Restoration of Aquatic Habitat and Fish Passage Degraded by Widening of Indian Highway 58 in Garhwal Himalaya

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Abstract: Sustainable approaches to the construction and widening of roads and highways are essential to offset negative influences on aquatic habitat and fish passage in the fragile ecosystem of the Himalayan Mountains in northern India. Evidence is growing that the expanding, poorly designed network of roads and trails in mountain areas, without giving due considerations to natural processes such as geological processes and climatic severity, such as heavy monsoon precipitation, is a major cause of habitat fragmentation and degradation of both terrestrial and aquatic habitats.

These effects have been quantified for aquatic primary producers (periphyton), aquatic benthic insects, and Snow Trout, a Himalayan teleost (Schizothorax richardsonii, Gray; Schizothoraichthys progastus, McClelland) that dwells in the upper Ganges River, following Indian National Highway 58 (NH-58) in the mountain region of Garhwal Himalaya, India (latitude 29 degree 61 minutes -30 degree 28 minutes N; longitude 77 degree 49 minutes -80 degree 6 minutes E). Indian Highway 58 is one of the most important highways, is 300-km long, and passes along the Alaknanda River (230 km), which is one of the parent streams of the Ganges (70 km) in the fragile mountain ecosystem of Garhwal Himalaya of northern India. Keeping in mind the heavy traffic on the highway, a RS 450 million (US $100 million) widening project was launched in 2001.

The widening of Highway 58 through massive cutting of mountain slopes, the disposal of tons of the cut material downhill into the waterways in an uncontrolled manner, and the improper water management of the slopes has resulted in intensive accumulation of soil and woody debris into the aquatic ecosystem from accelerated erosion, gulling, and landslides, resulting in drastic changes in the physico-chemical and biological profile of the aquatic habitat. Detrimental effects on transparency, current velocity, conductivity, bottom-substrate composition, dissolved oxygen, periphytonic production, and the production of benthic insect communities have been documented. Feeding, spawning, and the passage of the Snow Trout cold-water fish have been degraded or destroyed.

Subsequent to the widening of Highway 58, the annual gross primary production (Pg) of periphyton declined from 8771 g C m-3yr-1(96.48 k. cal m-3yr-1) to a value of 5952 g C m-3yr-1 (65.47 k cal m-3yr-1), a 32-percent decrease in aquatic habitat. The maximum biomass (standing crop) of aquatic insects declined from a mean monthly biomass of 4.926 g m-2 (February) to 1.848 g m-2, a 62-percent decrease, and a minimum monthly mean biomass of 0.408 g m-2 (August) to 0.126 g m-2, a 69-percent decrease. Subsequent to widening of the highway, the standing crop estimate of Snow Trout declined from a maximum mean monthly biomass of 2.955 g m-2 (February) to 1.201 g m-2, a 59-percent decrease, and a minimum monthly mean biomass (August) of 0.244 g m-2 to 0.082 g m-2, a 66-percent decrease. Annual productivity of Snow Trout declined from 1.309 g m-2 to 0.448 g m-2, a 66-percent decrease.

This decline is believed to have been caused by increased turbidity accompanied by a decline in depth and dissolved oxygen, accumulation of fine silt and suspended solids, a decrease in primary productivity, a decrease in general benthic-aquatic insects productivity, depletion of the food supply, and loss of cover.

We have recommended the following measures to restore habitat quality and connectivity of Snow Trout:

- Stream restoration and stream bank stabilization using these structures:
    - Toe walls
    - Retaining walls
    - Stone layers
    - Stone arches
    - Terraces
- Bioengineering methods by
    - Planting fast-growing plant species in combination with wire netting, gravel mining, and dredging in the impacted sites
    - Protecting riparian vegetation
    - Monitoring of water quality
    - Enhancement of fish food reserves
    - Sustainable approaches to road construction and widening
    - Proper drainage of water-saturated mountain slopes and spring runoff during monsoon season (July-August)
    - Sealing of side drains against underground water penetration alongside endangered sections of the highway
    - Construction of check dams for protection of steep gullies and side erosion of the river bed

We also recommend establishment of a strong partnership among experienced, expert

- Geologists
- Civil engineers
- Structural engineers
- Environmental biologists

Introduction

It is undisputed that the existence of roads is an imperative requirement for mobility, accessibility, and smooth development in Himalayan Mountains. Due to the young geology of the Himalayas and instability of their slopes, the region is prone to recurrent and often devastating landslides triggered by construction and widening of roads and highways.

