



ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2026): 4.97
IJAFS 2026; 8(4): 422-430
www.agriculturaljournals.com
Received: 04-02-2026
Accepted: 08-03-2026

R. Bhargavi
Tamil Nadu Dr. J.
Jayalalithaa Fisheries
University, Nagapattinam,
Tamil Nadu, India

Dr. K. S. Vijay Amirtharaj
Tamil Nadu Dr. J.
Jayalalithaa Fisheries
University, Nagapattinam,
Tamil Nadu, India

Bhanuprakash Ch.
P. V. Narasimha Rao
Telangana Veterinary
University, Telangana, India

Corresponding Author:
R. Bhargavi
Tamil Nadu Dr. J.
Jayalalithaa Fisheries
University, Nagapattinam,
Tamil Nadu, India

Influence of Rearing Temperature on Growth Performance and Sex differentiation of *Channa striata* (Striped murrel)

R Bhargavi, K S Vijay Amirtharaj and Bhanuprakash Ch

DOI: <https://www.doi.org/10.33545/2664844X.2026.v8.i4f.1412>

Abstract

Temperature is one of the most important environmental factors influencing growth, survival and sex differentiation in fishes. In *Channa striata* (striped murrel), rearing temperature significantly affects metabolic activity, digestive enzyme secretion, endocrine regulation and gonadal differentiation during early developmental stages. Several studies indicate that optimal temperature improves growth performance and feed utilization efficiency, whereas extreme temperatures induce stress responses and alter physiological functions. Temperature also plays a critical role in environmental sex determination by regulating gene expression associated with gonadal development. Understanding the influence of temperature on growth and sex differentiation is essential for improving seed production and culture efficiency of striped murrel. This review summarizes the current knowledge on temperature-dependent growth performance and mechanisms of sex differentiation in *Channa striata* and highlights future research needs for sustainable aquaculture development.

Keywords: Striped murrel, Temperature, Growth performance, Sex differentiation, Environmental sex determination

Introduction

The importance of the fisheries and aquaculture sectors in contributing to global food security and nutrition in the twenty-first century has been increasingly recognized (FAO, 2022) [37]. This sector also serves as an important source of income and livelihood to millions of people and fish represents a cost-effective and beneficial source of animal protein, making it a viable choice to alleviate hunger and address malnutrition within the nation (DoF, 2022) [9].

In India, the murrel landing from coastal states and union territories was 1.55 lakh tonnes during 2020-21 (DoF, 2022) [9]. Worldwide, the production of striped murrel reached 92,523 tonnes, with the predominant share of 70,802 tonnes from capture fisheries and 21,721 tonnes from aquaculture (Rawat et al., 2021) [97]. In the past decade, air-breathing fishes have experienced a consistent decline, primarily driven by factors such as over-exploitation, habitat loss, diseases, pollution, siltation, poisoning, dynamiting, and the introduction of alien species (Haniffa, 2000) [47]. As an air-breathing fish, *Channa striata* has the ability to thrive in shallow waters, derelict and weed infested water areas (Pati et al., 2004; Sakhare, 2015) [85, 102]. Among the murrels, striped murrel, *C. striata* is a preferred species since it grows better than *C. punctatus* (Senguttuvan and Sivakumar, 2010) possesses lesser cannibalistic habit than *C. marulius* (Pati et al., 2004; Sakhare, 2015). This species is mainly cultured in Thailand, The Philippines, Vietnam, Malaysia, Java, Taiwan, Hong Kong, Pakistan, India, and Bangladesh, (Courtenay et al., 2004; Dayal et al., 2013; Amin et al., 2015; Roy et al., 2020) [8, 26, 29].

Striped murrel is one of the important air breathing freshwater fishes of south east Asia (Dayal et al., 2013; Sakhare, 2015; Djumanto et al., 2020; Rawat et al., 2020; Gustiano et al., 2021; Kumar et al., 2021; Raizada et al., 2022) [29, 33, 45, 57, 93, 97, 102]. It is a promising species for aquaculture that grows quickly and can be raised at high stocking densities (Kumar et al., 2022). This fish is one of the main food fish and highly valued for its meat quality, appealing flavour, lesser intramuscular spines, nutritional content, organoleptic properties, medicinal properties like presence of bioactive components in its flesh like albumin (Mustafa et al., 2012) [72], amino acids (glycine, lysine, arginine) (Courtenay et al.,

(Courtenay et al., 2004; Zakaria et al., 2007) ^[126] and fatty acid (arachidonic acid 20:4n-6) (Courtenay et al., 2004) ^[26] involving in antinociception, gastroprotection, disease resistance, antioxidant and many people consume it to promote healing and manage pain following clinical procedures (Dayal et al., 2013; Sakhare, 2015; Roy et al., 2020; Ahmadi, 2021; Kumar et al., 2022, 2021; Raizada et al., 2022; Fatah et al., 2023) ^[2, 29, 39, 57, 93, 102].

In natural water bodies striped murrel breeds just before or during the onset of the monsoon, and its spawning season extends until the end of monsoon (Alikunhi, 1953; Pati et al., 2004; Dayal et al., 2013; Sakhare, 2015) ^[5, 29, 85, 102] and the spawning season varies significantly with geographical region and climatic condition (Raizada et al., 2022) ^[93]. The major problem in the culture of murrel is unavailability of adequate amount of good quality seed from the wild where there is a failure of monsoon and scarcity in availability of matured brood stock. Moreover, there is no established murrel seed supply centre anywhere in India. On the other hand, aquaculture practice of this species heavily relies on natural seed supply, thereby making a relatively minor contribution. Hence, it is very essential to introduce an induced seed production system as an alternative to the present unreliable dependency on the wild seed collection to supply fish seed to farmer. Parameswaran and Murugesan (1976) ^[82] were the first to attempt the captive breeding of murrel by using carp pituitary extract (Dayal et al., 2013; Raizada et al., 2022) ^[29, 93]. This fish can be induced to spawn using different agents, such as PGE (pituitary gland homogenates), h CG (human chorionic gonadotropin), LHRH analogue and Gn RH analogues (Ovaprim, Ovotide, WOFAH, Gonopro FH and Ovupin) along with dopamine antagonists (domperidone, pimozide) (Parameswaran and Murugesan, 1976; Haniffa, 2000; Pati et al., 2004; Marimuthu et al., 2007; Roy et al., 2016; Rawat et al., 2020; Kumar et al., 2022, 2021) ^[46, 47, 57, 66, 82, 85, 97, 100]. Some of the challenges noticed in culture of striped murrel is the paucity of data on reproductive characteristics such as gonad development and sex differentiation. Furthermore, there are no known morphological characteristics that can be used to consistently distinguish between male and female individuals throughout the maturing phase and the sex ratio tends to be skewed towards females (Tresnati and Fachruddin, 2019) ^[115]. Reproduction process in fishes were influenced by various environmental factors especially temperature and photoperiod (De Vlaming, 1972) ^[30] and nutritional factors as well (Ghaedi et al., 2019) ^[42]. Sex determination in fish is a complex and flexible mechanism regulated by genetic, physiological, and environmental factors (Devlin and Nagahama, 2002; Rougeot et al., 2008) ^[99]. Gonadal differentiation in teleosts exhibits diverse patterns, varying from the conventional scenario where individuals exclusively develop and acquire either testes or ovaries during sexual maturation, to instances of synchronous hermaphroditism where both functional male and female gonadal tissues coexist simultaneously. Within this spectrum, there exists a notable variety of strategies, including sex reversal and sex ratio bias in populations, stemming from differences in the frequency or timing of testis or ovary development in hermaphroditic gonads (Devlin and Nagahama, 2002) ^[31]. Temperature is one of the important environmental factors that plays significant role in biological processes of fish (Islam et al., 2019) ^[49]. Sex determination and sex differentiation processes are widely investigated in fish (Baroiller and d'Cotta, 2001; Santi et al., 2016) ^[14, 105]. The impact of temperature on sex differentiation is expected to

