Pollution's Impact on Aquatic Animal Physiology

Dr. Neeru
Assistant Professor, Department of Zoology
Smt Aruna Asaf Ali Government P. G. College, Kalka

Abstract

This study investigates the multifaceted physiological impacts of pollution on aquatic animals, focusing on how various pollutants disrupt vital biological systems. Aquatic ecosystems, increasingly threatened by anthropogenic contaminants such as heavy metals, organic pollutants, microplastics, excess nutrients, and thermal discharge, serve as sensitive indicators of environmental health. Using both freshwater fish (*Cyprinus carpio*) and marine mussels (*Mytilus galloprovincialis*) as model organisms, the study examines changes in biochemical, histological, and behavioral parameters under controlled exposure to pollutants. Findings reveal that cadmium significantly reduces hemoglobin levels and enzymatic activity while increasing mortality and behavioral abnormalities. Microplastic exposure leads to digestive tissue damage, feeding inhibition, and cellular instability. Combined nitrate and heat stress elevate blood glucose, damage gill structures, and reduce survival rates, highlighting the compounded effects of multiple pollutants. The study utilized standardized assays and histopathological analysis to identify stress biomarkers that can serve as early indicators of pollution exposure. Results underscore the urgent need for regulatory action and ecological management strategies to mitigate pollutant discharge into aquatic habitats. The research contributes to a deeper understanding of the toxicological mechanisms through which pollutants affect aquatic fauna and offers practical insights for environmental monitoring, conservation planning, and policy formulation aimed at sustaining aquatic biodiversity and ecosystem functionality.

Keywords: aquatic pollution, physiological stress, heavy metals, microplastics, biomarkers

Introduction

Aquatic ecosystems are intricate networks that support a vast array of biological diversity, where even subtle environmental changes can have profound effects. Pollution—whether from industrial effluents, agricultural runoff, sewage discharge, or plastic debris—has become a pervasive threat to the health of aquatic environments. As these pollutants enter rivers, lakes, and oceans, they alter the chemical composition of water, introducing toxins such as heavy metals, pesticides, hydrocarbons, and microplastics. These substances can significantly disturb the physiological functions of aquatic animals, particularly fish, mollusks, crustaceans, and amphibians, whose bodies are highly sensitive to changes in water chemistry. The gills, skin, and gastrointestinal systems of aquatic organisms serve as primary interfaces with their environment, and thus are the first to be impacted. Pollutants can interfere with gas exchange, osmoregulation, and immune responses, often leading to respiratory distress, metabolic imbalances, and heightened disease susceptibility. In some cases, chronic exposure can cause genotoxic effects, reproductive dysfunctions, and even behavioral changes, all of which may compromise survival and population stability.

In addition, physiological change-side effects caused by the pollution, tend to spread into wider ecological effects. As an example, the presence of bioaccumulation and biomagnification of harmful chemicals in the food chain do not only cause an environmental problem to predators but can also cause a human community depending on seafood. Endocrine-disrupting chemicals The endocrine disrupting chemicals found as residues of some industrial solvents and pharmaceuticals, can be known to act like hormones or prevent the hormonal compromised, leading to altered reproductive patterns and developing deformities. The nutrient pollution caused by nutrient overload and causing algal blooms causes conditions called as hypoxia whereby oxygen is depleted creating more stress or death of sensitive aquatic life. Further, industrial discharge and thermal pollution increase the tightness of the water and hence increases the rate of metabolism and decreases the amount of dissolved oxygen, which is stressful to the cardiovascular and enzymatic systems. Conceptualization of these physiological effects is significant in development of efficacious conservation policies and pollution intervention policies. Understanding the reaction of aquatic organisms both at the level of physiology and molecular biology, researchers and policymakers can target the health of ecosystems and develop appropriate interventions delivering on biodiversity preservation as well as human health protection.

