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Habitat Restoration and Mitigation the Impact of Transportation Network on Hyporheic Organisms Dwelling in the Upper Ganges, India

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Abstract: Integrated ecosystem approach is essential to offset adverse impact of transportation network on aquatic habitats in the fragile ecosystem of the Himalayan mountains. It is a cause of concern that the poorly designed network of roads and trails in mountain areas are expanding, without giving due consideration to natural processes of ecosystem function and climatic severity in the Himalayas. These effects have been quantified for a period of three-year (January 2003-December 2005) for hyporheic biodiversity (microphytobenthos, microzoobenthos and macro-zoobenthos) inhabiting upper Ganges, India (Latitude 29^0 $61^/$-30^0 $28^/$ N; Longitude 77^0 $49^/$-80^0 $6^/$ E). Transportation network of 495 km long passing along the upper Ganges, a project of US$ 250 million, is one of the most important networks in the mountain region of Garhwal Himalaya. Hyporheic organisms are instrumental for self purification of in-filtrated water through filtration, sedimentation, deposition and biological decomposition. Hyporheic biodiversity is less known or not at all known in Africa, Latin America, Australia and East Asia. Construction of roads and their widening along the upper Ganges, through massive cutting of mountain slopes, and disposal of tons of the cut material downhill into the waterways has resulted in intensive accumulation of soil, woody debris into the aquatic ecosystem from accel-erated erosion, gulling and landslides resulting in drastic changes in the physico-chemical and biological profile of the hyporheic biotope. Detrimental effects on conductivity, bottom substrate composition, dissolved oxygen and hyporheic organisms of upper Ganges have been documented. Subsequent to construction and widening activities of roads along the upper Ganges, a decline of 61% in annual mean density, 45% in alpha diversity and 21% in Shannon Wiener index (**H**) of hyporheic microphytobenthos was recorded during a three-year period. Hyporheic microphytobenthos of upper Ganges were represented by thirteen genera (*Diatoma, Navicula, Nitzchia, Pinnularia, Synedra, Acnanthes, Amphora, Coconeis, Cymbella, Fragilaria, Gomphonema, Gryosigma and Hantzchia*) of Bacillariophyceae, seven genera (*Hydrodictyon, Microspora, Pootococcus, Tetraspora, Spirogyra, Ulothrix and Cladophora*) of Chlorophyceae, five genera (*Anabena, Nostoc, Oscillatoria, Polycystis and Rivularia*) of Myxophyceae and four genera (*Gonatozygon, Closterium, Cosmarium, Desmidium*) of Desmidiaceae. A decline of 18% in mean annual density, 6% in alpha diversity and 7% in Shannon Wiener index (**H**) of hyporheic microzoobenthos was estimated. Hyporheic microzoobenthos were represented by seven genera of Rotifera (*Ascomorpha, Asplanchna, Brachionus, Lecane, Philodina, Trichocera and Rotaria*), nine genera of Copepoda (*Diaptomus, Epischura, Cyclops, Mesocyclops, Microcyclops, Achnanthocyclops, Phyllognathopus, Bryocamptus and Parastenocanis*) and one genera each of Cladocera (*Ceriodaphnia*), Ostracoda (*Cypridopsis*) and Malacostraca (*Stygobromus*). A depletion of 43% in annual mean density, 38% in alpha diversity and 9% in Shannon Wiener index (**H**) of macrozoobenthos was computed. Hyporheic macrozoobenthos of upper Ganges were represented by seven genera (*Ecdyonurus, Rhithrogena, Ephemerella, Caenis, Baetis, Heptagenia and Cloeon*) of Ephemeroptera, nine genera (*Hydropsyche, Psychomyia, Polycentropus, Leptocella, Glossoma, Hydroptila, Rhyacophila, Limniphilius, Mystacides*) of Trichoptera, eleven genera (*Chryogaster, Philorus, Tendipes, Limnophora, Forcipomyia, Pentaneura, Tabanus, Simulium, Dixa, Atherix, Antocha*) of Diptera, three genera (*Psephanus, Heterlimnius, Dinutes*) of Coleoptera, four genera (*Architestes, Octagomphus, Epicordula and Symptrum*) of Odonata and two genera (*Perla and Isoperla*) of Plecoptera. Most of the members of hyporheic organisms, sensitive to dis-turbance were completely missing at the impacted sites. The environmental degradation of hyporheic zone, decline in quantity and missing of sensitive hyporheic organisms are believed to have been caused by increased in water temperature, turbidity, total dissolved solids and biological oxygen demand, accompanied by a decline in dissolved oxygen, accumulation of fine silt and suspended solids blocking interstitial spaces in the hyporheic zone. We have recommended the following mitigation measures to restore habitat quality and protection of hyporheic organisms: 'functional habitat' recovery by physical reconstruction of channels based on geomorphological principles, removal of obstructions (gravel mining, and dredging in the impacted site), protecting of riparian vegetation, natural recovery of watersheds, sustainable approaches to road construction and widening, proper drainage of water saturated mountain slopes and spring runoff during heavy precipitation, sealing of side drains against water penetration into the under-ground alongside fragile sections of the highway, construction of check dams for protection of steep gullies and side erosion of the river bed for maintaining rich heterogeneity of river bed habitats, following minimum flow principle in the river and the establishment of strong co-ordination among transport planners, geologists, civil engineers, structural engineers, environmental biologists.

Introduction

Biodiversity is an object of a large international programme of the IUBS/SCOPE/UNESCO and is important for many scien-tific, economic and ethical means (Solbrig 1992). Biodiversity has been recently recognized as one of the most potential and essential characteristics of life for the proper functioning of fluvial ecosystem and a means of coping with natural and anthropogenic environmental changes. India is famous for its rich biodiversity. It is one of the twelve mega biodiversity countries of the world. Biodiversity of the hyporheic zones are largely overlooked in the calculation of global biodiversity and are less known than the diversity of organisms dwelling surface water. The state of knowledge on the biodiversity of hyporheic habitats of Africa, Latin America, Australia and South-East Asia are still poorly or not at all known.

