



Aquaculture Potential of Freshwater Swamp Eels (Synbranchidae), Highlighting *Monopterusuchia* Farming in India

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Abstract

Global aquaculture has experienced remarkable growth over the past decade, driven largely by the introduction of diverse fish species into farming systems. Among these, freshwater swamp eel (*Monopterusuchia*) farming offers a promising opportunity for diversification in tropical countries. Unlike the complex catadromous lifestyle of anguillid eels (Anguillidae), freshwater swamp eels complete their entire life cycle in freshwater, making them comparatively easier to rear and harvest with lower input costs. There are 23 known freshwater swamp eel species worldwide, including two in India: *M. albus* and *M.uchia*. Developing freshwater swamp eel farming in India could significantly advance the aquaculture industry by integrating both traditional and super-intensive production systems. However, existing studies on the biology and habitats of these species remain largely superficial, leaving their full aquaculture potential underexplored. This review article aims to provide researchers and stakeholders with insights into the biology and farming potential of *M.uchia* in India. It also highlights the domestic and international market potential of this species. Adopting this farming approach could diversify aquaculture production, create new opportunities

for both domestic markets and export, while supporting socio-economic development and national welfare.

Keywords: Freshwater swamp eel, *Monopterusuchia*, diversification, aquaculture, market potential

Introduction

Global aquaculture production has intensified rapidly with the introduction of new farming practices and advanced technologies, driven by increasing demand from a growing global population. Currently, global aquaculture production is estimated at approximately 94.4 million tonnes (Food and Agricultural Organization of the United Nations [FAO], 2024). Eels, consumed worldwide, play a significant role in the global fish industry, particularly in East Asian countries. More than 90% of eel production is based on Anguillid eels, which rely on wild-caught glass eels for stocking (Shiraishi & Crook, 2015). In the past 30 years, global eel production has increased substantially due to the expansion of eel farming. By 2018, 47 countries were engaged in eel production, generating a total output of 277,103 tonnes and facilitating 2.67 billion eel imports and exports (FAO, 2020). China dominates global eel production through aquaculture, accounting for more than 80% of the total production, with profit margins exceeding 60% (FAO, 2020). Japan is the largest consumer of eels, accounting for nearly 50% of global consumption. In Japan, when glass eel recruitment is scarce, the price of glass eel can surge to as high as USD 35,000 per kilogram, driven by

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demand for unagi production (WELT Food, 2025). Presently, the glass eel is priced around USD 15,000 per kilogram (Takeuchi, 2024). Major eel production regions are concentrated in Asia, including China, Japan, South Korea, Taiwan, and other areas, with secondary production occurring in Europe, Africa, and the United States (FAO, 2020). In China, the eel industry has developed an export-oriented industrial chain, with substantial economic returns from various stages, including glass eel rearing, grow-out eel culture, feed manufacturing, processing, and export integration, resulting in an annual output value of USD 1.5 billion (FAO, 2020). Globally, around 1,000 eel species have been reported, with approximately 125 species recorded in India (India Today, 2016).

The eel industry is heavily reliant on natural resources, and the declining availability of glass eels poses a serious threat to its development (Yuan, Yuan, Dai, Gong, & Yuan, 2022). Currently, eel farming is dominated by anguillid eels (Anguillidae); however, their complex catadromous lifestyle and the difficulty in producing early-life stages in captivity limit the potential for further production expansion of these species. In contrast, most freshwater swamp eels (Synbranchidae) complete their entire life cycle in fresh water, and some swamp eels have characteristics that make them amenable to captive rearing, thereby offering opportunities to expand commercial eel farming. To date, 23 species of freshwater swamp eels have been reported globally (Eschmeyer, 2016), highlighting their potential in aquaculture and export markets. In Asia, two genera of freshwater swamp eels are present: *Macrotrema*, with a single species, and *Monopterus*, comprising two species. India hosts the genus *Monopterus*, represented by *M. albus* and *M.uchia* (Neog & Konwar, 2023). Freshwater swamp eels are commercially important, particularly in India, where they are highly valued due to its palatability and high nutritional content (Devi, Laskar, Baruah, & Sharma, 2017; Neog & Konwar, 2023). Despite strong consumer demand, export value, and recognition of its medicinal properties, with a domestic price of Rs. 800 per kilogram, production levels remains significantly low. At present, farming practice involves the capture and rearing of juvenile freshwater swamp eels from wild, underscoring the need to develop standardized breeding and culture protocols to ensure sustainable seed production and support selective breeding programs. The successful establishment of

such protocols would reduce dependence on wild capture fisheries. Given the growing need to boost fish production through species diversification in response to evolving consumer demands, the development of freshwater swamp eel (*M.uchia*) farming could contribute to increased fish production in India's domestic and export markets. This review article focuses on freshwater swamp eel diversity, distribution, biology, induced breeding, existing farming practices, culture potential, domestic and export market potential, economic aspects, and future perspectives for the development of *M.uchia* farming in India.

***M.uchia* taxonomy, distribution, and biology**

Taxonomy

Freshwater swamp eels are classified under the family Synbranchidae within the order Synbranchiformes. The family encompasses four genera: *Macrotrema*, *Monopterus*, *Ophisternon*, and *Synbranchus* (Rosen & Rumney, 1972). Currently, the genus *Macrotrema* is represented by a single species; *Monopterus* comprises 13 species; *Ophisternon* includes six species; and *Synbranchus* consists of three species (Eschmeyer, 2016). Among these, the genera *Macrotrema* and *Monopterus* are restricted to Asian countries (Supiwong et al., 2019). In India, the genus *Monopterus* is represented by two species: *M. albus* and *M.uchia*. Both species are of aquaculture importance (Neog & Konwar, 2023), with *M.uchia* more commonly found in the northeastern part of India.

Taxonomical classification of the M.uchia – Hamilton, 1822:

Kingdom: Animalia

Phylum: Chordata

Sub-Phylum: Vertebrata

Class: Osteichthyes

Infraclass: Actinopterygii

Order: Synbranchiformes

Family: Synbranchidae

Genus: *Monopterus*

Species: *M.uchia*



Fig. 1. *Monopterusuchia*

M. cuchia is characterized by a slender, streamlined body with a tapering tail (Day, 1878), and lacks pectoral, pelvic, and dorsal fins (Fig. 1). Instead, the dorsal and anal fins are fused with the caudal fin, forming a continuous ribbon-like structure along the length of the gill region. The gills of *M. cuchia* are diminished, and the species possesses a pair of air-breathing sacs located on either side of the head (Talwar & Jhingran, 1991). Additionally, two supra-branchial chambers are present, each containing a complex labyrinthine organ (Mittal & Agarwal, 1977). Pharyngeal pouches develop early in life but become functionally active only at later stages (Mittal, Whitear, & Agarwal, 1980). *M. cuchia* population exhibits 11 distinct morphometric parameters listed in Fig. 2 and 3, of which eight measurements demonstrate significant sexual dimorphism. In comparison, five morphometric measurements of *M. albus* resemble those of *M. cuchia*, including lateral line length, upper jaw length, eye diameter, head width, and maximum body width (Devi, Baruah, & Sharma, 2016). Notably, female *M. cuchia* are larger than males (Fig. 4), whereas the

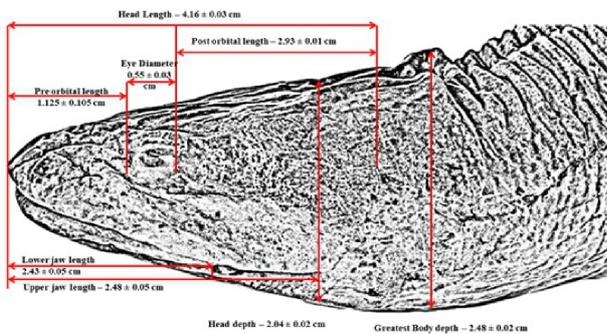


Fig. 2. Morphometric measurements of *Monopterusuchia* – Lateral View (Software: Adobe Illustrator V. 2022).

