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Review Article

Cage culture in North Eastern India: present status and future prospects

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Abstract

The North Eastern Region of India is rich in ichthyofaunal and aquatic resources. Cage culture in existing water bodies presents an immense opportunity to enhance fish production, generate employment, and improve socio-economic conditions in the region while maintaining ecological balance. About 1500 cages have been installed in the region in different water bodies like lakes, reservoirs, wetland and ponds. Different types of major and minor carps, silver barbs, anabas, snakeheads and catfish have been cultured with average productivity of 1 to 15 kg fish m^3. However, technology adoption in the area has been low due to concerns over ecological sustainability, economic feasibility, and natural disaster risks. This paper reviews the status and prospects of cage aquaculture, focusing on suitable water bodies and fish species while emphasizing the need for targeted research, community-based approaches, strong policies, and Governmental support.

Keywords: Aquaculture, Community-based Fisheries Management, High Altitude wet lands, Pradhan Mantri Matsya Sampada Yojana (PMMSY), Socio-economic Development

Highlights

- The paper reviews the current status of cage culture in the northeastern region of India
- Key government initiatives promoting cage culture adoption are highlighted
- Identifies major challenges and suggests practical strategies to overcome them
- Projects future prospects of cage culture across the northeastern region of India
- Provides a roadmap for sustainable fisheries development in the region

INTRODUCTION

The North Eastern Region (NER) of India is geographically located between latitude 21°57″ and 29°30″N and longitude 89°46″ and 97°30″E and comprises eight states viz. Arunachal Pradesh, Assam, Meghalaya, Manipur, Tripura, Mizoram, Nagaland and Sikkim. The region occupies an area of 262,184 km^2, which is about 8% of India's total geographic area and nurtures nearly 50% of the biodiversity in the country wherein about 32% is endemic (Avasthe and Patel, 2023). NER is rich in ichthyofaunal resources and is regarded as one of the world's hotspots for freshwater fish Biodiversity (Munilkumar *et al*., 2023). The majority of the populations in the region are non-vegetarians with fish as one of the most commonly consumed non-vegetarian items. Out of about 52 million populations in the region, over 90% of people consume fish in their diet (Singh *et al*., 2017).

The demand of fish for consumption in the region is huge, and people mostly prefer locally produced fish. Historically, the region's fishery resources remain poorly utilized, resulting in a fish yield significantly lower than the national average and an inadequate local supply to meet the population's needs. Of late, the region has made tremendous growth in fish production registering a jump of 50% in the last 7 years; i.e., from 4.03 lakh mt in 2014-2015 to 6.03 lakh mt in 2022-2023 (DoF, 2023). This may be attributed to the successful implementation of the Central Sector Scheme on Blue Revolution (BR) and Pradhan Mantri Matsya Sampada Yojana (PMMSY) that have brought about vast area expansion and technological interventions in aquaculture. One such scheme that made its way of expansion into NER is the cage culture.

In India, the freshwater aquaculture centers on pond-based farming systems. However, the growth of pond-based aquaculture is constrained by increasing cross-sectoral demands for water and land. Given these challenges, fish culture in enclosures such as cages and pens in open water bodies presents an opportunity

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to boost production without requiring additional land for fish farming (Debnath *et al.,* 2021). The cage culture concept that probably originated with fishermen using cages to accumulate harvested fish for the market grew into a farming system. The first cages used for actual fish farming were started in Southeast Asia about the end of the 18th century by using wood or bamboo and feeding the confined fish with trash fish and food scraps (Mal, 2021). Cage aquaculture is defined as the practice of rearing aquatic organisms within a confined volume of water, enclosed on all sides (including the bottom) with netting materials that allow free water circulation. It is a promising fish farming activity and about 20 freshwater fish species are farmed using cages across the globe (Gopalakrishnan *et al*., 2015). Cage culture can be practiced in almost any water body, as long as there is sufficient depth to keep the bottom of the cage net at least 2 m above the waterbed (Yengkokpam *et al*., 2023). Fish farming in cages offers many benefits over traditional land-based fish farming. Rearing fish in cages allows higher stocking densities, better feed management, and effective disease control compared to traditional fish farming methods (Bhattacharjya *et al*., 2023). Further, cage culture promotes effective utilization of existing water bodies for multiple purposes, thereby minimizing the need for land conversion and significantly reducing the environmental footprint of aquaculture practices (De Silva and Phillips, 2007).

