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Effect of hydropower on fishes of Uttarakhand

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Abstract
River Bhagirathi in Garhwal region Uttarakhand of northern India is dammed at four locations (Maneri Bhali Phase I, Phase II, Tehri Hydroelectric Dam and Koteshwar Dam) for hydro power generation resulting in the fragmentation of riverine habitat. These Dams have affected seasonal cycles of floods, natural flow regime, and has caused increased sedimentation in impounded section of river. River dams also have profound impacts on ecosystems by changing habitats, hindering migration, life-history stages and population dynamics of the biota. Most affected species have been found Schizothorax, Glyptothorax, Pseudecheneis, Garra, Labeo, Crossocheilus, Noemacheilus, Barilius, Psilorhynchus, Clupisoma, Mastacembelus, and migratory Tor, spp., which are indigenous rheophilic species requiring distinct habitats to fulfil their life cycle stages. Populations of fast flowing riverine species have been collapsed or even disappeared from fragmented sections of the river system.

Keywords: Uttarakhand, hydroelectric dams, fish migration, floods, river habitats

Introduction

Dams create obstacles for longitudinal exchanges along fluvial systems of the river. The building of a dam results in "discontinuities" in the River Continuum (Ward and Stanford, 1983). The number and size of reservoirs/ dams are increasing endlessly due to increasing world demand for energy and water. Huge number of dams have been built in hill states of India for harnessing the hydro energy besides water supply for drinking, household purposes and irrigation. These dams have been built over the rivers for many reasons including water supply, irrigation, power generation and leisure purposes which influence the natural river hydrograph and characteristics of the water. A regulated-river hydrograph may show a decrease in the median annual flow or changes to the timing and magnitude of high and low flows (King *et al*. 2003). The 'discontinuities' in the river continuum and irreversible alteration in the natural hydrological regime of rivers affects the habitat quality and the dynamics of the biota. The flow and water quality of river also gets altered, which have the potential of detrimental effects on river ecosystems (Poff *et al*., 1997; Richter *et al*., 2003). However, the river ecosystems recover from these effects after travelling a long distance downstream to dam due to resilience [1]. Along with that life of fishes got effected by these power plants some of the ill effects are as follows.

External fish injury: Hydropower technology is a clean and renewable energy source of increasing worldwide importance (Zarfl, Lumsdon, Berlekamp, Tydecks & Tockner, 2015). Hydropower is generated by changing the kinetic and potential energy from falling water into rotating shaft power, which can be used to drive an electricity generator (Paish, 2002). Unfortunately, downstream moving fish often enter the hydropower structure where they are unprotected to extreme risks of harm (Williams, Armstrong, Katopodis, Larinier & Travade, 2012). Various physical mechanisms can result in various forms of fish damage, counting collisions with the machinery (Killgore, Maynord, Chan & Morgan, 2001), bar screens or cleaning devices (Adam & Brujis, 2006; Nettles & Gloss, 1987; Skalski, Mathur & Heisey, 2002), shear stress near the turbine blades, in the draft tube and in the tailrace (Čada, Garrison & Fisher, 2007), barotrauma caused by pressure changes (Brown, Pflugrath, *et al*., 2012; Brown, Carlson, *et al*.,2012), cavitation forces within the runner case, turbulences and fluid shear within the suction hose as well as in the tailrace (Abernethy, Amidan & Čada, 2001) [2]. Subsequent injuries include scale loss, fin damage, haemorrhages, bruises, skin wounds, amputations of body parts or internal injuries, such as swim bladder rupture and emboli (Dedual, 2007; Ebel, 2013; Schneider, Hübner & Korte, 2012).

