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Original Article

Strategies to control invasion of Sailfin Armoured Catfish, *Pterygoplichthys* spp. in wastewater-fed aquaculture bheries of East Kolkata Wetland, India with suggestion of a modified barrier based on the biological and behavioural characteristics

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Abstract: Sailfin armoured catfish (*Pterygoplichthys* spp.), an alien invasive species of family Loricariidae has invaded extensively in wastewater-fed large aquaculture ponds (locally called 'bheries') of East Kolkata Wetlands (EKW), West Bengal, India. As there is no viable controlling method at present, commonly these fishes are removed by different physical methods and discarded. In the present study, we investigated the effectiveness and suitability of different in-practice *Pterygoplichthys* spp. control methods, based on on-field sampling, biological and behavioural study of the fish and also response analysis of the stakeholder's of EKW. The results indicate that in-practice eradication efforts, like 'repeated seine netting' with or without removal of *Eichhornia* sheath of the pond periphery and 'dewatering of pond' aiming to reduce or eradicate *Pterygoplichthys* spp., are not fully effective, because of the capture avoidance ability and burrowing habit of these fishes. We found deep and branching burrows of *Pterygoplichthys* spp. in aquaculture ponds of EKW, with maximum burrow depth of 58 cm, and water in that burrows even after 12 days of dewatering. Hence, it is suggested stakeholders to keep dewatered pond exposed to sunlight for at least four weeks or above to ensure complete water-out from the burrows in which *Pterygoplichthys* spp. take shelter or lay their eggs. 'Multilayer bamboo fencing' or 'combination of bamboo fencing and net barrier' use by the stakeholders of EKW to prevent intrusion or re-intrusion of *Pterygoplichthys* spp. were found only partially effective, because of the capability of these fishes to damage net-blocking through their hard dorsal and pectoral spines or entry through the holes dug across the barrier in beneath or banks of the sewage intake channel. Based on learning on the biological and behavioural characteristics of *Pterygoplichthys* spp., we then suggested a modified version of barrier to the stakeholder's of EKW, incorporating a sewage feeder pipeline, a concrete collection chamber with size separation arrangement made of hard materials like wire mesh and a dam of specific dimensions across the channel, for effective prevention of intrusion of these fishes in their aquaculture bheries.

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Introduction

Convention on Biological Diversity (2014) defined invasive species as "species that their introduction and/or spread outside their natural past or present distribution threaten biological diversity". Freshwater fishes form a key component of invasive alien fauna in many countries around the world, and non-native species contribute high proportions among them in several regions (Leprieur et al., 2008). High impact invaders when established in new habitats cause more chronic negative impact on native biota in terms of diversity loss, change in disturbance regime and retarding ecosystem succession (Simberloff et al., 2012; Paolucci et al., 2013; Hussan and Sundaray, 2020).

Pterygoplichthys spp., a non-native armoured 'Sailfin Catfish', having good capability of modifying their life history patterns to take advantage of new habitat, has successfully invaded in aquatic systems around the world including India and silently expanding its range (Chaichana et al., 2011; Rueda-Jasso et al., 2013; Hussan et al., 2019, 2020). The

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basket of biological traits like herbi-detrivorous feeding habit, high fecundity coupled with prolonged reproductive period, batch spawning and active parental care, broad physiological tolerance (*e.g.* salinity, pH, pollution), toleration of poor oxygen content in polluted water due to accessory respiration, capacity to down regulate metabolism during periods of food scarcity and rapid growth (Liang et al., 2005; German et al., 2010), coupled with lack of natural predators and non-use as food, are most likely contributing to its range expansion and aggressive invasion in different parts of the world including East Kolkata Wetlands (EKW) in India (Hoover et al., 2004; Hussan et al., 2019). Moreover, due to large amount of yolk, fishes of the genus *Pterygoplichthys* directly develop into a definitive adult phenotype (juvenile stage) without undergoing a true larval metamorphosis between the free-living embryo and the juvenile stage, which improves its competitiveness even in its early stages (Hoover et al., 2014). In EKW, these fishes were most likely introduced via aquarium hobbyist releases, and at present at least two species and also several intermediary forms of unknown identity, of the genus *Pterygoplichthys* co-exist in this ecosystem (Hussan et al., 2019; Hussan et al., 2020).

Negative impacts of *Pterygoplichthys* spp. and other loricariids on recipient ecosystems and aquatic communities have been reported widely (Chaichana et al., 2011; Nico et al., 2012; Hussan et al., 2019). These fishes often grow exponentially and reach high densities and alter aquatic systems through direct consumption of organic matter, algae and benthic-dwelling invertebrates (Chaichana et al., 2011), and thus can compete with natural and culture production of native small indigenous and economically important fishes (Hussan et al., 2019). *Pterygoplichthys* spp. can also cause decline in native fish abundance by consuming or destroying the eggs of native fishes (Hoover et al., 2014), and/or displacing them because of their aggressive territorial behavior (Wakida-Kusunoki et al., 2007). In EKW, significant decline in populations of native small indigenous fishes like *Puntius* sp. and *Chanda* sp. and depletion of productivity of commercial carp culture ponds due to *Pterygoplichthys* spp. invasion were reported (Kumar et al., 2018; Hussan et al., 2019). Hussan et al. (2019) also reported economic losses due to injuries/scratches on economically important fishes due to presence of a large quantity of armoured catfishes in the net during harvest, excavation in pond dykes and pond bottoms, and payment of incentives to the fishermen for catching/handling and discarding these fishes.

