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ECOLOGICAL THREATS OF BIOMAGNIFICATION: INSIGHTS FROM RECENT STUDIES

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ABSTRACT

Biomagnification is the increasing concentration of a substance like pesticides in organisms at higher levels of food chain. The contaminants might be heavy metals such as mercury, arsenics and pesticides such as polychlorinated biphenyls and DDT. In this review, we analyze the mechanisms and drivers of biomagnification and its impacts on ecologies and human populations. Differences in the chemical properties of contaminants (e.g., lipophilicity, persistence) and in environmental conditions (e.g., temperature, salinity), in combination with biological aspects related to organisms (e.g., trophic level, metabolic rate), are key factors influencing biomagnification. The ways in the which these factors interact complexly, to determine the extent and impart of biomagnification in different ecosystems. In ecological events, biomagnification can cause a loss of biodiversity, food web disruption and top predator populations to decline. Health problems in human are result of consumption of contaminated food in the food chain presenting with neurotoxic substances such as mercury and persistent organic pollutants (POPs). These effects include neurological diseases, suppression of the immune system and susceptibility to cancer development especially among vulnerable populations. These include some regulations that prevent the release of pollutants, environmental monitoring programs to know contaminant concentrations, outreach programs so citizens to promote a sustainable consumption and research about emerging contaminants and alternative solutions. Controlling biomagnification needs a kind of multidisciplinary approach to conserve ecosystems, human health and sustainability. By understanding the impact on our health, decreasing the risks associated with biomagnification allows is to help develop environment resilience and improve public health outcomes.

KEYWORDS: Biomagnification, contaminants, ecological impacts, human health, environmental pollution.

INTRODUCTION

Biomagnification is the progressive increase, magnification and accumulation of toxic substances at each progressive trophic level in a food chain-this has been recognized as a serious problem that concerns some of earths ecosystems with consequences for ecosystem health and biodiversity.[1] Resistant molecules are very common in the environment (i.e. heavy metal ions, pesticides, POPs, and etc) and resistant to degradation processes once they released into the environment and have ability to bioaccumulate in body tissues. In the case of these types of substances which bioaccumulate and are biomagnified along the food chain they reach high concentrations in apex predators, where they may have severe ecological and health effects.[2]

Recent research has been adding to the repertoire of known mechanisms and magnitudes of biomagnification in various ecosystems. For instance, it has been shown that aquatic systems have a very high potential for pollutant buildup. Among these contaminants, lipophilic substances are one of the most important groups; they have high lipid concentration in aquatic organisms and present environmental pollutants that are more retained in these environments, thereby they are easier to biomagnified.[3] ecosystems where, in addition to a range of factors such as soil composition and vegetation cover influence exposure pathways, significant biomagnification can be witnessed.[4]

Implications of Biomagnification further represents a challenging phenomenon in terms of ecological threat. These health effects increase the susceptibility of top predators, many already at risk,[5] to reproductive failure, developmental anomalies and mortality. Human health risks are equally important, as consumption of contaminated fish or wildlife may result in severe human effects including neurological disorders and cancers.[6]

This review article is based on more recent studies that describe the mechanisms and influencing factors of biomagnification from the levels to which it occurs in ecological and human health impacts. In this review article, we discuss the need for mitigation and management practices and policies. This is crucial for guiding lictors on conservation action, and protecting the integrity of ecosystems, and ultimately public health, from the extensive range of threats posed by persistent organic pollutants.[7]

Mechanisms of biomagnification

Biomagnification is a complex process that depends on several factors where the toxic substances are accumulated and magnified through the trophic level in ecosystems. Such knowledge forms an essential route towards understanding the processes through which biomagnification may take place and the consequences this could have for individuals within an ecosystem, typically including human beings.

Bioaccumulation and Bioconcentration

Bioaccumulation is accumulation of toxic materials at a rate higher than they can be broken down and digested by organisms in the environment.[8] It happens via two main ways, the direct uptake from the environment (Bioconcentration) and dietary intake (biomagnification).

