Year 2003 *Paper Sharma*2003*a*

Protection of an endangered fish Tor tor and Tor putitora population impacted by transportation network in the area of Tehri Dam Project, Garhwal Himalaya, India

Ramesh C. Sharma
Department of Environmental Sciences, H.N.B.Garhwal University

Sharma RC. 2004. Protection of an endangered fish Tor tor and Tor putitora population impacted by transportation network in the area of Tehri Dam Project, Garhwal Himalaya, India. IN: Proceedings of the 2003 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 83-90.

Protection of an endangered fish Tor tor and Tor putitora population impacted by transportation network in the area of Tehri Dam Project, Garhwal Himalaya, India

Abstract

Sound ecological practices in development of roads and highways are essential to protect the fragile ecosystem of the Himalayan mountains in northern India. Evidence is growing that the expanding, poorly designed network of roads and trails is a major cause of habitat fragmentation and degradation of both terrestrial and aquatic habitats. These effects have been quantified for two similar species of fish, collectively known as the Mahseer, which comprises Tor tor Hamilton and Tor putitora Hamilton, in the area of the construction of the Tehri Dam Project, located in the Garhwal Himalaya, India. The Tehri Dam Project will be one of Asia's highest dams (260.5 meters height), and fifth highest in the world. It is being constructed approximately 1.5 kilometers downstream of the confluence of the Bhagirathi and Bhilangana, which together form the Ganges River after meeting the Alaknanda River (30 degrees, 23 minutes N; 78 degrees 29 minutes E). The dam is a multipurpose project which costs more than 8,000 crores of Indian rupees (USD: $1,780 million). It will generate 2,400 M.W. of electricity, and irrigate 2.7 million hectares (6.6 million acres) of land, plus provide municipal drinking water to a large population. New roads have been constructed along the banks and in the riparian zone of the two rivers. This has introduced large amounts of woody debris and sediments into the waterways, resulting in drastic changes in the physico-chemical and biological profile of the aquatic ecosystem. Detrimental effects on transparency, current velocity, conductivity, substrate composition, dissolved oxygen and benthic communities have been documented. Feeding, spawning and migration routes of Mahseer have been degraded or destroyed. Subsequent to road development, standing crop estimates of Mahseer declined from a maximum mean monthly biomass of 0.492 g.m-2 (February) to 0.185 g.m-2, a 62% decrease, and a minimum monthly mean biomass (July-August) of 0.185 g.m-2 to 0.014 g.m-2, a 92% decrease. Annual productivity of Mahseer declined from 0.198 g.m-2.yr-1 to 0.054 g.m-2.yr-1 (73 percent). This decline is believed to have been caused by increase in turbidity, accompanied by a decline in dissolve oxygen, decrease in general benthic productivity, and loss of cover. We have recommended the following measures to restore habitat quality and connectivity for the Mahseer: stream restoration and stream bank stabilization, gravel

mining and dredging in the impacted sites, protecting of riparian vegetation, monitoring of water quality, enhancement of fish food reserves, rehabilitation of Mahseer in a hatchery / nursery, ecofriendly techniques for road development and maintenance, and the establishment of strong working partnerships among civil engineers, environmental biologists and the public.

PROTECTION OF AN ENDANGERED FISH *TOR TOR* AND *TOR PUTITORA* POPULATION IMPACTED BY TRANSPORTATION NETWORK IN THE AREA OF TEHRI DAM PROJECT, GARHWAL HIMALAYA, INDIA

Ramesh C. Sharma, D.Phil.; D.Sc. (Tel/Fax: 01370267740 (office), Email: drrameshcsharma@yahoo.com), Head, Department of Environmental Sciences, H.N.B.Garhwal University, Post Box-67, Srinagar-Garhwal, 246174, Uttaranchal, India

