UNDERSTANDING THE BIOLOGY OF INDIAN MAJOR CARPS: KEY INSIGHTS FOR SUSTAINABLE AQUACULTURE AND CONSERVATION

Abstract

Indian major carps are a cornerstone of India's aquaculture industry, supporting millions of livelihoods and contributing significantly to the country's food security. The major Indian carp species supports almost 70 to 75% of total freshwater fish production. The biological profiles of these carp species are diverse in many aspects and are adapted to specific environmental niches. Reproductive biology is critical for the sustainable management of these carp species, as it impacts aquaculture practices and natural habitat conservation. Conserving these carp species in fragile ecosystems faces challenges like overfishing, habitat degradation, water pollution, illegal fish introduction, and the impacts of climate change. A holistic approach combining habitat restoration, sustainable fishing practices, and community engagement is essential to mitigate these challenges. Taxonomy, classification, and distribution are fundamental for sustainable fish resource management and conservation. Accurate species identification and understanding of taxonomic relationships are vital for informed decision-making in aquaculture. Induced breeding is a widely used method for carp seed production, involving hormonal stimulation with pituitary extract or synthetic formulations. The Chinese type of carp hatchery system is efficient for mass-scale fish seed production, with a two-tier rearing system involving a nursery and fingerling phase. In conclusion, Indian major carps are significant for India's food security and the aquaculture industry. Understanding their biology, ecology, taxonomy, and reproductive processes is

Authors

Gyan Chandra
Department of Fisheries Resource Management,
College of Fisheries,
Kishanganj,
Bihar Animal Sciences University,
Patna, India.

Rupam Samanta
Department of Fisheries Resource Management,
College of Fisheries,
Kishanganj,
Bihar Animal Sciences University,
Patna, India.

Anjali Pushp
Department of Fisheries Resource Management,
College of Fisheries,
Kishanganj,
Bihar Animal Sciences University,
Patna, India.

Naresh Raj Keer
Department of Aquaculture
College of Fisheries, Kishanganj
Bihar Animal Sciences University,
Bihar, India.

critical for profitable, sustainable fish farming practices and conservation initiatives.

1. Introduction

The Indian major carps include catla (*Labeo catla*), rohu (*Labeo rohita*), and mrigal (*Cirrhinus mrigala*), and are known for their culinary appeal and also serve as a cornerstone of India's aquaculture industry. It supports livelihoods and plays a significant role in the economy and food security of a country like India. On a global scale, India ranks second in aquaculture. China manages to produce one-third of the entire fish harvest and cultivates two-thirds of the fish. Over the past two decades, Indian aquaculture has grown rapidly, expanding by six and a half times. Freshwater aquaculture has played a pivotal role, contributing over 95% of the total aquaculture production. India is endowed with an extensive aquatic resource base, encompassing 3.15 million hectares of reservoirs, 2.36 million hectares of ponds and tanks, and 0.19 million hectares of rivers and canals. In the mid-1980s, freshwater aquaculture represented only 34% of inland fisheries, but its share has surged to approximately 80% in recent years. The adoption of technologies such as induced carp breeding and polyculture in ponds and tanks has driven significant improvements in aquaculture productivity, transforming the sector into a rapidly growing industry. Carp culture, specifically the polyculture of three Indian major carps, as well as the composite culture of these species with three exotic Chinese carps (grass carp, silver carp and common carp), constitutes the prevailing practice. Among these, the three Indian major carp species contribute 70 to 75% of the total freshwater fish production, while the exotic carp species make up the remaining 25 to 30%.

