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The role of environmental stress in fish health: A review

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Abstract

Fish are regarded as a crucial indicator of alterations in the aquatic environment due to their position at the apex of the food chain. Monitoring these alterations is crucial for identifying modifications in the aquatic ecosystem. The principal elements influencing fish health are temperature, pH, dissolved oxygen, salinity, pesticide contamination, microplastics, and algal presence. These elements substantially influence fish health regarding development, reproduction, respiration, oxygen stress, and the internal enzymes associated with digesting and other metabolic functions. Alterations in global environmental conditions and anthropogenic pollutants result in modifications to fish populations, their lives, and their behavior and mobility, therefore directly or indirectly affecting the world economy and overall environmental equilibrium. This study presents a comprehensive analysis of the environmental alterations and determinants influencing fish health. It aims to elucidate impending environmental issues impacting fish, necessitating the development of methods and strategies to deal with these changes.

Keywords: Environmental stressors; Fish health; Temperature; PH; OD; Pollution

1. Introduction

Environmental stressors are external factors that can negatively impact the aquatic life, in particular fish as it considers as a key indicator of ecosystem health due to its sensitivity to environmental changes. Factors include natural and human induced stressors, Such as temperature, PH level, salinity and oxygen dissolve level [1]. Environmental stressors, encompassing both natural and human-induced factors, significantly impact aquatic life, particularly fish, which serve as key indicators of ecosystem health due to their sensitivity to environmental changes. Variables such as temperature fluctuations, pH levels, salinity, dissolved oxygen concentration, pollution, and water scarcity contribute to physiological stress, reducing fish tolerance to pathogens and increasing their susceptibility to infections [2]. Studies indicate that environmental stressors elevate the prevalence of bacterial, parasitic, and physiological disorders, with overcrowding and heavy metal contamination further exacerbating health risks. The severity of these stress effects varies among cold-water and warm-water fish, as well as between freshwater and marine species, highlighting the complex interactions between environmental conditions and fish immune responses. Understanding these dynamics is crucial for effective conservation strategies and sustainable aquatic ecosystem management [3].

The development rate of fish is a significant characteristic having ecological, evolutionary, and conservation ramifications [4]. Anthropogenic stressors, including global climate change characterized by temperature rise, salinity alterations, and ocean acidification, in addition to ecosystem disturbances and selective pressures from capture, have had a major impact on the growth rates of many different species of fish [5]

The effects of climate change on fish health are an increasing concern. Increasing temperatures, altering precipitation patterns, and ocean acidification impact the dissemination and intensity of diseases in fish populations [6]

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2. Physical stressor

2.1. Temperature

The recent increase in temperatures has significantly affected the health of fish and aquatic organisms overall. Environmental temperature is a critical environmental component that affects the habits and physiological processes of aquatic life [7]. A prolonged increase or decrease in temperature, or abrupt variations in the surrounding environment, are seen as indicators of a stressful situation [8].

Increased water temperature markedly accelerates the metabolic rate of fish, resulting in heightened energy requirements that affect their general physiological functions. With the acceleration of metabolism, fish necessitate increased oxygen to sustain elevated cellular activity, resulting in alterations in eating behavior—typically ingesting greater quantities of food or encountering irregular appetite patterns. Thermal fluctuations can adversely affect development, reproduction, and immunological function, rendering fish more vulnerable to stress and disease in high-density habitats where oxygen competition and water quality concerns are exacerbated activities [9].

Temperature is a primary factor that induces illness, particularly when it beyond the tolerance thresholds of a species, it also contributes to enhancing the presence of pathogens or reducing the immunity of fish carrying the pathogen, leading to the appearance of disease symptoms in fish [10]. Many bacterial and viral pathogens thrive at higher temperatures. For example, *Edwardsiella tarda*, a bacterial pathogen, spreads more aggressively in fish at elevated temperatures [11].

