DISCUSSION
Studies on ageing precision have offered a rather new perspective to fish biology research. Currently, the information on ageing precision is available only for a selected fish species. However, on account of its significance researchers have developed the stock assessment models based on precise age estimates (Dorval et al. 2013). Ageing precision attains further importance owing to its utility in age based calculations of growth estimates. Although India has a significant share in world fisheries production but so far information on the age and growth parameters (based on precise age estimates) of the selected fish species was not available in the published literature.

5.1. PRECISION OF AGE ESTIMATES

Selection of the appropriate method for age and growth determination in fishes often requires balancing precision and accuracy of the method with sample size limitations (DeVries and Frie, 1996; Zymonas and McMahon, 2009). The measure of precision is a valuable means of assessing the relative ease of determining the age of a particular structure or of assessing the reproducibility of an individual’s age estimations (Campana, 2001).

5.1.1. Scales

Scales are commonly used to estimate fish age and do not require sacrifice of fish (DeVries and Frie, 1996). In the present study, scales were found to be the most suitable ageing structure in *C. marulius* and *L. bata*. Scales had the highest within and between reader agreement and lowest ageing error in *C. marulius* and *L. bata* as compared to other alternative ageing structures. However, scales were inferior to other bony structures for ageing *C. punctata* and *H. moli/rix*. Scales are one of the most frequently used fish ageing structures due to their ease of collection and because fish can be released alive (DeVries
Assessment of ageing precision from different ageing structures (scales, opercular bones, otoliths, vertebrae and fin rays/spines) revealed scales to be the best structure for age estimation in *Micropterus salmoides* (Prentice and Whiteside, 1974), *Capoeta trutta* (Ozdemir and Sen, 1983), *Pomoxis nigromaculatus* (Kruse et al., 1993), *Morone saxatilis* (Welch et al., 1993), *L. rohita* and *C. marulius* (Khan and Khan, 2009) and *C. mrigala* (Khan et al., 2011a). In most of the cyprinids, age has been estimated from scales (Kamilov, 1984). A close agreement in length-age relationship was reported in *Ophicephalus punctatus* where age of fish was determined using scales and opercular bones (Qasim and Bhatt, 1964; 1966). Chatterji et al. (1979) studied the age and growth of *L. bata*, by the analysis of annuli found on the scales and by length-frequency distribution. Scales were easy to collect and process, but the growth marks in old specimens were very close to the edge and almost indistinguishable, as reported for *B. boops* from the Gulf of Lion (Girardin and Quignard, 1986). Scales have not proven to be as reliable as otoliths, for age estimation in certain fishes, because they can be lost and regenerated and because deposition ceases at older ages, thereby giving false age readings. However, we found that the annual rings on scales of *C. punctata* were often unclear and inconsistent irrespective of size of the fish. The imprecise and inaccurate age enumeration from scales has been attributed to reabsorption and deposition of false annuli due to stress and food limitation, and annuli becoming obscure because scale growth tends to cease as fish grow older (Beamish and McFarlane, 1987; Maceina and Sammons, 2006). In *H. moltitrix*, annual rings present on scales were not clear as compared to opercular bones and vertebrae. Several studies revealed that scales are not reliable for age determination in *Mugil cephalus* (Devasundaram, 1952); *Hilsa ilisha* (Pillay, 1958); *Upeneus tragula* (Thomas, 1969); *Barbus sarana* (Murthy, 1976); *Onchorhyncus clarkia* (Moring et al., 1981); *Salvelimus frontinalis* (Kozel and Hubert, 1987) and *Pomoxis annularis* (Hammer and Miranda, 1991). Moreover, different environmental conditions may also result in the formation of checks which sometimes are very difficult to distinguish from true annuli and may lead to some errors in age studies. Kamilov (1984) reported that annual marks present on the scales of *H. moltitrix* are diffused. In some scientific reports, the use of scales had been criticized mainly because of the frequent underestimation of the ages in *Helicolemus percoideus* (Withell and Wankowski,
IYYSS) and Ethoostoma caeruleum (Beckman, 2002). Lowerre-Barbieri et al. (1994) reported difficulties in reading annuli and low precision while estimating age using scales in Cynoscion regalis.

5.1.2. Otoliths

Comparison of age estimates from different ageing structures revealed that otoliths provided the most suitable age estimates in C. punctata, C. gariepinus, C. batrachus and W. attu based on their highest percentage of agreement and the lowest ageing error between independent readers. However, in C. marulius and H. fossilis, otoliths were reported as second best structure for ageing, as evident from PA, APE and CV values between the two independent readers and among the ageing structures. Otoliths are metabolically inert and thus do not reflect physiological changes that may occur throughout the life of fish (Phelps et al., 2007). Due to higher precision of age estimates from otoliths, researchers have suggested use of otoliths over other structures for age estimation in Pomoxis annularis (Boxrucker, 1986), Salvelinus namaycush (Sharp and Bernard, 1988), Capoeta capoeta umbra (Ekingen and Polat, 1987), Trachurus trachurus (Polat and Kukul, 1990), Pylodictis olivaris (Nash and Irwin, 1999), Ictalaurus punctatus (Buckmeier et al., 2002; Colombo et al., 2010), Clarias gariepinus (Khan et al., 2011b), etc. Vilizzi and Walker (1999) found that annulus counts from otoliths indicate age of older fish more accurately than scales. Mosegaard et al. (1989) observed that reader precision was high for both scales and otoliths obtained from Rutillus rutillus but scales underestimated the age in older specimens.

