



Invasion of non-indigenous suckermouth armoured catfish of the genus *Pterygoplichthys* (Loricariidae) in the East Kolkata Wetlands: Stakeholders' perception

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ABSTRACT

Rapid spread and population increase of suckermouth armoured catfishes belonging to the genus *Pterygoplichthys* (Loricariidae) in the East Kolkata Wetlands (EKW) in recent times is of increasing concern, because of the notable possibility that these non-native catfishes are adversely affecting fish germplasm and commercial fishery of this unique ecosystem. To study the present status of these loricariids and the invasion and impact dynamics in EKW ecosystems, field survey was conducted over a water spread area of 670 ha, comprising 120 fishermen ($N_2 = 120$) of 30 farms ($N_1 = 30$), between February and October, 2017 through a pre-tested, open-ended structured schedule. A total of 943 specimens of *Pterygoplichthys* spp. were collected and analysed for abundance, length-weight parameters, gonado-somatic index and relative fecundity. *Pterygoplichthys* spp. occurred at 29 (97%) of 30 surveyed farms and approximately 70% of the farm owners perceived that these fishes posed moderate to serious economic impact. Fish production cutback, small indigenous fish (particularly, *Puntius* spp.) depredation and bottom structure alteration are among the major negatives perceived; a positive note in terms of soil-bound nutrient release was reported by a few fishermen (1%). Channel through which sewage water intake occurred by gravitation has been perceived to be the main route of entry (77%), with significantly higher abundance around the periphery of the pond. Almost 80% respondents perceived an increased occurrence of these fishes over the last four years, with seasonal pattern of abundance. Culling of suckermouth after harvest was the most common method adopted to reduce population. Multi-layer screening in the inlet of sewage water into the ponds is perceived as most sought solution for control. Average direct and indirect financial losses due to *Pterygoplichthys* spp. in EKW was calculated as ₹0.092 lakh ha⁻¹ yr⁻¹, which points towards mounting pressure of loricariids in already dwindling economics and biodiversity of EKW.

Keywords: Biodiversity, East Kolkata Wetlands, Invasion, *Pterygoplichthys*, Sewage

Introduction

Invasions by non-native species have been recognised as one of the major threats to biodiversity (Garcia-Berthou, 2007) and are known to cause significant ecological and economic damage as evidenced from the classic publication of Elton (Elton, 1958). Human domination of the Earth's ecosystems and economic globalisation have accelerated the rate of introduction of non-native species (Kolar and Lodge, 2001; 2002; Rahel, 2002) leading to extinction of many native or endemic species worldwide (UN, 1992; Clavero and Garcia-Berthou, 2005; 2006). Aquaculture and aquaria are mainly responsible for introduction of ornamental and economically important fish species to newer environments (Chavez *et al.*, 2006). About one third of the world's worst aquatic invasive species are ornamental fishes (Padilla and Williams, 2004) and the ever increasing trade of ornamental aquarium fishes is one

of the most important pathways for aquatic bio-invasion (Rixon *et al.*, 2005; Raghavan *et al.*, 2013), which is one of the major causes of biodiversity loss, particularly in freshwater systems (Sato *et al.*, 2010). Taking advantage of limited number of legislations on fisheries, particularly on ornamental fish trade, many alien fish species have been covertly brought into India by hobbyists and aqua-industrialists for aesthetic or economic reasons for the past two decades (Lakra *et al.*, 2008; Singh and Lakra, 2011). Escape or releases of these non-indigenous species into natural water bodies has dramatically altered the native fish diversity of many natural water bodies of the country and contributed to the decline and extinction of numerous species (Peh, 2010; Singh and Lakra, 2011; Singh *et al.*, 2013).

Fishes of the family Loricariidae, represent a large family of the order Siluriformes including more than 700

species (Ferraris, 2007) that inhabit freshwater habitats of tropical America, mainly occurring in the lower, middle and upper Amazon River basin of Brazil and Peru (Weber, 2003; Page and Robins, 2006) and distributed between 35° S to 12° N latitude (Berra, 2001). Loricarids have been identified as great threat to global freshwater fish diversity (Orfinger and Goodding, 2018). Due to characteristic attractive appearance, these fishes have high popularity for the aquaria and species like *Pterygoplichthys pardalis* and *Pterygoplichthys multiradiatus* have been regularly bred and exported from Singapore (Muralidharan *et al.*, 2015). Although there is wide variation, loricariids are characterised by a depressed body covered by large bony plates, a unique pair of maxillary barbels and a ventral suction mouth (Covain and Fisch-Muller, 2007). Among the loricariids, many species of the genus *Pterygoplichthys* (subfamily Hypostominae) have established populations in many parts of the world. Loricariids begun to appear outside of their native range in the second half of the 20th century, first in Central America (Wakida-Kusunoki *et al.*, 2007) and later, they were introduced/invaded into inland water bodies of many countries across the world, *viz.*, Hawaii (Eldredge, 2000), Philippines (Hubilla *et al.*, 2007), Japan (Nakabo, 2002), Taiwan (Liang *et al.*, 2005; Wu *et al.*, 2011), Vietnam (Levin *et al.*, 2008; Zworykin and Budaev, 2013), Indonesia (Herder *et al.*, 2012), Malaysian Peninsula, Java, Sumatra and Singapore (Page and Robins, 2006; Samat *et al.*, 2008), Sri Lanka (Sumanasinghe and Amarasinghe, 2013), Israel (Golani and Snovsky, 2013), Turkey (Ozdilek, 2007), Bangladesh (Hossain *et al.*, 2008), Mexico (Armando *et al.*, 2007), Eurasia (Piazzini *et al.*, 2010; Chaichana *et al.*, 2011) and India (Knight, 2010; Sinha *et al.*, 2010; Bijukumar *et al.*, 2015). Intentional release of these fishes by the aquarium keepers, suppliers and breeders of aquarium fishes into natural water bodies and easy adaptation, breeding and high survival rate are probably the major cause of their worldwide invasion (Liang *et al.*, 2005; Page and Robins, 2006; Bijukumar *et al.*, 2015).

