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Coastal Ornamental Aquaculture as Livelihood Option and Its Vulnerability to Climate Change

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India is blessed with substantial brackishwater fish diversity all along the 8129 km coastline with an estimated potential brackishwater area of 1.24 million ha. The present coastal aquaculture, which is emerging as a significant foreign exchange earner, aims to increase food production for both the domestic and international markets. In recent times fishes used for recreational purpose is gaining importance. On the other hand, there is a pressing need to explore all the options to diversify the culture system. Ornamental fish keeping is a significant hobby world over. India is also a contributor to the world aquarium trade though its share is meagre. Presently around 150 species of indigenous small fishes are exported mostly freshwater in origin captured from wild resources. Overexploitation of wild stock will have disastrous consequences on the fragile ecosystem. However, considering the resources and emerging technologies, India can do better in the field of ornamental fish culture. Time has come to tap the potential of coastal ornamental aquaculture, thus providing livelihood option for coastal communities. However, at the same time, the threat of climate change is real, especially in the coastal ecosystem. These ecosystems are fragile which need development adaptive measures to deal with it. This paper describes the present scenario envisaging the strategies to tap opportunities in the brackishwater ornamental aquaculture for livelihood, addressing the challenges posed by climate change within a policy framework.

(***Key words:*** *Brackish-water ornamental fish, Climate change, Livelihood options, Technology interventions)*

Aquaculture in India is about bringing animal protein food on the plates of millions of people, contributing to nutritional and livelihood security along the way. India has done well until now, producing about 6.18 million tonnes, including 0.740 million tonnes of fish from brackishwater aquaculture in 2017 (FAO, 2018). The export earnings of about 47620 crore rupees during 2018-19 mainly comes from the brackishwater aquaculture sector. With an estimated resource of 8129 km of coastline and over 1.24 million ha of brackish water area, India is well endowed with brackishwater resources, supporting over 10 million people for livelihood and food security. Fish diversity is seen plenty in brackishwater lakes of India such as Chilika, Pulicat, Vembanad, Sunderbans (Ayappan *et al*., 2006). Although the primary focus of Indian aquaculture lies in the food production system through cultural practices of multiple species, ornamental fisheries could also be a potential livelihood provider as well as the foreign exchange earner. Like any other developed countries, Indian aquaculture is diversifying towards an increasing trend of recreational fish keeping with a tremendous rise in the number of ornamental fishery hobbyists every year.

The global trade in ornamental fish involves 125 countries worldwide and is worth US$ 15-30 billion each year (Evers *et al*., 2019). This total is dominated (90%) by freshwater fishes, most of which are sourced mainly from developing countries in Asia or South America. At the same time, the popularity of keeping fishes of marine origin is on the rise. The collection of marine ornamental fish for trade during the past three decades with the technological advances that increased the ability to maintain marine animals in captivity has developed into a multi-million-dollar industry (Ferse *et al*., 2012). However, with the intensification of aquaculture, there is an increased dependency on small wild fish as feed-ingredient (Naylor *et al*., 2000) of which many are economically high valued ornamental fishes.

The global marine ornamental fish trade is estimated

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at US$ 200-300 million. The marine ornamental fish trade is operated from South-East countries such as Philippines, Indonesia, Sri Lanka, Maldives and major pacific Island countries like Solomon Island, Australia, Fiji and Palau. These countries together supply more than 98% of the total marine ornamental fishes involved in trade (Sahayak, 2009).

Indian scenario

Marine ornamental fish are brought from Chennai or imported from the overseas market, especially from Bangkok to meet the demand of the hobbyists. The price of the marine ornamental fish is relatively high in the hobby shops of West Bengal and ranges between INR 350 to 1500 per piece. There is no report for the utilization of locally available marine ornamental fish in West Bengal (Mahapatra *et al*., 2014).

Marine aquarium fish trade is gaining popularity and becoming an important facet of the fisheries sector. There is enormous scope for expansion due to the rich diversity of over 400 species of marine ornamental fishes belonging to 175 genera and 50 families that thrive in the Indian marine ecosystem (Ajith Kumar and Balasubramanian, 2009). Although, minor developments in the exploitation of new species for export or the local market have taken place, no organized trade reform of marine ornamentals has been introduced to date. A great deal exists in vogue for the collection of indigenous ornamental fishes from the open water bodies of India. The situation adds a vital contribution to the local community in supporting their livelihood (Raghavan *et al*., 2013; Watson and Moreau, 2006).

It is reported that the fishes like Clown fish - *Amphiprion spp*./ *Premnas spp*., Neon goby- *Robiosoma oceanops*; Butterfly - *Chaetodon*, Parrot - *Callyodon*, Trigger - *Rhineacanthus*, Squirrel - *Neoniphon*, Seahorse - *Hippocampus kuda*, Moorish fish – *Zanclus cornutus*, Rabbit - *Siganus* are popular fishes in the Kolkata market. A quick survey revealed that prevailing prices of marine ornamental fish in Kolkata are Yellow tang (3-inch size) - INR 6000, Green wrasse - INR 1500, Rabbit fish - INR 2000 and Amphiprion - INR 1000 per piece.

