9 Fisheries and Aquaculture of Snow Trouts in the Trans-Himalayan Region

Suresh Chandra and Parvaiz Ahmad Ganie

Abstract

The Himalayas play a vital role in the livelihood support of human beings, and the significance of efficiently conserving these diverse natural resources has long been well recognized and established. The trans-Himalayas are home to ten of the world's largest river systems and are widely acknowledged as a center for the evolution and diversification of a wide variety of life forms. Ecologically and economically, significant aquatic biodiversity is found in rivers, streams, and lakes, which feature diverse altitudinal geomorphologies. The Schizothroacinae family of fish, better known as snow trouts, is the most abundant cyprinid family in the mountains. These fish are highly sought after for both their food and esthetic qualities. These fish are primarily herbivorous and have evolved to thrive in rivers and streams that experience high levels of precipitation and flooding. *Schizothorax* spp. and *Schizothoraichthys* spp. are found at lower altitudes, while *Diptychus* spp. are found at slightly higher elevations. Adverse effects on crucial life cycle phenomena have been exacerbated by multiple anthropogenic and climatic uncertainties, leading to biodiversity depletion. Captive culture, breeding, and larval developmental studies have been attempted. However, the upscaling of aquaculture practices for these species is still in the infant stages due to slow growth. Prioritizing snow trout species mapping, in situ and ex situ conservation strategies, upscaling of sustainable culture and breeding techniques, long-term monitoring of cold-water resources, and strengthening location-specific legal frameworks are imperative to conserve this important fishery.

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Keywords

Trans-Himalaya · Fisheries · Schizothroacine distribution · Captive farming · Conservation

9.1 Introduction

The significance of conserving these diverse biological natural resources of the Himalayas or food has long been recognized. The trans-Himalayan region, also known as the Hindu Kush Himalaya (HKH), is spread across eight countries, viz., Bangladesh, Myanmar, India, Pakistan, China, Nepal, Bhutan and Afghanistan. Diverse geomorphology and rich aquatic resources with productive ecosystems are the characteristics of HKH uplands, and the well-being of hilly people primarily depends on the presence and availability of these precious resources (Molden et al. 2014). The extreme climate unpredictability and difficult topography contribute to the HKH's high levels of diversity. An amalgamation of several biophysical and geographic factors, together with altitudinal zonation all along a long and steep elevation slope with a prominent rain shadow zone on the Tibetan Plateau, has resulted to high levels of species diversity and richness (Myers et al. 2000; Sharma et al. 2010; Zomer and Oli 2011).

Plate tectonics, which are responsible for the formation of mountains, have allowed the development of a wide range of climates, ecological gradients, and physical habitats, which together play a role in the diversification of ecosystems (Hua 2012) and the subsequent evolution of their constituent species (Tremblay et al. 2015). Since this area coincides with two very different floras (Palearctic and Indomalayan), its significant diversity of species is the result of both localized speciation from local progenitors and migration of organisms from other regions (Olson and Dinerstein 2002). Dense population with ethnic multiplicity have contributed to the region's high levels of agrobiodiversity, farming system and agroecosystem separation, and domestication of many important food animals and plants, making it one of the productive and intensively cultivated mountain region (Pandit et al. 2014).

Indian cold-water/hill fishery resources are concentrated mostly in the Himalayan region which are suitable for food, ornamental, and sport fisheries. The trans-Himalayas, Greater Himalayas, Lesser Himalayas, and Siwaliks are four different parallel and longitudinal mountain belts (Fig. 9.1 and Table 9.1) that run from south to north and have their own unique physiographic features and geological histories (Sehgal 1999).

There are 19 significant rivers that flow out of the Himalayas. The longest of which are the Indus and the Brahmaputra. Of the remaining 17 rivers, 9 (the Yamuna, Ganga, Ram Ganga, Kosi, Kali-Sharda, Karnali, Rapti, Gandak, and Bhagmati) and 5 (the Indus system's Beas and Sutlej) drain about 150,000 and 80,000 km^2, respectively.