Indian major carps are characterized by their diverse biological profiles, each adapted to specific environmental niches. The catla, for instance, is known for its surface-feeding habits and rapid growth rates. In contrast, the rohu is a column feeder, while the mrigal exhibits bottom-feeding habits. Understanding these distinct ecological niches and feeding behaviours is essential for successful aquaculture and habitat management. The reproductive strategies of these carp are of paramount importance for their sustainable management. Knowledge of reproductive biology is crucial for successful aquaculture practices and effective conservation in their natural habitat. Genetic diversity within Indian major carp's populations is critical for their resilience to changing environmental conditions and disease resistance. Maintaining and conserving this genetic diversity is essential for the long-term sustainability of these important species. Furthermore, ongoing carp genetics and genomics research provides valuable insights into selective breeding programs to improve growth rates, disease resistance, and overall aquaculture productivity. Conserving Indian major carps in fragile ecosystems faces several challenges. In general, overfishing, habitat degradation, and water pollution are significant threats to fisheries resources around the globe. Additionally, the introduction of non-native species and the impacts of climate change further complicate conservation efforts. Therefore, a holistic approach that combines habitat restoration, sustainable fishing practices, and community engagement is essential to mitigate these challenges. Sustainable aquaculture practices are vital for the conservation of Indian major carps and the economic well-being of those involved in the industry. Innovations such as integrated multitrophic aquaculture (IMTA) and environmentally friendly feed formulations can minimize the environmental footprint of carp farming. Furthermore, the adoption of responsible and ethical farming practices can enhance the reputation and marketability of Indian major carp's products. In conclusion, Indian major carps are not just a source of nutrition and livelihood but also hold cultural significance in India. Understanding their biology and ecology is central to their conservation and sustainable aquaculture. This book chapter will delve deeper into these aspects, drawing upon the latest research and insights to provide a comprehensive overview of the Indian major carps and the strategies needed to ensure their enduring presence in India's aquatic ecosystems.

2. Taxonomy, Classification and Distribution

Taxonomy is a fundamental tool for the sustainable management of fish resources, the conservation of aquatic biodiversity, and the successful operation of aquaculture facilities. Accurate species identification and understanding of taxonomic relationships are essential for making informed decisions in these fields. Taxonomy plays a pivotal role in aquaculture by enabling precise species identification, which is essential for the efficient management of fish stocks and resources. It guides selective breeding programs by identifying genetically desirable traits and improving production efficiency. In disease management, taxonomy helps assess species susceptibility and implement appropriate preventive measures, safeguarding the health of aquaculture populations. Additionally, taxonomy is crucial for biodiversity conservation efforts, aiding in the protection of endangered or threatened fish species and their habitats. It supports ecosystem monitoring by providing a framework for assessing changes in species composition and distribution. Accurate taxonomy also facilitates adherence to regulatory measures governing catch limits and size restrictions, ensuring the sustainability of fisheries and aquaculture practices. Overall, taxonomy is an indispensable tool for both the economic success and environmental responsibility of fish-related industries.

Labeo Catla

The Indian Major Carp, commonly known as the catla, is a freshwater fish native to the river systems of northern India, the Indus Plain, and the adjoining hills of Pakistan, Bangladesh, Nepal, and Myanmar. It has since been introduced to nearly all river systems, reservoirs, and tanks across India. The natural distribution of catla appears to be influenced by temperature rather than geographic location, with a minimum tolerance temperature of approximately 14°C. In the eastern Indian states, incorporating catla into pond culture practices was a traditional practice that spread to other Indian states during the latter half of the 20th century. Its rapid growth rate, compatibility with other major carps, unique surface feeding habits, and consumer preference have contributed to its popularity in carp polyculture systems among fish farmers in India, Bangladesh, Myanmar, Laos, Pakistan, and Thailand. The species has also been introduced to other regions, including Sri Lanka, Mauritius, Japan, and Israel. Currently, catla is an integral component of both three-species polyculture systems, alongside rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*), and six-species composite carp culture systems, which additionally include common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idellus*), and silver carp (*Hypophthalmichthys molitrix*).

