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REVIEW ARTICLE

Taxonomy, distribution, biology and conservation of vulnerable snow trout *Schizothorax richardsonii* (Actinopterygii: Cyprinidae: Schizothoracinae) in the Himalayan and sub-Himalayan region: A review

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Abstract
Fish are a significant component of the aquatic environment and are crucial in supporting and maintaining the entire ecological system, thereby making freshwater systems more resilient and sustainable. The structure of a fish community is influenced by biotic interactions and abiotic variables. In recent years, spanning from the last 5 to 10 years, conservationists and commercial fishermen have reported a significant decline in freshwater fisheries. The decline can be attributed to several factors, including the introduction of exotic species, construction of dams, anthropogenic activities, illegal fishing, and overfishing. *Schizothorax richardsonii*, is a highly valued freshwater fish, inhabiting the foothills of the Himalayan regions. The declines of *S. richardsonii* in the Himalayan region are more than 90% in some areas and the predicted overall reduction is inferred to be around 50% with similar rates. Withstanding all the variations in biotic and abiotic factors, the species is expanding its range of altitude and evolving according to the climate-driven shifts in the Himalayas and apparently, its current distributional range would be lost over time. In Indo-Himalayan ranges, there is a lack of conservative measures and as a result, despite its ecological importance, snow trout has been given a vulnerable status by IUCN 2020. This review aims to provide descriptive biology and discuss the anthropogenic impact on the population structure of snow trout and its conservation.

Keywords: Aquaculture, IUCN, Morphometric, Protection.

INTRODUCTION

Among all vertebrates, fishes have the highest species diversity with about 36,617 valid species in 5,246 genera out of which 18,597 are found in freshwater ecosystems (Fricke 2023). The freshwater system is one of the major biomes on earth consisting of 68.7% of cold water fisheries inhabiting mainly the Himalayas. The cold water fisheries are established as potential candidates for aquaculture and providing economical support in the Himalayan uplands. The most abundant and important cold water fishes belong to the order Cyprinidontiformes with 23 families including Cyprinidae (Fricke et al. 2023). Among these, the subfamily Schizothoracinae could serve as a model species for assessment of thermal stress due to its ability to survive near-zero temperatures in streams of lesser and greater Himalayas. They have evolved analogously to resemble trout, hence popularly known as snow trout (Kapila et al. 2002; Sharma et al. 2021a). *Schizothorax richardsonii* (Gray, 1832) is an endemic freshwater fish inhabiting rivers and streams of the Himalayan and sub-Himalayan regions in South Asia, Nepal, Bhutan, India, and Pakistan (Agarwal et al. 2009; Sarma et al. 2018; Agarwal 2019; Das et al. 2019; Fricke et al. 2023). Several taxonomical uncertainties lead to unreliable estimation of the location-specific distribution of this species however, the morphometric and molecular analyses based on complete mitogenomes analysis (Zhang et al. 2016) may serve as a probable taxonomic tool for the identification and classification of *S. richardsonii* (Shabanum & Dhanze 2016).

In the Himalayan riverine systems, the species

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richness of the fish is influenced by physicochemical and variable factors like velocity, temperature, water discharge (Oberdoff et al. 1995), numerous anthropogenic threats, and climate change (Nag & Bhatacharjee 2002; Gupta et al. 2017). Intense human intervention has resulted in habitat loss and degradation of the freshwater ecosystem thus affecting the fish species, especially in regions with high water demand (Sarkar et al. 2012). Also, the introduction of exotic species intensifies the significant loss of the species with irreversible changes in its natural population (Dudgeon et al. 2006). As a consequence of unnatural deaths, *S. richardsonii* has significantly declined with other 4.27% of cold-water fish species (*Cyprinion semiplotum, Botia rostrata, Aborichthys boutanensis*, and *Pseudecheneis sirenica*) and falls under the vulnerable category of the IUCN red list (Sharma 2019; IUCN 2020; Dey et al. 2021). The reassessment of the conservation status of the *S. richardsonii* is critically important as it is getting co-evolved with changing patterns of the Himalayan geomorphology (Sharma et al. 2021a). Thus, it leads to a continuous struggle for policymakers to design targeted and site-specific conservation plans for snow trout. Although, various protection amendments for freshwater biodiversity have been implemented at the global level (Linke et al. 2012; Heino et al. 2016). Here, much literature has been cited in order to dig out the ecology, biology, conservation, and population dynamics of *Schizothorax richardsonii* raising a huge concern for the conservation of this species before it becomes 'endangered'. There are several ongoing researches in the field of aquaculture explaining the morphology, biology, fishery, and culture of *S. richardsonii*, but in order to promote sustenance and conservation, a consolidated review report needs to be amended. In this review, we have briefly highlighted the habitat, geographical distribution, feeding habits, migratory patterns, reproduction, commercial exploitation and also emphasized on its vulnerability (Fig. 1). We have also discussed briefly the life history of snow trout that can be associated with population losses and vulnerability of the fish and several new threats that have emerged and are likely to jeopardize the future survival of this important fish species.

Taxonomy: There are 15 genera in the sub-family Schizothoracinae (family Cyprinidae) with a total of 100 species and 63 valid species under the genus Schizothorax (Zhang et al. 2018).

From Central Asia, 34 species have been reported, out of which 28 species of *Schizothorax* are found in the Indo-Himalayan region (*S. richardsonii, S. curvifrons*, *S. esocinus*, *S. kumaonensis, S. hugelli*, *S. labiatus*, *S. longipinnis*, *S. micropogon*, *S. molesworthi*, *S. nasus*, *S. niger*, *S. planifrons, S. plagiostomus*, *S. sinuatus* and *S. progastus*) (Misra 2003). On the basis of panoramic study of morphological datasets, currently Schizothoracinae is prorated into three divisions as 1) The primitive group (genera *Aspiorhynchus* and *Schizothorax*) 2) specialized group (genera *Diptychus, Gymnodiptychus,* and *Ptychobarbus*) and 3) highly specialized group (genera *Chuanchia, Gymnocypris, Herzensteinia, Oxygymnocypris, Platypharodon,* and *Schizopygopsis*) (He et al. 2004).

