiran and Ras Muhammed starting in May and continue to mid July. During this period spawners arrive in three groups. However, he did not mention whether these groups were the same parents laying successive batches of eggs or different spawning groups.

The analysis of the cyclic variations in the mean values of GSI for each of the maturity stages of *M. flavolineatus*, i.e. stages II, III, and IV, throughout the year is illustrated in Figure 10.3. This shows that even for fish maturing early in the year, values of GSI were also highest during June, July and September; these three months are therefore, the months of the highest gonadal activity throughout the different stages of sexual ovarian maturity, confirming the date of spawning in this species.

This timing of spawning coincides with the months of highest water temperature in the area of study (Table 1.1.), and this is considered as the major cause for the onset of spawning activity in fish (Nikolsky, 1963).

Comparing the monthly values of the gonado-somatic index with those of the condition factor 'K' of the gutted fish (K_{Gwt}, Figure 10.4) it was found that the general condition of the fish correlates well with these spawning times. Because of the exhaustion of the fish during spawning, the condition factor was lowest during and after spawning, with highest values, on the other hand, corresponding to the pre-spawning periods (Figure 10.4)

According to Oven (1961) the goatfish species are multiple spawners that lay several times in the year. The ovaries contain oocytes at various stages of maturation, and it is very difficult to distinguish those of subsequent years.

Whether the spawning population of this species consists of different year classes or whether the spawning group is a fractional spawner was tested through the analysis of size composition of the different stages of maturity throughout the year (Figures 10.5-10.7). Figure 10.5 shows that there are two size groups in the population of M. flavolineatus in maturity stage II, the first had a monthly average size ranging between 11 and 20 cm (SL) and was observed during the period from November through July, the second had an average size ranging between 14 and 19 cm (SL) and occurred during August and September.

Data presented in Figures 10.6 and 10.7, reveal that spawning activation starts among fish having a monthly mean size of about 19.4-20 cm (SL) (Stage III), but most definitely actual spawners have a size range of 15.6 to 24.8 cm SL (Stage IV) (Fig. 10.7). This indicates that the onset of sexual maturity, or rather, the size at first maturity is in the range of 14.4 to 21.2 cm (SL), or about 19.0±3.2527 cm (SL), i.e. fish of this species mature after their second year of life.

10.3.5. The nature of spawning of *M. flavolineatus*

Some fish usually lay the eggs in a single batch during the breeding season in one sexual cycle, but others deliver several batches of eggs during the breeding period, and spawning here is known as fractional.

Fractionation and periodicity of spawning means that inside the ripe ovary, there may be more than one size group of eggs which are released at intervals, i.e. in more than one spawning action. In these fish, spawning lasts for a long period according to the innate nature of the fish. For example *Tilapia* in the Nile has a long breeding season and the possession of more than one group of yolky eggs in the ripe ovary Lowe (1958) found that sometimes the breeding female of *Tilapia esculenta* (in Lake Victoria) may produce at least three and possibly four batches of eggs in a fairly rapid succession. She also added that ripe fish may be caught at all times.

In *M. flavolineatus* the ovary contains eggs of variable sizes during the period of gonad ripeness. As it approaches the spawning season, the eggs which are destined to be spawned in that season, mature progressively in successive batches. Thus in a ripe ovary, eggs at various stages of maturity are easily detected (Plate 10.IV.9); of these, the large yolky eggs are those which are ready to be spawned at the beginning of the breeding season. The groups of smaller sized eggs, will progressively mature, so that they are ready to be shed during the next spawning action, and so on. The fish is known to perform spawning more than one time in the spawning season.

It is possible to detect three batches of eggs in the maturing ovary of *M. flavolineatus* in the pre-spawning individuals at June/July and in September; there are small, moderate and large sized eggs. The three groups of eggs show an increase in their diameter from one group to the following, the range of the diameter of these successive groups was from 650, 800 and 900 µ, respectively.

Table 10.1 Monthly variation in the GSI of _M. flavolineatus_ from the Red Sea off Jeddah.

Month	Males N		Females N	
Dec.	5	0.1726	15	0.1732
Jan.	-		-	
Feb.	2	0.4058	-	
Mar.	21	.04249	51	0.5000
Apr.	11	0.4872	18	0.5147
May	15	0.9483	22	1.1702
Jun.	24	3.3879	43	4.3069
Jul.	7	1.2985	17	0.8262
Aug.	7	1.6187	12	2.0201
Sep.	6	3.7060	5	6.6127
Oct.	20	0.1889	42	0.2776
Nov.	9	1.3194	28	1.6578

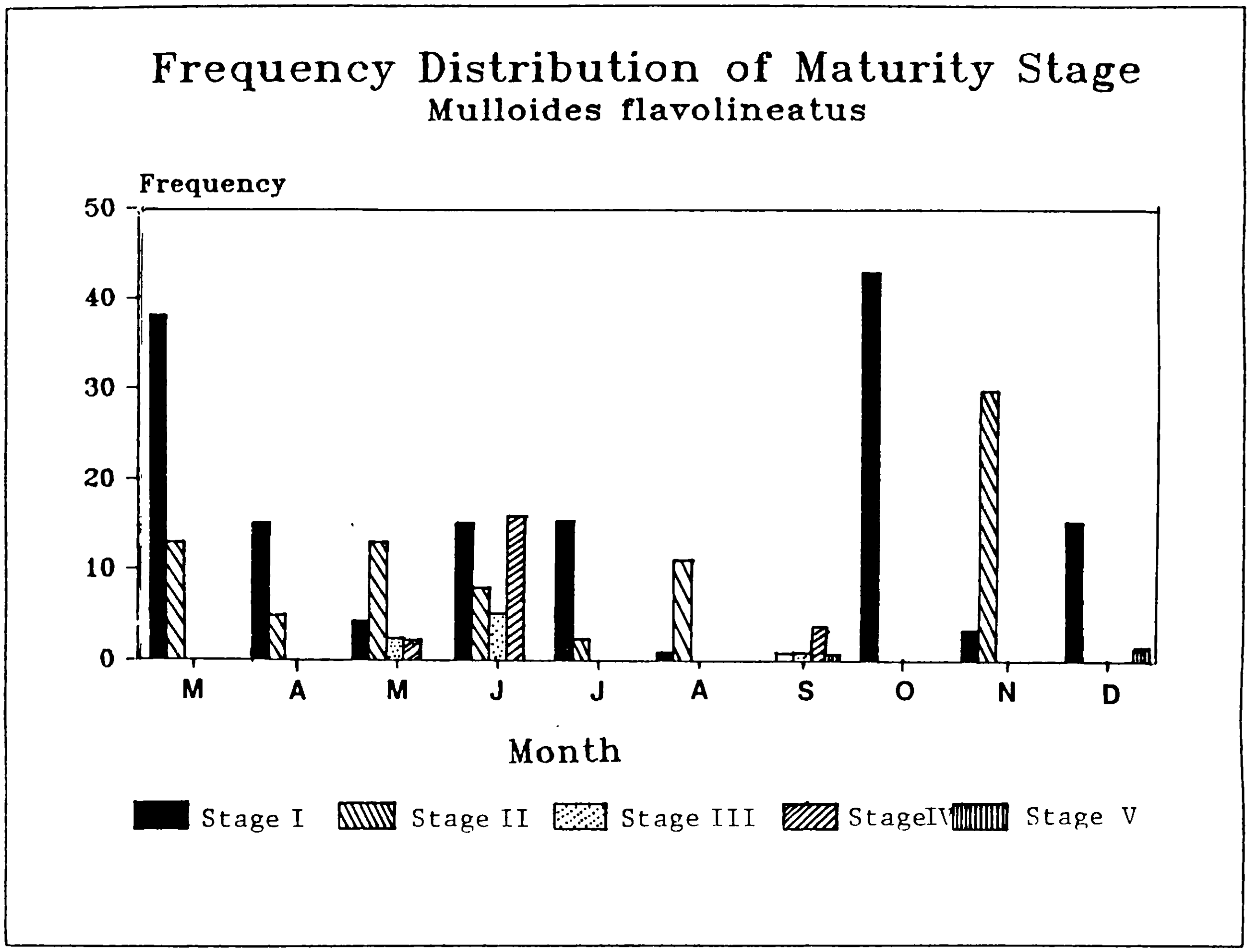


Figure 10.1. Frequency distribution of the different maturity stages of *Mulloides flavolineatus* caught off Jeddah.

