CONSERVATION OF AQUATIC BIODIVERSITY

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LAUNCHING WORKSHOP ON "SCIENTIFIC CONSERVATION PROGRAMME FOR INDIGENOUS FISH"

Editors

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Enclosure culture as climate-resilient aquaculture systems

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Abstract

India has vast and varied inland openwaters (viz., rivers, estuaries, reservoirs, wetlands, lakes etc.), which are important capture fishery resources of the country contributing significantly to the national economy while providing livelihood to millions of countrymen. Water area under reservoirs (approx. 29 lakh ha) and floodplain lakes & derelict waterbodies (approx. 7.98 lakh ha) are amenable for capture-based culture fisheries having huge potential in enhancing inland fish production. Enclosures (i.e., cages and pens) installed in such openwaters are useful for rearing fingerlings for *in-situ* enhancement programmes as well as for producing table fish having immense socio-economic implications for poor inland fishers. For installation of such enclosures, certain area of the waterbody, even if it is choked with aquatic macrophytes/ algal bloom and unproductive can be cleared off. This means that un-utilizable water areas are reclaimed for productive purposes. Floating nature of cage enclosures makes them most suitable for waterbodies which are affected by occasional flood and drought-like situations. Pen enclosures mostly installed in marginal areas of floodplain wetlands can be protected from high flood by increasing height of the net fencing on-demand. Economically important small indigenous fishes can be stocked in pens, which would reproduce in them and become a self-recruiting population providing nutritional securities to the fishers.

Climate-resilience of these technologies is already evident from large volume of work done on the subject, which will lead to higher adoption and consequent increase in fish production from inland openwaters.

Introduction

Improving productivity, making feeding more efficient and reducing losses from disease are required for sustainably intensifying aquaculture practices (De Silva and Soto, 2009; Troell et al., 2014a). In addition to many constraints aquaculture is facing including dependence on fish meal and fish oil, it is increasingly likely that aquaculture developments will face constraints related to availability of land and water resources (Troell et al., 2014b).

Floodplain wetlands of India cover over an estimated area of 3.54 lakh ha and constitute an important fishery resource in the states of Uttar Pradesh, Assam, West Bengal, Bihar and Manipur (Bhattacharjya, 2011). Assam has the largest area (1,00,815 ha) under floodplain wetlands (locally called *beels*) in the northeastern region of India (Bhattacharjya *et al.*, 2015). These wetlands are highly potential fisheries resources of Assam due to its rich nutrient load and availability of fish food organisms, on which a large number of fisheries depends for their livelihood. The floodplain wetlands are highly fragile but productive ecosystems with an estimated fish production potential of 1000-1500 kg ha^{-1} yr^{-1} (Sugunan *et al.*, 2000). Time-series analysis of fish catch data for the period from 2003-04 to 2013-14 collected from 50 stocked and 50 un-stocked *beels* under the Assam Fisheries Development Corporation Ltd., Guwahati showed that the average fish yield from un-stocked *beels* ranged from 186-265 kg/ha during the period with an average of 221 kg/ha/yr, whereas the annual average yield in the stocked *beels* ranged from 356-602 kg/ha during the same period with an average of 450 kg/ha/yr (Debnath et al., 2015). The average fish yield rates have considerably increased over the baseline average estimated by CIFRI during 1996-98 in selected beels of Assam (172.9 kg/ha/yr) (Sugunan and

Bhattacharjya, 2000) because of poor recruitment from their parent/ adjoining rivers, as most of the wetlands have lost their riverine connections. Thus, many floodplain wetland managers have started employing a number of fisheries enhancement tools partly to compensate for declining yield of natural fishes and partly encouraged by growing demand for wetland fishes.

Fisheries enhancement in inland openwaters refers to the process by which qualitative and quantitative improvement is achieved through exercising specific management options (Welcomme and Bartley, 1998).Studies have shown that fish yield rates from selected floodplain wetlands of Barak valley of Assam ranged from 250-1500 kg $ha^{-1}yr^{-1}$ where fish stock enhancement was practiced (Bhattacharjya and Sarma, 2010). Thus, supplementary stocking in these wetlands with carp fingerlings have increased their fish production substantially without using fish feed or fertilizers. However, non-availability of carp fingerlings of desired size (10 cm and above) in required quantities at the wetland site as well as high cost of carp fingerlings with associated high mortality during transportation are major constraints in practicing large-scale fish stock enhancement in them. *In situ* rearing of fingerlings in pens in the floodplain wetland appears to be a feasible option to overcome this constraint (Bhattacharjya *et al.*, 2015b). Pen aquaculture technology developed by CIFRI is an avenue for additional fish production in floodplain wetlands parallel to enhancement of their capture fisheries/ fish stock enhancement.

Climate change impacts on aquatic and marine ecosystems and associated livelihoods are growing (Shelton, 2014). It will directly and indirectly affect populations' range and productivity, habitats and food webs as well as affect fishery and aquaculture costs and productivity, fishing communities, their livelihoods and safety (Daw et al., 2009; Badjeck et al., 2010).

Conventional aquaculture systems :

Although a great deal of aquaculture involves growing fish/ shellfish species in ponds, but there exists a wide range of practices. There are differences in the structures used, the intensities of culture, the degree of water exchange and the factors to be considered in selecting suitable species and farm sites for aquaculture. All these factors are inter-linked to a considerate extent. For example, selection of a farm site will be influenced by, among other things, the intensity of culture, the amount of water exchange required and the biological characteristics of the species to be cultured. Culture structure, site and species to be cultured will depend on the economics of the entire venture. Before undertaking any such venture, it is mandatory to consider all these components very carefully, otherwise the venture may fail.