Distinguishing Biological Characteristics

The catla has a short, deep, and somewhat laterally compressed body, with a depth exceeding the head length. The head is very large, with its depth surpassing half the head length. The body is covered with large, conspicuous cycloid scales, while the head remains scaleless. The snout is bluntly rounded, the eyes are large and visible from the underside of the head, and the mouth is wide and upturned with a prominent, protruding lower jaw. The upper lip is absent, and the lower lip is very thick. Barbels are absent, and the lower jaw has a movable articulation at the symphysis without a prominent process. The gill rakers are long and fine, and the pharyngeal teeth are arranged in a three-row pattern of 5.3.2/2.3.5. The dorsal fin is inserted slightly ahead of the pelvic fins and has 14 to 16 branched rays, with non-osseous simple rays. The anal fin is short, the pectoral fins are long and extend to the pelvic fins, and the caudal fin is forked. The lateral line bears 40 to 43 scales. The dorsal colouration is greyish, transitioning to silvery-white on the flanks and underside. The fins are dusky.
Taxonomic classification

Kingdom:	Animalia
Phylum:	Chordata
Class:	Actinopterygii
Order:	Cypriniformes
Family:	Cyprinidae
Genus:	Labeo
Species:	*Labeo catla*

Labeo Rohita

Labeo rohita, more commonly known as rohu, stands as another remarkable species of freshwater fish within the Cyprinidae family. Among the three Indian major carps, rohu holds the top position, widely cultivated in polyculture carp systems. This graceful Indo-Gangetic riverine fish makes its home in the riverine networks of northern and central India. Its presence extends to the rivers of Bangladesh, Pakistan, and Myanmar. With remarkable success, rohu has been transplanted into nearly all riverine systems throughout India, including the freshwater expanses of Andaman, where a thriving population has been established. Rohu's reach extends beyond India's borders, as it has been introduced to numerous other countries, including Japan, Sri Lanka, the former USSR, Malaysia, China, the Philippines, Nepal, and certain African nations. Its rapid growth rate and high consumer preference have solidified rohu's position as the most important freshwater fish cultured in India, Bangladesh, Pakistan, and neighbouring countries. Recognizing its immense significance in aquaculture, efforts have been directed towards genetic improvement and selective breeding programs for rohu.

Identifying Biological Characteristics

Rohu, *L. rohita* is characterized by a bilaterally symmetrical body covered in cycloid scales, except for the head. Its moderately elongated body exhibits a more arched dorsal profile compared to the ventral profile. The snout is fairly depressed and projects anteriorly beyond the mouth, lacking a lateral lobe. Eyes are positioned dorsolaterally, making them inconspicuous from the underside of the head. The mouth is inferior and small, with thick lips featuring a distinctive inner fold on each side, either lobate or entire. A pair of small maxillary barbels is concealed within a lateral groove. Rohu lacks teeth on its jaws but possesses pharyngeal teeth neatly arranged in three rows. The upper jaw does not extend to the front edge of the eye. The dorsal fin comprises three or four simple (unbranched) rays and 12 to 14 branched rays, inserted midway between the snout tip and the base of the caudal fin. Both pectoral and pelvic fins are located laterally, with the pectoral fin lacking an osseous spine. The caudal fin exhibits a deep fork. The lower lip is typically connected to the isthmus by a narrow or broad bridge. Counts 12 to 16 pre-dorsal scales. A distinct and complete lateral line runs along the median line of the caudal peduncle, bearing 40 to 44 lateral line scales. Between the lateral line and the pelvic fin base, rohu presents six or six and a half lateral transverse scale-rows. The snout lacks any truncation and lateral lobes. Colouration is characterized by a bluish back contrasted by silvery flanks and belly.

