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REVIEWS

Fishery, biology, aquaculture and conservation of the threatened Asian Sun catfish

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Abstract We summarize the research on Asian Sun catfish, *Horabagrus brachysoma* (Günther), an endemic and threatened freshwater catfish from Western Ghats of India, and provide a comprehensive review of its taxonomy, distribution, biology, population, conservation and aquaculture. Although described in 1864, the taxonomy of *H. brachysoma*, particularly its familial affinities, continues to be in flux. The species, originally described from the erstwhile 'state of Cochin' in present day Kerala State, India, has a current distribution ranging from southern Kerala (8°N) to southern Maharashtra (16°N), where they are found in lowland westward-flowing rivers, as well as natural freshwater lakes and backwaters. As a much relished food fish, *H. brachysoma* is exploited throughout its range, predominantly through an unmanaged artisanal fishery. Although there are no scientific estimates of either the status or trends in overall population of this endemic catfish, anecdotal evidence and fisher-knowledge suggests drastic declines of several local populations. The fishery for *H. brachysoma* in the Periyar and Achenkovil rivers in the State of Kerala has been documented to be unsustainable. As a result of an overall population decline of 35 % due to overharvest and habitat loss, *H. brachysoma* is assessed as 'Vulnerable' on the IUCN Red List of Threatened Species™. Primary research on various aspects of feeding, reproductive biology and demography has generated a wealth of information on the species, but this knowledge is yet to be utilized for the development and implementation of in situ conservation or management plans. In view of its high consumer demand, efficient biological and eco-physiological characteristics, as well as the availability of a captive breeding technology, *H. brachysoma* is considered an emerging species for small-scale aquaculture. Priorities for scientific research to address knowledge-gaps, as well as strategies for effective conservation of this threatened freshwater catfish are discussed.

Keywords Bagridae · Endemic · Freshwater fish · Western Ghats · Yellow catfish

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Introduction

Close to 16,000 fish species depend on freshwater habitats (Pelayo-Villamil et al. 2015) of which many provide important socio-economic benefits and

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ecosystem functions (Brummet et al. 2013; Reid et al. 2013; Dugan et al. 2006). Freshwater fishes are considered a 'mega-diverse' group of vertebrates (Reid et al. 2013) with a high rate of new species descriptions (240.2 species year^{-1} during 2003–2013) (Pelayo-Villamil et al. 2015). They are nevertheless of high 'conservation-concern' as 20 % of the species (of the 6884 species assessed) are threatened with extinction and several species already extinct (IUCN 2015). Kottelat et al. (2012) mentions that 'there is hardly any type of terrestrial human activity that does not impact on freshwaters and thus on aquatic life'. A multitude of human-induced stressors including alteration and degradation of habitats, overfishing and exotic species introductions (Dudgeon 2011; Allan et al. 2005), have resulted in freshwater fishes becoming a taxa that is 'living on the edge'.

Conservation and management of freshwater fish resources is often constrained by the limited amount of information on life-history, reproductive biology and population status of most, especially imperilled species (Cooke et al. 2012). This data-deficiency is most severe in tropical biodiversity hotspots which not only harbour high levels of ichthyodiversity but are also areas facing high levels of anthropogenic threats (see for e.g. Kottelat et al. 2012; Dahanukar et al. 2011). The Western Ghats region in peninsular India known for its unique freshwater biodiversity (Molur et al. 2011; Raghavan et al. 2015) harbours 19 endemic genera of freshwater fishes, but limited information exist to conserve these resources. Many of these fishes not only have a restricted distribution, but are also threatened as a result of loss and degradation of habitats, alien invasive species and overharvest (Dahanukar et al. 2011). The Asian Sun catfish or the yellow catfish, *Horabagrus brachysoma* (Günther) (Fig. 1) is endemic to the Western Ghats region, of high conservation concern (Raghavan and Ali 2013), yet of prime importance to both local and international economies and livelihoods (Raghavan et al. 2013; Prasad et al. 2012; Sreeraj et al. 2007). Conserving endemic and threatened freshwater fishes like *H. brachysoma*, and simultaneously managing their commercial and/or subsistence fisheries is a difficult balancing act, requiring the availability of reliable information on the biology, ecology and population performance. Information available in the primary literature has been synthesised in the present paper, and future priorities for scientific research to fill existing knowledge gaps discussed.

