Climatic Change Effects on Fish Physiology in Fresh Water Bodies: A Review

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Review Article

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ABSTRACT

Salinity fluctuations can severely impact fish physiology resulting from climate change, affecting their health and homeostasis. They have specific salinity ranges for optimal health in many aquatic organisms and can cause mortality in deviations from these ranges can impair immune function and reduce growth. Climate change effects on fish physiology in freshwater bodies are interactions between species due to loss of habitat, extinction of species, the transmission of parasites and pathogens between species and future modifications of the distribution which are changes in the structure and composition of the population. Climate change is causing considerable changes in the ambient conditions of freshwater ecosystems, which has far-reaching ramifications for fish physiology. As temperatures rise, changes in water quality, oxygen availability and seasonal cycles have an increasing impact on fish metabolic processes, growth, reproduction and survival.

This study looks into how freshwater fish species adapt to these environmental stresses, with a specific emphasis on temperature-induced thermal stress, altered oxygen dynamics and the combined impacts of habitat fragmentation. We investigate fish's molecular and physiological adaptations, studying changes in metabolic rates, immunological function and reproductive timing in response to varying water temperatures, hypoxia and altered hydrological regimes. In addition, we consider how these stressors interact with pollutants and invasive species, further complicating the physiological responses of native freshwater fish populations. This study aims to improve understanding of the mechanisms underlying fish resilience in climate change, providing valued insights for management and conservation strategies aimed at preserving freshwater biodiversity in a quickly varying world.

The Applied Ecology Journal has occasionally seen significant contributions from studies assessing the ecological relevance or extensions of eco-toxicological research and we anticipate more groundbreaking contributions in the future. It is astonishing that, in recent years, studies on fish management have made up less than 1% to 2% of the Journal of Applied Ecology's content, considering the significance of these topics. The objectives of this article are to determine climate change impacts on fish physiology in freshwater bodies, determine temperature changes and their impact on fish physiology, effect on growth and development, on fish physiology responses in freshwater bodies, reproductive changes, impacts on freshwater fish species and management and conservation strategies.

Keywords: Temperature changes; Fish physiology; Reproductive changes; Freshwater species; Fish physiology stress responses

INTRODUCTION

People in poverty are most affected by climate change, despite being the group least accountable for greenhouse gas emissions. Globally, care is already witnessing how climate change is aggravating social and economic inequalities, gender inequality and development gains. Individuals within a species are impacted by climate change in terms of their survival, development, reproduction and distribution, but effects can also be seen at population, ecosystem and community levels. The following instances of observed climate consequences are meant to highlight some of the key mechanisms at play, as well as their intricacies and interrelationships. Temperature, salinity, wind fields, oxygen, pH and the water column's density structure are some climate-related drivers. The examples span a variety of scales, from modelling and observation of entire ecosystems and vast marine areas to experimental research on individual fish and a combination of field and experimental studies [1]. The following factors make fresh waters especially vulnerable to climate change: (i) many species in these fragmented habitats have limited ability to disperse as the environment changes; (ii) water availability and temperature are climate dependent; and (iii) many systems are already subject to a multitude of anthropogenic stressors [2]. On top of the other stresses that fish face habitat loss, pollution, disturbance, invasive species and fishing mortality-climate change is another one stocks already go through. This means that other anthropogenic influences, which are commonly more significant and direct impacts, must be taken into consideration when assessing the impact of climate change.

