Adaptive climate change resilient indigenous fisheries strategies in the floodplain wetlands of West Bengal, India

Uttam Kumar Sarkar, Koushik Roy, Gunjan Karnatak and Saurav Kumar Nandy

ABSTRACT

Floodplain wetlands are considered as biologically sensitive habitats and predicted to be the most impacted through climate change. They form an important fishery resource in West Bengal, India. Analysis of Indian Meteorological Department (IMD) derived climatic data has revealed a unanimous warming trend (0.18–0.28 °C) and decreasing rainfall (135.6–257 mm) among the studied districts (North 24 Parganas, Nadia and Kolkata) of West Bengal over the last three decades. Four floodplain wetlands under cooperative fisheries management were studied during February 2015 and December 2015. Data were collected through a structured communication process involving multiple interviews through multiple rounds of surveys and also from secondary sources. Six climate smart fishery strategies could be identified, namely Temporary pre-summer enclosure, Submerged branch pile (*Kata*) refuge, Autumn stocking, Torch light fishing, Deep pool (*Komor*) refuge and Floating aquatic macrophyte refuge fishery (*Pana chapa*). Few of them are capable of serving as conservation tools by providing refuge during summer or water stress and maintaining base stocks in the wetlands for recruitment in the following monsoon season. The present paper discusses the climate smart nature of these pre-existing indigenous fishery strategies. These strategies need to be optimized and may be used for adoption of sustainable climate smart fisheries management in floodplain wetlands.

Key words | adoptive measures, climate change, fisheries, India, wetland

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INTRODUCTION

Floodplain wetlands are biologically sensitive aquatic habitats and play a vital role in the recruitment of fish populations in the riverine ecosystems and provide nursery grounds for several indigenous fishes. They provide habitat for several aquatic germplasm resources, vary widely in size, shape, extent of riverine connection and offer tremendous scope for expanding both capture and culture fisheries (CIFRI 2000; Ramsar Convention Secretariat 2013; Sarkar *et al.* 2016). Wetlands are extremely rich in plant nutrients, as reflected by rich organic carbon and high levels of available nitrogen and phosphorus in the soil, and therefore have high biological productivity (Ramsar Convention Secretariat 2013). The changing river courses create many ox-bow lakes, sloughs, meander scroll depressions, back swamps and residual channels. The wetlands usually represent the lentic component of floodplains, excluding the lotic component (the main river channels, the levee region and the flats). In addition, tectonic depressions located in river basins are also included under wetlands (Leopold *et al.* 1964). Gangetic West Bengal represents the deltaic reaches of the river Ganga, its tributaries and distributaries, where the river course passes through alluvial plains of a very low gradient, resulting in extensive changes in floodplain configuration. All the

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wetland formations located at the floodplains in West Bengal are locally known as '*Beel*', '*Charha*' or '*Baor*', in vernacular language Bengali. They receive backflow water from the rivers during floods or from the huge catchment area following monsoon rains. The state has more than 150 *Beel, Charha* and *Baor* (wetlands) covering an area of 42,000 hectares, constituting 22% of the total freshwater area of the state with an average annual fish yield of 100–150 kg/ha (CIFRI 2000). A total of 85 fish species belonging to 33 families have been recorded from floodplain wetlands in India and it is reported to have a potential fisheries yield of 1,000–1,500 kg/ha/year, if managed scientifically (ICAR 2011).

Agriculture and allied activities such as fisheries and aquaculture is the single largest sector which acts as a growth engine by ensuring food and nutritional security to the masses besides providing raw materials to agro-based industries and also providing employment and thereby income to the rural folk of the state and Indian economy (Planning Commission Report 2008). Climate change is recognised as one of the leading challenges affecting the performance of agriculture, fisheries and the livelihood of people. Farmers are the hardest hit as they have to continuously respond to climatic variations (Dhanya & Ramachandran 2015). IPCC's Assessment Report 5 (AR5) indicates that climate change is likely to reduce agricultural productivity in the tropics and create threats to human security due to its direct and indirect impacts manifested on water resources, agriculture, coastal areas and resource-dependent livelihoods, especially in Asian countries. The increased occurrence of events such as summer thunderstorms, frequent intense drought of short duration, non-seasonal rains, prolonged monsoon and winter rains in Asia have been predicted. Specifically for the regions of South East Asia, of which India is a part, an accelerated hydro-cycle is anticipated which may result in frequent occurrence of high intensity short duration dry seasons followed by low intensity long duration wet seasons (IPCC 2014). Global warming and the resultant climate change are expected to increase the occurrences and intensity of extreme weather events, such as floods, droughts and severe cyclonic storms (IPCC 2012). Moreover, a decline in the total run-off for all the river basins, except Narmada and Tapti, is projected in India which will eventually create water stress in the associated wetlands (NATCOM-UNFCCC 2004; Sharma *et al.* 2015).

Wetlands are considered as biologically sensitive habitats and are predicted to be most impacted through climate change (Ramsar Convention Secretariat 2013; Sarkar & Borah 2017). It has been reported by several authors that due to climatic changes the fisheries in wetlands will be impacted and, to minimize those, alternative strategies need to be developed (Tonn 1990; CIFRI 2000; Thorp *et al.* 2006; Mamun 2007; Dudley *et al.* 2010; Pittock & Finlayson 2011; Lukasiewicz *et al.* 2012; Ramsar Convention Secretariat 2013; Sharma *et al.* 2015). For the enhancement of adaptive capacity and reducing vulnerability, especially in the most vulnerable regions, adaptation assessment is an important preliminary policy response (IPCC 2012). Dhanya & Ramachandran (2015) opined that adaptation strategies innovated at the farmer's level to cope with changing climate often arises out of need (planned adaptation); while some strategies are developed for a different purpose, or unknowingly prove to be climate change resilient later on (spontaneous adaptation). In view of the above, the objective of this study was to identify the existing climate change resilient fisheries strategies adopted by the local fisher folk in the floodplain wetlands of West Bengal, be it planned or spontaneous adaptation. The present study provided further discussion on these strategies as a potential tool to cope with the impacts of regional trends of changing climate for promoting sustainable wetland fisheries.

