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Editorial: Impacts of pollution on volatile-mediated interactions

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Chemically mediated interactions between organisms are ubiquitous in nature, with those mediated by volatile organic compounds (VOC) being most illustrative so far in contemporary chemical ecology in terrestrial ecosystems. It is generally recognized that most types of organisms, from bacteria to mammals, emit VOCs into their surroundings, and many can use them as signals to communicate with each other and/or as cues to detect other organisms. This can occur on multiple spatial scales, at intracellular, organismal, and ecosystem levels (Majchrzak et al., 2020; Thöming, 2021). For example, the VOC blends emitted by plants can mediate interactions with pollinators, seed dispersers, herbivores, and natural enemies (Zu et al., 2020), and can induce and prime defenses against herbivores and pathogens (Erb, 2018). Likewise, animal-emitted VOCs (e.g., sex, aggregation, and alarm pheromones) are crucial signals for intra- and interspecific communication (Khallaf et al., 2021). Past decades have witnessed a rapid growth in the study of the biosynthesis of various VOCs, and their eco-physiological functions and evolution, as well as some landmark discoveries of new interesting phenomena and new functions related to VOCs (Bagnères and Hossaert-Mckey, 2016). Despite this progress, it is still poorly understood how VOC-mediated interactions are being affected by an increasingly polluted world.

Volatile organic compound-mediated interactions are among the most sensitive interactions observed in nature, and as such are very vulnerable to environmental perturbation. Indeed, climatic change, environmental pollution, and the wide use of synthetic chemicals for pest and disease control have already begun to affect natural VOC landscapes, and concomitantly VOC-mediated interactions (Blande et al., 2014; Riffell et al., 2014). For instance, some important atmospheric pollutants (e.g., O_3 and NO_x) can alter the atmospheric behavior of VOCs (Li et al., 2016), and in doing so interfere with VOC-mediated plant-pollinator interactions (Girling et al., 2013; Lusebrink et al., 2015; Farre-Armengol et al., 2016; Cook et al., 2020; Ryalls et al., 2022), plant-herbivore interactions (Fuentes et al., 2013; Li et al., 2016), plant-plant interactions (Blande et al., 2010; Li and Blande, 2015), and insect-insect interactions (Arndt, 1995). Environmental pollution (e.g., soil, water, and air pollution) and the widespread use of synthetic pesticides (e.g., insecticides and fungicides) are predicted to worsen in the Anthropocene, particularly for countries in Africa, Latin America, and Asia as they industrialize and transition from low to middle incomes. Therefore, it is urgent and timely to enhance our understanding of the potential impacts of such pollutants on VOC-mediated interactions and also the underlying mechanisms of these impacts. This is particularly relevant to VOC-based pest and disease management and control strategies, which have been demonstrated to provide a more sustainable approach under field conditions (Pickett and Khan, 2016), but are likely to face increasing challenges as a result of ongoing environmental changes. To this end, our Research Topic on the "Impacts of Pollution on Volatile-Mediated Interactions" aimed to promote recent research and synthesis in this field, as well as to identify some emerging themes and ideas that promise to expand the field's horizons.

In the first article in this special issue, Knaden et al. reviewed the current state of anthropogenic impacts on insect chemical communication while focusing on fruit flies, mosquitoes, moths, and bark beetles. Not only did they highlight the different mechanisms through which anthropogenic pollutants could disrupt VOC-mediated plant-insect interactions, but they also assessed the potential effects of rising temperature and elevated atmospheric CO_2 levels. Furthermore, they reflected on the integrative approach of studying insect olfactory receptors and how these receptors will be affected by and respond to anthropogenic pollutants.

In the second article, David et al. investigated the effects of fungicide odor pollution on floral-odor learning and recognition by bumblebees *Bombus impatiens*. They showed that background fungicide odors could disrupt bumblebees' floral-odor learning and recognition, albeit the magnitude of such effects varied with the type and dose of the fungicides tested. Through characterizing fungicide odors and measuring electroantennographic detection (EAD) responses, they further identified sulfurous compounds as being disruptive to foraging behaviors of bumblebees. Fungicides and herbicides are known to be most commonly used in agricultural, forestry, and urban settings; however, their impacts on VOC-mediated chemical communication has received little investigation (Sprayberry et al., 2013). The study by David et al. bridges the knowledge gap of the adverse effects of agrochemical application on VOC-mediated interactions and should stimulate further research in this field.

In the third article, Dubuisson et al. investigated the effects of episodic exposure to high but realistic O_3 concentrations on the VOC emission and composition from flowering lavender *Lavandula angustifolia*. They found that in controlled conditions, acute exposure to high O_3 concentrations did not change VOC emission by the flowering plants *per se*, but transformed the VOC plume both quantitatively and qualitatively in the atmosphere. While the study did not investigate the ecological consequences, it did expand our knowledge on the varying effects of O_3 exposure on VOC emission and the consistent effects on VOC degradation.

In the final manuscript, Ryalls et al. presented a field-based study that assessed the combined impacts of diesel exhaust emissions and O_3 on ground-active invertebrates in wheat fields using a novel Free-Air Diesel and Ozone Enrichment (FADOE) facility. They found that air pollution, even at relatively low levels, adversely impacted invertebrate community composition, with the effects varying with functional traits and being greater under the diesel exhaust treatment than the O_3 treatment. Most interestingly, the combined pollutant treatment demonstrated reduced negative impacts, probably due to the reaction between NO_x and O_3 resulting in a mitigating effect. To our knowledge, this is one of the first studies to illustrate the interactive effects of different air pollutants on invertebrate communities, and emphasizes the importance of assessing ecological impacts under real-world pollution scenarios on invertebrate communities and the ecosystem services provided by them.

The articles in this Research Topic explore some of the many important ways in which environmental pollution is modifying VOC-mediated interactions, and propose new questions and promising research avenues that remain and deserve further investigation. We hope that these papers encourage further multidisciplinary and collaborative studies under both controlled and field conditions, using real-world pollution scenarios, to allow researchers to fully elucidate the complex impacts and mechanisms by which pollution modifies VOC-mediated interactions. The outcomes of such research will ultimately guide policy-makers to take effective measures to mitigate adverse impacts of pollution on VOC-mediated ecosystem processes and services in the Anthropocene.

Author contributions

TL led the writing of the article with substantial intellectual and writing contributions by RG. All authors approved it for publication.

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