Ref. Ares(2022)112206 - 07/01/2022

Effects of global change on the emission, fate, effects, and risks of chemicals in aquatic ecosystems

Marie Curie Actions

SHORT TITLE:	ECORISK2020
COORDINATOR:	Prof Dr Paul van den Brink
ORGANISATION:	Wageningen University
TOPIC:	H2020-MSC_ITN 2018
PROJECT NUMBER:	813124

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 813124

Deliverable: 5.5

Chemical effects on microbial ecological functions

The PhD project of ESR 9 (Sabrina Roth) has shifted from the main focus being chemical effects on microbial communities to various types of effects of chemicals on aquatic biota during global change. This change of plan was described in the ECORISK2050 half-time report. The deliverable 5.5 describes the main outcomes of the PhD project so far, which relate to the impact of chemicals on individual organisms as well as on ecosystem structure. The project is divided into four subparts:

1. Using chemical activity to identify chemical mixture effects on the model organism *Daphnia magna*

Chemicals occur in mixtures in the environment, which makes it difficult and complex to identify their effects. The two main reasons are: 1) measuring concentrations of all potential contaminants in the environment is unrealistic due to the technical challenges and analytical costs, and 2) the sum of the measured concentrations of different chemicals does not inform us about the exposure levels, because toxic concentrations are compound-specific. This makes the exposure, hazard, and risk assessments of chemical mixtures in the environment extremely challenging (Gobas et al., 2018). The concept of 'chemical activity' offers a way to overcome these constraints for chemical mixtures of neutral chemicals at concentrations below their specific toxicity

concentration, by enabling the conversion of concentrations of various chemicals into a common, unitless, currency (Gobas et al., 2018). In such cases, when many neutral organic chemicals are present at low concentrations, additivity of toxicity is often observed (Escher et al., 2002). This holds true even when the substances are not related chemically, or exhibit different modes of action when acting alone at acute levels (Escher and Hermens, 2002). The phenomenon is defined as baseline toxicity, or narcosis (Escher et al., 2002) and is related to disturbances in cell membrane functioning. Chemical activity relates a chemical's concentration to its maximum solubility in the environmental media (Gobas et al., 2018; Schwarzenbach, Rene P.; Gschwend, Philip M.; Imboden, 2003), it is additive, and correlates to baseline toxicity, thereby offering an integrative tool to quantify the biological potency of chemical mixtures in background areas addressing the following research questions and aims of this study.
The model organism *Daphnia magna* is used to test the effect of different chemical mixtures (PAHs, PCBs) at environmentally relevant concentrations using passive dosing with silicone rods (Fig. 1).

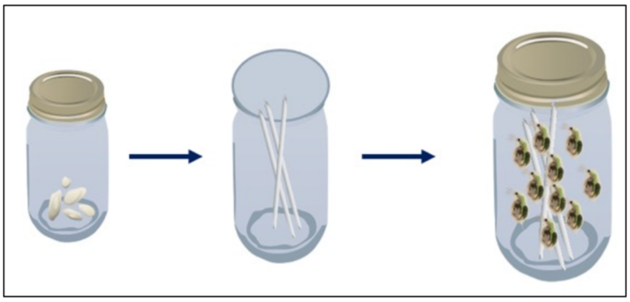

Figure 1: Passive dosing set-up. PAHs and PCBs crystals will be used to prepare saturated solutions in methanol that will further be used to load silicone rods with the needed chemical activity. These rods will be used to expose *Daphnia magna* to the intended chemical activities.