ICAR-Central Inland Fisheries and Research Institute (CIFRI) has demonstrated cage culture in diverse aquatic environments throughout India, such as reservoirs, floodplain wetlands (beels), lakes, and dams, proving effective for both nursery rearing and table fish production (Biswas *et al*., 2015; Bhattacharjya *et al*., 2023). Cages can be installed in both natural and artificial water bodies such as ponds, tanks, dams, reservoirs, lakes, rivers, streams etc. It is easy to manage and control the fish within an enclosure while at the same time, it offers the reared fish an environment of nutrient-rich natural water bodies (Debnath and Yengkokpam, 2024). The potential for cage culture in NER is strengthened by several factors such as rich fish biodiversity supported by diverse aquatic habitats, ranging from clean and cold-water streams to warm-water rivers and lakes, nutrient-rich floodplains and wetlands, vast reservoirs and barrages that are largely underexploited and untapped (Yengkokpam *et al*., 2023).

Present status of cage culture in NER

Since the availability of plain land is a constraint in most states of NER, expansion of aquaculture areas through the construction of new fish ponds is not easy and is risky and expensive. Further, the limited available plain lands are mostly used for different agricultural and horticultural crops. Diverting such productive lands for aquaculture may not be appropriate. For such cases, inland cage culture is a worthy option to consider. NER has about 7.52 ha of water resources in the form of tanks and ponds, reservoirs, oxbow lakes, beels and 20,875 km of rivers and canals. Most of these water bodies are conducive to cage farming. According to Munilkumar and Nandeesha (2007), cage culture is predominantly underutilized in the region and offers considerable potential for increasing fish production. Since 2010, the National Fisheries Development Board (NFDB) in collaboration with State Fisheries Departments, and various institutions under Indian Council of Agricultural Sciences (ICAR) has made significant efforts to demonstrate technology in the region to enhance fish production from existing resources and to highlight other socio-economic benefits. Fisheries research institutes have also undertaken experimental cage culture trials across various states in the region. For instance, 60 cages of 1 m^3 capacity were installed in forest waters of Tripura for rearing common carp (Debnath, 2025). In Assam, 100 cages of $4 \times 2.5 \times 2$ m and 15 cages of $5 \times 5 \times 2$ m were deployed in floodplain wetlands for culturing carps and Java Puthi (Kakati *et al*., 2018; Debnath *et al*., 2022). Similarly, 10 cages of $6 \times 4 \times 2$ m were set up in Loktak Lake, Manipur, for rearing pengba (ICAR-CIFRI, 2021), while 10 cages of $6 \times 4 \times 4$ m were installed in Doyang Reservoir, Nagaland, for common carp, silver barb, and Pangasius culture (ICAR-CIFRI, 2022). In Meghalaya, 6 cages of $6 \times 4 \times 4$ m were also installed for carps culture (Das *et al*., 2022). Experimental studies from these installations reported an average productivity ranging from 1 to 15 kg m^{-3} for different cultured fish species in the region (Debnath *et al*., 2022; Bhattacharjya *et al*., 2023; Yengkokpam *et al*., 2023; Debnath, 2025).

Thus, about 1500 cages have been installed in the region, of which 1359 cages were sanctioned under the PMMSY and the Blue Revolution Scheme over the last decade (DoF, 2023). If each cage produces approximately 1 tonne of fish annually, an estimated 1500 tonnes of fish can be harvested from these cages every year.

Suitable water bodies

Cage culture has been effectively demonstrated in multiple water bodies across the region, including the floodplain wetlands of Assam; Dumbur reservoir of Tripura; Loktak Lake, Khuga, and Mapithel reservoirs of Manipur; Serlui B reservoir of Mizoram; and Doyang

reservoir of Nagaland (Dorothy *et al*., 2018; Bhattacharjya *et al*., 2023; Debnath, 2023; Yengkokpam *et al*., 2023). Further, the Department of Fisheries, Government of Arunachal Pradesh demonstrated culture of Indian major carps and exotic carps using modular cages at the Borbeel fishery in Namsai district under the National Mission for Protein Supplement of RKVY (Anonymus, 2016). ICAR-Directorate of Coldwater Fisheries Research (DCFR) demonstrated cage culture of rainbow trout in Memencho Lake of Sikkim where the water is clear and cold (Sharma *et al*., 2018). The Department of Fisheries, Mizoram installed 100 modular cages in Serlui B Reservoir with carps and Pangasius with financial assistance from NFDB (Anonymus, 2024). Meghalaya State Fisheries Department, with support from ICAR institutes, demonstrated nursery rearing and grow-out production of selected species of carps and barbs in different types of cages in Nongmahir Reservoir and Umiam Lake (Das *et al*., 2022; Bhattacharjya *et al*., 2023).

