

Vermiculated sailfin catfish, *Pterygoplichthys disjunctivus* (Actinopterygii Siluriformes: Loricariidae)

Invasion, biology, and initial impacts in east Kolkata Wetlands, India

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**VERMICULATED SAILFIN CATFISH, *PTERYGOPLICHTHYS DISJUNCTIVUS*
(ACTINOPTERYGII: SILURIFORMES: LORICARIIDAE): INVASION, BIOLOGY,
AND INITIAL IMPACTS IN EAST KOLKATA WETLANDS, INDIA**

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Background. The East Kolkata Wetlands in India (a Ramsar site) are sewage-fed, nutrient-rich water bodies successfully used for fish production. The vermiculated sailfin catfish, *Pterygoplichthys disjunctivus* (Weber, 1991), exotic to India, has invaded these wetlands. The management and control of this catfish has been hindered, because of the lack of information on its abundance, population structure, biological traits, level of establishment, and competition with native fish species.

Materials and methods. Within 2013–2015 studies were carried out on the population structure of *P. disjunctivus*, its food habits, reproductive biology, and initial impacts in the wetlands through monthly and seasonal collection of samples, examination of food items, reproductive parameters, catch data, and gathering fishers experience.

Results. The length (TL) and weight of the specimens ranged from 10 to 55 cm and from 120 to 1250 g, respectively. Major food items of the catfish were detrital matter (%IRI 56), unidentified plant matter (%IRI 11), fish eggs (%IRI 11), polychaete worms (%IRI 5), and other minor items (%IRI 0.3 to 4). At 50% similarity, the food items of *P. disjunctivus* overlapped with that of *Macrognathus pancalus*, *Channa punctata*, *Nandus nandus*, *Anabas testudineus*, *Clarias batrachus*, *Oreochromis niloticus*, *Cirrhinus mrigala*, and *Cyprinus carpio* while at 80% it overlapped with that of *C. mrigala* and *C. carpio*. The fecundity of *P. disjunctivus*, in the wetlands, was the highest recorded for the species. Females attained the first maturity at 24 cm TL and reproduced multiple times within July–November. The breeding period of the species overlapped with 13 native fish species, of which it seriously overlapped with that of *Gudusia chapra*, *Amblypharyngodon mola*, *Pethia conchonius*, *P. ticto*, *N. nandus*, *C. punctata*, and *A. testudineus*. The sailfin catfish has established reproducing populations in the wetlands and reached ‘invasive’ proportions constituting 4.83% (300.04 t · year⁻¹) of the mean annual fish catch (6203.85 t · year⁻¹) from the wetlands. The invasive risk assessment showed a high risk of the species in the current scenario and probable climate change scenarios in future in the region.

Conclusions. *Pterygoplichthys disjunctivus* has successfully colonized the sensitive East Kolkata Wetlands, which might easily spread to neighbouring water bodies including the sensitive Ganga River and Sundarban mangroves and cause ecological and economic disturbance unless preventive measures are taken as the species has high invasive risk in the region.

Keywords: *Pterygoplichthys disjunctivus*, exotic fish, East Kolkata Wetlands, food overlap, reproduction character, invasive risk

INTRODUCTION

The South American sailfin catfishes, *Pterygoplichthys* spp., are indigenous inhabitants of the Amazon River basin (Page and Robins 2006), however, they have been intentionally or accidentally introduced to several other countries (Hoover et al. 2004), where they have successfully established and have caused ecological and

economic consequences (Nico et al. 2012). Competition with *Pterygoplichthys* spp. has negatively impacted native fisheries in several countries (Rueda-Jasso et al. 2013). Although *Pterygoplichthys* spp. have established in several countries (Copp et al. 2005), the information on their biology, ecology, establishment, and abundance, which is important for managing its spread, is not widely

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available. Food habits of *Pterygoplichthys disjunctivus* (Weber, 1991) were investigated in the USA (Nico and Martin 2001, Hoover et al. 2004) and Serbia (Simonović et al. 2010); sex ratio—in the Philippines (Jumawan et al. 2016), Hawaii (Yamamoto and Tagawa 2000), and Taiwan (Liang et al. 2005); fecundity—in the USA (Gibbs et al. 2008, 2017), Mexico (Rueda-Jasso et al. 2013), and the Philippines (Jumawan et al. 2016); and the size at first maturity and breeding period—in the USA (Gibbs et al. 2008), the Philippines (Jumawan and Herrera 2014), and Mexico (Rueda-Jasso et al. 2013). These parameters might differ within and/or across the regions of its occurrence. In India, *P. disjunctivus* was reported from states such as Andhra Pradesh, Bihar, Uttar Pradesh (Singh 2014), West Bengal (Anonymous 2008, Singh 2014), Kerala (Bijukumar et al. 2015), Tamil Nadu (Moorthy et al. 2016). However, there was serious information deficit on their abundance, population structure, biological traits, level of invasion and establishment, competition to native fish species, and ecological impacts in areas where they were reported. In order to provide inputs for its management and control, studies were taken up on its population structure, food habits, reproductive biology, and initial impacts in the East Kolkata Wetlands. Based on the information generated, possible strategies and local policy interventions for management and control of the species discussed, which will also help in managing the species, besides widening its biological information from the Indian region.

MATERIALS AND METHODS

Study area. East Kolkata Wetlands (88°20'E–88°35'E and 20°25'N–20°35'N), a Ramsar site since November 2002 (Kundu et al. 2008), consist of 254 natural and manmade water bodies, covering a total area of 12 500 ha, stretching over two districts, the North 24 Parganas and South 24 Parganas, of West Bengal, an eastern State in India (Fig.

