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Potential impacts of non-native fish on the threatened mahseer (*Tor*) species of the Indian Himalayan biodiversity hotspot

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Abstract

1. Mahseer (*Tor* spp.) fish species are critical components of locally adapted freshwater food webs across the Indian Himalayan biodiversity hotspot. However, multiple human stressors compounded by climate change have significantly depleted their populations over recent decades.

2. Mahseer species in many regions are now considered locally vulnerable or endangered. Hydropower projects in particular have fragmented populations, impairing genetic exchange, obstructing migratory paths, and changing the structure and functioning of riverine habitats, especially of formerly fast-flowing rivers.

3. Worryingly, literature survey and group discussions reveal that the increasing spread of non-native fish species further compounds threats to mahseer and overall freshwater ecology. Better understanding of the current distribution, habitat requirement and dispersal of non-native fish is therefore essential to manage the growing threats to mahseer in the Indian Himalayan region.

Keywords: human stressors, climate change, freshwater, Hindu Kush Himalaya, India, invasive species

1. INTRODUCTION

Although critical for the region's economy, with potentially significant impacts on water security across the broader Hindu Kush Himalayan (HKH) region, the Indian Himalayan (IH henceforth) rivers continue to be adversely affected by many human impacts, aggravated by climate change (Gupta et al., 2015). By 2050, temperature across the IH region is projected to increase by about 1-2°C compared with a 1960s baseline; the monsoon is expected to become longer/more erratic; precipitation is projected to change by 5% on average; and the intensity of extreme rainfall events is likely to increase (Shreshtha et al., 2015). Furthermore, climate models project substantial losses in glacial mass and area in the coming decades (up to 2030/2050/2100) for most parts of the IH region (INCCA, 2010).

The prevalence and spread of non-native fish species potentially compound pressures on rivers. These species can adversely affect native fish through hybridization (native x introduced fish), spread of novel pathogens, detrimental impacts on local food web and habitat structure, contaminant transfer, preferentially prospering in simplified hydrological regimes, and other competitive mechanisms (Gupta & Everard, 2019). Differing life strategies between native and introduced species (e.g. silver carp are filter feeders whereas common carp tend to dig up sediment) can change the character and functioning of whole ecosystems, in addition to direct competitive impacts, potentially changing the physical structure, water quality and species balance in river systems, particularly where modified by other human pressures. This article addresses the contributory stressor of the impacts of non-native fish species on mahseer fishes (cyprinids of the genus *Tor*), considering measures required to address this emerging concern.

2. NATIVE FISH SPECIES OF THE INDIAN HIMALAYA

A rich native diversity of freshwater fish fauna is supported by the IH region's numerous perennial and seasonal rivers. Numbers of freshwater fish species reported from the IH region (comprising the 12 IH states of Arunachal Pradesh, Assam, Himachal Pradesh, Jammu and Kashmir, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, Uttarakhand and West Bengal) (Figure 1) varies significantly from >60 species to >260 species (approximate range owing to conflicting numbers among available peer-reviewed and unpublished literature).

Fish variability (variability in species assemblages in different places) reflects both the adaptation of different species to specific local conditions, but also their vulnerability to ecosystem change. Many of these recorded species are included in the IUCN Red List of Threatened Species (IUCN, 2018): six of total IH fish species are classified as Endangered, 10 as Vulnerable, and all experience varying population trends. Regardless of conservation status, native fish species in IH rivers constitute primary resources for local uses and trade, including as sources of food or as game fish (for catch-and-release angling). They thereby benefit numerous IH mountain communities (Balti,

Arghons, Kinnaure, Lahules, Pangwal, Tharu, Bhotia, Jaunsari, Raji, Bhutiya, Lepcha, Apatani and Nyishi tribes), who are highly dependent upon local natural resources.

2.1 THE INDIAN HIMALAYAN MAHSEER (*TOR*) SPECIES

The Indian Himalayan mahseer (*Tor* spp.) are endemic to India and found in the Himalayan rivers (Figure 2). Its native name, mahseer ('maha seer'), refers to its large head or it being the 'great tiger' of the river. The mahseer are an internationally sought-after game fish (Pinder, Raghavan and Britton, 2015). Adult fish can exceed 3m in length, making it one of the largest freshwater fishes in India. Importantly, mahseer species have been described as having key ecological roles within rivers (i.e. top predators in the absence of mugger gharials, determinants of food chains, keystone species) (Everard & Kataria, 2011). This ensures that their protection leads to a range of ecological benefits through the protection of habitats and associated species (Gupta, Sivakumar, Mathur and Chadwick, 2014).

