4. GENERAL DISCUSSION

..............................................................................................................
4.1. **Chromosome Banding in Fishes** :

Differential banding of metaphase chromosomes has provided a powerful tool for the study of systematic and phylogenetic relationships among a variety of vertebrates. Although much of the work in this area has focused on mammals, considerable chromosome banding data also have been published on birds, turtles, snakes and amphibians (Baker et al., 1982, 1983; Stock and Bunch, 1982; Schmid, 1980; Stock and Mengden, 1975; Bickham and Baker, 1976; Mengden and Stock, 1980). Comparatively very little work on chromosome banding in fishes has been done. The reason for this largely being the difficulties in obtaining sufficient number of quality well-spread metaphase in fishes and most fish complements contain relatively a large number of comparatively small chromosomes (Gold, 1979). However, of late reports have started pouring in with reasonable good results in the fish chromosome particularly with respect to C-banding and NOR-banding, whereas not much success has been achieved with respect to bands producing linear differentiation. For example, the reports of G-R and Q-banding have given a confusing picture of chromosomes in several cases. However, some other types of linear or fluctuant differential
Banking like early and late replication banding and restriction enzyme banding have produced quite satisfactory results. The main types of differential staining applied in fishes have been discussed as follows:

4.1.1. **Serial banding (G-bands)**

Serial or fluctuant bands (commonly known as G- or R bands) are lateral striation or transverse bands along the arms of the chromosomes and in mammals are thought to represent regions of either differential DNA base sequence composition or differential chemical and/or thermal sensitivity (Comings, 1978; Jorgenson et al., 1978 and Holmquist et al., 1982).

G-band regions in mammals are known to be rich in AT-base pair, resistant to protein denaturation or detergent treatment, sensitive to thermal denaturation and late replicating. R-(reverse) bands are known to be rich in GC-base pairs, sensitive to protein denaturation or detergent treatments, resistant to thermal denaturation and early replicating (Kato and Moriwaki, 1972; Comings, 1978; Jorgenson et al., 1978; Neumann et al., 1980; Bickmore and Sumner, 1989). Serial bands produced by protein or heat denaturation treatment have been reported in only a few
fishes (Rishi, 1979; Wiberg, 1983; Sola et al., 1984; Hartley and Horne, 1983; Almeida Toledo et al., 1988). However, in most of the cases, the resolution of individual bands was poor and did not permit to preclude definitive karyotyping.

G-banding has become a common method to identify accurately the homologous pair of chromosomes in case of human and mammals (Sumner et al., 1971). G-banding has been attempted on fish chromosomes too but variable results have been reported by different workers. The occurrence of positive G-bands in fish chromosomes have been reported by Abe and Muramoto (1974) in Salvelinus leucomaenis and S. malma, Rishi (1978b) in Channa punctatus, Rishi (1979) in Colisa fasciatus; Rishi and Rishi (1981) in Channa Punctatus, Colisa fasciata, Mystus tengara, Puntius sophore and Labeo calbasu, Passakas (1981) in Anguilla Anguilla, Weiberg (1983) in A. Anguilla and Sola et al. (1984) in A. rostrata. The bands obtained in A. Anguilla by application of GAC and GTG technique of Sumner et al. (1971) by Weiberg (1983) are of good quality. Ojima et al. (1986) obtained G-like bands with the application of new method developed by Takayama and Tachibana (1981). Infact, their technique was of early replication banding. Zhou et al. (1989) reported good
G-banding with Brdu –BSG method in silver carp. Liu and Xuecong (1986) reported the use of BrdU culture method to gain high resolution G-banding in rice eel (Monopterus albus) and catfish (Silurus asotus). Gold et al. (1990b) produced distinct G-bands in a Cyprinid fish, Opsopoeodus emiliae using trypsin G-banding method. Lakra and Krishna (1994) reported G-banded karyotypes of three species of Indian major carps i.e., catla catla, Labeo rohita and Cirrhinus mrigala.

During the present course of investigations attempts were made to obtain G-bands by using Trypsin G-banding technique of Gold et al. (1990b). Good G-bands were obtained in danio rerio, Amblyceps mangois, Tryplophysa microps, Ptychobarbus conirostris, Xenentodon cancila and Puntius ticto.

The difficulty in obtaining good quality structural banding patterns on the fish chromosomes and other cold-blooded vertebrates seems to be related to their chromosomes structure. It is generally believed that the genomes of warm-blooded vertebrates can be divided into GC-rich and GC-poor compartments, whereas cold-blooded vertebrates either lack or show weak compartmentalization of their genomes by base composition (Bernardi, 1989). This
absence of compartmentalization in fish genomes can be the reason of failure in obtaining good G-bands.

4.1.2. **C-banding:**

C-bands represent the regions of constitutive heterochromatin (Summer, 1977) and predominantly contain transcriptionally inactive, highly repeated DNA sequences. Most C-banding techniques involve chromatin depurination (with acid) denaturation (with base) and preferential extraction of non-heterochromatin DNA in hot salt solutions (Coming, 1978). C-banding helps in revealing the distribution of constitutive heterochromatin and also to determine its role in the karyotype evolution, speciation and differentiation of sex chromosomes. C-banding has been quite successful in fish chromosomes. The C-heterochromatin has been documented for about 125 species of fishes (Table 48) spread over different families with primary emphasis on documenting the existence and location of C-bands on fish chromosomes.

C-banding techniques for C-heterochromatin in fish chromosomes was applied for the first time by Abe and Muramoto (1974) in two salmonid fishes (*Salvelinus leucomaenis* and *Salvelinus malma*) and Zenzes and Voiculescu (1975) in *Salmo trutta*. Subsequent to these reports,
Several workers successfully obtained C-bands in different fish species (table 48).

Liyod and Thorgaard (1988) and Cau et al. (1988) reported that treatment of metaphase chromosomes with specific restriction endonuclease enzymes followed by Geimsa staining produce C-bands on the chromosomes of rainbow trout and the muraemid, Muraena Helena respectively. Some workers have used fluorochromosomes to resolve C-bands. AT-enhancing fluorochromes such as quinacrine or DAPI have been used to resolve C-bands in Salmonids, a Poeciliid and several European percids (Haaf and Schmid, 1984; Mayr et al., 1987; Phillips and Hartley, 1988), whereas the GC-enhancing fluorochromosomes CMA have been used to resolve C-bands in north American percid (Amemiya and Gold, 1986).

In India, Rishi and Mandhan (1990) obtained C-bands for the first time in Labeo roita. Thereafter, several reports on C-banding in Indian fishes have been published (Rishi and Gill, Rishi and Thind, 1992; Rishi and Girdhar, 1992, 1993; Rishi and Thind, 1994 and Rishi et al., 1994). Excepting the reports from Rishi and co-workers, Indian fish species have remained unexplored
for C-banding. During the present study, C-banding has successfully been done in 10 species of fishes.

Most of the reports on C-banding in fishes reveal the distribution of C-heterochromatin to be of multisite type (Table 48). In most of the fishes C-heterochromatin is located on the centromeric and telomeric regions. However, intercalary C-bands and whole arm or whole chromosome C-bands have also been reported (Table 48). Garcia et al. (1987) has pointed out that constitutive heterochromatin may not be restricted to centromeric region in fishes. Rishi and Rishi (1992) reviewed C-heterochromatin in fishes and described a varied distribution of C-heterochromatin in fishes chromosomes.

The present observations revealed multisite distribution of C-heterochromatin in fishes investigated. In Mastacembelus pancalus, Amblyceps mangois and Ompok bimaculatus centromeric and telomeric C-bands have been recorded, while Channa gachua, Ptychobarbus conirostris, Schizothorax Richardsoni and Tryplophysa microps showed whole short arm or whole long arm or whole chromosome C-bands in addition to centromeric and telomeric C-bands. Schizothorax niger and Schizothoraiichthys labiatus showed intercalary C-bands besides centromeric and telomeric C-bands.
### Table 48. Chromosomal Constitutive Heterochromatin in fishes

<table>
<thead>
<tr>
<th>Species</th>
<th>Location of C-bands</th>
<th>References</th>
</tr>
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<tbody>
<tr>
<td><strong>Order: Acipenseriformes</strong></td>
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<td></td>
</tr>
<tr>
<td><strong>Family: Acipenseridae</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Acipenser ruthenus</em></td>
<td>C, WSA</td>
<td>Ojima et al. (1986)</td>
</tr>
<tr>
<td><strong>Family: Anguillidae</strong></td>
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<td></td>
</tr>
<tr>
<td><em>Anguilla Anguilla</em></td>
<td>C, I</td>
<td>Wiberg (1983)</td>
</tr>
<tr>
<td><em>A. anguilla</em></td>
<td>C, I, WSA</td>
<td>Park and Grimm (1981)</td>
</tr>
<tr>
<td><em>A. rostrata</em></td>
<td>C, I, WSA</td>
<td>Park &amp; Grimm (1981)</td>
</tr>
<tr>
<td><em>A. rostrata</em></td>
<td>C, I, WSA</td>
<td>Passakas (1981)</td>
</tr>
<tr>
<td><strong>Family: Congridae</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Conger myriasret</em></td>
<td>C</td>
<td>Ojima and Ueda (1982)</td>
</tr>
<tr>
<td></td>
<td>(sex pair of same size differ in C-banding)</td>
<td></td>
</tr>
<tr>
<td><strong>Family: Ophichthidae</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ophysurus serpens</em></td>
<td>C</td>
<td>Thode et al. (1985)</td>
</tr>
<tr>
<td></td>
<td>(NOR) coincident with C-negative region)</td>
<td></td>
</tr>
<tr>
<td><strong>Order: Atheriniformes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Family: Atherinidae</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Odontesthes bonariensis</em></td>
<td>C, T, I</td>
<td>Sola et al. (1988)</td>
</tr>
<tr>
<td><strong>Family: Oryziatidae</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Oryzias celebensis</em></td>
<td>C, I, WSA</td>
<td>Uwa et al. (1981)</td>
</tr>
<tr>
<td><em>O. curvinotus</em></td>
<td>C, I</td>
<td>Uwa et al. (1982)</td>
</tr>
<tr>
<td><em>O. latipes</em></td>
<td>C</td>
<td>Uwa &amp; Ojima (1981)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Contd..)</td>
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</table>
**Order: Characiformes**