The newly carved out state of Uttarakhand is one of the most important sites of rich biodiversity of the country due to its physiographic and climatic variability. The Ganges is the Holy River of India. A very long stretch of upper Ganges passes through Uttarakhand in addition to its origin from the Himalayan glaciers. A strong transportation network is necessary for human mobility and fast development of Uttarakhand. It is a cause of concern that the poorly designed network of roads and trails in mountain areas are expanding, without giving due consideration to natural process of ecosystem function and climatic severity in the Himalayas. These effects of transportation network have been quanti

fied for a period of three years (January 2003-December 2005) for hyporheic biodiversity inhabiting upper Ganges, India. This is for the first time that hyporheic zone in terms of impact of transportation has been explored in India in the form of present work.

The term 'hyporheic' was coined by Orghidan (1991). Schwoerbel (1961) defined the hyporheic zone to be an intermediate zone, bordered by the epigean water of the stream above and by the true water groundwater below. Gilbert (1991) defined hyporheic zone as an ecotone (overlapping zone) between groundwater and surface water, blending properties of both water sources. Edwards (1998) defined hyporheic zone as the volume of saturated sediment beneath and beside streams and rivers where groundwater and surface water mix. Where groundwater refers to the subsurface water that has not yet entered a surface flow channel, however, the surface water refers to water that has entered the stream channel directly as rainfall or surface runoff or indirectly from groundwater. The mixing of these two masses which often significantly stimulates biological activity. White (1993) defined hyporheic zone as the saturated interstitial areas beneath the stream banks that contain some proportion of channel water or that have been altered by channel water infiltration.

Williams and Hynes (1974) gave the term 'hyporheos' to the fauna of the hyporheic zone. According to Gilbert *et al* (1990), hyporheic zones are the important landscape features due to their physical and biological characteristics, their unique value and these spatial and temporal characteristics. These zones are water flow regulators, permanent sinks for organic and mineral matter and contaminants from watersheds, filter and buffer systems that protect groundwater quality and improve surface water quality. Supply of water and nutrients of hyporheic zone is maintained by interstitial spaces between substrata (boulder, cobbles pebbles, sand, *etc*.). Hyporheic zone is completely absent where the streambed is impermeable (bedrock or impermeable mud or clay). Hyporheic zones exist where the river flows through porous gravel that allows high infiltration rates of surface water (Clinton and Edwards, 2000).

The hyporheic zone *i.e.* groundwater/surface water ecotone exists in the different types of environment in all the countries. The main characteristics of these interfaces are their great variety of elasticity, permeability, biodiversity and connectivity (Gilbert *et al.* 1990). Ecotones are the zones where ecological processes are more diversified. Most of the stream limnologist regard hyporheic zone as refuge or/and hatchery for the stream fauna which is supposed to be continued to or very near to the sediment surface. Phreatobiologist regard hyporheic zone as the top most layer of the groundwater system, a zone with most intense interactions between epigeic and hypogeic systems. This hyporheic zone acts as a self purification zone.

The present paper attempts to provide manifestation of adverse impact of construction and widening activities of roads along the upper Ganges on the water quality and to quantify the impact on the density and diversity of hyporheic organisms during a three-year period. Several remedial measures for restoration of habitat quality and mitigation the deleterious effects of construction and widening of roads for the protection of hyporheos of the upper Ganges have been suggested and tried on many stretches of Upper Ganges.

Materials and Methods

Physiography of the Study Area

The study area is located in the Garhwal Himalayas, an important zone of the Himalaya and a part of the new state of Uttarakhand of North 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 (Dehradun, Tehri, Pauri, Uttarkashi, Chamoli and Rudraprayag) and covers an area of 30,029 Km². the area is very rich in terms of terrestrial and aquatic biodiversity. The entire region is bestowed with tremendous freshwater resources in terms of major fluvial systems of holy rivers of Ganges, Yamuna and their tributaries. Two major parent streams – Alaknanda and Bhagirathi form the Ganges after the confluence at Deoprayag. All the four world famous Indian Shrines (Badrinath, Kedarnath, Yamanotri and Gangotri) are located in this region. To cater the needs of heavy influx of pilgrims, a thick network of roads and national highways has been launched. Most of the roads and highways in Garhwal Himalayas have been constructed in the river valleys along the major rivers including the Holy River Ganges.

Geology of the Study Area

The study area encompasses the watersheds of two parent streams of Ganges- Alaknanda and Bhagirathi. The watershed of Alaknanda is characterized by flat-topped ridge, steep slopes and wide valley. The area is covered by three types of rocks of the upper Proterozoic ages (Valdiya, 1984). The area is represented by huge thinly foliated, highly folded, fractured and joined phyllite rock traversed by quartz veins and few basic intrusive in the form of sill and dykes. The phyllite is called Pauri phyllite (Kumar and Aggarwal 1975). Vertically folded, highly fractured, pinkish ripple and current bended quartzite rocks and intercalated with massive intrusive of meta volcanic rocks are under Garhwal groups of rocks. The tectonic features generally control the landform of an area; slopes of a drainage pattern are more sensitive to recent neotectonic activities. Wide valley of Alaknanda is characterized by the set of terrace formed by the river sifting and reducing the water discharge. The river flowing in the area was assumed to have heavy water discharge with laminar flow that reduced to its present level. Therefore, the sediments and load are deposited along the riverside in the form of terraced. Most of the lowest terraces are in contact of the river.

