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Anthropogenic Stressors and their Effects on Wildlife Health

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ABSTRACT

The pace of anthropogenic activities has been increasing more intensively than ever before in the last century, causing fundamental changes to the natural ecosystems and creating the threat of considerable impact on the health of wildlife worldwide. The industrialization, urban growth, agricultural intensification and climate change have brought the broad range of chemical, physical, biological and socio-ecological stressors, which interfere with the physiological, immunological and behavioral processes of the animals. These stress factors do not only negatively affect individual health and survival but also have effects on population relationship, biodiversity stability and ecosystem resilience. There has been growing evidence that persistent exposure to anthropogenic stressors suppresses immune resilience, disturbs endocrine signaling, causes genetic and epigenetic modifications and predisposes to infectious and zoonotic diseases. This review summarizes existing information on key groups of man-made stressors and clarifies how they operate at the mechanistic level to influence the health of wildlife. Moreover, it indicates species-specific susceptibility, interactions of various stressors, and the new methods of wildlife health surveillance. This review emphasizes the importance of conducting multidisciplinary studies and successful conservation plans to avert anthropogenic effects and protect the health of wildlife in rapidly evolving habitats by combining ecological, physiological, and One Health approaches.

Keywords: Anthropogenic stressors, Wildlife health, Environmental pollution, Physiological stress responses, Immune dysfunction, Biodiversity loss, Ecosystem health, One Health approaches.

1. INTRODUCTION

Over the past century human activities have increased at an unprecedented rate that

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has brought drastic changes to natural ecosystems of the entire world. The rapid industrialization, growth of urbanization, agricultural intensification, deforestation, mining and massive development of infrastructure have all changed the landscapes and disrupted the ecological balance. These anthropogenic stressors have altered habitat structure, resource availability and environmental quality subjecting wildlife to new and chronic stressors that did not exist in pre-industrial ecosystems to a large extent (Candolin et al., 2023; Pirotta et al., 2022). The anthropogenic stressors compared to natural stressor are usually chronic, additive and spatially extensive and most wildlife population cannot cope with such stressors. Consequently, the issue of wildlife health has become a very vital indicator of ecological integrity and environmental sustainability (Tyack et al., 2022). Increased pollution of the air, water, and soil and intensive farming activities have led to an increase in the levels of pollution of the environment around the ecosystem, as well as surplus of nutrients, pesticides, and chemical residues into the surrounding environment (Apoorva & Kundlas, 2024). Meanwhile, the influence of climate change in the world due to the emission of greenhouse gases has modified the temperature regimes, precipitation patterns and seasonality, which increased the exposure of wildlife to stress. These shifts in the environment are seldom independent, but they interact in complex ways to form complex stress landscapes, which physiological homeostasis cannot sustain in animals (Karaer et al., 2023; Simonis et al., 2025). They are causing wild species to be progressively displaced into fragmented ecosystems, changed food webs and changed environmental conditions, which place a constant physiological and behavioral strain on the species. Therefore, it is essential to learn how anthropogenic activities transform the ecosystem and create stressors that affect the health and survival of wildlife (Hammond et al., 2020).

Significantly, anthropogenic stressors are not limited to chemical pollutants but are a wide range of physical, biological, and socio-ecological factors. Urban and industrial noise pollution interferes with communication, predator-prey interaction and reproductive behaviors in many taxa. Illumination at night may cause disturbance to circadian rhythm, hormonal cycles and migration (Alaasam & Ouyang, 2021; Richard et al., 2021). The fragmentation of habitats limits gene flow and

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enhances population isolation whereas the introduction of species, by human activities, changes both the pattern of competition and the pathway of disease transmission. All of these changes are a paradigm switch in the selective pressures on wildlife, which tends to select generalist or opportunistic species and puts specialized and sensitive species at increased risk. This growing imbalance has far reaching consequences to biodiversity conservation and ecosystem stability, highlighting the urgent need to evaluate anthropogenic stressors wildlife health perspective (Dharmarajan et al., 2021; Fackelmann et al., 2021; Mahajan & Bhardwaj, 2021). Table 1.1 provides a summary of the key types of anthropogenic stressors and their health effects.