This paper's primary goal is to compile and evaluate data on how the climate impacts fisheries to (i) demonstrate how the climate impacts fish stock distribution, productivity and resilience, (ii) deepen our understanding of the mechanisms and (iii) learn from the past [3]. Because climate change impacts a wide collection of environmental elements that may have an impact on different processes at changed levels of biological organization, resolving the impact of climate change on fish populations is challenging. One or more species from the salmon (*Salmonidae*), minnow, carp, barb (*Cyprinidae*), cichlid (*Cichlidae*) and several other families usually form the foundation of freshwater fisheries. Inside the *Siluriformes*, or catfishes. Despite our emphasis on these families, we will occasionally use other freshwater fish to highlight important ideas [4]. Freshwaters are immediately impacted by climate change because of rising sea levels, more variable precipitation over time and between sites and warmer temperatures. Numerous people noticed the significant climate trends for freshwaters include decreasing rainfall over land between 10°S and 30°N after the 1970s, increased precipitation over land north of 30°N since 1901 and droughts in some areas and higher precipitation intensity in others [5]. Since the publication of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2007, the risks posed by climate change to human society and natural ecosystems have taken precedence. However, the significance of the possessions of climate change on efforts is sometimes overlooked in the setting of fisheries and aquaculture. It is challenging to overlook these industries, as well as riparian and coastal communities generally. However, although they have little impact, on fish physiology [6]. The Food and Agriculture Organization of the United Nations (FAO) considers inland waters to be lakes, rivers, streams, canals, reservoirs and other inland waters.

Although inland waters are typically considered to be freshwater, they can also include inland saltwater basins such as the Caspian Sea. Inland fish species and their biodiversity. Both arrest and aquaculture of inland fish species for consumption, profit, or leisure are considered inland fisheries. Because of the enormous volume of reported catch, sea fisheries frequently overshadow inland fisheries in discussions about global capture fisheries. Marine catches: inland clasps are around seven times worse than marine catches. However, limited or artisanal fishing in inland water suggests that inland fisheries produce is frequently unrecorded or significantly under-reported, according to several lines of evidence (such as consumption studies) [7]. It has been demonstrated and expected that biodiversity would be significantly impacted by global change on a local, regional and global scale. Even though there are many distinct types of anthropogenic influences associated with global change a lot of recent attention has been focused on climate change, which includes changes in land use, nitrogen removal and the invasion of exotic species. It has proposed that freshwater ecosystem biodiversity declines are particularly quick, matching or even surpassing estimates for the tropics, the cradles of biodiversity. Rainforests and Freshwater habitats sustain disproportionately high levels of biodiversity in their three-dimensional coverage, which causes this rate of decline.

LITERATURE REVIEW

Freshwater hosts at minimum 100,000 species, or roughly 6% of the estimated 1.8 million recognized species, even though they make up only 0.01% of the world's water and 0.8% of its surface area [8]. Adaptations on freshwater fishes for billions of people, fish is a major cause of animal protein; in some tropical nations, such as the Pacific islands, Bangladesh and the Maldives, fish accounts for over 60% of animal protein supply. In addition to risks already faced by other stressors, climate change which includes rising temperatures (T°C), Ocean Acidification (OA), Sea Level Rise (SLR) and Extreme Events (EE) pose a threat to global fisheries, aquaculture and seafood security. Higher temperatures may cause fish illnesses to occur more frequently. Furthermore, fish that migrate poleward for warm climates might act as hosts in carriers of parasitic illnesses in their modern surroundings [9]. Fish are the most prevalent and, generally speaking, the least understood of the vertebrate classes on a global scale. There are currently about 25,000 species known and the final total will likely show that fish make up three out of every five vertebrate species. Since roughly 100 new species are described each year, there must be far over 25,000 species in total. They have evolved a vast array of intriguing forms and functions and can be found in almost any type of aquatic habitat [10].

The distribution of fresh water is not uniform worldwide. About two-thirds of the world's liquid surface freshwater is found in the 21 largest lakes on Earth, which also inhabit a variety of natural and social environments. We found that most or all of these major lakes had quantitative data for seven ecological functions. Approximately 95% of the 1.35 million tonnes of fish that are taken annually in these lakes through marketable or artisanal methods come from the big lakes in Africa. The 21 lakes provide the movement of 195 million tonnes of goods annually and the production of at least 62.2 GW of electricity, with the Particularly significant those, being the Laurentian Great

Lakes. An additional 812 million m^3 of water is being taken out for cultivation. Depending on the social and environmental context, huge lakes offer different services to people.

