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Review

Snow trout fishes (*Schizothorax* spp.) of the Asiatic region: A review enlightening distribution, diversity and conservation issue

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Abstract

Snow trouts form an important group of food fishes in Asia, renowned for their nutritive values with high content of docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), amino acids and micronutrients which are highly beneficial to human health. They primarily inhabitat pristine highland rivers, streams and lakes. In Asia, 45 species of snow trouts belonging to genus *Schizothorax* have been described. The current production of snow trout largely comes from capture fisheries. Several natural and anthropogenic factors have adversely impacted their habitats leading to their population decline over the past decade, and IUCN has categorised the group as 'Vulnerable'. This paper documents scientific studies carried out across Asia on the taxonomy, biology, biotechnology, biochemistry, spawning and reproductive behaviour of snow trouts. Original GIS resource maps of 24 species, with valid photographs have been prepared to illustrate the potential distribution and type locality of each species within their respective aquatic ecosystems. The review also provides information on strategies for the conservation and rehabilitation of these fishes. It is expected that this review will serve as a comprehensive resource, offering valuable information about snow trout fishes in the Asiatic region on a single platform.

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Introduction

Schizothorax (Gray, 1830) is a genus of cyprinid fish found in southern and western China, northern South Asia (the Himalayas), central Asia and Iran with one species, *Schizothorax prophylax* present in Turkey (Coad and Ville, 2004). Snow trout was first discovered in Kashmir by Heckel (Heckel, 1838). Locally known as 'Asela' in the Himalayan and sub-Himalayan region and across much of Asia, snow trouts are found in several states of India (Uttarakhand, Jammu and Kashmir, Himachal Pradesh, Arunachal Pradesh, Sikkim) as well as in Nepal, Pakistan and Afghanistan (Day, 1876). Snow trouts are endemic to the Himalayas, commonly found in streams and lakes and are often referred to as sentinel fish species of the region (Kapila *et al*., 2002; Barat *et al*., 2016; Kamalam *et al*., 2019). Six important snow trout species of Indian Himalayan Region (IHR) are *Schizothorax richarsonii*, *S. labiatus*, *S. plagiostomus*, *S. progastus*, *S. curvifrons* and *S. niger*, all of which are known for their superior nutrient quality (Joshi *et al*., 2017, 2018). Snow trouts commonly inhabit the pristine coldwater streams and rivers of Himalayan region and are considered as nutrient-rich food source. They contain high amounts of docosahexaenoic acid (DHA), eicosapetaenoic acid (EPA), amino acids and micronutrients, all of which are highly beneficial to human health (Das *et al*., 2012; Mohanty *et al*., 2014, 2015, 2016a, b). They are primarily found in highland rivers, streams and lakes, although a few species occur in low-lying eco-systems such as the Balkash and Sistan basins (Fang, 1936; Yang *et al*., 2012). Snow trouts provide a significant amount of animal protein locally, particularly in the upstream Himalayan regions, where they represent a significant fishery (Mahanta and Sharma, 2010; Sarma *et al*., 2013; Joshi *et al*., 2016). However, habitat fragmentation, erratic climate change and destructive fishing practices have led to a global decline in their population over the last decade, and IUCN has categorised the group as vulnerable (Sarma and Shahi, 2019) (Table 2).

Classification

Snow trouts belong to the class: Actinopterygii, order: Cypriniformes, family: Cyprinidae, subfamily: Barbinae and genus: *Schizothorax*. There are 45 valid species recorded in Asia *viz,Schizothorax kumaonensis* (Menon, 1971), *Schizothorax plagiostomus* (Heckel, 1838), *Schizothorax biddulphi* (Günther, 1876), *Schizothorax chongi* (Fang, 1936), *Schizothorax cryptolepis* (Fang, 1936), *Schizothorax sinensis* (Herzenstein, 1889), *Schizothorax heterochilus* (Wu *et al*., 1999), *Schizothorax wangchiachii* (Fang, 1936), *Schizothorax curvifrons* (Heckel, 1838), *Schizothorax curvilabiatus* (Wu and Wu, 1992), *Schizothorax davidi* (Sauvage, 1880), *Schizothorax richardsonii* (Gray, 1830), *Schizothorax dolichonema* (Herzenstein, 1889), *Schizothorax dulongensis* (Shunyou, 1985), *Schizothorax edeniana* (McClelland, 1835), *Schizothorax elongatus* (Shunyou, 1985), *Schizothorax esocinus* (Heckel, 1838), *Schizothorax graham* (Regan, 1914), *Schizothorax griseus* (Pellegrin, 1931), *Schizothorax heteri* (Yang *et al*., 2013), *Schizothorax leukus* (Yang *et al*., 2013), *Schizothorax meridionalis* (Tsao, 1964), *Schizothorax huegelii* (Heckel, 1838), *Schizothorax labiatus* (Mc Clelland, 1835), *Schizothorax lantsangensis* (Tsao, 1964), *Schizothorax lepidothorax* (Yang, 1991), *Schizothorax lissolabiatus* (Tsao, 1964), *Schizothorax macrophthalmus* (Terashima, 1984), *Schizothorax macropogon* (Regan, 1905), *Schizothorax microcephalus* (Day, 1876), *Schizothorax microstomus* (Wei and Shunyou, 1982), *Schizothorax ninglangensis* (Wang *et al*., 1981), *Schizothorax molesworthi* (Chaudhuri, 1913), *Schizothorax nudiventris* (Yang *et al*., 2006), *Schizothorax oconnori* (Stewart, 1908), *Schizothorax waltoni* (Regan, 1914), *Schizothorax pelzami* (Kessler, 1870), *Schizothorax prenanti* (Tchang, 1930), *Schizothorax progastus* (Mc Clelland, 1835), *Schizothorax prophylax* (Pietschmann, 1933), *Schizothorax pseudoaksaiensis* (Herzenstein, 1889), *Schizothorax raraensis* (Terashima, 1984), *Schizothorax skarduensis* (Mirza and Sadiq, 1978), *Schizothorax yunnanensis* (Norman, 1923), *Schizothorax zarudnyi* (Nikolskii, 1959).

Taxonomy

Schizothorax was documented in three groups without defining a type (Heckel, 1838). *Schizothorax plagiostomus* and *S. sinuatus* were distinguished by a band of hard papillated structure on the chin, a ventrally located mouth and a well-developed cartilaginous horny structure on the lower jaw with, which placed them in the first group. In the second group, *S. curvifrons*, *S. longipinnis*, *S. niger*, *S. esocinus,* and in the third group *S. huegelii*, *S. micropogon*, *S. planifrons* and *S. esocinus* were included respectively, lacking the hard papillated structure at the rear of the chin (Heckel, 1838). The genus *Schizothoraichthys* was proposed to accommodate the species without suctorial disc (Mishra, 1959), which were classified under the genus *Schizothorax* (Heckel, 1838). It was opined that *S. plagiostomus* was the species with a sucker on the chin and the latter is a synonym of the former (Tilak and Sinha, 1975) supporting the view of Mishra (1959). The band of papillated-like patterns on the jaw was also reported by Menon (1971, 1974) and Jhingran (1992) in *Schizothorax*.

Two valid species of *Schizothorax viz, S. richardsonii* and a newly identified species, *S. kumaonensis* were reported from the coldwater Himalayan rivers of Uttarakhand (Menon, 1971). The existence of these two species in India, under the genus *Schizothorax* was further validated by Tilak (1987) and Talwar and Jhingaran (1991). *S. kumaonensis* differ from *S. richardsonii* in having a smaller head, which is five times smaller than the standard length (Menon, 1971). Since, the external morphological characters of Schizothoracid fishes are extremely similar, identifying them based solely on the these features is challenging (Chandra *et al*., 2012). Although the diagnostic characters of snow trout have been investigated for a long time (Mir *et al*., 2014), a comprehensive and concrete description of their taxonomic status has only been achieved recently (Chandra *et al*., 2012). The morphometric diversification among *S. richardsonii* population was studied across six rivers of Nepal (Wagle *et al*., 2015). Significant differences in morphometric characters were found in 17 out of 207 specimens, with notable deviations in shape and size. The results suggest that morphometric variations can be crucial tool in identifying fishes of this genus (Wagle *et al*., 2015). The morphometric characteristics of three species of *Schizothorax* from Lidder river of Jammu and Kashmir was studied during 2003-2005 (Bhat *et al*., 2010). Among these species, *S. esocinus* exhibited maximum growth and higher values of certain morphological characters. The maximum pre-anal length and caudal fin length were observed in *S. plagiostomus;* while the highest ratio between snout length and eye diameter was recorded in *S. labiatus* (Bhat *et al*., 2010). Advanced techniques for morphometric analysis in fish was described to explain diagnostic characteristics (Mojekwu and Anumudu, 2015). The morphometric typesets of *S. richardsonii* of Narayani River system in Nepal (including the Sabha, Melamchi, Indrawati, Koshi, Phalaku and Tadi-Khudi rivers) were observed to understand the population status (Wagle *et al*., 2015). Similar studies were also conducted to identify the morphometric typeset and distribution pattern of three species of Schizothoracines (*S. plagiostomus, S. esocinus* and *S. labiatus*) in the Lidder River in India (Bhat *et al*., 2013).