The classification of Schizothoracinae and the taxonomical status and evolutionary lineage of the genus *Schizothorax* is dubious (Jhingran 1991; Ahmed et al. 2014). This genus comprises of a collection of species that share a striking degree of morphological similarity and are frequently quite challenging to differentiate purely on exterior morphological characteristics (Chandra et al. 2012). The amalgamation of conventional taxonomical methods (morphological and osteological characters) and recent amelioration in DNA barcoding has paved the way for in-depth examination and identification of fisheries worldwide (Ward et al. 2005; Bhattacharya et al. 2016). Researchers have employed critical analyses of both *Cyt b* (Cytochrome b) and *COI* (Cytochrome oxidase subunit-1) sequences to clarify the molecular diversity of genus *Schizothorax* (Chandra et al. 2012; Akhtar et al. 2016; Shen et al. 2019; Ma et al. 2020).

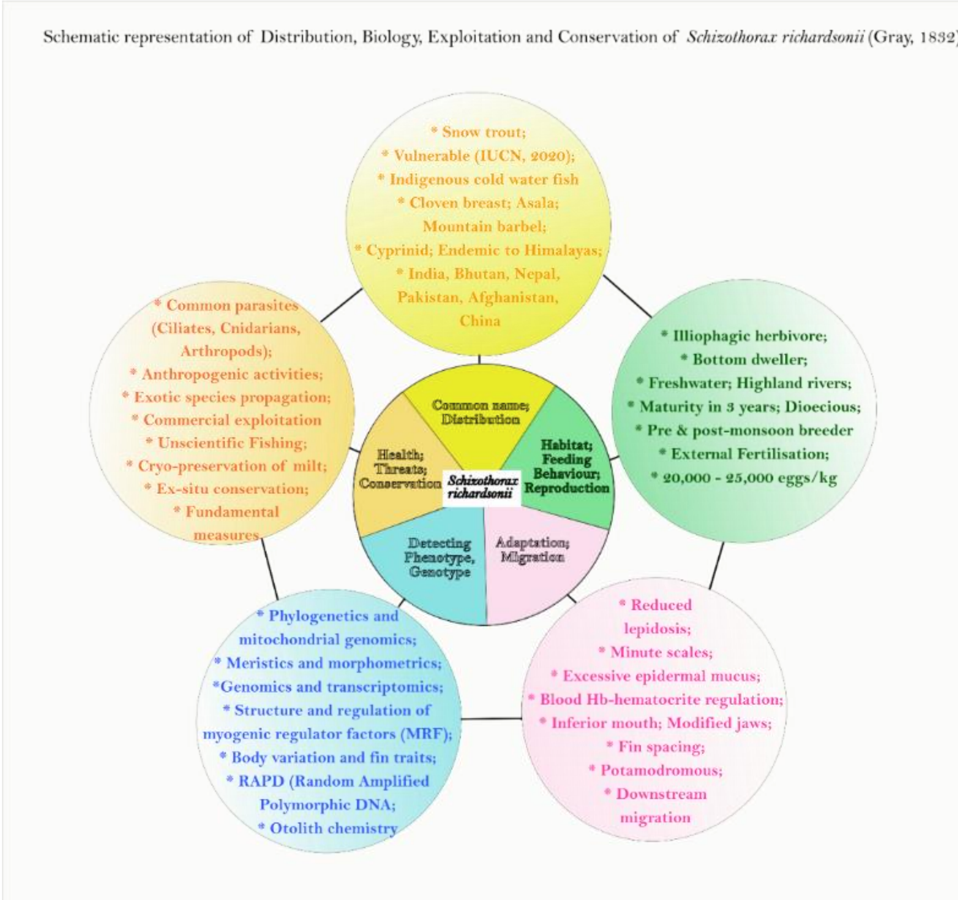

Fig.1. Brief summary of general biology, geographical distribution of Schizothorax richardsonii (Gray, 1832).

Chandra et al. (2012) found high genetic divergence across species and low genetic divergence within species, proving the effectiveness of *COI* barcodes for molecular characterization of *Schizothorax* species. 17 *Schizothorax* specimens from Neelum and Jhelum Rivers, Pakistan was molecularly identified based on *COI* (Akhtar et al. 2016). Recently, Ma et al. (2020) employed *COI* geneto successfully identify 185 specimens belonging to 11 *Schizothorax* species and Cyt. b gene to identify 264 specimens belonging to 23 *Schizothorax* species. Further, the taxonomic discrepancies, existence of cryptic lineages, and the emergence of new species in the genus *Schizothorax* can be resolved by examining genetic divergence between sequences and performing phylogenetic analysis (DeSalle et al. 2019).

Morphology: This fish species have a streamlined body covered with minute scales. The skin is smooth and soft to enable cutaneous respiration. Snowtrout possess blunt head with wide and levelled interorbital space and two pairs of barbels (Sharma & Mehta 2010). The pharyngeal teeth are arranged in three rows (4,3,2/2,3,4) and the lips are keratinised (Pandey & Nautiyal 1997). The inferior mouth is shorter than the upper jaw with a band of hard papillated adhesive organ. Adhesive organ is composed of keratinized epidermis cells (Das & Nag 2008) and aid in adhesion to rocky substrates. This keratinization of the peripheral row cells of adhesive organ might protect this structure against mechanical damage. The peripheral epidermal cells are made up of tonofilaments and mucous granules and the callus forms cavities encircled by tuberculated borders which support adhesion. The pectoral fins are shorter than the head and dorsal fin arises at pelvic fin anteriorly. The dorsal spine is serrated, strong and bony at the posterior end. On either side of the vent and anal fin, there is a sheath formed of tilted row of scales (Sharma & Mehta 2010).

