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Review

Current knowledge on the biology, captive breeding and aquaculture of the brackishwater catfish, *Mystus gulio* (Hamilton, 1822): A review

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ABSTRACT

Mystus gulio, the long whiskers catfish is a euryhaline fish, which thrives well in brackishwater and freshwater environments. This species is widely distributed from Sindh, India and Myanmar to Malay Archipelago and Sri Lanka. It is a popular food fish due to its taste, nutritional value and contribution to the nutritional security as an important small indigenous fish species in Sundarban area of India and Bangladesh. Recently, catch of this species has declined in the Sundarban due to over fishing and various inadvertent ecological changes. A number of scientific studies have investigated different aspects of its biology, breeding and aquaculture, but to date no comprehensive documentation is available. Therefore, the present review provides an insight into the status of food and feeding habit, reproductive biology, breeding, farming, nutritional requirement, disease and marketing of *M. gulio*, which will help in future development on seed production, farming, and conservation of this species. This review also highlights the research gaps such as nutritional requirements, round the year large-scale seed production and farming systems that will help to develop future aquaculture of *M. gulio* in South Asia.

1. Introduction

The long whiskers catfish, *Mystus gulio* (Hamilton, 1822), a member of the family Bagridae under the order Siluriformies is a euryhaline fish (Pandian, 1966) (Fig. 1). Commonly, it is called as nona-tengra in Bangladesh (Rahman, 1989) and West Bengal, India (Mukherjee et al., 2002), Kala-tenguah in other parts of India (Daniels, 2002), long-whiskered catfish in Sri Lanka (Pethiyagoda, 1991) and Nga-zin in Myanmar (Khin, 1948). Talwar and Jhingran (1991) have reported that this fish mainly inhabits brackishwater, and sometimes enters and lives in freshwater environment. Mukherjee et al. (2002) have reported its availability in sea and estuarine waters. Shafi and Quddus (2001) have documented its availability in canals, beels, haors, oxbow lakes, rivers and estuaries of Bangladesh, and in Sundarban delta (Ganges-Brahmaputra estuary) of India and Bangladesh (Huda et al., 2003). Although, *M. gulio* was described from the upper stretches of the Gangetic estuary by Hamilton (1822), it is distributed widely in seas, estuaries and tidal waters from Sindh, India and Myanmar to Malay Archipelago and Sri Lanka, and also from Sumatra and Siam (Day, 1878). Distribution is also reported along the estuarine and tidal water shores of Bangladesh, India, Sri Lanka, Indonesia, Vietnam, Pakistan, Java, Thailand, Malaysia and Myanmar (Day, 1878; Weber and de Beaufort, 1913; Smith and Schultz, 1945; Pethiyagoda, 1991; Talwar and Jhingran, 1991; Roberts, 1993; Jhingran, 1997; Kottelat, 2001; Senarathne and Pathiratne, 2007; Ng, 2010; Froese and Pauly, 2014). It is one of the major fisheries in Panama lagoon of Sri Lanka (Ellepola et al., 2014). It was recently reported from China (Dong et al., 2012).

This fish is very delicious and, therefore, enjoys a high consumer preference and market demand in eastern India and Bangladesh (Tripathi, 1996; Sarker et al., 2002; Begum et al., 2008b; Haniffa, 2009a,b). Recently, this fish has been documented as an ornamental fish (Ng, 2010; Gupta and Banerjee, 2014). Siddiqui (2007) has reported that it controls water pollution by consuming aquatic detritus. Ross et al. (2003) described that *M. gulio* as a small indigenous fish species (SIS), contains high nutritional value in terms of protein, micronutrients, vitamins and minerals making it a very suitable candidate species for aquaculture in Southeast Asia. Ray et al. (2014) have studied the antioxidant and protein contents in 16 SIS and found that *M. gulio* ranks the first in amount of protein (21.43%) and antioxidant levels (IC_{50} value: 364.18 μg mL^{-1}) compared to other studied SIS. They also reported the lipid and ash values as 5.6 and 4.42%, respectively. This fish species is traditionally farmed in rice fields and brackishwater areas of eastern India and Bangladesh, where it forms a valuable culture fishery (Pantulu, 1961). It is an important additional crop from

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Fig. 1. Adult *Mystus gulio*.

traditional shrimp farms in the coastal region (Sarker et al., 2002). Its market price in Sundarban delta, India and Bangladesh is very high ranges from $ 2.18–6.55 kg^{-1} (CIBA, 2015) to $ 1.37–1.79 kg^{-1} (Jasmine, 2013) respectively. There insufficient published data on its catch and production. However, in the world's largest mangrove ecosystem (Sundarban: the Ganges-Brahmaputra estuary), catch of this species has reduced by 33.6% between 1960 and 2000 (Patra et al., 2005) and during the same period catch was declined by 27.8% in south-western Bengal (Mishra et al., 2009). Further, it is reported that this species is in a state of vulnerable (IUCN, 2000; Mukherjee et al., 2002), near threatened (Patra et al., 2005) and least concern (Ng, 2010; Dubey et al., 2015; Hossain et al., 2015a, 2015b). Though, the species is not endangered, the natural population is decreasing due to over-exploitation and various inadvertent ecological changes making its natural habitat unfavourable (Alam et al., 2006b; Hossain et al., 2015a, 2015b).