Need to lessen the impact on the marine environment

Collection of fishes from the wild for the aquarium trade is a questionable practice over environmental impacts and sustainability (King, 2019; Raghavan *et al*., 2013; Watson and Moreau, 2006). Currently, the marine coastal environment is not utilized in the production of ornamental species. Captive culture can dramatically decrease the need to collect wild stocks, thereby conserving the natural fish population. Thus, there would not be a direct impact on the marine environment. (Tlusty, 2002).

In some countries, the coral reef ecosystem has been hit hard due to destructive fishing practices in addition to climate change effects (Patterson *et al*., 2009). There are no governing laws to protect the coral reef fishes from the aquarium trade (Mathews *et al*., 2012). There is a need to practice resource conservation through the development of 'reef-friendly' farming practices as an alternative to the wild collection and to restore degraded wild populations (Ostrowski and Laidley, 2001). Additionally, an extreme lack of apparent knowledge on post-harvest husbandry practices (poor handling and quarantine procedures) results in considerable mortality of the collected fish. Thus, adopting technologies of captive breeding with an enabling policy will help to promote the sustainable trade of coastal ornamental fishes.

Present status

According to Wabnitz *et al*. (2003), only 1-2% of marine species marketed are captive bred, while the remaining numbers are obtained from the wild only. A total of 1471 marine ornamental fish species are traded globally and among them, only 25% are bred in captivity and out of that, only 21 species are commercially produced (Dhaneesh *et al*., 2013)

The hatchery technology for 20 species of marine ornamental fishes such as clown fishes *Amphiprion percula* (True pecula/ clown anemone fish), *A. ocellaris* (Common clown/ False clown aenemone fish), *A. sandaracinos* (Yellow skunk clown), *A. frenatus* (Tomato clown), *A. clarkii* (Clark's anemone fish), *A. nigripes* (Maldives anemone fish), *A. perideraion* (Pink anemone fish), *Amphiprion ephippium* (Redsaddle back anemone fish), *A. sebae* (Sebae clown), *Premnasbi aculeatus* (Maroon clown/ Spine cheek anemone fish) and dotty back *Pseudochromis dilectus* (Redhead dottyback) have been developed. The species such as damsels *Dascyllus trimaculatus* (Three spot damsel), *D. aruanus* (Striped damsel), *Pomacentrus caeruleus*

(Blue damsel), *P. pavo* (Sapphire or Peacock damsel), *Neopomacentrus nemurus* (Yellow tail damsel), *N. filamentosus* (Filamentous tail damsel), *Chrysiptera cyanae* (Sapphire devil), *C. unimaculata* (One spot damsel) and *Chormis viridis* (Green chromis) have been bred under captivity for the first time in India (Madhu *et al*., 2013).

Potential brackish water species

The marine ornamental fishes are mostly inhabitants of coral and rocky areas and among mangrove forests. However, most of these fishes can be acclimatized to lower salinities in brackishwater. On the other hand, brackishwater species are abundantly found in the Gulf of Kutch, Gulf of Mannar, Palk Bay and in brackishwater lakes such as Chilika, Vembanad, Sunderbans, Pulicat lake, etc. The list of important fishes which are in demand for ornamental trade is provided in Table 1.

Why do we need to go for captive breeding?

Marine aquarium is getting popular with live wild-harvested rocks and live coral which raises concern over its sustainability and ecological impacts (Parks *et al*., 2003). On the other hand, efforts to develop suitable aquaculture technologies have been limited due to lack of larval rearing technique, proper feed and lack of knowledge on the life history of target species and appropriate handling, limited financial and technical assistance.

Ornamental fish and invertebrates culture is now considered as a feasible alternative to a wild harvest of specimens. Destructive collecting practices, combined with poor handling after collection, has damaged the reefs (Baquero, 1999). Aquaculture can help to sustain the ornamental fish industry, restore exploited and impacted wild populations. Moreover, the pressure is mounting from conservation groups and governments to restrict the collection from wild resources which render aquaculture as the only sustainable means to meet market demand for these products (Tulsty, 2002).