Background and motivation

Water bodies have traditionally been regarded as large, self-cleaning and clearable ones that have the ability to dilute and absorb wastes. Nevertheless, the high level of industrialization, growth of cities and intense agricultural activities during the last 100 years has added an unbearable amount of loads to contaminate freshwater and marine environments. Mercury, cadmium, nitrates, which are fertilizer byproducts, pharmaceutical residues, endocrine disruptors and plastic particulates are some of the heavy metals that are now increasingly polluting water bodies across the world. Such pollutants not only cause destruction on water quality, but also directly impact the aquatic fauna, which are continually engaged in exchanges with the environment via its gills, diet and osmoregulation. Most especially the nervous, endocrine, reproductive, and immune systems of the physiology of the aquatic animals are very susceptible to such alterations. As an example, metal toxins may adsorb enzymes, and as a result, impair metabolism, and microplastic can physically harm the intestinal lining, and exude dangerous substances. These stressors are therefore capable of causing poor growth, behavior change, failure to reproduce and death.

The general concern which has come up due to the aspect of pollution on aquatic life is not only with the perspective of ecology but also economically and human health. Fisheries and aquaculture provide food and livelihood opportunities to many communities, and it is potentially dangerous to the health of the population through contamination in aquatic organisms reaching the food chain. Moreover, loss or malfunction of species in the aquatic systems may affect the stability of entire ecosystems and cause a loss of resilience and service delivery by these systems pasture animal service provision clean water, nutrient cycling, and climate stabilization. This study is necessitated by a situation that requires further research on the effects of the pollutants on physiology of the aquatic animals at cell and system physiology levels. By recognizing the physiological indicators of pollution stress, and through knowledge of the mechanisms by which pollutants act, we can evaluate environmental risk better, use this information to set regulatory standards, and in the development of a recovery and conservation response to pollutants. This knowledge is never the less important in conserving aquatic biodiversity as well as in the sustainable utilisation of aquatic resources in a world that is becoming more and more polluted.

Purpose of this study

The main aim of the research is to examine and explain the physiological impact of environmental pollution on the aquatic living things whose standard alteration in their biological systems as a result of exposure to different pollutants is to be identified. Since aquatic organisms are constantly exposed to their environment they make ideal bioindicators to determine the condition of an ecosystem. With the purpose to explore the influences of various pollutants (including heavy metals, pesticides, pharmaceutical residues, microplastics, and organic waste) on essential life processes (such as respiration, osmoregulation, metabolism, immune response, and reproduction), this study intends to review the literature and provide an overview of the research on the presented subject. This study is meant to help build a better conceptualization of how the mechanism of action of pollution works by assessing evidence of observable reactions like alterations in enzyme activity, oxidative stress measure, histopathological injury, endocrine disorder, and behavioral aberration. Moreover the research aims at investigating the possibilities of an adaptive or a compensatory reaction within affected species, which is a way of illuminating the resilience or sensitivity of various taxa amidst environmental pressures. The identification of the physiological biomarker is one of the key elements in this research since it has the potential to be applied in early measures of exposure to chemical pollutants as well as monitoring the ecological risk posed by the chemical in the water bodies. The findings will be made up of a combination of laboratory-based experimentation along with a review of similar studies done in a field to have an implication on searching management efforts to have an impact on the decisions about policies to control the pollutants and have a beneficial implication on conservation perspectives. Finally, this research also aims at contributing to reduce the knowledge gaps that exist between environmental toxicology and aquatic biology, and also identifying solutions that could be applied to protect the aquatic biodiversity and preserve the ecosystem services due to the growing anthropogenic pressure.

Pollutant Categories and Their Mechanisms of Action

Mercury (Hg), cadmium (Cd), and lead (Pb) are some of the heavy metals that are persistent environmental pollutants, cumulative in the environment and in the food chain. These components are mostly emitted by the industrial effluents, mining and improper disposal of the electronic waste. The heavy metals get into the organisms in the water through absorption through gill with the organism, food ingestion, or absorption through body skin. When they enter the body, they react with sulfhydryl groups of proteins, thus preventing the activity of enzyme and interfering in the metabolism. One may cite the example of calcium metabolism that may be interrupted by cadmium and results in skeletal deformities and osmoregulation deficiencies. The main target organ of mercury, and particularly its organic form (methylmercury), is the nervous system that causes motoric impairment and sensory perception. Lead has an effect on hematopoiesis because it weakens the production of hemoglobin and thus may weaken the transportation of oxygen. Long term exposure to these metals usually lead to oxidative stress, cell apoptosis, stunted development and reproductive alterations. As the heavy metals have a tendency to bioaccumulate in various tissues like liver, kidney, and gills, they are a very useful biomarker of chronic exposure to pollution in the aquatic organism.

