JAWS AND TEETH
Introduction

The actual advance that assuredly compelled vertebrate evolution was the congregation of closable jaws used in feeding. The great deal about the feeding and evolution of fishes were clue in with the mechanics of jaw function and adaptive variation in jaw elements. The jaw elements which were involved in protrusion include the bones of the jaw like premaxilla, maxilla, mandible, ligamentous connections of these bones to the skull and to each other such as premaxilla to maxilla, ethmoid, and rostrum; maxilla to mandible, palatine, and suspensorium; mandible to suspensorium, and several muscles, notably the expaxials, levator operculi, hypaxials, adductor mandibulae, and levator arcus palatine. Differing among taxa many variations on this simplified description exist in terms of twisting of jaw bones, points of attachment and pivot between structures, inclusion of other small bony elements, and actions of muscles and ligaments on particular elements (Motta, 1984).

Fishes utilize suction to capture prey that feed on different prey such as phytoplankton, zooplankton, macroinvertebrates, and other; the larger the object, the more suction pressure must be produced to capture it. The rapid expansion of the buccal (mouth) cavity results in suction feeding, also known as inertial suction, from which creates negative pressure in the mouth relative to the pressure outside the mouth. Along with the water, particles in the water mass ahead of the fish are carried into the mouth. The jaws then close, pushing the water out the gill covers but retaining the prey in the mouth. Mechanically, gill rakers, jaw teeth, and
teeth on various non-marginal jaw bones (palate, vomer, tongue) act to prevent escape of the prey from the opercular chamber. Suction pressures vary during a feeding event in advanced percomorphs, increasing and decreasing four times. Preparation, expansion, compression, and recovery are the four phases of suction feeding (Lauder, 1983a and 1985). Some spectacular derivations that allow specialized feeding activities are modifications of this basic plan underscore. The suspensorium and maxilla are mechanically decoupled in cichlids. Movement of the suspensorium, independent of the maxilla results in jaw protrusion. The consequence of this decoupling of suspensorium and maxilla is that the jaw can be protruded via four different pathways: lifting the neurocranium, abducting the suspensorium, lowering the mandible, or swinging the maxilla. Cichlids make use of different combinations of jaw elements and protrusion pathways to feed on different prey types or in different habitats (e.g., Waltzek and Wainwright, 2003; Hulsey and De Leon, 2005). Fishes other than cichlids have reworked the basic elements of jaw protrusion and have evolved dramatic specializations that increase attack velocity or suction. (Lauder and Liem, 1981).

The adaptations of the mouth of fishes to their food are particularly evident in the form of mouth size, shape and structure of the oropharynx, dentition, gill rakers. All these structures are subject to diverse and significant variations and modifications in accordance with the feeding habits of different fishes. The diversity in feeding habits that the fishes exhibit is particularly the result of evolution leading to structural adaptation for getting food from the equally great diversity of
situations that have evolved in the environment. Conversely, the importance of food in the daily life of a fish is "reflected" in the form of mouth and jaws, dentition, the shape and size of the gill rakers etc, and therefore, the difference in their feeding habits. The relationship between the structure of the mouth and feeding habits has been studied recently by Sharma (1984), Datta and Dasgupta (1986), Bose and Islam (1986), De and Datta (1990), Dasgupta (1995, 1997) and Nath (1996) while studying the alimentary canal.

Literatures pertaining to the morpho-anatomical structures of the mouth in freshwater teleosts are fragmentary and many authors while studying the alimentary canal, briefly described the morphology and structural organisation of the mouth structures of different fish species (Vanajakshi, 1938; Khanna, 1961, 1962; Pasha, 1964 a, b, c; Lal et al., 1964; Sehgal, 1966; Moitra and Bhowmik, 1967; Lal, 1968; Sehgal and Salaria, 1970; Moitra and Sinha, 1971; Sinha, 1975; Sinha and Moitra, 1975, 1976, 1978; Kapoor et al., 1975).

Mouth structures are specialized that cover the jawbones, and border the anterior orifice of alimentary canal. In general, mouth structures associated in different fish species may be considered as mainly concerned with the selection, capture, deglutition and pre digestive preparation of food. The effectiveness of these structures is dependent on modifications in relation to food and feeding habits of the fishes and environmental niches inhabited by them. Morphological data are also key to understanding fish nutrition in ecology and aquaculture, and during development as well as mechanisms for physiological adaptations to a changing environment.
Functional morphology of fish can be used to provide explanation for differences between species in ontogenic diet switches (Peter, 1996). Mouth structure is related to the feeding type and habit of fish, and is highly variable between fish species, and the variation in mouth structure may partly explain the evolutionary success of fish (Keast and Webb, 1966). The position and size of the mouth show a close relationship to the location and size of food items, and the relative size of the mouth can be used to determine the size of food particles ingested (Hepher, 1988). Particles which are too small may not be detected or captured easily by the fish, while those which are too large may be too difficult to ingest quickly or whole (Lovell, 1989). Moreover, loss of nutrients from large and small food particles after soaking and softening, inevitably lead to wastage, pollution and nutrient leaching. For that mouth size appears to be a limiting factor in larval feeding with both live and artificial diets (Hyatt, 1979). There are differences between species (both fresh water and marine) in the proportion of mouth opening and fish length during ontogenic growth (Shirota, 1970; 1978a; 1978b; Walford and Lam, 1993, Kamali, et al., 2006). Dabrowski et al., (1983) cited in Hassan and Macintosh (1992) reported the differences in the mouth size between common carp larvae and three cyprinid fish species grass carp.