**Family: Anostomidae**

<table>
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<th>Chromosome Types</th>
<th>Reference</th>
</tr>
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<tbody>
<tr>
<td>Leporinus elongates</td>
<td>C</td>
<td>Galetti Jr. &amp; Foresti (1986)</td>
</tr>
<tr>
<td></td>
<td>(W-chromosome intensely stained)</td>
<td></td>
</tr>
<tr>
<td>L. obtusideus</td>
<td>C</td>
<td>-do-</td>
</tr>
<tr>
<td></td>
<td>(-do-)</td>
<td></td>
</tr>
<tr>
<td>Leporinus pian</td>
<td>C,T</td>
<td>Galetti, Jr. et al. (1991)</td>
</tr>
<tr>
<td>L. taeniatus</td>
<td>C,T</td>
<td>-do-</td>
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</table>

**Family: Characidae**

<table>
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<tr>
<th>Species</th>
<th>Chromosome Types</th>
<th>Reference</th>
</tr>
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<tr>
<td>Astyanax scabripinnis</td>
<td>C,T</td>
<td>Maistro et al. (1992)</td>
</tr>
<tr>
<td>Puranae</td>
<td>extra meta-Centric WC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(B-chromosome In some partial WC C-banded)</td>
<td></td>
</tr>
<tr>
<td>Colosoma macropomum</td>
<td>C,T,WSA,WLA</td>
<td>Almeida Toledo et al. (1987)</td>
</tr>
<tr>
<td>C. mitrei</td>
<td>C,I</td>
<td>-do-</td>
</tr>
<tr>
<td>Moenkhausia</td>
<td>C,I,WSA</td>
<td>Foresti et al. (1989)</td>
</tr>
<tr>
<td>Sanctaefilomenae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serrasalmus spilopleura</td>
<td>C</td>
<td>Galetti Jr. et al. (1985)</td>
</tr>
<tr>
<td>Triportheus guentheri</td>
<td>C,T</td>
<td>Bertollo &amp; Cavallaro (1992)</td>
</tr>
<tr>
<td>Colosome mitrei X</td>
<td>C,T,I</td>
<td>Almeida Toledo et al.</td>
</tr>
<tr>
<td>C. macropomum</td>
<td></td>
<td>(1987)</td>
</tr>
</tbody>
</table>

(Contd....)
**Family: Parodontidae**

*Parodon hilarii* C,T, most of Moreira-Filho et al. (1993)

The long arm

Of W-chromosome

C-positive

---

**Family: Notopteridae**

*Notopterus notopterus* C Rishi & Thind (1994)

Order: cypriniformes

---

**Family: prochilodontidae**

Semaprochilododus

*Taeniurus* C,T,I WSA Feldberg et al. (1987)

---

**Family: Apteronotidae**

*Apterontus albidrons* C,I (NOR Almeida-Toledo et al. 1981) coincide with C-bands

---

**Family: Cobitidae**

*Cobitis taenia*

*Striatus* C Saitho et al. (1984)


*Sabanefewia aurata* C Rab et al. (1991b)

*Balcanica* C present study

*Tryplophysa microps* C,T,WSA,WLA present study

---

**Family: Cyprinidae**

*Acheilognathus*

*Rhombeus* C Takai and Ojima (1988)

*Aspius aspius* C,T rab et al. (1990)

*Carassius auratus* C,WSA TKI and Ojima (1987)

*C.auratus longdorfi* C,WSA Takai and Ojima (1983)

*C.carassius* C,WSA Ojima (1987)

*Cyprinus carpio* C Ojima and Umeda (1978)

*Ischikauria staenackeri* C,I Takai and Ojima (1988)

(Contd....)
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<th>Fish Family</th>
<th>Scientific Name</th>
<th>Cytogenetic Details</th>
<th>Reference(s)</th>
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<tr>
<td>Labeo</td>
<td>Labeo rohita</td>
<td>C</td>
<td>Rishi and Mandhan (1990)</td>
</tr>
<tr>
<td>Notropis</td>
<td>Notropis lutrensis</td>
<td>C,T,I,WSA</td>
<td>Gold et al. (1986)</td>
</tr>
<tr>
<td>N. venustus</td>
<td>N. venustus</td>
<td>C,T,I,W,SA</td>
<td>-do-</td>
</tr>
<tr>
<td>Puntius</td>
<td>Puntius conchonius</td>
<td>C,WSA</td>
<td>Takai and Ojima (1986)</td>
</tr>
<tr>
<td>P. sophore</td>
<td>P. sophore</td>
<td>C</td>
<td>Rishi and Thind (1992)</td>
</tr>
<tr>
<td>P. ticto</td>
<td>P. ticto</td>
<td>C,T</td>
<td>present study</td>
</tr>
<tr>
<td>Sarcophalteichthys</td>
<td>Variegatus variegatus</td>
<td>W,WLA</td>
<td>takai and Ojima (1988)</td>
</tr>
<tr>
<td></td>
<td>Tinca tinca</td>
<td>C,T,C-band</td>
<td>Padilla et al. (1993)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Associated with NOR-region</td>
<td></td>
</tr>
<tr>
<td>Ptychobarbus</td>
<td>Ptychobarbus</td>
<td>C,T,WC</td>
<td>present study</td>
</tr>
<tr>
<td>Conirostris</td>
<td>Conirostris</td>
<td>C,T,WC</td>
<td>present study</td>
</tr>
<tr>
<td>Schizothoraichthys</td>
<td>Schizothoraichthys</td>
<td>C,T,I</td>
<td>Present study</td>
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<tr>
<td>Labiatus</td>
<td>Labiatus</td>
<td>C,T,I</td>
<td>Present study</td>
</tr>
<tr>
<td>Schizothorax niger</td>
<td>Schizothorax niger</td>
<td>C,T,I</td>
<td>Present study</td>
</tr>
<tr>
<td>S. richardsoni</td>
<td>S. richardsoni</td>
<td>C,T,WC</td>
<td>Present study</td>
</tr>
<tr>
<td>Zacco platypus</td>
<td>Zacco platypus</td>
<td>C</td>
<td>Takai &amp; Ojima (1988)</td>
</tr>
<tr>
<td>Z. temminki</td>
<td>Z. temminki</td>
<td>C,I</td>
<td>-do-</td>
</tr>
</tbody>
</table>

**Family: Prochilodontidae**

| Semaprochilodus | Insignis | C,I,WSA | Feldberg et al. (1987) |

**Order: Cyprinodontiformes**

**Family: Cyprinodontidae**

<table>
<thead>
<tr>
<th>Fundulus heteroclitus</th>
<th>Fundulus heteroclitus</th>
<th>C,WSA</th>
<th>kornfeild (1981)</th>
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**Family: Poeciliidae**

<table>
<thead>
<tr>
<th>Poecilia latipinna</th>
<th>Poecilia latipinna</th>
<th>C,T,I</th>
<th>Sola et al. (1990)</th>
</tr>
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(intense C-band) on W-chromosome

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<td><strong>Family: Ophiocephalidae</strong></td>
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</tr>
<tr>
<td>Channa argus</td>
<td>C,WLA</td>
</tr>
<tr>
<td>C asiatica</td>
<td>C,WLA</td>
</tr>
<tr>
<td>C maculata</td>
<td>C,WLA</td>
</tr>
<tr>
<td>C punctatus</td>
<td>C,WLA</td>
</tr>
<tr>
<td>C gachua</td>
<td>C,T,WSA</td>
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<td><strong>Family: Belontidae</strong></td>
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</tr>
<tr>
<td>Colisa fasciatus</td>
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</tr>
<tr>
<td>W-chromosome</td>
<td>Has long arm</td>
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<td>Blennius galerita</td>
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</tr>
<tr>
<td>B gatturugine</td>
<td>C,T,WSA, -do-</td>
</tr>
<tr>
<td>B paro</td>
<td>C,T,J,WSA -do-</td>
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<tr>
<td>B pholis</td>
<td>C,T,WSA,WSA -do-</td>
</tr>
<tr>
<td>B ponticus incognitus</td>
<td>C,T -do-</td>
</tr>
<tr>
<td>B sanguinotentus</td>
<td>C,T,I,WSA -do-</td>
</tr>
<tr>
<td>B trigloides</td>
<td>C,T,WSA,WSA -do-</td>
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<tr>
<td>Dicentrarchus labrax</td>
<td>C,WSA</td>
</tr>
<tr>
<td>D punctatus</td>
<td>C,WSA -do-</td>
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<th>Family: Cichlidae</th>
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<tr>
<td>Sarotherodon aurea</td>
<td>C,WSA,C,WSA</td>
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<tr>
<td>S galilaelus</td>
<td>C,WSA -do-</td>
</tr>
<tr>
<td>Tilapia zilli</td>
<td>C,WSA</td>
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<tr>
<td>Family</td>
<td>Genus</td>
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<td>Gobiesocidae</td>
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<td>Gobiidae</td>
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<td>G. schraaester</td>
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<td>Lucioperca lucioperca</td>
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<td>Schiaenidae</td>
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<td>Salmoniformes</td>
<td>Onchorhynchus nerka</td>
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<tr>
<th>Species</th>
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<tbody>
<tr>
<td>Salmo gairdneri</td>
<td>C, WSA</td>
<td>Thorgaard (1976)</td>
</tr>
<tr>
<td><em>S. gairdneri</em> ×</td>
<td>C, WSA</td>
<td>Thorgaard (1976)</td>
</tr>
<tr>
<td>S. frontinalis</td>
<td>C, WSA</td>
<td>Zenes and Voiculescu (1975)</td>
</tr>
<tr>
<td>S. trutta</td>
<td>C, J, WSA</td>
<td>Martinez et al. (1991)</td>
</tr>
<tr>
<td><em>Salvelinus alpinus</em></td>
<td>C, J, T</td>
<td>Hartley (1991)</td>
</tr>
<tr>
<td><em>S. leucomaenis</em></td>
<td>C, T</td>
<td>Abe and Muramoto (1974)</td>
</tr>
<tr>
<td><em>S. malma</em></td>
<td>C, T</td>
<td>-do-</td>
</tr>
<tr>
<td><em>S. malma malma</em></td>
<td>C, WSA, WLA</td>
<td>Ueda and Ojima (1983)</td>
</tr>
<tr>
<td><em>S. frontilanis</em></td>
<td>C, T, I, WSA</td>
<td>Ueda and Ojima (1983)</td>
</tr>
<tr>
<td><em>S. frontilanis</em></td>
<td>C, T, WSA</td>
<td>Hartley (1991)</td>
</tr>
</tbody>
</table>