But no systematic effort for suppressing its population and restricting its spread into new habitat has been reported so far, not only from EKW, but also from any other parts of the world. Only known eradication of an introduced loricariid catfish by direct human intervention was reported by Hill and Sowards (2015), who reported complete eradication of *P. disjunctivus* from lower Rainbow River of Florida by hand and fish spear with an effort of two years. Chaichana and Jongphadungkiet (2012) and Sumanasinghe and Amarasinghe (2013) also suggested physical effort like ‘intensive fishing’ as one of the effective and feasible means of controlling population growth of armoured catfishes. As an effort to restrict entry of *Pterygoplichthys* spp. in their aquaculture ponds and suppress its population, fish farmers of EKW are also practicing different physical methods like net-blocking, repeated netting and even dewatering of their aquaculture ponds (Hussan et al., 2019). But evaluation of effectiveness of these efforts on suppression of *Pterygoplichthys* spp. population has not been undertaken yet. Therefore, in this study we attempted to describe and evaluate the effectiveness and drawbacks of current management strategies associated with *Pterygoplichthys* spp. control in EKW, and suggest improvements for better prevention/elimination of the species from commercial carp culture bheries of the ecosystem. In the present study, we used the terms, ‘control’ to refer to all the efforts aimed to the prevention of new introductions and re-introductions, ‘eradication’ to refer to all efforts aimed at maintaining/reducing the population or eliminating the species from the system and ‘management’ to refer to all efforts aimed to control and eradicate the species.

Table 1. Analysis of factors for scoring against a management practice.

Factors	Analysis of factors for scoring
Effectiveness	Higher the effectiveness, Higher the score and *vice versa* (Very effective=5; Effective=4; Keeps population in control / Moderately effective=3; Not so effective/Little bit effective=2; Not at all effective=1)
Cheapness	Cheaper the cost, Higher the score and *vice versa* (Very cheap=5; Cheap=4; Not cheap nor costly=3; Costly=2; Very costly=1)
Ease of implementation	Lower the difficulty in implementation, Higher the score and *vice versa* (Very easy=5; Easy=4; Little bit difficult=3; Difficult=2; Very difficult=1)

Materials and Methods

Study site: The East Kolkata Wetlands (EKW), one of the Ramsar sites in West Bengal (Ramsar, 2019), located between 22°25'-22°40'N and 88°20'-88°35'E is the world's largest wastewater ecosystem created to sustain successive resource recovery systems in the form of vegetable farms, fish ponds and paddy fields. An estimated 30-50% of the sewage generated by the Kolkata City is treated and reused by the fishponds of the EKW and produces over 15,000 MT fish per annum from its 264 functioning aquaculture ponds, locally called bheries (Edwards, 2008; Hussan, 2016). *Pterygoplichthys* spp. got entry into this system through deliberate introduction and invaded widely in EKW water bodies through the sewage feeder channels (Hussan et al., 2019). We selected two sites, North-West site [Bidhanagar area (BID)] and South site [Anandapur area (ANA)], of EKW for the present study based on the abundance of the *Pterygoplichthys* spp.

Data collection: Between May to December, 2017 randomly 40 big farms (N1) [20 farms from each site] having water area >10 ha were surveyed. To get qualitative information and also to evaluate the usefulness of the in-practice management efforts related to the eradication, control and containment of *Pterygoplichthys* spp., a total of 80 respondents (N2) (one fisherman and farm manager/farm owner from each farm) were interviewed using a semi-structured interview schedule. The respondents were asked about the pros and cons of each method and also asked to give a score to each of the management practice against each factors (effectiveness, cheapness and ease of implementation), on a five-point scale (1, 2, 3, 4 or 5) following the concept detailed in Table 1. To cross-check the views of the key informants (interviewed respondents), we visited the selected farms, done sampling and recorded the number and biomass of *Pterygoplichthys* spp. removed by different methods. In-practice eradication efforts include repeated seine netting (RS), repeated seine netting after removing *Eichhornia* sheath of the pond periphery (RSE) and dewatering of water bodies (DW). In RS method, intensive, continuous seine netting covering portions of the water bodies are done throughout the year by the stakeholders of EKW for localized population reduction of invasive *Pterygoplichthys* spp. For on-field sampling, we had done 32 numbers of removal treatments covering a total of 15.36 ha water area of eight selected bheries using seine net of size 48x5.4 m and mesh size of 15 mm. As *Pterygoplichthys* spp. have tendency of hiding in burrows and in sheltered areas, RSE method include removal of *Eichhornia* sheath of the pond periphery first, followed to repeated seine net hauling. Physical sample of RSE were collected from three ponds using same seine net as RS. Dewatering of water bodies (DW) refer to removal of fishes after complete draining of water of the bheries. To prevent entry of invasive *Pterygoplichthys* spp. stakeholders of EKW are using two types of physical barriers, *viz.* layers of bamboo fencing (MB) or combination of both bamboo and net fencing (MBN). In case of MB, split bamboos are tied together side-by-side to form a mat, and then 2-3 layers (at a distance of 5-10 m) of such mats having different finger space are placed across in the sewage feeder channel. In MBN method along with 1-2 layers of bamboo fence, an additional layer of fine mesh net fence is placed either across the channel or in the outlet end (towards aquaculture pond) of the sewage intake pipe fixed by creating a dam across the channel.