In India, suckermouth armoured catfishes have been reported from Andhra Pradesh, Bihar, Kerala, Tamil Nadu, Telangana, Uttar Pradesh and parts of West Bengal (Knight, 2010; Sinha *et al.*, 2010; Singh, 2014; Bijukumar *et al.*, 2015; Muralidharan *et al.*, 2015; Mogalekar *et al.*, 2017; Rama Rao and Sunchu, 2017; Hussan *et al.*, 2018). Invasion of these fishes to the aquatic habitats have serious ecological and economic consequences (Nico *et al.*, 2012), as a result of food chain disruption by overgrazing of benthic algae (Liang *et al.*, 2005; Chavez *et al.*, 2006), competition with native fishes (Nico and Martin, 2001); substrate modification (Hoover *et al.*, 2004) and damage due to burrowing habit (Bunkley-Williams *et al.*, 1994). In East Kolkata Wetlands (EKW), *Pterygoplichthys* sp.

was first reported from Gomokpota Beel in 2009 (ICAR, 2009). Since then these catfishes have invaded widely and proliferated profusely in the water bodies of EKW (Hussan, 2016; Hussan *et al.*, 2016), which may be having negative effects on the native fishes as well as commercial fisheries of EKW. EKW, one of the Ramsar sites in West Bengal (Ramsar, 2017), located on the eastern fringes of the Kolkata City 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 (Edwards, 2008). Wastewater is introduced into the fishponds in batches or continuously, mainly taking advantage of gravity. Though effective area under fish farms in EKW has reduced from 7,300 ha in 1945 to around 2,481 ha in recent time (EKW, 2010), its 264 functioning aquaculture ponds, locally called bheries, currently produces over 15,000 t of fish per annum (EKW, 2010). Conversion of wetlands for settlements and agriculture, fragmentation of wetlands into relatively smaller patches, reduced capacity of the canals due to siltation, release of industrial waste water containing pesticides and heavy metals and injudicious introduction/ invasion of exotic fishes are posing threat to this unique ecosystem upon which livelihood of a large, economically underprivileged population of around 27,000 families depends (SAC, 2010).

The present study was conducted to investigate the abundance and status of invasion of loricariids of the genus *Pterygoplichthys* in EKW and to assess their impact on biodiversity, commercial fisheries and aquaculture economics of this wetland system of international importance under the Ramsar Convention.

Materials and methods

Data collection

Field survey was conducted over a water spread area of 670 ha ($S_1 = 670$ ha) of East Kolkata Wetlands (EKW, 22°25' - 22°40' N; 88°20' - 88°35' E) (Fig. 1) between February and October 2017. During this period, 30 big farms of 10 to 50 ha ($N_1 = 30$) in EKW were surveyed and 120 fishermen ($N_2 = 120$) of these farms were interviewed. Fish collection was accomplished through drag netting of around 78 ha ($S_2 = 78$ ha) of fish culture ponds of these farms at random points. Fishes were collected as bycatch in the commercial fish harvest from 3 sites of EKW: a) North-west site [Bidhanagar area (BID)], b) South site [Anandapur area (ANA)] and c) East site [Kolkata Leather Complex area (KLC)]. Specimens collected were identified based on the keys provided by Weber (1991, 1992), Armbruster (2001), Armbruster and Page (2006)

