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Review article

Effect of Temperature, pH, Salinity and Dissolved Oxygen on Fishes

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Abstract
Environmental factors, including temperature, pH, salinity, and dissolved oxygen, are paramount in shaping fish physiology, behavior, and survival. Fish, being highly responsive to these environmental shifts, undergo profound changes in metabolism, growth, and overall performance. Specifically, temperature variations can have acute or long-term effects, pH changes disrupt ion balance and respiratory efficiency, salinity affects osmoregulation and ion dynamics, and dissolved oxygen levels are fundamental for respiration and metabolic health. Understanding these intricacies is not just academic; it's crucial for fisheries management, conservation strategies, and anticipating the ramifications of broader environmental alterations. This review offers an in-depth analysis of these environmental impacts on fish, underscoring the significance of each factor in their physiology, adaptive behaviors, and ecological context.
Keywords: pH, salinity, dissolved oxygen, fish

1. Introduction

Fish are cold-blooded aquatic animals that depend highly on their surrounding environment for survival and growth. Environmental factors such as temperature, pH, salinity, and dissolved oxygen are critical in fish's life cycle and physiological processes. These environmental factors can significantly impact fish physiology, behavior, and population dynamics. Therefore, understanding the effects of these factors on fish is crucial for successful fisheries management and conservation [1]. Understanding these effects is not just about the well-being of individual species; it's about the bigger picture. Changes in fish behavior, reproduction, growth, and survival can alter predator-prey dynamics, nutrient cycling, and overall biodiversity within aquatic habitats [2].
Temperature influences various aspects of fish biology, including growth rates, metabolic rates, reproduction, and overall performance. Both acute and chronic temperature changes can have significant effects on fish physiology and behavior. Higher temperatures can accelerate metabolic processes, increase energy requirements, and lead to oxygen limitation, while lower temperatures can decrease metabolic rates, impair enzyme activities, and affect immune function. Temperature fluctuations can also influence the distribution and abundance of fish species, with potential implications for ecosystem dynamics [3].
pH represents the acidity or alkalinity of the water, affecting the ion balance and acid-base regulation of fish. Changes in pH can alter the availability and toxicity of certain substances, impacting fish at cellular and systemic levels. Acidic conditions (low pH) can disrupt ion regulation, impair enzyme activities, and compromise reproduction. Conversely, alkaline conditions (high pH) can lead to the accumulation of toxic substances, affect respiratory efficiency, and induce stress responses in fish [4].
Salinity, the concentration of dissolved salts in water, is a critical factor influencing fish physiology and osmoregulation. Fish species exhibit varying tolerances to salinity levels, and changes in salinity can disrupt ion balance, osmotic regulation, and reproductive processes. While euryhaline species can

tolerate a wide range of salinities, stenohaline species have specific salinity requirements, making them more susceptible to habitat alterations and salinity fluctuations [5]. Dissolved oxygen (DO) is essential for fish respiration and aerobic metabolism. Insufficient DO levels, often associated with eutrophication or pollutant inputs, can lead to hypoxic or anoxic conditions in water bodies, posing serious threats to fish survival and fitness. Low oxygen levels can impair growth, reproduction, and immune function, and may result in population declines or even mass mortality events [6].

Temperature, pH, salinity, and dissolved oxygen are critical environmental factors affecting fish physiology, behavior, and population dynamics. Changes in these environmental factors can significantly impact fish growth, reproduction, and survival. Therefore, understanding the effects of these factors on fish is crucial for successful fisheries management and conservation [7].

2. Temperature:

Fish exhibit a strong relationship between temperature and metabolic rate. As temperature increases, the metabolic rate generally rises, increasing energy requirements. Fish allocate energy differently under different temperature regimes, prioritizing growth and reproduction in optimal temperatures. However, under extreme temperatures, metabolic adjustments may occur to conserve energy and maintain essential physiological functions [8].

Temperature directly affects oxygen consumption rates in fish. Fish generally have higher oxygen demands as temperature increases due to increased metabolic activity (Table 1). Thermal tolerance limits define the upper and lower temperature thresholds at which fish can function physiologically. These limits are essential in understanding the potential impacts of temperature changes on fish survival and fitness [9].