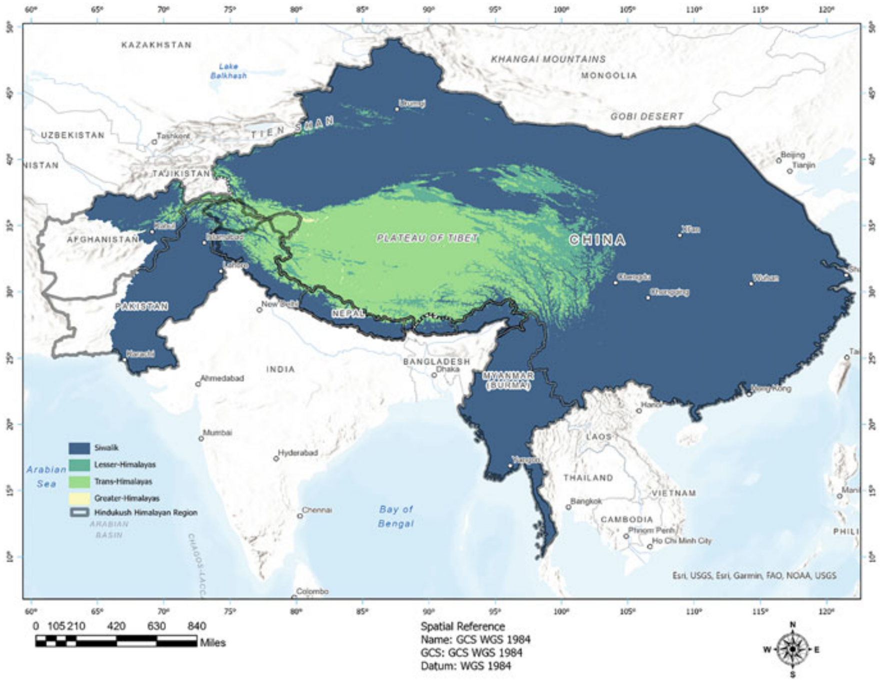

Fig. 9.1 Major Himalayan zones

Table 9.1 Major Himalayan region

S. no.	Division	Altitude	Area features
01	The greater Himalayas (Himadri)	Above 6100 m asl	Continuous and longest, mostly north part of Nepal and parts of Sikkim
02	Trans-Himalayas	Average altitude varies from 4500 to 6600 m asl	From west to east, stretches across the Himalayas
03	Lesser Himalayas (Himachal)	3700–4500 m asl	In the south and north of the Siwalik
04	Siwalik (outer Himalayas)	Average altitude about 900–1200 m asl	Siwalik is narrowest and lowest section of the Himalayas

(Source: Sehgal 1999)

These riverine resources are spread in about 12 states of India, from the north-eastern to northwestern Himalayan region and some parts of the Western Ghats. These rivers are home to a wide variety of fish species, which not only provide food and jobs for the locals but also offer plenty of adventure activities for tourists from near and far. However, a number of physicochemical, geochemical, and biological parameters of water, e.g., water temperature, dissolved oxygen, water velocity, turbidity, substratum, trophic status, food availability, etc., have an effect on the distribution and abundance of various species of cold-water fish (Sehgal 1988). Mostly, cold-water fishes are the natives of the Himalayan and sub-Himalayan regions (Sunder et al. 1999). According to Menon (1962), morphological adaptations let fish survive in the raging waters of the Himalayas. The Himalayan habitat has been recognized as an axis of origin and evolution of several biotic forms, since 17% of the total fish fauna of India has been reported from here (Ghosh 1997). Indigenous snow trouts mahseer, exotic trout, and common carp are among the economically important species found in the Himalayas' huge mountain fishery resources (Singh et al. 2014). Over 268 different fish species have been documented in the Himalayas.

9.2 Schizothoracinae Distribution

Schizothorax is a genus of cyprinid fish that was described by Gray in 1832. In the year 1838, Heckel made the initial discovery of the fish in Kashmir. Schizothoracinae, or "snow trout," are subfamily of the Cyprinidae that includes 10–13 genera and roughly hundred species (Mirza 1991). The physical characteristics of the schizothoracinae fish have led to their classification into three groups: the "primitive group," the "specialized group," and the "highly specialized group" (Cao et al. 1981). Primitive group includes *Schizothorax* and *Aspiorhynchus*. They share more characteristics with the outgroup *Barbodes hexagonolepis*, such as uroneuralia, three or four rows of pharyngeal teeth, reduced degradation of scales, and ambiguous special sexual dimorphism. *Ptychobarbus*, *Gymnodiptychus*, and *Diptychus* make up the specialized group. They are distinguished by the lack of uroneuralia, the presence of just one or two rows of pharyngeal teeth, and a considerable but moderate degree of degeneration of the scales. *Gymnocypris*, *Oxygymnocypris*, *Schizophygopsis*, *Chuanchia*, and *Platypharodon* are all members of a highly specialized group defined by the complete absence of barbels and scales and the presence of a well-developed canalis preoperculomandibularis (Qi et al. 2012).