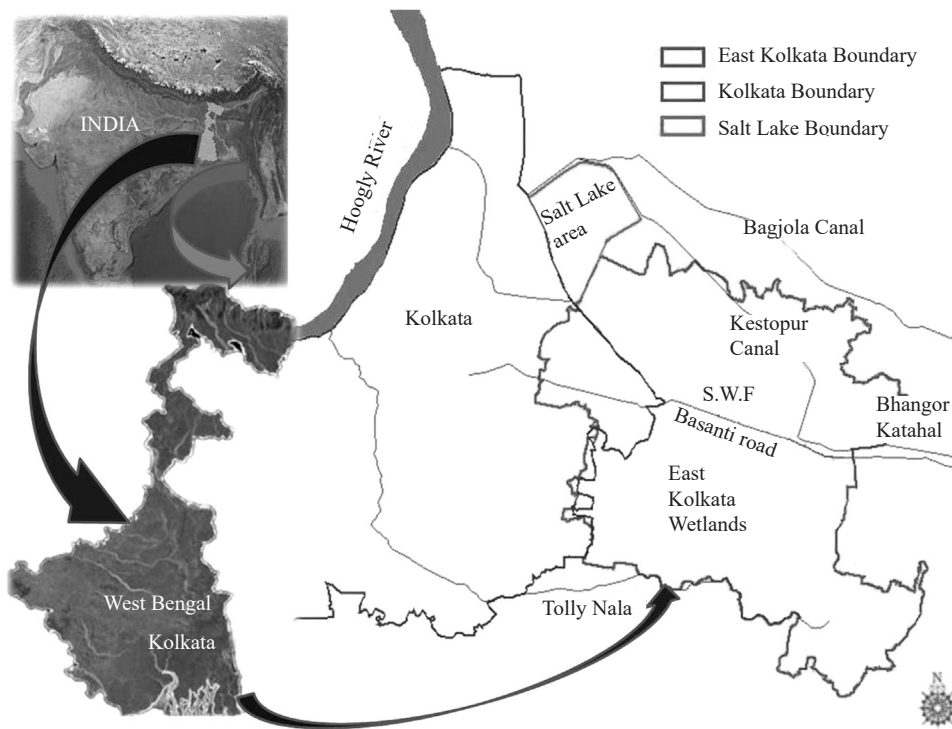


Fig. 1. The survey site: East Kolkata Wetlands, West Bengal

and Jumawan *et al.* (2011). Morphometric analysis was carried out following the methods of Armbruster (2003) and Armbruster and Page (2006). Measurements were taken with digital calliper to the nearest millimeter (mm) and weight to the nearest gram (g) using a digital balance.

To get quantitative data and to estimate magnitude of the impact of *Pterygoplichthys* spp. in pond fisheries of EKW, we conducted a face-to-face open ended questionnaire survey, as in-person interviews allow researchers to add clarifying questions and considered to be more effective than mailed questionnaires (Parkhurst *et al.*, 1987; Skaren, 1990; Trindade, 1991; Graham *et al.*, 2005). We involved the farm owner/farm manager and three long serving employees of each farm and interviewed them individually to affirm the results. Questions were asked mostly on the magnitude and trends of armoured catfishes presence in their ponds, whether any economic losses at their farms attributable to armoured catfishes and also about the impact they perceive to be causing by these catfishes. Although pond owners perception or observation of losses due to a factor not always reflect the actual economic concern (Freitas *et al.*, 2007) and likely to be biased by owner's economic interest (Kloskowski, 2005), their perceptions of damage embed by factor concern may be critical to get idea about the magnitude of concern and for identifying means for minimising losses (West

and Parkhurst, 2002). Information on damage control measures practiced by EKW farmers to control/eradicate *Pterygoplichthys* along with basic farm information like farm size, water supply source, species and age-classes of farmed fish, productivity, trends of harvesting of fishes including small indigenous fishes for the past 5 years were collected.

Data analysis

Descriptive statistics of frequency tables, simple percentage and averages were used for the generation of conclusion. Data were analysed thematically and computed as statistical tables and graphs. Overall perception percentage towards impact of *Pterygoplichthys* spp. was calculated by dividing the number of response against a particular perception by total number of respondents. The length-weight relationship 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. Phases within the reproductive cycle were identified based on Brown-Peterson *et al.* (2011). The gonado-somatic index (GSI) was determined only for females at advanced stages of spawning (n = 14) and calculated using the formula: $GSI = 100 \times (Wg / W)$ (Solomon and Ramnarine, 2007; Simon *et al.*, 2009) where Wg is the weight of wet gonad (g) and W is total wet body weight without gonad (g). Absolute fecundity (AF) was determined as the product of

gonad weight and oocyte density using the formula (Murua *et al.*, 2003):

$$F = \frac{\sum_i \frac{O_i}{W_i}}{n} * W_{\text{ovary}}$$

where, O_i = Oocyte density (oocytes / g ovary), W_i = weight of the subsample of the ovary, W_{ovary} = Weight of the entire ovary and n = No. of subsamples

Oocyte density (number of oocytes per gram of ovarian tissue) was determined by counting the number of oocytes from 3-5 subsample of ovarian tissue of known weight. Each subsample was weighed to the nearest 0.1 g and then dispersed manually to segregate and count all mature oocytes. Relative fecundity (RF) was calculated as $RF = AF / W$, where W is the body weight of fish.

Results

In our study, we found large number of suckermouth armoured catfishes (Loricariidae) with a wide range of body sizes, which indicates that a self-maintaining population of armoured catfishes have invaded EKW. These catfishes particularly of the genus *Pterygoplichthys* are not only occasionally found in the sewage distributaries of EKW, but are quite abundant in almost all the ponds surveyed. A total of 943 specimens of *Pterygoplichthys* spp. (Fig. 2)



Fig. 2. *Pterygoplichthys disjunctivus* (Weber, 1991)

were collected during the study, with abundance ranging from 3 to 22 nos. ha^{-1} . Abundance was found significantly lower in east side of EKW, that is around KLC area, where supply of wastewater through canal is limited and ponds are of comparatively smaller size which get dried up more frequently. Fish collection through netting (10 ± 5 nos. ha^{-1}) was found significantly lower in all sampling sites, than the perceived abundance of these fishes in EKW by the fishermen ($15-150$ nos. ha^{-1}) (Table 1). Netting error, burrowing habit of these fishes, regular culling of these fishes caught during food fish harvest and/or hide-outs of these fishes below *Eichhornia* layer along the periphery of the ponds are probably the reason behind the low catch achieved through netting.

