SUMMARY

The Tehri Dam is one of the five highest dams of the world, and the highest in Asia. The Tehri Dam is located on the Bhagirathi River, about 1.5 km downstream its confluence with the Bhilangana at Ganesh Prayag (Tehri) of Garhwal Himalaya, Uttarakhand, India (30° 22’ 54” N; 78° 29’ 3” E). The Tehri Dam Project has been designed to produce 2,400 MW of electricity and to irrigate 2.70 x 10^5 hectare of land. The construction of Tehri Dam started in June 1976 and its gestation period was almost thirty years. As a consequence of its impoundment, the lotic ecosystem of upper Ganges (Bhagirathi and Bhilangana) has been transformed into a huge lentic water body of 2.62 x 10^9 m^3 capacity. It is a mega project of Rs 8,824.12 crores. Several civil construction activities (rock stripping, digging of tunnels, construction of approach roads, coffer dam, main dam and the underground power house) in terms of primary actions had primary/direct impacts on mountain fluvial system transforming its geomorphology, altering bottom substrates composition and degrading its water quality. Inundation of feeding and spawning grounds of fish, choking of migration channels and massive removal of riparian vegetation were also resulted as a consequence of Tehri Dam construction. The secondary/indirect impacts manifested in terms of fragmentation of fish habitats, habitat isolation and shrinking of population periphyton, phytoplankton, zooplankton and aquatic benthic macroinvertebrates. The over all cumulative or synergistic impacts of Tehri Dam
reflected in terms of impairment of ecosystem function, loss of diversity and production of coldwater fish in general and production of Snow-trout and Mahseer in particular under the stressed mountain fluvial system. The assessment of impact of Tehri Dam construction on coldwater fish resources of mountain fluvial system was quantified for a period of two-year (September 2004 – August 2006). The major objective of the present work was to integrate hydrological profile with the dynamic process of fish composition, diversity and production for examining the potential problems in stressed environment of mountain fluvial system as a consequence of anthropogenic perturbations, and thereby to suggest ameliorative measures to protect the potential fish communities and to enhance their production in the Tehri Dam Reservoir. The main findings under the present study have been summarized as given below:

1. A detailed data on the Physiography and geology of the study area, brief history of the Tehri Dam Project (TDP) have been enumerated. Geologically, the Tehri Dam Project is located in the Lesser Garhwal Himalayas. The rock formations at the dam site are phyllites of Chandpur series. The entire area is also seismologically sensitive. A geological fault, Marh fault close to the Tehri Dam site is also a cause of concern.

2. Tehri Dam Project comprised of two stages: Stage I includes Tehri Dam Hydro Power Plant (1,000 MW) and Stage II encompasses the Koteshwar Dam Hydro Power Plant (400 MW) and Tehri Pump Storage Plant (1,000 MW). The Stage I of TDP has been completed in September, 2006 and the work on the Stage II (Koteshwar Dam Hydro Power Plant) has also been started in 2003. The present study was mainly focused over the assessment of the impact of Tehri Dam on the coldwater fish resources of mountain fluvial system.

3. Tehri Dam Project, a mega hydroelectric project has inundated the historical Tehri town, the Ganesh Prayag, which has reference in Skand Puran, along with 22 villages completely and 74 villages partially, thus, displacing about 70,000 persons of the area.
4. For assessing the impact of Tehri Dam on the coldwater fish resources of mountain fluvial system, two sampling sites, the reference site (S₁) and impacted site (S₂) were identified. The reference site (S₁) was identified at an elevation of 840.0 m above m.s.l., upstream the main dam and it was free from any impact of dam construction activities. The impacted site (S₂) was identified at an elevation of 635.0 m above m.s.l., 5 km downstream the Tehri Dam site and it received all the adverse impacts of Tehri Dam construction.

5. All the primary anthropogenic actions (rock stripping, digging of tunnels, construction of approach roads, coffer dam, main dam and the underground power house) of the Tehri Dam Project influenced the fluvial system of Bhagirathi River. During the construction phase of Stage I of TDP, a total 198.0 x 10⁵ m³ muck was generated. A huge amount of 5,884 t explosives (blasting gelatine) was used under various civil construction activities. The massive muck generation has interfered with the water ways in many ways. The blasting gelatine caused severe vibrations in the areas including the aquatic habitats.