Distribution in India and neighbouring countries: From the late Miocene epoch, a series of geological events have diversified and expanded the speciation of the genus *Schizothorax* Heckel, 1838 from its primitive ancestors and localized them in the great Himalayas with a very wide distribution. Since then, *Schizothorax* is the most dominant genus in the family Cyprinidae, inhabiting streams and rivers in the Himalayan and sub-Himalayan regions. Its distribution has been reported from India, Bhutan, Nepal, Pakistan, and Afghanistan. The Himalayan mountain range extends up to a 2400 km long arc from east-southeast to west-northwest (Wadia 1931). The westernmost ranges are distinctly bounded by the river Indus, the easternmost is demarcated by the Brahmaputra, and the north and south are the lower limits of Gangetic plains (Goswami et al. 2013, Sharma et al. 2021a). *Schizothorax richardsonii* distribution has been reported from Central, Eastern, and Western regions and also extends from Northwest Himalayas to Northeast Himalayas (Sehgal 1988; Shrestah 2002). Snow trout is regarded as a potential model organism to study climate-induced changes across the Himalayan riverscape as it has co-evolved with the changing patterns of the geomorphology (Sharma et al. 2021a). In a study, empirical findings revealed that snow trout would strongly persuade to mid elevated zones of the Himalayas due to climate-driven changes. Here, snow trout was found to be co-occurring with the genera viz., *Tor*, *Neolissochilus*, *Barilius*, and *Nemacheilus* (Majhi et al. 2013; Sharma et al. 2015). Recent reports predicted that in the near future, considerable range shifts and dramatic shrinkage in the population of snow trout could occur throughout the eastern Himalayas as compared to the western and central Himalayas reasonably due to the collapse of climatically controlled habitat (Sharma et al. 2021a).

Length-weight relationships (LWRs): The environment influences the length-weight relationship in fishes and these relationships are useful in differentiating small taxonomic units and computing the shift from the expected weight for the length of the fish as an indication of well-being of the fish (Chonder 1972). Researchers attempt to unveil the length-weight relationship and relative condition factor (Kn) to reflect the growth pattern of fish under study (Jhingran 1952). In the cases where the fish retains the same shape with constant specific gravity, it shows isometric (value of exponent 'b'= 3.0). A value less than 3.0 shows that fish becomes lighter and greater than 3.0 indicates heavier for a particular length as it increases in size (Wooton 1990). Particularly, the analysis of the length-weight data for *Schizothorax richardsonii* reveals that the value of 'b' is close to 3 and fish shows the isometric growth (Mohan 2006, Sharma & Dhanze 2010). In some recent studies, this fish showed negative allometric growth indicating a changing environment (Mehmood et al., 2021; Malik et al. 2021; Khanal et al. 2023). The intra-specific variation in the value of 'b' or 'n' is under the influence of several factors such as seasonal, physiological condition, sex, gonadal development, and nutritive condition of the environment. Furthermore, the 'Kn' value is a physiological indicator of the general well-being of any fish living in a given environment (Kumari et al. 2006) where 'K' value > 1 indicates that the general well-being of the fish is good whereas its values < 1 in some of the age groups indicate some issues in their habitat. In case of snowtrout, 'Kn' values have been reported almost constant and close to 1 in all size groups (Kumari et al. 2006; Sharma & Dhanze 2010; Neupane 2021).

Food and feeding habits: There are numerous studies indicating that the food habits of this species vary with the size and life cycle stages (Sehgal & Sar 1989; Sehgal 1990; Malik et al. 2018). In one of the tributaries of Ganga, and a few streams of Kashmir, the fish is a periphytic feeder, feeding on Bacillariophyceae (highly), Chlorophyceae, Cyanophyceae, detritus, and sand in this very preferential order and its diet is reported to have 75% plant matter and 25% of animal matter (Dipteran larvae, mayfly nymph, caddisflies larvae) (Shekhar et al. 2013; Koundal et al. 2016). Bacillariophyceae forms a major percentage of food throughout the year but decreases quantitatively during May-August whereas Chlorophyceae being the second major component of fish food increases quantitatively during May-August which may be due to the rise in water temperature and algal production (Shekhar et al. 2013). Apparently, feeding upon plants, aquatic insects, larvae, and nymphs results in alterations in the length of their gut during different stages of the life cycle i.e. longer in adults and shorter in juveniles (Koundal et al. 2013; Malik et al. 2018). The ventral position of the mouth is correlated with the bottom-feeding habit of the fish. With the help of a rasping mouth, it feeds on microbiota present on rocks and stones and on green and blue green algae.

In *S. richardsonii*, quantitative feeding in both sexes is low during monsoon and spring whereas to inflate the heat it is high in summer (May-June) due to high metabolism, rise in algal production, and allogenic inflow (Shekhar et al. 2013; Malik et al. 2018). Likewise, a slight increase in food intake during February-March and low quantitative feeding during April-May could be due to breeding (Jan et al. 1970; Jyoti & Malhotra 1975; Madhwal et al. 1984; Sunder 1985). After winter, the stimuli during the maturation of gonads and post-spawning activity increase the efficiency of the fish to build more energy reserves. A generalized picture that emerges from various studies indicates that values of the Enterosomatic index (ESI) and Gastrosomatic index (GSI) of this fish species are low while spawning and their index values increase during pre- and post-spawning periods i.e. June and October, respectively (Shekhar et al. 2013; Koundal et al. 2013; Malik et al. 2018).

