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INVITED COMMENTARY

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Temperature induced changes in species distribution increases sensitivity of aquatic invertebrate communities to chemicals

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Interactions between alterations in climate and the risks chemicals may have on biodiversity has many aspects including changes in the use of chemicals, their environmental fate, and their ecotoxicological effects on biodiversity. In this volume of Global Change Biology, Sinclair et al. (2024) investigated the impact of climate-induced changes in freshwater macroinvertebrate community composition on the future sensitivity of these assemblages to chemical stressors. They conclude that shifts in species composition due to climate warming will increase chemical risk and that the impact of chemical pollution on freshwater macroinvertebrate biodiversity may double or quadruple by the end of the 21st century. In this commentary, I will discuss how climate warming might influence the impacts of chemicals on (aquatic) ecosystems and explain why Sinclair et al. (2024) provides a novel contribution to this discussion and, herewith, fills a research gap as the route of influence they studied hardly been studied before.

The fact that temperature can affect the toxicity of chemicals has been known for several decades. Cairns et al. (1978) studied the interactive effects of chemicals and temperature and found that seven invertebrates species generally showed the classic response of increased sensitivity to two metals, chlorine, cyanide and phenol with increasing temperatures, although exceptions were also observed. In hindsight, this landmark report contained both examples of the climate-induced toxicant sensitivity (CITS), where exposure to a climate-related stressor makes an organism more sensitive to subsequent toxicant exposure and the toxicant-induced climate susceptibility (TICS), where toxicant exposure makes an organism more vulnerable to subsequent changes in climatic conditions, concepts (Hooper et al., 2013).

Most recent research has focused on the mechanisms driving CITS-based interactions, both at the individual level as the community/ecosystem level (Figure 1). The paper of Sinclair et al. (2024) provides a novel example of an indirect interaction between climate warming and chemical toxicity by considering how climate-induced changes in the spatial distribution of species alters the sensitivity of species assemblages to chemical toxicants.

The interaction between temperature and chemicals can be described at the individual level using mechanistic effect models such as toxicokinetic–toxicodynamic (TKTD) models. Mangold-Döring et al. (2022) used experimental data to parameterize a newly developed TKTD model, which included the effects of temperature on its parameters. They found that temperature influenced both the TK and the TD of two insecticides in the freshwater shrimp *Gammarus pulex*, overall leading to an increased sensitivity with increasing temperatures. This finding has been confirmed by other authors although reverse relationships have also been found, for example, for pyrethroids (Mangold-Döring et al., 2022).

The interactive effects of temperature and chemicals at the community and ecosystem level have been studied to a lesser extent. These interactive effects can be studied at the ecosystem level using mesocosms, which are able to show multitrophic community responses influenced by food-web interactions such as competition and predation. The few mesocosm experiments available on this interaction show that the combined effects are very context specific (e.g., type of chemical, duration and order of exposure). Whereas the combined effects are generally synergistic at the individual level they are often antagonistic at the community and ecosystem level (Dinh et al., 2022).

So, while the direct modulating effects of temperature on the response of individuals and ecosystems to chemicals have been studied to a certain degree, the thermal influence on the species distribution of invertebrates and, thus, on their sensitivity has been studied for the first time by Sinclair et al. (2024). They investigated this by predicting the species composition of aquatic macroinvertebrate

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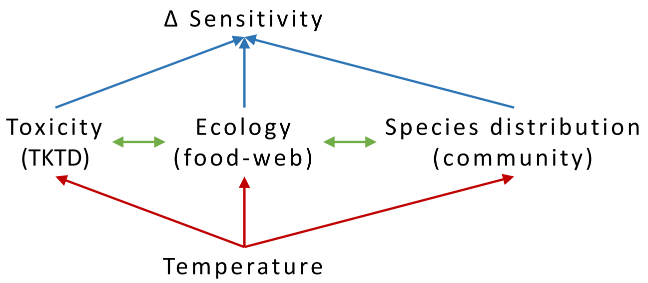

FIGURE 1 Possible routes of effects of temperature on the sensitivity of ecosystems to chemicals. In the first route, temperature changes rates in the toxicokinetics and toxicodynamics of chemicals inside individuals, herewith altering their sensitivity. In the second route, the sensitivity of communities is altered though temperature induced changes in the food-web structure, while the third route alters the sensitivity of communities to chemicals by changes in community assemblages though temperature induced changes in species distribution. Note that not all possible routes are included in Figure 1; temperature could, for instance, also influence the genetic diversity of species and communities, herewith altering their sensitivity.

communities for the period 2080–2099 under 4 future climate scenarios (increase by 1.28°C [RCP 2.6], 2.32°C [RCP 4.5], 2.70°C [RCP 6.0], and 3.78°C [RCP 8.5]), which were compared to the baseline scenario (1980–2000). These predictions were done for 608 minimally impacted sites in the UK using the River Invertebrate Classification Tool. It should be noted that these predictions are based on the current thermal preference of the taxa and exclude possible climate warming induced adaptation and migration of species. Therefore, the predictions for the south of the UK might suffer from the fact that species with a thermal preference for temperatures predicted to occur at the end of this century are underrepresented in the current species composition of the UK. The sensitivity of the baseline and future communities was predicted using the hierarchical species sensitivity distribution concept for 19 chemicals including heavy metals and pesticides. Results indicated that all four future climate scenarios will result in a significantly different community composition, favoring Mollusca, Malacostraca, Oligochaeta and some Insecta taxa, while other Insecta taxa will be impaired. For almost all (18 out of 19) chemicals, it was predicted that the three scenarios with the highest temperature increase resulted in a significantly higher sensitivity of the macroinvertebrate assemblages while this was also true for the scenario with the lowest temperature increase for most chemicals (15 out of 19). Carbaryl was the only chemical showing a decrease in toxicity due to climate warming induced changes in community composition (Sinclair et al., 2024). It should be noted that these results were obtained using the concentration which is hazardous to 5% of the taxa of the baseline scenario community (HC5) as a reference, which is a relatively high concentration. This HC5 value is also used as a threshold value of effects, so is not likely to occur at a large scale for chemicals registered in the EU (Maltby et al., 2005). As lower concentrations are associated to the lower, flat part of the cumulative species sensitivity distribution curve, a climate warming induced shift in the composition of this distribution will lead to smaller increases of community sensitivity when a concentration lower than the HC5 is used as a reference. But more importantly the sign of the changes will be valid whatever concentration is chosen, which highlights the importance of including climate warming induced changes in community composition into the multiple stressor research field investigating the interactive effects of temperature and chemicals on communities and ecosystems.

