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Identifying potential causes of fish declines through local ecological knowledge of fishers in the Ganga River, eastern Bihar, India

Subhasis Dey[1,2] | Sunil Kumar Choudhary[2] | Sushant Dey[1] | Kadambari Deshpande[3,4] | Nachiket Kelkar[3,4]

[1]Kanchi Sahu Lane, Bhagalpur, Bihar, India
[2]University Department of Botany, T.M. Bhagalpur University, Bhagalpur, Bihar, India
[3]Ashoka Trust for Research in Ecology and the Environment (ATREE), Bangalore, Karnataka, India
[4]Manipal Academy of Higher Education (MAHE), Manipal, Karnataka, India

Correspondence
Nachiket Kelkar, Ashoka Trust for Research in Ecology and the Environment (ATREE), Srirampura, Jakkur PO, Bangalore 560064, Karnataka, India.
Email: nachiket.kelkar@atree.org

Abstract
Local ecological knowledge (LEK) can offer insights into fisheries management by describing long-term changes that are difficult to unravel in data-poor river-floodplain fisheries. LEK is derived from complex interactions between fishers' observations of environmental change and their institutional capacities to manage fisheries. Hence, it is important to understand where and how LEK and formal scientific studies on fish species' decline could complement each other. In this paper, the causes of decline of 58 fish and two shrimp taxa were identified from LEK data (1999–2019) obtained from river–floodplain fisheries of the Gangetic plains (Bihar, India). Qualitative analyses of LEK were used to generate species-specific hypotheses and historical insights on their declines. Destructive fishing, overfishing and the Farakka barrage were cited by fishers as the major causes of declines. Potential reasons for these perceptions were explored in relation to fishers' experiences of conflicts in the region over fishing rights and access.

KEYWORDS
barrages, destructive fishing, fishery conflicts, Gangetic plains, overfishing, river-floodplain capture fisheries, species declines

1 | INTRODUCTION

Riverine capture fisheries are dynamic and complex socio-ecological systems that support the livelihoods and protein needs of millions of people across the developing world (Lynch et al., 2016; Welcomme et al., 2010). River–floodplain fish diversity and fisheries productivity have been globally threatened by large-scale flow alterations (dams/barrages/embankments), water pollution and intensive resource extraction over the last few decades (Dudgeon, 2011; Welcomme, 1995). Management of riverine fisheries with the aim to prevent overfishing (Allan et al., 2005; Stergiou, 2002) is often confronted with systems experiencing scarcity and unpredictability in relation to hydro-climatic variability and extremes of change (Halls & Welcomme, 2004; Tockner & Stanford, 2002; Vass, Das, Srivastava, & Dey, 2009). It is thus often difficult to disentangle impacts of overfishing from environmental drivers of change (Gamble & Link, 2009; Johannes, Freeman, & Hamilton, 2000; Stergiou, 2002). Further, long-term data on fish catches, total fishing effort and fish responses to impacts of environmental change and fishing pressure are non-existent or limited in most small-scale tropical fisheries (Bartley, Graaf, Valbo-Jørgensen, & Marmulla, 2015; FAO & WorldFish Center, 2008). Along with large-scale declines in river fisheries, inland aquaculture dominates most policy thinking and fisheries research in developing countries (Belton, Josepha, Asseldonk, & Thilsted, 2014; Katiha, Jena, Pillai, Chakraborty, & Dey, 2005). These changes have created significant knowledge gaps with consequences for the sustainable

Nachiket Kelkar and Subhasis Dey should be considered joint first authors.

management of tropical riverine fisheries. Most river-based fisheries have low-level capital and technological inputs leading to low revenue generation (FAO & WorldFish Center, 2008). As a result, capture fisheries are treated marginally or neglected in national and local policy-making and need specific attention (Béné, 2003; Deb, 2009; Smith, Khoa, & Lorenzen, 2005).

In this context, documenting and integrating insights from local ecological knowledge (LEK) of fishers with scientific monitoring can enable estimation of historical changes in data-poor inland capture fisheries (Campbell, 2007; Leite & Gasalla, 2013; Poizat & Baran, 1997; Silvano & Valbo-Jørgensen, 2008; Wilson, Raakjær, & Degnbol, 2006). Local ecological knowledge refers to experiential, adaptive, practice-based learning and accumulation of relevant knowledge by people who depend strongly on ecosystems (Berkes, Colding, & Folke, 2000; Fazey, Fazey, Salisbury, Lindenmayer, & Dovers, 2006; Santha, 2008; Lertzman, 2010; Davis & Ruddle, 2010). The continuity of local ecological knowledge systems depends on the institutional capacities of fishing communities to access and manage fisheries (Butler, 2005; Farr, Stoll, & Beitl, 2018; Wilson et al., 2006). River–floodplain fisheries often tend to be open access (Allan et al., 2005) and comprise of culturally heterogeneous and diffuse fisher groups, usually with weak institutional support (Béné, 2003; Deb, 2009; Lynch et al., 2016). Perhaps as a result, studies on local ecological knowledge from coastal and marine fisheries are more common (Drew & Henne, 2006) than from riverine or other inland capture fisheries (Jahan, Ahsan, & Farque, 2017; Silvano & Valbo-Jørgensen, 2008). Renewed attention to LEK has emerged from the limitations of formal science in estimating long-term changes in fisheries (Johannes et al., 2000). Ecological and socio-cultural regime shifts have to be connected to local knowledge on fisheries (Deb, 2015; St. Martin, McCay, Murray, Johnson, & Oles, 2007; Moller, Berkes, O'Brian Lyver, & Kislalioglu, 2004; Ruddle & Davis, 2013; Santha, 2008).

LEK representation is also motivated by local cultural politics and their interconnections with global concerns of environmental conservation (Murray, Neis, & Johnsen, 2006; Neves-Graça, 2006). Beyond just documenting or 'calibrating' scientific inferences, inclusion of LEK in fisheries management can give voice and participation to local fishers who have faced historic conflicts and social injustice (Agrawal, 1995; Deb, 2015). LEK can empower fishers affected by pressures of state power, neoliberalism and other local inequities that can alienate them from their livelihoods (Ruddle & Davis, 2013). This can help prevent the erosion of LEK and help fishers engage with policymakers by articulating their own experiences of environmental variability and fisheries management strategies (Agrawal, 1995; Aikenhead & Ogawa, 2007; Chambers & Gillespie, 2014; Matsui, 2015). LEK is also important in the historical and geographic sense. Under colonial management of river fisheries, scientific arguments were employed to justify control over 'erratic' or 'ignorant' fishers and address conflicts over fishery rights (e.g. see Day, 1877). Similarly, management principles from commercially intensive temperate fisheries have often been applied to small-scale, subsistence level tropical fisheries (Neves-Graça, 2006; Nygren, 1999). Representation of LEK can help understand conflicts between different knowledge systems on how river fisheries could be better managed (Kolding & van Zwieten, 2011; Pauly, Froese, & Holt, 2016; Reeves & Duncan, 2009; Welcomme, 1995, 1999; Winemiller, 2005).

Beyond the normative drive for levelling the fields of LEK and formal scientific enquiry (which are often considered ontologically and epistemologically disparate knowledge systems; Raymond et al., 2010), there is pragmatic desire for integration (Brook & McLachlan, 2008; Huntington, 2000; Lertzman, 2010; St. Martin et al., 2007; Moller et al., 2004). Murray et al. (2006) argued that the ontological division might be artificial. They showed that LEK systems are embedded in wider social networks, market linkages and scientific discourses. Thus, there is regular exchange of information between locally situated knowledge and the larger domain of science, as both complement each other. Even so, the scope to enhance linkages between LEK and formal science might be lost or be rendered irrelevant in changing fisheries and fisher communities experiencing rapid hydrological and climate change (Drew & Henne, 2006; Gómez-Baggethun & Reyes-Garcia, 2013; Aswani, Lemahieu, & Sauer, 2018). Degradation and transformation of LEK are also likely to negatively affect biodiversity conservation and sustainable fisheries efforts involving local communities (Aswani et al., 2018). Berkes et al. (2000) showed that LEK comes about through long-sustained iterations of trial-and-error and learning practices that converge upon principles of adaptive resource management. Gómez-Baggethun and Reyes-García (2013) commented that LEK is not a mere proxy for adaptation. Instead it is a dynamic response to changing ecological and social conditions that also change its relevance. For example, knowledge might rapidly evolve with new technology or changes in fish community composition, but may be lost in case of species extirpation. The origins of LEK lie in the everyday struggles of fishers to cope with natural variability and navigate difficult social arenas for access to fishing areas (St. Martin et al., 2007; Ruddle & Davis, 2013). The complexity and interconnectedness of LEK differ sharply from compartmentalised approaches of scientific monitoring and reasoning (Aikenhead & Ogawa, 2007; Lertzman, 2010; Matsui, 2015). Thus, LEK is not a mere information category, but contains a kaleidoscope of subjective framings, narratives, mythologies, metaphysical beliefs and folk taxonomies to interpret fish diversity, ecological observations, experiences and surprises (Berlin, 1973; Berkes, Kislalioglu, Folke, & Gadgil, 1998; Berkes et al., 2000; Deb, 2009; Huntington, 2000; Neves-Graca, 2006; Sugiyama, 2001). Navigating and reinterpreting the complexity of LEK with formal scientific methods may be imperfect, but still important (Davis & Ruddle, 2010; Wilson et al., 2006). LEK studies therefore need sustained integration with ecology and conservation research (Brook & McLachlan, 2008), as well as anthropological and sociological studies (Butler, 2005).