MATERIALS AND METHODS

Climate data analysis

District level climate data (mean air temperature and total annual rainfall) of the studied districts (North 24 Parganas, Nadia and Kolkata) were collected from the Indian Meteorological Department (IMD), Alipore over the last three and half decades (1980–2015). In order to provide an overall picture of the climate change trend over the region where the selected wetlands exist, the climate dataset for individual districts were merged, keeping in view the nearness of the districts to each other, and analysis was based on the average.

Collection of primary and secondary data

Four wetlands of West Bengal (Figure 1) under a cooperative mode of management were selected and investigations were carried out through field visits between February 2015 and December 2015. Each selected wetland is managed by a fisheries cooperative which consists of an elected cooperative manager (from the fishing community settled

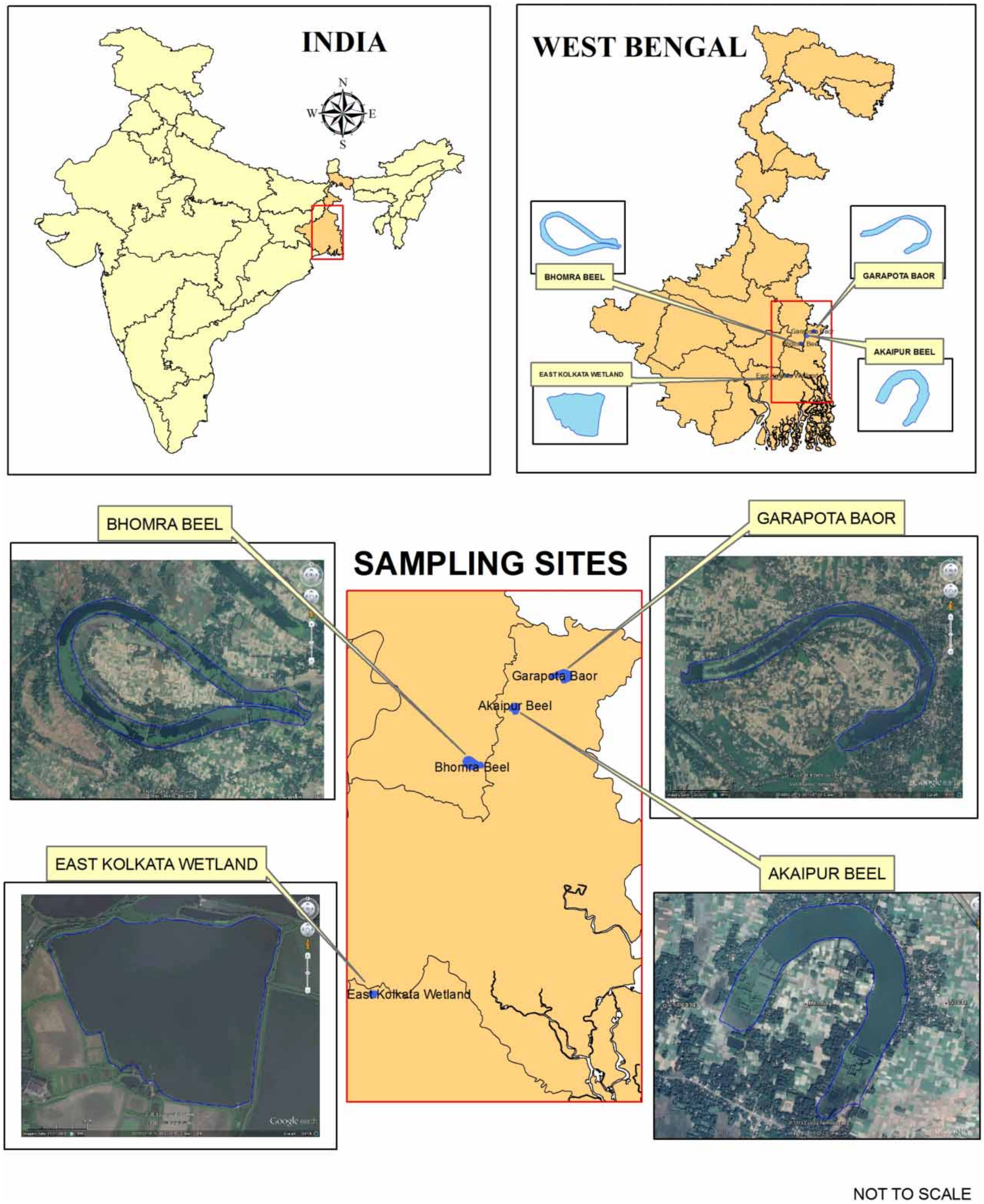

Figure 1 | Location of the Wetlands surveyed.

around the wetland itself), local fishermen and some local fish traders. The details regarding the studied wetlands including area, GPS coordinates and land use pattern are provided in Table 1.

The Delphi method of interrogative approach was followed during the study to collect authentic information (Linstone & Turoff 1975). However, the original Delphi method was modified to suit specific needs and overcome certain constraints associated with the participatory research at field level involving illiterate fisher folk as the primary source of data. A structured communication process was designed to collect group, sort and rank data and reach a consensus from a group of people by maintaining the anonymity of responses obtained from the individually interviewed respondents through multiple rounds of surveys. A set of open-ended questions on a specific issue were asked to various 'experts' individually in the first round. The responses to these questions were summarized and a second set of questions (second round) that sought to clarify areas of agreement and disagreement were formulated for the same group of experts after several weeks. A total of 80 interviewees, i.e. 20 interviewees in each wetland, were interviewed, which included a cooperative manager (1), associated fishermen (12) and fish traders (7) as 'experts' (Naskar *et al.* 2017).