Abstract: Sound ecological practices in development of roads and highways are essential to protect the fragile ecosystem of the Himalayan mountains in northern India. Evidence is growing that the expanding, poorly designed network of roads and trails is a major cause of habitat fragmentation and degradation of both terrestrial and aquatic habitats. These effects have been quantified for two similar species of fish, collectively known as the Mahseer, which comprises *Tor tor* Hamilton and *Tor putitora* Hamilton, in the area of the construction of the Tehri Dam Project, located in the Garhwal Himalaya, India. The Tehri Dam Project will be one of Asia's highest dams (260.5 meters height), and fifth highest in the world. It is being constructed approximately 1.5 kilometers downstream of the confluence of the Bhagirathi and Bhilangana, which together form the Ganges River after meeting the Alaknanda River (30 degrees, 23 minutes N; 78 degrees 29 minutes E). The dam is a multipurpose project which costs more than 8,000 crores of Indian rupees (USD: $1,780 million). It will generate 2,400 M.W. of electricity, and irrigate 2.7 million hectares (6.6 million acres) of land, plus provide municipal drinking water to a large population. New roads have been constructed along the banks and in the riparian zone of the two rivers. This has introduced large amounts of woody debris and sediments into the waterways, resulting in drastic changes in the physico-chemical and biological profile of the aquatic ecosystem. Detrimental effects on transparency, current velocity, conductivity, substrate composition, dissolved oxygen and benthic communities have been documented. Feeding, spawning and migration routes of Mahseer have been degraded or destroyed. Subsequent to road development, standing crop estimates of Mahseer declined from a maximum mean monthly biomass of 0.492 $g.m^{-2}$ (February) to 0.185 $g.m^{-2}$, a 62% decrease, and a minimum monthly mean biomass (July-August) of 0.185 $g.m^{-2}$ to 0.014 $g.m^{-2}$, a 92% decrease. Annual productivity of Mahseer declined from 0.198 $g.m^{-2}.yr^{-1}$ to 0.054 $g.^{m-}2.y^{r-1}$ (73 percent). This decline is believed to have been caused by increase in turbidity, accompanied by a decline in dissolve oxygen, decrease in general benthic productivity, and loss of cover. We have recommended the following measures to restore habitat quality and connectivity for the Mahseer: stream restoration and stream bank stabilization, gravel mining and dredging in the impacted sites, protecting of riparian vegetation, monitoring of water quality, enhancement of fish food reserves, rehabilitation of Mahseer in a hatchery / nursery, ecofriendly techniques for road development and maintenance, and the establishment of strong working partnerships among civil engineers, environmental biologists and the public.

Introduction

The Himalaya is among the highest and youngest mountains of the world, and it is still growing and undergoing structural changes. It is the provider of life support for six countries. Not only does the Himalaya control the climate of Asia, it has also moulded the lifestyles of the people who inhabit the lands in and around the mountain domain. The biodiversity of the Himalaya is extraordinarily high even in the global context. The entire Himalaya has been inaccessible with poor communication. Many development projects, including a network of transportation and river valley projects, have been launched in the Himalayan zone of India during the last three decades to overcome the problems of poor communication. Transportation networks are essential for human mobility and the transportation of materials. The Himalaya is a fragile mountain ecosystem, and it is vulnerable to any change. Transportation networks have caused a large-scale habitat fragmentation, which can lead to species extirpation or extinction. Therefore, it is very important to understand the vital links between aquatic ecosystems and transportation networks in the Himalaya to minimize conflicts between transportation systems and aquatic life and to restore habitat connectivity. Sound ecological practices in the development of roads are essential to protect the fragile ecosystem and the vital living components of the Himalayan mountains in northern India.

Considerable works have been done on the impact of transportation networks on aquatic ecosystems and fish life in America and Europe. However, no sincere effort has been made so far on the protection of fish influenced by the expanding transportation network in India. Therefore, it was felt desirable to asses the impact of transportation networks on two similar species of endangered Himalayan fish, collectively known as Mahseer, which comprises *Tor tor* Hamilton and *Tor putitora* Hamilton in the area of the Tehri Dam Project, located in the Garhwal Himalaya, India.

The Mahseer is an important game and food fish distributed along the Himalaya in India, Pakistan, Bhutan and Bangladesh. The native name *Mahseer* refers to its large scales and heads. The Mahseer is a migratory fish and attains a maximum weight up to 25kg. An 18kg (152cm length) Mahseer has been recorded under the present study. The fish is a column feeder and omnivorous (adult) planktivorous (juvenile). The ecological status of these species of Mahseer has been assigned as endangered by Singh and Sharma (1998), Anon (2001) and Sharma (2003).

