

Life history traits of freshwater fish population and implications on aquatic biodiversity conservation: a review

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ABSTRACT

Knowledge on life history traits of fish and habitat requirements are very important in implementation of fishery management programmes, domestication of species under captive conditions, stock identification, population dynamics, development of captive breeding technology, assessment of conservation status, utilization of fishes as biological control, *in situ* and *ex situ* conservation. Life history characteristics of fish, including maximum size, growth rate, size at maturity, fecundity and migratory behaviour, have important implications for populations as well as their risk of extinction. Though phenotypic differences in life history parameters do not provide direct evidence of genetic isolation between stocks, but can indicate the prolonged separation of fish and also provide a firm basis for separate management units. The variation in life history traits of fish indicate phenotypic plasticity of the species which could be an important adoption trait, allowing them to respond to ecologically/habitat changes during their life time. Review of literature indicates that information on the life history parameters of most of the freshwater fishes from different lotic and lentic waters is rather fragmentary and understudied. The present paper reviews the relevance of the studies on life history traits of fish population and their implications in biodiversity conservation, synthesis of latest developments, knowledge gaps, research priorities and highlight important issues related to conservation and management of freshwater fishes.

Key words: Biology, Conservation, Fish

Freshwater biodiversity has declined faster than either terrestrial or marine biodiversity over the past 30 years (Jenkins, 2003; UNESCO, 2003). According to IUCN Red list (2007), approximately 30% of the fish species are threatened globally most of which are freshwater. Many strategies and priorities have been proposed to solve this crisis. The threats affecting the life history parameters of freshwater fish are anthropogenic, biophysical, habitat alterations, reduction of natural habitat area, construction of dams, diversion or reclamation of river beds, introduction of non native species and climatic variations etc. The impact of these stresses lead to decline in effective population sizes, depending upon original population size and magnitude of the threat. Conservation efforts have been less by lack of information on biodiversity, distribution, habitat requirements, population dynamics, migration pattern and other essential life history traits.

In the recent years, the freshwater fish biodiversity in India are showing an alarming decline due to several factors and several species have been categorized as threatened in many parts of the country. This emphasizes an immediate need for initiating research and framing the strategies of actions for conservation and management techniques to protect these

aquatic life forms. The number of recognized finfish species in the world is estimated to be around 28,400 (updated to 29,300; <http://www.redlist.org/info/tables/table1.html>) and of these 11,952 are found in freshwater, and another 160 species require freshwater at one stage or the other, to complete their life cycle (Nelson 2006). According to Kottelat and Whitten (1996) East and South and Southeast Asian nations have a cumulative total freshwater finfish fauna of 7447 species, with Indonesia having the largest number of 1300. In India, 2,246 species of finfish have been recorded of which 756 from freshwater, 113 brakishwater and 1,368 from marine environment (Lakra and Sarkar 2009). However, the natural history of the vast majority of fishes is very poorly documented. Of the total freshwater fishes known so far from the country, limited information on life history of about 125 fishes are known till date, the life history traits and habitat requirements in respect of majority of fishes are still lacking and this forms one of the major constraints in taking appropriate policies for their conservation.

Fish as a group, apart from its economic value, from a biodiversity viewpoint, has the highest species diversity among all vertebrate taxa. Fishes have evolved a diversity of life history pattern (Breder and Rosen, 1966). Some species have very short life span, others may live for decades. Even within a species, there may be major variations in the life

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history patterns shown by different populations living at different geographic locations. Life history traits reflect the ways in which individuals vary their stage or age specific expenditures of reproductive efforts in response to intrinsic and extrinsic factors that influence survival and fecundity (Swain *et al.* 2005). Various hypotheses have been proposed to explain diversity in life history pattern. Life history has two usages in fish conservation ecology and can provide general insights into where attention might be most profitably focused in monitoring and research (Adams 1980). There is also a growing awareness about the life history traits of the ecologically significant unit (ESU) of a species and the need to conserve them (MacLean and Jones 1995). Biological, as well as, genetic characterization of wild stock of fish species will enable in linking ESU with evolutionary significant unit, thus the life history traits of the ESU of a species has great need to conserve them (MacLean and Jones, 1995) and intra species variation in life history traits has a strong genetic and environmental basis (Cadrin 2000, Lowe *et al.* 1998).

