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# Effects of changing climate on European stream invertebrate communities: A long-term data analysis

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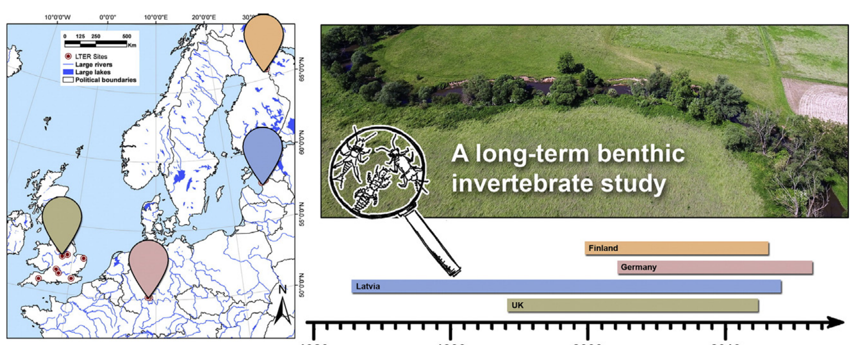
## HIGHLIGHTS

- We examined the effects of climate change on benthic invertebrate communities.
- Stronger effects of previous year climatic conditions than gradual changes over time
- No changes in overall abundance and number of taxa, but taxon-specific changes
- Stronger impact of temperature on sensitive taxa in agricultural regions
- Changing climatic conditions associated with changes in feeding group composition

## GRAPHICAL ABSTRACT

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## ABSTRACT

Long-term observations on riverine benthic invertebrate communities enable assessments of the potential impacts of global change on stream ecosystems. Besides increasing average temperatures, many studies predict greater temperature extremes and intense precipitation events as a consequence of climate change. In this study we examined long-term observation data (10–32 years) of 26 streams and rivers from four ecoregions in the European Long-Term Ecological Research (LTER) network, to investigate invertebrate community responses to changing climatic conditions. We used functional trait and multi-taxonomic analyses and combined examinations of general long-term changes in communities with detailed analyses of the impact of different climatic drivers (i.e., various temperature and precipitation variables) by focusing on the response of communities to climatic conditions of the previous year. Taxa and ecoregions differed substantially in their response to climate

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change conditions. We did not observe any trend of changes in total taxonomic richness or overall abundance over time or with increasing temperatures, which reflects a compensatory turnover in the composition of communities; sensitive Plecoptera decreased in response to warmer years and Ephemeroptera increased in northern regions. Invasive species increased with an increasing number of extreme days which also caused an apparent upstream community movement. The observed changes in functional feeding group diversity indicate that climate change may be associated with changes in trophic interactions within aquatic food webs. These findings highlight the vulnerability of riverine ecosystems to climate change and emphasize the need to further explore the interactive effects of climate change variables with other local stressors to develop appropriate conservation measures.



## 1. Introduction

Ongoing global climate change is regionally specific, but generally characterized by increasing global mean temperature and changing precipitation patterns, coupled with an increasing frequency of extreme temperature and precipitation events (Coumou and Rahmstorf, 2012; IPCC, 2014). While increasing temperatures may have long-term effects on riverine ecosystems, an increasing frequency of extreme weather events may have more immediate consequences for such ecosystems (Leigh et al., 2015). For example, a change in timing and a higher frequency of floods and droughts is changing the flow regime of rivers significantly (Blöschl et al., 2017; Daufresne et al., 2007; Feyen and Dankers, 2009; Hirabayashi et al., 2013) leading to severe consequences on the structure of riverine and riparian ecosystems (Bunn and Arthington, 2002; Lytle et al., 2017; Tonkin et al., 2017b; Woodward et al., 2016). Higher frequencies of extreme events may therefore have greater impacts on stream biota than steady changes in temperature and precipitation (Death, 2010; Lake, 2000; Mouthon and Daufresne, 2006).