The findings of Sinclair et al. (2024) are supported by those of Van den Berg et al. (2020), who predicted Southern European invertebrate species to be more sensitive to narcotic and acetylcholinesterase-inhibiting chemicals, which would also lead to an increased sensitivity of invertebrate communities to chemicals when climate warming would induce an upwards migration. The "why" question is not answered by the study of Sinclair et al. (2024), nor by Van den Berg et al. (2020). Sumon et al. (2018) found that the ephemeropteran genus *Cloeon* sp. was a factor of 186 to 1105 more sensitive in tropical Bangladesh compared to temperate the Netherlands, based on 4d-EC50 and 4d-LC50 values, respectively. This cannot be explained by the direct influence of temperature alone as Van den Brink et al. (2016) showed that an increase of the temperature from 10 to 18°C decreased their 4d-EC50 values by a factor of 1.7. Apparently, long-term adaptation to higher temperatures influence the physiology and/or life history characteristics of aquatic invertebrates others than the processes of toxicokinetics and toxicodynamics of chemicals alone, making them more sensitive to chemicals. By adding the aspect of species distribution to the global warming and chemicals debate, Sinclair et al. (2024) opens the windows for connecting different fields of research to investigate the mechanisms behind the findings that populations adapted to higher temperatures to be more sensitive than those adapted to ambient ones on the one side and include species movement and their demography into risk assessment of chemicals which take the effects of climate change into account on the other side.

AUTHOR CONTRIBUTIONS

Paul J. Van den Brink: Conceptualization; visualization; writing – original draft; writing – review and editing.

CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed for the current article.

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REFERENCES

Cairns, J., Buikema, A. L., Heath, A. G., & Parker, B. C. (1978). *Effects of temperature on aquatic organism sensitivity to selected chemicals*.

Bulletin 106. Virginia Water Resources Research Center. http://hdl.handle.net/10919/46542

Dinh, K. V., Konestabo, H. S., Borgå, K., Hylland, K., Macaulay, S. J., Jackson, M. C., Verheyen, J., & Stoks, R. (2022). Interactive effects of warming and pollutants on marine and freshwater invertebrates. *Current Pollution Reports*, *8*, 341–359. https://doi.org/10.1007/s40726-022-00245-4

Hooper, M. J., Ankley, G. T., Cristol, D. A., Maryoung, L. A., Noyes, P. D., & Pinkerton, K. E. (2013). Interactions between chemical and climate stressors: A role for mechanistic toxicology in assessing climate change risks. *Environmental Toxicology and Chemistry*, *32*, 32–48. https://doi.org/10.1002/etc.2043

Maltby, L., Blake, N., Brock, T. C. M., & Van den Brink, P. J. (2005). Insecticide species sensitivity distributions: Importance of test species selection and relevance to aquatic ecosystems. *Environmental Toxicology and Chemistry*, *24*(2), 379–388. https://doi.org/10.1897/04-025R.1

Mangold-Döring, A., Huang, A., van Nes, E. H., Focks, A., & van den Brink, P. J. (2022). Explicit consideration of temperature improves predictions of toxicokinetic–toxicodynamic models for flupyradifurone and imidacloprid in *Gammarus pulex*. *Environmental Science & Technology*, *56*(22), 15920–15929. https://doi.org/10.1021/acs.est.2c04085

Sinclair, T., Craig, P., & Maltby, L. L. (2024). Climate warming shifts riverine macroinvertebrate communities to be more sensitive to chemical pollutants. *Global Change Biology*, *30*, e17254. https://doi.org/10.1111/gcb.17254

Sumon, K. A., Ritika, A. K., Peeters, E. T. H. M., Rashid, H., Bosma, R. H., Rahman, M. S., Fatema, M. K., & Van den Brink, P. J. (2018). Effects of imidacloprid on the ecology of sub-tropical freshwater microcosms. *Environmental Pollution*, *236*, 432–441. https://doi.org/10.1016/j.envpol.2018.01.102

Van den Berg, S. J. P., Rendal, C., Focks, A., Butler, E., Peeters, E., De Laender, F., & Van den Brink, P. J. (2020). Potential impact of chemical stress on freshwater invertebrates: A sensitivity assessment on continental and National Scale Based on distribution patterns, biological traits, and relatedness. *Science of the Total Environment*, *731*, 139–150. https://doi.org/10.1016/j.scitotenv.2020.139150

Van den Brink, P. J., Van Smeden, J. M., Bekele, R. S., Dierick, W., De Gelder, D. M., Noteboom, M., & Roessink, I. (2016). Acute and chronic toxicity of neonicotinoids to nymphs of a mayfly species and some notes on seasonal differences. *Environmental Toxicology and Chemistry*, *35*, 128–133. https://doi.org/10.1002/etc.3152

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