Garhwal Himalaya is an important part of Himalaya located in the state of Uttaranchal of North India. The major Indian rivers (Ganges and Yamuna) and their tributaries (Alaknanda, Bhagirathi, Bhilangana, Mandakini, Pindar, and Nayar) have their origin in Garhwal Himalaya. Most of the roads in Garhwal Himalaya have been constructed in the valleys along the rivers. Therefore, any activity related to the construction and widening of roads has detrimental effects on the aquatic ecosystem and the organisms dwelling in it. Geology and the fragile nature of the region make this relationship of roads and the aquatic ecosystem more vulnerable.

Evidence is growing that the expanding, poorly designed network of roads and trails in mountain areas, without giving due consideration to natural processes such as geological processes and climatic severity, such as heavy monsoon precipitation, is a major cause of habitat fragmentation and degradation of both terrestrial and aquatic habitats. Massive cutting of the mountain slopes and disposal of the cut material downhill in an uncontrolled manner, uncontrolled blasting of rock in large quantities for road cutting, and improper water management in mountain terraces has resulted in intensive soil loss from accelerated erosion, gullying, and landslides.

Therefore, sustainable approaches to the construction and widening of roads and highways are essential to offset negative influences on the aquatic habitat and fish passage of the fragile ecosystem of the Himalayan Mountains of Northern India. Considerable work has been done on the impact of the transportation network on aquatic ecosystems and fish life in America and Europe. However, except by Sharma (2003), no sincere effort has been made so far on the restoration of aquatic habitat and fish passage degraded by roads and highways in India.

The present paper attempts to provide manifestation of the negative impact of Highway 58 on water quality and to quantify the impact on primary production (periphyton), secondary production (aquatic insects), and production of Snow Trout, an important Himalayan teleost. For Snow Trout, several remedial measures for restoring the habitat quality and connectivity degraded by the widening of NH-58 in Garhwal Himalaya have been suggested and tried on many stretches of the Alaknanda River.

The Snow Trout is an important coldwater fish distributed along the Himalayas in India, Pakistan, Bhutan, Nepal and Bangladesh. It contributes more than 65 percent of the total fish catch of Garhwal Himalaya. This is an important indigenous teleost dwelling in snow-fed hill streams of the Himalayas. Members of the subfamily Cyprininae pertaining to the family Cyprinidae are commonly known as Snow Trout. Snow Trout comprise mainly two genera: Schizothorax with a suctorial lower lip and Schizothoraicthys with a non-suctorial lower lip. The most important species of Snow Trout dwelling in Garhwal Himalaya streams are Schizothorax richardsonii (Gray) and Schizothoraichthys progastus (McClelland). The fish weigh up to 2.5 kg with a maximum total length of 45 cm. Snow Trout are surface feeders. They are local migratory fish and prefer temperatures between 5° to 20° Celsius (Singh and Sharma 1998, Sharma 2003).

Materials and Methods

Physiography of the study area

The study area is located in the Garhwal Himalaya, an important zone of the Himalayas and a part of the new state of Uttaranchal 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, Uttarakashi, Chamoli, and Rudraprayag) and covers an area of 30,029 km^2.

The area is very rich in biodiversity (animal, plants, and microbes). The entire region of Garhwal Himalaya is bestowed with tremendous freshwater resources in terms of major fluvial systems of Ganges and Yamuna and their tributaries. Due to the rich freshwater resources, Garhwal Himalaya is known as the 'tower of freshwater resources.' Two major parent streams, the Alaknanda and Bhagirathi, form the Ganges after confluences at Deoprayag.

A thick network of roads and highways has been launched in the region to cater to the needs of the heavy influx of tourists. Most of the roads and highways in Garhwal Himalaya have been constructed in the river valleys along the rivers.

Geology of the study area

The study area is characterized by a flat-topped ridge, steep slopes, and a wide valley. The area is covered by three types of rocks of the upper Proterozoic to lower Paleozoic 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 intrusions in the form of a sill and dykes. The phyllite is called Pauri phyllite (Kumar and Agrawal 1975). Vertically folded, highly fractured, pinkish ripple, and current-bent quartzite rocks, intercalated with a massive intrusion of meta volcanic rocks, are under the 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.

The wide valley of the Alaknanda River is characterized by the set of terraces formed by the river shifting 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 deposited along the riverside in the form of terraces. Most of the lowest terraces are in contact of the river.

The whole stretch of the Alaknanda River covers a distance of about 250 km and flows across the different lithotectonic units of Garhwal Himalaya. The river can be conveniently divided into three zones: Mana to Vishnu Prayag (highest gradient-I grade), Vishnu Prayag to Karanprag (moderate gradient-II grade), and Karanprayag to Devprayag (low gradient-III grade). National Highway 58 runs along the Alaknanda River from Badrinath to Devprayag (230 km) and Deoprayag to Rishikesh (70 km) along the Ganges.