Accurate age estimation using otoliths is also supported by the fact that otoliths continue to grow and form annuli even as body growth slows and asymptotic length is reached, and annuli reabsorption does not appear to occur during periods of food limitation or stress (DeVries and Frie, 1996). Otoliths were reported to be the most suitable ageing structure in Capoeta capoeta umbra (Ekingen and Polat, 1987) and Trachurus trachurus (Polat and Kukul, 1990). Sylvester and Berry (2006) reported
that otoliths were more accurate than scales and pectoral fin rays for age estimation in *Catostomus commersonii*. Isermann et al. (2003) demonstrated that whole otoliths were a more time-efficient method than scales or dorsal spines in *Sander vitreum*. Boxrucker (1986) and Kruse et al. (1993) also suggested that ageing whole otoliths was less time consuming. To use otoliths or any other ageing structure for age determination, the deposition of regular visible age marks is important. Otoliths age determination is considered to be more accurate because otoliths have a higher priority in utilization of calcium (Carlander, 1987).

However, otoliths do not always prove to be the most suitable structure for age reading in a number of fish species. This could be attributed to explanations such as (i) species-specific size and shape of otoliths that make its process of preparation and reading difficult, e.g. thick and small otoliths having irregular shape, (ii) use of whole otoliths may lead to underestimation of ages in comparison to sliced otoliths, and (iii) sections of otoliths must include the nucleus to minimize the age estimation error. Several authors have reported difficulty in reading the rings in the region near the focus of the otoliths (Erman, 1959; Kennedy and Fitzmaurice, 1969). Sometimes, the interpretation of the otoliths is complicated due to presence of false rings (Morales-Nin, 1992) which are often deposited corresponding to the crucial moments of the fish life cycle such as sexual maturity. There are reports that the use of whole otoliths, as used in the present study, can lead to underestimation of the ages when compared with sliced otoliths (Abecasis et al., 2006). Discontinuities in otoliths also appear to be related to ontogeny and habitat changes (Pannella, 1971).

Annual rings on otoliths were often difficult to interpret in *L. bata*. In *L. bata*, the first and second annuli were usually easily identified in younger fish. In older fish, as deposition occurs across the entire otolith surface and otolith thickness increases, identification of annual ring became more difficult. It seems plausible that the use of whole otoliths could have lead to underestimation of the ages which corroborates the findings on *Helicolenus dactylopterus* (Abecasis et al., 2006). Otoliths were reported to be inferior to scales and vertebrae for age estimation in *Leuciscus cephalus orientalis*
In *M. armatus* and *O. pabda*, otoliths were extremely small, and emerged less reliable than other alternate structures. Morales-Nin et al. (1998) found that factors such as definition of the otolith nucleus, development of annual or false rings and an extended spawning period, all contribute to the discrepancies between different otolith readings. Johal et al. (2000) experienced difficulty in age reading of *H. molitrix*, using otoliths which were small, hazy and fragile. Erman (1959) found that annual rings on otoliths were more difficult to identify. Ozdemir and Sen (1986) found that scales and vertebrae were better as compared to otoliths in *Leuciscus cephalus* for age reading.

5.1.3. Opercular bones

Opercular bones were found to be superior to other ageing structures in *H. molitrix* and second best ageing structure in *C. punctata, L. bata, M. armatus* and *O. pabda*. The determination of age and growth of fish from opercular bones is well documented for a number of fishes and has been found to be more satisfactory than other methods such as scales, vertebrae, spines or other hard parts in *Esox lucius* (Frost and Kipling, 1959), *Perca fluviatilis* (Shafi and Maitland, 1971) and *C. catla* (Khan and Khan, 2009). Several researchers have used opercular bones for age estimation in different fish species, such as *Tilapia melanotheron* (Fagade, 1974), *Bagrus meridionalis* (Tweddle, 1975) and *Labeo senegalensis* (Blake and Blake, 1978).

Rings on opercular bones of younger age group fishes were clearer and more easily identifiable than in the older age groups in *C. marulius* and *H. molitrix*. Similar observations have also been reported by other researchers (Nargis, 2006; Shafi and Maitland, 1971). Bardach (1955) considered superiority of the use of opercular bones to scales in yellow perch. Pazira et al. (2005) suggested vertebrae and opercles as appropriate structures for age estimation rather than otoliths in *Mastacembelus mastacembelus*. Sharp and Bernard (1988) reported that opercles provided age estimates nearly identical to those from otoliths and suggested the use of opercles in place of otoliths for many age and growth studies on lake trout (*Salvelinus namaycush*) from
Alaskan lakes. However, in some fishes opercular bones were reported to be less reliable as compared to other structures, such as otoliths and vertebrae in *Schizothorax o’connori* (Ma et al., 2011) and scales and otoliths in *L. rohita* and *C. marulius* (Khan and Khan, 2009). Khemiri et al. (2005) found opercular bones unsuitable for age estimation in *B. boops* from Tunisian waters. The loss of most of the primary annuli on opercular bones that represent the early period of life history compelled to reject these hard structures for age estimation in *M. mastacembelus*, as it could lead to underestimate the ages (Gumus et al., 2010).