Table 1.1: *Examples of man-made stressors including the sources and significant health effects on wildlife.*

Stressor Type	Common Sources	Major Physiological Effects	Example Outcomes
Chemical pollution	Industrial waste, pesticides	Endocrine disruption, oxidative stress	Reproductive failure
Noise pollution	Traffic, construction	Stress hormone elevation	Behavioral changes
Habitat fragmentation	Urbanization, agriculture	Nutritional stress, reduced movement	Population decline
Climate change	Greenhouse gases	Thermal stress, altered metabolism	Range shifts, mortality

2. Mechanisms Linking Anthropogenic Stressors to Wildlife Health

The anthropogenic stressors influence the wellbeing of the wildlife in diverse interdependent physiological, immunological, and behavioral pathways. The organismal level of exposure to environmental stressors activates the mechanisms of stress response, in particular, the hypothalamic-pituitary-adrenal (HPA) axis leading to the release of glucocorticoid hormones (Kaisin et al., 2021; Mirante et al., 2025). Although activation of stress responses in the short term may be adaptive, chronic exposure to anthropogenic stressor leads to long-term increase in stress hormones

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leading to disruption of energy distribution, suppression of immune activity and inhibiting growth and reproduction. Stressful events that are maintained also compromise homeostasis in animals making them highly vulnerable to diseases, parasitism and changes in the environment (Sokolova, 2021; Taborsky et al., 2022; Williams et al., 2025). Chemical contaminants are one of the largest manmade stressors that impact the health of wildlife. Heavy metals, persistent organic contaminants, pesticides, pharmaceuticals, and industrial chemicals may be bioaccumulated and biomagnified through the trophic levels exposing the top predators to excessive amounts of the chemicals. This is mainly composed of most of these pollutants that are endocrine-disrupting compounds which interfere with the hormonal signaling pathways needed in development, metabolism, and reproduction. Disturbed sex ratios, reduced fertility, defects of development, and altered behaviors have been linked to the interference of endocrine systems in large ranges of wildlife (Asenuga & Olagunju, 2023; Marlatt et al., 2022; Mohanty, 2024). Also, the chemical stressors have the potential to cause oxidative stress, cellular structure destruction, and changes in gene expression patterns, resulting in the long-term physiological dysfunction. There is growing evidence that this type of exposure may lead to genetic and epigenetic changes not only in those who go through the exposures, but also in future generations (García-Giménez et al., 2021; Han & Huang, 2021). Besides the chemical stressors, the physical and ecological disturbances have significant impacts on the well-being of the wildlife. Loss and fragmentation of habitats limits accessibility of food, shelter and breeding areas, compelling animals to be more energetic in order to achieve the basic needs of survival. The reproductive performance and immune capacity is hindered by the nutritional stress that is caused by the poor quality of food or the lack of food (Straub et al., 2023; Stuligross & Williams, 2020). The climate stressors, including heat waves, droughts, and extreme weather, also contribute to aggravation of physiological stress by exposing species to both thermal and ecological thresholds. These stressors are capable of interrupting the phenological matching in the species and their resources, like differences between the breeding season and food supply, which lead to higher death rates. All these factors together lead to a state of chronic stress, and this fact

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weaken resistance and make a person more prone to new infectious infections (Grossman, 2023; Hector et al., 2021). It has been noted that disease dynamics are a highly significant mediator of anthropogenic stressor to the health of wildlife. Stress can immunosuppress animals and reduce their resistance to pathogens, and the environment promotes the replication and survival of infectious agents (Vicente-Santos et al., 2023). Alteration of habitats and climatic alteration can alter the host-pathogen interactions, expand the geographical scope of the disease vectors, and increase contact between wildlife, livestock and humans. Such conditions contribute to the emergence and propagation of zoonotic diseases, and therefore the relationship that can exist between the condition of wildlife, ecosystems and human well-being (Gibb et al., 2020; White & Razgour, 2020). Regarding One Health, the decline in wildlife health under the influence of anthropogenic stressors presents the risks that go beyond the conservation issues and may impact the global population health and economic conditions (Goulet et al., 2024). The anthropogenic stressor-physiological dysfunction-disease susceptibility pathways are summarized in Figure 2.1.