Bioconcentration refers to the uptake of pollutants directly from the surrounding environment, such as water or soil, into an organism's body. This process is influenced by the chemical properties of the pollutant, such as its solubility and persistence. Lipophilic (fat-loving) substances, like many POPs, are more likely to bioconcentrate because they dissolve in the lipid-rich tissues of organisms. For instance, substances like polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT) are known for their high bioconcentration factors.[9]

Factors influencing biomagnification

Biomagnification is influenced by a complex interplay of chemical properties, environmental conditions, and biological characteristics of organisms. Understanding these factors is crucial for predicting and mitigating the impact of contaminants in various ecosystems.

Chemical properties

The inherent chemical properties of pollutants significantly affect their potential for biomagnification. Key properties include lipophilicity, persistence, and bioavailability.

Lipophilicity: Lipophilic substances tend to dissolve in fats rather than water, allowing them to accumulate in the fatty tissues of organisms. This property is particularly relevant for many persistent organic pollutants (POPs), such as polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT), which have a high affinity for lipid-rich tissues. As these contaminants move up the food chain, their concentration increases because they are not easily metabolized or excreted by organisms.[10]

Persistence: The persistence of a chemical in the environment and within biological systems is a critical factor for biomagnification. Persistent substances resist degradation processes such as photolysis, hydrolysis, and microbial decomposition, allowing them to remain in the environment for extended periods. For example, PCBs and DDT are highly persistent, leading to long-term environmental contamination and biomagnification.[11]

Bioavailability: The bioavailability of a contaminant determines its uptake by organisms.[12] Factors such as the chemical form of the pollutant, environmental conditions (e.g., pH, temperature), and the presence of other substances can influence bioavailability. Metals such as mercury, when methylated to methylmercury, become more bioavailable and toxic, significantly enhancing their biomagnification potential.[13]

Environmental conditions

Environmental factors play a crucial role in modulating the extent of biomagnification. These include temperature, salinity, and the presence of other pollutants.[14]

Temperature: Temperature influences the metabolic rates of organisms and the chemical kinetics of pollutants. In colder environments, such as the Arctic, metabolic rates are lower, leading to slower degradation and elimination of contaminants. This can result in higher biomagnification potential, as observed with mercury and POPs in Arctic marine food webs.

Salinity: Salinity affects the solubility and bioavailability of contaminants. In marine environments, the ionic composition of seawater can influence the speciation of metals, thereby affecting their uptake by marine organisms. For example, the bioavailability of mercury can vary with salinity, impacting its biomagnification in marine ecosystems.

Presence of other pollutants: The presence of other contaminants can affect the bioavailability and toxicity of pollutants. For instance, the co-occurrence of organic and inorganic pollutants can lead to synergistic effects, enhancing the overall biomagnification potential. Interactions between different pollutants can alter their chemical behaviour, uptake, and accumulation in organisms.

Biological factors

Biological factors, including species-specific traits, trophic position, and lifecycle characteristics, significantly influence biomagnification.[15]

Species-Specific traits: Different species exhibit varying capacities for bioaccumulation based on their physiology, feeding behavior, and habitat. Species with high fat content and those with specialized feeding habits are more likely to accumulate higher levels of lipophilic contaminants. For example, predatory fish such as tuna and sharks, which consume large amounts of prey, exhibit significant biomagnification of mercury and other contaminants.[16]

Trophic position: Organisms at higher trophic levels are more susceptible to biomagnification due to their position in the food chain. Apex predators, such as birds of prey, marine mammals, and humans, consume multiple lower-trophic-level organisms, leading to higher concentrations of accumulated contaminants. The process of trophic transfer results in increased contaminant levels with each successive trophic level.[17]

Lifecycle and Longevity: Species with longer lifespans and those that occupy higher trophic levels tend to accumulate more contaminants over time. The prolonged exposure and continuous dietary intake of contaminated prey lead to higher biomagnification potential. For instance, long-lived marine mammals such as whales and seals show significant biomagnification of POPs and heavy metals due to their extended exposure and high trophic status.

Ecological and Human health impacts

Biomagnification has profound implications for both ecological systems and human health. The accumulation of toxic substances at higher trophic levels can lead to detrimental effects on wildlife, ecosystems, and humans who are at the end of the food chain. Understanding these impacts is essential for developing strategies to mitigate the risks associated with biomagnification.