Studies on life history variation of freshwater fishes continue to have an important role to play in fish genetic resource management and conservation, despite the advent of biochemical and molecular genetic techniques which accumulate neutral genetic differences between groups. Life history characteristics, variations among populations and models of various fish species have been used for conservation and management programme of the freshwater fishes in many countries (Tibor 2004, Pearson and Healey 2003; Anna and Ramon 2002; Olson *et al.* 2004 and Villeneuve *et al.* 2005). Review of literature indicates most of the research on life history strategies of some selected freshwater fishes (carps, catfishes etc.) were focused earlier from limited geographical range/locations (Jhingran 1952, 1968, Das and Moitra 1955; David 1963; Jhingran and Khan 1979; Chakraborty and Murty 1972; Chaturvedi 1976; Pathani 1980; Johal and Tandon 1983; Nautiyal 1984; Abbas and Siddiqui 1987; Tondon and Johal 1993 and Bhatt *et al.* 1998) and very little attempt has been made so far for use of those information in conservation. It is also observed that though the biological information of Indian Major Carps has been documented in the FAO synopsis series (Jhingran 1979, Jhingran and Khan 1968 and Khan and Jhingran 1975), however, detailed comparative biological characterization and evaluation of various life history parameters (age and growth, size at maturity, early life stages etc.) from different wild stocks, within a species is lacking. Most of the earlier studies on freshwater fishes in India are either concerned with morphology, taxonomy, pollution (Singh and Dobryal 1983; Datta Munshi and Srivastava 1988; Talwar and Jhingran 1991; Menon 1992 and Jayaram, 1981) or the inland fisheries stocks or freshwater aquaculture systems (Jhingran 1975). Status of knowledge on fish life history strategies, trophic ecology, the population biology, distribution pattern and fish habitat requirements and their implication for

biodiversity conservation are very limited (Arunachalam 2000; Srivastava *et al.* 2001; Arthington and Lorenzen, 2004; Arthington *et al.* 2004; Singh *et al.* 2003; Bhat 2003; Dahanukar *et al.* 2004; Johal and Rawal 2005; Sarkar and Bain 2007 and Vinyoles and Sostoa 2007). Despite recent advances, river based spatio-temporal information is lacking on the species distribution, habitat requirements and habitat use pattern, migration and spawning cues, pattern of migration, reproductive biology, stock structure, climatic variation and impact on fish life history etc. for most of the aquatic system. The important component of life history parameters included are; 1) age and growth 2) age at first reproduction and reproductive life span 3) migration and life stages 4) reproductive season and regulating environment 5) pre spawning action 6) parental care 7) early life history and their survival 8) growth, population dynamics, survival and natural recruitment.

Overview of life history patterns

Life history characteristics of fish, including maximum size, pattern of growth, reproduction at first maturity, fecundity and migratory behaviour, have important implications for populations as well as their risk of extinction (Winemiller and Rose 1992). While life history theory has been increasingly used to assess exploitations threats to marine fish stocks arising from fishing pressure, there has been far less work on freshwater populations that face wider set of threats. Chonder (1999) has made a compilation of the existing information available on the different aspects of life history traits of forty-seven commercially important species of finfish and shellfish including 43 finfishes which include 25 species from cypriniformes, nine species from siluriformes, two species from perciformes, three species from channiformes and one species each from osteoglossiformes and clupeiformes. National Agricultural Technology Project (NATP), NBFGR, Lucknow undertook extensive studies on specific life history data of the prioritized endangered and commercial important fishes in the two hot spot area North east and Western Ghats regions of India and distinct populations have been reported (Sarkar *et al.* 2008, 2009). The NATP launched in January 2000 with 6 collaborators drawn from the North East and 6 from the Western Ghats regions. Under NATP, Workshops were held on "Germplasm Inventory, Evaluation and Gene Banking of Freshwater Fishes" which one at CMFRI, Cochin and other at North-Eastern Council, Shillong, Meghalaya. In both the workshops a separate working group was formed on use of life history trait parameters for conservation and various issues related to biological data analysis were prioritized. The working group strongly recommended the need of generating species specific life history data and requirement of habitat and ecological studies (Ponniah and Gopalakrishnan 2000 and Ponniah and Sarkar 2000). The group also discussed knowledge gaps and identified crucial

parameters like fecundity, batch fecundity, annual fecundity, size at first maturity, gonadosomatic index, age and growth, length-weight relationship, oocyte size frequency profile, relative condition factor, food and feeding etc. It was suggested that data available on life history traits in India may be brought out by NBFGR, Lucknow in general format similar to that of FAO synopsis.