The stretch of the Bhagirathi of upper Ganges (Gangotri to Rishikesh) falls under four major stratigraphic units; the Central Crystalline, the Garhwal Group, the Kumaun Group, Krol Formation and Tal-Quartzite. The Central Crystalline thrusts upon the Garhwal Group along the Main Central Thrust (MCT), while the North Almora Thrust delineates the Garhwal Group for the Kumaon Group. The Central Crystalline extends from Gomukh to Sanj, the Garhwal Group from Sanj to Dharasu, and the Kumaun Group from Dharsu to Sanknidhar. The Krol Formation extends from Sanknidhar to Byasi and the Tal-Quartzite extends from Byasi to Rishikesh.A tremendous increase in the gradient (10.3-30.0m km^{-1}) of the river channel was observed upstream of Uttarkashi. The gradient decreases to an average of 3.7 m km^{-1} between Uttarkashi to Deoprayag and about 1.0 m km^{-1} upto Rishikesh. The tributaries of Bhagirathi have a much steeper gradient. The upper most stretch of Bhagirathi (up to Harsil and adjoining areas) has cliff type slopes. Downstream at Dabrani, the cliff type slope has taken the form of repose slope at certain places, implying the remnant of old landslides. The repose type of slope was seen from Uttarkashi to Deoprayag. However, the cliff slope was again observed between Tehri and Deoprayag.

Mountain Specific Preconditions for Road Construction

Road construction and widening are very much dependent on the natural preconditions (climate, geology, topography and environment) in mountainous areas. Favourable preconditions generally result in modest construction/widening volume per km, whereas unfavourable preconditions can bring enormous work volume and be very expensive. The climate of Garhwal Himalaya is mainly dependent on the altitude and varies from sub-tropical to alpine and temperate. The annual rainfall differs from place to place, ranging from less than 250mm to 3,500mm. Most of the precipitation (80%) occurs during the monsoon period (July-August) creating tremendous problems for the road builders.

Garhwal Himalaya is affected by a constant tectonic uplifting which is accompanied by a down cutting of the river systems. The results of these natural forces are slopes which become steeper and steeper and therefore unstable. It is evident that such conditions make road widening a difficult task. The hilly belt of Garhwal Himalaya generally consists of rugged topography with tremendous difference in elevation ranging from 350 m above m.s.l. to 3,500 m above m.s.l. The resulting steep slopes are divided into many gullies and small valleys and the valley floors are extremely narrow. Such extreme conditions demand a very careful road construction and widening activities. Forest and vegetation cover is a must for a balanced ecosystem. Depletion of forest resources by cutting of trees for firewood (the source of energy) and the extension of farmland into steep and unstable areas has made the entire mountain area of Garhwal Himalaya as vulnerable. Such deforested and abandoned land has an accelerated water run-off in volume as well as in speed and is prone to slides. These four mountain specific preconditions have a negative influence on road construction and widening in Garhwal Himalaya.

Salient Features of Transportation Network Project Passing Along the Upper Ganges

The transportation network of 495 km long passing along the upper Ganges, a project of US $250 million is one of the most important networks in the mountain region of Garhwal Himalayas.It is a Y shaped transportation network. It is 230 km long passing along the Alaknanda River, 195 km long passing along the Bhagirathi River and 70 km long passing along the Ganges (figure 1). Alaknanda and Bhagirathi are the two major parent streams of Ganges. This transportation network caters the need of heavy traffic (0.85 million people per year), as it is used by the pilgrims for visiting the world famous Indian Shrines of Gangotri, Yamanotri, Badrinath, Kedarnath and Hemkunth Sahib.

Figure 1. Road passing along the holy River Ganges in Garhwal Himalaya.

Methodology

Sampling Protocol

Monthly sampling was conducted for a period of three-year (January 2003 to December 2005) at 0800-1100 hrs at all the sampling sites (two reference sites and two impacted sites; one each on Bhagirathi and Alaknanda). Samples for the analysis of physico-chemical and biological parameters were collected from the hyporheic biotope using stand pipe traps (Bretschko and Klemens, 1986). These traps consisted of metal tubes having a diameter of 10 cm and overall length of 177 cm. Some catching holes of 8mm diameter were made near the bottom of each tube. These tubes were sealed from the bottom. The interstitial dwellers along with substrate and water can only enter the loop through the catching holes. Three such traps were constructed and placed at different depths (15cm, 30cm and 50cm) for one hour period to obtain hyporheos from the hyporheic zone of Upper Ganges. Five replicates were collected from each depth for each sampling site.

The Siphoning Method of Sterba (1990) was employed for the collection of hyporheic organisms. Under this method, a plastic pipe was inserted into the stand pipe from the upper end and water was sucked from the free end of the pipe and collected into a bucket.

Substrate Composition and Particulate Analysis

Sediment particles ranged in from a fraction of micron to huge boulders measuring many meters in diameter. Geologists had developed grade scale consisting of named classes, each having definite lower and upper limits. From smallest to largest, the class names are clay, silt, sand, pebbles, cobbles and boulders. Pebbles, cobbles and boulders collectively form gravel. The size of substrate was measured following the phi (Φ) scale (Friedman and Sanders, 1978).

$$\text{Where,} \qquad \Phi = -\log_2 d$$
$$d = \text{diameter of particles in mm}$$

The value obtained in 0 units converted into mm following the Table of standard size classes of sediment given by Friedman and Sanders (1978).

Analyses of Physico-chemical Parameters

Samples were collected from hyporheic zone by Siphoning Method of Sterba (1990) from different depths (15cm, 30cm, 50cm) of hyporheic biotope. Physico-chemical parameters (temperature, conductivity, turbidity, total dissolved solids, pH, dissolved oxygen, free carbon dioxide, alkalinity, phosphates, nitrates and biochemical oxygen demand) were analysed following the methods outlined in Wetzel and Likens (1991) and APHA (1998).

