

INTERRELATIONSHIPS AMONG GENERA OF
CYPRINIDAE (TELEOSTEI) AS INDICATED BY THE
CAUDAL SKELTON

A. B. KOTALAWALA AND J. JINADASA

Department of Zoology
University of Sri Jayewardenepura,
Nugegoda,

Abstract

The studies on the osteology of caudal skeleton and the ray counts showed that the twenty one species of Cyprinidae studied fall into three groups, one containing four species, the other with 16 species and third group with one species. The first group with four species has the most primitive type of caudal skeleton containing six free hypurals, three epurals and sixteen or more branched rays. The second group which is the major group with sixteen species has lesser primitive type of caudal skeleton with six hypurals, two epurals and sixteen or more branched rays. The third group with one species has an advanced caudal skeleton with five free hypurals, two epurals and fifteen or sixteen branched rays.

Key words: Caudal skeleton, Hypurals, Epurals, Parhypural, Uroneurals.

1. Introduction

Characters of the caudal fin skeleton are widely used to demonstrate the phylogenetic relationships among fishes. Vladkove (1954) showed that in the taxonomy of chars (Salmonidae) the most important of the skeleton is the tail and the head. He brought about the differences and similarities among the species of the *Salvelinus*, and also the differences and similarities among the genera *Salvelinus*, *Cristivomer* and *Salmo* of Salmonidae. Norden (1961) showed that in the thymallines and coregonines of Salmonidae, the size and the shape of the 1st uroneural, its relation to the epurals and the modification of the 4th terminal nural arch and spine appear fairly constant, and these structures are quite similar. It is in the salmonines that most of the variations occur. Gosline (1961) showed the similarities among the subfamilies of Salmonidae and he also demonstrated that *Khulia*, *Cheatodon*, *Polydactylus* with six fin elements are primitive. Gosline (1965) used caudal characters with some other features such as circumorbital bones and suprabranchial organ to study the phylogeny of teleostei. According to him, unlike the other features which are practically undeterminable in fossils, the caudal skeleton can and have often been used in such material to excellent advantage. Top and Cole (1968) demonstrated that the retaining of a maximum number of independent bones in the caudal skeleton of *Scianops gill* (Teleostei, Scianidae) is a primitive

character. Rao (1977) showed that the caudal skeleton of the Indian lizard fishes (*Saurida* spp.) contain six independent hypurals. The reduction of the number of independent bones by fusion and hence the simplification of the caudal skeleton is an evolutionary advanced character. This is evident in the systematics of Bonitos (*Sarda*) and their relatives (Scombridae, Sardini) as described by Collette and Chao (1975). They used the features of the caudal skeleton also as a diagnostic character in the identification of species. The work of France, Andrews and Cole (1978) on *Hippoglossoides platessoides* (Pleuronectidae) clearly demonstrate that the evolved caudal skeleton is formed through the reduction and simplification by fusion of elements. In a study of *Luvarus imperialis* (Luvaridae), with a phylogenetic analysis of the Acanthuroidei (Pisces) James et al., (1989) refuted the earlier accepted hypothesis that *Luvarus* is related to carangoid and scombroid fishes. They used detailed information on the osteology and larval morphology of *Luvarus* and other groups in this study and formed a highly corroborated new hypothesis indicating the following taxonomic sequence:

Siganida—> Luvaridae—> Zanclidae—> Acanthuridae.

Based on the study of caudal and skull skeletons of American drum fishes (Scianidae) Jinadasa and Cole (1978) divided the genus *Paralonchurus* into two sub genera namely *Paralonchurus* and *Polyclemus*. These researchers have pointed out clear distinctions in the caudal and skull skeleton of the two sub-genera. Seven species of *Paralonchurus* and monotypic genus *Polyclemus* contain six free hypurals. According to Jinadasa and Cole (1978) they are also primitive fishes. More recently the caudal skeleton of twelve species of the genus *Puntius* of Sri Lankan cyprinids have been described by Jinadasa and Kotalawala (1991). They divided the twelve *puntius* species studied into two groups one containing eleven species and the other with one species. The monotypic group contained five free hypurals while the other group has six hypurals. According to them the *Puntius* species are also primitive fishes.

In this study we intend to present the detailed osteological descriptions of the caudal skeleton of all the species of this family. Later it may be possible to expand this study to encompass the entire osteology of the family so as to obtain a taxonomic review of the family Cyprinidae.