Considering the importance and potential of *M. gulio* in aquaculture, much research has been carried out on aspects covering morphology, food and feeding and reproductive biology (Gupta, 2014). However, there is inadequate information on its captive breeding, larval rearing, and culture, which is a pre-requisite for development of captive seed production and aquaculture of this species. Therefore, this review contains a compilation of all available information to highlight the scarcity of knowledge in the areas of captive breeding, nursery rearing, nutritional requirement and culture, which will provide useful directions to carry out further research and suggest its suitability as an aquaculture candidate species.

2. General biology

2.1. Growth pattern

Pantulu (1961) study in Hooghly estuarine system, India recorded age-wise difference in mean total length of 47.42, 87.66, 109.33, 130.00 and 158.67 mm at the age of 1, 2, 3, 4 and 5 year, respectively but no significant difference was there in mean total length on sex-wise. Whereas, Islam et al. (2008) made a study in brackishwater aquaculture farm at Paikgacha, Bangladesh and reported that females are generally larger than the males. In wild, maximum weight of 300 g was reported in India (Archarya and Iftekhar, 2000) and maximum length of 20 cm was reported in Myanmar (Vidthayanon et al., 2005). Kaliyamurthy (1981) and Dasgupta (1997) have reported positive allometric growth in *M. gulio*; on the contrary, isometric growth pattern has been conveyed by Pantulu (1961); Begum et al. (2010), and Mondal and Mitra (2016).

2.2. Food and feeding habit

Several studies (Pantulu, 1961; David, 1963; Pandian, 1966 and Kaliyamurthy and Rao, 1972; Siddiqui, 2007; Sabbir et al., 2017) described *M. gulio* as a carnivorous fish, which mainly feeds on crustaceans, zooplanktons, zoobenthos and fish. However, it was also described as an omnivorous fish by some researchers (Yusuf and Majumdar, 1993; Rajkumar et al., 2004; Begum et al., 2008b). Pantulu (1961) have documented the presence of prawns, fish, larvae of crab, kitchen refuse, insects, copepods and cladocerans in the gut content of *M. gulio* from Hooghly and Matlah estuary of West Bengal. In Cooum backwaters, Madras/Chennai, food of *M. gulio* consisted mainly of crustaceans and insects (Pandian, 1966). More elaborately, *M. gulio* mainly feeds on crustaceans, such as copepod, *Cyclops bicolor* and cladoceran, *Daphnia*, and insects, corixid bug *Micronecta scutellaris* and midge larvae, and pupae of *Chironomus* (Pandian, 1966). Tripathi (1996) described its insectivorous feeding habit. Siddiqui (2007) opined that *M. gulio* feeds on debris, zooplanktons, zoobenthos, other benthic invertebrates, fish eggs and larvae. Begum et al. (2008b) suggested that *M. gulio* is a euryphagous feeder as it feeds on a wide range of organisms ranging from plankton to invertebrates. They also reported that adult prefers to feed on insects and crustaceans, whereas the immature and juveniles prefer diatoms, copepods, cladocerans and rotifers. *M. gulio* has benthic feeding habit (David, 1963; Pasha, 1964; Kaliyamurthy and Rao, 1972; Yusuf and Majumdar, 1993 and Sherly, 2012). Inverse relation between feeding and breeding in *M. gulio* was reported with poor feeding in the peak breeding season (May and June) and high feeding during post-spawning season (August to April) (Homans and Vladykov, 1954. Pantulu, 1961; Pandian, 1966; and Mondal and Mitra, 2016).

3. Reproductive biology

3.1. Sexual dimorphism

M. gulio has sexual dimorphism, which is distinct and prominent. A muscular papilla with pinkish tip is prominent in male (Fig. 2), but absent in female (Fig. 3) (Mookherjee et al., 1941; David, 1963; Begum et al., 2008b). Females are generally larger than the males (Islam et al., 2008).

3.2. Sex ratio

Pantulu (1961) has reported 1:1 sex ratio (female: male) in wild population of Hooghly estuarine system, India. However, Kaliyamurthy (1981) has documented female population is more than that of male in total *M. gulio* population and female to male sex ratio is 1.27:1.00 in Pulicat Lake, India. Later it was supported by Islam et al. (2008), who observed the female and male sex ratio as 1.22:1 in brackishwater aquaculture farm at Paikgacha, Bangladesh. Recently, a female biased sex ratio of 1:0.15 was documented in Ashtamudi estuary, Kerala, India (Lal et al., 2016).