Qualitative and Quantitative Analyses of Hyporheos

Biological components of the hyporheic zone included microphytobenthos, macrozoobenthos and microzoobenthos. These were collected by filtering 5 litre water sample obtained by Sterba's siphoning method through a plankton net (48 µ m mesh). Retained material was washed with 4% formalin and stored in a sample jar. The collection was identified in the laboratory following Ward and Whipple (1992) and several keys of Fresh Water Biological Association, U.K. along with the help of several experts. Macrozoobenthos were separated from the sediment portion collected in the stand pipe traps. The sediment collected in different traps was transported to the laboratory separately within 1-2 hrs and were examined for the presence of macrozoobenthic organisms before being discarded. The organisms thus collected were identified and preserved in 4% formalin solution.

Results and Discussion

Direct Impacts/Primary Effects

The impact of transportation network on aquatic environment and hyporheic organisms dwelling in the upper Ganges were of three types- direct or primary impacts; indirect or secondary impacts; and cumulative and synergistic impacts. A large scale transformation in the geomorphology of upper Ganges at several places has taken place due to construction, widening and repairing activities of roads along the upper Ganges. A large stretch of fluvial system has been transformed into tench and dammed pool of sluggish currents of water from rapids, cascades, part of high water form riffles. The other section of the river has been converted into narrow, turbulent and turbid riffles from white and clear water pools as a result of large scale disturbances caused by disposal of tons of cut material downhill into the water ways of upper Ganges.

For roads, the frequency of erosion and landslide is generally related to the depth of the cuts, steepness of the slope, degree of vegetative cover, climatic conditions, geological structure and lithology. The higher the road cut, the greater the structural weakness that is created. The steeper the hill slope, the more likely it is that the forces of instability, such as gravity of saturation, will be greater than the forces for resistance, such as soil cohesion and root anchoring. Failure to establish protective vegetation on newly exposed slopes promptly following construction, allows running water to

excerbate slope stability problems. Inadequate drainage slopes has the same effect. Errors during construction including uncontrollable blasting can create road cuts, leading eventually to landslides (figure 2).

Figure 2. Landslides caused by uncontrolled blasting during road construction and widening along the upper Ganges.

Erosion from poorly constructed and inadequately rehabilitated sites can lead to downstream siltation and filling up of interstitial spaces by fine silt choking the flow of water into the hyporheic biotope of Upper Ganges. Serious impacts can occur because of the disruption and outright removal of streambed habitats and sometimes habitat isolation from the main fluvial system. These direct impacts are the easiest impacts to understand and predict because of the straight forward cause-effect relationships that are evident.

The composition of bottom substrate has been drastically altered by the construction, widening and repairing of roads along the Upper Ganges. Improper management of the slopes has resulted in increasing accumulation of silt, woody debris into the aquatic ecosystem from accelerated erosion.

Indirect Impacts/ Secondary Impacts

Indirect impacts are the consequences of direct impacts. The indirect impacts or secondary impacts of transportation network are environmental degradation and shrinking of population of hyporheos dwelling in the Upper Ganges.

Degradation in Water Quality

Degradation in the mean physico-chemical parameters of hyporheic biotope of Upper Ganges caused by the transportation network over a three-year period (January 2003-December 2005) has been presented in table 1.

Table 1: Degradation in the mean physicochemical parameters of the hyporheic biotope of Upper Ganges caused by transportation network during a three-year period (January 2003-December 2005)

Environmental Parameters	Reference site $\overline{X} \pm S.D.$	Impacted Site $\overline{X} \pm S.D.$
Water Temp. (^{0}C)	15.2 ± 2.95	16.4 ± 3.28
Conductivity (μ S.cm^{-1})	140.2± 12.95	143.6± 16.68
Turbidity (NTU)	64.5 ±110.20	70.6± 123.46
TDS (mg.l^{-1})	190.4 ± 81.12	197.5 ±89.96
pH	7.5 ± 0.25	7.8 ± 0.35
DO (mg.l-1)	13.6 ± 2.19	11.4 ± 1.81
Free CO2 (mg.l^{-1})	0.40 ± 0.07	0.45 ± 0.08
BOD (mg.l^{-1})	1.10 ± 0.78	1.45 ± 0.85
Total Alkalinity (mg.l^{-1})	65.1 ± 9.33	69.8 ± 10.12
Nitrates (mg.l^{-1})	0.029 ± 0.02	0.044 ± 0.12
Phosphates (mg.l^{-1})	0.088 ± 0.15	0.097 ± 0.85

Analysis of the data revealed that a considerable change in the water temperature in year 2005 (16.4 ± 3.28°C) was recorded in comparison to the temperature recorded at the reference sites (15.2 ± 2.95°C) in 2003. A minor change in the conductivity was also recorded from 140 ± 12.95 to 143.6 ± 16.68 µ S cm^{-1} over a three-year period. The drastic change in turbidity and total dissolved solids was recorded at the impacted sites. A slight change in the pH was also noticed. It increased from 7.5 ± 0.25 to 7.8 ± 0.35. A considerable reduction in the dissolved oxygen from 13.6 ± 2.19 to 11.4 ±1.81 was recorded in the hyporheic zone of upper Ganges. A minor change in other chemical parameters (free carbon dioxide, nitrates, phosphates and total alkalinity) was also recorded. A prominent change in the BOD was noticed. It increased from 1.10 ± 0.78 to 1.45 ± 0.05 mg l^{-1} due to construction, widening and repairing activities of roads over a three year period in hyporheic biotope of Upper Ganges.