Relevance assigned against each strategy was arrived at based on group discussion and consensus between fish traders and the fisheries cooperative manager of each wetland. Relevance of a particular strategy implies the domain of fisheries for which the strategy is felt to be most appropriate for application and further optimization. Under relevance, the term 'culture fisheries' is indicative of the domain of standard aquaculture or culture based fishery wherein fish seeds are stocked, cared for (managed), reared and harvested; whereas the term 'capture fisheries' is indicative of the domain wherein no such stocking or husbandry practices exist and is only restricted to random exploitation (fishing) of wild fish stocks. Lastly, the term 'culture based capture fishery' is indicative of an intermediate situation between the two extreme domains of fisheries (culture and capture). Similarly, ranking of fish groups dependent on different types of refuge in descending order of dominance was derived from expert knowledge (group discussed) of regular fishers who have been performing fishing operations in the refuge area over the years (Mamun 2007). Ranking was based on eye estimation of regular fishers from their practical field level experience on the average number of fishes pertaining to a particular group encountered during each haul by small meshed cast or drag net. Fish groups ranked higher are supposed to have the maximum chance of appearing frequently in repeated netting hauls from a particular refuge. Published literature focusing on the SWOT-like analysis of similar or related fisheries strategies in inland water resources were also consulted from peer reviewed scientific literature and the World Wide Web as a source of secondary information.

RESULTS AND DISCUSSION

Climate change trends over the region

Analysis of the IMD data on mean air temperature has revealed a unanimous warming trend and decreasing rainfall among the studied districts (North 24 Parganas, Nadia and Kolkata) of West Bengal. During the period of

Table 1 | Details of wetlands studied

S. no.	Name of wetland	Geomorphology	District	Coordinates	Area (approx.)	Land use pattern
1.	Akaipur *beel*	Closed, Ox-Bow lake	North 24 Parganas	23° 5′8.36″N 88°43′3.80″E	32 ha	Agriculture
2.	Bhomra *beel*	Closed, Ox-Bow lake	Nadia	22°59′14.59″N 88°37′40.33″E	83 ha	Agriculture
3.	East Kolkata Wetland	Open, Sewage fed low land	Kolkata	22°32′57.53″N 88°27′5.25″E	40 ha	Urban establishment
4.	Garapota *baor*	Semi-open, Ox Bow lake	North 24 Parganas	23°8′52.45″N 88°48′39.81″E	122 ha	Agriculture

1980–2015, the mean air temperature has increased in the range of 0.18–0.28 °C (mean 0.22 °C) (Figure 2). It has also been recorded that the total annual rainfall during the same period has decreased in the range of 135.6–257 mm (mean 192.5 mm) (Figure 2). The seasonal pattern of rainfall has shown that the average rainfall has decreased by 2.3–2.4% and 5.8–6.2% during pre-monsoon (January–April) and post-monsoon (September–December) respectively, while it has increased by 6.2–8.5% in the monsoon (May–August); clearly showing a narrowing monsoon calendar over the region. This climatic trend matches with the unanimous consensus of the wetland stakeholders who perceived increasing frequency in occurrence of floods during monsoon, earlier drying-up (shrinking) of wetlands and increasing water stress during pre-monsoon (Naskar *et al.* 2017). However, in addition to changing precipitation patterns over the region, other eco-geomorphological changes such as sedimentation and aquatic weed proliferation may also be driving the increasing water stress situation in the wetlands of the region (CIFRI 2016; Roy 2016; Naskar *et al.* 2017). The climatic trends reported here are in agreement with the historical climatic data analysis of the above mentioned districts of West Bengal, reviewed in a previous report (Sharma *et al.* 2015).

CLIMATE SMART NATURE OF THE INDIGENOUS FISHERIES STRATEGIES IN WETLANDS

The present study identified a total of six indigenous fisheries strategies from the studied floodplain wetlands of West Bengal, which may be used as a potential tool to cope with the impacts of regional trends of changing climate for promoting sustainable wetland fisheries (Table 2). Among the six strategies, three had relevance to culture fisheries, two had relevance to capture fisheries and one to culture based capture fisheries. Based on discussions with the wetland fisheries stakeholders (defined before), we suspect most of the indigenous fisheries' strategies identified were spontaneous adaptations, except that of *Temporary pre-summer enclosure* which may have been a result of planned adaptation. Difference of opinions between fishermen, fisheries cooperative managers and local fish traders in respective wetlands encountered during the study were negligible. Opinions among fishermen and the cooperative manager were more consistent and inter-twined than the fish traders. The operational details of the identified adaptation strategies are discussed below in detail.

Temporary pre-summer enclosure

Bhomra wetland, like other wetlands in the area, practices semi-intensive carp aquaculture in pens (installed within wetlands) and extensive culture fisheries in open waters (of the wetland) after the wetlands transform into a closed water body post monsoon. The carp species (*Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*, *Labeo bata*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *Cyprinus carpio*, *Puntius sarana*, *Puntius javonicus*) are deliberately stocked into the pens or open waters in advanced fry or fingerling stage, obtained from nurseries, and they form the

