Frontiers in Biosciences

ISSN: 3106-5937 | 3105945
Volume 2, Issue 4, 2025

PHYSIOLOGICAL RESPONSES OF LABEO ROHITA TO CLIMATE CHANGE: INSIGHTS FROM AQUATIC ECOSYSTEM ALTERATIONS

Rubina Tafsheen[*1], Kamal Muhsin[2]

[*1,2]*Assistant Professor, Department of Zoology, University of Lahore, Pakistan*

[*1]rabiaafzal78712@gmail.com, [2]kamalmohsin@yahoo.com

Keywords
Climate Change, Labeo rohita, Temperature Variation, Salinity Stress, Fish Physiology, Growth Hormone (GH), Aquaculture Impacts, Insulin-like Growth Factor (IGF)

Article History
Received: 10 October 2025
Accepted: 15 December 2025
Published: 31 December 2025

Corresponding Author: * Rubina Tafsheen

Abstract
Labeo rohita (rohu), a vital freshwater fish in South Asia, faces significant physiological stress from climate change, affecting regional nutrition and economies. Optimal survival occurs at 25–32°C, but rising temperatures and erratic precipitation reduce growth, protein efficiency, and survival. Temperatures of 34–36°C damage yolk and embryos, slowing hatching or causing total mortality. Salinity increases from seawater intrusion further impair survival, gill function, osmoregulation, and erythrocyte physiology. Thermal stress also suppresses growth hormone and insulin-like growth factor expression, compromising growth and immunity. Given rohu's economic and nutritional importance, adaptive strategies and improved management practices are critical to mitigate climate-induced impacts and sustain population health.

INTRODUCTION

Over the past couple of decades, people have focused on exploring its potential. Climate change has become a major global issue since the mid-nineteenth century due to natural factors and human activities (1). These changes affect temperature ranges, precipitation, salinity levels, acidity, and more in marine and freshwater ecosystems (2), drastically impacting the flora at these global levels (3). The contribution of fisheries is well-established in ensuring food security to support the growing population. Over the last couple of decades, people have focused on exploring its potential, and it is now expanding rapidly (4).

Fish is a high-quality source of essential fatty acids that are beneficial for heart health (5). Aquaculture, while essential to meet the demands of a growing population, faces threats from climate change, particularly regarding water availability, which poses a significant risk to fish production (6).

The impacts on fisheries are multifaceted, stemming from both direct and indirect effects of physical and chemical factors like temperature, winds, vertical mixing, salinity, oxygen, and pH (7). These factors directly influence the physiology, development, reproduction, behavior, and survival of individual fish (7). Climate change effects can be direct, such as changing water temperatures, hypoxia, ocean acidification or indirect, mediated through effects on prey species (8). Ultimately, these changes can lead to mass mortalities of aquatic species (9).The regional impacts on fisheries include alterations in stock productivity (10), which are further exacerbated by the effects of climate change on water quality, impacting fish growth, digestion, and overall physiological status (11). To mitigate these challenges and ensure the long-term sustainability of fisheries, better fisheries management practices are crucial. These practices can help reduce conflict, improve food security, and increase economic productivity in the face of climate change(12).

Unlike birds and mammals, fish are exothermic animals. Therefore, to cope with climatic changes, they have to undergo several chemical, biological, and behavioral modifications for survival. Take temperature, for example 1 °C rise enhances metabolism up to 10% body (13). Optimal water quality parameters, therefore, ensure successful fish culture (14, 15). On the other deviations in the desirable ranges of different water quality parameters alter metabolic functions of fish bodies, retard normal growth, diminish reproductive potential (Georges & Holleley, 2018; Uppanunchai et al., 2018), impair the immune system, making fish more prone to diseases ultimately leading to death. Chronic climatic changes reshuffle the existing ecological distribution of fishes and their habitat patterns. (16, 17) Ultimately, fish production declines and stakeholders incur economic losses (18, 19).

