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STUDIES ON THE DIGESTIVE SYSTEM OF *Siganus rivulatus* WITH SPECIAL REFERENCE TO ITS FOOD AND FEEDING HABITS

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ABSTRACT

The gross anatomy of the digestive system of **Siganus rivulatus** shows that the mouth is of the nibbling type and there is no sharp demarcation between the buccal cavity and pharynx, thus forming the bucco-pharyngeal cavity. The oesophagus is a long muscular tube and leads to the intestinal bulb as the stomach is absent in this fish. The intestine is long and coiled.

The liver is a dark brown organ with a broad left lobe and a narrow right one. The pancreas of S. **rivulatus** is of the "disseminatum and interhepatieum" type and the principal islet is absent.

The lining wall of the buccopharyngeal cavity is formed of mucosa, submucosa and muscularis. The mucosa consists of stratified epithelium, which is composed of polygonal cells, mucus-secreting cells with variations in their size and abundance, taste buds and club-shaped cells which are confined only to the pharyngeal region. The muscularis is composed only of circularly disposed striated muscle fibers.

The lining wall of the oesophagus consists of mucosa, submucosa, muscularis and serosa. The mucosa is made up of stratified epithelium with numerous mucus - secreting cells giving the appearance of stratification.

The wall of the intestinal bulb and intestine proper (duodenum, ileum and rectum) is similar to the oesophagus, but they differ in that the mucosa consists of columnar and goblet cells (simple epithelium), while the muscularis is made up of circular and longitudinal smooth muscle fibers.

Histochemical results revealed the presence of total carbohydrates, proteins, lipids and various digestive enzymes (B-glucuronidase acid-phosphatase and exo- and endo- peptidases) in the epithelial lining of the intestinal bulb of **S. rivulatus**.

The liver of this fish does not show lobular arrangement and the hepatic cells form acini. The constituent cell types of the islet tissue of **S. rivulatus** are mainly alpha, beta and gamma cells.

S. rivulatus is a herbivore, which feeds mainly on macrophytes, blue-green algae and diatoms. The percentage occurrence and percentage composition of these food items, their selectivity index and the degree of emptiness of the intestinal bulbs were calculated. It was found that this fish is mainly selective to macrophytes.

INTRODUCTION

Although studies on the digestive tract of fishes in relation to their food and feeding habits have received much attention (Al-Hussaini, 1945, 1946, 1947 a and b, 1949 a and b, 1952, Gohar and Latif, 1959), yet work in fishes belonging to family Siganidae is more or less limited. Among the few studies on the reresentatives of this family, concerning this aspect, one may mention those of Von Westrhagen (1974), Lundberg and Lipkin (1979) and Gushima (1981).

Recently, a world wide interest has been given to siganid fishes as a possible subject for mariculture (NASH, 1972). Thus, the present study is intended to throw some light on the gross and microscopic anatomy of the digestive system of **Siganus rivulatus**, as well as on its food and feeding habits.

MATERIAL AND METHODS

Samples of **S. rivulatus** were collected from the neighbourhood of the Marine Biological station at Ghardaga during the period from April 1984 to April 1985.

For the gross anatomy, fresh specimens were carefully dissected, examined and diagrams of the digestive system were made.

For histological studies, alive fishes were dissected and different parts of the digestive system were carefully removed and immediately fixed in aqueous Bouin's fluid (24 hrs) and Zenker's formal solution. The fixed material was dehydrated in an ascending series of ethylacohol, cleared in terpineol, embedded in paraffin wax and transversely sectioned at a thickness of 5-7 microns. Sections were stained with Mayer's haematoxylin and eosin for general structures. Mallory's triple stain and toluidine blue were used for revealing the connective tissues and mucus-secreting cells respectively. For the demonstration of the different cellular types of pancreatic islets, Heidenhain's azan stain was used.

The histochemical procedures employed were: PAS method for carbohydrates, Best's carmine for glycogen and Alcian blue for acid-musopolysaccarids. Mercuric brom-phenol blue and Sudan black B methods were used for the detection of total proteins and total lipids, respectively.

Moreover, the following methods were used to demonstrate the enzymes present. The Gomori's lead nitrate method for acidphosphatas, the Gomori's tween method for lipase, the silver proteinate method for endo-peptidases, the Mc cobe and Chayen method for exo-peptidases and the Naphthoal AS method for B-glucuronidase.

Photomicrographs of the stained section were prepared to illustrate the structure of the various parts of the digestive system.

For food and feeding habits studies, the intenstinal bulbs were preserved in 4% neutral formaline. The food items within these bulbs were identified to the lowest possible taxonomic level. Two methods were used for processing the data namely, the frequency of occurrence method (Allen 1935, Frost 1939, 1943 and 1946 a) and the percentage composition or points method as modified by Hynes (1950). Besides, the index of emptiness and selectivity index were calculated.

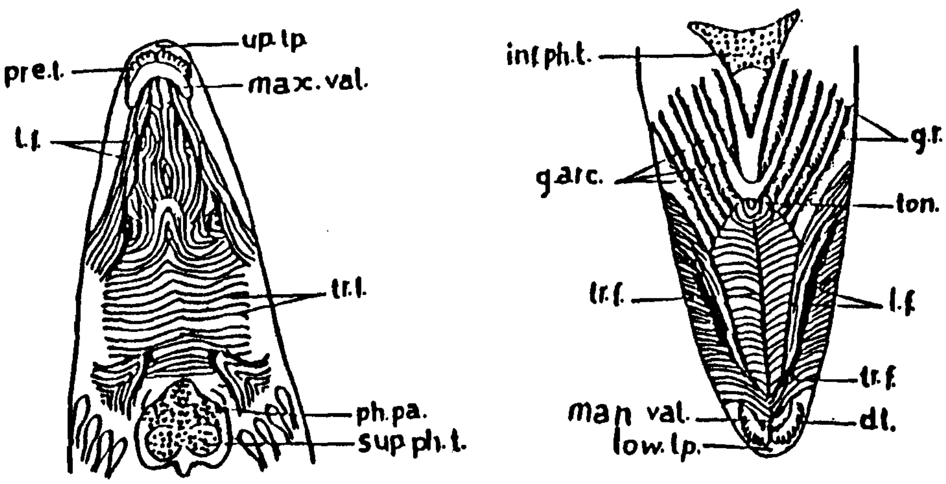
RESULTS

Gross Anatomy :

The alimentary canal of **Siganus rivulatus** begins with the mouth opening which leads to buccoo-pharyngeal cavity. This leads in turn to the oesophagus which opens into the intestine as the stomach is absent in this fish. The intestine consists of the intestinal bulb and the intestine proper (duodenum, ileum and rectum).