Suitable fish species

The major criteria for selection of suitable fish species for cage culture include fast growth rate, resistance to diseases, good feed conversion efficiency, and market demand (Kumar and Panwar, 2020). ICAR-CIFRI have demonstrated cage culture with various species of carps, snakehead, catfishes, etc., and found promising growth and survival rates with higher tolerance to diseases and better marketability. Carps including major carps like Catla (*Catla catla*), Rohu (*Labeo rohita*), Mrigal (*Cirrhinus mrigala*), Grass carp (*Ctenopharyngodon Idella*), Common carp (*Cyprinus carpio*) and minor carps including Calbasu (*Labeo calbasu*), Bata (*Labeo bata*), Gonius (*Labeo gonius*), Pengba (*Osteobrama belangeri*) are suitable for cage culture in NER (Biswas *et al*., 2015; Das, *et al*., 2017; Kakati *et al*., 2018; Debnath *et al*., 2022; Bhattacharjya *et al*., 2023; Yengkokpam *et al*., 2023). These authors further recommended cage farming for other important fish species like Silver barb (*Barbonymus gonionotus*), Java Puthi (*Puntius sarana*), Pangus (*Pangasianodon hypophthalmus*), Singhi (*Heteropneustes fossilis*), Kawoi (*Anabas testudineus*), Rainbow trout (*Oncorhynchus mykiss*), Snakehead (Channa spp.), Magur (*Clarias magur*).

Stocking density

For sustainability and economic purposes, the average stocking density recommended for carps (both major, minor and mix) culture in cages ranges from 200 to 300 fry m^{-3} for nursery rearing and 20-40 fingerlings m^{-3} for grow-out production in lakes, floodplain wetlands, reservoirs and ponds (Dutta and Bora, 2017; Sarmah *et al*., 2017; Das *et al*., 2018; Kakati *et al*., 2018; Yengkokpam *et al*., 2023). However, the actual stocking density may be based on species and their feeding nature. NFDB (2016) recommended stocking density of 60 to 100 fingerlings m^{-3} or 500 to 700 fry m^{-3} for Pangasius (*Pangasianodon hypophthalmus*) and 40 fingerlings m^{-3} for GIFT Tilapia.

Types of cages

Aquaculture cages can be of different types with various structures and designs based on the fish species to be cultured, intensity of operations, type of water bodies, and husbandry management (Gopalakrishnan *et al*., 2015). It can be of the fixed, floating, submersible, and submergible type or can be either stand-alone or in clusters (Gopalakrishnan *et al*., 2015). They can be placed at the bottom, mid-water, or surface of the water column. Floating cages are very popular in inland water systems as they are easy to manage (NFDB, 2016). They can be installed in water bodies with a water depth of 5 m or more, such as reservoirs, lakes, and deeper beels with less macrophage. Floating cages are commonly used for the rearing of fingerlings and table fish wherein the net bag hangs on floating frames (floaters) in water without touching the basin (Das *et al*., 2018; Bhattacharjya *et al*., 2023). In shallow water bodies like ponds, seasonal beels, floodplain wetlands etc., and fixed cages are used wherein the net bags are fitted in erected posts without touching the basin. This type of cage culture is suitable and economical for nursery rearing to raise fry to fingerlings which can later be released it to pond or into open water bodies for stock enhancement (Das *et al*., 2017). The most commonly used cages were rectangular or square in shape (Radhakrishnan *et al*., 2022). NFDB (2016) recommended a standard cage size of 6m (length) 4m (width) × 4m (height) for rectangular cages or 5 m × 5 m × 5 m square cage arranged in batteries of 6, 12, or 24 cages in a caterpillar design with catwalks for operational and planning efficiency. The most commonly implemented cage in the region is rectangular floating cage of dimension 6 × 4 × 4 m as per NFDB recommendation or 4 x 2.5 x 2 m for shallow water bodies with galvanized iron frames and plastic or PVC drum floaters (Kakati *et al*, 2018; ICAR-CIFRI, 2021; Das *et al*., 2022).