Temperature influences the growth and development of fish. Higher temperatures generally accelerate growth rates, while lower temperatures can lead to reduced growth. Temperature also affects size at maturity, with fish in warmer environments typically maturing smaller than those in more relaxed environments fish adjust their circulatory and cardiovascular systems in response to temperature changes. Higher temperatures can increase heart rate and blood flow, facilitating oxygen delivery to tissues. Conversely, lower temperatures can reduce heart rate and blood flow, affecting overall physiological function [10].

Temperature variations influence the immune system response of fish. Temperature changes can modulate immune system activity, affecting the efficiency of immune responses to pathogens and diseases. Elevated temperatures may enhance immune response, while lower temperatures can impair immune function, making fish more susceptible to infections [11].

Temperature plays a crucial role in determining the timing of fish spawning. Warmer temperatures often accelerate spawning, leading to earlier reproductive events. Fecundity, the number of eggs fish produce, can also be influenced by temperature, with higher temperatures generally associated with increased fecundity [12]. Temperature influences gonadal development in fish. Warmer temperatures can accelerate gonadal maturation, leading to earlier sexual development and breeding. Additionally, the temperature can impact the sex ratio of fish populations, with some species exhibiting temperature-dependent sex determination [13].

Temperature variations affect the survival and recruitment of fish larvae. Larvae have specific thermal requirements for survival and growth; temperature changes can impact larval development and survival rates. Temperature fluctuations may lead to shifts in recruitment patterns, potentially influencing population dynamics [14]. Temperature changes can influence the behavior of fish during courtship and mating. Fish may alter their reproductive behaviors, such as courtship displays and mate choice, in response to temperature variations. These behavioral adjustments can affect reproductive success and the genetic composition of fish populations. Each fish species has a unique thermal optima range, representing the temperature range in which they thrive. Temperature tolerance limits define the upper and lower thresholds beyond which the species can not survive.

Table 1. Effects of different temperature on fish.

Temperature	Effect on Fish	Reference
> 20°C	Optimal for most freshwater fish species, allows for maximum growth and reproduction	[18,19]
> 25°C	Increases metabolic rate, but can cause stress and decrease oxygen-carrying capacity of blood	[20]
> 28°C	Can cause cellular damage and lead to organ failure, decreased growth and reproduction	[21]
> 30°C	Can cause severe stress and mortality, especially in coldwater species	[22]
> 35°C	Lethal to most fish species within hours	[23]
< 5°C	Decreases metabolic rate and activity, can cause stress and decreased growth and reproduction	[24]
< 0°C	Can cause freezing of bodily fluids and tissue damage, decreased growth and reproduction	[25]
-1 to 4°C	Optimal for some coldwater fish species, allows for maximum growth and reproduction	[26]
5-10°C	Optimal for some coolwater fish species, allows for maximum growth and reproduction	[27]

Temperature changes can result in shifts in species distributions as they seek environments within their thermal tolerance range. We explore how certain fish species uniquely respond to temperature fluctuations, shedding light on the intricate dynamics of temperature-fish interactions.

1. Salmon (*Salmo salar*): As ectothermic organisms, salmon are particularly susceptible to temperature changes [15]. optimal growth occurs between 10°C and 14°C, while temperatures exceeding 20°C can be lethal due to increased metabolic stress and lowered dissolved oxygen levels. Spawning patterns of salmon are also temperature-dependent, with shifts potentially affecting their reproductive success.

2. Zebrafish (*Danio rerio*): Widely used as a model organism, zebrafish exhibit significant developmental changes when exposed to varying temperatures [16]. Typically, development rates increase with temperatures ranging from 24°C to 28°C but decrease or halt altogether outside this range

3. Clownfish (Amphiprioninae): Living in symbiosis with sea anemones, clownfish are found in warmer waters. However, prolonged exposure to temperatures above 30°C affects their symbiotic relationships and may lead to bleaching events [17].