Reproductive biology (Sexual dimorphism, Sex ratio, gonad maturity stages, spawning season, fecundity): Sexual dimorphism is quite evident where mature males are brighter in colour with straight ventral profile whereas mature females are with distended bellies (Ciji et al. 2021). During the initial growth phase, the ovaries are paired, flaccid, and translucent, but lately, in summers they become distended and fully matured with ripened ova (2.5-4.3mm) (Joshi 2004; Gandotra et al. 2009; Gandotra 2009). The quality of gametes and the activity of gonads are highly variable depending on multiple external factors such as feeding patterns and ambient temperature (Sabha et al. 2011; Bahuguna et al. 2011). The success rate of fertilization mainly depends on the qualitative and quantitative characteristics of semen (Bobe & Labbe 2010). The fish breed twice annually one with the onset of summer (April-May) in upstream water with a sudden rise in temperature (15-19°C) and the other during the monsoon (Sehgal 1988, Raizada et al. 1983).

Schizothorax richardsonii is characterized by slow growth and late sexual maturity in their surrounding rigorous environment (Chen & Cao 2000; Mohan 2005). Eggs are large-sized, laid in shallow pools, and remain attached to the substratum until the fry hatches. There is a linear relationship between the number of eggs and an increase in body length-weight or ovary's length-weight (Table 1) (Jan et al. 2014). In *S. richardsonii*, low fecundity was recorded within a range from 20,000-25,000 eggs/body weight (kg) (Shahnawaz & Pandey 2016). A long-term study was carried out from 1996-98 and 2016-19 that covered the fecundity rates of the *Schizothorax* during the timeline (construction to commissioning) of a hydroelectric power project at Uttarakhand, India. The study revealed a constant rate of fecundity and survival attributes due to its unique adaptive skills and shifting of the breeding grounds (Thapliyal et al. 2019).

Clear shallow water, gravelly sandy beds, with very feeble water flow are characteristics of spawning grounds of this species (Ali & Pandey 2016). There are studies exhibiting variation in the spawning cycles of *S. richardsonii*, describing its extemporary behaviour with respect to the water temperature, food availability, and photoperiodism (Bahuguna et al. 2011). Past studies showed that species spawn once or twice (April-May, July-August) or multiple times

Table 1. Intrinsic characteristics of *Schizothorax richardsoni.*

Species name	Geographical Occurrence (Himalayas)	(GSI) Highest-Lowest	Fecundity (eggs /g body weight).	References
Schizothorax richardsonii Growth (cm/year): 10.0-13.0 Size (cm): 13.0-16.0 Maturity age(year): 2-3 years	Throughout the Himalayas	-	25.0-80.0	Basavaraja (2007); Bhatt & Pandit (2016)
	Kashmir	-	2600-16605	Das & Koul (1965)
	Kashmir	-	6720- 27500	Rampal (1967)
	Sindh Nallah, Kashmir	-	2598-27312	Mir (1979)
	Alkananda from Garhwal Himalayas	Sep-April	3832 -5310	Misra (1982); Joshi et al. (2016)
	Sindh and Telbal Nallahs	-	2598-27846	Qadri et al. (1983)
	Garhwal region	Jan-Oct	1578-14316	Badola & Singh (1984); Baloni & Tilak (1985); Thapliyalal et al. (2012)
	Neeru Nallah, Bhadarwah	-	970-6035	Shekhar (1990)
	Kumaon river	-	8216-48490	Singh (1990)
	Kumaon river	-	1311-12702	Bhatt & Pathak (1992)
	River Gaula, district Kumaon,	July-Oct, Jan-Feb	2248-8726	Mohan (2005); Roy (2011)
	Rajouri district, J&K		3032-13321	Gandotra (2009)
	Nallu River, Lalitpur District	Sept – Nov, May	6294 to 67083	Wagle (2015)

depending upon different environmental conditions and elevations of the rivers/streams (Bishat & Joshi 1975; Jhingran & Sehgal 1978). The spawning season is determined on the basis of gonadosomatic indices (GSI), ova diameter, occurrence of brooders, eggs, and larval stages in the spawning grounds. In elite cases, the species have the ability to regulate their spawning season through migratory patterns due to dramatic changes in the thermal regime of each drainage and flood conditions created in mountain streams due to snow melting (Singh 1990; Bhatt & Pathak 1992; Rai et al. 2002; Joshi 2004). The antagonistic relationship between spawning and gonadotrophic hormones reported earlier stated that there is a decline in the levels of spermatocrit and sperm density with the onset of spawning in these fishes (Agarwal & Raghuvanshi 2009; Ciji et al. 2021).

Migratory patterns: The snow trout has potamodromous migratory behaviour and its exact migratory distance is yet to be ascertained. In rivers like Beas and Sutlej, *S. richardsonii* undertakes long-distance upstream migration from the Greater Himalayas to the Sivalik regions as it prefers underground water for spawning (Rai et al. 2002). However, in the upper Beas, the species spawns in monsoon when the water temperature is warm enough and continuously migrates downstream to spawn during winters (Petr et al. 2002). When the temperature increases in the summer and dissolved oxygen decreases, snow trout cannot be collected at lower elevations while in the winter season, it has been recorded from the same stream sites. So, the fish spend most of their life span in the upland waters but migrate downstream for breeding, feeding, and spawning during over-wintering, intense human intervention, and natural disasters (Jackson & Marmulla 2001).