vary based on the temperature level and the genetic background (Tessema et al., 2006) ^[114]. Higher temperatures drive sex determination towards the male phenotype (Pankhurst and Munday, 2011) ^[81]. Many report showed the influence of temperature on sex differentiation and sex ratio in various fishes like *Oreochromis mossambicus* (Wang and Tsai, 2000) ^[119], *O. niloticus* (Tessema et al., 2006; Bezault et al., 2007; Ali, 2009; Khater et al., 2017) ^[4, 15, 53] *Oncorhynchus mykiss* (Altunok and Peker, 2016) ^[6], *Clarias gariepinus* (Santi et al., 2016) ^[105], *Paralichthys olivaceus* (Wang et al., 2017) and *Cyprinus carpio* (Biswas et al., 2021) ^[18]. Global warming is a great concern of aquaculturists and fishery biologists. The rise in water temperature as a consequence of global warming is alarming for the field of aquaculture (Islam et al., 2019) ^[49]. Due to temperature fluctuation, significant variations in the sex ratio of striped murrel have been observed across different habitats (Raizada et al., 2022) ^[93]. Various studies consistently report low male-to-female sex ratios of 1:1.2, 1:1.5, 1:2, 1:2.1, 1:3 and 1:10.5 (Irmawati et al., 2017; Arma et al., 2014; Raizada et al., 2022) ^[12, 48].

General Biology of Striped murrel

Murrels are freshwater fishes belonging to the family Channidae. They are also called as Snakeheads because these fishes have head that very closely resembles snake (Marx, 2009) ^[52]. In the gill cavity, they have an air breathing organ called suprabranchial organ (Rahman and Awal, 2016; Kumar et al., 2022) ^[92] which help them survive in the water with relatively low oxygen and they exhibit jumping behaviour (Marx, 2009). These fishes are hardy in nature and can tolerate low oxygen content in water, high CO₂, high BOD and high ammonia content (Chakrabarty, 2006; Narejo et al., 2015; Rahman and Awal, 2016; Kumar et al., 2022) ^[73]. They also have aestivation behaviour (summer sleep) where it will become dormant inside mud during dry season (Marx, 2009; Kumar et al., 2022). The pectoral fin of the fish is about twice as long as the head and have 50- 57 scales in lateral series. Body is compressed posteriorly but cylindrical anteriorly, head depressed. The dorsal fin begins behind base of pectorals and extends beyond anal. The colour of the fish is olive green, dark greyish to black above, dirty green to white below, vertical (oblique) bands of grey or black from sides to the abdomen, spots and bands posteriorly on the dorsal fin, ventral and anals greyish with whitish spots and lines on the latter (Marx, 2009) ^[52].

Food and feeding habits of striped murrel

Fish gut content analysis is the only way to find feeding habits of snakehead as it is difficult to see the fishes feeding in their natural habitat (Amin et al., 2014) ^[7]. Striped murrels are highly carnivorous, piscivorous and cannibalistic in nature (Amin et al., 2015; Rahman and Awal, 2016; Ghaedi et al., 2019) ^[8, 42, 92] and selectively feed on frogs, insects, snakes, tadpoles, earthworms, molluscs found in natural waters (Amin et al., 2014; Laxmappa and Babu, 2014; Amin et al., 2015; Narejo et al., 2015; Rahman and Awal, 2016; Kumar et al., 2022) ^[60, 73]. According to Amin et al. (2014) ^[7], fry of these fishes mostly feed on copepods, followed by cladocerans, insects, molluscs, worms, shrimps and others but adults mainly prefer aquatic insects followed by shrimps, small fishes and others. True cannibalism is also observed in this species. (Chakrabarty, 2006).

Distribution and habitat of striped murrel

Striped murrel (*Channa striata*) is an important air-breathing freshwater fish. This species is also commonly called as striped snakehead and Chevron snakehead (Djumanto et al.,

2020; Kumar et al., 2021c; Raizada et al., 2022) [33, 57, 93]. They are widely distributed in Asia and Southeast Asian region and in Africa (Dayal et al., 2013; Amin et al., 2015; Rahman and Awal, 2016; Djumanto et al., 2020; Roy et al., 2020; Gustiano et al., 2021; Kumar et al., 2021b, 2022; Raizada et al., 2022;) [8, 29, 45, 92]. Striped murrel are naturally distributed in India, Bangladesh, Sri Lanka, Pakistan, Burma, China, Malaysia, Nepal, Singapore, Thailand, Vietnam, Korea, Kampuchea, Indonesia and Philippines (Chakrabarty, 2006; Rahman and Awal, 2016; Gustiano et al., 2021; Raizada et al., 2022; Yadav et al., 2022; Fatah et al., 2023) [39, 123].

Generally, murels occur in slow and fast flowing rivers, lakes, reservoirs, tanks, ponds, swamps, bheels, jheels, canal ditches, floodplains, muddy watersheds, brackishwaters, paddy fields, weed infested shallow waters and oxygen depleted polluted waters (Kilambi, 1986; Chakrabarty, 2006; Arma et al., 2014; Li et al., 2016; Roy et al., 2016; Djumanto et al., 2020; Kumar et al., 2022; Raizada et al., 2022; Fatah et al., 2023) [12, 33, 39, 54, 61, 93, 100].

Reproductive biology of striped murrel

Understanding the reproductive biology of species is essential for successful induced breeding (Kumar et al., 2022). Several researchers have described the reproductive biology of the striped murrel (Raizada et al., 2022) [93].

Secondary sexual characteristics

Sexes are separate in this species and can be easily identified during breeding season (Chakrabarty, 2006; Kumar et al., 2022; Raizada et al., 2022). The females have shorter anal fin basal length and larger eye diameter than males (Arma et al., 2014; Kumar et al., 2022) [12]. Mature female can be identified by protruding abdomen. Females have an oval gonadal opening that is slightly fleshier, pinkish, and closer to origin of the anal fin when compared to males. In contrast, males have a slimmer body, no bulge in belly button, an extended genital opening devoid of flesh, and, when they become adult, a minute genital papilla appears. When compared to females, the distance between the genital orifice and the anal fin is noticeably larger. Males typically have darker bodies when they mature (Raizada et al., 2022) [93].

Gonad structure

Striped murels are gonochoristic in nature and male possess testes and female possess ovary. The testes are paired but left lobe is slightly larger, thin, tubular, and are white to pinkishwhite in colour. ovary is paired, left lobe is slightly larger than right and cylindrical in shape, whitish to yellowish-orange in colour, and as the fish gets mature, the size of the ovary increases both in length and diameter. The testes is connected to coelomic cavity via mesorchium whereas ovary is via mesovarium (Kumar et al., 2022; Raizada et al., 2022) [93]. The ovotestis (intersex) type gonad also reported in these fishes with standard length 81-229 mm (Tresnati and Fachruddin, 2019; Raizada et al., 2022;) [115]. Developmental stage of gonad of striped murrel was given in Table 2.1.

Sex Ratio

The sex ratio of the species is influenced by factors such as the habitat, location, season and life stages of the fish. etc. Various study reported a low male to female sex ratio of 1:1.2, 1:1.5 (Li et al., 2016) [61], 1:2, 1:2.1, 1:3 and 1:10.5 (Raizada et al., 2022) [93]. According to Ahmadi (2021) [2], the sex ratios of snakehead sampled from Danau Bangau for three months (July, August, September) exhibited a sex ratio of 1:1.6, 1:1.1

and 1.2:1 (F:M) respectively and concluded that the sex ratio within the population was balanced since the above results are close to normal 1:1 ratio.