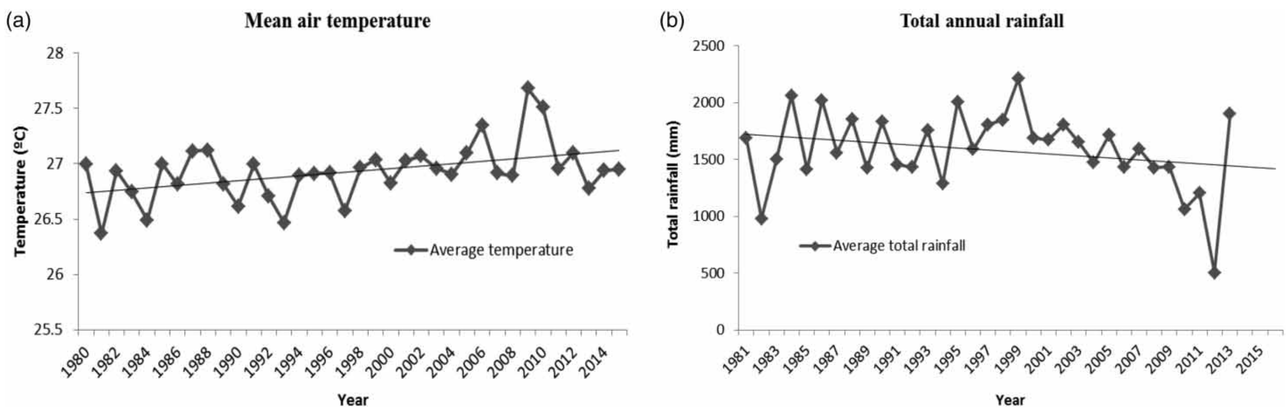

Figure 2 | Trend of increasing mean air temperature and decreasing rainfall in the studied districts (North 24 Parganas, Nadia and Kolkata) of West Bengal.

Table 2 | Summary of identified climate change resilient fisheries or aquaculture strategies adopted by the local fisher folk in some wetlands of West Bengal

S. no.	Name of the indigenous strategy	Location	Relevance[a]
1.	Temporary pre-summer enclosure	Bhomra *Beel*	Culture fisheries
2.	Torch light fishing	Bhomra *Bee*l	Capture fishery
3.	Deep pool (*Komor*) refuge	Akaipur *Beel*	Capture fishery
4.	Autumn stocking	East Kolkata Wetland	Culture fishery
5.	Submerged branch pile (*Kata*) refuge	East Kolkata Wetland, Garapota *Baor*	Culture fishery
6.	Floating aquatic macrophyte refuge (*Pana chapa*)	Garapota *Baor*	Culture based capture fishery

[a]Relevance = Domain of fisheries for which the strategy is felt to be most appropriate for application and further optimization; detailed in text (based on group-discussed consensus between fish traders and fisheries cooperative manager).

mainstay of fisheries' income from the wetland. On the other hand, the population of other groups of fishes such as catfishes and snakeheads are not artificially replenished through stocking as they are naturally sustained from autochthonous stocks of the wetlands (detailed in CIFRI (2000)). In perceptive water stress since 2010, the fishermen of Bhomra *beel* have innovated an adaptive strategy (Figure 3). A provision of enclosure is made around the deepest part of the *beel* during pre-summer, as the water level starts to recede. The advent of the idea of '*temporary pre-summer enclosure*' was originally to safeguard the stocked carps against poaching/illegal fishing in the shrinking wetland, allowing more time for the carps to grow and allowing harvesting over a longer period of time, based on size, for optimizing income. Therefore, this enclosure is also kept under supervision which includes night watchmen. The commercially important fishes, the majority of which consist of carps, are deliberately restocked within the enclosure after catching them from the surrounding waters with the help of cast and drag nets of varying mesh sizes. It should be noted that while relaying carps into the enclosure, other commercially important fishes encountered in the haul are also transferred depending on their market value. While the risks of predation of the carps within the enclosure from the relayed carnivorous fishes remain to be a researchable issue, the fisher folk ruled out this issue due to the large size of the carp. The fishes are harvested from the enclosures intermittently based on size, when the shallower part of the wetland dries up. This modified MSMH (multiple stocking multiple harvesting) process of relaying the high value fishes into the enclosures and subsequent harvesting of large sized individuals is continued for several weeks during January–March, after which fishing operations are ceased and the remaining stocks are left as is. Another responsible side of this adaptive strategy is the maintenance of a sizeable amount of fringe water area around the pre-summer enclosure that is not fished when there are signs of the shallower parts of wetland drying up, which typically occurs from March. Local fisher folk believe this strategy helps in the maintenance of base stocks of miscellaneous

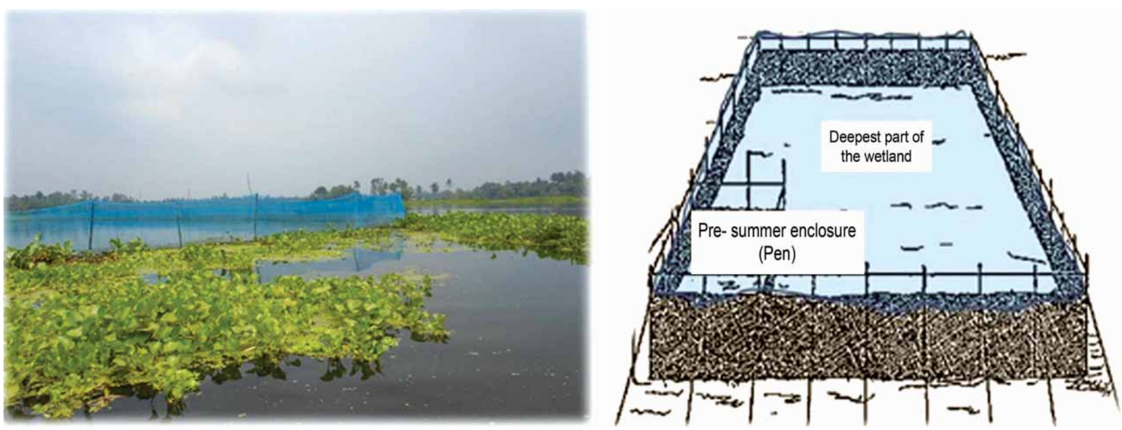

Figure 3 | Temporary pre-summer enclosure.

fishes in the wetlands, especially the high value catfishes and snakeheads, for breeding during pre-monsoon and monsoon to replenish the population. Before the advent of monsoon (April–May), net walls of the temporary pre-summer enclosure are removed part by part and sent for repairing; allowing gradual but restricted movement of fishes between the fringe area and enclosure for feeding or mating. The fishing, no-fishing decisions are taken and imposed by the management body of the fisheries cooperative responsible for managing the wetland, after conducting meetings with the member fishermen.