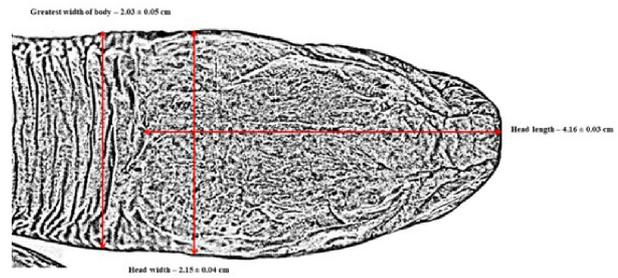


Fig. 3. Morphometric measurements of *Monopterusuchia* – Top View (Software: Adobe Illustrator V. 2022).

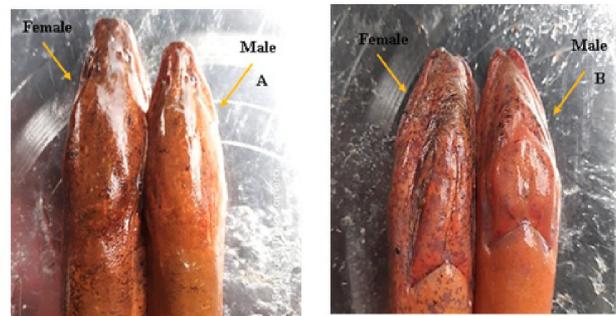


Fig. 4. Male and female of *Monopterusuchia* (Dorsal view: A; Ventral view: B)

opposite pattern is observed in *M. albus*. Furthermore, seven morphometric measurements differ significantly between *M. cuchia* and *M. albus*, namely pre-anal length, pre-orbital length, maximum body diameter, greatest body depth, lower jaw length, mouth gape, and head depth (Devi et al., 2017).

Distribution

Globally, the freshwater swamp eels are primarily distributed across Asian tropical and subtropical regions, the Indo-Australian Archipelago, West Africa (specifically Liberia), Mexico, and Central and South America (Nelson, Grande, & Wilson, 2016). *M. cuchia* typically prefers the muddy bottom and live in holes and crevices of the swamps, wetlands, and other shallow, stagnant, or slow-flowing water bodies such as ponds, canals, swampy areas, and rice fields. Owing to their air-breathing capability, they are able to survive in low-oxygen environments and live without water for 4 to 5 months (Neog & Konwar, 2023). The species holds significant economic, consumable preference, and medicinal value among tribal communities, viz, Hajong, Garo, Manipuri, Shaotal, and Rajbongshi of Northeastern India. In India, *M. cuchia* was predominantly found in 18 water bodies in

Assam and three water bodies in Manipur (Devi et al., 2017). The distribution of *M. cuchia* populations across these water bodies is demarcated in Fig. 5.

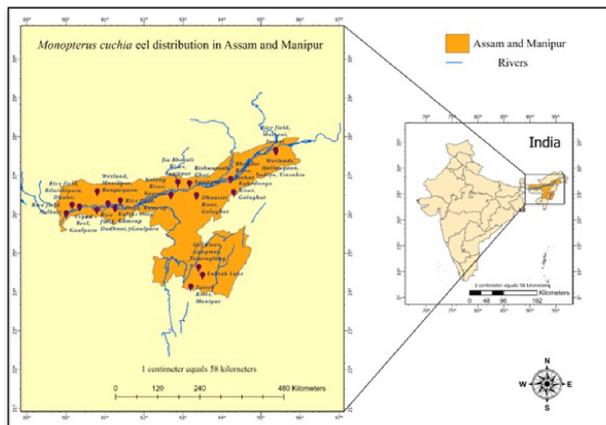


Fig. 5. The distribution of the *Monopterus cuchia* population in the water bodies of Assam and Manipur

Biology of *M. cuchia*

M. cuchia is reported to be a carnivorous species, feeding extensively on small fish, amphibians, crustaceans, echinoderms, insect larvae, and other aquatic invertebrates. This species typically exhibits isometric growth, with the relative condition factor (Kn) peaking during the spawning season, indicating maturity. Maturation generally occurs once the fish reaches a length of 25.2 to 65 cm (Miah et al., 2013; Miah, Naser, & Ahmed, 2015), and survival rate range between 80 and 94%. Providing water hyacinths as shelter can enhance both the survival and growth rates of the fish. *M. cuchia* demonstrates the highest growth in terms of weight gain when fed with bycatch, whereas growth was lowest when fed pellet feed (Miah, Naser, & Ahmed, 2015).

Reproductive Biology

Sexual differentiation

The male and female *M. cuchia* are difficult to distinguish during the resting season; however, distinct morphological traits become evident during the breeding season and aid in their differentiation. In females, the abdomen becomes noticeably swollen, exhibiting a pink to brownish coloration with a rough texture and spots all over the body. In contrast, males possess a smooth, brownish abdomen without spots over the entire body. Furthermore, the genital papilla is tubular in males, whereas it is round in females (Fig. 6). During the

breeding season, females attain a larger body size than males, with an average weight of 0.34 kg and a length of 78 cm.

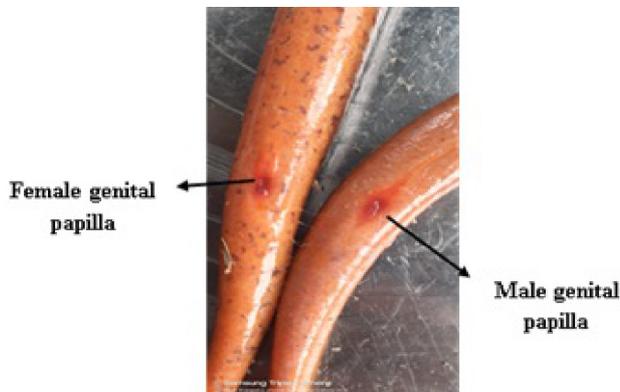


Fig. 6. Male and female identification through the genital papilla



Fig. 7. Male and female *Monopterus cuchia*

Gonadosomatic Index

In *M. cuchia*, the gonadosomatic index (GSI) attains its peak between April and June for both females and males, with the highest GSI value at 7.52 ± 1.15 in females and at 5.50 ± 1.25 in males, respectively. Additionally, this species was found to breed seasonally during the summer months (Narejo, Rahmatullah, & Rashid, 2003). In contrast,

Chakraborty (2018b) reported that gonadal development in both sexes progresses from December to May, reaching peak GSI values in May (2.52 ± 0.44 for males and 9.04 ± 1.02 for females). After this peak period, GSI values decline from June to November in both sexes. Generally, GSI values range from 0.70 ± 0.01 to 2.52 ± 0.44 in males and from 1.09 ± 0.02 to 9.04 ± 1.02 in females. However, Kurbah and Bhuyan (2018) observed that male GSI reached its peak value of 3.4 ± 0.8 in May, while the lowest value of 0.02 ± 0.1 was recorded in September. In females, the highest GSI value of 7.33 ± 0.081 was recorded in May, whereas the lowest value of 0.27 ± 0.089 occurred in December.

Male reproductive system

The male reproductive system consists of a single, elongated testis located beneath the swim bladder. The testis extends posteriorly and ventrally, connecting to the vas deferens, which subsequently fuse to

form a sperm duct that opens externally through the urinogenital aperture. Breeding is asynchronous, as the testis contains various types of spermatogenic cells within its lobules. The testis undergoes development through four distinct stages, with each stage being characterized by different colours. The different stages of testicular development are demarcated in Table 1 according to Chakraborty (2018b) and Kurbah and Bhuyan (2018).

a. Different stages of spermatogenesis of male *M. cuchia*

Spermatogenesis in the male is characterized by four distinct stages: spermatogonia, spermatocytes, spermatids, and spermatozoa (Miah et al., 2013; Chakraborty, 2018b). The structural characteristics, size, and corresponding developmental stages observed throughout the year are summarized in Table 2.