Table 2. The weight and total length (Mean±SD), maximum and minimum values recorded, and the calculated values for the total length-weight relationship for *Pterygoplichthys* spp. removed by different eradication methods at EKW, West Bengal, India.

Eradication method	n	Total length (mm)			Total weight (g)			$W = aL^b$		
		Max	Min	Mean± SD	Max	Min	Mean± SD	a	b	r^2
RS	264	483	145	322.87±87.72^a	810	46	317.39±207.62^a	0.019	2.74	0.948
RSE	210	452	132	298.69±86.61^b	690	39	272.13±167.51^b	0.016	2.82	0.913
DW	328	478	114	277.54±114.35^c	785	27	266.83±219.24^b	0.022	2.68	0.937

Values in the same column having different superscript letters are significantly different (P<0.05) among eradication methods.
RS = repeated seine netting, RSE = repeated seine netting after removing *Eichhornia* sheath, DW = dewatering of pond.

During the study, we also located burrows of *Pterygoplichthys* spp. on the pond dykes (exposed after dewatering of the ponds) as well as banks of sewage intake channels. The burrows were identified based on Nico et al. (2009) who reported most of the *Pterygoplichthys* spp. burrows as close to triangular. Data including burrow tunnel length/depth, burrow height- floor to roof at the entrance, and burrow width at entrance were collected. Measurements were taken using a combination of meter sticks, surveying rods, and tape measures. We also thoroughly studied the structural build up and installation practice of MB and MBN, to identify the drawbacks of these methods, in correlation to biological and behavioural characteristics of *Pterygoplichthys* spp. We also collected secondary information on biological and behavioural characteristics of *Pterygoplichthys* spp. from stakeholders of EKW and from literature search. Integrating this information, we then suggested a modified version of barrier, for effective prevention of intrusion of *Pterygoplichthys* spp. in the aquaculture bheries of EKW.

Data analysis: Length-weight relationship of the fishes removed was estimated using the equation, $W=aL^b$ given by Le Cren (1951); where L is the body length and W is the body weight of fish. Average number and biomass of fishes removed per unit effort were expressed simply as mean±SD and fishes removed per hectare efforts were calculated, individually, as follows and expressed as Mean±SD:

Fishes removed (as per hectare effort) = Number or biomass of fishes removed/Area covered during sampling.

To analyse the perception of the respondents, 'score' against each factor against each management practices given by each respondent were converted to percentage, to simplify the understanding, using following formula (modified after Paul et al., 2018):

Score in % = (Score obtained against a factor/ Maximum attainable score against the factor) × 100.

Then overall perception of the stakeholders towards in-practice control and eradication methods was calculated using 'Usefulness Index (Individual) (UI_i)', using the formula:

UI_i = Cumulative score against the management practice against all factors/Maximum attainable score against all factors) × 100

After that, overall efficiency of each management practices was calculated using the formula of Usefulness Index (Overall) (UI_O) = $\sum UI_i$/No. of respondent. UI_O value was used as an indicator of the overall efficiency of the management practices with minimum and maximum attainable value of 20 and 100, respectively. Greater the UI_O value, greater the overall efficiency and *vice versa*. Descriptive statistics of frequency tables, simple percentages and averages were used for the generation of conclusion.

Results

Large numbers of *Pterygoplichthys* spp. with a wide range of the body sizes were recorded during present study (Table 2), which indicates that a self-maintaining population of sailfin armoured catfish has established in EKW. The total length of the fishes collected was found in the range of 114 to 478 mm with a weight of 27 to 810 g. Although these fishes get slimmer with increasing length, as suggested by *b*-value, which is less than '3'; r^2 value of about 0.95 indicate a strong linear relationship between total length and total weight. As these fishes are not considered as important commercial fish because of their hard body armour and very little meat, farmers of

Table 3. Summary of the on-field eradication efforts in the ponds of East Kolkata Wetlands (EKW).