Temperature changes and their impact on fish physiology

Lethal thermal limits are impacted by the temperatures that fish are kept at and temperature tolerance and performance curves change with acclimation before being exposed. This serves as the foundation for defining two categories of fatal thermal limits: ultimate (acute) and incipient (or chronic) lethal temperatures. About 60 years ago, it was discovered that a fish's capacity to ingest oxygen and its heat tolerance were directly related Later, a comparable correlation was found between thermal optima for heart function, swimming ability and oxygen use There is a growing possibility that the circulatory system restricts tissue oxygen supply and the idea of oxygen-limited heat tolerance has been solidified for a variety of fish species, including several tropical and polar species and even certain aquatic invertebrates. No other fish can increase their stroke volume during exercise as well as salmonids; instead, they rely more on heart rate rises. Additionally, tachycardia plays a main role in postprandial rise in V_ b during digestion in rainbow trout (*Oncorhynchus mykiss*, for instance) and as an outcome, there is a substantial correlation between heart rate and V_O_2. For fish, the advantages of increasing heart rate or stroke volume have not yet been thoroughly described.

In the dog ventricle, myocardial oxygen consumption per unit of mechanical exertion rises with heart rate; in other words, efficiency gradually falls as the heart rate rises. Since weather and atmospheric temperature fluctuations are closely related to inland water conditions, Climate change can have significant direct and indirect effects on freshwater biota. Most freshwater animals are poikilothermic, with an internal temperature that varies with that of their environment: Water temperature therefore influences their main physiological processes and metabolic activity and has a strong effect on the survival, longevity and reproductive success of freshwater animals. For example, recent studies in rivers of northern Italy revealed that populations of the mayflies *Oligoneuriella rhenana* (Imhoff, 1852) (Ephemeroptera: Oligoneuriidae) and *Pothamantus luteus* (Linnaeus, 1767) (Ephemeroptera: Pothamantidae) develop faster in warmer environments.

Water polluted fishes

Through hormonal and neurological regulation of digestion, respiration, osmoregulation and every other facet of an organism's function and behaviour, temperature affects enzymatic reactions. The range and population abundance of a species is determined by the extremes of temperature that are fatal to individual organisms. Trout and salmon are more vulnerable to high temperatures, but goldfish, bass and carp can withstand them to a certain extent. Adult fish, however, are subject to these temperatures. It takes substantially lower temperatures for eggs to spawn and hatch. Many species only produce at temperatures above or below a particular threshold. This is the primary difference between fish that lived in icy water and those that lived in warm water. Although 90% of hot-water fish grow lesser bodies than their icy-water complements, warm-water fish attain sexual maturation faster than their cold-water counterparts. Reproductive issues and rarer children are the outcome.

Effect on growth and development

Electronics, fuel additives, building materials, paints, textiles, medical devices, food, bioremediation, wastage of water treatment technologies and own care items are just a few of the product uses that have been proposed for NMs (Nano Metals) Fish biology may find great use for some of these products and components. For instance, aqua feeds could benefit from the same application of NMs in different food technologies. The potential for novel medications or drug delivery systems will also be of notice to specialists in fish health. Aquaculture engineering can almost benefit from modern material science innovations, such as stronger and lighter materials for fish cage construction and novel sieve materials for sanitary water technologies on fish farms. One of the greatest crucial elements for species which are aquatic, particularly those that obtain their dissolved oxygen from water, is Dissolved Oxygen (DO). Water quality is indicated by DO levels. Numerous biotic and abiotic factors, including upwelling, respiration, photosynthesis, ice cover, pollution, mixing of various water bodies, air exchange and physical factors like temperature and salinity, can affect the concentration of DO.

