Our experiment highlights the profound impact of recurring HWs on the resilience of aquatic communities. Our findings align with the growing body of literature reporting the detrimental effects of HWs on aquatic ecosystems (Hermann *et al.* 2023, 2024; Polazzo *et al.* 2022; Ross *et al.* 2021). Critically, we show that a series of three, repeated HWs can erode the resilience of phytoplankton communities in freshwater ecosystems.

The observed trends in dissolved oxygen (DO) levels suggest a pattern of critical slowing down, indicated by the gradual reduction in recovery trajectory with repeated disturbances that eventually determined an erosion of resilience (Veraart et al. 2012). It should be noted that the positive value of resilience after the second HW, was only determined by the high DO concertation on day 10, which resulted in a positive resilience value as DO concentration on day 24 at the same level as in the control mesocosm, but we overall observed a gradual decline in DO after each HW (Fig. 2a).

Chlorophyll – *a*, on the other hand, showed a decline in concentration, as well as in resilience after each HW. The steady decline in resilience after every HW event, suggests an impaired recovery potential for chlorophyll – *a,* and thus aligns with the critical slowing down hypothesis. A recent experiment found that chlorophyll – *a* was actually increased by a first HW, but then returned to control level after a second HW (Huỳnh *et al.* 2024). The different responses of chlorophyll – a in Huỳnh *et al.* (2024) and our study may be related to the intensity of the HW treatment. Indeed, we applied a temperature difference of +8°C in the HW treatment, whereas a difference of +6°C was applied in Huỳnh *et al.* (2024). Additionally, the maximum temperature in the HW mesocosms in our study was 36 °C, whereas it never reached 32 °C in Huỳnh *et al.* (2024). The difference in absolute temperature may have determined the larger decline and loss of resilience in chlorophyll – a in our study, as the higher stress could have led to a larger reduction in the photosynthetic activity of phytoplankton. Yet, our results align with those of Veraart *et al.* (2012), where a gradual decline in photosynthetic activity was found in a phytoplankton species exposed to an increasing level of stress.

Phytoplankton biomass exhibited a less clear response. During and after the first HW, phytoplankton biomass declined. The biomass decline was associated to a significant compositional change after the first HW (day 10), and a loss of resilience. Yet, after the second HW, phytoplankton biomass recovered to control level, and no compositional difference was note between control and HW on day 24. The compositional similarity between communities in the control and HW mesocosms on day 24 suggests that after the first HW, which caused a significant change in composition, phytoplankton community composition recovered and was undistinguishable from the control. This recovery in biomass and composition determined an increased in resilience, suggesting a possible community rescue. However, the third HW determined a decline in biomass which was associated to a significant compositional turnover, and to reduced resilience. Particularly towards the end of the experiment, the compositional dissimilarity was driven by a significant reduction in the biomass of Cryptophyta, Dinophyta, and Chlorophyta in the HW treatment. The new community composition did not promote stress-tolerant species able to maintain phytoplankton biomass and increase resilience, as testified by the decline of both biomass and resilience. Although community rescue is usually linked to a strong compositional change, this compositional change should determine an increased resistance to stress and consequent ability to maintain community biomass and restore resilience (Fugère *et al.* 2020). Since we found the opposite (i.e. compositional change determined a decline in resistance to following HW and decline in biomass), we exclude that any rescue process happened in our experiment.

On the contrary, the increased compositional dissimilarity, linked to the reduced resilience, rather supports the critical slowing down hypothesis. Indeed, critical transitions to alternative stable states are often related to dramatic shifts in composition (Bertani *et al.* 2016; Meunier *et al.* 2024; Wernberg *et al.* 2016). The classic example is the shift from clear water state dominated by macrophyte to a turbid water state dominated by phytoplankton in shallow lakes (Scheffer 2009). The compositional shift is a common feature of critical transition across ecosystems and has been reported in marine (Meunier *et al.* 2024) and terrestrial systems (Eby *et al.* 2017). Hence, our study aligns with the body of literature describing a strong compositional shift which relates to dramatic changes in community biomass that may result in critical transitions (Eby *et al.* 2017; Meunier *et al.* 2024).

Ultimately, the response of phytoplankton to an HW depends on the thermal sensitivity of the species composing the community (Polazzo *et al.* 2022), and on the interactions between species that are established during and after the HW (Huỳnh *et al.* 2024; Polazzo *et al.* 2023; Seifert *et al.* 2015). In our experiment, although the intensity defined as the temperature difference between the HW treatment and the control was +8 °C for all HW events, the temperature in the control increased as we progressed from April to July. This resulted in the HWs having different absolute temperature. The strong decline in biomass and chlorophyll – *a* after the third heatwave may have been determined by the higher portion of species unable to cope with the stress posed by another, stronger HW. Despite the cumulative stress caused by recurring HWs, the intensity of an HW has been shown to impact differently planktonic communities not only during, but especially after the HW event (Seifert *et al.* 2015).

Yet, also a change in zooplankton activity could have contributed to the decline in phytoplankton biomass and chlorophyll - *a*. Although, the recurring HWs did not significantly affect zooplankton biomass or composition, at the end of the experiment mesocosms exposed to the recurring HWs had a larger proportion of Cladocera compared to control mesocosms. Cladocera are much more efficient grazers than Copepods and Rotifers (Sommer *et al.* 2002), and an increase in Cladocera may have resulted in an increased grazing, and thus stronger top-down control on primary producers, contributing to the overall phytoplankton biomass decline. A decline in Copepods and an increase in Cladocera is opposite to what was recently found in another freshwater mesocosm experiment, where Copepods increased after two consecutive HWs, leading to an overall weaker top-down control (Huỳnh *et al.* 2024). However, an increase in small Cladocera was reposted in another experiment where a zooplankton community was exposed to a HW of similar duration and intensity (Roth *et al.* 2022).

Overall, we highlight that it is not necessary for a community to tip in order to show a slowing down in recovery. van Nes & Scheffer (2007) suggested that critical slowing down may not only be related to a critical transition or tipping points but could also generically indicate a reduced tolerance of the system to repeated perturbations. Critical slowing down may thus provide important information in cases where the threshold leading to a critical transition has not yet been reached, thus working as an EWS, and may be informative for systems that do not have multiple stable states at all.

In conclusion, we show here that the repeated stress caused by increasingly stronger HWs led to a drastic change in the composition of the phytoplankton community. The new compositional configuration was unable to maintain and / or recover photosynthetic activity or biomass levels like unperturbed systems, suggesting an overall increase in vulnerability to subsequent perturbations. These results force us to evaluate the consequences of climate change-induced extreme weather events on the functioning of communities and ecosystems, particularly as they become more recurrent and severe in the near future.