The problems of *subjectivity* (Moller et al., 2004) and of *validation* (Matsui, 2015) are central to integrating LEK with scientific knowledge. Scientific studies that draw insights from LEK usually focus on validation (Davis & Ruddle, 2010; Deb, 2015; Gratani et al., 2011) so that consensus-based approaches to management can be developed (Aikenhead & Ogawa, 2007; Leite & Gasalla, 2013).

Subjectivities arise from interpretations of LEK, assertions of cultural politics, memories of change and history that accompany narratives of LEK (Agrawal, 1995; Moller et al., 2004; Sugiyama, 2001). The subjectivity of LEK affects whether validation is considered important and by whom (Gratani et al., 2011). New approaches address both issues and view knowledge as a larger 'social collaboration' for mutual learning by both LEK and formal science (St. Martin et al., 2007; Whyte, 2013). Here, LEK must be assessed critically, but with acceptance of what it is and why it is so (Ruddle & Davis, 2013).

In this spirit, information and insights were synthesised from long-term participatory engagement (1999–2019) with LEK systems of fishing people in the Ganga River, Bhagalpur district, Bihar, India. In the definition of LEK used in this study, traditional or indigenous ecological knowledge (TEK or IEK) is implicitly included, but discussions on the meanings of 'traditional' or 'indigenous' are left beyond the scope of this paper (see Kelkar, 2018 for a brief discussion on tradition in this fishery). The goal was to compile a database of local ecological knowledge (LEK) from experienced fishers in the region on 58 fish and two shrimp species. Using LEK data and fishers' perceptions, the primary objectives were as follows: (a) to generate hypotheses about causes of decline of fished species and (b) to assess qualitatively the likelihood of hypotheses on species declines, based on reported environmental changes (e.g. river flow alteration), fishery impacts (e.g. overfishing) and their links to fish/shrimp life-history traits. With these objectives, in-depth data collection on fishers' LEK and perceptions was conducted through interviews and interactive workshops. LEK information was then combined with published studies on causes of decline of fish species to detect convergences, divergences and surprises in the two sources of knowledge. How fishers' experiences of fishery conflicts could have influenced LEK and perceptions of change is also discussed. Finally, potential implications of LEK for fisheries management in the Ganga River were identified.

2 | METHODS

2.1 | Study area and historical context

The LEK assessment and database compilation focused on the Ganga River in the Bhagalpur district of Bihar, India (≈70 km from Sultanganj to Kahalgaon, Figure 1). Over 500 fisher families depend on the river and adjacent floodplain wetlands for fishing and allied activities. The largest fishing settlements are at Kahalgaon (Kagzi Tola), Bhagalpur (Barari) and Naugachia, apart from smaller clusters at Sultanganj, Janghira, Lailakh, Mirzapur, Bahattra, Tintanga and Raghopur (Figure 1). These fishers belong to marginalized communities from the Mallah (Nishad) and Gangota caste groups (including many sub-castes), who have experienced a long history of oppression, first at the hands of private owners of the fishery and later from 'mafia gangs' that took control of the open-access fishery on the Ganga River, through violence and extortion of catches. Details of these conflicts can be found in Kelkar and Krishnaswamy (2014), Choudhary, Dey, and Kelkar (2015) and Kelkar (2018). An adverse outcome of conflicts has been distress-induced labour migration of fishers to distant regions, many having by now permanently exited the dangerous setting (Kelkar, 2018). The department's association with fishers has existed since 1999 through long-term fisheries monitoring and research conducted in conservation programmes for endangered Ganges river dolphins and other biodiversity (Choudhary et al., 2015; Choudhary, Smith, Dey, Dey, & Prakash, 2006; Montana, Choudhary, Dey, & Winemiller, 2011). Documenting long-term

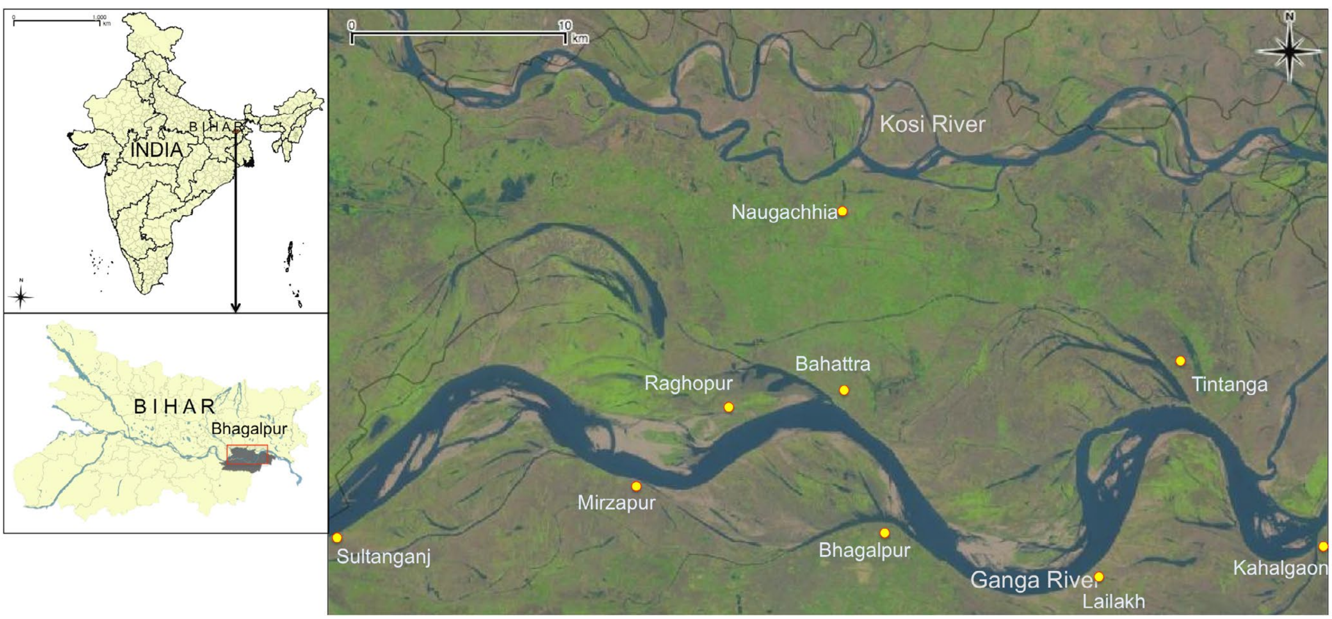

FIGURE 1 Map showing locations of fishing settlements in the Bhagalpur district, Bihar, India, from which local ecological knowledge (LEK) data were compiled for our study

insights from local ecological knowledge (LEK) is thus important to place environmental and social change in perspective, for the management of fisheries in the Ganga river–floodplain ecosystem.