The mouth of this species is small, slightly protrusible and directed downwards with a large upper lip and a small lower one (Fig. 1 a and b). The buccal cavity is narrow, but widens slightly as it passes backwards to the pharynx with no limit of demarcation, thus forming the buccopharyngeal cavity. The teeth are carried on the premaxillae and dentries of the upper and lower jaws respectively. On each jaw, there are minute teeth which are aligned in a single row, very close to each other forming a continuous serrated edge. There are two respiratory valves, the maxillary and mandibular valves (Figs. 1 a and b).

An inverted heart-shaped structure projects from the roof of the pharyngeal region, forming a horny pad covered with numerous pointed superior pharyngeal teeth (Fig. 1 a). The floor of the pharynx is slightly protruded to form a rudimentary "tongue", and its posterior part projects forming a triangular-shaped structure, whose apex points forwards, it carries minutes, pointed inferior pharyngeal teeth at the base (Fig. 1 b).



(a) (b)

Fig. (1)
Diagrams of the upper (a) and lower (b) jaws, showing their structures.

The oesophagus is a long muscular tube of uniform thickness (Fig. 2 a and b). It leads into a short and wide tube which corresponds to "the intestinal bulb" of Rogick (1931), or "the large arm of the intestine", of Curry (1939). The intestinal bulb gradually narrows posterior to form a long coiled intestine proper, the first part of which may be called the duodenum.

This region has a greater diameter than the rest of the intestine and its beginning is surrounded by five long pyloric caeca. Of these, two are sinisteral, one is medium, while the last two are dextral. The following part of the intestine (ileum) is thrown up into a certain number of loops. Then after, the ileum dilates a little forming the rectum which opens to the outside by the anus (Figs. 2 a and b).

The liver is a dark brown organ which consists of two lobes, a narrow right lobe and a comparatively broad left one (Fig. 2 b). The gall bladder is a greenish, club-shaped and thin-walled sac. It lies between the right lobe of the liver and the anterior portion of the oesophagus (Fig. 2 b).

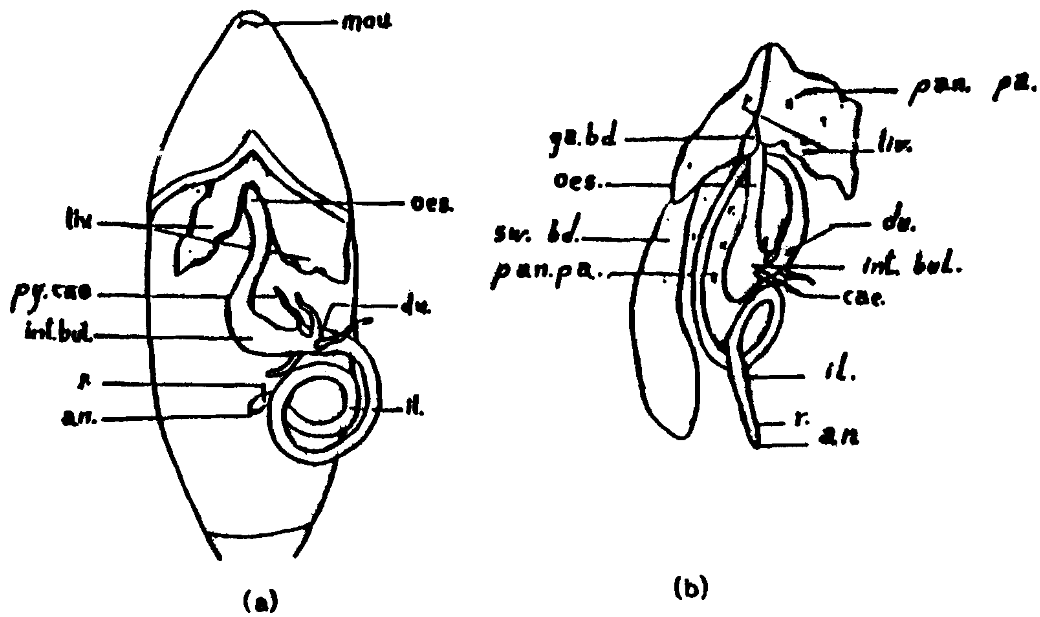


Fig. (2)
Diagrams showing the digestive system (a)
and pancreatic islets(b).

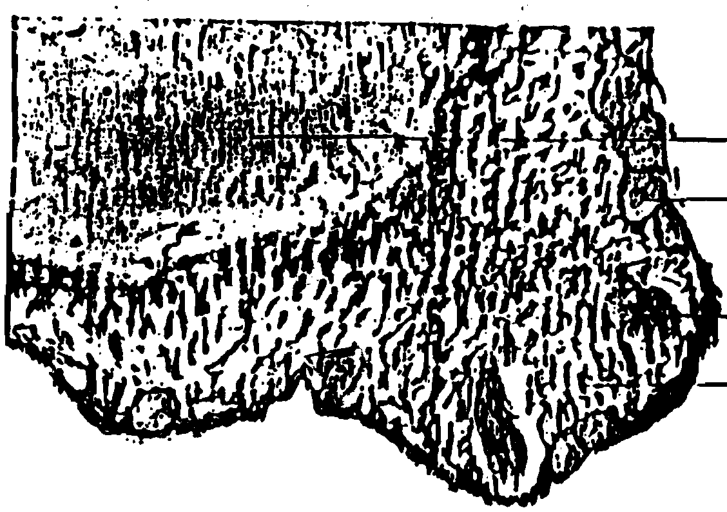


Fig. (3)
Photomicrograph of T.S. through the lining wall of the roof of the buccal cavity, showing the structure of the mucosa. (X425).