Acclimation regimes: This species is specialized for the torrential streams and has co-evolved with the changing patterns of Himalayan geomorphology. The thermal range reported for Indian snow trout ranges from 0-27 °C (Sharma & Mehta 2010) and the fluctuations in ambient temperature are responsible for influencing the spawning, ovulation, body morphology, and hematology (Qadri et al. 1983; Kapila et al. 2002). Due to remarkable uniformity in the body contours, *S. richardsonii* thrives well in the shallow zone of the fast water currents exhibiting greater variability corresponding to environmental fluctuations (Negi & Negi 2010; Shekhar et al. 2013; Wagle 2014). Lack of lipidosis on the ventral side of the body, reduced scales, and horizontally placed paired fins provide adhesion against the substratum for feeding (Das & Nag 2008; Sharma 2010; Hayden et al. 2014; Singh & Bisht 2017). The feeding structures of *S. richardsonii* including epithelia of the lips, rostral cap, adhesive pad, and lower lip undergo modifications to form keratinized, hard and sharp edges on the labial plate that confers the adaptation for its herbivorous mode of feeding (Singh et al. 2014; Koundal et al. 2016).

Habitat monitoring experiments suggested that the species could survive from hypoxia in winters, as the lowering in blood haemoglobin-haematocrit levels could limit the oxygen carrying capacity, with probable reciprocations in aerobic metabolism and thermal tolerance (Kamalam et al. 2019). The tolerance levels of fish undergoes irreversible and reversible changes with life stages, seasons, acclimation regimes, and nutrition conditions (Beitinger & Bennett 2000; Wagle 2015; Joshi et al. 2017). *Schizothorax* has survived through the evolutionary age of the Himalayas due to its adaptive skills and has acquired characters making it suitable for living in the fast-flowing and torrential hill streams (Rajput et al. 2013). Thus, snow trout has a great adaptive capacity to grow and reproduce in fast-flowing torrential river systems (Wagle 2015).

Phenotypic and genotypic provisions: By modification in the physiology and behaviour of snow trout, adaptive response to environmental change is allowed by the phenotypic plasticity of this fish which leads to changes in their morphological features, reproduction, or survival that moderate the particular effects of environmental factors like temperature, water current velocity, and latitude (Meyer 1987). For stock identification, many tools like meristic, morphometric, parasites as natural tags, traditional tags, otolith chemistry, molecular genetics, and electronic tags have been used (Negi et al. 2015; Regmi 2019). The different environmental features of habitats including water depth, temperature, velocity, and availability of different substrates affect the morphological features of inhabitant fishes (Rajput et al. 2013). Fin size and body shape specifically are two imperative morphological characters that contrast greatly in lentic vs. lotic habitats (Douglas & Matthews 1992). Due to its presence across a broad range of physico-chemical stream conditions, with a wide range of environmental and physiological tolerances, snow trout is a habitat generalist (Rajput et al. 2013).

The mitochondrial genome of *S. richardsonii* is 16,592 bp in length and comprises 22 tRNAs, 2 rRNA genes, 13 protein coding genes, and one putative control region, which consists of a microsatellite; $(TA)_{13}$ that exists between 16,469-16,494 bp (Goel et al. 2014). Recently, Next Generation Sequencing technology has become a tool to study the genetic behaviour of the fish species in response to their environment (Talwar et al. 2018). With the help of RNA sequencing of the liver tissue of the snow trout, a reference transcriptome database has been generated using Illumina HiSeq 2000 platform. Annotated blast matches revealed that differentially expressed transcripts correspond to critical chaperones and molecular pathways, previously shown to be important for thermal stress in other fish species (Barat et al. 2016). The transcripts identified as solute carrier transporter genes are categorized under 13 different protein families that play an integral role in cellular acclimation response (Barat et al. 2019). Slow growth in this important Himalayan cyprinid can be deciphered by the molecular characterization of the structure and regulation of the myogenic regulatory factors (MRFs; *myod*, *myf5*, myogenin *(myog)*, *myf6/herculin/mrf4*) as through the processes of cell determination and differentiation, MRFs play an important role in muscle growth (Rajesh et al. 2019).

The complementary study of phenotypic and genotypic variations can serve as an attempt at stock assessment of snow trout for rational exploitation, conducting conservation, and sustainable management measures. In a study to understand the environmental impact of the morphology of *S. richardsonii*, strong correlations were suggested between environmental and morphological features (Rajput et al. 2013). The different body and fin traits in snow trout are shown to be adapted for a specific habitat and also a negative correlation between body size and fin morphology has been suggested (Rajput et al. 2013). The relationship between AFL and A-CFBL (anal to caudal fin base length) in the species under investigation was found to be a significant feature as relatively smaller AFL and longer A-CFBL in *S. richardsonii* serve to distinguish it from *S. plagiostomus* (Pandey & Nautiyal 1997).

A more detailed analysis of multiple morphometric characters showed that characters such as standard length and pre-anal distance correlate with the total body length while dorsal fin and depth of anal fin correlated least with the total body length in a study conducted on samples collected from River Yamuna of the Uttarkashi district of Uttarakhand, India (Negi & Negi, 2010). They also showed that characters such as standard length, predorsal distance, preventral distance, preanal distance, maximum body depth, minimum body depth, caudal peduncle length, head length (HL), head width, pelvic and anal fin, pectoral, pelvic (ventral) increase in direct proportion with each other. On the other hand, postorbital distance and head depth are shown to highly correlate with the HL while eye diameter correlates least with the HL in snow trout (Negi & Negi, 2010). These morphometric characters are often categorized into genetically controlled (minimum variability), environmentally controlled (maximum variability), and intermediate characters (slightly controlled by environment). A number of morphometric characters that included HL, pre dorsal distance (PrDD), post dorsal distance (PoDD), depth of anal fin (DAF), length of anal fin (LAF), depth of dorsal fin (DDF), length of dorsal fin (LDF), length of pelvic fin (LPF), length of caudal fin (LCF), distance between pectoral and pelvic fin (DPP), maximum body depth (MBD), Minimum body depth (MiBD), head depth, eye diameter, pre-orbital and post orbital distance stated that 90% variation in morphometric characters of this species populations from Uttarakashi, India are genetically controlled opposing the fact that the maximum no. of morphometry are environment-biased (Negi & Negi 2010). Even the intraspecific variation investigation of the *S. richardsonii*, established on the basis of morphometric characters from rivers in the Western and Central Indian Himalayas displayed significant phenotypic heterogeneity which could be due to the local ecological conditions (Mir et al. 2013). Furthermore, the variation in the morphometric characteristics was also measured by using the Wilks λ tests of discriminant analysis showed that there are noteworthy variations in morphometric characteristics among few inhabitants due to phenotypic plasticity in response to uncommon hydrological conditions like variation in alkalinity, temperature and closeness may be due to similar habitat attributes (Mir et al. 2013).