Taxonomic Classification

Kingdom:	Animalia
Phylum:	Chordata
Class:	Actinopterygii
Order:	Cypriniformes
Family:	Cyprinidae
Genus:	Labeo
Species:	*Labeo rohita*

Cirrhinus Mrigala

Cirrhinus mrigala, more commonly known as mrigal, stands as a freshwater fish species belonging to the Cyprinidae family. Endemic to Indo-Gangetic riverine systems, mrigal holds a prominent position among the three Indian major carps cultivated widely across numerous Asian countries. Its significance in polyculture alongside other native species has long been established, particularly in India. However, records of its culture date back only to the early 20th century. Traditional mrigal culture remained confined to India's eastern regions until the 1950s. Initially, mrigal's superior growth rate and compatibility with other carps facilitated its establishment as a primary component in pond culture. The species was successfully transplanted into India's peninsular riverine systems, where it thrived and eventually spread throughout the country. Over time, mrigal gained recognition as a crucial component in the fish culture systems of Bangladesh, Pakistan, Myanmar, Lao PDR, Thailand, and Nepal. Additionally, mrigal introductions have been made in Sri Lanka, Vietnam, China, Mauritius, Japan, Malaysia, the Philippines, and the former USSR.

Identifying Biological Characteristics

Mrigal exhibits a bilaterally symmetrical and streamlined body with a depth that roughly approximates the length of its head. Its body is adorned with cycloid scales, while its head remains scaleless. The mouth is notably broad, featuring a blunt snout that often bears pores. The lips are transverse, with the upper lip being entire and distinct from the lower lip. The lower lip is less conspicuous and lacks distinct features. Rohu possesses a single pair of small rostral barbels. Its pharyngeal teeth are arranged in three rows, following the pattern

5.4.2/2.4.5. The lower jaw features a small post-symphysial knob or tubercle. The dorsal fin originates closer to the end of the snout than to the base of the caudal fin. The last unbranched ray of the dorsal fin is devoid of serrations and osseous structures. The dorsal fin, reaching a height equal to that of the body, comprises 12 or 13 branched rays. The lateral line bears 40 to 45 scales. Pectoral fins are smaller than the head. The caudal fin exhibits a deep fork, while the anal fin does not extend to the caudal fin. The lateral transverse scale-rows between the lateral line and the pelvic fin base number 6 to 7/5½ to 6. Typically, rohu displays a dark grey colouration on its dorsal surface, transitioning to a silvery hue underneath. The dorsal fin appears grey, while the pectoral, pelvic, and anal fins exhibit orange tips, particularly during the breeding season.

Taxonomic Classification

Kingdom	Animalia
Phylum	Chordata
Class	Actinopterygii
Order	Cypriniformes
Family	Cyprinidae
Genus	*Cirrhinus*
Species	*Cirrhinus mrigala*

3. Life Cycle, Reproduction and Biology

Understanding the life cycle and reproductive processes of Indian major carps is crucial for sustainable management and cultivation. Spawning usually occurs during the monsoon season when water conditions are favourable. During this time, mature female carp release their eggs into the water, and mature male carp release sperm, known as milt, which fertilizes the eggs. This process is often triggered by environmental cues such as changes in water temperature, rainfall, and photoperiod. Unlike some fish species, Indian major carps do not provide significant parental care. Once the eggs are laid and fertilized, both the male and female carp typically move on, leaving the eggs to develop independently. Once fertilization takes place, the eggs become fertilized and develop into embryos. This stage typically lasts a few hours, during which the embryos develop inside the egg capsules. As the embryos develop, they hatch from the egg capsules, and the larvae emerge. At this stage, the larvae are tiny and transparent. They are highly vulnerable to predation and environmental conditions. To survive, they rely on their yolk sacs for nourishment initially. As the larvae grow and absorb their yolk sacs, they transition into the fry stage. Fry are small fish with developed fins and scales. They are more mobile and begin to actively swim and explore their environment. During this stage, their diet primarily consists of zooplankton and phytoplankton, which are abundant in freshwater ecosystems. With continued growth and development, the fry becomes fingerlings. Fingerlings are larger than fry and have more pronounced features. They shift their diet to include larger food items, including dead and decaying plants. This stage is crucial for their overall development and survival. The final stage of the life cycle is when the fingerlings reach adulthood. Indian major carp's sexual maturity depends on various factors, including water temperature, food availability, and environmental conditions.

