CellPress

Trends in
Ecology & Evolution

Forum

Invasive species behaviour in a toxic world

Morelia Camacho-Cervantes [1,*,@] and Bob B.M. Wong[2,@]

Invasive species and chemical pollution both threaten biodiversity. Here, we discuss how pollution, through its impacts on wildlife behaviour, shapes invasion dynamics by altering species interactions. Addressing knowledge gaps will have implications for the management of invasive species and conservation of native ecosystems in an increasingly toxic world.

Biological invasions and chemical pollution

Biological invasions can bring about considerable harm to ecological communities by interfering with food webs, altering the environment, and ultimately leading to the extinction of native populations [1]. Invasive species not only pose a significant threat to the functioning of ecosystems, but also cost the global economy billions of dollars annually [2]. To manage and prevent invasions, it is critical to understand the mechanisms through which non-native species can establish and thrive in new environments. Behaviour has important population-level consequences through its effects on individual survival and reproduction, and this is especially crucial for the introduction, establishment and spread of non-native species, as behaviour can enable animals to more rapidly respond to changing environments than the time taken for genetic changes to accrue [3,4].

Chemical pollutants can have a wide range of adverse effects on exposed organisms, with consequences for environmental and human health [5]. Fuelled by the ever-increasing demands of human population growth, enormous quantities of chemicals are being released into the environment through various anthropogenic activities. Indeed, the rate of increase in the production and diversification of synthetic chemicals now outpaces all other major agents of global change, including rates of land conversion for agriculture and rising carbon dioxide levels [6]. At high enough concentrations, and with the potential to persist in the environment, it is perhaps unsurprising that chemical pollutants have been widely linked to a range of adverse impacts in exposed animals, from death in vultures to reproductive dysfunction in frogs [7].

Behavioural ecotoxicology: why does it matter for invasive species?

Less well studied, but no less important, are sublethal effects on behaviour that can be easily overlooked. Chemical pollutants can directly disturb the sensory systems of exposed organisms, leading to a decrease in their ability to perceive environmental cues that can influence behaviour [8]. Insights from the rapidly growing field of behavioural ecotoxicology has demonstrated that chemical pollution can also lead to changes in behavioural traits related to resource acquisition, reproduction, predator avoidance and social organisation by disrupting hormonal balance and impairing normal physiological and neurological processes [7,9]. As the behaviour of species can be altered in various ways due to chemical pollution, it is crucial to also consider the largely overlooked impacts of environmental toxicants on behaviour when studying biological invasions (Figure 1). Here, it is particularly important to understand how chemical pollution affects interactions between native and non-native species, given that such interactions could affect the likelihood of non-natives establishing and thriving in new environments.

For better or worse: native and non-native interactions in polluted environments

In the context of sensory disturbance, the impact of chemical pollutants on animal communication, particularly in the ability of individuals to recognise and interact with others of their own species, can create situations where native species might be more inclined to interact with non-natives. Non-natives, in this regard, could benefit from these associations if it enhances their survival, reproduction and prospects of establishing in new areas. For example, recent evidence shows that social interactions between natives and non-natives can lead to better learning, foraging efficiency, and predator avoidance for both species [3] (Box 1). In a reproductive context, behavioural interactions between closely related natives and non-natives can also result in the exchange of beneficial alleles (i.e., through hybridisation) [10]. However, while the outcome at first contact might be advantageous for both natives and non-natives, over time, if these behavioural interactions enable the non-natives to successfully establish and for their populations to grow, then native species could ultimately be outcompeted. Hence, the relative costs and benefits of chemically induced changes in behavioural interactions could differ depending on the actual stage of invasion (i.e., introduction, establishment, and spread).

Another important consideration is that native and non-native species might differ in their susceptibility to chemical pollution. Evidence suggests that successful invaders tend to be more flexible in their behaviour (as well as in their morphology and physiology). This could potentially give them an advantage when interacting with native species, especially if invaders have also had historical contact with chemical pollutants that may confer greater resistance. For example, urbanised environments are often a key source for the uptake of individuals (e.g., via transport vectors) that are