2. Materials and Methods:

One to three caudal fins with the last few vertebrae from each species of known standard length were digested in 2% Potassium hydroxide and stained in Alizarin Red S and was kept in 50% glycerol. Skeletons were examined and studied using a stereomicroscope under reflected light. Bones were disarticulated whenever necessary in 4% KOH solution. Bones were identified according to Goslin (1961) Norden (1961) Vladkov (1954) and Cole (1968) and drawings wherever necessary were made under the stereomicroscope. The following abbreviations were used throughout to label the bones.

List of Bones and Abbreviations :

EP	Epural.
HS	Haemal Spine.
HYP	Hypural.
LEP I	Unbranched Lepidotrichs.
LEP II	Branched Lepidotrichs.
NS	Neural Spines.
PHYP	Parhypural.
PU2	First Preural Centrum
PU3	Second Preural Centrum.
TP	Transparent Bony Plates.
U	Urostylar Vertebra.
UN1	First Uroneural.
UN2	Second Uroneural.

Identification of the species were done according to Deraniyagala (1952), Munro (1955), Mendis and Fernando (1962). Out of the 27 species that have been recorded for Sri Lanka 21 were collected. They are 16 cyprinines, 4 rasborinines and one abraminine (Table 1).

3. Results:

The caudal skeleton of all the species studied is built on a general plan consisting of two pairs of uroneurals (UN1, UN2), six unpaired free median hypurals (HYP1-HYP6), one unpaired parhypural (PHYP) and three unpaired median epurals (EP1, EP2, EP3) (Fig. 1). The last three vertebrae namely the Urostyle (u), the penultimate (PU2) and the antipenultimate (PU3) of the axial skeleton are involved in the caudal support. The dermal bones are the lepidotrichs which are paired, branched or unbranched rays.

The haemal spine and the neural spine of antipenultimate vertebra are opposite each other and are broader than those of other caudal vertebra. They extend backward to the bases of the unbranched lepidotrichs and articulate with them. The haemal spine of PU2 is also broad and extend backward to articulate with unbranched lepidotrichs. The neural spine of PU2 is stunted and articulate with the epurals (EP1 and EP2). In *Chela laubuca* and *Cyprinus carpio* the stunted neural spine of PU2 is divided into two to articulate with EP1 and EP2. (Fig1). But in *Rasbora daniconius* the undivided stunted neural spine of PU2 articulates with EP1 and EP2.(Fig 2). The inflected distal end of the urostyle (U) articulates firmly with the second uroneural (UN2) while the dorsal side of the urostyle firmly articulates with the first uroneural (UN1, Fig. 1.) Ventrally, the Urostyle articulates with the parhypural (PHYP) and with the first two hypurals (HYP1 and HYP2).

Table I.

Variation of the number of different caudal fin elements of different species of Cyprinidae

Subfamily	Species	Number of Hypurals	Number of Epurals	Number of rays		
				Branched	Unbranched	Total
Cyprininae	<i>P. filamentosus</i>	6	2	17	14	31
	<i>P. sarana</i>	6	2	17	14	31
	<i>P. dorsalis</i>	6	2	17—18	17	34—35
	<i>P. pleurataenia</i>	6	2	17	17—18	34—35
	<i>P. chola</i>	6	2	17	14—16	31—33
	<i>P. nigrofasciatus</i>	6	2 (rarely 3)	17	13	30
	<i>P. amphibiis</i>	6	2	17	16—18	33—35
	<i>P. bimaculatus</i>	6	2	17	15	32
	<i>P. vittatus</i>	6	2	17	15-16	31-33
	<i>P. melanamphyx</i>					
	<i>sinhala</i>	6	2	17	13	30
	<i>P. cumingi</i>	6	2	16-17	12-14	28-31
	<i>P. titteya</i>	5*	2	15-16***	17-19	32-35
	<i>Cyprinus carpio</i>	6	3**	17	14	31
	<i>Tor khudree</i>					
	<i>longispinis</i>	6	2	18	15	33
	<i>Garra ceylonensis</i>	6	2	17	18	35
	<i>Labeo procellus</i>					
	<i>lankae</i>	6	2	17	17	34
	Rasborinae	<i>Rasbora daniconius</i>	6	3**	17	14
<i>Danio aequipinnatus</i>		6	2	17	15	32
<i>Esomus danrica</i>		6	3**	17	17	34
<i>Amblypharyngodon</i>						
<i>melettinus</i>		6	2 (rarely 3)	17	17	34
Abraminae	<i>Chela laubuca</i>	6	3**	16	10	26

* 5 hypurals present only in *Puntius titteya*** 3 epurals present in *Cyprinus carpio*,
Rasbora daniconius, *Esomus danrica*
and *Chela laubuca**** 15 Branched rays present only in
P. titteya.