Using RAPD (random amplified polymorphic DNA technique), the genetic heterogeneity was found to be accelerated with respect to isolation and distance in sampling sites (Kapila et al. 2006). In a recent study, independent and dependent environmental variables were analysed using correlation coefficient and descriptive statistical parameters where the total length of fish species was high. Lohani et al. (2020) described the environmentally controlled variability in the specimens. So, the phenotypic and genotypic characters can provide insights in the phenotypic plasticity and conserved patterns of the fish species at the surroundings need to be studied throughout the time.

Concurrent pathogenesis: Very less information about interactions between *S. richardsonii* and

Table 2. List of ectoparasites and endoparasites known for their infection in various species of *Schizothorax*.

Species	Host	Site of infection	Locality
Myxobolus himalayaensis (Ahmed et al. 2019)	*Schizothorax richardsonii*	Gill filament	River Poonch (Madiana)
M. kashmirensis (Dar et al., 2017 b)	*Schizothorax esocinus*	Gills	J&K (India)
M. chushii (Dar et al. 2017 a)	*Schizothorax niger*	Gill lamellae	J&K (India)
M. nigerae (Dar et al. 2016)	*Schizothorax niger*	Gill lamellae	J&K (India)
M. linzhiensis (Li et al. 2017)	*Schizothorax oconnori*	Gill	China
Argulus spp. (Mallik et al. 2010)	*Schizothorax richardsonii*	Caudal and anal fins	Bhimtal (India)
Ichthyophthirius multifiliis (Mallik et al. 2015)	*Schizothorax richardsonii*	Dorsal body surface, caudal fins	Champawat, Uttrakhand, (India)

pathogens has been recorded, as a consequence, the concern for fish health remains subtle. There is a higher risk of diseases in cold water fish due to significant temperature fluctuations, which in the long run affects their population and diversity. A wide range of ciliates, cnidarians, and arthropods act as parasites that are responsible for a high infection rate and may increase the mortality of this fish species (Table 2) (Mallik et al. 2010; Ahmed et al. 2019). The majority of the studies have indicated that the known arthropod *Argulus* sp. commonly called as fish louse have become a major threat for the health management and aquatic crop production for fish in tropical and temperate regions. This ectoparasite mainly infested inland capture and culture fisheries of cyprinids, as temperatures of these water bodies provide an optimum environment for its life-cycle (Mallik et al. 2010). In *Argulus* infestation (Aurgulosis), the mortality due to re-infection increases, reportedly in 2008, stocks found to be infested due to secondary infection of this ectoparasite which became a major cause for low productivity of *S. richardsonii* and *T. putitora* in Uttrakhand, India. The infected *S. richardsonii* was recorded 51.2 %, whereas abundance and mean intensity of infestations were 1.05 and 2.06 respectively and the maximum prevalence (70.1%) was observed in September with the least in December (Mallik et al. 2010). Similarly, the endoparasite *Myxobolus* sp. causes necrosis, hyperplasia, and hypertrophy in the plasmodia of type FV2 of gill filament in its host fish species snow trout (Ahmed et al. 2019). *Myxobolus* sp. infection was examined in *Schizothorax richardsonii* with a prevalence of 26.25%. Further, investigation of a temperature-dependent ciliate parasite, *Ichthyophthirius multifiliis* that causes pinhead sized white spots (0.4-0.8mm) on the dorsal body surface and caudal fins of this fish species was reported (Mallik et al. 2015). Temperature-dependent infection pattern was noted with the maximum prevalence of 84.8% in month of July. Recently, a parasite *Saprolegnia parasitica* was isolated and identified from infected eggs and adults that was mutually present with *S. australis* in early stages of snow trout (Jen 2008). Another pathogenic bacterial sp., *Aeromonas hydrophila* is known to infect the hematopoietic tissue in spleen and kidney in this fish species (Uzma et al. 2020).

Fish species are known to harbour anti-microbial peptides (AMP) within the gut, as these AMP-like molecules enable the host's innate immune system to suppress various infectious microbes mainly bacteria and viruses. In 2014, hepcidin-like anti-microbial peptide was amplified, cloned and characterized exclusively from *Schizothorax richardsonii* which was found to be different from other cyprinids with a unique amino acid (Gln^{30}). The AMP molecule reported for its significant role in functioning of permeability of membrane molecules and thus enabling microbial retention (Chaturvedi et al. 2014).