Sampling site	Eradication method	No. of efforts	Area covered (ha)	Number of fishes removed per effort*	Biomass of fishes removed per effort (in kg)*	Number of fishes removed per-ha effort*	Biomass of fishes removed per-ha effort (in kg)*
EKW	RS	32	15.36	39.71±16.22[a]	14.69±5.96[a]	84.16±27.09[a]	29.74±9.72[a]
	RSE	11	6.15	49.45±21.98[a]	15.58±6.81[a]	87.34±32.97[a]	25.69±10.57[a]
	DW	03	14.30	1724±114.51[b]	529.47±63.55[b]	381.41±112.49[b]	118.52±45.62[b]

*Mean±SD. Values in the same column having different superscript letters are significantly different ($P<0.05$) among eradication methods. RS = repeated seine netting, RSE = repeated seine netting after removing *Eichhornia* sheath, DW = dewatering of pond.

Table 4. *Pterygoplichthys* spp. eradication methods: Analysis of stakeholder's perception on "Five Point Scale" and in percentage (n = N2=80).

Factors	Eradication methods		
	RS	RSE	DW
Effectiveness	2.69±0.70[a] (53.75±14.08)	2.81±0.69[a] (56.25±13.90)	4.56±0.57[b] (91.25±11.40)
Cheapness	2.22±0.83[a] (44.50±16.52)	2.63±0.60[b] (52.50±12.06)	3.04±0.74[c] (60.75±14.74)
Ease of implementation	2.38±0.79[a] (47.50±15.71)	2.12±0.56[b] (42.50±11.19)	3.61±0.61[c] (72.25±12.11)

Values in parenthesis represent the score value in %. Data in the same raw having different letters are significantly different ($P<0.05$) among eradication methods. RS = repeated seine netting, RSE = repeated seine netting after removing *Eichhornia* sheath, DW = dewatering of pond.

Table 5. Measurement of *Pterygoplichthys* spp. burrows found in water bodies of EKW, West Bengal.

Parameters	n	Min	Max	Mean±SD
Burrow height – floor to roof at entrance (cm)	13	8	16.7	11.99±2.67
Burrow width at entrance (cm)	13	9.8	20.6	15.22±2.82
Burrow tunnel length/depth (cm)	12	17	58	37.75±11.51
Burrow volume (cm^3)	12	1281	15751	7246±4076

*Burrows identified based on Nico et al. (2009) were only considered for the study.

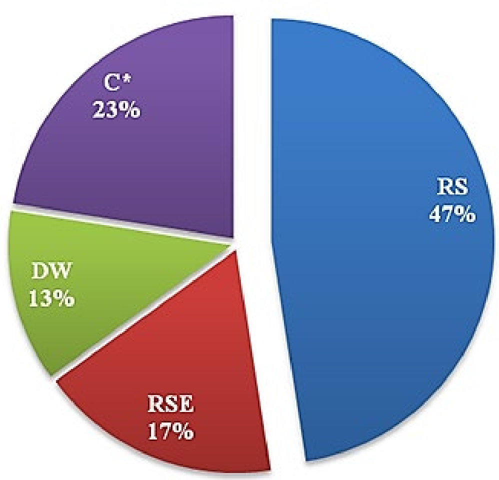

Figure 1. Proportion of farms practicing different *Pterygoplichthys* spp. eradication methods (n=N1=40) [*C: Combinations of RS, RSE or DW). RS = repeated seine netting, RSE = repeated seine netting after removing *Eichhornia* sheath, DW = dewatering of pond.

EKW are generally practicing 'culling after capture' as a measure to limit *Pterygoplichthys* spp. population (Fig. 1). A total of 7831 specimens were removed during present study by different eradication efforts, summary of which is presented in Table 3. The number and biomass of fishes removed by repeated seine netting (RS) or even by repeated seine netting after removing *Eichhornia* sheath of the pond periphery (RSE) were found indifferent statistically. Analysis of stakeholder's perception also indicates that, there is no significant difference in the effectiveness of RS and RSE (Table 4). Whereas, 381.41±112.49 numbers and 118.52±45.62 kg of fishes removed by per-ha effort of dewatering of ponds/bheries (DW) is about 4-5 times higher than RS or RSE. Though DW was found advantageous both in terms of effectiveness (Table 4) and feasibility (UI_O = 74.75±7.77) (Fig. 2), in many cases, even after dewatering and despite leaving ponds empty for 15-20 days, *Pterygoplichthys* spp. appeared once again when the ponds were filled with water. This is due to the refuge these fishes take in deep and branching

Table 6. *Pterygoplichthys* spp. control methods: Analysis of stakeholder's response on "Five Point Scale" and in percentage (n = N2=80).

Factors	Control Methods	
	MB	MBN
Effectiveness	1.97±0.39[a] (39.50±7.78)	2.97±0.55[b] (59.50±11.01)
Cheapness	3.91±0.62[a] (78.22±12.48)	3.46±0.55[b] (69.25±10.99)
Ease of implementation	3.78±0.56[a] (75.50±11.19)	3.64±0.48[a] (72.75±9.67)

Values in parenthesis represent the score value in %. Data in the same raw having different letters are significantly different (*P*<0.05) among eradication methods. MB = layers of bamboo fencing, MBN = combination of both bamboo and net fencing.