Culture systems may broadly be classified according to three criteria:

(a) Culture structure: describes what encloses or supports the aquaculture organisms. Broadly, aquaculture structures include ponds, tanks, raceways, racks, long-lines, floats,cages, pens etc.

(b) Water exchange: describes the amount of water exchange or the control over water flow to the system. Based on water exchange the culture system may be broadly classified into static, semi-closed, recirculating (closed) and open.

(c) Intensity of culture: it reflects the number of aquaculture organisms per unit area or water volume and also the ability of the natural productivity to support the crop. Broadly, the intensity of culture is described as intensive, semi-intensive or extensive.

The actual type of system used for aquaculture production may be a combination of the above criteria. For example, culture of major carps in India and China in pond system is a combination of extensive and static.

In general, a single structure is rarely used for the whole lifespan of a cultured species. For instance, the intensive culture of a particular fish from gamete to table size may successively involve the following structures:

- a small breeding-cum-fertilization tank
- a hatching tank with gentle flow-through of water
- a larval rearing tank with gentle circulation
- a fry rearing tank or small pond
- a pond for growing fingerling to large juveniles
- a large pond or a cage or a pen for grow-out culture

Pen aquaculture system :

Pens can be rectangular, square, circular or of any other shape depending on the morphometry of the site where pens are to be erected. These can be constructed using net-lined split-bamboo screens (called *bana* in Assam, India) with bamboo poles as support or by using only nets with bamboo or FRP poles. According to size, pens can be small or big; smaller pens are easier to manage while bigger pens facilitate better fish growth and are more economical in beels of Assam. Pens measuring 500-2500 m^2were found to be both economical and manageable, with larger pens costing less for construction per unit area (Alakesh Das MFSc thesis). The foremost step in pen culture is the selection of a suitable site. The site should be gently sloping with shallow water depth (1-2 m) which should retain water for at least 4-6 months in a year. If the beel margin is not suitable, pen can also be constructed inside the shallower part of wetland with nettings on all the four sides. Sites having mild water flow but protected from strong wind and wave action are favourable. The site should not have dense vegetation, but if present, should be removed and cleared before construction of pens. The water quality should be favourable for fish culture and the site should not be near to agricultural or other domestic run-off. Other considerations for a good site are good approachable roads, availability of labour, construction materials, easy accessibility for watch and ward, etc. Pens can be used for raising fingerlings or table fish. For raising fingerlings, carp fry can be stocked @ 3-5 Nos./m^2 so as to raise advanced fingerlings in 4-6 months duration. For rearing table fish, carp fingerlings can be stocked @ 1-2 No./m^2 and reared for

8-12 months. Polyculture of carps in pens with 40% surface feeders (catla *Catla catla* & silver carp *Hypophthalmichthys molitrix*), 20% column feeder (rohu *Labeo rohita*), 30% bottom feeders (mrigal *Cirrhinus mrigala* & common carp *Cyprinus carpio*) and 10% macrophyte feeder (grass carp *Ctenopharyngodon idella*) is normally practiced. Fish species of local importance such as *Osteobrama belangeri* (pengba) and *Labeo gonius* (kuri) performed well when stocked in net pens in Takmu pat of Manipur. *Labeo bata, Barbonymus gonionotus* and other small indigenous fishes like *Puntius sarana*, *Amblypharyngodon mola*, *Gudusia chapra* can also be stocked along with carps for additional income from the pens.

Historically, pen culture was first experimented in Japan during early 1920s (Alferez, 1977). In Japan, a pen enclosure was constructed covering an area of 27 ha for culture of yellow tail at Adoike near Takamatsu in the inland sea. Marine aquaculture production in Japan in 1973 was 83,800 tons, much of which came from pen culture systems. Yellow tail (*Seriola quinqueradiata*), red sea bream (*Pagrus major*), file fish (*Monacanthus cinhifer*) and rock fish (*Sebastesmar moratus*) were the main species cultured, but yellow tail formed about 95% of production. Culture of yellow tail was considered to be the most representative type of coastal fish culture in Japan (Fujiya, 1979). Pen culture was predicted in seventies that mariculture would succeed in the Pacific Coasts north of Seattle in North America, West Coast of Scotland and Norwegian Coast. In any case much of the new developments in Pen culture started with the researches in enclosure culture in Scotland by biologists and engineers together, under the White Fish Authority in early sixties. Hydrographic and engineering surveys were made in the relatively pollution-free inter-tidal and sheltered sea lochs of west coast of Scotland in association with the Dept. of Civil Engineering, University of Strathclyde, Scotland, and Ardtoe was chosen in 1965 as a site for a marine cultivation unit. Here a 2 ha inter-tidal area (bay) was enclosed by constructing two sea walls (with low level sluices) on rock foundation on either side of a central island. Quarter million artificially hatched plaice (*Pleuronectes platessa*) from White Fish Authority hatchery in Port Erin were stocked at Artdoe intertidal enclosure in 1965. While this was not a complete success, further improvements have been made at Artdoe itself and subsequently several other mariculture farms have been developed in the West Coast of Scotland by about 40 farming organizations (Milne, 1979a).

