BRIEF REVIEW OF LITERATURE
Chapter - I

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A. OSTEOCRANIUM

The studies on the osteocranium of teleosts have attracted the attention of Ichthyologists from ancient times. Gouan (1770) was probably the first to give a simple account of the bones of the cranium. Cuvier (1828), while studying the bones of the perches gave terminology to each bone and established the homology to the skull bones of man. Subsequent workers like Hallmann (1837), Owen (1848), Stannius (1854) and Huxley (1864) followed Cuvier's terminology into the piscine literature. The latter also studied the homologies of cranium in Emx.
and helped to define the criteria for the identification of bones as it is today. Studies on the osteology other than Cyprinidae were also attempted by earlier workers, viz., Parker (1873), McMurrich (1884) and Stohr (1884). Huxley (1876) while working on the jaw suspension of fishes introduced, for the first time, the terms hyostylic, amphistylic and diastylic to express the manner in which the mandibular arch is connected with the skull.

McClelland (1842) was a pioneer worker in the Cyprinidae who made use of the head and the jaw bones in his attempt to classify fishes into distinct sub-generic groups. SageMohl (1891), in his classic monograph, used the osteological criteria in the taxonomy of the Cyprinidae. His classification was based mainly on the differences shown by pharyngeal teeth etc., which are directly influenced by the environmental factors. He divided the cyprinoids into groups like Cyprinina, Leptobarbina, Rasborina, Abramidina and Rhodeina.

Regan (1911) remarked that the external characters were not sufficient enough to split the Cyprinoidae into families. He extensively used the osteology in the classification of Asiatic cyprinids. Accordingly,
he was able to group them into a number of subfamilies and arranged them in a phylogenetic manner.


Hubbs (1919, 1926) studied the opercular bones in teleosts and discussed their respiratory function. He also studied the skulls in Ostariophys, Haplopi, Syntognathi etc., and concluded that the factors like salt concentration and temperature induce changes in the development of skull bones. Goodrich (1930) made important contributions on the osteology of teleosts and discussed their significance in evolution. Koh (1930) studied the osteology of _Carassius auratus_. Gregory (1933), in his detailed investigations, was able to draw the evolutionary tree of various groups of the fishes, based on the structure of the skull.

Chu (1935) utilized the structure of the pharyngeal teeth and the structure of the scales in classifying the cyprinids of the Palaearctic region. He concluded that
the genera with a large number of rows of teeth are primitive than those with a single row. Based on his detailed studies, he divided the family Cyprinidae into eight subfamilies viz., Leuciscinae, Chondrostomatinae, Abraminae, Acheilognathinae, Hypophthalmichthyinae, Gobioninae, Cyprininae and Schizothoracinae.

Eaton (1935) gave an account of the evolution of the upper jaw bones, both protrusible and nonprotrusible, in teleosts. de Beer (1937) studied the development of the skull bones of fish and also discussed the homologies of these bones with those of other vertebrates. Haines (1937) gave a detailed account of the development of lower jaw bones in teleosts, with special reference to the origin and development of Meckel's cartilage. Westoll (1937) referred to the cheek bones in teleosts. Vasnecov (1939) while supporting Chu (1935), traced the evolutionary trends in the development of pharyngeal teeth in Cyprinidae.

Ramaswamy (1948, 1952a,b,c,d, 1953, 1955a,b) examined the osteocranium of Homalopteridae, Cyromochilidae, Gobioninae and Cyprininae and concluded that no set of characters can be used to distinguish the subfamilies of Cyprinidae.
Harrington (1955) described clearly the bones of the osteocranium of Notropis bifrenatus, an American cyprinid fish. Suslowska and Urbanowicz (1957) compared the cranial and the jaw bones of Aspius and other European forms with those of Esox and Cyprinus. They further commented that the morphology of these bones in Aspius is in accordance with the development from an omnivore into a carnivore type.