5.1.4. Vertebræ

Vertebræ were reported as the most suitable ageing structure in *M. armatus*, *H. fossilis* and *O. pabda* and second best structure in *H. moliurus*, *C. batrachus* and *C. gariepinus*. Vertebræ exhibited clear growth rings in *M. armatus*, *H. fossilis* and *O. pabda* and its age estimates were unbiased and precise showing highest percentage of agreement and the lowest ageing error between independent readers. Many studies have indicated that the reliability and consistency of vertebrae for age determination are relatively higher compared to other materials (Appelget and Smith, 1951, Duan and Sun, 1999, Mc Auley et al., 2006). Yilmaz and Polat (2002) reported that vertebrae can be approved as giving more accurate age estimates than scales in *Alosa pontica*. Polat et al. (2001) compared different bony parts of *Pleuronectes flesus luscus* for age determination and reported vertebrae as the most reliable structure having minimal ageing error. Mishrigi (1967) reported vertebrae as the most reliable part of the skeleton for age determination in *Lates niloticus*. In corroboration with the observations of Li and Xie (2008) on *Glyptosternum maculatum*, we also observed that as compared to other structures in *H. fossilis*, *M. armatus* and *O. pabda* vertebrae had regularly formed annual rings and were more consistent and easier to handle.

Yilmaz and Polat (2008) reported vertebrae as the most reliable bony structure for ageing *Cyprinus carpio* from three populations, by comparing scales, vertebrae, utricular
(lapillus) and lagenar (asteriscus) otoliths, dorsal and anal fin rays, opercles and subopercles. Growth of *C. batrachus*, was studied by El-Serafy (1981) from vertebrae. The rings on vertebrae were reported as a better indicator of growth (according to length frequency data) than those of pectoral spines in *C. gariepinus* (Clay, 1982). In a study on comparison of vertebrae, otoliths, and scales for ageing *Oncorhynchus keta*, Clark (1987) suggested that the time required to process and read vertebrae (twenty times as long as scales) made them less practical to use but the precision and accuracy involved with vertebrae made them the best of the three structures for age estimation.

For age determination in fishes, whole as well as sectioned vertebral centra have been used by many researchers. Oshitani et al. (2003) suggested that the observation of the vertebral surface is much better than observation of sections because of more accurate ring counting. Guinn and Hallberg (1990) reported that vertebrae and otoliths gave similar age estimates in *Lota lota*. In *Lutjanus johnii* (Bloch), sectioning of otoliths and vertebrae enhanced the ability to differentiate opaque zones in otoliths and interpret growth checks in vertebrae and produced higher age estimate than those obtained from whole vertebrae and otoliths (Marriot and Cappo, 2000).

Vertebrae have rarely been used to study age estimation in fishes which show clear annual rings in other structures that cause negligible or no damage to the fish. Vertebrae were reported to provide reliable age estimates in *Ophiodon elongatus* (Chatwin, 1956), but the author maintained that they are not practical for commercially caught fish due to the time required for processing the structure and the damage to the fish carcass caused during sampling. Annual rings on vertebrae were poorly defined, inconsistent and difficult to follow across the structure, making age reading difficult. Khemiri et al. (2005) used different bony structures for estimating the age of *B. boops* and reported vertebrae unsuitable for age estimation because of the presence of numerous minute marks unrelated to the cyclic events. Researchers have reported that rings present on vertebral centra were not very clear and showed numerous minute marks unrelated to cyclic events in fishes such as *Makaira nigricans* (Hill et al., 1989), *Boops boops* (Khemiri et al., 2005) and *Cirrhinus mrigala* (Khan et al., 2011a).
5.1.5. Fin rays/ spines

In the present investigation, fin rays and spines were inferior to other structures for ageing C. punctata, C. marulius, L. bata, H. molitrix, M. armatus, H. fossilis, C. gariepinus, C. batrachus and O. pabda. They had the lowest percentage of agreement and highest average percentage of error and coefficient of variation values between readers. In W. attu, pectoral spines were reported as second best ageing structure. Due to difficulty in the correct identification of annuli in fin rays/spines, fish age may be underestimated. In this investigation, the annuli on fin rays and spines showed less clarity than other structures for age estimation. Several researchers have reported difficulty in the interpretation of annuli using pectoral spines of Ictalurus punctatus and Pylodictis olivaris (Sneed, 1951; Marzolf, 1955; Mayhew, 1969; Prentice and Whiteside, 1975; Turner, 1982). A reduction in the accuracy of spine age estimates as a result of annulus loss was reported in Morone saxatilis and Salmo trutta (Welch et al., 1993; Graynoth, 1996).

In many species, the spine nucleus may be reabsorbed and replaced by a hole (vascularization), which may eliminate the first rings (Kohli, 1989; McFarlane and King, 2001). In old fish, the lumen of the pectoral spine enlarges with age and obscures initial growth increments, resulting in a consistent underestimation of age in C. gariepinus (Clay, 1982; Quick and Bruton, 1984). If first annulus is not identified correctly, the fish age will be underestimated leading to an overestimation of growth and natural mortality coefficients, which in turn may have drastic implications to fish stock management advice and decisions (Leaman and Nagtegaal, 1987; Casey and Natanson, 1992). A reduction in the accuracy of spine age estimates as a result of annulus loss was reported in Morone saxatilis and Salmo trutta (Welch et al., 1993; Graynoth, 1996). As fish age, expansion of the central lumen erodes early annuli (caused by increasing amounts of vascularized tissue in the central part of the spine as it changes in structure with age), thereby causing the true age of older fish to be underestimated (Gonzalez-Garcés and Farina-Perez, 1983; Franks et al., 2000; Brusher and Schull, 2009). Turner (1982) reported that some annuli in spines are composed of multiple growth rings. False marks
are usually distinguishable in younger fish because of their proximity to true annuli; in
older fish, however, false marks may become more problematic and lead to
overestimation of fish age. Finally, in slow growing and old individuals, spine annuli near
the edge tend to merge and may be indistinguishable (Lai et al., 1996; Kocovsky and
Carline, 2000), thereby increasing the chance of biased age estimates (Buckmeier et al.,
2002). Buckmeier et al. (2002) reported that the underestimation and lack of precision for
ageing icterurids using spines occur due to the expansion of the central lumen, which
obliterates early formed annuli, the appearance of multiple growth rings, and poor
sectioning techniques. The imprecise age estimates by spines/rays in the present study
could also be attributed to relatively poor quality of sections using jeweller’s saw as
compared to the low speed isomet saw.