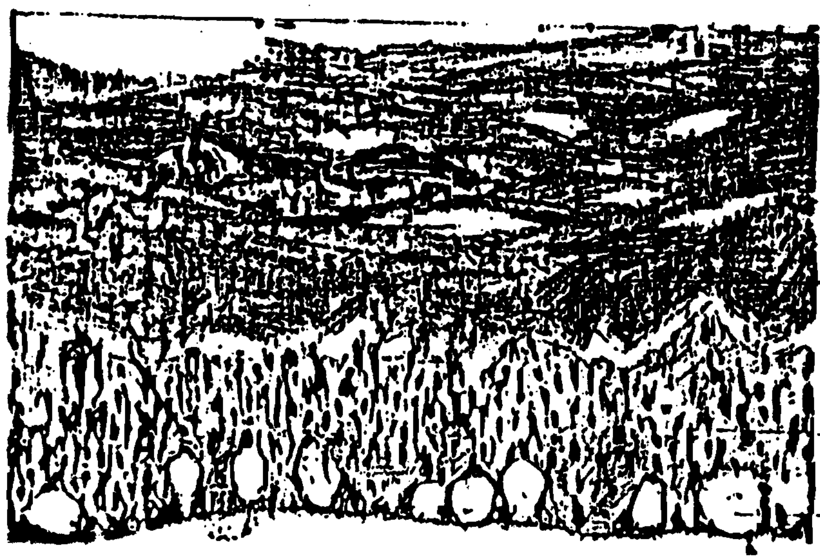


Fig. (4)
Photomicrograph of T.S. through the lining wall of the buccal floor, showing the structure of mucosa. (X 425).

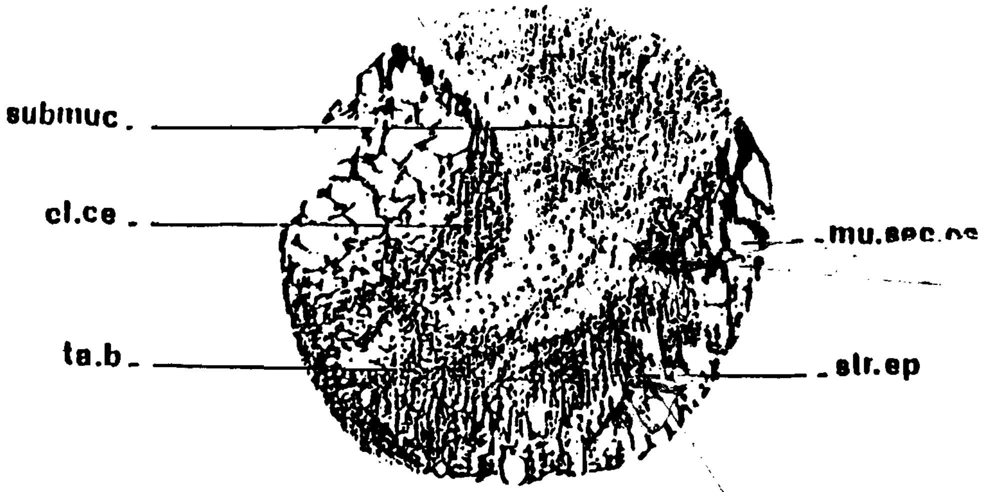


Fig. (5)
Photomicrograph of T.S. through the lining wall of pharynx, showing the structure of mucosa and submucosa. (X425).

Oesophagus

The wall of the oesophagus is made up of four coats, the mucosa, submucosa, muscularis and serosa.

The mucosa is composed of a highly folded stratified epithelium which consists of a basal row of short columnar cells followed by several rows of polygonal and mucus secreting ones. The mucus secreting cells are very numerous on the peripheral layer of the stratified epithelium and in some regions, they give the appearance of stratification. These cells vary from saccular to oval in shape (Fig. 6). When filled with mucus, the cytoplasm of these cells attains a reticulated appearance.

The submucosa is well developed and is composed of highly vascularized areolar connective tissue (Fig. 6). The muscularis is composed of a thick layer of circularly arranged striated muscle fibres. The serosa consists of simple squamous epithelium.

Intestine

The different layers of the intestine exhibit much the same general features as the oesophagus, except for the shape, height and width of their mucosal folds.

Fig. (6)
Photomicrograph of T.S. through the oesophagus, showing the structure of mucosa and submucosa. (X 425).

Intestinal bulb

The mucosa is thrown up into numerous folds and it consists of simple-columnar epithelium containing goblet cells (Fig. 7 a & b). The columnar cells are tall, slender and their nuclei are elongated and basal in position. A well defined striated border (top plate) covers the free surface. The goblet cells, on the other hand, are irregularly scattered in the intestinal epithelium, but they are more frequent at the basal parts of the folds (Fig. 7b).

The submucosa is composed of highly vascularized areolar connective tissue with a large number of lymphocytes (Fig. 7 a & b). The muscularis is composed of an inner circular and an outer longitudinal smooth muscle layer (Fig. 7 a).

Fig. (7 a)
Photomicrograph of T.S. through the intestinal bulb showing its general structure. (X 125).