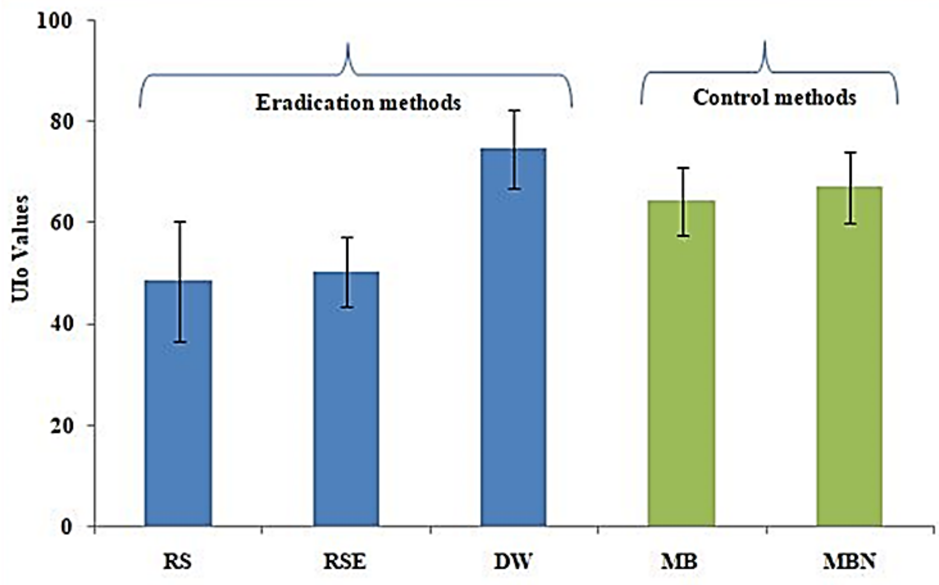

Figure 2. Overall usefulness (UIO values) of different eradication and invasion control methods (n=N2=80). RS = repeated seine netting, RSE = repeated seine netting after removing *Eichhornia* sheath, DW = dewatering of pond, MB = layers of bamboo fencing, MBN = combination of both bamboo and net fencing.

burrows, large number of which were recorded during the study (Table 5). Maximum burrow depth of 58 cm, and water in burrows even after 12 days of dewatering was recorded during present study.

Sewage intake channels are the major pathway of *Pterygoplichthys* spp. intrusion into the bheries of EKW, and hence farmers are using different types of physical barrier *viz*. layers of bamboo fencing (MB) or combination of both bamboo and net fencing (MBN) (Fig. 3), to avert its intrusion into their pisciculture bheries. Although these methods are cost-effective and also easier to implement, their effectiveness were found in the range of 40-60% only (Table 6) and overall usefulness were found almost indifferent (Fig. 2). Major drawbacks of MB and MBN were identified as frail materials and improper installation with respect to biological and behavioural characteristics of *Pterygoplichthys* spp.

Discussions

As the invasion of *Pterygoplichthys* spp. can results in serious ecological and economic consequences (Nico et al., 2012), by directly interacting with native animals and physically altering the invaded aquatic habitats (Chaichana et al., 2011; Wei et al., 2017), adequate management efforts are needed urgently for effective control of their population growth and range expansion in India, including EKW (Hussan et al., 2016, 2019). Eradication efforts aimed at eliminating an invasive species from a given system through 'Early Detection and Rapid Response', are considered as the second most cost-effective method to deal with invasive species, after prevention (QDPI, 2001). Physical eradication methods like RS has been