Fig. 1 Fingerling and semi-adult *Horabagrus brachysoma*

Taxonomy and systematics

Horabagrus brachysoma was described by Günther (1864) as *Pseudobagrus brachysoma*. Jayaram (1955) allocated *Pseudobagrus brachysoma* to a newly erected genus *Horabagrus*, the generic name being a combination of '*Hora*' honouring Sunder Lal Hora (a globally renowned ichthyologist and zoogeographer from India) and '*bagrus*' (for the catfish family Bagridae), and the species name combining the words '*brachys*' (for short) and '*soma*' (referring to the height of the body nearly equal to the length of the head) (www.etyfish.org).

Though the type locality was mentioned as 'Cochinchine' (=current day Vietnam) in the original description (Günther 1864), it was later clarified to be 'Cochin' (an erstwhile state in southern India) (see Jayaram 1952). *Pseudobagrus chryseus* described by Day (1865) is considered as a synonym of *H. brachysoma* (Jayaram 1952; Pethiyagoda and Kottelat 1994), and so is *Horabagrus melanosoma* (see Ali et al. 2014).

Horabagrus is one of the three endemic genera of catfish that occur in peninsular India (two other endemic genera are *Horaglanis* and *Kryptoglanis*). Superficially, *Horabagrus* is similar to the North American *Ictalurus* or to the Asian *Mystus* (Armbruster 2011), but *H. brachysoma* can be easily identified by the combination of characters including eyes placed in a line with the angle of the mouth and visible from the ventral surface, barbels do not exceed beyond head, teeth form an uninterrupted subcrescentic transverse band across the palate, anal fin long and possesses 23–29 rays, very short adipose dorsal fin, its yellow coloured body and a distinctive black spot with a yellow ring on the shoulder (Jayaram 1952, 1955, 2010). Detailed information on the general body shape, appearance, morphometric characters and meristics are mentioned in Ali et al. (2014), Katwate et al. (2012) and Jayaram (1966, 2009).

The systematics of *H. brachysoma* however, is still in flux. The exact familial affinities of *H. brachysoma* within the order siluriformes continues to be under debate, with the species placed in the family Bagridae (Pethiyagoda and Kottelat 1994; Jayaram 1966; Mo 1991), Horabagridae (Sullivan et al. 2006; Hardman 2005) and Schilbidae (Kottelat 2013; Jayaram 2010; Ferraris 2007) at various points in time.

Distribution and habitat

Horabagrus brachysoma is endemic to the rivers, natural lakes, backwaters and associated inland canal systems between 8°N and 17°N latitudes in three peninsular Indian states, viz., Kerala, Karnataka and Maharashtra (Fig. 2). While the state of Goa is geographically located between Karnataka and Maharashtra, there are no records of this species from the rivers of this region.

In Kerala, the fish occurs in 22 of the 41 westward-flowing rivers, viz, Neyyar, Ithikkara, Pallikal, Ayroor, Mamom, Kallada, Achankovil, Pampa, Manimala, Meenachil, Muvattupuzha, Periyar, Chalakudy, Karuvannur, Puzhakkal, Kechery, Chaliyar, Tirur, Karyangod, Valapattanam, Shiriya and Peruvamba, as well as the Vembanad Lake (including lowland regions of its confluent rivers and associated irrigation canals), Sasthamkotta Lake, Muriyad and Kole Wetlands, and the Azhikode estuarine system (Ali et al. 2014; Raghavan and Ali 2013; Thomas and George