Natural preconditions for road construction and widening in Garhwal Himalaya

Road construction and widening are very much dependent on the natural preconditions (climate, geology, topography, and environment) in mountainous areas. Favorable 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 subtropical to alpine and temperate. The annual rainfall differs from place to place, ranging from less than 250 mm to 3500 mm. Most of the precipitation (80 percent) occurs during the monsoon period (July-August), creating tremendous problems for the road builders.

Garhwal Himalaya is affected by a constant tectonic uplifting 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 a tremendous difference in elevation ranging from 350 m above mean sea level (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 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 vulnerable. Such deforested and abandoned land has accelerated water runoff in volume and speed and is prone to slides. These four natural preconditions have a negative influence on road construction and widening in Garhwal Himalaya.

Salient features of the Indian Highway 58

Highway 58 is one of the most important highways and is 300 km long, passing along the Alaknanda River (230 km) and the Ganges (70 km) in the fragile mountain ecosystem of Garhwal Himalaya of northern India. NH-58 caters to the needs of heavy traffic (0.5 million people per year) and is used by people visiting the world-famous Indian shrines of Badrinath, Kedarnath, and Kemkunth Sahib, in addition to world-heritage sites (Nanda Devi Biosphere Reserve and Valley of Flowers).

Keeping in mind the heavy traffic on NH-58, in 2001 a project costing over Rs 450 million (US $100 million) for widening the highway was launched. The basic objective of widening NH-58 is to make it double lanes for the smoother running of traffic. This project is expected to be completed in March 2007. The details of the widening work on different stretches of NH-58 are presented in Table 1.

Table 1. Details of widening works of NH-58.

Stretch	**km**	**Activity**	**Expected Completion**
Byasi-Kodiyala	08	Cutting Work	March 2006
Bagwan-Srinagar-Srikot	20	Hotmix	April 2005
Pharasoo-Kaliasaur-Rudraprayag	21	Cutting Work	April 2005
Bugwan-Rudraprayag	60	Construction of culvert and Hotmix	March 2006
Gauchar-Karnaprayag	32	Cutting Work	March 2006

Methodology

Physico-chemical analysis of the water quality of the aquatic habitat of the Alaknanda River was made following the methods outlined in Wetzel and Likens (1991) and APHA (1998). Primary productivity of periphyton was determined by incubating substrates in a 1.93-liter molded-polystyrene chamber (Rodgers et al. 1978) for a four-hour incubation (0800-1200 hrs). A submersible pump (powered by an attached battery pack) supplied water circulation in the chamber. A variable resistor allowed variable flow in the chamber. Black-plastic tape was used to cover the dark (opaque) chambers. For the oxygen produced over a given time period, calculations were made after running modified Winkler's test on each of the samples.

Calculations for gross primary productivity (Pg) were made as follows:

Gross Primary Productivity (Pg): Total oxygen produced = Oxygen at end, light chamber not covered (minus) oxygen at end, black-taped chamber

The values obtained in mg. l-1 oxygen were converted to milligrams of carbon per cubic meter (mg C m-3) multiplying the value by 375.36 (Strickland and Parsons 1960). The values in mg Cm-3 can be converted to grams of dry weight by multiplying the milligrams of carbon by two and dividing by 1000. The values of dry weight were converted to calories of energy multiplied by 5.5 (Benton and Warner Jr. 1972).

The productivity of aquatic insects (secondary productivity) was determined by the biomass method (Winberg 1971, Downing and Rigler 1984). For the study of density, biomass, and production of the Snow Trout, 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 exponential:

$$G = \frac{\log_e \overline{w}_2 - \log_e \overline{w}_1}{t}$$

Where and = mean weight of the fish at times t1 and t2, respectively.

To estimate monthly production, mean biomass () was multiplied by the instantaneous growth rate (G): P= G (Chapman 1978). The annual production (g.m-2.yr-1) was estimated for Snow Trout.

Results and Discussion

Morphometric transformation of fish habitat
A large-scale morphometric transformation of the habitat of Snow Trout in a large section of the Alaknanda River has taken place due to widening activities on NH-58. As a consequence of these construction activities accompanying the road widening, a large stretch of the fluvial system has been transformed into a trench and a dammed pool of sluggish currents of water from rapids, cascades, and part of the high water from 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 the large scale of disturbances caused by disposal of tons of cut material downhill into the waterways of the Alaknanda River (figure 1).

Figure 1. Disposal of cut material downhill into the Alaknanda River caused by the widening activities on NH-58.

The composition of bottom substrates has been drastically altered by the widening activity of NH-58. Improper management of the slopes has resulted in intensive accumulation of soil, woody debris into the aquatic ecosystem from accelerated erosion, gullying, and landslides.