Coastal ornamental fishes - livelihood and economic importance

Collection of wild ornamental fishes has been supporting livelihoods in several parts of the developing countries. The practice is an important local economic

Table 1. *Potential brackish water ornamental fish species of India*

Fish species	Description
Monodactylus argenteus	**Identification character:** Adults are bright silver with yellow and dusky dorsal fin tip. Small juveniles more colorful with yellow over most of the dorsal fin and two vertical black bands over the head (Kuiter and Tonozuka, 2001). **Habitat:** Inhabits tropical freshwater, brackish water as well as marine. Pelagic-neritic and occupy a depth range 0 - 12 m (Fricke *et al*., 2011). **Distribution:** Indo-West Pacific: Red Sea and East Africa (Heemstra, 1984), Persian Gulf (Jawad, 2013) to Samoa, north to the Yaeyamas, south to New Caledonia and Australia (Blaber, 1980), Freshwater tidal zone of the Mekong delta (Rainboth, 1996), India - West Bengal coast (Kar *et al*., 2017; Yennawar *et al*., 2015). **Feeding Biology:** Feeds on plankton and detritus (Fischer *et al*.,1990; Allen *et al*., 2002). **Reproductive Biology:** Maximum length reported is 27.0 cm SL male/unsexed (Allen *et al*., 2002). Length at maturity - 13.0 cm. Young ones migrate to sea to attain sexual maturity, and mature fish migrates to freshwater for spawning. They are highly territorial (Lieske and Myers, 1994). **Economic Importance:** Ornamental Value.
Monodactylus falciformis	**Identification character:** Adults are silvery with dusky dorsal and anal lobes while juveniles are dusky with dark vertical bars (Heemstra, 1986). **Habitat:** Inhabits tropical freshwater, brackish water as well as marine. Reef-associated and oceanodromous (Riede, 2004). They inhabit coastal waters including estuaries and lagoons. **Distribution:** Western Indian Ocean, Red Sea to False Bay, South Africa, Madagascar (Desoutter, 1986). **Feeding Biology:** Carnivorous and feeds primarily on invertebrates. **Reproductive Biology:** Max length reported is 31.0 cm TL male/unsexed (Heemstra, 1986). Serial spawning occurring in the near-shore marine environment. **Economic Importance:** Juveniles can be kept in the aquarium (Talwar and Jhingran, 1991).

Toxotes jaculatrix	**Identification character:** Silvery colour and a dorsal fin towards the posterior end. It has distinctive, semi-triangular markings along its sides. **Habitat:** Inhabits tropical freshwater and brackish water (Riehl and Baensch, 1991), Reef-associated and amphidromous (Riede, 2004). Occurs in brackish mangrove estuaries and penetrates rivers and small streams (Allen *et al*., 2002). Also occur near overhanging vegetation on reefs (Lieske and Myers, 1994; Kuiter and Tonozuka, 2001). **Distribution:** Asia and Oceania: India eastward to the Philippines, and south to Indonesia, Vanuatu, Solomon Islands, Papua New Guinea, and northern Australia. **Feeding Biology:** Form small aggregations (Kuiter and Tonozuka, 2001) and feeds at the surface during the daytime on floating debris which includes insects and vegetable matter. **Reproductive Biology:** The maximum length reported is 30.0 cm TL male/unsexed (Talwar and Jhingran, 1991). They are oviparous and have distinct pairing during breeding. Eggs are demersal and adhesive. Males guard and aerate the eggs. **Economic Importance:** Collected for the aquarium trade.
Abudefduf sordidus	**Identification character:** A greyish damselfish with six whitish bars on the head and body that are narrower than the adjacent dark bars, a prominent black saddle on the upper part of the caudal-fin base. **Habitat:** Inhabits tropical marine and brackish water, reef-associated and non-migratory in nature. They dual in depth range 0 - 3 m (Allen, 1986). They inhabit rocky lagoons, reef flat shorelines and piers subject to mild surge. Juveniles are common in tide pools (Lieske and Myers, 1994). **Distribution:** Indo-Pacific: Red Sea and East Africa to the Hawaiian and Pitcairn islands, north to Japan, south to Australia. **Feeding Biology:** They are benthopelagic (Mundy, 2005) and occasionally form schools. They generally feed on algae, crustaceans and other invertebrates during the day. **Reproductive Biology:** Max length reported is 24.0 cm TL male/unsexed (Allen and Erdmann, 2012) They are oviparous, has distinct pairing during breeding and eggs are demersal and adhere to the substrate. Males guard and aerate the eggs and are highly territorial (Breder and Rosen, 1966; Lieske and Myers, 1994). **Economic Importance:** Aquarium trade.
Amblyeleotris gymnocephala	**Identification character:** Characterized by whitish or pale grey colour and presence of dark brown stripe from behind the eye to upper edge of gill cover. **Habitat:** Inhabits Tropical marine and brackish water, reef-associated and amphidromous (Riede, 2004). Dual in a depth range 5 - 35 m (Allen and Erdmann, 2012). Occur in coastal sand slopes, mangroves and bays (Kuiter and Tonozuka, 2001). **Distribution:** Occurs in Indo-West Pacific region (Talwar and Jhingran, 1991). **Feeding Biology:** They feed on benthic invertebrates and zooplanktons. **Reproductive Biology:** Max length: 14.0 cm TL male/unsexed (Burgess *et al*., 1990), Amphidromous. **Economic Importance:** Commercial aquarium trade.
Amblygobiusalbi maculatus	**Identification character:** Males have 3 black spots near base of 2nd dorsal fin and round spots on cheek. Females have brown-edged band from upper lip to upper operculum (Hoese, 1986). **Habitat:** Inhabits tropical marine and brackish water (Baensch and Debelius, 1997). Reef-associated and found upto a depth of 10 m (Roberts *et al*., 2005). Often found in sandy areas around coral reefs and constructs burrows in the sand (Sano *et al*., 1984). Also present in seagrass beds at adult stage. **Distribution:** Distributed widely in Indo-West Pacific: Red Sea and East Africa south to Durban (South Africa), including most islands in the western Indian Ocean islands (Kapoor *et al*., 2002); Indonesia, Australia and South Pacific islands. They are also found in Japan, Philippines (Hoese, 1986) and Persian Gulf (Carpenter *et al*., 1997). **Feeding Biology:** Feeds on microalgae and benthic invertebrates. They are epibenthic and littoral, entering estuaries and lagoons. **Reproductive Biology:** The maximum length observed is 18.0 cm SL male/unsexed (Hoese, 1986). Usually seen in pairs, hovering above the substratum. They build its burrow in sand or silty sand by moving out mouthfuls of sediment (Randall, 1995). Monogamous mating as both obigate and social (Whiteman and Côté, 2004). **Economic Importance:** Aquarium trade.