Fish Behaviour: It has been verified that the potential for fish to become stranded can be strongly tied to behaviour and social hierarchy (Shirvell 1994; Berland *et al*. 2004). Dominant and sub-dominant fish react differentially to flow changes, with less dominant fish retorting 15 more readily than dominant fish that hold territories (Mäki-Petäys *et al*. 1997). This mobility may make them less susceptible to becoming stranded by hydropeaking operations. In an experimental hydropeaking study in Newfoundland, juvenile Atlantic salmon demonstrated two distinct movement patterns in reply to flow change; one pattern being strong site fidelity and the second extensive movement, suggesting a possible dominance based behavioural module to observed responses (Scruton *et al*. 2002a, 2003, 2005). Under changing flows, fish experience confinement and discomfort related to inter- and intra-specific competition and potential exposure to predators, and fish will react to this stress by abandoning their station/territory and moving to find more favored habitat conditions. Bradford (1997), for example, observed that juvenile salmonids in side channels were sensitive to flow changes and emerged from cover moving towards faster flows in the main channel as flows decreased. A number of juvenile salmonids demonstrate a marked shift in behaviour between summer and winter, and this behavioural shift is considered an adaptation to avoid predation, minimalize energy spending and avoid harsh environmental conditions (Cunjak *et al*. 1998; Valdimarsson and Metcalf 1998; Hiscock *et al*. 2002). In an experimental hydropeaking study in Newfoundland, differences in movement by juvenile Atlantic salmon between summer and winter suggested fish were sheltering more in the substrate in winter and were therefore not as exposed to flow conditions as in summer, when they would be more actively foraging (Scruton *et al*. 2005) [3]. The authors cautioned that while this winter behaviour of sheltering in the substrate may reduce energetic costs related with hydropeaking related flow changes, it may increase the potential for fish to become trapped and/or stranded during flow reductions. This may mainly be a concern in habitats that are subject to dynamic ice formation and anchor ice manufacture, such as higher gradient, coarse substrate reaches (Stickler *et al*. 2007).

Mitigation: As movement and migration are obligatory elements in the life cycle of many fishes (Lucas, Baras, Thom, Duncan & Slavík, **2001**), but hydropower dams reducing river connectivity and thereby blocking or slowing down fish migration are considered one of the main challenges for restoring and maintaining supportable fish populations worldwide. To complete an anadromous or catadromous life cycle, fish require unhindered migration routes between freshwater and seawater, for both descending and ascending migrants, and a range of mitigation measures have been tried to address this problem [4].

Mitigation measures need to be suitably aligned to the individual location and the specific behaviour of the targeted species. For instance, downstream migrating salmonid smolts are mainly surface leaning and follow the main river flow. Thus, mitigation measures for Atlantic salmon (*Salmo salar*) smolts are adjusted to this behaviour and guide fish away from the turbine inlet towards a safe bypass and further downstream. The guidance assemblies can be mechanical barriers that prevent fish from entering hazardous areas or behavioural barriers, repelling fish from hazardous area and/or guiding fish towards a safe area. When collected in a safe area, mechanical fish collection systems remove and transport fish further downstream; alternatively, fish swim past the obstacle and into the tailrace via bypass channel systems. However, despite good purposes, some mitigation measures are inefficient or only benefit a part of the population. Moreover, since the migration delay and turbine passing are both associated with mortality, there are potentially strong selection processes at hydropower intakes**.**

Mortality: Mortality of juvenile and adult fish in acute cases of GBT is generally credited to anoxia resulting from stasis of the blood (Weitkamp and Katz 1980). In very severe cases the bubbles in the blood stream can be large enough to block blood movement through the heart, but more normally the stasis occurs in the gills (Weitkamp and Katz 1980). It was the high rate of mortality in salmonids associated with GBT on the Columbia River during the mid 1960's and early 70's that brought GBT and TGP to the forefront of scientific investigation. One report during this period estimated that 6% to 60% of adult salmonids died in the middle Columbia River during the period from 1965-1970 (Meekin and Allen 1974). There is a massive body of literature on mortality trials for pacific salmonids, and this work was brief in Weitkamp and Katz (1980) [5]. Direct mortality can also occur in larval (i.e., yolk sac stage) fish (Weitkamp and Katz 1980). In this situation the bubbles form between the yolk sac and the perivitelline membrane and death occurs when the vitelline membrane ruptures (Weitkamp and Katz 1980). Many authors have related the sublethal symptoms of GBT with a higher probability of mortality. Fish with severe bubbles or blisters in the mouth have been observed to refuse food (Dawley and Ebel 1975).

Materials and Methods

Sample Collection

The Tehri Dam is the tallest dam in India. It is a multi-purpose rock and earth-fill embankment dam on the Bhagirathi River near Tehri in Uttarakhand, India. Bhagirathi is a large glacial fed and turbulent Himalayan river in India. It emerges from Gangotri glacier (Gaumukh), Latitude: 30o 56'N; Longitude: 79o 03'E at an elevation of 3812 m above sea level. Traditionally it is also considered to be the source of the mighty river Ganga. It flows for about 217 km before merging with river Alaknanda at Devprayag (474 m asl). The terrain between Gaumukh to Gangotri (3037m asl) is essentially devoid of biota due to hostile conditions.