2.2 | Data collection

2.2.1 | Identifying causes of decline of fished species from LEK data

Causes of decline of fished species were identified from long-term collection of LEK data from 110 fishers. Data collection was based on informal assessments (semi-structured/unstructured interviews at fish markets/landing sites/village corners, participatory exchanges, and during household surveys of socio-economic status and well-being of fishers) and a formal LEK assessment (group discussion and interactive workshop). Informal and formal assessments differed in the manner of recording information. In informal assessments (from 1999 to 2019), field notes were written and information recorded after interactions with fishers. From field notes, fishers' LEK narratives and perceptions were then used to extract LEK data. Informal assessments involved regular dialogue and mutual exchange of information between the fishers and authors (based on observations of both). For the formal assessment (in 2013), fishers were told in advance about the aim of the discussion, and information was directly recorded as they spoke. Details of the formal LEK assessment are provided below. Only male fishers were interviewed, because fisherwomen engaged only in local trade and never fished (Bibha Kumari, 2016).

2.2.2 | Formal LEK assessment

In March 2013, an interactive workshop and discussion programme was conducted to compile local ecological knowledge (LEK) about 60 commonly fished species' groups (58 fish and 2 shrimp taxa) in the river (Table 1). For this daylong workshop, ten veteran fishers aged between 60 and 85 years (with 40–60 years of active fishing experience) were invited. The workshop was moderated by the lead authors and reporting and database compilation tasks were shared across all authors. Workshop proceedings were simultaneously recorded in audio (.wav) format and information encoded in spreadsheet software. Species-wise LEK responses were entered so that row represented a fish species and the columns represented different ecological and fishing-related attributes. All participants were asked to share their own experiences on causes of decline of fish species, whose pictures would be projected on a screen. Old and recent maps of the region (to represent river channel course changes over time) were also displayed to help fishers in contextualizing their LEK responses. Participants responded in turns or passed answers, based on what they knew of particular species. The whole process was actively moderated to enable equal opportunity to all fishers to speak and participate. Contrasting experiences or debates, or even disagreements, were recorded in detail by rapporteurs and discussed after each species assessment. In case disagreements were due to differing spatial locations (of fishing) or variable perceptions about extent of declines, participants were urged to arrive at a consensus on the upper limits of some estimated attributes (e.g. spawning season duration). If consensus was not possible, all differing responses were recorded nonetheless. The workshop was undertaken in Hindi (with some respondents also speaking in the local *Angika* dialect) and in a friendly manner entirely respectful of the respondents' willingness to respond and by adhering to local customs. After the workshop, all recorded responses were scanned thoroughly in three iterations to ensure that no transcription errors remained in the database generated from the LEK workshop.

All information from informal sources (1999–2019) and from the workshop (2013) was included in a single LEK database. The database contained a species-by-attributes table for the chosen taxa. Specific observations, beliefs and reported perceptions on different species were stored in separate .txt files for further analyses.

2.2.3 | Assessing the likelihood of hypotheses on fish declines

'Average percent decline' for different fish species was calculated from fishers' reports over the last three decades, and different causes of decline under environmental or anthropogenic change and fishery impacts were categorised as the dominant themes. Percent declines of different species were correlated with their life-history traits (migratory behaviour, overlap of breeding season with catch season, habitat associations, movements). Causes of decline from LEK on fish life-history traits were compared qualitatively with published information to assess the degree of match between them. This helped arrive at testable hypotheses on causes of decline for different species. The derived hypotheses were assigned as low, moderate or high likelihood, based on Silvano and Valbo-Jørgensen (2008). The first criterion for assignment was the degree of consensus on the reported cause across fisher participants. The second was the qualitative extent of matching information between published studies on the species (Appendix S1) and the dominant perception of fishers. Due to limited published information on causes of decline for many species, there were cases when these criteria were not balanced (e.g. high consensus among fishers but lack of published information). Here, any of the two criteria were considered important. Additionally, (a) knowledge of all fish species was not uniform across fishers, (b) degree of consensus on species was variable and (c) some declines were better documented than some others in published literature. In such cases, LEK consensus was considered crucial in identifying potential causes of declines.

2.2.4 | Causes of decline in relation to fish life-history traits and fishery characteristics

Qualitative methods were used to summarise fuzzy and complex LEK data. In keeping with objective 2, causes of decline were assessed in relation to both life-history traits and fishery characteristics reported by fishers. From the LEK database, information on (a) species life-history traits (reproductive biology, migratory movements,

TABLE 1 List of species included in our LEK assessment

Family: subfamily[a]	Species[b]	Figure reference number[c]	Status in fisheries and reported % decline	Reported causes of decline (hypotheses)	Likelihood of hypotheses
Dasyatidae	*Pastinachus sephen* Forskkal 1775	–	R20–R45, −99	BD	High
Anguillidae	*Anguilla bengalensis* Gray 1831	–	R10–R45, −90	BD	High
Notopteridae	*Chitala chitala* Hamilton 1822	43	FY, −90	OF, DF	High
Notopteridae	*Notopterus notopterus* Pallas 1869	8	FY, −95	OF, DF	Low
Clupeidae	*Gudusia chapra* Hamilton 1822	7	FY, −75	OF, DF	High
Clupeidae	*Gonialosa manmina* Hamilton 1822	8	FY, −75	OF, DF	High
Clupeidae	*Corica soborna* Hamilton 1822	1	S, −65	DF	Moderate
Clupeidae	*Tenualosa ilisha* Hamilton 1822	33	R10–R30, −99	BD	High
Engraulidae	*Setipinna brevifilis* Valenciennes 1848	22	FY, NA	–	–
Cobitidae	*Botia dario* Hamilton 1822, *Botia lohachata* Chaudhuri 1912	–	S, −40	–	–
Nemacheilidae	*Lepidocephalichthys guntea* Hamilton 1822	–	S, −40	–	–
Danionidae: Chedrinae	*Salmostoma bacaila* Hamilton 1822, *Salmostoma phulo* Hamilton 1822	14	S, −90	OF	Moderate
Danionidae: Chedrinae	*Cabdio morar* Hamilton 1822	11	FY, −90	DF	Low
Danionidae: Chedrinae	*Securicula gora* Hamilton 1822	17	O, −99	DF	Moderate
Danionidae: Rasborinae	*Amblypharyngodon mola* Hamilton 1822	–	O, −99	–	–
Cyprinidae: Labeoninae	*Crossocheilus latius* (=*Tariqilabeo latius*) Hamilton 1822	13	S, −72.5	–	–
Cyprinidae: Labeoninae	*Labeo calbasu* Hamilton 1822	40	FY, −80	OF, DF, BD	Moderate
Cyprinidae: Labeoninae	*Gibelion catla* (=*Labeo catla*) Hamilton 1822	47	S, −75	DF, OF, BD	High
Cyprinidae: Labeoninae	*Labeo rohita* Hamilton 1822	46	S, −90	DF, OF, BD	High
Cyprinidae: Labeoninae	*Labeo gonius* Hamilton 1822	36	S, NA	–	–
Cyprinidae: Labeoninae	*Cirrhinus mrigala* Hamilton 1822	41	S, −75	DF, OF, BD	High
Cyprinidae: Labeoninae	*Bangana ariza* (=*Gymnostomus ariza*) Hamilton 1807	25	S, −50	–	–
Cyprinidae: Labeoninae	*Chagunius chagunio* Hamilton 1822	–	S, NA	–	–
Cyprinidae: Smiliogastrinae	*Systomus sarana* Hamilton 1822	26	S, NA	DF	Moderate
Cyprinidae: Smiliogastrinae	*Puntius sophore* Hamilton 1822	10	FY, −75	DF	Low
Cyprinidae: Smiliogastrinae	*Pethia conchonius* Hamilton 1822	9	FY, −75	DF	Low
Cyprinidae: Smiliogastrinae	*Osteobrama cotio* Hamilton 1822	12	S, NA	–	–
Bagridae	*Sperata aor* Hamilton 1822	39	FY, −85	OF	High
Bagridae	*Sperata seenghala* Sykes 1839	42	FY, −85	OF	Moderate
Bagridae	*Hemibagrus menoda* Hamilton 1822	35	S, −98	TH, OTH	Moderate
Bagridae	*Mystus cavasius* Hamilton 1822, *Mystus vittatus* Bloch 1794	16, 19	FY, −95	OF	Moderate
Bagridae	*Rita rita* Hamilton 1822	38	FY, −95	OF	High
Sisoridae	*Bagarius yarrelli* Sykes 1839	48	S, −70	OF	Low

(Continues)

TABLE 1 (Continued)

