Summary
Silver carp, *Hypophthalmichthys molitrix* (Val., 1844) belongs to the order Cypriniformes, family Cyprinidae and subfamily Hypophthalmichthysinae (= Leuciscinae). This fish is recognized throughout the world because of its versatility in aquaculture operations, as it is the world's most cultivated fish species. This species represents the Chinese low land faunistic complex and naturally occurs in the river system in the south and central China (Yangtze, West river, Kwangsi, Kwangtung, Pearl river) and in Amur River drainage of former USSR. This Chinese carp has been introduced all over the world from its natural home mainly for aquaculture. There are now 84 records (it has ranked 6 amongst the introduced fish species of the world) of introduction of silver carp in 73 countries and seems that this fish has established in more than 35 countries. Aquaculture, stocking, establishment of wild population, rearing trials in rice fields, control of aquatic blooms, filling of a vacant niche, experiment, sport, accidental introduction and use of its pituitary extracts, have been the main reasons for its introduction in most of the countries. It was experimentally introduced in 1959 from Japan to India to control phytoplankton blooms. In 1971, forty seven specimens of silver carp in the size range of 290 to 530 mm got washed down to the Gobindsagar during rainy season from the nearby Deoli fish farm and following this accidental introduction the species formed a breeding population and brought about a
phenomenal increase in fish yields. As a result of this introduction the total annual fish production of Gobindsagar increased from 1,60,000 kg in 1970-71 to 1,135,000 kg in 1997-98. During 1976-March 2000 total catch of silver carp has changed from 8,000 kg (1.45%) to 9,19,000 kg (81%), whereas the total catch of indigenous fishes e.g. *Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*, *Tor putitora* and *Labeo dero* has gone down drastically. In order to pinpoint the reason of its establishment, the investigation on the some aspects of biology and fishery of *H. molitrix* were carried out during August 1998- May 2000, except closed seasons.

Morphometric analysis showed that there were almost high correlations between different morphometric parameters of silver carp. Hence, it can be concluded that almost all the body characters increase in direct proportion to each other. The results indicated that some of the body proportions of male and female silver carp were significantly different (ANOVA, p < 0.05). Based on these results, head depth, depth of dorsal and anal fins, length of pectoral, pelvic and caudal fins, length of caudal peduncles and minimum body width in males were greater than females. Multiple stepwise regressions indicated that total length could be estimated by using the following formulas:

**Pooled data :**

\[ TL = 5.626 + (0.735 \times SL) + (0.731 \times LCF) + (0.198 \times FL) + (0.664 \times INTOD) \]

**Female :**

\[ TL = -3.895 + (0.869 \times SL) + (1.168 \times LPF) + (0.599 \times LCF) \]

**Male :**

\[ TL = -16.738 + (0.935 \times FL) + (0.897 \times LCF). \]
The result of present study showed that the diet of silver carp was dominated by *Cyclotella* sp. (diatom) followed by Chlorophyceae, Cyanophyceae, Crustacea, Dinophyceae and Rotifera. Analysis of gut contents of silver carp from Gobindsagar (pooled data) indicated that zooplankton comprised only 7.7% by number and 19.3% by volume of the fore–gut contents of this fish, hence silver carp could be considered almost as phytoplankton feeder. The present work showed that the majority of the plankton found in the intestine of silver carp was *Cyclotella* (62.25%) with the size range of 5 – 25 μm indicates that silver carp is able to collect food particles smaller than distance between its gill rakers. Probably, excretion of mucus plays an important role in collecting such small particles. By applying Costello method, it can be concluded that *Cyclotella* is very important food item while the others are general food items in the diet of silver carp in this water body. Study of diet overlap index of different size groups showed that the value of “D” varied between 0.461 (moderate) to 0.972 (high), indicating that the diet of small size groups were significantly different from those of large size groups.

The results revealed that, there was a significant relationship between length and weight in all the cases (ANOVA, p < 0.001) and total length was highly correlated with the weight of the fish ($r \geq 0.986$ and $r^2 \geq 0.972$). The value of “b” was slightly greater than 3 (3.064 – 3.140) but did not differ significantly from 3. So, length-weight increased almost as a cube length exhibiting an ideal growth. However, the female specimens of silver carp seem to have a relatively better rate of increase in weight with that of length. No gradual tendency of increasing or decreasing of “b” values was observed.
in different months. Study of different hard parts of *H. molitrix* indicated that growth rings were more clear on the cross sections of first pectoral fin rays, postcleithra, urohyal bones than scales of silver carp.

Scales of silver carp like other fishes consist of a calcified layer and a fibrillar plate. Scales of silver carp showed severe signs of resorption. In the resorption sites, asymmetrical osteocalast cells, covered with folds were found. The size range of these cells was 4 – 6 μm. They had protruding cell processes. However, the shape of the cells, which was observed in the intercircular space, was slightly different from those in the cavities and it may be due to change in the activity of these cells. There were also present few compact cells lacking cell processes.