This strategy may be useful in future climate scenarios where accelerated hydro-cycle resulting in frequent occurrence of high intensity and low duration dry season followed by wet seasons is being expected in parts of South East Asia (IPCC 2014). This particular strategy can partly sustain the fisheries or aquaculture dependency of the local fisher folk community during dry seasons.

Torch light fishing

Torch light fishing is an easy and effective fishing method under low water level conditions (reduced depth). A group of men sets a trap and then lights a torch along the margins of the *beels* (Figure 4). Positively photo tactic fishes/ shellfishes are lured into the trap. Bulk catches consists of small prawns and crustaceans locally termed as '*ghuso chingri*'.

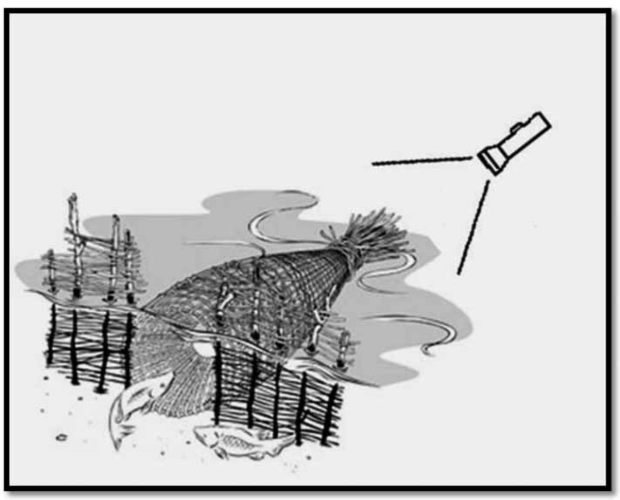

Figure 4 | Schematic diagram of torch light fishing.

This fishing strategy is not very popular but is widely accepted among the fisher folk of Bhomra *beel* due to its low efficiency and the social stigma associated with it being regarded as a *poacher's fishing technique*. If applied on a larger and improved scale it might prove to become a convenient fishing strategy in low water conditions (pre-monsoon) like many light fishing techniques applied worldwide in marine waters (FAO 2014).

Deep pool refuge

Deep-water pools broadly refer to a variety of relatively deep aquatic habitats surrounded and connected to shallower aquatic environments (Baird 2006). Regions of deep pools, locally termed as '*komor*', created naturally or by digging activities of crabs and catfishes over the years, are well demarcated by the experienced fishermen in Akaipur *beel*. Here, water is deep during summer and serves as a summer refuge to many fishes. A total of 24 varieties of fishes were reported to be dependent on this refuge, the majority of which are bottom dwelling ones with carnivorous feeding habits (Table 3). Fishing activity in this zone is prohibited throughout the year except during February–March. Owing to a number of scattered deep pools in the Akaipur wetland, the majority of the large deep pools are fished, leaving only a few smaller deep pools; which are treated as sanctuaries for summer refuge. Fishing in deep pools is done with nets having mesh size greater than 20 mm (mostly 30 mm) to avoid catching smaller sized individuals. All fishing activities remain closed from April until June for allowing the small indigenous fishes to breed, which is decided by the fisheries cooperative society of the wetland. However, it is felt that the present strategy needs further technical intervention and stringent regulation as indiscriminate fishing of deep pool refuges may prove detrimental to the fisheries in the long run. The fisher folk community claims that when most part of the wetland dries up, deep pools either ensure the availability of harvestable fish stocks during dry months or provide summer refuge to base stocks for recruitment in the preceding seasons. Similar viewpoints were highlighted in a study from a few wetlands of Bangladesh, adjacent to West Bengal (Mamun 2007).

Deep-water pools in the stream or wetland beds are known to serve as important dry season refuges for fish

Table 3 | Common fishes utilizing refuge in deep pool (*komor*) refuge of Akaipur *beel* during summer

S. no.	Group	Local names	Scientific names	Feeding habit (FishBase 2015)	Habitat preference (FishBase 2015)	Rank of abundance[a]
1.	Catfishes	*Boal, Ayre, Tengra, Magur, Singhi*	*Clarias batrachus, Heteropneustes fossilis, Wallago attu, Mystus tengara, Mystus vittatus, Sperata aor*	Carnivore	Benthic	1
2.	Murrels	*Lata, Shol, Gozar*	*Channa marulius, Channa punctatus, Channa striatus, Channa gachua*	Carnivore	Benthic	2
3.	Perches	*Chanda, Kat chada, Nados, Koi, Bheda, Podkoi*	*Chanda* sp., *Parambasis* sp., *Anabas testudineus, Nandus nandus, Trichogaster* sp.	Carnivore/ Omnivore	Benthic/ Pelagic/ Surface	3
4.	Eels, Gars, Half beaks	*Baims, Cuche, Pakal*	*Macrognathus* sp., *Mastacembelus armatus, Monopterus cuchia, Anguilla bengalensis*	Carnivore/ Omnivore	Benthic	
5.	Carps	*American rui, Mrigal, Kalbose, Bata, Raag bata, Grass carp*	*Cyprinus carpio, Cirhinus mrigala, Cirrhinus reba, Labeo calbasu, Ctenopharyngodon idella*	Herbivore/ Omnivore	Benthic/ Pelagic	4

Source: Based on the information given by fishermen in a group.
[a]Abundance = Average number of fishes pertaining to a particular group encountered during each haul by small meshed cast or drag net. Derived from group discussed knowledge of regular fishers (based on eye estimation), who have been performing fishing operations in the refuge area over the years.