6. A large scale of morphometric changes in mountain fluvial system was resulted. The impacted site was drastically affected due to the several civil construction activities. The embankment of the river eroded at many places. The natural composition of bottom substrata was replaced by the big boulders, cobbles and fine silt. The geomorphology of the river was altered drastically. The sequence of pool-riffle was changed. The riffles, rapids and cascades were converted into dammed pools at some places. However, the wide white water pools were converted into turbid and narrow pools at other places. These microhabitats of rapids, riffles and pools are very important in the mountain headwater fluvial streams for aquatic life including fish.

7. Environmental degradation of the mountain fluvial system of upper Ganges was recorded as a consequence of direct impact of Tehri Dam construction. The water velocity, turbidity, total dissolved solids and the free carbon dioxide increased substantially. However, the hydromedian depth, transparency and dissolved oxygen
decreased significantly at the impacted site. All these physico-chemical environmental variables have indirect bearing on the abundance of aquatic organisms in terms of time and space.

8. The secondary/indirect impacts in terms of shrinking of populations of aquatic organisms were recorded as a consequence of Tehri Dam construction. The density of periphyton-phytoplankton reduced from 530.54 ± 285.80 units l\(^{-1}\) to 255.0 ± 126.38 units l\(^{-1}\) over a period of two-year. However, the zooplankton reduced from 50.50 ± 7.78 units l\(^{-1}\) to 35.0 ± 4.24 units l\(^{-1}\) during the period of study. A drastic change in the benthic macroinvertebrates was observed. They reduced from 895.83 ± 623.70 units m\(^{-2}\) to 172.92 ± 171.45 units m\(^{-2}\) during two-year period.

9. The alpha diversity for periphyton-phytoplankton was reduced from 40 to 25 as a consequence of the Tehri Dam construction. The beta diversity was calculated to be 1.231. Bacillariophyceae reduced from 366.79 ± 183.88 units l\(^{-1}\) to 195.50 ± 88.17 units l\(^{-1}\), Chlorophyceae from 110.92 ± 66.85 units l\(^{-1}\) to 41.0 ± 25.56 units l\(^{-1}\) and Myxophyceae from 52.83 ± 35.07 units l\(^{-1}\) to 18.50 ± 12.64 units l\(^{-1}\) at the impacted site (S\(_2\)) due to the degradation of the downstream environment as a consequence of Tehri Dam construction.

10. The alpha diversity for zooplankton was recorded maximum (9) at the reference site and minimum (8) at the impacted site. The beta diversity calculated for zooplankton was 1.058. The Cladocera reduced from 11.50 ± 3.54 units l\(^{-1}\) to 4.50 ± 2.12 units l\(^{-1}\); Protozoa reduced from 21.0 ± 1.41 units l\(^{-1}\) to 18.50 ± 0.71 units l\(^{-1}\); Copepoda from 8.0 ± 0.0 units l\(^{-1}\) to 6.50 ± 0.71 units l\(^{-1}\) and Rotifera from 10.0 ± 2.83 units l\(^{-1}\) to 5.50 ± 0.71 units l\(^{-1}\) at the impacted site.

11. The alpha diversity of benthic macroinvertebrates reduced significantly from 27 to 13 as a consequence of Tehri Dam construction. The beta diversity of benthic macroinvertebrates was recorded 1.350. The Ephemeroptera reduced from 465.63 ± 331.85 units m\(^{-2}\) to 96.67 ± 71.82 units m\(^{-2}\), whereas, the Trichoptera reduced from
146.88 ± 96.49 units m$^{-2}$ to 23.13 ± 28.79 units m$^{-2}$. The members of Diptera reduced from 148.96 ± 85.64 units m$^{-2}$ to 41.25 ± 44.29 units m$^{-2}$; Coleoptera from 62.50 ± 31.79 units m$^{-2}$ to 2.50 ± 9.73 units m$^{-2}$; Hemiptera from 34.38 ± 28.78 units m$^{-2}$ to 2.92 ± 1.86 units m$^{-2}$; Plecoptera from 20.83 ± 17.37 units m$^{-2}$ to 2.50 ± 3.61 units m$^{-2}$ and Odonata from 7.29 ± 15.57 units m$^{-2}$ to 1.04 ± 3.61 units m$^{-2}$ during a span of two-year study. The density of Mollusca also reduced from 9.38 ± 16.28 units m$^{-2}$ to 2.92 ± 7.53 units m$^{-2}$.