Morphological traits of the individuals collected were carefully evaluated and compared between fish caught in the EKW and several common *Pterygoplichthys* spp. reported in different scientific papers. Based on external traits and pattern of the colouration/spots in belly we found about 16% individuals have greater resemblance with *P. disjunctivus* (Fig. 3a-b) and all other (84%) fishes have intermediate patterns (Fig. 3c-f), not fully resembling any *Pterygoplichthys* species description externally. *P. pardalis* which has spotted pattern with discrete black spots on the ventral side of the body (Armbruster and Page, 2006) was not recorded during the study; however, specimens with intermediate patterns were encountered which would most probably be hybrid between *P. pardalis* and *P. disjunctivus*.

Total length (TL) of the fishes collected was found in the range of 229 to 498 mm with weight (W) of 86 to 1200 g. The largest specimen of 1200 g with intermediate belly pattern was collected in the month of June from Bantala area of ANA. Although these fishes get slimmer with increasing length, as indicated by 'b' value, which is less than '3'; r^2 value of 0.941 indicates a strong linear relationship between total length and total weight. No significant difference was found in 'b' value and 'r²' value among the localities (Table 2). Occurrence of ripe female, apparently at maturing or spawning phase with ovary occupying >50% of body cavity, orange in colour

Table 1. Summary of the sampling in the ponds of East Kolkata Wetlands (EKW)

| Sampling site | Survey area (S_1) (ha) | Area netted (S_2) (ha) | <i>Pterygoplichthys</i> collected (from S_2) (no.) | Abundance as per on-field netting (no. ha^{-1})* | Abundance as per stakeholders (no. ha^{-1})* |
|---------------|----------------------------|----------------------------|-------------------------------------------------------|-----------------------------------------------------|-------------------------------------------------|
| BID | 315 | 26 | 417 | 14.0 ± 5.0^a | 80.0 ± 32.0^a |
| ANA | 245 | 30 | 361 | 11.0 ± 4.0^a | 69.0 ± 23.0^a |
| KLC | 110 | 22 | 165 | 7.0 ± 2.0^b | 33.0 ± 13.0^b |
| Pooled | 670 | 78 | 943 | 10.0 ± 5.0 | 59.0 ± 30.0 |

*Mean \pm SD. Sampling sites: Bidhanagar area (BID), Anandapur area (ANA), Kolkata Leather Complex area (KLC). Values in the same column having different superscript letters are significantly different ($p < 0.05$) among sampling sites. Data in the last row represent the overall results of EKW.



Fig. 3. Abdominal patterns of various specimens of *Pterygoplichthys* spp. a-b: *P. disjunctivus* species group; c-f: Inter-grades (Jumawan *et al.*, 2011)

Table 2. The weight and total length (Mean \pm SD), maximum and minimum values recorded, and the calculated values for the total length-weight relationship for *Pterygoplichthys* in three sites at EKW, West Bengal, India

| Locality/Site | n | Total length* (mm) | | | Total weight* (g) | | | W = aL ^b | | |
|---------------|-----|--------------------|-----|---------------|-------------------|-----|---------------|---------------------|------|----------------|
| | | Max | Min | Mean \pm SD | Max | Min | Mean \pm SD | a | b | r ² |
| BID | 417 | 498 | 232 | 315 \pm 69 | 1200 | 91 | 289 \pm 231 | 0.0179 | 2.81 | 0.938 |
| ANA | 361 | 467 | 229 | 304 \pm 65 | 830 | 86 | 227 \pm 170 | 0.021 | 2.76 | 0.929 |
| KLC | 165 | 412 | 267 | 318 \pm 54 | 530 | 140 | 277 \pm 134 | 0.0183 | 2.77 | 0.946 |
| Pooled | 943 | 498 | 229 | 327 \pm 69 | 1200 | 86 | 319 \pm 218 | 0.0176 | 2.79 | 0.941 |

with strong vascularisation, thin ovarian wall containing large oocytes from the month of August indicate onset of spawning of these fishes from the month of August/September in EKW. The mean length and weight of 14 gravid females of armoured catfish found during the study was 310 \pm 27 mm (SL) and 518.0 \pm 132 g, respectively. Ovary weights were recorded between 21.50 and 73.0 g and absolute fecundity estimates for the 14 females varied from 1606 to 4482, with a mean estimate of 2705 eggs per ovary. The average GSI was calculated as 8.52 \pm 2.65 with highest individual GSI value of 12.86 recorded in the month of October in a fish weighing 482 g. The average relative fecundity of females was 6.31 \pm 1.97 oocytes per g (Table 3).

Majority of the farms (80%) we visited reported rapid increase in the quantity of armoured catfishes in their farms over last 3-4 years (Fig. 4) with notable impact on fish stock (Fig. 5) and annual income from fisheries (Fig. 6). Seventy percent (21/30) of the farms perceived a 'significant' (moderate or large) negative effect on their annual income by armoured catfishes, whereas, 16% perceived small to no effect. These catfishes were not reported to prey on cultured fishes, but nine out of thirty farms experienced significant stock depletion in their ponds due to proliferation of these catfishes. Proliferation of armoured catfish is also perceived as one of the reason behind the reduced abundance of small indigenous fishes, particularly *Puntius* spp. and *Chanda* spp. in EKW (Fig. 7).