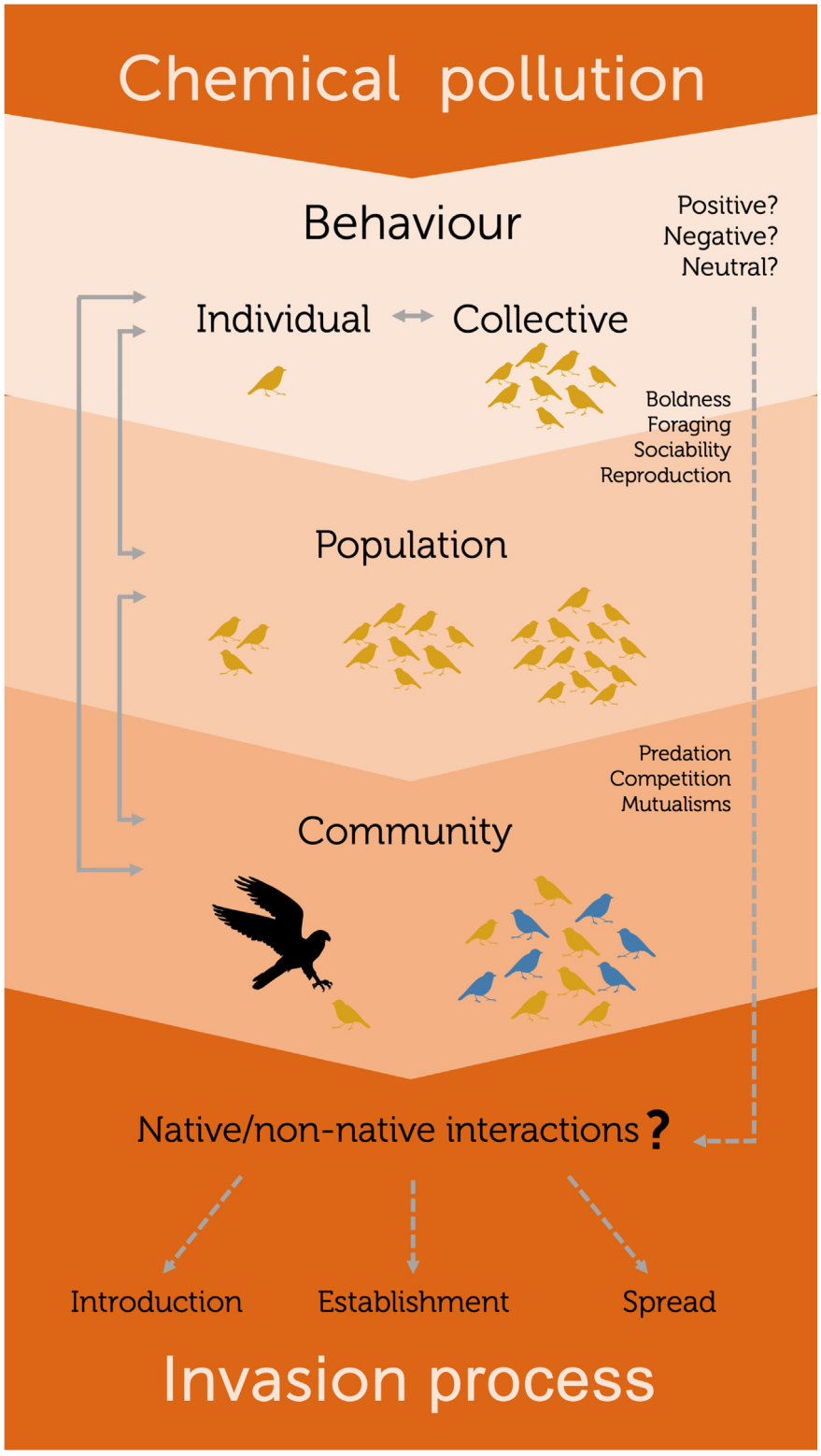

Figure 1. Chemical pollution could change invasion dynamics through changes in behaviour. Chemical pollution can affect both individual and collective behaviour, with consequences for population and community dynamics [7–9]. Effects of chemical pollution on heterospecific interactions in invaded communities could affect the probability of invasion success for non-natives. Colour of individuals represent different species, list of behaviours includes those that could potentially be affected by chemical pollution in a positive, negative, or neutral way. Dashed lines represent effects not investigated yet; solid lines represent effects known to occur.