12. The shrinking of populations of periphyton/phytoplankton, zooplankton and benthic macroinvertebrates has also influenced the abundance and growth of coldwater fish resources. The construction of huge physical barrier in terms of coffer dam and finally the main dam has obstructed drastically the longitudinal migration of migratory fish species. It has also resulted in fragmentation and isolation of fish habitats. A large scale of destruction of fish habitats, removal of riparian vegetation, inundation of feeding and spawning grounds of fish at various places was resulted due to the dam construction activities.

13. Overall cumulative or synergistic impact of Tehri Dam construction was reflected in terms of disruption of function of fluvial system and the loss of fish diversity. The inference on the loss of fish diversity was not possible under a study of two-year period. Therefore, the long-term study made by Sharma (1984 a) was taken in consideration for comparison. A total of 23 species belonging to 11 genera and 4 families of fish were reported from the Bhagirathi River 23 years ago (Sharma, 1984 a). Now under the present study, only 16 fish species belonging to 7 genera and 3 families were found in the natural environment. It reduced to 10 fish species belonging to 6 genera and 3 families as a consequence of Tehri Dam construction. It does not mean that 13 species has lost their existence. It may be possible that the migratory fish species might have shifted to safer habitats. Others may be struggling for their survival.
14. After the impoundment, the coldwater fish populations of Bhagirathi were fragmented into four longitudinal zones. These zones were - zone A (reference site); zone B (reservoir); zone C (impacted zone) and zone D (downstream/tailrace zone between Koteshwar and Deoprayag).

15. Monthly sampling of fish for a period of two-year revealed that the lowest number of fish species (04) was found in the periphery of zone B (reservoir). While, the maximum number of fish species (17) was found in the zone D (downstream/tailrace zone). A total of 16 fish species were found in the zone A (reference site) and 10 fish species were found in zone C (impacted zone).

16. A prominent impact on fish catch composition of Bhagirathi was recorded due to Tehri Dam construction. The fish catch composition studied by Sharma (1988) revealed that overall the maximum contribution (57.9 %) to the total fish catch was made by snow trout (*Schizothorax* sps) followed by *Garra* sps (10.3 %), *Tor* sps (9.1 %) and *Schizothoraichthys progastus* (6.3 %) in the natural environment of Bhagirathi. However, after the deleterious effects of Tehri Dam construction, *Schizothorax* sps contribution to the total fish catch reduced significantly to 19.6 % with the complete disappearance of high altitude migratory fish species (*Crossocheilus latius, Glyptothorax pectinopterus, G. madraspatnam, G. cavia* and *Pseudechenies sulcatus*) from the impacted site.

17. Analysis of fish catch composition made under the present study revealed that the *Schizothorax* sps contributed 54.1 % to the total fish catch with the complete absence of *Schizothoraichthys progastus* at the reference site. The Mahseer (*Tor* sps) reduced from 9.1 % to 4.0 %. However, a negligible contribution (0.6 %) was made by *Labeo dero*, a migratory hillstream fish due to the blockade of longitudinal migration.

18. Shannon-Wiener diversity indices computed for the coldwater fish dwelling the Bhagirathi River revealed that the diversity index reduced from 2.61 to 1.83 during a span of two-year. It shows a clear indication of the degradation of water quality.
19. The concentration of dominance was observed comparatively high (0.26) at the impacted site than the reference site (0.09).

20. The alpha diversity was recorded maximum (19) at S₁ and minimum (12) at S₂ during first year of observation. It was found maximum (16) at S₁ and minimum (10) at S₂ after the impoundment and the beta diversity for fish was calculated to be 1.29.