Degradation of physico-chemical aquatic environment
Degradation in the mean physico-chemical parameters of the aquatic environment of the Alaknanda River caused by the widening of NH-58 over a three-year period (January 2002-December 2004) is presented in Table 2.

Table 2. Degradation in the mean physico-chemical parameters of aquatic environment of the Alaknanda River caused by widening of NH-58 during a three-year period (January 2002-December 2004)

Parameter	**Standard Site** (S1) (± SD)	**Impacted Site** (S2) (± SD)
Air temperature (°C)	21.42 ± 6.50	21.78 ± 6.53
Water temperature (°C)	13.35 ± 2.51	14.02 ± 2.21
Hydromedian depth (m)	2.34 ± 1.34	1.51 ± 1.20
Conductivity (µScm-1)	80.56 ± 24.67	82.09 ± 25.18
Relative humidity (%)	46.21 ± 5.58	41.65 ± 5.75
Water velocity (m.sec-1)	1.375 ± 0.685	1.15 ± 0.702
Turbidity (NTU)	85.21 ± 78.37	121.65 ± 84.73
Transparency (m)	1.581 ± 0.637	1.20 ± 0.416
Photoperiod (LH day-1)	11.76 ± 1.20	11.76 ± 1.20
TDS (x 102 mg.l-1)	4.90 ± 4.80	5.94 ± 4.94

Table 2 (continued)

Parameter	Standard Site (S1) (± SD)	Impacted Site (S2) (± SD)
pH	7.45 ± 0.05	7.65 ± 0.07
Dissolved oxygen (mg l-1)	13.8 ± 3.12	8.54 ± 0.68
Free carbon dioxide (mg l-1)	0.92 ± 0.31	1.01 ± 0.16
Total alkalinity (mg l-1)	39.54 ± 6.54	37.51 ± 5.10
Phosphates (mg l-1)	0.030 ± 0.011	0.036 ± 0.012
Nitrates (mg l-1)	0.023 ± 0.012	0.30 ± 0.013
Silicates (mg l-1)	0.039 ± 0.34	0.043 ± 0.038
Sulphates (mg l-1)	1.576 ± 0.486	1.545 ± 0.612
Chlorides (mg l-1)	3.104 ± 1.112	3.281 ± 0.765

Analysis of the data revealed that a slight change in the water temperature in year 2004 (14.02 ± 2.21 °C) was noticed in comparison to the temperature recorded before the project (13.35 ± 1.34 °C). The drastic change in hydromedian depth (HMD) was recorded at the impacted site (1.50 ± 1.20 m) in comparison to the depth at the reference site (2.34 ± 1.34m). Conductivity was also influenced from the natural condition (80.56 ± 24.67 μmho cm-1) by the widening activities at the impacted site (28.09 ± 25.18 μmho cm-1).

The water velocity has been altered to a great extent at the impacted zone (1.15 ± 0.072 m sec-1-) versus the water velocity at the unaltered site (1.375 ± 0.685 m sec-1). A considerable change in the suspended material in the water at the impacted section (121 ± 84.73 NTU) was recorded versus the reference site (85.21 ± 78.37 ± NTU). A reduction in dissolved oxygen was also recorded at the impacted site (8.54 ± 0.68 mg l-1) versus the reference site (13.8 ± 0.12 mg l-1). A minor change in other chemical parameters (free CO2, phosphates, nitrates, sulphates, chlorides, and silicates) was also noticed at the impacted zone of the Alaknanda River in comparison with the study made before the initiation of the NH-58 project.

Trophic depression in the aquatic environment

The biotic profile of the aquatic environments of the Alaknanda River is characterized by the presence of periphyton and macrophytes at the primary trophic levels and zooplankton and aquatic benthic insects at secondary trophic levels. These biotic components act as food for hill stream fishes. The natural composition of these organisms was also drastically influenced by the widening activities of NH-58. The percentage of aquatic insects was reduced from 50.83 percent to 30.06 percent over a period of three years (figure 2) as a consequence of the degradation of aquatic environment caused by the NH-58 widening activities.