Box 1. Invasive species, pollution, and the decline of Mexico's goodeid fishes

The Mexican Central Plateau is home to a group of endemic freshwater fishes known as goodeids or splitfins. According to the IUCN Red List, of the 40 known goodeid species, three are now extinct in the wild and a further 28 are listed as endangered or critically endangered. The decline of goodeids is attributed to a range of anthropogenic factors, including pollution and the impact of invasive species, such as non-native poeciliid fishes [12]. Facilitative behavioural interactions from goodeids could increase the survival and invasion success of several invasive poeciliid species, as it allows the latter to overcome the disadvantages of small population size during the initial stages of the invasion process [3]. Chemical pollution can affect the behaviour of poeciliids including changes in social, reproductive, and foraging behaviours [7,9]. What we still do not know is how chemical pollution might affect the behaviour of goodeids, and how differences in pollutant-mediated changes in behaviour (if any) might, in turn, alter the interactions of poeciliids and goodeids inhabiting the Mexican Central Plateau (Figure I). This case emphasises the need to incorporate the effects of chemical pollution on behaviour in both native and non-native species to better understand invasion dynamics in an increasingly polluted world.

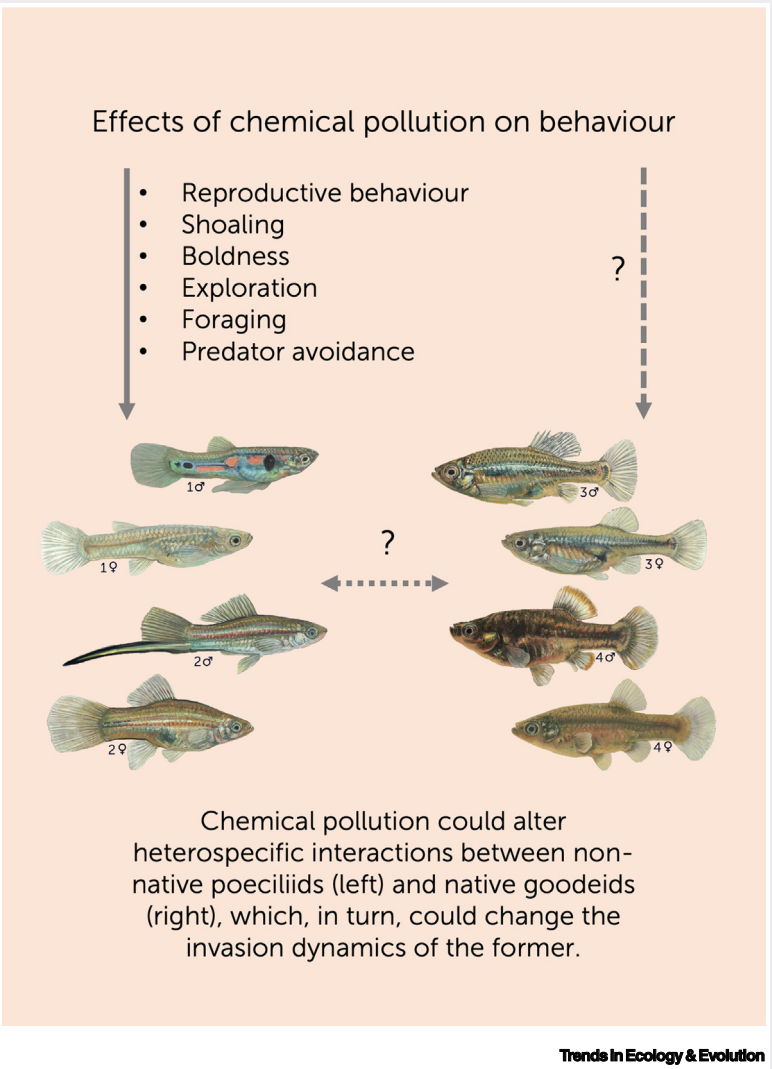

Figure I. Potential behavioural effects of chemical pollution on the heterospecific interactions between native goodeids and non-native poeciliid fishes. Solid line represents behaviours that are known to be affected by chemical pollutants while dash lines represent unknown effects. Species shown: (1) guppy, *Poecilia reticulata*; (2) green swordtail, *Xiphophorus helleri*; (3) olive skiffia, *Skiffia lermae*; and (4) picotee splitfin, *Zoogoneticus quitzeoensis*. Image credit: Emerson Balderas.

more likely to come in contact with a variety of toxicants. Consequently, these individuals may have already built up a tolerance to them [10]. Biological invasions involve multiple stages (i.e., transport, introduction, establishment, and spread), and each stage can potentially act as a selective filter for traits associated with invasion success [11]. Such processes may include selection for higher plasticity or act as a filter for more resilience [10,11], which could result in a greater tolerance to chemical pollution.