Resource distribution and diversity

The extensive diversity of snow trout In the Himalayas is well documented (Table 1). The diversity is linked to their ancestors settled in various and diverse habitats, evolving into new species through a series of physical changes up to the late Miocene epoch (Li *et al*., 2009; Yang *et al*., 2012; Regmi, 2019; Mouludi *et al*., 2020). In the trans-Himalayan region, snow trouts are predominantly found in the cold-water streams from Jammu and Kashmir (Sunder and Bhagat, 1979) to Nainital Lake, where a new species *S. kumaonensis* was described (Menon, 1971). *S. plagiostomus* (Fig. 1) is an important indigenous fishery in the upland rivers of Jammu and Kashmir accounting for 10-20% of all commercial landings (Raina *et al*., 1985). This species is also distributed in the eastern Himalayas and Bhutan at altitudes ranging from 1180-3000 m (Jhingaran, 1982). Similarly, *S. plagiostomus* has been described in the rivers, lakes and reservoirs of Nepal at altitudes from 300 to 3,323 m (Shrestha, 1981). Notably, some high-altitude lakes in Nepal harbour only *Schizothorax* spp. (Ferro, 1978; Pradhan, 2009). In Tarim River and Boston Lake of Xijiang, China, *S. biddulphi* (Fig. 2) inhabits in areas with little or no current, feeding on benthic invertebrates, algae and small fragments of macrophytes (Tian-you, 1984; Zhang, 1998). *S. chongi* (Fig. 3), *S. cryptolepis*, *S. sinensis*, *S. heterochilus* and *S. wangchiachii* (Fig. 4) are found in the upper parts of the Yangtze basin in China (Mc Clelland, 1839; McAllister, 1990; Ye *et al*., 2011).

The 'sattar' snow trout, *S. curvifrons* (Fig. 5) is native to the highlands of south-central Asia ranging from Iran to China, where it dominates various freshwater habitats (Wu and Wu, 1992). *S. curvilabiatus* is recorded in the downstream regions of the

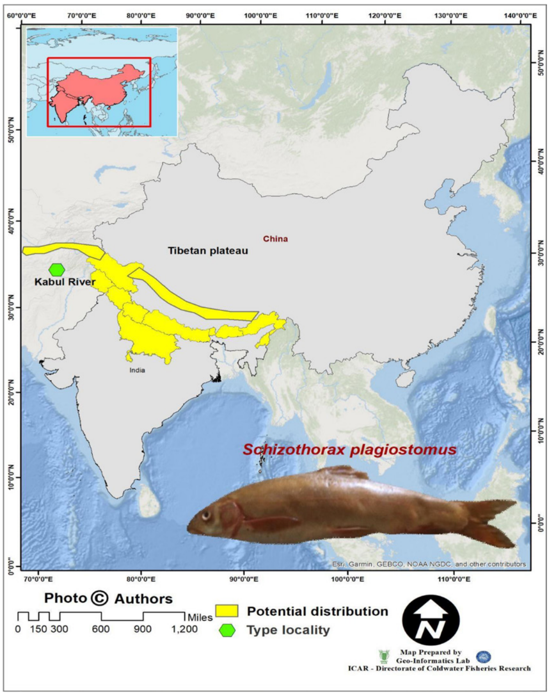

Fig.1. Map showing the type locality and potential distribution of *S. plagiostomus*

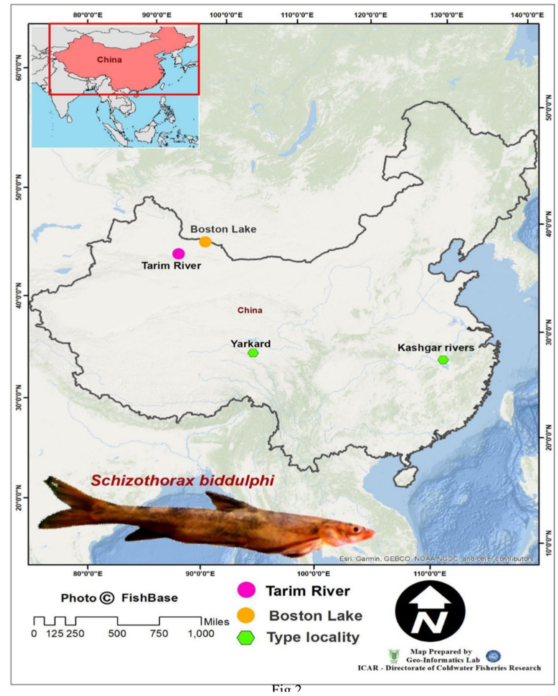

Fig. 2. Map showing the type locality and potential distribution of *S. biddulphi*

Table 1. Diversity and distribution of snow trouts in the Asiatic region

Species	Distribution	References	Remarks
Schizothorax richardsonii (Gray, 1832)	India, Pakistan, Tibet, Nepal, Afghanistan	Joshi (2004); Talwar and Jhingaran (1991)	Endemic species
S. kumaonensis (Menon, 1971)	India	Sunder and Bhagat (1979)	Endemic species of Nainital Lake, India
S. plagiostomus (Heckel, 1838)	India, Nepal	Raina *et al*. (1985); Shrestha (1981)	Indigenous fishery in the upland rivers of Jammu and Kashmir, India and Nepal
S. biddulphi (Günther, 1876)	China	Zhang (1998); Tian-you (1984)	Endemic to Tarim River and Boston Lake of Xijiang, China
S. chongi (Fang, 1936)	China	Ye *et al*. (2011); McAllister (1990); McClelland (1839)	Found in the upper parts of the Yangtze basin
S. cryptolepis (Fu & Ye, 1984)	China	Ye *et al*. (2011); McAllister (1990); McClelland (1839)	Found in the upper parts of the Yangtze basin
S. sinensis (Herzenstein, 1889)	China	Ye *et al*. (2011); McAllister (1990); McClelland (1839)	Found in the upper parts of the Yangtze basin
S. heterochilus (Fu & Ye, 1986)	China	Ye *et al*. (2011); McAllister (1990); McClelland (1839)	Found in the upper parts of the Yangtze basin
S. wangchiachii (Fang, 1936)	China	Ye *et al*. (2011); McAllister (1990); McClelland (1839)	Found in the upper parts of the Yangtze basin
S. curvifrons (Heckel, 1838)	China and Iran	Wu and Wu (1992)	Native to the highlands of south-central Asia from Iran to China
S. curvilabiatus (Wu & Tsao, 1992)	China	Ali *et al*. (2014); Wu and Wu (1992)	Recorded in the downstream of river Yarlung Tsangpo, Tibet
S. davidi (Sauvage, 1880)	China	Zhang (1998)	Endemic to Szechuan and Yunnan Provinces of China