**Family: Umbridae**

*Umbra limi*       C, T       Kligerman and Bloom (1977)  

**Coincide with C-band**

**Family: Scorpienidae**

*Scorpaena notata* C, T, NOR in C-positive Region Thode et al. (1985a)  

Contd...
Order: Siluriformes

Family: Bagridae


Family: Callichthyidae

*Aspidoras fuscoguttatus* C,T Oliveira et al. (1993)

*Brochis britskii* C,T,WSA -do-

*B. splendidens* C,T,WSA -do-

*Callichthys callichthys* C,WSA -do-

*Corydoras panda* C,WSA -do-

*C. aeneus* C,WSA -do-

*C. rabanti* C,WSA -do-

*Dianema urostriata* C,I -do-

*Hoplosternum littorale* C,I -do-

*Hoplosternum sp.* C,I -do-

Family: Clariidae

*Clarias petrachus* C, -do-

Family: Heteropneustidae


Family: Pimelodidae

*Pimelodella kronei* C,WSA Almeida-Toledo et al. (1992)

*P. transitoria* C,WSA -do-

Family: Siluridae

*Ompok bimaculatus* C,T present study

*Silurus glanis* C,I,T,WSA Rab et al.(1991a)

Family: Amblycepidae

*Amblyceps mangois* C,T Present study

Order: Mastacembeliformes

Family: Mastacembelidae

Contd......
<table>
<thead>
<tr>
<th>Species</th>
<th>C,T</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mastacembelus</td>
<td></td>
<td>Present study</td>
</tr>
<tr>
<td>Pancalus</td>
<td>C.T</td>
<td>Present study</td>
</tr>
<tr>
<td>Macrognathus aculeatus</td>
<td>C</td>
<td>Rishi et al. (1994)</td>
</tr>
</tbody>
</table>

**Order: Tetradontiformes**

**Family: Balistidae**

<table>
<thead>
<tr>
<th>Species</th>
<th>C</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melichthys vidus</td>
<td>C</td>
<td>Kitayam and Ojima (1984)</td>
</tr>
</tbody>
</table>
General hypothesis have been put forth to explain the possible role of C-heterochromatin in karyotype evolution of fishes. Hinegardener and Rosen (1972) pointed out that loss of C-heterochromatin may be responsible for emergence of smaller genome size during the course of evolution. Kornfeild et al. (1979) suggested that elimination of C-heterochromatin accompanies the phyletic evolution of fishes. The presence of intercalary C-heterochromatin, however, suggests chromosomal rearrangements by pericentric inversions (Zenzes and Voiculescu, 1975). Phillips and Zajicek (1982) suggest that C-banding could be a better device for intraspecific comparisons since C-heterochromatin is one of the most rapidly evolving part of the genome. In view of wide range of heterochromatin sites in fishes, it is proposed that most fish genomes are in a state of flux and are prone to lose or gain of DNA. The wide variation in C-heterochromatin has been considered responsible for the large scale chromosomal polymorphism exhibited by many fish groups (Rishi and Rishi, 1992). A continuous and random variation of DNA content in fish species, which otherwise exhibit similar karyotypes, may be entirely due to variability in the heterochromatin fractions of their DNA which are also phenotypically inconsequential.
Some examples have come to light where sex-chromosomes have differentiated in a cryptic fashion and these can be visualized only by C-banding (Ojima and Ueda, 1982; Haaf and Schmid, 1984; Galetti Jr. and Foresti, 1986; Mayr et al., 1987; Thode, 1987; Rishi and Gill, 1992). Ojima and Ueda (1982) could observe W and Z chromosomes in Conger myriaster in which they had earlier failed to identify these elements having similar size and morphology. Haaf and Schmid (1984) reported an interesting case of homomorphic W and Z chromosomes in Poecilia sphenops va. Melanistica with intense C-banding on the long arm of W-chromosome. Galetti Jr. and Foresti (1986) also found the W-chromosome having intense C-banding in species of the genus Leporinus. Mayer et al. (1987) observed totally heterochromatized Y in Lucioperca luciperca, Gymnocephalus cernus, G. schraestee, and perca fluviatilis. They (1987) could also observe heteromorphic sex-chromosomes in Lepidogaster candollei with Y being totally heterochromatic. In Colisa fasciatus, Rishi and Gill (1992) found the long arm of W to be fully heterochromatic in WZ sex chromosomes. Bertollo and Cavallano (1992) found heteromorphic pair in Triparthous guentheri where W was totally C-band positive and Z with heterochromatin only at telomeric and centromeric regions.

No sex chromosomes could be detected in any of
The fish species on the basis of C-banding in the present study indicating the absence of well defined sex chromosomes. It seems that C-banding can help to detect the sex chromosomes only in those forms in which an accumulation of highly repetitive sequences have taken place on the element of the homomorphic sex chromosome pair (Singh et al., 1976).

In fishes, NORs have been found associated with C-band region such as in Umbra limi (Klingerman and Bloom, 1977), scorpaena notata (Thode et al., 1985a) and Colisa fasciatus (Rishi and Gill, 1992). However, the significance of the association of NORs with C-positive regions is not yet clear. During the present study, an association of NOR with C-band has been observed in Tryplophysa microps.

4.1.3. **NOR-Banding**:

NOR-Bands (With silver) represent the chromosomal sites of 18S and 28S ribosomal RNA (>RNA) which presumably were actively transcribed at a preceding interphase (Howell, 1977, 1982). The silver-staining reaction itself is apparently specific for a NOR-associated, non-histone protein that selectively binds
NOR-banding patterns are now known for well over 200 species of fishes (Gold et al., 1990). In most cases, emphasis has been laid only on documenting NOR-bands on fish chromosomes. However, NOR-banded phenotypes have been used to address systematic, population or cytogenetic problems by workers like Amemiya and Gold (1988), Gold (1988), Gold et al. (1988), Gold et al. (1990a), Amemiya and Gold (1990a,b), Li and Gold (1991), Jenkin and Gold (1992) on North American Cyprinids and studies by Phillips and colleagues on salmonid fishes (Phillips et al., 1986, 1988 and 1989).

The visualization of nuclear organizing regions (and reduces) ionic silver. NOR-banding with GC-base pair banding fluorochromes chromomycin A₃ (CMA) or mithramycin has been observed in nearly all vertebrates groups except mammals (Schmid, 1982; Amemiya and Gold, 1986; Schmid and Guttenbach, 1988). Unlike silver, CMA and mithramycin apparently stain DNA and differentiate NORs regardless of previous genetic activity of chromosomal stage (Amemiya and Gold, 1986; Schmid and Guttenbach, 1988). Both fluorochromes, however, can also selectively stain heterochromatin (Amemiya and Gold, 1986), suggesting that some caution is advisable before considering a CMA or mithramycin bright region on a chromosome as a NOR.
(NOR) on the chromosomes has become now an important parameter adding to the structural details of the karyotypes. For silver staining most researchers employ Howell and Black’s (1980) one step method using a colloidal developer. The Ag-NOR staining technique of mammalian chromosomes (Goodpasture and Bloom, 1975; Hsu et al., 1975) was first time applied in fishes in case of Fundulus chromosomes by Howell and Black (1979). Since then a lot of work has been done on localization of NORs in fishes. On the basis of available literature, it has been observed that the number of NORs, the morphology of NOR-bearing chromosomes and the position of the NORs on the chromosomes show marked diversity. Closely related species with very similar karyotypes may show different NOR sites. Therefore, the NORs can serve as an important aid for species differentiation and fish systematics.

Foresti et al. (1981) studied NORs in five species of Order Gymnotiforms viz., Gymnotus carapo, Apteronotus albifrons, Sternopygus macrurus, Eigenmannia Virescens and Eigenmannia sp. And reported polymorphic nature of NORs in the group. In Eigenmannia sp. They reported intraspecific variability of NOR-bearing pair and an increase in the length of that region, the larger one being about six times the size of the smaller. They
Suggested that an increase in the ribosomal genes in the NORs of certain species occurred during the evolution of this group.

Feldberg and Bertollo (1985) studied NORs in 10 neotropical species of family Cichlidae (perciforms). In eight species, the NORs were located on first pair of the complement, while in the remaining two, NORs were located on a relatively large but not the first pair in the karyotype. The NORs location showed variation from interstitial position in short arm/long arm to terminal on long arm or short arm.