Catla, a eurythermal species, thrives in water temperatures between 25 and 32 degrees Celsius. Its reproductive pattern is intriguing, with eggs initially demersal and gradually becoming buoyant. Early-stage larvae exhibit a strong preference for surface and subsurface waters and demonstrate phototactic behaviour. These young fish begin feeding three days after hatching, even while their yolk sacs are still present. As they grow, the number of gill rakers and gill filaments increases, enhancing their ability to filter and consume various food items. Catla fry are planktophagic, primarily feeding on zooplankton such as rotifers and cladocerans. In contrast, adult catla, predominantly surface and mid-water feeders, also exhibit planktophagic behaviour and show a preference for zooplankton, particularly crustaceans, rotifers, insects, and protozoa, along with some algal and plant matter. Catla typically matures around two years of age. During the monsoon season, they migrate to the upper reaches of rivers to spawn. The spawning season generally coincides with the southwest monsoon in northeastern India and Bangladesh (May to August) and in northern India and Pakistan (June to September). Catla's fecundity varies but can range from 100,000 to 200,000 eggs per kilogram of body weight. Breeding catla in captivity poses challenges as it requires specific environmental conditions for successful spawning. Under normal conditions, catla can grow up to 1-1.2 kg in the first year, while rohu and mrigal can reach 700-800 g and 600-700 g, respectively.

Rohu, another eurythermal species, is unable to thrive in temperatures below 14 degrees Celsius. It is a fast-growing species, capable of reaching an approximate total length of 35-45 cm and a weight of 700-800 g within a single year under standard culture conditions. In polyculture settings, rohu typically exhibits a growth rate that surpasses that of mrigal but falls short of catla. Both sexes of rohu attain first maturity at two years of age, while complete maturity is achieved at four years for males and five years for females. Under natural conditions, spawning takes place in the shallow and marginal areas of flooded rivers, often during the southwest monsoon season, spanning from April to September. In captivity, proper feeding can induce maturity by the end of the second year, but natural breeding in pond environments is usually not viable, necessitating induced breeding. Rohu's fecundity varies considerably, ranging from 226,000 to 2,794,000 eggs depending on the fish's size and ovary weight. The average fecundity range is approximately 200,000-300,000 eggs per kilogram of body weight.

Mrigal, also a eurythermal species, exhibits tolerance to temperatures as low as 14 degrees Celsius. In aquaculture settings, mrigal typically achieves an average weight of 600-700 grams within the first year, subject to standard stocking density and management practices. Among the three Indian major carps, mrigal tends to exhibit a slower growth rate compared to catla and rohu. Under typical rearing conditions, mrigal is usually raised for a maximum of two years, as its growth rate declines with age. However, in natural waters, mrigal has been observed to survive for up to 12 years. Maturity in mrigal is typically attained within two years under captive conditions. Since mrigal requires a riverine environment for breeding, natural breeding in ponds is unlikely to occur. Instead, induced breeding in hatcheries using hormonal induction methods has proven to be successful. Mrigal exhibits high fecundity, which increases with age. The spawning season aligns with the onset and duration of the southwest monsoon, typically occurring from May to September in India, Bangladesh, and Pakistan. The preferred breeding temperature range is between 24 and 31 degrees Celsius.
Induced breeding has emerged as a widely adopted technique for seed production in aquaculture, addressing the demand for various fish species, including catla, rohu, and