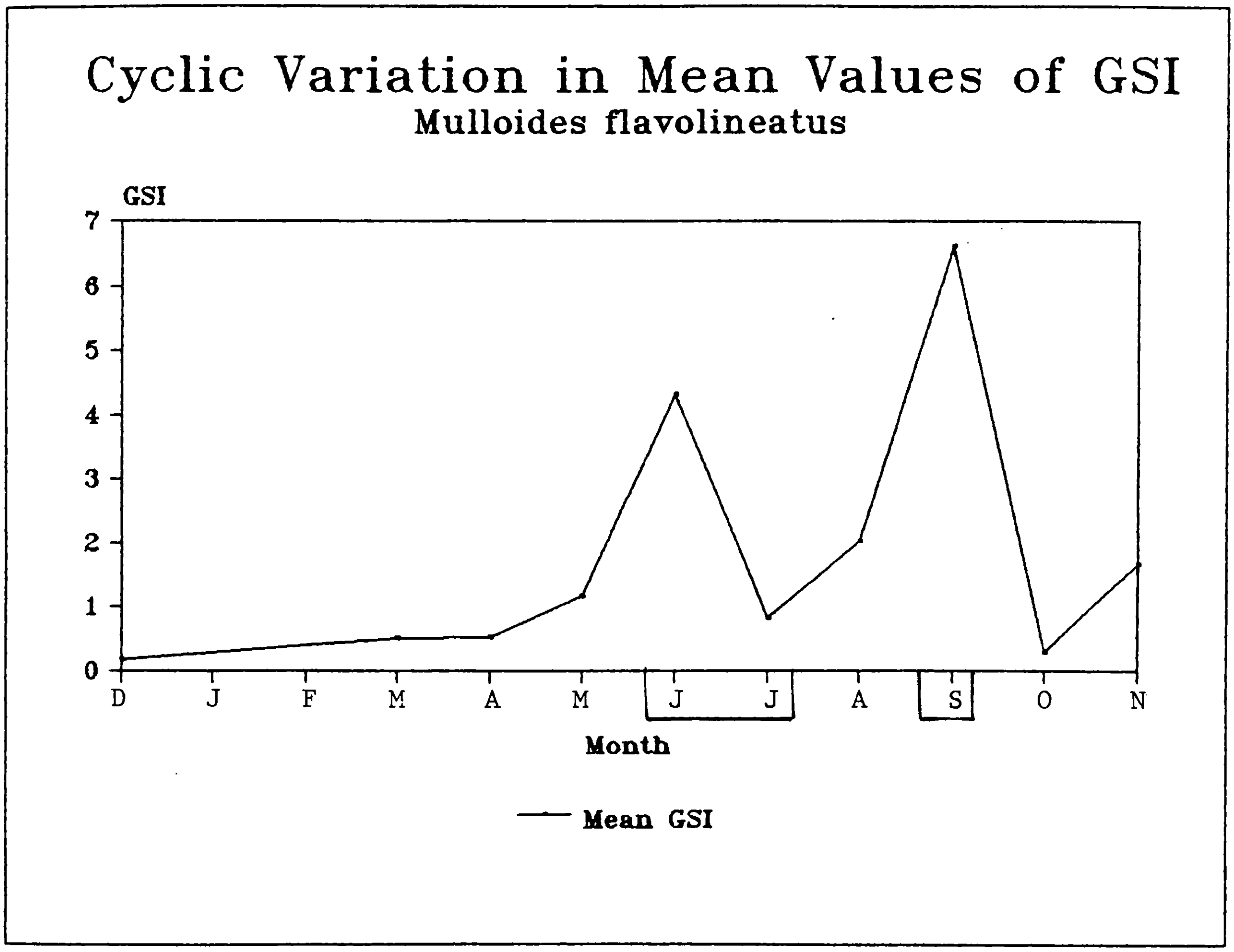


Figure 10.2. Cyclic variations in mean values of the gonado-somatic index (GSI) of <u>Mulloides flavolineatus</u> 1986.

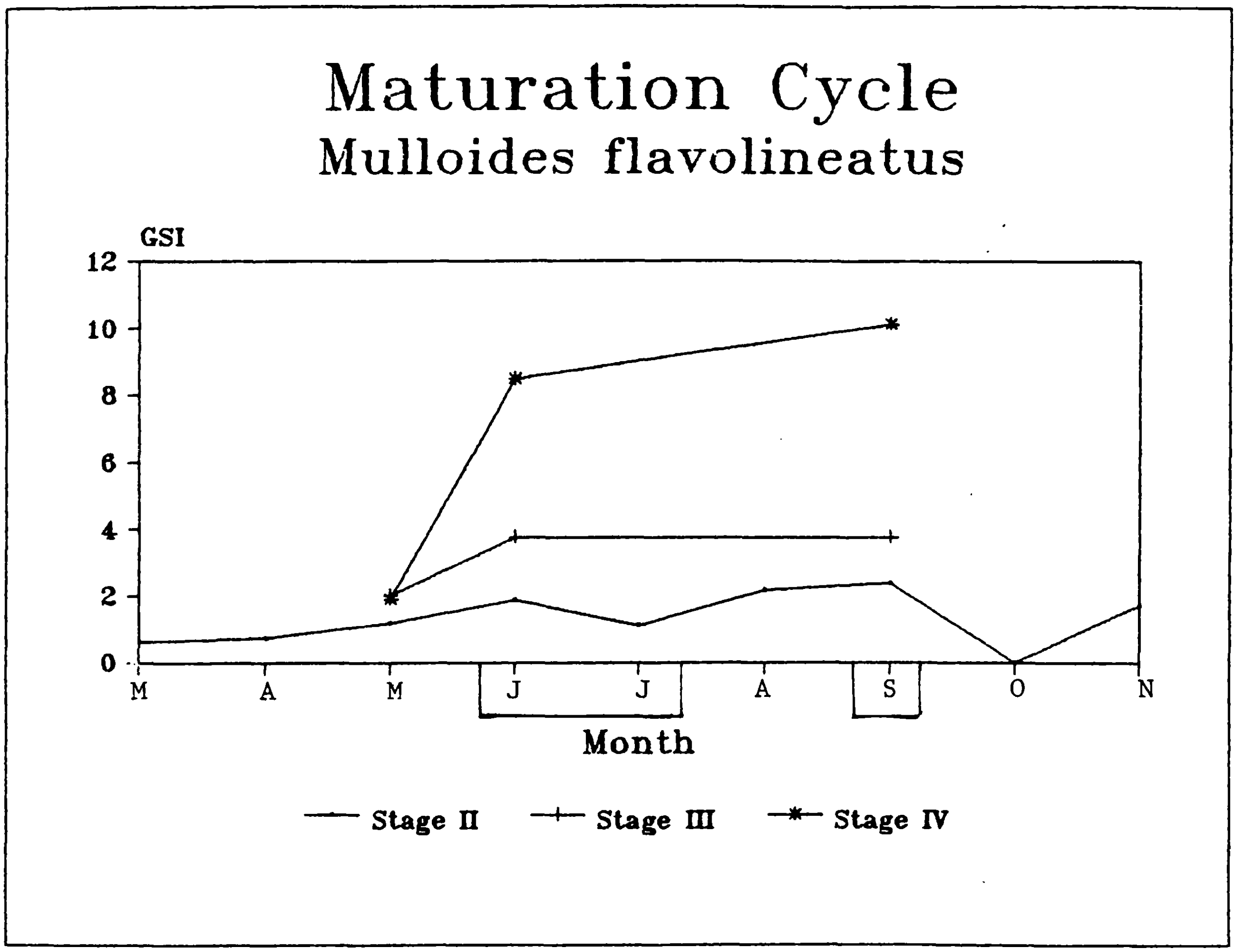


Figure 10.3. Monthly variation in the gonado-somatic index (GSI) of the different maturity stages of *M. flavolineatus*.