The ribosomal RNA gene expression in the genomes of evolutionary diploid (Scardinus erythrophthalmus, Leucaspius delineatus, Tinca tinca) and polyploidy species (Cyprinus carpio, Carassius carassius, C. auratus auratus and C. auratus gibelio) of cyprinidae were investigated by Mayr et al. (1986) using silver nitrate and counterstain-enhanced fluorescence technique. The diploid species exhibited only one pair of chromosomes with NORs, whereas in tetraploids (Carassius auratus auratus and C. carassius) three Ag-NORs were present and in hexaploid (C. auratus gibelio) four NORs found to be present. In Cyprinus carpio they observed the presence of only one pair of NORs.
They suggested partial or complete functional inactivation of the third and the fourth NORs in the evolutionary tetraploid species of carp (*Cyprinus carpio*) and considered it as a mechanism to prevent the detection of metaphase NORs, because silver staining demonstrates only transcriptionally active rRNA genes. Earlier comparative investigations on evolutionary tetraploid (2n=100) species of Cyprinidae comprising *Cyprinus carpio* (Takai and Ojima, 1982), *Carassius auratus auratus*, *C. auratus* subsp., *C. auratus buergeri*, *C. auratus grandoculis* and *auratus cuvieri* (Taki and Ojima, 1982; Ojima and Yamono, 1980) consistently led to the detection of only two AG-NORs associated with the 12th largest chromosome pair.

Takai and Ojima (1986) published a list of about 80 species showing the morphology of NOR bearing homologous number of NORs, location and types of NORs. They categorized the NORs in fishes into seven categories. They observed that the NOR-bearing chromosomes showed various forms among the different species but most of them belong to telocentric/acrocentric or subteloacentric type (54%) and some to submetacentric type (35.7%) with very vast range of size from largest (in many pomacentrids) to smallest (in *Rhodeus ocellatus ocelatus*).
Most species of fishes show only small NORs on a single pair of chromosomes. This usual condition has been considered as fundamental and original in fishes by Takai and Ojima (1986). Thode (1987) considered the fishes with only one pair of NORs as of ancestral status. The large NORs found in some Cyprinids and gymnotids may be as a result of an increase in the DNA content by accidental translocation, duplication or other mechanisms (Takai and Ojima, 1986). Multiple NORs might have been induced due to partial translocation of NORs to other non-NOR bearing chromosomes. However, this assertion has been put to question by findings of multiple NORs in more and more species. Even a completely opposite explanation, though less plausible that single pair NORs might have resulted by the aggregation of multiple-site NORs, is also possible.

Some of the important reports about NOR studies are those of Klingerman and Bloom (1977), Kornfeild et al. (1979), Uwa and Ojima (1981), Uwa et al. (1981), Uwa et al. (1982), Takai et al. (1987), Suzuki et al. (1988), Lopez et al. (1989), Ueda et al. (1988), Oberdorff et al. (1990), Sanchez et al. (1990), Vitturi et al. (1990), Sola et al. (1990), Takai and Ojima (1991), Ren et al. (1991), Rab et al. (1991a,b), Almeida-Toledo et al. (1992), Magtoon and Arai (1993), Padilla et al. (1993), Zhang and Zeng (1993) and Tatewaki and Kitada (1994).
In Indian fishes, some work on the analysis of NORs has been done by Rishi et al. (1991), Rishi and Manjusha (1991), Rishi and Thind (1992), Rishi and Gill (1992), Rishi and Girdhar (1992), Rishi et al. (1993), John et al. (1992), Rishi and Thind (1994), and Rishi et al. (1994).

Gold and Amemiya (1986) worked out 14 species of Cyprinidae and observed at least 10 different NOR phenotypes. Based on their findings, they conclude that North American Cyprinids are far less conservative in terms of chromosomal evolution than previously believed. Amemiya and Gold (1988) found the study of NORs useful in both cytotaxonomy and cytosystematics of North American Cyprinids. Gold et al. (1988) studied NOR phenotypes of eight species of North American Cyprinid genus Notropis (subgenus Cyprinella). All the eight species had a single pair of chromosomal NORs. In four of the five Cyprinella species, the NORs were located terminally on the arm of medium-sized metacentric chromosome pair, in the fifth Cyprinella sp., the NORs were located on short arms of the large submetacentrics pair and in the remaining three species, the NORs were located on short arms of the medium-sized submetacentric pair. Amemiya and Gold (1990a) worked out seven species of North American Cyprinids and gave
The NOR studies may also throw light on the secondary diploidization, that succeeds the polyploidy origin of some species. Phillips et al. (1986) showed only one pair of NORs in each of the six species of salmonid fishes (Oncorhynchus). Therefore, these species which are regarded as tetraploid in origin must have secondarily consolidated NORs only in one pair of chromosomes during the process of regressive diploidization. During the course of present study two Cyprinid species, Schizothoraichthys labiatus (2n=98) and Ptychobarbus conirostris (2n=84), thought to be tetraploids in origin have been found to bear only one pair of NOR on a subtelocentric pair in each and the process of regressive diploidization seems to be cause of the presence of the single pair of NORs in these species.

The occurrence of multiple NORs is not uncommon in fishes. This type NOR distribution has been reported in some species of the family Cyprinidae (Takai and Ojima, 1984). Two pairs of NORs were reported in Sacrocheilichthys variegates, variegates, Tribolodon hakonensis, Moroco jouyi, Zacco platypus, three pairs in Ischikauia steenackeri and four pairs in Zacco termmincki. Takai and Ojima (1986)
again observed two pairs of NORs in *Pungtungia herzi* and *Hemibarbus barbus*. Gold *et al.* (1990a) also observed multiple NORs in four species of North American Cyprinids. In one of the species, *Phenacobius mirabills* they observed the presence of three pairs of NORs. Rishi and Gill (1992) reported three pairs of NORs in *Colisa fasciatus*. Again Rishi and Thind (1992) reported the presence of 2 pairs of NORs in case of *Puntius sophore*. Multiple NORs have also been reported in *Moenkhausia sanctifilomenae* (Foresti *et al.* 1989). Rishi and Thind (1994) reported an interesting rare case of multiple NORs in *Notopterus notopterus*. They found that NORs were present on all the 42 elements of the complement. However, one pair possessed very prominent and large NORs than the others.

The heteromorphic NORs have also been reported in fishes (Gold, 1984; Amemiya and Gold, 1986; Phillips *et al.*, 1986; Rishi and Manjusha, 1991; Rishi and Gill, 1992). The heteromorphism may be either functional (when one NOR shows more activity) or structural due to the presence of more rDNA cistrons present on one homologous and may be due to variable distribution or activity of ribosomal cistron (Takai and Ojima, 1986; Foresti *et al.*, 1989).

Various workers have tried to explain the varied locations of NORs in the chromosomes of several species. NOR location in interstitial region in many forms of
Balistidae probably originated by tandem fusion between NOR-bearing chromosomes and other chromosomes (Kitayama and Ojima, 1984; Takai and Ojima, 1986). Rishi et al. (1993) also reported the interstitial NOR pair in *Channa punctatus* (Ophiocephalidae). They suggested that the condition might have been produced through pericentric inversion or even through centric fusion of two acrocentric chromosomes, one of which had telomeric NOR. They considered this state of NORs in *C. punctatus* a derived one.

During the course of present study 5 species of fishes provided satisfactory results with silver staining viz., *Danio rerio*, *Ptychobarbus conirostris*, *Schizothraichthys labiatus* (Cyprinidae), *Tryplophysa microps* and *T. stoliczkae* (Cobitidae). In all only single pairs of NORs have been observed, which were homomorphic. In *Danio rerio*, NORs were present on the telomeres of the long arms of the largest subtelocentrics pair, in *Tryplophysa microps* and *T. stoliczkae* these were present on the telomeres of the 2nd pair of metacentric, whereas in *Ptychobarbus conirostris* and *Schizothraichthys labiatus*, these were present on the telomere of short arms of a subtelocentric pair. Presence of NORs in 2nd metacentric pairs in *Tryplophysa microps* and *Tryplophysa stoliczkae* suggest a close relationship of the two species.
4.2. Karyotype Evolution in fishes

Considering the large number of fish species, the variation in their morphological characters, habitat of most diversified environmental conditions and antiquity of the group as a whole, one might expect a corresponding karyotypic diversification. In fact, this is not exactly the case. There exists uniformity in the karyotypes even among members of distant orders with different evolutionary age of about tens of millions years (Gold, 1979). Despite the uniformity in fish karyotype in general, variations with regard to both chromosome number as well as morphology in different taxa are recorded. The diploid chromosome numbers in fishes range from 12 in Gonostoma bathyphylum (Post, 1974) or 16 in Spharichthys osphoromonoides (Calton and Denton, 1974) to $2n=446+$ in Diptychus dipogon (Yu and Yu, 1990). The diploid numbers show peak at 46, 48 and 50. In nearly 70% of species, the diploid number range from 44 to 50 and in about 80% these lie in the range of 40 to 56 (Rishi, 1989).

In the interpretation of karyotypic evolution it is often assumed that primitive fish karyotype consists of 48 rods from which the karyotypes of all existing fish forms have been derived (Nogusa, 1960; Post, 1965; Roberts, 1967; Ohno et al., 1967, 1968 and many
Others) but the issue seems it to be resolved. The discovery of 48 acrocentrics in Pacific hag fish, *Eptatretus stouti* (Taylor, 1967) and the occurrence of 48 rods in the majority of fishes studied prior to 1967 led to the idea that the primitive karyotype of ancestral vertebrate might consist of 48 rods. Therefore most of the subsequent workers assumed the karyotype evolution in different groups of fishes based on this basic assumption of 48 rods as the primitive diploid number. However, Manna and Khuda–Bukhsh (1977a,b) pointed out that many of the fishes reported earlier to have 48 rods showed quite a few biarmed chromosomes when reinvestigated by deploying some better techniques, although the peak remained at 48 after substantial data accumulated. Therefore, they opined that the rationale behind attributing chromosomes of mixed morphology (both uniarmed rods and biarmed ones) to account for the karyotypic evolution in various groups of fishes, mainly through structural rearrangements of various nature, such as pericentric inversions, Robertsonian fusion / fission etc. seemed to be a better proposition. But the discovery of 2n=24 acrocentrics in two species of freshwater eels (Rishi and Haobam, 1984b; Kitaba and Tagwa, 1973), 2n=36 rods in two species of *Myxine* (Kitada and Tagwa, 1973), low diploid numbers ranging from 14 to 42 in a large number of fish families (Khuda-Bukhsh et al., 1986), showing NF less than 36 in some cases, would
possibly call for a more cautious predictions on the perimitive karyotype of fish, particularly in the absence of chromosomal data in many intermediate forms including Ostracoderm fishes (Khuda-Bukhsh, 1984) and for the difficulty of explanation in derivation of the low diploid numbers of 16 to 24 in some species from the assumed 48 rods or mixed type. Ojima (1983) and Khuda-Bukhsh et al. (1986) even gave hint if a lower diploid number (2n=24?) beassigned to the first group of fishes, freshly evolved from primitive chordates, from which multi directional evolution proceeded with polyploidy as an early event accompanied by other forms of structural rearrangements like pericentric inversions and Robersonian fusion/fission and deletions etc. From the available data, it becomes clear that almost all types of chromosomal rearrangements have played a role in the evolution of fish karyotypes (Manna and Prasad, 1971; Rishi, 1989). Polyploidization, Robertsonian fusion/fission, pericentric inversions and addition and subtraction of heterochromatin have contributed in evolving the karyotypes in fishes. The role of each type of rearrangements have been discussed below.