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S. dolichonema (Herzenstein, 1889)	China	Ye *et al*. (2011)	Endemic to Yangtze basin of China
*S. dulongensis (*Huang, 1985)	China	Wu and Wu (1992)	Endemic to Yangtze basin of China
S. edeniana (McClelland, 1842)	Afghanistan	Zhang (1998)	Found in the higher altitudes of Afghanistan *i.e.,* Mijdan valley and Sir-i-Chusmah
S. esocinus (Heckel, 1838)	India, Pakistan, Afghanistan, Nepal and China	Mir *et al*. (2014)	Dominant in the Himalayas of India, Pakistan, Afghanistan, Nepal and China
S. grahami (Regan, 1904)	China	Chen and Yang (2008)	Endemic to lake Dianchi along with its tributaries and adjoining rivulets in Yunnan Province of China
S. griseus (Pellegrin, 1931)	China	Wu and Wu (1992)	Found in Jinshajiang and Nanpanjiang rivers in Guizhou Province
S. heteri (Yang, Zhen, Chen & Yang, 2013)	China	Huang *et al*. (1988)	Found in the Irrawaddy River drainage of China
S. leukus (Yang, Zhen, Chen & Yang, 2013)	China	Yang *et al*. (2013)	Found in the Irrawaddy River drainage of China
S. meridionalis (Tsao, 1964)	China	Yang *et al*. (2013)	Found in the Irrawaddy River drainage of China
S. huegelii (Heckel, 1838)	India	Yunfei (1987)	Endemic to Jammu and Kashmir, India
S. labiatus (McClelland, 1842)	India, Nepal, Pakistan, Afghanistan and Tibet	Talwar and Jhingaran (1991)	Endemic species
S. lantsangensis (Tsao, 1964)	China	Yunfei (1987)	Upper Mekong River basin in Yunnan
S. lepidothorax (Yang, 1991)	China	Yang (1991)	Fuxian Lake of Yunnan Province
S. lissolabiatus (Tsao, 1964)	China	Huang *et al*. (1988)	Mekong and Black Pearl rivers
S. macrophthalmus (Terashima, 1984)	Nepal	Huang *et al*. (1988)	Endemic fish of the alpine freshwater Rara Lake located in Rara National Park
S. macropogon (Regan, 1905)	China	Yunfei (1987); DeTping and Xiao Tyong (2006)	Restricted to the Yarlung Zangbo River, China
S. microcephalus (Day, 1877)	Afghanistan	McAllister (1990)	Endemic to Panj River
S. microstomus (Hwang, 1982)	China	Wu and Wu (1992)	Lugu Lake in Ninglang, Yunnan
S. ninglangensis (Wang, Zhang & Zhuang, 1981)	China	Shuo *et al*. (2020)	Lugu Lake in Ninglang, Yunnan
S. molesworthi (Chaudhuri, 1913)	India and China	Yunfei, 1987	Commonly caught from the Brahmaputra River drainage
S. nudiventris (Yang, Chen & Yang, 2009)	China	Yang, 1991	Upper reaches of Mekong River,
S. oconnori (Lloyd, 1908)	China	Yunfei (1987)	Upper reaches of Brahmaputra River drainage
S. waltoni (Regan, 1905)	China	Yunfei (1987)	Upper reaches of Brahmaputra River drainage
S. pelzami (Kessler, 1870)	Afghanistan, Turkmenistan and Iran	Berg (1964)	Endemic species
S. prenanti (Tchang, 1930)	China	Geng *et al*. (2012)	Yangtze basin
S. progastus (McClelland, 1839)	India and Nepal	Talwar and Jhingaran (1991)	Endemic species
S. prophylax (Pietschmann, 1933)	Turkey	Cicek *et al*. (2018)	Endemic to Egirdir Lake
S. pseudoaksaiensis (Herzenstein, 1889)	China	Luan *et al*. (2016)	Endemic species
S. raraensis (Terashima, 1984)	Nepal	Dimmick and Edds (2002)	Rara Lake of Nepal
S. skarduensis (Mirza & Awan, 1978)	Pakistan	Mirza and Sadiq (1978)	Endemic species
S. yunnanensis (Norman, 1923)	China	Li *et al*. (2016)	Endemic to upper parts of the high altitudinal rivers
S. zarudnyi (Nikolskii, 1897)	Iran and Afghanistan	Kalbassi *et al*. (2008)	Sistan basin lakes
S. niger (Heckel, 1838)	Indian and Pakistan	Sabha *et al*. (2017); Mir *et al*. (2014); Barat *et al*. (2016)	Endemic species

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Table 2. IUCN Red List Status of snow trouts distributed in the Asiatic region

Species	IUCN red list status
Schizothorax richardsonii (Gray, 1832)	Vulnerable
S. kumaonensis (Menon,1971)	Data deficient
S. plagiostomus (Heckel, 1838)	Vulnerable
S. biddulphi (Günther, 1876)	Not evaluated
S. chongi (Fang, 1936)	Not evaluated
S. cryptolepis (Fu & Ye, 1984)	Not evaluated
S. sinensis (Herzenstein, 1889)	Not evaluated
S. heterochilus (Fu & Ye, 1986)	Least concern
S. wangchiachii (Fang, 1936)	Near threatened
S. curvifrons (Heckel, 1838)	Least concern
S. curvilabiatus (Wu & Tsao, 1992)	Data deficient
S. davidi (Sauvage, 1880)	Not evaluated
S. dolichonema (Herzenstein, 1889)	Not evaluated
S. dulongensis (Huang, 1985)	Not evaluated
S. edeniana (McClelland, 1842)	Not evaluated
S. esocinus (Heckel, 1838)	Vulnerable
S. grahami (Regan, 1904)	Critically endangered
S. griseus (Pellegrin, 1931)	Least concern
S. heteri (Yang, Zhen, Chen & Yang, 2013)	Not evaluated
S. leukus (Yang, Zhen, Chen & Yang, 2013)	Not evaluated
S. meridionalis (Tsao, 1964)	Data deficient
S. huegelii (Heckel, 1838)	Not evaluated
S. labiatus (McClelland, 1842)	Not evaluated
S. lantsangensis (Tsao, 1964)	Data deficient
S. lepidothorax (Yang, 1991)	Endangered
S. lissolabiatus (Tsao, 1964)	Least concern
S. macrophthalmus (Terashima, 1984)	Least concern
S. macropogon (Regan, 1905)	Near threatened
S. microcephalus (Day, 1877)	Not evaluated
S. microstomus (Hwang, 1982)	Not evaluated
S. ninglangensis (Wang, Zhang & Zhuang, 1981)	Not evaluated
S. molesworthi (Chaudhuri, 1913)	Data deficient
S. nudiventris (Yang, Chen & Yang, 2009)	Not evaluated
S. oconnori (Lloyd, 1908)	Least concern
S. waltoni (Regan, 1905)	Least concern
S. pelzami (Kessler, 1870)	Least concern
S. prenanti (Tchang, 1930)	Not evaluated
S. progastus (McClelland, 1839)	Least concern
S. prophylax (Pietschmann, 1933)	Critically endangered
S. pseudoaksaiensis (Herzenstein, 1889)	Vulnerable
S. raraensis (Terashima, 1984)	Critically endangered
S. skarduensis (Mirza & Awan, 1978)	Vulnerable
S. yunnanensis (Norman, 1923)	Data deficient
S. zarudnyi (Nikolskii, 1897)	Not evaluated
S. niger (Heckel, 1838)	Not evaluated

Yarlung Tsangpo River in Tibet inhabiting mainly the rapid streams and rivers with gravel bottoms and rocks (Wu and Wu, 1992; Ali *et al*., 2014). In the Szechuan and Yunnan Provinces of China, *S. davidi* (Fig. 6) is commonly found (Zhang, 1998). *S. richardsonii* (Fig. 7) is widely distributed in the Himalayas and adjacent countries. It acclimatises well to the coldwater streams and rivers with rocks and boulders, feeding mostly on plankton, plants and periphytic communities available in the eco-system (Talwar and Jhingaran, 1991). *S. dolichonema* (Fig. 8) is found in the upper parts of fast-flowing rivers in the Yangtze basin of China (Ye *et al*., 2011). *S. dulongensis* (Fig. 9) inhabits clean rivers with rocky substratum, in the Yunnan Province of China, feeding mainly on algae and detritus (Wu and Wu, 1992). In the higher altitudes of Afghanistan *i.e.,* Mijdan Valley and Sir-i-Chusmah, *S. edeniana* is commonly distributed (McAllister, 1990). *S. elongatus* originated from the high altitude fast flowing rivers of southern and western China (Zhang, 1998). The 'chirruh' snowtrout, *S. esocinus* (Fig. 10) is mostly dominant in the Himalayas of India, Pakistan, Afghanistan, Nepal and China which inhabits sandy and gravel-bottom rivers (Mir *et al*., 2014). *S. grahami* (Fig. 11) is endemic to lake Dianchi and its tributaries as well as adjoining rivulets in Yunnan Province of China (Chen and Yang, 2008). *S. griseus* (Fig.12) is found in Jinshajiang and Nanpanjiang rivers in Guizhou Province and also in the Yangtze River and in the upper reaches of the Pearl as well s Mekong rivers of southern China (Wu and Wu, 1992). *S. heteri* (Fig. 13), *S. leukus* (Fig. 14) and *S. meridionalis* (Fig.15) are found in the Irrawaddy River drainage of China having rocky and sandy substrata (Huang *et al*., 1988; Yang *et al*., 2013). *S. huegelii* is found in the fast-flowing cold river streams of Jammu and Kashmir, usually hiding under huge boulders (Yunfei, 1987).