In India, the first pen culture was attempted in oxbow lakes in the year 1978 (Banerjee and Pandey, 1978) and Abraham (1980) reported rearing of carp hatchlings in pens, since then several experiments had been conducted on the pen culture in swampy tanks, beels and reservoirs (Swaminathan and Singit 1982; Yadava*et al.*, 1983).CIFRI, Barrackpore (1979), was constructed a bamboo enclosure of 250 m^2, fixed in the littoral areas of Poongar swamp and reared with advanced fry and fingerlings of C. *mrigala* and *Labeo fimbriatus* for 90 days.In India, brackishwater pen aquaculture technique progress particularly in Tamil Nadu in the brackishwater near KiJJai, (Anon, 1982).An experimental pen was installed in ox-bow lake in Muzaffarpur (Bihar) stocked with C. *catla, L. rohita* and *C. mrigala,* at the ratio of 5: 4: I having an average size of 100 g, all the fishes achieved remarkable growth over 1 kg in 6 months and at Kallai, an experimental pen culture on *P. monodon* in backwaters gave the production of 250 kg/ha of *P. monodon* (James, 1986). In-situ carp seed rearing was attempted in Bhavanisagar and Tungabhadra reservoirs in pens for rearing spawn and fry of carps and in Pillaimadom lagoon in Mandapam, near Rameswaram to culture mullets and milk fish (Ayyappan, 2005).

Pens installed in two floodplain wetlands of Assam *viz.* Goruchora (Golaghat district) and 46-Morakollang (Morigaon district) for raising fingerling of Indian major carp seed (Gorai *et al.,* 2006). The pens were stocked at 30,000 fry per ha, in a ratio of 3:2:1 of *C. catla, L. rohita* and *C. mrigala* fry respectively. The average initial length and weight of fry at the time of stocking for

C. catla, *L. rohita* and *C. mrigala* were 5.45 cm (1.80 g), 4.51 cm (1.15 g) and 4.65 cm (1.12g), respectively. The pens were harvested after a rearing period of 145 days with an average growth of *C. catla* (19.0 cm, 85.1 g), *L. rohita* (15.8cm, 52.8 g) and *C. mrigala* (15.8 cm, 42.9 g) in Goruchora wetland, while in 46-Morakollang wetland it was recorded as 17.0 cm (63.8 g) for *C. catla,* 15.4 cm (55.9 g) for *L. rohita* and 14.0 cm (41.5 g) for *C. mrigala*. The production in terms of fish biomass (fingerlings) was estimated at 2106 and 1780 kg/ ha in Goruchora and 46 Morakollang wetlands, respectively. The cost-benefit ratio was calculated as 1.40 (Goruchora) and 1.77 (46-Morakollang), which can be considered as significant economically (Gorai *et al.*, 2006).Chandra (2010) reported that, CIFRI adopted pen culture technology in Haribhangabeel which is located in Nagaon district covering water area of 125 ha. The maximum, minimum and average depth of water in the beel is 4.24m, 3.03m and 3.64 m, respectively. The ownership of the Haribhanga wetland was with Assam Fisheries Development Corporation (AFDC). The fishing right of the beels were leased out to the lessee for seven years on the rent of 5.75 lakh per year from 2002-2003 to 2008-2009 by the government. The research conducted by CIFRI in the year 2006-2007 and the result of the research shows that the productivity potential of this beel is 1060 kg/ha/year.

Rajak *et al.* (2016) was conducted an experiment on pen culture in Chota Bhagirathi, where fish pen construction is different from traditional pen farming practices. Pen farmers of this river enclosed their farming area by pen frame. Only two side of the pen were covered i.e. up side and down side of the river. One frame was placed at the upper stretch and another on the down stretch along the entire width of the river. A frame was constructed using small units of fence (locally called bana). A bana was prepared by bamboo splits and joint together with coconut fibre rope, coir rope or nylon ropes. The size of each bana (approx. 6 ft height and 8 ft in length) varied from pen to pen. Several bana (15-30) were joined together to form pen frame in one side and same kind of frame was placed on another side of the river. The structural framework was prepared using 2.5 m long bamboo poles (fixed in the bottom-mud vertically along the guide rope at 1.0 m intervals) with upper & middle bamboo bracing. Pen screen (12 mesh/cm) of desire depth was lined inside the pen structure. The whole frame was supported on each side by long bamboo poles having gap of 7-8 ft between two pens. Longivity of these types of pen frames varied from 1-1.5 yr.

Mane *et al*. (2017) was conducted a pen culture at Dhimbe reservoir, Maharashtra, India located at 19^0 06' N, 73^0 44' E to study the effects of stocking density on the growth, survival and yield of carp fry reared in pen. They used pens of 6 mm mesh size with knotless, treated webbing were constructed using wooden ballies, bamboo poles. The distance between each pole was 2.5 meter and the water levels in all pens were 2 meters. During the experimental period, the fishes were fed with 36% protein diet containing 10% rice bran, 40% ground nut oil cake, 7.0% maize, 20% soyabean, 20% acetes, 2% vitamin mixture and 1% mineral mixture @ 2–3 % body weight twice daily. Feeding was done by bag feeding method by fixing bamboo poles randomly in the pen. The wooden ballies and bamboo poles of pens were routinely monitored and maintained during the experimental period. Das *et al.* (2017) studied pen culture demonstrations carried out in floodplain wetlands (beels) located in different districts of Assam spread across both the Brahmaputra and Barak valleys. These pen aquaculture demonstrations were carried out for pilot-scale validation of the ICAR-CIFRI technology in collaboration with Assam Fisheries Development Corporation Limited (AFDC Ltd.), Guwahati and Bodoland Territorial Council (BTC) Kokrajhar. The size of the pens constructed ranged from 2415 to 4990 m^2, which were categorised in to four size groups *viz.*, 2400-2499 $m^2(P_1)$, 2500-3499 $m^2(P_2)$, 3500-4499 $m^2(P_3)$ and 4500-4999 $m^2(P_4)$. The fixed capital cost per crop was calculated considering 3 crops per year.

Pen aquaculture technology was successfully demonstrated and perfected by ICAR-Central Inland Fisheries Research Institute (ICAR-CIFRI), Barrackpore, India as an avenue for additional fish production in floodplain wetlands parallel to enhancement of their capture fisheries/fish stock enhancement, wherein a manageable part of marginal areas of the wetland are encircled with net-lined split-bamboo screens (*bana*) for rearing of carp fingerlings/table fishes.