Several pre-studies have been conducted to test and improve the experimental setup, to identify the optimal chemical activity range for exposure, to test the loading of the water phase for the experimental set up (Fig. 2A-C), and to identify the optimal exposure time (48 hours; Fig. 2D). The main experiment is currently under preparation. Additionally to the control (i.e., no chemical treatment), the study organism *Daphnia magna* will be exposed to a PAH-mixture, a PCB-mixture, a single PAH compound (acenaphthene), and a single PCB compound (PCB-153). The PAH-mixture will consist of four compounds (acenaphthene, acenaphthylene, fluorene, fluoranthene) and the PCB-mixture of five compounds (PCBs 28, 101, 52, 138, 118, 153). To identify non-lethal effects, biomarkers (DNA/RNA ratio, proteins) will be analyzed.

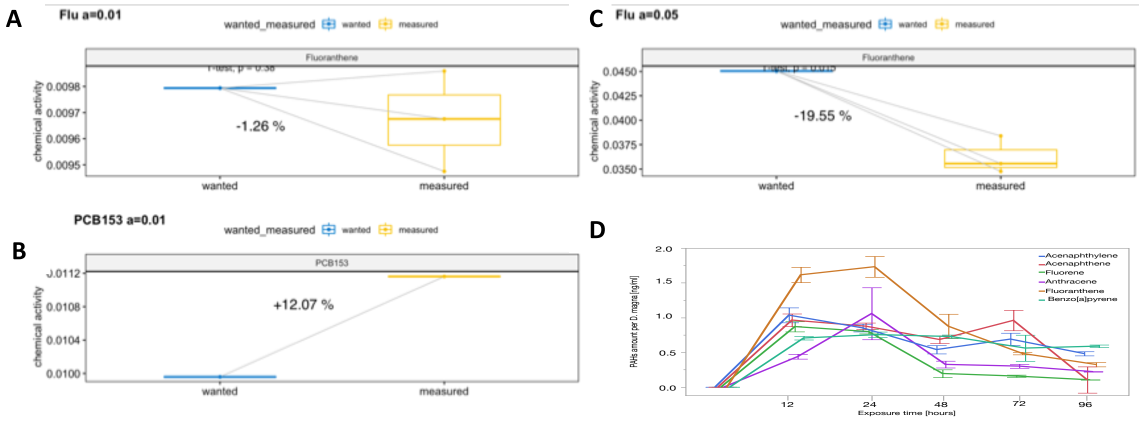

Figure 2: A-C. Water phase loading. Loading of the water phase using loaded silicone rods has been tested with fluoranthene at a=0.01 (A), PCB-153 at a=0.01 (B), and fluoranthene a=0.05 (C). The water phase has been analysed via GCMS to confirm the exposure concentration. **D.** *Daphnia magna* have been exposed to a PAH mixture of six compounds (acenaphthylene, acenaphthene, fluorene, anthracene, fluoranthene, benzo[a]pyrene) over different time periods (12, 24, 48, 72, and 96 hours). The chemical concentrations of the compounds have been extracted from the animals, to identify the time when the PAHs have reached equilibrium between the exposure media and the animals.

2. Combined effects of heatwaves and an herbicide on freshwater zooplanktonic communities

Understanding the impacts of climate change and its extreme events, particularly heatwaves, on aquatic ecosystems requires exploring interactions with other anthropogenic stressors, such as pesticide pollution. Freshwater planktonic communities are important energy suppliers for higher trophic levels and play a key role in gross primary production and community respiration in aquatic ecosystems. However, these ecosystems suffer from pesticide pollution caused by unintentional exposure via spray drift and runoff. The herbicide terbuthylazine serves as alternative pesticide to atrazine, which is banned in the EU (Bethsass and Colangelo, 2006; Stipičević et al., 2015), yet, it has demonstrated lethal effects on phytoplankton communities, leading to indirect starvation of zooplankton (Pereira et al., 2017).
As part of the ECORISK secondment from ESR 9 (Sabrina Roth) at the IMDEA Water institute, an indoor microcosm experiment was performed together with ESR 8 (Francesco Polazzo) and the local supervisor Andreu Rico. Natural freshwater zooplanktonic communities were exposed to a simulated heatwave (one-week duration) and the herbicide terbuthylazine (15 μg/L) in different combinations of the two stressors to identify whether the combination of both stressors causes higher vulnerability in the zooplankton community as if applied alone.
The changes within the zooplankton community composition, total abundance, taxa richness, and taxa diversity were assessed.
Findings revealed that the heatwave increased the total zooplankton abundance, likely due to metabolism stimulation (Brown et al., 2004) (Fig. 3B), whereas the terbuthylazine application shifted the zooplankton community composition indirectly due to effects on phytoplankton (Fig. 3A). The combination of both stressors, i.e., heatwave + terbuthylazine, resulted in additive effects, in which terbuthylazine effects predominate, reducing the phytoplankton abundance and, thus, affecting the zooplankton community indirectly via the lacking food availability. Impacts on