Climate change, driven by anthropogenic activities as illustrated in Fig. 1, is significantly impacting aquatic ecosystems and the physiology of fish species like *Labeo rohita*. As exothermic animals, fish are particularly vulnerable to changes in water temperature, with even small increases affecting their metabolism (20). Rising temperatures can alter metabolic functions, retard growth, diminish reproductive potential, and impair the immune system, making fish more prone to diseases (11). For instance, extreme thermal stress can induce liver problems and anaemia in *Labeo rohita*, ultimately leading to mortality (21). These physiological stresses can lead to decreased growth performance and altered metabolism (21), and in the long term, can reshuffle the ecological distribution of fishes and their habitat patterns, leading to economic losses in fish production."

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ISSN: 3106-5937 | 3105945
Volume 2, Issue 4, 2025

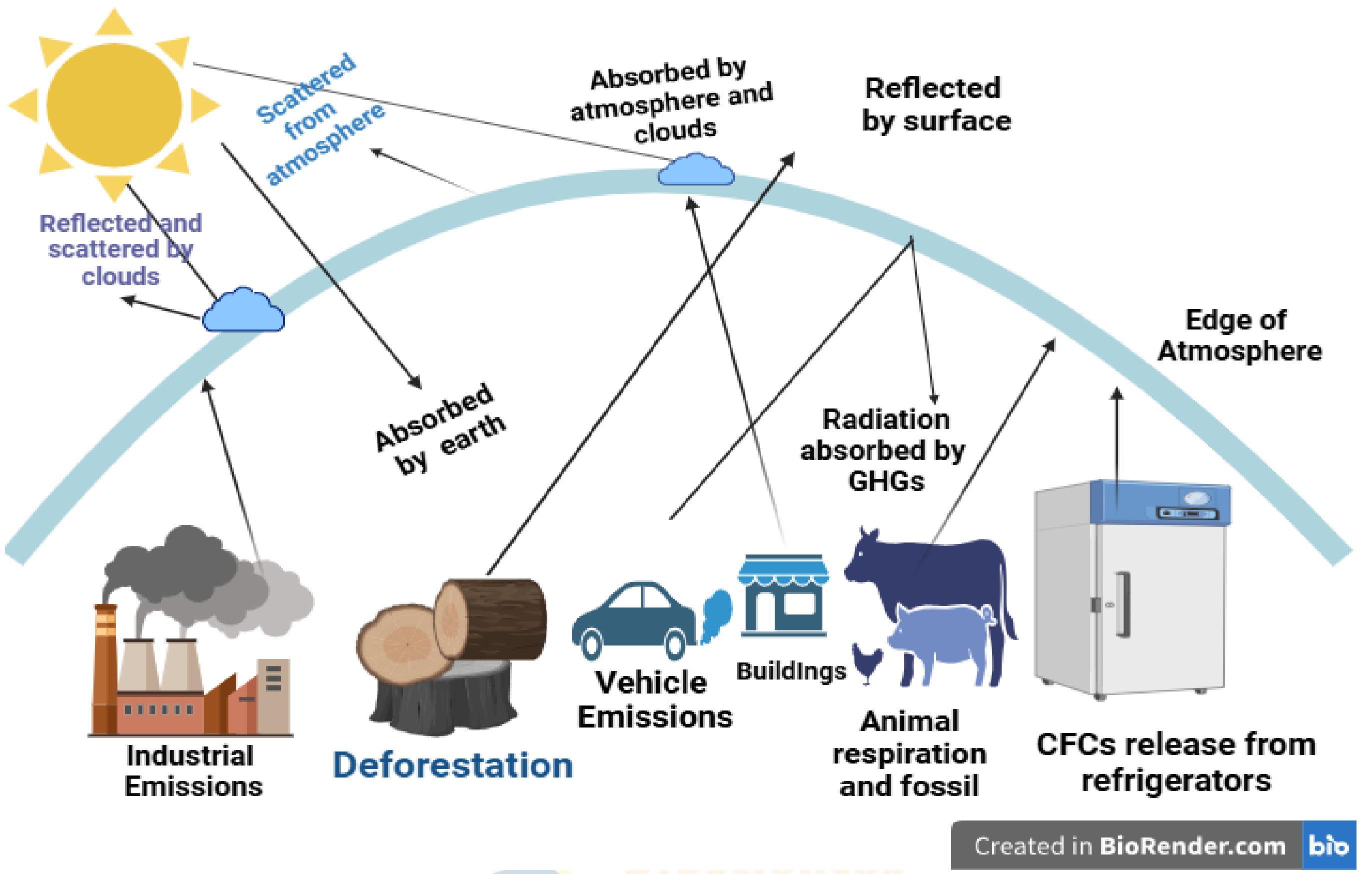

Fig. 1 Anthropogenic Cause of Climate change

Fish fauna of Pakistan

Pakistan hosts both endemic and exotic freshwater species (22). There are 193 native species present in the freshwater ecosystem (23, 24). Out of them, 31 species are edible and are successfully cultured in current fish farming practices (25). Rohu (*Labeo rohita*) is very popular among both farmers and consumers. Other than Pakistan, it is also common in Bangladesh, India, Myanmar, Nepal, and Vietnam. It is a column feeder and performs best at 25^{0}C °C to 30 °C (21, 26). Rohu meat is very delicious and hence well accepted among consumers in India, Pakistan, Myanmar, and Bangladesh (27-29). Exclusively, its contribution to GDP is quite high in Bangladesh (3.47%) (30).

Notably, Rohu's contribution to the gross domestic product of Bangladesh is substantial, accounting for approximately 3.47% (31). Aquaculture technology is crucial for addressing animal protein shortages and controlling high prices. Pakistan's tropical location means it often faces rainfall scarcity, leading to high salinity in land and underground water, which stresses commercial fish species and hinders fish culture industry growth(32).

The Physiological Effects of Temperature Variations on Labeo rohita