For a correct understanding of the feeding habits of a fish, a study of the anatomy of the organs of feeding and digestion is necessary. 'An examination of the special relations of food and feeding structures gives clues, not only to the present significance of fishes but also their past effect on life at large, showing how they must have modified the course of
evolution' (Forbes, 1888). The feeding apparatus exhibits one of the most significant examples of correlation, and the investigation of the food of a fish will be incomplete without a study of its alimentation.

The mouth, buccal cavity and pharynx are associated with the selection, seizure, orientation and predigestive preparation of the food. The form and position of the mouth, dentition on the jaws and in the bucco-pharynx and the gill rakers show a close relation with the mode of feeding and the kind of food (Al-Hussaini, 1947b; Tortonese, 1952; Gohar and Latif, 1959; Khanna, 1962; Greenwood, 1964; Kazansky, 1964; Khanna and Pant, 1964; Dalela, 1969 and many others). Descriptions of mouth types are given by Suyehiro (1942); Al-Hussaini (1947b), and Nikolsky (1963). Interest in the mechanics of feeding action in teleosts has recently increased largely due to the papers of Alexander (1966, 1967a, b, 1969, 1970), a study by Osse (1969), and a brief account by Gupta (1971). Earlier, the cycle of events in the feeding process was considered by Al-Hussaini (1949a), Girgis (1952a), Greenwood (1953), Matthes (1963), Branch (1966), Field (1966) and Vrba (1968). Greenwood (1964) reported that the paedophagous *Haplochromis parvidens* has large and expansible jaws and quite poor oral dentition. It engulfs the snout of a mouth-breeding female and consequently forces her to jettison the brood direct into its mouth. Bogachik (1967) detailed the mechanism of breaking and splitting of shells in the labrids *Ctenolabrus* and *Crenilabrus*. the bucco-pharynx bears a variety of specialized structures for specific purposes. The "lamellar organ" of the palate in *Labeo horie* presumably represents an expansion of the sensory surface of the buccal
mucosa (Girgis, 1952b); in Cirrhina mrigala (Ham.) it serves as an accessory respiratory organ (Majumdar, 1952) and in Labeo dero (Hem.) it has a digestive function (Lal et al., 1964b; cf. Majumdar and Sexena, 1961).

The tongue, not always sharply demarcated and not freely movable, rarely with a movable tip, generally possesses a skeletal support, striated muscles and connective tissue (Kapoor, 1957d; Maggese, 1967; Mikuriya, 1972). A thin keratinization of tongue epithelium has been observed in Gadus morhua (Bishop and Odense, 1966). The tongue is better developed in carnivorous, particularly piscivorous species (Khanna, 1959). Tandon and Goswami (1968) expressed the view that the tongue of Channa species, apart from supplementing the function of the teeth in the retention of prey, may also compensate for the absence of barbels and other integumentary sense organs. The protrusible tongue in the microphagous Dorosoma petenense (Gunth.) is an adaptation for occasional zooplankton predation (Schmitz and Baker, 1969). In adult Plecoglossus altivelis T. and Schl. a fleshy tongue-lappet, comprising a main median flap and two lateral flaps arising from the posterior part of the main flap and devoid of skeletal structures, extends from the symphysis to the tongue (Iwai, 1962). This, in association with comb-like teeth on the jaws and with a profuse mucus secretion by mucous cells on the tongue lappet and by palatal glands opposite to it, collects the algal particles scraped off by the comb-like teeth.

Dentition in fish varies greatly. The teeth vary widely in position, even the lip (Pillay, 1953) and tongue (Thomson,
1954; Khanna, 1959; Mohsin, 1962; Pasha, 1964c; Bucke, 1971) are not excluded. Information on the fixation of teeth is provided by Soule (1969a), on the importance of teeth in food retention by it files and Poole (1967), on the (fine) structure of teeth by Isokawa et al., (1959, 1964, 1968, 1970), Poole (1967), Soule (1969b). The following papers on the various aspects of pharyngeal teeth are recommended, their origin (Edwards, 1929), taxonomic significance (Chu, 1935), loss and replacement phenomena (Schwartz and Dutcher, 1962), bones and muscles with their functions (Girgis, 1952a; Eastman, 1971), and changes in the feeding habits during onto genesis (Hickling, 1966; Lange, 1966). The pharyngeal masticatory apparatus (pharyngeal teeth and chewing pad), an important acquisition correlated with the feeding regime, is best developed in herbivorous fishes where it is employed in tearing and triturating vegetable material (Hickling, 1966). In *Varicorhinus capoeta sevangi* (Fil.), pharyngeal teeth with flat tops together with the chewing pad act as a press to squeeze water out of food (Verighina, 1969a). A relationship between the development of the apparatus and the share of plant food in the diet has been indicated (Al-Hussaini, 1949a; Vasisht, 1959; Khanna and Mehrotra, 1970). The elaboration and perfection of the filter apparatus varies (Verigin, 1957; Matthes, 1963; Kazansky, 1964).