Weitzman (1962) assessed the primitiveness of endoskeleton in characid fish, Brycon meeki and compared it with that of Cyprinidae and Catostomidae. Rastogi (1963) and Saxena and Khanna (1963) studied the endoskeleton of Catla catla without discussing its systematic position. Matthes (1963) studied the jaw bones of a few African Cyprinidae and pointed out that the speed at which the jaws could be closed depends upon the presence of a high or low ascending process. Alexander (1964-67) concluded that the protrusion of the premaxillaries and lowering of the lower jaw produces a suckorial mode of feeding amongst cyprinids.

Saxena and Bakshi (1964) made a comparative study on the modifications of the opercular apparatus in relation to environmental factors in over ten species of cyprinoids. The osteocranium and the entire endoskeleton
of *Cirrhina mirage* were discussed by Saxena (1966) and Chandersekhar (1976) respectively. Das and Daftari (1967a,b) studied the skull bones in *Oreina sinuatus* and *Schizothorax asochinus*. Gardiner (1967) gave a detailed account of the preopercle in teleosts. Jarvik (1967), in his studies on the skulls of teleosts, homologised the frontal and the parietal bones to those of the tetrapods.

McAllister (1968) used the structure of the branchiostegal rays of teleosts in the classification of fishes. Vashist and Verma (1968) highlighted the interspecific variations in their studies on the osteology of nine species of *Puntius* viz., *P. sarana*, *P. tor*, *P. tetrapugatus*, *P. conchonius*, *P. ticto*, *P. stigma*, *P. chrysopterus*, *P. chole* and *P. sophora*. They also attempted to trace the evolution of the species on the basis of osteological characters. Vandewalla (1968) worked out the anatomical peculiarities of the head skeleton of two species of *Barbus*. The osteology of this genus was further studied by Qasim et al. (1970) and Al Jafervs et al. (1977).

Nelson (1969) traced the phylogeny of teleostean fishes on the basis of gill arches. Dixit (1972) described the complete endoskeleton of *Schizothorax richardsonii*.
Roberts (1972), in his studies of interrelationship of Ostariophysans, reviewed the group characters of three main orders of Ostariophysi, viz., Characiformes, Cypriniformes, and Siluriformes and remarked that the loss or reduction of a character is a sign of advanced nature and vice-versa.

Tiwari (1972) worked out the neurocranium in embryos of Rasbora daniconius. Weisel (1972) studied the skull bones of Catostominae and compared them with those of cyprinoid fishes. He conjectured from his studies that the catostomid skull is not only an interesting study in adaptation but is also of interest in the information it reveals on the origin and relationship of cyprinids.

Mirza's (1973) osteological studies were based on a number of species of Puntius from Punjab and Sind. He noticed a large frontoparietal fontanelle in the roof of the cranium of P. sophore.

Gosline (1973) described the upper and lower jaw bones in Cypriniformes. In 1974, he divided the old world cyprinids into two groups on the basis of the presence or absence of a gap between supraorbital canals. Gosline (1975) discussed the taxonomic importance of dermosphenotic in the cyprinids.
Takaya (1974), while studying the facial membrane bones of over hundred species of Teleostei from the South Eastern area of Central Japan, observed the usefulness of various extreme shapes of the urohyal in classifying the teleosts.

Sorescu (1975, 1978) compared the skull bones, the Weberian apparatus and the pectoral girdle in the sub-families Leuciscinae, Danioninae, Cultrinae, Barbinae, Xenocyprinidae, Cyprininae, Gobioninae, Abramidinae, Acheilognathinae from Europe, Asia and North America and dealt with the variability in order to clarify their phylogeny. She correlated the modifications of the skull bones with the evolution of the extensibility of the mouth.