Review of literature indicates that information on the life history of the freshwater fishes from different lotic and lentic waters is rather fragmentary, and understudied. Khan (1943) studied the development of some freshwater fishes of Punjab including *Cirrhinus mrigala*. Mookerjee *et al.* (1944) and Mookerjee (1945, 1946) described the distinguishing character of the fry of common Indian carp and the eggs of fresh waterfishes of West Bengal, respectively. Ahmad (1944), Alikunhi and Rao (1951) and Alikunhi (1956) described the early stages in the development of major carps and minor carps. Mazumdar (1957) has prepared a key for the identification of fertilized eggs of common freshwater fishes. Chacko and Kurian (1949) have reported in brief, about the early life development in *Catla catla*. Sharma and Chandy (1961) studied on the alimentary tract and feeding habit of *C. chitala*. Dey *et al.* (1980) describes about the breeding behavior, growth and fecundity of *C. chitala*. Natarajan and Jhingran (1963) have made detailed studies on the biology of *C. catla* from the river Yamuna. Kamal (1969) has reported an account on the age and growth of *C. mrigala* from the river Yamuna. Among others, Chakraborty and Murty (1972) studied on the life history of Indian major carps *C. mrigala*, *C. catla*, and *Labeo rohita* with special reference to their distinguishing characteristics in the embryonic as well as post larval stages. Though considerable studies has been done in fishery population biology and age and growth of some freshwater fishes by Tandon and Johal (1995) but the validation with other hard parts and analysis in respect to different wild population has not been well studied. Studies on fishery biology particularly age and growth, length weight relationship, maturity and fecundity of IMC have been done by various authors (Jhingran *et al.* 1988). Screening of literature shows that very limited research on major carps has been done after Alikunhi and Jhingran (1975). The details of the life history traits of endangered *Labeo dussumieri* have been thoroughly studied by (1995b, 1997). Ramakrishniah (2000) reported some biological aspects of catfishes endemic to Peninsular India. Engeszer *et al.* (2007) and Mahapatra *et al.* (2004) reported geographic range, biotic and abiotic habitats, and life cycle of the zebrafish across sites in Northeast India. Biswas (1991) made several attempts to study life history traits of *Labeo pangusia*. Recently well distinct variation of life history traits of *Chitala chitala*, *Catla catla*, *Labeo rohita* from various wild population have been reported (Sarkar *et al.* 2006; 2008a; Deepak *et al.* 2008 and Sarkar *et al.* 2009) and alternative conservation strategies are suggested (Sarkar *et al.* 2008b).

The life history data has been well analyzed in order to make habitat specific relationship of different life history data set and developing a modal value of traits using statistical softwares by several countries. Notable efforts to document or understand life-history diversity include Breder and Rosen (1966), Balon (1975, 1984), Page (1983) and Winemiller and Rose (1992). Winemiller and Rose (1992) proposed that the essential features of the primary life history strategies can be captured by the interrelationships among three basic demographic parameters: survival, fecundity, and onset and duration of reproductive life. Breder and Rosen (1966) described reproductive modes of marine and freshwater fish groups, reviewing virtually everything known fish reproduction to that date. The organization of Breder and Rosen (1966) is by phylogenetic groups, with detail descriptions of breeding behaviour and life history traits for individual species. Winemiller (1992), to tie life history traits to habitat, suggested that the original *r* versus *K* dichotomy of reproductive strategies failed to capture some important variance in fish reproduction and suggested three basic patterns in freshwater fish life history, including equilibrium, opportunistic and seasonal modes. Winemiller and Rose (1992) has reviewed 16 life history traits for 216 North American fish species of 57 families by multivariate analysis and showed fundamental differences between marine and freshwater species in modal values for numerous traits, like clutch size, egg size, spawning season, and degree of parental care, but patterns for the marine and freshwater species, in separate principal component analysis were very similar. It is reported that reproductive diversity in fish is enormous (Breder and Rosen 1966) with noteworthy inter specific (in some cases intraspecific) variation in most traits. Some of the fundamental traits relative to reproductive success of a species include size at first maturity, number of eggs, reproductive season length or timing and longevity (Wootton 1984), as well as the number of clutches per female per year, and the variation in those traits aiming populations or individuals or within a species. Egg production combined with longevity provides the familiar *l* and *m_x* on which life table *s* lifetime reproductive expectation or output is based but this has already been measured for fish in the wild. For live-bearing fishes, fecundity is determined by the number of embryos; inter brood interval, and length of breeding season (Hubbs and Mosier 1985). Breder and Rosen (1966) summarized the reproductive modes of most fresh-water and marine families, worldwide, with respect to secondary sex characteristics, mating system, breeding sites, kind of eggs, paternal care, and migration. Detenbeck *et al.* (1992) also compiled, fundamental data on life-history characteristics for a large number of North American freshwater fishes. Miller (1996) calculated costs and benefits of small body size, and its implications for life-history. Balon (1975, 1984) provided a classification of evolution of reproductive modes in fishes, detailed transitions in life stages of fishes, and

describe general size relationships among gametes, larval sizes, and adult body size. Wootton (1984) has analysed enormous data on size at maturity, life span, months of spawning, fecundity, egg diameter, time to hatching, migration for 162 freshwater Canadian species, showing correlations of the various parameters classifying the species into 10 clusters having similar traits. The strongest correlations were between body size and life span, body size and egg size, and spawning months and egg size (due to autumn spawning salmonids with large eggs). Wootton (1984) concluded that in a given geographic region, only a certain number of types of reproductive strategies are possible, in that environmental factors, morphology, and phylogeny constrains the kinds of strategies that can evolve. Paine (1990) showed differences between darters (Percidae) with small and large body size, with the latter exhibiting the combined traits of fast growth, maturation at large body size, larger clutches, shorter spawning seasons, and longer reproductive life spans. Winemiller (1992) hypothesized a triad of life history strategies termed periodic, opportunistic and equilibrium. According to their classification, periodic fishes delay maturation to a size sufficient for producing large clutches, often with synchronous spawning and promoting survival of adults during adverse environmental conditions. Egg size is small in periodic fishes, but growth larvae and young-of-year are rapid. Periodic spawners also tend to be migratory, moving to best places at the right time within a relatively predictable seasonal environment. Opportunistic strategy fishes are typically are of small body size, with early maturation, frequent reproductive bouts over a long spawning season, rapid larval growth, and high population turnover rates, with a resulting high intrinsic rate of population increase, and population of these small fishes are often present at high density in spite of high adult mortality (Winemiller and Rose 1992). It is reported that there are numerous schemes for describing and categorizing overall life history strategies for freshwater fishes. Breder and Rosen (1966) provide the most comprehensive descriptive summary, worldwide. Balon (1984) and others have provided various schemes for classification of reproductive traits, while Winemiller and Rose (1992) provide the most detailed and integrated assessment of broad life history patterns to date.