The morphological specializations of the feeding apparatus of fishes in relation to their diet have received much attention following the work of Greenwood (1953, 1959 and 1965) on cichlids. Much of our current understanding of the functional morphology of pharyngeal jaw systems is derived from studies on the Labroidei (e.g., Liem, 1973, 1978; Liem
and Osse, 1975; Liem and Greenwood, 1981; Stiassny, 1981; Zihler, 1982; Liem and Sanderson, 1986; Stiassny and Jensen, 1987) and to a lesser extent the Cyprinoidei (Chu, 1935; Girgis, 1952; Schwarz and Dutcher, 1962; Hickling, 1966; Sibbing et al., 1986). Most work concerning the structure and replacement of pharyngeal teeth has involved fishes with somewhat discrete dental formulas, such as those shown by cypriniform fishes (e.g., Boulenger, 1904; Chu, 1935; Weisel, 1967; Nakajima, 1979, 1984). Parenti (1987) used jaw and tooth morphology (including pharyngeal jaws and teeth) in her appraisal of beloniform phylogeny; Foster (1975) described the formation of teeth in the poecilid Xenentodon cancila; and Moy Thomas (1934) tooth formation in larval Belone belone (Belonidae).

Among fishes, diversity of the food resources leads to evolution of various adaptive characters in the pharynx, which plays an indispensable role in the retention, manoeuvring and transport of food for swallowing. The pharynx, in teleost, is characterized by the presence of gill arches. These are located at the boundary between the pharyngeal cavity and the opercular chamber on either side of the head. The gill arches, in general, are equipped with gill rakers toward their pharyngeal side and are considered to play an important role in feeding. The palatine cushions in Gobio gobio (L.) act as food selectors (Al-Hussaini, 1949a).

A thick or cushiony papillated palatal organ (pharyngeal pad), is reported in some members of Cyprinidae, Catostomidae, Cobitidae, (Curry, 1939; Dorier and Bellon, 1952; Girgis, 1952a, b; Majumdar, 1952; Jara, 1957; Majumdar and Saxena, 1961; Weisel, 1962; Lal et al., 1964b;
Khanna and Pant, 1964; Miller and Evans, 1965; Eastman, 1971; Mester, 1971) and Salmonidae (Sutterlin and Sutterlin, 1970). This organ removes excess water from the ingested food (Jara, 1957). The role of pharyngeal pads in assisting in feeding and its gustatory function are generally accepted. Another set of interesting but generally overlooked structures, the pharyngeal organs (pharyngeal cushions, pharyngeal pads, hanging pharyngeal disc), structurally and functionally totally different from the epibranchial organs though similarly located occur on both sides of the pharynx in various species of Mugil (Ghazzawi, 1935; Al- Hussaini, 1947; Pillay, 1953; Mahadevan, 1954; Thomson, 1954; Nagar et al., 1961; Kawamoto and Higashi, 1965; Agrawal and Bala, 1967; Yoshida, 1967). According to Kawamoto and Higashi (1965), each organ in Mugil cephalus L. is round, flattened anteriorly and sunken inter posteriorly, with neither any evidence of contained food nor any direct connection of the organ with the pharyngeal cavity. The organ has many small pharyngeal teeth over the entire outer surface between the pharyngeal teeth of the posterior side and many strong spines on the outer surface of the ring wall of its anterior part. It is supported by a thin bony skeletal system of cylindrical bones firmly connected by epipharyngeal bones, and hangs freely from the upper side of the pharyngeal cavity. There is a considerable change in size and shape of the pharyngeal lobe in the sea and in fresh water. Al-Hussaini (1947b) reported that the superficial teeth on the pharyngeal organs are absent in Mugil auratus Risso. Thomson (1954) stated that the teeth on the pharyngeal organs become more numerous or apparent with age in Australian species of mullet. Fukusho (1972), describing the
organogenesis of the digestive system of *Liza haematocheila* T. and Schl., also dealt with the development of the pharyngeal organs. Functionally, the presence of generally claw-shaped teeth with forked bases and fibrous ligaments, with their tips directed towards the opening of the pharynx, and that of taste buds on the external surface of the organ, indicate an auxiliary digestive role.


The teeth, together with the nearby, curved, triangular special gill rakers of the modified fifth branchial arch, act in
selecting food from the ingested material and conveying it to the pharynx. The lack of a connection between the pharynx and the cavity of the organ indicates that it cannot be a temporary concentrating site (Kawamoto and Higashi, 1965). Their roles in straining (Pillay, 1953; Nagar et al., 1961; Agrawal and Bala, 1967) and in food selection (Mahadevan, 1954), had been described earlier. Yoshida (1967) stated that the detritus and microbenthos feeder, *Mugil cephalus*, seems to strain the food contained in bottom muds by the first and second gill rakers, and drain and concentrate it by the action of the third and fourth gill rakers, hanging pharyngeal discs and pharyngeal rakers.

The number of gill rakers may not be uniform within the same species, for example in *Salvelinus* (Reshetnikov, 1961; Martin and Sandercock, 1967). The gill raker equipment may vary in fishes with identical modes of feeding (Khanna and Mehrotra, 1970). The gill rakers taste, filter or prevent the escape of food material in different fish (Iwai, 1963, 1964; Kapoor, 1965). Western (1969) reported corresponding gill raker development in relation with the increase in fish size: food size ratio in *Cottus gobio* L. and *Parenophrys bubalis* Euphrasen.
MATERIALS AND METHODS

For the study of jaws and teeth of *Mastacembelus armatus*, *Wallago attu* and *Clarias batrachus*. The fishes were collected randomly from Kaigaon Toka, Aurangabad District (M.S) India. They were washed and preserved in 10% formaline solution. The preserved fishes were cut and opened at each angles of the mouth. The roof and floor of the buccopharynx were properly washed and preserved in 70% alcohol and glycerine for stretching. The jaws, teeth, gills and gill rakers were examined properly for detailed studies.
RESULTS

*Mastacembelus armatus*

Food and feeding Habits

The food analysis of *Mastacembelus armatus* revealed that it consisted of crustaceans, aquatic insects, annelids, molluscs, fishes, aquatic plant materials and sand and mud particles (Chapter 2). Thus *Mastacembelus armatus* shows carnivorous type of feeding habit.

