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FOREWARNING ON SOME POLLUTANTS AND THEIR EFFECTS ON WATERFOWL

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Abstract

Anthropogenic pollution is becoming increasingly widespread in ecosystems worldwide. In recent years, we have observed negative consequences for many species, particularly birds. This review focuses on the impacts of common anthropogenic pollutants on aquatic birds, detailing a range of effects from direct mortality to sublethal impacts, including reduced fitness. There are interactions between these pollutants that can amplify their effects beyond those of each pollutant individually. Despite this, research on these interactions is still limited and requires more targeted investigation. As threats to avian species and anthropogenic pollution continue to rise, implementing mitigation measures is crucial for the preservation of these birds. This paper aims to evaluate specialized scientific articles, highlight, and understand the threats that bird species face.

Key words*: environmental contamination, pollutants interactions, toxic effects, wild bird.*

INTRODUCTION

Biodiversity is at a critically declining level and its current rates are much more frequent than the average natural extinction rate (Barnosky et al., 2011; Tittensor et al., 2014). We have seen the shocking loss of two-thirds of global mammals, birds, fish, reptiles, and insects (Hoffmann et al., 2010), and this severe drop in biodiversity can be attributed to extreme human activity that stresses the species (Hallmann et al., 2017). Waterfowl occupy significant spaces in freshwater and marine ecosystems and serve as sentinels of environmental wellbeing but have been under unprecedented threat from anthropogenic pollution (Degernes, 2008). These avian species are totally reliant on aquatic environments for survival, reproduction and migration, thus their populations and functioning within ecosystems are subject to many environmental stressors (Zhang & Ma, 2011). Numerous studies show that waterbirds serve as valuable bioindicators of the health of aquatic ecosystems, where population dynamics and physiological conditions may serve as biomarkers of the quality of habitats (Arya et al., 2025). The accelerated rate of industrialization, urbanization, and increasing crop cultivation has caused the pollution of water bodies with pollutants such as heavy metals, organic micropollutants, persistent organic pollutants (POPs), microplastics and pharmaceutical substances (Liu et al., 2024; Swarup & Patra 2005). These pollutants do not occur in isolation, but work synergistically to create intricate ecotoxicological systems that challenge the adaptations of waterbird populations at a global scale (Liu et al., 2024). But rising environmental pollutants in aquatic environments are causing serious risks to their health, behavior, and survival. Pollutants, heavy metals, oil spills, plastics, pesticides and industrial waste can accumulate and they enter the food chain, and in the process, they reach birds at the top. Such contaminants interfere with the biologic systems, limit reproduction and disturb the physical and adaptive behaviour of aquatic birds (Shahid et al., 2021). The effects of these pollutants are crucial for the design of conservation measures as well as biodiversity conservation in aquatic regions (Pandiyan et al., 2023; Arya et al., 2025). It is an alarming decline in bird populations associated with environmental pollution, and

these include climate change, loss of habitat fragmentation, invasive species' invasion, spread of pathogenic agents and quality compromise due to pollution. We must raise awareness of these problems to safeguard our avian wildlife and the fragile environment we live (Maxwell et al., 2016; Ceballos et al., 2017). Thanks to their mobility, as well as important roles in many interrelated ecosystem processes, birds are vital to ecosystem functioning and resilience (Whelan et al., 2008; Wenny et al., 2011). They are able to supply all four kinds of ecosystem services: provisioning, regulating, cultural, and supporting (Whelan et al., 2008). Unfortunately, one of the crucial contributions that birds represent to ecosystem health is overlooked. The benefits we gain from bird populations are often at least indirect and may support and manage other processes that promote human health in general (e.g. seed transfer, nutrient cycling, pest control, regulation, ecosystem engineers). Some birds even aid in plant pollination (Wenny et al., 2011). Even though some bird species may not seem particularly charming, they still provide vital ecosystem services. Birds provide various services that benefit human health and well-being. They are a source of nutrition, and their feathers have historically been used for insulation and bedding (FAOSTAT, 2019). Numerous bird species hold significant cultural importance, reflected in the rapidly growing industries of birdwatching and hunting, which play a vital role in the economies of various regions (Mustin et al., 2011; Carver, 2013; Ma et al., 2013; Kronenberg, 2014; Richard et al., 2021).