Parallelly, Heckel (1938) first described the genus *Schizothorax* without assigning it a type. He divided these fish into three groups: A, B and C. The fishes that are distinguished by the presence of a strip of hard papillated structure at the lower jaw, chin, and mouth with a fine cartilaginous horny structure were classified in group "A." Both *Schizothorax plagiostomus* (Fig. 9.2) and *Schizothorax sinuatus* were included in this section. Groups B and C lack the strip of rigid, papillated tissue behind the chin. Without being aware of Heckel's publication, McClelland (1938) explained the fishes under a new genus called *Oreinus* with the species *Oreinus guttatus* (McClelland), *Oreinus richardsonii* (Gray), and *O. esocinus* in his monograph on Indian Cyprinidae. Misra (1962) proposed the genus *Schizothoraichthys* to encompass the species without a suctorial disc that Heckel (1938) had placed within the genus *Schizothorax*. *Schizothorax plagiostomus* and *Orienus guttatus*, according to Tilak and Sinha (1975), are the species with a sucker at the chin; the latter is a synonym of the former. They also backed Misra's (1962) assertion that fish without a

Fig. 9.2 *Schizothorax plagiostomus*

Fig. 9.3 *Schizothorax richardsonii*

hard strip of papillated structure at the chin are appropriately accommodated under a new generic name, *Schizothoraichthys.* The fish with a papillated strip of structure at the chin fall within the genus *Schizothorax*, which was also acknowledged by numerous other writers (Misra 1962; Menon 1971, 1974; Jhingran 1982). *S. richardsonii* and *S. kumaonensis* were both confirmed as two distinct species by Menon (1971). The genus *Oreinus* was reinstated by Talwar (1978), who also combined *Schizothoraichthys* with the genus *Schizothorax* and removed it from the synonymy of *Schizothorax* in 1839. According to Tilak (1987) and Talwar and Jhingran (1991), there are two species of *Schizothorax* in India: *S. richardsonii* (Gray) (Fig. 9.3) and *S. kumaonensis* (Menon). Small-sized head that is five times shorter than the average length distinguishes *Schizothorax kumaonensis* from *Schizothorax richardsonii*. The other genera of fish that include snow trout are *Diptychus*, *Ptychobarbus*, *Schizothoraichthys*, *Schizopygopsis*, and *Lepidopygopsis.* Menon (1974) listed 15 species within the Schizothoracinae subfamily and placed 2 species in the genera *Oreinus*, namely, *Oreinus richardsonii* (Gray) and *O. kumaonensis* (Menon), while placing other species under the genera *Schizothorax*. He also united the genera *Schizothorax* with *Schizothoraichthys*. Jayaram (1999) added *Gymnocypris biswasi* (Talwar) to the list of the 16 species that make up this subfamily. But according to CAMP (1998), this species was thought to be extinct.

The genus *Schizothorax* is mostly found at elevations ranging from 300 to 1820 m. This species has been found suitable for both the upper and lower reaches of a river. Snow trouts, also known as asla, are not only an important natural fishery

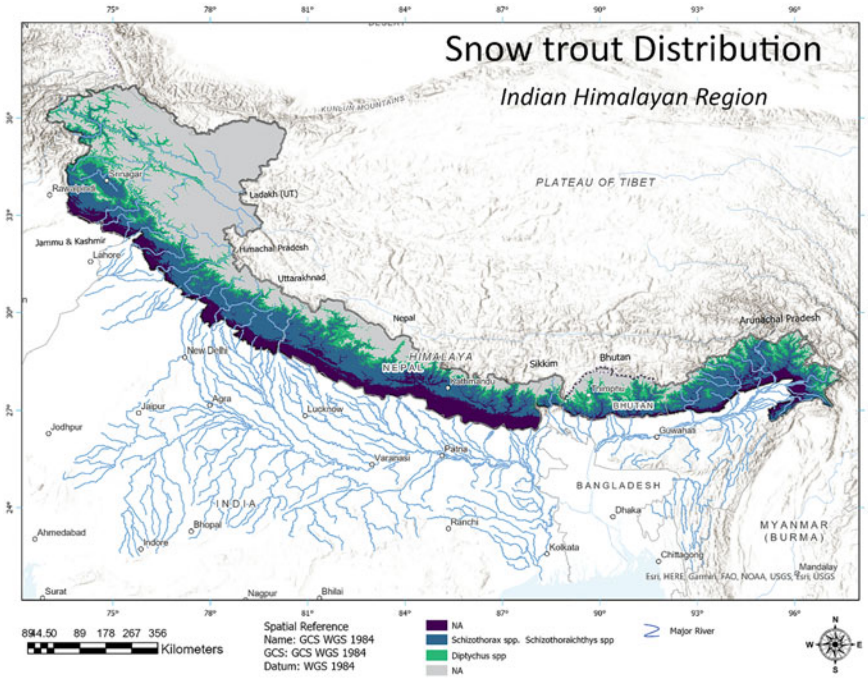

Fig. 9.4 Snow trout distribution in the Indian Himalayan region

in torrential streams, but they are also adapted to lentic systems as well (Sehgal 1988). The cold-water Schizothoracinae groups of fishes are soundly adapted to the Himalayan and Central Asian fast-flowing torrential rivers and streams. The *Schizothorax* spp. and *Schizothoraichthys* spp. are distributed in the regions having an altitudinal range of 750–2500 m asl, whereas the *Diptychus* spp. inhabit a slightly higher altitudinal range of about 2500–3750 m asl (Fig. 9.4).