The 'kunar' snowtrout, *S. labiatus* (Fig. 16) is found in the high altitudinal rivers of India, Nepal, Pakistan, Afghanistan and Tibet (Talwar and Jhingaran, 1991). *S. lantsangensis* is endemic to the upper Mekong River basin in Yunnan, feeding mainly on periphyton (Yunfei, 1987). *S. lepidothorax* is known to be originated in the rocky bottoms and fast-flowing rivers of Fuxian Lake in the Yunnan Province of China (Yang, 1991). Similarly, *S. lissolabiatus* (Fig. 17) is found in the upper high altitudinal reaches of Mekong, Black and Pearl rivers in China (Huang *et al*., 1988). Nepalese snow trout *S. macrophthalmus* (Fig. 18) is an endemic fish of the alpine freshwater Rara Lake located in Rara National Park (Huang *et al*., 1988). *S. macropogon* (Fig. 19) is restricted to the Yarlung Zangbo River (upper Brahmaputra) in Tibet, China (Yunfei, 1987; De Tping and Xiao Tyong, 2006). *S. microcephalus* is predominantly recorded in the sandy bottoms of the coldwater areas of Panj River in Afghanistan (McAllister, 1990). *S. microstomus* and *S. ninglangensis* are endemic species of Lugu Lake in Ninglang, Yunnan (Wu and Wu, 1992; Shuo *et al*., 2020). The blunt nosed snow trout, *S. molesworthi (*Fig. 20) is commonly caught from the Brahmaputra River drainage in India and China, where it is heavily exploited for food (Yunfei, 1987).

S. nudiventris is distributed in the upper reaches of Mekong River, China, feeding mainly on periphyton present in the substratum of the river (Yang, 1991). *S. oconnori* (Fig. 21) and *S. waltoni* (Fig. 22) are also distributed in the upper reaches of Brahmaputra River drainage having sandy bottom (Yunfei, 1987). *S. pelzami*, commonly known as 'Transcaspian Marinka' is endemic to Afghanistan, Turkmenistan and Iran, mostly available in the fast-flowing rivers (Berg, 1964). *S. prenanti* is distributed in the middle and upper regions of coldwater streams of the Yangtze basin in China (Geng *et al*., 2012). 'Dinnawah snow trout', *S. progastus* (Fig. 23) is widely spread in the North-eastern Himalayan rivers of India and coldwater areas of Nepal (Talwar and Jhingaran, 1991). *S. prophylax* is endemic to Egirdir Lake in Turkey (Çicek *et al*., 2018) whereas in central Asia and western China, the 'Ili marinka', *S. pseudoaksaiensis* is recorded in the mid altitudinal streams (Luan *et al*., 2016). *S. raraensis* locally

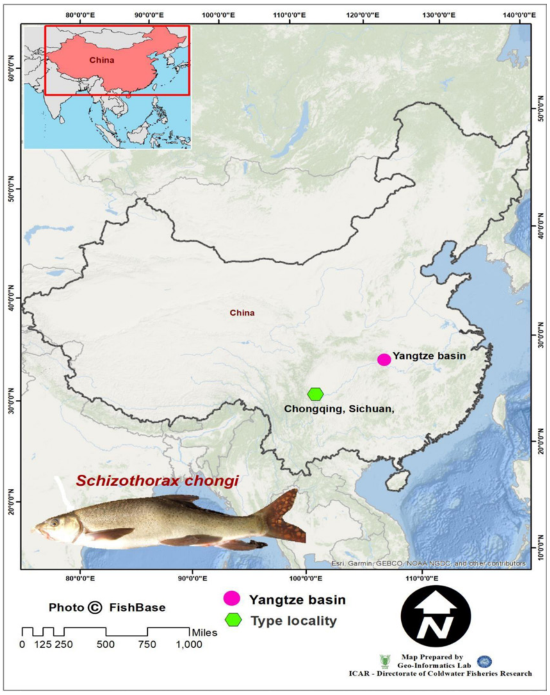

Fig.3. Map showing the type locality and potential distribution of *S. chongi*

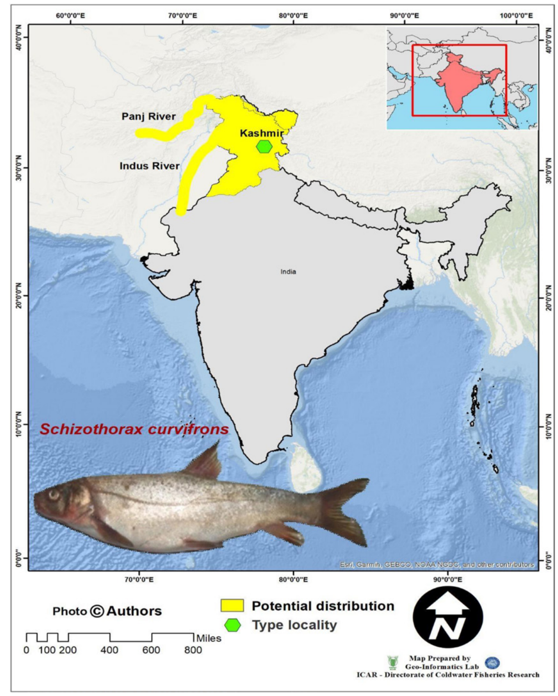

Fig. 5. Map showing the type locality and potential distribution of *S. curvifrons*

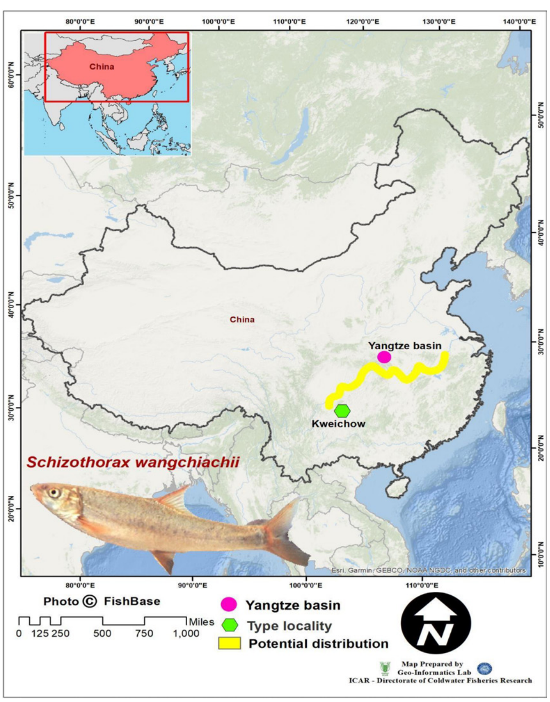

Fig.4. Map showing the type locality and potential distribution of *S. wangchiachii*