Table 1. Different maturity stages of the testis of the male *Monopterus cuchia*

Stage of maturity	Testis Characteristics				References
	Length group (cm)	Texture	Color	Histological examination	
Premature stage (Stage I)	10.5-11.5	Turgid	White	The tubules had a short diameter and were compactly packed, predominantly with spermatogonia. The walls of the tubules were thick.	Chakraborty (2018b); Kurbah and Bhuyan (2018)
Early maturing (Stage II)	11.6-12.4	Turgid and folded structure	Opaque and creamy whitish	The tubules had a large diameter, with spermatocytes and spermatids predominating. Spermatogonia were localized near the germinal epithelium only. The walls of the tubules were thin.	
Mature (Stage III)	12.5-14.2	Turgid, folded, and tight structure	Creamy whitish	The tubules had a very large diameter and were filled with spermatids and spermatozoa.	
Spent (Stage IV)	10.5-12.8	Loose	Dull white	The lumen of the tubules is irregular, with a gap between the germinal epithelium and the sparse germ cells, which include residual spermatozoa.	

Table 2. Different stages of spermatogenesis of male *Monopterusuchia*

Stages	Month of development	Size of the cell (μm)	Structure	References
Spermatogonia	December to mid-February	18.4	The structure is spherical and basophilic, characterized by a network of chromatin material and nucleoli.	Miah et al. (2013); Chakraborty (2018b)
Spermatocytes	Late February to March	8.4	The structure is spherical and contains a centrally positioned nucleus.	
Spermatids	April	5.3	The nuclei exhibited uniformly condensed chromatin material.	
Spermatozoa	May to June	6.0	The spermatozoa were crescent-shaped with a short tail.	

Female reproductive system

The female reproductive system of *M.uchia* is characterised by a single, elongated ovary that exhibits multiple stages of oocyte development. The ovary is cylindrical in shape and is suspended within the abdominal cavity (mesovarium). It consists of a single ovarian lobe enclosed by an ovarian membrane and contains numerous ovarian lamellae protected within the ovarian cavity. The ovarian cavity is connected to the oviduct, which opens externally through the genital pore. The ovary typically in length measures between 11.1 to 15.9 cm in length, and the developing and maturing ovaries exhibit colors including creamy, brownish, and yellowish hues, respectively (Miah et al., 2013; Chakraborty, 2018b). The different stages of ovarian maturity are detailed in Table 3.

a. Different stages of oogenesis of female *Monopterusuchia*

Oogenesis in females is characterized by six distinct oogenesis stages: oogonia, early perinuclear stage (EPN), late perinuclear stage (LPN), early vitellogenic stage (EVS), advanced vitellogenic Stage (AVS), and atretic stage (AS) (Miah et al., 2013; Chakraborty, 2018b). The structural characteristics, cell sizes, and corresponding developmental stages observed throughout the year are summarized in Table 4.

Nutritional profile of *Monopterusuchia*

The nutritional profile of *M.uchia* varies seasonally, with the protein content in eel flesh reported to be

approximately 14 g (Miah, Naser, & Ahmed, 2015). In contrast, Rana, Faruque, Eshik, Hasan, and Rahman (2019) reported protein contents ranging from 17.3% to 19.3%, while the fat content ranged from 0.3% to 2.4%, moisture content from 78.9% to 79.9%, and ash content from 1.1% to 1.2%. However, Faruque, Bhuiyan, Fatema, and Hasan (2019) observed protein contents ranging from 16.42% to 16.80%, with fat contents between 0.71% and 0.83%, ash contents between 0.98% and 1.02% and moisture content ranging from 80.71% to 81.25% in both males and females. The freshwater swamp eel species is notable for its high concentrations of lysine and glutamic acid, where lysine plays an essential role in protein synthesis and overall growth, and glutamic acid contributes significantly to cellular metabolism and brain function. Additionally, arginine, glycine, and aspartic acid are present in relatively higher amounts compared to other amino acids in the protein profile (Faruque et al., 2019; Rana et al., 2019).

Similarly, *M.uchia* eel contains twenty-five different fatty acids, as presented in Table 6. The total percentage of saturated fatty acids (SFAs) ranges from 33.9% to 55.8%, compared to monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs) throughout the year. Among the SFAs, palmitic acid (C16:0) was the most prevalent, accounting for 15.98% to 22.10%. The predominant MUFAs were oleic acid (C18:1) and palmitoleic acid (C16:1). Within the PUFAs, linoleic acid was the most abundant, ranging from 5.4% to 17.79%, along with significant amounts of α -linolenic acid (C18:3)

Table 3. Different maturity stages of the gonad of the female *Monopterusuchia*

Stage of maturity	Length group (cm)	Size (μm)	Ovary characteristics		Histological examination	References
			Texture	Color		
Privitello-genesis	12.2-14.8	10.5	Turgid and folded structure	Opaque and creamy white-brownish	The tubule is densely populated, predominantly with oogonia, and exhibits a thick wall. The nuclei are enlarged and contain numerous nucleoli. The cells are basophilic with dense and homogeneous cytoplasm. There is an increased number of follicular cells surrounding the oocyte, and the zona radiata is visible.	Miah et al. (2013); Chakraborty (2018b)
Vitello-genesis	14.9-15.9	11.2	Turgid and folded structure	Creamy yellowish	The ovary is expanded and occupies the entire cavity. The oocyte is compact and contains numerous yolk granules. The nucleus is relatively small and contains nucleoli. The oocyte is encased by a well-defined zona radiata.	
Atretic stage	15.9-11.1	10.2	Loose	Dull brown creamy	The lumen of the tubules is irregular. Atretic oocytes resulted from the reabsorption of both non-vitellogenic and partially vitellogenic oocytes, while the atresia of mature oocytes was due to the reabsorption of mature oocytes.	

and arachidonic acid (C20:4). Additionally, the n-3 to n-6 fatty acid ratio ranges from 0.90 – 0.93 in *M. cuchia* (Faruque et al., 2019; Rana et al., 2019).

Induced breeding of *M. cuchia*

M. cuchia typically spawns from May to June, during the summer months. The average fecundity of this species ranges from 150 to 924 eggs (Kurbah & Bhuyan, 2019). The ova diameter of *M. cuchia* was found to be 3 to 4 mm between September to May, consistent with findings by Singh, Towheed, and Munshi (1989). In comparison, the closely related species *M. albus* had a similar ova diameter; however, it was not uniform (Khanh & Ngan, 2010). Usually, the juveniles or the adults of *M. cuchia* typically weigh between 190 g and 280 g and are collected from wetlands, bheels, swamps, lakes, and rivers. They were reared in ponds with a depth of

1 to 1.25 m, where plankton blooms are induced by using fertilisers such as urea, TSP, and cow dung prior to stocking. Additionally, the ponds are covered with water hyacinths and PVC pipes to create shelter and simulate a natural habitat. Typically, juveniles and adults are fed earthworms or small fish at 3% of their body weight to facilitate broodstock development (Begum, Pramanik, Khan, & Mahmud, 2017). Other fish species such as *Mastacembelus pancalus*, *Cyprinus carpio*, *Channa punctatus*, and *Lepidocephalus guntea* were also stocked because they are multiple spawners, and the larvae of these species are naturally consumed by the adults themselves, which is vital for the broodstock development.

The first attempts at induced breeding of *M. cuchia* using pituitary gland extract were initiated by Rahmatullah, Rahman, and Ahmed (2005). How-

Table 4. Different stages of oogenesis of the female *Monopterusuchia*

Stages	Month of development	Structure	References
Oogonia	May and June	Oogonia are small, spherical cells that are characterized by the presence of a single, prominent nucleolus. These cells represent the earliest stage in oocyte development, serving as the progenitors for subsequent stages of oocyte maturation.	Miah et al. (2013); Chakraborty (2018b)
Early Perinucleolus Stage (EPN)	January	The nucleoli are situated at the periphery of the nucleus. This stage is characterized by basophilic cells with a dense, homogeneous cytoplasm.	
Late Perinucleolus Stage (LPN)	January to Mid February	The cytoplasm is homogeneous and basophilic. At this stage, the oocytes are distinguished by the presence of a small yolk nucleus.	
Early Vitellogenesis Stage (EVS)	April	In the initial stage of the secondary growth phase, transparent cortical alveoli begin to appear. During this stage, the number of alveoli increases, leading to only a small zone of basophilic cytoplasm remaining around the nucleus in the larger oocytes. The formation of yolk granules follows the micropinocytosis of vitellogenin and the fusion of endocytic vesicles.	
Advanced Vitellogenesis Stage (AVS)	May	The oocytes progressively enlarge, with their nuclei becoming centrally positioned within the cells. During this growth phase, cortical alveoli are distributed throughout the oocyte, appearing at both the periphery and in the perinuclear region. This distribution reflects the ongoing development and maturation of the oocytes, as the cortical alveoli contribute to the formation of the yolk and other essential components required for subsequent stages of oocyte development.	
Atretic Stage (AS)	Late July to February	Atretic oocytes arise from the reabsorption of both non-vitellogenic and partially vitellogenic oocytes. In contrast, the atresia of mature oocytes is specifically due to the reabsorption of oocytes that have reached full maturity. This process reflects a selective mechanism where oocytes that do not progress or reach the final stages of development are systematically removed, ensuring that only the most viable oocytes continue to advance through the maturation process.	