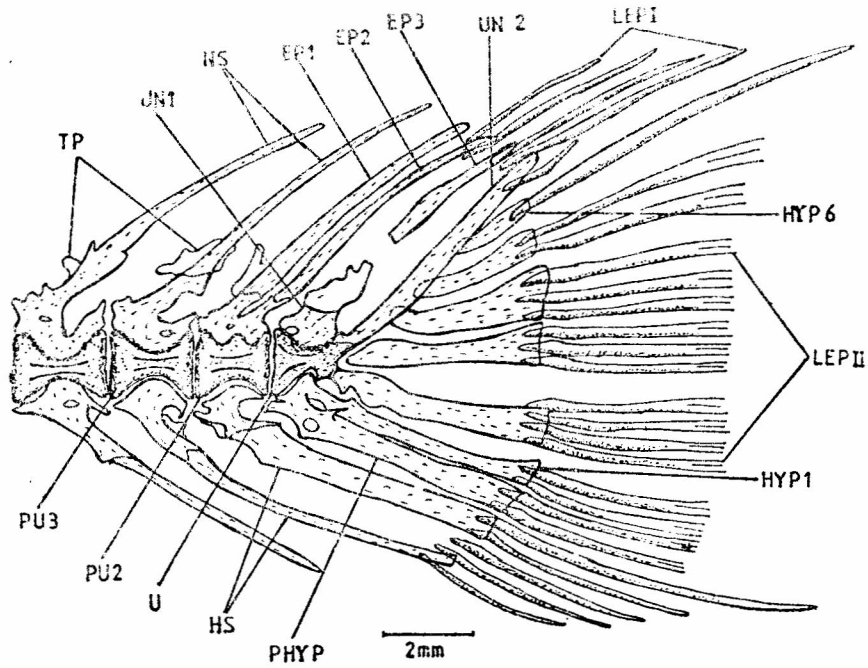


Fig. 1. The caudal skeleton of *Chela laubuca*

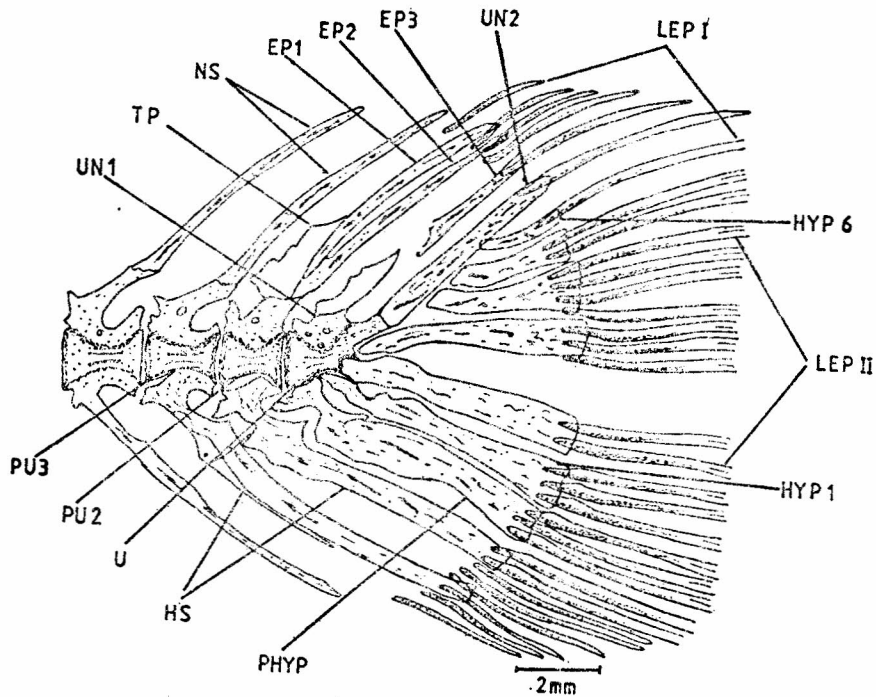


Fig. 2. The caudal skeleton of *Rasbora daniconius*

3.1 Epurals (EPI, EP 2 and EP 3 Fig. 1)

The epurals are rod shaped bones of which EP1 and EP2 are long and look like a neural spine of a caudal vertebra. The third epural (EP3) is short and is half the length of the first two. The first two epurals are sessile and firmly articulates with the stunted neural spine of PU2. The third epural is free and the shape of its proximal end is species specific (Fig. 3). The distal ends of all epurals articulate with the unbranched rays.