Threats: Among all the taxa, endemic freshwater fish species are the most vulnerable throughout the world due to intense human intervention in freshwater riverine system (Magurran 2009, Sarkar et al. 2012). Habitat alteration by dams, unscientific methods of fishing, illegal boulder/sand mining, poaching, indiscriminate fishing and introduction of alien species are largely responsible for the vulnerability of *S. richardsonii* (Singh & Bisht 2017). From past few decades, the human population in Indian Himalayas has been increasing at faster rates, and the energy requirement and electricity building projects are being forced into the Himalayan landscape to meet the demands. The government of India has issued policies to exploit the riverine system of the Indian Himalayas, which is hypothetically proven to cause serious damage to biodiversity and changes in the ecosystem (Pandit & Grumbiene 2012). The causes of vulnerability have been poorly understood and have not been regulated yet and thus the effects of threats cannot be addressed (Richter et al. 1997). An array of various factors such as habitat loss, habitat fragmentation, and overenthusiastic collection have increased the risk of extinction for this fish and many other fish species (Dudgeon et al. 2006). Certain favourable parameters of Himalayan rivers such as the perennial flow of streams, steep gradients and stable rock banks are projecting them for hydro-electricity development thus posing the ecological assets and aquatic resources including fisheries under severe threat (Joshi et al. 2017). Here, the extensive construction of dams and inappropriate regulation of the riverine system in the Himalayas, caused a decline in the species richness and altered the rates of fish diversity by hampering fish migration (Agarwal et al. 2009; Pandit & Grumbine 2012; Mali & Chutia 2017; Bhatt et al. 2017; Singh 2018; Agarwal et al. 2018). In a few cases, the hydro-power built over Chenab rivers in the central Himalayas, has demolished their natural habitat by blocking the migratory routes of the snow trouts sp. (viz. *Schizothorax richardsonii*, *Schizothorax plagiostomus*, *Schizothorax curvifrons*) (Agarwal 1996, Agarwal 2001). Also, the increased siltation at bottoms in Pong Dam reservoir has affected the downstream fishing and also the catch percentage has been diminished specifically for *Schizothorax richardsonii* (Gray) (Sharma 2018). In Nepal, the Indrasarobar reservoir was formed by damming the Kulekhani River as part of long-term hydroelectric power dvelopment which led to diversion in the fish species composition and rapid decline in snow trout (Swar 1990). In spite of being a prime rheophilic species, *S. richardsonii* (Sharma et al. 2021b), has still not been considered while designing the dams in basins like Parvati, where flow fluctuations act as chief stressors for the native snow trout (Johal et al. 2021).

The unscientific methods used for fishing i.e., bleaching powder, insecticides, dynamiting, hammering and electric current are responsible for the mass mortality of all sizes of fish (Badoni et al. 2018). The introduction of alien species is one of the major threats to native fish populations. Common carp, introduced in the Kashmir has almost exterminated the indigenous schizothoracids of the Valley (Agarwal 2009). Likewise, the acceptance of brown trout as a sport fish in the Himalayan region poses superfluous reproductive pressure on the snow trout that warrants quantification through future research (Sharma et al. 2021b). Also, a rapid deterioration in the catches of this species in the Himalayas as the result of predatory brown trout preying upon their younger stages (Raina and Petr 1999; Petr et al. 2002). Due to climatic change, S. richardsonii has been predicted to lose its habitat by 16% in the coming 30 years and around 26% by 2070. Moreover, the declines of snow trout in the Himalayan region are more than 90% in some areas and the overall reduction is inferred to be <50% with similar rates predicted in the future (Sharma et al.

2021a).

The extraction of boulders, cobbles, gravels, and sand from the river bed alters the stream morphology and is further responsible for the disturbance of the breeding ground of fish species (Hassan et al. 2017). Degradation of habitat, inhibition of spawning migration, and intensive fishing pressure population have led to the rapid decrease of snow trout (Bruton 1995). Reports indicating the dramatic decline in growth and population size of snow trout in Ladakh (Sivakumar 2008) and Kashmir in the last five years was due to very slow growth, low fecundity, and early maturity of the species (Mir et al. 2012). Slow growth to maturity and short growth period and are the main constrictions deterring its growth and population (Mir et al. 2012). The International Union for the Conservation of Nature and Natural Resources (IUCN) developed the major classification system internationally used for the assessment of the threat status to each species and snow trout has been given the vulnerable status (Vishwanath 2018; IUCN 2020). *Schizothorax richardsonii* is considered as vulnerable according to IUCN 2020 and needs urgent fortification and proactive conservation efforts prior to its complete disappearance in most of its range.