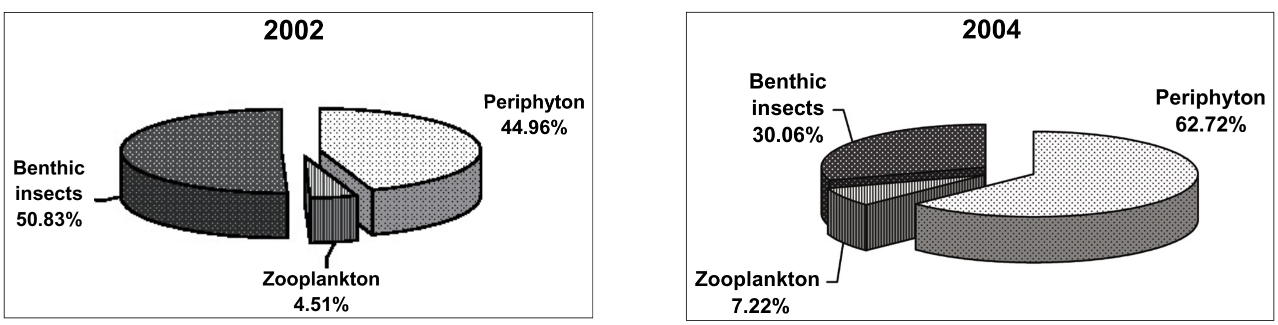

Figure 2. Impact of widening activities of NH-58 on the percentage composition of aquatic organisms of the Alaknanda River, Garhwal Himalaya, over a period of three years.

The road-widening activities of the Alaknanda River drastically influenced the primary production of the aquatic environment contributed by aquatic plants. The annual gross primary production of periphyton was reduced from 8771 g C m-3 yr-1 (96.48 k. cal. m-3 yr-1) to a value of 5952 g C m-3 yr-1 (65.47 k. cal. m-3 yr-1), a 32-percent decrease in aquatic primary production over a three-year period (figures 3 and 4) The peak in primary production was recorded during November-December (winter months), when the transparency of the water was recorded to be very high.

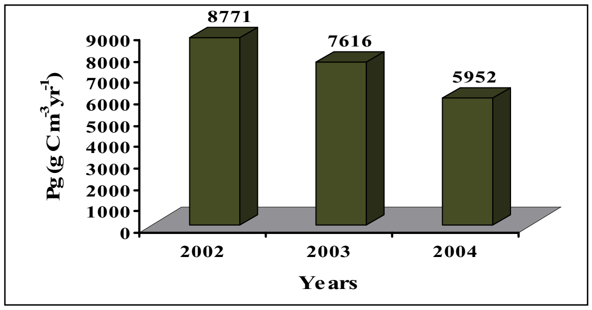

Figure 3. Impact of NH-58 widening on the annual carbon value of aquatic environment of the Alaknanda River.

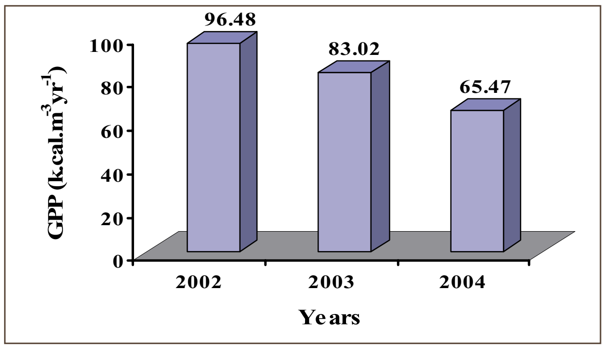

Figure 4. Impact of NH-58 widening on gross primary production (Pg) over a period of three years (32 percent decrease).

The maximum biomass (standing crop) of aquatic insects declined from a mean monthly biomass of 4.926 g m-2 (February) to 1.848 g m-2, a 62 percent decrease and a minimum mean monthly biomass 0.408 g m-2 (August) to 0.126 g m-2), a 69-percent decrease (table 3).

Table 3. Impact of widening of NH-58 on the mean monthly biomass (g m-2) of aquatic insects

Month	2002 (g m-2)	2004 (g m-2)
January	3.342	1.062
February	4.926	1.848
March	4.788	1.812
April	3.624	1.362
May	2.052	0.708
June	0.672	0.258
July	0.420	0.138
August	0.408	0.126
September	1.092	0.408
October	1.632	0.606
November	2.022	0.738
December	2.400	0.846

Impact of widening of NH-58 on the life of Snow Trout

Inundation of Spawning and Feeding Grounds of Snow Trout

The inundation of spawning and feeding grounds of Snow Trout inhabiting the Alaknanda River was observed at the impacted site of the river. As a result of the road-widening activities of NH-58 and a phenomenal change in turbidity and silting pattern, the failure of spawning or ineffective spawning of Snow Trout was observed. The presence of gravel, pebbles, sand, and bank-side vegetation is a prerequisite for Snow Trout to build their spawning nests (redds).