mrigal. This method utilizes hormonal stimulation to trigger controlled reproduction in these fish species, enabling the mass production of fish fry or fingerlings. However, it is crucial to recognize that the success of induced breeding can vary depending on the species and necessitates adherence to specific protocols. The induced breeding process typically involves hormonal induction employing either carp pituitary extract or commercially available synthetic formulations of purified salmon gonadotropin and dopamine antagonists such as Ovaprim, Ovatide, and Wova-FH. When utilizing pituitary extract, females receive an initial stimulating dose of 2-3 mg/kg body weight, followed by a subsequent dose of 5 to 8 mg/kg after a 6-hour interval. Males typically receive a single dose of 2-3 mg/kg administered concurrently with the second female injection. In the case of synthetic formulations, females are injected with a single dose of 0.4-0.5 ml/kg body weight, while males are injected with 0.2-0.3 ml/kg. The Chinese circular hatchery system has gained widespread recognition for seed production due to its proven efficiency in large-scale operations. Broodstock, typically stocked at 3-5 kg/m^3, are administered suitable inducing agents and released into a breeding tank with a water depth of approximately 1.5 meters. Fertilized eggs are collected 8-12 hours post-injection and subsequently transferred to hatching tanks for further incubation (64-72 hours). The hatched fish typically undergo a two-tier rearing system, comprising a 15-20-day nursery phase dedicated to fry rearing, followed by a 2–3-month phase for fingerling production.

4. Conclusion

In conclusion, the Indian major carps play a pivotal role in India's aquaculture industry and have significant economic, nutritional, and cultural importance. These species have witnessed impressive growth and transformation in recent decades, expanding freshwater aquaculture production and contributing to the livelihoods of millions of people. Freshwater aquaculture, driven by technologies like induced breeding and polyculture, has become the backbone of the Indian aquaculture sector. India's abundant aquatic resources, including reservoirs, ponds, tanks, and rivers, have provided a fertile ground for the growth of these carp species. While in the mid-1980s, freshwater aquaculture represented only a portion of inland fisheries, it now dominates, constituting nearly 80% of the total production. The cultivation of the three major Indian carp, alongside the composite culture of exotic carp species, represents the prevailing practice. These major Indian carp species contribute significantly, making up 70 to 75% of freshwater fish production. It's important to note that each of these species has distinct ecological niches and feeding behaviours, necessitating a deep understanding for successful aquaculture and habitat management. Their reproductive strategies are central to sustainable management and knowledge of their reproductive biology, essential for both successful aquaculture and effective conservation in their natural habitat. Additionally, maintaining genetic diversity within these carp populations is vital for resilience to changing environmental conditions and disease resistance, which can be achieved through selective breeding programs. The conservation of these Indian major carps faces various challenges, such as overfishing, habitat degradation, water pollution, illegal exotic fish introduction, and the impacts of climate change. Mitigating these challenges requires a holistic approach that includes habitat restoration, sustainable fishing practices, and community engagement. This is critical to ensure the long-term sustainability of these species and the ecosystems they inhabit. Furthermore, the adoption of sustainable and eco-friendly aquaculture practices is crucial for both conservation efforts and the economic well-being of those involved in the industry. Innovations such as integrated multitrophic aquaculture (IMTA) and responsible farming practices reduce the environmental footprint and enhance the marketability of Indian major carp's products. In conclusion, the Indian major carps are not just fish; they are integral to the cultural, economic, and nutritional fabric of India. Their biology, ecology, and sustainable management are keys to preserving these species and the industry that relies on them. The chapter provides a broad overview of these important carp species, emphasizing their significance and the strategies needed to ensure their continued presence in India's aquatic ecosystems. By combining scientific knowledge with responsible practices, India can secure the future of these remarkable fish and the livelihoods they support.

References

[1] Ayyappan, S., & Jena, J. K. (2003). Grow-out production of carps in India. Journal of Applied Aquaculture, 13, 251-282.

[2] Ayyappan, S., & Jena, J. N. (2001). Sustainable freshwater aquaculture in India. In T. J. Pandian (Ed.), Sustainable Indian Fisheries (pp. 83-133). National Academy of Agricultural Sciences, New Delhi, India.