Labeo rohita belongs to the family Cyprinidae. Among the three major Indian carp, its share is 53.7% and is most prevalent in Pakistan, Bangladesh, Nepal, and North India (33). It performs well at 25-32°C (34) because the water temperature is a key parameter in its life cycle. Fluctuations in temperature influence feeding behavior, adaptability, and ecological distribution (Yoon et al., 2022). Extremely high temperatures diminish the reproductive potential and decrease immunity in fish, increasing the occurrence of diseases that decrease the fish population in a given area (35).. (34, 36). Temperature determines the biodiversity of a particular region and area. Higher temperatures discourage the promotion of life, well-being, and survival. Therefore, life continues diminishing under unfavorable temperature regimes (37). (38). However, when temperature increases to 32-36 °C, there is a gradual decline in daily weight gain, protein efficiency ratio, and survival rate (38). 34°C temperature causes yolk and zygote destruction and slows down incubation time and hatching rate. At 36 °C hatching rate approaches with total death of developing eggs and embryos (39).

In Pakistan Kotri Barrage downstream area runs 155 km adjacent Indus River delta. Climate change have adversely affected the biodiversity of this ecosystem (40) due to frequent temperature fluctuations and changing patterns (41). In the winter and summer seasons, water temperatures are from 9°C to 34 °C, respectively, which deviates from the normal temperature for *Labeo rohita.* Hence, such unfavorable temperature regimes induce unfavorable effects on spawning behavior, fecundity, hatching, and survival of young ones as well as breeders. Southern Punjab, Sindh province, and some parts of Baluchistan experience very high temperatures during the summer season, and most of the summer sustains at 50^0C, occasionally exceeding this figure (42, 43). Indian major carp, including rohu, cannot tolerate such high temperatures (44). Contrary to the southern areas of Pakistan, northern areas like Skardu and Baltistan experience low-temperature extremes that fall to -2°C (45), which is injurious and lethal for Indian major carp. These temperature fluctuations increase energy demands to sustain the physiological functions of the body. This, in turn, enhances metabolic functions immediately with a multifold increase in oxygen demands. These reactions and activities run perpetually back and forth proportionate to the climatic variations (34), (46), (47).