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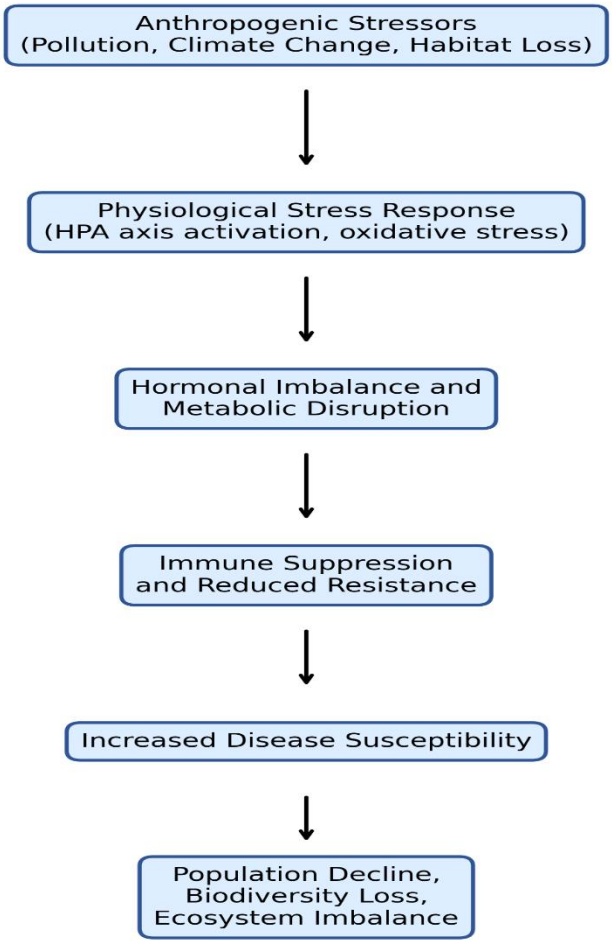


Figure 2.1 *Mechanisms by which the anthropogenic stressors can intervene in physiology, immunity, and disease susceptibility.*

3. Ecological Consequences, Knowledge Gaps, and the Need for Integrated Approaches

The health impacts of anthropogenic stressors on wildlife are not only limited to the individual organism but also affect the population dynamics, community interactions and how an ecosystem functions (Katzner et al., 2020). Such population changes could be due to an inability to reproduce successfully, disease outbreaks and increased mortality rates among the species that have slow life cycles or poor ecological fitness. As populations are on the rise or become extinct, the ecological processes include predation, pollination, seed dispersal, and so on get disrupted, and

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the impacts propagate throughout the ecosystem (Donoso et al., 2020; Fricke et al., 2022). Biodiversity loss causes ecosystems to become less adaptive to environmental changes, making it less capable of absorbing disturbances and recovering in response to environmental change (Hong et al., 2022). Despite the growing awareness of these issues, there are significant gaps in knowledge of the interaction of different anthropogenic stressors to influence the health of wildlife. Most of the studies in the past have traditionally dealt with single stressors under controlled condition, whereas real world expose animals to the complex mixtures of stressors at the same time (Jerem & Mathews, 2021; Orr et al., 2020). Synergistic and cumulative impact can be greatly under-estimated, but can result in consequences that are much worse than those predicted by individual stressors alone. Additionally, responses to stressors differ among species and therefore risks cannot be assessed easily because species are sensitive to different natural factors whose sensitivity is diverse in nature based on life history characteristics, ecological specialization and evolutionary history. Sublethal effects that do not necessarily result in instant death but have lasting impacts on fitness, behavior and viability of populations are also not well known (Beauchesne et al., 2021; Liess et al., 2020; Stockbridge et al., 2020). These gaps are to be filled by way of carrying out a substantial amount of interdisciplinary studies, involving ecology, physiology, toxicology, immunology, and molecular biology. The advances in the field of wildlife surveillance and monitoring of health have the potential to increase what is known and managed on the anthropogenic impacts. The early detection of stress responses and the risk of diseases in free-ranging populations is possible with the help of biomarker development, remote sensing technologies, non-invasive sampling methods, and molecular tools (Barroso et al., 2023; Schilling et al., 2022). Notably, proper conservation and management responses have to deal with the underlying causes of anthropogenic stress but not just deal with symptoms. This involves decreasing pollution, protecting and restoring habitats, promoting sustainable use of land, and integrating wildlife health concerns into the environmental policy and development plans (Plowright et al., 2021; Schmeller et al., 2020). An integrative and holistic approach is necessary in order to lower the effects of anthropogenic stressors on the health of wildlife. A