Table 3. Sex and maturity stages of *Pterygoplichthys* collected from EKW during July to October, 2017

| Sex | Maturity stage | Number of individuals | Standard length (SL) (mm) | Weight (g) | GSI |
|---------|-----------------------|-----------------------|---------------------------|------------|-------------|
| Unsexed | Immature | 27 | 266 ± 64 | 323 ± 84 | - |
| Male | Developing | 16 | 306 ± 52 | 457 ± 98 | - |
| | Developing | 21 | 272 ± 31 | 383 ± 121 | - |
| Female | Mature/spawning stage | 14 | 310 ± 27 | 518 ± 132 | 8.52 ± 2.65 |

Data represented as mean± SE; GSI: Gonadosomatic index

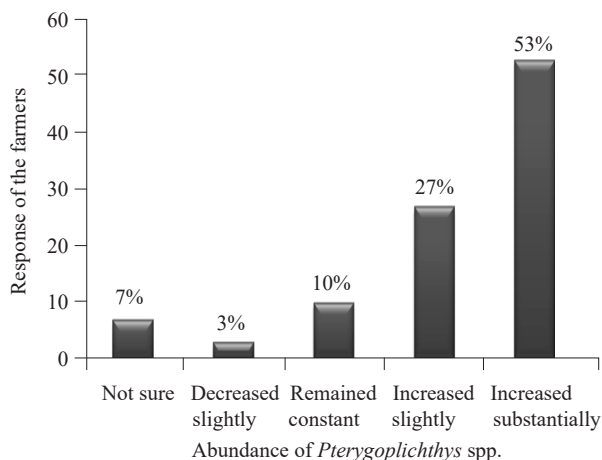


Fig. 4. Status of abundance of *Pterygoplichthys* spp. in EKW during 2014-17 (n = N₁ =30)

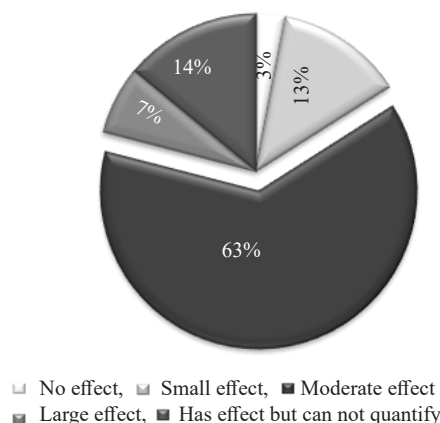


Fig. 6. Effect of *Pterygoplichthys* spp. on annual income from fisheries of EKW (n = N₁ =30)

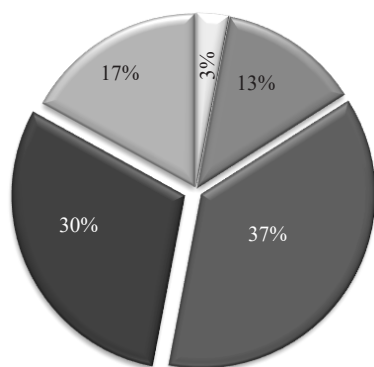


Fig. 5. Impact of *Pterygoplichthys* spp. on fish stocks of EKW ponds (n = N₁ = 30)

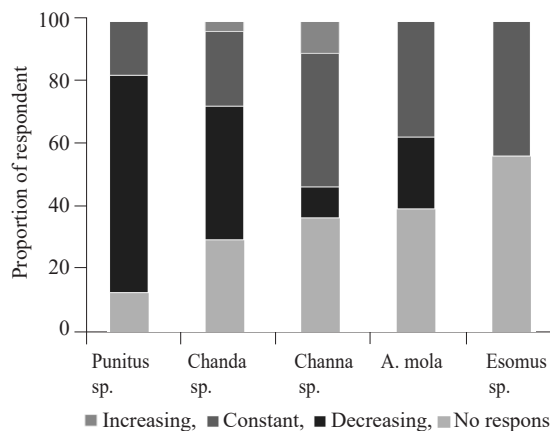


Fig. 7. Trends of indigenous small fishes catch at EKW between 2014 and 2017 (n = N₂ =120)

Channel through which sewage water is taken to the pond using gravitational advantage has been perceived as the main route of entry (77%) (Fig. 8), with significantly higher abundance around the periphery of the pond, particularly below the *Eichhornia* layer (Fig. 9). Abundance in terms of number was reported to be higher after monsoon (Fig. 10). Depredation of economically important food fishes and small indigenous fishes as well as damage

to fishing gear were perceived to be the main negatives caused by *Pterygoplichthys* spp. Injuries/scratches in the bodies of economically important fishes due to presence of large quantity of armoured catfishes in the net during harvest were reported by 14 respondents of 6 farms. Excavation of burrows in pond dykes and pond bottoms along the periphery, by these fishes were also reported. Amid all negatives, a positive note in terms of soil-bound nutrient release by these fishes was reported by one fisherman (Table 4). As control measure, all the farms studied (100%) employ culling of the fishes out

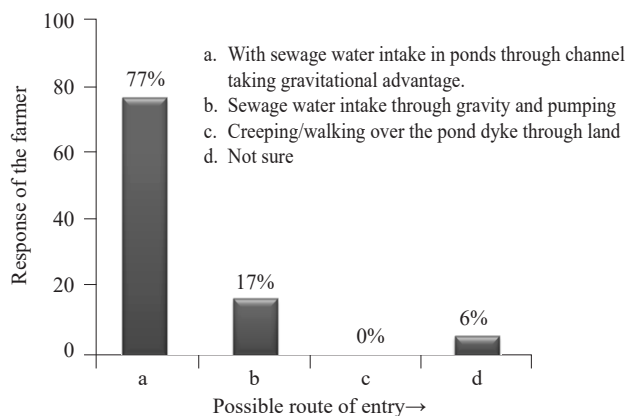


Fig. 8. Possible route of *Pterygoplichthys* spp. entry into the ponds of EKW (n = N₂ =120)