Aplocheilus blockii	**Identification character:** They swim slowly or stay stationary, often in small groups. Black blotch on the dorsal fin of females. **Habitat:** Inhabits tropical marine and brackish water (Riehl and Baensch, 1996). Benthopelagic and non-migratory. Inhabits stationary and sheltered waters of rivers (Talwar and Jhingran, 1991) mainly coastal and brackish, especially where there is surface vegetation or cover. **Distribution:** Reported from India (Menon, 1999), Pakistan (Mirza, 2002) and Sri Lanka (Seegers, 1997). **Feeding Biology:** They feed on insects, larvae and fish fry and are considered valuable for mosquito control (Pethiyagoda, 1991). **Reproductive Biology:** The maximum length reported is 6.0 cm TL male/unsexed (Menon, 1999). Lay and fertilize a single egg each time. This species will deposit eggs in woollen mops, fine-leaved plants or mosses, or filamentous algae depending on what is available. **Economic Importance:** Commercial aquarium trade.
Arothron hispidus	**Identification character:** The body of this species is generally greenish-brown in colour, the back, sides and caudal fin profusely speckled with white spots, and the belly marked with white bars (Myers, 1991). **Habitat:** Inhabits Tropical marine and brackish water, reef-associated, non-migratory and found in depth range of 1 - 50 m (Allen and Erdmann, 2012). Juveniles are common in weedy areas of estuaries. They are also found in coastal bays and estuaries, in shallow with sparse seagrass growth (Kuiter and Tonozuka, 2001). **Distribution:** Distributed widely in Indo-Pacific: Red Sea and East Africa (Smith and Heemstra, 1986) to Panama, north to southern Japan and the Hawaiian Islands. Eastern Pacific: Baja California and the Gulf of California to Panama (Bussing, 1995). Also reported from India (Allen and Robertson, 1994; Kapoor *et al*., 2002.) **Feeding Biology:** They feed on fleshy, calcareous, or coralline algae, detritus, mollusks, tunicates, sponges, corals, zoanthid anemones, crabs, tube worms and echinoderms (Myers, 1991). They are benthopelagic (Mundy, 2005) and usually solitary and territorial on sandy to rubble areas. **Reproductive Biology:** Max length reported is 50.0 cm TL male/unsexed (Allen and Steene, 1988). They are Oviparous in nature (Breder and Rosen, 1966). **Economic Importance:** Aquarium trade
Awaous grammepomus	**Identification character:** The body is olive green in colour and lighter below. The head is violet to olive green with black straks. The caudal fin has 7-9 transverse blackish streaks. **Habitat:** Inhabits tropical fresh water and brackish water, benthopelagic and amphidromous in nature (Riede, 2004). Found in streams and rivers and often enters estuaries and usually associated with streams having a gravel or sand substrates. **Distribution:** Asia: Sri Lanka to New Guinea (Rainboth, 1996). Also reported from India (Talwar and Jhingran, 1991). **Feeding Biology:** They feed mainly on filamentous algae (Pethiyagoda, 1991) and Diptera and small fishes and crustaceans. **Reproductive Biology:** Maximum length reported is 15.0 cm SL male/unsexed (Rainboth, 1996). **Economic Importance:** Minor Fisheries, commercial aquarium trade.
Congrogadus subducens	**Identification character:** Colourations are varied and can change it's colour-spots or blotches on body form reticulations and crossbands; paler ventrally (Winterbottom, 1985). **Habitat:** Inhabits tropical marine and brackish water. Reef-associated and are found in a depth range 0 - 10 m (Allen and Erdmann, 2012). They inhabit coastal waters, often in brackish conditions (Kuiter and Tonozuka, 2001). **Distribution:** Distributed in Indo-West Pacific, Nicobar Islands, Andaman Sea and Japan to the tropical coasts of Australian (Winterbottom, 1985). **Feeding Biology:** Predatory and will eat crustaceans and smaller fish. **Reproductive Biology:** Maximum length is 45.0 cm TL male/unsexed (Allen and Swainston, 1988). Cyclical reproductive activity and the species may not be a protogynous hermaphrodite (Winterbottom *et al*., 1984). **Economic Importance:** Aquarium trade.