1). The climate of the area is sub-tropical, with the mean annual rainfall of 200 cm (Kundu et al. 2008). Surface water temperature ranged within 29–32°C; pH 6.7–8.2, and dissolved oxygen 3.92–6.77 ppm (Roy et al. 2016). The sewage generated by Kolkata city is being channelized through about 4000 ha of these water bodies as settling ponds, facilitating biological, physical, and chemical processes that treat the sewage and improve the water quality through natural, inexpensive manner. The nutrient-rich waters promote a large number of naturally occurring indigenous fish species, besides rich fisheries and aquaculture (Kundu et al. 2008). Culture-based fisheries through the stocking of economically important Indian and Chinese major carp species and harvesting them at marketable size are being regularly practised in 23 wetlands, having areas varying from 26.67 to 146.67 ha, covering a total area of 1914.62 ha. Fisheries of these wetlands are being managed by local co-operatives, private owners, and the Government. The study was carried out from 2013 to 2015 in six of these wetlands: Nalban (146 ha), Natar (100 ha), Gompota (93.3 ha), Jhagrasis (73.3 ha), Captain (113 ha), and Sardar (53.3 ha), covering a total of 578.9 ha (Fig. 1), which is 30.7% of the total wetland area.

Sample collection and identification. Samples of *Pterygoplichthys* spp. were collected monthly from fishers' catch in the early hours of the day and also through arranged fishing when there was no regular fishing. Seine nets of 50 m length and 3 m width having 30 mm mesh were used by fishers for fishing. To compensate for the sampling deficiency, especially of smaller size groups, small mesh seine net (10 mm mesh size) were also used in arranged fishing. The nets were operated twice a fishing day at random locations in each of the six wetlands. The species were identified based on different morphological and 16 meristic (Table 1) characters of different size groups following Page and Robins (2006), Covain and Fisch-Muller (2007).

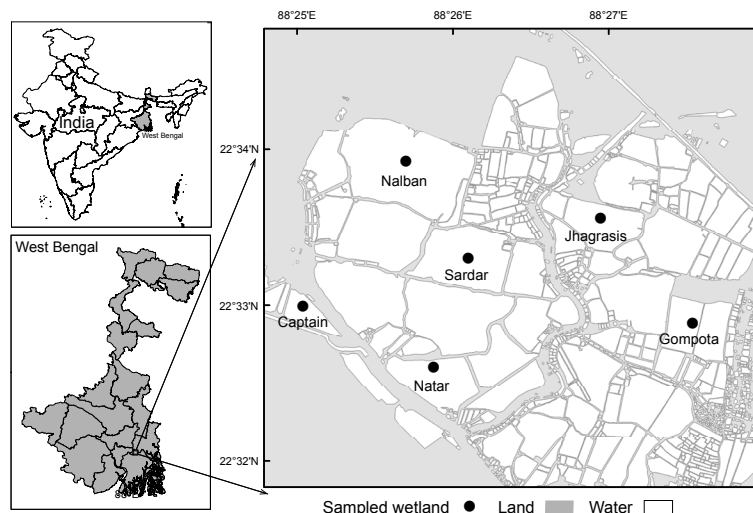


Fig. 1. East Kolkata Wetlands cluster in West Bengal, India (88°20'E–88°35'E and 20°25'N–20°35'N), showing the wetland complex and the six wetlands, named Nalban (146 ha), Natar (100 ha), Gompota (93.3 ha), Jhagrasis (73.3 ha), Captain (113 ha), and Sardar (53.3 ha) from where data and samples were collected

Table 1 Meristic characters of *Pterygoplichthys disjunctivus* ($n = 100$) from East Kolkata Wetlands, India for the period of 2013–2014

Character	Count
DF rays	9–14
Pectoral fin rays	6–8
Pelvic fin rays	5
Anal fin rays	5–6
Caudal fin rays	13–14
Lateral line plates	26–30
Abdominal plates	5–7
Dorsal plates	3–5
Dorsal inter radial plates	10–13
Anal inter radial plates	3
Pectoral inter radial plates	1
Pelvic inter radial plates	2
Pectoral fin plates	5–9
Pelvic fin plates	7–11
Post anal plates	12–17
Plates between DF and ADF	6–7

DF = dorsal fin, ADF = adipose fin.

Length frequency. In order to assess population structure with regard to available size groups, the length and weight of *P. disjunctivus* in catches were recorded from as many specimens as possible, at monthly interval during 2013 through 2015. After blotting off water from the body, the total length (TL), from tip of the snout to the longest caudal fin ray, was measured using a measuring board to the nearest 0.1 cm and weighed on an electronic balance sensitive to 0.01 g, in the field itself. The monthly length data were pooled and length frequency distribution was plotted.

Diet composition. Samples of fish species, as given in Table 2, were collected twice in each season during the study period, covering three major seasons of the region comprising Pre-monsoon (February–May), Monsoon (June–September), Post-monsoon (October–January), with November–January being winter with cooler temperature. The sample size varied from 20 to 30 specimens of each species in all available size groups from each season. They were dissected in the field and viscera preserved in 4% formalin to prevent further digestion. In the laboratory, the digestive tracts were separated from viscera. The gut contents were collected and identified qualitatively and

Table 2 Major food item of *Pterygoplichthys disjunctivus* and other common fish species from East Kolkata Wetlands, India for the period of 2013–2014, based on the presence or absence

Gut contents	<i>Anabas testudineus</i>	<i>Ambassis</i> spp.	<i>Channa punctata</i>	<i>Clarias batrachus</i>	<i>Puntius</i> spp.	<i>Nandus nandus</i>	<i>Macrogonathus pancalis</i>	<i>Gibelion catla</i>	<i>Labeo rohita</i>	<i>Cirrhinus cirrhosus</i>	<i>Hypophthalmichthys molitrix</i>	<i>Cyprinus carpio</i>	<i>Ctenopharyngodon idella</i>	<i>Oreochromis niloticus</i>	<i>Pterygoplichthys disjunctivus</i>
Decapods	+		+	+	+	+	+			+		+		+	+
Aquatic insects	+		+	+	+	+	+	+	+	+		+		+	+
Small fish	+		+	+		+	+								+
Crustaceans	+		+	+		+	+		+	+		+		+	+
Fish larvae	+		+	+		+	+			+		+		+	+
Fish eggs	+		+	+		+	+			+		+		+	+
Decapod larvae	+		+	+	+	+	+	+	+	+		+		+	+
Polychaeta worms	+		+	+		+	+			+		+		+	+
Annelids worms	+		+	+		+	+			+		+		+	+
Molluscs	+			+						+		+			+
Unidentified plant matter	+								+	+		+	+	+	+
Unidentified animal matter	+	+	+	+	+	+	+	+	+	+		+		+	+
Detrital matter	+	+	+	+		+	+	+	+	+		+	+	+	+
Zooplankton	+	+			+		+	+	+	+	+	+			
Phytoplankton		+			+			+	+		+		+		
Floating algae		+			+			+	+		+	+	+	+	
Filamentous algae									+	+	+	+	+	+	+
Diatoms		+			+			+	+	+	+	+			
Macrophyte parts									+	+		+	+	+	+
Protozoans			+		+	+	+	+		+		+			+