Materials and Methods

Physiography of the Study Area

The study area is located in the Garhwal Himalaya, an important zone of the Himalaya and a part of the new state Uttaranchal of India (Latitude: 29 degrees 26 minutes - 31 degrees 28 minutes N; Longitude: 77 degrees 49 minutes - 80 degrees 6 minutes E). It encompasses six districts and covers an area of 30,029km^2. The area is very rich in biodiversity (animals, plants and microbes). The entire region of Garhwal Himalaya is bestowed with the tremendous freshwater resources in terms of major fluvial systems of the Ganges and Yamuna and their tributaries. A total of nine big river valley projects of 978.75 M.W. installed capacity has been completed; eight projects, including Asia's highest project (260-meter height) of 5,174 M.W. installed capacity, are in the process of construction.

Salient Features of the Tehri Dam Project

The Tehri Dam Project is a mega dam costing 8,000 crores of Indian rupees (USD: $1,780 million). It is being constructed by the Tehri Hydro Development Corporation (THDC) with the government of India in collaboration with Russian engineers. The dam site is surrounded by three sides of mountains of 1,000-2,000m above sea level. The dam is being constructed approximately 1.5km downstream, the confluence of Bhagirathi and Bhilangana, which together form the Ganges River after meeting the Alaknanda River. The hydroelectric project will generate 2,400 M.W. and irrigate 6.6 million acres of land plus provide municipal drinking water to a large population. The catchments area of the project is 7,511km^2. The work on the project started in 1979 and is expected to be completed by the end of 2004. Two construction agencies (J.P. Industries Ltd; Thapar Intrafor Co. Ltd) are involved for with the construction of the project. The entire area of the project has a thick network of transportation for human mobility and transportation of materials. A total length of 88km of road network has been constructed in the catchments area of the Tehri Dam Project. Out of this, 39km has been constructed along the bank of Bhagirathi and 14 km along the bank of Bhilangana and in the riparian zone of two rivers. Various road construction activities (rock stripping / bladding / culverts, etc.), frequent land slumps and land slides during heavy precipitation have introduced large amounts of woody debris, soil and sediments into the waterways.

Methodology

Two references sites (S_1), one each on Bhaigirathi and Bhilanagan rivers, and four sites (S_2) at the impacted area, two each on Bhagirathi and Bhilangana, were identified in the project area for collection of water samples and obtaining data related to the aquatic primary production and production of Mahseer (*Tor tor; Tor putitora*). The present study was undertaken for over two decades; however, the data have been taken for a four-year period, November 1997- October 2001, the critical period for drastic impacts on the aquatic environment and Mahseer. For limnological analyses of the degradation of the aquatic environment, standard methods outlined in APHA (1981) and Wetzel and Likens (1991) were followed. Primary production was estimated following the methods of Gardner and Gran (1927) and Rodgers *et al.* (1979). Estimation of the production of aquatic insects (secondary producers) was made following the methods outlined in Downing and Rigler (1984). For the study of density, biomass, and production of the Mahseer (*Tor tor* and *Tor putitora*), the three small seine nets (TSSN) methods of Penczak and O' Hara (1983) were employed. The value for instantaneous growth (G) was estimated, when growth is considered to be exponential.

Where $\overline{W}_1$ and $\overline{W}_2$ = mean weight of the fish at time t_1 and t_2 respectively. To estimate monthly production, mean biomass ($\overline{B}$) was multiplied by the instantaneous growth rate (G): P = $\overline{W}$ G (Chapman, 1978)

The annual production (g.m^{-2}.yr^{-1}) was estimated for Mahseer at all the sites (reference and impacted sites).

Results and Discussion

Manifestation of Environmental Degradation

a. Morphometric Transformation of Fish Habitat

A large-scale morphometric transformations of the habitat of the Mahseer in a large section of Bhagirathi and Bhilangana rivers in the environment of the impacted sites have taken place due to transportation networks in the area of the Tehri Dam Project. As a consequences of these road construction activities, a large stretch of the fluvial system has been transformed into a trench and dammed pools of sluggish currents of water from rapids, cascades part of high water current of riffles. The other section has been converted into narrow turbulent and turbid riffiles from wide and clear water pools as a result of large-scale of disturbances of sand, gravel and stones. The composition of bottom substrates has been drastically altered by the road construction and maintenance activities.