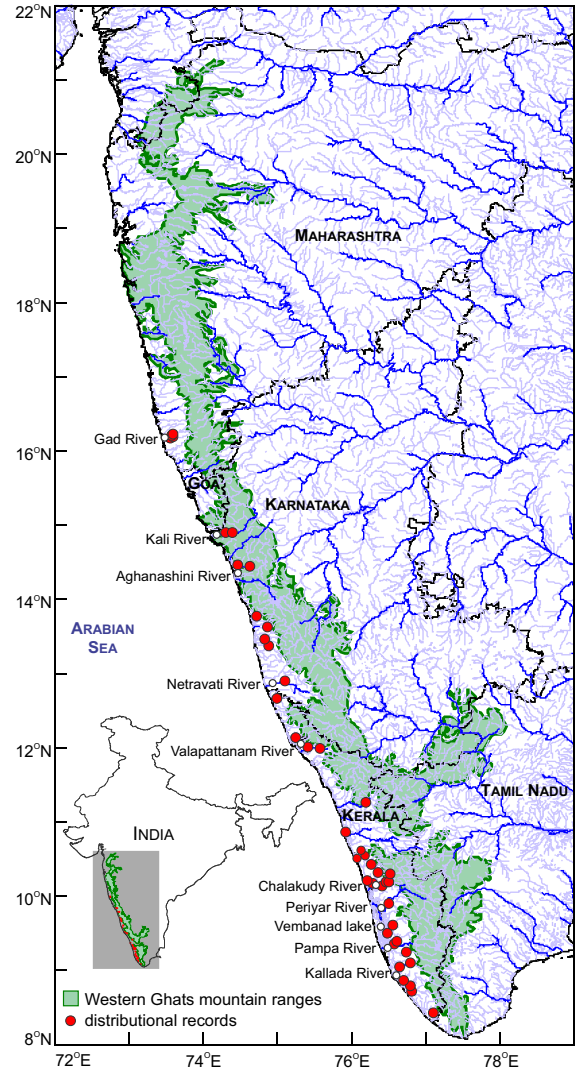

Fig. 2 Distribution of *Horabagrus brachysoma* in peninsular India

2013; Nandan et al. 2012; Zeena and Beevi 2011; Renjithkumar et al. 2011; Baby et al. 2010; Jayaram 2010; Raghavan et al. 2008; Bhargavan et al. 2008; Ali et al. 2007; Girijakumari 2007; Muneer et al. 2007; Kurup and Radhakrishnan 2006; Sreeraj et al. 2006; Narayanan et al. 2005; Thomas 2002; Thomas et al. 2003; Day 1865). It is also likely that the fish occurs in at least some of the remaining 19 westward-flowing rivers in Kerala, but has not yet been recorded due to lack of comprehensive studies. In the state of Karnataka, they are known from the Rivers Nethravati, Kali and Aghanashini (Muneer 2006; Bhat 2001).

Recent records from the rivers and associated tank systems in Sita, Swarna, Sowparnika and Varahi (see Rao et al. 2013; Shetty et al. 2015; Venkateshwarlu and Shetty 2013) which have been published in predatory open-access journals (see Raghavan et al. 2015; Beall 2015) need to be verified. The northern most limit of distribution of *H. brachysoma* is in the state of Maharashtra where a population was recently discovered in River Gad (Katwate et al. 2012).

Apart from its native range in peninsular India, *H. brachysoma* has also been recorded from the Kranji Reservoir in Singapore (C.W. Looh, Singapore, pers. comm. January 2008; see Fig. 3), which may have been a result of introduction via the aquarium trade. A record of this species from an irrigational canal in La Plata, Lajas, Puerto Rico in 2012 (F. Grana pers. comm. cited in Neilson 2015) also needs to be verified.