3.3. Size and age at maturity

Minimum size at maturity is the shortest length at which mature

Fig. 2. Male *M. gulio* with prominent muscular genital papilla.

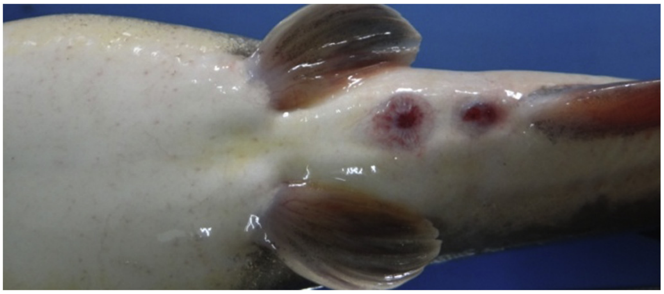

Fig. 3. Female *M. gulio* with round genital opening.

specimen is observed. Minimum size at maturity of *M. gulio* was 6.2 cm in Hooghly estuary (Pantulu, 1961); 7.9 cm in Matlah and Kulti estuaries (David, 1963); 8.2 cm in Chilka Lake (Jhingran and Natarajan, 1969); 5.4 cm in Lake Pulicat (Kaliyamurthy, 1981). Recently, Lal et al., 2016 in Ashtamundi estuary have described minimum length at first maturity (length at which 50% of the fish population is in mature condition) of *M. gulio* male and female as 8.3 and 8.5 cm, respectively. We have observed that *M. gulio* attains sexual maturity at an average weight and length of 56 g and 6.5 cm, respectively in 6 months of grow-out period in brackishwater pond culture system (unpublished data).

3.4. Fecundity

Fecundity is one of the most important biological characteristics of fish and it plays a significant role to evaluate commercial potentiality of fish stock. Fecundity is defined as the number of eggs produced by an individual female (Lagler, 1949). This is useful to assess the abundance and reproductive potential of a fish stock (Das et al., 1989). In all fishes, the number of eggs increases with increase in their length (Dewan and Doha, 1979). David (1963) has observed that 1 g ovary of *M. gulio* contained 4149 ova. Similarly, Kaliyamurthy (1981) has reported that 1 g ovary of *M. gulio* (size: 10.5 to 24.5 cm) contained on an average 4089 ova and the fecundity factor was 244, and fecundity ranged from 1285 to 24,768 with an average of 4754. Sarker et al. (2002) have found the fecundity of *M. gulio* with total length in the range of 10–12 cm and 20–22 cm varying from 11,887-21,589, respectively, and they also noticed the direct relation between weight of ovary and fecundity. Dasgupta (2002) observed the fecundity of *M. gulio* (total length: 11.50–20 cm) ranged from 425 to 18,199. Islam et al. (2008) noticed the fecundity of *M. gulio* (total length: 12.30 to 24.50 cm) ranged from 3891 to 1,68,358 with an average of 32,909. They also observed a linear relation of fecundity to total length, body weight, gonad-length and gonad weight of *M. gulio*. Recently, Lal et al. (2016) documented the fecundity of *M. gulio* (size: 14.5–23.0 cm) from 5950 to 1,41,210. Islam et al. (2008) and Lal et al. (2016) reported maximum fecundity in the month of July, during which *M. gulio* has the highest gonadosomatic index with mature stage of ovarian development.

3.5. Gonadosomatic index

Gonadosomatic index (GSI) is used as an indicator of the stage of ovary maturation and degree of ripeness. GSI values of both male and female *M. gulio* increase from March onwards reaching a peak in July followed by a gradual decrease up to December (Sarker et al., 2002; Islam et al., 2008; Lal et al., 2016).

3.6. Spawning season

July was reported as the peak spawning month for *M. gulio* in Hooghly estuary Pantulu (1961). The peak spawning season in Pulicat Lake and Cooum backwater, Tamil Nadu, is during September–October (Pandian, 1966; Kaliyamurthy, 1981), however, in Cooum water, a small percentage of fish breeds twice in January (Pandian, 1966). Jhingran and Natarajan (1969) observed a wide breeding season that ranges from June to November. In Bangladesh, breeding season is March–November with July as the peak spawning month (Sarker et al., 2002; Islam et al., 2008). Thakur (1975) described that *M. gulio* breeds in sea waters adjacent to estuarine zone and larvae/ juveniles are available from March to May. Mukherjee et al. (2002) examined the spawning behaviour of *M. gulio* and reported that it dwells and breeds in the estuaries during the monsoon. In all the cases, spawning activity has been reported to be correlated with monsoon season, which lowers the temperature and salinity that act as prime environmental cues to stimulate final oocyte maturation (FOM) and spawning.

