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Editorial: Behavioral ecological insights into organismal responses to anthropogenic environmental change: a multi-stress perspective

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Editorial on the Research Topic
Behavioral ecological insights into organismal responses to anthropogenic environmental change: a multi-stress perspective

Multiple stressors in the Anthropocene

Humans epitomize the concept of the ecosystem engineer, and as a species, are transforming earth's environments at unprecedented rates (Vitousek et al., 1997). These rapid environmental changes pose diverse challenges for organisms and, although they can also provide benefits (Willmott et al., 2022), often introduce multiple sources of stress (Orr et al., 2020). For instance, habitat fragmentation and biodiversity loss alter resource availability (Dirzo et al., 2014), light, noise and chemical pollution interfere with sensory processing and signal detectability (Halfwerk and Slabbekoorn, 2015), and chemical contaminants and higher temperatures associated with global warming introduce toxicological, epidemiological, and thermoregulatory challenges (Urban, 2015; Sonne et al., 2020). The effects of anthropogenic stressors may be particularly pronounced in urban areas (Marzluff, 1997; Shanahan et al., 2013; Grunst et al., 2019; Grunst et al., 2023). However, not even protected areas, such as natural parks and reserves, or isolated regions, such as polar environments, are immune from anthropogenic impacts. Noise pollution and skyglow from distant urban centers penetrate protected areas (Buxton et al., 2017; Torres et al., 2020; Kyba et al., 2023), volatile chemicals reach remote areas through long-range transport (Jonsson et al., 2022), and climate change exerts global influence (IPCC, 2021). Although independent effects of anthropogenic disturbance factors have been increasingly documented, combined effects have been less explored (Orr et al., 2020). In dynamic, multi-stress environments, stressors are likely to have additive or interactive biological effects, with net outcomes differing in magnitude, and even direction, from those predicted based on single stressor effects alone.

Importance of behavioral and physiological responses to multiple stressors

Through this Research Topic, we aimed to forward behavioral ecological and ecophysiological insights into organismal responses to multiple stressors, especially within ecosystems impacted by anthropogenic environmental change. Behavior and physiology are highly plastic, and thus serve as primary mechanisms whereby animals adapt to environmental change (Tuomainen and Candolin, 2011). We highlight the importance of considering interplay between multiple stressors when predicting behavioral and physiological responses to changing environments in the Anthropocene (Figure 1), and underscore that how individuals negotiate stress landscapes may have cascading effects on populations, species interactions and ecosystem functioning.

Themes in the behavioral ecology of multiple stressor responses

Collectively, studies in this special issue highlight five central themes (Figure 1). First, these studies demonstrate the diversity of often co-occurring anthropogenic stressors (artificial light, noise, invasive species, chemical contaminants, habitat alteration, warming conditions, altered resource availability) that can exert effects on behavior, physiology and fitness, and that a wide range of behavioral and physiological traits, within diverse and interacting organisms, can be affected. For instance, Lynn and Quijón's review of impacts of artificial light at night (ALAN) in intertidal settings documents effects on behavioral traits spanning the domains of communication, predator avoidance, reproductive behavior, parental care, competitive interactions, and diel activity patterns in diverse intertidal macro-invertebrates and vertebrates.

Second, studies in this issue highlight that, among behavioral traits, sexual signals, such as bird and frog song, may be especially sensitive to combined effects of light and noise pollution, which commonly co-occur and both of which act as sensory pollutants (Halfwerk and Slabbekoorn, 2015; Swaddle et al., 2015). Smit et al. show that artificial light at night (ALAN) and anthropogenic noise had independent effects on the song characteristics of túngara frogs (*Engystomops pustulosus*), and in combination, had interactive effects that deemed the signal more conspicuous than predicted based on additive effects alone.

Third, habitat quality and resource availability are key to mediating effects of multiple types of stressors on behavior, physiology and fitness. Monniez et al. show that the hatching success of blue tits (*Cyanistes caeruleus*) was negatively related to noise pollution in urban parks. Nevertheless they also demonstrate that hatching success can be improved by vegetation cover, highlighting a potential management solution. Similarly, Sebastiano et al. found that effects of viral disease on Magnificent frigatebird (*Fregata magnificens*) chicks are mitigated by another form of environmental enrichment, namely, food supplementation. Moreover, Pelletier et al. found that northern