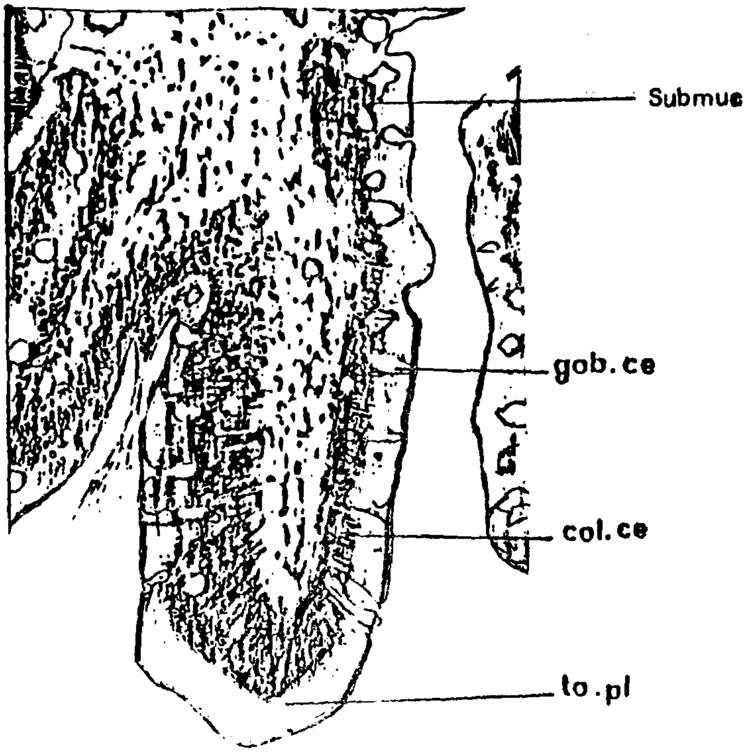


Fig. (? b)
Photomicrograph of T.S. [illegible] the intestinal bulb, showing the stru[illegible] cosa. (X 245).

Histochemical studies have sh[illegible] t the lining epithelium of the intestinal bulb of *Siganus rivulatus* [illegible] ongly with carbohydrates (PAS, Best's carmine and Alcian blue) a[illegible] ins (mercury bromphenol blue). On the other hand, a moderate re[illegible] was noticed with Sudan black B stain for lipids (Fig. 8 a-e).

Detection of enzymes in the intestinal bulb showed an intense reaction of B- glucoronidase, a moderately positive reaction for exo-and endo-peptidases and acid-phosphatases. On the contrary detection of lipase gave a negative result (Fig. 9 a-c).

Intestine proper

The histological structure of the duodenum, ileum and rectum resembles that of the intestinal blub, except that the mucosal folds of the duodenum

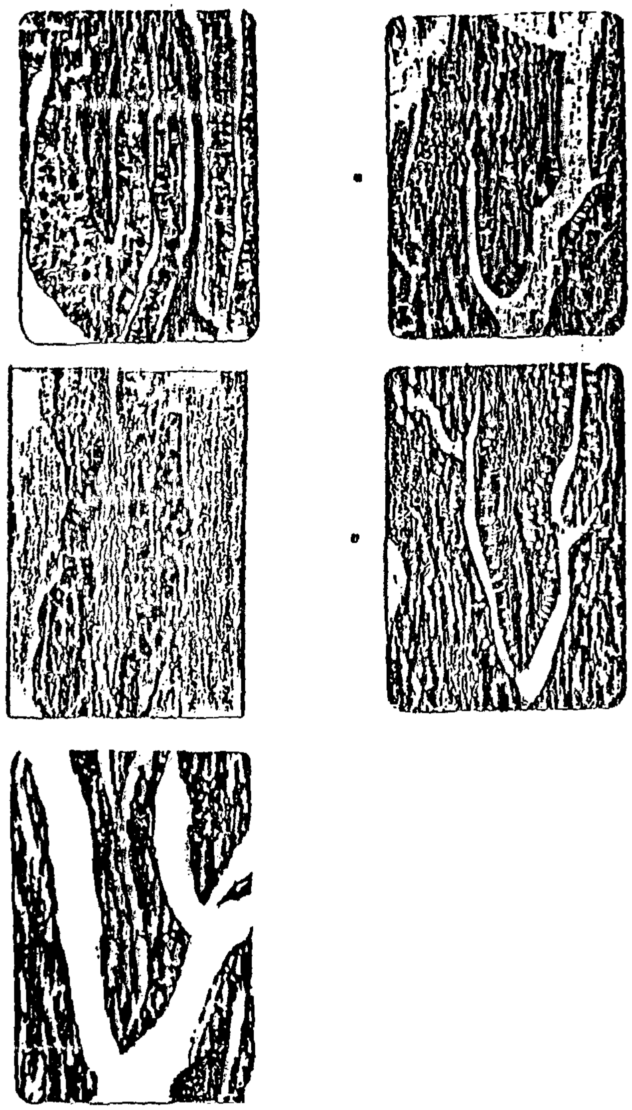


Fig. (8)
Photomicrograph showing carbohydrates (A), glycogen (B), mucopolysaccharides (C), total protiens (D) and total lipids (E) in the mucosa of the intestinal bulb.
(X 250).

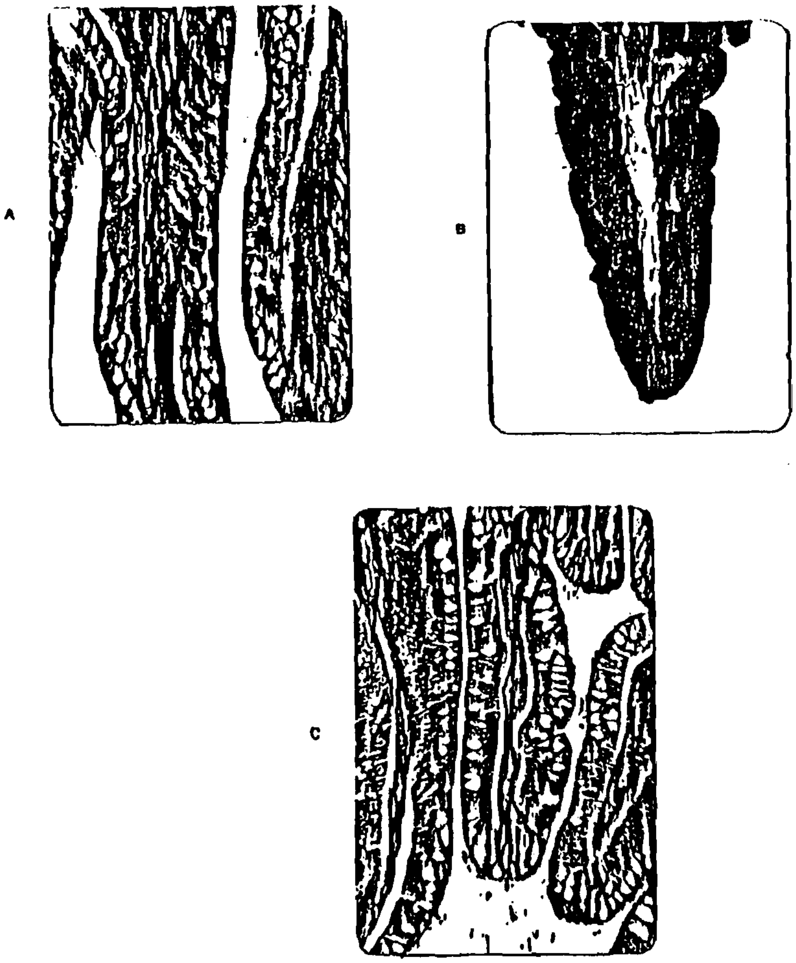


Fig. (9)
Photomicrograph showing B-glucuronidase (A), protienase (B), and phosphatase (C) reactions of the mucosa of the intestinal bulb. (X 250).