Shrinking of Population of Hyporheos

The hyporheic biodiversity of upper Ganges is characterized by the presence of microphytobenthos, microzoobenthos and macrozoobenthos. Subsequent to construction and widening activities of roads along the upper Ganges, annual mean density of hyporheic microphytobenthos was reduced from 184.8 ± 174.5 ind.l^{-1} to 71.8 ± 75.96 ind. l^{-1}, a 61% decrease (figure 3). Hyporheic microphytobenthos of upper Ganges were represented by thirteen genera (*Diatoma, Navicula, Nitzchia, Pinnularia, Synedra, Acnanthes, Amphora, Coconeis, Cymbella, Fragilaria, Gomphonema, Gryosigma and Hantzchia*) of Bacillariophyceae, seven genera (*Hydrodictyon, Microspora, Protococcus, Tetraspora Spirogyra, Ulothrix, and Cladophora*) of Chlorophyceae, five genera (*Anabaena, Nostoc, Oscillatoria, Polycystis and Rivularia*) of Myxophyceae and four genera (*Gonatozygon, Closterium, Cosmarium and Desmidium*) of Desmidiaceae.
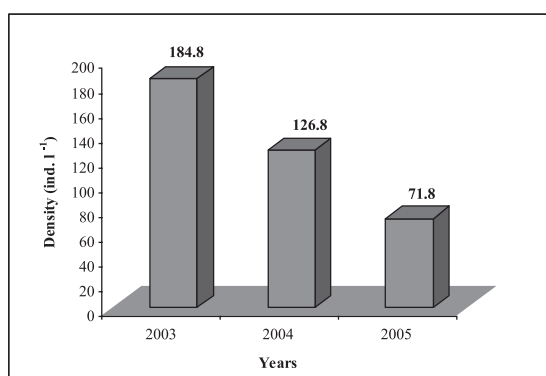

Figure 3. Impact of construction and widening of roads on the annual mean density (ind. l^{-1}) of hyporheic microphytobenthos dwelling Upper Ganges over a period of three-year (61 percent decrease).

Subsequent to construction and widening activities of roads along the upper Ganges, alpha diversity of hyporheic microphytobenthos decreased from 11 to 6 (45% decrease) and Shannon Wiener index ($\overline{H}$) from 1.92 to 1.52 (21% decrease) during a three-year period. Concentration of dominance (C) calculated for hyporheic microphytobenthos increased as a consequence of the impact during a period of three-year (table 2).

Table 2: Mean monthly variations in alpha diversity, Shannon and Wiener diversity index ($\overline{H}$) and concentration of dominance (C) of hyporheic microphytobenthos dwelling Upper Ganges caused by transportation network during a three- year period (January 2003-December 2005)

Month	Alpha Diversity		H?		C	
	2003	2005	2003	2005	2003	2005
January	19	08	2.15	1.95	0.16	0.16
February	19	08	2.25	1.90	0.15	0.16
March	15	08	2.17	1.85	0.15	0.17
April	13	08	1.99	1.72	0.21	0.22
May	09	05	2.07	1.53	0.12	0.20
June	08	04	1.94	1.37	0.14	0.20
July	04	02	1.33	0.69	0.22	0.33
August	05	02	1.39	0.69	0.21	0.33
September	06	04	1.63	1.30	0.17	0.26
October	09	07	2.01	1.69	0.14	0.19
November	14	08	2.06	1.76	0.18	0.20
December	15	08	2.10	1.77	0.17	0.19
Annual ($\overline{X}$)	**11.33**	**6.0**	**1.92**	**1.52**	**0.17**	**0.22**

The annual mean density of hyporheic microzoobenthos dwelling upper Ganges declined from 225.6 ± 130.8 units l-1 to 186.0 ± 130.1 units l^{-1}, a decrease of 18% due to the adverse impact of transportation network during a three- year period (figure 4). Hyporheic microzoobenthos were represented by seven genera of Rotifera (*Ascomorpha, Asplanchna, Brachionus, Lecane, Philodina, Trichocera and Rotaria*), nine genera of Copepoda (*Diaptomus, Epischura, Cyclops, Mesocyclops, Microcyclops, Achnanthocyclops, Phyllognathopus, Bryocamptus and Parastenocaris*) and one genus each of Cladocera (*Ceriodaphnia*), Ostracoda (*Cypridopsis*) and Malacostraca (*Stygobromus*).
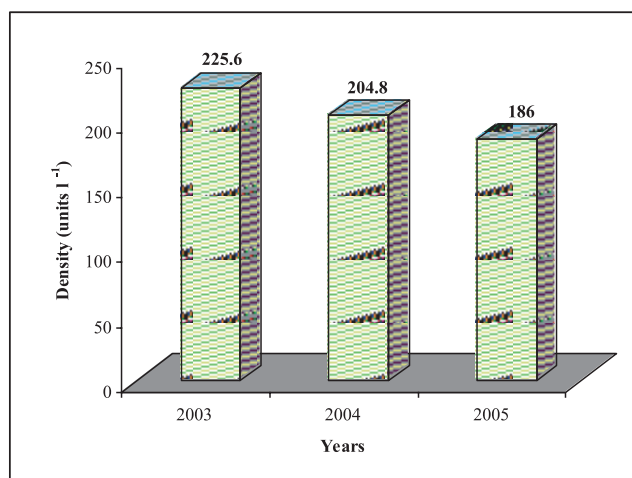

Figure 4. Impact of transportation network on the annual mean density (units l^{-1}) of hyporheic microzoobenthos inhabiting Upper Ganges over a period of three-year (18 percent decrease).

Alpha diversity of hyporheic microzoobenthos dwelling in Upper Ganges decreased from 16.83 to 15.83 (6% decrease) and the Shannon Wiener index ($\bar{\text{H}}$) decreased from 2.73 to 2.53 (7% decrease) due to the deleterious impact of transportation network during a three-year period. Concentration of dominance (C) did not show any change in hyporheic microzoobenhos (table 3).