b. Degradation in Physi-Chemical Aquatic Environment

Mean values of physio-chemical parameters of the aquatic environment of Bhagirathi and Bhilangna rivers in the area of the Tehri Dam Project at reference site (S_1), and at the impacted site (S_2) recorded over a four-year period, November 1997-October 2001, have been presented in table 1. Analysis of the data revealed that a slight change in the water temperature at the impacted site (15.09±2.69^{0}C) was noticed based on the reference site (14.43±2.73^{0}C). A drastic change in the hydromedian depth (HMD) was recorded at the influenced site (1.702±1.327m) in comparison with the depth at the reference site (2.514±1.550 m). Conductivity was also influenced from the natural condition (81.70±26.6 μ.mho.cm^{-1}) by the transportation network at the impacted site (83.09±28.18 μ.mho cm^{-1}). The water velocity has been altered to a great extent at the impacted site (1.351±0.809 m.sec^{-1}) versus the water velocity at the reference site (1.475 ± 0.799 m.sec^{-1}). A considerable change in the suspended material in the water at the impacted site (128.73 ± 108.73 NTU) was recorded versus the reference site (115.26 ± 105.37 NTU), leading to a reduction in the visibility (transparency) in the water column. A significant change in the concentration of dissolved oxygen was recorded at the impacted site (8.17±0.69 mg.l^{-1}) versus the reference site (12.78±0.54 mg.l^{-1}). A minor change in other chemical parameters (free CO_2, phosphates, nitrates, sulphates, chlorides and silicates) was also noticed at the impacted site.

c. Trophic Depression in the Aquatic Environment

The biotic profile of the aquatic environment of Bhagirathi and Bhilangana is characterized by periphyton, phytoplankton, and macrophytes at the primary trophic level, and zooplankton and aquatic benthic insects at secondary trophic level. These biotic components act as food for the hillstream fish Mahseer. The natural composition of these organisms was also influenced drastically by the transportation network. The population of aquatic macroinvertebrates reduced drastically. Primary production contributed by aquatic plants was drastically influenced by road construction activities. Annual net primary production (Pn) of aquatic plants was reduced (43%) to 40.94 k.cal.m^{-2} from 72.43 k.cal. m^{-2} during the span of the four-year study (fig.1). The peak in primary production was recorded during November-December (winter months) when transparency of water was recorded to be high.

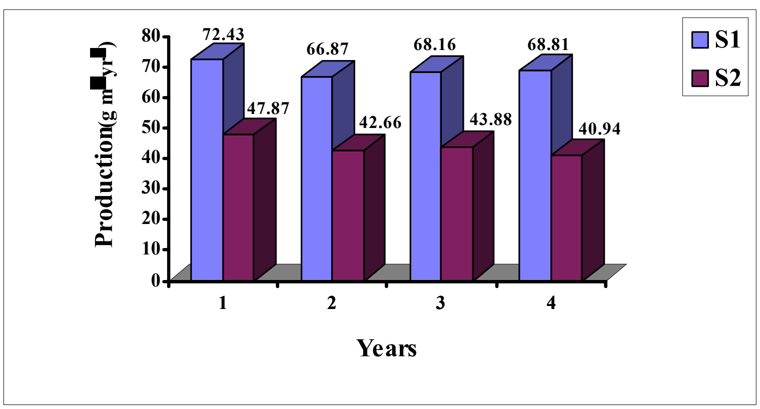

Fig. 1. Annual net primary production (Pn) of aquatic environments influenced by transportation networks in the area of the Tehri Dam Project.

Table 1.
Degradation in physico-chemical aquatic environment caused by the transportation network during a four-year period (November 1997- October 2001).

Parameter	S_1	S_2
	$\overline{X}$ ±SD	$\overline{X}$ ±SD
Air Temperature (°C)	23.58±7.50	23.98±7.54
Water Temperature (°C)	14.43±2.73	15.09±2.69
Hydromedian depth (m)	2.514±1.55	1.702±1.327
Conductivity (μ S cm^{-1})	81.70±26.67	83.09±28.18
Relative humidity (%)	46.27±6.05	42.65±6.26
Water velocity (m sec^{-1})	1.475±0.799	1.351±0.809
Turbidity (NTU)	115.26±105.37	128.73±108.73
Transparency (m)	1.389±0.634	1.201±0.534
Photoperiod (LH day^{-1})	11.78±1.27	11.78±1.27
TDS* (x 10^2 mg l^{-1})	5.90±5.40	6.40±5.40
pH	7.60±0.07	7.54±0.12
Dissolved oxygen (mg l^{-1})	12.8±4.54	8.17±0.69
Free Carbon dioxide (mg l^{-1})	0.97±0.36	1.03±0.19
Total alkalinity (mg l^{-1})	38.13±6.18	35.52±4.25
Phosphates (mg l^{-1})	0.031±0.013	0.035±0.015
Nitrates (mg l^{-1})	0.025±0.013	0.032±0.013
Silicates (mg l^{-1})	0.040±0.36	0.045±0.031
Sulphates (mg l^{-1})	1.678±0.596	1.535±0.656
Chlorides (mg l^{-1})	3.164±1.124	3.319±0.865