Water changes in DO levels have an impact on fish physiology. The effect of dissolved oxygen on the physiology of freshwater fish will be the main topic of this review. Swimming, nourishing, illness management, survival, breathing, metabolism, growth, reproduction, health limits, immunity and pressure in freshwater fishes are all covered in detail in this research review. On freshwater fishes' physiology responses. One of the main environmental issues that might harm biodiversity is the proliferation of aggressive species. Although several life history characteristics are crucial for making introduced species more invasive, little is known about the physiological elements that enable some species to successfully invade. It has been hypothesized that disrupted ecosystems provide a breeding ground for excellent invaders. Invasive species may respond more physiologically and behaviorally to this stressor in unfavourable circumstances, such as hypoxia episodes.

Over a range of Dissolved Oxygen (DO) values, we examined the physiological and behavioural characteristics of two freshwater fish species: the native stone loach (*Barbatula barbatula*) and the European bullhead (*Cottus gobio*), an aggressive fish species in Scotland. Molecular biology markers can be used to identify the genes involved in fish oxidative stress and the environmental factors that influence them. Fish health and industrial production are negatively impacted by oxidative stress. The expression of fish genes throughout oxidative pressure can reveal causes which result in new treatments. Fish oxidative pressure genes and paths are being shown by transcriptomics, proteomics and genomes, leading to the development of new management techniques. Fish health is impacted when ammonia is present in a culture system. Even small amounts of ammonia harm other tissues, including the gills. Long-term exposure to ammonia causes fish to become more susceptible to illness, develop poorly and become less resilient to handling. However, increased ammonia causes direct death. The structures of bodily tissue are the focus of histopathology.

Any atypical change in cells might indicate the existence of different diseases and the impact of harmful chemicals. Abdullah, et al. documented several histological modifications in the liver of *Tilapia nilotica* raised which is in heavy metal-contaminated water, including hazy oedema, hepatocyte vacuolar and hydropic abnormalities and noticeable coagulative necrosis. The pathological changes in the liver and gills of *Alburnus* and Perch from contaminated Dame Lake were examined by Velcheva, et al. They found that the cytoplasm of the hepatocytes deteriorated eventually becoming necrotic and infiltrated with inflammatory cells. Abdullah, et al. have observed similar scratches in *Tilapia nilotica* fish.

Reproductive changes

Stress physiology and the physiology linked to maturation and spawning seem to be closely related. For instance, rainbow trout stocks under stress and those at rest exhibit significantly different levels of the key stress response factor cortisol in the blood. Stress can affect immune capacity, which lowers broodfish reproductive fitness. Next, we examine the impacts of stressors delivered at various stages of reproductive development and make conjectures regarding the effects of stressor intensity. Comparing the stress-induced concentrations of cortisol, one of the main stressors, among species and stocks of the rainbow trout, *Oncorhynchus mykiss*, a fairly well-studied organism, serves as an example of the polymorphic character of the stress response. Through interactions with the endocrine stress response, a fish's social environment can also have an impact on reproduction. According to Leitz (1987), social influences influenced the regulation of testicular steroidogenic ability in *Betta splendens*, a siamese fighting fish. Social interactions also cause stress in the African cichlid *Haplochromis burtoni*, as evidenced by elevated cortisol levels in the blood determined that because the size of the testes and GnRH neurons in the hypothalamic-preoptic region appear to be inversely correlated with social status, the fish's reproductive competence is also impacted by the same social interaction.

Brown trout

Crowding affects, the reproductive hormones of brown trout (*Salmo trutta*); stressed fish exhibit higher plasma stages of cortisol in ATH and lower stages of circulating testosterone in 11-keto-testosterone. Remarkably, stress increased plasma gonadotropin levels. These results suggest that stress may hurt fish reproduction. A key physical determinant of fish life, the temperature has a particularly strong impact on the regulation of all reproductive procedures, including gamete maturation and growth, ovulation and spermiation, spawned, embryogenesis, hatched and larval and juvenile progress and survival. Fever is typically supposed of as secondary cue to photoperiod in phasing the reproductive seasonality in reproductive established adults, yet it theatres a significant role in truncating reproductive episodes and synchronizing the last phases of reproductive maturity. Through its rate-determine the effects on embryogenesis and hatched eggs as fine as successive larval growth, growth and survival, temperature plays an equally significant part in modulating post-fertilization procedures.