MATERIALS AND METHODS

This paper offers a brief review of the literature on the effects of common anthropogenic pollutants on aquatic birds, focusing on stress and pollution-related impacts, the search was conducted using the Web of Science database, Research Gate. Research papers that were freely accessible were utilized; for those that were not available for free, requests were made directly to the authors to obtain their work. The methodology involved a critical analysis of the existing literature and was conducted on 12 January 2026. The search query included specific keywords or a combination of terms related to birds and particular types of pollutants found in the title or abstract (pollutants, wild bird, toxic effects, water pollutants, etc). This initial search yielded over 80 records; after the screening process, studies that did not align with the objectives of the present research were excluded.

RESULTS AND DISCUSSIONS

Pollutants are those substances introduced into the environment that might lead to damages or disruptions in the natural balance of ecosystems, human health and nature. These chemicals can be natural (such as volcanic ash) or man-made (like pollution from industry, plastics, or pesticides) (Manisalidis et al., 2020). The pollution issue is one of the more prevalent worldwide problems, however, over the last century more industrialisation, urbanisation and unsustainable consumption habits made it very high due to which it is one of the most urgent global issues (Borah et al., 2020). Ecologically, it involves pollutants disrupting ecosystems, devastating biodiversity and causing acid rain, eutrophication and warming world-wide (EEA, 2021). Many birds have exposure to various pollutants simultaneously, and each pollutant category, e.g., various chemicals can contain various compounds contaminated, as well as natural stressors driving multi-component interactions (Grace et al., 2024; Wang et al., 2024). Collectively and separately, these pollutants are likely to be contributing to the population decline. There is still a lack of understanding on how species could vary in their susceptibility, and combined pollution overall effects. It is important to examine the additive effects of pollutants which often coexist in the same place and period (Wang et al., 2024). To increase our understanding of environment effects, we need to assess joint effects of pollutants of the same dimensions with comparable spatial and temporal scales. Moreover, by taking the time complexity of a lot of pollutants in realistic asynchronous scenarios into account, we can provide even better estimates for their cumulative effects (Roşu et al., 2024). It is critical to establish clear insights for the effective pollution