[3] Basavaraju, Y., &Varghese, T. J. (1980). A comparative study of growth rate of rohu - mrigal and mrigal - rohu hybrids and their parental species. Mysore Journal of Agricultural Sciences, 14(3), 388-395.

[4] Bharti, B. K., Saharan, N., Chandra, G., Prakash, C., Kumar, K., & Kumar, S. (2013). Effect of ß-carotene enriched diet on growth, survival and coloration of angel fish, pterophyllum scalare (Schultze, 1823). *Indian Journal of Animal Nutrition*, *30*(3), 294-298.

[5] Chandra, G, Saini, VP, Kumar, S, Fopp-Bayat, D. Deformities in fish: A barrier for responsible aquaculture and sustainable fisheries. *Rev Aquac*. 2023; 1-20. doi:10.1111/raq.12872

[6] Chandra, G., & Bharti, B. K. (2018). Assessment the effect of supplementary feeding on fish production in rural fish farming practices. *Journal of Experimental Zoology India*, *21*(2).

[7] Chandra, G., & Fopp-Bayat, D. (2021). Trends in aquaculture and conservation of sturgeons: A review of molecular and cytogenetic tools. Reviews in Aquaculture, 13, 119-137.

[8] Chandra, G., & Saxena, A. (2012). Effect of dietary Spirulina level on growth and chemical composition of carcass in Rohu, *Labeo rohita* (Hamilton). *Journal of Experimental Zoology, India*, *15*(2), 583-585.

[9] Chandra, G., & Saxena, A. (2013). Morphometric characteristics and conservation of the vulnerable fish, *Eutropiichthys vacha* (Hamilton, 1822) in the rivers of Ganga and Kosi, North India. Journal of Experimental Zoology, India, 16(1), 97-99.

[10] Chandra, G., & Saxena, A. (2014). Fisheries and Management Status of Gogabeel Lake, Katihar, Bihar. Ecology, Environment and Conservation. Supplement Issue: 123-126.

[11] Chandra, G., Chaudhary, P. K., & Kumar, M. (2022). Integrated fish farming system: A way towards sustainability and prosperity of farmers.

[12] Chandra, G., Misra, V. K., & Singh, S. (2020). Fish Faunistic Diversity in Kosi River at Supaul, Bihar. Journal of Krishi Vigyan, 9(si), 106-109.

[13] Chandra, G., Saxena, A., & Barat, A. (2010). Genetic diversity of two riverine populations of *Eutropiichthys vacha* (Hamilton, 1822) using RAPD markers and implications for its conservation. Journal of Cell Molecular Biology, 8(2), 77-85.

[14] Choudhury, S. N. (1995). Shrimp and carp aquaculture and the environment. In Bangladesh Study Report. Regional Study and Workshop on Aquaculture Sustainability and the Environment. Manila, Asian Development Bank & Bangkok, Network of Aquaculture Centres in Asia-Pacific. [Draft report]

[15] CIFA. (2004). Annual Report Central Institute of Freshwater Aquaculture. Bhubaneswar. CIFA, 99 pp.

[16] CIFA. (2004). CIFA technologies. Central Institute of Freshwater Aquaculture, Bhubaneswar, Odisha, India.

[17] FAO. (2016). Fishery and aquaculture statistics 2014. Food and Agricultural Organization, Rome, 204 pp.

[18] FAO. (2017). National aquaculture overview: India. Country profile fact sheets. FAO Fisheries and Aquaculture Department, FAO, Rome. http://www.fao.org/fishery/factsheets/en (Accessed 1 December 2017).

[19] Fopp-Bayat, D., Chandra, G., & Nitkiewicz, A. (2022). How Cold Shock Affects Ploidy Level and Early Ontogenetic Development of the Sterlet, A. ruthenus L. *International Journal of Molecular Sciences*, *23*(1), 494.

[20] Fopp-Bayat, D., Nitkiewicz, A., & Chandra, G. (2021). First report on embryonic and larval development of 2n/3n mosaic sterlet. *Animal*, *15*(9), 100317.