Numerous biological, physicochemical and other elements can also directly or incidentally affect the quality of the water and, in turn, its appropriateness for fish and other aquatic animal production and distribution. Every aquatic organism, including fish, has a decrease or rise that could have an impact on their bodily processes and result in extreme stress. According to Boyd, every water quality metric influences and interacts with other parameters, sometimes in intricate ways. There is also a complex relationship between water quality parameters and how they affect fish development, health and reproduction. Reduced growth rates, infection-related mortality and diminished reproductive potential are just a few of the negative long-term effects that could result from even mild stress brought on by changes in environmental factors.

Impacts on freshwater fish species

The functioning of ecosystems and biodiversity worldwide is seriously threatened by weather alteration, which has previously had an impact on a variety of habitats and biota. Due to their isolation and fragmentation within a terrestrial landscape, freshwater ecosystems and the creatures that live there are especially susceptible. As a result, freshwater fish species in Australia have a wide range of reproductive, morphological and physical adaptations that continue under definite environmental circumstances. Due to their size (30% of the region's area) and proximity to the present sea level, Northern Australia's coastal freshwater mudflats are at risk from sea level rise.

The probability of saltwater intrusion into coastal freshwater wetlands is also increased by stronger cyclones and the storm surges that accompany them. This can lead to floristic changes, such as the cost of Melaleuca Forest and upstream immigration of mangroves, as well as a geomorphological modification from freshwater marshlands to their salty mudflats. Wetland-dependent species like blue-eyes (*Pseudomugil tennellus* and *P. gertrudae*) and penny fish (*Denariusa bandata*) would be locally exterminated as wetlands quickly transformed into saline mudflats. Numerous other species, including the diadromous barra-Wetlands on coastal floodplains provide a crucial nursery habitat for mundi (*Lates calcarifer*). A change from a marsh to a salty environment. The primary productivity, food web, fish assemblage structure and general biodiversity would all be significantly impacted by mudflat habitat.

Due to their common adaptation, fish species are specifically vulnerable to variations in river current regimes. Life-history arrangements like migration and breeding are impacted by river regime characteristics, particularly flow seasonality. Fish populations may be adversely affected by increases in flow plenty for tropical rivers, such as the Mekong with a larger movement of peaks and decreases in low river currents. While the increase in the harshness of flood peaks might relocate adults which harms juveniles and larvae (e.g., Harvey 1987), increases in the annual mean high flow may enhance the amount of habitat available on flood plains e.g., for spawning. In protection pools, crowded, stressful situations can worsen due to strong drops in little flow and greater stream current deficiencies, which leads to population losses and changes in the species mix of fish. The freshwater fish species' biogeography supplies are influenced by physiological heat tolerances. Fish species are frequently categorized according to their climatic zones, with temperate, sub-arctic and sub-tropical fishes being distinguished.

Temperate fishes

Three thermal classifications include temperate fishes: warm (like *Cyprinidae*), cool (like *Percidae*) and cold (like Salmonidae) water fishes. Freshwater fish distributions are projected to be impacted by climate change, since certain species may either relocate to higher latitude environments or vanish from low liberty latitude boundaries of their own range. A few foreign species and a tiny, distinctive group of local species make up the Patagonian lakes' fish fauna. The physiology of the species under consideration determines the belongings of environmental changes on Patagonian fish diversity. The 29 fish species that make up the freshwater ichthyofauna includes only two classes of lampreys found in South America, several interesting salmonids, one exotic cyprinid and Neotropical fishes (characids and Siluriformes), as like as marine dispersants (galaxiids) and oceanic essentials of local source (percichthyids, atherinopsids and mugilids). In particular, the idea of fish's thermal niche-that is, considering temperature as both a physiological and ecological resource-depends heavily on thermal tolerance. Because fresh and marine waters have varying thermal inertia, seasonal thermal changes cause differing temperatures, which affect aquatic primary production and planktonic feeding opportunities. Therefore, the larvae of G. maculatus marine diadromous and *Aplochiton* spp. Prefer to feed the poleward during the winter. Due to extinctions brought on by the loss of habitat, effluence, the introduction of which species live in just one place like exotic species, overexploitation and some other human events, the world's aquatic biodiversity is changing and disappearing at an alarmingly rapid rate.