Fecundity

Murels are batch spawner where more than one batch of oocytes will be present in maturing ovary (Qasim and Qayyum, 1962; Sakhare, 2015) [88, 102]. The fecundity of striped murrel varies in different regions. Alikunhi (1953) [5] stated that depending on the size of the fish, the number of eggs produced will vary which can range from a few hundred to thousands. The recorded relative fecundity of striped murrel is between 10.5-36.5 eggs/g of body weight (BW) of female (Ali, 1999; Kumar et al., 2022) [3]. Ali (1999) [3] stated that the mean absolute fecundity of striped murrel ranged from 4326-9017 eggs/g BW. Kilambi (1986) [54] estimated the fecundity of this species which ranged from 1688 to 7146. Narejo et al. (2015) [73] claimed that the estimated fecundity of striped murrel was from 3000-12000 eggs in a female of

33.4 to 50.8 cm length (TL).

Maturation

Alikunhi (1953) [5] reported that striped murrel will attain their sexual maturity at the end of the first year (Sakhare, 2015) [102] in natural farm conditions but at a large size of 234 mm to 317 mm with ovaries of IV gonadal stages. Islam et al. (2013) also documented that this species attains its sexual maturity at the age of one year. According to Parameswaran (1975) this species matures in the first year itself at a minimum size of 173 mm (male) and 179 mm (female). However, in some studies it was mentioned that striped murrel attains sexual maturity at the age of two years old (Raj, 1916; Bhattacharya, 1946; Mookerjee et al., 1948; Chakrabarty, 2006) [17, 70, 94].

Natural spawning

Intense breeding of striped murrel takes place during rainy months (Alikunhi, 1953; Dayal et al., 2013) [5, 29]. Striped murels breed naturally during south-west monsoon (July-August) and also in North east monsoon (October-December) in flooded rivers and ponds and in natural waters in India (Alikunhi, 1957; Haniffa et al., 2000; Chakrabarty, 2006; Marimuthu et al., 2007; Roy et al., 2016) [4, 47, 66, 100]. The spawning season varies significantly with geographical region and climatic condition. It breeds from May to July and November to January in Southern India, July to August in Northern India, April to June in Central Laos, April to November in Southern Taiwan, May to August in Bangladesh, April to December in Korea and May to September in Sri Lanka (Alikunhi, 1953; Kumar et al., 2022; Raizada et al., 2022) [93].

Murels spawn in ditches, ponds, and flooded paddy fields (Raizada et al., 2022) [93]. Striped murels are monogamous where one male pair with one female and the breeding pair remain together for the whole breeding season (Haniffa et al., 2000; Chakrabarty, 2006; Kumar et al., 2022; Raizada et al., 2022) [47]. This species is batch spawner and reproduces twice to three times annually (Rawat et al., 2020).

During spawning, the breeding nest will be built by male using aquatic vegetations and both parents show parental care in this species by actively guarding the yellow colour egg mass but male will involve primarily in parental care (Alikunhi, 1953; Amin et al., 2015; Kumar et al., 2022; Raizada et al., 2022) [5, 93]. Parental care is observed up to the fingerlings stage (4-6 cm length) in the earthen pond (Marimuthu et al., 2001) [65].

Snakehead fry starts to swim vertically with the right eye side up after two days of hatching (Amin et al., 2015) ^[8].

Induced breeding

Application of hormonal treatments to enhance fish maturation have been successfully practiced in aquaculture. Nonetheless its effectiveness varies based on the target species, dose, frequency, and implementation time (Ath-thar et al., 2021) ^[13]. Parameswaran and Murugesan (1976) ^[82] were the first to record captive spawning on striped murels in India, using carp pituitary extract (CPE) (Chakrabarty, 2006; Raizada et al., 2022) ^[93].

Haniffa et al. (2000) ^[47] compared the efficacy of natural (Pituitary extract and HCG) and synthetic hormones (Luteinizing hormone releasing hormone analogue and ovaprim) in inducing spawning in murrel. The latency period was long in pituitary extract (24 h) and HCG (26 h) injected fish when compared to synthetic hormones. Ovaprim yielded better fertilisation rate (95-98%) and duration of hatching was 21-23 h. They also observed that the ova diameter was also bigger (1.34- 1.45 mm) in ovaprim injected fish and concluded that Ovaprim could be the best hormone for the induction of spawning in murrel.

Marimuthu et al. (2001) ^[65] administered 50 mg of pituitary extract per kg of BW of murrel brooders and maintained the sex ratio of 2:1 (M: F). They noticed spawning after 6h of hormonal injection. They noticed that male was more actively involved in courtship and also guarded the fertilized eggs. Marimuthu et al. (2007) ^[66] induced Striped murrel with Ovateide at 0.2 ml/kg, 0.4 ml/kg and 0.6 ml/kg BW. The male female ratio used was 2:1. At 0.4 ml/kg and 0.6 ml/kg of injection, the fishes exhibited complete spawning with the fertilisation and hatching rate of 98.7±0.6% and 91.6±1.5%, respectively.

Francis et al. (2011) ^[40] reported that kisspeptin at 0.05 µg/g BW had a greater impact on GSI and steroid hormone levels in both male and female fish compared to the other concentration (0.01 µg/g BW) tested.

Dayal et al. (2013) ^[29] reported induced breeding of striped murrel using Ovaprim at 0.5-0.8 ml/kg BW and 2.0-2.4 ml/kg BW for female and male respectively. After injection, the fishes have been released into four different systems such as FRP tank, hapa, small pond (size 9.1 9 6 9 1.3 m) and big earthen pond. The female to male sex ratio of 4:6 was followed in all the experimental systems. Among the four systems, fertilization and hatchability rate was 76-81% and 82-92% respectively in small pond system and 85-91% and 88-92% respectively in big earthen ponds. There was no great success in the other two systems.

Paray et al. (2013) induced murrel to breed by administering HCG at 6000 IU/Kg BW by intramuscularly at a male female ratio of 1:1 in fibre tank. They reported spawning after 22-30 h giving injection and mentioned that parental care improves hatching rates and protects eggs from fungal infections and from predation.

Radona et al. (2020) ^[90] induced murrel with Pregnant mere serum gonadotropin (PMSG) and antidopamine (AD) hormones at three different doses such as 2.0 m L/kg, 2.25 m L/kg and 2.5 m L/kg once in every 10 days for the period of 30 days. They have also induced ovulation during IV gonadal stage of maturity using LHRHa at 0.6 m L/kg, HCG at 500 IU + LHRHa at 0.6 m L/kg and oxytocin 1 IU + LHRHa 0.6 m L/kg. They concluded that murrel brood stock induced with PMSG + AD (2.5 m L/kg) had the highest gonadosomatic index (3.21±0.26%) and fecundity (5.268±410 eggs per fish)

at the fourth stage of gonadal maturation (IV GMS) whereas, the ovulation study showed that striped murrel broodstock induced with a combination of HCG 500 IU + LHRHa 0.6 ml/kg had the fastest ovulation latency period (21 hours 8 minutes) with highest ovulation rate (100%).

Rawat et al. (2020) injected both male and female murrel (1:1 ratio) with salmon gonadotropin releasing hormone analogue (sGnRHa) with dopamine antagonist at 1 ml/kg BW of fish and observed 30-95% fertilization rate.