Mouth

During the present study it was observed that the mouth of *Mastacembelus armatus* is pointed, oblique, and horizontal crescentic cleft, sub terminal or inferior in position bounded by upper and lower labial folds and surrounded by fine but firm jaws, the upper jaw and lower jaw. The upper jaw is longer than the lower jaw and projects beyond over the lower one forming an inverted ‘Y’ shaped opening. The snout is long, tri lobed and with fleshy appendage, consisting of a middle firm, solid and pointed process and two lateral soft, hallow and blunt ridges. There is a shallow groove in the ventral surface of the upper jaw which leads into the mouth. The gape of the mouth is wide enough and extends back as far as the anterior eye margin or somewhat forward of this point. The upper jaw consists of the premaxilla which is a weakly curved, rod like element, characterized by its short ascending process. Anteriorly each premaxilla curves medially to form a midline symphysis. The premaxillae are not protrusible. The lower jaw consists of dentary which is a long bone and although straight is directed mesiad. Its symphysis lies posterior to the median connection of the premaxilla and there is a low symphysial
projection on its anteroventral edge. The mouth leads into the buccal cavity (Plate 4a, 4b, 4c and 4d).

**Buccal cavity**

During the course of study it was observed that the buccal cavity of *Mastacembelus armatus* is narrow and widens into pharynx. Its roof is formed by the base of the cranium and side walls, and the floor of the buccal cavity is formed by the urohyal and branchial arches. It is observed that the smooth mucous membrane with a large number of mucous secreting cells line the walls of buccal cavity (Plate 4b).

**Pharynx**

Pharynx of *Mastacembelus armatus* is observed to be wide, spacious and dorso-ventrally compressed arising from narrow buccal cavity (Plate 4b).

**Tongue**

Tongue of *Mastacembelus armatus* is observed to be well developed triangular with thick mucous membrane which is affixed along the mid dorsal line of the floor of the buccopharyngeal cavity (Plate 4b, 4c and 5a).

**Teeth**

During the study it was observed that numerous teeth are present in *Mastacembelus armatus*. They are present on upper and lower jaws and pharynx. They are sharp, pointed, tiny, robust, subequal, inclined inwards, villiform organised in patches. There are two set of elliptical patches of superior and inferior pharyngeal teeth directed towards the gullet. On the upper jaw tooth-bearing alveolar surface of the premaxilla is broadest anteriorly and tapers posteriorly. The teeth are arranged in 1-8 irregular rows (depending upon the position along the premaxilla) and decrease in size medially. On the
lower jaw long and narrow dorsal alveolate surface of the dentary is toothbearing. This toothed surface contains 3 rows of caniniform acrodont teeth. Teeth of the outer row are somewhat larger than the inner teeth. It was observed that the vomerine and palatine teeth are absent (Plate 5b and 5c).

**Gill rakers**

It was observed that gill rakers are absent in *Mastacembelus armatus*. In the place of gill rakers there is an uneven gill arch surface (Plate 4b, 4c and 4d).

**Wallago attu**

**Food and Feeding habits**

The food analysis of *Wallago attu* revealed that it consisted of crustaceans, molluscs, aquatic insects, detritus, fishes, amphibian tadpole larvae and sand and mud particles (Chapter 2). Thus *Wallago attu* shows carnivorous and predaceous type of feeding habit.

**Mouth**

During the present study it was observed that the snout of *Wallago attu* is depressed, spatulate and somewhat protruded. Mouth is anterior, superior, subterminal, oblique large, wide and very deeply cleft, surrounded by strong upper and lower jaws. The jaws are unequal and are provided with numerous pointed teeth. The lower jaw is longer than the upper jaw. The upper jaw consists of the premaxilla which is more curved as compared to *Mastacembelus armatus*, and is rod like element. Anteriorly each premaxilla curves medially to form a midline symphysis. The premaxillae are not protrusible. The lower jaw consists of dentary which is a long and curved bone and is directed mesiad. The gape of the mouth is very wide and reach far beyond the posterior margins of the eyes.
Wallago attu has two pairs of barbels, one on each side of the mouth. The maxillary pairs of barbels are longer than the mandibular. The maxillary pair of barbels from each lateral side extends to the anterior margin posterior of anal fin. The mandibular pair of barbels extends to the angles of the mouth. The mouth leads into the buccal cavity (Plate 6a and 6b).

**Buccal cavity**

The buccal cavity of Wallago attu is observed to be wide and spacious. The roof of buccal cavity of Wallago attu is formed by the base of the cranium. The side walls and the floor of the buccal cavity are formed by the branchial arches. Posteriorly the buccal cavity leads into a chamber called pharynx (Plate 6b).

**Pharynx**

It is observed that the pharynx of Wallago attu is dorso-ventrally compressed. The pharynx is broad and wider anteriorly and narrower posteriorly. It was observed that pharynx is elevated dorsally and ventrally so that the space between the roof and the floor is lesser as compared to buccal cavity. The roof of the buccal cavity is slightly arched and its floor is almost flat. The roof of the pharynx is supported by the pharyngobranchials and epibranchials and the floor by the ceratobranchials, hypobranchials and basibranchials. The lateral sides of the pharynx are perforated by gill clefts. The pharynx narrows down posteriorly and opens by the gullet into the oesophagus. (Plate 6b, 6c and 6d).