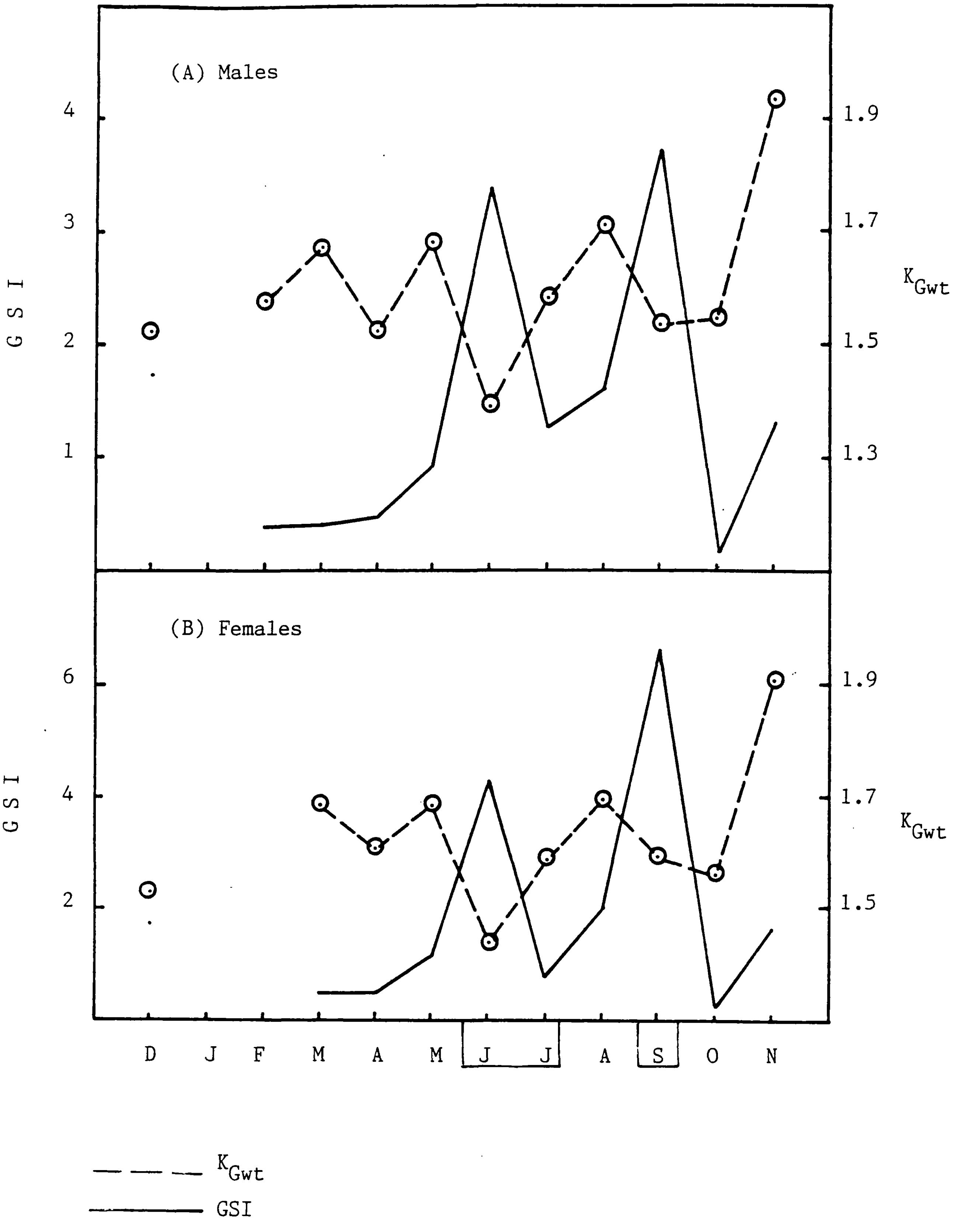


Figure 10.4 Monthly variation in the condition vs. GSI of males and females *M. flavolineatus* off Jeddah (1986).