Temperatures about 20°C facilitate healthy growth and reproduction in most freshwater species, whereas values beyond 25°C enhance metabolism while induce stress, diminish the supply of oxygen, alongside can result in organ failure or mortality at extreme levels (above 35°C) [12,13,14,15,16,17]. In contrast, temperatures under 5°C inhibit activities, decelerate metabolism [18], and impede development, posing issues of tissue damage and freezing at temperatures below 0°C [19]. Coldwater species flourish at temperatures ranging from -1°C to 4°C, whereas cool water species favor 5–10°C, rendering temperature an essential aspect in aquaculture, environmental management, and species conservation during climatic stress [20,21].

3. Chemical stressor

3.1. PH level

Fish possess a sophisticated internal system for regulating acid-base balance, essential to sustaining physiological activities. Any alteration in the acidity or alkalinity of the surrounding environment influences this internal balance, hence affecting enzyme and metabolic function, as well as ionic balance [22].

Enzymes are biological molecules that possess an optimal pH for normal functioning. Thus, Normal gastric acidity enhances the function of digestive enzymes like pepsin, but a pH imbalance impairs digestion and nutrient absorption, adversely affecting fish development [23]. The respiratory system of fish is influenced by pH variations, which affect the oxygen-binding capacity of hemoglobin, demonstrating altered oxygen affinity in relation to the surrounding pH levels. Elevated acidity diminishes the blood's capacity to bind oxygen, hence impairing the efficacy of the respiratory system, as well as alkalosis can affect the respiratory function [24,25].

The pH level may interfere with the normal balance of ions and electrolytes, acidosis, leads to elevated ion concentrations in plasma, resulting in hypercalcemia and hyperkalemia, whereas alkalosis conversely induces hypocalcemia and hypokalemia [26]. the optimal pH range for most freshwater fish is between 6.5 and 9.0, while for saltwater fish, it's 6.5 to 8.5, supporting maximum growth and reproduction [27,28]. pH levels below 6.5 or above 9.0 are generally stressful, leading to reduced growth and reproduction [29,30]. More extreme values, such as below 6.0 or above 9.5, are considered life-threatening to most fish species, potentially causing death if exposure is prolonged [31,32]. Waters with pH lower than 4.0 or higher than 10.0 are extremely dangerous and can lead to severe physiological stress or mortality [30,33,34]. Some species may tolerate pH ranges of 4.0–6.0 or 8.5–9.5, but often with reduced reproductive capacity or mild stress [34,35]. The alteration in the balance of acids and bases is intricately linked to fish disease, since this alteration facilitates the proliferation of certain viruses and bacteria inside the aquatic habitat of fish, resulting in an elevated infection rate [36].

3.2. Salinity

Salinity is a crucial indicator for aquatic organisms, affecting species distribution, physiology, and ecology. Typical salinity levels vary due to precipitation, evaporation, water flow, and anthropogenic activity [37].

Salinity significantly influences various biological and physiological processes in fish. Rates of death are affected, as freshwater species tolerate less than 5 ppt, while marine fish endure above 30 ppt. Growth rates differ among species based on their ideal salinity range, and osmoregulatory capacities also vary per species [38]. Breeding processes were adversely affected at elevated salinity levels, while behavioral alterations include modified swimming habits [34,39]. Salinity stress modifies activity of enzymes, protein production, and ion regulation, thus raising energy demands for homeostasis preservation [40,41]. Increased salt elevates cortisol levels and stress reactions while inhibiting the immune system [42,43]. The metabolic rate typically increases with a low salinity, while gill function fluctuates based on environmental conditions [44,45]. Ion absorption decreases, but the energy costs related to ion regulation rise [46,47]. Salinity interferes with acid-base balance, gene expression related to ion transport, and energy distribution across physiological functions [48,49,50].

3.3. Dissolved Oxygen

Dissolved Oxygen (DO) Are the free molecules that exist in water without combine with another component, and it consider a key factor to aquatic life in water. Primary suppliers of oxygen in ponds are phytoplankton photosynthesis and mechanical aeration, whereas the principal consumers of oxygen are fish respiration and microbial activity in the water column and substrate, DO levels diminish as respiration surpasses photosynthesis, with the most critical period for low dissolved oxygen concentrations occurring at night [51]. It's crucial for fish species for respiration, metabolism and other physiological function. Environmental conditions regarding oxygen partial pressure, water temperature, and salinity as well as oxygen consumption by aquatic organisms (biological oxygen demand) would affect the amount of DO in the water column [52].