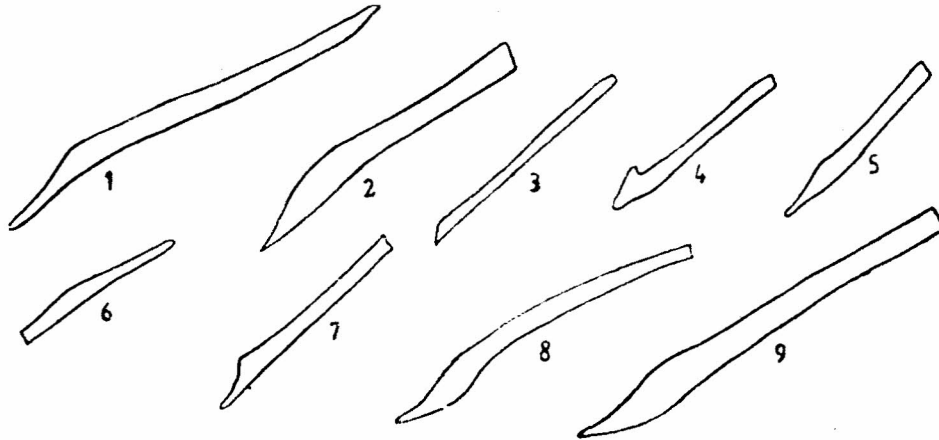


Fig. 3. The shape of the third epural

- | | |
|---------------------------------------|----------------------------------|
| 1. <i>Cyprinus carpio</i> | 2. <i>Labeo procellus lankea</i> |
| 3. <i>Danio aequipinnatus</i> | 4. <i>Esomus danrica</i> |
| 5. <i>Amblypharyngodon melettinus</i> | 6. <i>Chela laubuca</i> |
| 7. <i>Rasbora daniconius</i> | 8. <i>Garra ceylonensis</i> |
| 9. <i>Tor khudree longispinus</i> | |

The number of epurals vary within the species studied. Out of the 21 species studied four species, contained three epurals (Ep1 Ep2 and Ep3, Table 1). These species are *Cyprinus carpio* from Cyptininae, *Rasbora daniconius* and *Esomus danrica* from Rasborinae and *Chela laubuca* from monotypic sub family Abraminae. All the other species such as all species of *Puntius*, *Tor khudree longispinis*, *Danio aequipinnatus*, *Amblypharyngodon melettinus*, *Garra ceylonensis* and *Labeo procellus lankae* had two epurals (Ep1 and Ep 3). Occasionally there were some anomalies regarding the number of epurals in *Puntius nigrofasciatus*, *Esomus danrica* and *Amblypharyngodon melettinus*. Generally *P. nigrofasciatus* has two epurals but occasionally there are specimens having epurals with two tail ends (Fig. 4). The constricted mark along this doubled epurals indicate that a fusion of EP1 and EP2 is going on. This may be an indication of a three epural condition leading to a two epural condition by fusion. Although *Amblypharyngodon melettinus* belong to the group containing two epurals, there were occasional specimens with three epurals. Generally *Esomus danrica* specimens contained three epurals but occasionally there were specimens with two epurals.