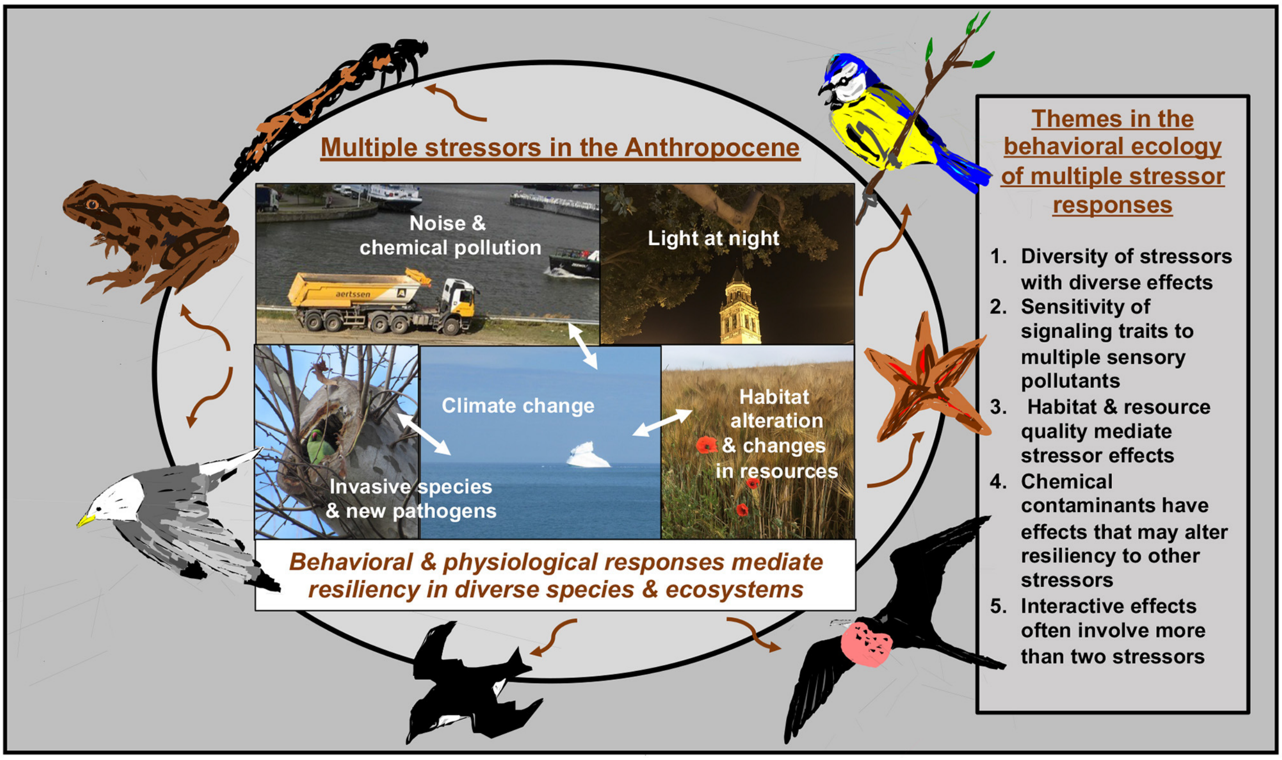

FIGURE 1
Conceptual framework and central themes in the behavioral ecology of multiple stressor responses in the Anthropocene.

gannets (*Morus bassanus*) changing mates (a stressful event) were induced to increase parental effort only in years with low food availability, with negative consequences for physiological state.

Fourth, chemical contaminant exposure is a prevalent anthropogenic stressor which can combine with other environmental conditions to exert potent behavioral, physiological and fitness effects. Costantini et al. demonstrate that black-legged kittiwakes (*Rissa tridactyla*) with high levels of perfluoroalkyl substances (PFAS) displayed less chromatic beaks, gaps, and tongues, and higher plasma concentrations of carotenoids, suggesting that PFAS exposure can interfere with carotenoid metabolism and expression of integument carotenoid-based sexual signals. This study also demonstrates that exposure to different contaminants may have non-equivalent effects, as mercury levels had no effect on coloration.

Fifth, as anthropogenic environmental change is upending entire ecosystems, interactive effects are likely to involve more than two stressors. For example, Monroe et al. report that toadlets of the Gulf Coast toad (*Incilius nebulifer*) had elevated baseline corticosterone when exposed to any combination of warmer water, reduced water levels, or invasive predators, but when exposed to all three, instead showed a stronger response to acute stress. These changes in adrenocortical function may modulate changes in antipredator defense mechanisms and energy storage, aiding toads in persisting in the face of environmental change.

Tip of the iceberg

The articles gathered here focus on diverse taxonomic groups, geographical regions, anthropogenic stressors, and biological response variables. This variety pays tribute to the ubiquitous nature of anthropogenic environmental change, the breadth of behavioral and physiological processes implicated, and the diversity of multiple stressor effects. Nevertheless, this work represents only the tip of an iceberg, with many response variables, such as effects on cognition and movement patterns, unrepresented, and many stressors also left to be explored. We hope that this collection will stimulate the development of future research projects to fill these knowledge gaps.

Author contributions

AG and MG drafted the editorial, with input from CA and ME regarding the significance of the articles comprising this special issue. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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