Table 1: Mortality rate of Labeo rohita at different temperatures in Southern Punjab, Pakistan

Temperature	Mortality Rate	References
28°C	0%	(34)
25°C	16%	(34)
20°C	22%	(34)
15°C	43%	(34)
10°C	85%	(34)
30°C	1%	(34)
33°C	2%	(34)
35°C	3%	(34)

These temperature variations are more obvious in outdoor farming systems because of poor control over environmental variables (36, 48). Despite the nature of aquaculture, resource temperature effects are almost universal. In semi-intensive fish culture systems, higher temperature causes eutrophication due to higher nutrient levels, which in turn multiply the toxic form of ammonia that causes high fish mortality (49-51). This poor conversion of ammonia into nontoxic forms hampers proper protein utilization that fish take in. Fish becomes moribund and its immune system weakens, and fish becomes more prone to prevalent diseases (52-54). This scenario induces wastage of expensive feed and deteriorates water quality, resulting in heavy losses to the producer. If such climatic changes persist success of any aquaculture endeavor is not only difficult but impossible (55, 56) (57, 58) (48).

Table 2: Optimal temperature for growth and development of Labeo rohita in Asia

Area	Temperature	Reference
West Bengal	34°C	(59, 60)

Frontiers in Biosciences
ISSN: 3106-5937 | 3105945
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Indus River Delta	30°C	(59, 60)
Indian subcontinent	28-30°C	(59, 61)
Faisalabad (Punjab)	24-26°C	(61)
Khulana (Bangladesh)	28-30°C	(59, 61)
Mymensingh (Bangladesh)	33°C	(62)
Bangladesh	30-32°C	(62)

The above table is showing the Optimal temperatures for the growth and development of Labeo rohita vary across Asia. Optimal temperatures for Labeo rohita growth and development vary geographically. In West Bengal, the optimal temperature is 34°C, and in the Indus River Delta, it is 30°C (59, 60). Across the Indian subcontinent, the ideal range is 28-30°C (59, 61). More specifically, in Faisalabad, Punjab, the optimal temperature range is 24-26°C, while in Khulana, Bangladesh, it is 28-30°C (59, 61). Mymensingh, Bangladesh, has an optimal temperature of 33°C, with the general range for Bangladesh being 30-32°C (62). Higher temperatures darken the yolk sac, which fails to provide sufficient nutrients, particularly impacting embryonic development (62).

Effect on embryonic development

Temperature elevations increase incubation duration and decrease hatching rate. Delayed hatching increases the mortality of embryos. At optimal temperature hatching rate sticks to 80%, and when this temperature approaches 340 hatching rate gradually increases an observed decrease from 80%-26% increase (63). Higher temperature darkens the yolk sac, which fails to provide the required nutrients to the developing embryo. Embryos deform and succumb to death (63).

Effect on gill morphology

Gills maintain water and salt balance in the body (osmoregulation). The rise in water temperature (36 ˚C) increases the metabolic rates of the fish's body, which demands more oxygen. Fish increase water intake for oxygen extraction. Gills are overburdened and stressed. To cope with such unfavorable conditions, they pursue some morphological and physiological modifications (64). Due to this modification modifications cells grow abnormally (hyperplasia), blood vessels swell (telangiectasis), tissue damage (epithelial necrosis), and enlargement of chloride cells are common (65).

Effect on erythrocyte physiology

Erythrocytes contain hemoglobin. Hemoglobin contents show the physiological status of rohu. Temperature variations affect the Size and quantity of erythrocytes (66). Higher temperature decreases oxygen content in water and disturbs metabolic functions. Prolonged exposure to low oxygen can cease development and growth, and weaken the immune system. Nuclear and cellular anomalies develop in RBCs, and fish succumb to death (66).

RBCs carry oxygen and transport it to various parts of the body to carry out the physiological functions of the fish. During cell division, elevated temperature disrupts the chromosome-nuclei integration in *Labeo rohita*. Into the micronucleus formation. Used caused affects the at 30 ^{0}C, 33^{0} C, and 36 ˚C micronucleus formation rate was 0.5%, 0.8% by and 1.4% respectively. At 360, micronucleus formation is higher in erythrocytes than in fingerlings. This decreases the oxygen-carrying capacity of erythrocytes to different parts of the body, which disturbs metabolic functions. Fish lose their disease immunity and become susceptible to diseases (67).