Pen culture experiments were initiated by ICAR-CIFRI, Barrackpore in 1989 in Dighalibeel, Kamrup, Assam wherein common carp (*Cyprinus carpio*) seed was successfully raised. Another set of experiments on pen culture was conducted in Bagheswari beel, Mandira, Kamrup district in 1996-97. This was followed by large-scale demonstration of the technology in over 10 beels of Assam under the NATP (Jai Vigyan) sub-project during 1999-2003. The Institute continues to refine the technology of pen culture in selected wetlands of Assam, Manipur, West Bengal, Bihar, Uttar Pradesh. CIFRI has developed/ refined low-cost and simple technologies for fish culture in pens erected in shallow areas (water depth up to 2 m) of wetlands. The previous field experiments/ demonstrations have shown that fingerlings raised in enclosures are well adapted to the wetland environment and, therefore, survive and grow well when they are released in the wetland proper. Further, pens can also be used to raise table fish, which is especially suitable for weed-choked wetlands, where recapture of stocked fingerlings is difficult.

Site for pen installation should have a gentle slope and have water depth of less than 2 m during the rearing season. A mild water flow is desirable. However, the area should not experience strong wind and wave action. Proposed site should not have dense aquatic and terrestrial vegetation. Easy availability of required construction materials at reasonable rates, cheap labour, good communication and social environment are other important considerations in site selection.

Pen culture can be carried out throughout the year. However, the pens may be submerged by flood/ surface run-off waters during the peak rainy moths (June to August) especially in seasonally open wetlands. Similarly growth of most native candidate species is slowed down during the peak winter months (December-January). Therefore, the periods that are ideal for undertaking pen culture in most wetlands of the region are September to December and February to May.Small pens are easier to manage, and require less cost. However, construction of bigger pens facilitates better fish growth and is more economical. Past studies conducted by the Institute have shown that pens measuring 500-2500 m^2 are found to be both economical and manageable.

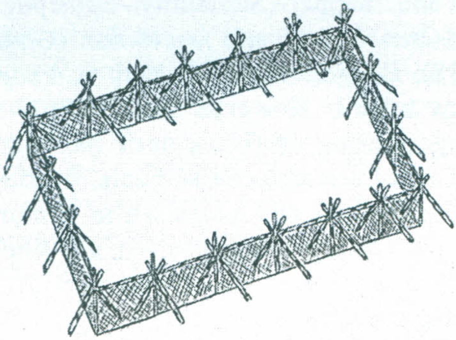

Fig. Schematic diagram of a pen constructed using nets (nylon or HDPE) supported by bamboo poles and installed in a wetland/ lake/ pat

Cage aquaculture system :

Cage aquaculture is undergoing rapid changes in response to escalating global demand for fish proteins. The cage farming system is intensifying day-by-day and expanding into newer untapped openwater culture areas such as lakes, reservoirs, rivers and coastal brackish waters (Halwart et al., 2007).Planning and siting of cage aquaculture facilities can be a potential adaptation measure in response of climate change (Shelton, 2014), which is especially true for waterbodies that are vulnerable to floods, strong waves, storms etc. The site should have at least 2 m depth of water, good dissolved oxygen content, mild winds/ waves, easy accessibility from land, low anthropogenic pressure and low macrophyte infestation (especially submerged). However, even in macrophyte-choked water bodies, a selected area can be cleared and utilized for cage culture.

Cage aquaculture is common in Central and South-east Asia in countries such as China, Philippines, Indonesia and Thailand (Beveridge 1996, Beveridge and Stewart 1998). Throughout these regions a wide range of marine and freshwater species are cultured in cages including seabass (*Lates calcarifer*) (Rimmer and Russel 1998), grouper and snapper (Subfamily: Epinephelinae) (Seng 1998), tilapia (*Oreochromis* spp.), milkfish (*Chanos chanos*) (Bagarinao 1998), *Pangassius*, Grass carp (*Ctenopharyngodon idella*) and many others. However, there is little documentary evidence of cage rearing of fishes until the end of the 19th century. In the Great Lake area of Cambodia, floating cages have been used for more than 100 years while in Indonesia both floating and anchored cages have been in use since the 1940s. 'Traditional' small-scale cage culture activities may be distinguished from the intensive cage production systems by their reliance on natural construction materials and low levels of feed inputs. 'Modern', intensive cage aquaculture typified by the use of synthetic, manufactured materials and commercial feed inputs first appeared in Japan with the culture of yellowtail (*Seriola quinqueradiata*) in the 1950s. Atlantic salmon (*Salmo salar*) was first cultured in Norway a decade or so later while tilapia cage culture originated in the USA during the late 1960s (Beveridge, 1996). Commercial cage culture is mainly restricted to the culture of higher-value (in marketing terms) compound feed fed finfish species (Atlantic salmon, Coho salmon, Chinook salmon), marine and freshwater carnivorous fish species (Japanese amberjack, red seabream, yellow croaker, European seabass, gilthead seabream, cobia, sea-raised rainbow trout, Mandarin fish, snakehead) and numerous omnivorous freshwater fish species including Chinese carps, tilapia, Colossoma, and catfish (Tacan and Halwart, 2007).