Temperature plays a crucial role in fish specie's' physiological processes, growth, reproduction, and overall well-being. Different temperature ranges affect fish differently, influencing their metabolism, oxygen-carrying capacity, organ function, growth, and reproduction. Temperature above 20°C is optimal for most freshwater fish species, as it allows maximum growth and reproduction. As the temperature increases above 25°C, fish experience an elevation in metabolic rate. However, high temperatures can also cause stress and decrease the oxygen-carrying capacity of the blood, impacting fish physiology [28]. When exposed to temperatures above 28°C, fish may suffer cellular damage and organ failure, leading to decreased growth and reproduction [29].

Table 2. Effect of different pH on Fish

pH Level	Effect on Fish	Reference
6.5-9.0	Optimal for most freshwater fish species, allows for maximum growth and reproduction	[45]
< 6.5	Stressful for most fish species, can cause reduced growth and reproduction	[45]
< 6.0	Life-threatening to most fish species, can cause death if exposure is prolonged	[46]
> 9.0	Stressful for most fish species, can cause reduced growth and reproduction	[47]
> 9.5	Life-threatening to most fish species, can cause death if exposure is prolonged	[48]
< 4.0	Life-threatening to most fish species, can cause death if exposure is prolonged	[49]
6.5-8.5	Optimal for most saltwater fish species, allows for maximum growth and reproduction	[50]
< 6.5	Stressful for most saltwater fish species, can cause reduced growth and reproduction	[51]
6.5-9.0	Optimal for most freshwater fish species, allows for maximum growth and reproduction	[52]
< 6.5	Stressful for most fish species, can cause reduced growth and reproduction	[53]
< 6.0	Life-threatening to most fish species, can cause death if exposure is prolonged	[52]
> 9.0	Stressful for most fish species, can cause reduced growth and reproduction	[55]
> 9.5	Life-threatening to most fish species, can cause death if exposure is prolonged	[56]
< 4.0	Life-threatening to most fish species, can cause death if exposure is prolonged	[55]
6.5-8.5	Optimal for most saltwater fish species, allows for maximum growth and reproduction	[58]
< 6.5	Stressful for most saltwater fish species, can cause reduced growth and reproduction	[59]
4.0-6.0	Tolerable range for some fish species, may exhibit reduced reproductive capacity	[60]
8.5-9.5	Tolerable range for some fish species, may experience mild stress	[61]
> 10.0	Life-threatening to most fish species, can cause severe physiological disturbances	[62]

Temperatures exceeding 30°C can result in severe stress and mortality, particularly in Cold water fish species [30]. Extremely high temperatures, such as those exceeding 35°C, can be lethal to most fish species within hours [31]. At temperatures below five °C, fish experience decreased metabolic rate and activity. This can lead to stress and reduced growth and reproduction [32]. Subzero temperatures can cause freezing of bodily fluids and tissue damage, resulting in decreased growth and reproduction [33].

3. pH

Fish possess sophisticated mechanisms to maintain their internal acid-base balance, which is crucial for proper physiological functioning. pH changes in their environment can disturb this balance, leading to disruptions in acid-base regulation. Acidic or alkaline conditions can challenge fish homeostasis, affecting ion regulation, enzyme activity, and metabolic processes pH alterations affect the respiratory system of fish, impacting oxygen transport and delivery to tissues.

Enzymes, being biological catalysts, have optimal pH levels at which they function most efficiently, deviations from this optimal pH can denature enzymes or alter their configurations, subsequently affecting their catalytic activity (Table 2). The active sites of enzymes can lose their effectiveness, thereby diminishing their substrate-binding capabilities [34]. Digestive Enzymes: Acidic environments within the stomach facilitate the activity of digestive enzymes like pepsin [35]. Altered pH levels can impede the digestive process, affecting nutrient absorption and fish growth. Respiratory Enzymes: Fish hemoglobin, which carries oxygen, shows varying affinity to O2 depending on the surrounding pH [36]. This can lead to altered oxygen-carrying capacity and overall respiration efficiency.Immune Responses: Acid-base imbalances can inhibit enzymes involved in immune responses, leaving fish susceptible to diseases [37]. Acidic conditions can induce respiratory acidosis, leading to decreased oxygen-carrying capacity of blood and impaired respiratory function [38]. Alkaline conditions, on the other hand, can lead to alkalosis, potentially affecting fish respiration.pH changes can disrupt ion and electrolyte balance in fish. Acidic conditions can cause an increase in plasma ion concentrations, leading to hypercalcemia and hyperkalemia. Alkaline conditions, conversely, may result in hypocalcemia and hypokalemia [39]. These imbalances can affect vital physiological processes such as osmoregulation and muscle contraction. Fish employs various acid-base regulatory mechanisms to cope with pH changes. These include ion transporters, ion exchange epithelia, and specialized cells in the gills and kidneys [40]. Understanding the adaptability of these mechanisms is crucial for predicting fish responses to pH alterations. Changes in pH can influence the distribution patterns of fish species. Some species exhibit pH preferences, being more abundant in specific pH ranges. Altered pH levels can result in shifts in fish distribution, potentially impacting community composition and overall biodiversity [41].