and some species also rely on them for spawning (Roberts & Baird 1995; Baird *et al.* 2001; Poulsen *et al.* 2002; Baird & Flaherty 2005; Baird 2006). Deep pools are also important because they are cooler than shallow areas; this is particularly crucial during the dry season when temperatures rise and water levels drop, making shallow areas very hot and often uninhabitable (Tubtim & Hirsch 2005; Baird 2006). Sedimentation is the largest threat to these naturally occurring sanctuaries, i.e. deep pool regions in rivers, streams and wetlands (Poulsen *et al.* 2002; Hirsch & Wyatt 2004). A recent study evaluated the ecological importance of deep pool refuges in an Indian river and emphasized that such zones are naturally occurring fish sanctuaries which need to be protected for the sake of biodiversity conservation (Sarkar *et al.* 2013). If these areas are not fished during the summer as well, some of the indigenous fish germplasm will remain naturally conserved in these zones for re-establishment in the next season, even when a majority of the wetland had dried up. It can be considered as a climate change resilient strategy for sustainable wetland fisheries management in regions prone to high intensity and short duration droughts under climate change regime predicted for South East Asia in IPCC (2014) AR5.

Autumn stocking

In the face of increasing water stress during dry months a counter strategy for aquaculture in East Kolkata wetland has been developed. The stakeholders agreed unanimously on the trend that there has been an increasing tendency of focusing the release of majority fish seeds, mostly carp fingerlings (discussed above), by the fisheries cooperative society during autumn, i.e. between early October to mid November. This strategy is proving viable for the wetland as it does not dry up completely during summer and harvesting is normally done before the advent of monsoon (June), allowing the stocked fishes to grow over 6–7 months. Fishers believe that the rationale of this decision has two faces. First, the overall hydrobiology of the water body stabilizes after monsoon (Roy 2014), and most of the limnological parameters become congenial during autumn–winter to support juvenile fish (Mamun 2007). It is also believed that there is lesser chance of escapes of stocked fishes, as the monsoon is deliberately avoided for stocking. Second, the traditional ecological knowledge of the fishers indicate that in a tropical climatic setup like that which exists in the region, fishes stocked during autumn–winter get a prolonged stress free situation to thrive in before conditions of water stress sets in from March onwards (Mamun 2007). It should be noted that winter in the area is already of a mild nature as the minimum air temperature barely drops below 13 °C, that too only during the last week of December. The minimum air temperature in the area during winter usually stays between 18 and 24 °C, also reported by Sharma *et al.* (2015). It has been observed that the winter time (December–January) mean air temperature of West Bengal, India has been significantly ($p < 0.05$) increasing at 0.01–0.02 °C/year during the last six decades (1950–2010) (Rathore *et al.* 2013).

If abundant fish seed, i.e. fingerlings, are available, this strategy may prove beneficial in future climatic scenarios as warmer winters are being expected for South East Asian regions (IPCC 2014). This will partly override the hindrance of low food conversion efficiency and slow growth rates of fishes generally encountered during winter (ICAR 2011; IPCC 2014). This traditional ecological knowledge driven indigenous adaptive strategy has been identified as relevant for aquaculturists to effectively cope with the water stress situations in wetlands, which does not dry up during summer.

Submerged branch pile refuge

Periphyton based practices have been developed independently and are being used to catch fish in the open waters of various parts of the world. In India (West Bengal), the practice is known as *Huri* and in Bangladesh it is called *Katha*. In West Bengal, the practice involves fixing of unused bamboo sticks or tree branches vertically in the water to act as substrates for colonization by the plankton, microbes, invertebrates and other organisms that make up periphyton (Das & Sahu 2012). In the studied wetlands, dried and dead tree branches are plinthed randomly in the deepest parts of the water body during summer months. Wild plants/shrubs with extensive networks of branches and sub-branches are preferred. This is done primarily to prevent poaching or unauthorized fishing (Figure 5). Although the provision of submerged branch pile refuge was existent in both East Kolkata wetland and Garapota *baor,* recently this provision has been discontinued in East Kolkata wetland owing to the liability of careful and complete removal of these plinthed branches prior to final harvesting. Local fisher folk perceive that these zones

Figure 5 | Submerged branch pile refuge (*kata)* based fishery.

serve as locally eutrophic food rich micro-habitats for fishes within the wetland due to the growth of periphyton and associated fauna on the submerged parts of the branches, which has also been reported (Das & Sahu 2012). Fish settle there for food, shelter and some for spawning purposes. They also serve as small scale sanctuaries, i.e. the fishes find safe shelter from predation and catching. The commonly used materials for constructing *kata* sanctuary are listed in Table 4. Table 5 indicates the fishes which utilize this refuge. A total of 45 varieties of fishes were reported to be dependent on this refuge, the majority of which are pelagic and surface inhabitants with mainly herbivorous or omnivorous feeding habits.

The fish farmers in West Bengal and Bangladesh traditionally believe *shaola* (periphyton) growing on the substrate form good food for the fish and serve as

Table 4 | Materials used for constructing submerged branch pile (*Kata*) refuge in East Kolkata Wetland and Garapota *baor*

S. no.	Local names of materials	English names	Uses
1.	*Banshser nola, Konchi*	Bamboo stick	• Framing and fixing the *kata* zone • Prevents poaching
2.	*Gacher dal*	Tree branches (Tamarind, Mango, Hijol, etc.)	• Shelter for larger fish • Bark, exuviate and/or gum of such trees are also used as food by fishes
3.	*Gacher gora*	Tree roots (Bamboo, mango)	• Provides good shelter for smaller fish

Source: Survey data on submerged branch pile materials from hatchery manager, fishermen and fish traders.