Similar to Radona et al. (2020) ^[90], Ath-thar et al. (2021) ^[13] also tested the efficacy of PMSG and AD hormones in inducing spawning in striped murrel and injected the fishes with 3 different doses of hormone like 1.5 ml/kg, 1.75 ml/kg and 2 ml/kg BW of fish. They recorded that at 2 ml/kg, egg diameter (1.45±0.023 mm) was the largest and has the highest estradiol-17β concentration (105±0.550 ng/ml). Kumar et al. (2021a) ^[57] implanted HCG hormone pellet intramuscularly and observed full maturity in brooders after 3 weeks of hormone implantation. Then they intramuscularly administered female and male fishes with HCG @ 2000 IU/kg and 1500 IU/kg BW; carp pituitary gland extract (PGE) @ 10–15 mg/kg BW and 7.5–10 mg/kg BW; Ovateide/Ovaprim @ 0.6 ml/kg BW and 0.4 ml/kg BW, respectively and reported better success rate in carp PGE. They also observed that the spawning time was 16–18 h at 26–28 . °C

Factors influencing breeding of striped murrel

Reproductive process of fish is known to be influenced by various environmental factors especially photoperiod and temperature (De Vlaming, 1972) ^[30]. Brood stock nutrition is also essential for gonadal development and fish reproduction. Improved brood stock nutrition leads to higher egg and sperm quality, as well as increased seed production (Ghaedi et al., 2019) ^[42].

Damle et al. (2023) ^[28] has identified the effect of habitat manipulation on early gonad maturation of

C. striata in captive condition by using four habitats such as tank with clean reservoir water without macrophytes and soil base, tanks provided with floating (Water hyacinth, *Eichhornia* sp) and submerged (Water thyme, *Hydrilla* sp) aquatic macrophytes without any soil base, tanks provided with only soil base (15-20 cm) without any macrophytes and tanks provided with both soil base and macrophytes. After three months of rearing, fish given with macrophytes and soil base matured early, with eggs measuring 1.29±0.21 mm and the majority of late granular stage oocytes and spermatozoa in the ovary and testes, respectively. The study found that providing a 15- 20 cm bottom soil base and covering 20-30% of the water spread area with aquatic macrophytes in the brood raising tank improved gonadal maturation in captive striped murels during the premonsoon season.

Mollah et al. (2009) ^[69] has investigated the effect of stocking density on the growth and breeding performance of broodfish and larval growth and survival of *C. striata*. Initially, the brood fish were stocked at 3 different stocking densities viz., 4 (357.22g / m²) , 6 (541.78g / m²) and 8 (719.18g / m²) at 1:1 male-female ratio and fed with washed and chopped poultry viscera twice a day and with live silver carp fry twice a week. The broodfish spawned naturally at chambers that stocked at a density of 357.22g / m² and 541.78g / m² and the best breeding performance was exhibited in fishes stocked at 541.78 : g / m² . Then 4-5 days old larvae were stocked in 9 bowls of 10 l capacity at stocking density of 20, 40 and 60 larvae each (stocking density 2,4,6/l larvae, respectively). They reported that larvae stocked at 2 larvae/litre had

significantly higher health condition (13.31 ± 0.69 mg/mm) and survival rate ($80.0 \pm 3.0\%$).

Srivastava and Singh (1991) ^[111] documented the effect of constant photoperiod-temperature on ovarian activity in *C. punctatus*. The results showed that long photoperiod-warm temperature regime (LD 12 : 8-30°C) stimulates ovarian recrudescence and prolongs the spawning period while ovary development was inhibited at short photoperiod-warm temperature regime (LD8 : 12-30°C) .

Yadav et al. (2022) ^[123] studied the GSI of male and female striped murrel (*C. striata*) in Etawah district of Uttar Pradesh from January to June. GSI value was minimum at pre-spawning period (January) and reached maximum at maturation period (June) and the corresponding values were 2.274 ± 0.014 and 4.32 ± 0.24 in female and in male it was 0.138 ± 0.026 and 0.23 ± 0.018 .

Ha et al. (2021) ^[46] noted the impact of various salinities 0, 3 and 6 ‰ on the reproductive physiology of *C. striata*. The results showed that highest GSI ($5.8 \pm 2.62\%$) of female was found in 3 ‰ while the lowest was found in control ($3.85 \pm 1.95\%$). The highest vitellogenin concentration was showed by 6‰ treatment, whereas the absolute fecundity and the relative fecundity were the highest at the 3‰ treatment.

Effect of temperature on fish

Temperature is one of the important environmental factors that plays significant role in growth, metabolism and other biological processes of fish (Islam et al., 2019) ^[49]. Fishes being an ectotherm, rely greatly on temperature for growth and maturation (Kuparinen et al., 2011) ^[58]. Hence, deviation from its optimal range due to various reasons may have significant effect on the processes that depends on temperature.

Effect of temperature on growth of fishes

Temperature is recognised as one of the most important single abiotic parameters impacting fish growth, feed intake, and feed conversion (Ali, 2009) ^[4]. Ali (2009) ^[4] studied the effect of temperature (20, 25, 30 and 35°C) on growth of Nile tilapia (*Oreochromis niloticus*) fry for 60 days and reported that the final mean weight was significantly higher at 25 and 30°C compared to 20 and 35°C. The highest body weight was recorded at 30°C that was 18.24 g followed by at 25°C that was 13.16 g. Daily weight gain (DWG) and feed conversion ratio (FCR) were higher at 25 and 30°C. At all temperature, survival rates remained unaffected. And they concluded that growth rate was increased with increasing water temperature and at 30°C reached its optimum and then declined significantly at 35°C.

Qin and Fast (1998) documented the effect of temperature, size and density on culture of striped murrel. They reared murrel in low and high temperature with two stocking densities (15 and 30 / m²) . The average high temperature was 27.0°C : (24.6-28.8°C) and low temperature was 21.7 °C (20.5-23.2°C) . The results showed that fish gained more weight at high temperature and low stocking density.

Effect of temperature on maturity and reproduction of fishes

Temperature affects virtually all aspects of reproduction in fish including gametogenesis and gamete maturation, ovulation/ spermiation, spawning and subsequent early development (Pankhurst, 1997) ^[80].

Lahnsteiner and Leitner (2013) ^[59] reported the effect of temperature on gametogenesis and gamete quality in Brown Trout, *Salmo trutta*. According to Pankhurst et al. (1996)

elevated holding temperature resulted deleterious effect on ovulation, egg production and fertility but there was no observed effect on endocrine parameters associated with vitellogenesis in the rainbow trout *Oncorhynchus mykiss*. Usman et al. (2015) ^[116] documented the influence of monthly variation in water temperature on artificial breeding of common carp (*Cyprinus carpio* L.). Glasser et al. (2004) ^[43] investigated the effect on temperature along the reproductive axis (brain–pituitary–gonad) of grass carp (*Ctenopharyngodon idella*) by analysing gonadotropin and maturation-inducing steroid (MIS) profiles during spawning induction at regulated temperatures of 24°C and 28°C to determine their impact on ovulation success.

Effect of temperature on survival of fishes

Okunsebor et al. (2015) ^[76] documented the effect of temperature (26°C, 28°C, 30°C and 32 °C) on fertilization, hatching and survival rates of *Heterobranchius bidorsalis* (Eel-like fattyfin catfish) eggs and hatchlings and reported that fertilization and hatchability was significantly highest at 28°C and 30°C . Similarly, survival rate of hatchling also higher at 28°C temperature and concluded that 28-30°C as best temperature for higher fertilization and hatchability.