Over-exploitation of fishes and the ecosystems that support them, combined with broader pressures leading to deteriorating environmental conditions (Figure 3), are the most probable factors explaining the marked decline in mahseer species observed in some IH rivers (Nautiyal et al., 2013). Mahseer and many other IH riverine fish species depend on the rocky beds of streams and rivers, many of them in moderately cold climatic regions. This renders them susceptible to rapid development-driven changes along these vulnerable linear habitats, the cumulative pressures from which reduce the distributional ranges of different species fragmenting them into a small number of major river systems with a commensurate increase in population vulnerability. The size (length and weight ratio) of numerous large fish species has also been observed to be decreasing in a number of IH rivers (Gupta et al., 2014). Large fish are often only found now in some larger perennial pools, often enclosed within the legislative boundaries of protected areas (National Parks, Wildlife Sanctuaries, Community Reserves, Conservation Reserves) or safeguarded by temple sanctuaries or by religious taboos and traditions (Gupta et al., 2015).

Declines in populations of mahseer species in their natural habitat have been attributed to urbanization, indiscriminate fishing, overexploitation, removal of riparian vegetation, and chemical and physical alterations of natural habitat (Everard & Kataria, 2011). These species have unique mesohabitat requirements that vary between seasons, ranging from pools and glides in fast-flowing streams and rivers with boulder and cobble substrates. Juveniles are often observed in riffle habitat over finer gravel/sand substrates. As a result, aggregate mining (for sand and boulders from river beds) (Gupta et al., 2015) has a potentially major impact on the species using these habitats as juveniles or for breeding.

Growing numbers of hydropower projects in the IH place additional stresses on the populations and structure of mahseer communities (Rajvanshi et al., 2012). Adverse ecological impacts from

dams include habitat fragmentation and deterioration, particularly resulting in the loss of crucial spawning and nursery habitats, with wider adverse impacts on biological diversity arising from modifications to water quality, flow regimes, and sediment flows including both siltation in stilled flow but also failure to replenish habitat in sediment-starved reaches downstream of the impoundments (World Commission on Dams, 2000). Hydropower projects also disrupt longitudinal connectivity by creating barriers to migration, and can also change local microclimate (temperature, precipitation, etc.) compounding threats to mahseer populations. Further pressures on populations arise from lack of adequate legal protection as fish are not included within the definition of 'wild animals' under India's Wildlife (Protection) Act 1972 (Pinder & Raghavan, 2013), creating no incentive or requirements to consider the needs of fish in dam design. Water discharge is a further key driver of fish distribution patterns in IH rivers, with low 'environmental flows' and changes to the annual hydrograph of rivers having profound implications for mahseer. Knowledge gaps relating to the ecological needs and distribution of the numerous mahseer fish species create further obstacles to their protection and sustainable management (Nautiyal et al., 2013). For example, little robust information is available about their critical spawning and nursery habitat requirements.

3. NON-NATIVE FISH OF THE IH REGION

Non-native fish species are defined as those introduced beyond their native range either deliberately (e.g. to support aquaculture, enhance a reservoir or a recreational fishery, by the ornamental fish trade or for mosquito control), accidently (e.g. through bait releases, aquaculture escapes, or ballast water transport) (Gupta & Everard, 2017) or in pursuit of well-intentioned but ill-informed religious practices (Everard, Pinder, Raghavan, & Kataria, 2019) (Table 1). Such species have the potential to affect native fish species adversely by producing a greater number of offspring, preying on native species, having a higher growth rate, a larger body size and longer life span, or competing for similar food resources and habitat (Ricciardi & Rasmussen, 1998).

Data obtained through extensive field studies (2010-2018 by ME and NG) and an in-depth literature survey using Google Scholar (326 peer-reviewed and non-peer reviewed papers, and a range of unpublished articles read in full and included in the analysis) provided an evidence base of non-native fish species recorded from the IH region (Table 1). Unstructured group discussions were also conducted with communities residing along the banks of the IH rivers (n=189; 179 males, 10 females; 16-72 years). The guiding questions were: (a) What is your age? (b) What is your gender? (c) Do the carps and trout feature in your daily fish landings? (d) Do these non-native species contribute to your daily income as much as the local species? (e) Are these non-natives more preferred for personal consumption? (f) Any other comments.