* Total dissolved solids

Annual secondary production of aquatic insects was also drastically influenced by the transportation network. It was reduced from 4.458 g $m^{-2}yr^{1}$ to 1.512 g $m^{-2}y^{-1}$, a 62% decrease during the span of the four-year study (figure 2).

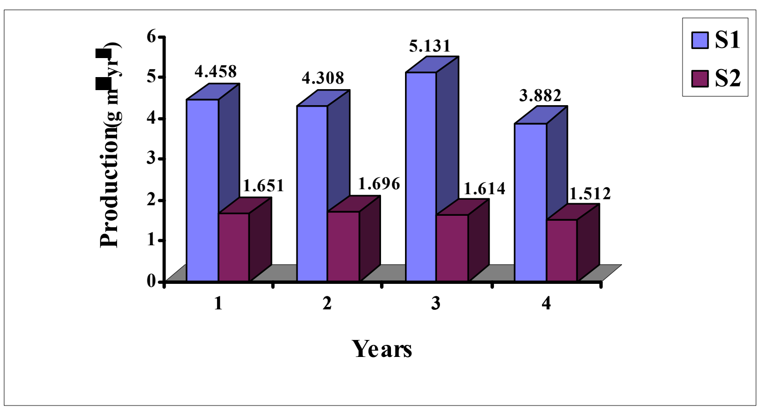

Fig. 2. Annual secondary production of aquatic insects influenced by the transportaion networks

Impact of Transportation Network on the Life of Mahseer (*Tor tor* and *Tor putitora*)
As a consequence of transportation networks in the area of the Tehri Dam Project, the Mahseer, a finest sport and food fish is struggling hard for its survival in the stressed habitats caused by the anthropogenic perturbations. Various life activities of the Mahseer are drastically influenced.

a. Inundation of Spawning and Feeding Grounds of Mahseer
The inundation of spawning and feeding grounds of Mahseer inhabiting Bhagirathi and Bhilangana was observed at the impacted zone of the rivers. As a result of the transportation network, a phenomenal change in the characteristics of substrate composition and drastic changes in turbidity and silting patterns, the failure of spawning or ineffective spawning of endemic Mahseer were observed. The presence of gravel, pebbles, sand and bankside vegetation are prerequisite for Mahseer to build their spawning nests (redds).

b. Choking of Breeding Grounds and Migration Channels
Environmental degradation, brought about by intensified road construction activities at Tehri, has affected adversely the migratory fish species (*Tor tor* and *Tor putitiora*). Due to land slides, slumps, and other construction activities, substantial morphometric transformations have occurred in the fish habitat, which obstruct the movement of Mahseer from the foot hills to upper reaches of the river and tributaries for breeding purposes. Both Mahseer species need clean, stable, well-oxygenated, gravel habitats to spawn in. After the eggs are laid in the gravel, well-oxygenated water must pass over the eggs (Sharma 1984).

c. Impact on Production of Mahseer
Subsequent to road development, standing crop estimates of Mahseer declined from a maximum mean monthly biomass of 0.492 $g.m^{-2}$ (Feburary) to 0.185 $g.m^{-2}$, a 62% decrease, and a minimum monthly mean biomass (July - August) of 0.185 $g.m^{-2}$ to 0.014 $g.m^{-2}$, a 92% decrease. Annual prodcutivity of Mahseer declined from 0.198 $g.m^{-2}. yr^{-1}$ to 0.054 $g.m^{-2}. yr^{-1}$, 73 percent decrease (fig. 3).