21. The coefficient of similarity (47.6 %) at both the sampling sites indicates a lesser homogeneity between the two sampling sites. The less similarity between these two sampling sites indicated unstability and heterogeneity. The index of dissimilarity (52.4 %) indicates the reverse situation of the coefficient of similarity. A statistical t-test was also calculated between the fish species caught at both the sampling sites. The value of t-stat for Schizothorax sps (t = 7.046; p > 0.001), Tor sps (t = 4.138; p > 0.001), Labeo dero (t = 5.557; p > 0.001), Garra sps (t = 3.388; p < 0.01), Barilius sps (t = 3.259; p > 0.01) and Noemacheilus sps (t = 2.646; p < 0.05) indicated the significant difference in the density of fish populations at both the sampling sites.

22. The in-depth cumulative impact of Tehri Dam construction and its impoundment on the production of fish was restricted to the very important and most common fish species, Snow-trout (Schizothorax richardsonii) and Mahseer (Tor tor and Tor putitora) dwelling the mountain fluvial ecosystem.

23. The Snow-trout (Schizothorax richardsonii Gray) is stenophagia herbivorous bottom feeder. It has two spawning periods in a year, one in February-March, while the other in September-October. Snow trout is a non-migratory fish and moves locally in search of food and suitable feeding and spawning grounds. The mean biomass of Snow-trout reduced from 2.889 g m⁻² to 0.080 g m⁻² as a consequence of Tehri Dam construction over a period of two-year study.

24. A positive growth of Snow-trout was observed during autumn, winter and early summer months. It may be due the availability of large quantity of food in a natural
environment during these seasons. The annual production of Snow-trout declined from 0.921 g m⁻² yr⁻¹ to 0.207 g m⁻² yr⁻¹ during a span of two-year.

25. Multiple regression gives the idea of significant relationship of Snow-trout with the various environmental variables of mountain fluvial system. A significant relationship of Snow-trout was found with air temperature (r = -0.694; p > 0.01), water temperature (r = -0.752; p < 0.01), water current (r = -0.604; p > 0.01), hydromedian depth (r = -0.554; p > 0.05), turbidity (r = -0.433; p > 0.05), total dissolved solids (r = -0.502; p > 0.05), dissolved oxygen (r = 0.812; p = 0.001), free CO₂ (r = -0.564; p > 0.05), pH (r = -0.649; p > 0.05) and nitrates (r = -0.744; p > 0.001). Almost the same relation was found at the impacted site (S₂) with air temperature (r = -0.744; p > 0.001), water temperature (r = -0.680; p > 0.01), water current (r = -0.699; p > 0.01), hydromedian depth (r = -0.518; p > 0.05), turbidity (r = -0.542; p > 0.001), total dissolved solids (r = -0.413; p > 0.05), dissolved oxygen (r = 0.521; p > 0.01), free CO₂ (r = -0.579; p < 0.05), chlorides (r = -0.650; p > 0.01), nitrates (r = -0.609; p < 0.05) and phosphates (r = -0.567; p > 0.05).

26. A highly positive correlation was observed between the production of Snow-trout and the zoobenthos (r = 0.758 and p > 0.001), zooplankton (r = 0.756 and p > 0.001) and periphyton-phytoplankton (r = 0.648 and p < 0.05) at the reference site. Almost similar relationship was observed at the impacted site.

27. A comparison of the estimation of the impact of Tehri Dam construction on the annual production of Snow-trout under the present study with the earlier study made twenty years back (Sharma, 1991) revealed that a substantial reduction in the production of Snow-trout was resulted. It reduced from 0.405 g m⁻² yr⁻¹ to 0.295 g m⁻² yr⁻¹.

28. The Mahseer (Tor tor Hamilton and Tor putitora Hamilton) is one of the largest and finest sport fishes of Himalayan streams. The fish is very sensitive to any environmental change. There is an ontogenetic difference in feeding habits of
Mahseer. The adults of Mahseer are euryphagic omnivorous column feeder while the juveniles are planktivorous filter feeders. These are migratory fish and ascend the upper Ganges in order to spawn in suitable habitats March. They stay there in the upper reaches up to September and then migrate back to the lowland area due to onset of winter.