Schizothoraichthys ecosinus, S. progastus, and *Schizopygopsis stoliczkae* occur in the upper reaches and are known as rheophilic species. In the intermediate hill regions, *S. longipinnis, S. planifrons, and S. micropogon* are common species. In lower altitudinal regions, *S. richardsonii* and *S. niger* are frequently found (Sehgal 1999). Snow trouts inhabit streams from Jammu and Kashmir to Nainital in India (Sundar and Bhagat 1979). According to Jhingran (1982), the distribution of this species ranges from Assam and the eastern Himalayas to Bhutan and Sikkim at elevations between 1100 and 3000 m. From 300 to 3323 m in height and 8 to 22 °C, it has been observed in rivers and lakes/reservoirs of Nepal (Shrestha 1981). The schizothoracine group of fishes has evolved a series of both morphological and physiological traits confined to regions at either high altitudes or high latitudes to adapt to the cold and hypoxic environment and plays important roles in the trophic web (Chen and Cao 2000). The snow trout is a unique fish to the Himalayas and can be found across the region's streams and lakes. It is frequently considered to be a sentinel fish species (Kapila et al. 2002).

Snow trouts have a disputable taxonomy as far as their classification is concerned (Day 1876; Tilak 1987; Wu and Wu 1991; Chen and Cao 2000). Researchers across the globe have documented different numbers of genera under this group. Sharma (1989) has documented 28 species of snow trout from the Himalayas and sub-Himalayas, which span China and Pakistan. Eleven species of snow trout have been identified in Nepal, belonging to three distinct genera: *Schizothorax* (two species), *Schizothoraichthys* (eight species), and *Diptychus* (one species) (Yadav et al. 2014). Tilak (1987) described 12 *Schizothorax* species from India. Nelson (1994) identified 13 subfamilies in Afghanistan and Pakistan. Twelve species belonging to six genera of schizothoracinae have been described from Pakistan: *Schizothorax* (02), *Schizothoraichthys* (05), *Schizocypris* (01), *Diptychus* (02), *Ptychobarbus* (01), and *Schizopygopsis* (01) (Mirza and Awan 1979). Nineteen species of Schizothoracinae have been recorded from Indian highlands, with only *Lepidopygopsis typus* (Raj) being endemic to the Western Ghats (Sunder and Joshi 2002).

As per www.fishbase.org (Fishbase n.d.), snow trouts are grouped into two subfamilies, viz., Schizothoracinae and Schizopygopsinae. The Schizothoracinae consists of 5 genera, viz., *Aspiorhynchus*, *Percocypris*, *Racoma*, *Schizopyge*, and *Schizothorax*, with a total of 69 existing species. Meanwhile, the Schizopygopsinae consists of 9 genera, viz., *Chuannchia*, *Diptychus*, *Gymnocypris*, *Gymnodiptychus*, *Herzensteinia*, *Oxygymnocypris*, *Platypharodon*, *Ptychobarbus*, and *Schizopygopsis*, with a total of 32 species.

9.3 Habitat

The predominant fish in the chilly waters of the hilly terrains is the snow trout (*Schizothorax* and *Schizothoraichthys* species) (Rajbanshi 2002). They thrive in the cold, hyperoxic waters of the hill streams and upland lakes of the Himalayan region and prefer higher altitudes. According to reports, the fish are a short and potamodromous and migrate for feeding and spawning. They move upstream in the summer to find a suitable breeding ground, temperature, and water current for laying eggs and then downstream in the winter months to cope with the sharp drop in water temperature and in quest of suitable food (Yadav et al. 2014). *Schizothorax* species acquire an adhesive organ for attachment in the swiftly moving water as a result of the biological conditions of the hill streams. In hill stream fishes, the anchorage mechanisms take the shape of real suckers, sticky organs with ridges and grooves, or irregular folds (Ojha 2002). In captivity, slow development patterns, a tendency to hide and prefer to take cover behind rocks or gravel, tolerance for a wide range of environmental fluctuations, and circular collecting in the middle of the bottom of ponds and tanks have all been noted. Additionally, despite the species' ability to survive a wide range of temperatures (0–32 °C), it favors snow-fed torrential streams and pools with temperatures between 8 °C and 22 °C (Sharma 1989).