Influence of temperature on sex differentiation and sex ratio in fishes

Gonadal sex differentiation in gonochoristic fish is often labile and controlled by two interacting processes: genetic sex determination (GSD) and environmental sex determination (ESD) (Baroiller and d 'Co tta , 2001; Wang et al., 2017; Biswas et al., 2021) ^[14, 18]. During the early stages of development, fish sex can be changed by factors such as changes in water temperature and pH , as well as the presence of endocrine disrupting chemicals (EDCs) in the water (Tresnati and Fachruddin, 2019) ^[115]. Fish, like reptiles and amphibians, exhibit ESD, the main environmental factor influencing sex seems to be temperature (TSD - Temperature Sex Determination) (Baroiller and d 'Co tta , 2001; Biswas et al., 2021). In the hirame *Paralichthys oliaceus*, high and low temperatures lead to monosex male populations, whereas intermediate temperatures result in a 1:1 sex ratio (Baroiller and d 'Co tta ; , 2001). Several studies have explored temperature-induced sex differentiation in teleosts (Santi et al., 2016) ^[105]. Santi et al. (2016) ^[105] reported the thermosensitivity of the sex differentiation process in the African catfish (*Clarias gariepinus*). During ontogenesis, fish were exposed to high temperatures (36°C) for three days at different periods.

Altunok and Peker, (2016) ^[6] reported the sex ratio in response to high temperature during early development of rainbow trout (*Oncorhynchus mykiss*) in farmed stocks. Ali (2009) ^[4] documented the effect of temperature (22, 27, 32 and 37°C) on the sex ratio of *O. niloticus* fry held in fibreglass aquarium for 28 days and reported significantly higher proportion of males (89%) in high temperature treatment (37°C) with low survival rate (79%). Tessema et al. (2006) ^[114] and Bezault et al. (2007) ^[15] also reported that high temperature has significantly increased the male population in Nile Tilapia.

Wang and Tsai (2000) ^[119] reported the effects of temperature on the deformity and sex differentiation of tilapia, *Oreochromis mossambicus*. Biswas et al. (2021) ^[18] identified the critical thermosensitive period and the effect of temperature on sex differentiation in *C. carpio*. Tresnati and Fachruddin, (2019) ^[115] examined the sexual development of

C. striata for which they collected fishes from wild and stated that females were larger and more in number compared to males in the same population (2 female:1 male). With these observations, they suggested that “*C. striata* is at least potentially hermaphroditic, and its gonads can undergo a differentiation phase and recommended further study on the genetic mechanisms and/or environmental influences which determine gonad development and sex differentiation in *C. striata*” (Tresnati and Fachruddin, 2019) ^[115].

Irmawati et al. (2017) ^[48] reported a strong female bias (1:3) sex ratio for the *C. striata* population obtained from Bantimurung River. Similarly, Arma et al. (2014) ^[12] reported extreme female bias (1:10.5) in sex ratio of *C. striata* from the Batangase area in Maros District, also in South Sulawesi Province, Indonesia. Zhou et al. (2018) ^[129] studied the gonadal sex differentiation in hybrid murrel of *Channa argus* (♂) × *Channa maculata* (♀) and reported that ovarian formation was observed at 13 DPH whereas, testicular formation was observed at 29 DPH. However, so far there are no reports available on sex ratio of *C. striata* in Indian water and effect of temperature on sex ratio of *C. striata* worldwide. Similarly, no data has been reported on the onset of sex differentiation and thermal influence on the onset of sex differentiation in *C. striata*.

References

1. Abol-Munafi AB, Tarn BM, Ambak MA, Ismail P. Effect of different diets on growth and survival rates of snakehead (*Channa striata* Bloch, 1797) larvae. *Korean J Biol Sci*. 2004;8:313-317.
2. Ahmadi AP. Sex ratio, gonad maturity level and gonadosomatic index of snakehead (*Channa striata*) from Danau Bangkai, Indonesia. *AACL Bioflux*. 2021;14:3299-3309.
3. Ali AB. Aspects of the reproductive biology of female snakehead (*Channa striata* Bloch) obtained from irrigated rice agroecosystem, Malaysia. *Hydrobiologia*. 1999;411:71-77.
4. Ali MA. Effect of different temperatures on growth and sex ratio of Nile Tilapia (*Oreochromis niloticus*) fry. *J Anim Poult Prod*. 2009;34:10497-10505.
5. Alikunhi KH. Notes on the bionomics, breeding and growth of the murrel, *Ophicephalus striatus* Bloch. *Proceedings/Indian Academy of Sciences*. 1953:10-20.
6. Altunok M, Peker Z. Sex ratio response to high temperature during early development of rainbow trout (*Oncorhynchus mykiss*) in farmed stocks. 2016.
7. Amin SMN, Ara R, Mohammad H, Arshad A. Food habits of snakehead, *Channa striatus* (Bloch), in the lotic streams of Universiti Putra Malaysia, Malaysia. *J Food Agric Environ*. 2014;12:979-981.
8. Amin SMN, Muntaziana MPA, Kamarudin MS, Rahim AA, Rahman MA. Effect of different stocking densities on growth and production performances of Chevron snakehead *Channa striata* in Fiberglass tanks. *North Am J Aquac*. 2015;77:289-294.
9. Department of Fisheries Ministry of Fisheries, Animal Husbandry & Dairying Government of India. Annual report. 2022-23.
10. APHA. Standard methods for Examination of the Water and Wastewater. 22nd edition. American Public Health Association, Washington, D.C; 2005.
11. Argue BJ, Phelps RP. Temperature effect of sex ratios in *Oreochromis niloticus*. 1995.
12. Arma NR, Illijas MA, Irmawati MA. Morphometric and meristic characteristics of snakehead fish for hatchery production. *Proceeding of the 3rd International and National Seminar on Fisheries and Marine Science*. 2014:198-201.
13. Ath-thar MH, Gustiano R, Sundari S, Kurniawan K, Prakoso VA, Kusmini II. Pregnant mare's serum gonad hormones and antidopamine treatments on the maturation of snakehead (*Channa striata*). *Aquac Aquar Conserv Legis*. 2021;14:173-180.
14. Baroiller JF, d'Cotta H. Environment and sex determination in farmed fish. *Comp Biochem Physiol Part C Toxicol Pharmacol*. 2001;130:399-409.
15. Bezault E, Clota F, Derivaz M, Chevassus B, Baroiller JF. Sex determination and temperature-induced sex differentiation in three natural populations of Nile tilapia (*Oreochromis niloticus*) adapted to extreme temperature conditions. *Aquaculture*. 2007;272:S3-S16.
16. Bhatnagar A, Devi P. Water quality guidelines for the management of pond fish culture. *Int J Environ Sci*. 2013;3:1980-2009.
17. Bhattacharya R. On the life-history of *Ophicephalus striatus* (Bloch). *Proc Indian Sci Congr*. 1946;33:180.
18. Biswas C, Chakraborty S, Munilkumar S, Gireesh-Babu P, Sawant PB, Chadha NK, Krishna G, Dasgupta S. Effect of high temperature during larval and juvenile stages on masculinization of common carp (*Cyprinus carpio*, L). *Aquaculture*. 2021;530:735803.
19. Boyd CE. General Relationship Between Water Quality and Aquaculture Performance in Ponds. *Fish Diseases*. Elsevier. 2017:147-166.
20. Chakrabarthi NM. Murrel & Murrel culture. Narendhra Publishing House, Delhi. 2006:29-54.
21. Chang CH, Mayer M, Rivera-Ingraham G, Blondeau-Bidet E, Wu WY, Lorin-Nebel C, Lee TH. Effects of temperature and salinity on antioxidant responses in livers of temperate (*Dicentrarchus labrax*) and tropical (*Chanos Chanos*) marine euryhaline fish. *J Therm Biol*. 2021;99:103016.
22. Cho HC, Hwang IJ, Baek HJ. Histological analysis of early gonadal development and sex differentiation in chameleon goby, *Tridentiger trigonocephalus*. *Dev Reprod*. 2014;18:51.
23. Chowdhury S, Saikia SK. Oxidative Stress in Fish: A Review. *J Sci Res*. 2020;12:145-160.
24. Clesceri LS. Standard methods for examination of water and wastewater. *Am Public Health Assoc*. 1998;9.
25. Conover DO, Heins SW. The environmental and genetic components of sex ratio in *Menidia menidia* (Pisces: Atherinidae). *Copeia*. 1987:732-743.
26. Courtenay WR, Williams JD, Britz R, Yamamoto MN, Loiselle PV. Identity of introduced snakeheads (Pisces, Channidae) in Hawaii and Madagascar, with comments on ecological concerns. 2004.
27. Craig JK, Foote CJ, Wood CC. Evidence for temperature-dependent sex determination in sockeye salmon (*Oncorhynchus nerka*). *Can J Fish Aquat Sci*. 1996;53:141-147.
28. Damle D, Kumar R, Ahilan B, Pillai BR, Chidambaram P, Swain PP, Debbarma J, Sundaray JK. The effect of habitat manipulation on early gonad maturation of *Channa striata* in captive condition. *Indian J Anim Res*. 2023;57:1462-1468.
29. Dayal R, Srivastava PP, Bhatnagar A, Raizada S, Chowdhary S, Yadav AK, Lakra WS. Captive spawning of the striped murrel, *Channa striatus* (Bloch) using