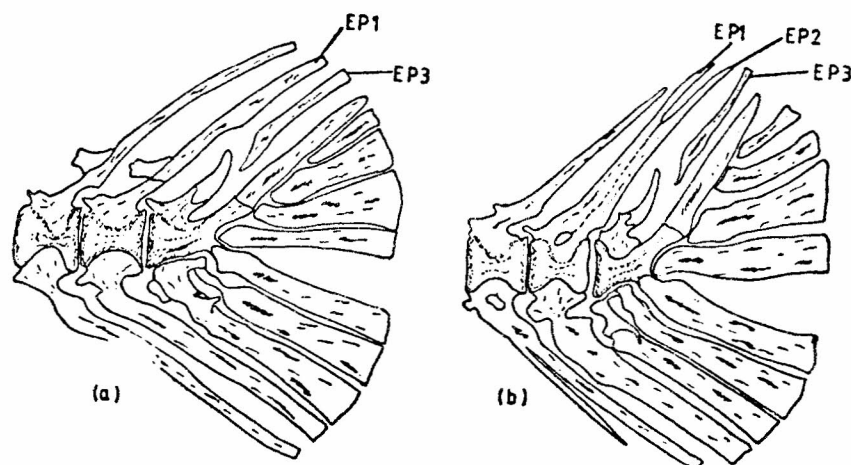


Fig. 4. The caudal skeleton of *P. nigrofasciatus*
 a) with two epurals b) with three epurals

3.2 Uroneurals (UN1 and UN2)

There were two pairs of uroneurals in all the species studied. The first pair of uroneurals (UN1) is short and stout and firmly articulate with the dorsal side of the urostyle. The laterally flattened second pair of uroneurals (UN 2) is long and its proximal end firmly articulates with the inflected distal end of the urostyle. The free distal end of UN 2 articulates with one or two unbranched rays.

3.3 Parhypural (PHYP Fig 1).

Parhypural is an unpaired flattened long bone, loosely articulated to the ventral side of the urostyle. Proximally this bone bears a dorsolaterally directed spine (Hypurophyses of Nursall 1963) which provides attachment for the hypochordal longitudinal musculature. This spine is more prominent in *Rasbora daniconius* and *Danio aequipinnatus* than in other species. The distal end of the parhypural is broad and articulates with branched rays.

3.4 Hypurals (HYP1-5 Fig i)

There are six free hypurals in all the species studied except *Puntius tittैया* where there is only five free hypurals. Hypurals are unpaired, laterally compressed broad elements. They form a broad base to articulate with the branched rays of the caudal fin. The narrow proximal end of the first hypural (HYP1) articulates with the enlarged proximal end of parhypural which articulates with the ventral side of the urostyle. The second and third hypurals (HYP2 and HYP 3) directly articulate with the ventral side of the inflected posterior end of the urostyle, while the fourth, fifth and sixth hypurals (HYP 4 HYP 5 HYP 6) articulate with the postventral margin of the second uroneural.

The articulation of HYP 2 with the urostyle is firm while the articulation of HYP 3 with the urostyle is loose. The length and breadth of hypurals gradually decrease from HYP 1 to HYP 6. The free distal ends of hypurals articulate with the branched lepidotrichs where the number varies from 15 to 18.

3.5 Lepidotrichs (Lep I and Lep II Fig 1)

Lepidotrichs are dermal bones which form the paired fin rays articulating with bones of the caudal skeleton. They are of two types: branched (LEP II) and unbranched (LEP I). The branched lepidotrichs are long and articulate only with parhypural and hypurals. Therefore they are confined to the middle portion of the caudal fin. The unbranched rays articulate with the neural spines and haemal spines of penultimate vertebrae, epurals and the 2nd uroneural. Therefore they are confined to the dorsal and ventral sides of the group of branched rays. In all species the bases of rays are peg-like without an enlarged procurrent spur of Jonson (1975). The number of branched rays vary from 15 to 18 in all the species studied. The minimum number of branched lepidotrichs 15 is present in *P. titteya* while in others it is more than 15. In some specimens of *P. titteya* there were 16 branched rays. The unbranched rays varies from 10 to 19 while the total number of rays vary from 28 to 35 (Table 1).

3.6 Transparent Bony plates (TP Fig. 1)

These are transparent bony plates articulated with the neural spines, the haemal spines and the epurals in all the species studied (TP Fig. 1).

4. Discussion

In fishes such as *Salmo gairdneri*, *Oncorhynchus gorboscha*, *Salvelinus fontinalis* and *Thymallus arcticus* of Salmonidae there are seven free hypurals (six hypurals and one parhypural) and three uroneurals (Norden, 1961). *Elops affinis* (Elopidae) have eight hypurals (7 hypurals and one parhypural) and three uroneurals (Norden, 1961). As shown by Gosline (1961) the caudal skeleton of *Kuhlia*, *Cheatodon* and *Polydactylus* have six free hypurals. The Scianids or American drum fishes such as *Scianops Gill*, *Paralonchurus*, *Lonchurus* had six free hypurals (Topp and Cole 1968, Jinadasa and Cole 1978). These fishes are considered to be primitive. More primitive fishes such as *Amia* have even more free hypurals, (15 independent ones).