Plus sign denotes the presence; blank cells indicate the absence; Based on 90 specimens of *P. disjunctivus* and 60 to 75 specimens for all other species.

quantitatively (microscope Nikon Eclipse 50i with image processing features). To ascertain if the sample size was satisfactory to adequately describe the diet composition, the method of Ferry and Caillet (1996) was followed. For *P. disjunctivus*, the Index of Relative Importance (IRI) of gut items was determined following (Pinkas et al. 1971) and expressed in percentage as

$$IRI_i = (\%N_i + \%V_i)\%O_i$$

where N_p , V_p , and O_i represented the percentage of number, volume, and frequency of occurrence of i food item, respectively. Data from different seasons were pooled for comparison among the species. The food items of *P. disjunctivus* overlapped with those of other important fish species in the wetland such as *Anabas testudineus* (Bloch, 1792), *Ambassis* spp., *Channa punctata* (Bloch, 1793), *Clarias batrachus* (Linnaeus, 1758), *Puntius* spp., *Nandus nandus* (Hamilton, 1822), *Macrogathus pancalus* Hamilton, 1822, *Gibelion catla* (Hamilton, 1822), *Labeo rohita* (Hamilton, 1822), *Cirrhinus mrigala* (Hamilton, 1822), *Hypophthalmichthys molitrix* (Valenciennes, 1844), *Cyprinus carpio* Linnaeus, 1758, *Ctenopharyngodon idella* (Valenciennes, 1844), *Oreochromis niloticus* (Linnaeus, 1758) was assessed using Bray Curtis similarity on PRIMER-E software (Clarke and Gorley 2006) based on the presence or absence of food items in the gut.

Reproduction parameters. A subsample of 30 specimens, representing all available size groups of *P. disjunctivus* collected each month from the wetlands during 2013 and 2014, were used for assessing reproduction parameters. After measuring length and weight, their gonads were dissected and weighed. These were then preserved in neutral buffered formalin (4% formaldehyde). Sexes were recorded after examining the gonads. The sex ratio was calculated using Binomial Proportion test (Snedecor and Cochran 1967) on the pooled data for the two years. Fecundity was estimated by counting the number of mature ova in known weights of samples taken from the anterior, posterior, and middle portions of each lobe of the paired ovaries. The total number of mature ova in the ovary was calculated following Grimes and Huntsman (1980). The relative fecundity was calculated by dividing the fecundity by the weight of the corresponding female. The mean monthly gonadosomatic index (GSI), for every month during 2013–2014, was calculated as

$$GSI = 100W_G \cdot W_T^{-1}$$

where W_G is the gonad weight and W_T is the total weight of fish and expressed as a percentage. The reproductive period (length of breeding season) was determined by plotting the mean GSI values against the respective months and the months with peak GSI were considered as breeding period. The cumulative percentage frequencies of mature females in samples were plotted against their respective length classes and the length at which 50% of the samples were mature was taken as length at first maturity (Ellis 1971). The breeding periodicity (how

many times the fish breeds in a breeding season) was determined by plotting the mean percentage frequency of oocytes of different diameters present in the mature ovary. The oocyte diameter was measured using a dissection microscope with a calibrated length measuring function. Diameters of the first 100 oocytes each from samples taken from anterior, posterior, and middle portion of both lobes of ovary were measured. The mean frequency of the oocyte diameter was plotted against class intervals of 0.2 mm, from 30 mature ovaries. The numbers of major peaks in the plot for different size class of oocytes were taken as periodicity or frequency of breeding. The overlap of breeding period of *P. disjunctivus* with that of other native fish species was expressed at by month-wise plotting of known breeding periods of each species as available in the literature, with that of the breeding months of *P. disjunctivus* in the wetlands in the presently reported study.

Fish catch data collection. Catch data for *Gibelion catla*, *Labeo rohita*, *Labeo bata* (Hamilton, 1822), *Cirrhinus mrigala*, *Hypophthalmichthys molitrix*, *Ctenopharyngodon idella*, *Cyprinus carpio*, and *Oreochromis niloticus*, from the wetlands were maintained by the wetland managers as part of the organized culture-based fisheries. The weights of these fishes caught in each fishing operation in a year, as recorded by the fisheries managers, were added to calculate annual catch. The data for the years 2013 through 2015 were used for arriving at the mean annual catch. For other indigenous fish species, no catch data were available as their fishery is highly diffused and subsistence in nature. Catch data of *Pterygoplichthys* spp. were not recorded by the fisheries managers as the catch was discarded being of no use. Arrangements were thus made with the wetland managers and/or fishers to additionally record the catch data of *Pterygoplichthys* spp. during the study period.

Invasiveness and risk assessment. The invasiveness of the species was assessed within the framework suggested by Colautti and MacIsaac (2004). The Aquatic Species Invasiveness Screening Kit (AS-ISK) by Copp et al. (2016) was used for invasive species risk assessment. Other nuisances of the species in the wetlands were recorded by informal interview and group discussions with members of the fisheries co-operatives, fisheries managers, and fishers based on their experience and observation.

RESULTS

A total of 2300 catfish specimens comprising of various size groups were collected from the wetland over a period of three years. They were subsequently identified as *Pterygoplichthys disjunctivus* (Weber, 1991). As described by Covain and Fisch-Muller (2007), the specimens had their body slightly compressed dorsoventrally, covered in bony armour; possessed a pair of maxillary barbels and ventral suction mouth. Dark brown to chocolate coloured vermiculate patterns and spots present all over the body; the vermiculations were more prominent on the ventral side. However, on smaller specimens, these colourations were not clearly distinguishable. The 16 meristic characters

measured are shown in Table 1. Occasionally specimens with similar meristic characters, but with less vermiculate colourations, as described for *Pterygoplichthys pardalis* (Castelnau, 1855) (see Page and Robins 2006), were also recorded in the collections. Because species identification of these fish was difficult and almost impossible in the field, the occasionally recorded doubtful samples were not considered for analysis and the population was considered majorly of that of *P. disjunctivus*. The number of specimens recorded along with each fishing operation in the wetland varied from 12 to 60. The maximum abundance in catches was recorded during winter months (November–January). Smaller specimens were not frequently recorded in fishers' catch, however, the arranged fishing using small mesh seine nets yielded smaller size groups, especially from marginal areas of the water bodies. The total length and the total weight ranges of specimens recorded were 10–55.00 cm 120–1250 g, respectively. The length frequency distribution is shown in Fig. 2. The maximum frequency in the samples was for 31–40 cm length class.