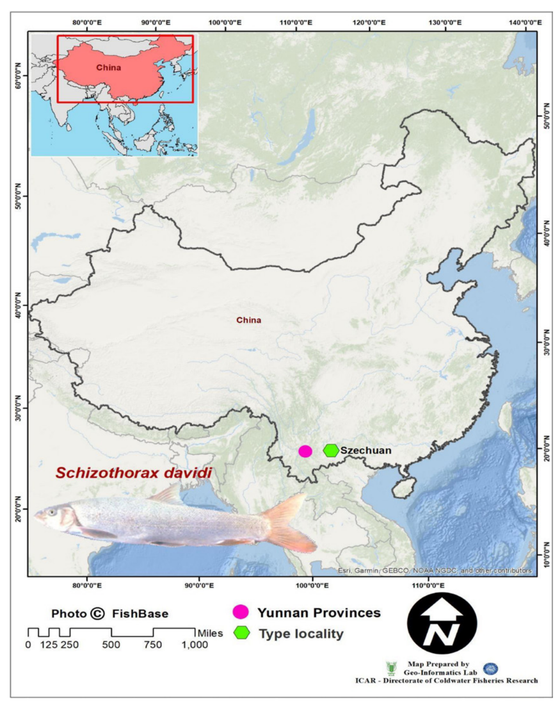

Fig. 6. Map showing the type locality and potential distribution of *S. davidi*

known as 'Rara' snow trout was first collected in 1979 in the alpine freshwater Rara lake of Nepal (Dimmick and Edds, 2002). *S. skarduensis* is distributed in the shallow coldwater streams of Pakistan having large boulders and gravels at the bottom (Mirza and Sadiq, 1978). *S. yunnanensis* was described from the upper parts of the high altitudinal rivers of Yunnan (Li *et al*., 2016), whereas *S. zarudnyi* from the Sistan basin lakes of Iran and Afghanistan (Kalbassi *et al*., 2008). The 'alghad' snow trout, *S. niger* (Fig. 24) is found in the coldwater streams of Kashmir, Pakistan and several Himalayan rivers of India (Mir *et al*., 2014; Barat *et al*., 2016; Sabha *et al*., 2017).

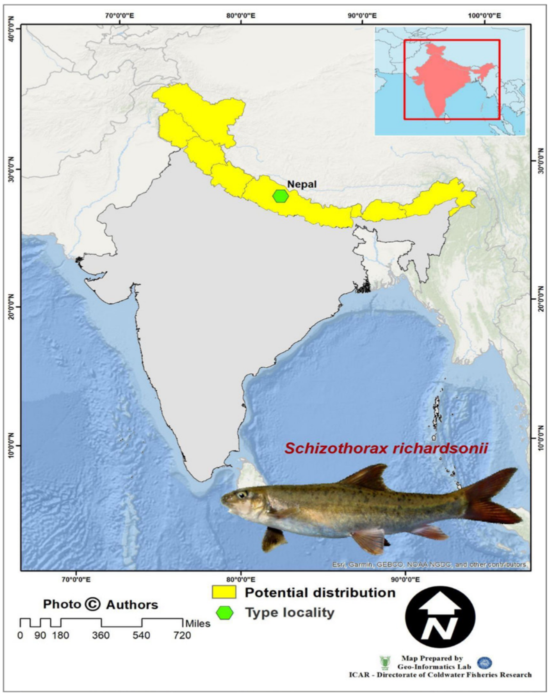

Fig. 7. Map showing the type locality and potential distribution of *S. richardsonii*

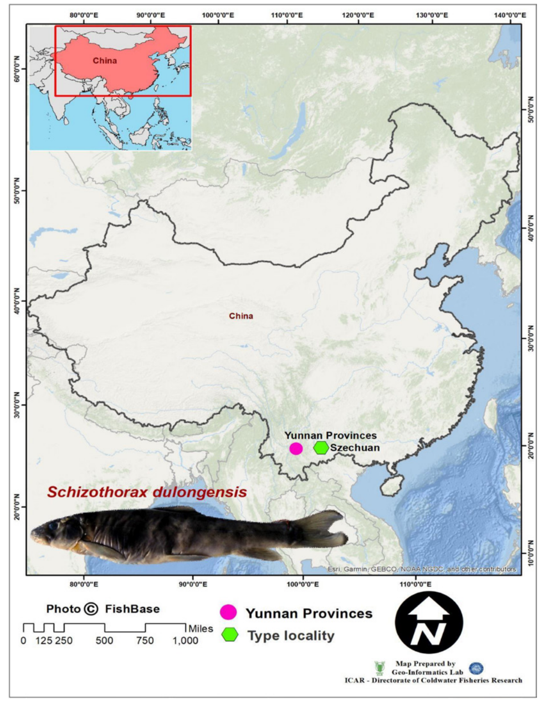

Fig. 9. Map showing the type locality and potential distribution of *S. dulongensis*

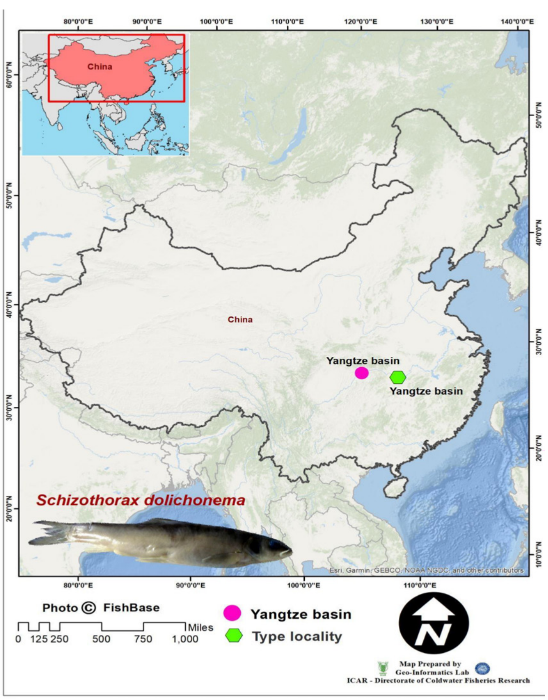

Fig. 8. Map showing the type locality and potential distribution of *S.. dolichonema*

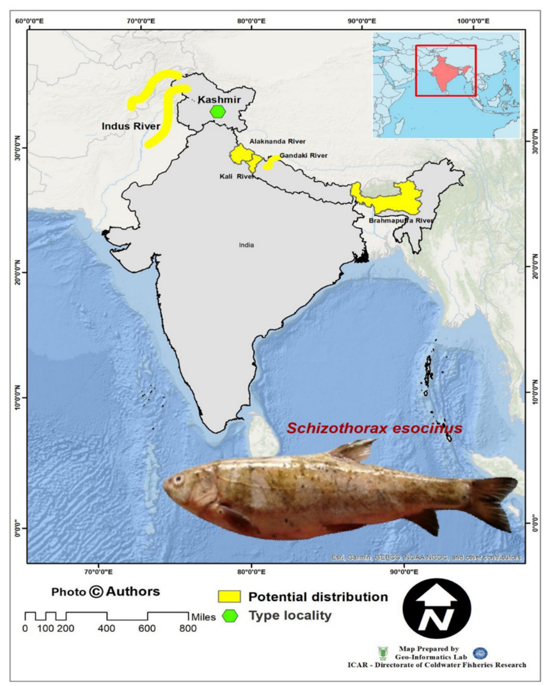

Fig. 10. Map showing the type locality and potential distribution of *S. esocinus*

Spawning and reproductive biology

The spawning periodicity of *S. richardsonii* has been described based on the biology of gravid fishes, higher gonado-somatic index (GSI) and bimodal ova diameter polygon with a male and female ratio 1:1.09. It is established that the fish breeds twice in a year *i.e.*, July-October and January-February (Joshi, 2004; Mohan, 2005). The population of *S. richardsonii* was studied in river Balkhila, a tributary of river Alaknanda from IHR (Joshi *et al.*, 2016) in which the fecundity varied from 16552 to 30408 of eggs per kg fish body weight (Joshi *et al.*, 2005). A similar study on the reproductive parameters of *S. plagiostomus* recorded fecundity and GSI during different breeding seasons (Jan and Ahmed, 2016). The reproductive biology of *S. niger* showed a male:female of 1:2 and