However, fin rays were reported to be the most suitable ageing structure by
several researchers. Burnet (1969) reported dorsal fin rays to be more suitable than the
otoliths for ageing *Salmo trutta*. Dorsal fin rays were found to be more suitable compared
to other structures for ageing *Barbus rajanorum mystaceas* and *Capoeta trutta* (Polat,
1987a and 1987b). In *Liza ramada*, population from Mersin Bay, fin rays were found to
be the most reliable bony structure for age determination followed by scales, vertebrae,
otoliths and operculum (Gocer and Ekingen, 2005). *Chelidonichthys kumu* was reported
to be aged satisfactorily by using fin rays for live specimens and otoliths for dead
specimens (Staples, 1971). If non-lethal procedure is needed for age determination of
common carp population, then pectoral fin rays have been recommended for fish up to
the age of 13 years (Phelps et al., 2007). The authors also explained that most ages in
common carp were overestimated by scales, vertebrae and opercles through age 6 but
underestimated beyond age 10.

### 5.2. GROWTH ESTIMATION

The von Bertalanffy growth equation follows the assumption that fish grows
towards some theoretical maximum length, and the growth rate declines as the fish
reaches its ultimate length (Beverton and Holt, 1957). The VBGF is commonly used in describing fish growth (Chen et al., 1992). This function has only three parameters, making it statistically robust compared to models with more parameters (Booth, 1997). In the present study, growth parameters exhibited variations in their values for each selected fish species when compared to the earlier reports such as, *C. marulius* (Dua and Kumar, 2006); *C. punctata* (Qasim and Bhatt, 1966; Mustafa and Graaf, 2008); *L. bata* (Chatterji et al. 1979); *H. moliatrix* (Rao and Natarjan, 1979), *H. fossilis* (Kohli and Goswami, 1989; De Graaf, 2003); *C. gariepinus* (Bruton and Allanson, 1980; Yalein et al. 2002; Okogwu, 2011); *C. batrachus* (Thakur, 1981) and *W. attu* (Goswami and Devaraj, 1996). However, there were no earlier reports on *M. armatus* and *O. pabda*. Species-wise growth parameters have been discussed below:

### 5.2.1. *Channa marulius*

In *C. marulius*, age was determined using scales which provided the precise age estimate as compared to other ageing structures. The estimated maximum length (*L*∞) of 91 cm for *C. marulius* is smaller than that reported by Dua and Kumar (2006) (*L*∞ = 99 cm) from Harike wetland, Punjab. *L*∞ is seen as a capacity for growth (Bagenal and Tesch, 1978) and inter-population differences in this parameter correspond to varying environmental conditions. Cailliet and Goldman (2004) reported that growth model estimates are greatly affected by the lack of very young or old individuals. The results indicated that there was very fast growth in first year of life. This was followed by a gradual decrease in growth rate with increase in age. Dua and Kumar (2006) reported maximum annual increment in first year of life and in the subsequent years it decreased with age except 5+ age class in *C. marulius*. Ugwumba (1989) investigated fast growth in tropical fishes especially before onset of sexual maturity. After attainment of maturity, food consumed by fish is not used for linear growth alone but for ripening of the gonads and other metabolic processes. No significant differences were observed between calculated and observed mean length in the present study. High variability in observed length at age indicates that length may be poor predictor of age for *Aeipensur oxyrinchus*
(Stevenson and Secor, 1999). They stated that high variability may result from amplification of early growth differences over a long life span. Growth parameters in the present investigation were assumed to represent the general population, irrespective of sex differences in growth, which may also introduce bias into the results. According to Stevenson and Secor (1997) von Bertalanffy curve may have been driven upwards at younger ages by the potential maximum growth rate of the population. At later ages, the curve is pulled downward as slower growing individuals enter the fishery, increasing k and decreasing L∞.

5.2.2. Channa punctata

In *C. punctata*, age was determined using otoliths which provided the precise age estimates. The VBGF equation indicated that the fish grew rapidly during first three years of life and then the growth rate gradually decreased. Mustafa and Graaf (2008) estimated the growth parameters (L∞ and k) of *C. punctatus* from Ashura beel (L∞=24; k=1.1), Dikshi beel (L∞=24; k=1.2), Mara beel (L∞=24; k=0.9), Shapla beel (L∞=24; k=1.2) and Medi beel (L∞=24; k=0.9) in Bangladesh. There could be some differences between growth characteristics from one area to another area for reasons of food availability, hydrographical and climatic conditions, and fishing mortality rates (Consoli et al., 2010). In the current study, no significant difference was noticed between observed and calculated mean lengths. Qasim and Bhatt (1966) reported that in *C. punctatus* theoretical lengths obtained from the von Bertalanffy equation agreed very closely with the observed lengths. Bhatt (1970a) observed that theoretical values agreed with the observed values closely in *Ophicephalus striatus*. Variations in the growth parameters of the fish inhabiting different waterbodies may be attributed to a number of biotic and abiotic factors, as discussed above. The back-calculated lengths (VBGF) using the age estimates from scales (non-lethal) and otoliths (most suitable ageing structure) did not show any significant variation. Therefore, either of the structures could be used for growth estimation in *C. punctata*. 
5.2.3. *Labeo bata*