Table 5 | Common fishes utilizing refuge in *Kata* (submerged branch piles) and *Pana chapa* (Floating aquatic macrophyte refuge) zones of Garapota *baor*

S. no.	Group	Local names	Scientific names	Feeding habit (FishBase 2015)	Habitat preference (FishBase 2015)	Rank of abundance[a]
1.	Carps	*Big head, Silver carp, Catla, Mrigal, Raag bata, Grass carp, American rui, Kalbose, Rui, Bata, Pona*	*Aristychthys nobilis, Hypophthalmichthys molitrix, Catla catla, Cirhinus mrigala, Cirrhinus reba, Ctenopharyngodon idella, Cyprinus carpio, Labeo calbasu, Labeo rohita, Labeo bata*	Herbivore/ Omnivore	Surface/ Pelagic	1
2.	Small Indigenous Fishes (SIFs)	*Maya, Pod koi, Jhaya, Chapra, Ghutum, Mula, Mourola, Punti, Dhela, Darkina, Kholse, Sarpunti*	*Amblypharyngodon mola, Badis badis, Esomus danricus, Gudusia chapra, Lepidocephalichthy guntea, Aplocheilus panchax, Osteobrama* sp., *Pethia* sp., *Puntius* sp., *Rasbora daniconius, Salmophasia bacaila, Salmophasia phulo, Systomus sarana,*	Herbivore/ Omnivore	Surface/ Pelagic	2
3.	Catfishes	*Magur, Singhi, Tengra, Pabda, Ayre, Boal, Pangas, Pangos tengra*	*Clarias batrachus, Heteropneustes fossilis, Mystus tengara, Mystus vittatus, Ompok pabda, Sperata aor, Wallago attu, Pangasius* sp.	Carnivore	Benthic	3
4.	Murrels	*Lata, Shol, Gozar*	*Channa gachua, Channa marulius, Channa punctatus, Channa striatus*	Carnivore	Benthic	
5.	Other fishes	*Pholui, Bele*	*Notopterus* sp., *Glossogobius giuris*	Carnivore/ Omnivore	Pelagic/ Surface	4
6.	Perches	*Koi, Chanda, Nados, Bheda, Kat chada,*	*Anabas testudineus, Chanda* sp., *Nandus nandus, Parambasis* sp., *Trichogaster* sp.	Carnivore/ Omnivore	Pelagic/ Surface/ Benthic	
7.	Eels, Gars, Half beaks	*Bam, Pakal, Kakle*	*Macrognathus* sp., *Mastacembelus armatus, Xenentodon cancila*	Carnivore/ Omnivore	Benthic	5

Source: Based on the information given by fishermen in a group.
[a]Abundance = Average number of fishes pertaining to a particular group encountered during each haul by small meshed cast or drag net. Derived from group discussed knowledge of regular fishers (based on eye estimation), who have been performing fishing operations in the refuge area over the years.

protection against poaching. Indian major carps are grown under this system in aquaculture ponds to sustain the rural population (Das & Sahu 2012). In Bangladesh, the best result has been achieved if the surface area of the substrate is equal to approximately 50–100% of the pond's surface area. Zones of submerged branch pile refuge (*kata*) are trophically rich because of the formation and abundance of periphyton, epiphytic organisms, boring insects and mollusks on the submerged surfaces of the wood, root systems. Moreover, due to the decay of the woody material, enriched bottom mud exists at the foot of the submerged branch piles (Pusey & Arthington 2003; Mamun 2007). Various investigations indicate that zones of submerged branch pile, i.e. *kata* serves as a good fish aggregation place with high species diversity (Welcomme 1985; Pusey & Arthington 2003; Mamun 2007; Lukasiewicz *et al.* 2012). The periphyton method seems to hold promise for the farming of any herbivorous fish which is capable of harvesting periphyton from substrates. This strategy can be considered as a sustainable approach to safeguard fish stocks with provisions of abundant natural food and appropriate protection during low water conditions which will be evident in regions with projected low precipitation and/or high temperature as indicated in IPCC AR5.

Floating aquatic macrophyte refuge

Due to perceptible weed infestation in Garapota *baor* (wetland), local fisher folk have innovated a way to utilize the weed mass in harmony with the fisheries and aquaculture operations in the area. After monsoon when the water level stabilizes, a voluntary and controlled refuge for fishes is created in the wetland during September–October by gathering floating weed masses within a bamboo frame made of tied bamboo poles (Table 6). Such localized patches of floating weed masses gathered within a floating bamboo frame are termed as '*Pana chapa*' or '*Dhap*', whose area generally covers between 0.9 and 1.2 ha (Figure 6). Several such weed refuges are maintained in the wetland, serving as fish aggregating devices. Simultaneously, multiple stocking of carp fingerlings (discussed under Temporary pre-summer enclosure) in the closed wetland at 10,000 nos./ha is done by the fisheries cooperative society between September to early November, i.e. after the cessation of monsoon. Like other wetlands in West Bengal, the carp fingerlings (purchased by the fisheries cooperative society) are deliberately stocked in Garapota wetland since they form the mainstay of fisheries' income, while the population of other groups of fishes (such as catfishes, snakeheads and featherbacks) are not artificially replenished since they are naturally sustained from autochthonous stocks of the wetlands or received along with river water influx during monsoon (detailed in CIFRI (2000)). The rationale of using floating refuges is to provide a localized shelter/refuge to a diverse population of fishes including the stocked ones. After the releasing of carp seed and setting up of '*Pana chapa*' (floating aquatic macrophyte refuge), the area is left undisturbed. Before initiating fishing activities in the weed refuge during February–March, attempts are made with large meshed drag nets (>30–40 mm mesh size) to fish shallower open waters of the wetlands. The original idea is to catch the stocked carps that have not taken shelter under the weed refuge; however other fishes, large enough, are also caught during this act. The fishers believe that this fishing activity frightens other fishes in the vicinity and probably compels them to seek shelter under the weed refuges that have not yet been disturbed, resulting in a higher congregation of fishes under the refuge. During February–March, harvesting is targeted from the refuge mostly for catching the stocked fishes. Just before harvesting, net walls (<10 mm mesh size) are raised all around the weed refuge to surround and trap all the assemblages of fishes. Then, weed masses are gradually removed and fishing is done simultaneously by groups

Figure 6 | Floating aquatic macrophyte refuge (*Pana chapa*) based fishery.