ever, these were unsuccessful due to higher doses experimented within the study, which caused mortality among the breeding population. Similarly, Miah, Ali, Zannath, et al. (2015) reported unsuccessful induced breeding attempts using pituitary gland extract, human chorionic gonadotropin (HCG),

gonadotropin-releasing hormone (GnRH), and Ovuline (a synthetic hormone) in *M.uchia*. Recent advancements in technology and knowledge on reproductive biology and behaviour have helped the success of induced breeding of different species. Hence, the first successful attempt on the induced

breeding of *M. cuchia* was achieved by Begum et al. (2017) using various hormones (cPGE, cuchia PG (Pituitary Gland), ovaprim, pregnyl, and HCG) with different dosages in different substrates (hapas, cement cisterns, and ponds). Hormones such as cPGE, cuchia PG (Pituitary gland), ovaprim, and HCG were inefficient in elucidating the breeding and spawning response of *M. cuchia* in hapas and cement cisterns, but pregnyl hormones were highly successful in ponds. Female with an average size of 350 g and male with an average size of 230 g were used for breeding. Female brooders were injected with pregnyl at a single dosage of 1000 IU/kg body weight, while male brooders received a single injection of 500 IU/kg body weight. The brooders were then released into ponds at a ratio of 1:1 (M: F), where several spawning pits were prepared by the brooders. Around 3000 larvae were collected from the spawning pits after drying up the pond completely. It is reported that each spawning pits were held with one male and one female during the spawning season, where the females were found to be guarding the eggs. Similarly, Kurbah and Bhuyan (2019) reported the successful attempt on induced breeding using Gonopro-FH (1 mL/kg for females; 0.3 mL/kg for males), resulting in a fecundity of 924 eggs with 75–80% fertilization and 80–85% hatching

rate. However, only very few studies were reported on the induced breeding attempt on the *M. cuchia*; hence, a wide exploration is required to standardise captive maturation and breeding protocols for commercial seed production and to enrich the declining native population. Begum et al. (2017) described the larval rearing protocols of *M. cuchia*. Three-day-old larvae were collected and stocked at 1,000/m² in two cement cisterns (2.74 × 1.82 × 1.00 m) and a tray (1.0 × 0.5 × 0.12 m). The units were covered with clay soil in the bottom, and the tanks were provided with water hyacinth for shelter. Water depths were maintained at 0.45 m (cistern) and 0.12 m (tray), and showers were turned on at frequent intervals to improve oxygenation and hygiene. Larval yolk sacs were fully absorbed by the 12th–15th day, after which larvae were fed boiled egg yolk (morning) and earthworm juice (two feedings) at 80–90% body weight for the first three days post-yolk sac absorption. From the third day onward, the larvae were fed earthworm, zooplankton, and chopped tubifex thrice daily at 5–10% body weight. Initial mean size was 4.86 ± 0.24 cm, 0.07 g (tray) and 4.16 ± 0.28 cm, 0.07 g (cistern). After four months, fry reached 10.68 ± 1.89 cm, 1.09 g (tray) and 10.78 ± 0.28 cm, 1.02 g (cistern), with survival rates of 80% and 77%, respectively.

Table 5. Amino acid profile of *Monopterus cuchia*

Amino Acids	Percentage of Amino Acids	References
Threonine	0.81	Faruque et al. (2019); Rana et al. (2019)
Valine	1.02	
Methionine	1.35	
Isoleucine	1.18	
Leucine	1.30	
Lysine	2.44	
Essential Amino Acids	8.10	
Aspartic Acid	1.38	
Serine	1.03	
Glutamic Acid	2.14	
Glycine	1.96	
Alanine	1.03	
Histidine	1.21	
Tyrosine	1.03	
Arginine	2.12	
Non-Essential Amino Acids	11.90	

Culture potential and practices of *M. albus*

M. albus can be cultured using two main methods based on water conditions: stagnant water culture and running water culture. The primary objective of these methods is to rear eels at higher stocking densities in confined areas while providing additional oxygen and food to maximize production within a short period. Based on the culture methods,

freshwater swamp eel farming can be categorized as: 1) monoculture and 2) polyculture. In polyculture, the selection and stocking density of co-cultured species depend on their expected roles in the ecosystem. Suitable species for polyculture include silver carp, bighead carp, common carp, mud carp, and striped mullet. Currently, *M. albus* breeding and seed production remain largely unexplored, with most farmers relying on wild capture. Hence,

Table 6. Fatty acid profile of *Monopterus albus*

Fatty Acids	Percentage of Fatty Acids	References
Saturated Fatty Acids		
Caproic acid (C6:0)	2.28	Faruque et al. (2019); Rana et al. (2019)
Caprylic acid (C8:0)	3.46	
Lauric acid (C12:0)	5.04	
Tridecanoic acid (C13:0)	0.28	
Myristic acid (C14:0)	4.10	
Pentadecylic acid (C15:0)	1.14	
Palmitic acid (C16:0)	19.29	
Stearic Acid (C18:0)	5.10	
Arachidic Acid (C20:0)	1.44	
Behenic Acid (C22:0)	0.36	
Lignoceric Acid (C24:0)	1.63	
Total Saturated Fatty Acids (SFA)	44.15	
Monounsaturated Fatty Acids (MUFAs)		
Myristoleic Acid (C14:1)	1.17	
Pentadecenoic Acid (C15:1)	0.41	
Palmitoleic Acid (C16:1)	9.26	
Oleic Acid (C18:1)	21.91	
Eicosenoic Acid (C20:1)	0.27	
Total Monounsaturated Fatty Acids (MUFAs)	33.03	
Polyunsaturated Fatty Acids (PUFAs)		
Hexadecadienoic Acid (C16:2); n-3	0.90	
Hexadecatrienoic Acid (C16:3); n-3	1.69	
Linoleic Acid (C18:2); n-6	9.86	
á Linolenic Acid (C18:3); n-3	2.54	
Eicosadienoic Acid (C20:2); n-6	0.43	
Arachidonic Acid (C20:4); n-6	2.39	
Eicosapentaenoic Acid (C20:5, EPA);n-3	0.29	
Docosapentaenoic Acid (C22:5); n-3	2.07	
Docosahexaenoic Acid (C22:6 DHA); n-3	2.60	
Total Polyunsaturated Fatty Acids (PUFA)	22.79	

developing and standardizing a culture protocol was an urgent need to explore the commercial farming of *M. cuchia* in India.