3.7. Breeding periodicity

Ova diameter distribution showed a single peak, which indicates that individual fish spawns only once in a breeding season (Pantulu, 1961; David, 1963; Pandian, 1966 and Kaliyamurthy, 1981; Islam et al., 2008). Islam et al. (2008) observed that ova diameter ranges from 450 to 1000.2 μm and average highest value (841.8 ± 76.98 μm) was in the month of July with a single peak.

4. Induced breeding and larval rearing

There are no available reports on natural spawning of this species in captivity. At Kakdwip Research Center of ICAR-Central Institute of Brackishwater Aquaculture, we have observed that it attains maturity in pond condition but fails to spawn, and this may be due to failure in attaining FOM and ovulation (Unpublished data). The widely adopted method to overcome this reproductive dysfunction in fish is hypophysation. The first report of induced breeding of *M. gulio* was documented by Mukherjee et al. (2002) in India. They collected adult broodstock from *bheri* (manmade impoundments in coastal wetlands or brackishwater tide-fed impoundments), acclimatized in tank for 15 days and fed with a conventional feed (mustard oil cake: rice bran: dry fish: 1:1:5). Ripe male and female with mature ovary in the sex ratio of 2:1 were selected during the month of June for induced breeding. Captive breeding was carried out in a 200 L round earthen cistern (60 cm dia), filled with saline water (salinity 20 ppt). Double and single doses of synthetic hormone ‘ovaprim’ were administered to both female and male, respectively. The dose of ovaprim used was 2.5 mL kg^{-1} body weight to female and 1.0 mL kg^{-1} body weight to male. Latency period and incubation period were 12 and 20 h, respectively, at 29 ± 1 °C temperature. Newly hatched larvae measured 3.5–4.2 mm in length with a small yolk sac, which was absorbed within 36 h after hatching. During larval rearing, newly hatched larvae were fed with *Artemia* nauplii after complete absorption of yolk sac. They suggested that an utmost care of larvae should be taken after 24 h of hatching as maximum mortality occurs during this time.

Ray (2005) demonstrated induced breeding of *M. gulio* through natural spawning and stripping method in semi-saline (3–5 ppt) and freshwater environment. He collected the mature brood fish from estuaries and tidal water of Hooghly-Matlah estuary. Brooders were acclimatized to semi-saline and freshwater condition. To induce the spawning, two doses of carp pituitary gland extract at the rate of 15 mg kg^{-1} body weight with an interval of 6 h were injected to the female. Male was injected with the same dose at the time of second dose to female. Sex ratio was maintained in the breeding tank at 1:2 (female: male). For attachment of adhesive eggs, aquatic plant (*Vallisneria* sp.) was placed in breeding tank as egg collector. The reported average diameter of fertilized eggs was 1.056 mm. Contrary to the earlier observation of Mukherjee et al. (2002), there was a very short latency period of 4–5 h and long incubation period of 38 h at almost similar temperature of 28 °C. Apart from temperature, latency period in fish also depends on type of hormone used for breeding. In induced spawning of fish, HCG elicits shorter latency period than LHRH because of the difference in mode of action; HCG acts directly at the level of the gonad, whereas LHRH acts on the brain (Zohar and Mylonas, 2001). In stripping method, fish were injected with ovatide at the dose of $1\,mL\,kg^{-1}$ to male and $2\,mL\,kg^{-1}$ to female and after 15 h, females were stripped and males were dissected out to collect milt that fertilized the eggs.

Induced breeding, spawning behaviour and larval raring of *M. gulio* were documented by Alam et al. (2006a and 2006b) in Bangladesh where a single dose of ovaprim at the rate of $1\,mL\,kg^{-1}$ body weight was administered to both male and female. A breeding set consisted of one female and two males. Spawning activity was observed after 5 h of injection, though the latency period was 6–8 h at ambient temperature.