Choking of breeding grounds and fish passage
Environmental degradation brought about by intensified road-widening activities in the Alaknanda River catchment has adversely affected the local migratory fish species (*Schizothorax richardsonii*, Gray; *Schizothoraichthys progastus*, McClelland). Due to land slides, slope failures, sliding of the retaining wall, and disposal of tons of cut material downhill into the waterways, substantial morphometric transformations have resulted in the fish habitat that obstruct the free movement of Snow Trout into the breeding grounds. To spawn, both species of Snow Trout need clean, stable, and well-oxygenated gravel habitats, shaded with riparian vegetation. After the eggs are laid in the gravel, well-oxygenated water must pass over the eggs (Sharma 1991).

Impact on Production of Snow Trout
As a consequence of the massive scale of road-widening activities in the entire valley of Alaknanda, the Snow Trout (an important food fish of Indian Himalaya) is facing a lot of survival problems in the degraded and stressed habitats. Various stages of the life cycle (migration, spawning, incubation, and rearing) of Snow Trout are drastically influenced (figure 5).

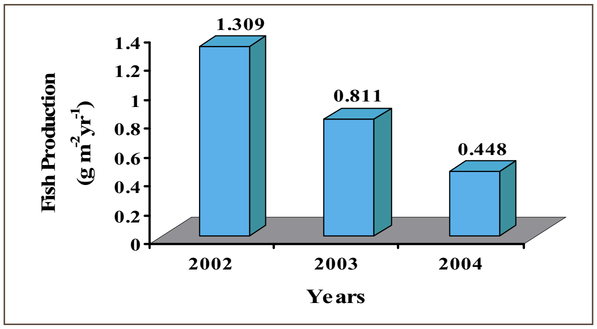

Figure 5. Impact of widening of NH-58 on the annual production (g m-2yr-1) of Snow Trout of the Alaknanda River.

Mountain ecosystems play a key role in providing forest cover, feeding perennial river systems, conserving genetic diversity, and providing an immense resource base for livelihood to local inhabitants. However, the mountain ecosystems are among the most fragile ecosystems in terms of susceptibility to natural and anthropogenic shocks. There has been a significant adverse impact on the mountain fluvial ecosystem caused by construction and widening of roads and highways. In order to protect and restore the aquatic ecosystem for fish survival, the complex inter-relationships between fish and their habitat must be understood.

All cold-water fish species, including Snow Trout dwelling in Himalayan water, need relatively unaltered or pristine freshwater habitats during part or all of their life-cycle stages. Fish migration, spawning, incubation, and rearing are examples of life-cycle stages.

The successful completion of each of these stages is dependent on one or more of the following environmental conditions of the fresh water habitat:

- Water temperature
- Depth
- Velocity
- Turbidity
- Dissolved oxygen
- Bottom substrates
- Cover
- Food supply

Different aquatic communities are broadly associated with habitat features based on the following (Wetzel 1983, Cole 1994):

- Water temperature
- Salinity
- pH
- Flow velocity
- Plant nutrients
- Bottom substrates
- Water clarity
- Dependability of oxygen concentration
- Concentration of toxic material (Wetzel 1983, Cole 1994)

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, Greta Britain, 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 runoff 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, recolonization 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 modification of streams had a direct deleterious effect on the trout population, and large trout were denied suitable natural hiding places (holes, undercut, and bank vegetation).

The relationship between fish life and suspended solids was the first to be considered by the European Inland Fisheries Advisory Commission in their Technical Paper Series (EIFAC 1964). This relationship has since been reviewed by Alabaster (1972) and Alabaster and Lloyd (1980). Trout population in stream sections affected by high suspended solids had lower densities than in unaffected stretches (Scullion and Edwards 1980).

The long linear ecosystems (rivers and streams) are particularly vulnerable to fragmentation. There is a growing concern about the role of road crossings in altering habitat and disrupting river and stream continuity. Little consideration has been given to the ecosystem processes such as natural hydrology, sediment transport, fish and wildlife passage, or the movement of woody debris (Jackson 2003).

According to Mann and Penczak (1986), productivity levels of fish are affected by both biotic and abiotic influences, with the latter being of prime importance. Biotic variables (cover, food, and 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 and the amount and quality of autochthonous and allocthonous organic matter (Naiman 1983, Minshall et al. 1983) and temperature and its range (Elliot 1976, Edward et al. 1976). Thomas (1998) studied the effects of highways on western cold-water fisheries of North America. Highway network activities have an adverse impact on cold-water 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, where any sediment deposited into streams could have adverse effects.

Management of aquatic habitat may be as simple as adding a bottom structure, such as artificial reefs or spawning gravel for protective cover on reproduction (Kohler and Hubert 1993). Many degraded habitats can be cost-effectively aerated to increase oxygen concentration, fertilized to increase productivity of aquatic plants, or dredged to remove sediments. Habitat management integrates the management of entire watersheds. Sustaining an optimum balance of surface water and groundwater contributes to aquatic habitats by controlling erosion of sediments and nutrients.