Horabagrus brachysoma is a benthic inhabitant occurring mostly in the lowland areas of rivers (Raghavan and Ali 2013). Although they have an affinity towards mud and sand as substrate, they have also been recorded from deep riverine pools (Ali et al. 2007), and observed taking refuge inside submerged roots of *Pandanus* and *Aponogeton* vegetation along shallow rivers and stream banks (Katwate et al. 2012; Padmakumar et al. 2010). In irrigation canals, *H. brachysoma* is known to inhabit darker areas adjoining granite side pitching (Bindu 2006).

Diet and feeding habits

Horabagrus brachysoma is unspecialized and opportunistic in its feeding habits (Padmakumar et al. 2009; Prasad and Ali 2008; Sreeraj et al. 2006). They are nocturnal (Katwate et al. 2012) omnivorous feeders (Padmakumar et al. 2009; Prasad and Ali 2008; Sreeraj et al. 2006), capable of widening its dietary food spectrum in response to prey availability (Sreeraj et al. 2006). The gut content of specimens collected from river zone locations near inhabited areas were found to comprise predominantly kitchen and domestic wastes (Bindu 2006), suggesting the possibility of using the species for waste-water management'.

Moderate ontogenic changes were observed with regard to feeding specificity (Sreeraj et al. 2006). For example in the River Periyar, *H. brachysoma* was found to switch from an animal-based to plant-based diet during its growth phases (Prasad and Ali 2008), while few qualitative differences in the diet were observed among various size classes of this species in Vembanad Lake (Sreeraj et al. 2006). Stream dwelling yellow catfish have been reported to feed in shoals at night, and have been observed foraging and feeding for crustaceans present in leaf litter (Katwate et al. 2012).

Fig. 3 *Horabagrus brachysoma* caught from the Kranji Reservoir in Singapore (Photo Courtesy: C.W. Looh)

Reproduction in the wild

Information on sexual dimorphism in *H. brachysoma* is contradictory. While Kurian and Inasu (1997) observed that male specimens were larger and heavier than females of the same age group, Chandran and Prasad (2014) observed that females were always bigger than males at the same age. Studies on the mean length at first maturity (L_{50}) revealed that male *H. brachysoma* mature between 175 and 188 mm TL, whereas females do so between 168 and 185 mm TL (Chandran and Prasad 2014; Bindu et al. 2012). Female *H. brachysoma* arrives in the spawning ground in advance of the males and the former dominates the sex ratio at the spawning grounds during the course of the breeding season (Bindu et al. 2012). The sex ratio (male:female) observed in exploited stocks varied from 1:1.97 (Bindu 2006) to 1:1.3 (Prasad et al. 2012). The sex ratio of exploited populations of *H. brachysoma* is however known to be unrepresentative of the true sexual composition in their natural habitat as netting of all individuals is not easily achievable due to the cryptic characteristics of the species (Bindu et al. 2012).

Despite having a prolonged breeding season, *H. brachysoma* are single spawners season (Chandran

and Prasad 2014). The peak breeding months of June–July, coincides with the south-west monsoon in peninsular India (Chandran and Prasad 2014; Bindu et al. 2012). The Asian Sun catfish is known to be highly fecund (Bindu et al. 2012); however absolute fecundity estimates varied between habitats (Chandran and Prasad 2014; Bindu et al. 2012; Kurian and Inasu 2003). The highest absolute fecundity between 1140 (fish with a total length of 205 mm and total weight of 900 mg) and 123,968 (fish with a total length of 340 mm and total weight of 6500 mg) were observed in specimens collected from the Vembanad Lake (Bindu et al. 2012). *Horabagrus brachysoma* does not show any parental care (Bindu et al. 2012).

Population

There are no reliable scientific estimates of the population status of *H. brachysoma*. However studies citing anecdotal and inferred evidence have suggested drastic declines in the populations of this species, especially in Vembanad Lake (Padmakumar et al. 2010).