zooplankton communities, being at the base of the aquatic food web, may escalate up the food chain, potentially causing consequences for freshwater ecosystems.
This experiment helped to better understand the effect on zooplankton communties when exposed to multiple stressors.

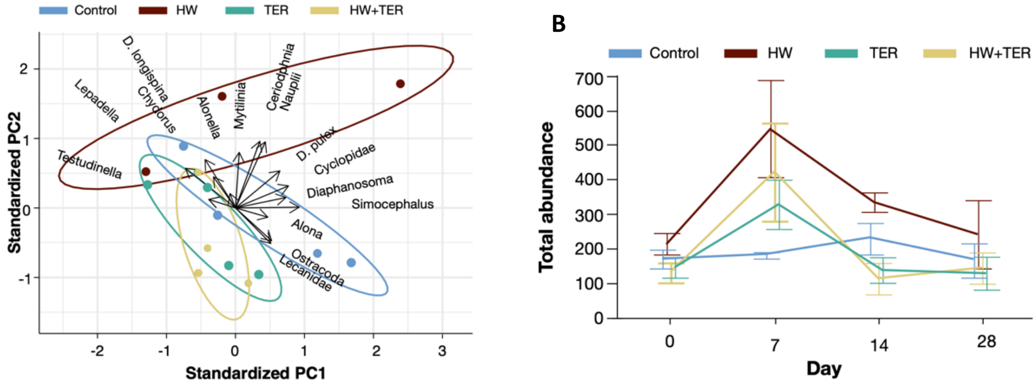

Figure 3: A. The Principal Component Analysis (PCA) indicating the relationship between the stressors (control, heatwave, terbuthylazine, both in combination) and the individual taxa on day 14. The length and direction of the arrows indicate the influence of each stressor for each taxon, respectively. **B** Total abundance was measured over time in all treatments: control (blue), heatwave (HW, red), terbuthylazine (TER, green), and the combination of heatwave and terbuthylazine (HW+TER, yellow). Each error bar is constructed using one standard error from the mean.

3. Combined effects of heatwaves and micropollutants on various trophic levels in freshwater ecosystems, including microbial communities

Microbial communities are essential drivers of biogeochemical cycles (Falkowski et al., 2008) and ecosystem functioning, both in terrestrial (Laforest-Lapointe et al., 2017; Young and Crawford, 2004) and aquatic ecosystems (Caston et al., 2009). Aligning with the species-sorting model (Leibold et al., 2004), microbial communities are shaped by the local environment (Logue and Lindström, 2010), such as temperature (Ziegler et al., 2019), salinity (Herlemann et al., 2011), resource availability (Pradeep Ram et al., 2020), or environmental degradation processes (Mykrä et al., 2017). Concurrently, they can react rapidly (within minutes) to changes in the surrounding environment (Salman and Libchaber, 2007; Siliakus et al., 2017). These changes and fast adaptation of survival strategies are facilitated by short generation times and other mechanisms, like cell membrane modification or changes in biochemical processes (Siliakus et al., 2017; Smith and Romesberg, 2007). Due to their fast response to stressors, microbial communities have been used to identify alterations in anthropogenic pollution (Torres et al., 2019), water temperature (Ziegler et al., 2017), or water quality (Santos et al., 2019) in various ecosystems. Albeit microbial communities convey high potential to be used as bioindicators of physical, chemical, and biological measures upon ecosystem health (Astudillo-García et al., 2019), knowledge is still scarce when it comes to multiple stressor effects involving temperature fluctuations such as HWs in combination with chemicals.