Habitat use and migration

Fish habitat is defined as "habitat for fish is a place or for migratory fishes, a set of places in which a fish, a fish population or fish assemblage can find the physical and chemical features needed for life, such as suitable water quality, migration routes, spawning grounds, feeding sites, resting sites and shelter from enemies and adverse weather" (Orth and White 1993). Most fish have complex life cycles involving several morphologically distinct, free-living stages such as eggs, larvae, juveniles and adults. In the course of

their lives, fishes will grow by several orders of magnitude in mass and their resource and other ecological requirements may change drastically. As a consequence, many aquatic organisms undergo ontogenetic shifts in habitat requirements. To meet the different requirements of different life history stages, fishes require access to a variety of habitats in the course of their life cycle. This requirement has two implications: (1) a variety of habitats must exist and (2) must be able to migrate between them (actively or passively). Migration requires some degree of connectivity between aquatic habitats, which can be highly fragmented and separated spatially. The life history of a given species is not fixed but can vary in space or time. There is abundant evidence that life history characteristics can vary among populations of a species (Heins and Baker 1987, Hubbs 1996), and also that life history features like mortality curves can vary within a population across time (Bervan and Gill 1983). The study of fish habitat and migration has emerged as a key area of fisheries research in the recent years. Most aquatic organisms require access to a variety of habitats in the course of their cycle to meet the different requirements of different life history stages. Embryos, larvae and juveniles must find appropriate shelter and feeding grounds in order to reach the size threshold at which they maximize their survivorship. Many fisheries in the rivers are based mainly on migratory species. The high abundance attained by these species may be a consequence of their tactic of migrating towards nutrient rich habitats to spawn and using floodplain habitats as nursery grounds.

The study of fish migrations has emerged as a key area of fisheries research in the Mekong River Basin (Warren *et al.* 1998). Balon (1975) listed the requirements for a comparative framework useful for predicting the response of fish populations to different kinds of environments and disturbances. Sarkar and Bain (2007) observed species and life stages occupying a statistically distinct subset of the river habitats and were grouped to identify classes of river habitat for conservation. Most species and life-stage groups specialized on specific habitat conditions revealed by multivariate analyses of variance and a principal component analysis. The most numerous and diverse group was associated with deep depositional habitats with sandy substrate and a third group of three species of adults and juveniles were intermediate in habitat use. They suggested that river conservation for fish faunas should maintain both erosional and depositional channel habitats with depths, substrates, and current velocity. The life history variation on size and growth in stream dwelling Atlantic Salmon have been reported by Letcher and Gries (2003). Recently, elemental analysis of fish otoliths has emerged as a powerful technique that can provide a natural tag for determining potential areas of endangered fish habitat, population structure and movement of individual fish specie. The composition of fish otoliths reflects some of the habitat

condition under which a fish was reared and otoliths composition can record differences in ambient water conditions specific to habitats used during a fish life history (Travis and Gillanders 2005; Campana *et al.* 2000; Branzner *et al.* 2004). For fishes, three demographic strategies have been suggested to result from adaptive responses to environmental predictability (i.e. seasonality): periodic, opportunistic and equilibrium (Winemiller and Rose 1992). The migration related to spawning of Himalayan mahseers has been well studied by Nautiyal (2000). The distributions of tropical freshwater fishes at the drainage basin scale can be partly explained by the match between life history strategies and seasonality gradients in hydrological conditions (Tedesco *et al.* 2008). Mangel *et al.* (2006) introduced new tools for use of life history data when prioritizing habitats for conservation and management, with application to Essential Fish Habitat (EFH).