[21] Gopakumar, K., Ayyappan, S., Jena, J. K., Sahoo, S. K., Sarkar, S. K., Satapathy, B. B., &Nayak, P. K. (1999). National Freshwater Aquaculture Development Plan. CIFA, Bhubaneswar, India, 75 pp.
[22] Gupta, S. D., Rath, S. C., Dasgupta, S. D., & Tripathi, S. D. (1995). A first report on quadruple spawning of *Catla catla* (Ham.). VeterinarskiArhiv, 65(5), 143-148.
[23] Hayat, M. (1995). Shrimp and carp aquaculture and the environment. Pakistan Study Report. In Regional Study and Workshop on Aquaculture Sustainability and the Environment. Manila, Asian Development Bank, and Bangkok, Network of Aquaculture Centres in Asia-Pacific. [Draft report]
[24] Jayaram, K. C. (1981). The Freshwater Fishes of India, Pakistan, Bangladesh, Burma, and Sri Lanka. Handbook of Zoological Survey of India, Volume 2. Calcutta, India. 475 pp.
[25] Jayasankar, P. (2018). Present status of freshwater aquaculture in India: A review. Indian Journal of Fisheries, 65(4), 157-165.
[26] Jena, J. K., Aravindakshan, P. K., & Singh, W. J. (1998b). Nursery rearing of Indian major carps fry under different stocking densities. Indian Journal of Fisheries, 45(2), 163-168.
[27] Jena, J. K., Aravindakshan, P. K., Chandra, S., Muduli, H. K., & Ayyappan, S. (1998a). Comparative evaluation of growth and survival of Indian major carps and exotic carps in raising fingerlings. Journal of Aquaculture in the Tropics, 13, 143-150.
[28] Jhingran, V. G. (1968). Synopsis of Biological Data on Rohu, *Cirrhinus mrigala* (Hamilton, 1822). FAO Fisheries Synopsis No. 32, FAO, Rome, Italy.
[29] Jhingran, V. G. (1991). Fish and Fisheries of India. Hindustan Publishing Corporation (India), Delhi, India. 727 pp.
[30] Khoke, U. C. (1995). Shrimp and carp aquaculture and the environment. Myanmar Study Report. In Regional Study and Workshop on Aquaculture sustainability and the environment. Manila, Asian Development Bank & Bangkok, Network of Aquaculture Centres in Asia-Pacific. [Draft report]
[31] Misra, V. K., Uchoi, D., Singh, C. P., Kumar, A., Chandra, G., Kumar, V., ... & Singh, I. J. (2020). Changes in hematological parameters of a freshwater fish, Cyprinus carpio (communis) exposed under pulp and paper mill effluent.
[32] Pathak, S. C., & Palanisamy, K. (1995). Shrimp and carp aquaculture and the environment. India Study Report. In Regional Study and Workshop on Aquaculture sustainability and the environment. Manila, Asian Development Bank & Bangkok, Network of Aquaculture Centres in Asia-Pacific. [Draft report]
[33] Singh, D. M. (1995). Shrimp and carp aquaculture and the environment. Nepal Study Report. In Regional Study and Workshop on Aquaculture sustainability and the environment. Manila, Asian Development Bank & Bangkok, Network of Aquaculture Centres in Asia-Pacific. [Draft report]
[34] Somalingam, J., Maheshwari, U. K., & Langer, R. K. (1990). Mass production of intergeneric hybrid catla (*Catla catla* x *Labeo rohita*) and its growth in ponds, small and large reservoirs of Madhya Pradesh. In P. Keshavanath& K. V. Radhakrishnan (Eds.), Proceedings of the workshop on carp seed production technology (pp. 49-52). Asian Fishery Society Indian Branch, Mangalore, India.
[35] Talwar, P. K., &Jhingran, A. G. (1991). Inland Fishes of India and Adjacent Countries. Volume 1. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, India. 541 pp.