- sGnRH, in gangetic plains of India. Proc Natl Acad Sci India Sect B Biol Sci. 2013;83:65-70.
30. De Vlaming VL. Environmental control of teleost reproductive cycles: a brief review. J Fish Biol. 1972;4:131-140.
 31. Devlin RH, Nagahama Y. Sex determination and sex differentiation in fish: an overview of genetic, physiological, and environmental influences. Aquaculture. 2002;208:191-364.
 32. Dey S, Botta S, Kallam R, Angadala R, Andugala J. Seasonal variation in water quality parameters of Gudlavalleru Engineering College Pond. Curr Res Green Sustain Chem. 2021;4:100058.
 33. Djumanto, Setyobudi E, Simanjuntak CP, Rahardjo MF. Estimating the spawning and growth of striped snakehead *Channa striata* Bloch, 1793 in Lake Rawa Pening Indonesia. Sci Rep. 2020;10:19830.
 34. Do TTH, Nguyen TKH, Nguyen TE, Tang MK, Yasuaki T, Nguyen TP. Effects of temperature on growth performance, survival rate, digestive enzyme activities and physiological parameters of striped snakehead (*Channa striata*) at fry stage. CTU J Innov Sustain Dev. 2021;13:10-20.
 35. EL-Shafei HM. Assessment of some water quality characteristics as guide lines for the management of pond fish culture in Lake Manzala, Egypt. Int J Fish Aquat Stud. 2016;4:416-420.
 36. Esa YB, Dadile AM, Syukri F, Christianus A, Diyaware MY. Evaluation of Fecundity, Fertilization, Hatching, and Gonadosomatic Index of Exotic *Clarias gariepinus* (Burchell, 1822) and Native *Clarias macromystax* (Gunther, 1864) under Semi-Arid Conditions of Nigeria. Animals. 2023;13:1723.
 37. FAO. The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome, FAO. 2022.
 38. FAO. The State of World Fisheries and Aquaculture 2024. Blue Transformation in action. Rome. 2024.
 39. Fatah K, Riani E, Pratomo H. Reproductive Biology of Striped Snakehead (*Channa striata*, Bloch, 1793) in Floodplain of Lubuk Lampam, South Sumatra. Sainmatika J Ilm Mat Dan Ilmu Pengetah Alam. 2023;20:102-113.
 40. Francis T, Rajagopalsamy CBT, Jeyakumar N, Venkatasamy M, Archanadevi C. Role of kisspeptin on gonadal maturation of Striped Murrel *Channa striatus*. Indian J Sci Technol. 2011;8.
 41. Gao Z, Wang HP, Rapp D, O'Bryant P, Wallat G, Wang W, Yao H, Tiu L, MacDonald R. Gonadal sex differentiation in the bluegill sunfish *Lepomis macrochirus* and its relation to fish size and age. Aquaculture. 2009;294:138-146.
 42. Ghaedi A, Hosseinzadeh H, Hashim R. Effect of different protein levels on reproductive performance of snakehead murrel *Channa striatus* (Bloch 1793). 2019.
 43. Glasser F, Mikolajczyk T, Jalabert B, Baroiller JF, Breton B. Temperature effects along the reproductive axis during spawning induction of grass carp (*Ctenopharyngodon idella*). Gen Comp Endocrinol. 2004;136:171-179.
 44. Godwin J, Luckenbach JA, Borski RJ. Ecology meets endocrinology: environmental sex determination in fishes. Evol Dev. 2003;5:40-49.
 45. Gustiano R, Kurniawan K, Kusmini II. Bioresources and diversity of snakehead, *Channa striata* (Bloch 1793): a proposed model for optimal and sustainable utilization of freshwater fish. IOP Conference Series: Earth and Environmental Science. 2021:012012.
 46. Ha NT, Thuy LT, Nguyen TE, Phuong NT, Huong DT. Effects of salinity on selected reproductive physiological parameters of striped Snakehead fish *Channa striata*. Aquac Aquar Conserv Legis. 2021;14:3157-3169.
 47. Haniffa MA. Induced breeding of tropical air breathing fishes with natural and synthetic hormones. Endem Fish Divers West Ghats NBFGR-NATP Publ. 2000;1:295-298.
 48. Irmawati TJ, Nadiarti YB, Utami MS. The characterization of snakehead (*Channa* sp.) from Bantimurung River, Maros Regency, South Sulawesi. Pros Simp Nas IV Kelaut Dan Perikan. 2017;1.
 49. Islam MA, Uddin MH, Uddin MJ, Shahjahan M. Temperature changes influenced the growth performance and physiological functions of Thai pangas *Pangasianodon hypophthalmus*. Aquac Rep. 2019;13:100179.
 50. Jobling M. Temperature and growth: Modulation of growth rate via temperature change. Semin Ser-Soc Exp Biol. 1997;61:225-254.
 51. Jobling M. Environmental tolerances and preferences. Fish Bioenerg. Chapman Hall Lond. 1994:207-294.
 52. Marx K. Training manual on Murrel culture. NFDB. FC&RI, TANUVAS. 2009:75.
 53. Khater EG, Ali SA, Mohamed WE. Effect of water temperature on masculinization and growth of Nile tilapia fish. J Aquac Res Dev. 2017;8:8-12.
 54. Kilambi RV. Age, growth and reproductive strategy of the snakehead, *Ophicephalus striatus* Bloch, from Sri Lanka. J Fish Biol. 1986;29:13-22.
 55. Kling LJ, Hansen JM, Jordaan A. Growth, survival and feed efficiency for postmetamorphosed Atlantic cod (*Gadus morhua*) reared at different temperatures. Aquaculture. 2007;262:281-288.
 56. Kono S, Goldberg SM, Hall NFT, Fadley CS. Azimuthal anisotropy in core-level X-ray photoemission from c (2×2) oxygen on Cu (001): experiment and single-scattering theory. Phys Rev Lett. 1978;41:1831.
 57. Kumar R, Damle DK, Pillai BR. Hormonal Influence on Induced Maturation and Spawning in Striped Murrel, *Channa striata*. Recent Updat Mol Endocrinol Reprod Physiol Fish Imperative Step Aquac. 2021:63-76.
 58. Kuparinen A, Cano JM, Loehr J, Herczeg G, Gonda A, Merilä J. Fish age at maturation is influenced by temperature independently of growth. Oecologia. 2011;167:435-443.
 59. Lahnsteiner F, Leitner S. Effect of temperature on gametogenesis and gamete quality in brown trout, *Salmo trutta*. J Exp Zool Part Ecol Genet Physiol. 2013;319:138-148.
 60. Laxmappa B, Babu GV. Present status and prospects of Murrels farming in Andhra Pradesh, India. Int J Fish Aquat Stud. 2014;1:22-31.
 61. Li K, Shieh B, Chiu Y, Huang D, Liang S. Growth, diet composition and reproductive biology of the invasive freshwater fish chevron snakehead *Channa striata* on a subtropical island. Zool Stud. 2016;55.
 62. Liu Y, Wang Z, Li X, Zhao J, Chen W. Effect of Different Environmental Stresses on the Antioxidant Capability of Air-Breathing Loach, *Paramisgurnus dabryanus* (Sauvage, 1878). Pak J Zool. 2021;53.
 63. Lowry OH, Rosebrough NJ, Farr AL, Randall RJ. Protein measurement with the Folin phenol reagent. J Biol Chem. 1951;193:265-275.