The present work shows that cleithra are useful for age determination of silver carp. The major value in the use of cleithra as an ageing technique for this fish is as a means of verifying scale readings and of improving confidence in age determination, especially for older fish. The postcleithrum shows oval shape in its transverse section when cut in the middle region. Like other hard parts, the annual growth pattern of postcleithrum is comprised of an opaque zone and a translucent or hyaline zone, the latter called annulus or annual mark or annual ring, representing a time of reduced growth, and former represents a zone of active growth. Examination of urohyal bones of silver carp showed that the annuli were clear on the vertical (lateral) wing of this bone. Like postcleithra and cleithra detection of first annulus in old specimens was difficult. This can be solved by either superimposing of the diameter of first annulus of small samples on a large one or by preparation of
cross sections of urohyal bones. The first pectoral fin ray of silver carp consists of two closely joined rays. But outwardly, they appear to be a single ray because of their jointed heads. Study of the thin sequential cross-sections obtained from near the base of these rays under transmitted light show that growth bands are distinct in the form of translucent and opaque zones and they can be used for age determination with high degree of precision and reliability. Study of the otoliths of *H. molitrix* showed that the annuli were not distinct on both the sagittae and lapilli. However after grinding, polishing and etching, some annuli became clear. Presence of high correlation between length or weight of hard parts of silver carp with length or weight of this fish indicating that hard parts increase in direct proportion to the length or weight of the fish, and it is important for fisheries biologists and archeologists. Study of these relationships can provide a mathematical relationship between parameters, so that if one is known, the other can be computed. The back-calculated lengths of silver carp *Hypophthalmichthys molitrix* were compared by direct proportional method of Dahl-Lea (DPM), Fraser-Lee method, body proportional hypothesis (BPH) and scale proportional hypothesis (SPH) using scales, cleithra and urohyal bones. The linear relationships were found between body length-scale radius, body length-cleithrum length and body length-urohyal length with high value of correlation coefficient ($r=0.949, 0.984$ and $0.974$ respectively). It was observed that out of 180 comparisons, which were made between different methods and structures at ages 2-7, the differences were statistically insignificant in 132 (73.33%) cases ($P \geq 0.05$). There were no significant differences among different methods in older age classes and between Fraser-Lee and BPH at all ages. Therefore, any of the
methods can be applied for the calculation of growth parameters or for more accuracy, the mean back-calculated lengths for all the four methods described here can be taken for calculation of growth parameters.

Comparison of elemental composition of sagittal otoliths detected by EDX and EPMA techniques also indicated that more elements were detectable by EPMA method. EDX technique showed the occurrence of oxygen, calcium, silicon and phosphorus, whereas EPMA detected calcium, strontium, phosphorus, sulphur, zinc, aluminium, iron and magnesium, which shows different in sensitivity and accuracy of these two techniques.

The analysis of data indicated that, annual length increment (h) specific rate of linear growth (C_l), growth characteristic (C_m) and growth constant (C_n) decreased with the increase in age in H. molitrix, however, in males these values were negative in age class 7. The values of index of specific average size (h) were observed to be 112.98, 113.01 and 110.82 mm for combined, female and male specimens respectively. On the basis of values of growth constant (C_n), three distinct phases were distinguished in all the cases. (i) Inactive sexual phase between the age classes 1 – 3; (ii) Active phase between the age classes 4 – 6; (iii) old age between 7 – 8 in case of combined, unsexed data and females and 7 in case of males.

Based on growth parameters derived from mean length at age data of silver carp the respective asymptotic lengths (L_\infty) for combined, females and males were estimated to be 1075.94, 1014.88 and 842.50 mm, shows that females attain greater ultimate size than males. In the present work $\phi'$ (phi
prime = log k + 2 log L\(_\infty\)) was estimated to be 5.4544, 5.4595 and 2.5151 for combined, unsexed; female and male samples respectively.

Analysis of 457 samples of *H. molitrix* from Gobindsagar reservoir revealed that the population of this fish belonged to age classes 1 – 8. Age class 3 comprised 29.5% of the population followed by age classes 4 (26.5%), 5 (16.2%), 2 (14.4%), 6 (8.5%), 7 (2.4%), 8 (1.3%) and 1 (1.1%) respectively.

The harvestable size of this fish was found to lie between age classes 2–3 when the total fish length varies between 430.2944 - 565.1889 mm. However, the minimum theoretical harvestable size of males was observed to be less than females. From the growth data it is clear that fishes are vulnerable to the fishing gear in age classes 3 – 5, therefore most of the fishes are caught after they had added substantially to the existing stock and this may be one of the reasons for dominance of this species in commercial catches from Gobindsagar. On the contrary, some of indigenous fishes like *Tor putitora* are netted below their harvestable size hence catch is declining.