**4.2.1. Polyploidization:**

Polyploidization is a process by which chromosome number gets increased by an exact multiple of the chromosome set. The instances of occurance of
Polyploidy in fishes and the possible role of polyploidy in evolution of fish karyotypes will be discussed in chapter on “polyploidy in fishes”.

Absence of well defined sex mechanism and occurrence of higher diploid number as well as higher DNA contents in several fish species have prompted researchers to take an account of the role played by polyploidy in the evolution of fish karyotypes (Ohno, 1970; Ojima, 1982b; Allendorf and Thorgaard, 1984 and Harteley, 1987).

In most cases of polyploidization, subsequent regressive functional and structural diploidization process have occurred after tetraploidization (Ohno, 1970) to make the species of tetraploid origin secondarily diploid. Because of this, the species at present possessing higher 2n and higher DNA content are not to be called polyploidy but of polyploidy origin.

Examples of fishes having evolved through polyploidy come across in Orders – Acipenseriforms (Serebrjakova, 1979), Siluriforms (Hinegardener and Rosen, 1972; Nayyar, 1966) and families-Salmonidae and Thymallidae (Ohno, 1970, 1974), Cyprinidae (Ohno and Atkin, 1966; Khuda-Bukhsh et al., 1986; Rishi and Shashikala, 1994 and the present study), Cobitidae (Khuda-Bukhsh et al., 1986; Khuda-Bukhsh and Nayak, 1982; Rishi and Haobam, 1990b; Hitotsumachi et al., 1969; Ueno and Ojima, 1976;
Ueno et al., 1980) and catostomidae (Uyeno and Smith, 1972).

During the course of present study four species of family Cyprinidae i.e., Schizothorax niger, S. richardsoni, Schizothoraichthys labiatus (each with 2n=98)and Ptychobarbus conirostris (2n=84)are suspected to be polyploidy in origin. The presence of one pair of NORs in Schizthoraichthys labiatus and Ptychobarbus conirostris suggest regressive functional regressive functional and structural diploidization process having occurred following ployploidization. Channa gachua reinvestigated during the present study has also been considered to polyploidy (Triploid) in Origin.

4.2.2. Robertsoni Rearrangements

Change in chromosome number without a change in number of chromosome arms (NF) is brought about by the process of Robertsonian fusion and fission. Fusion decreases the diploid number, whereas fission brings about an increase in 2n number. White (1973) suggested that Robertsonian fusion occurs more often than the fission. On the same basis, the species with uniarmed elements are regarded as primitive.
Robersonian rearrangements have been very commonly implicated in the evolution of salmonids *Salmo gairdneri* (2n=60), *S. aquabonita* (2n=56) and an un-named red band trout (2n=58), each has NF=104 (Wilmot, 1974; Gold and Gall, 1975) and thus the role of Robertsonian changes is quite clear here. Similarly, *S. clerki* (2n=64) and *S. apache* (2n=56) have been reported to have NF=106 (Simon and Dollar, 1963; Miller, 1972) despite different chromosome numbers. Gold et al. (1977) constructed an evolutionary pathway of North American trouts on the basis of the Robertsonian mechanism. They reported two subspecies of the cut-throat trout, *S. clarki clarki* and *S. clarki henshawi*, having 2n=68 and 64 respectively but with the same NF of 104. Ohno et al. (1965) described an interesting case of intra-individuals polymorphism in *S. irridius* explicable on the basis of Robertsonian changes. Robertsonian intra-individuals polymorphism has been reported in *s.salar* (Roberts, 1968, 1970; Ohno et al., 1969; Gold and Gall, 1975; zenzes and vaiculescu, 1975) and *s.gairdneri* (hartely and Horne, 1982).

In family Gobidae, a complex chromosome polymorphism has been reported in *Gobius fallax* by Thode et al. (1988). They observed inter- and intra-individuals variation in the diploid numbers (2n=38 to 43) arising
Mainly through Robertsonian transformation. Le Grande and Fitzsimon (1976) observed $2n=28$ Fitzsimon (1976) observed $2n=28$ ($20m+4st+4t$) in *Mugil curema* as against $2n=48$ (all acrocentrics) found in other species of Mugillidae. They found that the size of metacentrics of *M. curema* was almost twice as that of uniarmed chromosome of *M. curema* or that of *M. cephalus* and suggested the reduced number of $2n=28$ in *M. curema* to be the result of Robertsonian fusions. Sofradzija (1977) explained the karyological evolutions in the genus *Leucicus* mainly on the basis of Robertsonian rearrangements.

Fan and Fox (1991) observed a constant NF value of 48 in *Pleuronects Platessa* with intraindividual populations having $2n$ range from 46 to 48 and suggested Robertsonian polymorphism in them. Arafjev (1991) suggested the origin of metacentrics in the karyotypes of black sea Blennies, *Blennus sanguinolentus* as a result of Robertsonian fusion of acrocentrics. In carps and catfishes, Robertsonian arrangements have not directly been identified rather they supplement the main Non-Robertsonian mechanisms operating in the evolution of karyotypes in these fishes.
4.2.3. Non-Robertsonian changes/rearrangement

The non-Robertsonian rearrangements include pericentric and paracentric inversions which have been suggested to have played a very important role in karyotypic evolution of many organisms. The most important of these changes are the pericentric inversions. The changes which involve a shift in the position of the centromere on the chromosomes bring about variations in the total number of chromosomal arms (NF) without affecting the diploid number. However, if a pericentric inversions is such that both the segments about the centromere are of the same length, it may not affect the arm number value and may remain undetected in the metaphase chromosomes just like the paracentrics inversions. The difference of arm numbers in several species of fishes with $2n=48$ is an evidence of the occurrence of such changes (Manna, 1984; Rishi, 1989 and Lakra and Rishi, 1991).

Manna and Prasad (1977), while working on the karyomorphology of 5 species of the families Osphronemidae, Nandidae and Mastacembelidae (all with $2n=48$ chromosomes), emphasized the role of 'pericentric inversions' or centromeric shift along with some other structural rearrangements.
The role of paracentric inversions cannot be clearly discussed because these changes do not result in any change in the chromosome morphology. But as a matter of fact the species possessing apparently similar karyotypes might be differing in several segments of the chromosomes. Much chromosomal literature shows that variability in the diploid numbers is relatively less than the diversity in the NF values. This suggests that pericentric inversions have played an important role in the evolution of fish karyotypes.

Ojima et al. (1972) suggested the importance of pericentric inversions in their study of 15 species of Cyprinids from Japan. Manna and Prasad (1973a) suggested that pericentric inversions, fusion or fision of arms according to Robertsonian principle and sometimes polyploidy were responsible for evolution of karyotypes in various species of genus Channa. Le Grande (1975) also suggested the role of pericentric inversions in the evolution of flat fishes, Symphurus plaguisa, Etropus cossotus, Paralichthys olivaceous and Rhombus macoticus (all with 2n=48).

Nygren et al. (1975) observed significant changes in NF values of several Cyprinid fishes and
Accounted this due to pericentric inversions. Das and Kar (1977) supported the assumption of the role of peracentric inversions in the karyotypic evolution of fishes on their study in *Rita chrysea* and *Heteropneustes* fossils. Avise and Gold (1977) found greater rate of Robertsonian fusion / fission among the centrarchids than among the North American Cyprinids which have higher rate of centromeric rearrangements. Gold et al. (1978) estimate rates of speciation and chromosome number change within North American Cyprinid genera and found that fewer chromosome number changes occur per speciation event than in many vertebrates. Nevertheless, they found some differences in arm number and assumed that non fusion / fission rearrangements have played a role in the evolution of North American Cyprinids. On the whole, however, they indicated that arm number evolution in North American Cyprinid has been conservative.

Gold et al. (1981) indicated that there does not seem to be a direct relationship between chromosomal evolution and speciation in North American Cyprinids. The observations of the factors such as absence of the primitive number in several families (Denton, 1973; Park, 1974), marked differences in karyotypes of fish species on record; occurrence of polyploidy species, a modal number of 50 chromosomes in cyprinids and so on (Manna and
Khuda - Bukhus, 1977a) suggest the karyotype evolution in fishes to be multi directional.

Orlando et al. (1985) suggested the predominant role of pericentric inversions bringing chromosomal changes in family parodontidae. Feldberg and Bertollo (1985) stressed that the pericentric inversions were probably the main event that led to the karyotypic evolution of neotropical cichlids. During their study on 9 species of family Labridae, Vitturi et al. (1989) reported the cause of karyotypic evolution as pericentric inversions, whereas Rab et al. (1987) believed that chromosomal evolution of both European and North American periods was not accompanied by numerical changes but by nono- Robertsonian rearrangements altering centromeric position on particular chromosomes. Arefjev (1990) observed that the main mechanism of karyotypic evolution in characiforms is by pericentric inversions.