The Asian Sun catfish grows to a maximum size of 450 mm in total length (Talwar and Jhingran 1991). The length-weight relationship of both male and female *H. brachysoma* in various riverine ecosystems of Kerala has been observed to be isometric with 'b' values (or the scaling exponent in the allometric relationship $W = aL^b$, where W is the weight and L is the standard length and a is the normalization) not significantly different from 3.0 (Prasad et al. 2012; Ali et al. 2008; Kumar et al. 1999). However, in Vembanad Lake, this species showed an acute negative isometric growth pattern with 'b' values in the ranges of 1.76–2.11 (Bindu 2006; Prasad et al. 2005), a phenomenon possibly influenced by the poor environmental conditions especially the high level of pollution and low availability of food items in the ecosystem (Prasad et al. 2012). Based on annual length frequency data of specimens collected from markets located along the River Periyar, the demographic parameters of the species (Prasad et al. 2012) were—asymptotic maximum length (L_∞) = 388 mm, growth co-efficient (K) = 0.55 year^{-1}, growth performance index (ø) = 4.99, total mortality rate (Z) = 5.64 year^{-1}, natural mortality rate (M) = 1.04 year^{-1} and fishing mortality (F) = 4.60 year^{-1} for the last three parameters are rates per population size. The longevity for this species has been estimated at 5.45 years (Prasad et al. 2012) and the minimum population doubling time computed to be between 1.4 and 4.4 years (Froese and Pauly 2014).

Fishery

Horabagrus brachysoma is an important food fish exploited throughout its distribution range by traditional fishers using gill nets operated from dug-out canoes, cast nets, drag nets, stake-nets, hook-and-line (Prasad et al. 2012; Sreeraj et al. 2007; Bindu 2006), as well as banned 'local' gears such as '*peru vala*' (a form of drift gill-net) (Kumar et al. 2007). The fishery is unmanaged and unregulated and is considered to pose a major threat for the species (Raghavan and Ali 2013).

Horabagrus brachysoma is an important species that is caught during the monsoon floodplain fishery (*Oothapiditham* in vernacular), a practice that involves the large scale exploitation of fishes undertaking breeding migrations (Shaji and Laladhas 2013). Often, more than 100 kg of mature *H. brachysoma* are caught in a week-long monsoon floodplain fishery with gears including traditional fishing traps, gill nets and electrocution (Shaji and Laladhas 2013). In the Vembanad Lake, the fishery for *H. brachysoma* is carried out through the year, but the highest catches were observed during the months of December to March (Bindu 2006).

In the River Pampa, a little more than 17 metric tons of *H. brachysoma* was landed during the years 2007–2009 (Renjithkumar et al. 2011) while the annual landings of this species in various regions of Vembanad Lake ranged from 2 and 439 metric tons during the years 1995–2004 (Sreeraj et al. 2007; Bindu 2006; CICFRI 2001; Kurup et al. 1995).

Harvests of *H. brachysoma* in River Periyar are dominated by sexually immature 1+ class (Prasad et al. 2012). Determining the relationship between size at first maturity and size range of exploited populations, Prasad et al. (2012) indicated that both growth fishing (harvest of individuals before they grow large enough to contribute substantially to the spawning stock) and recruitment fishing (exploitation of the spawning stock) of *H. brachysoma* is taking place in River Periyar. Irrational exploitation of *H.*

brachysoma including fishing of spawning females and fingerlings as small as 32 mm is also prevalent in the Vembanad Lake and in the Achankovil River (Kumar et al. 2007; Sreeraj et al. 2007). Local knowledge of fishers in the Gad River basin in Maharashtra State which represents the northern most limit of the species' range, suggests that intensive fishing for *H. brachysoma* is carried out during its spawning season (Katwate et al. 2012). Overall, the fishery for *H. brachysoma* in many rivers appears to be unsustainable, driven by excessive fishing effort, with overfishing of stocks documented conclusively from at least two rivers (Periyar and Pampa) in the state of Kerala (Prasad et al. 2012; Prasad 2008).

Although *H. brachysoma* is known to be a popular species in the international aquarium trade (Raghavan et al. 2013; Sreeraj et al. 2007), there is very little information on the magnitude or dynamics of wild collection of this species for the pet trade.