In India, cage culture was attempted for the first time in case of air breathing fishes like *Heteroneustes fossilis*, *Anabas testudineus* in swamps (Dehadrai*et al.*, 1974).There were several attempts for replacing the ground nurseries. Studies conducted by Natarajan*et al* (1979) and Menon (1983) showed encouraging results with survival levels of ranging 25-85% during raising carp fry in floating cages. Among carnivorous fishes, the giant murrel, *Channa marulius* cultured at density of 40 fish/m^3in cages fed with trash fish, grew to an average size of 200 g in 6 months, recoding a net production of 0.8 kg/m^3/month. Further, trials on cage culture carried out at Darbhanga (Bihar) and Guwahati (Assam). under Coordinated Research Project on air breathing fish culture demonstrated production level of 0.3, 0.7, 1.0, 1.7, 1.5 and 1.3 kg/m^3/month in *Anabas testudineus*, *Heteroneustes fossilis*, *Clarias batrachus*, *Channa striatus*, *Channa punctatus*, respectively (Dehadrai, 1972). The experiments conducted by Central Institute of Fisheries Education, Mumbai, depicted highly encouraging results that, it is the cage culture and cage rearing of seed on large scale, that can alone revolutionized the desired fish production from open water bodies (Dubey, 2004). Experiments at Powai lake, Mumbai shows that, *Labeo rohita* grows 3.24 g to 54.72 g within 43 days with survival of 50.72%, whereas during the same period *Cyprinus carpio* with a density 50 No./m^3 grew from 0.293 g to 31.34 g with a survival of 75.26% and with a density of 57.37% (Kohli *et al.,* 2002). The production from grow out cages; in general, vary greatly depending on the type of management of inputs. Further, the number of fish that can be stocked in the cages depends on the carrying capacity, water exchange, species of fish, and quality and quantity of supplemental feed input.

Beels are freshwater floodplain wetlands. Floodplains and their associated wetlands are utilized by human beings throughout the world. The floodplains wetlands in India are an important resource for livelihood both for rural and urban communities. These wetlands are widely distributed throughout the Eastern and Northeastern part of India under the river Ganga and the Brahmaputra basins. Floodplain wetlands form the prime fishery resource in the state of Uttar Pradesh, Bihar, West Bengal, Assam, Manipur, Tripura, Arunachal Pradesh and Meghalaya, where they are commonly known as beel, moan, tal, jheel, pat boar, chaur, etc (Jha, 1989). These wetlands are one of the most productive aquatic environments of the world, as they can produce benefits eight times more than those of a paddy field of an equivalent area (Jhingran, 1989). They are resilient and highly dynamic ecosystems supporting large number of plant and animal species, many of which has commercial importance. These wetlands play an extremely important role in fish production leading to livelihood security besides having a number of other direct or indirect values.

In India, the practice of cage aquaculture is still in infant stage and there is need to popularize this culture practice especially in inland openwaters of India where the existing waterbody is also used for aquaculture in addition to capture fisheries. It has been recommended to expand cage aquaculture up to 1% of the total water area of the beels so that there is no problem of eutrophication in years to come (Das et al., 2017). Experiments are presently being carried out in some floodplain wetlands (beels) of Assam, India to optimize stocking density of *Labeo bata* and *Labeo gonius* fingerlings in cages supported by GI platforms (commercialized by ICAR-CIFRI, Barrackpore in 2017) for the first time in India.

Labeo bata (bhangon) is one of the commercially important minor carps having good consumer preference especially in Eastern part of India. This is a highly priced fish; even 15-20 g size of bhangon have good market value (Dutta et al., 1996). In a survey conducted for fish consumers of Assam, bhangon was the highest preferred fish among the minor carps (Shodhganga, 2014). *L. bata* are generally cultured in aquaculture ponds and data are not available for its rearing in net cages. In our earlier experiments, the optimum stocking density of *Labeo rohita* fry (Biswas et al., 2015) and *Cirrhinus mrigala* fry in net cages was standardized at 200 and 300 fry m^{-3}, respectively in beels of Assam.

Cage culture in inland open waters is proven to be a successful technology providing economic benefits of producing high biomass per unit area. This technology can be adopted under various agro-climatic conditions. Cages are used for rearing aquatic organisms in a volume of water enclosed on all sides with cage netting materials including bottom, while permitting the free circulation of water through the mesh of cages. Cage aquaculture has become a common technology in Central and South-east Asian countries such as China, Philippines, Indonesia and Thailand (Beveridge 1996, Beveridge and Stewart 1998). A wide range of marine and freshwater species are cultured in cages including seabass (*Lates calcarifer*) (Rimmer and Russel 1998), grouper and snapper (Subfamily: Epinephelinae) (Seng, 1998), tilapia (*Oreochromis* spp.), milkfish (*Chanos chanos*) (Bagarinao 1998), *Pangassius*, Grass carp (*Ctenopharyngodon idella*) and many others. 'Traditional' small-scale cage culture activities may be distinguished from the intensive cage production systems by their reliance on natural construction materials and low levels of feed inputs. 'Modern', intensive cage aquaculture typified by the use of synthetic, manufactured materials and commercial feed inputs first appeared in Japan with the culture of yellowtail (*Seriola quinqueradiata*) in the 1950s. Atlantic salmon (*Salmo salar*) was first cultured in Norway a decade later while tilapia cage culture originated in the USA during the late 1960s (Beveridge, 1996).