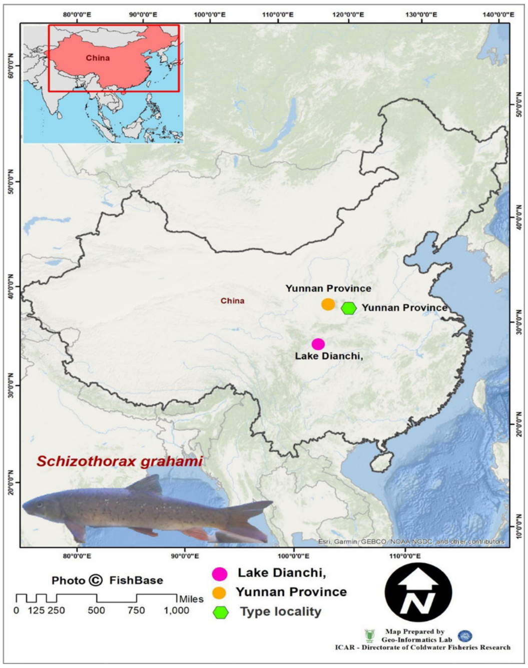

Fig.11. Map showing the type locality and potential distribution of *S. grahami*

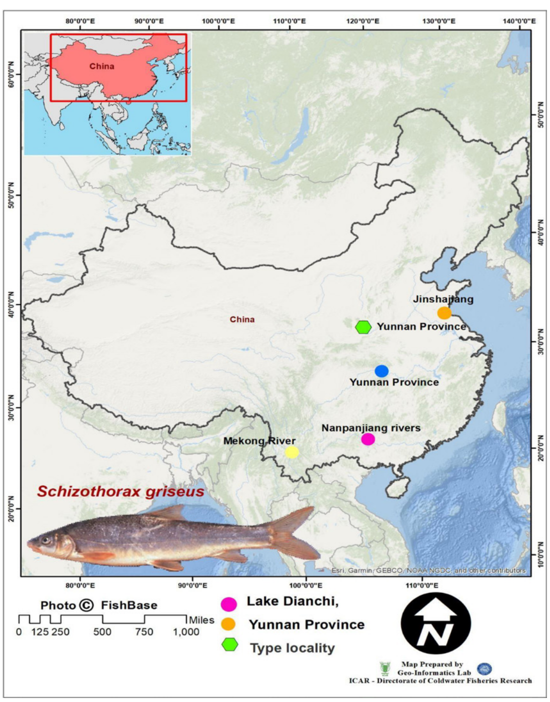

Fig. 12. Map showing the type locality and potential distribution of *S. griseus*

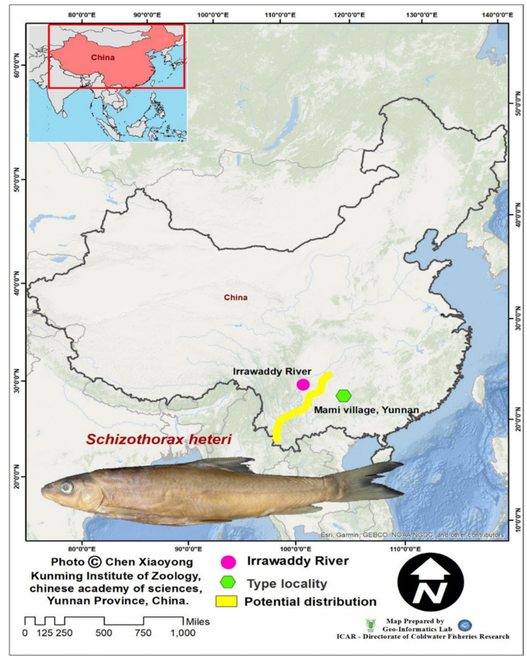

Fig. 13. Map showing the type locality and potential distribution of *S. heteri*

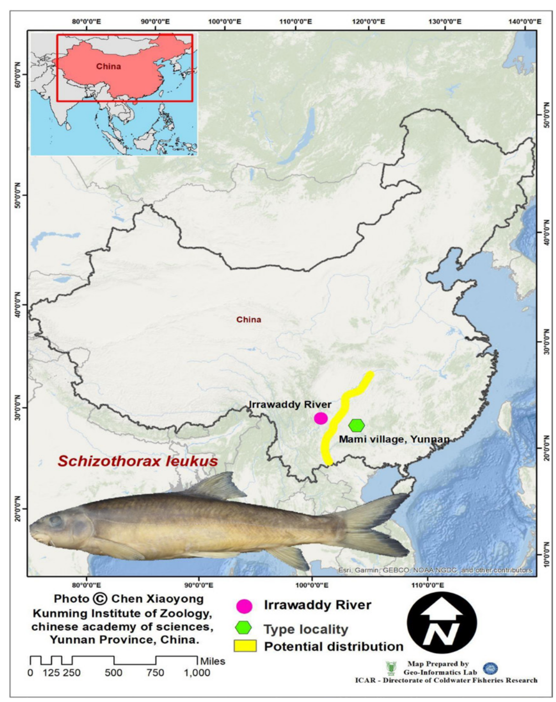

Fig. 14. Map showing the type locality and potential distribution of *S. leukus*

peak spawning during March to mid-May, once in a year (Sabha *et al*., 2017). In *S. plagiostomus* from the river Lidder in Kashmir of IHR, spawning parameters such as fecundity, sexual maturity in relation to ovary and testes development as well as liver-somatic index were assessed (Jan and Ahmed, 2016). The average GSI of female fish ranged from 1.05±0.62 to 14.95±2.69, while in males, the values varied from 4.13±0.47 to 14.83±2.97 respectively (Jan and Ahmed, 2016). A study on the fecundity of *S. curvifrons* from Jhelum River, Kashmir, India recorded absolute fecundity ranging from 4,762 to 17,196, while the relative fecundity ranged from 23 to 76 ova per gram body weight (Qadri *et al*., 2015). Periodic changes in various reproductive parameters including hormone secretion as well as morphological and cellular changes in gonads were analysed to understand the changes in plasma steroid hormones, and lipid transport proteins which are basically precursor of egg yolk. This study delineated two distinctive spawning periods *i.e.* September

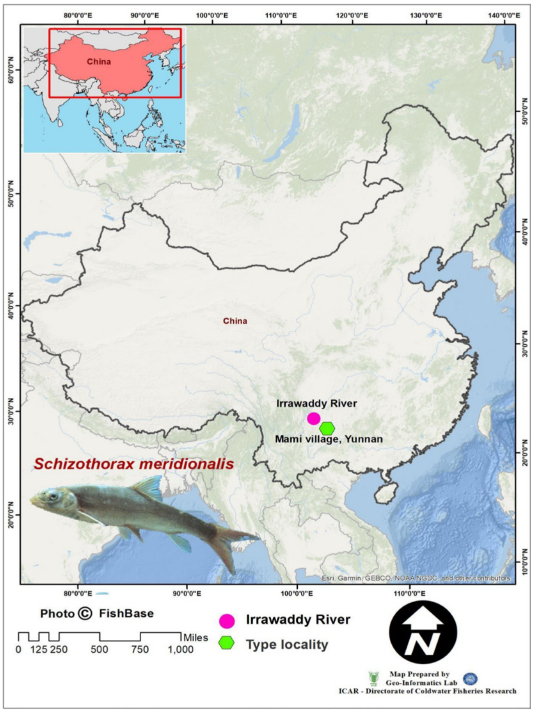

Fig. 15. Map showing the type locality and potential distribution of *S. meridionalis*

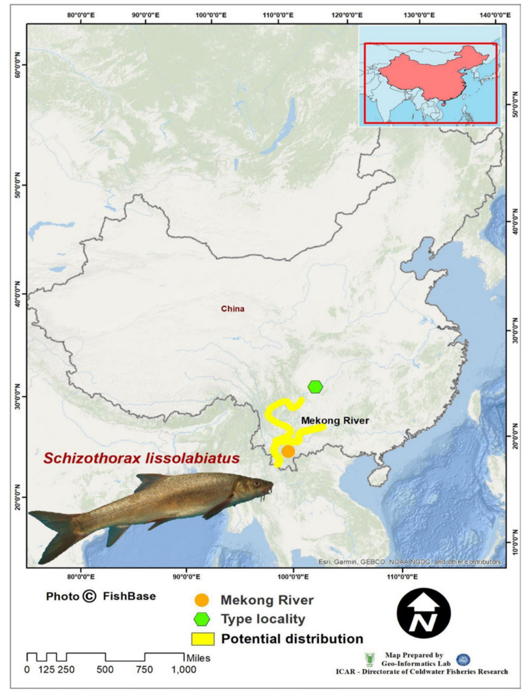

Fig. 17. Map showing the type locality and potential distribution of *S. lissolabiatus*