The respondents were from the communities located along the rivers. As many households as possible were approached to ensure that a significant number of responses were obtained for the

analysis. The community selection was based on the voluntary willingness and the availability of members in the study area. Consent was requested and obtained from all the participants to make notes of the conversations. All responses were kept anonymous so that respondents felt free to express their views. Discussions took place primarily in Hindi. Gender sensitivity was considered, including questioning of women by a female member of the research team, although no inhibition was encountered in wider discussions with female or other informants. Conversation flowed freely with no evidence of it being dominated by any individuals. Researchers fluent in Hindi translated the responses, taking written notes in English and collating them following the meeting. Additional input was derived from literature searches (as seen in the citations used in this paper).

The unstructured group discussions showed that, although non-native species (carp and trout species) were featuring to a great extent in daily fish landings and were retained for personal consumption or sale in the local markets, the market value of these species was significantly less in comparison to previously caught native fish (e.g. 1 kg of mahseer fish can sell for INR 500-1000 (USD 8-16) in the local fish market, in comparison with greatly fluctuating prices of non-native fish species due to their high availability). In addition, respondents, especially females, mentioned that the 'taste' of the 'new arrived fish' was 'not as good as a mahseer' (*Tor* spp.) hence, not preferred by the head of their households (the oldest decision-maker currently residing with the family).

The data obtained showed that records of the non-native fish species with known distribution increased between the years 1970–2000, 2001–2010 and 2011–2017 in five of the IH States (Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh), indicating their increasing pervasion across the IH region (Figure 4). Available literature suggested that the distribution of non-native fish species is increasing in the IH region over the 2011–2018 period compared with their original sites of introduction (Table 1, Figure 4). Although this pattern could reflect increasing numbers of research papers published in 2011–2017 (66 published papers) reflecting increased field research relative to the periods 1970–2000 (11 papers) or 2001–2010 (35 papers), informal discussions with freshwater researchers (N=17) working in the IH region for the past decade supports the perception that increasing numbers of non-native species were found by more recent surveys (NG, pers. comm.).

With the exception of six non-native species for which insufficient data were available (eastern mosquitofish (*Gambusia holbrooki*), western mosquitofish (*Gambusia affinis*), eastern brook trout (*Salvelinus fontinalis*), splake trout (*Salvelinus namaycush* x *Salvelinus fontinalis*), Atlantic salmon (*Salmo salar*) (currently under investigation – it may be a misidentified trout as this species would struggle to live out its adult life stage in warm water), and Nile tilapia (*Oreochromis niloticus*)), the seven remaining species and subspecies (common carp (*Cyprinus carpio carpio*), brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), mirror carp (*Cyprinus carpio specularies*), silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*)

and crucian carp (*Carassius carassius*)) had increased their present distribution significantly from their original region of introduction (Table 1). Some of these species for which data are not available also need to be studied to ensure that they have not established stable populations in smaller patches in the region (Gupta & Everard, 2019).

First records of non-native fish species from the IH region verified by one of the authors (AB) in early November 2017 provide additional evidence that invasions are increasing. These include brown trout (1500-2000 g in weight) from the upper reaches of Siyom River (Arunachal Pradesh, 2000-2500 m); brown and rainbow trout downstream of Tawang-Chu River (Arunachal Pradesh, 4000m); and the wallago catfish (*Wallago attu*) and bullseye snakehead (*Channa marulius*) from the Kameng/Jia Bharali and Buroi rivers (Assam/Arunachal Pradesh). Changes in fish species diversity, particularly the establishment and proliferation of these non-native species, can further undermine ecosystem vitality and functioning, particularly in already-disturbed habitats, putting native mahseer species under additional threat.