64. Manasrah R, Raheed M, Badran MI. Relationships between water temperature, nutrients and dissolved oxygen in the Northern Gulf of Aqaba, Red Sea. *Oceanologia*. 2006;48.
65. Marimuthu K, Haniffa MA, Arockiaraj AJ, Muruganandam M. Spawning and parental behavior in the induced bred murels. *Indian J Fish*. 2001;48:409-411.
66. Marimuthu K, Kumar D, Haniffa MA. Induced spawning of striped snakehead, *Channa striatus*, using Ovate. *J Appl Aquac*. 2007;19:95-103.
67. Meijide FJ, Nostro FLL, Guerrero GA. Gonadal development and sex differentiation in the cichlid fish *Cichlasoma dimerus* (Teleostei, Perciformes): a light-and electron-microscopic study. *J Morphol*. 2005;264:191-210.
68. Mohamed HA. Physico-chemical characteristics of Abu Za'baal ponds, Egypt. 2005.
69. Mollah MFA, Mamun MSA, Sarowar MN, Roy A. Effects of stocking density on the growth and breeding performance of broodfish and larval growth and survival of shol, *Channa striatus* (Bloch). *J Bangladesh Agric Univ*. 2009;7.
70. Mookerjee HK, Ganguly DN, Bhattacharya RN. On the bionomics breeding and development of *Ophiocephalus striatus* (Bloch). *Proc Zool Soc Bengal*. 1948;1:58-64.
71. Morioka S, Vongvichith B, Chanthasone P, Phommachane P, Suzuki N. Reproductive season, age estimation and growth in a striped snakehead *Channa striata* population in Nasaythong District, Vientiane Province, Central Laos. *Aquac Sci*. 2016;64:183-191.
72. Mustafa A, Widodo MA, Kristianto Y. Albumin and zinc content of snakehead fish (*Channa striata*) extract and its role in health. *IEESE Int J Sci Technol*. 2012;1:1.
73. Narejo NT, Jalbani S, Dastagir G. Breeding biology of snakehead, *Channa striatus* (Bloch) from District Badin Sindh, Pakistan. *J Boil*. 2015;3:434-436.
74. Nelson JS. *Fishes of the world*. Hoboken John Wiley Sons. 2006.
75. Ntengwe FW, Edema MO. Physico-chemical and microbiological characteristics of water for fish production using small ponds. *Phys Chem Earth Parts ABC*. 2008;33:701-707.
76. Okunsebor SA, Ofojekwu PC, Kakwi DG, Audu BS. Effect of temperature on fertilization, hatching and survival rates of *Heterobranchius bidorsalis* eggs and hatchlings. *Br J Appl Sci Technol*. 2015;7:372-376.
77. Oyedemi SO, Yakubu MT, Afolayan AJ. Effect of aqueous extract of *Leonotis leonurus* (L.) R. Br. leaves in male Wistar rats. *Hum Exp Toxicol*. 2010;29:377-384.
78. Paglia DE, Valentine WN. Studies on the quantitative and qualitative characterization of erythrocyte glutathione peroxidase. *J Lab Clin Med*. 1967;70:158-169.
79. Pandit NP, Nakamura M. Effect of High Temperature on Survival, Growth and Feed Conversion Ratio of Nile Tilapia, *Oreochromis niloticus*. *Our Nat*. 1970;8:219-224.
80. Pankhurst N. Temperature effects on the reproductive performance of fish. *Global warming: implications for freshwater and marine fish*. 1997:159.
81. Pankhurst NW, Munday PL. Effects of climate change on fish reproduction and early life history stages. *Mar Freshw Res*. 2011;62:1015-1026.
82. Parameswaran S, Murugesan VK. Observations on the hypophysation of murels (*Ophicephalidae*). *Hydrobiologia*. 1976;50:81-87.
83. Paray BA, Haniffa MA, Innocent X, Rather IA. Effect of feed quality on growth and survival of striped snakehead, *Channa striatus* (bloch, 1793) hatchlings. 2016.
84. Parihar MS, Javeri T, Hemnani T, Dubey AK, Prakash P. Responses of superoxide dismutase, glutathione peroxidase and reduced glutathione antioxidant defenses in gills of the freshwater catfish (*Heteropneustes fossilis*) to short-term elevated temperature. *J Therm Biol*. 1997;22:151-156.
85. Pati MP, Rath SC, Thomas PC. Brood rearing, induced spawning and egg incubation of *Channa striatus* in an indoor system with a note to its second breeding in the same season. *J Aquac*. 2004:7-12.
86. Patiño R, Davis KB, Schoore JE, Uguz C, Strüssmann CA, Parker NC, Simco BA, Goudie CA. Sex differentiation of channel catfish gonads: normal development and effects of temperature. *J Exp Zool*. 1996;276:209-218.
87. Pörtner HO, Peck L, Somero G. Thermal limits and adaptation in marine Antarctic ectotherms: an integrative view. *Philos Trans R Soc B Biol Sci*. 2007;362:2233-2258.
88. Qasim SZ, Qayyum A. Spawning frequencies and breeding seasons of some freshwater fishes with special reference to those occurring in the plains of northern India. *Indian J Fish*. 1962;8:24-43.
89. Qin J, Fast AW. Effects of feed application rates on growth, survival, and feed conversion of juvenile snakehead *Channa striatus*. *J World Aquac Soc*. 1996;27:52-56.
90. Radona D, Kusmini II, Prihadi TH, Khasani I, Astuti DN. Hormonal induction for maturation, ovulation and successful level of spawning on striped snakehead (*Channa striata*). *Aquac Aquar Conserv Legis*. 2020;13:118-124.
91. Raghuveer K, Senthilkumaran B, Sudhakumari CC, Sridevi P, Rajakumar A, Singh R, Muruganankumar R, Majumdar KC. Dimorphic expression of various transcription factor and steroidogenic enzyme genes during gonadal ontogeny in the airbreathing catfish, *Clarias gariepinus*. *Sex Dev*. 2011;5:213-223.
92. Rahman MA, Awal S. Development of captive breeding, seed production and culture techniques of snakehead fish for species conservation and sustainable aquaculture. *Int J Adv Agric Env Eng*. 2016;3:117-120.
93. Raizada S, Rawat A, Srivastava PP, Lal KK. Cannibalism mitigation in striped murrel, *Channa striata*, with hatchery seed weaned on pellet diet: A review. *Rev Aquac*. 2022;14:1213-1233.
94. Raj BS. Notes on the freshwater fish of Madras. *Rec Zool Surv India*. 1916;12:249-294.
95. Rajendiran P, Jaafar F, Kar S, Sudhakumari C, Senthilkumaran B, Parhar IS. Sex Determination and Differentiation in Teleost: Roles of Genetics, Environment, and Brain. *Biology*. 2021;10:973.
96. Rajwa-Kuligiewicz A, Bialik RJ, Rowiński PM. Dissolved oxygen and water temperature dynamics in lowland rivers over various timescales. *J Hydrol Hydromech*. 2015;63:353-363.
97. Rawat A, Raizada S, Srivastava PP. Growth and survival of hatchery produced and feed weaned striped murrel *Channa striata* (Bloch, 1793) fingerlings in cement tanks. *Indian J Fish*. 2021;68:52.
98. Ri L. Evaluation of Water Temperature and Dissolved Oxygen Regimes in River Neretva. 2010.