Materials for fabrication of cage

Cages can be fabricated using locally sourced materials like inexpensive bamboo and nylon to more robust materials like steel and HDPE (Trond, 2016). The materials should ensure durability and stability to achieve optimal results (NFDB, 2016). Commonly used materials for cage frames include bamboo, mild steel, galvanized iron, poly-vinyl chloride (PVC), and high-density polyethylene (HDPE). Most of the cages installed in the region are either bamboo (both frame and cage) or bamboo/galvanized iron frames with HDPE or nylon mesh nets and plastic/PVC drum as floaters (Kakati *et al*, 2018; Bhattacharjya *et al*., 2023). Bamboo-based frames are not recommended for commercial cage fish farming due to their limited durability and insufficient strength to withstand water turbulence (NFDB, 2016). Floats are often made of plastic drums with bamboo walking platforms (Salin *et al*., 2023). The mesh size of the nets should not be smaller than half an inch to ensure good water circulation through the cage while holding relatively small fingerlings (Masser, 2007).

Government initiatives in promoting cage culture

Guidelines for cage culture in inland open water bodies of India: In one of its initiatives to popularize cage culture in the country, the then Department of Animal Husbandry, Dairying & Fisheries (DADF), Government of India, in 2016, set up a National Level Committee to Develop Guidelines for Cage Culture in Inland Open Waters (NCGCC) spearheaded by NFDB (NFDB, 2016). The main objectives of the committee were: (a) to evaluate the capacity of this culture system to enhance production, employment, income generation, and additional advantages, (b) to evaluate the potential environmental and socio-economic effects, (c) to recommend precautions to be implemented and (d) to propose methods for disseminating and expanding this technology to maximize advantages sustainably. However, the committee identified critical data gaps for developing such guidelines, particularly concerning the environmental and social impacts of cage culture activities. To address this gap, it was decided to formulate guidelines utilizing existing research from institutions and supplementary data from public sources. The "Guideline for Cage Culture in Inland Open Water Bodies of India," was published in September 2016 by NFDB (NFDB, 2016) that outlines detailed recommendations for site selection, culture procedures, and management practices. According to the guideline, cage culture is permitted in water bodies that have surface area of at least 1,000 ha at full reservoir level (with exceptions for deep abandoned mines), average depth of no less than 10 m, with the designated cage area maintaining a year-round depth of at least 10 m and a mandatory clearance of 6 m between the cage bottom and the reservoir floor. To ensure water quality, cage culture is prohibited in water bodies where the total phosphorus concentration exceeds 0.02 mg L^{-1} or total nitrogen exceeds 1.2 mg L^{-1}. Furthermore, the use of exotic species in cage culture is strictly forbidden, with the only exceptions being Pangasius and GIFT tilapia. The guideline also establishes the standard size of cage into $6 \times 4 \times 4$ m and limits on the number of cages allowed based on reservoir size: reservoirs between 1,001 and 2,000 ha may host up to 500 cages; 2,001 to 3,000 ha, up to 1,000 cages; 3,001 to 4,000 ha, up to 1,500 cages; 4,001 to 5,000 ha, up to 1,900 cages; 5,001 to 10,000 ha, up to 3,000 cages; and those exceeding 10,000 ha, up to 5,000 cages.

Mission cage culture of NFDB

In 2017, the erstwhile Department of Animal Husbandry, Dairying & Fisheries, Govt. of India launched "Mission Cage Culture" with the objective of enhancing fish production by achieving additional fish production of 75,000 metric tonnes through cage culture by the end of 2022 (NFDB, 2016). The mission had the target of installing 25,000 cages and a task force comprising of members from the DADF, NFDB, and ICAR-CIFRI and ICAR-CMFRI was constituted to ensure time-bound progress. In order to achieve the targets, a cluster-based approach was adopted in the implementation of the mission in identified areas wherein NFDB supervised the works and monitored the activities in collaboration with the State Governments in selected reservoirs. For better outcomes, the Mission Cage Culture adopted several strategies, which includes policy and scheme-level interventions to fill the demand-supply gaps, an integrated approach for enhancing fish production in the targeted water bodies, an increase in farming units of cage infrastructure, diversification of cultured fish species, and an area-specific and need-based approach for productivity enhancement - where only fingerlings are used for stocking in cage culture. Additionally, the promotion of culture-based fisheries in all identified open water bodies was emphasized.