In *L. bata*, age was determined using scales which provided the precise age estimates. The estimated maximum length ($L_\infty$) of 38.3 cm for *L. bata* is smaller than that reported by Chatterji et al. (1979) ($L_\infty = 450$ mm). In the present research work, VBGF equation indicated that the fish grew rapidly during first two years of life and then the growth rate gradually decreased. Chatterji et al. (1979) also reported that growth rate of fish was high during 1st and 2nd years and decreased gradually afterwards till the 7th year. The authors further suggested that decrease in calculated lengths with increasing age has been due to attainment of maturity since most of the growth potential is used for gonad building rather than dimensional growth after second year class. Similar findings have been reported for *C. catla* (Johal and Tandon, 1992); *L. rohita* (Tandon and Johal, 1993) and *Tor putitora* (Tandon et al., 1993). Abbas and Siddiqui (1987) also reported that the specific growth rate decreased with increasing age and size of fish.

5.2.4. *Hypophthalmichthys molitrix*

In *H. molitrix*, age was determined using opercular bones which provided the accurate age estimates. In the current study, the growth rate of fish was found to be high during first, second, third and fourth year of life after which growth rate decreased successively in higher age classes. The values of growth parameters for *H. molitrix* were smaller than those reported by Rao and Natarjan (1979) ($L_\infty = 103$; $k = 0.56$) and close to those reported by Li et al. (1990) ($L_\infty = 78.4$; $k = 0.20$). Differences among all of the estimated parameters could be due to a number of factors such as, different sampled locations or different age groups employed to fit VBGF function. Fish populations that have different geographical distributions, even when belonging to the same species, may exhibit highly variable individual growth rates (Wootton, 1990). The back-calculated lengths (VBGF) using the age estimates from scales (non-lethal) and opercular bones (most suitable ageing structure) showed significant variation. Therefore, in *H. molitrix*, scales cannot be used for growth estimation. It has been commonly observed that in case
of fishes having scales or spines-rays, the age estimates are commonly recorded by counting the number of annuli on non-lethal structures. However, the growth equation developed by imprecise ageing structure could result into misleading assessment of several population characteristics which are dependent on precise age and growth estimates.

5.2.5. *Mastacembelus armatus*

In *M. armatus*, age was determined using vertebrae which provided the precise age estimates than opercular bones and pectoral spines. The VBGF equation indicated that the fish grew rapidly during first three years of life and then the growth rate gradually decreased. Decrease in calculated lengths with increasing age has been attributed to attainment of maturity and it is well known fact that most of the growth potential is used for gonad building rather than dimensional growth. No significant differences were observed between calculated and observed mean lengths. Body growth data is crucial not only to understand the status of fish populations but also for estimating standing stock, yield and biomass (Froese, 1998). This type of data is necessary to provide the basis for species conservation and a sustainable fishery (Volta and Giussani, 2010). In *M. armatus*, significant variation was found between back-calculated lengths (VBGF) of pectoral spines (non-lethal) and vertebrae (most suitable ageing structure). Therefore, pectoral spines cannot be used for growth estimation in place of the most suitable structure.

5.2.6. *Heteropneustes fossilis*

Age was determined using vertebrae of *H. fossilis*, which provided precise age estimates as compared to otoliths and pectoral spines. The growth function (VBGF) equation indicated that the fish grew rapidly during first two years of life and then the growth rate decreased. Graaf (2003) investigated the parameters of von Bertalanffy
growth function for *H. fossilis*, *C. punctata*, *Colisa fasciatus*, *Puntius sophore*, *Lepidocephalus guntea* and *Mastacembelus pancalus* and found that all species are fast growing, reaching their asymptotic length almost within 2 years and have a relative short life span of 2-5 years. Kohli and Goswami (1989) reported that *H. fossilis* attained a length of 143-175 mm in 1st year; 195-209 mm in 2nd year; 223-235 mm in 3rd year and 249-253 mm in the 4th year of life. The growth of fishes can be affected by many factors such as food limitations, maturation level, sex, environmental conditions, and population size as well as fishery pressure. Insignificant difference was found between the back-calculated lengths (VBGF) of pectoral spines (non-lethal) and vertebrae (most suitable ageing structure. Hence, in *H. fossilis* pectoral spines could be used for the growth estimation next to the vertebrae. Monteiro et al. (2006) suggested that in most cases the differences in growth parameters could probably be attributed to a combination of sample characteristics (range of sizes and sample sizes), ageing methodology used, and geographical differences.

5.2.7. *Clarias gariepinus*

In *C. gariepinus*, age was determined using otoliths which provided the precise age estimates. In *C. gariepinus*, Bruton and Allanson (1980) reported asymptotic lengths 76.0 cm for male and 67.4 cm TL for female. Spare et al. (1992) reported that growth parameters differ from species to species and also stock to stock even within the same species as a result of different environmental conditions. Zivkov et al. (1999) suggested that the estimated parameters from the von Bertalanffy equation $L_\infty$ and $k$ are sensitive to the age structure of the sample. In the current study, the growth rate of fish decreased with increasing age. Yalcin et al. (2002) studied the growth rates of *C. gariepinus* using vertebrae that provided reliable age estimation. It is important to understand the consequences of assigning unreliable growth parameters to a fully exploited stock, as predictions of fish populations from models rely heavily on input data, including age and growth (Lessa and Duarte-Neto, 2004). Insignificant variation was observed between the back-calculated lengths (VBGF) at estimated ages by using pectoral spines (non-lethal)
and otoliths (most suitable ageing structure). Therefore, in *C. gariepinus* pectoral spines can also be used for growth estimation.