management and policy formulation (Jackson et al., 2021). Pollutants are categorized by the medium they contaminate - air, water, soil - or by their nature, like chemical, biological or physical agents. The most researched and dangerous are air pollutants (e.g., particulate matter, nitrogen oxides, sulphur dioxide, ozone), water pollutants (e.g., heavy metals, nitrates, phosphates, organic compounds), and soil pollutants (e.g., pesticides, persistent organic pollutants, industrial waste). Other categories in this sense are noise, light, and thermal (World Health Organization, 2024). Air pollutants result from burning fossil fuels (for vehicles, power plants, industrial processes), burning biomass, burning waste as if it were human activity, and also the burning of natural sources such as volcanic eruptions or forest fires. The main air pollutants with global health implications include PM_{25} (fine particles), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3) (World Health Organization, 2023; Nathanson, 2025). In addition, indoor air pollution is of utmost importance, particularly in developing countries where solid biomass or coal are employed as a cooking & heating equipment in poorly ventilated areas (Bilal et al., 2021). Water contamination from either point sources (industrial effluents, wastewater discharges) or non-point sources (agricultural runoff carrying fertilizers, pesticides, and sediments). Heavy metals including lead, mercury, and arsenic, and organic pollutants, such as polychlorinated biphenyls (PCBs) and pharmaceuticals, provide long-term threats to aquatic ecosystems. Soil pollution via deposition of air pollutants, industrial or mining waste runoff, persistent pesticide use, heavy metals accumulation (Johnson et al., 2021). Noise pollution (non-chemical) is a pollutant in that it interferes with human well-being, wildlife behaviour, and ecosystem function. Sources can be traffic and commerce, construction, and urban infrastructures (Goines et al., 2007). Pollutants can affect air quality, biodiversity, ecosystem services and biogeochemical cycles. Acid rain (from SO_2 and NO_x) can, for instance, degrade forest soils and aquatic ecosystems. Eutrophication in lakes and coastal areas caused by nutrient runoff with nitrogen and phosphorus is one of the most common causes of eutrophication, which also leads to algal blooms, oxygen depletion and mass mortality of fish. Organics and heavy metals accumulate and bioaccumulate in food webs, becoming bio-challenging for both top predators and humans (Lovett et al., 2009; Richard et al., 2021). Common pollutants and ways to be exposed. Bioaccumulation / biomagnification. Aquatic pollution among species represents a serious global biodiversity threat, with waterbirds being one of the organisms most vulnerable to the effects of the compounded impact of chemical pollutants. Birds are key indicators of ecosystem health and pollution levels that capture their ecosystem functioning through their position in food chains, feeding behaviour, and close relationship with aquatic ecosystems (Burger & Gochfeld, 2004; Egwumah et al., 2017). Bioaccumulation and biomagnification are two important concepts in defining the impact of pollutants toward these organisms (Richard et al., 2021). Bioaccumulation is the gradual accumulation of toxins within an individual's body via the ingestion of water, food or direct contact with chronic chemicals. Biomagnification, in contrast, is the upward trend in the concentrations of pollutants as they are transmitted from one trophic level to another, resulting in elevated concentrations of pollutants in predators often birds that are piscivorous or omnivorous (Richard et al., 2021). The bioaccumulation process is influenced by the chemical characteristics of the pollutants, the physiology of the organisms and the environment. Substances with high persistence (POP - persistent organic pollutants) and low solubility in water, combined with that they are highly lipophilic tend to be most preferentially deposited in the tissues of organisms (Elliott & Bishop, 2011). Biomagnification is the process whereby pollutants increase in concentration from trophic level to trophic level. In this way, a contaminant may be found in low concentrations in water or phytoplankton but reach toxic levels in organisms at the top of the food chain, such as piscivorous waterfowl (e.g., gulls, cormorants, pelicans, or fish-eating birds of prey) (Furness, 1993). Bioaccumulation and biomagnification are essential processes in understanding pollutants' effect on aquatic