Within the ECORISK2050 WP5 Effects, the ESR numbers 7 (Markus Hermann), 8 (Francesco Polazzo), 9 (Sabrina Roth), and 10 (Annika Mangold-Döring), worked on a review article under the supervision of the supervisors (Anna Sobek, Paul van den Brink, Andreu Rico) and an invited expert from the field (Michelle Jackson, Oxford University). This review article (https://doi.org/10.1111/gcb.15971) has been published in Global Change Biology in November 2021, focussing on the combined effects of heatwaves and micropollutants on various trophic levels in freshwater ecosystems, including microbial communities. A scoping review (Munn et al., 2018) was performed to gather the available knowledge on the impact of heatwaves alone and in combination with micropollutants on different trophic levels within freshwater ecosystems and identify potential knowledge gaps. Initially, data on the effects of heatwaves on different trophic levels in freshwater systems was assembled, interpretated, and transformed into information on effects on entire food webs (Fig. 4).

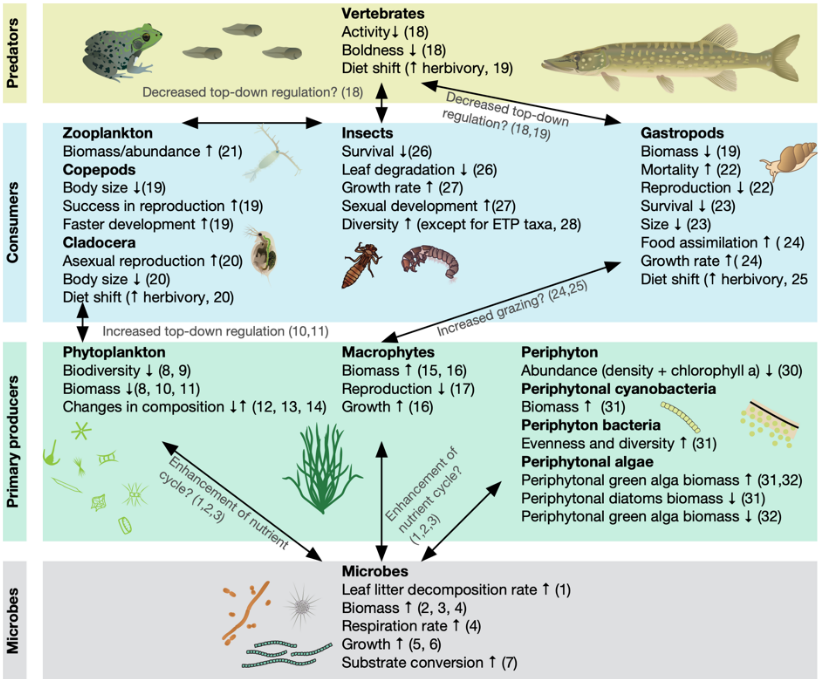

Figure 4. Graphical representation synthesizing the results found in the literature on the effects of heatwaves on aquatic food- webs. Arrows connecting different organism groups indicate trophic and/or indirect effects. Upward arrows indicate an increase/raise and downward arrows indicate a decrease of the evaluated ecological parameter. Numbers in brackets refer to references: (1) Duarte et al. (2013), (2) Donnelly et al. (1990), (3) Fernandes et al. (2012), (4) Stelzer et al. (2003), (5) Zeng et al. (2014), (6) Zamarreño et al. (2009), (7) Höfle (1979), (8) Remy et al. (2017), (9) Egger et al. (2012), (10) Velthuis et al. (2017), (11) O'Connor et al. (2009), (12) Maazouzi et al. (2008), (13) Bergkemper and Weisse (2017), (14) Weisse et al. (2016), (15) Bertani et al. (2016), (16) Hansson et al. (2020), (17) Li et al. (2017), (18) Mameri et al. (2020), (19) Carreira et al. (2016), (20) Nguyen et al. (2020), (21) Johnsen et al. (2020), (22) Cremona et al. (2020), (23) DeWhatley and Alexander (2018), (24) Leicht and Seppälä (2019), (25) Carreira et al. (2020), (26) Zhang et al. (2020), (27) Vander Vorste et al. (2017), (28) Prato et al. (2008), (29) Fornaroli et al. (2020), (30) Hao et al. (2020), (31) Piggott et al. (2015), (32) Bondar- Kunze et al. (2021)