Gut contents of 90 specimens of *P. disjunctivus*, ranging from 15 to 55 cm TL, were examined. Cumulative food item curve (Ferry and Cailliet 1996) approached an asymptote at 25 guts, demonstrating the sample size was satisfactory to adequately describe the diet composition. The gut contents consisted of 16 items, predominantly detrital matter with IRI of 56%, followed by unidentified plant matter (IRI 11%), fish eggs (IRI 11%), polychaete worms (IRI 5%), along with other minor items like unidentified animal matter, filamentous algae, phytoplankton, aquatic insects, crustaceans, decapods larvae, annelid worms, molluscs, fish larvae, and protozoans (Fig. 3). No marked variation in major food items, based on their presence or absence, was recorded among the available sample size groups. Major food items of *P. disjunctivus*, other common indigenous fish species, and exotic food fishes in the wetlands are shown in Table 2. Comparing the food items of *P. disjunctivus* with those of native fish species in the wetlands such as *Anabas testudineus*, *Ambassis* spp., *Channa punctata*, *Clarias batrachus*, *Puntius* spp., *Nandus nandus*, *Macrogathus pancalus*, *Gibelion*

catla, *Labeo rohita*, *Cirrhinus mrigala*, and exotic food fishes, *Hypophthalmichthys molitrix*, *Cyprinus carpio*, *Ctenopharyngodon idella*, and *Oreochromis niloticus*, in terms of similarity is shown in Fig. 4. At 80% similarity the food items of *P. disjunctivus* overlapped with that of *C. mrigala* and *C. carpio*, while at more than 60% it overlapped with that of *M. pancalus*, *C. punctata*, *N. nandus*, *A. testudineus*, *C. batrachus*, *O. niloticus*, *C. mrigala*, and *C. carpio* and showed no similarity with other species (Fig. 4).

The overall sex ratio of the species was 2.2 females for every male. The sex ratio varied significantly ($P \leq 0.05$) during July–January. There were more females in the samples during July–January, as high as 2.7 females for every male (Table 3). The fecundity of the smallest mature female (20 cm TL, 200 g of body weight) was 4348 and relative fecundity was 22 g⁻¹ and for the largest female (55 cm TL, 1250 g of body weight) the fecundity was 9567 and relative fecundity was 8 g⁻¹. Larger females had lower relative fecundity. Examining the percentage of spawning capable females carrying mature oocytes in the ovary, against their respective total lengths, showed that 50% of the females in the population matured at 24 cm TL (Fig. 5). Monthly mean GSI of females showed peaks during July–November and it declined sharply from December–January and continued so until June before increasing from July (Fig. 6), indicating July–November as the breeding period. The GSI values showed interannual variation among 2013 and 2014 in terms of magnitude, the overall trend, however, was similar. The oocyte diameter ranged from 0.5 to 3.3 mm. The frequency of occurrence of oocytes of different diameters, when plotted against the respective class interval of 0.2 mm resulted in two major and a minor peak (Fig. 7). The largest peak consisted of oocytes of >2.9 to 3.3 mm diameter; the next one consisted of oocytes of >1.9 to 2.9 mm, and the smallest peak consisted of still smaller size class of oocytes (>1.1 to 1.9 mm).

The breeding period of *P. disjunctivus* in the wetlands overlapped with those of native species like *Gudusia chapra* (Hamilton, 1822), *Amblypharyngodon mola*

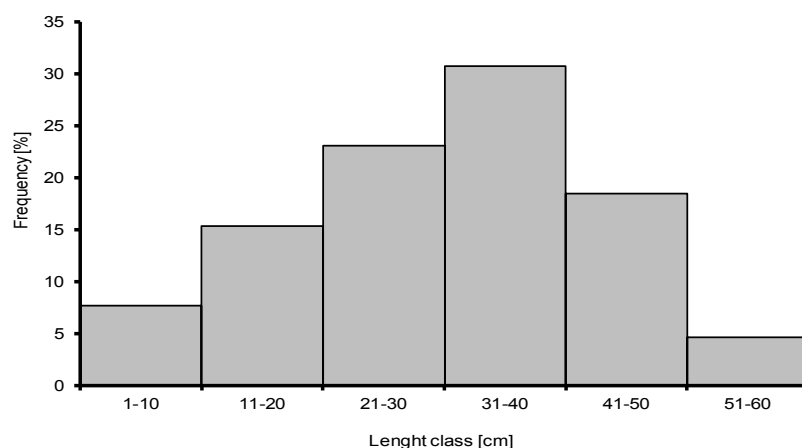


Fig. 2. Length frequency distribution of *Pterygoplichthys disjunctivus* from East Kolkata Wetlands, India for the period of 2013–2014

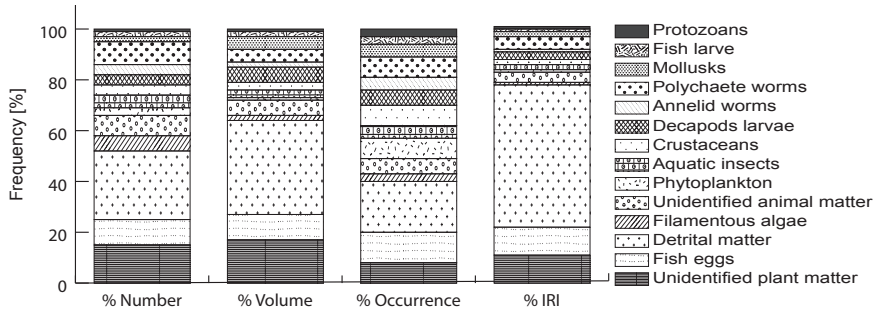


Fig. 3. Percentage of number, volume, occurrence, and the Index of Relative Importance of the major gut contents of *Pterygoplichthys disjunctivus* from East Kolkata Wetlands, India for the period of 2013–2014