Governmental financial assistance and subsidy

Cage culture supports the PMMSY's concept of "more crop per drop" by maximising fish production from existing water resources. The PMMSY has also

Table 1. Cage culture schemes and subsidy under BR & PMMSY

Scheme Component	Unit Cost	Govt. Subsidy
Establishment of Cages in Cold Water Regions	Rs 5 lakh/cage	60% for SC/ST/Women applicants and 40% for the other categories
Installation of Cages in Reservoirs	Rs 3 lakh/cage	-do-
Integrated Development of Reservoirs	Rs 3 lakh/cage	-do-

Source: Guidelines in Brief on CSS on Blue Revolution: Integrated development and management of Fisheries, DADF (NFDB, 2016); PMMSY Operational Guidelines (DoF, 2020)

Table 2. Inland cages installed in NER under BR and PMMSY Schemes

Sl.	State	BR 2014-15 to 2019-20	PMMSY 2020-21 to 2021-22	Estimated average production capacity (t/cage)*
1	Arunachal Pradesh	-	-	-
2	Assam	633	150	783
3	Manipur	72	200	272
4	Meghalaya	20	-	20
5	Mizoram	116	-	116
6	Nagaland	-	-	-
7	Sikkim	-	-	-
8	Tripura	168	-	168
Subtotal (NER)		**1009**	**350**	**1359**
Country Total (India)		14810	15554	
% of cages installed in NER against whole India		**6.8%**	**2.25%**	

Source: Handbook of Fisheries Statistics (DoF, 2023)
*considering an average of 1 ton fish per cage of 6 × 4 × 4 m size cage (96 m^3)

highlighted the vast potential of cage culture in untapped reservoirs, beels, lakes etc. and has stressed the need of disseminating the technology from demonstration level to commercial production. The scheme as detailed in Table 1 offers attractive subsidies to farmers for wider adoption of cage culture technology across the country.

As per "Handbook of Fisheries Statistics-2023" of the Department of Fisheries, Govt. of India, 1009 numbers of cages were installed in NER under BR scheme (2014 to 2020) and 350 numbers have been so far installed under PMMSY Scheme (2020-22) as shown in Table 2. Most of these cages were used for raising carp and catfishes in reservoirs, lakes and high-depth beels. There were 14810 and 15554 numbers of cages installed under BR and PMMSY schemes respectively across the country during the same indicated period which suggested that only 6.8% and 2.2% of the total cages have been installed in NER region. There were a few more cages installed in the region through NFDB-funded projects, Rashtriya Krishi Vikas Yojana (RKVY), and by ICAR-CIFRI for demonstration/experimental purposes.

These data indicated that in spite of vast available resources and attractive Governmental financial support, adoption of cage culture in the region is still low which suggest the need to research further into the gap and challenges and bring out the possible strategies to resolve the same.

Future prospects

The Northeastern States of India is home to diverse water bodies with varied ecological zones that support a wide array of aquatic life, many of which are indigenous and endemic to the region. However, not all water bodies are suitable for cage culture. NFDB recommended cage culture in large water bodies (surface area >1,000 ha) such as estuaries, lagoons, lakes, and large/medium reservoirs whose depth is >10 m so as to allow a minimum clearance depth of 6 m from the cage bottom (NFDB, 2016). While cage culture in rivers, streams, and small water bodies is not recommended due to ecological reasons, it is evident from the table below (Table 3) that there is tremendous scope for the development of cage culture in medium/large reservoirs and floodplain wetland/beels/oxbow lakes and sustainable farming methods and fish species may be explored for utilization of the vast available resources.