At 36°C, thermal stress causes an elevation in blood glucose and white blood cell (WBC) counts in rohu. The increase in blood sugar levels stimulates the release of stress hormones such as adrenaline and cortisol, which in turn promote excessive gluconeogenesis and glycogenolysis (66). This cascade of physiological responses results in a reduced feed conversion ratio and diminished feed efficiency, ultimately impairing the growth performance of the fish (68).

Effect on GH and IGH

The hypothalamus-pituitary-liver (somatotropic) axis serves as the primary regulator of growth and development. External and internal factors influence this axis, which governs the activity of growth hormone (GH) and insulin-like growth factors (IGFs) (69). Growth hormone (GH) and insulin-like growth factor (IGF) play significant roles in the growth of rohu.GH activates liver cells to produce IGF-1 that increases the proliferation of cells, and muscle growth and development, leading to better growth. GH plays an important role in steroidogenesis, sexual maturation, hematogenesis gametogenesis (70). Normal temperature for rohu is 28-33°C. When the temperature approaches, it suppresses the expression of insulin-like growth factors (IGF-1 & IGF-2) in the liver and the expression of growth hormone (GH) in the juvenile pituitary. Finally, it retards weight gain, specific growth rate, and increases FCR. Temperatures affect the like insulin-like the insulin-like the insulin-like (57).

Salinity

Salinity is one of the abiotic factors of aquatic ecosystems. It adversely affects the growth, immunity (either general or specific), metabolism, and cognitive behavior (71). Rohu tolerates salinity up to 6–8 ppt, but survival drops sharply beyond 8 ppt, with 100% mortality at 14 ppt within a week(72). Due to climate change, sea water level increases, which causes intrusion of saline water into inland especially in coastal areas (73). The aquaculture industry faces challenges, especially in Bangladesh, due to these climatic changes (30, 74). A 2%, 4%, and 6% increase in salinity level decreases the survival rate of rahu from 98-83%, followed by 98-72%, followed by 98-64%, respectively. Every 2% increase in salinity level causes approximately 2% decrease in body weight (71).

The Physiological Effects of Temperature Variations on Labeo rohita

Rohu exhibits maximum growth at 33–34°C (67, 75), but temperatures ≥36°C reduce hemoglobin, red blood cell counts, and growth rates while increasing cellular abnormalities and mortality (67). At 35°C, muscle transcriptome analysis reveals downregulation of genes involved in energy metabolism and stress response (76).

Effect of Seasonal Variation and Moisture Content on Haemato-biochemical Parameters

Seasonal changes influence several blood parameters in fish. Concentrations of red blood cells (RBCs), haematocrit (HCT), hemoglobin (Hb), and white blood cells (WBCs) peak in the summer, are lower in spring, and are lowest in winter. Conversely, parameters like mean corpuscular hemoglobin concentration (MCHC), mean corpuscular volume (MCV - *assuming MCHV meant MCV*), and mean corpuscular hemoglobin (MCH) reach their highest levels in winter, followed by spring and then summer. Body composition also varies seasonally; moisture content, which is important for fish shelf life, fluctuates. This variation in moisture is directly connected to biochemical factors, notably lipid (fat) concentration. In Rohu fish, moisture typically ranges from 70.81% to 74.76%. Critically, moisture and fat levels have an inverse relationship in Rohu: as moisture content increases (like in winter), the fat concentration decreases (77).

