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Health Impacts of Mercury Toxicity on Fish in an Aquatic System

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Abstract: Mercury toxicity significantly threatens aquatic ecosystems, particularly impacting fish populations and human well-being. This article exposes the effects of mercury contamination on aquatic life and their habitats. Mercury primarily originates from natural degassing and anthropogenic activities and accumulates in aquatic organisms, most notably in predatory fish, through bio-accumulation and bio-magnification. This bio-accumulation, driven by microbial transformation to methyl-mercury, leads to elevated concentrations in top-level predators. The consequences of mercury exposure on fish physiology are stunted growth, reproductive impairments, and compromised immunity, with potential ramifications for population dynamics and ecosystem resilience. This study delves into specific impacts of mercury on fish, ranging from bone deformities to liver damage, developmental anomalies, neurotoxic effects, and disruptions in reproductive systems. The interplay between ecological, physiological, and human health effects underscores the need for a comprehensive understanding of mercury's underlying mechanisms. Monitoring mercury levels in aquatic systems emerges as a crucial strategy for ensuring fish populations' health and ecosystems' sustainability. Urgent collaborative efforts are imperative to address this global concern, promote harmonious coexistence between human activities and aquatic environments, and secure the availability of safe and nutritious fish for future generations. In conclusion, this article highlights the urgent necessity for targeted interventions and informed decision-making to mitigate the influence of mercury contamination on aquatic ecosystems.

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Introduction

Vast and teeming with diverse life forms, aquatic ecosystems play a vital role in the global ecological balance. Fish are essential elements that support food webs, nutrient cycling, and the general stability of an ecosystem (Vanni et al., 2002; Hall et al. et al., 2007). However, these organisms increasingly face a silent yet pervasive threat of mercury toxicity (Barkay et al.; I., 2005). Mercury, a naturally occurring element, is a heavy metal that has been a persistent environmental pollutant for decades(Braune et al. et al., 2005). Inorganic mercuric salts and organomercury constitute the majority of the mercury (Hg) present in all environmental media, i.e., water, sediments, and biota. The environment's most common forms of mercury are the mercuric salts $HgCl_2$, HgS, and Hg $(OH)_2$ (USEPA 1997a)

One primary concern is the accumulation and increase of mercury in aquatic food chains. Mercury, approximately 10,000 tons, originates from degassing of the earth's crust and anthropogenic activities, such as industrialization and burning fossil fuels (Nittler et al., S. Z. 2019). The levels accumulate in aquatic organisms over time(Souza-Araujo et al., M. B. G. 2016). Mercury exists in different forms, with methyl-mercury being the most harmful and easily absorbed form (Gochfeld, M. 2003; Wang et al. 2015.). In aquatic environments, microorganisms change inorganic mercury into methyl-mercury, making it easier to absorb (Hong et al.,2012). As smaller fish eat these microorganisms and become prey to larger fish, mercury accumulates in higher levels of the food chain, a process called bio-magnification (Suedel et al.,1994). As a result, predatory marine fish at the

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top of the food chain end up having dangerously high levels of mercury, which can have severe consequences for their health and those who rely on them as a food source (Hall et al., 2007).

There is substantial evidence that prolonged exposure to high levels of mercury can disrupt critical physiological processes in fish, leading to stunted growth, reproductive complications, and weakened immune functions (Crump et al.; V. L., 2009). These effects harm individual fish and have broader impacts on population dynamics and the resilience of ecosystems (Gentile et al. et al.,1983). Additionally, mercury toxicity can affect the behavior of marine fish, which is crucial for their survival and interactions within the ecosystem at the cellular and molecular level (Boudou et al., D., Ribeyre, F., & Saouter, E.,1991). The oxidative stress hypothesis suggests that mercury-induced reactive oxygen species cause damage to cellular components, leading to oxidative stress and subsequent disruptions in physiological processes (Lushchak et al., 2016; Hermes-Lima, M.2002). This oxidative damage can harm cell membranes, DNA, and essential cellular functions. Furthermore, mercury has been found to affect gene expression and alter molecular pathways (Sevcikova M. et al.,2011).

The implications of mercury toxicity go beyond marine ecology and affect human health. Since aquatic fish are a valuable source of protein and nutrients (Zahir et al.; R. H., 2005) consuming affected fish poses serious health risks for humans. Mercury can accumulate in aquatic systems and be transferred to humans when consumed, particularly in larger predator fish like tuna, swordfish, and sharks (Wang, W., 2012). Methyl-mercury, a potent neurotoxin, is particularly harmful to the neurological development of fetuses and young children (Choi et al.,1989). This highlights the interconnections between marine ecosystems, human well-being, and the need for comprehensive environmental management strategies. Studies have determined mercury concentrations in fish, evaluated the health hazards associated with eating fish, and recommended fish intake (Liu et al., 2018; Jeevanaraj et al., 2016). However, the aberrant growth of marine fish brought on by mercury poisoning is less well understood.

The health impacts of mercury toxicity on aquatic ecosystems involve complex interactions between ecology, physiology, and human health. Understanding the mechanisms behind mercury's toxic effects is crucial as ecosystems continue to face its influence. This article aims to explore the multifaceted repercussions of mercury contamination on aquatic populations and their habitats. By understanding mercury's reach and impact holistically, we can make informed decisions, implement targeted interventions, and foster a more sustainable coexistence between humanity and the delicate aquatic environments we rely on.