The negative effects of environmental change in fish have been cumulative and interactive. Predictive understanding and effective management requires more holistic ecosystem approaches. The concept of recovery of ecosystem 'integrity' as the most appropriate means for obtaining optimum sustained benefits has gained considerable credence.

Restoration of Aquatic Habitat and Fish Passage

Efficiently protecting and restoring aquatic habitat and fish passage degraded by the transportation network is one of the most-needed management actions for natural resource managers throughout the world (Forman and Sperling 2002). Aquatic-habitat enhancement should be undertaken integrating natural channel-design techniques, aquatic-vegetation restoration techniques, and more traditional hydraulic and channel-design engineering practices (Welsche 1985; Nyman 1998, 2003). Successful treatments or techniques that directly protect or restore aquatic habitat impacted by roads are wildlife and fish passage improvement, channel and floodplain structure placements, and reconnecting water bodies (Doyle 2003). The utilization of passive treatment systems to mitigate the effects of acid mine drainage and acidic leachate discharge is a recent innovation in the restoration of aquatic ecosystems (Brookens et al. 2003).

Development of mountain-specific and sustainable infrastructures in mountainous areas requires multi-disciplinary inputs (Deoja 1994). Protecting and restoring aquatic habitat and fish passage of Snow Trout in the Alaknanda River along NH-58 in Garhwal Himalaya has become a priority. Therefore, the following measures have been recommended to restore habitat quality and connectivity for the Snow Trout.

Stream restoration and stream bank stabilization

Stream restoration and stream bank stabilization of the Alaknanda River can be made by improving the stability of a slope or to regaining stability of a slope after failure. Three different measures can be applied: improving the slope by making it as dry as possible (drainage system), supporting the slope by structures, or stabilizing by bioengineering methods. These three methods should be combined to achieve the optimum success. Stream-bank stabilization can be made through the protection structures (toe walls, retaining walls) to retain soil masses, other structures like stone layers, systems of stone arches, and terraces for preventing slope-surface erosion caused by the widening of NH-58. All these methods (improving the slope, support of the slope by structures, and bioengineering) have also been recommended by Schaffner (1987).

Bioengineering erosion-protection measures will be very effective in stabilizing unstable slopes at several locations on NH-58. Bioengineering measures consist mainly of planting fast-growing nonpalatable (Alnus spp.) species suitable to the climatic conditions of the site. Most important is the plant's capacity for deep rooting, thus increasing the soil surface and water-absorption power (drainage effect). There should be proper drainage of water-saturated slopes and spring runoff during monsoon seasons (July- August).

Another surface erosion protection measure is the combination of planting and mini-terrace construction out of wood. Finally, mini toe walls made of wood were also constructed. It has to be emphasized that areas with new plant cover have to be fenced off or watched by a watchman to avoid foraging by free-grazing animals, causing an eventual failure of the protective measure. The best method to prevent erosion on the uphill of NH-58 would be not to touch the mostly unstable slopes. They should be left uninhabited with their original forest cover.

Slopes drainage system

The activity of widening of NH-58 is a massive interference with the environment. Therefore, it should be handled with the utmost care. Thus 'kid-glove' approaches to road construction and widening should be applied, which include automatically the principle of preventing and minimizing erosion. Following this concept, slope failures have to be immediately repaired to prevent further extension and avoid the possibility that they become uncontrollable. Where the water runoff is not tightly checked, the system has to be improved to prevent creeps and slides. Early failures of the toe walls due to heavy precipitation during monsoon season (July-August) are very common in Garhwal Himalaya (figure 6). Therefore, several big culverts and check dams have been constructed for proper drainage throughout the length of NH-58 along the Alaknanda River in Garhwal Himalaya (figure 7).

Figure 6. Early failure of toe wall due to heavy precipitation during monsoon (July-August) on NH-58.

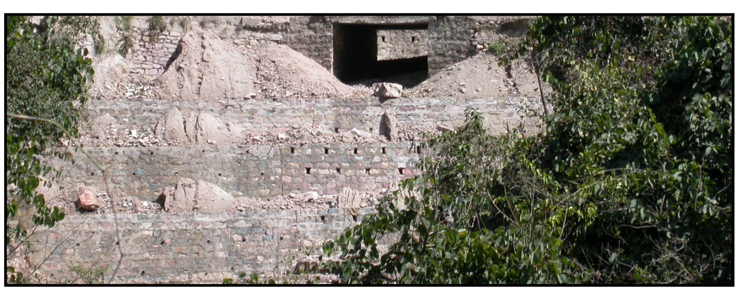

Figure 7. Construction of big culverts and check dams along NH-58 for proper drainage.