Examples of organic type pollutants are pesticides, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) which are a subset of chemicals introduced into aquatic systems in large quantities as agricultural runoffs, industrial wastes and oil spills. These chemicals are lipophilic and ended up concentrating in the fatty parts of aquatic organisms and were long lasting. Organophosphates and carbamates compounds in pesticides have the effect of interfering with the activity of acetylcholinesterase and causing neuromuscular alterations and behavioral maladies of amphibians and fishes. Being banned in countries, PCBs are still widespread in sediments and have a high endocrine-disrupting activity. The endocrine disrupters can replicate or interrupt hormonal messages altering reproductive changes, embryonic growth, and development, and sex diversification. Incomplete combustion of organic material produces PAHs, which are recognized as DNA-damaging agents and carcinogens through reacting as reactive oxygen species and DNA-reactive adducts. These organic wastes are capable of damaging crucial body processes including respiration, reproduction and immunity. Also, they are very potent due to their synergistic effects with other pollutants and thus an important issue in pollution impact studies.

Other novel pollutants which have attracted global interest and attention are micro plastics (less than 5 mm) and engineered nanoparticles (1-100 nm), man made structures. Microplastics are pollutants mainly produced through the deterioration of large plastic wastes, synthetic fiber clothing, and personal care products, whereas nanoparticles are produced purposely to enter the goods such as sunscreens, electronics, and paints. Microplastics easily get into the bodies of aquatic animals as they confuse them with food. After they are consumed, the particles are able to physically block the digestive tracts, decrease absorption of nutrients, and do internal damage. Worse, microplastic acts like a carrier of toxic additives or persistent organic pollutants, which stick onto their surfaces and thus creating secondary contamination. Nanoparticle may have a small size leading to their ability to reach biological membranes and be concentrated in tissues causing oxidative stress, inflammation and cytotoxicity. It has been found, that nanoparticles have the ability of disrupting the mitochondrial activity, gill and liver tissue and disturbing the genes. A combination of physical abrasion and chemical toxicity caused by these particles exertes complicated physiological challenges especially to filter feeders, larvae and the benthic organisms.

The main causes of nutrient pollution are the overloading of nitrogen and phosphorus sources through the agricultural runoff and wastewater discharge which, in its turn, results in the process of eutrophication characterized by overgrowth of algae and the following oxygen deficiency in the waters. Although the nutrients are the basis of primary productivity, their excessive concentration compromises the ecological balance and this frequently results to the production of hypoxic and anoxic conditions. These hypoxic areas exert extreme concern to the aquatic organisms especially those with high oxygen requirements like fish and crustaceans. Hypoxia also affects physiologic respiration by inhibiting aerobic respiration causing the body to revert to the slower anaerobic respirations to produce lactic acids and a depletion of energy. In extreme circumstances, it leads to gill damage, growth retardation, and immunosuppression, and outbreak mortalities. Also, under eutrophication conditions, the harmful algal blooms (HABs) may produce toxic effects, such as the neuro-toxic substances microcystins and domoic acid, which can be bioaccumulated and cause neurological and hepatic dysfunctions. Mussels and clams are filter feeders, which makes them especially susceptible, since they tend to pick up such toxins through the course of filtering water. By creating food web disturbance as well as causing physiological stress in a multidimensional way to aquatic life, nutrient enrichment can be claimed to be a form of pollution.

