When nature decides who stays and who goes: Priority effects extirpating the non-native brown trout *Salmo trutta fario* L. population from a Himalayan river

Climate-induced stochastic events bring forth idiosyncratic changes in habitat and community assemblage patterns of an area. Nature governs its priorities in such incidents, where native taxa are preferred over the invasive 'late-comers', thus leading to extirpation of the latter, according to the concept of 'priority effects'[1]. This stronghold of nature strictly comes into play when an ecosystem is least altered from its natural state. River Asiganga in Uttarakhand, India was chosen as a case study to understand this theory, where cloudburst-induced flash floods are considered to be a reason for the complete wipe-out of non-native brown trout (*Salmo trutta fario*), leaving behind the native snow trout (*Schizothorax* species).

High adaptability and plasticity in terms of life-history traits render the brown trout as one of the most invasive fishes causing extinctions of native species across the globe[2]. Owing to its high establishment rates and predation pressures, the brown trout was also threatening endemic fish biodiversity of Himalayan rivers[3]. This has been observed in Asiganga, where brown trout was reported predating the snow trout fingerlings[3]. Snow trout belongs to the sub-family Schizothoracinae, which originated in Asia during the first interglacial period[3,4]. Brown trout, on the other hand, is an evident 'late comer' in this area. It was introduced into India during the British reign, mostly for sport and commercial purposes[5]. Dodital, a natural high-altitude cold lake (3075 amsl), also the origin of River Asiganga, was one of the major stocking sites of exotic trouts in Uttarakhand during 1910 (refs 6, 7). The brown trout established itself thereon throughout the river, until its confluence with the Bhagirathi at Gangori.

Asiganga is characterized by its torrential flow regime with diverse habitats. The geographical area of the river is infamous for multiple flash floods and unstable topography, owing to active processes of erosion[7,8], thus rendering the river highly vulnerable to aberrant changes in hydrology. However, there was no report of flood events influencing fish species composition and assemblage structure in the past[3,9].

A major cloudburst on 3 August 2012 led to a massive flash flood, which unexpectedly changed the flow regime and habitat structure of the river. A fivefold increase in discharge was recorded for Asiganga, rising from 135 to 2665 m^3/s in merely an hour[8]. It took a toll on human lives ($n = 35$) and property (Rs 61,244.12 lakh). Such stochastic aberrations in flow result in habitat changes, undoubtedly affecting the freshwater fauna of any river.

There was no study thence conducted in this river basin which could reveal the impacts of such a drastic event on ichthyofauna. However, long-term studies preceding this event reported abundant brown trout in Asiganga along with native snow trout population[3,8–12]. Studies conducted just before the flash flood by the present authors, corroborated the same[13]. Further, there have also been occasional records of other native fishes, viz. *Naziritor chelynoides*, *Glyptothorax conirostris*, *Pseudecheneis sulcata* and *Nemacheilus rupicola* in Asiganga[8,13].

As part of the ichthyofaunal studies under the National Mission for Sustaining the Himalayan Ecosystem (NMSHE) project, surveys were conducted from June 2017 to June 2018 at 14 points along the river, with an interval of 500 m from downstream to upstream starting at Gangori. Cast nets (100 and 30 mm mesh size) were casted 16 times at each sampling point. After casting, the nets were allowed to stay for about 3 min, and then skillfully retrieved. Drag and minnow nets were also used which resulted in the encountering of snow trout fingerlings.