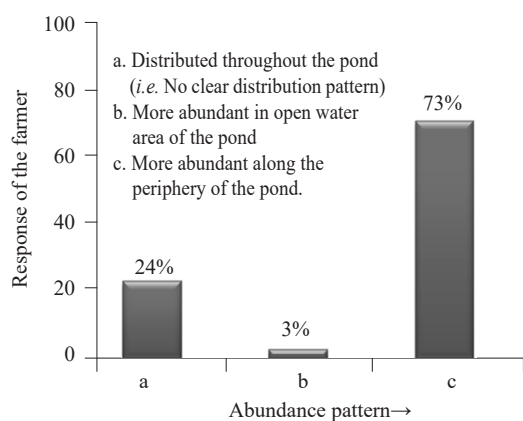


Fig. 9. Distribution pattern of *Pterygoplichthys* spp. in ponds of EKW (n = N₂ =120)

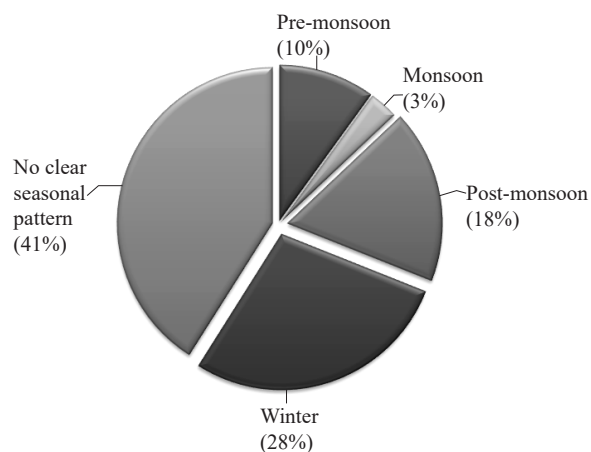


Fig. 10. Seasonal abundance pattern of *Pterygoplichthys* spp. in EKW (n = N₂ =120)

of the pond. Three farms also reported to pay additional amount to the fishermen in order to motivate them to catch *Pterygoplichthys* spp. as many as possible (Table 5). Multi-layer screening in the inlet of sewage water into pond and culling after repeated netting/drying has been perceived as the most sought solution for control (Table 6). One of the farms reported reduced abundance of *Pterygoplichthys* spp. in one of their ponds in which water depth increased to 6-7 ft after renovation. Direct and indirect financial losses by the stakeholders of EKW due to *Pterygoplichthys* spp. were calculated between ₹0.0625 lakh and 0.193 lakhs ha⁻¹ yr⁻¹ (Table 7).

Table 4. Attitude and perception of respondents towards *Pterygoplichthys* spp. (n = N₂ =120)

| Response category | No. and % of respondents | Community perception towards <i>Pterygoplichthys</i> spp. | Overall Perception (%) |
|-------------------|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------|------------------------|
| Positive | 0 (0%) | - ... | 0% |
| | | - Overgrazing the wetland | 17% |
| | | - Cause of pond productivity depletion | 43% |
| | | - Cause of reduction in fish production and thus results in economic loss | 87% |
| | | - Cause of small indigenous fish depredation | 73% |
| Negative | 117 (97.5%) | - Cause of damage to fishing net | 67% |
| | | - Block access of other fishes in and around their dominion | 13% |
| | | - Changing pond bottom/dyke structure by excavating deep holes | 67% |
| | | - Small-scale bank/bund erosion | 13% |
| | | - Cause of injury to other fishes due to strong dorsal and pectoral spines of these catfish | 17% |
| | | - Impact on overall income from fisheries is not significant | 2.5% |
| Neutral | 03 (2.5%) | - Being voracious herbivore may be good for algal control in wastewater pond | 1% |
| | | - Good demand in many places as aquarium fish | 2% |
| | | - Though cause changes in pond bottom structure; ploughing of pond bottom by these fishes may be good for soil-bound nutrient release | 1% |

Table 5. Mitigation measures reported by the respondents to reduce *Pterygoplichthys* spp. in their farms (n = N₂ = 120)

| Control/preventive measures | No. of response | % of respondents |
|-------------------------------------------------------------------------------------------------------------------------------------|-----------------|------------------|
| Culling after repeated netting | 120 | 100% |
| Removal of whole <i>Eichhornia</i> layer of the pond to net-out these fishes completely, as they concentrate below this vegetation. | 3 | 2.5% |
| Pay the fishermen @ ₹2.00 per kg of <i>Pterygoplichthys</i> spp. caught to motivate them to catch as many as possible for killing. | 11 | 9% |

Table 6. Farmers' opinion on effective solution to control *Pterygoplichthys* spp. (n = N₂ = 120)

| Variable | % of respondents |
|------------------------------------------------------------------------------------------------------------------|------------------|
| Don't Know | 24% |
| Culling after repeated netting/drying | 33% |
| Multi-layer screening in the inlet of sewage water to pond (while water is taken by utilising gravity gradient). | 31% |
| Pumping of sewage water from sewage distributaries to pond with proper screening | 12% |