pH changes can affect fish reproductive success and larval survival. Altered pH levels during spawning and embryonic development can impair fertilization, hatching, and larval survival rates. Fish with specific pH requirements for successful reproduction may face challenges in environments with changing pH regimes [42]. pH alterations can influence fish sensory perception and behaviour. Fish rely on chemoreceptors to detect changes in pH for predator avoidance, prey detection, and navigation. Changes in pH can disrupt these sensory capabilities, potentially impacting foraging, mate choice, and migration behavior [43]. Altered pH levels can influence the interactions between fish and other organisms. Changes in pH can affect the physiology and behavior of prey species, predator-prey relationships, and symbiotic associations. Disrupted interactions can cascade ecosystem dynamics [44].

pH is a crucial environmental factor that influences the physiological processes and overall health of fish. Fluctuations in pH levels can have significant effects on fish populations. The optimal pH range for most freshwater fish species typically falls between 6.5 and 9.0, allowing for maximum growth and reproduction [63].

6.5-9.0 Optimal for most freshwater fish species allows maximum growth and reproduction [64]. Water quality in ponds for aquaculture. pH levels ranging from 6.5 to 9.0 are optimal for most freshwater fish species. This pH range provides favorable conditions for their growth and reproduction, contributing to healthy populations [64].

4. Salinity

Salinity is a crucial parameter in aquatic ecosystems, influencing fish species' distribution, physiology, and ecology. Natural variations in salinity occur due to rainfall, evaporation, and freshwater inflow, while anthropogenic activities can also lead to salinity fluctuations. This review article explores the physiological and ecological implications of salinity changes on fishes, providing insights into the mechanisms underlying their responses (Table 3). Understanding salinity variation’s' effects is essential for effectively managing and conserving fish populations in diverse aquatic environments [65].

Euryhaline species are organisms that can tolerate a wide range of salinities. Examples: Mummichog (*Fundulus heteroclitus*): A small fish found along the Atlantic coasts of the US and Canada

Table 3. Effect of salinity on fish.

Effect	Tolerance Value	Reference
Mortality	<5 ppt for freshwater fish >30 ppt for marine fish	[54,56]
Growth	Optimum range varies depending on species	[58,60]
Osmoregulation	Varies depending on species	[61]
Reproduction	Reduced reproductive success at extreme salinity levels	[62]
Behavior	Altered swimming patterns and orientation	[63]
Physiology	Changes in enzyme activity and protein synthesis	[64]
Ion regulation	Increased energy expenditure to maintain ion balance	[65]
Stress response	Increased cortisol levels and stress-related behavior	[66]
Immune function	Reduced immune function at extreme salinity levels	[67]
Metabolism	Increased metabolic rate at low salinity levels	[68]
Heart rate	Varies depending on species and salinity level	[69]
Ionoregulatory costs	Increased energetic costs to maintain ion balance	[70]
Acid-base balance	Altered acid-base balance at extreme salinity levels	[71]
Ion uptake	Reduced ion uptake at low salinity levels	[72]
Gill function	Altered gill morphology and function	[73]
Gene expression	Altered expression of genes related to ion transport and osmoregulation	[74]
Energy allocation	Altered energy allocation to different physiological processes	[75]