Climate variation and impacts on fish community

While it is broadly acknowledged that changes in the climate have the potential to impact fish population, relatively few studies have addressed this issue in developed and developing countries. It is well documented that global warming is causing the world's waters to heat up while rainfall patterns and sea levels are changing (WWF 2006) and therefore fishes are increasingly threatened by climatic change (Walther *et al.* 2002). Reports indicate that warm water fish sturgeon and bass, generally benefit from increased water temperature, whereas cold-water fish like trout and salmon tend to suffer. Even a 2°C increase in water temperature reduced the growth rate (Dockray *et al.* 1998), survival (Reid *et al.* 1997) and reproductive success (Vanwinkle *et al.* 1997) of rainbow trout. Temperature extremes, high winds, extreme precipitation and storm events have all been shown to impact the growth, reproduction and metabolism of fish species. Increase in the intensity or frequency of such events as a result of climate change could substantially increase fish mortality in some lakes. Climate change would also result in shifts in the distribution of fish species. It has been recorded that the warming associated with a doubling of atmospheric CO₂ could cause the zoogeographical boundary for freshwater fish species to move northward by 500 to 600 kilometers, assuming that fish are able to adopt successfully. Such changes in species distribution would affect the sustainable harvests of fish in rivers and lakes. It is also expected that warm water fish will migrate to regions currently occupied by cool and coldwater fish. Climate change also effects on water levels. Lower water levels in the Great lakes, resulting from increased evaporation and shifts in surface-water and groundwater flow patterns, would threaten shoreline wetlands that provide vital fish habitat and fish nursery grounds. The lower water levels would expose new substrate, may facilitate the invasion of exotic and/or aggressive aquatic plant species. Global

warming has also significantly reduced overall phytoplankton numbers as reported by Schulman (2005).

Life history and stock identification

Identification of fish stocks is necessary to fisheries management for allocation of catch between competing fisheries, recognition and protection of nursery and spawning area, and for development of optimum harvest and monitoring strategies (Smith *et al.* 1990; Begg *et al.* 1999). Differences in the life history parameters among groups of fish have long been used as a basis for the identification of fish stocks because of the relative ease of assessing these parameters and their dual functionary as input into fisheries stock assessment and managing strategies (Begg *et al.* 2005). The NBFGR has taken lead to identify the stock structure of selected prioritized fish in the XIth plan under network mode using morphological and molecular tools.

The main advantage in using life history and morphological traits in studies of population structure is that these traits are often related to fitness to natural selection. The analysis of morphometric and meristic characters has been widely used by ichthyologists to differentiate among different species and among different populations within a species (Tudela 1999, Murta 2000) and continue to be used successfully (Tzeng 2004, Ognjanovic *et al.* 2008). Studies of morphologic variation among populations continue to have an important role to play in stock identification, despite the advent of biochemical and molecular genetic techniques which accumulate neutral genetic differences between groups. The morphological attributes of an organism are not autonomous, and changes in variation aspects of morphology are coordinated (Zelditch *et al.* 1992). These morphological variations depend upon the anatomical, functional, ecological, behavioral and evolutionary factors. Harding *et al.* (1993) used seven morphometric measurements of American lobster larvae from the northwestern Atlantic ocean and identified three spatial groups, inferring three phenotypic stocks. They also found a significant effect of temperature on the morphometric variables and extended phenotypic analysis closer to genotype stock identification. Olsoen and Vollestad (2001) reported significant differences in early life stages (ELS) between the two populations of brown trout from the same stream, living either above or below an impassable waterfall and most of the ELS had an additive genetic component. Wood and Bain (1995) reported morphological variation between microhabitat generalist and specialist species and suggested that all species may vary in morphology relative to their environment. Turan (2004) observed significant phenotypic plasticity of the morphometric and meristic counts among Mediterranean horse mackerel samples and suggested relationship between the extent of phenotypic divergence and geographic distance. They also stated that significant morphological differences do not necessarily demonstrate restrictions of gene flow

among populations. The meristic characters are known to vary under the influence of environmental factors especially temperature during early life stage (Barlow, 1961). Natrajan et al (1977) reported three-intra species population of *C. catla* from Rihand reservoir on the basis of size of the pectoral fins. Kristjansson (2005) opined that most of the freshwater population has apparently evolved after isolation of marine sticklebacks in freshwater. After colonization of freshwater habitats, they show rapid morphological changes and associated genetic isolation within few generations.

Many cases demonstrate that either closely related or distantly related fishes have substantially different life history strategies within the same kind of habitat (Schloemer 1947, Cambray 1994) which may be due spreading out of reproductive timing of species so that the young do not all saturate the environment simultaneously (Kramer 1978). Life history traits are influenced not only by the abiotic environment or environmental variability but also by biotic interactions like predation (Reznick and Miles 1989). Within a stream different levels of predator threat in which life history traits of a single species can be compared in similar environments differing mostly in predator threat. There are some reports that reviewed broad relationships between genetic structure of populations and general life history traits. Vrigenhoek *et al.* (1987) found different levels of genetic divergence related to life history traits in *Poeciliopsis* and Arctic char.

