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Multiple-stressor effects on stream macroinvertebrate communities: A mesocosm experiment manipulating salinity, fine sediment and flow velocity

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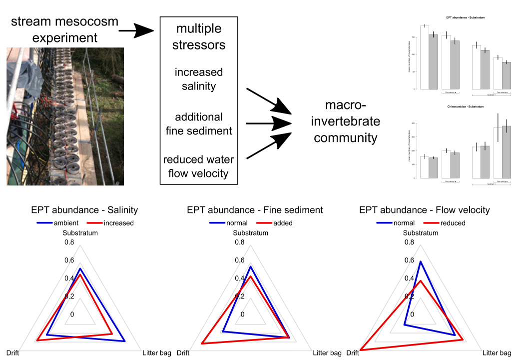
HIGHLIGHTS

- Multiple stressor effects on stream invertebrate communities are poorly understood.
- We tested effects of three globally important stressors in a field experiment.
- Increased salinity, added sediment and reduced flow affected many invertebrates.
- Stressor responses can vary across microhabitats.
- Multiple stressors may interact, often in unpredictable ways.

GRAPHICAL ABSTRACT



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ABSTRACT

Stream ecosystems are impacted by multiple stressors worldwide. Recent studies have shown that the effects of multiple stressors are often complex and difficult to predict based on the effects of single stressors. More research is needed to understand stressor impacts on stream communities and to design appropriate counteractions. We carried out an outdoor mesocosm experiment to assess single and interactive multiple-stressor effects on stream macroinvertebrates in a setup with controlled application of three globally important stressors, namely, reduced stream flow velocity, deposition of fine sediment and increased chloride concentration in a full-factorial design. Each mesocosm comprised three compartments (channel substratum, leaf litter bag and drift net) that were individually analyzed and also compared. We identified 102,501 specimens in total (mainly to family level), 36.5% of which were found in the substratum, 60.6% in litter bags and 2.9% in the drift. Added fine sediment and reduced flow velocity had strong negative single-stressor effects on the abundances of EPT taxa, i.e. Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies), and a positive effect on chironomid abundances in the substratum. Increased salt concentration reduced abundances of Ephemeroptera. Chironomids migrated from litter bag to channel substratum when water velocity was reduced and Leptophlebiidae in the opposite direction when sediment was added. All three stressors caused higher drift propensities, especially added fine sediment.

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Both additive and complex multiple-stressor effects were common. A complex three-way interaction affected EPT richness in the substratum, demonstrating the need to evaluate higher-order interactions for more than two stressors. Our results add further evidence that multiple-stressor interactions, notably increased salinity with other stressors, affect a variety of invertebrate taxa across different habitats of stream communities. The results have direct implications for water management as they highlight the need to re-evaluate defined salinity thresholds in the context of multiple-stressor interactions.

1. Introduction

Freshwater ecosystems are disproportionately threatened by biodiversity loss compared to terrestrial and marine ecosystems (Sala et al., 2000). This loss has direct consequences for freshwater ecosystem services and human wellbeing (Dudgeon et al., 2006; Vörösmarty et al., 2010). Halting and reversing the degradation of freshwaters is therefore an urgent challenge, but doing so requires a thorough understanding of the causal links between anthropogenic stressors and their biological consequences. A main concern in this context is that multiple stressors mostly act in concert when impacting biodiversity in stream ecosystems (Ormerod et al., 2010). For example, land-use change has led to increased hydromorphological pressures along with increased nutrient and sediment influxes and pollution (Foley et al., 2005). These effects are further modified by global climate change leading to alterations in discharge patterns (e.g., intermittent flows) and temperature. While the effects of individual stressors on stream biota have been investigated in many studies, a growing body of research has shown that the effects of single stressors can be altered in complex ways in the presence of other stressors, leading to ecological surprises (Jackson et al., 2016; Ormerod et al., 2010). Therefore, understanding the interactive effects of multiple stressors remains a central challenge in both ecological science and management.