Howes (1978) discussed the osteology of the long-headed cyprinid fish, Luciobrama macrocephalus from East Asia and China. In order to find out the exact systematic position and the nearest relatives of Luciobrama, he compared its osteological characters with those of over 150 other cyprinid genera. He commented upon the usefulness of osteological characters as indicators of relationship and functions.
B. WEBERIAN APPARATUS

In 1820, Weber, in his classical memoir entitled "De auris et auditu hominis et animalium. Pars I de animalium aquatilium", was the first to describe the existence of a peculiar connection between the auditory organ and the swim bladder through a chain of interconnected ossicles. Weber (1820) further contended that the chain of bones is homologous with the auditory ossicles in Mammalia and named them the clausstrum, the stapes, the incus and the malleus. He assigned to them an auditory function. This important discovery attracted the attention of many workers who studied this feature in many other Ostariophysi.

Following the investigations by Weber, an anonymous paper (1821) on the anatomy of the Weberian apparatus in Cyprinus brama was published. They followed the guidelines of Weber (1820), homologising these ossicles to the ear ossicles of mammals and assigning them the function of hearing.

Müller (1842), on the basis of the Weberian apparatus and the swim bladder, established the family Characinidae with the genera included by Cuvier in Clupeidae and Salmonidae. He showed that the characins, cyprinids and
siluroids possess an "internal token of identity" regardless of the presence or absence of the superficial characters.

In connection with the study of the structure and development of the Weberian apparatus in the Ostariophysii, much emphasis was laid by earlier investigators on the nature of the centrum of the anterior vertebrae. According to Baudelot (1868), the complex vertebra of Cyprinidae was formed by the fusion of the second vertebral centrum with the third vertebral centrum.

Hasse (1873) and Wright (1884) adopted the view that they were hydrostatic in function. Nusbaum (1881) described the anatomy of the Weberian apparatus in some cyprinids. In the year 1891, SageMehl showed that the fish families possessing a Weberian apparatus were to be considered as a natural group to which he gave the name Ostariophysea (bone bladder). A number of workers have since then studied this structure but only a few like SageMehl (1891) realized the implications of relationships based on this structure. He accepted the theory of Hasse (1873) but uncritically looked upon the ossicles as registering changes in the atmospheric pressure and, thus, endorsed Weber's views (1820) regarding the functions of the Weberian ossicles.
Bridge and Haddon (1893) published an exhaustive monograph on the Weberian apparatus and swim bladder of siluroids. Although their work is very extensive and the first of its kind, yet the descriptions of the pars sustentaculum and the pars auditum seem inadequate for the purpose of taxonomy. They did not emphasize the taxonomic importance of this apparatus. Instead, they used the swim bladder as a taxonomic feature. They further contradicted Weber's homologies of these ossicles with those of mammalian ear ossicles and used the terms clastrum, scaphium, intercalarium and tripus to designate these ossicles and called them as the Weberian ossicles.

Nussbaum (1908) gave a detailed description of the development and the morphology of the Weberian ossicles in *Cyprinus carpio* and also studied the relationship of the swim bladder with the anterior vertebrae.

Regan (1911), in connection with his description of the order Cypriniformes, arranged the families and the subfamilies in a phylogenetic manner on the basis of characters of the skull, the Weberian apparatus and the swim bladder. He also described the various developments of the second and fourth pleural ribs.
A semisystematic work on several cyprinids, based primarily on the Weberian ossicles, was done by Sachs (1912). Nusbaum (1908), Thilo (1908), Sachs (1912), Hora (1922) and Adams (1928) held the view that the Weberian ossicles were derived mainly from the anterior vertebrae. Hora (1924, 1931) gave detailed account of the structural modifications in the swim bladder in relation to the changing environment.

Evans (1925) worked out the anatomy of the air bladder and the Weberian apparatus in Rutilus rutilus and about twelve other species of cyprinoids. A comprehensive work on the use of the Weberian apparatus as a taxonomic character was that of Chronilov (1927, 1929). In 1927, he gave a comparative account of the Weberian ossicles in a number of cyprinids and in 1929, he demonstrated the familial distinctions in the Weberian apparatus and the swim bladder mechanisms in cyprinoids and siluroids. He preferred to use Weber's terminology and gave an account of the direct and indirect transmission systems by the Weberian apparatus and the swim bladder.