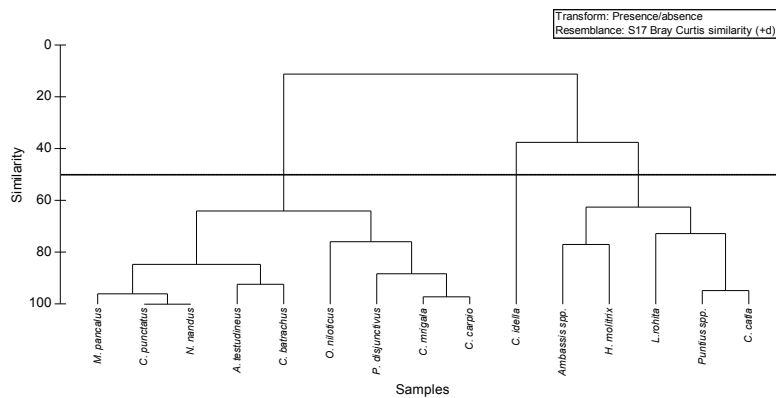


Fig. 4. Food items overlap of *Pterygoplichthys disjunctivus* with other fish species from East Kolkata Wetlands, India for the period of 2013–2014

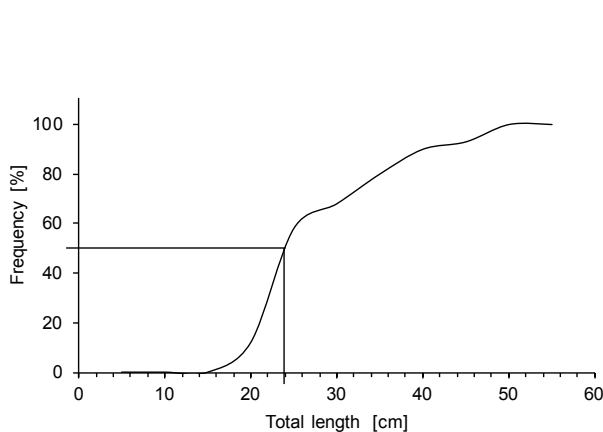


Fig. 5. Length at first maturity of *Pterygoplichthys disjunctivus* from East Kolkata Wetlands,

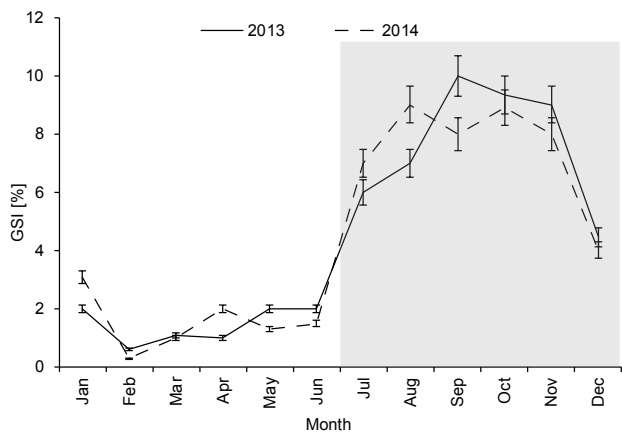


Fig. 6. Monthly progress of the gonadosomatic index of *Pterygoplichthys disjunctivus* from East Kolkata Wetlands, India for the period of 2013–2014

(Hamilton, 1822), *Pethia conchoni* (Hamilton, 1822), *Pethia ticto* (Hamilton, 1822), *Puntius sophore* (Hamilton, 1822), *Trichogaster fasciata* Bloch et Schneider, 1801, *Macrognathus pancalus*, *Macrognathus aral* (Bloch et Schneider, 1801), *Mystus vittatus* (Bloch, 1794), *Nandus nandus*, *Channa punctata*, and *Anabas testudineus*. Of these, it seriously overlapped with that of *G. chapra*, *A. mola*, *P. conchoni*, *P. ticto*, *N. nandus*, *C. punctata*, and *A. testudineus* (Table 4).

As part of culture-based fisheries, the wetlands were regularly stocked with Indian major carps (*Gibelion catla*, *Labeo rohita*, and *Cirrhinus mrigala*), Indian medium carp, *Labeo bata*, and exotic carps such as *Cyprinus carpio*, *Hypophthalmichthys molitrix*, and *Ctenopharyngodon idella* under the management of local fisheries cooperatives, private individuals, and in some cases, Government agencies. There has not been any evidence of breeding of these species in the

wetlands. Their fishery is sustaining on regular stocking of hatchery-reared advanced fingerlings by the fishery managers. Some of the cooperatives have been stocking *Oreochromis niloticus* also along with the above species, which has established self-recruiting populations in the wetlands, nevertheless is a preferred food fish among the local population. The fish catch composition of the six sampled wetlands showed the maximum proportion of *H. molitrix* (27%) followed by *G. catla* (22%), *L. rohita* (13%), *O. niloticus*, and *C. idella* (11% each) and the rest by other species. Among the sampled wetlands, the total fish yield ranged from 1.27 to 6.20 t · ha⁻¹ · year⁻¹. Of this, *Pterygoplichthys* spp. formed 0.02 to 0.45 t · ha⁻¹ · year⁻¹.