A number of studies have investigated the effects of several globally important stressors, such as deposited fine sediment, eutrophication, flow velocity reduction, influx of pesticides or temperature increase on stream biota (e.g., Liess and von der Ohe, 2005; Matthaei et al., 2010; Piggott et al., 2012, 2015b; Rasmussen et al., 2012) and ecosystem function (Bruder et al., 2016; Piggott et al., 2015a). Agriculturally derived fine sediment is known to affect streams by filling open gravel matrices (Soulsby et al., 2001), leading to a decline in habitat quality (Wood and Armitage, 1997), changing community composition and increasing the propensity of animals to drift (Larsen and Ormerod, 2010; Rosenberg and Wiens, 1978). In particular, species richness and densities of pollution-sensitive taxa belonging to the insect orders Ephemeroptera, Plectoptera and Trichoptera (EPT) often decline upon fine sediment addition (reviewed in Jones et al., 2012), whereas increased abundances can be observed for some taxa such as chironomids (Kreutzweiser et al., 2005). Erosion and sedimentation are directly dependent on stream water flow velocity. Thus, a reduction in flow velocity causes fine particles in suspension to deposit.

Reduced flow alone (due to abstraction for irrigation or hydroenergy generation) can also cause a decrease in stream habitat conditions and species densities and richness (reviewed by Dewson et al., 2007). The combined effects of deposited fine sediment and reduced flow have been investigated in a multiple-stressor context in two recent experiments, which reported mainly negative synergistic (Matthaei et al., 2010; New Zealand) or negative additive combined effects (Elbrecht et al., 2016; Germany) on invertebrate responses such as total EPT abundance as well as abundances of common mayflies and chironomids.

Secondary salinization of rivers is a globally important stressor that is likely to be amplified by climate change (Cañedo-Argüelles et al., 2013). This anthropogenic increase in salinity is due to irrigation, mining and/or use of deicing agents and can affect osmoregulation, oxygen consumption and growth rates of aquatic organisms (reviewed by Cañedo-Argüelles et al., 2016; Cañedo-Argüelles et al., 2013). Many aquatic macrophytes and aquatic invertebrates are sensitive to changes in salinity (Hart et al., 1991), and macroinvertebrate communities have been shown to change as a result of salinization (e.g., Braukmann and Bohme, 2011; Horrigan et al., 2005; Piscart et al., 2005). Despite the growing awareness of salinization as a threat to stream communities and ecosystems, its effects in the context of multiple stressors are largely unknown.

To address this knowledge gap, we investigated the individual and interactive effects of increased salt (chloride) concentration, deposited fine sediment and reduced water flow velocity on macroinvertebrate community dynamics in a full-factorial, outdoor stream mesocosm experiment. We assessed responses of the macroinvertebrate communities inhabiting the benthic substratum (compartment 'channel substratum') and in leaf litter bags (compartment 'litter bag') to characterize the behavioural dynamics of organisms moving between these microhabitats in response to stressors. Further, we quantified the propensity of invertebrates to drift after stressor application, a key behavioural response to stressor impacts (e.g., Gibbins et al., 2007; Magbanua et al., 2016).

Based on the aforementioned studies, we tested three single-stressor hypotheses:

1. Increased salinity will enhance the propensity of salt-sensitive invertebrate taxa such as mayflies to drift out of the mesocosms, resulting in reduced abundances in mesocosm substrata and litter bags.
2. Deposited fine sediment will result in strong community shifts in the substratum due to infilling of interstitial spaces, whereas surface-dwelling litter bag communities will be less affected.
3. Reduced flow velocity will negatively impact invertebrate communities in both compartments.

We further tested whether the effects of increased salinity together with other stressors resulted in independent (i.e. additive) or interactive (i.e. synergistic or antagonistic) multiple-stressor effects, to determine stressor combinations of greatest management concern.

2. Materials and methods

2.1. Study site

The experiment ran for 46 days in the Boreal spring from 8 March to 22 April 2014 in outdoor stream mesocosms located beside the Felderbach (Germany, North Rhine-Westphalia, 51°20′59.09″N, 7°10′14.03″E, 136 m a.s.l.). During spring, agricultural activities (the ultimate cause of two of the three manipulated stressors, sedimentation and water abstraction) are higher compared to autumn or winter. The Felderbach is a fairly natural, second-order Central European 'type 5' stream (small coarse material dominated upland streams; Sommerhäuser and Pottgiesser, 2005). While the riparian vegetation of the stream's upper reaches consists predominately of alder trees (*Alnus* sp.), the middle reaches, where the experiment was conducted, are dominated by grassland. The stream's mean nitrate concentration is 3.62 mg/L (SD ± 1.53; ELWAS-Web (http://www.elwasweb.nrw.de/, accessed 21.07.2016), LANUV, 2001–2013, n = 24), the mean ammonium concentration 0.07 mg/L (SD ± 0.09; ELWAS-Web, LANUV, 2001–2013, n = 24) and the mean