The Tehri Dam reserves a reservoir for irrigation, municipal water supply and the generation of 1,000 megawatts (1,300,000 hp) of hydroelectricity. Tehri Dam is a 260.5 m (855 ft) high rock and earth-fill embankment dam. Its length is 575 m (1,886 ft), crest width 20 m (66 ft), and base width 1,128 m (3,701 ft). The dam creates a reservoir of 4.0 cubic kilometres (3,200,000 acre·ft) with a surface area of 52 km^2 (20 sq mi). The fitted hydrocapacity is 1,000 MW along with an added 1,000 MW of pumped storage hydroelectricity [6]. The lower reservoir for the pumped-storage plant is created by the Koteshwar Dam downstream.

Methods

The stretch of 217 km of river Bhagirathi from its origin (Gaumukh) to its meeting with Alaknanda at Devprayag was measured to study the extent of physiographic alteration in river caused by hydro power projects (HPPs). Depending on the availability to reservoir/river, numbers of random sites were selected for collection of fish samples and sampling of physico-chemical attributes. Investigational fishing was carried out during daytime (06:00-17:00 hrs) with the help of local fishermen [7]. Fishes were collected with cast nets (dia. 2.0 m, mesh size 1.8 x 1.8 cm), gill nets (mesh size 1.2 x 1.2 cm, L x B = 12 x 1.5 m) and 'phans' (indigenous nets, using several fine nylon loop knotted over a long nylon cord of 5-8 m length, rope is spread on the bottom of stream cross section with stones tied in few loops). Indigenous fish traps *viz*. 'goda', 'pot trap' were also used (Singh and Agarwal, 2014a).On each sampling site, cast net were used at least twenty times during each sampling juncture along the river length. Fish samples were also collected from nearby market and lending centre connected with the river system. Identification of fish samples was done with the help of Day (1878), Talwar and Jhingran (1991), Badola (2009) and Jayaram (2010). Taxonomic discrepancies at species level were resolved using the latest database. Subsequently evaluation, fish were collected from freshwater and oxygen supply and were afterwards released into the river downstream of the power plant. All investigators (scientists or trained fisheries technicians) previously went through a detailed training exercise on the use of the protocol. Fish assessment was done in the same way for all species and treatments. One senior scientist coordinating the experiments was permanently present to assure quality control.

Results and Discussion

Effect on bioenergetics of fishes.

Morphometric Transformation of Fish Habitat A large-scale morphometric transformations of the habitat of the fishes in a large section of Bhagirathi and Bhilangana rivers in the environment of the obstructed sites have taken place due to transportation networks in the area of the Tehri Dam Project. As a result of these road construction activities, a large stretch of the fluvial system has been converted 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 turbulences of sand, gravel and stones. The configuration of bottom substrates has been drastically altered by the road construction and maintenance activities. Along with that it also increases water temperature which effect Bioenergetics of fishes [8].

The bioenergetics of organisms can be defined as a simple mass balance between consumption of energy via intake of food, and the output of energy into various metabolic purposes (egestion, excretion, respiration, Specific dynamic action), growth, and reproduction (Kitchell *et al*. 1977). All metabolic purposes are governed by temperature, and the rate of respiration is strongly influenced by the level of motion of the organism, which in the case of fish, includes swimming to either keep position, feed, or relocate. A decrease in energy consumption or an increase in metabolic costs via a alteration in temperature or increased activity cost will ultimately have negative effect on the energy offered for growth and reproduction. Therefore, any variation in the environment that has the potential to disturb these functions will have significances to the fitness of the individual and can influence population health. The potential bioenergetic impacts of any flow alteration will be largely determined by the size and scale of the river system and the scope of the alteration, river 20 geomorphology, habitats and their distributions. Generally, small streams respond more quickly and extremely to hydrological events and flow changes than larger rivers and consequently species inhabiting smaller dynamic systems are often measured more resilient to environmental changes (Mathews and Stiron 1981; Gordon *et al* 1992) [9]. Similarly, the timing of the flow changes in relative to the life history of the affected fish species will be an important factor of any bioenergetic consequences. Overall, the relationship between altered flow and bioenergetics is extremely complex.