Begum et al. (2009) recorded the embryonic and larval development of *M. gulio* as: latency period of 6–8 h; fertilized eggs were adhesive, demersal and spherical in shape; yolk sphere contained no oil globule; egg incubation period of 18–20 h at ambient temperature; yolk sac exhausted by the end of third day and larvae commenced exogenous feeding before completion of yolk sac absorption. Fry attained the length of 19 to 21 mm in 20 days and became fingerlings (25–30 mm) in 30 days. Haniffa et al. (2009a) have successfully bred *M. gulio* through administration of ovatide. Successful breeding of *M. gulio* in re-circulatory aquaculture system (RAS) with administration of single dose of either human chorionic gonadotropin (HCG) or LHRHa, and its larval rearing technology were developed by CIBA (2015). This achievement of consistent hatchery based seed production and larval rearing technology will pave way for establishment of small scale backyard hatchery by small and marginal farmers. Further, this technology will encourage consistent hatchery based seed production and enhance aquaculture production. Recently, Kumar et al. (2018) documented the captive breeding of *M. gulio* with administration of human chorionic gonadotropin, and its larval rearing. They reported that hatching of embryo started after an incubation period of 17.5 h at an ambient temperature of $29 \pm 1\,^{\circ}C$, newly hatched larvae measured 2.17 ± 0.29 mm in total length which started feeding 36 h after hatching. They also recommended larval stocking density of 25 number L^{-1} and four times feeding with *Artemia* spp. nauplii at the density of 3000 number L^{-1} for *M. gulio* larval rearing.

5. Culture

This species is euryhaline and suitable for culture in both fresh and brackishwater environments (Tripathi, 1996; Rajkumar et al., 2004; Siddiky et al., 2015). *M. gulio* is widely cultured in the paddy fields and brackishwater areas of West Bengal and Odisha (Pantulu, 1961; Troell, 2009) and in sewage-fed brackishwater system of West Bengal (Ray, 2005). Alam et al. (2006a) and Begum et al. (2008c) documented the farming of *M. gulio* with shrimp following traditional trapping and holding method in *bheri* of Bangladesh. Similarly, Siddiky et al. (2015) suggested suitability of this fish for mixed culture with shrimp and high density monoculture.

5.1. Nursery rearing

Nursery rearing of yolk-absorbed spawns of *M. gulio* seems to be a critical phase due to switching over from planktonic feeding habit to accepting other feeds (Siddiky et al., 2015). A twenty one days nursery rearing trial of 7-day old larvae (average length and weight: 5.73 mm; 1.31 mg) of *M. gulio* was conducted by Islam et al. (2007) in brackishwater (8 ppt) pond culture system. In this experiment, larvae were fed with *Artemia* nauplii and formulated wet feed prepared from boiled egg, fish meat, yeast, milk powder, wheat flour, vitamin and minerals. They reported that survival (67.33%) and growth (average length and weight: 20.12 mm; 79.96 mg) were almost double in the *Artemia* fed group compared to other formulated wet feed consuming group. Mou et al. (2013) documented the pond nursery of *M. gulio* (age: 5 days; average length: 5 mm) at a uniform stocking density of 250 individuals m^{-2} with the use of organic and inorganic fertilizers. Supplementary feed with a mixture of finely powdered mustard oil cake, rice bran and fish meal at the ratio of 2:3:5 was provided twice daily. Result of this study showed that application of organic fertilizer gave higher survival of 69.35% than the inorganic and mixed fertilizers, however it did not affect final weight (0.83–0.93 g) and length (2.70–2.79 cm) during the four week of pond nursery. Begum et al. (2008a) recommended ideal stocking density of *M. gulio* during pond nursery as 200–250 individuals m^{-2}. In their experiment, five-day old captive-bred *M. gulio* larvae (average body length: 4.53 ± 0.83 mm and average body weight: 0.003 g) were stocked at four different densities of 200, 250, 350 and 450 number m^{-2} and reared for 42 days. During the trial, fish were fed with a mixture of fine rice bran, mustard oil cake and fishmeal at a ratio of 2:1:1. At the end of experiment, it was found that stocking density of 200 to 250 m^{-2} was ideal, as it gave maximum survival (89.25%), final weight (0.460 g) and specific growth rate (5.10% day^{-1}). In related species, *Mystus cavasius*, ideal stocking density for nursery rearing is 20 m^{-2} recommended by Rahman et al. (2013).