Sealing of side drains
Sealing of side drains should be made immediately against water penetration into the underground alongside endangered sections. Site drains should be discharged only into natural brooks, rivulets, and rivers. Steep gullies carrying 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.

Gravel mining and dredging in the impacted sites
Fine silt and suspended solids are accumulated in the riverine ecosystem of the Alaknanda River. Snow Trout have difficulty in respiring, and their eggs are smothered. Turbidity reduces plant productivity to the extent that photosynthesis is impaired by reduced sunlight. Recreational opportunities are also lost.

Sediments usually refer to soil particles that enter the water column from eroding land. Sediments consist of particles of all sizes, including fine clay particles, silt sand and gravel. Suspended sediments can be traced to the road-construction source. Restoration of the impaired ecosystem of the Alaknanda River caused by the activities of widening NH-58 can be done in different ways to improve the aquatic habitat. Dredging and gravel mining are among the important ways to restore the impaired ecosystem. Dredging involves widening and/or deepening river channels to facilitate migration of fish. Dredging also maintains the flow of water and prevents clogging caused by silt.

Protecting the riparian vegetation
Riparian vegetation, stream bank morphology, overhanging vegetation, undercut banks, aquatic vegetation, and deep-water pools of the Alaknanda River are drastically altered by the debris generated by the widening of NH-58. These natural structures provide adult and juvenile cold-water fish with shade, resting areas, and protection from predation.

Riparian management is extremely critical for fish and wildlife populations (Thomas 1986). Riparian vegetation provides habitat cover for fishes and other wildlife, moderates stream temperatures, serves as a food source, and helps in stabilizing embankments (Welsch 1992). Riparian zones of the Alaknanda River received an inappropriate amount of the impact of the road cutting and widening of NH-58.

Riparian zones often are the most productive sites in a region because floodplains frequently have rich soils with plentiful moisture. They have a greater diversity of plant and animal species than adjoining ecosystems. Healthy riparian systems purify water as it moves through the vegetation by retaining sediments and by retaining water in aquifers beneath the floodplain. Riparian zones often are a diverse mix of wetland and upland vegetation, all of which are linked closely with the floodplain groundwater.

Maintaining proper amounts of herbaceous vegetation is a critical part of increasing sediment deposition and enhancing channel restoration in a hill stream system (Clary et al. 1996). Conversion of shrubland or woodland to herbaceous vegetation can greatly increase water yields. This is because grasses and forbs generally transpire much less water than do woody plants.

Recovery of ecosystem integrity
The negative effects of environmental change in fish habitats have been cumulative and interactive. Predictive understanding and more effective management require a more holistic ecosystem approach. Recovery of ecosystem ‘integrity’ is the most appropriate means for obtaining optimum sustained benefit and has gained considerable credence.

Monitoring of water quality
Monitoring of water quality of the Alaknanda River ecosystem is a prerequisite for maintaining the optimum physico-chemical conditions for Snow Trout. Monitoring of water quality will provide base data for improving the water quality for successful completion of different stages of life cycle (migration, spawning, incubation, rearing) of Snow Trout.

Sustainable approaches to the construction and widening of roads and highways
Development of mountain-specific and sustainable roads and highways in Garhwal Himalaya requires multidisciplinary inputs. An integrated development strategy based on geological, engineering, socioeconomic, and environmental factors is required for the construction and widening of roads and highways in mountainous areas. Mountain-specific design and approaches for construction of roads and their widening require access to comprehensive knowledge of geology, geotectonic, engineering, and economic analysis. Traditional civil engineers must be trained in mountain-specific skills.

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Biographical Sketch: Professor Sharma has a distinguished academic career. He graduated with zoology honors and obtained a master’s degree in zoology in freshwater fishery biology. He obtained his doctorate (Ph.D.) in the environmental biology of fish and his doctor of science (D.Sc.) in environmental biology. For more than thirty years, he has had a wide experience teaching and researching environmental monitoring, bioenergetics, limnology, resource management, aquatic biodiversity, hyporheic biodiversity, microbial diversity, and transportation and environmental issues in the Himalayas. More than 12 research projects have been completed on these aspects. Under his supervision, 18 doctoral-research students have earned doctoral degrees and seven more students are engaged in research. He has sufficient professional experience and exposure by way of visiting and working at different research laboratories in India and abroad

(Canada, the Czech Republic, Poland, Sweden, and the United States.). He has published more than 104 research articles in journals of international repute. He has received 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, and Indira Gandhi National Environment Award 2005). He is a fellow of many national and international societies. Currently, he is the professor and chairman of the Department of Environmental Sciences, H. N. B. Garhwal University, Srinagar-Garhwal, Uttaranchal, India.

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