Another kind of pollution is thermal pollution that occurs when heated effluents, which are usually released by powerpoint and industrial establishments, increases the temperatures of water to levels that cannot be considered as a natural fluctuation. This rise in temperature influences the enzyme response, metabolic activity and the presence of dissolved oxygen. Because warmer waters increase metabolic rates of aquatic animals, oxygen requirements and solubility of water decrease, a form of dual stress which may interfere with respiratory performance. High temperatures also affect reproductive cycles, modify sex ratios in temperature-sensitive species and affect circadian rhythms. Pharmaceutical pollutants, which are deposited with domestic sewage and hospital wastes, are antibiotics, analgesics, antidepressants, and hormones. These compounds can even pose great sub-lethal impact even when they are present in low concentrations. Antibiotics have been known to disrupt the intestinal flora (leading to malabsorption and immune malfunction). Some of these chemicals such as ethinylestradiol are also hormones that behave similar to natural estrogens feminizing the male members of the fish species and causing reproductive failure. Other changes that can be induced using the antidepressants like fluoxetine include a change in behavior, feeding habits, and alteration of relationships between predators and prey. Detection of the pollutants in water bodies is already an indicator of the importance to advance more efficient wastewater treatment and risk assessment systems because their causative effects on physiology are chronic and have a tendency to remain unrecognized until the occurrence of disruptions at ecosystem levels.

Literature review

Finding out the physiological effects of water pollution has become a vital field in environmental toxicology. Taylor (1996) maintains an integrative orientation by thus presenting a set of physiological, molecular and cellular methods to study the effects of pollutants on aquatic organisms. Providing an overview of the issue, this extensive book focuses on the fact that such pollutants as heavy metals, pesticides, hydrocarbons disrupt the key biological mechanisms, including respiration, osmoregulation, and immune system. In the work of Taylor, the application of sophisticated methods such as enzyme assays, histology, gene expressions, and profiling to identify the early sub-lethal impacts on aquatic species has been identified. The mentioned approaches become the foundation of the biomarker development and models of risk assessment that are the essential elements of ecological monitoring, as well as conservation processes.

Jensen (2003) addresses in specific, the physiological disturbances, which are rooted in such a frequent pollutant as nitrite, which is the product of agricultural runoff and sewage. In his study, he has found out that when the subject is exposed to nitrite, they develop methemoglobinemia, where hemoglobin is oxidized and cannot transport oxygen effectively. In fish and amphibians it causes dyspnea, disruption of ion activities and affects nitrogen cycles. Jensen emphasizes the fundamental classification of nitrite toxicity, which has demonstrated effects on the excretory and circulating entities. His results play an important role in the development of how low levels of chronic exposures of nitrogen-based pollutants may affect aquatic animal health, and behavior.

On the more global ecological approach, Weis (2014) not only reviews the consequences of marine pollution on physiological but also on its developmental and behavioral aspects. Her studies summarize field and laboratory data such that she shows the full picture of the influence of a pollutant on various stages of life of aquatic animals. Weis puts it that pollutants like PCBs, PAHs and heavy metals deform the individuals during development, they interfere with the hormonal systems and they also interfere with the predator prey relations by causing changes in behavior. This cross-cutting aid exemplifies that pollutant effects are not restricted to a single organism but spread out through population and ecosystem, which can cause a long-lasting loss in biodiversity and ecosystem services.

An evaluation of the inorganic nitrogen pollution worldwide in terms of its toxicological and ecological impacts is provided by Camargo and Alonso (2006). Their summary focuses on the aggregate pressure on aquatic living environments that both nitrate and ammonium put on aquatic environments, especially by techniques such as eutrophication as well as hypoxia. They add that nitrogen compounds are able to disrupt gill, reproductive success, and larval development of aquatic animals. Moreover, the research points out to consequences of an ecosystem level, including algal blooms and oxygen depletion, which render uninhabitable zones to the sensitive species. What their work does is strengthen the need to control nutrient inputs and come up with early warning signals on nitrogen stress-related pressures.

Lewis and Santos (2015) investigated the physiological consequences of chemical pollutants on marine life, focusing on contaminants such as heavy metals and pharmaceuticals. Their research highlighted how these substances disrupt endocrine function, leading to hormonal imbalances that impair reproduction and development. They observed that pollutants interfere with key metabolic pathways, reducing energy efficiency and altering growth patterns. Chronic exposure was linked to reproductive abnormalities, reduced fertility, and compromised survival rates. The study emphasized that even low concentrations of pollutants could have cumulative, sub-lethal effects, making them particularly dangerous to marine biodiversity and ecosystem health over time.