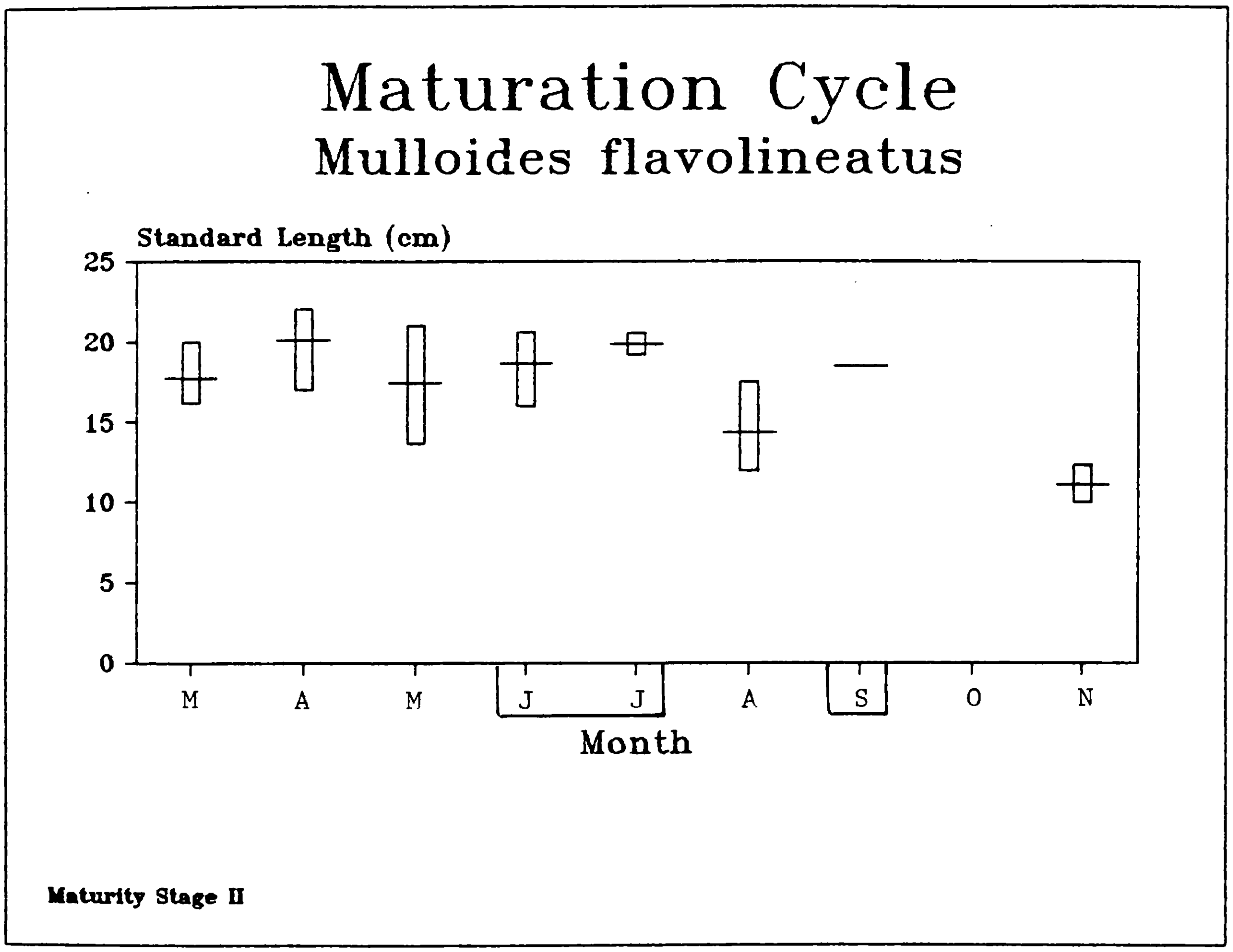


Figure 10.5. Mean and range of fish length of maturity stage II

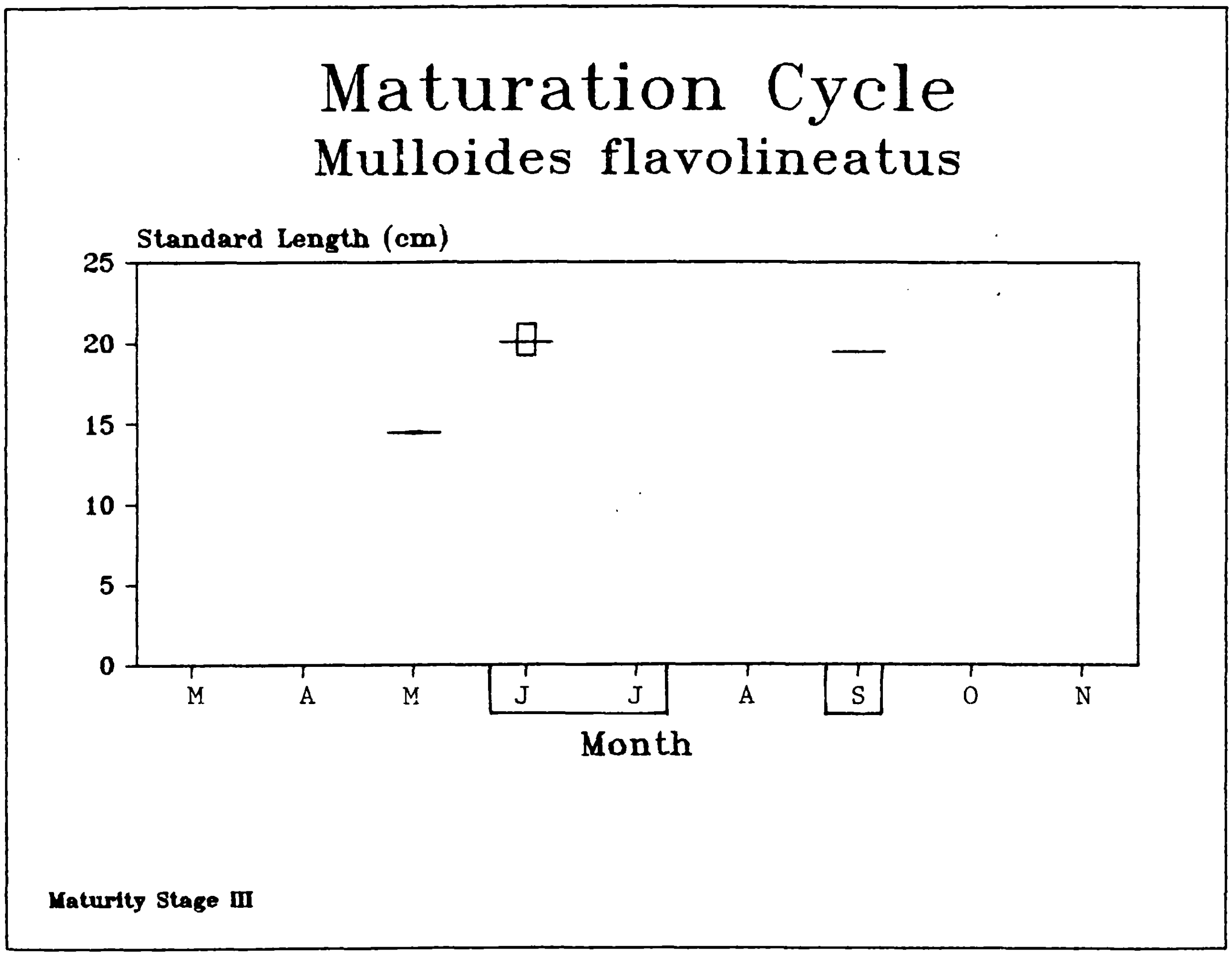


Figure 10.6. Variation in fish size of maturity stage III.

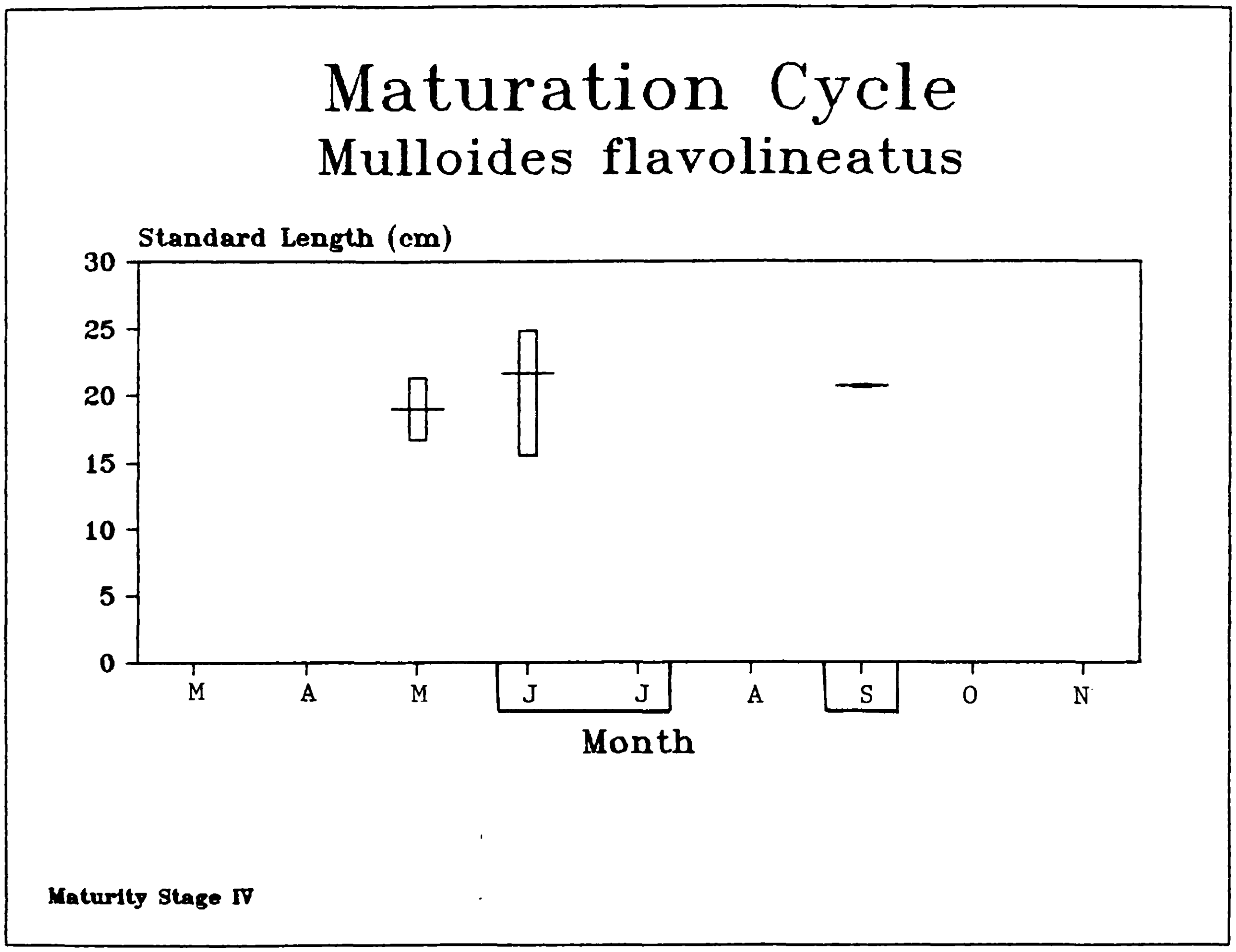


Figure 10.7. Monthly variation in size of fish of maturity stage IV.