### 5.2.8. *Clarias batrachus*

In the present work, the asymptotic length estimated by the VBGF was close to the maximum observed size. Small differences between estimates of $L_\infty$ and observed maximum length indicated that the estimated $L_\infty$ values were reasonable (Taylor, 1958; Moreau, 1987; Chen et al., 1992). The growth function (VBGF) equation of *C. batrachus* indicated that the fish grew rapidly during first five years of life and then the growth rate decreased. As discussed elsewhere, the decrease in calculated lengths with increasing age in our study may be due to the attainment of maturity since most of the growth potential is used for gonad building rather than dimensional growth. A population that has been more heavily fished than others might show smaller length-at-age (Yamaguchi et al., 2004). Comparing results of growth of *C. batrachus* with the previous study (Thakur, 1981) the value of $L_\infty$ (39.2 cm) in the present study was close to the value obtained by Thakur (1981) (405.6 mm). Values of $k$ (0.48) and $t_0$ (0.07) reported in our study were almost similar ($k = 0.48$ and $t_0 = 0.02$) to that investigated by Thakur (1981). In *C. batrachus*, back-calculated lengths (VBGF) at estimated ages between pectoral spines (non-lethal) and otoliths (most suitable ageing structure) showed significant variation. Therefore, in *C. batrachus*, pectoral spines cannot be used for growth estimation.

### 5.2.9. *Wallago attu*

In *W. attu*, the observed maximum length was greater than that reported by Goswami and Devaraj (1996). The growth parameters may vary regionally or methodologically, differences in size of the largest individual sampled, species, sex and age (Goncalves et al., 2003). According to estimates of the von Bertalanffy growth equation, growth of *W. attu* is high during the first 5 years of life, with the growth rate
slowing down considerably after reaching 5 years of age. It has been reported by Brown (1946) that the size of the fish is most important factor which affects the growth in population. The comparatively larger fishes grow faster and their removal leads to an improvement of the growth rate of smaller fishes and addition results in slow growth rate of smaller fishes. Differences among estimated parameters could have been a consequence of several factors such as (i) different methods used for age estimation, (ii) different size distributions and (iii) different sampled locations (Ma et al., 2010). In *W. omu*, insignificant variation was found between the back-calculated lengths (VBGF) at estimated ages by using pectoral spines (non-lethal) and otoliths (most suitable ageing structure), so pectoral spines can also be used successfully for growth estimation.

5.2.10. Ompok pabda

In *O. pabda*, age was determined using vertebrae which provided the precise age estimates than opecular bones and otoliths. In *O. pabda*, the asymptotic length (L∞) obtained from VBGF is closed to the maximum length recorded. In the present research work, estimated VBGF equation indicated that the fish grew rapidly during first two years of life and then the growth rate gradually decreased. Ezzat et al. (1992) reported that during the first year of life most of the consumed food is used for growth in length while at sexual maturity food is used for maintenance of gonad formation and growth in weight. Calculated lengths at age derived from von Bertalanffy growth equation were not significantly different from the observed lengths. In *O. pabda*, back-calculated lengths (VBGF) at estimated ages between pectoral spines (non-lethal) and vertebrae (most suitable ageing structure) showed significant variation. Therefore, pectoral spines cannot be used for growth estimation in *O. pabda*. 
5.3. LENGTH-WEIGHT RELATIONSHIP (LWR)