9.4 Feeding Habits

Snow trouts are mostly illiophagic herbivores in nature because of their transverse inferior mouth position. The mouth is well adapted for scratching the periphyton and microbiota that mostly grows over the bottom rocks, stones, boulders, and other substrates. The schizothoracine groups of fish are mostly bottom dwellers. Blue-green or green algae and aquatic insects are predominantly part of its gut content. The early stages, like fry and fingerlings, are generally insectivorous and consume mainly the larvae of *Diptera*, nymphs of mayflies, and larvae of flies. The juveniles consume primarily diatoms, detritus, blue-green algae, and insect larvae. Bigger-sized fish subsist mainly on diatoms, blue-green algae, green algae, insect larvae, and detritus. While browsing the algae from the attached objects, they upturned their bodies, showing their shiner ventral portion in order to grab the algae forcefully. It is reported that change in habitat and husbandry alters the gut microbiota of snow trout and *Cetobacterium somerae* was abundant in wild stock while *Flavobacterium* and *Aeromonads* were dominant bacteria in captive *S. richardsonii* (ICAR-DCFR 2019). Intestinal enzyme profile of riverine *Schizothorax richardsonii* has also been studied to understand the food and feeding habit of the fish (Nilssen et al. 2015).

Food and feeding habits of *S. plagiostomus* have been studied by Jan and Ahmed (2019), and they concluded it to be benthic herbivore with diatoms forming the important constituent of the food. The food items mainly constituted of plant material (62.02%); mud, sand, and detritus (31.01%); and animal matter (6.07%). Sunder (1984) in his study on *S. curvifrons* reported that the gut composition is represented by sand and mud (17.51%), dissolved organic matter (40.33%), zoo-plankton (2.00%), phytoplankton (38.78%), and other miscellaneous matter (1.38%). In their study of the seasonal variations in the gut contents of *S. esocinus* and *S. curvifrons*, Kausar et al. (2012) found that the average percentage of vegetable substance, animal matter, unidentified animal matter, unidentified vegetable matter, and sand particles in the gut contents was 51.25%, 12.43%, 6.25%, 27.67%, and 2.695%, respectively. Sabha et al. (2017) discovered that *S. niger* was a herbivorous fish that mostly consumed green algae, plant fragments, diatoms, detritus, and unidentifiable stuff (scales of fishes, ropes, sand/silt). Detritus, plants that are adhering to rocks and stones (including algae), and the related invertebrate fauna for *S. niger* were all documented by Shaf and Yousuf (2012) from Dal Lake in Jammu and Kashmir, India.

9.5 Trial on Artificial Feeding

Trials undertaken at various farms showed that the bigger-sized fish in the size range of 36–140 g reared and domesticated in flow-through systems for 1 year efficiently consumed floating pelleted feed. The optimum feed intake was found to be dependent on the water temperature. Generally, from April onward, when the water temperature rises above 17 °C, the acceptability of feed gradually increases in captive condition. The optimum feed intake is found during April to September when the water temperature ranged between 17 °C and 24 °C. It has been reported that the feed intake gradually reduces in the winter months with minimal feed intake at the farm. Keeping boulders in raceways during captive rearing not only helps in the development of natural food in the form of periphyton but also provides shelters for the stocked fish. Compounded wet diets have also been tried with the agglomeration of ingredients like groundnut oil cake (20%), soya flour (38%), rice polish (20%), fish meal (20%), and vitamin mineral mix (2%), having crude protein of 35%, soaked in the water to make a small ball for feeding the stocked fish (ICAR-DCFR 2019). The role of vitamin C and *Achyranthes aspera* seeds enriched diets on growth, digestive enzyme activities, and expressions of genes has indicated significant growth in captive reared snow trout, *Schizothorax richardsonii* (Kumar et al. 2021).

9.6 Growth and Reproductive Biology

Regarding growth attainment in the wild, earlier reports indicated that *S . richardsonii* collected from the wild was up to 48 cm with a weight of 1.5 kg (Rajbanshi 1971), 60 cm (Talwar and Jhingran 1991), and up to 5.0 kg (Rai et al. 2002), but the information on the age of this species is lacking. Slow growth in captive conditions under different densities and attainment of maturity at a small size for *Schizothorax richardsonii* were identified as the major constraints (Agarwal et al. 2007; Negi and Negi 2010; Joshi 2006; Mir et al. 2013; Rayal et al. 2020). Compared to other snow trout species, *S. plagiostomus* attains a size of up to 60 cm of 2.5 kg (Raizada 1985).

The snow trout is considered a hardy fish, spawning easily in natural water bodies having a low flow rate. Snow trout generally attains maturity at an age of 3+ years. The breeding and spawning areas are characterized by shallow clear water and sandy and gravelly beds, with very feeble water flow. The mature female lays eggs in shallow pools (50–70 cm depth) and remains attached to the substrate till hatching stage (Sehgal 1988). Spawn of most of the schizothoracids can be observed in the creeks and seasonal tributaries, connecting the main lakes and rivers. The adhesive eggs are laid in the gravel of the pools or on the borders of the main streams. The vitelline membrane of large-sized eggs (3.0–4.0 mm in diameter) is completely filled with the yolk.