Long-term biomonitoring is crucial to identify actual and potential trajectories of climate change effects on communities (Jackson and Fuereder, 2006; Parmesan and Yohe, 2003) and especially to disentangle the effect of steady changes and immediate response to recent climatic conditions and extreme events. A previous long-term study on stream invertebrate communities in the UK revealed that total abundance tended to decline over time in response to increasing winter temperatures (Durance and Ormerod, 2007). However, the authors found contrasting effects of rising temperature on communities depending on local conditions (Durance and Ormerod, 2007). Recent findings by Bowler et al. (2017) demonstrated that long-term shifts in aquatic communities due to climate change were less predictable than in terrestrial communities, indicating that complex interactions in the riverine multiple stressor context may explain different responses of freshwater communities. Similar observations were made in large rivers in France where a transition towards generalist and tolerant (often invasive) species was observed (Floury et al., 2013). This transition, however, was partially confounded by local improvement in water quality that explained the settlement of new pollution-sensitive taxa (Floury et al., 2013). To date, most studies on the ecological effects of climate change have focused on long-term changes in average conditions, while the implications of altered climate extremes remains poorly understood despite being key drivers of ecological change (Smith, 2011).

The mechanisms by which climate change affects invertebrate communities will depend on many factors including species traits (e.g. thermal preferences), and regional conditions (Easterling et al., 2000; Jähnig et al., 2017). For example, communities in mountainous regions with lower temperatures and/or higher flow velocity are more likely to experience loss of taxa and range reductions resulting from increasing temperatures and reduced flow (Buisson et al., 2008; Domisch et al., 2011; Poff et al., 2010; Sauer et al., 2011). Similarly, cold stenotherm taxa in the colder regions of Europe might be negatively affected by increasing temperatures as they lack northern refuges, while eurytherm taxa might benefit from changing thermal conditions and be able to expand their range (Hering et al., 2009; Jyväsjärvi et al., 2015). Climate change and extreme events may also influence the quality and quantity of feeding resources and thus specifically affect certain trophic guilds (functional feeding groups; FFGs). Changes in the trophic composition of invertebrate communities could adversely affect aquatic food webs and ecosystem functioning. To investigate the response at different levels of biological organization, a multi-taxa approach incorporating the ecological role of each taxa is essential (Woodward et al., 2010).

Here we combined taxonomic richness and species abundance metrics, sensitivity metrics (i.e., biomonitoring indices), and functional metrics (Feld and Hering, 2007; Hering et al., 2004) to analyze the community response to changing climate. Similar to previous studies we considered overall taxonomic richness and abundance (e.g., Durance and Ormerod, 2007; Floury et al., 2013; Hallmann et al., 2017; Vaughan and Ormerod, 2012). Furthermore, we investigated the response of changes in numbers and abundance of widespread freshwater insects (Ephemeroptera, Plecoptera and Trichoptera; EPT-taxa), that are known to be susceptible to a broad variety of stressors (Hering et al., 2004; Piggott et al., 2012). Foremost, sensitive groups like Plecoptera are expected to be vulnerable to warming temperatures, since they show frequent cold-adaptation and have very narrow environmental tolerances (Fochetti and de Figueroa, 2006; Pritchard et al., 1996; Tierno de Figueroa et al., 2010). Additionally, we analyzed classic sensitivity metrics like saprobic indices (Rolauffs et al., 2004; Zelinka and Marvan, 1961) and the ASPT (Average score per taxon, an index of the Biological Monitoring Working Party, see Armitage et al., 1983) that have traditionally been used in the European Union to assess the organic pollution of streams (Hering et al., 2004). These metrics are also expected to be affected by climate change, as increased temperatures can reduce oxygen concentrations in water (Verberk et al., 2016). Finally, we considered FFGs, as previous studies have suggested that climate change has the potential to modify their composition (e.g., by affecting detrital decomposition rates or algal consumption; Pyne and Poff, 2017). Detrital shredders and algal grazers were suggested to be disproportionately vulnerable to projected thermal warming and streamflow reductions (Pyne and Poff, 2017), probably because many of these taxa belong to cool-adapted taxa that may be close to their thermal maxima (Boyero et al., 2012). Additionally, invasive species might displace congeneric native species, without being functionally redundant (as shown for amphipods: Bacela-Spychalska and van der Velde, 2013; Jourdan et al., 2016). A change in FFGs could therefore induce a strong effect on energy flow dynamics of the stream detritus-based food web (Graça, 2001; Pyne and Poff, 2017), indicating the vulnerability to climate change also at a functional level.

In our study, we investigated the long-term responses of benthic invertebrate communities to climate change and examined the short-term responses of these communities to the climatic conditions (and extreme events) experienced over the year leading up to sampling. We used data from 26 sampling sites within the Long-Term Ecological Research (LTER) network (Haase et al., 2016; Mirtl et al., submitted) located in four European countries, where benthic invertebrates were surveyed annually for between 10 and 32 years. We used a set of 20 different metrics to cover responses at different levels of biological