Family: subfamily[a]	Species[b]	Figure reference number[c]	Status in fisheries and reported % decline	Reported causes of decline (hypotheses)	Likelihood of hypotheses
Sisoridae	*Gogangra viridescens* Hamilton 1822	2	S, −75	–	–
Pangasiidae	*Pangasius pangasius* Hamilton 1822	49	R25, −95	BD	High
Siluridae	*Wallago attu* Bloch & Schneider 1801	45	FY, −50	–	–
Siluridae	*Ompok pabda* Hamilton 1822	24	S, −80	OF, DF	High
Heteropneustidae	*Heteropneustes fossilis* Bloch 1794	18	S, −99	WL	Moderate
Ailiidae	*Clupisoma garua* Hamilton 1822	15	FY, −75	–	–
Ailiidae	*Eutropiichthys vacha* Hamilton 1822, *E. murius* Hamilton 1822	21	FY, −75	–	–
Ailiidae	*Silonia silondia* Hamilton 1822	–	R10, −95	BD	Moderate
Ailiidae	*Ailia coila* Hamilton 1822	15	FY, −75	BD	Low
Horabagridae	*Pachypterus atherinoides* Bloch 1794	6	S, −70	DF, OF	High
Belonidae	*Xenentodon cancila* Hamilton 1822	20	FY, −90	BD	Moderate
Synbranchidae	*Monopterus cuchia* Hamilton 1822	–	S, NA	–	–
Mastacembelidae	*Mastacembelus armatus* Lacepede 1,800	34	S, −95	DP, OTH	Low
Mastacembelidae	*Macrognathus aral* Bloch & Schneider 1801, *M. pancalus* Hamilton 1822	30	S, −95	DP, OTH	Low
Mugilidae	*Rhinomugil corsula* Hamilton 1822	31	S, −95	DF, BD	Moderate
Mugilidae	*Sicamugil cascasia* (=*Minimugil cascasia*) Hamilton 1822	5	S, NA	DF, BD	Low
Ambassidae	*Chanda nama* Hamilton 1822, *Parambassis ranga* Hamilton 1822	3 4	FY, NA to −80	DF	Low
Sciaenidae	*Johnius coitor* Hamilton 1822, *J. gangeticus* Talwar 1991	29	S, −98	BD	Moderate
Nandidae	*Nandus nandus* Hamilton 1822	23	S, NA	–	–
Gobiidae	*Glossogobius giuris* Hamilton 1822	32	FY, −75	BD	Low
Osphronemidae	*Trichogaster fasciatus* Bloch & Schneider 1801	–	S, −75	WL	–
Channidae	*Channa marulius* Hamilton 1822	44	FY, −90	OF, DF	High
Channidae	*Channa striata* Bloch 1793	37	FY, −90	OF, DF	Low
Channidae	*Channa punctatus* Bloch 1793	–	FY, −90	OF, DF	Moderate
Tetraodontidae	*Leiodon cutcutia* Hamilton 1822	–	O, NA	–	–
Crustacea: Penaeidae	*Penaeus* spp. Fabricius 1798	–	FY, −90	DF, OF, BD	Moderate
Crustacea: Palaemonidae	*Macrobrachium* spp. Spence Bate 1868	50	R35, −99	BD	Moderate

Note: Key: status in fisheries: FY, Fished round the year, regularly; O, Occasionally caught (in a year) and generally uncommon; R5, Rare, caught occasionally in 5 years; R10, Rare, caught occasionally in 10 years; and R20, Rare, caught occasionally in 20 years; S, Seasonal fishing; and so on. Reported percent decline is derived from LEK consensus-based estimates of decline from 1991 till date among fishers (total $n = 110$), NA indicates non-response to query about perception of decline. Primary causes of decline: BD, Barrages and Dams; DF, Destructive fishing techniques; DP, Diseases due to poisoning; OF, Overfishing; OTH, Other unknown causes; PO, Pollution; TH, Thermal regimes altered; WL, Wetland loss. Fishers identified a primary cause (underlined) when they reported more than one cause of decline.

[a]Updated names of families and genera from Fricke, Eschmeyer, & van der Laan (2019) are also provided.

[b]Taxonomic order and species names of fishes follow Froese and Pauly's FishBase (2019). Crustacean species' names and taxonomic details are shown separately at the end.

[c]Figure reference numbers for each species must be used to locate them in Figures 1–5 of the paper.

habitat preferences) and (b) fishery characteristics (catch seasonality, gear use, investment of effort) was gleaned. Pictorial and graphical representations were chosen for effective representation of these data. Different species were placed under the causes of decline attributed to them by fishers. Fish species were mapped on an ichthyograph (Flitcroft et al., 2016) based on their spawning seasonality. The graph was compared with a seasonal fish catch calendar prepared from fishers' inputs.

2.2.5 | Fish size declines and potential effects of overfishing

Size reduction of fished species is a simple indicator of potential overfishing. To test for this, average maximum weights (Wmax_LEK) of different fished species reported by fishers were compared with empirical data on Wmax from FishBase (Wmax_FB; Froese & Pauly, 2019) and other species-specific literature sources (Appendix S1). A linear regression analysis was run between the natural logarithms of Wmax_LEK and Wmax_FB for all species. The magnitude and sign of the linear model slope were interpreted as potential indicators of responses to overfishing for each species through possible size reduction (based on McLean & Forrester, 2017). Species that fell below a hypothetical 1:1 line on the plot could be overfished (Wmax_LEK < Wmax_FB) and those above the line not overfished (Wmax_LEK ≥ Wmax_FB).

2.2.6 | Influence of fishers' experiences of conflict on LEK

Insights from the historical context of fishery conflicts in the study area (see above) were discussed to understand how fishers' experiences might have influenced their LEK narratives. This was done with in-depth discourse analyses of narratives of fishers about past and present conflicts over fishing rights, access and gears used.

3 | RESULTS

3.1 | Causes of fish species declines

Participants perceived catches had declined between 30% and 99% across fish species compared with 30 years ago (Table 1). According to fishers, the main causes of fish decline (Table 1, Figure 2) were destructive fishing practices (36%), overfishing by fishers (31%), and interruption of fish movement by barrages, which accounted for declines of 25% of the species. 'Destructive fishing' was defined by fishers as indiscriminate harvest of different fish sizes (including young fish fry, eggs and larvae), involving the use of mosquito nets, seines or poisons. Overfishing was equated with excessive fishing effort (more people fishing, more boats or gillnets being used). Fishers often cited more than one reason for decline of a species group. Some other reported causes (for 7% of species) were related to floodplain wetland loss or changes in thermal regimes of floodplain wetlands or impaired connectivity of river channels with floodplain habitats where juvenile fish could grow. No specific causes of decline were assigned by fishers for 15 species groups (25% of total assessed), citing limited knowledge or uncertainty. Details on causes of declines mentioned by fishers, with hypotheses, are presented in Appendix S2.

3.2 | Likelihood of hypotheses on causes of declines

Of the 60 species (assessed as 57 species groups), causes of decline for 16, 16, 10 and 15 species had 'high', 'moderate', 'low' and 'none' likelihoods. For 8 out of 10 species, there was a moderate to high degree of consensus among participants and the literature, in identifying barrages as the main cause of decline (i.e. moderate or high likelihood) (Figure 3). Of 28 species, 11 had high, ten moderate and seven low likelihoods (Figure 3) to have declined due to overfishing or destructive fishing. Four species were thought to have declined by 'other causes' that had low or moderate likelihood.

3.2.1 | Barrages and migratory species

Marginally steeper decline rates were assigned by respondents to catadromous and potamodromous migrant species (mean 88.2% ± 11% *SD* decline) than non-migrant, resident fish species (79.5% ± 15.5% *SD*), although percent decline estimates overlapped. Perceptions of decline for migrant species were related with the dramatic collapse of the migratory spawning clupeid hilsa,*Tenualosa ilisha* (Hamilton), in less than a decade after the construction of the Farakka barrage in 1975. This decline has been widely documented (Jahan et al., 2017; Ray, 1998). Hilsa were last reported by fishers as coming to spawn in sizeable numbers in 1982–1983. Stocks of *Pangasius* catfishes, anguillid eels and *Macrobrachium* shrimp also declined rapidly after construction of the Farakka barrage. Some fishers tended to first attribute the decline of any fish species to the Farakka barrage, but after this initial reply, they would gradually modify their responses to include destructive fishing (defined below), especially for resident species. The decline of major carp species *Gibelion catla* (Hamilton), *Labeo rohita* (Hamilton) and *Cirrhinus mrigala* Hamilton (Cyprinidae: Labeoninae) were attributed to multiple causes. Although the impacts of upstream dams (1960s to 1990s) and the Farakka barrage (1975) were emphasised, excessive spawn collection for aquaculture in the 1960s and 1970s was also mentioned. Jhingran and Ghosh (1978) also attributed major carp declines in the Ganga to excessive spawn and juvenile collection for aquaculture, apart from water pollution and habitat degradation. It is possible that government extension programmes focusing on spawn collection of major carps influenced the fishers' opinion.