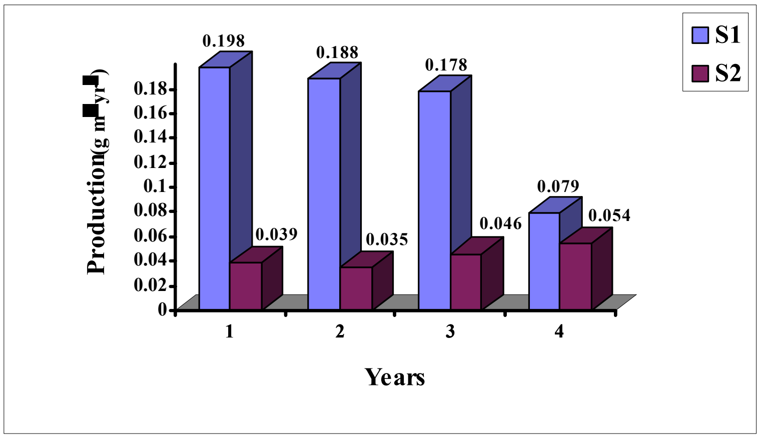

Fig. 3. Impact of transportation network on annual production of Mahseer in an aquatic environment of theTehri Dam Project

Due to road construction activities in the area of the Tehri dam project, large-scale morphometric transformation of the fish habitat resulted. A phenomenal change in the extent of cover (place of shelter) for fish and in the characteristics of substrate composition and degradation of the aquatic environment (high turbidity, total dissolved solids, reduction in access of light and dissolved oxygen) was observed, causing diminution of food resources (primary production and secondary production), inundation of feeding and spawning grounds in addition to blocking of migration channels. Choking of breeding grounds of Mahseer in the Bhagirathi and Bhilangana rivers was also observed at the impacted area affecting their production. Therefore, it makes logic sense to discuss production of Mahseer in the context of these altered environmental variables.

Early work on the influence of inorganic sediment on aquatic life has been reviewed by Cordone and Kelley (1961). The effects of construction of the M11 motorway in Essex, U.K., were studied by Extence (1978). The macro-invertebrate communities above and below the entry of motorway run-off became progressively dissimilar over the study period. Certain groups, such as stone flies, may flies and cased caddis flies, were largely absent at the outset. These studies show that the high suspended solids carried by run-off during civil engineering operations can have a marked effect on the ecology of the received stream. Their long-term effects could, however, prove to be small since, once the works are completed and winter spates have carried the bulk of the material away, recolonisation can occur from upstream. This view finds support in the studies of Barton (1977) who noticed that the reduced fish population (24 to 10 $kg.ha^{-1}$) immediately below the site of highway construction returned to the original level after the work had been completed. Duvel et al. (1976) reported that “modifications of streams” had a direct deleterious effect on trout populations, as large trout were denied suitable natural hiding places (holes, undercut, banks vegetation). The relationship between fish life and suspended solids was the first to be considered by the European Inland Fisheries Adversary Commission in their Technical Paper Series (EIFAC 1964), and it has since been reviewed by Alabaster (1972) and Alabaster and Lloyd (1980). Trout populations in stream sections affected by high suspended solids had lower densities than in unaffected stretches (Scullion and Edwards 1980)

According to Mann and Penczak (1986), productivity levels of fish are under both biotic and abiotic influences, with the latter being of prime importance. Biotic variables (cover, food, predation) have more influence in stable environments. Zaleswaki and Naiman (1985) demonstrated that abiotic factors (fluvial geomorphology, geology and climate) were of primary importance in many situations. Zaleswki et al. (1985) stressed that growth rates in headwaters (low order streams) are primarily restricted by abiotic factors especially temperature and trophic status. Egglishaw (1970) demonstrated a relationship between fish production, and availability of water flow and feeding sites. According to Power (1973), the presence of cover in the form of boulders and large stones greatly enhances the holding capacity of the river for fish, and hence influences the production level. A deleterious effect of turbidity on fish production was noticed by Starrett and Fritz (1965). According to them, turbidity probably affects the procurement of food by sight-feeding fish. It also affects production of plankton and other food resources of fish.

The production level of fish is also dependent on light access, amount and quality of autochthonous and allochthonous organic matter (Naiman 1983; Minshall et al. 1983) and temperature and its range (Elliot 1976; Edward et al.1976). Thomas (1998) studied the effect of highways on western coldwater fisheries of North America. Highway network activities have an adverse impact on coldwater fish through loss of fish habitat, changes in habitat quality, isolation of populations, reduction, and invertebrate food supplies. Sheehy (2001) reported that roads are the major sources of sediment deposited in streams. This is especially critical when roads are adjacent to streams with sensitive species; and any sediment deposited into streams could have adverse effects.