Table 3

Sex ratio (male: female) of *Pterygoplichthys disjunctivus* from East Kolkata Wetlands, India sampled within 2013–2014

Month	Sex ratio (male ÷ female)	P value
Jan	1 ÷ 2.1	2.134982*
Feb	1 ÷ 1.2	0.686311
Mar	1 ÷ 1.1	0.593511
Apr	1 ÷ 1.0	0.436436
May	1 ÷ 1.2	0.598768
Jun	1 ÷ 1.0	0.436436
Jul	1 ÷ 2.2	2.478392*
Aug	1 ÷ 3.0	2.622511*
Sep	1 ÷ 3.4	2.754673*
Oct	1 ÷ 3.0	2.622511*
Nov	1 ÷ 3.2	2.687346*
Dec	1 ÷ 3.1	2.661551*
Overall	1 ÷ 2.2	2.456983*

*P ≤ 0.05

Informal interview of fishers and fisheries managers of the wetlands revealed the presence of *Pterygoplichthys* spp. in all the wetlands in the area. Stocking rate of major carps remained more or less same in all the wetlands. The mean annual yield (t · ha⁻¹ · year⁻¹) of the sampled wetlands for 2013 to 2015 was thus extrapolated to the total area of the East Kolkata Wetlands undergoing culture-based fisheries (1915 ha), which amounted to 6203.85 t · year⁻¹. Of this *Pterygoplichthys* spp. formed 300.04 t · year⁻¹ constituting 4.83% of the total estimated annual fish catch of East Kolkata Wetlands. The species-wise fish catches from the wetlands are shown in Table 5. While the unorganized subsistence fish catch was constituted by other indigenous fishes as given in Table 4, which breed naturally in the wetlands. However, no data is available on the catch of these species.

The invasiveness assessment showed the species in the wetlands is at Stage V, which is classified as ‘invasive’. In AS-ISK, 49 questions represented the Basic Risk Assessment (BRA), and six Climate Change Assessment (CCA) questions to assess risks of introduction, establishment, dispersal, and impact. Minimum values for BRA and CCA scores are 12 and 24 and maximum are 64 and 76, respectively. Running AS-ISK resulted in BRA Score of 42.5 and BRA + CCA Score of 54.5, at mean thresholds limits of 34 for BRA and 40 for BRA + CCA at confidence limits of 0.70, 0.74, 0.38 for BRA + CCA, BRA, and CCA, respectively. The detailed scores and assessment outcomes are presented in Table 6.

DISCUSSION

Pterygoplichthys spp. have been widening their distribution in India, ever since Ajithkumar et al. (1998) reported it from the wild. Anonymous (2008) reported *P. disjunctivus* in fisher’s catch of East Kolkata Wetlands. The sewage-fed, nutrient-rich, warmer waters of East

Table 4

Overlap of the breeding period of *Pterygoplichthys disjunctivus* with that of native fish species from East Kolkata Wetlands, India for the period of 2013–2014

Species	Breeding months												Reference
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
<i>Gudusia chapra</i>													Vinci et al. 2005
<i>Amblypharyngodon mola</i>													Suresh et al. 2007
<i>Pethia conchonius</i>													Mitra et al. 2011
<i>Pethia ticto</i>													Manissery et al. 1979
<i>Puntius sophore</i>													Mitra et al. 2005
<i>Trichogaster fasciata</i>													Mitra et al. 2007
<i>Macrornathus pancalus</i>													Suresh et al. 2006
<i>Macrornathus aral</i>													Abujam and Biswas 2011
<i>Mystus vittatus</i>													Hossain et al. 2006
<i>Nandus nandus</i>													Hossain et al. 1991
<i>Channa punctata</i>													Prasad et al. 2011
<i>Anabas testudineus</i>													Hora and Pillay 1962

Shaded areas denote breeding periods.

Kolkata Wetlands (Kundu et al. 2008) are congenial for *Pterygoplichthys* spp., as they are highly tolerant to low water quality and thrive well in sewage outflows (Nico and Martin 2001). The majority of the specimens sampled were of *P. disjunctivus*, however about two percent of the samples were doubtful; more resembling *P. pardalis* as described by Page and Robins (2006). The size range reported for Loricariid family is 30–50 cm, however individuals have been reported to grow up to 70 cm TL (Anonymous unpublished*). The length range reported for the species from in India was 27.02–57.44 cm TL (Bijukumar et al. 2015). The size ranges (total length/weight) recorded in the presently reported study were 10.5–55.00 cm and 120–1250 g, respectively. The length frequency of samples (Fig. 2) showed the presence of all size groups, indicating a self-recruiting population in the wetlands. The maximum frequency in catches was for 31–40 cm length class, while that of smaller specimens was low. As adult *P. disjunctivus* are active during daytime while juveniles are passive (Nico 2010), they might hide in crevices or under vegetation, hence were not getting caught.

The percentage frequency and percent IRI of gut contents of the fish showed detrital matter as the major item (% frequency 27 and IRI 56%) followed by fish eggs and unidentified plant matter (IRI 11% each), Polychaete worms (IRI 5%) along with other minor items (Fig. 3). *Pterygoplichthys disjunctivus* is a benthic forager, consuming mainly detritus and algae and can negatively impact native benthic feeders (Anonymous 2014). The species also consume eggs of other fishes from the bottom substratum (Hoover et al. 2004), which is evident from Fig. 3 with 27% frequency of numbers and 11% IRI of fish eggs in the gut. Hence the species in the wetlands

can negatively impact population of several native fish species, especially those having early benthic life history stages. At more than 50% similarity, food items of *P. disjunctivus* overlapped with that of indigenous species like *Macrornathus pancalus*, *Channa punctata*, *Nandus nandus*, *Anabas testudineus*, *Clarias batrachus*, *Cirrhinus mrigala* and exotic species like *Oreochromis niloticus* and *C. carpio*. Of these, it seriously overlapped (at 80%) with that of *Cirrhinus mrigala* and *Cyprinus carpio* (Fig. 4). *Pterygoplichthys disjunctivus* being demersal (Froese and Pauly 2019), food item overlap with the above species (Fig. 4), might exert competition for food and can seriously reduce energy source to them, especially for *C. mrigala* and *C. carpio*. Among the stocked major carp species in the wetlands, the lowest production was for *C. mrigala* and *C. carpio*, while maximum catch from the wetlands came from *Hypophthalmichthys molitrix* and *C. catla* (Table 5), the plankton feeders (Froese and Pauly 2019), with no serious food overlap with *P. disjunctivus*. *Pterygoplichthys* spp. displaced several species of minnows in Texas rivers (Orr and Fisher 2009), Hence the large populations of *Pterygoplichthys* spp. in the East Kolkata Wetlands would negatively impact local fish species.