3.2.2 | Impacts of overfishing and destructive fishing

Importantly, the distinct categories of 'destructive fishing' and 'overfishing' defined by fishers often overlapped and were not mutually exclusive in fishers' narratives. Large mosquito nets and seine nets with mesh sizes of 1–10 mm ('destructive fishing') were blamed by fishers for declines in fish yields post-1991 (when the fishery became open-access). These gears are used in side-channel inlets regularly in the dry-season and post-monsoon recession phase. Both types of nets have large catches per operation, ranging from 50 to 100 kg of fish in 4 hr. The use of pesticides and other poisons was also stated to cause *en*

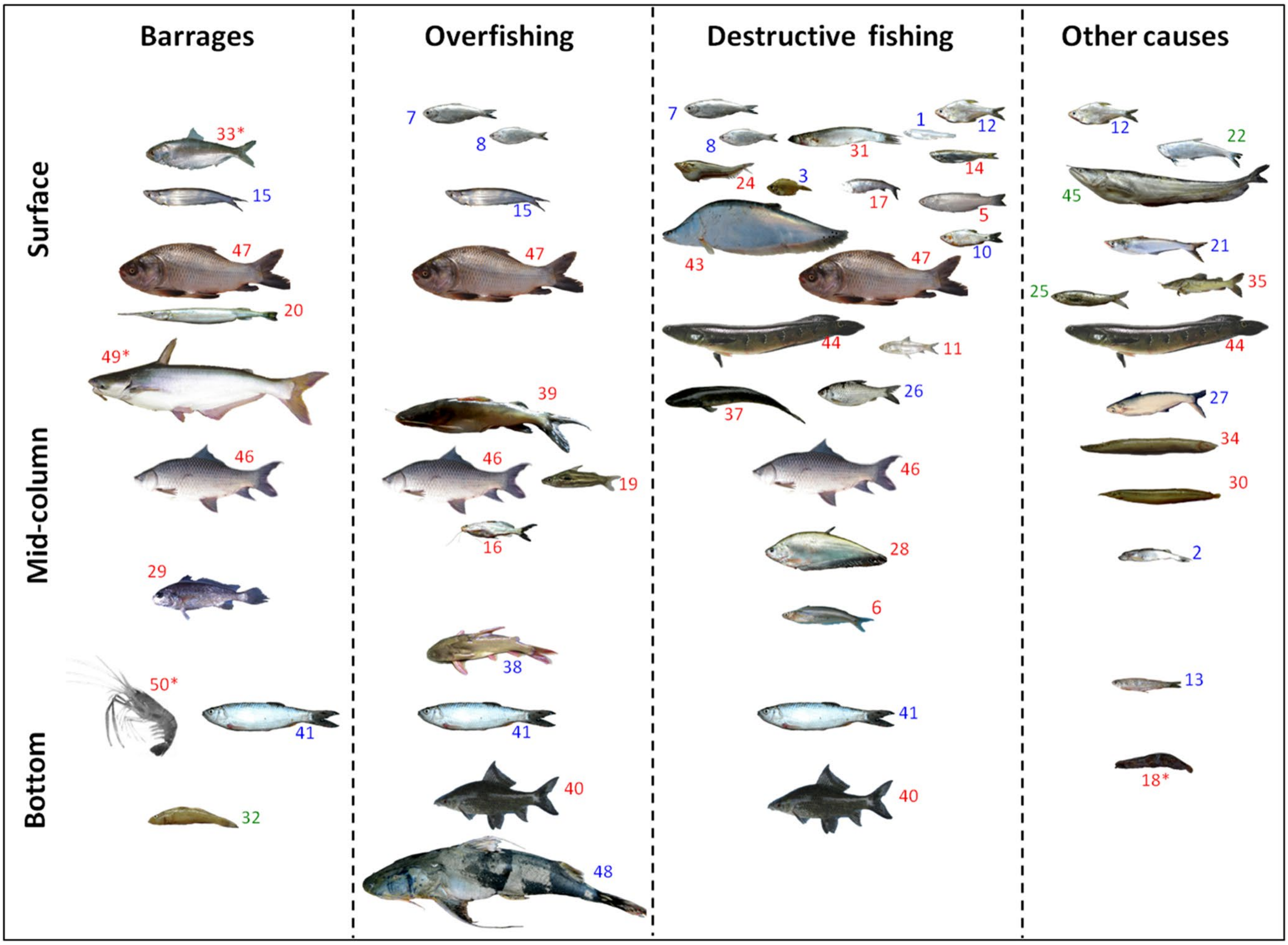

FIGURE 2 Causes of decline of river fish species (names and numbers in Table 1) with respect to their position in the water column, as stated by fishers. Red numbers indicate species that were thought to have declined >90%, blue indicate declines >75% and green indicate declines from 50% to 75% (asterisks denote fish species depleted to extreme levels). Overfishing and destructive fishing were thought to be the main factors causing declines, followed by barrages (not shown here in that order). Surface- and mid-column dwelling fish species had undergone greater decline than bottom-dwelling species. Other causes included (1) loss of floodplain wetland habitats, (2) changes in temperature regimes, (3) pollution impacts and (4) unknown causes

masse fish kills in side-channels, which caused temporary declines in fish catches by 'destructive fishing'. In addition to such methods, 'overfishing' due to increase in numbers of people fishing, increase in nets used per fishing boat and excessive harvesting of fishes in gillnets were cited as important drivers of fish declines (Figure 2). Overall reductions in gillnet mesh sizes were reported by fishers as a consequence of overfishing. Large nets (200–300 mm mesh size) are hardly used now, as large fish are seldom caught. A reduction in mesh sizes in this fishery over a similar period was reported by Kelkar, Krishnaswamy, Choudhary, and Sutaria (2010). Overfishing was attributed by fishers to the dominantly used gillnet mesh sizes from 20 to 100 mm.

3.2.3 | Fish size reduction in response to fishing pressure

A strong and statistically significant positive correlation was detected between Wmax_LEK and Wmax_FB (linear regression: $\log_e$(Wmax_LEK) = 0.865*$\log_e$(Wmax_FB) – 0.34, $R^2 = 0.837$, $p < .0001$, $F = 236.7$, $df = 46$). Fitted values indicated close correspondence of Wmax_LEK with Wmax_FB with Wmax_LEK usually lower than Wmax_FB for most species (Figure 4). Wmax_LEK estimates indicated a size-reduction effect of fishing, which matched fishers' perceptions about the decline of many fish species. There were notable exceptions to this pattern, for example the catfish *Bagarius yarrelli* (Sykes) (fish number to locate in figures: 48) and the knifefish *Chitala chitala* Hamilton (43). Wmax_LEK for these species exceeded Wmax_FB, as fishers could have exaggerated sizes of these large species. Some fishers' estimates could also be positively biased by their memory of past catches. Significantly lower Wmax_LEK of the catfishes *Clupisoma garua* (Hamilton) (27) and *Rita rita* (Hamilton) (38) indicated overfishing (Figure 4).