Exotic fish

Since the exotic fish known as Nile Perch (*Lates niloticus*) was presented, the pond's biological and physical characteristics have undergone significant alteration. The introduction of *Oreochromis mossambicus* has put the indigenous goby *Mistichthys luzonensis* in Lake Buhi in Asia in danger of going extinct. Due to comparable ecological needs, *O. mossambicus* may pose a threat to the survival of native cyprinid fishes like *Labeo* by competing with them. There have been instances of freshwater turtle disappearances in Asian nations as a result of widespread gill net fishing for tilapias. It might be challenging to ascertain however common thinking is being used across several vocabularies because biological attacks are described using so many distinct terminologies.

Exotic, nonindigenous, unfamiliar, xenic, harmful, weedy, pest and foreign are some more names for non-native fish, for instance.

Freshwater fish species

Within this category, freshwater fishes like African catfish, Chinese and Indian carps and tilapias (*Oreochromis spp.*) contribute significantly to aquaculture external of their usual range. This has resulted in a high number of outflows from aquaculture connections and the creation of natural breeding diversity. For instance, almost 25 billion is being spent annually on recreational fishing throughout Europe. Fish species (mostly salmonids) that are prized for their flesh and athleticism are introduced for sport fishing. The rainbow trout's scientific name is *Oncorhynchus mykiss* (Walbaum) and brown trout and brown trout are the most extensively distributed of them. Largemouth bass (*Micropterus salmoides*; Lacepede), trout (*Salmo trutta* L.) and brook trout (*Salvelinus fontinalis*; Mitchell).

DISCUSSION

Management and conservation strategies

The growing human population, loss of forests and anthropogenic climate change which expected to intensify adverse impacts on freshwater ecosystems which the risk of species extinction. Furthermore, climate change threatens around 50% of all freshwater fish species worldwide. Freshwater biodiversity that is powerfully dependent on calcium dies when the calcium pleased of the surroundings deteriorates, providing another serious threat to global biodiversity. To promote biodiversity, elements such as species variety, population water quality and habitat must be regularly assessed. Current research on freshwater biology and ecologies is very limited. As a result, data gathering and the development of particular plans for the preservation of freshwater biodiversity should be arranged. Conservation ecologists and politicians have not paid enough attention to this issue, which results in a scarcity of data and complete evaluations on freshwater biodiversity in particular.

They detect emerging dangers and refresh our understanding of ongoing freshwater conservation difficulties, with a focus on topics that could have global, negative consequences. The scope consists of: (i) dangers recognized by skilled judgement and backed by source of literature; (ii) terrorisations that vary in extent, physical area and/or occurrence over the world (iii) hazards that are completely novel during the year. Carrizo, et al. found that 84% of vulnerable freshwater megafauna distributions are located outside of existing protected areas. Finally, freshwater ecosystems are hotspots. Endangerment arises from the intersection of biological diversity and human freshwater use, which extends beyond land-based activities. Gallardo et al. (2016) conducted a global meta-examination of 151 articles and 733 belongings of invasive species which is in watery habitats between the years nineties and twenties. The study found significant negative impacts on number of macrophytes, fish and zooplanktons.