are longer and highly branched, while in the ileum and rectum they become comparatively shorter and simpler than the duodenum. Moreover, the goblet cells are comparatively more numerous in the duodenum and rectum than the ileum (Figs. 10-12).

Liver

The liver is enclosed in a thin covering of fibrous connective tissue capsule and made up of characteristic closely packed hepatic acini. The hepatic cells are pyramidal in shape with round basal nuclei. Scattered in the hepatic tissue are blood sinusoids and hepatic ductules. Eash ductule is lined with simple cuboidal epithelium, surrounded by a connective tissue sheath (Fig. 13).

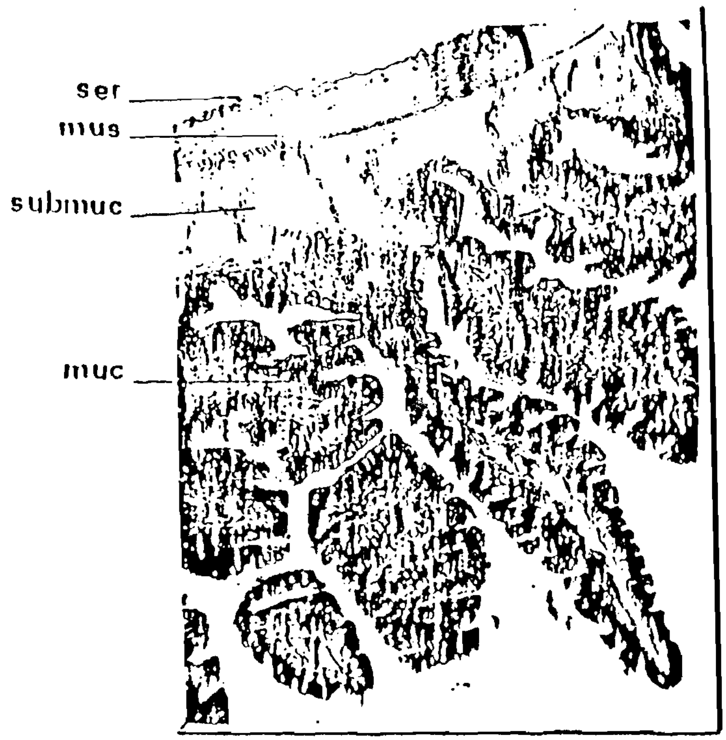


Fig. (10)
Photomicrograph of T.S. through the duodenum showing its general structure. (X 125).

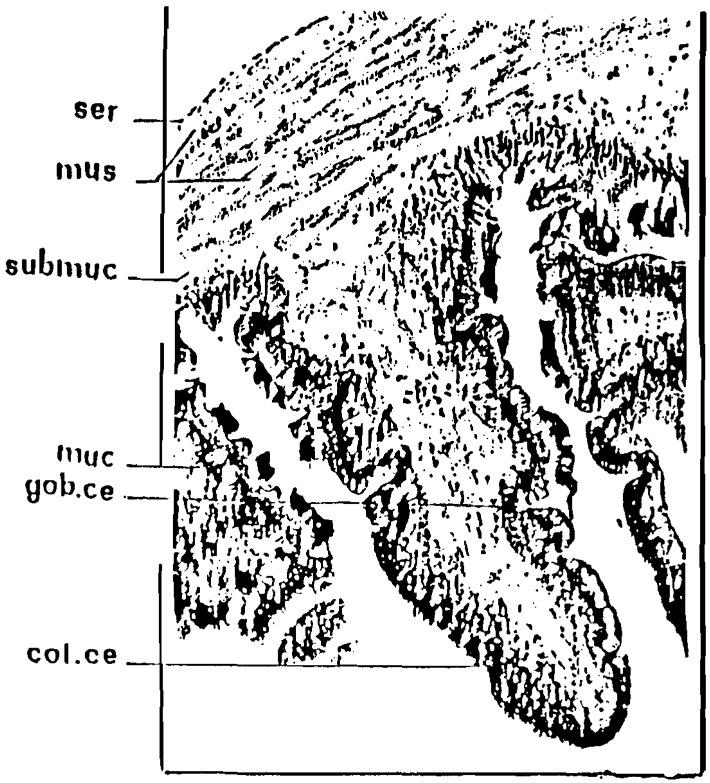


Fig. (11)
Photomicrograph of T.S. through the ileum showing its general structure. (X 135).

Fig (12)
Photomicrograph of T S through the rectum showing its general structure. (X 125).

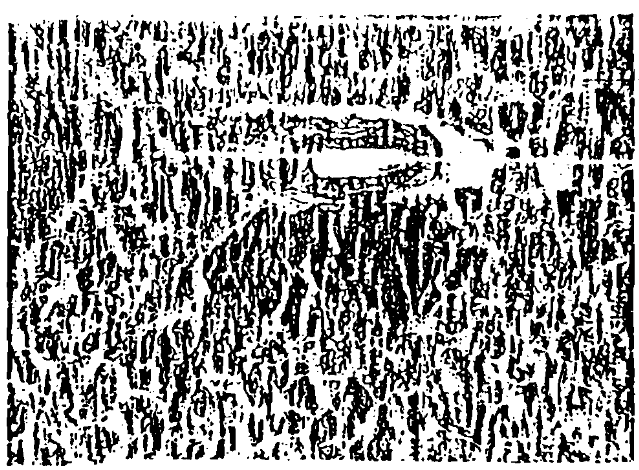


Fig. (13)
Photomicrograph of a section through the liver showing its general structure. (X 425).