Table 7. Calculated direct and indirect financial losses due to *Pterygoplichthys* spp. in EKW (per ha per year)

| Variable | Calculated loss (₹)** | | |
|-----------------------------------------------------------------------------------------------------|-----------------------|--------|---------|
| | Min. | Max. | Average |
| Loss of harvest of cultured fish (IMCs): min. 57 kg and max. 200 kg @80 kg ⁻¹ | 4,560 | 16,000 | 6,897 |
| Scaling down harvest of small indigenous fishes: min. 0.23 kg and max. 1.2 kg @100 kg ⁻¹ | 23 | 120 | 59 |
| Loss in terms of fish food organism depletion*** | 1,239 | 2,602 | 1,763 |
| Loss in terms of incentive to fishermen to catch these fishes as much as possible | 21 | 95 | 48 |
| Loss in terms of damage to fishing gears | 208 | 208 | 208 |
| Loss in terms of pond bottom/dyke deterioration | 200 | 300 | 237 |
| Total loss per ha per yr | 6,251 | 19,325 | 9,212 |

** Loss calculation is indirectly based on the response of the farmers

*** Calculated as cost of sewage water used/need to be use in excess to maintain productivity

Discussion

Establishment of *Pterygoplichthys* population in the water bodies of EKW may be related to the congenial environment in the form of *Eichhornia* shed and ample food in the form of detritus provided by this ecosystem (Mendoza *et al.*, 2009; Rueda-Jasso *et al.*, 2013; Hussan, 2016). *Eichhornia* mats provide shelter as well as breeding ground for *Pterygoplichthys* and thus greater abundance of these fishes was noticed along the periphery of the ponds. Catch of more number of non-gravid smaller sized adult fishes from open water area during breeding season also indicate their preference for shelter/hide-outs, particularly by gravid fishes, during breeding season. It may also be an indicator of intra-species competition for shelter for successful breeding as well as for protecting offsprings from threats. To obtain actual abundance status of *Pterygoplichthys* spp. in EKW, alternate fishing techniques such as repeated netting after removal of *Eichhornia* layer in the ponds or catching after complete drying of the ponds may need to be used. Occurrence of the four common species of *Pterygoplichthys* from lentic

as well as lotic water bodies in different parts of India have been reported (Muralidharan *et al.*, 2015; Bijukumar *et al.*, 2015; Reenamole and Ambili, 2016; Rama Rao and Sunchu, 2017).

Majority (84%) of the specimens recorded during the present study have intermediary belly pattern, suggesting dominance of probable hybrids between *P. disjunctivus* and *P. pardalis* or other species of this genus, in EKW. Wu *et al.* (2011) also hypothesised possible natural and/or artificial hybridisation of *Pterygoplichthys* spp. with complicated intra-specific variations and suggested that hybrid between *P. pardalis* and *P. disjunctivus* might have increased the fitness of their offspring and thus facilitated superiority of this hybrid population into invaded environments. In India, intermediary forms of *Pterygoplichthys* spp. with unknown identity were also reported by Bijukumar *et al.* (2015) from the drainages of Thiruvananthapuram City, Kerala.

The size range of the armoured catfish found in our study was comparable to that of *P. disjunctivus* in Adolfo

Lopez Mateos El Infiernillo Reservoir, Michoacan-Guerrero, Mexico (Rueda-Jasso *et al.*, 2013) and of *Pterygoplichthys* spp. in drainage of Kerala (Bijukumar *et al.*, 2015). The maximum size specimen recorded (1200 g) from EKW is also comparable with the armoured catfish collected from Churumuco, Mexico which was 520 mm in total length (TL) and 1280 g in weight (Rueda-Jasso *et al.*, 2013). Possible existence of still larger individuals of *Pterygoplichthys* spp. in EKW cannot be discounted as Gibbs *et al.* (2013) concluded that *P. disjunctivus* can live up to 5.25 years and grow up to 51.5 cm standard length (SL) with a rapid growth rate of approximately 10 cm per year. Negative allometric growth of *Pterygoplichthys* spp. with 'b' value of 2.79 found in the present study comply with the findings of Liang *et al.* (2005), Samat *et al.* (2008) and Rueda-Jasso *et al.* (2013), which indicates that the fish tend to become thinner and less round with increasing length. Fluctuation in 'b' values of *Pterygoplichthys* spp. between locations of EKW could be attributable to the fish's response to different ecological conditions, as reported by many other researchers (Sangun *et al.*, 2007; Samat *et al.*, 2008). Strong correlation between total length and weight found in the present study ($r^2 = 0.941$) was similar to that of *P. disjunctivus* reported from Mexico (Rueda-Jasso *et al.*, 2013). The number of eggs per brood of *Pterygoplichthys* recorded in the EKW (AF = 2705 ± 826 eggs per fish) is comparable with the total fecundity of *P. disjunctivus* recorded in Mexico (2447 ± 252 eggs per fish) (Rueda-Jasso *et al.*, 2013) or fecundity of *Hypostomus* sp. and *Pterygoplichthys* sp. reported from Texas (Cook-Hildreth *et al.*, 2016); but far lower than that reported for *P. disjunctivus* caught from Marikina River, Philippines (AF = 7705 ± 216 eggs per fish) (Jumawan *et al.*, 2016) or *P. pardalis* from Langat River of peninsular Malaysia with > 4000 eggs per fish (Samat *et al.*, 2016).