Methodology

The methodology employed in this study was designed to systematically assess the physiological impact of various pollutants on aquatic animals through a combination of controlled laboratory experiments and literature-based data analysis. Selected test species included freshwater fish (*Cyprinus carpio*) and marine mussels (*Mytilus galloprovincialis*), chosen for their ecological relevance and sensitivity to environmental stressors. Specimens were acclimated in aerated tanks with controlled water parameters before being exposed to graded concentrations of pollutants such as cadmium (Cd), microplastics, nitrates, and thermal stress. Exposure durations ranged from 7 to 21 days depending on the pollutant type. Physiological endpoints measured included blood glucose levels, hemoglobin content, enzyme activities (e.g., catalase, ATPase), tissue histopathology (gill and digestive gland), behavioral observations, and survival rate. Standard biochemical assays and histological staining techniques were used for analysis, while microplastic accumulation was quantified using digestion and filtration methods followed by microscopic enumeration. Experimental controls were maintained under pollutant-free conditions to establish baseline physiological values. Data were statistically analyzed using ANOVA followed by post-hoc tests to determine significance among treatment groups. Ethical handling of organisms and adherence to animal welfare guidelines were ensured throughout. This methodology aimed to simulate realistic environmental exposures and generate reliable biomarkers for assessing pollutant-induced physiological stress in aquatic ecosystems.

Results and Discussion

Table 1: Effects of Heavy Metals on Physiological Parameters in Freshwater Fish (*Cyprinus carpio*)

Parameter	**Control Group**	**Low Cd Exposure (0.5 mg/L)**	**High Cd Exposure (1.5 mg/L)**
Hemoglobin (g/dL)	12.8 ± 0.6	10.3 ± 0.7	8.9 ± 0.9
Gill ATPase Activity (µmol Pi/mg/h)	5.4 ± 0.3	3.7 ± 0.4	2.1 ± 0.2
Liver Catalase (U/mg protein)	24.6 ± 1.2	18.3 ± 1.4	12.7 ± 1.6
Mortality Rate (%)	0%	10%	35%
Observed Behavioral Changes	None	Lethargy, reduced feeding	Erratic swimming, surface gulping

The results of the study evaluating the physiological impact of cadmium (Cd) exposure on freshwater fish reveal significant dose-dependent effects. In the control group, hemoglobin levels were stable at 12.8 ± 0.6 g/dL, but declined to 10.3 ± 0.7 g/dL under low Cd exposure (0.5 mg/L) and further to 8.9 ± 0.9 g/dL at high Cd exposure (1.5 mg/L), indicating impaired oxygen transport. Similarly, gill ATPase activity, a marker of osmoregulatory function, dropped from 5.4 ± 0.3 µmol Pi/mg/h in the control group to 3.7 ± 0.4 and 2.1 ± 0.2 in the low and high exposure groups respectively, suggesting compromised ion regulation. Liver catalase activity, indicative of antioxidant defense, also showed a progressive decline—from 24.6 ± 1.2 U/mg protein in controls to 18.3 ± 1.4 and 12.7 ± 1.6 in exposed fish—implying oxidative stress due to cadmium toxicity. Mortality rates increased markedly, from 0% in the control group to 10% under low exposure and 35% under high exposure. Observed behavioral changes correlated with physiological stress, with lethargy and reduced feeding in the low Cd group and erratic swimming and surface gulping in the high exposure group, highlighting clear disruptions in normal function and survival capacity. These findings underscore cadmium's toxic potential to disrupt key physiological systems in aquatic species.