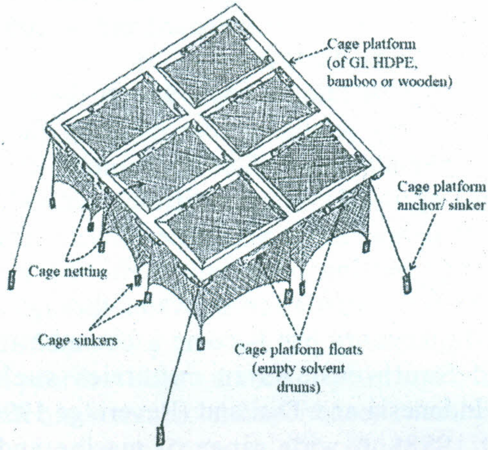

Fig. Schematic diagram of a set of floating cages showing its platform, floats, sinkers and nettings

In India, cage culture was attempted for the first time in case of air breathing fishes like *Heteroneustes fossilis*, *Anabus testudineus* in swamps (Dehadrai *et al.*, 1974).There were several attempts for replacing the ground nurseries with hapas/ cages. Studies conducted by Natarajan *et al.* (1979) and Menon (1983) showed thathigh survival rate ranging from 25-85% while raising carp fry in floating cages. Among carnivorous fishes, the giant murrel, *Channa marulius* cultured at density of 40 fish/m^3 in cages fed with trash fish, grew to an average size of 200 g in 6 months, recoding a net production of 0.8 kg/m^3/month. Further, trials on cage culture carried out at Darbhanga (Bihar) and Guwahati (Assam) under Coordinated Research Project on Air Breathing Fish Culture demonstrated production level of 0.3, 0.7, 1.0, 1.7, 1.5 and 1.3 kg/m^3/month for *Anabus testudineus*, *Heteropneustes fossilis*, *Clarias batrachus*, *Channa striatus*, *Channa punctatus*, respectively (Dehadrai, 1972). Fish production levels from cages used for growing marketable fish vary greatly depending on the type of management of inputs. Further, the number of fish that can be stocked in the cages depends on the carrying capacity, water exchange, species of fish, and quality and quantity of supplemental feed input.

Rearing and raising of fishes in cages is gaining importance all over the world because of its increasing technical, ecological, social and economic advantages over capture fisheries and conventional aquaculture. Cage fish culture technology is (i) compatible, non-competitive and complementary to other systems, (ii) applicable to almost all aquaculture species, (iii) idealfor open waters with low fish yield such as inland reservoirs, large rivers, coastal estuaries and other waterbodies relatively protected from turbulent waves and storms, and (iv) technologically simple, not-much capital intensive. It has social advantages in that landless people can find habitation and employment in cage aquaculture (Costa Pierce, 2002).

Small-scale cage aquaculture has been shown to be a flexible technology adaptable to the needs of poor people. By providingthe cages under the ownership of the landless farmers promoted the use of otherwise 'fallow' waterbodies (Hambrey*et al.*, 2001). Operations carried out over shorter periods, such as fish overwintering, nursing, and fattening in small cages, fit well with the income-generating strategies of the poor by providing them with a potential source of income in periods of hardship and shortage (McAndrew *et al.*, 2000). When integrated in ponds, cage culture allows the simultaneous farming of fish species at different tropic levels (caged fish are fed high-protein diets, while pond filter feeding species depend on caged fish wastes), enabling incremental production of biomass per unit of water while recycling nutrients (Yang and Lin, 2000).

Floodplains wetlands in India are an important resource for livelihood both for rural and urban communities. These wetlands are widely distributed throughout the Eastern and Northeastern part of India under the river Ganga and the Brahmaputra basins.

They form the prime fishery resource in the state of Uttar Pradesh, Bihar, West Bengal, Assam, Manipur, Tripura, Arunachal Pradesh and Meghalaya, where they are commonly known as beel, moan, tal, jheel, pat, boar, chaur, etc. (Jha, 1989). These wetlands are one of the most productive aquatic environments of the world, as they can produce benefits eight times more than those of a paddy field of an equivalent area (Jhingran, 1989).As most of the beels have lost their riverine connections, the main source for auto-stocking of fish seed have been blocked, particularly those infested with weeds (Sugunan, 2000). In such a scenario rearing and culture of fishes in cages is advocated as a potential tool for beel fisheries enhancement especially in situations where the beel is heavily weed-choked.

At present, cage culture systems are much diverse varying from traditional family-owned operations to modern commercial large-scale farming operations. Salmon and trout cage culture in northern Europe and the Americas has reached commercial success and the whole world is attracted towards cage aquaculture following them. Many factors were responsible for the rapid rise and success of cage farming of salmon and trout, such as reliable seed supply, suitable water areas, market acceptability, corporate investment, supportive government regulatory environment (Tacon and Halwart, 2007).

Enclosure culture of SIFs :

Small indigenous fishes (abbreviated as SIFs), many of whom were known as 'weed fishes' earlier, are getting much more research attention throughout the world basically because of their nutritional significance in providing high quality proteins, fats, vitamins and minerals at higher concentrations at lower prices in human diet. The main characteristic of most of the SIFs is that they are climate-resilient species and naturally breeds in inland waters at relatively short time intervals. Most of the SIFs are tolerant of relatively poorer water qualities compared to major carps and catfishes. These are small in size, naturally found in open waters and ponds, and also they breed naturally without any artificial inducement. Mola (*Amblypharyngodon mola*), Puti (*Puntius sophore*, *P. chola*, *P. ticto*), Darkina (*Esomus danricus*), Chanda (*Parambassis ranga*, *Pseudambassis baculis*, *Chanda nama*), Goroi or spotted snakehead (*Channa punctatus*), Spiny eel (*Macrognathus pancalus*, *M. aral*, *Mastacembelus armatus*), Chela (*Chela cachius*), Chapra (*Gudusia chapra*), Gourami (*Colisa fasciatus*, *C. lalia*, *C. sota*) are some of the small nutritious self-recruiting fishes that need to be popularized as a complementary or supplementary species in carp polyculture in ponds and tanks or stock enhancement in open waters (beels) of NE region.