The need for dissolved oxygen varies across different fish species. DO concentration is quantified in mg/L or as a percentage of saturation [53]. When the DO content falls below 5-6 mg/L in freshwater, aquatic organisms enter a hypoxic state [54], hypoxia could be defined as the values of DO that negatively affect the physiology or behavior of fish [55]. Mild hypoxia only led to a reduction in blood oxygen saturation and pO2, whereas both acute and chronic hypoxia caused a decline in blood pH, pO2, total oxygen content, and plasma Na+ and Cl levels [56].

DO concentrations in aquatic habitats are significantly affected by external variables such as temperature, salinity, depth, and barometric pressure [57]. Severe weather conditions can exacerbate the extent of hypoxic zones in aquatic environments and induce alterations in fish behavior, ecology, and functionality [58]. The asphyxiation threshold is associated with the social behaviors of fish. Generally, fish living in the higher and middle layers of a water body has a higher asphyxiation threshold than those living the bottom layers [59]. Generally, fish evade regions where oxygen levels fall below a certain threshold [60].

The incidence of parasitic infection, especially from endoparasites, rises as they predominantly inhabit the body cavity and tissues, adapting to low-oxygen environments, exemplified by *Trichodina mutabilis, Pomphorhynchus laevis*, and *Rhabdochona congolensis*, which are intestinal parasites that embed in the gut wall of fish [61].

Vibrio is a bacterium species which flourishes in high-salinity environments (30-35 ppt) and warm conditions. These bacteria do not require an aerobic environment and may withstand low-oxygen circumstances [62], which may impair fish immunity and increase their susceptibility to vibriosis [63].

Aeromonads are facultative anaerobes capable of switching between aerobic and anaerobic metabolic processes. Behavioral switching is controlled by gene expression and triggered by the molecular detecting of oxygen concentrations [64]. Fish diseases linked to Aeromonas spp. encompass hemorrhagic septicemia, ulcer disease, and motile Aeromonas septicemia [65].

3.4. Pollution

One of the significant impacts to aquatic life is pollution, represented by heavy metal, pesticides, untreated sewage water and microplastic which the main factors for the spreading of various disease. The pollutants bring toxic hazard chemical to water bodies causing disturbance to the physiological and immunological balance of the water [66].

3.4.1. Heavy metal

The bioaccumulation of heavy metals in freshwater fish is influenced by several variables, including fish traits and external environmental conditions. Factors pertaining to fish encompass age, size (weight and length), eating behaviors, and physiological characteristics, whereas external environmental factors comprise the concentration and bioavailability of metals in the water column, physicochemical qualities of water, and various meteorological conditions. Excessive amounts of heavy metals are detrimental [67]. Due to their bioaccumulation in organisms, detrimental effects on biota, and potential to induce mortality in various life forms, they destabilize ecosystems. All heavy metals induce mutagenesis and metabolic disturbance in organisms, even if some are essential micronutrients [68].

The buildup of heavy metals in various fish tissues often varies based on the tissues' shape and function. Metabolically active tissues, like gills, liver, and kidneys, exhibit greater accumulations of heavy metals compared to less active tissues like skin and muscles [69]. Hazardous heavy metals also impact the health and welfare of fish. Reports indicate that contamination of the river with wastewater containing heavy metals has generated stress in the freshwater fish Channa punctatus, rendering it weak and more susceptible to illnesses [70].

Freshwater fish are more vulnerable to heavy metal exposure than marine fish. This is due to the fact that, unlike marine fish, which frequently lose water and absorb salt, freshwater fish generally gain water and expel salt [71].

Heavy metal contamination is considered a potential factor contributing to the reduction of freshwater fish populations and other aquatic species in freshwater habitats. Reports indicate that heightened pollution in the Indus River, Pakistan, has led to a reduction in both the quantity and variety of freshwater fish and other aquatic species in this waterway [72].