It has been observed that the value of mortality rate of combined and unsexed specimens *H. molitrix* between age classes 3–8 to be 0.350 and 0.456 based on the Jackson’s method and Chapman and Robson method respectively. It was estimated to be 0.391 and 0.495 for females (age classes 4 – 8) and 0.518 and 0.600 in males (age classes 3 – 7) bases on Jackson’s method and Chapman and Robson method respectively. It was calculated to be 0.669, 0.649 and 1.035 for combined, female and male based on the linear method respectively. The values obtained by the linear method are greater
than Chapman and Robson method and also Jackson’s method and males have greater values, in all three methods.

The diameter of oocytes of silver carp ranged between 0.026–1.724 mm. The oocytes diameter increased with increase in the size of the fish. They were dominant in the months of April and May, while in the other months fish remains in inactive stages of seasonal sexual maturity indicating that one spawning season can be considered for this fish. SEM study of egg surface of *H. molitrix* showed that the surface of zona radiata was wavy and uneven with uniform distribution of almost round pores. The pores had lips, pore openings were 0.250-0.375 (0.281)μm in diameter, and pore distribution density was 2.629μm⁻². Microvilli like structure with lengths of 0.375–1.625 μm with a mean of 1.028 μm were fond in the pore opening region. The micropyle region was not flat. The micropyle was found to be almost circular and micropyle canal was located in its center. The micropyle canal had a diameter of 9.5μm. Round or oval accessory pores with a size range of 0.692–1.154 (an average of 0.877) were also observed in the canal. GSI peaked in the month of May in females and in the months of April and May in males. It is due to increase in gonad weight indicating that the breeding season falls after this month. High value of the GSI in the end of May and sharp decreases in the month of August and September shows that the fish spawns during June – July and there is only one spawning season for this fish.

Present study showed that *H. molitrix* is a highly fecund fish and its fecundity increases with size and age. This high fecundity is necessary for this
fish shedding bathypelagic (semi floating) eggs into the river system. The total fecundity ranged from 355313.38 to 1417711 eggs per female with an average of 769750.1 eggs. The relative fecundity ranged from 70.89 to 175.52 (121.6047±33.8495) eggs per g of total weight of the fish and 83.94 to 226.12 (150.7720 ± 45.0650) eggs per g of gutted weight. Total fecundity was correlated significantly with total length (p < 0.05), total weight, gutted weight (p < 0.01).

The sex structure of the population was studied in different months. In various months, there was no significant difference from the expected sex ratio of 1 : 1 ($X^2 < 3.841$ at $p < 0.05$), except in the month of April 2000 in which females were dominant ($X^2 = 4.114, p > 0.05$). However, the overall sex ratio for the population was significantly different from 1 : 1 ($X^2 = 5.426, p > 0.05, 0.89 M:1 F$).

In silver carp, sexual dimorphism was observed with regard to the presence of serrations on the inner surface of several front rays of pectoral fins (up 8th rays) in male specimens. This secondary sexual characteristic of the males is formed long before maturity, and once formed, persists throughout its lifetime. The number of these spine like structures ranged from 65 to 120 on the first pectoral fin ray of males. The height of those was found to be vary between 0.339mm to 1.356mm in individual fish with a mean of 0.692 mm for 11 specimens. Distance between two spines was observed to be 0.237mm to 0.847mm with a mean of 0.450mm. They were almost conical and sharp especially during breeding season. The presence of serrations on the pectoral fins of males throughout the year shows that the role of these
structures is something more than sexual playing and they can also be used for aggressive displays. Silver carp exhibited some other secondary sex characteristics including variation in fin length and body depth. Based on the present investigation, head depth, depth of dorsal and anal fins, length of pectoral, pelvic and caudal fins, length of caudal peduncle and minimum body width in males were found to be greater than females. However, fully ripe females exhibited soft bulging abdomens and swollen pinkish vents.

From physico-chemical data collected during different months it is evident that Gobindsagar reservoir with high values of total alkanity, specific conductivity, dissolved oxygen and alkaline pH along with nutrients and salts being received from the inflowing waters and the biodegradation processes within it, has productive capacity thus has provided a suitable habitat for fishes especially *H. molitrix* which comprises the major of catch of this water body.

The fisheries of Gobindsagar reservoir is highly drifted in favour of *Hypophthalmichthys molitrix* from indigenous fishes due to ecological advantage for silver carp in terms of wide feeding regime, availability of food especially *Cyclotella*, high fecundity (355313.38 - 1417711) and congenital breeding grounds. Silver carp in cold regime of water of Gobindsagar has found an environment similar to its original habitat China, because as Satluj river when Bhakra dam has been constructed, originates from China.