Twenty nine out of thirty farms surveyed reported occurrence of *Pterygoplichthys* spp. in their farms. Traits like ability to withstand water pollution (Welcomme and Vidthayanom, 2003), tolerance to poor oxygen content in water due to their ability for accessory respiration with diverticula of the gastrointestinal tract (Armbruster, 1998), capacity to downregulate metabolism during periods of scarcity of food (MacCormack *et al.*, 2003), less vulnerability to predation due to spiny fins and hardened external morphology (Zworykin and Budaev, 2013) may have facilitated establishment of self-maintaining populations of *Pterygoplichthys* spp. in EKW. Eighty percent of the farms reported rapid increase of *Pterygoplichthys* spp. population in their farms, which may also be linked to its feeding and reproductive behaviour. They feed primarily on periphyton and detritus (Ozedilek, 2007), which are usually abundant in EKW.

These fishes have capacity to alter the ecosystem and biodiversity of the invasion sites (Hoover *et al.*, 2004; Zworykin and Budaev, 2013), which stakeholders of EKW also ascertained. They reported *Pterygoplichthys* as one of the reason for the declining species diversity and depleted catches of small indigenous fishes in their water bodies. This grasp of the EKW stakeholders corroborates with the findings of Mendoza *et al.* (2009) who reported displacement of native fishes from Lake Okeechobee, Florida by *P. multiradiatus*. Destruction of spawning and shelter ground and alteration of food availability for natives by grazing on benthic algae and detritus are cited as the reason of native fish decline in *Pterygoplichthys* invaded water bodies (Hossain *et al.*, 2008; Hoover *et al.*, 2004; Mendoza *et al.*, 2009; Knight, 2010). Pond productivity depletion reported by most of the stakeholders during the study, may be due to sequestration of nitrogen and phosphorus of the system by *Pterygoplichthys*, through their body armour (Capps *et al.*, 2009; Capps and Flecker, 2013). Loss in total fish production due to *Pterygoplichthys* recorded in EKW, concur the findings of Sumanasinghe and Amarasinghe (2013), who reported 21% replacement of commercial fishes in Polgolla Reservoir of Sri Lanka by accidentally introduced *P. pardalis*.

Changes in pond bottom/dyke structure by excavating deep holes perceived by more than 67% of the interviewees of EKW is in accordance with the findings of Nico *et al.* (2009) who reported that, male of adult loriciid catfishes excavate and maintain burrows (holes) in the banks of water bodies for use as spawning and nesting sites. Nico *et al.* (2009) recorded all or most burrows of *Pterygoplichthys* spp. concentrated within one meter depth of the river bank, suggesting low depth preference by these fishes. Damage of fishing net by these fishes as reported by the fishers of EKW, not only contribute to economic loss, but also makes fishing nets less effective for catching target species (Sumanasinghe and Amarasinghe, 2013). Economic losses to fishermen by *P. multiradiatus* by damaging equipment such as cast and gillnets and displacing native fishes in India (Krishnakumar *et al.*, 2009); by *P. disjunctives* and *P. pardalis* by damaging cages and nets and reducing availability of more desirable fish in Laguna de Bay, Philippines (Chavez *et al.*, 2006) were also reported.

Eradication of these fishes is regarded difficult, potentially time consuming and not feasible economically (Hill and Sowards, 2015) and hence efforts should be focused to contain the current established populations and preventing future introductions (Lawson *et al.*, 2015; Hill *et al.*, 2017). So, to prevent new introduction, EKW farmers are sieving sewage water through multilayer

screen before taking it to their ponds and also practicing intensive netting to limit upsurge of existing population. Sumanasinghe and Amarasinghe (2013) also concluded 'intensive fishing' as one of the effective and feasible means of controlling population growth of armoured catfishes. Hill and Sowards (2015) 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) suggested physical effort as the most effective way to control the spread of these species to other natural water bodies. They also opined for biological control using native predatory fishes in already invaded water bodies. In an experiment at Thailand they found that the bagrid catfish, *Hemibagrus wyckioides* and the marbled sleeper *Oxyeleotris marmorata*, readily prey on juvenile *P. pardalis* (0.6-10 cm total length) and concluded that these fishes can be used for early life-stage removal of *P. pardalis* (<10 cm size). In India we also need to look for such options with our indigenous fishes.

The non-indigenous armoured catfishes of the genus *Pterygoplichthys* has caused havoc throughout the water bodies of aquaculture systems of EKW. Perception of stakeholders also points towards mounting pressure of these fishes on the already dwindling indigenous fishes and economy of EKW. The magnitude of impacts of these fishes is yet to be assessed in India, though these catfishes have already invaded in water bodies of wide parts of the country starting from North-east to Kerala with a serious mark of their reckless aggression. In this juncture, we suggest systematic studies on armoured catfishes to: i) record the number of armoured catfish species existing in the country, ii) gather knowledge on biology of these fishes critically investigating their habits including niche, mechanism of invasion, food habits, reproduction and ecological adaptability and iii) develop techniques for their utility as ingredient for feed preparation or other means through value addition, as they may contribute a substantial amount of protein. Eventually, a concerted effort is urgently required to check armoured catfishes to save our indigenous fish diversity and ecosystems. Changing their sex through genetic manipulation may be tried as one of the best efforts to check their population else their severity may bring ecological catastrophe particularly in aquaculture of EKW in near future when we have no way to restore such precious wetlands.

Acknowledgements

Authors are thankful to the fishermen of EKW for their support and co-operation; Director, ICAR-CIFA for providing facilities and encouragement; and Mr. Gourab Choudhury, SRF, RRC-Rahara, ICAR-CIFA for the help rendered in morphometric data collection.

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