**Tongue**

It is observed in Wallago attu that the mucosal thickening at the anterior part of the floor of the buccal cavity is suggestive of a tongue like structure analogous to a true
tongue. The tongue is attached to the floor of the buccal cavity on its ventral surface. It is not capable of eversion and takes no part in the capture of prey (Plate 6b and 6d).

**Gill arches**

It was observed that in *Wallago attu* ventro-lateral wall of the pharynx is perforated by gill slits and the four pairs of gill arches bear gill lamellae and the gill rakers. The gill rakers are long, pointed structures. Gill rakers are biserial and dimorphic, they are of monacanth type (Plate 6b, 6d, 7d and 7e).

The first, second, and third gill arch carries two rows of oral and aboral gill rakers each while the fourth gill arch bears a single row of oral gill rakers. The gill rakers of the first gill arch are the longest and of the last gill arch are the smallest. The length of the gill rakers is maximum in the middle and minimum at the sides in all the gill rakers. The first, second and third gill arches carry two rows each with 31 to 32 rakers while the fourth gill arch bear a single row of 31 to 32 rakers. The gill rakers are strong, pointed and antero-dorsally directed. In addition to these, on each side of the pharynx, there is single row of rakers. The gill-rakers are short, being the longest on the first branchial arch and gradually reduced thereafter. The gill-rakers of the first branchial arch are about double in length as compared to the second gill arch and so on. In the case of third, fourth and fifth branchial arches they give an appearance of conical shaped teeth, set wide apart. Gill rakers form a broad sieve like structure preventing the escape of larger particles of food and provide additional grip for holding the prey (Plate 6b, 6d, 7d and 7e).
In the middle of the posterior region on the roof of pharynx, just at the opening of the oesophagus i.e. the gullet (Plate 6b), are placed two semi-circular oval patches, of superior pharyngeal teeth (Plate 6b, 6c, and 7c). Over the fourth pharyngobranchial and the third and fourth epibranchial is an oval pad which bears the fine superior pharyngeal teeth (Plate 7c). The right patch is somewhat forward in position (Plate 6b and 6c). These patches are near to each other anteriorly but diverge posteriorly (Plate 6b and 6c). On the floor, opposing the superior pharyngeal teeth by their posterior halves are two triangular shaped curved patches of inferior pharyngeal teeth immediately behind the fourth gill arch (Plate 6b and 6d). The superior pharyngeal teeth are larger than the inferior pharyngeal teeth. The fifth ceratobranchial is expanded in its greater part into a plate-like structure which bears the fine inferior pharyngeal teeth (Plate 6b and 6d). Each patch bears minute teeth. These patches are very near anteriorly and apart posteriorly (Plate 6b and 6d). Inferior pharyngeal teeth are in the form of minute denticles and are seen only with the help of a hand lens. Anterior half of the inferior pharyngeal teeth oppose the elevated part of the anterior pharynx while posterior half of these oppose the superior pharyngeal teeth (Plate 6b).

Pharyngeal teeth might not be used for mastication of food due to their very minute forms and might merely serve to prevent the regurgitation of the prey, when once it is taken into the pharynx. It was observed during the stomach content analysis that the prey (food) was swallowed whole, without any mastication. Pharyngeal teeth may take a firm grip of the prey between them and quieten the prey, before it is gulped in.
Teeth

It was observed that numerous teeth are present in *Wallago attu*. They are present on the upper and lower jaws and pharynx. They are sharp, pointed, robust, sub-equal, inclined inwards, villiform. The buccal region was observed to bear the maxillary, mandibular and vomerine teeth and horny pad teeth (Plate 6b, 6c, 6d, 7a and 7b). The pharyngeal region consists the pharyngeal teeth (Plate 6b, 6c, 6d and 7c). Maxillary teeth, vomerine teeth and pharyngeal teeth are present on the roof of the buccal cavity (Plate 6b, 6c, 7a and 7c) but the mandibular teeth and horny pad teeth are present on the floor of the buccal cavity (Plate 6b, 6d, and 7b). Maxillary teeth are actually borne on the premaxillaries. Vomerine teeth are present on a pair of oval patches which are present on the vomerine bones. Pharyngeal teeth are also located on a pair of oval patches (Plate 7c). Mandibular teeth are borne on dentaries (Plate 7b). A pair of horny pads bears the horny pad teeth. These are quite superficially embedded teeth present on the jaws are of very large size but those on the horny pad are smaller in size. Teeth are of homodont and polyphyodont type. They are backwardly curved so as to prevent the escape of prey (Plate 7c).

*Clarias batrachus*

Food and feeding Habits

The food analysis of *Clarias batrachus* revealed that it consisted of crustaceans, fishes, aquatic insects, molluscs, aquatic plants and debris, amphibian tadpole larvae and sand and mud particles (Chapter 2). Thus *Clarias batrachus* shows omnivorous type of feeding habit.
**Mouth**

During the study it was observed that the head of *Clarias batrachus* is much dorso-ventrally depressed, mouth is a broad tranverse slit at the front end of the snout, terminal surrounded by fleshy and papillated upper and lower lips. The upper lip is fleshier than the lower one. The upper and lower lips are fused with each other by a skin fold at the mouth corners. The gape of the mouth is not much wide and reaching far more behind the margins of the eyes. Mouth is surrounded by strong upper and lower jaws and are provided with numerous teeth. The upper jaw consists of the premaxilla which is curved rod like element. Anteriorly each premaxilla curves medially to form a midline symphysis. The premaxillae are not protrusible. The lower jaw consists of dentary which is a long and curved bone and is directed mesiad. The mouth is observed to be surrounded by four pairs of barbels, one pair of nasal, one pair of maxillary and two pairs of mandibular barbels. The maxillary pair of barbels reaches base or middle of the pectoral fin. *Clarias batrachus* use them for searching the food (Plate 8a).