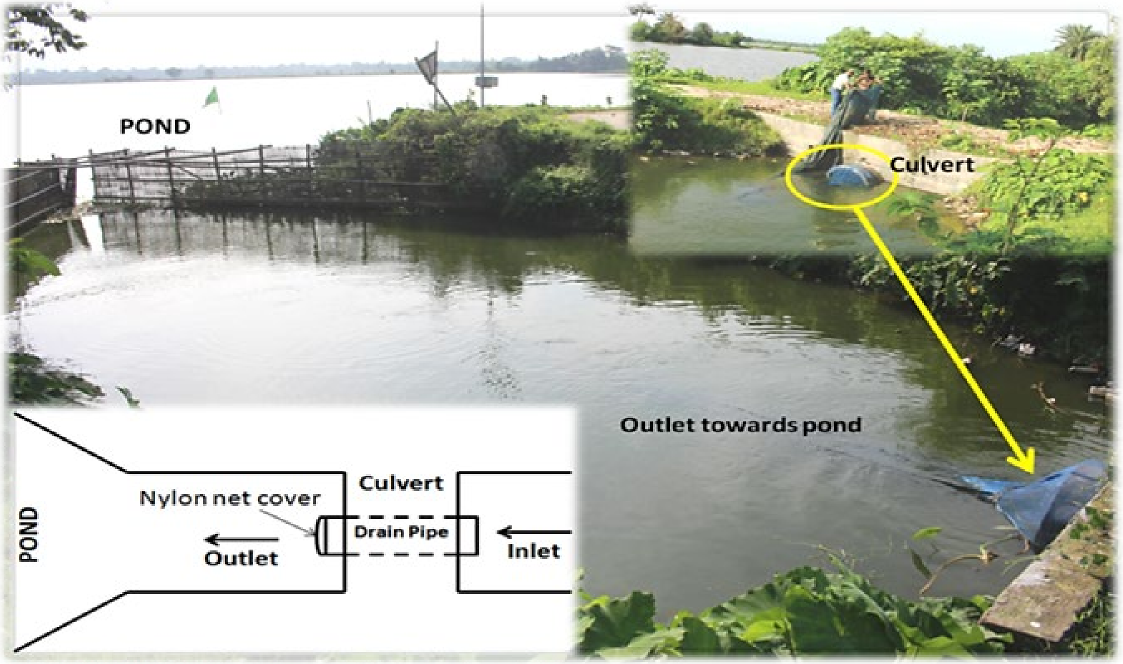

Figure 3. Traditional Physical Barrier in use at East Kolkata Wetland.

reported effective in controlling pond and lake populations of invasive fishes, such as topmouth gudgeon, *Pseudorasbora parva* in the United Kingdom (Britton et al., 2010). But in EKW, though most practiced, the effectiveness of RS to eradicate *Pterygoplichthys* spp. in-terms of per-ha effort was found only about 22% compare to DW. Thus, complete eradication of *Pterygoplichthys* spp. by RS from EKW is unlikely, because of the large sizes of the water bodies and heavy vegetation coverage along the pond periphery making it difficult to net whole water body at a time, and locate individuals within vegetation coverage (*Eichhornia* shed). Even after removing *Eichhornia* sheath effectiveness of repeated seine netting (*i.e.* RSE) did not improve significantly (only 23% effective compare to DW in-terms of per hectare effort). This is mainly because of the burrowing habits and capture avoidance ability of these fishes. Generally, males of *Pterygoplichthys* spp. excavate deep burrows in the banks and sides of the water bodies, which these fishes use as spawning and nesting sites, and as hide-outs, particularly in early life stages (Nico et al., 2009). The greater number of younger individuals hauled per unit effort of RSE also indicates their preference for hide-outs in the early stages. While the number of fishes removed per-ha effort by RSE (87.34±32.97) was higher than the number of fishes removed by RS (84.16±27.09), biomass removed by RSE (25.69±10.57 kg) was found lesser than RS (29.74±9.72 kg).

Taking advantage of this behavior, target removal of the colonized young one's from hide-outs and/or egg masses from male-guarded burrows during the spawning season, thus can offer an option for localized control of *Pterygoplichthys* spp. population by restricting recruitment (Orfinger and Goodding, 2018). Such a policy was proven successful in restricting the population growth of invasive red lionfish (*Pterois volitans*) locally in the United States (Barbour et al., 2011). Habitat manipulation, such as removing protective cover of vegetation, armouring of pond dyke walls, thus preventing egg deposition can offer a useful technique for altering the abundance of *Pterygoplichthys* spp. within EKW. While possible, these strategies can be expensive and would likely impact aquatic ecosystems unfavourably (Holdich et al., 1999; Simberloff, 2001). Therefore, RS or RSE can be effectuated regularly, as a suppression tool, to keep population of *Pterygoplichthys* spp. under control, which has very high recruitment potential.

Dewatering, though considered as the most feasible tool for complete eradication of invasive species from controlled environment (Copp et al., 2007), in many circumstances dewatering may not be fully effective and also often need an increased investment of money and time (Collier and Grainger, 2015). Hence in EKW practice of this method is largely limited to small water bodies, having water area upto 10-15 ha. In the case of *Pterygoplichthys* spp. achieving 100% removal by simple DW is most unlikely, as they take shelter in deep branching burrows and also lay eggs there (Zworykin and Budaev, 2013). Moreover, these fishes are resilient to hypoxia, anoxia, and brief aerial exposure due to their ability of aerial respiration through the modified gastrointestinal tract (Armbruster, 1998; Cook-Hildreth, 2009). Gibbs and Groff (2014) reported that these fishes can survive out of water even more than 30 hours. Eggs of these fishes are also very resistant to the environmental conditions and can develop normally even at low water levels, the only condition being that they should be covered with water (Hoover et al., 2014). All these adaptations enable *Pterygoplichthys* spp. to withstand potentially lethal events and stressors such as droughts and polluted water. Therefore, to ensure 100% eradication of *Pterygoplichthys* spp. even after draining, ponds of EKW needs to be sun-dried for at least four weeks or above to ensure complete water-out from the burrows. Kozak and Policar (2003) concluded that dewatering method may yield greater efficacy in controlling invasive fishes, when used alongside another eradication technique such as the application of chemicals.