Conservation: Conservation involves social, political, and economic imperatives, modification, and maintenance of the genetic identity and integrity of the species in their natural habitat with genetically sustainable fishery (Margules & Pressey 2000; Lakra et al. 2007). The conservative measure entails the identification and protection of important river stretches in the Himalayas that constitute crucial habitats of snow trout for conservation and restoration. These measures need to follow regulations established by state environmental authorities, ecologists, local communities, and conservationists. Instead, lack of management leads to various constraints such as the construction of dams, and commercial exploitation that were followed up irrespective of these integrated approaches. Till records, over 292 dams are commissioned or proposed in Himalayan rivers which is a prominent habitat of snow trout (Pandit & Grumbine 2012). The dam constructions have led the distribution of snow trout to a very restricted area occupancy, moreover directed them to shift their habitat to mid-level altitudes. In the aquatic realms, snow trout is subjected to several biogeographical constraints such as physiographical barriers as well as by dendritic arrangement of riverine ecosystems (Rodriguez 2002; Olden et al. 2010; Singh 2019). The limited adaptability to human-intervened habitats and food resources could be the critical assessed factors that can hamper the population of snow trout in the Himalayas. Practically, the generation of vulnerability of this species could be avoided by conserving the habitats of native species before they become extinct (Moyle 1995). The availability of resources for conservation is very limited and needs to be rationally allocated (Sarkar & Bain 2007). Actions needed for the conservation of snow trout require site/area protection, resource, and habitat protection, habitat management, invasive species control, species recovery, species reintroduction, ex situ conservation, formal education, awareness, communication, and legal policies. Earlier, few policies have been implemented such as Ecosystem-based fishery management (EBFM) supporting fisheries by addressing some of the unintentional consequences of fishing such as destruction of habitat, mortality of non-target species, and variations in the structure and function of ecosystems (Pikitch et al. 2004). In high-altitude regions of the Himalayas and Peninsula, the taxonomic study of all commercial fish species such as mahseer, snow trout, and common carp will be essential prerequisite steps to any broad program of resource conservation with a full checklist indicating the status of each species (Mijkherjee et al. 2002; Talwar et al. 2020). The random fishing in the natural environment could compromise the structure and function of the ecosystem if achieved without disturbing biodiversity. In order to balance both quantitative and selective fishing, the productive capacity of resources for the snow trout must be increased (Zhou et al. 2010). In 2012, the Wildlife Institute of India suggested terminating a number of hydropower projects/dam construction to prevail in biodiversity conservation and management in the Himalayas. Very few commissioned projects were accepted with strict guidelines and regulations mainly including the reduced water flow speed (Rajvanshi et al. 2012). Research regarding population size, distribution and trends, life history and ecology, harvest, use, and livelihoods is needed for the conservation of snow trout. The river reaches, terrestrial protected areas that are managed by local stakeholders can act as management tools for biodiversity conservation as they have the potential to safeguard fish species (Gupta et al. 2015). During these studies, it has been found that encouraging vegetation throughout the streams has a greater impact on water alkalinity that is compatible with fish growth and survival. Likewise, some patches can be declared as sanctuaries by the Fishery Department to protect the fauna and the fish must be covered under the Schedule list of the Wildlife (Protection) Act (1972) (Sarkar et al. 2008; Raut et al. 2019). The biotechnology tools may establish completion of future demands that succeed with cryopreservation of brooders milt and introducing native population into the hatchery for artificial breeding (Agarwal et al. 2009; Rathore 2016; Hagedorn et al. 2018; Singh 2019) and stock protection from being totally eliminated due to natural disaster, sudden outbreak of disease, over exploitation, etc. (Agarwal 2011). Also, the technology of artificial fecundation of pond-raised brooders and rearing of young ones in controlled conditions has been developed at research institutes (Singh 2016). In Indian cold-water fishes, induced spawning is difficult but artificial fertilization can be achieved by stripping mature brooders. A detailed study and extensive research must be performed before introducing any exotic species as it is reported that these species could challenge the lifestyle of native species and affect their abundance, in reality, the snow trout could be pinned down in competitive limits of the natural habitat (Raina & Petr 1999). To achieve protection goals and for the conservation of aquatic ecosystems, the main challenge is the creation of markets wherein the value of fish killed is lower than living fish for consumption or sale where this outstrips sustainable limits (Everard and Kataria 2011). To restore this fishery, the first initiative for artificial propagation was attempted in Kashmir, and success was achieved in obtaining pure and healthy seeds of different species such as *Schizothoraichthys niger*, *S. esocinus*, *S. curvifrons*, *S. micropogon* and *Schizothorax richardsonii* through artificial fecundation (Joshi 2001; Sarma et al. 2018).

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مقاله مروری

آرایه‌شناسی، پراکنش، زیست‌شناسی و حفاظت گونه آسیب‌پذیر قزل‌آلای برفی، *Schizothorax richardsonii* (پرتوبالگان: کپورماهیان: خواجو ماهیان)در مناطق هیمالیا و زیرحوضه آن: مروری

میقالی بهاراتی[1]، شکر نگار[1،2]، پانکاج یاداو[1]، سنها سیواچ[1]، پادما دلکار[1]، شیتل یاداو[1]، سوناکشی مودل[1]، تارانا نگی[3]، رام کریشنا نگی[1*]

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چکیده: ماهی‌ها جزء مهمی از محیط آبی هستند و در حمایت و حفظ کل سیستم اکولوژیک حائز اهمیت هستند، در نتیجه سیستم‌های آب شیرین را انعطاف‌پذیرتر و پایدارتر می‌کنند. ساختار جامعه ماهی به فعل و انفعالات زیستی و متغیرهای غیر زنده بستگی دارد. ساختار جوامع ماهیان وابسته به فعل و انفعالات زیستی و متغیرهای غیر زیستی است. طی ۵ تا ۱۰ سال گذشته، حامیان محیط‌زیست و ماهیگیران تجاری، به‌دلیل ورود گونه‌های غیربومی، سدسازی، فعالیت‌های انسانی، ماهیگیری غیرقانونی و صید بی‌رویه، کاهش شدیدی را در شیلات آب شیرین نشان داده‌اند. *Schizothorax richardsonii* یک ماهی آب شیرین بسیار ارزشمند است که در دامنه‌های هیمالیا حیات دارد. کاهش *S. richardsonii* در برخی مناطق هیمالیا بیش از ۹۰٪ است و کاهش کلی پیش‌بینی شده حدود ۵۰٪ با نرخ‌های مشابه عنوان شده است. با مقاومت در برابر متغییرهای زیستی و غیر زیستی، دامنه پراکنش این گونه در نقاط مختلف از لحاظ ارتفاع از سطح دریا زیاد شده است و با توجه به تغییرات آب و هوایی در هیمالیا، دامنه گسترش در حال تغییر است و ظاهراً دامنه توزیع فعلی آن در طول زمان از بین می‌رود. در مناطق هند-هیمالیا، اقدامات حفاظتی وجود ندارد، در نتیجه، علی‌رغم اهمیت اکولوژیک، ماهی قزل‌آلای برفی براساس لیست IUCN 2020 وضعیت آسیب‌پذیری پیدا کرده است. هدف از این بررسی، ارائه زیست‌شناسی توصیفی و بحث در مورد تأثیر فعالیت‌های انسانی بر ساختار جمعیت ماهی قزل‌آلای برفی و حفاظت از آن است.

کلمات‌کلیدی: آبزی‌پروری، IUCN، ریخت‌سنجی، حفاظت.