Freshwater ecosystems might be the most endangered species in the world. Freshwater ecosystems have higher biodiversity declines compared to terrestrial ecosystems. Freshwater habitats support about 10,000 fish species, accounting for a global fish diversity is 40% and a global vertebrate diversity are 25%. Intimidations to worldwide freshwater populations include overexploitation, water pollution, flow manipulation, habitat destruction/degradation and exotic species invasion. Exotic species have had significant impacts on native species, such as Nile perch which is in Lake Victoria, crayfishes in Europe and salmonids in Southern Halves lakes. Impacts on rivers and streams are expected to increase. Exotic worldly plants like *Tamarix* spp. (Tamaricaceae) can have indirect impacts on riparian muds and river flow in North America and Australia. Freshwater biodiversity conservation is a considerable challenge because of the complexity imposed by catchment divisions and saltwater barriers. In the non-appearance of human disruption, small gene flow and confined radiation result in significant inter-drainage variance and high levels of biodiversity endemism.

Chinese paddlefish, *Psephurus gladius* (Martens), weighs 300 kg. Possible weight of 500 kg and height of up to 3 meters. The Yangtze is critically endangered and endemic. The main issues are overfishing and pollution. Gezhouba Dam (1981) restricted breeding movements after population collapse, bringing the species near extinction. Freshwater stingray (*Himantura Chao* Phraya), Monkolprasit and Roberts (potentially up to 600 kg) The Mekong, Chao Phraya, Fly and Mahakam rivers are vulnerable to overfishing, pollution and habitat destruction, particularly in the Chao Phraya. Unconfirmed records indicate this ray may be one of the largest freshwater fish in the world, a little-known species. Inland fishes provide critical ecological services to populations around the world but are particularly vulnerable to the effects of climate change. Fish respond to climate change in diverse and subtle ways, posing challenges for fish conservation, climate change adaptation and management professionals. Although climate change is known to affect fish worldwide.

As a result, a significant focus of freshwater biodiversity conservation and land-use planning in these regions has been to minimize nutrient and sediment pollution from point and nonpoint sources, due to their negative impacts on aquatic habitat conditions and the creatures they support. We focused on 15 stream fish species for which significant biological information was available in the WLEB: rock perch (*Ambloplites rupestris*); spotted scorpionfish (*Cottus bairdii*); northern pike (*Esox lucius*); green darter (*Etheostoma blennioides*); rainbow darter (*E. caeruleum*); northern sucker (*Hypentelium nigricans*); brook silverside (*Labidesthes sicculus*); long ear sunfish (*Lepomis megalotis*); smallmouth bass (*Micropterus dolomieu*); spotted sucker (*Minytrema melanops*); Silver redhorse (*Moxostoma anisurum*); Golden redhorse (*M. erythrurum*); Greater redfish (*M. valenciennesi*), yellowfin tuna (*Notropis stramineus*) and trunk perch (*Percina caprodes*) display a wide variety of functional traits. For example, they occupy different habitat zones (e.g., benthic *vs.* pelagic; fast *vs.* slow currents) and feeding guilds (e.g., detritivorous, piscivorous, omnivorous), vary in thermal preferences (e.g., warm *vs.* cold waters) and sensitivity to disturbance (e.g., intolerant *vs.* tolerant) and differ in morphology, reproductive behavior and life span.

CONCLUSION

This review provides a detailed overview of intricate and adaptive climate change effects on fish physiology in freshwater bodies, behaviour responses, stress physiology in fish, reproductive changes, fish physiology on fish's species and conservation and management strategies that have climate change adaptations due to temperature variations, storms and seasonal changes. To address these gaps, your study could include field studies to collect data from freshwater bodies with varied environmental circumstances (temperature, oxygen and water quality). Experimental research involves using controlled laboratory setups to model climate scenarios (higher temperatures, altered pH, oxygen deprivation) and investigate their effects on freshwater fish physiology (metabolism, growth and reproductive success). Genomic and proteomic approaches use genomic and proteomic methods to examine molecular responses in fish and discover adaptive pathways. Modelling to use predictive models, determine how climate change will affect fish physiology and behavior over time under various climate scenarios.

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AUTHORS CONTRIBUTION

Iqra Nawaz was the primary author of this article and was responsible for its conception, data collection, analysis and drafting Mr. Shahid Mahmood provided guidance throughout the research process, offering critical feedback and ensuring the scientific rigor of the article.

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