Table 3: Mean monthly variations in Alpha diversity, Shannon Wiener diversity index ($\bar{\text{H}}$) and concentration of dominance (C) of hyporheic microzoobenthos dwelling Upper Ganges caused by transportation network during a three-year period (January 2003- December 2005)

Month	Alpha Diversity		H'		C	
	2003	2005	2003	2005	2003	2005
January	19	19	2.90	2.72	0.05	0.05
February	19	19	2.88	2.70	0.05	0.05
March	19	18	2.87	2.69	0.05	0.05
April	19	17	2.87	2.69	0.05	0.05
May	19	17	2.81	2.65	0.05	0.07
June	13	13	2.51	2.25	0.08	0.08
July	14	12	2.30	2.14	0.08	0.04
August	14	13	2.26	2.10	0.04	0.04
September	15	14	2.51	2.30	0.05	0.04
October	16	15	2.85	2.71	0.05	0.05
November	17	16	2.90	2.72	0.05	0.05
December	18	17	2.92	2.72	0.05	0.05
Annual ($\bar{\text{X}}$)	16.83	15.83	2.72	2.53	0.05	0.05

A detrimental impact on the hyporheic macrozoobenthos of upper Ganges was also observed. Annual mean density of hyporheic macrozoobenthos declined from 419.2 ± 124.1 n. m^{-2} to 240 ± 116.9 n. m^{-2}, a decrease of 43% as consequence of transportation network during a three-year period (figure 5). Hyporheic macrozoobenthos of natural environment of upper Ganges were represented by seven genera (*Ecdyonurus, Rhithrogena, Ephemerella, Caenis, Baetis, Heptagenia and Cloeon*) of Ephemeroptera, nine genera (*Hydropsyche, Psychomyia, Polycentropus, Leptocella, Glossoma, Hydroptila, Rhyacophila, Limniphilius and Mystacides*) of Trichoptera, eleven genera (*Chryogaster, Philorus, Tendipes, Limnophora, Forcipomyia, Pentaneura, Tabanus, Simulium, Dixa, Atherix and Antocha*) of Diptera, three genera (*Psephanus, Heterlimnius, Dinutes*) of Coleoptera, four genera (*Architestes, Octagomphus, Epicordula*, and *Symptrum*) of Odonata and two genera (*Perla* and *Isoperla*) of Plecoptera. Most of the members of hyporheic organisms, sensitive to disturbance were completely missing at the impacted sites.
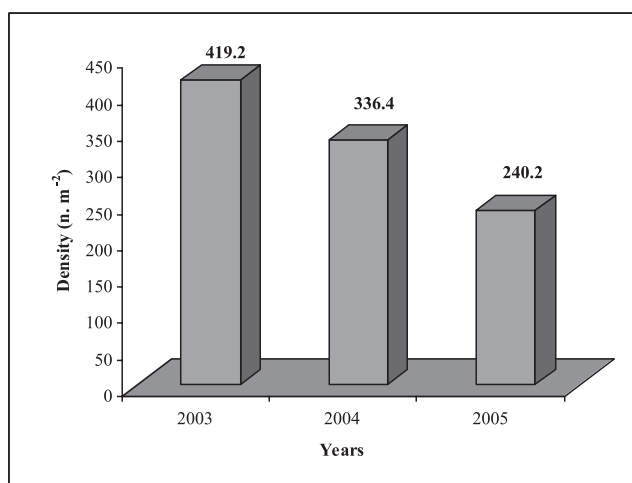
Figure 5. Impact of transportation network on the annual mean density (n. m^{-2}) of hyporheic macrozoobenthos inhabiting Upper Ganges over a three-year period (43 percent decrease).

Alpha diversity of hyporheic macrozoobenthos inhabiting Upper Ganges decreased from 16.0 to 9.58 (38% decrease) and Shannon Wiener index ($\overline{H}$) reduced from 2.35 to 2.01 (9% decrease) as a consequence of transportation network during a period of three-year. Concentration of dominance (C) of hyporheic macrozoobenthos increased during a period of three-year as a consequence of construction and widening of roads along the Upper Ganges (table 4).

Table 4: Mean monthly variations in alpha diversity, Shannon Wiener diversity index ($\overline{H}$) and concentration of dominance (C) of hyporheic macrozoobenthos dwelling Upper Ganges caused by transportation network during a three-year period (January 2003-December 2005)

Month	Alpha diversity		$\overline{H}$		C	
	2003	2005	2003	2005	2003	2005
January	22	12	2.85	2.30	0.07	0.13
February	22	12	2.81	2.28	0.07	0.14
March	16	10	2.36	2.04	0.12	0.15
April	16	10	2.43	2.10	0.11	0.14
May	14	09	2.15	1.77	0.15	0.22
June	13	09	1.98	1.71	0.19	0.24
July	12	08	1.81	1.61	0.14	0.24
August	10	07	1.51	1.45	0.10	0.18
September	14	08	2.30	2.14	0.11	0.10
October	15	09	2.50	2.20	0.10	0.11
November	17	10	2.65	2.25	0.09	0.13
December	21	11	2.80	2.27	0.07	0.12
Annual ($\overline{x}$)	16.00	9.58	2.35	2.01	0.11	0.16