Length-weight relationships give information on the condition and growth patterns of fish (Bagenal and Tesch, 1978). In morphometry, length-weight relationships are a valuable and standard result of fish sampling programmes. These relationships are considered necessary to estimate various morphological and physiological aspects such as growth rates, length and age structures, and other mechanisms of fish population dynamics (Kolher et al., 1995). In fish, the weight is considered to be function of length (Weatherley and Gill, 1987). When the specific gravity of a fish remains unchanged and retains the same shape during its lifetime, it is growing isometrically and the value of length exponent \( b \) would be exactly 3.0 (Wootton, 1990). The results revealed that *C. marulius*, *L. bata*, *C. gariepinus* and *W. attu* showed isometric pattern of growth; this type of relationship had been reported in fishes that maintain a constant body shape (Kumar et al., 1999). When the value of \( b > 3 \) or \( b < 3 \) the fish is considered to show allometric growth pattern (Tesch, 1971). Naeem et al. (2012) reported isometric growth (\( b \) value close to 3) in *L. bata*. Several authors have reported allometric pattern of growth in different fish species such as *Ethmalosa jimbrata* (Ekeng, 1990; Marcus, 1984); *Tilapia mariae* (King, 1991); *Chrysichthys auratus* (Shenouda et al., 1994); *Pseudotolithus elongatus* (King, 1996). In the present study, *H. molitrix*, *M. armatus* and *C. batrachus* showed negative allometric (\( b < 3 \)) growth while *C. punctata*, *H. fossilis* and *O. pabda*, showed positive allometric (\( b > 3 \)) growth. Sharma et al. (2009) have reported allometric pattern of growth in *C. batrachus* from Maulagarh wetland of Chandausi, Moradabad. Gupta et al. (2011) reported that allometric coefficient was close to isometric value (\( b = 3.08 \)) during the pre-monsoon, negative allometric growth in monsoon periods while positive growth in post-monsoon in *O. pabda*. Negative allometric pattern of growth was reported in *H. molitrix* (Ye et al., 2007) and in *W. attu* (Saini et al., 2010). As the values of \( b \) increases, the size of the fish also increases because the fish usually grows proportionately in all directions. However, the changes in fish weight in general are actually greater than the changes in its length. However, the body shape of fish tends to change as the length increases. The value of \( b \) then becomes greater than 3 as the fish becomes fatter, or when the \( b \) value is lower than 3, the fish is slimmer (Ibrahim, 1984).
The length-weight relationship in fishes can be affected by several factors including habitat, seasonal effect, degree of stomach fullness, gonad maturity, sex, preservation techniques and differences in the observed length ranges of the specimen caught (Tesch, 1971). However, these factors were not investigated in the present study. In most fishes of tropical and temperate regions b values have been reported to range from 2.7 to 3.3 (Gonzales et al., 2000). In the present study, the b value estimated from length-weight relationship for all the selected fish species lies between the common range values. Beverton and Holt (1957) suggested that the departure of the b value from 3 is rare in adult fishes. The exact relationship between length and weight differs among species of fish according to their inherited body shape, and within a species according to the condition (robustness) of individuals, sometimes reflected by the food availability and growth with in the weeks prior to sampling (Yousuf and Khurshid, 2008). Pathak (1975) reported b value of less than 3 for Labeo calbasu from Soni River. Harish Kumar et al. (2006) reported b values less than 3 for the males and females of Rasbora daniconius from Karnataka. Mercy et al. (2002) reported b value of 3.04 for P. denisonii from Kerala and suggested that values above 3 are possible in some conditions such as in farming and other stress free environments. Morphological changes due to age also cause substantial changes in the exponent of length on weight. Tesch (1968) viewed the exponent (n) values of 3, which indicates that the specific gravity of the tissue remains constant throughout its life for an ideal fish. Probably due to this reason, the n value is found to be very close to 3 in many cases. Hence it is generally called the cube law. However, fish normally do not retain same shape of the body throughout their life span and the relationship may depart from the cube law. The length-weight information on all selected fish species except for L. bata and O. pabda was present in the FishBase database (Froese and Pauly, 2010) for other waterbodies, but not for the river selected for the present study. The value of b reported by other researchers for H. moliitrix (Rao and Natarajan, 1979), L. bata (Chaterjii et al., 1977), O. pabda (Gupta et al., 2011) and C. punctata (Hossain et al., 2006b) was different from those obtained in the present study. The observed differences in the values can be attributed to the combination of one or more of the following factors: (i) differences in environmental or habitat factors; (ii) differences in the length ranges; and (iii) differences in the number of specimen
examined. Values of b for all the selected fish species were within the normal range of 2.5 - 3.5 as suggested by Froese (2006).

5.4. LENGTH-LENGTH RELATIONSHIP (LLR)

Results for length-length relationship between total length (TL), fork length (FL) and standard length (SL) of each selected fish species indicated that these are highly significant (P < 0.001), with most of the coefficient of determination (R²) values being > 0.9. Fishbase showed no reports of length-length relationships for O. pabda and L. bata. Due to the lack of published literature dealing with LLRs for these species, result comparisons were not possible, except for O. pabda by Gupta et al. (2011) who reported highly significant (P < 0.001) length-length relationships, with r² values being > 0.992. Length-length relationships are important in fisheries management for comparative growth studies (Moutopoulos and Stergiou, 2002). In fisheries studies, fish length can often be measured more rapidly and easily than mass. The knowledge of the length-weight relationship makes it easier to determine the mass where only the length is known. The length-weight (LWR) and length-length (LLR) relationships have been applied for basic uses in the assessment of fish stocks and populations (Ricker, 1968). Length-length relationship had been studied in several fish species, such as Salmo trutta (Arslan et al., 2004); Barbus albanicus; Leuciscus cf. svallize and Lepomis gibbosus (Bobori et al., 2006); Eutropiichthyes vach (Soomro et al., 2007) and Boops boops (Kara and Bayhan, 2008). Le Cren (1951) stated that for the variations of LLRs in the same species from different locations, the ecological conditions of the habits or variation in the physiology of animals, or both, are responsible.

5.5. CONDITION FACTOR (K)

Condition factor is used to compare the condition or well-being of fish and are based on the hypothesis that the heavier fish of a given length are in better physiological
condition (Bagenal, 1978). The condition of fish is subjected to great number of variations depending upon the various factors in the nutritional and biological cycles of the species. The condition factor may vary when average weight of the fish is not increasing in direct proportion to the cube of its length (Wooten, 1990). Therefore, when \( b = 3 \), \( K \) would remain constant. If, however, the weight increases more rapidly than the cube of length, \( K \) would increase with increasing length. When the weight increases less than the cube of length, \( K \) would tend to decrease with the growth of the fish (Javaid and Akram, 1972). *C. marulius, L. bata, C. gariepinus and W. attu*, appear to follow the cube law as the value of \( b \) of length-weight relationship is not significantly different from 3 (\( b \) for an ideal fish) and therefore \( K \) remains almost constant. Zafar et al. (2003) reported that condition factor of *C. catla* remains fairly constant with increasing length or weight. In the present research work the value of \( b \) is more than 3 in *C. punctata, H. fossilis, W. attu* and *O. pabda*. The value of \( b \) more than 3 showed significant positive relationship between \( K \) and fish length, indicating that \( K \) will increase with increasing length (Anderson and Gutreuter, 1983; Cone, 1989). Conversely, there is a negative relationship between \( K \) and fish length, when the value of \( b \) is less than 3, which leads to decrease in \( K \) with increasing length (Cone, 1989). Condition factor (\( K \)) appears to increase with increasing length and weight in the present study. The condition factor may vary with increasing length when average weight of fish does not increase in direct proportion to the cube of its length (Naeem and Salam, 2004). Therefore when \( b = 3.0 \), \( K \) remains constant. If, however, the weight increases more rapidly than cube of length, the \( K \) would increase with increase in length. When weight increases less than the cube of length, \( K \) would tend to decrease with the growth of the fish (Naeem et al., 2000, Naeem and Salam, 2004).