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conceptual framework that can be useful in addressing these issues is One Health approach that recognizes interdependence between human and animal as well as ecosystem health (Goulet et al., 2024). Through this, by overcoming the barriers in disciplines and enhancing teamwork between scientists, conservationists, policymakers, and the public health professionals, it is achievable to establish strategies that help to protect wildlife, as well as sustain human development. As the anthropogenic stress of the world is constantly increasing and changing, the health of wildlife is both an ethical and ecological requirement and part of the global environmental health and resilience (Browne et al., 2021; Uhart & Sleeman, 2024).

4. FUTURE DIRECTIONS AND LIMITATIONS

Despite significant advances in the knowledge of the impact of anthropogenic stressors on the health of wildlife, some limitations still limit the ability to comprehensively measure the risks and develop effective conservation planning. The main weakness of the current studies is that much of the research is single stressor studies that are done under controlled or short-term conditions, which do not reflect the complexity of real-life situations where wildlife is exposed to multiple and interacting stressors. The effects of chemical, physical, and ecological stressors are not well comprehended, especially in their cumulative and synergistic action at sublethal levels, that may not cause immediate mortality but may severely affect the long-term fitness and viability of a population. Moreover, there is a bias in the data availability primarily towards charismatic and easily reachable species, which creates information gaps on unstudied taxa and ecosystems, particularly in developing areas. In future research, integrative, longitudinal, and field-based studies that investigate integrated exposure to stressors at more than one biological level (that is, molecular and physiological responses, population and ecosystem outcomes) should be given priority. The development of molecular biology (epigenetic profiling and omics-based methods) has the potential to provide the most promising resources to determine the presence of early biomarkers of stress and disease vulnerability in wildlife populations. Subsequently, surveillance and predictive ability can be improved by the combination of remote sensing, ecological modeling, and non-invasive health monitoring tools. Notably, interdisciplinary cooperation of the One

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Health framework must be reinforced to connect the information of wildlife health with the environment change and human activities. The resolution of these research gaps will be critical towards the formulation of evidence-based mitigation measures and adaptive conservation policies that will be able to protect the health of wildlife in changing environments at a rapid rate.

5. CONCLUSION

Anthropogenic stressors are considered to be one of the largest and most extensive threats of wildlife health in the contemporary world. Higher industrialization, urbanization and enhanced agricultural activities, pollution and climate change have all changed the ecosystems exposing wildlife to chronic and complicated stress factors disturbing physiological homeostasis, immune competence and behavioral predictability. Chronic exposure of stress agents by humans has been reviewed in this paper and has proved to affect the health of individuals negatively, predispose an individual to diseases, causes a reduction in population, which ultimately destabilizes biodiversity and ecosystems. These impacts do not just affect single species but extend into ecological networks, and this is an indication of the interrelatedness of the health of wildlife and the functionality of the ecosystem.

The relevance of having a holistic and mechanistic perception of anthropogenic stressor effects on wildlife health at biological levels is highlighted in this review. Mitigation efforts should begin by early monitoring of the stress response, identification of vulnerable species, and special conservation strategies that will address the erosion of the environment and the risk of disease. The One Health, ecological, and physiological approaches to the issue have a strong foundation offering the best methodology of connecting the health of wildlife with wider environmental and population health issues. Since the burden on nature imposed by human activities has only grown, the wellbeing of wildlife should be established as a central element of sustainable development and environmental management of the planet. Multidisciplinary strategies that are proactive will be necessary to minimize the anthropogenic effects and ensure the integrity of wildlife species and ecosystems among future generations.

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