Certain heavy metals, including cadmium (Cd), lead (Pb), arsenic (As), and mercury (Hg), are highly toxic to metal-sensitive enzymes, leading to growth suppression and mortality in organisms. These metals disrupt activity of enzymes and interfere with vital components necessary for the functioning of cells [73].

3.4.2. Microplastics

Microplastics, characterized as plastic particles smaller than 5 mm, arise from several sources, including the breakdown of plastic trash, synthetic fabrics, and industrial activities [74]. These particles persist in the atmosphere owing to their chemical stability, minimal degradation rates, and widespread presence in marine and freshwater ecosystems [75]. Fish, being aquatic species, are most vulnerable to microplastic contamination via direct ingestion and trophic transmission, which raises concerns over ecological imbalances and potential human health hazards associated with seafood intake [76].

The accumulate of microplastics in fish presents substantial risks to their physiological activities, including metabolism, immunity, and reproduction. Due to their capacity to absorb deleterious chemicals and microbiological infections, microplastics function as vectors for contaminants, hence intensifying their toxicological effects [77].

Exposure to microplastics and subsequent bioaccumulation disturbs hematological parameters, leading to decreased red blood cell counts and hemoglobin levels, hence impairing oxygen transport, metabolic function, inducing oxidative stress, and causing immunological dysregulation across several fish species [78,79]. Neurotoxic effects were shown by decreased swimming activity and increased erratic movement in MP-exposure such as zebrafish females are more likely to be impacted than male fish [80].

Large-scale loach *Paramisgurnus dabryanus* (Dabry de Thiersant, 1872) suffers from cross-generational reproductive harm as a result of polyethylene MPs, which decrease egg production and increase offspring mortality [81]. Nano-plastics (NPs) and microplastics (MPs) both reduce the ability to reproduce and cause hormonal abnormalities, which in turn affect fish fertility [82]. Fish experience oxidative stress and inflammation as a result of plastic deposition in their muscles and digestive tract [83]. Microplastics cause oxidative stress, harm tissues, and inhibit fish development in the freshwater fish, red tilapia *Oreochromis niloticus* (Linnaeus, 1758) [84].

3.4.3. Pesticides

Are chemical or biological compound thar are modify to manage or eliminate harmful pets. Pesticides infiltrate the aquatic system through several pathways, such as water form crop fields, water from domestic uses, wind carry to nearby water bodies, soil and contaminated groundwater, leading to physiological and biochemical changes that cause variations in enzyme activity and hormonal imbalances within fish species, hence increasing their susceptibility to illness by altering their nutritional components [85,86,87].

Pesticides exhibit significant endurance owing to their propensity for bioaccumulation in living organisms, extended half-lives, and lipophilic properties, which provide resistance to degradation and substantially enhance their persistence in the environment both in the short and long term [88]. Numerous research has examined the detrimental impact of pesticides on fish health, characterized by a reduction in hemoglobin, red blood cell count, and packed cell volume, with an increase in leukocyte count, Furthermore, it impairs the fish's immune system, generates oxidative stress, and increases the susceptibility to health issues [89,90].

Numerous categories of pesticides are available, including insecticides, which are used to control insect infestations. For instance, African catfish *Clarias gariepinus* (Burchell 1822) exposed to chlorfenvinphos has brain dysfunction due to the disruption of cholinergic signaling pathways via acetylcholinesterase inhibition [91]. As for the Common carp Cyprinus carpio (Linnaeus, 1758) when exposed to chlorpyrifos at a dose of 116 μg/L greatly increased the production of pro-inflammatory markers, notably interleukin-1 beta (IL-1β) and its receptor Interleukin-1 Receptor Type 1 (IL-1R1). The elevation in expression was seen in both spleen and head kidney tissues, demonstrating an intense immune reaction to chlorpyrifos being exposed to it [92].