3.2.4 | Spawning behaviour, catch seasonality and overfishing

Typically, species caught in their spawning seasons were considered overfished, but heavy fishing of juveniles in the flood recession

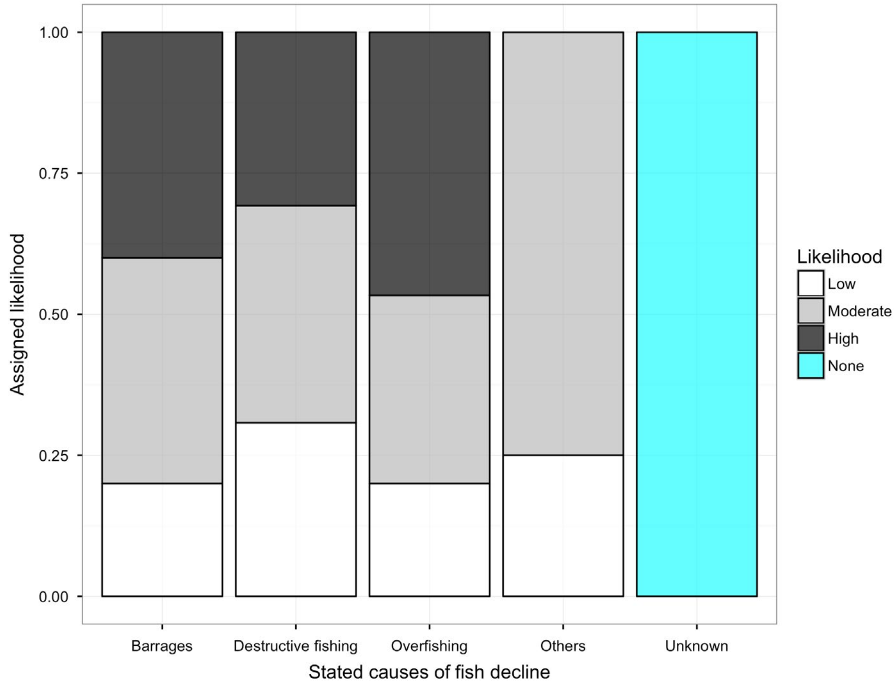

FIGURE 3 Low, moderate or high likelihoods assigned to fisher responses on causes of fish declines based on (1) independent observations and published literature, (2) consensus between LEK respondents and (3) field observations by authors. Numbers of species (total *n* = 57) to which different causes were assigned were as follows: (1) Barrages (*n* = 10), (2) Destructive fishing (*n* = 13), (3) Overfishing (*n* = 15), (4) Others (*n* = 4) and (5) Unknown (*n* = 15). A relatively even distribution of low, moderate and high likelihoods is seen (barring the categories 'Others' and 'Unknown')

period (see de Graaf, Born, Uddin, & Huda, 1999) was reported as destructive fishing.

Significant overlap between spawning seasons of fish species and the season of their highest catches in a year was evident (Figure 5). River fishing effort is concentrated in the post-monsoon months (October–November), dips in winter (December–January) and again picks up from February to June. Effort is lowest in July and August and increases from September. Seasonality of effort levels captured species spawning during the flood pulse (July–September) in their immediate post- and pre-spawning periods. For both summer and winter spawners, fishing intensity was high over a major part of their spawning season (Figure 5).

In general, information on spawning season, reproductive strategies, habitat associations and other ecological data from LEK matched closely with published literature on freshwater fish life histories (Montana et al., 2011; Qasim & Qayyum, 1959; Talwar & Jhingran, 1991; Vass, Mondal, Samanta, Suresh, & Katiha, 2010; Vass, Tyagi, Singh, & Pathak, 2010; Welcomme, Winemiller, &

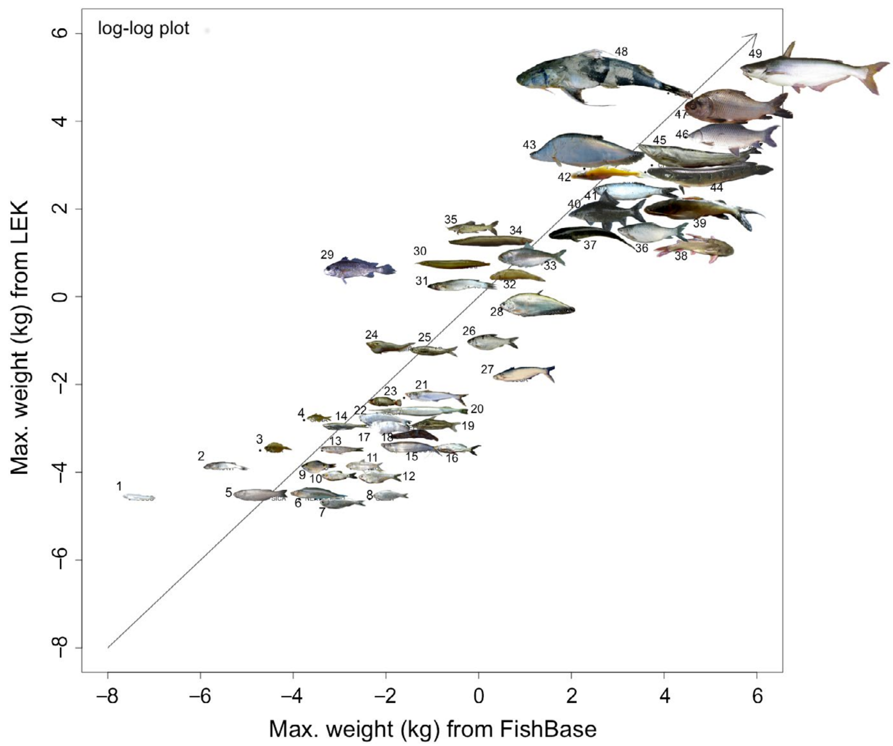

FIGURE 4 A comparison of the maximum fish weights reported by LEK (Wmax_LEK) and the maximum fish weights available from the literature (Wmax_FB). Species below the 1:1 line might be locally overfished as compared to those on or above the line. The distance of fish species below and away from the line was used a simple proxy for intensity of fishing effects

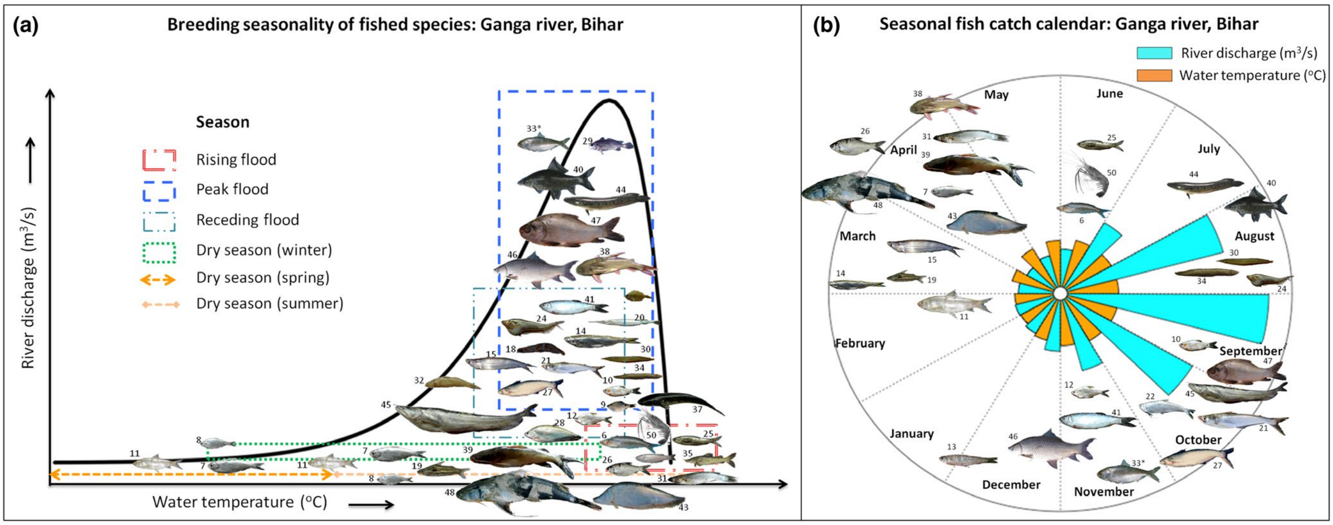

FIGURE 5 (a) An ichthyograph showing spawning seasonality of different fish/shrimp species in relation to river discharge and water temperature for the Ganga River. River discharge in the Ganga River (at Hathidah, 1986–2015) ranges between 800 m^3/s in the peak dry season (February–April) and 60,000 m^3/s in the peak flood season (August–September); river water temperatures range from 12°C in winter to 32°C in peak summer. (b) An annual fish catch calendar for the study area is shown in a circular plot. Flood spawners are mostly caught in non-spawning periods, whereas summer and winter spawners are caught mostly during their spawning season. Positions of different species on the ichthyograph are approximate and only for graphical representation