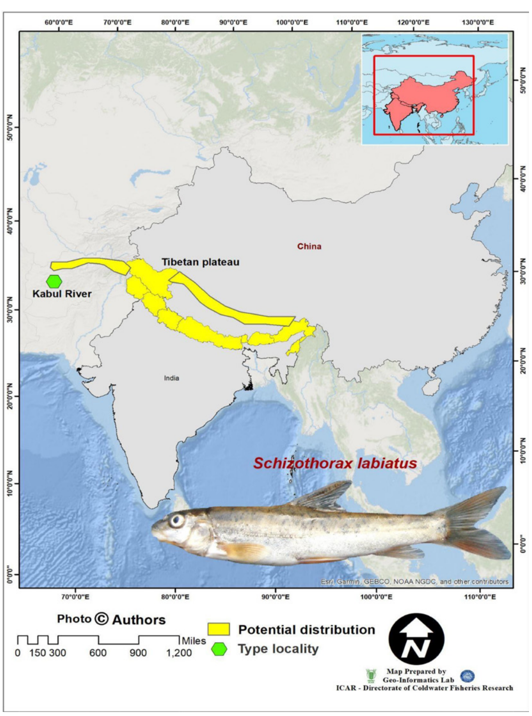

Fig. 16. Map showing the type locality and potential distribution of *S. labiatus*

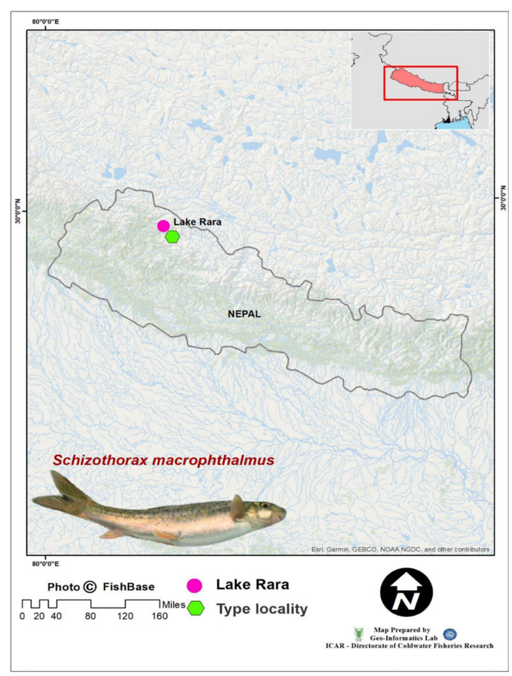

Fig. 18. Map showing the type locality and potential distribution of *S. macrophthalmus*

and February, particularly for the female fish (Ciji *et al*., 2021). The findings demonstrated that in coldwater riverine habitats of IHR, *S. richardsonii* breeds from the end of February to the beginning of April and similarly from September to the first week of October (Joshi, 2006). Absolute fecundity of *S. plagiostomus* ranged from 3,474 eggs in a fish measuring 345 mm total length (TL) and weighing 315 g to 13,916 eggs in a fish measuring 540 mm TL and weighing 1,370 g (Agarwal *et al*., 1988). Studies in different water bodies of Jammu and Kashmir revealed a high degree of positive correlation among the snow trout population (Gandotra *et al*., 2009). Studies on the reproductive biology of *S. niger* in the Nigeen Lake of Kashmir, recorded male:female ratio of 1:2.44 and size at first maturity of 14.82 cm (Sabha *et al*., 2017).

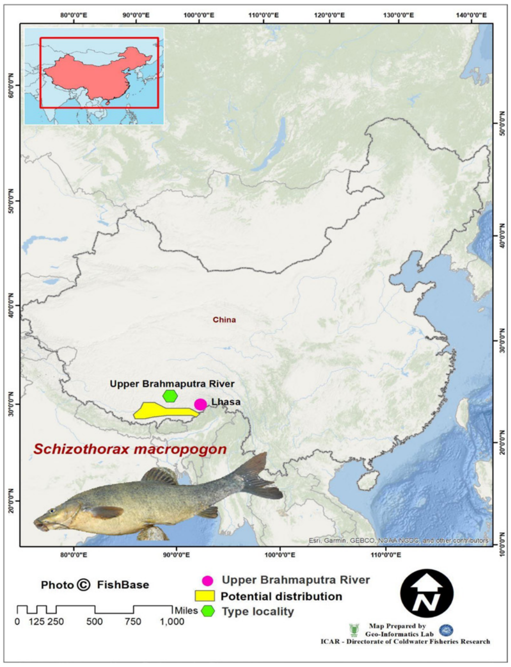

Fig. 19. Map showing the type locality and potential distribution of *S. macropogon*

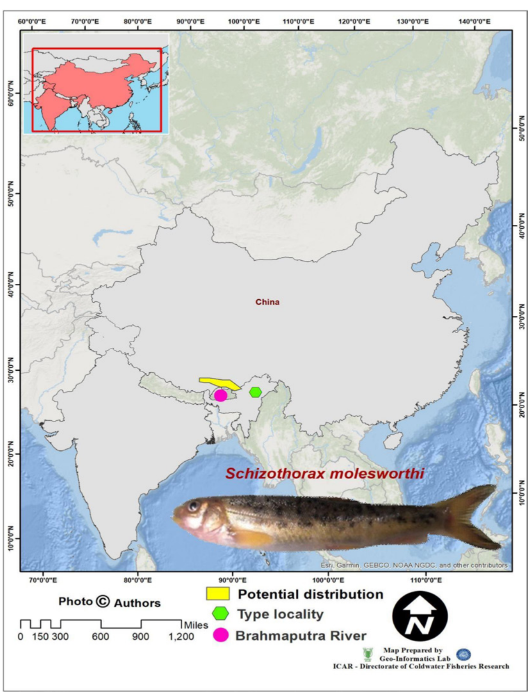

Fig. 20. Map showing the type locality and potential distribution of *S. molesworthi*

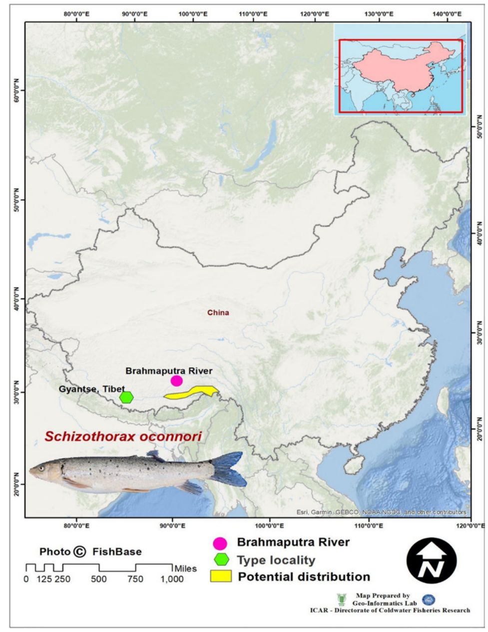

Fig. 21. Map showing the type locality and potential distribution of *S. oconnori*

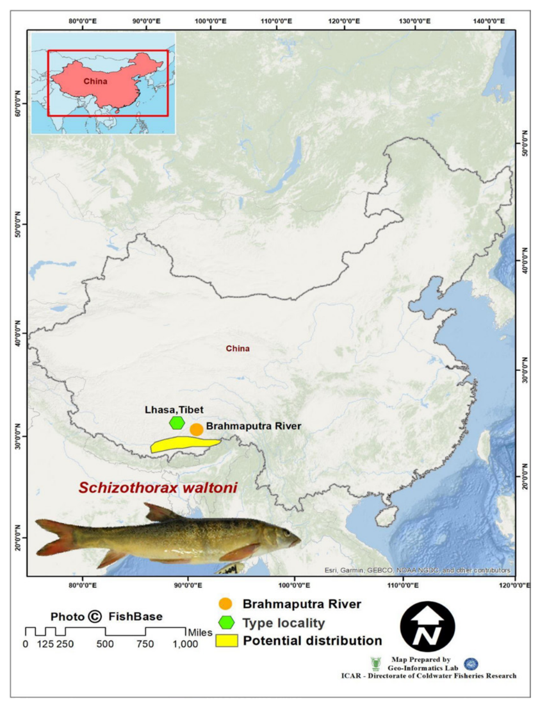

Fig. 22. Map showing the type locality and potential distribution of *S. waltoni*