Eradication of an established population of non-native species is considered as a less biologically and economically feasible option as the species occupies more area and most of the detection methods are not completely reliable (Pluess et al., 2012; Tobin et al., 2014). Hence, the best and most cost-effective way to reduce total impacts from non-native invasive species is to prevent their arrival and establishment (IUCN, 2000; Lodge et al., 2006; Keller et al., 2007). Prevention strategies include regulation, border protection, public engagement, and public-private partnerships to restrict introduction (Mack et al., 2000). Prevention of re-introduction is also critical for any successful eradication (Bomford and O'Brien, 1995). Physical control using fish barriers or screens are sometimes very effective in preventing new fish entry or excluding eradicated fish following removal to promote restoration of the degraded habitat (Collier and Grainger, 2015). Brammeier et al. (2008) reported 'physical barrier' method as 95-100% effective to prevent the transfer of aquatic invasive species on a small scale. But in EKW, in-practice physical barrier methods, like use of layers of bamboo fencing (MB) or combination of both bamboo and net fencing (MBN) were found only partially effective in preventing *Pterygoplichthys* spp. intrusion. Lower effectiveness of MB or MBN in EKW were found related with the shortcoming of these structures and their implementation, in correlation to biological and behavioural characteristics of *Pterygoplichthys* spp. These fishes have tendency to excavate burrows in the banks and peripheral area of aquatic bodies. Generally, males of these fishes dig deep and branching burrows, length of which can extend even upto 1.2-1.5 m and are often horizontal in direction (Nico et al., 2009; Capps et al., 2011). During present study, we also recorded number of burrows in dykes of aquaculture bheries and also in the banks of sewage feeder channels, average length of which was 37.75±11.51 cm, with maximum of 58 cm. In addition, these fishes have tendency of digging burrows in the steep and exposed portion of the banks, just above the water level (Nico et al., 2009), and hence sufficient dyke height to be maintained above the maximum water level for effective control of these fishes. *Pterygoplichthys* spp. also can damage net-blocking and even hard structures, like cages, thorough their hard dorsal and pectoral spines (Wakida-Kusunoki et al., 2007; Zworykin and Budaev, 2013). These biological and behavioural oddities of *Pterygoplichthys* spp. were not taken into consideration in use of MB and MBN in EKW, and hence these fishes got their way in the aquaculture bheries, by passing through the holes dug across the barrier in beneath or banks of the channel or by damaging the net blocking or through the finger spaces of the bamboo fencing. Therefore, a modified

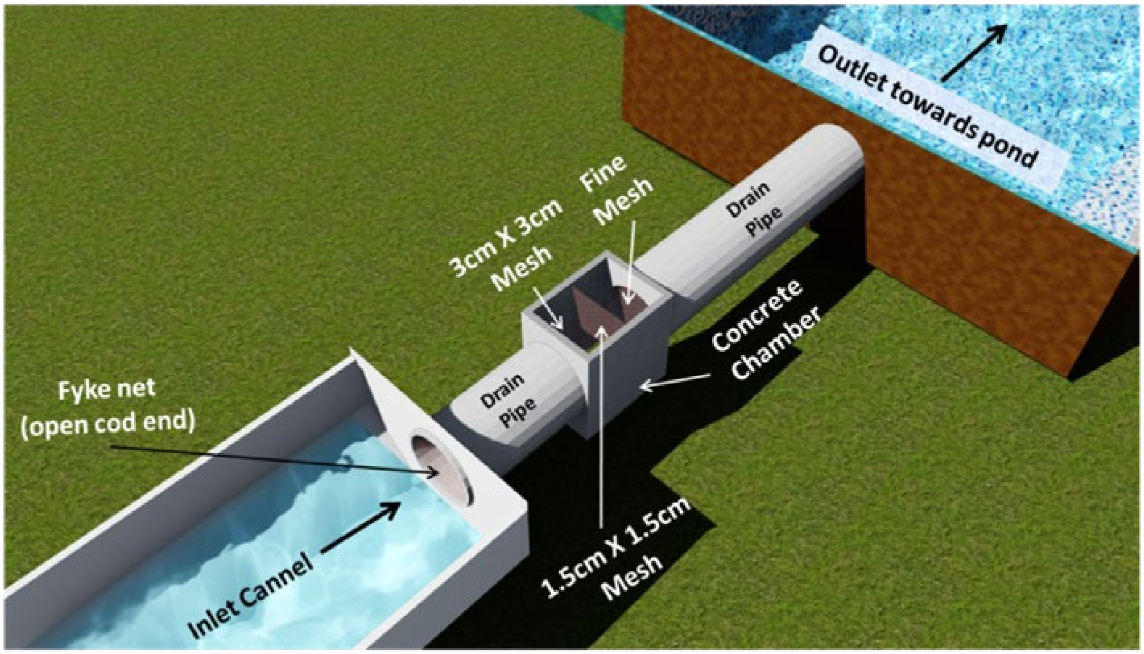

Figure 4. Photographic image of the suggested 'Modified Vertical Barrier (MVB).