In the present study on Mahseer production influenced by the transportation network, it seems acceptable that production levela are regulated by abiotic (increased turbidity, total dissolve solids, diminution of feeding and spawning grounds and extensive destruction of cover for fish) and biotic (food resources, primary and secondary production) factors. Thus, the depletion in the production of Mahseer seems understandable as a consequence of the transportation network in the area of the Tehri Dam Project.

Remedial Measures for the Protection of Mahseer

The following measures have been recommended to restore habitat quality and connectivity for the Mahseer (*Tor tor* and *Tor putitora*):

- Stream restoration and stream bank stabilization should be undertaken at the sites of morphometric transformations and fragmentation of the fish habitats.
- Gravel mining and dredging in streams should be undertaken for removing excess sedimentation, soil and woody debris.
- Riparian vegetation should be protected, as it produces cooling water temperature, cover for the fish, and habitat for aquatic insects.
- Efforts should be made for the enhancement of fish food reserves.
- There should be monitoring of the water quality of streams adjacent to the roads in the area of the Tehri Dam Project by the Tehri Hydro Development Corporation (construction agency).
- Natural fish passages (riffle grade controls for sand / gravel bedded, and flow constrictor / step pools for cobble / boulder bedded streams) should be constructed for providing easy passage to the Mahseer for migration.
- THDC should make the necessary efforts for early establishment of a hatchery / nursery for the rehabilitation of Mahseer.
- Ecofriendly techniques for road construction and maintenance should be employed in the area of the Tehri Dam Project
- A strong partnership should be established among civil engineers (road construction agency), environmental biologists, and the public for minimizing the conflicts between the transportation network and the Mahseer.

Acknowledgements: I am pleased to acknowledge the important role of the U.S. Department of Transportation and Katie McDermott, Director, Technology Transfer, CTE, NC State University, USA, in enabling me to contribute to ICOET 2003.

Biographical Sketch: Born on January 1st, 1954, in a village of northern India, Dr. Sharma has a distinguished academic career. He passed his graduation with zoology honours and obtained a masters degree in zoology with freshwater fishery biology. He obtained his doctorate (D.Phil.) in environmental biology of fish and doctor of science (D.Sc.) in environmental biology. His wife, Dr. Vineet Ghildial, is a senior faculty at the Department of Humanities (Sanskrit) at H.N.B.Garhwal University. He has two sons (one aged 20 and another 16 years). He has been teaching and undertaking research for almost three decades on environmental monitoring, energetics, limnology, resource management, aquatic biodiversity and transportation and environment in the Himalayas. Several research projects have been completed on these aspects. Sixteen doctoral research students have been conferred to doctoral degrees and five more students are engaged in research under his supervision. He has sufficient professional experience and exposure by way of visiting and working at different research laboratories in India and abroad (USA, Sweden, Poland, Czech Republic and Canada). He has published more than 90 research articles in journals of international repute. He has been awarded many gold medals (NATCON Environment Gold Medal 2001, Zoological Society of India Gold Medal 2002). He is also a fellow of many national and international societies. Currently, he is the Chairman, Department of Environmental Sciences, H.N.B. Garhwal University, Srinagar-Garhwal, Uttaranchal, India.

References

Alabaster, J.S.,1972. Suspended solids and fisheries. Proc. Poyal Soc. London, 180, 395-406.

Alabaster, J.S. and Lloyd, R., 1980. Water Quality Criteria for Freshwater Fisheries. London: Butterworths.

Anon. 2001. National Burea of fish Genetic Resources, Annual Report, Lucknow.

APHA, AWWA-WPCF, 1981. Standard Methods for the Examination of Water Sewage and Industrial Waste. Washington: American Public Health Association.

Barton, B.A., 1977. Short-Term effect of highway construction on the limnology of a small stream of southern Ontario. Freshw. Biol. 7: 99-108.

Cordone, A.J. and Kelley, D.W. 1961. The influence of inorganic sediment on the aquatic life of stream. *Calif. Fish. Game* 47: 189-228.

Chapman, D.W. 1978. Production in fish population. *Ecology of Freshwater Fish Production* (S.D. Gerking, ed.) pp. 5-25. Blacwell Sci. Publ. Oxford.