Table 3. Potential water resources for fisheries development

States	Medium & Large Reservoir	Tanks & Ponds	Beels/Oxbow Lakes/Derelict Water	High Altitude Wetland	Other than rivers & canals
	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)
Arunachal Pradesh	164*	29087	1382.7	11422.0*	57894.8
Assam	1863	85067.5	69719.2	-	404516.9
Manipur	1182	11892.8	29161	-	-
Meghalaya	1562*	4537.9	297.9	-	302.54
Mizoram	8000	5494.7	10	-	-
Nagaland	2258	3570	1110		-
Sikkim	-	-	-	3050.0*	-
Tripura	3049.3	29913.2	-		-
Total	**18078.3**	**169563.1**	**101680.8**		**462714.3**

Source**:***SAC, 2011; Handbook of Fisheries Statistics (DoF, 2023)

Lakes and floodplain wetlands: NER is known for its vast wetlands which serve as an important repository of diverse aquatic flora and fauna. Wetland delivers 45% of the world's natural productivity and ecosystem services (SAC, 2011). Assam has the largest number and area of wetlands in the region with records of 3513 large wetlands (> 2.25 ha) covering about 101231 ha (Hazarika *et al*., 2005). Manipur occupies the second place with 155 wetlands occupying an estimated area of 52,959 ha whereas Loktak Lake alone occupies an area of 24,672 ha and contributes to more than 50% of the State's fish production (Sharma, 2014; Dorothy *et al*., 2018). Cage culture has proven successful in large and deep lakes and wetlands for some specific fish species such as carp, catfish, etc. for both nursery rearing and fish production (Debnath and Yengkokpam, (2024). Das *et al*. (2018) recommended the installation of cages in beels for in situ production of carp fingerlings that can be later released in the same in beels for fish stock enhancement. Further, there are 1490 high altitude wetlands (HAW) spread out over 14,472 ha which are concentrated in Arunachal Pradesh and Sikkim (SAC, 2011). These wetlands may also be explored for the potentiality of cage culture to rear high-value coldwater fish species.

Reservoirs: NER has more than 30 reservoirs wherein 85% of the total water area are under medium and large reservoirs spread over an area span of 18078 ha (SAC, 2011; DoF, 2023). Tripura has the highest number of reservoirs with Dumbur as the largest (3049 ha). Other important reservoirs include Serlui and Tuirial of Mizoram, Sindga, Khuga, and Thoubal/Mapithal of Manipur, Umiam (Barapani) of Meghalaya, Subansiri of Arunachal Pradesh and Doyang of Nagaland. Cage culture has been successfully demonstrated in those major reservoirs across the region and is evident that there is a good scope of expansion for the enhancement of fish production (Goswami, 2015; Das *et al*., 2017; Hussan *et al*., 2018; Bhattacharjya *et al*., 2023).

Pond/Tanks: In-pond cages are proven successful for raising carp fingerlings that can be adopted by fish farmers, especially those who do not have specific pond area dedicated for nursery rearing or for stock enhancement of open waterbodies like lakes, reservoirs, rivers and beels (Das *et al*., 2017). In-pond cages can also be used for rearing different fish species or growth stages within the same pond at the same time period, based on consumer demands.

Potential impact of cage culture on socio-economic status: Cage culture can potentially improve the socio-economic status in Northeast India by utilizing the region's abundant water resources to generate income and employment, especially in rural and tribal areas. It requires minimal water area, offers high returns in a short time, and encourages participation of women and youth. With proper support, cage farming can enhance food security, reduce migration, and uplift livelihoods by integrating communities into sustainable aquaculture practices (Rajesh *et al*., 2020).

Challenges and mitigation strategies

Sustainability: The sustainability of this aquaculture technology solely lies in the management practices followed as the fish culture activity is directly carried out in existing natural water bodies and ecosystems. Any negligence and mismanagement of cage culture could adversely hamper the natural ecosystem like severe eutrophication, introduction of predators, pathogenic micro-organisms, and non-native fish

species, etc. (Gopalakrishnan *et al*., 2015; NFDB, 2016). These factors could potentially upset the trophic chain and impact the resource resilience and local biodiversity balance (Gopalakrishnan *et al*., 2015). For long-term sustainability, the authors suggested avoiding the use of trash fish for feed and following green guidelines in the seed supply chain. Use of fish feed (without/minimum use of fish meal) by alternative protein sources such as soybean meal and plant leaf meal in feed formulation can promote sustainability in cage culture (Dorothy *et al*., 2018). NFDB (2016) suggested avoidance of using sinking feed to prevent wasted feed accumulation at the bottom to prevent cage fouling and related environmental impacts.