It is important to note that non-native fish species are likely to have adverse impacts on the native mahseer species, especially when coupled with the increasing human impacts and projected climate change in the region. The authors are of the opinion that mahseer are affected where rivers have been converted into reservoirs. These reservoirs can support native species provided that non-native fish are absent, and this is well documented in the case of Gobindsagar reservoir in the Indian Himalayan state of Himachal Pradesh. In addition, non-native fish are hardy/tolerant species and have high reproductive rates, whereas natives are sensitive and have poor growth and reproductive rates (ca. 10 cm yr^{-1} [Nautiyal, 2012]).

From the available literature for the region, there is no report, record or study on the direct impact of non-native species on mahseers. This study is the first of its kind highlighting this important issue. Although no direct interactions have been observed between adult brown trout and mahseer, in some places the spawning grounds of mahseer in the upstream reaches of the Indian Himalayan rivers overlap with brown trout habitats. For example, adult mahseers are present in the middle reach of the Pindar River (a tributary of the Alaknanda River), whereas in the upstream areas (Malkhet region), both brown trout and mahseer young have been observed by the authors. It could be assumed that being carnivorous, brown trout may impair the recruitment of mahseers in this particular habitat. In addition, the authors have observed that most of the mahseer habitats in Northeast India (especially in lower reaches) are slowly being infiltrated by a few species of the carnivorous warmwater fishes of the Brahmaputra valley.

4 DISCUSSION

Management of non-native fish to protect mahseer species has yet to feature as a central concern and management priority in the IH region. Knowledge gaps constitute major impediments to the

sustainable management of the mahseer and wider biodiversity in IH rivers, particularly with respect to potential impacts on associated services compounding the observed increasing human stressors and climate change impacts. It is therefore worrying that there is a lack of mahseer-specific strategy in the Indian Himalayan State Action Plans on Climate Change (SAPCC) to address the potential impacts of non-native fish species. As most SAPCCs are currently being revised, the findings of this study can provide baseline information to the continuing amendment of these plans if satisfactorily conveyed to State Climate Change Nodal Officers, informing a precautionary approach to appropriate and anticipatory management actions. The role of mahseer and other native species as indicators of overall system vitality and ecosystem service provision may serve as a more powerful lever for policy reform than fish conservation in a more isolated sense.

Strategic early intervention in management of the spread of non-native fish species may yield significant benefits across the IH region through water security and ecosystem service enhancements, providing a primary justification for prioritizing management activities. Conversely, neglecting non-native fish species invasions represents a potentially serious risk, compounding problems that may be less easy to manage as invasive species become established and naturalized. It is also important to recognize that benefits from positive ecosystem management extend beyond local scale, including up to catchment scale (water quality, hydrology, nutrient flows, etc.) and global scale (carbon storage), creating further impetus for precautionary responses.

The management of non-native fish species in the region will also be an effective delivery platform for international commitments such as the UN Sustainable Development Goals (SDGs), Disaster Resilience Reduction (DRR) under the Sendai Framework, and climate commitments including those under the Paris Agreements 2015 pertaining to adaptation (securing water resources in a changing climate). Practical management of non-native fish species will also be consistent with international approaches to nature conservation, for example under the Aichi Biodiversity Targets, including Target 9: 'By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment'.

For the Indian Himalayan region, eradication by removal programmes or containment of non-native species could be attempted from specific reaches of rivers densely populated by non-native fish. Initiatives to manage and control non-natives have been promising against the common carp in Australia, and the topmouth gudgeon *Pseudorasbora parva* in England and Wales (Britton, Gozlan, & Copp, 2011). Nonetheless, it will be important to assess first the risks posed by non-native species on the mahseer in the region through rigorous field studies. Furthermore, it will be beneficial to rule out the species which do not share the same habitat of mahseer, and focus on those that do, with the potential for impact on the native mahseer.

Policy-makers need to be informed about the significance of invasion by non-native fish species. Further research is recommended to build upon the current, still fragmented knowledge base, augmenting it with scientific study on trends in water quantity and quality, on populations of both mahseer and invasive fish species, and on feasible control and mitigation measures. The results can then be used to revise and implement policies for positive management of mahseer and other natural resources.