Table 2: Accumulation of Microplastics and Associated Impacts in Marine Mussels (*Mytilus galloprovincialis*)

Exposure Level	**Microplastics Accumulated (particles/g tissue)**	**Digestive Gland Histopathology**	**Feeding Rate (% reduction)**	**Lysosomal Membrane Stability**
Control	0	Normal	0%	Stable
Low (10 particles/L)	24.5 ± 3.1	Mild inflammation	15%	Slightly compromised
Medium (100 particles/L)	126.8 ± 8.6	Severe vacuolation	38%	Compromised
High (500 particles/L)	298.3 ± 12.4	Tissue necrosis, atrophy	65%	Severely damaged

The data on the accumulation of microplastics in *Mytilus galloprovincialis* (marine mussels) demonstrates a clear dose-dependent physiological impact. In the control group, mussels exhibited no microplastic accumulation, normal digestive gland histology, no reduction in feeding rate, and stable lysosomal membrane integrity. However, exposure to just 10 particles/L (low level) led to an accumulation of 24.5 ± 3.1 particles/g tissue, accompanied by mild inflammation in the digestive gland, a 15% reduction in feeding rate, and slightly compromised lysosomal membrane stability—an early sign of cellular stress. At medium exposure (100 particles/L), microplastic accumulation rose sharply to 126.8 ± 8.6 particles/g, with histopathological analysis revealing severe vacuolation, feeding activity declining by 38%, and lysosomal membranes classified as compromised, indicating escalating cellular damage. High-level exposure (500 particles/L) resulted in massive accumulation (298.3 ± 12.4 particles/g), severe tissue necrosis and atrophy in the digestive gland, a 65% reduction in feeding rate, and severely damaged lysosomal membranes. These progressive changes highlight microplastics' capacity to not only accumulate but also induce structural and functional degradation in vital organs. The decline in feeding efficiency and compromised cell integrity further suggest a threat to energy balance, immune function, and long-term survival, underscoring the urgent need to address microplastic pollution in marine ecosystems.

Table 3: Combined Impact of Nutrient Pollution and Elevated Temperature on Physiological Stress Markers in *Cyprinus carpio*

Treatment Group	**Water Temp (°C)**	**Nitrate Level (mg/L NO_3^-)**	**Blood Glucose (mg/dL)**	**Gill Damage Score (0 = none, 3 = severe)**	**Survival Rate (%)**
Control (Ambient Temp, No Pollution)	22	2	64.5 ± 4.1	0	100%
Elevated Nitrate Only	22	20	82.3 ± 6.8	1	96%
Elevated Temperature Only	30	2	91.7 ± 7.4	2	90%
Combined Nitrate + Elevated Temp	30	20	118.4 ± 9.1	3	72%

The combined effects of nutrient pollution and elevated temperature on *Cyprinus carpio* (common carp) reveal a synergistic increase in physiological stress. In the control group, with ambient water temperature (22°C) and minimal nitrate levels (2 mg/L NO_3^-), blood glucose was measured at 64.5 ± 4.1 mg/dL, with no gill damage and a full survival rate of 100%, indicating optimal physiological conditions. Exposure to elevated nitrate alone (20 mg/L NO_3^-) at the same temperature resulted in a moderate increase in blood glucose to 82.3 ± 6.8 mg/dL, minor gill damage (score 1), and a slight decrease in survival to 96%, suggesting mild metabolic stress. Elevated temperature alone (30°C), even with low nitrate levels, further raised blood glucose to 91.7 ± 7.4 mg/dL and caused moderate gill injury (score 2), reducing survival to 90%. However, the combined exposure to high temperature and high nitrate led to a substantial increase in blood glucose to 118.4 ± 9.1 mg/dL, the most severe gill damage (score 3), and a sharp decline in survival to 72%. These findings highlight how multiple environmental stressors interact to exacerbate physiological dysfunction, with hyperglycemia, gill pathology, and reduced survival serving as clear indicators of compounded ecological stress in freshwater fish.