In India, the freshwater swamp eels are usually collected at night in the lower reaches of rivers, wetlands, swamps, ponds, beels, and similar aquatic environments. Juveniles weighing between 50–70 g are considered ideal for stocking, and common collection gear includes scoop nets, bag nets, dip nets, screen nets, plankton nets, and Japanese elver nets (Dorairaj, Soundararajan, & Kandasamy, 1980). Juveniles are transported in insulated containers with adequate aeration. Stocking density primarily depends on the quality and quantity of the water. In running water ponds, the stocking density is generally higher compared to stagnant ponds. Eels of size 50–70 g are stocked in all ponds at a density of 10 eels per square meter. Adequate hiding places are essential for high survival rates, and artificial feeding is a crucial component of eel farming. Initially, juveniles may not consume feed for several days but gradually adapt to regular feeding. They require dark environment for feeding, and the feeding area should be equipped with shelters. To prevent water contamination, feed should be placed in a wire basket or tray. Eels can be grown in the compost prepared using farm-grown vegetables, vegetable waste (Anouba Manipur, 2021), and live feed, such as earthworms and tubifex, provided at a rate of approximately 2–3% of the estimated body weight. Successful culture of *M. cuchia* was experimented within a tank system having a capacity of 1.5 m³, where eels with an initial weight of 24.62 ± 0.14 g grew to 109.69 ± 2.92 g within 60 days. The highest production yield was about 4.07 kg in the earthen-ditch system with a 92.5% survival rate compared to plastic and backyard tanks. During the culture period, fish were fed with small live fish, earthworms, small dead fish, snails, small frogs, and chicken viscera, with the diet proportion formulated according to the nature of the system (Miah, Ali, Jannat, Naser, & Ahmed, 2015). Consequently, the experiment conducted on the successful rearing of fry in cemented cisterns showed a significant growth response. Fry with an initial body weight of 0.66 ± 0.05 g were stocked in cemented cisterns (2.75 m³) at 75, 100, and 150 no's per m². After 45 days, the cistern stocked with 75 no's per m² exhibited the highest growth performance, attaining a mean body weight of 5.32 ± 0.04 g and an average survival rate of 70.34 ± 1.25%. Throughout the experimental

period, fish were fed with a diet containing earthworm juice and slices at 20–50% of their body weight across all the treatments (Sharmin, Sarwer, Das, & Rahman, 2016). Similarly, the effect of stocking densities on the growth performance of *M. cuchia* was studied by Chakraborty, Shahroz, and Lucky (2018), where fish stocked at a rate of 7410 fingerlings per ha in an earthen pond (0.14 ha) resulted in superior growth performance and survival rate compared to other treatments stocked with higher densities (9880 and 12,350 fingerlings per ha), with a significant weight gain of 362.10 ± 5.74 g from 99.10 ± 1.80 g in a span of 240 days and highest production rate of 2505.73 ± 8.38 kg per ha with a FCR of 1.95 ± 0.04 and a survival rate of 93.40 ± 1.27%. Rearing of *M. cuchia* in different ditches, namely concrete, tripal, and normal, also influenced the growth performance, where normal ditch treatment has shown significant weight gain of 416 ± 1.3 g from the initial body weight of 98 ± 8 g compared to the other treatments. In contrast, the survival rate was very high in the tripal ditches (99%) compared to the normal ditches (60%). Additionally, being a carnivorous fish species, the fish were fed with a diet consisting of small dead fish, earthworms, small live fish, snails, small frogs, and aquatic insects throughout the experiment (Hosen, Eliyana, & Chhanda, 2019). Domestication of *M. cuchia* in earthen ponds and in plastic tanks with and without mud was carried out in the study by Jahan et al. (2020), where different types of feed (dead fish, live fish, and formulated feed) were used across the treatments. However, the highest weight gain was observed in the earthen pond fed with live fish, indicating the significance of live feeds in the diet. Supplementation with poultry viscera in the diet of *M. cuchia* was explored in the study of Bashak et al. (2021), where the highest weight gain was obtained in the lower stocking density of 9880 no's per ha compared to other treatments containing higher stocking densities. However, in the Indian context, the use of chicken/poultry viscera as a diet for the fish growth causes significant pollutant in the aquatic ecosystem and deteriorates the water quality. Alternatively, Das et al. (2022) reported that culturing fish in an earthen pond by feeding with a diet containing live fish (60%) and vermicompost (40%) provided a significant growth rate.

These findings emphasize the critical role of live feed in promoting optimal growth performance. However, reliance on dead fish, live fish, or other

unconventional feed sources presents significant drawbacks, as these approaches neither ensure commercial profitability nor the water quality, thereby limiting their practical application in large-scale aquaculture of *M. cuchia*. In this context, the development of formulated feeds provides a sustainable alternative. For instance, Chowdhury, Mahmud, and Jahan (2019) successfully formulated a supplementary diet consisting of fish paste (50%), fish meal (40%), rice bran (5%), and wheat flour (5%). The results demonstrated remarkable growth performance, with fish reaching 165–176 g from an initial body weight of 50–70 g over a five-month culture period when fed at 2–3% of body weight. These findings suggest that well-balanced, nutritionally rich formulated feeds not only enhance growth efficiency but also address sustainability challenges, thereby offering a more viable option for commercial aquaculture of *M. cuchia*. Hence, the development of a suitable formulated feed will ensure profitability and sustainability.

Success story of the *cuchia* farming in Manipur

In Manipur, farmers typically cultivate *M. cuchia* using vermicompost derived from mushroom residues as a substrate. The procedure consists of several stages: collecting paddy straw, cultivating mushrooms, preparing vermicompost, stocking eels, and harvesting (Anouba Manipur, 2021). This process is detailed in Fig. 8. The harvested eels are subsequently marketed in smoked form and are also processed according to traditional methods practiced within Manipur, as illustrated in Fig. 9 and 10.

In India, the culture potential of *M. cuchia* is predominantly concentrated in the north-eastern states, which are endowed with an abundance of beels, swamps, marshes, rivers, and lakes. Despite

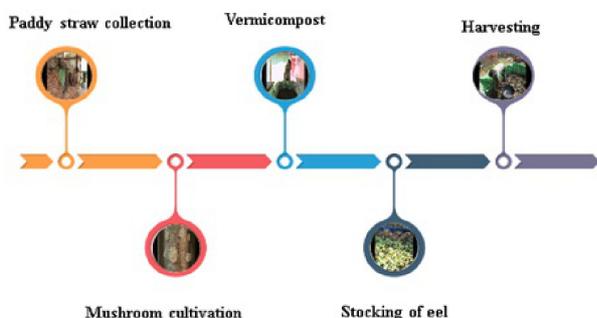


Fig. 8. *Monopterus cuchia* culture in Manipur using vermicompost of mushrooms



Fig. 9. Smoked *Monopterus cuchia* sold in the market of Manipur.



Fig. 10. Ngaprum curry, a traditional dish prepared from *Monopterus cuchia* in Manipur

this natural advantage, most scientific research and farming practices on *M. cuchia* have been conducted in Bangladesh, while India is yet to fully harness its potential. Recently, efforts have been initiated in Manipur to develop cost-effective farming practices for this species. However, baseline data essential for the systematic development of *M. cuchia* farming in India remain highly inadequate. Therefore, extensive exploratory studies are needed, particularly in the north-eastern states, to establish a solid foundation for its culture. In this regard, research institutions and state fisheries departments should take a proactive role by promoting *M. cuchia* farming through schemes such as the Pradhan Mantri Matsya Sampada Yojana (PMMSY) and by formulating appropriate guidelines and policies to support the sustainable and commercial development of *M. cuchia* farming in the country.

Disease management

Eels are susceptible to parasitic infections, primarily caused by two parasites: *Argulus* spp. and *Ergasilus* spp. (Khan, 2008). Cestode infections are also common in eel populations (Das, Kar, & Kar, 2014). Disease prevalence is generally higher in females compared to males. Standard disease control methods involve disinfecting the water or flushing the tanks thoroughly with large volumes of water (Miah, Naser, & Ahmed, 2015).