Matveev (1929), Watson (1939) and Mookerji et al. (1952) gave important descriptions on the development and adult structures of these ossicles in various
cyprinoids. These workers, all separately, tried to tackle the problem embryologically by extending their observations on rudd, gold fish and carp minnows, 

*Acipenser sturio*. They were able to define the exact homology of the ossicles in Cyprinidae. They all opined that these ossicles were derived, in part, from the anterior vertebrae and in part, from the structures associated with them.

Sarabahi (1933) worked out the morphology of the Weberian apparatus in *Labeo rohita*. Krumholz (1943) studied the morphology of the Weberian ossicles in sixteen species of Nematognathi and Eivantognathi. He pointed out the differences of the Weberian ossicles in both the groups of fishes and made use of the various morphological forms of the tribus to distinguish the two orders. He commented that the morphology of the Weberian ossicles is stable within each species and hence, forms an important taxonomic tool and further contended that the taxonomic significance of this apparatus is more pronounced in cyprinoids than in siluroids. Nelson (1948) gave a comparative account of the morphology of the Weberian apparatus of Catostomidae and used it as a taxonomic character. He discovered that the overall form of the Weberian apparatus is determined by the shape of the body of the individual fishes.
Subsequently, Ramaswamy (1952a, b, c, d, 1955a, b) described in detail the comparative account of the Weberian apparatus and the gas bladders in Homalopteridae, Gobioninae, Cyprininae, Gyrinocheilidae and Psilorhynchidae and traced the phylogenetic position of each subfamily. He used the structure of the tripus as a taxonomic tool in ascertaining the systematic position of the families and the subfamilies.

Marshall and Jones (1952) and Krandikar et al. (1954) have contributed much towards the study of the swim bladder. Alexander (1962) gave important descriptions of the Weberian apparatus and the swim bladder of characinooids and cyprinoids and supported Chranilov’s theory of treating the Weberian apparatus and swim bladder as a special transmission system. He (1962, 1966) made valuable additions to our knowledge of functional aspects of the swim bladder of Ostariophysi and assigned it the function of an important buoyant organ in maintaining the fish at various depths.

Lal (1964, 1971) studied the Weberian apparatus and the swim bladder of Tor putitora and Labeo dero. Niazi (1967) made a comparative study of the Weberian apparatus in different species of Barbus which was also supplemented by subsequent authors (Sorescu, 1975; Howes, 1976, 1978).
Lamba (1966, unpublished) and Sahota (1970, unpublished) gave an account of the Weberian apparatus of *Labeo dero* and *L. cyprinoides* without discussing their systematic position. Vashist and Verma (1968) studied the comparative osteology of the Weberian apparatus in nine species of *Puntius* and tried to trace its evolution. Das and Daftari (1967) and Das and Peers (1969) dealt with the comparative osteology of the Weberian apparatus in Kashmir fishes viz., *Oreinus sinuatatus*, *O. plagiostomus*, *Cyprinus carpio*, *Labeo dero* and *Schizothorax asochinus*. The osteological studies of the Weberian apparatus on *Schizothorax richardsonii*, *Barilius bengalensis* and *Barilius bala* were attempted by Dixit (1972) and Vishwa Prakash (1972, unpublished) without discussing its systematic value.

Roberts (1972), on the basis of his studies on the group characters of *Ostariophysi*, used the osteology of the Weberian apparatus as a taxonomic character. On the basis of the available data on the Weberian apparatus, swim bladder and *ossa suspensoria*, he assessed the primitiveness of families such as Gymnotidae and Characidae as compared to Cyprinidae and Catostomidae.

Sorescu (1972, 1975), while studying the Weberian apparatus of the representatives of the subfamilies
Danioninae and Cultrinae, listed the primitive and specialized characters exhibited by these skeletal structures. Chandersekhar (1976) studied the Weberian apparatus of Cirrhina mrigala without discussing its taxonomic importance.