29. The annual mean biomass of Mahseer reduced from 0.252 g m$^{-2}$ to 0.020 g m$^{-2}$ as a consequence of Tehri Dam construction during a period of two-year. A positive growth of Mahseer was observed from January till May due to the good environmental conditions and sufficient food in natural environment during the first year of study. A negative growth was recorded during the monsoon season, which may be due to the scarcity of food during this period. However, the Mahseer showed an irregular growth during the period of second year of observation.

30. The annual production of Mahseer reduced from 0.129 g m$^{-2}$ yr$^{-1}$ to 0.053 g m$^{-2}$ yr$^{-1}$ during first year of observation. It reduced from 0.024 g m$^{-2}$ yr$^{-1}$ to 0.009 g m$^{-2}$ yr$^{-1}$ during second year due to the Tehri Dam construction. The production of Mahseer reduced drastically during the second year of observation. It may be due to the closure of the tunnel, which obstructed the longitudinal movement of Mahseer.

31. The Mahseer production was found to be influenced by various environmental variables such as air temperature, water temperature, water current, hydromedian depth, turbidity total dissolved solids, dissolved oxygen and free CO$_2$. Mahseer prefers optimum temperature. It does not like neither too hot nor too cold water. Thus, the production of Mahseer was found to be positively correlated with the air temperature ($S_1$: $r = 0.479$; $p > 0.5$ and $S_2$: $r = 0.481$; $p < 0.5$) and water temperature ($S_1$: $r = 0.455$; $p > 0.5$ and $S_2$: $r = 0.495$; $p > 0.5$). A positive correlation of Mahseer production was observed with the zoobenthos ($r = 0.169$), zooplankton ($r = 0.109$) and periphyton-phytoplankton ($r = 0.372$) in the natural environment. The same trend was observed at impacted site (zoobenthos: $r = 0.193$; $p > 0.5$; zooplankton: $r = 0.629$; $p < 0.5$ and periphyton-phytoplankton: $r = 0.637$; $p < 0.5$).
32. A comparison of the estimation of the impact of Tehri Dam on the annual production of Mahseer made under the present study with the study made twenty years back (Sharma, 1991) revealed a sharp decline in the Mahseer production from 0.161 g m$^{-2}$ yr$^{-1}$ to 0.069 g m$^{-2}$ yr$^{-1}$. This may be due to the myriad of factors generated by the construction of Tehri Dam.

33. A huge reservoir (2.62 x 10$^9$ m$^3$ capacity) created as a consequence of impoundment of Bhagirathi resulted in several environmental problems like heavy sedimentation, submergence of riparian vegetation, soil erosion at the rim of the reservoir, thermal stratification, inundation of feeding, spawning and breeding grounds and blockade of longitudinal movement of coldwater migratory fish. These environmental problems should be addressed for the management of reservoir fisheries. A host of suggestions have been given for mitigating these problems.

34. For managing the aquatic environment of Tehri Dam Reservoir and to check from further degradation, several mitigating measures (construction of retaining walls, rip-rapping with rocks, installation of gabions, construction of breakwater structures to reduce the energy of waves, growing buffer strips of natural vegetation along the shore, Destratification of deep water by air bubbling/injection to generate water movement, restoration and creation of new dish habitats, construction of fish passages/fish ladder and facilitation of downstream movement of fish) have been given.

35. A strategy for the management of downstream fish habitats in terms of water flow augmentation, fixing of seasonal discharge limits, sluicing, turbine pulsing and improving environmental conditions has been suggested.

36. Several measures in terms of stocking of suitable native fish species, control of undesirable fish species, promotion of captive breeding and aquaculture practices through cage culture have been recommended for the management of reservoir fish.
Introduction of few exotic fish species (*Ctenopharyngodon idella* and *Hyprophthalmicthys molitrix*) can be tried in the Tehri Dam Reservoir.

37. A strict restriction on mesh size of the fishing net and declaration of closed season and closed areas during the breeding season of the coldwater fish should be imposed. For overall development of reservoir fisheries and their management, institutional support and political recognition of this sector is a prerequisite.

38. In Uttarakhand, the fisheries development has not been given priority over hydroelectric generation and irrigation. The State Water Policy is still to be finalized. It is the right time that the reservoir fisheries development and management should be given priority as many reservoirs are coming up in Uttarakhand after construction of several dams.