Conservation and management

The IUCN Red List of Threatened Species™ has assessed the extinction risk of *H. brachysoma* as 'Vulnerable' under criteria A2bd, because of an overall population decline of 35 % due to overharvest and habitat loss (Raghavan and Ali 2013). It has been suggested that unless management plans are implemented, the excessive fishing effort and subsequent overexploitation in some rivers (Prasad et al. 2012; Prasad 2008) may lead to a collapse of the fishery. The threat from unregulated fishing is exacerbated by additional stressors in the species' habitat including pollution and sand mining (Prasad 2008; Ali et al. 2007; Sreeraj et al. 2007).

Populations of *H. brachysoma* occurring in the river-stretches flowing through, the Idukki Wildlife Sanctuary and the Thattekad Bird Sanctuary in Kerala (Chhapgar and Manakadan 2000) are protected (incidentally) because their habitats are within the protected-area network of the State.

Management of the *H. brachysoma* fishery is hindered by an absence of a history of any successful fisheries management initiatives in the inland waters of Kerala, where the largest share of harvests takes place (Prasad et al. 2012). Based on a study on the population dynamics of the species from River Periyar, various management strategies including restrictions on gear (minimum mesh size of 160–180 mm for gill nets), enforcement of minimum size limits (200 mm) and implementation of closed seasons (May–August) have been proposed (Prasad et al. 2012). Seasonal (early monsoon) ban on fishing of *H. brachysoma* has also been suggested as a conservation measure in Maharashtra (Katwate et al. 2012).

Ex situ conservation strategies (milt cryopreservation and captive breeding) have been developed and piloted for *H. brachysoma* (Padmakumar et al. 2010, 2011; Sajan 2013; Ponniah et al. 2000), and captive-bred fish have been ranched in the Vembanad Lake (during 2000–2003 and subsequently in 2006) and Sasthamkotta Lake (2007–2008) (Padmakumar et al. 2010, 2011), resulting in population improvements (Raghavan and Ali 2013). In-situ conservation measures such as protected breeding zones and sanctuaries, which have been successfully tested for a co-occurring species, *Etroplus suratensis*, in the Vembanad Lake (Padmakumar et al. 2010) could be adapted for *H. brachysoma* as well.

Genetic analyses of a three riverine populations (viz., Nethravati, Chalakudy and Meenachil) of *H. brachysoma* using microsatellite and allozyme markers (Muneer 2006; Muneer et al. 2007, 2009, 2011) revealed low levels of heterogeneity (e.g. $H_{obs} = 0.472$ against an $H_{exp} = 0.649$ of mean values for microsatellites; see Muneer et al. 2009). Similarly F_{IS} value of 0.507 for both microsatellite and allozyme markers revealing heterozygote deficiency (or inbreeding) within these populations (Muneer et al. 2009). The low genetic variability and inbreeding in population is alarming given the high exploitation levels of this species.

Both the allozyme-based and the microsatellite-based studies (Muneer et al. 2007, 2009) also observed that the three riverine populations were genetically distinct (or would comprise different gene pools), thus requiring separate attention as distinct conservation or management units. This has important implications for conservation of *H. brachysoma*, as different populations of the species which are geographically isolated with no chance of inter-breeding evolve in isolation. Although intra-population and inter-population variation of alleles at specific loci studied is a positive signal, the reduced heterozygozity (within populations) is a matter of concern. Thus management actions should target these independent populations

separately and aim to improve their genetic variability (heterozygozity).

Going by the indications of results of Muneer (2006) and Muneer et al. (2007, 2009, 2011) on "isolated gene pools" of *H. brachysoma*, it is highly likely that more genetically isolated populations of this species exist, as many westward flowing rivers where this species occurs are non-interconnected. Information pertaining to ranching and population restoration activities conducted for the species (Padmakumar et al. 2010, 2011) do not mention consideration of this important fact.