Howes (1978) discussed the comparative morphology of the Weberian apparatus in Luciobrama macrocephalus and many other cyprinids and its bearing on the taxonomy.

C. GIRDLES

The osteological studies on the girdles received attention from the Ichthyologists from early times, of which the reference may be made to Parker (1868), McMurrich (1884) and Haller (1905). Regan (1911) used the features of the pectoral girdle in his taxonomic studies. Goodrich (1930) traced the evolution of the girdles in teleosts. Sarabahi (1933) gave morphological accounts of the skeletal elements of the girdles in Labio rohita. The osteological studies on the girdles were also attempted by Hookerjee (1935) in Psilorhynchus balitores, Hora and Hookerjee (1935) in Psilorhynchus homaloptera and Sheldon (1937) in Nematognathine fishes. Chang (1945) worked the morphology of the girdles in homalopterid fishes.
Rauther (1950) described the pectoral girdle in *Pelacanthus*. Ramaswamy (1952), while carrying out the detailed osteological and phylogenetic studies of the osteocranium and the Weberian apparatus, made passing remarks on the girdles in *Garra mullya*, *Crossocheilus latius*, *Gyrinocheilus kasmakoi*, *Pilorhynchus* and *Parapsilorhynchus*. Weitzman (1962) contributed to the comparative skeletal morphology of *Brycon meeki* and the cyprinoids in general.

Saxena and Chandy (1965) dealt with the functional morphology of the pelvic girdle in the Indian hill-stream fishes viz., *Crossocheilus latius punjabensis*, *Garra mullya*, *Pilorhynchus sugatio*, *Gazara cenis*, *Laguvia riberol* etc. The osteological studies of the girdles of *Catla catla* and *Cirrhina mrigala* were made by Saxena and Khanna (1963) and Saxena (1966). Sorescu (1968) used the morphology of the pectoral girdle as a principal character in differentiating the cyprinoid subfamilies. While doing so, she placed reliance on the similarity of the shape of elements to indicate affinity. Jessen (1972) highlighted the interrelationship between Actinopterygi and Brachiopterygi on the basis of the morphology of the pectoral girdle. Shukla
and Verma (1972) described the girdle bones of *Barilius brols*.

Ansari and Khan (1975) and Ludenberg and Edie (1976) studied the girdle bones in a number of cyprinids. Howes (1978), while making comparison of pectoral and pelvic girdles of *Luciobrama macrocephalus* with other cyprinids, used the size of the cleithral-coracoid fenestra for his taxonomic studies. He remarked that little variation is found in pelvic girdles of cyprinoids.

**D. CAUDAL SKELETON**

The studies on the caudal skeleton in cyprinids are equally important. Agassiz (1833) while working on the fossil fishes, introduced for the first time, the terms homocercal and heterocercal. His views were supplemented by Huxley (1852), Ryder (1884) and Bridge (1896).

Whitehouse (1910, 1917), Totton (1914) and Barrington (1937) studied in detail the developmental stages of the caudal skeleton in various fishes and concluded that the number of the hypurals and the length of the urostyle are important characters in deciding the primitive or advanced nature of the tail in fish.
Sarabahi (1933) described the skeletal elements of the caudal fin of *Labeo rohita*. However, subsequent authors working on the morphology and osteology of caudal skeleton used Barrington’s (1937) parameters for discussing its primitive or advanced nature. Prominent amongst them are Eaton (1945), Mookerjee et al. (1952), Saxena and Khanna (1963), Saxena (1968), Buhan (1972) and Shukla and Verma (1972).

Nybelin (1972), while working on *Elops*, suggested that the morphology of the caudal skeleton is a good touchstone in questions of phylogenetic relationship. Roberts (1972) studied the (10+9) as the count for principal caudal rays in cyprinids. Howes (1978), however, observed (9+9) in all the cyprinid genera studied by him.