In the central Himalayan rivers, *S. richardsonii* usually spawns twice a year during July–October and February–May. However, in Himachal Pradesh, it has been reported that the fish breeds thrice a year during March, May–June, and October–November (Sarma et al. 1998). The batch spawning of *Schizothorax* spp. may facilitate in achieving better offspring survival (Lambert and Ware 1984; Bhatnagar 1964; Qadri et al. 1983). Jan and Ahmed (2019) reported that *S. plagiostomus* spawned twice in a year. The temperature of the water may be the most important environmental factor in synchronizing its breeding (Papoulias et al. 2006). In recent studies conducted at the ICAR-Directorate of Coldwater Fisheries Research (ICAR-DCFR), Champawat Center, fecundity of *S. richardsonii* was found in the range of 10,560 to 35,000/kg body weight with a male to female ratio of 7:3 (ICAR-DCFR 2019).

S. plagiostomus reaches sexual maturity at the size of 18–24 cm in length and spawns twice a year, i.e., in March–April and September–October (Raizada 1985). However, Jhingran and Sehgal (1978) reported that at different riverine elevations, *S. plagiostomus* spawned only once a year.

9.7 Artificial Breeding of *Schizothorax Richardsonii*

Significant success has been achieved in the breeding of farm-reared broodstock at ICAR-DCFR's experimental fish farm, Champawat, Uttarakhand, India (Fig. 9.5). Female brooders, collected from Sarju, Lohawati, Gaudi, Ladhiya, and nearby streams of Chhirpani, were stripped. The rate of fertilization ranged from 35 to 45% and the hatching rate was 60–75%. The overall survival from fertilized eggs to swim-up fry ranged between 20 and 30% and from swim-up fry stage to advanced fry was in range of 65–80%. Success in breeding and seed production of *S. richardsonii* has been achieved with pond-raised captive brooders. The broodstocks were fed with floating pelleted feed at 2–3% of body weight and reared in raceways with a stocking density of 4–6 nos./m^2. Maintaining a water flow rate of 20–30 L/min, monthly cleaning, and providing shelters in the raceways are found useful in attaining gonadal maturity of the stock (ICAR-DCFR, Annual report-2018-2019).

9.7.1 Stripping and Fertilization

For stripping, male and female brooders were selected from the raceways and brought to the hatchery. The dry method of fertilization was followed in the dark, without adding water. By gently pressing the abdomen from the pelvic fin area to the vent area, eggs were stripped. Well-matured eggs were yellowish to yellowish orange in color and uniform in size. A 100 g of fish will typically lay between 1200 and 2000 eggs; four to five females are used in each batch to achieve better breeding output. A similar method is used for the stripping of males for milt collection, avoiding blood and fecal contamination. The milt of two to three males was used for fertilizing the eggs of a single female to ensure superior fertilization. The milt and eggs were thoroughly mixed, and for activating the sperms, water was

Natural habitat of *S.richardsonii*

Captive rearing in raceways at ICAR-DCFR, Champawat

A Haul of snow trout brooders

Mature specimen of *S.richardsonii*

Stripping of eggs

Stripping of male fish

Mixing of gametes

Washing of fertilized eggs

Washed gametes

Incubation of eggs

Fig. 9.5 Captive breeding of *S. richardsonii* added. These eggs were kept in plastic trays for 10–15 minutes to harden. After proper cleaning and water hardening, eggs were transferred into hatching trays for incubation under flowing water conditions. Dead eggs were removed manually.

9.7.2 Incubation of Fertilized Eggs

At a water temperature range of 17–21 °C, the incubation period was recorded to be 5–11 days. The further development of newly hatched spawn to free swimming stage was temperature dependent, ranging from 5 days at 24 °C to 24 days at 12 °C (Fig. 9.6). However, also recorded were >90% at 20–24 °C, 65% at 17 °C, and <50% at 11–14 °C. The hatching rate was higher (50%) during October and November than during February and March (<25%). A low survival and a long incubation in running water conditions are mainly due to a slightly low water temperature during incubation of *S. richardsonii* eggs (Sehgal 1999; Joshi 2004).