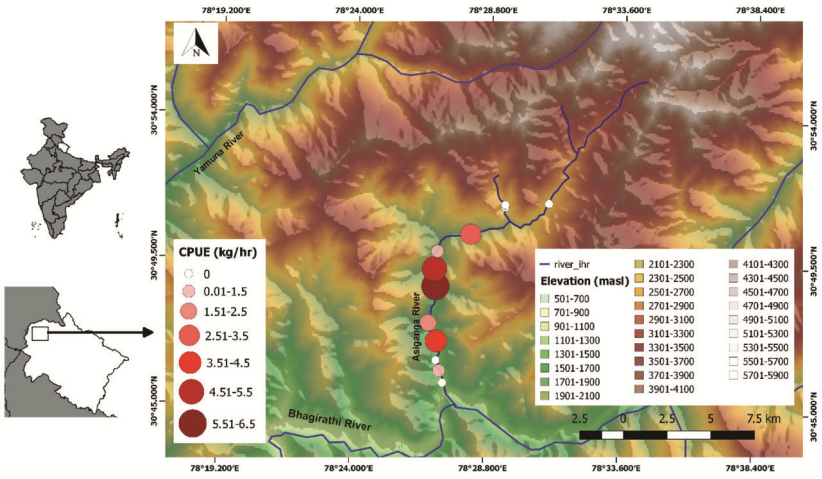

Figure 1. Map of the study area with CPUE (kg/h) of snow trout along the sampling sites of River Asiganga.

Figure 2. Snow trout caught during sampling in River Asiganga.

In total, 18 surveys with 124 casts for a duration of 11.13 h were carried out. The catch per unit effort (CPUE) of the cast net was calculated by dividing the catch of each sampling site by the number of hours fished. The average CPUE from a catch containing only the snow trout was 1.75 kg h^{-1}, ranging between 0.22 and 6.14 kg h^{-1}, while no individual of brown trout was encountered throughout the year (Figures 1 and Figure 2). Therefore, we elucidate the extirpation of non-native brown trout from the Asiganga. The present observation clearly underlines the 2012 flash flood as the undoubted reason for extirpation of brown trout population from Asiganga.

Continuous modifications in hydrological patterns over the years must have made the native snow trout much more resilient to natural stochasticity than the exotics; thus helping in their retention[1]. There have been various studies that determined the causes for success and failure in establishments of invasive fishes. Deer Creek in California, USA with entirely natural and unaltered flow regime, was reported free of non-natives when sudden events of altered hydrology served as environmental resistance[14]. Another study on Eel River reported the occurrence of resilient natives in river sections with natural hydrology, whereas the non-natives resistant to natural aberrations, were minimally encountered therein[15]. On the contrary, tributaries of Santa Cruz River, Arizona, USA documented extirpation of natives, when the upstream was dammed. However, in areas where flash floods were prevalent and flow was natural, non-natives were washed out from the basin[16].

A river, unaltered by human interventions, provides greater probabilities for natives to occupy their original niche in lieu of extirpation of competitive non-natives. This is due to the long acclimatization and co-evolution of native fishes with temporally changing hydrology and geomorphology. A dam, as is the case of Santa Cruz River, creates a permanent static and stable habitat, which is perfectly controlled even under extreme vagaries of hydrological patterns. Such a habitat builds favourable conditions for non-natives, which stay safe from local wipe-out scenario such as flash floods[17].

Extirpation of the brown trout population in Asiganga is a perfect instance of 'priority effects' in a natural system[1]. Although this invasive species is highly resilient to varied habitats worldwide, the extreme entropy of nature, like the Asiganga flash flood, is a positive indication where nature takes decisions in favour of native biota. Asiganga nevertheless being an unaltered river, would provide equal opportunities to leading freshwater invaders like the brown trout, if environment and habitat favour it in the future. The resurgence of brown trout in Asiganga, if it occurs, would lead to a better understanding of adaptive capabilities of both the brown trout and snow trout; the former towards environmental resistance and the latter towards biological resistance due to the invasive brown trout.

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AASHNA SHARMA[1]
VINEET KUMAR DUBEY[1]
PRAKASH NAUTIYAL[2]
JEYARAJ ANTONY JOHNSON[1]
YOGESH KUMAR RAWAL[3]
KUPPUSAMY SIVAKUMAR[1,*]

[1]*No. 18 Chandrabani, Wildlife Institute of India, Dehradun 248 001, India*
[2]*Aquatic Biodiversity Unit, Department of Zoology and Biotechnology, Hemwati Nandan Bahuguna Garhwal University, Srinagar 249 161, India*
[3]*Department of Zoology, Panjab University, Chandigarh 160 014, India*
**For correspondence.*
e-mail: ksivakumar@wii.gov.in