Ecological impacts

Species Diversity and Population dynamics: Biomagnification can significantly affect species diversity and population dynamics, particularly among top predators. High levels of toxic substances such as heavy metals and persistent organic pollutants (POPs) can cause reproductive failures, developmental abnormalities, and increased mortality rates.[18]

Reproductive failures: Many studies have documented the impact of biomagnification on the reproductive success of wildlife. For instance, elevated levels of DDT and its metabolites have been linked to eggshell thinning in birds of prey, leading to reduced hatching success and population declines in species such as the bald eagle and peregrine falcon.[19]

Developmental abnormalities: Contaminants like mercury can disrupt the development of nervous systems in wildlife, causing behavioural and physiological abnormalities. Studies on fish and amphibians have shown that mercury exposure can lead to deformities and impaired survival rates.[20]

Increased mortality rates: High contaminant levels can lead to direct mortality in wildlife. For example, marine mammals such as seals and whales have been found with lethal concentrations of PCBs and other POPs, contributing to population declines.

Ecosystem stability

The health of apex predators is crucial for maintaining ecosystem stability. When these species are affected by biomagnification, it can lead to cascading effects throughout the food web.

Top-Down control: Apex predators play a key role in controlling the populations of their prey. When predator populations decline due to contaminant exposure, there can be an overabundance of prey species, leading to imbalances in the ecosystem.

Biodiversity loss: The decline of top predators can result in a loss of biodiversity as the balance of species within the ecosystem is disrupted. This loss can affect ecosystem functions and services, such as nutrient cycling and habitat structure.[21]

Human health impacts

Humans are susceptible to the effects of biomagnification through the consumption of contaminated food, particularly fish and other wildlife that are high on the food chain.

Neurological effects

Exposure to mercury and other neurotoxic substances through diet can lead to severe neurological disorders in humans.[22]

Mercury exposure: Methylmercury, a highly toxic form of mercury, accumulates in fish and marine mammals. Human consumption of contaminated seafood can result in neurological impairments, especially in developing fetuses and young children. Symptoms include cognitive deficits, motor skill impairments, and sensory disturbances.[23]

Lead and PCBs: Other contaminants like lead and polychlorinated biphenyls (PCBs) can also have neurotoxic effects, leading to developmental delays, learning disabilities, and behavioural problems in children.[24]

Immune system suppression

Persistent organic pollutants (POPs) such as dioxins and PCBs can weaken the human immune system, making individuals more susceptible to infections and diseases.

Immune dysregulation: Studies have shown that high levels of POPs can alter immune function, reducing the body's ability to fight off infections and increasing the risk of autoimmune diseases.[25]

Cancer risk: Several contaminants that biomagnify in the food chain are known carcinogens, posing long-term cancer risks to humans.

Dioxins and PCBs: Long-term exposure to dioxins and PCBs has been associated with an increased risk of cancers, including liver, breast, and prostate cancer. These substances can disrupt hormonal functions and promote the development of tumors.[26]

Endocrine disruption

Many contaminants that biomagnify are endocrine disruptors, which interfere with the normal functioning of hormonal systems in humans.

Hormonal imbalances: Chemicals such as PCBs, DDT, and certain plasticizers can mimic or block hormones, leading to reproductive issues, thyroid dysfunction, and metabolic disorders. These imbalances can have serious health consequences, particularly in vulnerable populations like pregnant women and children.[27]

CASE STUDIES

Mercury in fish: One of the most well-documented cases of biomagnification affecting human health is mercury in fish. Populations that rely heavily on fish for their diet, such as certain indigenous communities, are particularly at risk.[28]

Minamata disease: This neurological syndrome was first identified in Minamata, Japan, due to industrial mercury pollution. The local population, consuming contaminated fish, suffered severe neurological damage, leading to regulatory actions and greater awareness of mercury pollution.[29]

CONCLUSION

Biomagnification poses significant ecological and human health risks due to the accumulation of toxic substances in the food chain. This review has explored the mechanisms, factors influencing biomagnification, and its profound impacts on ecosystems and human populations. In conclusion, biomagnification is a critical environmental issue that requires urgent action. By implementing effective mitigation strategies and adopt global cooperation, we can minimize the ecological and human health risks associated with biomagnification and build strong and healthy ecosystems.

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