Thus, the karyotypic evolution in fishes has been multi directional with pericentric inversions, Robertsonian translocations and other mechanism such as polyploidy playing the key role.
4.2. **SEX CHROMOSOMES IN FISHES**

A great majority of fishes reproduce bisexually. A clear cut detection of sexuality on the basis of chromosomes, as in higher vertebrates, has still not been possible in case of fishes. It is generally believed that sexually in fishes may be at primitive level of evolution, both male and female determiners may distributed on the autosomes and expression odds sex depends on a balance of the sex genes (Rishi, 1989).

A majority of worked out fish species, sex chromosomes have not been distinguished and therefore, many workers are of the opinion that chromosomes in fishes are still at a very low level of differentiation (Gold, 1979; Ojima, 1982c; Manna, 1983, 1984).

Fishes exhibit an almost complete range of sexuality from hermaphroditism, unisexuality, bisexuality to gonochorism and almost every type of sex chromosomes have been observed in fishes which can be categorized as male heterogamety, female heterogamety and multiple sex chromosomes. Sex chromosomes have been identified in about 109 species (including present study) out of about 1700 cytologically worked out fishes (Table 49). Out of the 109 species for which sex chromosomes have been identified 47
Species show XX:XY (male heterogamety), 14 show XX:XO (male heterogamety), 34 show ZZ:ZW (female heterogamety), 3 show ZZ:ZO (female heterogamety), 11 species show multiple sex elements with male heterogamety and one species bears multiple sex-elements with female heterogamety (Fig. 107).

The heterogamety in fishes has been abduced from genetic rather than cytological evidences by earlier workers. In some insistence, however, the sex chromosomes have also been identified following the inheritance pattern of non-allelic sex-linked marker genes which affect morphological traits. The male heterogamety (XY) with XX:XY type of sex-machanism has been demonstrated for poeciliid fishes, including two species of genus *Poecilia* (Winge, 1922; Breider, 1935), several species of genus *Xiphophorus* (Kosswig, 1935, 1959; Bellamy 1935; Gordon, 1946, 1947; Kallman, 1965) and for the Cyprinodontid *Oryzias latipes* (Aida, 1921). On genetic basis male homohamety condition has been demonstrated in *Platypoecilus* (Bellamy, 1922; Fraser and Gordon, 1929) and *Poeciliopsis* (Miller and Schultz, 1959), while genetic evidence of XX:XY male heterogamety has been reported for *lebistes reticulates* (Winge, 1923), *Betta splendus* (Kaiser and Schmidt, 1951), *Carassius auratus* (Yamamoto and Kajishim,
1968). In all these species for which there is genetic evidence of heterogamety, the sex chromosomes do not appear morphologically differentiated, with a possible exception of one stock of *Xiphophorus maculates* which may have heteromorphic X and Y- chromosomes (Anders et al., 1969). The *X. maculates* has been reported to be both male and female heterogametic. Bellamy (1922) and Gorden (1972) found that the domesticated stocks of *X. maculates* of unknown origin were female heterogametic and male homogametic (ZW:ZZ), while Kossing (1935) and Bellamy (1936) found *X. variatus* to show XX:XY type of male heterogamety. Gordon (1946, 1947) discovered Mexican population of *X. maculatus* to be male heterogametic.

Cytological evidences of heterogamety for several fishes have been reported by earlier workers. Chen and Ebeling (1968) reported female heterogamety. (WZ:ZZ) in *Gambusia affinis*. They found the diploid count of 2n=48 in males *G. affinis* to comprise 2 submetacentrics and 46 acrocentric chromosomes and in female to contain one metacentric, 2 submetacentric and 45 acrocentric chromosome. On the basis of observations of different chromosome morphology in male and female they suggested that the single metacentric chromosome and one acrocentric constitute the heteromorphic sex-pair in female and the single smallest acrocentric in the female is present as a
Pair in male and represents the homologous pair. In the same species, *G. affinis*, female heterogamety was further confirmed by Cataudella and Sola (1977) and Black and Howell (1979). Campos and Hubbs (1971) described female heterogamety (WZ:ZZ) in three more Gambusiine fishes (Table 49). However, Sharma and Tripathi (1982b) could not distinguish any heteromorphic sex pair in case of *G. affinis* holbrooki. Female heterogamety (WZ) has been reported in some other fishes too (Table 49).

Haaf and Schmid (1984) recorded sex chromosomes (ZW:ZZ) in case of *Poecilia sphenops* by application of banding technique. Moreira Filho et al. (1993) reported female heterogamety (ZW:ZZ) in *Pardon hilarii* (Parodontidae), W chromosome being large subtelocentric and Z being metacentric in female *P. hilarii*, while the male karyotype being characterized by ZZ metacentric pair. C-banding pattern showed that in addition to the small blocks in pericentric and telomeric regions of short arm, a considerable portion of the long arm of W was found to be C-band positive. In contrast Z-chromosome had C-band in the pericentric region.

During the present study *Danio rerio* (Cyprinidae) revealed female heterogamety (WZ:ZZ)
W- chromosome being small metacentric and Z- chromosome being largest submetacentric.

ZO/ZZ type of female heterogamety has been reported in *Colisa fasciatus* (Rishi, 1979) and *Lipidocephalicthys guntea* (Sharma and Tripathi, 1988).

Male heterogamety (XY) is one record in *Bathylabus milleri* (Ebeling and Setzer, 1971), *B. ochotensis* (Edeling and Chen, 1970), *Carassius auratus* (Ojima, 1982c), *Apocryptichthys cantoris* (Das, 1983), *Hoplias lacerdae* (Bertollo et al., 1979), *Mystus teganara* (Das and Srivastava, 1973), *M. guli* (Choudhari et al., 1993) and in many other species (Table 49).

During the course of present study a cyprinid fish, *Scizothoichthys labiatus* collected from Laddakh revealed the heteromorphic sex chromosome in male (XY), of which X was found to be submetacentric whereas Y chromosome was found to be telocentric.

XO:XX type of male heterogamety has been reported in *Scopelengys tristi* Symphurus plaginsa, *Parvilux ingens* (Chen, 1979), *Lampanyctus ritteri* (Chen and Ebling, 1974), *Triacanthus brevirostris* (Choudhary et al., 1982) and some other species (Table 49).
Multiple sex-mechanism for first time was described in Cyprinodon, *Onycorhynchus nerka* (X<sub>1</sub>X<sub>2</sub>Y male and X<sub>1</sub>X<sub>1</sub>X<sub>2</sub>X<sub>2</sub> female) by Uyeno and Miller (1971). Rishi (1976b) described X1X1X2:X2X2Y – type mechanism in *Callichrous bimaculatus*. Thorgaard (1978) reported X<sub>1</sub>X<sub>1</sub>X<sub>2</sub>X<sub>2</sub>/XY<sub>2</sub>Y mechanism in *Onychorhynchus nerka*, whereas Moreira et al. (1980) described W<sub>1</sub>W<sub>1</sub>W<sub>2</sub>W<sub>2</sub>/W<sub>1</sub>W<sub>2</sub>Z – type mechanism in *Apareinodon affinis*. (Table 49).

Unisexual forms have been described in *Poecilia Formosa* by Hubbs and Hubbs (1932, 1946). Some natural and laboratory stocks of triploid clones of *P. Formosa* are also reported to exist (Rasch et al., 1965; Schultz and Kallman, 1968, Rasch et al., 1970). Schultz (1967, 1971) reported unisexual diploids and triploids of *Poeciliopsis* species. Cherfas (1966) described certain populations of *Carassius auratus gibelio* to be all female triploid with 2n=3x=14 and gynogenetic.

Haaf and Schmid (1984) observed female heterogamety in *Poecilia Sphenops* var. *melanistica* with the help of banding in apparently homomorphic sex-chromosomes. This study has opened a new way to study more about sex-chromosomes in fishes. A study of more taxa with application of modern techniques like chromosome banding may be useful in distinguishing the sex-chromosomes in fishes.
<table>
<thead>
<tr>
<th>Species</th>
<th>Reference</th>
</tr>
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<tbody>
<tr>
<td>A. Male heterogamety</td>
<td></td>
</tr>
<tr>
<td>i) XX:XY -type</td>
<td></td>
</tr>
<tr>
<td>1. Accrina cernua (Percidae)</td>
<td>Lieder (1963)</td>
</tr>
<tr>
<td>2. Apocryptichthus Cantoris (Gobiidae)</td>
<td>Das (1983)</td>
</tr>
<tr>
<td>3. Argentina silus (Argentidae)</td>
<td>Ebeling et al., 1971</td>
</tr>
<tr>
<td>4. Bathylagus Milleri (Bathylagidae)</td>
<td>Ebeling and setzer (1971)</td>
</tr>
<tr>
<td>5. B. stilbius (Bathylagidae)</td>
<td>Ebeling and chen (1970)</td>
</tr>
<tr>
<td>7. B. ochotensis (Bathylagidae)</td>
<td>Ebeling and chen (1970)</td>
</tr>
<tr>
<td>11. Carassius auratus (Cyprinidae)</td>
<td>Ojima (1982c)</td>
</tr>
<tr>
<td>12. Cottus polux (Cottidae)</td>
<td>Nogus (1960)</td>
</tr>
<tr>
<td>15. Evynnis Japonica (Centrarchidae)</td>
<td>Murofushi et al. (1983)</td>
</tr>
<tr>
<td>17. Gasterosteus Wheatlandi (Gasterosteidae)</td>
<td>Chen and Ruddle</td>
</tr>
</tbody>
</table>
18. Geophagus
   Brasiliensis (Cichlidae)
Michele and Takahashi (1977)