The work of Goslin (1961) clearly demonstrates that evolution of the caudal skeleton in modern teleosts is towards reduction and simplification by fusion of elements. According to this, the replacement of six hypurals by two triangular hypural plates of *Hippoglossoides platessoides* (Pleuronectidae, Frame, Andrews and Cole 1978) is considered as a more evolved character. The replacement of six hypurals by one triangular plate of bone in *Cybiosarda elegans*, *Orcyonopsis*, *Sarda chiliensis*, *Sarda sarda*, *Gymnosarda unicolor* and *Allothunnus fallai* is considered to be a more advanced character (Scombridae, Collette and Chao 1975).

This study suggests that the caudal skeleton can help to regroup the systematic levels of fishes. Recently, the genus *Parolonchurus* (Scianidae) was divided into two subgenera *Parolonchurus* and *Polyclemus* mainly on the basis of the characters of caudal and skull skeleton (Jinadasa and Cole 1978). By studying the larval and adult osteology of *Luvarus imperialis* (Luvaridae) and Acanthuroidei (Pisces) the earlier accepted hypothesis that *Luvarus* is related to carangoid and scombroid fishes has been refuted and a highly corroborated new hypothesis indicating a new phyletic sequence has been presented (James et. al., 1989). More recently the work on *Puntius* species (Cyprinidae) based on caudal skeleton by Jinadasa and Kotalawala (1991) indicated that the genus *Puntius* can be divided into two groups, one with five hypurals and the other with six hypurals.

According to Gosline (1961) and Nybelin (1963) fishes with a large number of hypurals and branched rays are primitive. Based on the above criterion it is evident that all the cyprinids studied are much more primitive than most species referred to above. The species studied have other primitive features such as wing like bones (TP) that articulate with neural spines, haemal spines and epurals. Further, the epural 1 and epural 2 are almost identical to neural spines of the caudal vertebrae. Also the second uroneural firmly articulates with the urostyle. The procurrent spur of Jonson (which is considered as an advanced character) is also absent altogether in all the species studied. Therefore in general all the Cyprinids studied are primitive fishes.

A reduction of the number of hypurals, epurals, uroneurals and branched lepidotrichs is an advanced character. Based on the above features, the species studied can be divided into three groups. Among all the species studied *Puntius titteya* is the most advanced one. It has five hypurals, two epurals and sixteen or fifteen branched rays.

The least advanced group included *Cyprinus carpio*, *Esomus danrica*, *Rasbora daniconius* and *Chela laubuca*. They have six hypurals, three epurals and more than fifteen branched rays. The other sixteen species, *Puntius filamentosus*, *P. sarana*, *P. dorsalis*, *P. pleurotaenia*, *P. chola*, *P. nigrofasciatus*, *P. amphibius*, *P. bimaculatus*, *P. vittatus*, *P. melanamfix sinhala*, *P. cumingi*, *Tor khudree longispinis*, *Danio aequipinnatus*, *Amblypharyngodon melettinus*, *Garra ceylonensis* and *Labeo procellus lankae*, are evolutionary-wise in-between these groups. They had 6 hypurals, 2 epurals and more than fifteen branched rays. The number of uroneurals and parhypurals were constant in all the species studied.

The occurrence of anomalies of caudal skeleton of *P. nigrofasciatus*, *Amblypharyngodon melettinus*, *Esomus danrica* and the separation of the species studied into three groups can be explained according to the hypothesis given by Norden (1961). According to him the primitive condition of caudal skeleton consists

of three distinct neural arches with spines. The paired uroneurals are remnants of the neural arches and the epurals are remnants of the neural spines. Thus if the primitive condition consisted of three neural arches with spines the following progressive reductions may have occurred during the evolution of these three groups of cyprinids.