Technology adoption: There is poor adoption of cage culture technology amongst the farmers in the region in spite of large potential water bodies, attractive Governmental subsidies and successful demonstrations in different water bodies with various fish species across the States of NER. There is a need for more awareness and technical training on cage fabrication, installation, culture and sustainable management. To encourage farmers, more awareness is required on various Governmental schemes and subsidies that support cage culture such as PMMSY and its sub-schemes like "Aquaculture crop Insurance Scheme" which provides incentives for crop loss, and "Group Accident Insurance Scheme" which provides insurance claims of accident/death to fishers/farmers.

Research and development: The technology adoption in the region is still low as indicated above which suggests the need for further in-depth research development based on the region-specific needs such as specific design and fish species suitable for specific water bodies (low-depth floodplain wetlands, mountain streams and rivers, very deep barrages etc) with economic feasibility. For example, Assam has vast floodplain wetlands but with high weed infestation and low depth which according to the guidelines laid down in the BR and PMMSY for cage culture, is unsuitable. Furthermore, States such as Sikkim and Arunachal Pradesh have vast HAW area which could potentially be used for the production of high-value cold-water fish using cages, requiring specific research, demonstration and guidance for implementation by farmers. NFDB (2016) also stated the lack of information on actual water resources suitable for cage culture, carrying capacity, etc, which suggested the need for resource mapping and more research and development on the technology.

Vulnerabilities to natural disasters: Cage culture directly involves activity in open water bodies and therefore, is vulnerable to natural disaster risks such as storms, floods, and cyclones etc that could damage the cages and lead to crop loss. Cage culture involves the risk of operating in a hazardous environment, necessitating the implementation of all safety measures to prevent injury and fatalities during cage installation and farming management (NFDB, 2016). As per NFDB guidelines, the PMMSY sub-scheme such as the "Aquaculture crop insurance scheme" provides incentives of up to Rs. 1.0 lakh for one crop cycle and unit up to 1800 m^3 of cage per farmer in the event of crop loss due to natural disaster. The "Group Accident Insurance Scheme" with zero premium contribution from the fisher/farmers provides insurance claims to a certain amount in the event of an accident leading to hospitalization, disability, and death.

Climate change can also impact cage farming through temperature variance and erratic changes in climate like rainfall, snowfall, cyclones, and storms etc which may damage and or destroy the cages and the rearing crops. To address these issues, strategies like using climate-resilient fish species, robust cage designs (GI/HDPE), proper site selection, seasonal stocking, and real-time water monitoring are essential, along with farmer training and policy support (Dutta and Sarma, 2016; Rajesh *et al*., 2020).

Policy and Institutional support: As cage culture is a fishery activity being carried out in open water bodies, resource mapping by respective States for the demarcation of suitable water bodies where cages can be installed, is a basic requirement (NFDB, 2016). As the Government currently promotes the establishment of Fishermen Cooperative Societies (FCS), Farmer Producer Organizations (FPOs) etc, these institutions should be provided licenses to carry out cage culture. Debnath (2023) recommended a "community-based cage culture" in NER with close involvement and participation of the local community, for sustainability and livelihood promotion. Private entrepreneurs or investors engaging in cage culture in the open water bodies of Northeast India must be supported by robust Government laws to safeguard the interests of local fishermen and fishing communities, who possess primary rights to the natural resource (NFDB, 2016). Sugunan (2015) recommended supportive Government policies, financial incentives, and collaborations between research institutions, Government agencies, and local communities to further cage culture.

Conclusion

The northeastern region of India holds significant potential for the development of cage culture by judiciously utilizing existing water resources, including reservoirs, lakes, floodplain wetlands, and mini-barrages. Properly managed cage culture can augment the production of aquatic environments through intense aquaculture, by optimizing space and regulating feeding practices. The success of cage culture has been well demonstrated across different water bodies of the region with various suitable fish species. Cage aquaculture can not only boost fish production but also foster entrepreneurship and employment generation opportunities thereby, contributing to the upliftment of economic, social as well as nutritional status of the local fisher folks. While the potential for development and benefits are significant, it is also essential to ensure the ecological balance and integrity of water ecosystems. The various challenges for the development of the technology in the region can be efficiently mitigated with more research and development to suit the regions' geographical, climatic and farmers' conditions and with proper policies. There are attractive Governmental schemes with financial subsidies/incentives that promote cage culture in inland water bodies. However, for widespread dissemination and adoption, more awareness programs, technical training and hand-holding supports are still required.

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Data availability statement: The data that support the findings of this study are available from the corresponding author on reasonable demand.

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