Further, it was looked in detail into the potential consequences of the effects of both stressors, heatwaves and micropollutants in combination, on the individual trophic levels (1), microbial communities, (2) primary producers, (3) consumers, and (4) predators.

Findings revealed that microbial communities living in aquatic environments, are exposed to complex mixtures of micropollutants (Escher et al., 2020), still it remains unknown how these communities might react towards additional extreme event stressors, such as heatwaves. Several fluxes and processes, e.g., degradation, nutrient cycling, or growth, may be disturbed by the effects of both stressors, i.e., heatwave and micropollutants, applied in combination (Fig. 5). Studies have shown that exposure to heatwaves alone may shift entire community compositions and may, possibly, increase the sensitivity towards chemical stressors. This study emphasises the importance of the ecological functions of microbial communities for the entire ecosystem and highlights that the ability of microbial communities to recover from and their resilience towards extreme climate events is still understudied but urgently needed to help identify their thresholds in a changing climate (Bardgett and Caruso, 2020).

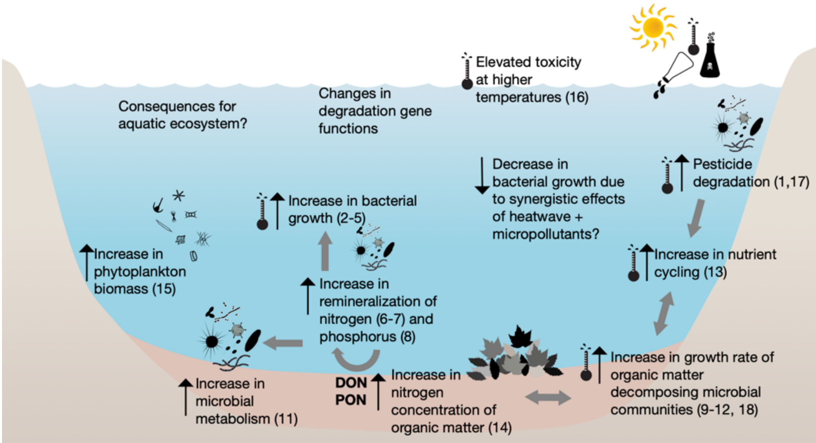

Figure 5. Conceptual overview of the potential combined effects of heatwaves and chemicals on microbial communities. Black upward or downward arrows indicate an increase or decrease of the respective processes. Grey arrows indicate direct and indirect effects on other processes. The thermometer symbol indicates an effect related to temperature only, whereas the symbols of the thermometer and of the chemical together indicate a combined effect of both. (1) Bighiu & Goedkoop (2021), (2) Zeng et al. (2014), (3) Zamarreño et al. (2009), (4) Höfle (1979), (5) White et al. (1991), (6) Berthelot et al. (2019), (7) Hayes et al. (2019), (8) Klausmeier et al. (2004), (9) Duarte et al. (2013), (10) Donnelly et al. (1990), (11) Stelzer et al. (2003), (12) Fernandes et al. (2012), (13) Phillips et al. (2017), (14) Kaushik and Hynes (1971), (15) Pomeroy and Wiebe (1988), (16) Delnat et al. (2021), (17) Wickham et al. (2020), and (18) Arias Font et al. (2021)