PLATE 10.I

Fig. 1: External morphology of the immature ovary (thread-like stage) (Bar = 2 cm)

Fig. 2: External morphology of the intermediate ovary (Stage II) (Bar = 2 cm)

Fig. 3: External morphology of the maturing ovary (Stage III) (Bar = 2 cm)

Fig. 4: External morphology of the ripe ovary (Stage IV) (Bar = 2 cm)

PLATE 10.1

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④

PLATE 10.II

Fig. 1: A cross section showing the general structure of the immature ovary (x42)

Fig. 2: An enlarged part of the above section (x168)

Fig. 3: A part of a cross section showing the general structure of the intermediate ovary, Stage II (x168)

Fig. 4: An enlarged part of the above section (x240)

N : Nucleus

Nu : Nucleolus

OL : Ovarian lamellae

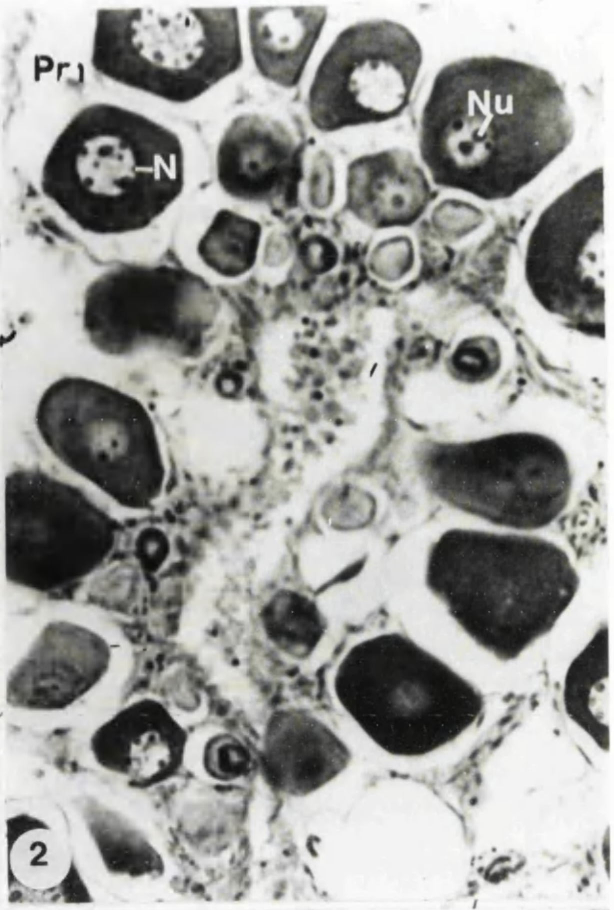
OW : Ovarian wall

Pm : Premeiotic oocyte

Pv : Previtellogenic oocyte

PLATE 10.11


1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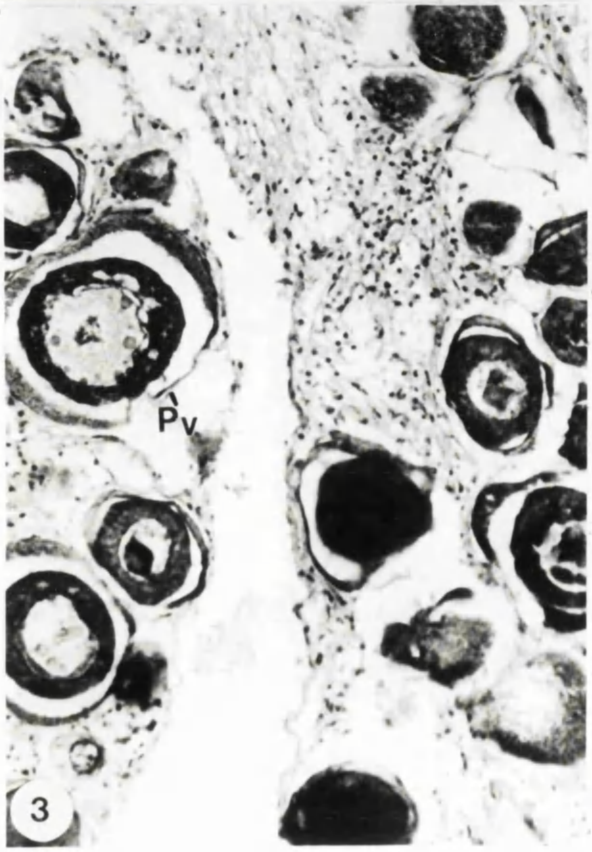
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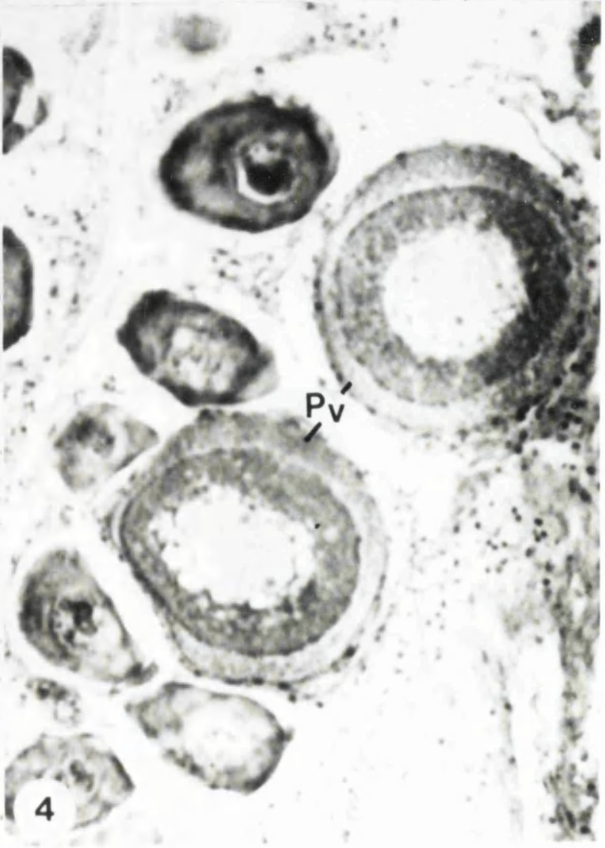
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PLATE 10.III

Fig. 5: An enlarged part of the previous section showing the general structure of an oocyte with vacuolized cytoplasm and some previtellogenic oocytes (x360)

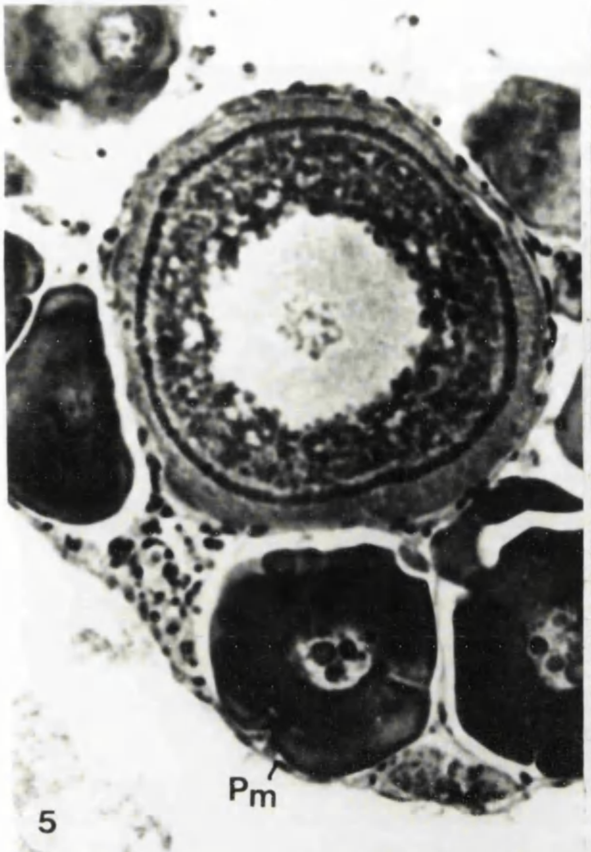
Fig. 6: A part of a cross section showing the general organization of a maturing ovary (x80)