**Buccal cavity**

The buccal cavity of *Clarias batrachus* is observed to be wide and spacious. The roof of buccal cavity of *Clarias batrachus* is formed by the base of the cranium. The side walls and the floor of the buccal cavity are formed by the branchial arches. It was observed that buccal cavity is elevated dorsally and ventrally so that the space between the roof and the floor is lesser as compared to pharynx. The roof of the buccal cavity is slightly arched and its floor is almost flat. Posteriorly the buccal cavity leads into a chamber called pharynx (Plate 8b).
**Pharynx**

It is observed that the pharynx of *Clarias batrachus* is more dorso-ventrally compressed as compared to *Wallgo attu*. The pharynx is broad and wider. It was observed that pharynx is the space between the roof and the floor which is greater as compared to buccal cavity. The roof of the pharynx is supported by the pharyngobranchials and epibranchials and the floor by the ceratobranchials, hypobranchials and basibranchials. The lateral sides of the pharynx are perforated by gill clefts. The pharynx continues posteriorly and opens by the gullet into the oesophagus (Plate 7b).

**Tongue**

The tongue in *Clarias batrachus* is observed to be broad and depressed and free around the edges, which is affixed along the mid dorsal line of the floor of the buccal cavity (Plate 7b and 7d).

**Gill arches**

It was observed in *Clarias batrachus* that the ventrolateral wall of the pharynx is perforated by gill slits and the five pairs of gill arches bear gill lamellae and the gill rakers. The gill rakers are long, fine structures.

The size and number of the gill rakers is greatly reduced on the third, fourth and fifth gill arches where they give more an appearance of conical shaped teeth, set wide apart.

The gill rakers are strong, pointed and anterodorsally directed. In addition to these, on each side of the pharynx, there is single row of rakers. Gill rakers form a broad sieve like structure preventing the escape of larger particles of food and provide additional grip for holding the prey (Plate 8b and 8d).
In the middle of the posterior region on the roof of pharynx, just at the opening of the oesophagus i.e. the gullet (Plate 7b), are placed in two semi-circular oval patches, of superior pharyngeal teeth. Over two semi-circular oval patches there are fine superior pharyngeal teeth. The right patch is somewhat forward in position (Plate 8b, 8c and 9a). These patches are near to each other anteriorly but diverge posteriorly (Plate 8b, 8c). On the floor, opposing the superior pharyngeal teeth by their posterior halves are two small triangular shaped curved patches of inferior pharyngeal teeth immediately behind the fifth gill arch (Plate 8b, 8d and 9b). The superior pharyngeal teeth are larger than the inferior pharyngeal teeth (Plate 9a and 9b). The fifth ceratobranchial is expanded in its greater part into a plate-like structure which bears the fine inferior pharyngeal teeth. Each patch bears minute teeth. These patches are very near to each other anteriorly and wide apart posteriorly. Inferior pharyngeal teeth are in the form of minute denticles and are seen only with the help of a hand lens (Plate 8b, 8d and 9b). The inferior pharyngeal teeth of the lower jaw opposes the superior pharyngeal teeth of the upper jaw (Plate 8b).

Inferior pharyngeal teeth are not used for mastication of food and merely serve to prevent the regurgitation of the prey, when once it is taken into the pharynx. It was observed during the stomach content analysis that the prey (food) was swallowed whole, without any mastication. Pharyngeal teeth take a firm grip of the prey between them and quieten the prey, before it is gulped in.
Teeth

It was observed that numerous teeth are present in *Clarias batrachus*. They are present on the upper and lower jaws and pharynx. They are small, multiple rowed. The buccal region was observed to bear the maxillary, mandibular and vomerine teeth and horny pad teeth. The pharyngeal region consists the pharyngeal teeth (Plate 8b, 8c 8d, 9a, 9b, 9c, 9d and 9e). Maxillary teeth, vomerine teeth and pharyngeal teeth are present on the roof of the buccal cavity (Plate 8b, 8c, 9a, 9d and 9e) but the mandibular teeth and horny pad teeth are present on the floor of the buccal cavity (Plate 8b, 8d, 9b and 9c). Maxillary teeth are actually borne on the premaxillaries. Maxillary teeth are present in two more or less confluent patches which are little curved and two times as broad as long (Plate 8b, 8c and 9d). Vomerine teeth are present on a crescentic patch which are present on the vomerine bones (Plate 8b, 8c and 9e). Pharyngeal teeth are also located on a pair of oval patches (Plate 8b, 8c and 9a). Mandibular teeth are borne on dentaries and present in two contiguous, quadrangular patches with posterior, exterior corner laterally produced (Plate 8b, 8d and 9e). A pair of horny pads bears the horny pad teeth. These are quite superficially embedded Teeth present on the jaws are of large size but those on the horny pad are smaller in size. Teeth are of homodont and polyphyodont type (Plate 8a, 8b and 9a).

DISCUSSION

It was observed that *Mastacembelus armatus* is a carnivorous and voracious fish. Details of food and feeding habits of *Mastacembelus armatus* is given in Chapter No. 2.
The morphology of jaws and teeth of *Mastacembelus armatus* shows a number of interesting modifications which reflects the carnivorous mode of feeding habit with several morphological characters such as, the mouth which is equipped with fine but firm jaws. The upper jaw is longer and projects out over the lower one. The pointed mouth may facilitate probing of food items which may be under submerged objects and bottom deposits. There are numerous small but sharp and strong teeth on jaws which are villiform do not show any enlargement into canine or incisor type of dentition. The nature of dentition suggests that it may help in grasping and holding the active prey and preventing its escape. The absence of gill rakers appears to be compensated by higher efficiency of dentition in performing the assigned function than is normally seen in predatory fishes having tooth like gill rakers to supplement the role of teeth. In the place of the gill arch there is an uneven gill arch surface.