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Table 1: Non-native fish species in the IH region (modified from Gupta and Everard, 2019)

Common name	Scientific name	Introduced region; year of introduction	At present reported from
Common carp	*Cyprinus carpio carpio*	Jammu and Kashmir; 1956	Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh
Brown trout	*Salmo trutta*	Jammu and Kashmir; 1899	Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh
Rainbow trout	*Oncorhynchus mykiss*	Jammu and Kashmir; 1904	Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh

Mirror carp	*Cyprinus carpio specularis*	Himachal Pradesh, Uttarakhand; 1947	Himachal Pradesh, Uttarakhand
Silver carp	*Hypophthalmichthys molitrix*	Himachal Pradesh; 1971	Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh
Grass carp	*Ctenopharyngodon idella*	Uttarakhand; 1971	Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh
Crucian carp	*Carassius carassius*	Jammu and Kashmir; 1956 – 1958	Jammu and Kashmir, Uttarakhand
Eastern mosquitofish	*Gambusia holbrooki*	Data not available	Jammu and Kashmir
Western mosquitofish	*Gambusia affinis*	Data not available	Jammu and Kashmir, Uttarakhand
Eastern brook trout	*Salvelinus fontinalis*	Jammu and Kashmir; 1969	Data not available
Splake trout	*Salvelinus namaycush* x *Salvelinus fontinalis*	Jammu and Kashmir; 1959 – 1970	Data not available
Atlantic salmon	*Salmo salar*	Jammu and Kashmir; 1959 – 1970	Data not available
Nile tilapia	*Oreochromis niloticus*	Data not available	Jammu and Kashmir

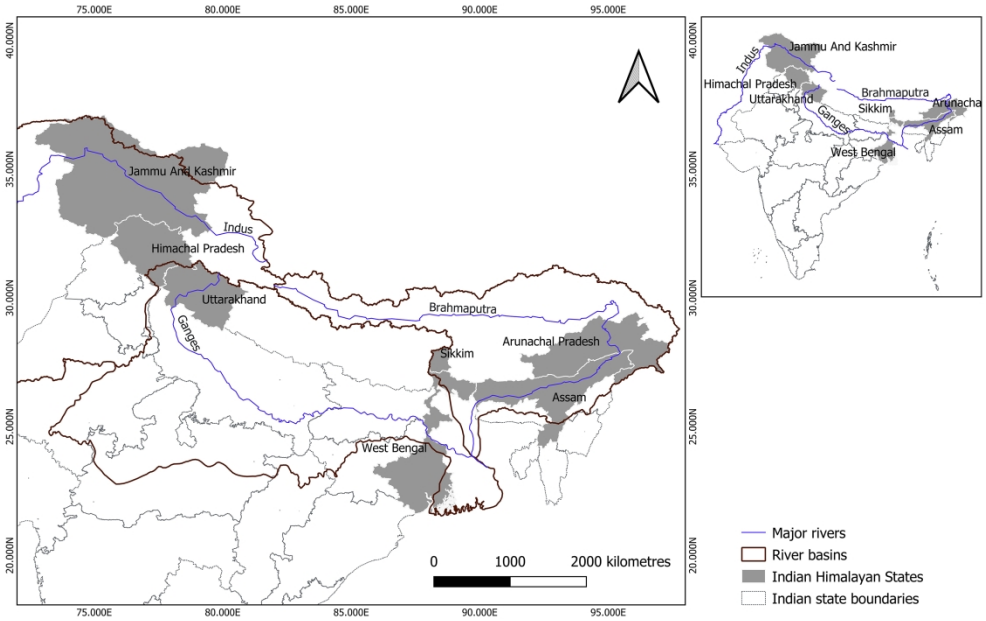
Figure legends

Figure 1: The IH States examined for this study, and major rivers of the Indian Himalayan region

Figure 2: The golden mahseer (*Tor putitora*) of the Indian Himalayan region (Photo credit: Misty Dhillon)

Figure 3: Sand mining from the Kosi River in the Indian Himalayan State of Uttarakhand (Photo credit: Nishikant Gupta)

Figure 4: The current distribution of non-native fish species (1970 – 2000; 2001 – 2010; 2011 – 2017) in the IH States (Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh)