Fig. 7: An enlarged part of the above section showing some maturing oocytes (x240)

Fig. 8: An enlarged maturing oocyte showing its general structure (x360)

FE : Follicular epithelium
N : Nucleus
Nu : Nucleolus
Pm : Premeiotic oocyte
Pv : Previtellogenic oocyte
V : Vacuoles
Yv : Yolk vesicles
ZR : Zona radiata

PLATE 10.III



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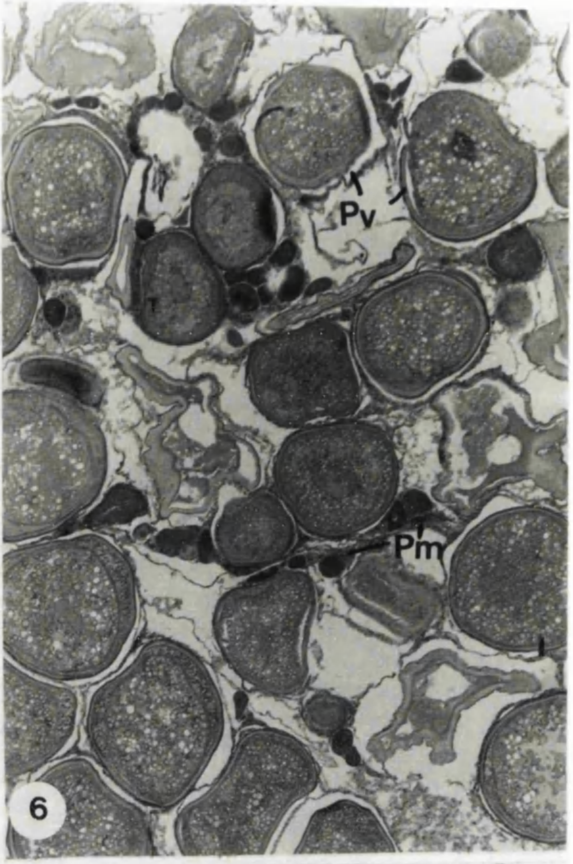

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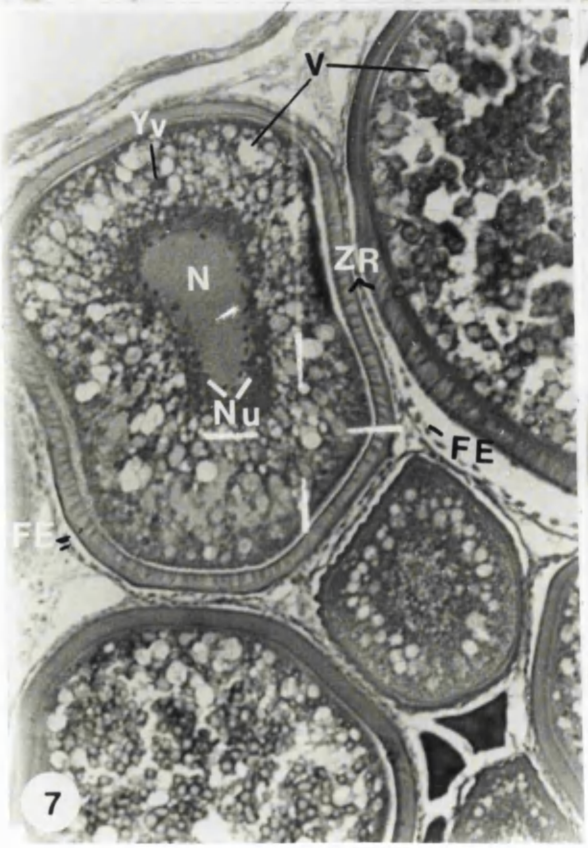

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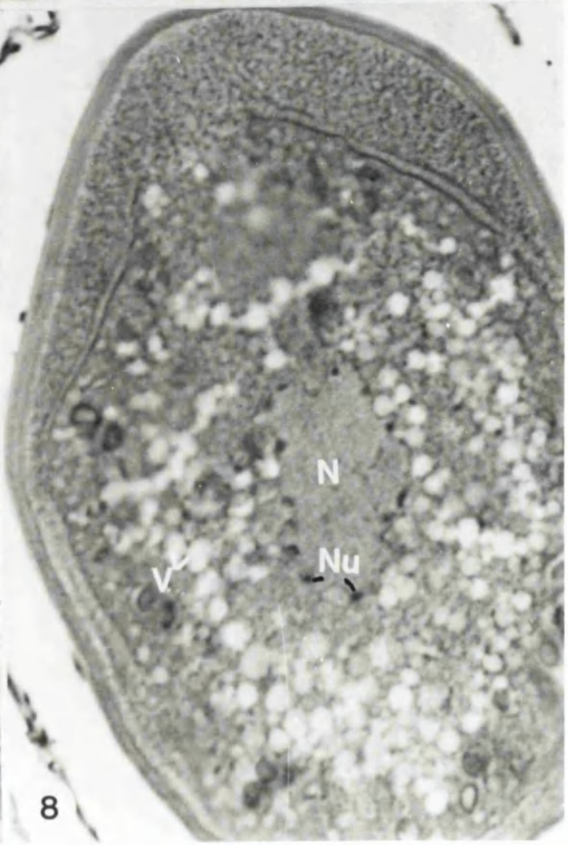

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PLATE 10.IV

Fig. 9: A part of a cross section through the maturing ovary (Stage III) showing its general structure (x80)

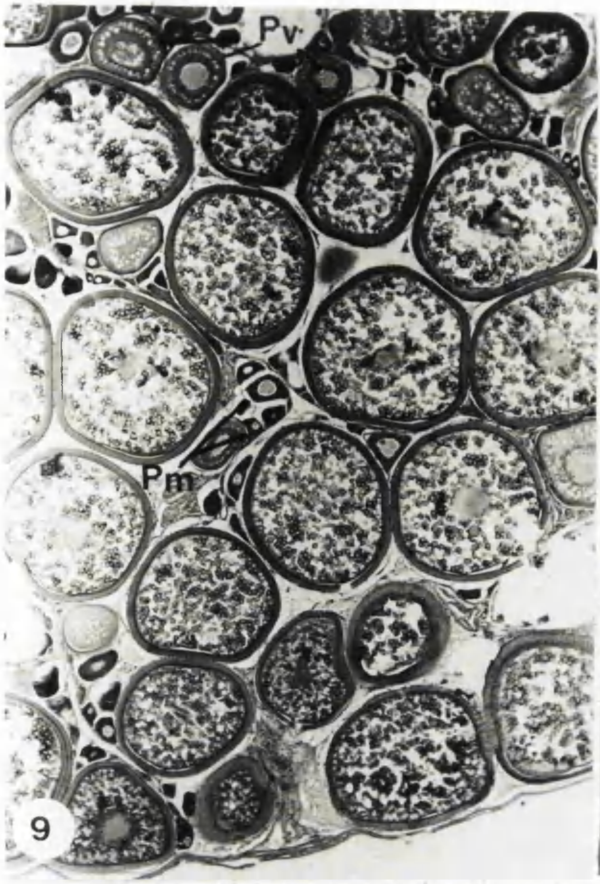
Fig.10: An enlarged part of the above section showing maturing oocytes of different stages (x168)