Culturing small fish punti (*Puntius sophore*) and/ or mola (*Amblypharyngodon mola*) in pond polyculture systems with large carps (rohu *Labeo rohita*, catla *Catla catla* and mirror carp *Cyprinus carpio*) in Bangladesh was a success story (Wahab, Alim and Milstein, 2003). They demonstrated that the polyculture system was viable, as addition of these two SIFs did not reduce the production of large carps. In that experiment, large carps were stocked at 10000 no./ ha at a species ratio 1:1:1. Small fishes were stocked at three different stocking densities – 0, 25000 or 50000 no./ ha. While analysing the effect of stocking mola and/or punti on large carps and on each other, they found that catla production was not affected by the addition of the small fish. However, the growth of rohu was significantly (30-40% reduction) affected by mola, not by punti. On the other hand, mola had positive effect on growth rate and harvest weight (25-30% increase) of mirror carp. The addition of small fish did not significantly affect total yield and food conversion ratio.

Table. An example of compatible fish species for polyculture in ponds or stock enhancement in beels with their spatio-trophic habits

Species	Spatio-trophic habits	Stocking density (no./ha)
Catla (*Catla catla*)	Surface feeder, zooplankton forms the major diet.	3300
Rohu (*Labeo rohita*)	Column feeder, plankton/ periphyton and organic debris forms the major diet.	3300
Common carp (*Cyprinus carpio*)	Bottom feeder, omnivorous (including detritus).	3400
Punti (*Puntius sophore*)	Surface feeder, omnivorous (small insects, algae, plankton)	25000
Mola (*Amblypharyngodon mola*)	Surface feeder, omnivorous (unicellular algae, protozoa, rotifer, small crustaceans)	25000

Debnath et al. (2019, abstract in APA19 at Chennai), opined that the development efforts aimed at fishers and fish farmers in the developing world focused on helping them to build their capacity to adapt to climate change. Small indigenous fishes (SIFs) have high consumer preference, and hence they demand high price in Northeastern region of India. An experiment was conducted to assess feasibility of culturing high value SIFs (*Amblypharyngodon mola*, *Gudusia chapra* and *Puntius* spp.) along with Indian major carps (IMC) in pens installed in a floodplain wetland (beel) of Assam. Five pens of 10 m x 10 m (100 m^2area) were constructed in 47-Morakolong beel (seasonally open wetland), Morigaon district, Assamwith low-cost and locally available materials. The IMC (*Catla catla*, *Labeo rohita* and *Cirrhinus mrigala*) were stocked at 2:1:1 ratio @ 3 no./ m^2 in all the pens. Five different species combinations (treatments) were tested i.e., P1 (IMC only), P2 (IMC +*A. mola* @ 30 no./ m^2), P3 (IMC + *G. chapra* @ 20 no./ m^2), P4 (IMC + *Puntius* spp. @ 20 no./ m^2) and P5 (IMC + all three SIFs @ 1/3rd of the original stocking density of each species). The stocked fishes were fed with formulated pelleted feed containing 30% CP @ 3-4% body weight of IMC twice daily and cultured for five months. The highest fish production was obtained from P3 (1.48 kg/ m^2) followed by P2 (1.46 kg/ m^2), P5 (1.3 kg/ m^2), P4 (1.08 kg/ m^2) and P1 (1.05 kg/ m^2). Economic analysis of the pen culture operation indicated that culturing IMC with *G. chapra* or *A. mola* was the most profitable one with B:C ratio of 1.54 and 1.51, respectively. Rearing of IMC with all the three SIFs was observed to be more economical (B: C ratio of 1.35) than culturing IMC alone. However, culturing IMC alone or with *Puntius* spp. recorded similar returns. All the three SIFs bred naturally in the pens as indicated by the presence of various size range of the fish. Our result indicated that culturing of locally preferred high value *G. chapra* and *A. mola* along with IMC in pens was economically profitable yielding higher returns than culturing IMC alone. In conclusion, pen aquaculture practice in floodplain wetlands of Assam can be adopted as polyculture of SIFs with major carps instead of culturing only major carps for additional income of the wetland fishers and conservation of SIF in the changing climatic scenario.

Climate-resilient fish species for enclosure culture :

Resident fish populations of any inland waterbody are naturally resilient to the micro-climate of that waterbody. This may not be the case with the fish stocked or ranched from outside. Hence, fishers should identify those species that are naturally present and conserve them. The small indigenous fishes (SIFs) are normally the resident populations that are resilient to their environment. For example, Mola (*A. mola*), Puti (*P. sophore*, *P. chola*, *P. ticto*), Darkina (*E. danricus*), Chanda (*P. ranga*, *Pseudambassis baculis*, *Chanda nama*), Goroi or spotted snakehead (*Channa punctatus*), Spiny eel (*Macrognathus pancalus*, *M. aral*, *Mastacembelus armatus*), Chela (*Chela cachius*), Chapra (*Gudusia chapra*), Gourami (*Colisa fasciatus*, *C. lalia*, *C. sota*) etc. In addition to these fishes, the exotic carps (*C. idella*, *H. molitrix*, *C. carpio*) are also more resilient compared to the major carps. Catfishes namely *Clarias magur* and *Heteropneustes fossilis* are highly valued and resilient species that can be cultured at very high stocking densities. Minor carps namely *Labeo bata* and *L. gonius* have shown to be winter tolerant species in enclosure culture demonstrations in Assam, India. Culture of native species may be encouraged to reduce vulnerability of fishers in the changed climatic scenario (Shelton, 2014).