Aquaculture

In view of its high demand as a food as well as an aquarium fish (Sreeraj et al. 2006, 2007), *H. brachysoma* is considered a potential species for diversification of freshwater aquaculture in India (Dalvi et al. 2009; Raghavan 2006). Aided further by its high demand as a food and aquarium fish (Sreeraj et al. 2006, 2007), its adaptability to different environments including those characterized by high turbidity, low oxygen content (Padmakumar et al. 2010) and high temperatures (Dalvi et al. 2009), an ability to subsist on a wide range of food (Prasad and Ali 2008; Sreeraj et al. 2006) as well as good growth and survival in captivity (Sahoo et al. 2014). The species has also been prioritised as a 'small indigenous fish' (SIF) species (Sarkar and Lakra 2010) due to their link with local livelihoods and poverty alleviation, and has especially noted to be of importance to small-scale rural aquaculture systems (Hakkim and Prasad 2005), which are characterized by low inputs.

Captive breeding and embryonic development

The yellow catfish does not breed spontaneously in captivity, and hormonal manipulation is required to facilitate spawning—a technique that was first developed by the Kerala Agricultural University, India (Padmakumar et al. 2010, 2011; Bindu and Padmakumar 2008, 2014) and subsequently at the Central Institute of Freshwater Aquaculture, Bhubaneswar, Orissa, India (Sahoo et al. 2014). Large scale breeding for catering to the international aquarium trade is also known to take place in Thailand.

Carp pituitary extract (50–60 mg kg^{-1} body weight) and Ovaprim® (1–1.5 ml kg^{-1} body weight) have been used to induce spawning in *H. brachysoma* (Padmakumar et al. 2011; Sahoo et al. 2014), with variations in latency period (8–14 h), fertilization rate (60–99 %) and hatching rate (23–95 %) observed between trials (Bindu and Padmakumar 2014; Padmakumar et al. 2011; Sahoo et al. 2014). Unlike other catfish species, the fertilized eggs of *H. brachysoma* are heavily yolked, golden-yellowish in colour and spherical in shape (Bindu and Padmakumar 2014; Padmakumar et al. 2011). Hatching occurs 22–27 h after fertilization at 24–26 °C and newly hatched larvae measures 3.82–5.0 mm (Bindu and Padmakumar 2014; Sahoo et al. 2014). Larvae subsist on endogenous nutrition until 4 days post-hatch after which they require exogenous feeding (Padmakumar et al. 2011).

Larval and fry rearing

Larval *H. brachysoma* grow to an average size of 6.0–7.5 mm in a week (Bindu and Padmakumar 2014). While a stocking density of 7 individuals L^{-1} has been considered optimum for ensuring maximum survival and growth of *H. brachysoma* larvae (Sahoo et al. 2010a), a density of 400 individuals/0.6 m^3 density (fry size of 10.7 ± 0.47 mm) was considered ideal for achieving highest weight gain and growth rate in fry (Sahoo et al. 2010b). However, if both individual size and number of individuals for fingerling stocking are not constraints, then the maximum number of fry that survived in a minimum rearing space can be achieved at a density of 1600 individuals/0.6 m^3 tank (Sahoo et al. 2010b). Suitable water quality requirements for fry rearing has been estimated at 7.2–7.6 (pH), 6–7 mg L^{-1} (dissolved oxygen), 90–120 mg L^{-1} (alkalinity) and 0.006–0.1 mg L^{-1} (ammonia) (Sahoo et al. 2011). Survival during fry nursing (up to 85 days) of *H. brachysoma* has been estimated at 50–75 % (Bindu and Padmakumar 2014). Studies have also revealed that *H. brachysoma* larvae need to be reared for at least 14 days before transferring them to fingerling tanks (Sahoo et al. 2015). When fed at a rate of 10 % of the biomass, *H. brachysoma* fry attained a size of 26.2 ± 2.39 mm in 30 days (Bindu and Padmakumar 2014). In spite of these studies, there is however very little information that is available on the ideal temperature required for

achieving highest survival and growth in larvae and fry of *H. brachysoma*.