Ellochelon vaigiensis	**Identification character:** This species is distinguished by the robust body with olive-brown colour dorsally, flanks and belly silvery to whitish. Fins are yellowish white with dusky margins except caudal fin yellow and pectoral black dorsally and yellow ventrally which is completely black when young (Harrison and Senou, 1997; Allen and Erdmann, 2012). **Habitat:** Inhabits tropical marine, freshwater and brackish water. They are reef-associated (McDowall, 1997), catadromous and occurs in a depth range of 0 - 5 m (Bacchet *et al*., 2006). Form large schools, frequently in mangrove areas (Randall and Steene, 1990). **Distribution:** They are distributed in Indo-Pacific between Red Sea and East Africa to the Tuamoto Islands, north to southern Japan, south to southern Great Barrier Reef and New Caledonia. **Feeding Biology:** They feed on phytoplankton, small algae and detritus organisms. **Reproductive Biology:** They are oviparous; eggs are pelagic and non-adhesive (Breder and Rosen, 1966). **Economic Importance:** Juveniles used as bait fish (Harrison and Senou, 1997); Ornamental value.
Etroplus suratensis	**Identification character:** Adults are oval in shape with a short snout. Gray-green in color with dark barring and a dark spot at the base of the pectoral fin, many scales with a pearly spot. **Habitat:** Inhabits tropical brackish water (Baensch and Riehl, 1985). Benthopelagic and are found in depths of 10 m. Can tolerate fresh or marine waters for short periods (Carpenter, 2001). **Distribution:** Western Indian Ocean (11°N - 6°S): India and Sri Lanka (Talwar and Jhingran, 1991). **Feeding Biology:** They feed on filamentous algae, plant material and insects. **Reproductive Biology:** Eggs are attached to a submerged log, rock or sometimes roots and weeds, in still or slow-flowing water after spawning. Parents guard and aerate the eggs until the hatching, usually about 4 days. The fry remain in shoal around their parents during initial weeks.Parents do not feed during spawning until the fry become independent. **Economic Importance:** Food fish, Ornamental fish.
Pastinachus sephen	**Identification character:** Distinguished by a large, plain, dark stingray with an angular snout and pectoral disc; tail long and broad-based, less than twice body length. They are dark brown or black dorsally without conspicuous markings, white ventrally. Tail is black in color (Compagno *et al*., 1989). **Habitat:** Inhabits tropical marine, fresh water and brackish water. Reef-associated and amphidromous. They ae found in a depth range of 0 - 60 m in lagoons, reef flats, and reef faces (Michael, 1993). Also occur in rivers far from the sea (Compagno *et al*., 1989). **Distribution:** Distributed in Northern Indian Ocean: Red Sea to Pakistan. **Feeding Biology:** Feed on bony fishes, worms, shrimp, and crabs (Michael, 1993). Distinct pairing with embrace (Breder and Rosen, 1966). **Reproductive Biology:** They exhibit ovoviparity (aplacental viviparity), with embryos feeding initially on yolk, then receiving additional nourishment from the mother by indirect absorption of uterine fluid enriched with mucus, fat or protein through specialized structures. Size at birth is about 18 cm or larger (Last and Stevens, 1994). **Economic Importance:** Ornamental value.
Periophthalmus barbarus	**Identification character:** They are olive-green or rusty-brown in color dorsally, paler ventrally; small, blue ocelli scattered over flanks and dorsum, and some oblique, black bands may be present on dorsal part of flanks (Harrison, 2003). **Habitat:** Inhabits tropical marine, fresh water and brackish water (Riehl and Baensch, 1991); reef-associated and amphidromous (Riede, 2004). They are found on muddy substrates (Harrison, 2008). Occasionally found in freshwater, but close to the shore. **Distribution:** Distributed in Africa: West-African coast, from Senegal to Angola, including most offshore islands - Macias Nguema, São Tomé, and Principe islands. Also reported from Mauritania, Western Central Pacific: Guam. Reported from India, Thailand, Bangladesh, Philippines and Australia. **Feeding Biology:** Amphibious air-breather (Martin and Bridges, 1999); skips or walks on sand or mud in search of food; Adult feed chiefly on arthropods (crabs, insects, etc.) of the mud surface. Also included in the diet is the white mangrove, Avicennia nitida (Irvine, 1947). **Reproductive Biology:** Spawn in burrows (Miller, 1981). **Economic Importance:** Ornamental value.