However, Herbicides are formulated targeting particular weeds or undesirable vegetation, while limiting damage to desirable plants [93]. Hematological and biochemical alterations induced by Bispyribac sodium at a dosage of 0.800 mg/L in Piapara *Leporinus obtusidens* (Valenciennes, 1836) include a reduction in red blood cell count, with increases in cholesterol, total plasma protein, urea, creatinine, globulin, and the albumin/globulin ratio. Additionally, elevated levels of albumin and enhanced enzymatic activity of alkaline phosphatase (ALP), alanine aminotransferase (ALT), and aspartate aminotransferase (AST) [94].

Fungicides are a class of pesticides particularly formulated to manage fungi that cause plant diseases and endanger agricultural harvests. Walking catfish *Clarias batrachus* (Linnaeus, 1758) exhibited substantial decreases in protein, amino acids, glycogen, nucleic acids, and the enzyme succinic dehydrogenase in both liver and muscle tissues, with elevated levels of lactic dehydrogenase, protease, and Glutamate Oxaloacetate Transaminase in response to exposure to mancozeb [95].

4. Biological Stressors

4.1. Algae

Harmful algal blooms (HABs) are a persistent and severe problem in lakes and coastal areas. They adversely affect aquatic organisms by depleting dissolved oxygen, with effects lasting from many days to months. These blooms are hazardous and consist of substantial biomass and poisons [96]. These HABs adversely affect aquatic life and contaminate the atmosphere via toxin release [97]. Fish and bacteria consume these toxins, frequently resulting in significant mortality owing to inadequate oxygen levels and excessive toxins [98].

Algal blooms often arise in nutrient-rich ponds or regions of organic pollution, although they may also occur under standard feeding practices or subsequent to fertilizer application [99]. Fish exposed to algal toxicosis have abnormal swimming patterns, show lethargy, progress to convulsions, and may eventually succumb. Smaller and less resilient fish species often perish first, but whole pond fish populations may eventually be decimated [100].

4.2. Overcrowded

Overcrowding refers to an excessive rise in the population of species within a confined space. Crowding can lead to decreasing in oxygen dissolve and nutrition, while increasing in disease spreading rate and aggressive behavior in certain species. This constitutes an environmental stressor since it heightens competition among various species for resources such as food, oxygen, and habitat. Overcrowding resulted in the accumulation of harmful waste, such as CO2, owing to the respiratory processes of the fish. Outbreaks of harmful microorganisms occur in high stocking densities, resulting in the widespread dissemination of diseases [101].

Rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792) raised under high-density conditions exhibit increased cortisol and lactate levels, indicative of stress, along with the downregulation of essential immune genes such as HSP70, IL-1β, and TNF-α, diminished complement function and disrupts lipid metabolism, resulting in increased lipolysis and β-oxidation while lowering fatty acid synthesis [102,103].

These stresses collectively result in diminished development, compromised immunity, and increased incidence of disease outbreaks. Sustainable fish management requires species- and stage-specific stocking density strategies to ensure welfare, health, and production.

5. Conclusion

The cumulative effects of global climate changes such as increasing temperature, PH level, salinity, oxygen dissolve associated with other variation such as pollution, heavy metal ions, overcrowded and Alge has the direct and indirect effect on fish health, metabolism, behavior and habitat. These factors consider a pressure on fish physiology leading to immunosuppressants, elevate in diseases incident and reduce population considerably the fish play role as key indicator for Aquatic ecosystem integrity. The increasing temperature of the water will decrease the oxygen dissolve in water and also increasing the metabolic rate of the aquatic organisms leading to extra pressure on oxygen demand, furthermore, the warmer water hold less dissolve oxygen than cooler water. The temperature also affects the salinity by increasing the evaporation rate of water bodies causing salinity to rise, leading to disease spreading rate. The pH fluctuates directly in correlation with the concentration of dissolved oxygen in the water. An increase in pH correlates with a decrease in the concentration of dissolved air in water, and inversely. Pollution in its all types can alter the optimum PH level for aquatic ecosystem, it can decrease the PH level which allowing the opportunistic bacteria to thrive and inhibition beneficial bacteria that help break down organic matter and maintain water quality.

An overview, all these factors are affecting fish health, growth, and reproduction leading to higher risk on human consumption.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declared no conflict of interest

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