The overall sex ratio of the species in the samples collected was 2.2 females per 1 male; the ratio was higher during July–December (Table 3). Jumawan et al. (2016) reported an overall sex ratio of 1.15 female for every male in the Marikina River, in the Philippines. They also reported a significantly higher number of females (1.89 females for every male) during the breeding period (July). Males of *P. disjunctivus* exhibit strong parental care by constructing nesting burrows and guarding eggs (Orr and Fisher 2009). As the sex ratio was assessed based on capture based sampling using seine nets, the burrow-dwelling nature of

Table 5

Mean annual fish catch from six East Kolkata Wetlands, India sampled and estimated total fish production from the wetlands, including *Pterygoplichthys* spp.

Species	Fish catch of sampled wetlands [$t \cdot ha^{-1} \cdot year^{-1}$]						Mean [$t \cdot ha^{-1} \cdot year^{-1}$]	Total for EKW [$t \cdot year^{-1}$]
	Sardar	Jhagrasis	Nalban	Natar	Gompota	Captain		
<i>Gibelion catla</i>	0.27	1.47	1.00	0.20	0.15	1.24	0.72	1382.52
<i>Labeo rohita</i>	0.14	0.68	0.90	0.18	0.14	0.45	0.41	789.96
<i>Labeo bata</i>	0.04	0.23	0.00	0.05	0.05	0.08	0.07	141.46
<i>Cirrhinus cirrhosus</i>	0.14	0.27	0.10	0.10	0.08	0.17	0.14	271.32
<i>Hypophthalmichthys molitrix</i>	0.81	1.12	2.00	0.37	0.16	0.80	0.88	1678.69
<i>Ctenopharyngodon idella</i>	0.10	0.15	1.00	0.18	0.08	0.59	0.35	667.06
<i>Cyprinus carpio</i>	0.08	0.01	0.50	0.10	0.10	0.17	0.16	304.82
<i>Oreochromis niloticus</i>	0.09	0.68	0.50	0.45	0.08	0.30	0.35	667.97
<i>Pterygoplichthys</i> spp.	0.14	0.05	0.20	0.02	0.45	0.10	0.16	300.04
Total	1.80	4.64	6.20	1.63	1.27	3.89	3.24	6203.85

Individual wetlands have the following size: Sardar (53.3 ha), Jhagrasis (73.3 ha), Nalban (146 ha), Natar (100 ha), Gompota (93.3 ha) Captain (113 ha); Values are mean of three years from 2013 through 2015; EKW = East Kolkata Wetlands (1915 ha area).

* Anonymous 2015. Global Invasive Species Database. [Species profile *Pterygoplichthys* spp.] [Accessed 21 June 2019] <http://www.iucngisd.org/gisd/species.php?sc=1561>.

males in breeding season makes them less vulnerable to capture in the nets, resulting in a lesser proportion of males in sample collections in the breeding season.

The fecundity ranged from 4348 to 9567 for 20–55 cm TL; 200–1250 g fish with relative fecundity of 22 g⁻¹ and 8 g⁻¹ respectively, which is higher than that reported for the species by Gibbs et al. (2008, 2017) from Florida; Rueda-Jasso et al. (2013) from Mexico; and Jumawan et al. (2016) from the Philippines. The warmer environment and the difference in food might be playing a role in higher fecundity of the fish in East Kolkata Wetlands. In East Kolkata Wetlands, females attained the first maturity at 24 cm TL (Fig. 5). In Florida, the females attained sexual maturity at 26 cm Gibbs et al. (2008); in the Marikina River, the Philippines at 26.7 cm standard length (Jumawan and Herrera 2014) and at 19.2 cm in El Infiernillo Reservoir, Mexico (Rueda-Jasso 2013). There is wide variation in size at first maturity across different geographical locations. This discrepancy could be due to a difference in environmental and climatic conditions. The progress of monthly mean ovarian GSI showed peaks during July–November, indicating the breeding period in East Kolkata Wetlands, although with minor inter-annual fluctuations between 2013 and 2014 (Fig. 6). By following the progress of GSI, Gibbs et al. (2008) reported its breeding season in Volusia Blue Spring, Florida as of May to September, which extends until October. In El Infiernillo Reservoir, Mexico, the highest reproductive activity occurred from June to October (Rueda-Jasso et al. 2013). In the Marikina River, the Philippines, the breeding period was June to September (Jumawan and Herrera 2014). In East Kolkata Wetlands, the breeding period extended to five months from July to November; nevertheless, July–September was common in all the reports. Local environmental and climatic differences might be responsible for this difference.

The occurrence of oocytes of different diameter in mature ovaries showed size ranges of 0.5 to 3.3 mm, which formed three peaks (Fig. 7). Two major peaks were closely set, indicating that they were ready to be shed in batches and the smallest one might get mature and shed subsequently. This indicated that the species has three successive spawning periods in the breeding season. Gibbs et al. (2008) reported three oocyte size classes (ranging from 0.5 to 4.0 mm in diameter) in *P. disjunctivus* and considered it a multiple spawner. This character is common in loriciariids and consistent with *P. disjunctivus* releasing several batches of oocytes during spawning season (Winemiller 1987). However, the maximum oocyte diameter recorded in the presently reported study was 3.3 mm compared to that reported by Gibbs et al. (2008). The higher fecundity of the species in East Kolkata Wetlands might be limiting the size of oocytes as fecundities were lower in cases where oocyte diameters were higher for the fish (Gibbs et al. 2008). Comparison of the breeding period of *P. disjunctivus* with that of 13 native fish species in the wetlands showed serious overlapping with *Gudusia chapra*, *Amblypharyngodon mola*, *Pethia conchonius*, *P. ticto*, *Nandus nandus*, *Channa punctata*, and *Anabas*

Table 6

Aquatic Species Invasiveness Screening Kit (AS-ISK) assessment of *Pterygoplichthys disjunctivus* for the study area (eastern India)

Question/parameter	Score
BRA	42.5
BRA Outcome	High
BRA + CCA	54.5
BRA + CCA Outcome	High
Score partition	
A. Biogeography/Historical	18.5
1. Domestication/Cultivation	4.0
2. Climate, distribution and introduction risk	1.0
3. Invasive elsewhere	13.5
B. Biology/Ecology	24.0
4. Undesirable (or persistence) traits	8.0
5. Resource exploitation	2.0
6. Reproduction	1.0
7. Dispersal mechanisms	4.0
8. Tolerance attributes	9.0
C. Climate change	12.0
9. Climate change	12.0
Answered questions	55
A. Biogeography/Historical	13
1. Domestication/Cultivation	3
2. Climate, distribution and introduction risk	5
3. Invasive elsewhere	5
B. Biology/Ecology	36
4. Undesirable (or persistence) traits	12
5. Resource exploitation	2
6. Reproduction	7
7. Dispersal mechanisms	9
8. Tolerance attributes	6
C. Climate change	6
9. Climate change	6
Sectors affected	
Commercial	17
Environmental	11
Species or population nuisance traits	31
Thresholds	
BRA	34
BRA + CCA	40
Confidence limits	
BRA + CCA	0.70
BRA	0.74
CCA	0.38

BRA = Basic Risk Assessment, CCA = Climate Change Assessment.

testudineus (Table 4) and might pose competition for breeding space with those of benthic breeding habits.