4. Effects of global climate change on the human exposure of chemicals from the Swedish environment

As part of the ECORISK secondment of ESR 9 (Sabrina Roth) at the Swedish Environmental Protection Agency (November – December 2021), a literature review is currently in progress to gather and synthesize information on future human exposure to chemicals occurring in the environment and how these exposures may be influenced by climate change. This literature review will help to synthesise data for a modelling component that will be used to establish the prediction of three different future scenarios in Sweden. This project is a cooperation with the Swedish Environmental Protection Agency (Naturvårdsverket) which has been added as ECORISK partner to the consortium in October 2021.
The review envisions to cover the following subsections: 1) indoor air quality, 2) flooding, 3) droughts, 4) landslides, 5) pesticide use, 6) environmental toxins in food, and 7) UV radiation.

In the scope of global climate change, the temperatures in Sweden are expected to rise by 3-6°C until 2100 (Eklund et al., 2015). In an emission model used by Kong and colleagues (2014) (Kong et al., 2014), changing temperature was identified as the most important driving factor of chemical emissions by climate change. The authors predicted an increase of chemical concentrations in air by a factor of up to 2.8 caused by increased temperature (Kong et al., 2014). Researchers conclude that climate change is likely to increase the human exposure to chemicals originating from agriculture (Boxall et al., 2009). Climate change is not only likely to modify the essential organisation and ecosystem functioning of environmental systems, but it is also highly likely affecting the mobility and harmfulness of chemical pollutants (Noyes et al., 2009).

In Northern Europe as a whole, future precipitation is projected to increase on average (Jacob et al., 2014; Strandberg et al., 2015), and flood events may result not only in the chemical contamination of surface waters, but also carry the contamination also further on to both soil or ground water (Cozzani et al., 2010).

As per the European Environmental Agency (EEA), in most of Europe droughts are expected to occur more frequently with higher intensity and duration in the future (Campana et al., 2018; "European Drought Centre," 2021). During droughts, more oxygen can enter soils which leads to more oxidation of organic matter and reduction of inorganics (e.g., sulfides) (Stirling et al., 2020). This oxidation causes acidification of the soil, mobilizes metals, and negatively impacts the water quality (Stirling et al., 2020).

Additionally, with raising temperatures, the pesticide applications are expected to increase together with growing crop pest pressures after milder winters (Reilly et al., 2001). Although warmer temperatures may reduce the risk caused by pesticides, the general impact of higher temperatures is likely leading to the application of higher pesticide volumes and (Delcour et al., 2015) doses, frequency of application, or different varieties of pesticide types (Bloomfield et al., 2006; Goel et al., 2005; Hall et al., 2002; Miraglia et al., 2009; Noyes et al., 2009; Rosenzweig et al., 2001). Thus, the changing climate and the rising temperatures that come with it, is likely to increase the pesticide exposure (Choudhury and Saha, 2020) not only to the direct environment but also in higher trophic levels at the end of the food chain (Delcour et al., 2015).

Furthermore, the global radiation in Sweden is increasing by 0.3% per year and the average solar radiation in Sweden has increased by 8% since the mid 1980s from 900 kWh/m2 (1985) to 1 000 kWh/m² (2016)(SMHI, n.d.). With an increasing solar radiation, children and adults are likely to use more sunscreen, making them prone to extended exposure towards sunscreens. Sun protecting cosmetics contain several substances, including UV filters, perfumes and preservatives, of which many may contain allergenic properties (de Groot and Roberts, 2014).

This review aims to give an understanding of how the human exposure towards chemicals may be impacted by Global Climate Change in Sweden.

Contributing:

Stockholm University, Anna Sobek

Fundación Imdea Agua, Andreu Rico

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