Population dynamics

Dynamics of fish population seeks to provide the basic framework for scientific advice in respect of optimization, which is the central theme of fisheries resource management. Fisheries resources are highly dynamic and mobile and furthermore are beyond the visual horizon and many of the behavioral aspects are still unknown. Fisheries resources are renewable resources and therefore, a judicious management and exploitation are of paramount need to draw sustainable yield for the years to come. The influence of hydrology on population dynamics is most striking in seasonal floodplain systems where aquatic habitat may expand and contract by over three orders of magnitude and populations may respond with extreme cycles of production and mortality (Welcomme and Hagborg 1977; Halls and Wellcome 2003). Overall quantitative modeling of population dynamics in relation to habitat factors, such as hydrological attributes and land use change, is a relatively recent development (Halls and Welcomme 2003, Minte-Vera 2003). Beamesderfer *et al.* (2007) studied the available life history information on green sturgeon and developed a simple population model to inform interpretations of status and threats identified significant research needs for and supports a precautionary approach in conservation and management in the face of uncertain assessments of status and risk. More studies are required, in particular with respect to systems where large scale

hydrological modifications are likely in the future. However, climate change is likely to lead to significant hydrological change within the next few decades and understanding population responses to such changes will become increasingly central to fisheries management and conservation.

Reproduction and recruitment

Reproduction strategies, recruitment of freshwater fishes in the natural waters are crucial for conservation and management. Relative indices of recruitment (the number of fish that have attained the age at which they are vulnerable to fishing) and abundance or biomass of early life history stages in putative fish stocks can provide information on year class strength and stock resilience, as well as stock relatedness. Several authors have suggested significant regional variation in reproductive parameters (Williams 2006; Ebiswa 1999; Adams *et al.* 2000; Platten *et al.* 2002). However very less data is available of these complex processes. Various recruitment models or hypothesis have been put forward, attempting to explain how fish in early life history stages encounter sufficient quantities of food of the right size, while avoiding predation. One of the preeminent hypotheses is the match/mismatch hypothesis of Cushing (1990), which recognizes that fish spawn at approximately the same time each year and the prey abundance is less predictable and more responsive to environmental conditions. Halls et al (2000) found the recruitment of a typical floodplain fish to be strongly dependent upon spawning stock biomass and biolimiting nutrient concentrations. Harris and Gehrke (1994) proposed flood recruitment model similar to the flood pulse concept (Junk *et al.* 1989), to explain how some species of fish in the Murray – Darling basin, Australia respond to rises in flow and flooding. Humpheries *et al.* (1999) proposed the low flow recruitment hypothesis, which describes how some fish species spawn in the main channel and backwaters during periods of low flow and rising temperatures. Recently, King (2002) proposed five reproductive strategies among fishes of Australian Floodplain Rivers (generalists, flood opportunists, low flow specialists, main channel specialists and floodplain specialists).

Growth parameters and age profile

Body growth is an important population process in fish, because it has a major impact on population biomass development as well as reproduction. Strong geographic differences in age or size composition, if not reflective of fishing gear differences and other factors, suggest independence of recruitment or other biological or fishery factors as a basis for assuming discrete stocks (Begg and Waldman 1999). Growth in river and floodplain fish is strongly influenced by environmental conditions, including hydrobiology (De Graf *et al.* 2001), food resources and

population density (Halls 1998).

Age and growth studies are important aspect of modern fishery biological researchers as information on these are essential for interpretation of the fluctuation in the fish population from location to location and to evolve management practices for conservation (Johal and Tandon 1983, Sheshappa, 1999). They stressed the need for undertaking studies more intensively on all important species of Indian fishes from all water bodies to have a distinct population structure. Recent studies on age and growth of fishes using scale and other hard parts are reported by several authors (Kagwade 1971, Hanumantha Rao 1974, Pathani 1981, Tandon and Johal 1983, Tandon *et al.* 1993, Desai and Srivastava 1990, Khan 2000, Madan Mohan 2006, Licandio *et al.* 2006, Sarkar *et al.* 2006, Takaki 1960, Al-Dham and Wahab 1991, Vidalis and Tsimenidis 1996 and Kerstan 2000. In India most of the studies on age and growth were done by scale and less attempts were made so far on other hard parts and their validation with scale.

The other notable works done is Menon (1950, 1953) in which he has given a detail review of the studies in this line during the first five decades of the century; his review not only gives a good summary of earlier work but also encourages workers in the tropical region of the world (specially India) to continue further studies. He believed that internal physiological rhythms rather than environmental factors were determining the formation of the growth ring but when once their periodical regularity in appearance is proved they could be utilized for age determination. Sarojini (1958) studied the annuli in the scales of *Mugil cephalus* and *M. percia* of West Bengal and found that in each species their number, identity and relative size were constant throughout life. The annuli were formed regularly about the same season every year and the lateral line scale were same in number throughout the life of the fish. Das and Fotadar (1965) proved that the existence of the annuli in the scale of the many freshwater fishes of northern India such as *Anabas testudinius*, *Mugil cursula*, *Hilsa ilisha*, *Cirrhinus mrigala*, *C. reba*, *Labeo bata*, *Barbus sarana* and *Gudusia chapra*. Tandon and Johal (1983) found annual rings in the scales of *Puntius sarana* from river Ghaggar in Rajasthan and in Sukhna lake in Punjab, formed during March-May owing to spawning stress. But food and temperature also were suspected to have added a role in the formation of these rings. Johal and Kingra (1988) have suggested the harvestable size of the golden mahseer *Tor putitora* for its conservation. Realizing the importance of age and growth, Johal *et al.* (1993) conducted studies on other species like *Colisa fasciata* and *Labeo calbasu*, the former from the village tank Ludhiana (Punjab) and the latter from river Ghaggar. Good annuli were found both the species. *L. calbasu* population grew better in the river than in the reservoir; juveniles of the 1⁺ and 0⁺ year-classes (i. e. the one year and 0 year olds) as well as the advanced age phages of this species were absent in the