9.7.3 Embryonic Development

The yellow-orange colored eggs after hatching develop into creamish-yellow colored sac fry, which are tender with a large yolk sac (Fig. 9.6). The length of the sac fry (alevins) varies from 7.5 to 9.5 mm. Appearance of eye spots and development of eyes started after 20–24 h of hatching, and black color melanin pigments are produced after 72 h of hatching. After the yolk sac absorption, the fry start exogenous feeding on a supplementary diet. Dorsal and caudal fin development begins on the fifth day after hatching, whereas paired and unpaired fins were completed between the 20th and 25th days (Joshi 2004). After complete absorption of the yolk sac, fry were reared in small troughs inside the hatchery, ensuring a running clean water supply. Hatching and rearing troughs were 40–50 cm wide, 20 cm deep, and up to about 2.5 m in length. During the incubation period, developing eggs were treated with formaldehyde for half an hour as a prophylactic measure to prevent the attack of fungal infections. The juveniles, after a rearing period of 1 month, were transferred to small nursery raceways of 30 m^2. The stocking rate may vary from 100 to 500/m^2. The water flow in the nursery tank is maintained at a rate of 20–25 L/min ((ICAR-DCFR 2019).

9.8 Health Issues in Captive and Wild Stocks

Although extensive studies on fish diseases have been made by a number of researches on important cultivable species, however, reports on fish disease incidences on *Schizothorax* spp. are meager. Attempts were made by ICAR-DCFR on captive rearing and other aspects. In captive rearing of *S. richardsonii*, fungal infection during post monsoon months, ulceration over skin due to argulosis in foot hill streams and lakes, white spot diseases, and monogenic trematode infection over

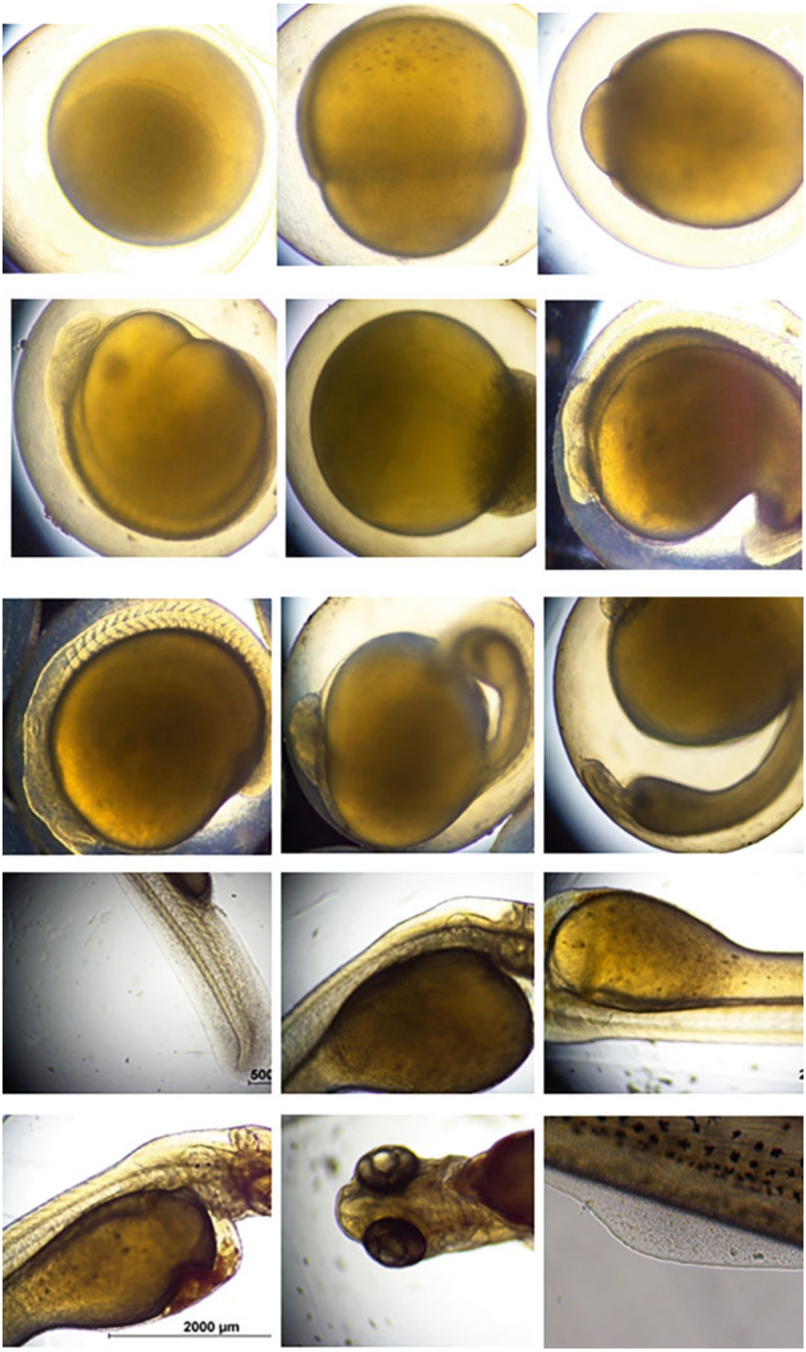

Fig. 9.6 Embryonic development of *S. richardsonii*

the gills have been observed. These parasites typically target the fins and skin, leaving infected fish lethargic and undernourished. Such cases were observed in the wild, mostly likely as a result of environmental pressures. In severe infection, large-scale mortality occurs. Among these, saprolegnia infections and argulosis in cage reared stock located in foot hill areas were common.