Diagnostic characters

The examination of morphometric (24 nos.) and meristic (5 nos.) characters in *S. labiatus* revealed a significantly high degree of correlation ($p<0.05$) and linear relationships in morphometric characters, while the meristic characters counted were constant in all the fishes irrespective of their sizes (Jan and Ahmed, 2020). The biology and diagnostic characters of *S. zarudnyi* indicated that the fish prefers to feed on vegetable and animal protein and taxonomic characters mostly remains same in both male and female fishes showing allometric growth (Gharaei, 2012). The genus *Schizothorax* in the Kashmir Valley, forms two distinctive monophyletic groups. The first group includes *S. niger, S. curvifrons* and *S. plagiostomus,* while the second clade comprises *S. esocinus* and *S. labiatus* (Bashir *et al*., 2016). Differences in morphometric characteristics were observed among the population of

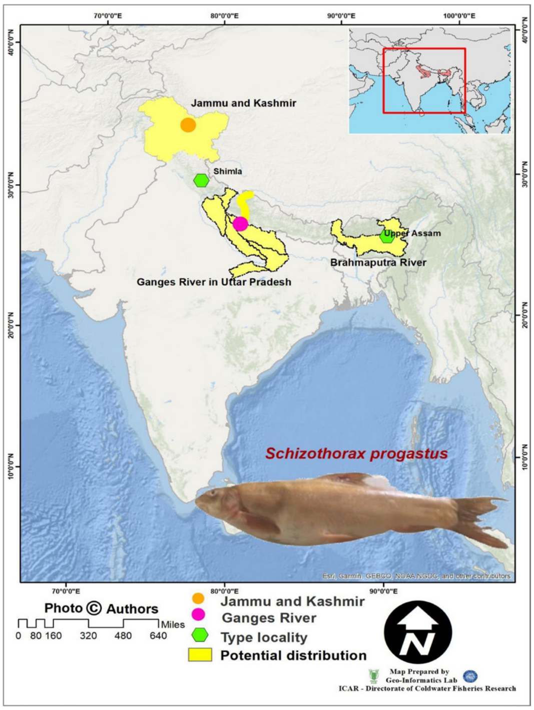

Fig. 23. Map showing the type locality and potential distribution of *S. progastus*

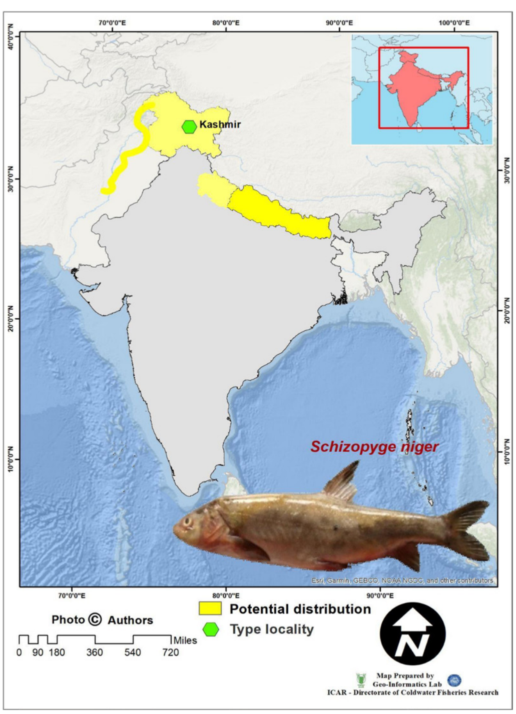

Fig. 24. Map showing the type locality and potential distribution of *S. niger*

S. richardsonii in six major rivers (Wagle *et al*., 2015). The adhesive organ (AO) of *S. richardsonii* studied by Das and Nag (2008) was found to consists of a crescent-shaped callus part, modified labial fold and numerous tubercles. In order to determine the growth pattern and health of the fish, an analysis on the length-weight relationship and well-being of *S. labiatus* was carried out round the year in river Jhelum of Kashmir, revealing a negative growth (Farooq *et al*., 2017). Similarly, the morphometric and health parameters of *S. richardsonii* were assessed in 254 samples collected from Ravi, Sahoo, Sewa, Teesta and Indus rivers in India (Tyagi *et al*., 2014). An attempt was also made to evaluate the correlation between length and weight of *S. richardsonii* and *S. plagiostomus* populations in the Kameng drainage in eastern IHR to understand their population structure ((Sarma *et al*., 2017; Ganie *et al*., 2018; Kunal *et al*., 2021). In Chah Nimeh reservoir of Sistan, Iran, the morphometric and meristic characters of 89 specimens of *S. zarudnyi* were studied in both male and female fishes of diverse size groups (Gharaei, 2012).

Conservation

Snow trout distribution in the IHR and across Asia is influenced by topographic, hydrogeomorphic and climatic variables. It is well established that the geographical distribution of living organisms is principally governed by climatic factors (Brown *et al*., 2004; Ebrahimi *et al*., 2017). However the addition of hydrogeomorphic factors has created new pragmatic forecasts for aquatic organisms (Buisson *et al*., 2008; Chatfield *et al*., 2010; Filipe *et al*., 2013; Bae *et al*., 2018; Ruaro *et al*., 2019). The mid-altitudinal region of the Himalayas is a key habitat for snow trout and the aquatic eco-systems in these areas should be given top priority in any conservation approach (Cao *et al*., 1981). Literature principally based on primary field surveys indicates that the initial dominance of *Schizothorax* species in mid-altitudinal regions is eventually replaced by their derivatives in the higher and lower altitudinal regions (Edds, 1993; Sehgal, 1999; Shrestha, 1999; Sarma and Shahi, 2019). To reduce uncertainties in forecasts, a large set of environmental data is repeatedly required for analysis (Thuiller *et al*., 2004; Gardner *et al*., 2019). The available data on snow trout composition in various streams and rivers indicate the existence of a good number of snow trout species in Asia. However, overfishing and habitat destruction has led to decline in their populations (Vishwanath *et al*., 2011). Snow trouts being bottom dwellers prefer rapid water flow and gravel bottoms (Sehgal, 1999). Inadequate water and disturbances at the bottom are the factors affecting the abundance of Schizothoracids (Mahanta and Sarma, 2010). *Ex-situ* conservation can go a long way in conserving this fishery in the hill streams (Sharma and Mehta, 2010). Snow trouts thrive in areas with heavy fast-flowing waters with spill and whirlpools (Rajput *et al*., 2013; Tare *et al*., 2017). The *Schizothorax* group is highly sensitive to climatic change with their minimum elevation range mostly confined below 1000 m, primarily inhabiting major rivers (Mandal and Jha, 2013; Ashok, 2014). Climate changeis predicted to affect the downstream areas of Ganga and Indus rivers in the IHR altering natural water flow and spatial interactions (Immerzeel *et al*., 2010). This could result in the isolation of fish due to the displacement of natural fish groups. Studies have reported that climate change can lead to the range narrowing and localised disappearance of many cold water adapted fishes (Comte and Grenouillet, 2013; Comte *et al*., 2013). This scenario presents a challenge in understanding the occurrence and geographical dominance patterns of these fishes in the Himalayas. The lakes of IHR are exposed to harmful radiations that alters the distribution pattern of zooplankton, which in turn affects the habitat of snow trout (Inaotombi and Sarma, 2020; 2021). Continuous monitoring of the health of snow trout fishes in the IHR and initiating sustainable action plans are therefore strongly recommended

(Mahanta and Sarma, 2010; Sarma, 2015). In order to boost sustainable development of snow trout fisheries in the open water bodies, it is recommended to undertake regular assessments of snow trout fishery resources; protection of habitats; new research initiatives on species, stock validation, as well as exploration of important aquatic ecosystems in Asia for ichthyofaunal diversity, ecobiology and discovery of new snow trout species.

Conclusion

Snow trouts are important bio-indicators and sentinel fish species of Indian Himalayan lotic ecosystems and significantly contribute to both nutritional and livelihood security of the people residing in the Himalayan region. Understanding the diversity of these fishes in the Asiatic region, particularly in India will help to take up science led innovative programmes for their rehabilitation and conservation. This comprehensive review highlights the need for further intensive research to resolve the species ambiguity of snow trouts in the region.

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