Nutrition and health management

Juveniles and adults of *H. brachysoma* have all major digestive enzymes viz. carbohydrases, proteases, and lipases thereby enhancing their ability to digest all major types of nutrients present in formulated diets (Prasad and Suneesha 2013). Nutrition and health management are two aspects of the aquaculture of *H. brachysoma* on which very little research has been undertaken. Fingerlings are known to adapt to natural and formulated diets (Raghavan 2006; Hakkim and Prasad 2005). A semi-moist feed of fish and prawn meat elicited a higher feeding response and led to increased growth than commercial and laboratory-prepared pellet feeds (Raghavan 2006). The optimum dietary protein requirement of fingerling *H. brachysoma* is estimated to be between 35 and 39 % based on highest growth rate and best feed utilization (Prasad 2014; Giri et al. 2011).

Ecophysiology

Though Prasad and Charles (2010) observed that the overall haematological profile of the species is not considerably different from other catfishes, they suggested that the lymphocytes of *H. brachysoma*, unlike other teleost fishes, appeared to participate in phagocytosis associated respiratory burst. *Horabagrus brachysoma* is reported to have improved adaptive capabilities to warm temperatures (Dalvi et al. 2009). This adaptation of *H. brachysoma* towards higher temperature can be attributed to the induction of heat-shock protein (HSP) 70, which acts as molecular chaperone and protect the cell against aggregation of denatured proteins (Dalvi et al. 2012). The ideal temperature range for the culture of *H. brachysoma* is estimated to between 31 and 33 °C thereby making them ideal candidates for aquaculture in tropical conditions (Dalvi et al. 2009).

Grow-out culture

Grow-out culture is the least studied and understood aspect of the aquaculture of the Asian Sun catfish. While there are no results from either experimental studies or real-world situations of the grow-out culture and farming of *H. brachysoma*, it has been suggested that the species is suitable for both monoculture as well as polyculture in systems such as large earthen ponds as well as smaller homestead ponds, coconut channels and polders, rice-fish farming systems, small floating cages made of locally available, low-cost materials (Raghavan 2006).

Priorities for research

Understanding the systematics, phylogenetic position and evolutionary biogeography of *H. brachysoma* is an important area of research that needs to be urgently addressed. Although substantial amount of information is available on various aspects of the biology and fishery of *H. brachysoma*, they have not been use for the purpose of developing and implementing conservation actions or fishery management plans. Developing a 'species conservation-action plan' is an important priority given the threatened status of the species. Population studies such as those carried out by Prasad et al. (2012) need to be expanded to other areas in the distribution range of *H. brachysoma*, especially in rivers (for e.g. Chalakudy) and backwaters (for e.g. Vembanad) where they are known to be intensively exploited. Data extracted from long term citizen-science initiatives such as the 'Vembanad Fish Count' (see Sridhar 2013) could possibly shed light on the trends in the spatiotemporal changes in population of this species in the Vembanad Lake.

In spite of being a candidate species for aquaculture, there have been very little efforts to understand aspects of nutrition and other husbandry practices of *H. brachysoma*. Research needs to be conducted to establish the optimum requirements (for all life stages) for amino-acids, lipids, fatty acids, carbohydrate, vitamins and minerals as well examine the effects of various larval feeds and feeding strategies in the aquaculture of *H. brachysoma*. In addition, there is also a need to prioritize studies that examine feeding management practices (feed types, feed rations), and improvement of flesh quality through nutritional interventions. Similarly, studies aimed at understanding the impacts of rearing environmental stressors such as light intensity, stocking density, tank color, prey density, water temperature and ph, on both the larvae and juveniles could help improve survival and create best management practices for *H. brachysoma*

hatcheries. Currently there are no studies on any aspects of the grow-out culture of *H. brachysoma* including water quality requirements, stocking density and health management. The delay in the availability of such information will hinder the future development of large-scale aquaculture of the Asian Sun catfish.

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