birds. At the top of food chains, these birds accumulate toxins in concentrations that are highly toxic and contribute to severe health conditions, declining populations as well as ecological chaos. Historical examples, as those from DDT or PCBs, illustrate both the weak point in aquatic ecosystems and their ability to rejuvenate with the control of pollution sources. Long term impact of emerging pollutants on biodiversity requires effective monitoring, stringent environmental policies, and active community participation (Anderson et al., 1975). Waterbirds are extremely susceptible to being contaminated because they depend on water resources and wetlands, according to researchers. Bottom-feeding and consuming sediment expose them to pollutants (Beyer et al., 2008; Veríssimo et al., 2025). Sediments from aqueous sources collect heavy metals, organic pollutants, and debris that can also persist in the digestive tracts of waterbirds for extended periods (Beyer et al., 2008; Veríssimo et al., 2025). Diverse bioavailability of these contaminants is influenced by sediment chemistry and pH. Exposure of bioaccumulate sediments may influence physiology, reproductive fitness, behaviour and population dynamics (Elliott & Bishop, 2011). Sources of pollution in water and soil include industrial effluents such as heavy metals (Hg, Pb, Cd), petroleum hydrocarbons, persistent organic pollutants (POPs), and industrial solvents. These pollutants arise from various activities related to industrialization, leading to significant impacts on both water and soil quality. Accidental leaks and overflows can result in irreversible contamination, which can have lasting effects on aquatic organisms that depend on these environments (Ding, 2025). Ascensive farming practices lead to diffuse pollution from excessive use of fertilizers and pesticides. Chemicals such as neonicotinoids, glyphosate, and nitrogen compounds are washed into wetlands by rainfall, disrupting ecosystem processes (Wania & Mackay, 1996). Poorly upgraded treatment plants release toxic substances from rivers to the environment as microplastics, pharmaceuticals, and detergents. These chemicals cause ecological stress and negatively impact those organisms that are exposed to the contaminants (EPA, 2019). Oceans transport sector, oil pollution and waterfowl impacts are negative and affect water birds via water pollution, changes in plumage and functional impairment (Burger & Elbin, 2015). In recent years, human pollution has seriously compromised waterfowl populations, with some species being threatened by extinction. Past DDT-induced eggshell thinning has been preventing reproduction, though populations started bouncing back after the pesticide was banned. In order to save waterfowl, we need to limit pollution and minimize toxic chemicals, recycle well, minimize oil spills, and protect wetlands. Environmental education is an essential element in creating sustainable and responsible living in nature (Anderson et al, 1975; Heinz & Hoffman, 2003; Burger & Elbin, 2015). Pollution negatively affects waterbird populations, leading to declines in most species found in polluted estuaries, rivers, and coastal areas (Luo et al., 2024). Migratory waterbird declines are associated with polluted staging habitats, indicating that pollution in specific habitats can impact species that have wide geographic ranges (Luo et al., 2024). Protected areas can provide conservation benefits, yet their effectiveness at protecting waterbirds from pollution is variable and frequently inadequate. Well-managed areas with habitat restoration and pollution control can enhance waterbird populations, however, few have proper infrastructure to monitor and remedy pollution (Gaget et al., 2021). Long-term monitoring, using combined conventional biomonitoring and advanced methods such as biomarker analysis, is vital to detect pollution effects on populations at an early stage (Gaget et al., 2021). In order to make relevant comparison by region and time, standardized methods for contaminant analysis and effects-based monitoring are required. Although pollutant concentrations of conventional pollutants decrease, recovery of waterfowl populations is incomplete. There are instances in which some populations have become better stabilized, although researchers attribute partial recovery to changes to ecosystem structure (i.e., changes in prey fish composition), invasive species, climate change and interactions with recovering predator populations. These findings reaffirm that without other anthropogenic stressors, pollution

abatement alone is insufficient to restore population levels to historical levels or ecosystem function (Breton et al., 2008).

CONCLUSIONS

The research reviewed here conclusively demonstrates that environmental pollutants pose major threats to waterfowl populations globally. Lead, mercury, organochlorine pesticides, PCBs, dioxin-like compounds, PFASs, and plastic debris all have documented adverse effects on species reproduction, immune function, behaviour, and survival. These effects have caused severe population declines in some species and geographic regions, particularly in areas with traditional contamination or continuing high levels of pollution. The coming decades present both challenges and opportunities for waterfowl conservation in the context of pollution. On the one hand, emerging pollutants, including PFASs and microplastics, threaten to create new waves of environmental contamination that require regulatory response and remediation efforts. On the other hand, the growing scientific understanding of pollutant toxicology and mechanisms of action allows for the development of increasingly sophisticated strategies for pollution prevention, remediation, and biomonitoring.

Future research should utilize integrative approaches that examine multiple stressors simultaneously, assess the effects of mixtures of pollutants rather than the toxicity of a single compound, and link molecular and physiological biomarkers to population-level outcomes. In addition, because water birds are inherently adaptable and evolving species, research should investigate the potential for rapid genetic and phenotypic adaptation to polluted environments, taking into account the adaptive costs of such adaptation. Only through continued scientific investigation, coupled with aggressive pollution prevention and remediation efforts, can waterfowl populations be recovered and conserved.

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