Pancreas

The number of endocrine islets is large and these islets are of various sizes. (Fig. 14). They are surrounded by exocrine zymogenous tissue. Each islet consists of alpha, beta and gamma cells of which the former two are abundant and uniformally distributed (Fig. 15).

The alpha cells are either rounded or conical in shape with large, round central nuclei. The cytoplasm is coarsely and densely granular and appears red in color.

The beta cells are elongated and arranged in cordal or rosette forms around the blood capillaries. They possess rounded nuclei, the cytoplasm has numerous evenly distributed fine granules and it appears faint blue in color.

The gamma cells are generally found at the periphery. They are rounded or ovoid in shape with round central nuclei. The cytoplasm is a granular and it appears faintly stained.

Fig. (14)
Photomicrograph of a section through a pancreatic islet of S. rivulatus.

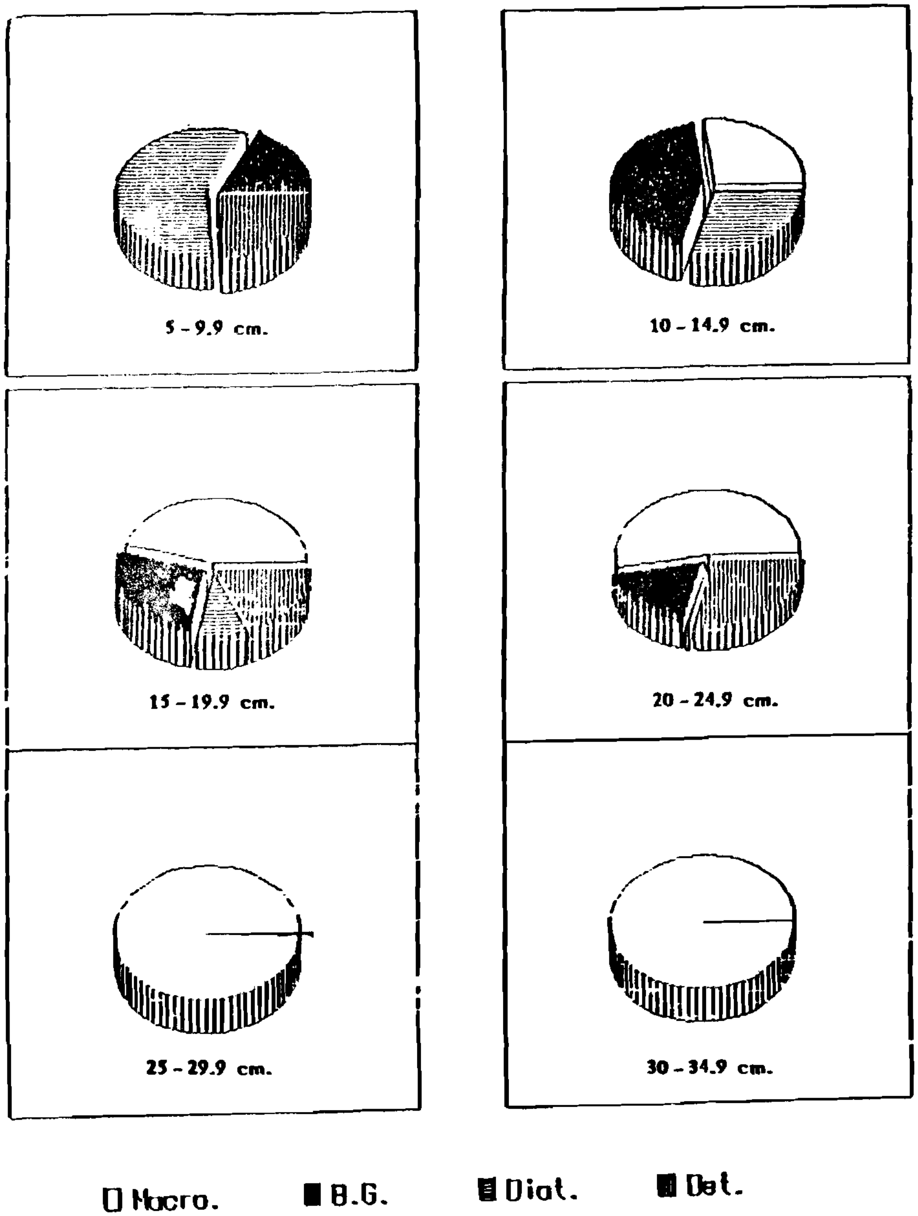


Fig. (17)
Percentage composition of the different food items in the intestinal bulbs of *S. rivulatus* in relation to length.

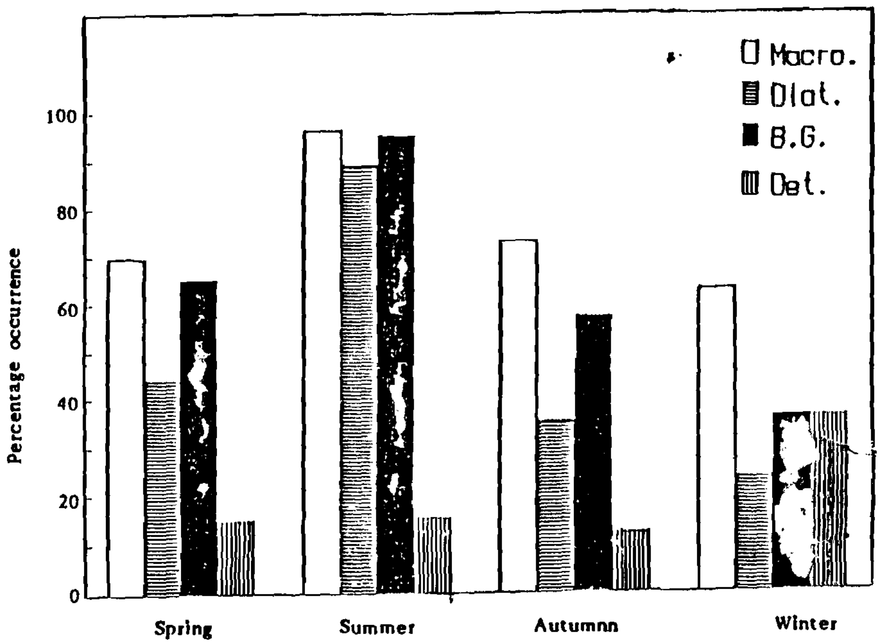


Fig. (18)
Percentage occurrence of the different food items in the intestinal bulbs of **S. rivulatus** in relation to season.