5.2. Monoculture

Mondal and Mitra (2016) experimented monoculture of *M. gulio* in brackishwater tide-fed impoundments, locally called *bhery* for a period of 12 months, without supplementary feeding. In this experiment, *M. gulio* fry (1.78 ± 1.5 g) stocked at density of 1 m^{-2} attained an average body weight of 82.5 ± 3.20 g. In an experiment for a period of 150 days, stocking densities (8, 12 and 16 m^{-2}) had no significant impact on final size (11.83–12.42 g) (Siddiky et al., 2015). However, total production was highest (950 $kg\,ha^{-1}$) in higher stocking density and survival was maximum (64.41%) in the lowest stocking density, when fishes were fed with a commercial pellet feed (30% crude protein) at the rate of 4 to 6% of estimated biomass daily. They recommended high stocking density farming for this species. Hosen et al. (2017) reported highest weight gain (1573%) and survival percentage (95%) of *M. cavasius* at the lowest stocking density of 10 m^{-2} than that of 12 and 15 m^{-2}. In this four month of culture period, fishes were fed with a commercial feed (30% protein) at the rate of 5% of calculated biomass daily. Haniffa et al. (2009a) stocked *Mystus montanus* (1.5–2.5 cm and weight: 1.3–1.5 g) at the rate of 40 m^{-2} in 600 m^2 pond and fed with chicken manure, rice bran, corn flour and finger millet at the ratio of (19:2:2:2). In four month of culture, fish attained 150–250 g with production of 5000 $kg\,ha^{-1}$. Kohinoor et al. (2006) demonstrated production of 1370 to 1535 $kg\,ha^{-1}$ in six months of *M. cavasius* monoculture. Kohinoor et al. (2004) reared *M. cavasius*, (initial weight of 3.94–4.06 g) at three different stocking densities of 40, 50 and 60 m^{-2} for a period of 6 months. During the experiment, commercial pellet feed containing 25% protein was used at the rate of 4–6% of estimated biomass. Organic manure (cattle manure) was applied at the rate of 1000 $kg\,ha^{-1}$ at fortnightly intervals. Results of this experiment showed final mean weight (41.42 ± 6.20 g) and net benefit were significantly higher in the lowest stocking density of 40 m^{-2}.

CIBA (2015) has developed a monoculture technology of *M. gulio* in brackishwater system; where *M. gulio* 30- day old fingerlings 0.85 g were stocked at two different densities of 1 and 2 number m^{-2} in brackishwater tide-fed ponds, in triplicates. After seven months of farming, mean weight of 58 ± 3.30 and 56.8 ± 3.10 g were achieved at 1 and 2 m^{-2} stocking densities, respectively. There was no significant ($p > 0.05$) difference in weight gain, however total production (1200 $kg\,ha^{-1}$) was significantly ($p < 0.05$) higher at higher stocking of 2 m^{-2}. Here, we have used formulated diet (protein 30% and lipid 6%) as supplementary feed at the rate of 5% of estimated biomass daily. Cost of production came around \$ 1.17 kg^{-1} and it had a ready market of minimum \$ 3.64–7.28 kg^{-1}, which is economically lucrative. High density farming (20–40 number m^{-2}) in small backyard ponds (300 to 500 m^2) will be an ideal practice.

5.3. Polyculture

Polyculture of *M. gulio* at a stocking density of 40 m^{-2} with *Oreochromis niloticus* (60 m^{-2}) and *Rhinomugil corsula* (40 m^{-2}) gave total production of 3866.37 kg ha^{-1} than monoculture total production of 1682.50 kg h^{-1} in 120 days (Hossain et al., 2015a, 2015b). Cage culture of *M. gulio* at the stocking density of 150 m^{-2} gave the highest total production than those of 100 and 250 number m^{-2} (Hossain et al., 2015a, 2015b).

M. gulio attained an average body weight of 50 g in a culture period of 4.5 months at the stocking density of 0.1 m^{-2} in polyfarming with *Liza parsia* (stocking density, 0.1 m^{-2}) and *Penaeus monodon* (stocking density, 15–17.5 m^{-2}) (Abraham, 2014). Farming of other related species, such as *M. tengra* and *M. cavasius* with carps was documented by Mondal et al. (2017) and Kohinoor et al. (2009), respectively. *M. tengra* juveniles (initial size: 5.09 ± 0.48 cm, 1.38 ± 0.11 g) stocked at the density of 0.5 number m^{-2} with carp (1.4 number m^{-2}) attained an average size of 31.56 ± 2.08 g, 13.92 ± 0.88 cm in 12 months of culture periods (Mondal et al., 2017). They have used no supplementary feed; however, house-hold dining waste (11.37 kg ha^{-1} day^{-1}) and farm yard manure (200 kg ha^{-1} $month^{-1}$) were applied. Culture of *M. cavasius* with Indian Major Carps and *Ompok pabda* was successful as a low input carp polyculture method (Kohinoor et al., 2009).

5.4. Rice-fish culture

In monsoon months, along the coastline, high rain-fed areas which are generally mono-cropped with freshwater rice cultivation. After this crop, usually fields remain fallow due to high saline soil, and are used for farming of salt tolerant rice variety and brackishwater fish (Bhaumik et al., 2013). Culture of brackishwater prawn and fishes in rice fields of West Bengal was described by Pillay and Bose (1957). Total fish production was 100–200 kg ha^{-1} from a traditional type of rice-fish culture system, where *Liza parsia, Liza tade, Rhinomugil corsula, Lates calcarifer* and *M. gulio* and prawns were the main species farmed (Pillay and Bos, 1957). Farming of *M. gulio* and other *Mystus* spp. in rice field is practiced in India and Bangladesh (Pantulu, 1961; Halwart and Gupta, 2004). Total production of fish from rice-fish culture is in ranges of 500–2000 and 116–605 kg ha^{-1} in India and Bangladesh, respectively (Halwart and Gupta, 2004). Recently, Bhaumik et al. (2013) reported intensification of rice-fish farming from low input systems to high input systems. They conducted an experiment with different combination of rice-fish culture systems, such as pelleted feed without Asian seabass (*L. calcarifer*); pelleted feed with Asian seabass; traditional feed without Asian seabass; traditional feed with Asian seabass. In this experiment, in addition to natural stocking during high tide, shrimp *P. monodon* seeds were stocked together with fish seeds namely L. *calcarifer*, *L. parsia, L. tade* and *M. gulio* at the rate of 10,000–15,000 number ha^{-1}. At the end of culture period, maximum production of 1049.8 kg ha^{-1} was reported in pelleted feed system without L. *calcarifer*.