Cumulative and Synergistic Impacts
Cumulative and synergistic impacts are generally the consequences of single impact, multiple interrelated impacts or multiple unrelated direct and indirect impacts. In all cases, individual impacts cannot be considered in isolation, but rather must be seen as components of the more serious cumulative or synergistic effects. Prediction of cumulative and synergistic impacts is difficult because of uncertainties regarding the interrelationships of individual impacts (Spaling and Smith 1993; Lawrence 1994; Bedford and Preston 1996; CEAA 1998). The cumulative and synergistic impacts of transportation network on the hyporheic organisms and the physico-chemical environment of the vulnerable and fragile hyporheic biotope of upper Ganges was seen in the form of impairment of ecosystem function and loss of biodiversity under ecological stress. Overall quality of surface water and ground water was also degraded due to shrinking of population of hyporheos of upper Ganges as a consequence of construction, widening and repairing of roads and highways along the Holy River. Consequences of transportation network on hyporheic zone of upper Ganges in terms of primary, secondary and cumulative effects have been depicted in figure 6.
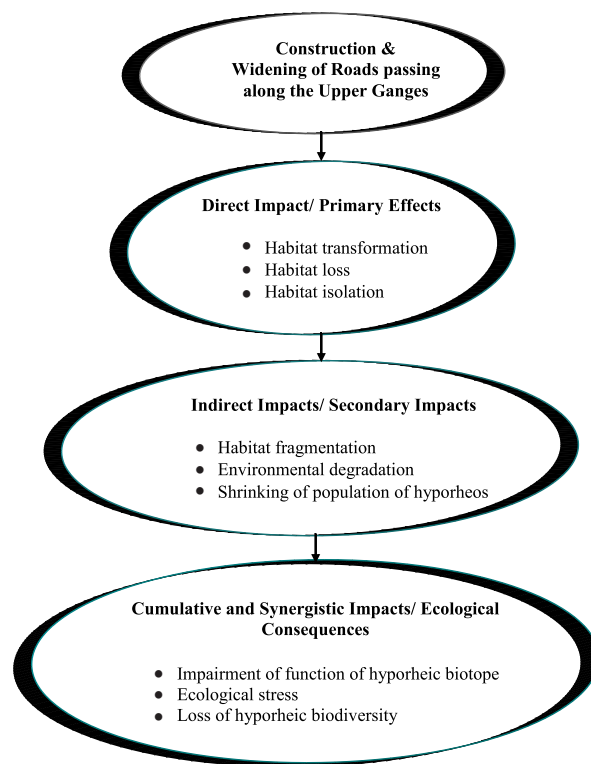
Figure 6. Consequences of construction and widening of roads in terms of direct, indirect and cumulative impacts on hyporheic organisms.

The environmental degradation of hyporheic zone and decline in quantity and missing of sensitive hyporheic organisms are believed to have been caused by increase in water temperature, turbidity, total dissolved solids and biological oxygen demand, accumulation of fine silt and suspended solids blocking interstitial spaces in the hyporheic zone of upper Ganges, Garhwal Himalaya. In order to protect and restore hyporheic biotope for hyporheos survival, the complex inter-relationships between hyporheic organisms and their habitat must be understood.

The construction of roads affects soil and land stability. Instability tends to be most pronounced in hilly areas where geological features exacerbate construction related destabilization. Creation of steep cuts in rapidly weathering rock, removal of basal support of slopes, loading of unstable surfaces, inadequate drainage provisions, removal of and vibrations from blasting and traffic may lead to slope failure and erosion (Sharma 2003).

Considerable research has established that most pervasive threats to biological diversity involve roads (World Bank 1997). There have been extensive studies done on the impacts of roads on the environment (Oxley et al 1974; Oxley and Fenton 1976; Waechter 1979; Clevenger 1998; Bryon 1999; Clevenger et al. 2002). They have concluded that roads can be a serious threat to the maintenance of biological diversity. Erosion from poorly constructed and inadequately rehabilitated sites can lead to downstream siltation, ruining aquatic life. Serious impacts can occur because of the disruption and outright removal of streambed habitats. According to Jackson (2003) the linear ecosystems, rivers and streams are particularly vulnerable to fragmentation caused by road construction. According to him little consideration is given to ecosystem processes such as natural hydrology, sediment transport and the movement of woody debris.

Aquatic ecosystems are dynamic assemblages supported by the interaction of physical, chemical and biological features within the environment. Biota within these ecosystems exhibit specific tolerances and limitations to various physico-chemical conditions of the environment they inhabit (Brookens et al. 2003). According to Armantrout (2001) anthropogenic pressure on river in turn affect the inhabiting biological communities which disturb the ecological balance of nature. 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 stoneflies, mayflies and 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.

Ward and Voelz (1990) suggested that site specific geomorphic features are important in structuring the hyporheic communities of alluvial rivers. Creue des Châtelliers and Regrobellet (1990) also hypothesized a link between geomorphological and hydrological processes and the distribution and abundance of hyporheic organisms. Thus, it is very

much clear about the consequences of construction, widening and repairing of roads and highways passing along the upper Ganges in terms of environmental degradation and shrinking of population of hyporheos.

Habitat Restoration and Mitigation Measures

Habitat management of hyporheic biotope integrates the management of entire watersheds. Sustaining an optimum balance of surface water and ground water contribute to aquatic habitats controlling erosion of sediments and nutrients. The adverse impacts of environmental change on hyporheic organisms have been cumulative and interactive. Predictive understanding and effective management requires a more holistic ecosystem approaches. Recovery of ecosystem 'integrity', the most appropriate means for obtaining optimum sustained benefits has gained considerable credence. Aquatic habitat enhancement should be undertaken integrating the natural channel design techniques; aquatic vegetation restoration techniques and more traditional hydraulic and channel design engineering practices (Welsch, 1992; Nyman, 1998, 2003).Development of mountain specific and sustainable infrastructure in mountain areas require multidisciplinary inputs (Deoja 1994). As mountain ecosystem is characterized by temperate climate with large daily and seasonal variations in temperature and often harsh growing conditions. Mountain ecosystems tend to be less resistant than those that do not experience such harsh conditions and extremes, therefore, the impacts on mountains are generally longer lasting. Protecting and restoring hyporheic habitats of upper Ganges, the holy river of Indians, has become a priority, as Ganges water is considered sacred by Indians. Therefore, we have recommended the following mitigation measures to restore habitat quality and protection of hyporheic organisms:

'Functional Habitat' Recovery

River restoration is a complex science, combining hydrology, geomorphology and ecology. It has so far only been applied in such an integrated fashion to a few sites in Europe (Brookes 1995). 'Functional habitat' is a tool for evaluating the heterogeneity of existing rivers. It is a core biotope in river channels which controls the function of the entire ecosystem. It contains a distinct macro-invertebrate assembly and that habitat diversity controls biodiversity. The concept of a suite of 'functional habitat' in the river channels was introduced in U K in 1991.Impairment of 'functional habitat' may lead to the collapse of the entire ecosystem. Therefore, the recovery of 'functional habitat' in upper Ganges is very important. 'Functional habitat' recovery in the Upper Ganges is possible by physical reconstruction in terms of widths, depths, velocities and channel edges (which are readily achievable by technical means) based on geomorphological principles for maintaining the habitat diversity.