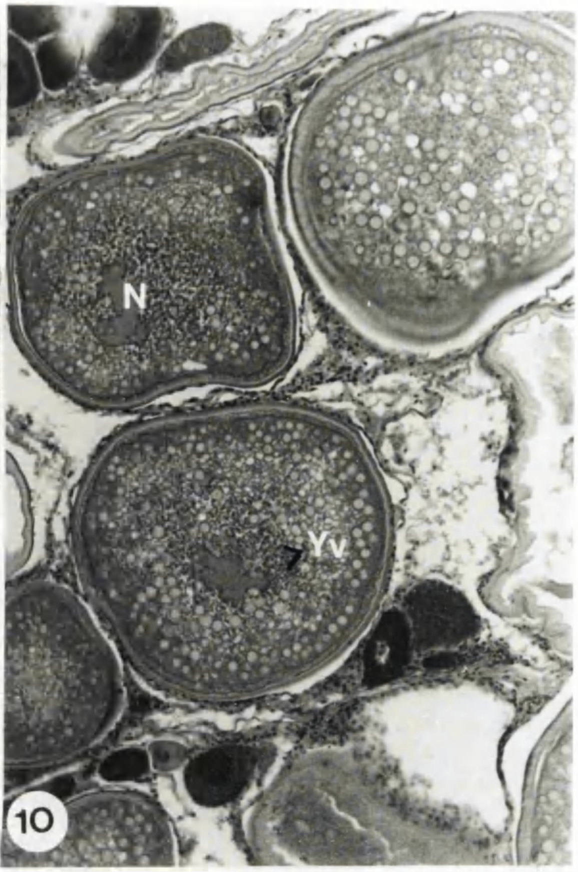
Fig.11: An enlarged maturing oocyte (Stage IV), notice the thin zona radiata and the irregular shape of the nucleus (x240)

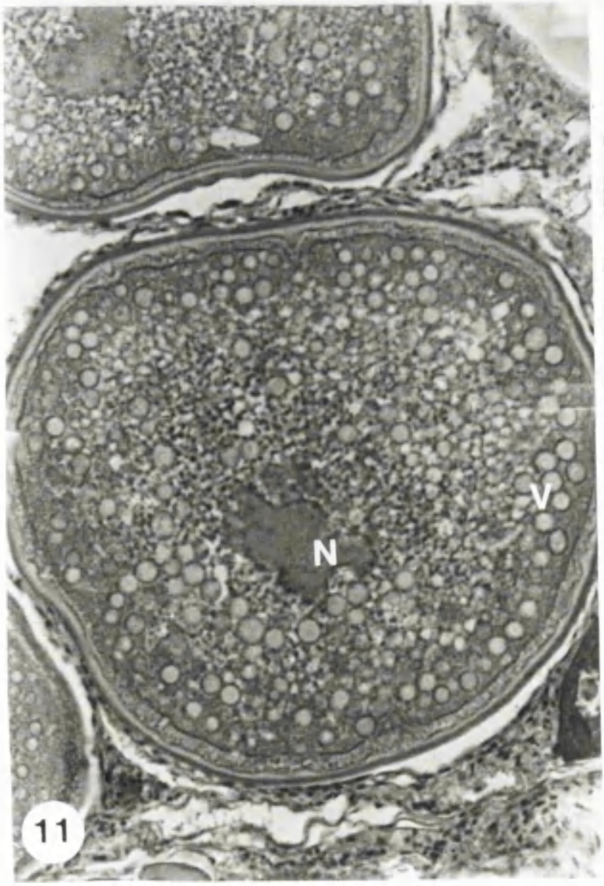
Fig.12: A part of a cross section of a spent ovary (Stage V), showing its general structure (x80)

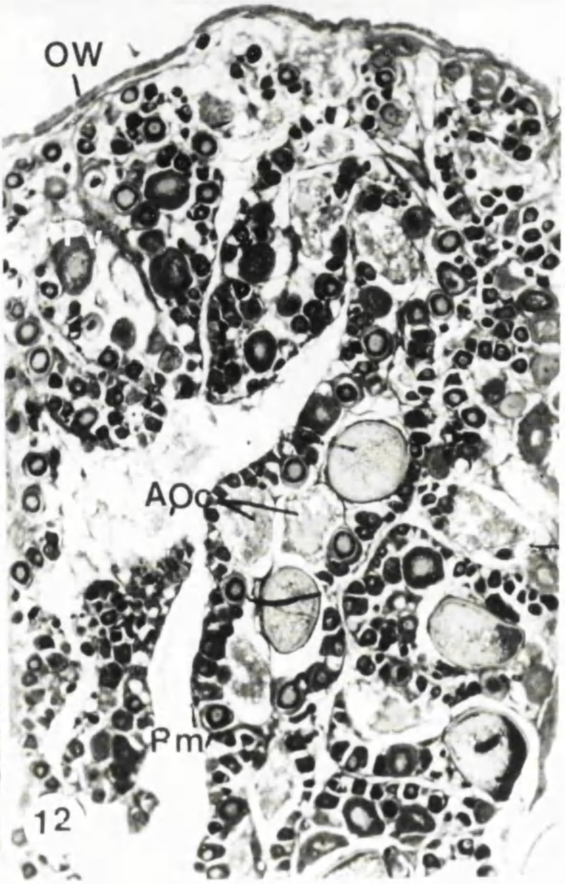
A.OC : Atrelic follicle
N : Nucleus
O.W. : Ovarian wall
Pm : Premeiotic oocyte
Pv : Previtellogenic oocyte
V : Vacuoles
Yv : Yolk vesicles

PLATE 10.IV









CHAPTER 11

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSIONS

The present study investigates, through macro- and microscopic examination, the correlations between both the morphological and histological structure of the different parts of the alimentary canal and the feeding habits of the economic fish in the commercial fisheries of Jeddah district. It also deals with the biological aspects of the fisheries of one of the commercial fish species of economic importance to the consumers in this area of Saudi Arabia.

During the course of this study, monthly samples from 20 fish species caught from the fishing grounds in the vicinity of Jeddah, were used to analyze the different morphological and histological characteristics of their alimentary canals.

From the analysis of the stomach content of the selected fish species, they could be divided into four feeding categories, i.e. planktivorous, represented by *Rastelliger kanagurta*; omnivorous, represented by *Itherapon jarbua*; herbivorous, including *Scarus ghabban* and *Siganus rivulatus*; and carnivorous, further subdivided according to the preferred animal food item into a) invertebrate+fish eaters, to include *Plectrorhynchus schotaf*, *Platycephalus tuberculatus*, *Lethrinus lentjan*, *Lutjanus flaviflamma* and *Gerres oyena*; b) fish+invertebrate eaters, to include *Lutianus bohar*, *Scomberomorus lysan*, *Carangoide bajad* and *Aethaloperca rogaa*; c) fish feeding solely on invertebrates to include *Mulloides flavolineatus*, *Adioryx spinifer*, *Plectrorhynchus gaterina* and *Caesio suevicus*; and d) fish feeders to include *Tylosurus choram*, *Sphyraena genie* and *Caranx ignobilis*.

From the comparative study of the morphology of the alimentary canal of the different feeding categories it was concluded that the gut length is the major adaptive specialization in the feeding ecology of these fish species. The length of the gut relative to the body length was found to be longest in planktivores than in herbivores, and intermediate in omnivores. In carnivores, that had the shortest relative gut length, it was found that the gut length is correlated with the size of the prey; being greater in those that consume smaller animals, e.g., *M. flavolineatus*, and shorter in those that consume larger animals, e.g., *C. suevicus*, regardless of the number of their pyloric caeca.

The morphometric regressions of the different parts of the alimentary canal against body length proved that, in general, gut length increases more than the fish length, and that in carnivorous fish that feed on invertebrates, in any proportions of their diets, the number of pyloric caeca do not correlate with fish size.