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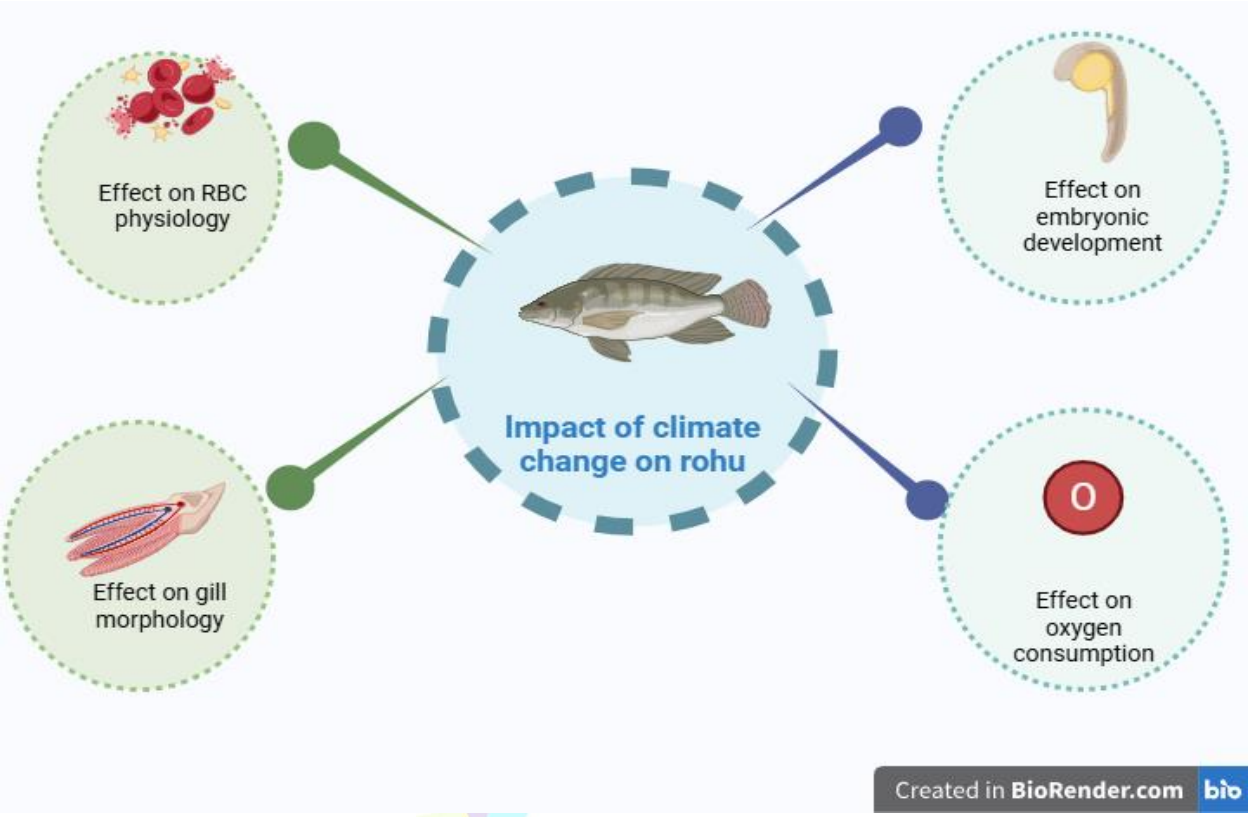
Fig. 1 Overall impact of Climate change on Labeo rohita (rohu)



Conclusions

We concluded that, climate change poses significant physiological challenges to Labeo rohita (rohu), a vital freshwater fish species in South Asia. Rising temperatures and fluctuating water quality parameters disrupt metabolic functions, impair growth, reduce reproductive success, and increase susceptibility to diseases. Extreme temperature variations—both high and low—lead to increased mortality, especially during critical developmental stages such as embryonic and larval phases. Salinity intrusion, another consequence of climate change, further reduces survival rates and damages vital tissues like gills, compounding the stress on the species.These environmental stressors not only threaten the sustainability of rohu populations but also jeopardize the livelihoods of communities' dependent on aquaculture and fisheries. If current climatic trends persist, the viability of fish farming and the broader aquaculture industry will be at risk, with significant economic and food security implications. Therefore, urgent adaptation strategies and improved management practices are essential to mitigate these impacts and ensure the continued contribution of Labeo rohita to regional economies and nutrition. Future research should focus on identifying genetic strains of rohu with greater resilience to temperature and salinity fluctuations, and there remains a gap in understanding the long-term physiological and ecological impacts of compounded climate stressors on this species.

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