Choking of breeding grounds and migration channels

Environmental degradation, brought about by increased road construction activities at Tehri has affected badly the migratory fish species (Tor tor and Tor putitiora) consequently to Land Slides, slumps, and other construction activities, substantial morphometric transformations have arose in the fish habitat, which obstruct the movement of Mahseer from the foot hills to upper reaches of the river and tributaries for breeding purpose. Both the Mahseer species need clean, stable, well oxygenated, gravel habitats to spawn in.Subsequently the eggs are laid in the gravel, well oxygenated water must pass over the eggs (Sharma, 1984). 6ICOET 2003 Proceedings 87 Making Connections b. Choking of Breeding Grounds and Migration Channels Environmental degradation, brought about by increased road construction activities at Tehri, has affected badly the migratory fish species (Tor tor and Tor putitiora). Due to land Slides, slumps, and other building activities, substantial morphometric alterations have occurred in the fish habitat, which hinder the movement of fishes from the foot hills to upper reaches of the river and tributaries for breeding purposes [10]. Fishes 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).

Injuries due to dams

Injuries of body parts is increased due to dam and field-based fish injury assessment that includes vitality and four general health criteria, as well as nine lethal and sub-lethal injury types across 18 body parts. Scale loss, tears/rips in the fins and haemorrhages are most commen injuries in the area of dam. Two cycloid-scaled species from the natural fish community with a high variety and different patterns of scale loss were chosen: bleak, *Alburnus alburnus* L. (Cyprinidae) and *S. trutta* (Salmonidae) [11]. In accordance with the field-based visual estimation, the fish was separated into the individually analysed four body regions: left and right, front and back. Scaled areas were marked using the *Magnetic Lasso Tool* in PS CS 6, and the proportion of scale loss was calculated using the number of pixels of scaled area versus potentially scaled area.

Competition and behaviour

Competition among juvenile salmonids has been shown to influence the tendency to move from preferred habitats in response to hydropeaking, and this is in part related to species, size and resulting social hierarchy (Shirvell 1994). Dominant and sub-dominant fish may react differentially to flow changes, with less dominant fish responding more eagerly than dominant fish that hold territories (Mäki-Petays *et al*. 1999). Mobile sub-24 dominants may be more profitable under long term hydropeaking conditions as there may be a selective advantage for individuals with a mobile habitat selection strategy (Hutchings 1986). Kemp *et al*. (2003) found that only a fraction of juvenile Atlantic salmon parr redistribute themselves in response to changes in discharge, suggesting parr showed a high degree of site faithfulness under both stable and fluctuating flows (e.g., Huntingford *et al*. 1998; Armstrong *et al*. 1998). This was in part related to social hierarchy as sub-dominant fish showed stronger site attachment in the presence of competitors, in contrast to the observations of Mäki-Petays *et al*. (1999). Regardless, site fidelity could increase the possibility of stranding during hydropeaking power production (Halleraker *et al*. 2003). In a Newfoundland study of response of juvenile Atlantic salmon to flow changes simulating hydropeaking operations, fish demonstrated two distinct movement patterns. One group demonstrated strong site fidelity while the second group moved considerably, suggesting a possible dominance based behavioural constituent to the observed responses (Scruton 2002a and b; Scruton *et al*. 2003).

Mitigation

There is mounting evidence like construction of dam that impacts on wild animal populations are not limited to ecological changes but may also involve strong directional selection and contemporary evolutionary changes. In specific, harvest-induced selection and evolution of life-history traits, such as growth and development, have received much attention, while fewer studies have investigated human-induced selection and evolutionary change of animal behavioural traits [12]. Despite being a global threat to freshwater fish migration and therefore population viabilities.

F. Mortality
Any impairment of the lateral line may affect the fish's ability to sense its environment which may make it more susceptible to predators or injuries (Stroud *et al*. 1975; Schiewe and Weber 1976; Weber and Schiewe 1976). Also, mortality due to a secondary infection in fish that had recovered from GBT was observed by Weitkamp (1976).

Remedial Measures for the Protection of Fishes
The following measures have been recommended to restore habitat quality and connectivity for the fishes:

- 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 improvement 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.
- Ecofriendly techniques for road building 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 fishes.

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