19. Hoplias
   Lacerdae (Erythrinidae)
Bertollo et al. (1979)

20. H. malabaricus (Erythrinidae)
Bertollo et al. (1979)

21. Lepadogaster
   Candollei (Gobiesocidae)
Thode (1987)

22. Leporinus
   Lacustris (Anostomidae)
Galetti et al. (1981)

23. Macrurineus
   Brachistius (Mormyridae)
(Uyeno (1973)

24. Melamphase
   Parvus (Melamphicidae)
Ebeling and Chen (1970)

25. Mogrunda obscura (Gobiidae)
Nogusa (1960)

26. Mystus gulio (Bagridae)
Das (1893), Choudhari et al.

27. M. tengara (Bagridae)
Das and Srivastava (1973)

28. Noturus taylori (Ictaluridae)
Le Grande (1981)

29. Osteoglossum
   Bicirrhus (Osteoglossidae)
Uyeno (1973)

30. Parapercis
   Sexfasciata (Percidae)
Ojima et al. (1984)

31. Perca fluviatilis (Percidae)
Lieder (1963)

32. Plectostomus
   Anastroides (Loricariidae)
Michele et al. (1977)

33. Salmo gairdneri (salmonidae)
Thorgaard (1977)

34. Scardinius
   Erythro-phthalinus (Cyprinidae)
Fontana et al. (1970)

35. Scopelengys
   Labiatus (Cyprinidae)
Present study

36. Scopelengys
   Tristis (Neoscopelidae)
Ebeling and Chen (1970)

(Contd.....
37. Scopelogadus mizolepis  
   (Anoplogastridae)  
38. Scopeloberyx robustus  
   (Anoplogastridae)  
39. Symbolophorus californiensis  
   (Myctophidae)  
40. Unidentified sp.  
   (Myctophidae)  
41. -do-  
42. -do-  
43. -do-  
44. Vimba vimba (Cyprinidae)  
45. Xiphophorus maculatus  
   (Poeciliidae)  
46. X.xiphidium (Poeciliidae)  
47. Gorra gotyla gotyla  
   (Cyprinidae)  
   i) XO:XX-type  
1. Coris julis (Labridae)  
2. Diademichthus lineatus  
   (Gobiesocidae)  
3. Glaxias platei (Glaxiidae)  
4. Gobiodon citrinus (Gobiidae)  
5. Lampanyctus ritteri  
   (Myctophidae)  
6. Lepomis cyanellus  
   (Centrarchidae)  
7. Oncorynchus nerka  
   (Salmonidae)  

Ebeling & chen (1970)  
Ebeling and chen (1970)  
Chen and Ebeling (1974)  
Chen (1969)  
Chen (1969)  
Chen (1969)  
Rudek (1974)  
Foerster and Anders (1977)  
Foerster and Anders (1977)  
Sharma and Agarwal (1980)  
Cateudella et al. (1973)  
Arai et al. (1977)  
Campos (1972)  
Arai and Swada (1974)  
Chen and Ebeling (1974)  
Becak et al. (1966)  
Thorgaard (1978)  
(Contd....
8. Parvilux ingens (Myctophidae) 
9. Plectostomus macrops 
   (Loricariidae) 
  michele et al.(1977) 
10. Scopelengys tristis 
11. Sternoptyx diaphana 
   (Sternoptychidae) 
  Ebeling and chen (1970) 
12. Symphurus plagiusa 
   (Pleuronectidae) 
  Le Grande (1975) 
13. S.plagiusa (Pleuronectidae) 
14. Triacanthus brevirostris 
   Triacanthidae) 
  Choudhary et al . (1982) 

B. Female Heterogamety
i) ZW:ZZ –type
1. Anguilla Anguilla 
   (Anguillidae) 
   Passakas (1981) 
2. A. japonica (Anguillidae) 
   Passakas (1978) 
   Park and Kang (1979) 
3. A.rostrata (Anguillidae) 
   Passakas (1981) 
4. Apeltes quadracus 
   (gasterosteidae) 
   Chen and Reisman (1970) 
5. Aplocheilus panchax 
   (Cyprinodontidae) 
   Khuda Bukhus (1979a) 
6. Boleophthalmus poddaerti 
   (Poeciliidae) 
   Subrahmanyam (1969) 
7. Colisa fasciatus 
   (Belontidae) 
   Rishi (1979) 
8. Conger myriaster 
   (congridae) 
   Ojima and Ueda (1982) 
9. Danio rerio (Cyprinidae) 
   Present study 
10. Epinephalus tauvima 
    (serranidae) 
    Das (1983) 
    (Contd....
11. *Gambusia affinis*  
(Poecillidae)  
Chen and Ebeling (1974)

12. *G. gaigei* (Poecillidae)  
Chen and Ebeling (1974)

13. *G. holbrooki* (Poecillidae)  
Yoshida and Hayashi (1971)

14. *G. hartadoi* (Poecillidae)  
Chen and Ebeling (1968)

15. *G. nobilis* (Poecillidae)  
Chen and Ebeling (1968)

16. *Astroconger myriaster*  
(Congridae)  
Park and Kang (1979)

17. *Lepidocephalichthys berdmorei*  
(Cobitidae)  
Rishi and Haobam (1990b)

18. *Trichogaster fasciatus*  
(Belontiidae)  
Sharma and Tripathi (1988)

19. *Leporinus elongates*  
(Anostomidae)  
Galetti Jr. and Foresti (1986)

20. *L. reinhardti* (-do-)  
Galetti Jr. and Foresti (1986)

21. *Leporinus sp.* (-do-)  
Galetti Jr. and Foresti (1986)

22. *L. Obtusideus* (-do-)  
Galetti Jr. et al. (1981)

23. *L. silvestris* (-do-)  
Galetti Jr. et al. (1981)

24. *Molleinesia sphenops*  
(Poecillidae)  
Rishi and Gaur (1976)

25. *Mystus tengara* (Bagridae)  
Rishi (1973b); Rishi and Rishi (1981)

26. *Parodon hilarii*  
(Parodontidae)  
Moreire-Filho et al. (1993)

27. *Platypoecilus maculatus*  
(Poecillidae)  
Uyeno and Miller (1971)

28. *Salar kalla* (Carangidae)  
Das (1983)

29. *Semaprochilodus insignis*  
(Prochilodontidae)  
Feldberg et al. (1987)

30. *S. taeniurus* (-do-)  
Feldberg et al. (1987)

31. *Sauride undosquamus*  
(Synodontidae)  
Nishikawa and Sakamoto 1977)  
(Contd....)
32. Trichnotus ovatus (Carangidae) Das (1983)

33. Triporthous guentheri (Characidae) Bertollo & Cavallaro (1992)

ii) ZZ : ZO - type

1. Colisa fasciatus (Belontidae) Rishi (1979)

2. Cynoglossus Puncticeps (Cynoglossidae) Pense (1965)

3. Lepidocephalychthys guntea (Cobitidae) Sharma & Tripathi (1988)

iii) ZZ : ZW (Morphologically undifferentiated) - type


C. Multiple Mechanism

i) X1X1X2X2 : X1X2Y - type

1. Callichrous bimaculatus (Siluridae) Rishi (1976b)


3. Cyprinodon sp. (Cyprinodontidae) Uyeno & Miller (1971)

4. Carmenella pulchra (-do-) Levin & Foster (1972)

5. Megupsilon aporus (-do-) Uyeno (1973)


7. Unidentifield sp. (Goodeidae) Uyeno & Miller (1972)

8. Unidentifield sp. (Poeciliidae) Uyeno & Miller (1972)
ii) XIXXY - type

1. Onchorynchus nerka
   (Salmonidae)
   Thorgaard (1978)
   \[W1W1W2 : W1W2Z\] - type

1. Apareinodont affinis
   (Palodontidae)
   Moreire Filho et al. (1980)
   \[XXAA : XYAA\] - type

1. Eigenmannia sp.
   (Sternopygidae)
   Almeida-Toledo et al. (1984)
4.4. Polyploidy in Fishes

Polyploidy is uncommon among bisexual vertebrates. On the contrary, polyploidy is of common occurrence among higher plants where it has played a significant role in speciation and evolution. In certain amphibians polyploidy has been reported (Becak et al., 1966, 1967, 1970). Muller (1925) suggested that in animals the disturbance of sex chromosome mechanism results in the production of intersexes which are unable to reproduce. Muller's theory is supported by the fact that almost all cases of animal polyploidy occur in such groups in which the distinct sex chromosome mechanism is either lacking or is so primitive that it would not hamper the establishment of polyploidy (Suomalainen, 1958). According to Stebbins (1950) the developmental processes of cellular differentiation are much more complicated in animals and are more liable to be disturbed by polyploidy. Christensen (1961) suggested that gametes from different species stand a greater chance of meeting in plants than in animals because majority of latter have internal fertilization. Consequently, one might expect polyploidy to occur in animals with external fertilization. Such type of fertilization is true in case of majority of the fish species which stand out as one of the reasons of polyploidy in fishes.

Svardson (1945) reported polyploidy in salmonid fishes. The occurrence of tetraploid populations in nature are quite common in fishes. Certain populations of Cobitis biwae (Cobitidae) have been reported to be polyploidy by by Ueno and Ojima (1976) and Ueno et al. (1980). In the specimens of C. biwae collected from Kinki water bodies (Japan), they recorded 96 chromosomes and
referred them as tetraploids. Cobitis taenia taenia and C. taenia striata have also been reported to have diploid as well as tetraploid populations (Ueno & Ojima, 1976; Ueno et al., 1980). The fundamental arm number in the tetraploid forms was observed to be over twice that of the diploid ones.