Periophthalmus argentilineatus	**Identification character:** Background colour brownish to dark grey on dorsum and sides, ventrally whitish; head ventrally white; many small white speckles on cheeks and opercula; silvery vertical stripes on flanks. **Habitat**: Inhabits tropical marine, fresh water and brackish water. Reef-associated, amphidromous and found in depth range 0 - 1 m (Fricke *et al*., 2011). They are a resident intertidal species with homing behavior (Gibson, 1999; Kuiter and Tonozuka, 2001) and amphibious air-breather (Martin and Bridges, 1999; Louette, 2004). They actively shuttling back and forth between rock pools and air. **Distribution:** They are distributed in Indo-Pacific: southern Red Sea to South Africa, east to the Marianas and Samoa; north to Ryukyu Islands, south to western Australia and Oceania. Also reported from India (Kapoor *et al*., 2002). **Feeding Biology:** They feed on worms, crustaceans, and insects (Myers, 1999) and can stay out of the water for up to 37 hours if kept moist. **Reproductive Biology:** Males dig reproductive burrows in front of the first trees of the mangrove forest, in areas not covered by the vegetation, and jump with the spread fins to attract females from the distance, then inducing them to spawn inside their burrows; during the period of cohabitation consecutive spawning events take part; then only the male guards the eggs, always remaining nearby the nest and maintaining an air phase in the egg chamber; during high tide, when the nest is submerged, the male enters the burrow. **Economic Importance:** Aquarium trade.
Scatophagus argus	**Identification character:** They are ground colour greenish and juveniles have large roundish blotches, about size of eye, or with about 5 or 6 broad, dark, vertical bars. In large adults, spots may be faint and restricted to dorsal part of flanks. **Habitat:** Inhabits tropical marine, fresh water and brackish water waters (Riehl and Baensch, 1996). They are reef-associated and amphidromous (Riede, 2004). They occur in a depth range of 0 - 5 m (Allen and Erdmann, 2012). **Distribution:** Distributed in Indo-Pacific: Kuwait to Fiji, north to southern Japan, south to New Caledonia. Reported from Samoa, Tonga (Randall *et al*., 2003), and the Society Islands (Allen, 1991). **Feeding Biology:** They feed on worms, crustaceans, insects and plant matter (Mills and Vevers, 1989; Kuiter and Tonozuka, 2001; Allen *et al*., 2002). **Reproductive Biology:** They are reported to be a multiple spawner (Cai, 2010). **Economic Importance:** Aquarium trade.

activity in many regions, though desired information on its contribution to the livelihoods of local coastal communities is mostly missing (Wabnitz *et al*., 2003).

A species does not have to be completely cultured in captivity to get benefit from aquaculture production. As mentioned previously, aquaculture production of juveniles and subsequent release to the wild (enhancement or ranching) can help collectors as well as decreasing the impact on the wild species. Besides, many farm-produced fish are more suitable for aquarium keeping and are of higher quality compared to wild-caught fish (Stayman, 1999). Aquaculture production can be remarkably efficient compared to a wild harvest for fish that are difficult to catch. Marine ornamental trade was not affected by the economic crisis between 2000-2011 and accounted for a total of 135 million Euros (Leal *et al*., 2016). Between 1.5 and 2 million people worldwide are believed to keep marine aquaria (Wabnitz *et al*., 2003). The trade is worth an estimated US$ 200-330 million annually. Corals, invertebrates and fish are collected and transported mainly from Southeast Asia, but also increasingly from several island nations in the Indian and Pacific Oceans to consumers in the United States, the European Union (EU) and Japan.

Collection to controlled production - the way forward

Technology adaptation

Over the years, the mariculture technologies have been refined, and it is imperative that appropriate technologies may be adapted to increase the number of coastal ornamental fish species for captive multiplication. The two key bottlenecks that currently limit the expansion of the marine ornamental fish culture are the captive maturation and spawning and the identification of appropriate first-feed items for marine ornamental fish larvae. Rural areas face a lack of continuous power supply for running aeration and filtration systems in such production systems. The commercial culture of marine ornamental finfish is still in its infancy, but advances can be made more rapidly using insights from years of research and development with marine food fish species (Ostrowski and Laidley, 2001).

Broodstock development and nutrition

The controlled reproduction of broodstock is required to ensure a constant supply of seeds throughout the year. The farmers need to maintain a variety of species depending on the market demand. Unlike the marine ornamental fish, brackishwater species have the advantage of adapting to freshwater, which makes it more versatile. Many species display elaborate and ritualized reproductive behaviours that require deeper tanks and specific reef substrates. Many hobbyists have had considerable success spawning ornamental fishes through the introduction of live rock and other natural substrates into home aquaria. However, live rock cannot be easily removed and cleaned. These could also harbour a variety of pathogens and other organisms that can seriously affect broodstock health. Similar success could be achieved with simple artificial structures that can be easily removed and cleaned while still providing suitable substrates for spawning behaviours.

The nutritional requirements of broodstock have to be met either through the use of commercial diets supplemented with dietary additives or through the use of frozen feeds, such as krill, squid, fish, *Spirulina* and other algae to provide the correct environmental stimuli to induce reproductive activity. Most marine fishes studied to date have seasonal reproductive cycles in which gonadal development and spawning are controlled by either photoperiod and/or temperature (Lam, 1983).