Harvesting and economic aspects of *Monopterus albus* farming

Eels are typically harvested at a size of 100–200 g after a culture period of six months (180 days). Production levels vary with the culture system, with running-water systems yielding nearly four times higher output compared to still-water culture (Dorairaj et al., 1980). Economic assessments further highlight the profitability of *M. albus* farming. Chakraborty et al. (2018) reported a net profit of Tk. 517,329/ha (equivalent to Rs. 3.73 lakh/ha) over a two-month culture cycle, with a benefit–cost ratio (BCR) of 2.16, thereby confirming its high economic viability. Similarly, Chowdhury et al. (2019) observed net profits ranging from Tk. 8,302 to 11,472 (~Rs. 5,987–8,273) in ponds measuring 60–180 m² stocked at a density of 10 per m² over a five-month culture period. Furthermore, Ferdoushi, Mariya, and Hasan (2021) documented the outcomes of *M. albus* fattening in polyculture systems, where average yields were 979 kg/acre for *M. albus*, 368.33 kg/acre for singhi, 330 kg/acre for magur, and 1,027.5 kg/acre for tilapia. The total production cost was Tk 276,957.35/acre (~Rs. 2.00 lakh), with feed and fingerlings comprising the major cost components. Gross revenue was estimated at Tk 452,025.58/acre (~Rs. 3.26 lakh), resulting in a net return of Tk 173,907.72/acre (~Rs. 1.25 lakh) and a BCR of 1.65, demonstrating the economic viability of *M. albus* fattening in polyculture systems. Collectively, these findings underscore both the production potential and profitability of *M. albus* farming in Bangladesh. In the Indian context, particularly in the north-eastern states, the development of cost-effective culture practices supported by standard operating procedures (SOPs) would provide significant opportunities for enhancing farmer income and promoting sustainable aquaculture. Usually in India, *M. albus* fetches a price of Rs. 800 per kg in the

domestic market of Manipur in 2025 during local market survey (Fig. 11). In comparison, the domestic market price for carp in the same region is significantly lower, typically ranging from Rs. 150 to Rs. 200 per kilogram. This stark contrast highlights the higher market value and demand for freshwater swamp eel compared to carp in Manipur. Additionally, the export market also has a great demand for freshwater swamp eel in China, Japan, Hong Kong, Taiwan, Thailand, Singapore, and the USA (Hasan, Sarker, Nazrul, Rahman, & Al-Mamun, 2012). Hence, developing the *M. albus* farming in India will provide insights into increasing the domestic consumption and foreign trade, which will eventually lead to the rise in fish consumption, generate employment and enhance economic growth.



Fig.11. *Monopterus albus* sold in the domestic fish market of Manipur

Value-added products of eel and their export value

Eel is highly sought after for its taste and perceived medicinal benefits, resulting in substantial market and export value. For example, Japan is the largest consumer of eel, accounting for 50% of global consumption. In 2024, the eel product unagi is priced largely according to glass eel recruitment, with glass eel prices reaching approximately USD 15,000 per kilogram during periods of low availability (Takeuchi, 2024). This underscores the importance of cultivating freshwater swamp eel, highlighting its potential to enhance domestic consumption, diversify market offerings, and increase India's export revenue.

Table 7. Value-added products of Japanese eel and its export value (Alibaba, n.d.)

S.No.	Value-added products	Price per kg
1	Fried eel	Rs.1200/-
2	Dry eel fish	Rs.1200 – 4000/-
3	Canned eel	Rs. 3200 – 3600/-
4	Eel fish maws	Rs. 1600/-
5	Grilled eel	Rs. 1200/-
6	Eel sauce	Rs. 1600/-
7	Eel powder	Rs. 80 – 300/-
8	Frozen eel	Rs. 800 – 1600/-
9	Roasted eel	Rs. 1400 – 1600/-
10	Smoked eel	Rs. 1300/-

SWOT analysis of *Monopterusuchia* farming

Strength of *M. cuchia* farming

1. Low-cost enterprise for farmers: Farming of *M. cuchia* represents a low-cost venture for farmers, making it an accessible and economically viable option for many rural and small-scale aquaculture operations (Miah, Naser, & Ahmed, 2015).

2. High export and domestic market demand: There is significant demand for *M. cuchia* in both international and domestic markets. This high demand supports lucrative export opportunities and a robust domestic market, providing substantial revenue potential for producers (Hasan et al., 2012; Miah, Naser, & Ahmed, 2015).

3. Diversification of aquaculture in India: Inclusion of *M. cuchia* farming contributes to the diversification of aquaculture practices in India. This diversification helps in enhancing the sustainability of aquaculture systems and encourages innovation in farming methods.

4. High nutritional value: *M. cuchia* is a nutritionally balanced food source, rich in essential proteins, fatty acids, vitamins, and minerals. Its high nutritional content makes it a valuable addition to diets, both for local consumers and international markets (Miah, Naser, & Ahmed, 2015; Faruque et al., 2019; Rana et al., 2019).

5. Potential for live market sales: *M. cuchia* can be sold live and in processed forms in the market, which often command higher prices. This ability to

sell live and processed eels provides added market flexibility and increased profit margins (Chakraborty et al., 2018; Chowdhury et al., 2019; Ferdoushi et al., 2021)

6. Increased disease resistance: Compared to some other eel species, *M. cuchia* exhibits greater resistance to parasitic diseases, which can reduce the need for medical treatments and increase overall farm productivity and profitability (Khan, 2008; Miah, Naser, & Ahmed, 2015)

7. Medicinal value: *M. cuchia* are believed to have medicinal properties, which adds to their value and appeal, especially in traditional and alternative medicine markets (Neog & Konwar, 2023; Sarmah, Mahanta, Shireen, & Choudhury, 2025).

8. Integrated farming and polyculture: *M. cuchia* farming can be integrated into various aquaculture systems and practiced alongside other species in polyculture systems. This approach enhances resource utilization, improves farm efficiency, and supports ecological balance (Ferdoushi et al., 2021).

Weakness encountered in *Monopterusuchia* farming

1. Breeding and seed production technology: The development of effective breeding and seed production technologies is crucial for the sustainable culture of *M. cuchia*. Efforts were made to achieve successful breeding; however, advanced techniques and research in this area would facilitate a consistent supply and improve the overall efficiency of eel farming operations (Rahmatullah et al., 2005; Miah, Ali, Zannath, et al., 2015, Miah, Naser, & Ahmed, 2015; Begum et al., 2017; Kurbah & Bhuyan, 2019; Mely, Rahman, & Islam, 2025)

2. Consumer acceptance: Consumer acceptance of *M. cuchia* is an important factor influencing its market potential. Understanding and promoting the eel's culinary appeal and nutritional benefits can help increase its popularity and demand among consumers (Neog & Konwar, 2023).

3. Lack of awareness about culture practices and nutritional benefits: There is a significant lack of awareness regarding the culture practices and nutritional benefits of eels among farmers and consumers. This gap in knowledge hampers the adoption of eel farming and limits consumer demand, underscoring the need for educational

Previous research works on the farming and natural/induced breeding practices of *Monopterus cuchia*

Table 8. The list of research work on the farming and natural/induced breeding practices of *Monopterus cuchia*

S. No.	Title of the study	Findings of the study	Reference
1.	Effect of temperature on food, growth and survival rate of freshwater mud eel, <i>Monopterus cuchia</i> (Hamilton) during aestivation period	The study on <i>M. cuchia</i> revealed that feed intake and growth were strongly influenced by temperature, with the lowest feeding rate (2.9 g/kg/day) at 14.4 °C and the highest (12 g/kg/day) at 27 °C, while no feeding occurred at or below 12 °C. Average food intake nearly doubled from winter (266 g) to spring (438 g), and although the mean final weight slightly decreased from 82.4 g to 78.45 g, no mortality was observed during the experiment.	Rahman, Narejo, Ahmed, Bashar, and Rahmatullah (2005)
2.	Reproductive biology, artificial propagation, and larval rearing of two freshwater eels, <i>Monopterus cuchia</i> and <i>Mastacembelus armatus</i>	This study shows that the induced breeding in <i>M. cuchia</i> with pituitary gland extract was unsuccessful, as brood mortality occurred at higher doses. However, natural breeding was achieved in cisterns provided with water hyacinths and muddy tunnels. In terms of growth performance, the species attained a mean weight of 18.75 ± 2.3 g with 100% survival when fed chopped cooked fish, while the use of car tyres as shelters resulted in the highest weight gain (22.53 ± 2.24 g) and 100% survival.	Rahmatullah et al. (2005)
3.	Breeding biology and induced breeding status of freshwater mud eel, <i>Monopterus cuchia</i>	In this study, the breeding biology of <i>M. cuchia</i> was investigated, and induced breeding was attempted using various hormones, including pituitary gland extract (PG), human chorionic gonadotropin (HCG), gonadotropin-releasing hormone (GnRH), and Ovuline (a synthetic hormone), under different environmental conditions. However, no successful induction of breeding was achieved in this species.	Miah, Ali, Zannath, et al. (2015)
4.	Rearing and production performance of freshwater mud eel, <i>Monopterus cuchia</i> in different culture regimes	The study concluded that <i>M. cuchia</i> reared in earthen ditches exhibited the highest weight gain among all treatments, primarily attributed to the provision of live feed.	Miah, Ali, Jannat, et al. (2015)
5.	Effect of different stocking densities on growth and survival rate of <i>Monopterus cuchia</i> fry reared in cemented cisterns	The findings of the study concluded that stocking the fish at the rate of 75 per m ² achieved the highest weight gain, specific growth rate, and survival compared to 100 per m ² and 125 per m ²	Sharmin et al. (2016)
6.	Induced breeding attempt of vulnerable freshwater mud eel, <i>Monopterus cuchia</i>	Induced breeding of <i>M. cuchia</i> was successful in pond habitats using Pregnyl, yielding about 3,000 larvae from six pits. After four months, fry reared in trays reached 10.68 cm and 1.09 g with 80% survival, while those in cisterns grew to 10.78 cm and 1.02 g with 77% survival. The findings of the study concluded that induced breeding is effective for conserving the vulnerable species.	Begum et al. (2017)
7.	Reproductive cycle of the mud eel, <i>Monopterus cuchia</i> (Hamilton-Buchanan, 1822) in Bangladesh	In <i>M. cuchia</i> , testes exhibited four stages (spermatogonia to spermatozoa) with peak maturity from April to July, while ovaries showed oogenesis, vitellogenesis, and atresia, with maturation prominent in May. The highest gonad weights were recorded in May, marking the peak reproductive activity and spawning season.	Chakraborty (2018b)
8.	Effect of stocking density on survival, growth, and production of mud eel, <i>Monopterus cuchia</i> (Hamilton) under semi-intensive pond aquaculture	Culturing of <i>M. cuchia</i> at a density of 7410 fingerlings per ha yielded the highest weight gain, specific growth rate, survival rate, and net profits.	Chakraborty et al. (2018)