Cowx, 2005; Winemiller, 2005; Zeug & Winemiller, 2007). This information was used to find explanations for causes of declines fishers attributed to different species. The monsoon flood pulse is known to be the primary driver of fish spawning and productivity in the Gangetic plains (de Graaf, 2003; de Graaf et al., 1999; Halls & Welcomme, 2004; Jahan et al., 2017; Montana et al., 2011; Payne, Sinha, Singh, & Huq, 2004; Payne & Temple, 1996; Sinha et al., 1999). Flood-spawning fish species were distinguished by fishers into early-monsoon (rising-flood) spawners, peak-monsoon spawners and late-monsoon or receding-flood spawners (Figure 5). Species identified as dry-season (winter, spring, or summer) breeders were *Cabdio morar* Hamilton (11), *Osteobrama cotio* (Hamilton) (12), *Gudusia chapra* (Hamilton) (7), *Gonialosa manmina* (Hamilton) (8), *Mystus cavasius* (Hamilton) (16), *Bagarius yarrellii* (48), *Chitala chitala* (43), *Sperata aor* (Hamilton) (39) and *Sperata seenghala* (Sykes) (42). Species with nest-building, parental care and high fecundity (*Sperata*, *Mystus*, *Chitala*) versus broadcast spawners without parental care (*Wallago attu* Bloch & Schneider, 45) were also identified. Fishes living nearer to the surface or bottom had lower egg numbers than mid-column dwelling fishes, according to fishers.

3.2.5 | Observations on habitat associations, fish movements and population dynamics

Species associated with clear water or sandy substrates were thought to show lesser declines over time (decline of 73.5% ± 17.7% *SD*) than species associated with muddy and rocky substrates (87.3% ± 10.8% *SD*). No differences were perceived in percent declines of 'fishes that moved along with sand' (whitefishes or rheophilic species) and 'fishes that hide in water-jungles' (blackfishes or plesiopotamic species associated with vegetation in side-channels and inlets). Different species were classified according to 'lanes' they used along the river 'highway'. For example, one participant narrated how two species of the danionid genus *Salmostoma* [*S. bacaila* (Hamilton) (14) and *S. phulo* (Hamilton)] differed in their use of the river channel. *Salmostoma phulo* lived in more sheltered and vegetated areas, about an arm's distance from the shoreline, and had lower fecundity than *S. bacaila*, because eggs were not broadcast. *Salmostoma bacaila* lived along the 1st and 3rd quartiles of distance from the shoreline and had higher fecundity, as it was a broadcast spawner in clear water zones. Differential flow velocity along these 'lanes' was the reason provided for their different spawning strategies. Another example was from a fine description of the spawning behaviour of the bagrid catfish *Rita rita* (38): 'During peak flooding in August, when banks erode and chunks of silt fall into the river, *Rita* lay small batches of eggs on pads of grass-roots stuck to these chunks… as the chunks disintegrate, the eggs are carried by the sinking roots…'. Young *Wallago* (a silurid catfish) were described to feed exclusively on bivalves during September–October, in the first year of growth. These detailed descriptions gave useful insights on causes of decline, but were not found in any published literature.

Observations of complex processes such as mortality rates of juvenile fishes were also evident from LEK data. For instance, sources of mortality from observations of stomach contents of fish were estimated by a fisher who had gutted them: 'in winter and spring, larvae of small fishes like *Cabdio morar* (11), *Salmostoma* spp. (14), *Gibelion catla* (47), *Osteobrama cotio* (12), *Sicamugil cascasia* (Hamilton) (5) and *Rhinomugil corsula* (Hamilton) (31) disperse along shallow, sandy banks. Predatory fishes like *Wallago* feed on 5%–10% of them and mosquito nets remove almost 75% of the stock before other large predatory fish can eat them. The remaining 15%–20% might then be able to survive'. Although the numbers do not matter, that fishers keep track of such processes is of great interest.

Some fish species were reported to have now become regular in catches after initial declines. Species such as the danionid *Cabdio morar*, a dry-season spawner, was thought to have started repeated, year-round spawning. According to them, multiple bouts of spawning was a new adaptation by this fish species to changing flow regimes due to periodic releases of water from upstream dams in the dry season. Other species showing possibly compensatory and repeated spawning responses to fishing intensity were the Ailiid catfishes *Eutropiichthys vacha* Hamilton (21) and *Clupisoma garua*, and the Clupeid *Gudusia chapra* (7) (Figure 5). It is difficult to confirm these hypotheses at present, but they offer avenues for further research.

The LEK domain of fishers also extended to the floodplain, where many juvenile fishes disperse to grow and recruit to the larger population in the next season (de Graaf et al., 1999; Humphries, King, & Koehn, 1999; King, Humphries, & Lake, 2003). High pesticide use and agricultural disturbances were linked by respondents to reduction in algal densities in floodplain wetlands, which could have disrupted growth and survival of herbivorous fish larvae. Due to higher macrophyte growth in wetlands, water temperatures had changed, causing higher mortality of eggs of fishes like *Hemibagrus menoda* (Hamilton) (a bagrid catfish seasonally caught in this fishery). Degradation of floodplain wetlands was a dominant theme in the 'other causes' of decline cited by fishers.

3.2.6 | Impacts of environmental variability on fish catches

Aged respondents (>80 years of age) said that they had been fishing since the early 1940s. As children, they travelled with their father or uncles on long fishing trips in spring and early summer all the way to Dhaka (the capital of present-day Bangladesh). After India's independence and partition, such extended fishing trips largely stopped. Exceptional past years that caused significant perturbations and changes in fishing practices were also remembered by veteran fishers. For instance, this included the drought of 1970–1971, which was followed by the high flood-event of 1971–1972, when fish catches were very high after a period of poor catches. A similar effect was reported for 2015–2016 (a very strong El Niño drought year) followed by strong flooding in 2016–2017. The flood pulse of 2016–2017 was likened by fishers to the one of 1971–1972 based on high post-flood catches of the highly prized carp *Gibelion catla* in 2016. Long-term reduction in dry-season river flow was also mentioned as a major factor behind reduced fish catches. However, temporal variability in hydro-climatic factors was not explicitly identified as the primary reason for fish catch declines.

4 | DISCUSSION

Flow regulation and alteration by dams and barrages, pollution and overfishing of spawn have been unequivocally identified as the major drivers of fishery declines by many studies (Das et al., 2013; Jhingran & Ghosh, 1978; Kelkar, 2014b; Payne et al., 2004; Payne & Temple, 1996; Sarkar et al., 2012; Talwar & Jhingran, 1991). The spatial scale of these studies was basin-wide so flow alterations were identified as the main threat. The Ganga in eastern Bihar experiences 'near-natural' flow regimes due to numerous tributaries joining the river downstream of Patna (Das, Samanta, & Saha, 2007; Payne et al., 2004; Vass, Tyagi, et al., 2010). This could explain why declines in flow were not perceived as a major threat by local fishers. Overfishing impacts were dominant at the local scale, as per fishers' responses. It is interesting that overfishing and destructive fishing were identified by fishers as bigger problems than climatic variability or flow alterations.

In Abbott and Campbell's (2009) study on floodplain fisheries in the Zambezi River, narratives of overfishing and the effect of intensive fishing practices on fish stocks (affected by marine fishery discourses) were also dominant. Low importance was attributed by fishers to the inherent variability of tropical river–floodplain ecosystems, while the dominant narrative of overfishing repeated at all levels: from fisheries department and state government officials to researchers to fishers. Fishers from Zambia were blamed by fishers from Namibia for using destructive fishing methods (Abbott & Campbell, 2009). Here, the perception of overfishing resulted from the positions of fishers within social, ethnic and institutional interactions. Friend and Arthur (2012) also emphasised the importance of nuanced and critical engagement with the overfishing discourse in the Mekong. It is commonly seen that, as fisher numbers increase, individual fishers' catches reduce and perceptions of overfishing kick in. This can result in difficulties in identifying attributing causes to observed trends. Therefore, the narratives of overfishing and destructive fishing held by fishers in the study area need to be critically evaluated.