Enclosuresfor ornamental fisheries :

Ornamental fish is an important commercial component of aquaculture. Fish with attractive colour pattern, swimming behaviour and more resistant to captivity stress are considered as good candidate species.An enclosure is more of an open fish rearing system than land-based ponds,raceways or tanks and there is greater degree of interaction between the caged or pen-reared fish and the outside environment compared to other systems.Fish keeping is the second most popular hobby in the world, next only to photography.India's share of the international ornamental fish trade is marginal (<1%) but it is growing consistently over the years. Of the total number of fishes traded by India, approximately 85% are native ornamental fishes sourced from the Western Ghats and North-East India, which are two major biodiversity hotspots region of the world, with Assam standing out as the major contributor (Bhattacharjya and Choudhury, 2004).In pen enclosure system indigenous ornamental fishes can be easily bred by providing their own natural environmental conditions or by inducement. Pen enclosures can act as the simplest and cheapest meansof breeding and seed production of fish on a small-scale in rural areas. In comparison to tank breeding, pen and happa breeding will have low maintenance cost. There will not be any need for artificial aeration for the fish and no labour cost for cleaning tanks. Gold fish is cultured globally in happas with high economic returns (Biswas et al., 2015).

Adaptability to varied environment and weather conditions :

Debnath et al. (2015) observed that the main threat of climate change on the numerous floodplain wetlands (*beels*) of river systems is because of irregular and excessive precipitation during the southwest monsoon (June-September) and the associated flash floods adversely impacting aquatic and terrestrial organisms and resources. These beels are a repository of a variety of fish and shellfish species. Many of these species are sensitive to changes in water level and temperature. Regular floods could be highly beneficial for fisheries of floodplain wetlands as well as their connecting rivers because they help in free to-and-fro migration of major fishes between the two inter-dependent aquatic ecosystems. However, very high rainfall and abnormal floods will aggravate the problem of siltation of the river and its associated wetlands, thereby reducing water availability for the icthyo-denizens further. The detailed effects of climate change and direction of change on the physical and biological processes that affect individual fisheries are uncertain. Currently, the magnitude of global climate change is such that most of its effects on freshwater fisheries could be easily masked by or attributed to other anthropogenic influences, such as deforestation, overexploitation and land-use change. Since it is impossible to reverse the global warming and climate change phenomena, the only thing that needs to be done is to minimize the foreseen harms in the future.

Experiments and demonstrations conducted in the country show that enclosures (pens and cages) installed in inland waters are suitable for all-weather conditions. If pen enclosures installed in the marginal areas of waterbodies are exposed to low-water levels, the enclosures may be removed and shifted to some other areas. On the other hand, if pen enclosures are about to be submerged due to excessive rain/ flood, the fencing height can be increased using bamboo-screen or only netting or using both. If cage enclosures are considered, floating cages are naturally all-weather fish rearing units provided there is minimum permissible depth for fish rearing in the waterbody. Cages also offer additional benefits in terms of portability of the cage battery when the weather demands so – for example, cages can be moved to another location if water velocity, macrophyte infestation, water depth, turbidity, predator or susceptibility to encroachment etc. is suspected to affect the reared fish in cages. Therefore, enclosures are offering definite advantages over land-based aquaculture systems.

Conclusion :

Climate change and its impacts are inevitable. Population explosion, consumerism, urbanization, industrialization and overall development of human societies have put overwhelming pressure on natural resources. Inland fisheries resources are not immune to the effect of climate change, which is manifested in the form of events such as erratic flood, drought, storm, hailstorm etc. Adapting to the changed climatic scenario is the only option left with fishers dependent on such resources. Fish farmers and fishers are required to understand that (i) changes in the temperature and rainfall (two very crucial climatic parameters for inland fisheries) can be appropriately utilized through proper planning and execution of seed production and farming activities, (ii) resident and dominant fish species in open waters are the ones that are climate-resilient and climate-tolerant, (iii) enclosure culture technologies are simple but useful tools for producing stocking material (advanced fingerlings) and table fish providing economic and social benefits, (iv) deeper areas of natural waterbodies can serve as critical habitats for fish stocks, (v) low-cost fencing around flood-prone wetlands/ beels can protect their stock from escapement, (vi) responsible fishing methods/ gears must be adopted for sustainable fisheries, (vii) small indigenous fishes should be conserved and/or transplanted because they can provide nutritional and income security, and (viii) scientific fisheries management of inland waters including enhancement with regard to fish stock, fish species and environment is crucial for securing livelihoods in the face of more severe and impending risks of climate change.

It is believed that application of climate-smart practices such as pen and cage culture systems will reduce the impact of climate change, improve inland fisheries' mitigation potential and increase resilience of fishers. The experience gained in India in general and NE in particular with regard to enclosure culture needs to be shared among stakeholders, so that adoption of the technologies is wider, because without large-scale adoption in vast openwaters of the country, the enclosure aquaculture technologies cannot bring in visible change in production and productivity of these waterbodies.

Precautions for enclosure culture :

Several precautions have to be taken to maximize the growth and survival of the fishes in enclosures. One need not feed newly stocked fish for first 2 days as they are stressed due totransportation. Monitoring growth and health of fishes every 15 days is required. In the event of reduction in water level, the cage frame can be dragged to a place where at least 30-50 cm gap between cage bottom and *beel* bottom is available. Choking of cage wall due to bio-fouling caused by the growth of attached algae can prevent water exchange. To avoid this, 4-5 common carp *Cyprinus carpio* or Japanese puthi *Barbonymus gonionotus* can be stocked in each cage/ pen to graze on interior wall of the mesh. If choking problem persists, then exchange the cage sequentially every 2 weeks with a new cage for sun-drying the fouled cages and after drying, rub the cage wall with hands, then jerk vigorously to detach and remove the fouling material. The exterior of the cage may be scrapped with the help of a coir-made broom. Remove dead fish, if any, from the pen/ cage immediately. Repair any holes formed in cage wall immediately to prevent fish escape.

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