ranging between 10 and 14.9 cm. Their maximal percentage occurrence and percentage composition was recorded in summer. Blue-green algae were represented by the following genera: **Oscillatoria, Lymgba** and **Phormidium.**

C - Diatoms

Diatoms were found in 23.28 % of the examined intestinal bulbs and constituted only 6.82 % of the diet. Generally the percentage occurrence of diatoms did not show a specific trend, while their percentage composition decreased with the increase in fish length. No diatoms were recorded in the intestinal bulbs of fishes having lengths more than 25 cm. The highest percentage occurrence and percentage composition of diatoms were recorded in summer. The main genera of diatoms recorded in the intestinal bulbs of **Siganus rivulatus** were: **Navicula, Nitszchia, Licmophora, Pleurosigma, Cocconeis** and **Amphora.**

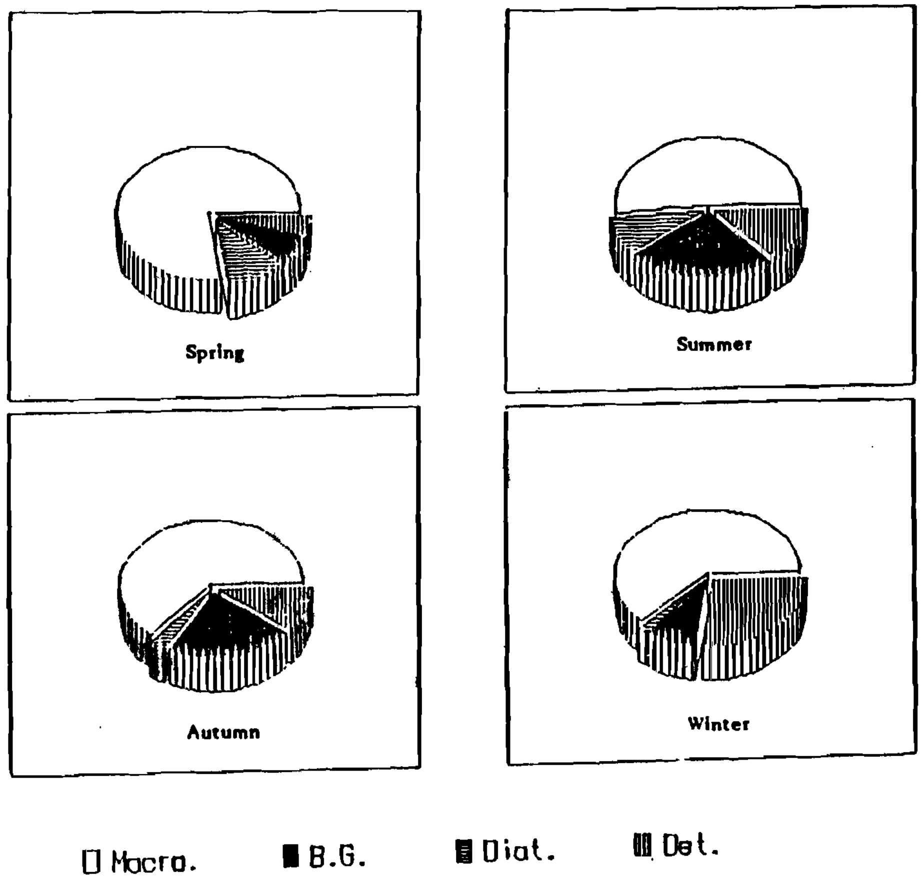


Fig. (19)
Percentage composition of the different food items
in the intestinal bulbs of *S. rivulatus*
in relation to season.

D - Detritus

Detritus material was found in 17.30 % of the examined intestinal bulbs and composed 13.09 % of the total food. The percentage occurrance and percentage composition of detritus did not follow a specific trend with length, but they are highest in fishes having a total length of 22-24.9 cm. The highest percentage occurrence and percentage composition of detritus were recorded in winter.

Index of Emptiness

This index gives an idea on the seasons of intensive feeding. To obtain it, the percentages of full and empty intestinal bulbs are calculated in relation to the total number of intestinal bubls examined.

The percentages of full and empty intestinal bulbs of **Siganus rivulatus** are given in table (1). The results indicate that intensive feeding starts in spring (86 %), attains its highest value in summer (93.6 %) and then begins to decrease in autumn (89.35 %). This decrease continues,until a minimum is reached in winter (50.5 %). This shows that winter is the season of low feeding intensity in this fish.

TABLE (1)

Seasonal variations in the relative number of empty and food containing intestinal bulbs of **Siganus rivulatus.**

Seasons	Total	Full		Empty	
		No.	%	No.	%
Spring	143	123	86.01	20	13.99
Summer	141	132	93.60	9	6.40
Autumn	112	100	89.30	12	10.70
Winter	111	56	50.45	55	49.55

Selectivity Index

This index gives a good idea on the feeding preference (food selection). It is calculated according to the following formula given by Berhaut (1973):

$$\text{Selectivity index "F"} = n / NE$$

Where n = the number of fish stomachs containing a certain food item.

NE = the total number of stomaches examined.

According to Berhaut (1973) there are three categories:

1- Accidential : where F is less than 0.1.
2- Secondary : where F lies between 0.1 - 0.5.
3- Preferential : where F is greater than 0.5.

Table (2) shaws the selectivity indices for the various food items found in the intestinal bulbs of **Siganus rivulatus.** Macrophytes, blue-green algae and diatoms have indices more than 0.5, indicating the selectivity of these three food items as preferential food by **Siganus rivulatus** On the other hand detritus can be considered as a secondary food items as its selectivity index does not exceed 0.170.