99. Rougeot C, Prignon C, Kengne CVN, M  lard C. Effect of high temperature during embryogenesis on the sex differentiation process in the Nile tilapia, *Oreochromis niloticus*. *Aquaculture*. 2008;276:205-208.
100. Roy NC, Chowdhury SK, Das SK. Observation of hapa breeding technique of striped snakehead, *Channa striatus* (Bloch, 1793) under captive conditions. *Int J Fish Aquat Stud*. 2016;4:413-417.
101. Sacobie CF, Benfey TJ. Sex differentiation and early gonadal development in brook trout. *North Am J Aquac*. 2005;67:181-186.
102. Sakhare VB. Fecundity of air-breathing fish *Channa striatus* (Bloch) from waterbodies of Beed District, Maharashtra, India. *Int J Aquac*. 2015;5.
103. Salaah S. The influence of global warming on oxidative stress and antioxidant defense system in blue tilapia (*O. aureus*). *Aswan Univ J Environ Stud*. 2021;0:0-0.
104. Santhosh B, Singh NP. Guidelines for water quality management for fish culture in Tripura. ICAR Res Complex NEH Reg Tripura Cent Publ. 2007;29.
105. Santi S, Gennote V, Toguyeni A, M  lard C, Antoine N, Rougeot C. Thermosensitivity of the sex differentiation process in the African catfish, *Clarias gariepinus*: Determination of the thermosensitive period. *Aquaculture*. 2016;455:73-80.
106. Schulte PM. TEMPERATURE | Effects of Temperature: An Introduction. *Encyclopedia of Fish Physiology*. Academic Press, San Diego. 2011:1688-1694.
107. Seale A. The fishery resources of the Philippine Islands. Bureau of Printing. 1908.
108. Senguttuvan M, Sivakumar AA. Observations on the age and growth of *Channa striatus*(Bloch) in Ukkadam Lake, Coimbatore, Tamil Nadu, India. *Indian J Fish*. 2010;57:7-12.
109. Shen ZG, Wang HP. Environmental sex determination and sex differentiation in teleosts  how sex is established. *Sex Control Aquac*. 2018;85-115.
110. Singh SP, Ahmad T, Sharma J, Chakrabarti R. Effect of temperature on food consumption, immune system, antioxidant enzymes, and heat shock protein 70 of *Channa punctata* (Bloch, 1793). *Fish Physiol Biochem*. 2021;47:79-91.
111. Srivastava SJ, Singh R. Effects of constant photoperiod-temperature regimes on ovarian activity during the annual reproductive cycle in the murrel, *Channa punctatus* (Bloch). *Aquaculture*. 1991;96:383-391.
112. Stone NM, Thomforde HK. Understanding your fish pond water analysis report. Cooperative Extension Program, University of Arkansas at Pine Bluff, US. 2004.
113. Takahara S, Hamilton HB, Neel JV, Kobara TY, Ogura Y, Nishimura ET. Hypocatalasemia: a new genetic carrier state. *J Clin Invest*. 1960;39:610-619.
114. Tessema M, M  ller-Belecke A, H  rstgen-Schwark G. Effect of rearing temperatures on the sex ratios of *Oreochromis niloticus* populations. *Aquaculture*. 2006;258:270-277.
115. Tresnati J, Fachruddin L. Sex differentiation and gonadal development of striped snakehead (*Channa striata* Bloch, 1793). *IOP Conference Series: Earth and Environmental Science*. 2019:012007.
116. Usman I, Auta J, Abdullahi SA. Effect of monthly variation in water temperature on artificial breeding of common carp (*Cyprinus carpio* L.) in Zaria, Nigeria. *Int J Fish Aquat Stud*. 2015;3:353-356.
117. Vinagre C, Madeira D, Narciso L, Cabral HN, Diniz M. Effect of temperature on oxidative stress in fish: Lipid peroxidation and catalase activity in the muscle of juvenile seabass, *Dicentrarchus labrax*. *Ecol Indic*. 2012;23:274-279.
118. Wang DD, Zhang GR, Wei KJ, Ji W, Gardner JP, Yang RB, Chen KC. Molecular identification and expression of the *Foxl2* gene during gonadal sex differentiation in northern snakehead *Channa argus*. *Fish Physiol Biochem*. 2015;41:1419-1433.
119. Wang LH, Tsai CL. Effects of temperature on the deformity and sex differentiation of tilapia, *Oreochromis mossambicus*. *J Exp Zool*. 2000;286:534-537.
120. Wedekind C. Managing population sex ratios in conservation practice: how and why. *Top Conserv Biol*. 2012;81-96.
121. Wessels S, Samavati S, H  rstgen-Schwark G. Effect of early temperature treatments on sex differentiation in Nile tilapia, *Oreochromis niloticus* lines selected for high and low thermo-sensitivity. *Aquaculture*. 2011;316:139-142.
122. Wolfe BW, Fitzgibbon QP, Semmens JM, Tracey SR, Pecl GT. Physiological mechanisms linking cold acclimation and the poleward distribution limit of a rangeextending marine fish. *Conserv Physiol*. 2020;8:coaa045.
123. Yadav KC, Kumar D, Pal AJ, Nigam R, Srivastawa AS. Study of gonado-somatic index (GSI) of male and female striated murrel *Channa striatus* (Bloch, 1793) in Etawah district. 2022.
124. Yang F, Ye H, Takeuchi Y, Liu F, Xu D. Characterization of the sex differentiation and gonadal development in small yellow croaker (*Larimichthys polyactis*) and its hybrid (*L. polyactis* ♀ × *L. crocea* ♂). *Fish Physiol Biochem*. 2021;47:1467-1476.
125. Yang Q, Ma Z, Zheng P, Jiang S, Qin JG, Zhang Q. Effect of temperature on growth, survival and occurrence of skeletal deformity in the golden pompano *Trachinotus ovatus* larvae. *Indian J Fish*. 2016;63:74-82.
126. Zakaria ZA, Mat Jais AM, Goh YM, Sulaiman MR, Somchit MN. Amino acid and fatty acid composition of an aqueous extract of *Channa striatus* (Haruan) that exhibits antinociceptive activity. *Clin Exp Pharmacol Physiol*. 2007;34:198-204.
127. Zhang G, Yin S, Wang Y, Li L, Wang X, Ding Y, Zang X, Zhang H, Jia Y, Hu Y. The effects of water temperature and stocking density on survival, feeding and growth of the juveniles of the hybrid yellow catfish from *Pelteobagrus fulvidraco* (♀) × *Pelteobagrus vachelli* (♂). *Aquac Res*. 2016;47:2844-2850.
128. Zhang X, Wu Y, Zhang Y, Zhang J, Chu P, Chen K, Liu H, Luo Q, Fei S, Zhao J, Ou M. Histological observations and transcriptome analyses reveal the dynamic changes in the gonads of the blotched snakehead (*Channa maculata*) during sex differentiation and gametogenesis. *Biol Sex Differ*. 2024;15:70.
129. Zhou A, Xie S, Wang Z, Chen Y, Fan L, Wang C, Wang M, Zou J. Gonadal sex differentiation in hybrid snakehead of *Channa argus* (♂) × *Channa maculate* (♀). *Aquac Res*. 2018;49:2345-2348.