1. The last two neural arches may have fused to form the second pair of uroneurals while the spines have remained separate as two epurals. A 3rd neural arch and spine remain but they are separate from the 3rd terminal centrum and form the other uroneural and the epural. Examples of this type have been found in *Cyprinus carpio*, *Rasbora daniconius*, *Esomus danrica* and *Chela laubuca*. They have three epurals and two uroneurals.
2. The last two neural arches may have fused to form the second pair of uroneurals and one of the spines remained separate and formed an epural. The other spine is lost or fused with the spine of a 3rd arch. The arch and the spine of the 3rd arch remained separate as an uroneural and as an epural. This type of caudal fins have two uroneurals and two epurals. This type of caudal skeleton was noted in specimens of all *Puntius* species, *Tor khudree longispinis*, *Danio aequipinnatus*, *Amblypharyngodon melettinus*, *Garra ceylonensis* and *Labeo procellus lankae*. Both these groups contained six hypurals except *Puntius tittaya*.
3. Although *Puntius tittaya* belongs to the group containing two uroneurals and two epurals, the loss of one hypural and the reduction of number of branched rays set it apart from the original group as a more advanced form. Therefore *P. tittaya* seems to be the most evolved of the fishes studied.

The rare occurrence of anomalous specimens of *P. nigrofasciatus* with double tailed epural (which is partly fused epural 1 and epural 2 Fig. 4) seem to agree with the hypothesis of Norden (1961). According to him the primitive condition of the caudal skeleton consists of three distinct neural arches and spines and during evolution progressive reductions, fusions or losses of elements may be occurred. So, the two epural condition of *P. nigrofasciatus* and also of other species may have originated by the fusion of primitive neural spines (1 and 2) during the evolution of this group of fishes. Generally *Esomus danrica* contains three epurals, but occasionally there are specimens with two epurals. This also may fit the hypothesis of Norden. Therefore, in the evolution of the Cyprinidae the reduction of the number of epurals may have occurred by the fusion of spines.

Based on the osteology and the ray counts of caudal skeletons of the species studied it may be concluded that fishes of the family cyprinidae belong to three new categories and their phylogenetic relationship as suggested by us is shown in Fig. 5. However, their correct taxonomic relationship could be fully resolved only after a study of other uncollected species and after a more detailed study of their entire osteology.

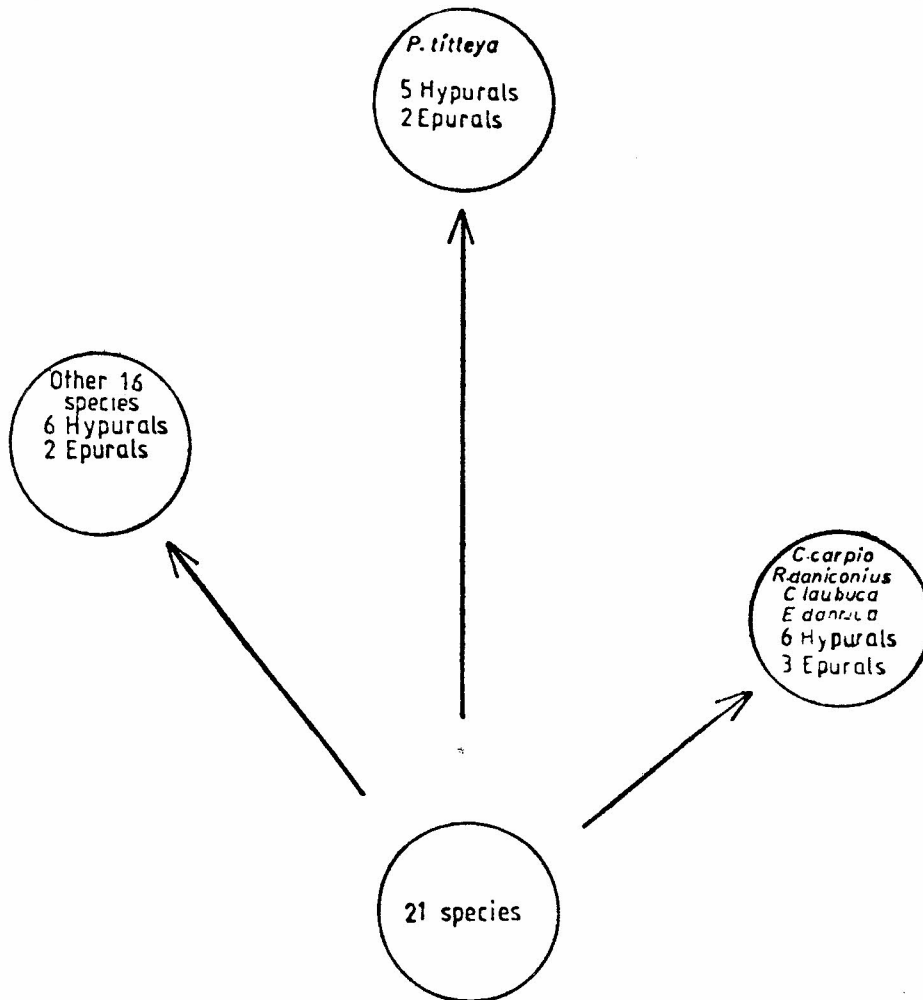


Fig. 5. The grouping of 21 species of Cyprinidae as indicated by the caudal skeleton.