The relative contributions of environmental drivers, large-scale anthropogenic pressures (e.g. flow regulation by barrages), and local fishing pressures need to be estimated for the Ganga River. LEK is based inherently on fishers' experiences and is akin to fisheries-dependent data. Thus, LEK could deviate from evaluations based on fishery-independent data. Divergences and convergences in these data sets will be of great importance in future fisheries assessments.

4.1 | Historical experiences of fishery conflicts and LEK

LEK and fisher perceptions of overfishing or destructive fishing were strongly linked to the history of fishery conflicts in the area. The end of the *Panidari* (water-lording) system of private control on the Ganga at Bhagalpur was referred to by fishers as a life-changing event for them. In 1991, a long struggle by these fishers led to the abolishment of nearly 400 years of feudal control on river fisheries in the region. Since then the fishery has operated as an open-access regime (Kelkar, 2014a). During discussions on the state of fisheries post-1991, mixed responses emerged. Fishers from Kahalgaon, who were most involved in the struggle, believed that open-access provided more freedom and opportunity for fishing work, but most other fishers were unhappy about open-access fishing (Kelkar, 2014a). They said that fishing was now under the control of anti-social elements (mafia gangs) that ran destructive fishing gears such as channel-barricading mosquito nets, and routinely harassed and threatened fishers with violence. It is important to situate LEK in the context of this long-standing social conflict and its politics (Butler, 2005; Kelkar, 2014a, 2018; Mesquita & Isaac-Nahum, 2015). The best example of this is the problematic distinction by fishers between 'overfishing' and 'destructive fishing' that emerged from gear-use conflicts. Hence, in spite of overlaps, these two categories are separately discussed in this paper.

Farr et al. (2018) showed that fishery management regimes influence the content and expression of LEK. Continuing conflicts over access and gear use, and the long experience of discrimination, violence, poverty and social-economic marginality dominated the perceptions of fisher respondents (Choudhary et al., 2015; Kelkar, 2018; Kelkar & Krishnaswamy, 2014). Experiences of conflict weighed upon their narratives of conflict and associated sharing of LEK responses. The overwhelming response—that destructive fishing and excessive harvests of fish were the primary cause of decline for many species—illustrated this well. This perception of mosquito nets has also been encountered in other regions of Africa and Asia (Bush et al., 2017; Short, Gurung, Rowcliffe, Hill, & Milner-Gulland, 2018), but there is no demonstrated link between their use and observed declines in fish abundance and sizes (Bush et al., 2017). Impacts of different levels and types of fishing on small-scale riverine fisheries need to be investigated along with environmental variability (Abbott & Campbell, 2009). Studies across the world are showing that indiscriminate fishing of immature fishes can affect fish stocks (Castello, McGrath, & Beck, 2011; Ngor et al., 2018; Vasilakopoulos, Neill, & Marshall, 2018). In the Xingu river, Brazil, similar issues with gillnets were commonly expressed (Mesquita & Isaac-Nahum, 2015), although gillnet use itself was regular and widespread among respondent fishers. The distinction by fishers between overfishing and destructive fishing is also of interest to future studies and current discussions on selectivity and effort regulations on fish stocks, as with debates on 'balanced harvesting' (Kolding & van Zwieten, 2011; Pauly et al., 2016). Undoubtedly, fishers' perceptions and political positions had a bearing on how their LEK could be integrated with scientific studies and management policies for river fisheries in the Ganga.

4.2 | Implications of LEK for fisheries management in the Ganga River

Fish stocks in the Ganga River have been declining (Das et al., 2013; Payne et al., 2004; Payne & Temple, 1996; Ray, 1998; Sarkar et al., 2012; Vass et al., 2009). In the Ganga River in Bihar, open-access river–floodplain fisheries from 1991 onwards have brought severe conflicts over fishing rights and access to fishing areas. Along with risks and dangers, open access has allowed greater mobility to fishers and might buffer livelihoods of marginalized fishing communities (Choudhary et al., 2015). Insights from LEK can help better understand these difficult challenges to fisheries management. Although overfishing was cited as a big concern by fishers, reductions in numbers of river fishing boats and people in the last 15 years are evident from field observations (rapid exit from this fishery is also described in Kelkar, 2018). It was stated by fishers that intensifying seasonal fishing effort with destructive fishing practices would offset any reduction in the total number of fishing trips. Even the number of nets used by an individual fisher from a single boat had increased three- to fivefold. From a management perspective, there is a clear need to estimate empirically impacts of fishing effort, gear use intensity, catchability and selectivity on fish stocks. According to the Bihar Fish Jalkar Management Act by the Govt. of Bihar in 2006, and later amendments, the use of nets with mesh sizes <40 mm is prohibited in all flowing waters of the state. The known illegality of mosquito nets (1 mm) and seine nets (10–15 mm) mesh sizes might enhance negative perceptions about them. However, most gillnets being used in the river are also illegal, having mesh sizes <40 mm (Kelkar & Krishnaswamy, 2014). Gillnet users have been demanding 24 mm to be the legally allowed mesh size limit (Choudhary et al., 2015). These intersections between law and practice need to be addressed with adaptive management practices and could even involve modifying current legal considerations on fishing allowances and catch limits.

The overarching importance of this exercise is that, to our knowledge, this is the first such assessment from the Ganga River in India. LEK was used as background information by Poizat and Baran (1997) in the Mekong to compare with their fish sampling results. A slightly different approach was followed here, where long-term fish catch monitoring data were not correlated with LEK, acknowledging a priori the imperfect match between the two epistemological fields. Rather, LEK narratives of fishers were used to generate testable hypotheses with different likelihoods for different species. Contributions of LEK to fish life-history trait data are vital, given the very limited information available on fish ecology and life histories from the Gangetic plains (but see Payne et al., 2004; Vass et al., 2009; Vass, Tyagi, et al., 2010). Information from government agencies is based on aggregate surveys of 'fisheries status' (Das et al., 2007; Sinha et al., 1999; Vass et al. 2009) than on hypothesis-driven ecological studies of fish species and communities (Montana et al., 2011). LEK will thus help better understand causes of fish decline, shifting baselines and capacities of fishers to adapt with fishery conflicts and change in the Gangetic plains. Inland capture fisheries are a livelihood system that is shrinking and increasingly vulnerable to social conflicts, economic and policy neglect, and the continuing ecological degradation of river–floodplain ecosystems. As water infrastructure development projects (e.g. embankments, waterways) unfold across the Gangetic basin, these trends could continue. In this regard, insights from this study are of great relevance to policy and management interventions for conservation and sustainability of small-scale riverine fisheries in the Gangetic plains.

4.3 | Reflections on the LEK assessment

This LEK assessment must not be treated *sensu stricto* as a fact-finding or validation exercise. LEK is a body of experience with high heterogeneity, contradictory perceptions, and its own imperfections (much like formal science on complex tropical fisheries!). Beyond merely finding consensus, it will be necessary to discuss disagreements and debates over the impacts of different fishing practices on the fisheries, fish life histories and other observations. LEK information showed close matches with published empirical studies, but also helped identify important gaps. Whereas fishing impacts and barrages were stated as the primary threats by fishers, responses about climate change effects on fisheries were limited (variability in rainfall, extreme flooding, ENSO-drought in 2015–2016 etc.). This could be because fishers have always been used to dealing with high environmental variability. In one participant's words, 'there are good years and bad years in fishing… by May we generally know what to expect in the coming flood season. If May skies are too wet, then we are bound for a poor flood, which means less fish in October and November'.

This summary of fishers' LEK may not be comprehensive or complete—as it would be impossible. By spreading data compilation over two decades, maximum coverage of information was attempted by the study. Many LEK insights arrived gradually and also evolved in this timeframe, often in response to particular situations on the river. Personal and professional connections with fisher collaborators led to sustained exchanges on LEK, but its critical evaluation was considered important by this study. Frank and open platforms of communication through long associations with fishers have been helpful in doing so. This study has thus been guarded from any romanticised interpretations or essentialist assumptions in the LEK insights it summarises.

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AUTHOR CONTRIBUTIONS

N.K., Sb. D., Ss. D. and S.K.C. conceptualised the study. N.K., K.D. and Sb. D. wrote the paper. N.K. and K.D. analysed the data. All authors collected data, organised workshops and conducted relevant fieldwork.

ORCID

Kadambari Deshpande https://orcid.org/0000-0002-2140-9177

Nachiket Kelkar https://orcid.org/0000-0002-7881-7382

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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