catches. In *C. fasciata* the annual weight increased directly with age and there was growth compensation between the third and fourth years. Johal and Dua (1994) experimented on the effects of non-lethal doses of endosulfan and suggested that scales could also be used as indicator of pollution as their surface became eroded with poisonous substances. They used electron microscopy in this work also. These authors continuing the work in the same line on *Channa punctatus* (Johal and Dua 1995) found the scale margins “disorganized” when exposed to endosulfan and these scales contained phosphorus, calcium, aluminium, iron, sulphur, silica and chlorine elements in them. Recently, study on age pattern of *C. chitata*, Sarkar *et al.* (2007) reported maximum 6+ ages of *C. chitala* from four river basins namely river Bhagirathi, Koshi, Saryu and Ganga (Kanpur) while only 3+ age classes were observed in the other locations (river Ganga, Rajmahal), river Gomti, river Satluj) indicating wide variation of the distribution of population structure across geographical range as has been reflected in age composition which may be due to habitat alterations or over fishing etc.

Age at first reproduction and reproductive life span

Reproductive life history parameters provide fundamental information to assist in understanding biological processes that may be responsible for maintaining the underlying stock structure of a species (Begg 1998). Age at maturity reflects an evolutionary compromise between the costs and benefits to fitness of reproducing comparatively early or late in life (Hutchings 2002, Roff 2002). Individual stocks can develop phenotypic and genotypic differences in these parameters over time due to reproductive isolation (Waldman *et al.* 1988), which arise from diverse environmental conditions, differential selection pressure, and evolutionary divergence through drift and local adaptation (Dizon *et al.* 1992, Waldman 1999). According to Schaefer (1987) knowledge of the temporal and spatial extent of spawning can provide information on intraspecific variation in life history parameters that can be used to discriminate separate stocks. Reproductive trait has been reported to be partly under genetic and environmental control. Many studies show intraspecific differences between populations in life history traits, including age at first reproduction, which can be related to thermal effects like winter mortality (Conover 1992) or to food availability (Jonsson and Sandlund 1979). Baltz and Moyle (1984) showed that populations of tule perch *Hysteroecarpus traski* had marked differences in age at first reproduction, which related to longevity and size of broods. Additionally, within a population, some individual may mature earlier or at smaller size than others, often as a result of the existence of alternative reproductive strategies or in response to predation pressure (Belk 1995). Stearns (1983) showed marked difference in age at first maturation in *Gambusia* that had been introduced to various bodies of water in Hawaii, as well as marked plasticity in age or size at

maturation. Significant differences among population of Atlantic salmon have been reported in size of eggs, age at maturity and almost 500 fold increases in fecundity (Hutchings and Jones 1998). There is also considerable evidence to suggest that population variation in life history traits reflects adaptation by fishes to local environment (Taylor 1991, Conover and Schultx 1997). Stearns and Crandall (1984) provided a mathematical and empirical argument that plasticity in timing of maturity is adaptive, allowing fishes to optimize their fitness in differing demographic situations. Thorpe (1994) argued that age at maturity differences among salmonid populations suggested multiple solutions as evolutionary stable strategies (ESS) within species. There are reports on latitudinal differences in life history traits in freshwater fishes. Mills (1988) showed a range in age at first reproduction from 1 to 13 years of age for minnows *Phoxinus phoxinus* from south to north across their range, with concomitant trade-offs in growth and clutch size. In a recent study Sarkar *et al.* (2008) reported that the size at maturity and mean maturity percentage was considerably varied in male and female *Chitala chitala* (a featherback) across different river basins studied. Their study also showed that the male *C. chitala* attained maturity a year earlier than females, which may be attributed to the faster growth of males than females.