Ingested organisms are generally swallowed whole, particularly when large, with no mastication. The fish lacks structural adaptation to consume items which require oral grinding. The mouth gape is wide enough to support intake crustaceans. Diameter and capacity of the buccopharyngeal cavity are equally accommodating.


Mastacembelidae have a non-protrusible upper jaw, which is exceptional among percomorphs as jaw protrusibility is characteristic for most neoteleosts (Travers, 1984b). Requirements of a strong bite have led to secondary loss of
upper jaw movements in teleosts and also in other predacious forms as noted by Gosline (1980).

Sufi (1956) and Roberts (1980) while comparing the Mastacembelid and Synbranchid fishes stated that mastacembelid spiny eels have developed a unique, flexible trunk like extension of snout, while in synbranchids such extension of mouth is absent. The trunk like extension of the snout in mastacembelids is variably developed and is absent in related Chaudhuria. In Macroganthus at its most highly specialized condition bears tooth plates on ventral surface of the trunk like extension.

Frost (1928 and 1930) observed that the maxillaries were excluded from the gape of mouth in mastacembelelids. Nelson (1969) and Rosen and Greenwood (1976) observed that gill arches are reduced in mastacembelids.

Sulak and Shcherbachev (1997) described the dentition on the vomer and the premaxillare-ethmoid complex while studying the diagnostic characters of Synaphobranchus kaupii and Synaphobranchus affinis.

Similar results were observed by Dutta (1989, 1990), Serajuddin and Mustafa (1980) and Serajuddin et al., (1998) on feeding while studying the biology of Mastacembelus armatus.

Similar results were observed by Agrawal and Tyagi (1963) while studying morphology and physiology of Mastacembelus pancalus. Khanna and Pant (1964) while studying digestive tract and feeding habits of teleost fishes observed similar results.

The position and size of the mouth shows a close relationship to the location and size of food items, and the
relative size of the mouth can be used to determine the size of food particles ingested (Hepher, 1988). Particles which are too small may not be detected or captured easily by the fish, while those which are too large may be too difficult to ingest quickly or whole (Lovell, 1989). Moreover, loss of nutrients from large and small food particles after soaking and softening, inevitably lead to wastage. For that mouth size appears to be a limiting factor in feeding with both live and artificial diets (Hyatt, 1979).

Travers (1984), Britz (1996), Vreven (2005a and 2005b) and Britz (2007) have studied the feeding morphological characters while classifying the Mastacembelidae family.

During the study it was observed that *Wallago attu* is a predaceous and voracious piscivore catfish. Details of food and feeding habits of *Wallago attu* is given in Chapter No. 2. The morphology of jaws and teeth of *Wallago attu* revealed that it shows a number of interesting modifications which reflects the piscivory mode of feeding habit, with several morphological characters such as, wider gape of which mouth reaches far beyond the posterior margins of the eyes. Large conical shaped teeth like gill rakers set wide apart on the gill arches, forming broad sieve like structure preventing the escape of larger particles of the food and providing addition grip for holding the prey, presence of a pair of oval patches. Having superior pharyngeal teeth opposed by triangular shaped curved patches with inferior pharyngeal teeth might be used for regurgitation and take a firm grip of the prey between them and quiten the prey before it is swallowed. Teeth are long sharp backwardly curved so as to prevent the escape of the prey.
It was observed that *Clarias batrachus* is an omnivorous and voracious fish and details of food and feeding habits of *Clarias batrachus* is given in Chapter No. 2. While studying the morphology of jaws and teeth of *Clarias batrachus* it was observed that it shows a number of interesting modifications which reflects the omnivorous mode of feeding habit with several morphological characters such as, the gape of the mouth, which is not much wide and reaching far more behind the margins of the eyes. Mouth is surrounded by strong upper and lower jaws and is provided with numerous teeth. Strong gill rakers, pointed and antereodorsally directed forming broad sieve like structure preventing the escape of larger particles of the food and providing addition grip for holding the prey.

Forbes (1888) described that mollusc is an important element in catfish diet. While some authors have reported that catfishes consume whole molluscs, along with the shell (Graham, 1999; Ledford and Kelly, 2006). Forbes (1888) suggested that catfishes were able to separate molluscs bodies from their shells. He stated that a catfish seizes the foot of the molluscs while the latter is extended from the shell, and tears the animal loose by vigorously jerking and rubbing it about. Forbes (1888) continued by speculating that a catfish might be able to crack shells in its jaws to consume the soft parts. He strengthened his argument by stating that no fragment of a shell was ever found in the stomachs, but the bodies of the animals had invariably been torn from the shell. Forbes (1888) stated, the capacious mouth, admit objects of relatively large size and of nearly every shape, the jaws, each armed with a broad pad of fine sharp teeth, are well calculated to grasp and hold soft bodies as well as hard, the gill-rakers are of average
number and development and the pharyngeal jaws broad, stout arches below and oval pads above, with thin opposed surfaces covered with minute, pointed denticles serve fairly well to crush the crusts of insects and the shells of the smaller molluscs and to squeeze and grind the vegetable objects which appear in the food. The use of jaws in tearing molluscs from their shells is probably the most peculiar feeding practice of these catfishes.