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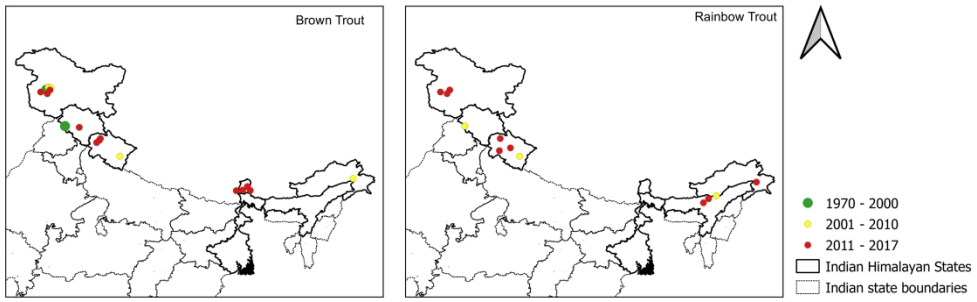

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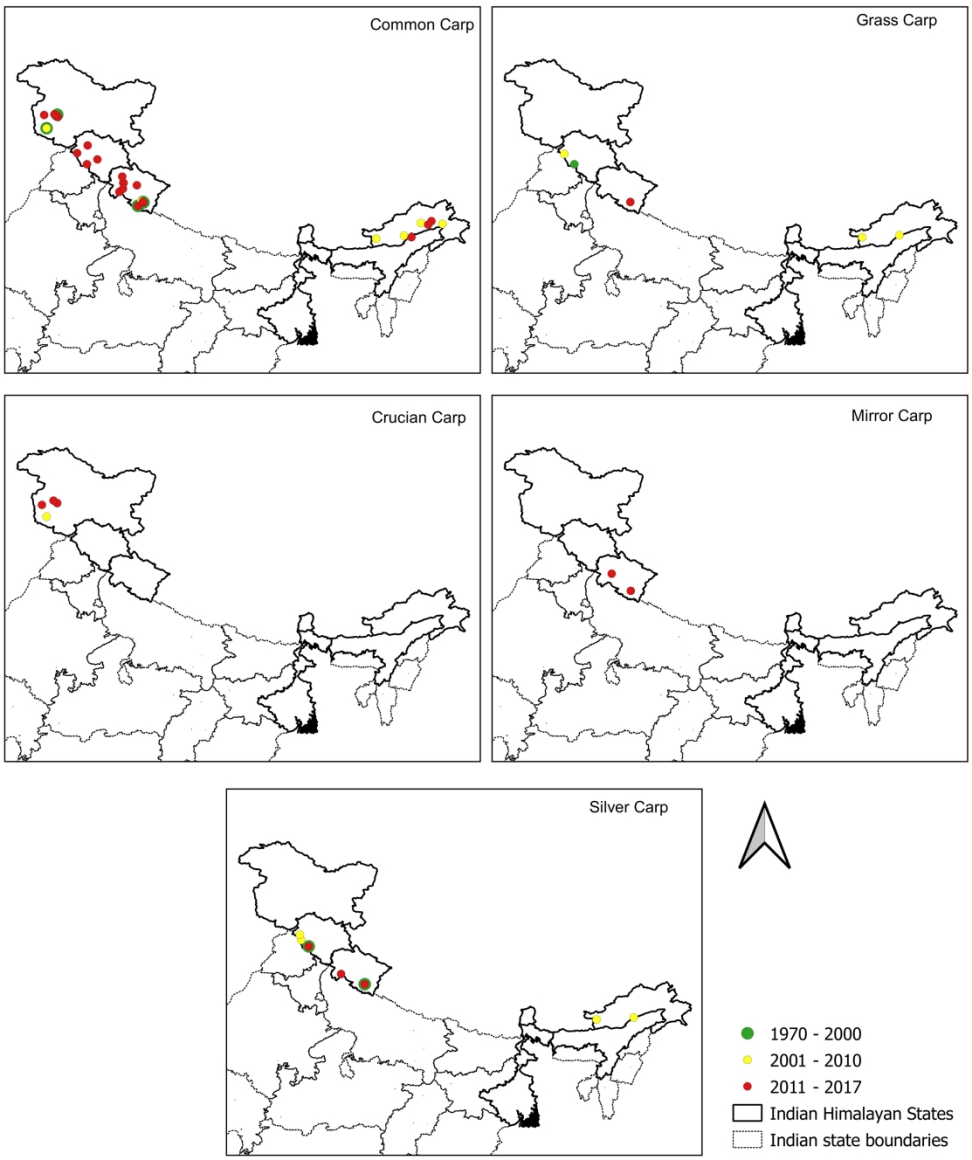

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