Early life history traits

Early life history is of crucial importance for the future performance of an individual, and interest in the study of ELS of fish has increased considerably in recent years, as a tool to identifying and conserving potential areas of natural fish nurseries (Nakatani *et al.* 1997, Baumgartner *et al.* 1997). Review of literature indicates role of early life stages of fish in identifying phenotypic, genetic stocks and also ecosystem framework from various geographical locations (Hare 2005). Larval morphometrics also have been used in stock identification similar to adult morphometrics (Harding *et al.* 1993, Burke *et al.* 2000). A growing embryo or larvae faces different environmental challenges and natural mortality is high in early life stages (Dickie *et al.* 1987). Paine (1984) and Paine and Balon (1986) described highly differing early ontogenetic sequences for various darters species, and relate microhabitat, drifting of larvae, feeding, and overall strategies for survival to the differences in timing of development of vitelline circulation or oral structures in these species. The quantity and quality of habitat in a stream may change rapidly relative to the potential to allow maintenance of eggs. In lakes, there is lower probability of disruption of spawning by flowing water, but driven waves can destroy shallow water nests. Other catastrophic destruction of eggs or larvae is common. Predators can cause significant mortality of eggs or larvae in nests. Temperature fluctuation can also kill larvae. Cowx (1990) showed for both roach and dace populations in English rivers that growth of each species varied within a

river system, that faster growth allowed one or the other species to differentially dominate the local assemblages, and that reproductive effort was positively related with growth rate. Victor and Brothers (1982) showed that daily and annual growth of fallfish in different populations was strongly linked to conditions in the local habitat, including stream size, and was also density dependent. Winemiller and Rose (1992) pointed out a variety of fishes with divergent life history strategies frequently co-exists in the same habitats.

Management measures relevant for conservation

Life history theory can provide some general insights into where attention might be most profitably focused in monitoring and research (Barthouse *et al.* 1990). Winemiller and Rose (1992) pointed out that a variety of fishes with divergent life history strategies frequently coexist in the same habitats. Diversity of life history strategies are consequently observed among species that perceive the same environment very differently from another and as a consequences, management efforts designed to abate a problem for a given species may sometimes have unanticipated effects on sympatric species that exhibit alternative strategies. Management measures aimed at conserving freshwater fish biodiversity should be inserted into the fishery policies of the different State Departments. In addition, the information given can be utilized by central and state government agencies, such as the other Development Authority, Fisheries Management Society etc. who are deeply involved in implementing various measures for the protection of the aquatic biodiversity. The information on population size, genetic stock and geographical distribution of threatened and endemic species should be strengthened by undertaking extensive micro geographical explorations. The knowledge of area of distribution and information on the micro geographical characteristics of the critical habitats of these ecologically sensitive fishes will be inputs for identification and prioritization of conservation areas /aquatic reserves for the conservation of the species. Information regarding trophic ecology, migration, breeding behaviour and breeding and spawning grounds of fishes should be generated through extensive surveys and analysis. Such information is essential for both *ex situ* and *in situ* conservation of the species. Techniques should be developed for the captive breeding and broodstock development of fishes of potential economic importance. Commercial scale exploitation of the species only be encouraged after standardizing these techniques. Such information should be extended to the small and large-scale aquarists for the enhancement of ornamental fish exports. Broodstock maintenance centres and hatcheries should be established exclusively for indigenous endangered and critically endangered fishes for their *in situ* conservation and aqua ranching as a substitute for their natural recruitment. Investigation on the invasive nature of exotic species in the natural habitats should be carried out with a view to establish

how many of them could achieve natural breeding populations and also to what extent their feeding spectrum habits overlap with that of the indigenous fishes. The introduction of exotic and alien species of fishes in open waters for the purpose of resource augmentation should be discouraged and before any exotic species are introduced, its potential threat to local species should be studied and the introduction shall be subjected to the establishment of non threatening nature of the species.

CONCLUSION

The conservation of aquatic germplasm resources is an increasingly important field of scientific endeavor. When an increasingly number of species are being reported to be endangered and threatened, there needs to be a focus on maintenance of the genetic component of biodiversity and the preservation of evolutionary processes. The variation indicates phenotypic plasticity of the species which could be an important adoption trait, allowing them to respond to ecological/habitat changes during their life time. Therefore, conservation needs must be aimed towards preserving existing biodiversity and also the evolutionary processes that foster biodiversity. The review and synthesis of the aspects life history traits discussed above clearly indicate that the information on the life history traits of the fishes of all the freshwaters is essential to carry out conservation, ecology and aquatic resource management programme. Virtually, very limited information in these lines are available in respect of majority of critically endangered and endangered freshwater fishes and therefore, their reproductive capability, constraints, spawning season, habitat are beyond any sort of prediction. Similarly, a full advantage of the local species of aquaculture, ornamental or capture fisheries for conservation and sustainable utilization, the specific information on life history traits is imminent. The dearth of information on the life history traits of many food and ornamental species is the major bottleneck in their introduction in the international markets and taking full advantage in the era of IPR. Therefore, it is essential to prioritize research on above for helping the planners in taking policy decisions and framing of legislation, to bring out interspecific and intraspecific variations among species inhabiting different localities, useful in the selection of ideal brood stocks for captive breeding programmes and also in attaining capability to undertake species-specific rehabilitation programmes. It is hoped that the results of NBFGR's new programme of Genetic Stock Identification will generate location specific data on genetic stocks of the prioritized fishes which could be useful for biodiversity conservation and management.

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