The external stimuli that initiate final maturation and spawning are generally distinct from the stimuli that trigger gonadal development (Kuo, 1995). Moreover, these stimuli differ significantly between species and are often difficult to elucidate. In order to induce natural spawning, several institutes are currently examining novel approaches to induce spawning of captive ornamental broodstock, such as the Yellow Tang (*Zebrasoma flavescens*), including hormone administration in the diet (Thomas and Boyd, 1989; Roelants *et al*., 2000).

Larval nutrition

Generally, the marine or brackishwater fishes need live feed during their first feeding stage. The most suitable live feed organisms identified based on the food and feeding habits of the fish. Thus, gut content analysis of larvae collected from their natural habitat is essential. The inability of larvae to utilize individual live feed organisms may not be linked with size alone, but with the swimming behaviour of the prey or other environmental or behavioural cues. It is necessary to develop mass culture techniques and devise a feeding regime based on a mix of live feed organisms provided at specific times during larval development.

Managing stress during transportation

The mortality of tropical fish before reaching the aquarium market is significant. Mortality during the transportation is due to a range of factors, including improper capture techniques, handling practices and stress. Thus there is a need to improve the understanding of ecological processes underlying the physiology of the fish, including sustainable harvesting, transportation and stress management. A salinity stress test may be used to identify fish lots of good quality for transport, apply health prophylaxis to eradicate parasites and optimize other techniques such as starvation of the fish or addition of salt to the transport water to enhance the stress resistance of the fish (Lim *et al*., 2003). A natural extract of *Glycine tomentella*, which had antioxidant and anti-inflammatory activities has been found to reduce stress responses during live grouper fish transport (Wu *et al*., 2020). These will serve as an alternative for the commercial anaesthetics, *i.e*. eugenol and tricaine methane sulfonate (MS222). In addition, a modular live fish transport system with oxygen delivery, automated water treatment and delivery apparatus may also be utilized.

Certification

Green certification ensures environmental and socio-economic sustainability in addition to enhanced product quality, safety and traceability. Based on an international workshop organized by the Marine Products Exports Development Authority (MPEDA), India, in association with UNCTAD and Project PIABA, Brazil on Green certification of ornamental fishes in October 2008, a guideline was developed (Silas *et al*., 2011). The aspects such as collection from the wild, handling, transport, holding, breeding and culture facilities, conditioning for export, infrastructure and maintenance of records to conform should be taken into consideration. Accordingly, a certificate may be issued that the fish has been caught/ produced/reared in a manner that ensures social and environmental sustainability, certifying its quality as regards to health and bio-security issues (Iyer *et al*., 2016). Alternatively, the appropriate certification process may also be developed based on the standards designed by the Marine Aquarium Council (MAC, 2001). The certification scheme should be able to track a fish from a collector or a farm to a hobbyist. It should also help in monitoring changes to fish population resulting from the collection or any captive breeding practice for the trade

Policies

To meet the compelling demands and to provide impetus to the fisheries and aquaculture development in India, a Draft National Fisheries Policy (NFP) framework has been prepared. Under this, ornamental fisheries, collection and trade of native ornamental fish species from natural waters is to be regulated by the States/UTs. For the promotion of growth of ornamental fisheries, institutional support and efforts for breeding, rearing and promotion of trade of indigenous ornamental fishes is envisaged. Till now no specific policy for marine ornamentals exists (Radhakrishnan, and Dineshbabu, 2012) and adequate policies need to be framed to (1) Promote economic and societal benefits from conservation, (2) Regularise exports of aquarium fish taken from captive breeding programs or areas effectively managed for conservation, (3) Determine biodiversity and population status and trends with indicators that diagnose and manage declines with sufficient resources based on scientific assessments like of size limits, maximum sustainable yield, (4) Implement restrictions on the harvest of overexploited species to maintain sustainability and (5) Encourage research in the public-private sector by linking government agencies with supporting ornamental fish farmers.

Impact of climate changes in ornamental fish/ aquaculture

On breeding

Changes in the environmental temperature can directly affect the reproductive performance of fishes. Warming above the optimal temperature will result in reductions in offspring quantity and quality (Donelson *et al*., 2010). At more extreme warming, the reproduction may be ceased (Pankhurst and Van Der Kraak, 1997). The temperature will directly influence the gonadal development, sex determination, maturation and sensitivity of reproductive hormones and enzymes (Donelson *et al*., 2010; Pankhurst and Munday, 2011).

On population

Climate change may influence the populations as it will tend to reproduce within a narrow seasonal and temperature range (Pankhurst and Van Der Kraak, 1997). Climate change also influences the genetic composition of the population (Visser, 2008), the pattern of immigration (Holt and Gomulkiewicz, 1997).