Table 6 | Materials used for creating Floating aquatic macrophyte refuge (*Pana chapa*) in Garapota *baor*

S. no.	Local names of materials	English/Scientific names	Uses
1.	*Kochuri pana/ Dhap*	*Eicchornia crassipes* (Water hyacinth), *Monochoria hastate* (Arrow leaf pondweed)	• Provides shed, cover and/or hideout for fish • Roots and leaves used as food source • Provides protection from aerial predators • Supports growth of insects, insect larvae and flagellates • Roots and leaves used as food source • Leaf used as hiding place for predator and prey fishes. Submerged stem provides periphyton food source • Forage area of insectivore fish • Submerged stem provides periphyton food source
2.	*Topa pana*	*Pistia* sp.	
3.	*Kolmi*	*Ipomea aquatica* (reptans)	
4.	*Helancha/ Hinche*	*Enhydra* sp.	

Source: Survey data on aquatic macrophyte refuge materials from hatchery manager, fishermen and fish traders.

of fishermen with nets having varied mesh sizes. This process continues for about 10 days till most of the larger fishes, mainly carp, trapped within the enclosure are exhausted. However, other groups of fishes are also encountered and caught during the process. Afterwards, the net walls around the enclosure are removed and the weed refuge is completely disassembled. A total of 45 varieties of fish were reported to be dependent on this refuge, the majority of which are pelagic and surface inhabitants with mainly herbivorous or omnivorous feeding habits (Table 5). The fishes' dependency on floating aquatic macrophyte refuge (*pana chapa*) and submerged branch pile refuge (*kata*) were found to be quite similar. It should also be noted that quite a large amount of open waters are left around and between the weed refuges, which the local fisher folk believe to contain sufficient base stocks of indigenous fishes for sustaining the population naturally. Fishing in these open waters, i.e. outside the weed refuges, is also regulated by the fisheries cooperative society as certain areas of the wetlands, being too deep, are not fished and are perceived as sanctuaries for base stocks during peak summer (April–May). Moreover, the use of fine meshed (<10 mm) nets in open waters during harvesting months (February–March) are also prohibited. Fishing activities in the wetland remain closed during April–May to allow the indigenous fishes to breed. On the other hand, being semi-open in nature, the wetland regains its seasonal connectivity with the feeder streams from Icchamati River nearby during monsoon, which is believed to replenish indigenous fish stocks in the wetland.

Increased CO_2 levels and temperatures associated with climate change are likely to increase the growth and geographical distribution of invasive aquatic weed species (Brock & Vierssen 1992; Close *et al.* 2012). Most evidence suggests that most of the aquatic weeds assessed are likely to benefit overall from climate change (Bowes & Salvucci 1989; Lonsdale 1993; Madsen & Sand-Jensen 1994; Dukes 2002; Zedler & Kercher 2004; US EPA 2008; Low 2012). Heavy infestation of exotic aquatic weeds, if kept unchecked, will pose a threat to fish germplasm (Sarkar *et al.* 2008). However, as the weed refuge in Garapota *baor* is present in only a small fraction (<10 ha) of the total wetland area (>100 ha), local fisher folk believe with confidence that the presence of such localized floating weed masses in such a small area of the wetland does not create any significant adverse water quality issues in the system or place stress on the fish population. It is a proven fact that many fishes hide, associate, breed, feed, rest or predate under such weed covers (Graff & Middleton 2011; Lukasiewicz *et al.* 2012). The presence of overhanging vegetation significantly influences the fish assemblage pattern in the water bodies (Dubey *et al.* 2012). Wetland vegetation also provides a surface for fish to attach their eggs or create nests. When the eggs hatch, the vegetation becomes both a protective cover and a food source. Young fish dart into the wetland vegetation to hide (Graff & Middleton 2011). The provision of controlled wetland vegetation increases freshwater habitat quality and can decrease water temperatures raised through climate change (Lukasiewicz *et al.* 2012). Furthermore, they are trophically rich micro habitats because of the abundance of periphytic algae, epiphytic organisms, boring insects and mollusks on the submerged surfaces of the weed foliage and their root systems (Pusey & Arthington 2003; Mamun 2007). This technique can serve as an exemplary adaptive strategy to sustain fisheries/aquaculture in wetlands under future climate change scenarios where accelerated and widespread weed infestation in water bodies is expected (IPCC 2014). However, more intervention is needed to fine tune this adoptive strategy. This particular indigenous fisheries strategy is perceived to be fruitful and sustainable by the stakeholders, but nonetheless, further investigation is necessary.

The present study has documented and discussed some common climate change adaptive indigenous fisheries strategies in some wetlands of West Bengal, India but there may be more in other states of India. There is a need to carry out focused studies on a larger scale throughout the country to create a comprehensive repository of such climate change resilient fishery strategies already present in the inland water bodies of India. These indigenous fisheries strategies can be further optimized, promoted and demonstrated across different geographical locations for adoption in order to achieve sustainable climate change resilient wetland fisheries development.

CONCLUSION

Identification and documentation of such climate change resilient fisheries and/or aquaculture strategies will help in assessing the preparedness of the fisher folk community to cope with and adapt to the impact of gradual climate change in inland water bodies such as floodplain wetlands. These strategies can be used as a potential tool for adoption or converted into local level mitigation practices in wetlands where climate change resilient fisheries and/or aquaculture strategies are non-existent. It will also ensure the practice of sustainable climate change resilient fisheries management or aquaculture.

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