Such differences in susceptibility to pollutants could, in turn, result in asymmetric changes in behaviour between species (e.g., by making individuals of certain species bolder or more aggressive) [7,9]. Such asymmetries could lead to a shift in the way natives and non-natives interact by, for example, changing competition and predation dynamics within the invaded community. Likewise, contaminants that disrupt reproductive behaviours could affect the quality and quantity of offspring that are produced. If such changes lead to different population level responses between natives and non-natives (e.g., if there is a decline in one species but not the other), we would expect the nature of the interactions between natives and non-natives to also change (Figure 1).

Towards a more integrative approach to managing invasive species

Understanding the complex dynamics of invasive species and the ways in which they interact with natives is critical for effective conservation and management strategies. However, there is still a significant gap in our understanding of how chemical pollution can affect these heterospecific interactions, which play a crucial role in shaping invasion dynamics. Chemical pollution could be providing a scenario that is beneficial for invasion success and, by creating the opportunity for short-term beneficial interactions for natives, delays the recognition of the invasive

species' negative impacts until it is too late to effectively mitigate the consequences of the invasion. We highlight the need to investigate and understand the role of chemical pollutants in disrupting behavioural interactions between natives and non-natives and evaluate their potential contribution to invasion success. Disruptions caused by chemical pollution to heterospecific behavioural interactions add a new axis to the complexity of invasion dynamics. By better understanding the ways in which chemical pollution can affect heterospecific interactions in the invasion context, we can improve our ability to manage the impacts of invasive species in native ecosystems.

Acknowledgements

We thank the APEC-Australia for Women in Research Fellowship (to MCC) and the Australian Research Council (FT190100014 and DP220100245 to BBMW) for funding, and Emerson Balderas for use of his fish illustrations.

Declaration of interests

No interests are declared.

[1]Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autonoma de Mexico, Ciudad Universitaria, 04510, Mexico City, Mexico
[2]School of Biological Sciences, Monash University, Clayton, Victoria 3800, Australia

*Correspondence:
mcc@cmarl.unam.mx (M. Camacho-Cervantes).
@Twitter: @mo_cace (M. Camacho-Cervantes) and @BBM_Wong (B.B.M. Wong).

https://doi.org/10.1016/j.tree.2023.07.006

References

1. Stevenson, E.A. *et al.* (2023) Synthesising 35 years of invasive non-native species research. *Biol. Invasions* 25, 2423–2438
2. Diagne, C. *et al.* (2021) High and rising economic costs of biological invasions worldwide. *Nature* 592, 571–576
3. Camacho-Cervantes, M. *et al.* (2023) Could non-native species boost their chances of invasion success by socializing with natives? *Philos. Trans. R. Soc. B* 378, 20220106
4. Wong, B.B.M. and Candolin, U. (2015) Behavioral responses to changing environments. *Behav. Ecol.* 26, 665–673
5. Gruber, K. (2018) Cleaning up our future health. *Nature* 555, S20–S22
6. Bernhardt, E.S. *et al.* (2017) Synthetic chemicals as agents of global change. *Front. Ecol. Environ.* 15, 84–90
7. Bertram, M.G. *et al.* (2022) Frontiers in quantifying wildlife behavioural responses to chemical pollution. *Biol. Rev.* 97, 1346–1364
8. Michelangeli, M. *et al.* (2022) Predicting the impacts of chemical pollutants on animal groups. *Trends Ecol. Evol.* 37, 789–802
9. Saaristo, M. *et al.* (2018) Direct and indirect effects of chemical contaminants on the behaviour, ecology and evolution of wildlife. *Proc. R. Soc. B* 285, 20181297
10. Oziolor, E.M. *et al.* (2019) Adaptive introgression enables evolutionary rescue from extreme environmental pollution. *Science* 364, 455–457
11. Chapple, D.G. *et al.* (2022) Biological invasions as a selective filter driving behavioral divergence. *Nat. Commun.* 13, 5996
12. Suárez-Rodríguez, M. *et al.* (2023) Population growth and behavioural interactions of a critically endangered fish with co-occurring native and exotic species. *Freshw. Biol.* 68, 698–710