Histological studies on the alimentary canal of the four major feeding categories were performed on four of the economically important fish species inhabiting the fishing grounds off Jeddah, i.e., a carnivore, *Tylosurus choram*; a planktivore, *Rastelliger kanagurta*; a herbivore, *Siganus rivulatus*; and an omnivore, *Iherapon jarbua*. From this study it was found that in the four fish species, the order of the various layers in different regions of the gut was generally uniform and regular as in any teleost of the corresponding feeding habits, with the exception of the stratum compactum that was not uniformly present in the alimentary canal of all the studied fishes. It was found to be absent in *T. jarbua*.

The histological structure of the different regions of the alimentary canal of the four fish categories were, however, very distinct for each category. In general, carnivores and omnivores showed almost the same structures in the different parts with the exception of the absence of stomach and pyloric caecae in carnivores. Thus in the oesophagus, goblet cells were numerous in *I. choram* and *I. jarbua*, while they were few in the other two species. In addition, the oesophageal glands were of a well developed structure in the planktivorous fish, *R. kanagurta*, but were absent in the herbivore *S. rivulatus*, while in fish feeding on food of animal origin there existed structures that gave a false impression of goblet cells in their oesophagus. Stratum compactum, on the other hand, was absent in animal eating fish and present in plankton and plant eating fish. Moreover, the intermediate layer of the muscularis was present only in animal eating species. The serosa of the different fish categories varied widely being of the mucosal-fold type in *I. choram*, secondary and tertiary branches in *I. jarbua*, secondary folds in *S. rivulatus* and of the villi type in *R. kanagurta*.

The stomach was absent in the carnivorous fish *I. choram*, and in the representatives of the other three groups it showed little variations in the structure of its layers. Thus in the mucosa, gastric glands were richer in zymogen granules in *R. kanagurta* than in the other two species as judged by the intensity of staining of their cytoplasm. The submucosa showed no differences between species. In the muscularis, however, the muscularis mucosa was present only in the herbivore fish *S. rivulatus* and absent in the other two species.

The pyloric caeca had almost the same differences in their structure between the different categories. The mucosal epithelium was finger-shaped in the plankton feeder and in the form of villi in the herbivore. In the sub-mucosa the tunica propria was conspicuous in the plankton feeder, highly conspicuous in the omnivore and highly conspicuous with many lymph cells in the herbivore. The stratum compactum was more developed in the herbivore and the omnivore fish species, and absent in the plankton feeder.

All these differences in the histological structure of the different parts of the alimentary canal are well correlated to the type of food ingested by the fish species under investigation.

The study of the biological aspects of the *Mulloides flavolineatus* inhabiting the fishing grounds off Jeddah included the study of their feeding habits, their age and growth patterns, the mortality rates of the population and their reproductive biology.

In order to perform such a study, fish samples were collected on a monthly basis for over a year, during which a total of 714 specimens, representing the different sexes and covering the length range between 10 cm and 25 cm (Standard Length), were analyzed.

The study of the food and feeding habits of *M. flavolineatus* showed that this fish is a nocturnal feeder that consumes mainly small crustacea and invertebrate organisms among reef communities in the Red Sea.

It was found that this fish feeds intensively during winter and spring seasons, times that correspond with the "resting" stages of their spawning activity, since the study of their reproductive cycle showed that this fish is an active spawner during fall and summer times. The timing of these periods of active feeding was also correlated with the general condition of the fish. The monthly variations in the condition factor were found to match the corresponding variations in the gonado-somatic index of this fish.

In general, *Amphithoe* and *Elasmopus* were the most prefered amphipod ingested by this fish, *Solenocera choprai* was the most abundant shrimp in their diet. *Cirolana* was the preferred isopod and *Scyra acutifrons* was the most abundant brachyuran in their stomachs. Molluscs were second in order of abundance among ingested food items.

Seasonal variations in the diet composition of *M. flavolineatus* showed that the fish feeds mainly on crustacea and molluscs in spring and summer time, while it feeds on polychaetes in winter. The seasonal variations in the preference of the different food items seemed to vary according to the sex of the fish. Thus, "indeterminate sex" fish had the largest spectrum of ingested food items during spring and summer, while males and females showed this wide range of selection of food items only during summer.

M. flavolineatus was found to be a versatile fish in its feeding pattern, the type of food in its stomach was found to change with fish size. Thus in small sizes, the fish was found to feed only on crustacea, and as it grows in length, it shifts its diet to become more dependent on molluscs together with crustacea which are the most abundant food item in bigger fishes.

The length-weight relationship of *M. flavolineatus* showed that this fish have a relatively low value of the exponent "n", i.e. <3, indicating that this fish becomes slightly lighter for its length as it grows longer. Furthermore, it was found that females have a higher value of this exponent than males, being 2.6003 and 2.5308, respectively. This suggests that females become relatively slightly heavier than males as they grow in length.

Values of the condition factor were consequently found to decrease with fish size. However, it was found that the values of condition factor for M. flavolineatus were higher than those of other goatfish species in any locality and suggests that this fish thrives well in the waters of the Red Sea off Jeddah.

Annual growth rings were identified on the scales of Mulloides flavolineatus, and these were used for the back-calculation of their lengths at age. Males were found to be represented by five age groups, while six age groups of females were found in the area of study.

The values of length (in cm) at age for males and females are given below :

Age	1	2	3	4	5	6
Males	11.12	14.11	18.61	21.14	22.3	
Females	11.03	15.69	17.77	22.06	23.12	24.72

This species was found to slow down its growth rate during the first three years of its life, after which it slightly increased in length, the average annual increment ranged between 1 and 11 cm. The annual increment in weight also showed a similar pattern as in any other of the goatfishes, i.e. it showed its highest rate of increase during their fourth year of life.

Female superiority in size, over males, was only noticed in fishes of age two and older, this dimorphism in size was, however, very slight.

The von Bertalanffy growth model was found to fit this fish species, and the growth parameters were found to be:

	Males	Females
L_∞	28.96 cm	28.57 cm
K	0.2482 cm.yr^{-1}	0.2975 cm.yr^{-1}
t_o	0.8423 yr	0.5449 yr

The study of the mortality rates exerted on *M. flavolineatus* revealed that, in spite of the fact that both males and females are almost equally exposed to natural mortality rates, yet males have much higher total mortality values than females and this is because males are subjected to higher fishing mortality rate than females. This suggests that females are more affected by density independent causes of mortality than males. Survival rates of both sexes showed that only 5.2% of males live after their fifth year of life as opposed to 16.49% of females that live after their sixth year of life, a measure of fishing intensity on males, which is over the safe level for the population to sustain.

The study of the reproduction cycle and the determination of the spawning season of *M. flavolineatus* was performed through the micro- and macroscopic observation of the successive stages of maturation of the oocytes and the ovaries, as well as through the monthly variations in the gonado-somatic index (GSI) of the fish.

It was found that this fish is a multiple-spawner, that yields two broods at an interval of three months, the first in June and the second in September. The maximum values of GSI for both sexes were 3.3879 and 4.3069 in June, and 3.7060 and 6.6127 in September for males and females, respectively.

The onset of sexual maturity was estimated to be initiated in fishes of 14.4 cm of length (SL), the largest first-spawner being 21.2 cm in length (SL). In other words, most fish would spawn at a length of 19 cm (SL), i.e. after their second year of life.

In conclusion, from the biological information of this fish, one might say that, although Mulloides flavolineatus had a higher growth performance indicators than many other goatfish species, yet its low values of condition factor, and high natural mortality, suggest that this fish would do much better in areas of better water quality. Therefore, the possibility of introducing such fish in mariculture should be considered. Since its growth rates are, at present, high, and under controlled conditions could become much higher than in the wild.

Until such actions have taken place, it remains the fact that under the actual levels of fishing effort, this fish is moderately exploited, but the relatively high rates of fishing mortality exerted on males may lead to an unbalanced population in the standpoint of sex ratio. This recommends further studies on the gear selectivity for this fish in order to achieve such a balance in the exploitation rates of both sexes, and this would benefit the fisheries of this species.

The increase in the exploitation levels should be restricted to the post spawning periods for fishes older than 3 year of life and longer than 19 cm in length (SL).

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