5. Acknowledgement

The senior author wishes to thank Professor Winston E. Ratnayake for encouraging him to undertake research on the taxonomy of Sri Lankan fishes.

References :

1. Collette, Bruce B. and Chao, Labbish N. 1975. Systematics and Morphology of the Bonitos (Sarda) and Their Relatives (Scombridae, Sardini). Fish. Bull. 73 (3) 1975.
2. Collette, Bruce B. and Russo, Joseph, L. 1978. An Introduction to the Spanish Mackerels, Genus *Scomberomorus*. Proceedings of the Mackerel Colloquium, March 16, 1978.
3. Deraniyagala, P. E. P. 1952. A Coloured Atlas of Some Vertebrates from Ceylon I Pisces. Cey. Natn. Muse. Pub. Colombo i—xii: 1—49. . .
4. Frame D. W., Andrews T. J. and Cole C. F. 1978. Osteology of the American Plaice *Hippoglossoides platessoides*. Postilla 173 Peobo. Muse of Nat. His. Yale UHive. New Haven Ct. 06520.
5. Gosline W. A. 1961. The Perciform Caudal Skeleton. Copeia 1961 3: 265-270.
6. Gosline W. A. 1965. Teleostean Phylogeny. Copeia 1965 (2).
7. James C. T., David Jonson, G., Izuminakamuru, and Collette, B. B. 1989. Morphology of *Luvarus imperialis* (Luvaridae) with a Phylogenetic analysis of the Acanthuroidei (Pisces). Smiths. Contri. to Zoo. 489 Smiths. Insti. Press. Washington D.C.
8. Jinadasa J. and Cole C. F. 1978. Revision of the American Drums *Paralanchurus* and *Lonchurus* (Pisces Scianidae), Manus. Repo. 228. The Ohio State Univ. Columbus, Ohio U.S.A.
9. Jinadasa, J. and Kotalawala A. B. 1991. Interrelationships Among the Species of the Genus *Puntius* (Teleostei, Cyprinidae) as indicated by the Caudal Skeleton. Vidyo. J. Sci. (1991) 3 (1): 99-107.
10. Johnson D. G. 1975. The Procurent Spur and undiscrbed Perciform Caudal character and its Phylogenetic Implications. Occasional Papers. Calif. Acad. of Sci. 121:23.
11. Mendis A. S. and Fernando C. H. 1962. A Guide to the Freshwater Fauna of Ceylon Fish. Res. Stat. Dept. of Fish. Ceylon.
12. Munro I. S. R. 1956. The Marine and Freshwater Fishes of Ceylon. Dept. of Exter. Affai. Canberra.
13. Norden C. R. 1961. Comparative Osteology of Representative Salmonid Fishes with particular reference to the Greyling (*Thymallus arcticus*) and its Phylogeny. Jour of Fish. Res. Boad of Canada 18: 679-791.
14. Nursall, J. R. 1963. The Hypurophysis an Important Element of the Caudal Skeleton Copeia 1963 2: 458-459.

15. Nybelin O. 1973. Comments on the Caudal Skeleton of Actinopterygians. Supplement No. 1 Jour. of Linn. Soc. (Zoo 1).
16. Rao, V. S. K. 1977 Systematics and Comparative Osteology of Indian Lizzard Fishes (Saurida Spp.). Ind. Jour. of Sci. 24 (1 and 2): 143-171.
17. Topp, R. W. and Cole C. F. 1968. An Osteological Study of the Sciaenid Genus *Sciaenops Gill* (Teleostei, Scioenidae). Bull. of Mar. Sci. 18 (4) Dec. 1968: 902-945.
18. Vladkov, V. D. 1954. Taxonomic characters of the Eastern North America Chars (Salvelinus and Christivomers) Jour. of the Fish. Res. Board of Canada xi: 904-934