Duvel, W.A., Volkher, R.D., Specht, W.L. & Johnson, F.W. 1976. Environmental impact of stream channelization. *Wat. Resour. Bull.* 12: 799-812.

Downing, J.A. and Rigler, F.H. 1984. A Manual on Methods for the Assessment of Secondary Productivity in Freshwater (2nd ed.) IBP Handbook no. 17. *Blackwell Sci. Publ.*: 1-501.

Edwards, R.W., Densem, J.W. and Russel, P.H. 1976. An assessment of the importance of temperature as a factor controlling the growth rate of brown trout in streams. *J. Animal. Ecol.*48: 501-507.

Egglishaw, H.J. 1970. Production of salmon and trout in a stream in Scotland. *J. Fish. Biol*.2: 117-1436

Elliott, J.M. 1976. The energetics of feeding, metabolism and growth of brown trout, Salmo trutta L. in relation to body weight, water temperature and ration size. *J. Anim. Ecol.* 45: 923-948.

Extence, C.A. 1978. The effects of motorway construction on an urban stream. *Environ. Pollut*. 17:245-262.

Gaardner, J. and Gran, H. H. 1927. Investigation on the production of plankton in the osloford. Rapp. Proc Vervaux Reunions conseil Intern. *Exploration. Mer.* 42: 1-48.

Mann, R.H.K. 7 Penczak, T. 1986. Fish production in rivers: review. *Pol. Arch. Hydrogiol.* 33(3-4), 233-247.

Naiman, R. J. 1983. The annual pattern and spatial distribution of aquatic oxygen metabolism in boreal forest watersheds. *Ecolo. Manogr.* 53:73-94.

Penczak, T. 1981. Ecological fish production in two small lowland rivers in Poland. *Oceologia* 48: 107-111.

Penczak, T and O'Hara, K. 1983. Catch-effort efficiency using three small seine nets. *Fish. Mgmt.* 14: 83-92.

Power, G. 1973. Estimates of age, growth, standing crop and production of salmonids in some north Norwegian rivers and streams. Rep. Inst. Freshwat. Res. Drottninghom 53: 78-111.

Rodgers Jr, J.H., Dickson, K. L. and Cairns Jr, John. 1979. A review and analysis of some methods of periphyton. Wetzel, R.L. (ed.) *Methods and Measurements of Periphyton: A Review*: 142-167, ASTM Specl Tech. Publ. Philadelphia, USA.

Scullion, J. and Edwards, R.W. 1980. The effect of pollutants from the coal industry on the fish fauna of a small river in the South Wales Coalfield. *Environ. Pollut.* 21: 141-153.

Sharma, R.C. 1984. Studies on the spawning ecology of Mahseer of the river Bhagirathi of Garhwal Himalayas. *Proc. Fifth All India Symp. Dev. Biol.* (Agarwal, S.K. & Goel, S.C. eds.) pp. 147-155.

Sharma, R.C. 2003. Fish diversity and their ecological status in protected areas of Uttaranchal. Verma, S.R. (ed.) *Protected Habitats and Biodiversity,* Nature Conservators Publ. 8: 617-638.

Sheehy, D.M. 2001. Reconditioning and stabilization of unpaved roads for reducing road maintenance and impacts on fisheries habitat. *Proceedings of the 2001 International Conference on Ecology and Transportation*: 121-131.

Singh, D. and Sharma, R.C. 1998. Biodiversity, ecological status and conservation priority of the fish of the river Alaknanda, a parent stream of the River Ganges (India). *Aquatic Conservation: Marine and Freshwater Ecosystems* 8: 761-722.

Thomas, Allan, E. 1998. The effects of highways on western cold water fisheries. *Proc. IEOWET*: 249-252.

Wetzel, R.G. and Likens, G.E. 1991. *Limnological Analyses*. Springer-Verlag, New York, Inc: 1-391.

Zalewski, M. and Naiman, R.J. 1985. The regulation of riverine fish communities by a continuum of abiotic-biotic factors. *Habitat Modifications and Freshwater Fisheries* (Alebaster, J.S. ed.) pp. 3-9. London: Butterworths.

Zalewski, M., Frankiewiez, P. & Brewinska, B. 1985. The factors limiting growth and survival of brown trout Salmo trutta m. fario L. introduced to different types of streams. *J. Fish Biol.* 27(A): 59-73.