On physiology and cellular activities

Climate change will directly affect the physiological process and the level of individual performance. The rate of the cellular and physiological process will speed up as the temperature rises, especially during the early life cycle, including embryonic and larval development (Rombough, 1997; Byrne *et al*., 2013). Survival will be at risk as stored energy reserves may be depleted more rapidly (Donelson *et al*., 2012). Oxygen utilization, food utilization, growth, prey-predator relationship will be affected by climate change.

On growth

Growth rate increases with increasing water temperature up to the optimal limit (Vivekanandan and Pandian, 1977). However, the elevated water temperature can lead to a reduction in energy available for growth and physical condition (Munday *et al*., 2008; Donelson *et al*., 2010). The productivity of some regional fisheries stocks may be enhanced as growth and recruitment increases.

Body deformities

Due to increase in temperature and evaporation, the effect of heavy metals may be pronounced to affect body deformities in fish larvae (Sfakianakis *et al*., 2015), mouth damage and deformities (Slooff, 1982) due to zinc pollution in wild fish populations. Climate change implications will have a direct effect on egg and larval survival, including the recruitment and body characteristics of juveniles (Nicholson *et al*., 2008).

Disease

The densities of fish species can affect the disease and parasite transmissions. In the context of global climate change, host-parasite relationships are expected to be affected by multiple factors such as parasite range extension, increased virulence, modified temporal dynamics of host-parasite interactions, decreased host condition and increased frequency of disease outbreaks (Marcogliese, 2008; Gallana *et al*., 2013; Paull and Johnson, 2014). Notably, infections might become more detrimental for hosts under increased temperature conditions because of enhanced parasite growth (Macnab and Barber, 2012), higher metabolic demands in ectothermic hosts (Muñoz *et al*., 2015) and negative impact of infections on host metabolic machinery (Seppänen, 2008).

Responding to future challenges of climate change

Climate change will influence fish reproduction and production while sea-level rise can inundate crop producing lands creating land unsuitable for cultivation. During the last few decades, there has been sea-level rise by an average of 3.1 mm yr^{-1} as a result of climatic and non-climatic factors (Dangendorf *et al*., 2017). The globally averaged surface temperature rise has been projected to be 1.1-6.4°C by the end of the 21st century (2090-2099) which is mainly due to the thermal expansion of the ocean (Mohanty *et al*., 2010). Ingress of saltwater in low lying areas from the sea and change in migration pattern, natural breeding and nursery grounds of many fishes will be the norm. Because of the change in the aquatic environment, the aquatic biodiversity will be altered with more invasive species. There will be changes in the timing of plankton blooms and composition, resulting in a potential mismatch between prey and predator. Higher water temperature will also bring changes in the physiology and sex ratios of fish species. Altered timings of spawning, migrations will disrupt the recruitment and the problem of disease occurrences on the epidemic scale are some of the consequences of global warming. The sector has to understand and cope with climate change vulnerability and build the capacity to adapt and respond by adopting technologies. In the coming decades, the coastal region will face many challenges due to growing human populations, degradation of land and loss of cropland to urbanization. Anthropogenic activity has made a substantial contribution to the upper ocean warming (above 700 m) that has been observed since the 1960s (Cheng *et al*., 2019), with the surface waters warming by an average of 0.7°C per century from 1900 to 2016 (Huang *et al*., 2016). With the appropriate technologies and farming systems, farmers can use flooded and saline areas no longer suitable for crops to culture fish. Looking into the future, horizontal expansion is likely to be limited. Instead, increases in production can be achieved by an increase in intensification of productivity under controlled or semi-controlled conditions. With proper simulation models, recirculatory aquaculture systems (RAS) could be adopted to produce high-quality ornamental fish throughout the year (Halachmi, 2006). Thus marine ornamental fishes like clownfish have been successfully bred and grown for the global market in Arava desert region of Israel, where more than 18 farms are located.

Coastal ornamental fish culture has the potential to help in natural resource conservation through domestication, captive maturation and seed production of different native ornamental fishes and formulate a package of practices for farmers who can earn their livelihood and for entrepreneurs who can generate profit from this trade. The ornamental fish trade is a potentially sustainable activity capable of supporting rural coastal communities. Institutional support and efforts for breeding, rearing and promotion of the business of indigenous ornamental fishes need to be intensified to facilitate growth in this segment. Guidelines on collection and trade for green certification of native ornamental fishes are to be developed. Establishment of ornamental fish clusters with both backward and forward linkages and buyback arrangements to be put in place. To develop the sector, numerous challenges related to infrastructure, critical inputs, technological interventions are to be met which require investment. With a clear enabling policy, the Governments may try to attract private investment through public-private partnership model to develop infrastructure and value chain to cater to the needs of the market. This will create an impetus to livelihood security for rural poor in the coastal area while it can provide employment opportunities through entrepreneurship development. At the same time, the farming system should also be ready to meet the challenges of climate change. The adaptive responses, coupled with low-carbon climatesmart farming system, hold the key to the success of coastal ornamental aquaculture.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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