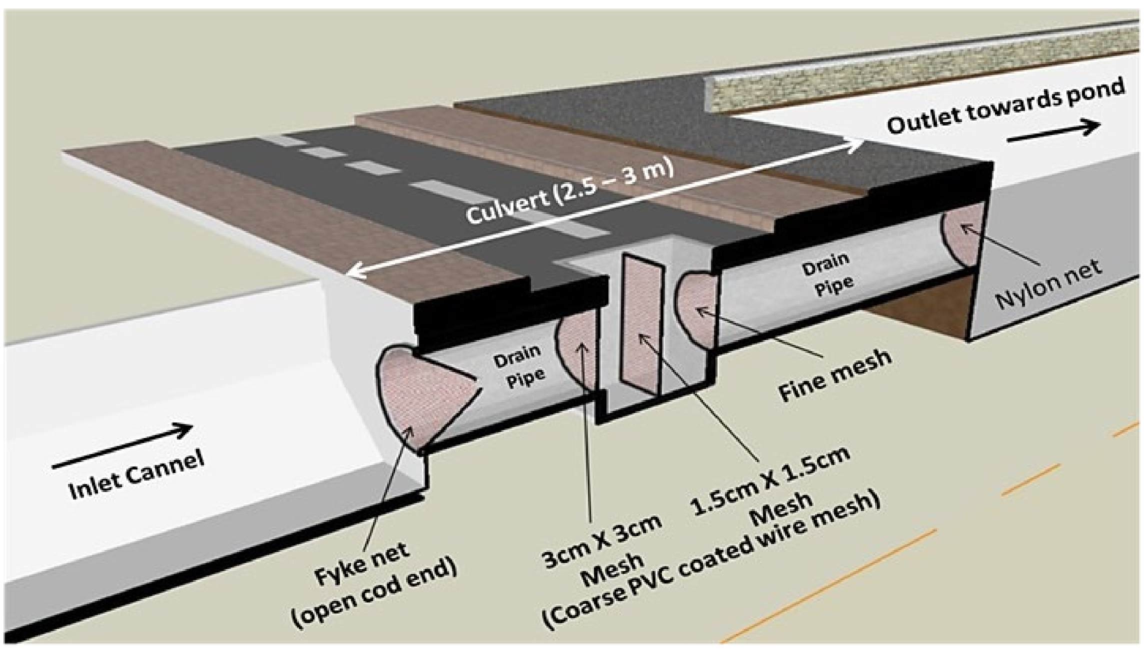

Figure 5. Cross section of the suggested 'Modified Vertical Barrier (MVB).

version of barrier, named hereby as 'Modified Vertical Barrier (MVB), was suggested taking into consideration these biological and behavioural characteristics of *Pterygoplichthys* spp. to minimise their intrusion in the bheries of EKW (Figs. 4, 5). MBV suggested includes a sewage feeder pipeline, a concrete collection chamber with size separation arrangement and a dam of specific dimensions across the channel, to cope with the biological and behavioural oddities of these fishes. Juvenile and adult *Pterygoplichthys* spp., which have capability to damage plastic net by their hard dorsal and pectoral spines can be retained by PVC coated wire mesh (square mesh 3x3 cm and 1.5x1.5 cm size) and fine-mesh fishing net as third layer will optimise retention of smaller ones having softer and thinner armour (e.g. *P. pardalis* stretch out their body fins at size >10 cm) (Chaichana and Jongphadungkiet, 2012; Gibbs et al., 2013). Moreover, debris blockage issues that discourage many EKW stakeholders to use fine mesh net as barrier can be minimised through this separation technique. Considering the burrowing characteristics of *Pterygoplichthys* spp. recorded during present study and also described by Nico et al. (2009) and Capps et al. (2011), a dam width of 2.5-3.0 m across sewage feeder channel and height of at least one meter above maximum water level was suggested for MBV. Ruebush et al. (2012) found that, barrier designed considering the behavioural characteristics of fish (named as 'bubble barrier') was successful in preventing *Hypophthalmichthys nobilis* and *H. molitrix* from moving upstream in the Illinois River of United States. Whereas, an attempt to prevent migration of *Pacifastacus leniusculus* in the River Buaa at the border between Sweden and Norway, using a simple barrier was reported unsuccessful, as behavioural aspects of the fish like ability to crawl a height and travel distances over land were not addressed in application of the barrier (Johnsen et al., 2008).

The present study concurs the remark of Hill and Sowards (2015), who stated *Pterygoplichthys* spp. eradication as difficult, potentially time consuming and not economically feasible. Hence, efforts need to explicitly focus towards containing the current established populations and preventing future expansions of *Pterygoplichthys* spp. (Lawson et al., 2015). Exploiting these fishes as human food or as an animal feed ingredient, may be an option towards limiting its population. But though these fishes have good nutritional quality and potential for uses as human food fish in the form of fresh fillets, processed product like surimi (Rueda-Jasso et al., 2013); fishermen, as well as general public in and around EKW, are averse to eating these catfishes. Educating the public, especially fishers and other stakeholders not to release unwanted *Pterygoplichthys* spp. into water bodies or water channels, also has paramount importance, as most transfer between catchments are human-assisted (Lintermans, 2004; Maceda-Veiga et al., 2016).

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