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|-----|--|--|--|
| 9. | Growth of freshwater mud eel (<i>Monopterusuchia</i>) in different water condition, feed and probiotics | An experiment on the growth and production of <i>M. cuchia</i> fed with different feeds and reared under different water sources has significantly influenced growth and production. The best performance was recorded in pond water with probiotics, yielding the highest weight gain (16.39 ± 2.35 g), production (65.56 ± 9.4 g/m ² /year), and survival. Thus, pond water combined with probiotic feed was identified as the most suitable condition for <i>M. cuchia</i> culture. | Rahman, Hossain, Billah, Al-Asif, and Ferdous (2018) |
| 10. | Freshwater mud eel (<i>Monopterusuchia</i>) culture with supplementary feed at on-farm management | <i>M. cuchia</i> cultured with supplementary feed for 5 months showed weight gain from 157–176 g across all sites, with the best growth in Mymensingh Sadar. Net profits ranged from Tk. 8,302–11,472, the highest in Mymensingh Sadar and lowest in Haluaghat. The results indicate that <i>cuchia</i> farming under on-farm management is profitable and feasible. | Chowdhury et al. (2019) |
| 11. | Growth performance of freshwater mud eel, <i>Monopterusuchia</i> in different ditches conditions | <i>The findings of the study concluded that</i> in a six-month trial, <i>M. cuchia</i> exhibited the highest growth performance in normal ditches (T3), although survival was lowest (60%). In contrast, tripal ditches (T2) ensured maximum survival (99%) with satisfactory growth, indicating T2 (tripal ditches) as the most suitable system for <i>cuchia</i> culture under balanced growth and survival conditions. | Hosen et al. (2019) |
| 12. | Induced breeding and larval rearing of <i>Monopterusuchia</i> (Hamilton, 1822) under the agro-climatic conditions of Meghalaya, India | Induced breeding of <i>M. cuchia</i> was successfully achieved for the first time in India using the synthetic hormone Gonopro-FH. A dosage of 1 ml/kg body weight for females and 0.3 ml/kg for males resulted in natural spawning, with 75–80% fertilization and 80–85% hatching. The fecundity of a 344 g female was recorded as 924 eggs. | Kurbah and Bhuyan (2019) |
| 13. | Evaluation trial on production performance of freshwater mud eel (<i>Monopterusuchia</i>) in farmer's pond | The findings of the study concluded that the production performance of <i>M. cuchia</i> in the farm trial yielded the highest production of 31.9 ± 2.56 kg with the net profit of 3211 BDT (~Rs. 2324) | Chowdhury, Shofiquzzoha, and Bhadra (2020) |
| 14. | Domestication technique of commercially important freshwater mud eel, <i>Monopterusuchia</i> (Hamilton, 1822) | The study concluded that the domestication of <i>M. cuchia</i> was successfully achieved in earthen ponds using live fish as feed. | Jahan et al. (2020) |
| 15. | Growth performance and culture economics of mud eel semi-intensively cultured under varying stocking densities in rain-fed earthen ponds | The study on <i>M. cuchia</i> culture in semi-intensive rainfed ponds showed that stocking density strongly influenced growth, survival, and economics. The lowest density (T1, 9880/ha) produced the highest final body weight (349.40 g), SGR (0.58), and survival (85.14%), along with the best cost-benefit ratio (0.39). Although net yield and gross benefit were higher at the highest density (T3, 19760/ha), overall production efficiency and profitability were superior at the lower stocking density, highlighting T1 as the most sustainable option. | Bashak et al. (2021) |
| 16. | Economics of freshwater mud eel fattening (<i>Monopterusuchia</i>) in polyculture system: a case study from Nilphamari, Bangladesh | The study on <i>M. cuchia</i> fattening in polyculture systems showed average productions of 979.17 kg/acre (<i>cuchia</i>), 368.33 kg/acre (<i>singhi</i>), 330 kg/acre (<i>magur</i>), and 1027.5 kg/acre (<i>tilapia</i>). Total costs were BDT 276,957.35/acre, with feed and fingerling costs being the most significant, while gross revenue and net return were BDT 452,025.58 and 173,907.72/acre, respectively, yielding a BCR of 1.65. The production function indicated that optimizing feed and fingerling investment could further enhance profitability | Ferdoushi et al. (2021) |
| 17. | Growth performances and biometric indices of mud eel, <i>Monopterusuchia</i> , from the cultured pond of Southern Bangladesh | The study evaluated the growth performance of <i>M. cuchia</i> across Kalapara, Amtoli, and Bauphal upazilas, showing the highest final weight (128.07 g), weight gain (84.52 g), and production (1.47 kg/m ² /6 months) in Kalapara, while Bauphal recorded the lowest values. Length-weight relationships were highly significant ($R^2 > 0.98$), with isometric growth in Amtoli and positive allometric growth in Kalapara and Bauphal. Condition factor values (0.92–1.13) confirmed overall healthy growth across sites, highlighting Kalapara as the most favorable culture location for culture | Islam et al. (2021) |

18.	Growth and yield performance of a sustainable aquaculture of <i>cuchia</i> , <i>Monopterusuchia</i> (Hamilton, 1822) under different type of feeds in Bangladesh	The study demonstrated that feeding <i>M. cuchia</i> with a combination of live fish and boiled fish muscle (T2) ensured significantly higher growth, survival, and production compared to live feed (T1) and supplementary feed (T3). As water quality remained suitable across treatments, the enhanced performance was attributed to the feeding regime, suggesting T2 as a sustainable and efficient strategy for <i>M. cuchia</i> culture in Bangladesh.	Khan, Islam, Haque, Rahman, and Mahmud (2021)
19.	Growth and production performance of mud eel, <i>Monopterusuchia</i> (Hamilton, 1822) using different types of feed in the northern region of Bangladesh	The findings of the study concluded that incorporating 60% of live fish spawn and 40% of vermicompost in the diets of <i>M. cuchia</i> yielded the highest weight gain and the survival rate.	Das et al. (2022)
20.	Growth performance and economic analysis of swamp eel (<i>Monopterusuchia</i>): An application of Cobb-Douglas production function	The study found that <i>M. cuchia</i> farming achieved over 80% survival when fed with fish fry and snail meat, with significant differences observed among feed types, particularly vermi meals, dried fish, and fish fry. Production analysis revealed that the cost of fish fry feed and seed had negative correlation with gross income, while dried fish and labor costs showed positive associations, highlighting the economic importance of optimized feeding practices in <i>M. cuchia</i> farming.	Rana et al. (2022)

initiatives and information dissemination (Chakraborty, Azad, Bormon, Ahmed, & Faruque, 2010; Miah et al., 2013; Miah, Naser, & Ahmed, 2015; Rana et al., 2022).