Effects of Mercury Contamination on Fish

Microorganisms, e.g., bacteria, the primary transfer agent in which mercury is transported to fish (Wagner I.,2003), endanger fish species in freshwater systems since these systems tend to have high bio-availability of microorganisms (Berninger G. et al.,1991). Due to the high absorption of mercury by bacteria and phytoplankton (Schaefer J.K et al.,2014; Pickhardt & Fisher N.,2007), which are food to fish, they tend to increase the mercury concentration in fish through bio-accumulation since they are consumed. The bio-accumulation rate of mercury in freshwater and marine fish varies greatly, and its level is influenced by changes in metabolic and environmental traits across different species (Zheng N.A. et al.,2019). Mercury can cause metabolic, genetic, psychological, and neurological alterations in fish, even at low levels (Huang W.et al.,2011).

i. Bone formation

Fish exposed to mercury are more likely to develop bone abnormalities, which can have a devastating impact on their ability to hunt, avoid predators, and migrate over long distances, in addition to their ability to grow and maintain their external morphological characteristics (Zheng N.A. et al.,2019). In fish, kyphosis (*sacral curvature*), scoliosis (*lateral curvature*), and lordosis (*sacral Doris*) are the most often seen deformities (Morcillo P. et al.,2016b). Fish with abnormalities, especially spinal malformations, have more incredible difficulty interacting with their environment and hence have lower survival rates (Noble C. et al.,2012). Though insufficient nutrition can also induce bone

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malformations, mercury ions are the primary culprit since they change the notochord's structure during fish development (Zheng N.A et al.,2019)

ii. Liver impairment

A quantitative proteome study subsequently showed that mitochondria are the main target for mercury attack in cells, resulting in cytoskeletal degradation, cellular inflammation, and alterations in energy metabolism (Chen et al., 2017; Wang et al., 2013). This finding supports that mercury may cause liver damage when it enters the body. According to Wang et al. (2013), the liver of medaka (*Oryzias melastigma*) treated with various concentrations of mercuric chloride demonstrated that exposure to mercury enhanced mercury accumulation in the liver and consequently damaged the liver's ultrastructure, thus interfering with its functions.

iii. Embryo development

Pollution of aquatic systems with mercury during the developmental stage, i.e., embryonic and larval phases, can impact the development of several fish organs, such as improper cardiovascular and eyeball growth and development (Huang W. et al., 2011). Since the infancy stage is the most vulnerable to mercury toxicity (Yoshimasu K. et al.,2014), the majority of fish suffer damage at this stage because mercury can stimulate energy-intensive detoxifying processes and consume a substantial quantity of energy, which reduces the amount of energy that would otherwise be available for development (Sfakianakis D. et al., 2015). As a result, this may result in physical abnormalities, premature growth, and possibly death. Huang et al.'s 2011 study found that mercury levels greater than 20 μgL^{-} subchronic toxicity testing on red sea bream may raise death rates, decrease spawning success, and cause reproductive harm in larvae.

iv. Nervous system

Mercury monitoring should be enhanced in aquatic systems to enhance fish production since Hg alters an organism's nervous system, a vital organization (Baatrup E.,1991). Neurotoxicity can damage and possibly kill nerve cells, which are vital for processing and transmitting impulses in the cerebral cortex as well as other components of the neurological system (Lee J.W. et al.,2019). According to a recent study of medaka (*Oryzias melastigma*) (Wang et al.,2015), inorganic mercury exposure can cause neurotoxicity through the generation of oxidative strain, malfunctioning of the fibers creating the prokaryotes and eukaryotic cells, and metabolic dysfunction. In a previous study, the levels of proteins increased by at least 20 percent following fish being exposed to methyl-mercury, according to a proteomic examination of brain tissue. According to Berg et al.,2010, these proteins were linked to the main cellular targets and processes that cause methylmercury-induced neurodegeneration. Mercury can also cause long-term neurological harm by altering the number of neurotransmitters and neuroglia in some areas of the brain (Capriccio V.L. et al., 2019). Changes can follow these alterations in swimming behaviors, thus can lead to starvation and, thereafter, death.

v. Reproductive system

Since mercury bio-accumulates in fish, adult fish are at a high risk of being affected by mercury exposure. Fish gonads can accumulate mercury, harming the reproduction process and preventing fish gonads from growing and developing properly (Liao C.Y. et al.,2006). A key variable in the healthy development of the fish reproductive organs is the hypothalamic-pituitary-gonadal axis, which regulates the reproduction process by secreting several hormones (Dang et al.,2015). Exposure to mercury may modify the expression of genes associated with the hypothalamic-pituitary-gonadal axis and change the levels of sexual hormones, which may impact fertility in fish. According to Zhang et al. (2016), inorganic mercury exposure has been reported to result in chronic oxidative stress, which damages fish gonad tissue. After fish exposure to mercury, male testicular hormone levels are significantly reduced, and tissue necrosis and spermatogenic degeneration are evident.

Conclusion

A severe hazard to aquatic environments, especially the related fauna, and flora, is mercury toxicity. The aquaculture business experiences a permanent setback due to the catastrophic impacts

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metals such as mercury have on aquatic species, mainly fish. In order to be utilized as a tool for future genotoxicity-related studies by scientists in related fields, this article discusses the damaging effects of mercury on fish with a focus on the infancy, development, and reproduction of fish. Accumulation of mercury in aquatic organisms, especially fish, has become a significant global problem that must be resolved. Key study goals now include identifying the mercury's sources and comprehending how it moves across the aquatic environment. Monitoring the fish and surrounding ecosystems is necessary to increase the aquaculture business's sustainability and provide healthy fish.

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