9.8.1 Fungal Infections

Frequent incidences of fungal infections are very common. Fluctuations in water temperature, high organic load, and impaired water quality are found to be primarily responsible for fungal infections. Fungal infections are typically secondary in nature, however, they were more prevalent when incubating eggs in cold water due to frequent temperature changes.

9.8.2 Argulosis

Schizothorax sp. has been found to be highly susceptible to argulosis infection (Figs. 9.7 and 9.8). The occurrence has been reported when water temperature ranged between 22.0 °C and 25.5 ± 1.5 °C in cage reared *S. richardsonii* and *S. plagiostomus*. Ulcerations over the skin with abnormal swimming, excessive mucus production, fin erosion, and inflamed skin wounds in body surfaces were observed (ICAR-DCFR 2021).

Fig. 9.7 Fungal infected *S. richardsonii* specimens

Fig. 9.8 *Argulus* sp. collected from infected cage reared *S. richardsonii*

9.9 Threats to Snow Trout Fishery

A region or nation's fish biodiversity has economic and aesthetic significance. However, in a changing environment, there are increasingly substantial risks to both biodiversity and the stability of ecosystems that are felt globally, necessitating the development of a number of strategies and goals. Aquatic resources are facing numerous dangers and are dwindling quickly, which is considered a sign of a global "biodiversity crisis" in freshwater (Abell 2002). The following are the main dangers to the Himalayan region's snow trout fishery:

1. The construction of small and big dams over significant rivers that are home to fishes in the schizothoracinae group threatens the survival of snow touts because dams impede fish migration in addition to causing mechanical harm to fish species. Additionally, the enormous amount of water discharged causes 100% supersaturation of the dissolved gas. When a large amount of water is released, there is strong aeration and high gas pressure at the dam site, which increases the likelihood of gas bubble disease in fish downstream.
2. One of the biggest dangers to endemic snow trout species has been the introduction of foreign species, particularly trout and Chinese carps. These outcompete the snow trouts for food and habitat owing to their resilient nature.

3. As a result of the effects of climate change and global warming, the climate in the Himalayan region is deteriorating, which is harming the region's natural aquatic systems. The pristine feeding and breeding sites of native cold-water fish species like snow trouts will be negatively impacted by the altered ecoclimatic conditions, having an impact on their population, maturity state, and spawning and related important life cycle phenomena. Additionally, it affects phenological fluctuations, food chains, microhabitats, stream flow regimes, and overall productivity.
4. When kept in captivity, snow trouts experience a variety of issues, including delayed growth, a lack of proper feed for the larvae and brood stock, protracted sub-ambient temperatures, etc. These elements work together to impede fish culture by limiting fish growth and reproduction.
5. The reduction of natural habitat area, habitat alterations, loss of germplasm, shrinkage of resources, and so on as a result of reducing water discharge in rivers, siltation, overfishing, pollution of water bodies, and climatic intricacies are some of the factors that are impeding snow trout populations.

9.10 Conservation Strategies

The threats and difficulties that numerous man-made and climatic factors pose to snow trout fisheries are significant, so it is essential to make conservation efforts for fisheries revival through raising public awareness, along with standardization and upscaling of culture and captive seed production for expanding ranching programs. Moreover, any approach to landscape conservation throughout the Himalayas must prioritize the mid-elevation regions, which are the best habitat for snow trout. The following are some of the important considerations that must be made when managing the snow trout fisheries:

1. Prioritizing mapping of the snow trout species over time and space is necessary to understand their current and potential future distributional shifts, if any, and to build effective development and conservation plans.
2. Standardization and upscaling of culture and breeding practices in order to enhance production in lentic and lotic systems along with the development of live gene bank in fish farms.
3. Intensive efforts on reproductive biology in order to prepare population recovery strategies.
4. Thorough preservation and biomonitoring of all cold-water resources over a wide geographic and temporal range to evaluate danger perspectives in relation to biodiversity.
5. A decision must be made regarding resource ownership.
6. A location-specific legal framework must be created and strictly followed.

9.11 Conclusion

The schizothoracinae group of fishes is the most widespread and economically important in the trans-Himalayan region. The main cause of mountain fishery's extreme vulnerability and rapid decline are anthropogenic and climatic externalities. To overcome the challenges and threats, in situ and ex situ conservation strategies, including live gene bank establishment, breeding and seed production protocols, and implementation of strict legislations, need to be formulated and developed to save the snow trout fisheries of the temperate Himalayan region.

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