5.5. Physico-chemical parameters of water for farming

During pond nursery of *M. gulio*, physico-chemical parameters, such as temperature (32.5–35.5 °C), salinity (3–5 ppt), transparency (27–72 cm), pH (7.90–8.80), total alkalinity (179–250 ppm) and dissolved oxygen (4.8–8.9 ppm) of water were studied by Mou et al. (2013). Begum et al. (2008a) estimated different water quality parameters, such as salinity, temperature, transparency, dissolved oxygen, pH, alkalinity, NO_3-N, PO_4-P in ranges of 4.23–4.38 ppt, 25.28–25.64 °C, 36.00–37.38 cm, 6.53–6.02 ppm, 8.29–8.35, 172.50–163.13 ppm, 1.36–1.28 ppm, 1.08–1.18 ppm, respectively during pond nursery of *M. gulio*.

In bhery, physico-chemical parameters of water such as: temperature, salinity, dissolved oxygen, pH, alkalinity, nitrite-nitrogen, total ammonia-nitrogen, nitrate-nitrogen and phosphate-phosphorous were estimated as 14.7–33.6 °C, 4.2–19.8 ppt, 5.87–9.58 ppm, 7.85–8.50, 160–168.9 ppm, 0.009.33–0.024.47 ppm, 0.021–0.044 ppm, 0.069–0.111 ppm and 0.021–0.043 ppm, respectively for *M. gulio* farming (Mondal and Mitra, 2016). Siddiky et al. (2015) reported different water quality parameters, such as transparency (24–28 cm), pH (7.8–9.45), alkalinity (111–495 ppm) and dissolved oxygen (2.3–5.85) for *M. gulio* farming in earthen pond. Bhaumik et al. (2013) recorded water temperature (20.2–32.7 °C); total dissolved solids (3.01–5.24 ppm); total ammonia (143.1–165.0 ppm); nitrate- nitrogen (0.091–0.117 ppm); hardness (1589.3–2500.4 ppm); transparency (15.2–22.6); pH (7.1–7.9) and salinity (2.4–15.2 ppt) in rice-fish culture of *M. gulio* with other brackishwater fish and shrimp. All above documented water quality data were within optimum rages for brackishwater aquaculture (Chakraborti et al., 2002). From the above cited literatures, it is noticed that the ranges of some important physico-chemical parameters, such as salinity, temperature, dissolved oxygen and pH for farming of *M. gulio* are 3–19.8 ppt, 14.7–35.5 °C, 2.3–9.58 ppm and 7.1–9.45, respectively.

6. Nutritional requirement

Begum et al. (2008c) have tested the effect of different protein levels, such as 30, 35 and 40% in feed on growth and maturity of *M. gulio* for a duration of 140 days, and observed that higher the protein level better the growth and maturity. Maheskumar et al. (2006) incorporated Superliv (a herbal fish growth promoter from Ayurvet, India) at three graded levels, 0.25%, 0.50%, and 0.75% in the diet of *M. gulio*. They observed that 0.75% Superliv added diet gave better weight gain, protein efficiency ratio and feed conversion ratio. In another study, Kumaraguru et al. (2004) observed the effects of Nutripro-Aqua (a herbal based commercial feed additive, Sneha Farms Pvt. Ltd., Hyderabad, India) at 0.0%, 0.25%, 0.50%, and 0.75% on growth performance of *M. gulio*. After a 120-day culture period, a 0.50% Nutripro-Aqua diet showed the best performance in terms of weight gain, specific growth rate, protein efficiency ratio and feed conversion ratio. Rajkumar et al. (2013) incorporated Cholymbi (a commercial non-hormonal growth promoter, Lyka Laboratories, Mumbai, India) in isoproteinous diet at the levels of 0%, 0.25%, 0.50%, and 0.75%. They concluded that 0.50% Cholymbi added diet provided better weight gain, protein efficiency ratio and feed conversion ratio. A level of 0.75% Lykamin (mineral and vitamin supplement) in feed of *M. gulio* improved specific growth rate, weight gain, protein efficiency ratio and feed conversion ratio (Rajkumar et al., 2004).