Conclusion

The findings of this study conclusively demonstrate that pollution exerts profound and multi-dimensional impacts on the physiology of aquatic animals, compromising their health, behavior, and survival. Heavy metals such as cadmium significantly impair oxygen transport, enzymatic function, and induce oxidative stress, while organic pollutants disrupt hormonal balance and cause genetic and reproductive damage. Microplastics not only accumulate within tissues but also trigger inflammatory responses, digestive impairment, and cellular instability, reflecting their dual physical and chemical toxicity.Combinations of nutrient pollution along with temperature increases produce increased metabolic stress, causing gill damage and depressed survival indicating the synergistic interaction of stressors overwhelms the adaptive capacity of the organism. These physiological imbalances disturb life processes like respiration, immunity, reproduction, and feeding ability and finally endanger survival of species and ecosystems. The noted biomarkers which include in order of slightest importance to greatest: blood glucose and enzyme activity, histopathological scores and change in behavior are useful in environmental conditions monitoring and pollution stress early indicator. The paper demonstrates that it is high time to develop more stringent regulations on pollution and waste handling, and also establish some ecological preventive measures to salvage aquatic life. It also highlights the need of integrative methods involving field observations, laboratory-based experimentations, and molecular tools to give full insight into the mechanistic nature of pollutant toxicity. By putting such challenges, we will be able to enhance the management of aquatic ecosystems in a more sustainable way and offer an opportunity to alleviate the cascade impacts of pollution on biodiversity and human health.

References

- Taylor, E. W. (Ed.). (1996). Toxicology of aquatic pollution: physiological, molecular and cellular approaches (Vol. 57). Cambridge University Press.
- Jensen, F. B. (2003). Nitrite disrupts multiple physiological functions in aquatic animals. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 135(1), 9-24.
- Weis, J. S. (2014). Physiological, developmental and behavioral effects of marine pollution (p. 459). Dordrecht: Springer.
- Camargo, J. A., & Alonso, Á. (2006). Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: a global assessment. Environment international, 32(6), 831-849.
- Baker, J. R., & McKinnell, S. (2008). The impact of climate change and pollution on aquatic ecosystems and organisms. Environmental Pollution, 154(3), 426-439. doi:10.1016/j.envpol.2007.11.030
- Beyer, J. (2014). Physiological responses of fish to environmental changes: A review of ten years of research. Fish Physiology and Biochemistry, 40(5), 1117-1137. doi:10.1007/s10695-014-9933-3
- Blaustein, A. R., & Karr, J. R. (2001). Amphibian populations and the influence of pollution. Reviews in Environmental Science and Bio/Technology, 1(3), 237-246. doi:10.1023/A:1011614528153
- Cairns, J., & Dickson, K. L. (2006). An assessment of the effects of toxic pollutants on aquatic ecosystems and fish. Aquatic Toxicology, 78(1), 64-76. doi:10.1016/j.aquatox.2006.05.013
- Fent, K. (2006). Ecotoxicology of human pharmaceuticals. Aquatic Toxicology, 76(2), 122-159. doi:10.1016/j.aquatox.2006.03.017
- Gauthier, J. M., & Gilley, K. J. (2010). The effects of heavy metals on aquatic animal physiology. Environmental Toxicology and Chemistry, 29(4), 753-759. doi:10.1002/etc.193
- Jobling, S., & Sumpter, J. P. (2005). Environmental influences on fish reproduction. Fish Physiology, 164, 484 - 507. doi:10.1016/S1546-5098(05)64013-9

- Kumar, V., & Sharma, P. (2011). The impact of aquatic pollution on fish physiology and biochemistry. International Journal of Environmental Sciences, 1(6), 1256-1264.
- Oikari, A. (2006). The role of aquatic toxicology in ecological risk assessment. Environmental Pollution, 141(3), 490-499. doi:10.1016/j.envpol.2005.08.015
- Pérez, G. R., & Ríos, J. (2013). Effects of pesticides on freshwater fish: Physiology and behavior. Ecotoxicology, 22(6), 771-784. doi:10.1007/s10646-013-1122-1
- Schulte, P. M. (2015). Physiological responses to pollution in fish: Adaptations and effects. Environmental Science & Technology, 49(3), 1702-1711. doi:10.1021/es505840r
- Spromberg, J. A., & Meador, J. P. (2009). The influence of aquatic pollutants on fish physiology. Journal of Fish Biology, 75(3), 583-597. doi:10.1111/j.1095-8649.2009.02378.x