TABLE (2)

Selectivity indices of various food items in the intestinal bulbs of **Siganus rivulatus.**

Food items Food items	Selectivity indices
Macrophytes	**0.81**
Blue-green algae	**0.66**
Diatoms	**0.53**
Detritus	**0.17**

DISCUSSION

The analysis of the contents of the intestinal bulb of **Siganus rivulatus** indicates that this fish feeds on macrophytes, blue-green algae and diatoms and the anatomical adaptations of the alimentary canal is in accordance with this habit.

The mouth of **Siganus rivulatus** is of the nibbling type. The teeth on the premaxillae and dentries of the upper and lower jaws respectively are arranged in a single row very close to each other, forming serrated edges. The superior and inferior pharyngeal teeth are pointed. Accordingly, the mouth and teeth are adapted for seizing, tearing and mincing the food.

The stomach is absent and instead there is only an intestinal bulb, a fact which has been also reported in some other fishes. Scomberesox provides an example of a predatory fish which lacks the stomach (Barrington, 1957); Hippocampas and Syngnathoides are planktonic stomachless fishes (Al-Hussaini, 1947 b) and scarids and labrids are representatives of stomachless coral feeders (Gohar and Latif, 1961). So it seems difficult to correlate the stomachless condition to any clearly defined type of nutrition. In general, thus intestinal bulb, lies immediately behind the oesophagus and simulates a stomach, so it acts for storage and digestion.

The elongation and simplification of the alimentary tract are in conformity with the findings of Sarbahi (1940), Al-Hussaini (1949 a) and Pillay (1953) in other herbivorous fishes.

The mucus-secreting cells of the bucco-pharyngeal lining and oesophageal wall, increase in an antero-posterior direction, thus helping in lubrication of food.

The taste buds, are numerous on the lining wall of the buccal rood and pharyngeal region. In this respect **Siganus rivulatus** resembles **Rutilus rutilus** (Al-Hussaini, 1949 a). He stated that this fact indicates that in these fishes taste and not sight plays the major role in feeding.

Histochemical studies on the intestinal bulb showed that the variation observed in the activities of digestive enzymes may reflect the feeding habit of **Siganus rivulatus.** This may explain the weak lipolytic and moderate proteolytic enzymes activities and the strong activity of B-glucuronidase which is responsible for carbohydrate digestion. This is in agreement with the feeding habit of this fish as a herbivore (Al-Hussaini, 1947 b; von Westerhagen, 1974 and Lundberg and Liphin, 1979).

The mucosa of the intestine proper consists of simple columnar cells and goblet cells in between. Al-Hussaini. (1949 a & b) mentioned that the mucous secreted by the teleostean columnar epithelial cells lining the intestine acts for lubrication of the ingested food and protect the mucosal lining of the intestine from mechanical injury. This lining cells have a striated boarder or closely packed villi, which is characteristic for increasing the obserbative surface area. Such a case is similar to the finding of Yoakim and Khidr (1985) in **Chrysichthys auratus.**

It is well known that the diffused and disseminated types of teleost pancreas are always accompanied with the presence of an intrahepatic pancreas. In **Siganus rivulatus** this seems valid, and the hepatic tissue is invariably invaded by pancreatic strands along with the hepatic portal vein.

The principal islet is missing in **Siganus rivulatus,** thus the endocrine tissue is represented by numerous scattered small modules in the intestinal mesenteries similar to those observed in most teleost tissues by McCormick (1924), Honma and Tamura (1968), Khanna and Singh (1971), Rizkalla and Amer (1972) and Khanna and Gill (1973).

The islet tissue consists of three main types of cells namely alpha, beta and gamma cells. This coincides with the finding of Rizkalla (1967) in **Clarias lazera.** The alpa and beta cells correspond in almost every respect to the alpha and beta cells described by most authors in the islet of fishes (Jackson, 1922; Leiner & Schmidt, 1957 and Falkmar, 1961). Hirano and Honma (1972) came to the conclusion that the islet of **Thunnus thynnus** is composed of A- B- C and D cells. Khanna and Gill (1973) reported that the islet tissue of **Mastacemblus armatus** and **Mystus senghala** is made up of A1- A2 and B- cells, whereas Yoakim (1977) found that the islet tissue of **Schilbe mystus** consistes A1- A2, B and C cells. Nakamura and Yokote (1971) pointed out that the C cells may be regarded as a fuctional stage of C cells. On the other hand, Yoakim (1977) was of the opinion that the C cells may be represent a distinct cell type rather than a functional stage of another cell type. This seems to be the case with the cells of islet tissue of **Siganus rivulatus** as transitional stages were not noticed.

LIST OF ABBREVIATIONS

an	anus
c.m.ly	circular muscle layer.
cl.ce	club cell.
col.ce	columner cell.
d.t	dentary teeth.
du	duodenum.

low.lp	lower lip.
lym	lymphocytes.
man.val	mandibular valve.
max.val	maxillary valve.
mou	mouth.
mu.sec.ce	mucus-secreting cells.
muc	mucosa.
mus	muscularis.
oes	oesophagus.
pan.is	pancreatic islet.
pan.pa	pancreatic patch.
pan.ts	pancreatic tissue.
ph.pa	phayngeal pad.
po.ce	polygonal cell.
pre.t	premaxillary teeth.
py.cae	pyloric caeca.
r	rectum.
ser	serosa.
st.co	stratum compactum.
str.ep	stratified epithelium.
sub.muc	submucosa.
sup.ph.t	superior pharyngeal teeth.

ph.pa	phayngeal pad.
po.ce	polygonal cell.
pre.t	premaxillary teeth.
py.cae	pyloric caeca.
r	rectum.

ser	serosa.
st.co	stratum compactum.
str.ep	stratified epithelium.
sub.muc	submucosa.
sup.ph.t	superior pharyngeal teeth.
sw.bd	swim bladder.
ta.b	taste bud.
to.pl	top plate.
ton	tongue.
tr.f	transverse fold.
up.lp	upper lip.
α ce	alpha
β ce	beta cell.
γ ce	gamma cell.

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