7. Disease

There is a scarcity of published documents on disease outbreak in *M. gulio* farming, except *Cymothoa indica*, which parasitized *M. gulio* during cage farming in India (Rajkumar et al., 2005). Asmat and Haldar (1998) reported *Trichodina mystusi*, a new species of *Trichodinid ciliophoran* from *M. gulio*. Another parasite, *Trichodina canningensis* was reported in gill of *M. gulio* by Asmat (2001). In West Bengal, prevalence of helminths, Acnthocephalans such as *Pallisentis* spp., *Raosentis podderi* and *Acanthogyrus* spp. are common in *M. gulio* during monsoon months (Guchhait et al., 2017). Fishes found in polluted water of Veli Lake, Thiruvananthapuram, India got affected by tumors (erythrophorma) and dysplastic vertebrae (Beena et al., 2013). Jyothi et al. (2013) and Anbarasu and Chandran (1998) studied the non-specific immune response to *Aeromonas hydrophila* infection in *M. gulio*. Moreover, immunostimulatory effect of vitamin C on the humoral and cell mediated immunity of the bagrid catfish, *M. gulio* was examined (Anbarasu and Chandran, 2001). Overall, this species is a hardy animal with no mass mortality reported due to disease outbreak.

8. Marketing

In Bangladesh, retail price of SIS, which include *Mystus* spp. varies significantly between markets and months, due to seasonal availability, freshness, size, consumer preference and the involvement of market intermediaries (Rahman et al., 2012; Jasmine, 2013). Price of *Mystus* spp. in retail market of Bangladesh varies from $. 1.37 to 1.79 kg^{-1} (Jasmine, 2013). In India, *Mystus* spp. is sold in market at the rate of $. 1.89 kg^{-1} (Haniffa et al., 2009a). A market survey was conducted in peri-urban and rural fish markets of lower Sundarban area by Roy et al. (2016). From the survey, it was found that in the months of April–June, SIS have the maximum supply in fish markets because of their higher availability from natural water. Among all SIS of fish, maximum contribution to the market is made by *M. gulio* (29.39%) followed by *Clarias batrachus* (walking catfish: 10.86%), *Anabus testudineus* (climbing perch: 10.43%), *Amblypharyngodon mola* (mola carplet: 10.22%), *Puntius ticto* (two-spotted barb: 6.38%), *Heteropneustes fossilis* (stinging catfish: 5.53%) and others (Sinha et al., 2014). Recently, we have conducted a survey on marketing of *M. gulio* in Sundarban area and observed that this fish has a very high market demand with prices ranging from $ 2.18–6.55 a kg. Price is directly related to size variation, such as smaller size (50–70 g), medium size (50–70 g) and larger size (> 100 g) are sold at $ 2.18, 5.10 and 6.55 kg^{-1}, respectively by wholesaler to retailer who in turn sells after adding an additional of $ 0.44 to 0.73 kg^{-1} (CIBA, 2015).

9. Conclusion

Decline in fish catch due to overfishing and rampant killing of fish juveniles through destructive fishing gears have made natural fisheries no more a profitable venture (Roy et al., 2016). In Sundarban, small fishes from the natural water bodies, such as canals, paddy fields, channels contribute around 15.65% to the household income of fishermen (Roy et al., 2016). As the demand and price of the SIS, including *M. gulio* are high in market, it is essential to produce adequate quantity through aquaculture that can support an alternate livelihood (Roy et al., 2016). However, the major challenges for its aquaculture are paucity of wild seeds and unavailability of hatchery produced seeds. Present review suggests that ample information is available on food and feeding habit, and reproductive biology of *M. gulio*, however, there is limited knowledge on captive breeding, nursery rearing, nutritional requirement, farming technology, disease occurrence and marketing which may have direct implications in aquaculture. We have compiled and discussed all available published documents related to its aquaculture, and this will definitely provide directions to carry out further research on different aspects of *M. gulio* to promote its aquaculture. Moreover, the need of the hour is to conserve this species and explore its potential for aquaculture. Despite the continuous efforts from researchers on induced breeding, larval rearing and farming, no major steps toward setting up of large- scale seed production units to meet up the seed requirement, and farming to fulfill the market demand have been taken so far. Further, standardization of optimum water quality requirements, nutritional requirement, right kind of supplementary feed for larval rearing and farming are critical research gaps for the development of *M. gulio* aquaculture. Suitability of *M. gulio* farming in different culture systems, such as tank (re-circulatory /flow through system) and cage is an important area of future research. Research on domestication, captive maturation of *M. gulio* through hormonal and environmental manipulation will help to meet up the year-round seed requirement for farming.

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