It can survive in freshwater, brackish water, and seawater.European Eel (*Anguilla anguilla*): This fish can move between freshwater and marine environments during its life cycle [66]. Atlantic Salmon (*Salmo salar*): Known to migrate between freshwater (where they spawn) and the ocean [67]. Stenohaline species are those organisms that can only survive within a narrow range of salinity. Examples: Goldfish (*Carassius auratus*): A freshwater fish that cannot survive in high salinity environments [68]. Open Ocean Fishes (e.g., Marlin, Tuna): Marine species adapted to consistent ocean salinities and are not typically found in areas with fluctuating salinity like estuaries [69]. Fish possess various adaptations to maintain osmotic and ion balance in response to changes in salinity. Freshwater fish face the challenge of preventing water influx and maintaining ion concentrations, while marine fish must regulate water loss and cope with higher ion concentrations. Salinity variations can disrupt these processes, affecting fish osmoregulation and ion balance [70]. Salinity changes can induce stress responses in fish, releasing cortisol, a stress hormone. Elevated cortisol levels can have physiological and behavioral implications, influencing metabolism, growth, reproduction, and immune function. Fish exhibit varying degrees of stress tolerance to salinity alterations, with some species more resilient than others [71].

Salinity fluctuations can impact fish metabolic rates and energy allocation. Fish exposed to low-salinity environments may experience reduced metabolic rates due to decreased physiological demands. In contrast, high salinity conditions can increase energy expenditure and metabolic stress. These changes in metabolic activity can influence fish growth, reproduction, and overall fitness [72].

Gill morphology and function are crucial in fish respiration and ion regulation. Salinity changes can affect gill structure and function, influencing gas exchange efficiency and ion transport

Table 4. Effects of dissolve oxygen on Fish.

Dissolved Oxygen Level	Effect on Fish	Reference
> 6 mg/L	Optimal for most fish species, allows for maximum growth and reproduction	[80]
5-6 mg/L	Adequate for most fish species, growth and reproduction may be slightly reduced	[81]
3-5 mg/L	Stressful for many fish species, growth and reproduction significantly reduced, increased susceptibility to disease	[77,82]
< 3 mg/L	Life-threatening to most fish species, can cause death if exposure is prolonged	[83]
> 6 mg/L	Optimal for most fish species, allows for maximum growth and reproduction	[84]
> 5 mg/L	Optimal for rainbow trout, enhances immune system, decreases susceptibility to disease	[85]
> 4 mg/L	Required for metabolic activity, including respiration, digestion, and growth	[86]
> 3.5 mg/L	Optimal for tilapia, allows for maximum growth and feed conversion efficiency	[87]
2-3 mg/L	Stressful for many fish species, growth and reproduction significantly reduced, increased susceptibility to disease	[88]
1-2 mg/L	Severe stress for many fish species, increased mortality and decreased growth and reproduction	[89]
< 1 mg/L	Life-threatening to most fish species, can cause death if exposure is prolonged	[90]
< 0.2 mg/L	Lethal to most fish species within minutes	[91]
Fluctuating levels	Can cause stress and damage to fish gills and tissues	[92]

Fish can exhibit physiological adaptations in their gills to cope with varying salinity conditions, such as alterations in ion transporters and monocyte density [73]. Salinity variations influence fish distribution patterns and habitat suitability. Some fish species exhibit euryhaline characteristics, tolerating various salinities and occupying diverse habitats. However, changes in salinity can alter the availability of suitable habitats, leading to shifts in fish distributions and potential impacts on community dynamics [74]. Salinity changes can significantly impact fish reproduction and larval survival. Many fish species have specific salinity requirements for successful spawning, egg development, and larval survival. Deviations from optimal salinity ranges can result in reduced reproductive success, hatching failure, and decreased survival rates of fish larvae [75]. Salinity alterations can influence fish feeding ecology and trophic interactions. Changes in salinity can affect the distribution and abundance of prey species, altering feeding opportunities for fish. Furthermore, modifications in salinity gradients can disrupt predator-prey relationships and the structure of food webs [76].