Condition is variable and dynamic in individual fish within the same sample. An average condition of each population varies seasonally and yearly in between the sex, developmental stages of the gonad, especially the ovary affect the weight considerably (Weatherly, 1972; Hile, 1936). The condition factor may be influenced by the developmental stage of the gonads and by the degree of stomach repletion. The condition factor does not only reflect the feeding condition of the fish but the gonad development as well (Lizama et al., 2002).
Generally, the increase in condition factor is attributed to the gain in weight accompanied by the maturation of gonads during the pre-spawning period and sharp decline in the values is the result of mature fishes becoming spent, leading consequently to lowering of weight and condition. Thompson (1943) has pointed out that the high and low K values in Pleuronectus platessa are found before and after spawning. A loss of condition follows release of ova and sperms. The other factor which seems to govern the rise and fall of K is feeding rate of fish (Qasim, 1957; Bal and Jones, 1960; Bhatt, 1971). Bhatt (1970b, 1971) observed in Mystus seenghala and H. fossilis that the increase and decrease of K value gave no indication of spawning season of these fish. He observed that the feeding rhythm was closely related to K than the cycle of gonad weight. It, therefore, appears that besides the sexual cycle and food intake, other factors may also be responsible for the variations in condition factor value.

Undernourished or thin fish has a condition factor less than 1. Adequately fed or fat fish has a condition factor greater than 1. The K value between 1.40 - 2.0 represents the excellent condition of fish (Barnham and Baxter, 2003). In the present study, the mean condition factors ranged from 0.90-1.43. The value obtained from the study showed that all species studied were in good condition. Condition (K) value increased proportionately with the length of the fish.

5.6. CONCLUSION

It may be concluded from the present study that scales were the most suitable ageing structure in C. marulius and L. bata. Otoliths showed most clear and sharp annual rings in C. punctata, C. gariepinus, C. batrachus and W. attu. Otoliths could also be used as an alternative structure to the best ageing structure in C. marulius and H. fossilis. Opercular bones were the most suitable ageing structure for H. moliitrix, and they can also be used as an alternative to the most precise ageing structure in C. punctata, L. bata, M. armatus and O. pabda. Vertebrae were reported as the best structure for ageing M.
armatus, H. fossilis and O. pabda. They can also be used as an alternative to the best ageing structure in H. molitrix, C. gariepinus and C. batrachus. In W. attu, pectoral spines can be used as an alternative to the best ageing structure (otoliths). If size-class is not taken into account, then in C. marulius, all the selected ageing structures except dorsal fin rays could be used for mean age estimation. In case of C. punctata, L. bata and O. pabda, opercular bones might be used for mean age estimation with no significant differences in age readings in comparison to the best ageing structure i.e., otoliths (C. punctata), scales (L. bata) and vertebrae (O. pabda). While in H. molitrix, C. gariepinus and C. batrachus, vertebrae could be used for mean age estimation with no significant differences in age estimates in comparison to the most suitable structure i.e., opercular bones (H. molitrix) and otoliths (C. gariepinus and C. batrachus). In M. armatus, age estimates from the best ageing structure (vertebrae) showed significant differences with age readings of the other selected structures. Otoliths, in H. fossilis, could be used for mean age estimation with no significant differences in age readings in comparison to the most suitable ageing structure i.e., vertebrae. In W. attu, pectoral spines might be used for age estimation with no significant differences in age estimates in comparison to the otoliths (best ageing structure).

Calculated total length from the von Bertalanffy growth equation and observed total length did not show significant differences in any of the selected fish species. The back-calculated lengths at estimated ages using non-lethal ageing structure (scales or spines/rays) and the most suitable structure showed significant variation in H. molitrix, C. batrachus, M. armatus, and O. pabda while, insignificant differences were found in C. punctata, C. gariepinus, H. fossilis and W. attu. The k value across all the species ranged from 0.21-0.49/year suggesting rapid growth in the selected fishes. The estimates of \( t_0 \) in the present study ranged from -0.07 to -1.62 for all the selected fish species, which supports the reliability of the determined ages. Findings of the present study are based on the samples that comprised relatively less number of higher age fishes. Therefore, care should be taken to utilise the findings in case of fish specimens older than reported here.

The study of length-weight relationship in selected fish species showed that C. marulius, L. bata, C. gariepinus and W. attu showed isometric pattern of growth. C.
*punctata, H. fossilis and O. pabda* exhibited positive allometric growth \((b>3)\) while *H. molitrix, M. armatus* and *C. batrachus* showed negative allometric growth \((b<3)\). All length-length relationships [between total length (TL), fork length (FL) and standard length (SL)] were highly significant with the high values of coefficient of determination \((R^2)\). Condition factor values obtained from the study showed that all selected fishes were adequately fed and in good condition. The results of the present research work may be utilized by researchers, fishery managers, and policy makers for sustainable fishery management and conservation of the selected fish species.