The mean annual fish catch data for 2013 to 2015 showed the consistent presence of *Pterygoplichthys* spp. in catches, constituting about 4.83% (300.04 t · year⁻¹) of the mean catch (6203.85 t · year⁻¹) from East Kolkata Wetlands (Table 5). This, however, did not

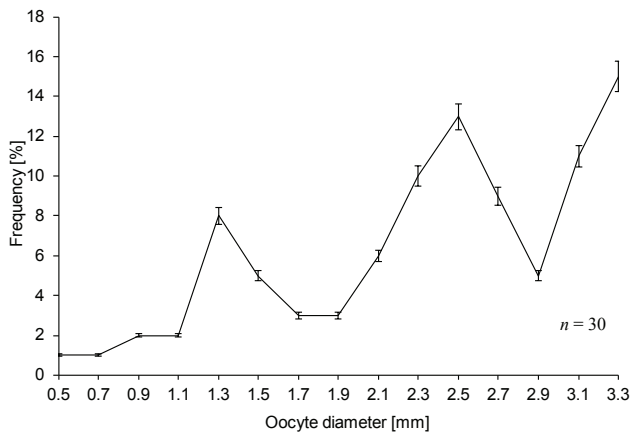


Fig. 7. Frequency of occurrence of oocytes of different diameter in mature ovary of *Pterygoplichthys disjunctivus* from East Kolkata Wetlands, India for the period of 2013–2014

include all size groups as fishers mostly use seine nets of 30 mm mesh hence smaller sizes were not caught. The abundance varied among the sampled wetlands with a mean catch of $0.16 \text{ t} \cdot \text{year}^{-1}$. As they are of no use to the local population, the biomass could otherwise have been useful fishes.

Numerous burrows, mostly along the peripheral boundaries of the wetlands, were recorded, some of which harboured *Pterygoplichthys* spp. According to fishers, these burrows often caused water leakage from the wetlands. The catfish often damaged fishing nets by tearing while hauling. Fishers had to spend considerable time in removing them out of the nets and discarding. Fishers and the local population do not find any use for this species and are averse in handling it with bare hands. Although the stocked major carps form the mainstay of fisheries, the fisheries managers and fishers complained of the drastic decline of local fish species, which are highly relished by the population. The species in the wetlands have established reproducing populations and has become widespread having found congenial habitat in absence of natural predators; the presence of ample food, coupled with multiple breeding and long breeding seasons, resulting in higher recruitment and successful colonization. They have also been recorded from adjacent sewage channels, rivulets as well as aquaculture ponds and wetlands from adjoining districts too. Under the framework of Colautti and MacIsaac (2004) on terminology for various stages of species invasion, potential invaders begin as propagules residing in a donor region (stage 0), some of which are transported (stage I), propagules survive transport and become introduced (stage II), then get localized and numerically rare (stage III), become widespread but rare (stage IVa), localized but dominant (stage IVb) or widespread and dominant (stage V) and can be considered invasive if the species is in Stage IVa, IVb, or V. The species in the region can thus be classified under stage IVa through stage V, hence reached 'invasive' proportions. *Pterygoplichthys* spp.

being extremely resilient and invasive, eradicating or controlling them are extremely difficult and often impossible (Armbruster 1998). Running AS-ISK resulted in BRA Score of 42.5 and BRA + CCA Score of 54.5, at medium thresholds for BRA and BRA + CCA with the outcome for both as 'high' indicating a high risk of the species in the assessment region and also future climate change scenarios (Table 6).

Pterygoplichthys disjunctivus has been introduced in India through aquarium fish trade (Singh and Lakra 2011). The city of Kolkata in West Bengal, bordering the East Kolkata Wetlands is one among the major aquarium fish trade hubs in India, where *Pterygoplichthys* spp. have been traded, indicate a possible way of entry of the species to the wetlands. Fishers and wetland managers recalled the history of the species in the wetlands dating back to 20 years as to hobbyists releasing the species to the wetlands, nearby canals or homestead ponds when they no longer wanted to keep it in aquarium tanks. A similar observation has been reported by Bijukumar et al. (2015) from Kerala, the second southernmost state in India. East Kolkata Wetlands can act as a reservoir for the species and they may find way, directly or indirectly, to streams and rivulets connected with the wetlands, that ultimately meet the Ganga River passing through West Bengal. As *Pterygoplichthys* spp. tolerate salinity up to 12‰ and are able to thrive under mesohaline conditions for extended periods (Kumar et al. 2018), can easily invade the sensitive brackish water ecosystems of the lower Ganga, the Hooghly–Matla estuary, and the Sundarban mangrove ecosystems. The fish has been recorded from the extensive floodplain wetlands, natural ponds, and aquaculture farms existing along the lower Ganga basin, which are treasure troves of valuable indigenous fish species and also produce a large quantity of fish through capture, culture, and culture-based fisheries, which are at risk. Although the guidelines for import of exotic fish species in India are well established, there is what happens after the species are traded. Intensive fishing, especially along the marginal areas of water bodies using smaller-mesh seine nets and removal, particularly during the breeding season and plugging of burrows and finding use and demand for fishmeal, animal, or human food, can increase fishing pressure on their population thereby reducing their population. There is also need for framing and implementation of management plans in areas where the species are reported; monitoring traders, hobbyists and public as to the status of the species in their holdings and legislation to prevent the entry of such species into natural waters.

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