5. Dissolve oxygen

Dissolved oxygen (DO) is a vital component of aquatic environments, crucial in supporting fish life. It is essential for fish specie's respiration, metabolism, and overall physiological functioning. This review article aims to explore the effects of dissolved oxygen on fish, examining the physiological responses and ecological simplification (Table 4). Understanding the impact of DO variations is crucial for effectively managing and conserving fish populations in diverse aquatic ecosystems [74].

Dissolved oxygen influences the fish's metabolic rate and oxygen demand. Oxygen is essential for various physiological processes, including energy production through aerobic respiration. Changes in dissolved oxygen levels can alter metabolic rates, affecting fish energy expenditure, growth, and reproduction. Fish adapt their metabolism in response to variations in dissolved oxygen to maintain homeostasis [75].

Insufficient dissolved oxygen can induce stress responses in fish. Prolonged exposure to low oxygen conditions, known as hypoxia, can lead to physiological stress and impact fish health and performance. Fish species differ in their tolerance to hypoxia, with some exhibiting higher resistance due to physiological adaptations, such as enhanced oxygen transport capacity or anaerobic metabolism [76]. When oxygen is scarce, many fish species resort to anaerobic metabolism. During anaerobic respiration, fish derive energy from glucose without using oxygen, producing lactic acid as a byproduct. Glycolysis: The primary anaerobic pathway, where glucose is broken down to produce ATP, generating lactic acid in the process [77]. Lactate Utilization: Some fish species can further metabolize lactate in their liver, converting it back to glucose in a process called the Cori cycle [80].

Dissolved oxygen levels play a critical role in fish reproduction and larval development. Adequate oxygen availability is essential for successful spawning, egg development, and survival of fish larvae. Oxygen-deprived conditions can reduce hatching success, developmental abnormalities, and increased mortality rates among fish embryos and larvae [79].

Dissolved oxygen gradients influence fish habitat selection and distribution patterns. Fish species exhibit preferences for specific dissolved oxygen ranges, selecting habitats that provide optimal oxygen conditions for survival and physiological needs. Variations in dissolved oxygen levels can influence the fish distribution, community composition, and habitat suitability [80].

The influence of dissolved oxygen levels on fish behavior and movement patterns is examined in this section. It discusses how Fish may alter their swimming speed, foraging behavior, and habitat selection in response to variations in oxygen availability. The section also explores the potential cascading effects on predator-prey interactions and community dynamics [81].

6. Conclusion

The effects of temperature, pH, salinity, and dissolved oxygen on fishes are significant factors that influence their physiology, behavior, and ecological interactions. Each factor has distinct impacts on fish populations, ranging from metabolic and reproductive processes to distribution patterns and overall survival. Understanding and managing the effects of these factors are vital for sustainable fisheries management, conservation efforts, and the overall health of aquatic ecosystems. Climate change and human activities challenge fish populations by altering these factors. Therefore, it is essential to consider the interactions between temperature, pH, salinity, and dissolved oxygen and develop strategies to mitigate their impacts on fish populations and aquatic ecosystems.

Continued research, monitoring, and implementation of appropriate management practices are crucial for maintaining healthy fish populations, supporting biodiversity, and preserving the balance of our water bodies. By understanding and addressing the effects of temperature, pH, salinity, and dried oxygen on fishes, we can make informed decisions to protect and sustain our valuable aquatic resources. Comprehensive Ecosystem Management: Recognize the need for holistic strategies addressing multiple stressors.Species-Specific Conservation: Prioritize vulnerable fish species in conservation efforts. Climate Adaptation: Adapt fisheries management to climate-induced changes.Balancing Human Needs: Strive for a balance between human and fish population needs. Multi-Factor Interactions: Explore complex interactions among environmental factors. Long-Term Monitoring: Establish ongoing environmental and fish population tracking.Genetic Adaptation: Investigate genetic adaptability of fish populations. Ecosystem-Based Management: Shift towards holistic ecosystem-focused approaches. Innovative Mitigation:

Develop creative strategies for mitigating environmental effects. Public Engagement: Engage local communities and stakeholders in conservation. Policy Integration: Advocate for science-based policy decision.

Data Availability statement

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

All authors declare that, they have no conflict of interest.

Author Contributions

All authors participated in the initial draft creation, reviewed the manuscript, and contributed othe editing process.

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