Similarly Taki, (1974) and Taki, (1978) while studying the fishes of Lao Mekong Basin and Rainboth, (1996) while studying the fishes of Cambodian Mekong observed that mouth of *Wallago attu* very deeply cleft, its corner reaching far behind eyes. Teeth in jaws set in wide bands; vomerine teeth in two small patches. Barbels two pairs; maxillary barbels extending to anterior margin posterior of anal fin, mandibulary barbels to angle of mouth. Similar results were reported by Rainboth, (1996) in *Wallago attu* that the gill rakers are modified into large conical shaped teeth set on the gill arches.

A definite correlation exists between the structure of the gill rakers and pharyngeal teeth on one hand, and feeding habits on the other hand (Suyehiro, 1941, Al-Hussaini, 1947b, and Girgis, 1952). In *Wallago attu* the gill rakers are present in the form of conical teeth on the second, third and fourth gill arches and are numerous and stout. It can be said that the anatomical arrangement of gill rakers and pharyngeal teeth of *Wallago attu* are adapted to predaceous feeding habits by the study of stomach contents.

Similar results were observed by Kindred (1919), De Beer (1937) in *Amiurus calus*, Berg (1937) in *Ostariophysii*, Dharmarajen (1936) in *Otolithus ruber*, Srinivasachar (1955,
1956a, 1956b, 1957a, 1957b and 1957c) in *Ophiocephalus, Silonia, Pangasius Ailia, Mystus, Rita, Arius, Plotosus Heteropneustes* and Bhimachar (1933), Nawar (1954) in some Indian catfishes while studying the morphology of the skull.

Identical results were reported by Bornbusch (1995) while studying phylogenetic relationship within the Eurasian catfish family Siluridae. Ng and Ng (1998) in Asian catfish *Silurichthys* Vigliotta, (2008) studied several species such as *Brachysynodontis, Hemisynodontis, Microsynodontis and some Synodontis* that bear typical conical and gently recurved teeth.

PLATE-4

a) Lateral view of mouth of *Mastacembelus armatus*.

b) Buccal cavity of *Mastacembelus armatus* showing maxillary teeth, (MNT) mandibular teeth, (T) tongue, (SPT) superior pharyngeal teeth, (IPT) inferior pharyngeal teeth, (UJ) upper jaw, (LJ) lower jaw, (CB) ceratobranchial, (OP) oval pad and (TP) Triangular pad.

c) Lower jaw or floor of the mouth of *Mastacembelus armatus*.

d) Upper jaw or roof of the mouth of *Mastacembelus armatus*. 
PLATE - 4

a

b

SPT  IPT  T  LJ
MXT  UJ  OP  TP  CB  MNT

C  D
a) Magnified view of lower jaw of *Mastacembelus armatus* showing (T) tongue.

b) Magnified view lower jaw of *Mastacembelus armatus* showing (MT) mandibular teeth.

c) Magnified view upper jaw of *Mastacembelus armatus* showing maxillary teeth and (FA) fleshy appendage
a) Lateral view of mouth of *Wallago attu*.

b) Buccal cavity of *Wallago attu* showing (UJ) upper jaw, (MXT) maxillary teeth, (OP/SPP) oval pad or superior pharyngeal pad, (G) gullet, (VT) vomerine teeth, (SPT) superior pharyngeal teeth, (GR) gill raker, (LJ) lower jaw, (MNT) mandibular teeth, (CB) ceratobranchial, (TP/IPP) triangular pad or inferior pharyngeal pad, (T) tongue, (GA) gill arch and (IPT) inferior pharyngeal teeth.

c) Upper jaw or roof of the mouth of *Wallago attu*.

d) Lower jaw or floor of the mouth of *Wallago attu*. 
PLATE-7

a) Magnified view of upper of *Wallago attu* showing maxillary teeth.

b) Magnified view of lower jaw of *Wallago attu* showing mandibular teeth.

c) Magnified view of the superior pharyngeal pad or oval pad on upper jaw of *Wallago attu* showing superior pharyngeal teeth.

d) Magnified view of the second gill arch of the *Wallago attu* showing gill raker.

e) Magnified view of the first gill arch of the *Wallago attu* showing larger gill raker.
a) Lateral view of mouth of *Clarias batrachus*.

b) Buccal cavity of *Clarias batrachus* showing (UJ) upper jaw, (MXT) maxillary teeth, (OP/SPP) oval pad or superior pharyngeal pad, (G) gullet, (VT) vomerine teeth, (SPT) superior pharyngeal teeth, (GR) gill raker, (LJ) lower jaw, (MNT) mandibular teeth, (CB) ceratobranchial, (TP/IPP) triangular pad or inferior pharyngeal pad, (T) tongue, (GA) gill arch and (IPT) inferior pharyngeal teeth.

c) Upper jaw or roof of the mouth of *Clarias batrachus*.

d) Lower jaw or floor of the mouth of *Clarias batrachus*. 

PLATE-9

a) Magnified view of the superior pharyngeal pad or oval pad on upper jaw of *Clarias batrachus* showing superior pharyngeal teeth.

b) Magnified view of the inferior pharyngeal pad or triangular pad of lower jaw of *Clarias batrachus* showing inferior pharyngeal teeth.

c) Magnified view of lower jaw of *Clarias batrachus* showing mandibular teeth.

d) Magnified view of upper jaw of *Clarias batrachus* showing maxillary teeth.

e) Magnified view of upper jaw of *Clarias batrachus* showing vomerine teeth.