4. Dependence on wild collection: The current reliance on wild collection for *M. cuchia* presents challenges in terms of sustainability and supply consistency. Transitioning to aquaculture methods could mitigate overfishing pressures and ensure a more reliable and controlled supply of eels (Chakraborty, 2018a; Rana et al., 2022; Mely et al., 2025).

5. Limited research: There is insufficient research in the field of *M. cuchia* farming. Increased research efforts are needed to address gaps in knowledge, improve farming techniques, and develop innovations that can enhance the productivity and profitability of eel aquaculture (Miah, Naser, & Ahmed, 2015; Mely et al., 2025).

6. Non-engagement of stakeholders and entrepreneurs: The lack of engagement from stakeholders and entrepreneurs in *M. cuchia* culture presents a barrier to the development of the industry. Greater involvement from these key players is essential for fostering investment, advancing technology, and scaling up aquaculture practices (Miah, Naser, & Ahmed, 2015; Mely et al., 2025).

Opportunities to improve *Monopterus cuchia* farming

1. Standardizing breeding and seed production technology: Establishing standardized breeding and seed production technologies is essential for the efficient and sustainable farming of *M. cuchia*. This involves developing reliable methods for spawning, hatching, and growing eel larvae, ensuring a consistent quality and supply of seed stock. Standardization helps in optimizing production processes and improving overall farm productivity (Chakraborty, 2018a; Rana et al., 2022; Mely et al., 2025).

2. Training on culture practices and nutritional and economic benefits of eel farming: Providing comprehensive training on eel culture practices, including proper husbandry techniques, water management, and disease control, is crucial for successful eel farming. Additionally, educating farmers and stakeholders about the nutritional and economic benefits of eel farming can enhance understanding and encourage wider adoption of these practices. This training helps in maximizing both the health benefits and profitability of eel farming operations (Miah, Naser, & Ahmed, 2015; Rana et al., 2022; Mely et al., 2025).

3. Value addition: Implementing value addition strategies involves processing eels into various

products, such as smoked or dried eels, to enhance their market value. By adding value to eel products, farmers can achieve higher revenue and diversify market opportunities. This approach also helps in reaching premium markets and increasing profitability (Anouba Manipur, 2021; Alibaba, n.d.)

4. Species diversification: Diversifying the species cultivated alongside *M. albus* can enhance farm resilience and productivity. Integrating different species in polyculture systems can optimize resource use, improve ecological balance, and reduce the risks associated with monoculture practices. Species diversification also opens new market opportunities and helps in managing environmental impacts (Ferdoushi et al., 2021).

5. Entrepreneurship development: Fostering entrepreneurship in eel farming involves supporting and encouraging individuals and businesses to invest in and manage eel aquaculture ventures. This includes providing access to financial resources, technical expertise, and business development support. Developing a strong entrepreneurial base can drive innovation, expand the industry, and create job opportunities (Miah, Naser, & Ahmed, 2015; Islam et al., 2020).

6. Utilization of unused and abandoned areas for eel farming: Repurposing unused or abandoned areas for eel farming can make productive use of neglected land. This practice can help alleviate land pressure, promote sustainable land use, and increase the overall capacity for eel production. Utilizing these areas can also contribute to regional economic development (Chakraborty et al., 2010; Miah, Naser, & Ahmed, 2015; Mely et al., 2025).

7. Socio-economic upliftment of local communities: The development of eel farming can have a positive impact on local communities by creating employment opportunities, increasing income, and supporting economic growth. By involving local communities in aquaculture activities, eel farming contributes to socio-economic upliftment, improves livelihoods, and enhances overall community well-being (Miah, Naser, & Ahmed, 2015; Chakraborty, 2018a; Neog & Konwar, 2023).

Threats related to *Monopterus albus* farming

1. Polluting the natural habitat: The discharge of excess nutrients, chemicals, and waste from domestic areas can degrade water quality, harm aquatic

ecosystems, and disrupt local flora and fauna. This pollution can result in the loss of biodiversity and the deterioration of ecosystem health (Chakraborty, 2018a; Rana et al., 2022; Mely et al., 2025).

2. Over-exploitation: Over-exploitation of eel populations through wild capture poses a significant threat to their sustainability. Excessive harvesting can deplete eel stocks faster than they can replenish, leading to population declines and potential ecological imbalances. Sustainable management practices are crucial to prevent over-exploitation and ensure the long-term viability of eel species (Miah, Naser, & Ahmed, 2015; Chakraborty, 2018a; Islam et al., 2020; Bharati, 2023; Mely et al., 2025).

3. Parasite infections: Eels are susceptible to various parasitic infections, which can negatively impact their health and growth. Parasites such as *Argulus* and *Ergasilus* can cause diseases that lead to high mortality rates and reduced quality of farmed eels. Effective disease management strategies, including regular health monitoring and appropriate treatments, are essential to mitigate the impact of parasitic infections (Khan, 2008; Das et al., 2014; Miah, Naser, & Ahmed, 2015).

4. Use of destructive fishing practices: Destructive fishing practices, such as using harmful gear or techniques that damage habitats, can have detrimental effects on eel populations and their environments. Sustainable fishing practices are necessary to minimize environmental damage and protect eel populations (Miah, Naser, & Ahmed, 2015; Chakraborty, 2018a; Islam et al., 2020; Bharati, 2023; Mely et al., 2025).

5. Destroying the natural breeding grounds: Human activities and industrial developments that alter or destroy natural breeding grounds can severely impact eel populations. Loss of spawning and nursery habitats, such as wetlands and estuaries, can hinder the reproductive success and recruitment of eels, leading to declines in population numbers and disruptions in their life cycle (Miah, Naser, & Ahmed, 2015; Chakraborty, 2018a; Islam et al., 2020; Bharati, 2023; Mely et al., 2025).

6. Biomagnification problems: Biomagnification occurs when pollutants, such as heavy metals or pesticides, accumulate in higher concentrations as they move up the food chain. Eels, being higher trophic-level predators, are particularly vulnerable to the effects of biomagnification. Accumulation of

toxins in eel tissues can pose health risks to humans and wildlife that consume them and can impact overall ecosystem health (Miah, Naser, & Ahmed, 2015).

7. Climate change effects on larval transport and baby eel recruitment: Climate change can alter environmental conditions and the recruitment of juvenile eels. Changes in these conditions can disrupt the distribution and availability of suitable habitats for larvae and juveniles, leading to fluctuations in eel populations and potentially impacting their survival and growth rates (Mely et al., 2025).

Conclusion

The article provides a comprehensive overview of the current status of *M. cuchia* eel farming, encompassing production potential, culture practices, aquaculture prospects in India, and associated economic aspects. It highlights the aquaculture potential and value-addition opportunities of *M. cuchia*, offering valuable insights into how species diversification can enhance Indian aquaculture. In the Indian context, *M. cuchia* culture represents a promising avenue for expanding the aquaculture sector. This species, known for its relatively low input requirements and cost-effective farming processes, offers a viable alternative to traditional fish farming practices. Establishing *M. cuchia* eel farming can significantly reduce dependence on wild capture fisheries, thereby mitigating resource overexploitation and ensuring a more sustainable supply of eel products. Additionally, the development of *M. cuchia* farming can stimulate domestic consumption, as this species is already in demand in northeastern India. This expansion can also lead to increased export opportunities, further boosting the economic returns from the aquaculture sector. The *M. cuchia* farming has the potential for contributing to the diversification of eel production, complementing existing practices and reducing the pressure on wild eel populations. As eel farming continues to grow, inclusion of *M. cuchia* can help stabilizing the global supply chains and supporting sustainable practices. Moreover, value addition through the production of high-quality, cultured *M. cuchia* can enhance international market competitiveness and generate economic benefits at both local and global levels. Overall, the successful implementation of *M. cuchia* farming in India could serve as a model for other countries looking to diversify their aquaculture sectors, reduce reliance

on wild fisheries, and increase both domestic consumption and export value.

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