Removal of Obstructions

Fine silt and suspended solids are accumulated in the interstitial spaces of hyporheic biotope, resulting in the choking of natural circulation of water in the interstitial spaces of hyporheic zone of upper Ganges. Suspended sediments can be traced to road construction source. Dredging out gravel mining is one of the important ways for removing obstruction and restoration of the impacted sites. Dredging also maintains the width, depth and flow of water and prevents from clogging with silt.

Restoration of Riparian Corridor
Riparian vegetation, stream bank geomorphology, overhanging vegetation, undercut banks and hill slope vegetation of Upper Ganges have been drastically altered by the muck generated by the construction, widening and repairing of roads passing along the Upper Ganges. Riparian vegetation moderates stream temperature provides habitat cover and helps in stabilizing embankments. Maintaining proper amount of herbaceous vegetation is a critical part of increasing sediment deposition and enhancing channel restoration in hill stream system (Clary and Thornton 1996). Afforestation of hill slopes is instrumental for reducing the capacity of weathering and erosion caused by transportation network.

d. Erosion Mitigation

Erosion of stream banks can be minimized through ecological and engineering approaches (Howell 1999; Sharma 2005). The following practices should be taken into consideration in the mountain areas:

- Grading slopes appropriately to provide traps for eroding debris;
- Strengthening the bases of slopes through enlargement of the toe of the rock to be slid;
- Securing steep cut slopes by the use of reinforcing structure at their bases;
- Construction of restoration walls to prevent mass movement of soil; and
- Netting exposed slopes with coir, jute or synthetic geotextile, followed promptly by revegetation by fast growing non palatable species suitable to climatic conditions of the site.

Perforated Roadbeds

Groundwater flows and surface water flowing in rivers, streams and intermittent channels are frequently interrupted by road corridors or roadbeds. So, the common solutions are bridges, culverts and porous road bed material (Stoeckeler, 1965; Brown, 1982; Gilje, 1982; Swanson *et al.*, 1988; Forman and Deblinger, 2000). Excessive drainage may lead to a lowered water table and spread of wetlands on the upslope side, while down slope the water table drops. Pea stream

flows may also rise where roads intercept groundwater and channelize the water into surface flow (Jones and Grant 1996, Wemple *et al.*, 1996). Therefore, a perforated road bed with an abundance of water crossing location, rather than a few major crossings, normally would better mimic natural flows as well as the resulting hyporheic habitats of upper Ganges. Early failures of toe walls due to heavy precipitation in monsoon season (July-August) are very common in Uttarakhand. Therefore, several big culverts and check dams are being constructed for proper drainage throughout the length of roads and highways passing along the Upper Ganges (figure 7).

Figure 7. Construction of big culvert and check dam for proper drainage throughout the length of the road passing along the Upper Ganges.

Sealing of Side Drains

Sealing of side drains is an effective mechanism against water penetration into the underground alongside endangered sections of the road. Side drains should be discharged only into natural brooks, rivulets, rivers and side drain of the road. Steep gullies carrying an increased water volume due to road water discharge should be protected by check dams as far down as necessary to avoid depth and slide erosion of the river bed.

Principle of Minimum Flow in River

Defining minimum stream flow requirements presents one of the top problems of aquatic biodiversity and water management almost all over the world. In Garhwal Himalaya, stream regulations during the last decade as well as increasingly intensive water uptakes for hydropower projects in addition to obstruction created by road construction in rivers and receding of Himalayan glaciers due to global warming contributed to the need of a new approach to maintain the minimum flow in the upper Ganges. Transportation network along the upper Ganges has caused a massive geomorphological transformation in the Bhagirathi and Bhilangana ecosystems. For the protection of the hyporheic organisms from the intensive sedimentation of suspended solids, a minimum flow of 25 cm of hydromedian depth is required throughout the year in upper Ganges.

Sustainable Mountain Specific Road Construction

Development of mountain specific sustainable approaches for construction, widening and repairing of roads in Garhwal Himalayas requires multi-disciplinary inputs based on geological engineering (geo-environmental appraisal of the area in terms of slope stability, likely and debris flow material, avoiding construction of roads on the old paleochannels), socio-economic and environmental factors. Mountain specific design and approaches require access to comprehensive knowledge of geology, geo-tectonic, civil engineering, environmental biology and economic analysis.

Biographical Sketch: Professor 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.) and Doctor of Science (D. Sc.) in Environmental Biology. He has a wide experience of teaching and research for more than thirty two years on environmental monitoring, bioenergetics, biodiversity and transportation ecology in the Himalayas. More than 14 research projects have been completed on these aspects. Twenty three doctoral research students have been conferred to doctoral degrees and seven 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 114 research articles in the journals of international repute. He has been conferred several awards and gold medals (NATCON Environment Gold Medal 2001,

Zoological Society of India Gold Medal 2001, Environmentalist of the Year Award 2003, Recognition Award Gold Medal 2004, Indira Gandhi National Environment Award 2005). He is a fellow of many national and international societies. Currently, he is Professor and Chairman, Department of Environmental Sciences, H.N.B. Garhwal University, Srinagar-Garhwal, Uttarakhand, India.

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