Nayya (1966) described an autotetraploid origin of Wallago attu (2n=86) from a species with a karyotype closely related or even ancestral to that of Ompok bimaculatus with 2n = 40. Muramoto et al. (1968) described the Cobitid, Botia macracantha (2n=98) to be tetraploid in relation to Acanthophthalmus khulli with 2n=50 (Cobitidae). Similarly a diploid-tetraploid relationship has been suggested between Misgurnus anguillicaudatus (2n=50) and M. fossilis (2n=100) by Raicu and Taisescu (1972). Tetraploid state of polyploidy has been demonstrated in some other species like Carpio, Carassius auratus, Aulopyge hugeli, Acrossocheilus summatranus, Barbus barbus, B. barbus plebejus, B. meridionalis petenyi, Tor putitora, T. khudree, T. tor and Schizothorax niger (Wolf et al., 1969; Fontana et al., 1970; Berberovic and Sofradzija, 1972; Sofradzija and Berberovic, 1973; Cataudella et al., 1977; Ojima and Takai, 1981; Khuda-Bukhsh, 1980a,b, 1982; Khuda-Bukhsh and Nayak, 1982; Rishi and Shashikala, 1994). On the basis of established chromosome number 2n=100, Barbus barbus (Wolf et al., 1969), B. meridionalis petenyi (Sofradzija and Berberovic, 1973) and B. barbus plebejus (Cataudella et al., 1977) have been considered tetraploids in relation to other Barbus species with 2n=50. Three different karyotypes revealing chromosome numbers 100, 156 and 206 indicating diploid and tetraploid states have been reported in

Yu and Yu (1990) recorded 2n=446+ in case of Diptychus dipogon and regarded it to be 16-ploid or 20-ploid in relation to other members of subfamily Schizothoracine which is known to include only polyploids with five different kinds of 2n chromosome numbers viz., 90, 92, 94, 98 (tetraploids) and 148 (hexaploids). Cytological indication of polyploidy in Indian fishes has been reported in four genera of family Cyprinidae viz., Tor (Khuda-Bukhsh, 1980a, 1982; Khuda-Bukhsh et al., 1986; Rishi and Shashikala, 1994), Schizothorax (Khuda-Bukhsh and Nayak, 1982; Sharma et al., 1992 and present study), Schizothoraciceps (Tripathi and Sharma, 1987), Wallagututt of family Siluridae (Nayyar, 1966; Rishi and Singh, 1983; Sharma and Tripathi, 1984b), three species of genus Botia of family Cobitidae (Khuda-Bukhsh and Nayak, 1982; Rishi and Haobam, 1990b; Khuda-Bukhsh et al., 1986) and two species of family Ophiocephalidae, Channa gachua and C. stewartii (Sharma and Agarwal, 1981a; Manna Prasad, 1973; Rishi and Haobam, 1990 and the present study) (Table 50).

Most of the suspected polyploid forms are found at higher altitude streams or water bodies. It seems probable that extreme temperature variation in water bodies (touching freezing point in winter) and rapidly flowing nature rendering adverse conditions of living, might have played some role in inducing
polyploidy. They might have gained adaptive advantage, thereby selected by nature. However, in none of these forms multivalent formation has been reported during meiosis, thus suspected polyploidy level and origin of these species need to be confirmed by DNA estimation (genome size) and/or LDH isozyme studies. The non-occurrence of multivalents may be consequence of diploidization of the polyploids.

The concepts of polyploidization is reinforced by analysis of nuclear DNA content (Ohno et al., 1967; Ojima and Hitotsumachi, 1969; Hinegardner and Rosen, 1972; Schmidtke et al., 1979 etc.). The first report on DNA values for fishes was provided by Ohno and Atkin (1966), when DNA values of 8 species of fish were compared with those of placental mammals. According to Ohno and Atkin (1966) the high DNA value of the lung fish, *Lepidosiren paradoxa* coupled with smaller number of large metacentric chromosomes were polytenic and the genome had been increased through polyploidization. Since sex-chromosomes act as a barrier to polyploidization, it was assumed that this multiplication occurred millions of years ago before the formation of sex-chromosomes. Other examples of using DNA values as a tool to substantiate polyploidy are also available. Ohno et al. (1967) found *Barbus tetrazona* and *B. fasciatus* with 2n=50 to have a DNA value of 20-22% that of placental mammals compared to the gold fish and the carp which had the diploid chromosome number of about 100 and the DNA value of 50-52% that of Placental mammals and regarded the carp and the gold-fish to be tetraploids with respect to the two species of *Barbus*. On the similar
grounds Ojima et al. (1972) proposed the diploid-tetraploid relationship between gold-fish and Acheilognathus and Rhodeus. Ohno et al. (1969) and Ohno (1970) regarded the salmonid fishes with diploid complement consisting of about 100 chromosome arm number and a DNA content of 80% that of placental mammals tetraploid in relation to the clupeoidea with a DNA content of 40% and diploid complement consisting of 48 acrocentrics. Uyeno and Smith (1972) found increased DNA values of 50% that of placental mammals for 14 species of Catostomids which had 2n number ranging from 96 to 102. They suggested that these forms evolved by tetraploidy from a Cyprinid-like form with a diploid number of around 50. The study of DNA estimation in more and more species and the comparisons of DNA values and chromosome counts in different species certainly can provide an insight into the diploid-polyploid relationships in different groups of fishes.

Among the vertebrates, viable triploids are less frequent in nature and with very few exceptions they have been found only in certain unisexual forms among fishes (Schultz, 1971). Rasch et al. (1965) presented a cytophotometric evidence for triploidy in hybrids of the gynogenetic fish, Poecilia formosa. Prehn and Rasch (1969) demonstrated a triploid somatic chromosome complement of 2n=3x=69 for a member of naturally occurring variety close to P. formosa. The triploidy has been reported in a few individuals of Salmo gairdneri (Cueller and Uyeno, 1972), Carassius auratus (Kobayasi et al., 1970; Kobayasi, 1971). Gold and Avise (1976) provided first report of a natural triploid individual (2n=75) from the wild in case of Hesperoleucas symmetricus (Cyprinidae) and suggested its
probable origin by normal fertilization of a rare diploid unreduced ovum by a haploid sperm. Sofradzija and Berberovic (1978) examined both male and female individuals of *Cobitis taenia* from waters of Bosnia and reported female individuals to have a triploid set consisting of 75 chromosomes, while males were diploid with 2n=50 and indicated that female triploid population of *C. taenia taenia* propagated by gynogenesis. Two more Cyprinids viz., *Opsariichthys uncirostris* with 2n=78 (Ojima et al., 1972) and *Perilampus atpar* with 2n=70 (Tripathi and Sharma, 1987) seem to be triploids in relation to other members of the family.

Morelli et al. (1983) reported the occurrence of natural triploid of *Astyanax schubarti* from Brazil. *A. schubarti* is characterized by a diploid number of 36 chromosomes. In their report Morelli et al. (1983) reported the presence of 54 chromosomes in a specimen of *A. schubarti*. The occurrence of viable triploids in bisexual fishes in nature demonstrate that polyploidy can be tolerated in some fishes and hence suggests that polyploidy may perhaps be more wide spread in fishes than previously suspected.

During the present study 5 species of fishes viz., *Channa gachua* (2n=78), *Ptychobarbus conirostris* (2n=84), *Schizothoraichthys labiatus* (2n=98), *Schizothorax niger* (2n=98), and *S. richardsoni* (2n=98) are suspected to be polyploidy in origin. *Channa gachua* (2n=78) is suspected to be triploid in origin, whereas *Schizothoraichthys labiatus*, *Schizothorax niger* and *S. richardsoni* (2n=98 in all) are suspected to be tetraploids in origin. *Ptychobarbus conirostris*
may be considered triploid or tetraploid in origin. NOR studies in *P. conirostris* and *Schizothoraichthys labiatus*, however, revealed only one pair of NORs in these two species. Similar results have been reported in case of *Onychorhynchus* by Phillips *et al.* (1986). Therefore, these species which have been regarded as tetraploids in origin, must have secondarily consolidated NORs only on one pair of chromosomes during the process of regressive diploidization.
Table 50. List of Indian fishes showing cytological indication of Polyploid origin.

<table>
<thead>
<tr>
<th>Name of the species</th>
<th>2n</th>
<th>Suspected Polyploidy level</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Family: Cyprinidae</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. <em>Perilampus atpar</em></td>
<td>75</td>
<td>3X</td>
<td>Tripathi and Sharma (1987)</td>
</tr>
<tr>
<td>2. <em>Schizothoraichthys progastus</em></td>
<td>98</td>
<td>4x</td>
<td>Rishi et al. (1983)</td>
</tr>
<tr>
<td>3. <em>S. labiatus</em></td>
<td>98</td>
<td>4x</td>
<td>Present study</td>
</tr>
<tr>
<td>5. <em>S. richardsoni</em></td>
<td>98</td>
<td>4x</td>
<td>Sharma et al. (1992) and Present Study</td>
</tr>
<tr>
<td>6. <em>Psychobarbus conirostris</em></td>
<td>84</td>
<td>4x</td>
<td>Present Study</td>
</tr>
<tr>
<td>7. <em>Tor khudree</em></td>
<td>100</td>
<td>4x</td>
<td>Khuda-Bukhsh (1980b, 1982)</td>
</tr>
<tr>
<td>10. <em>T. mosal mahanadicus</em></td>
<td>100+2</td>
<td>4x</td>
<td>Khuda-Bukhsh et al. (1986)</td>
</tr>
</tbody>
</table>
Family : Cobitidae

11. *Botia* birdi
   98 4x Khuda-Bukhsh and Nayak (1982)

12. *B. hymenophysa*
   90 4x Rishi and Haobam (1990b)

13. *B. birdi*
   98 4x Khuda-Bukhsh et al. (1986)

Family : Ophiocephalidae

14. *Channa gachuna*
   78 3x Sharma and Agarwal (1981a) and present study.

15. *Channa stewardii*
   104 4x Rishi and Haobam (1990a)

Family : Siluridae

16. *Wallago attu*
Fig. 107. Types of sex chromosomes in fishes.

MH1 = XX-XY type male heterogamety
MH2 = XX-XO type male heterogamety
FH1 = ZZ-ZW type female heterogamety
FH2 = ZZ-ZO type female heterogamety
MMH = Multiple male heterogamy
MFH = Multiple female heterogamy