Science of the Total Environment 593–594 (2017) 27–35

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Additive effects prevail: The response of biota to multiple stressors in an intensively monitored watershed

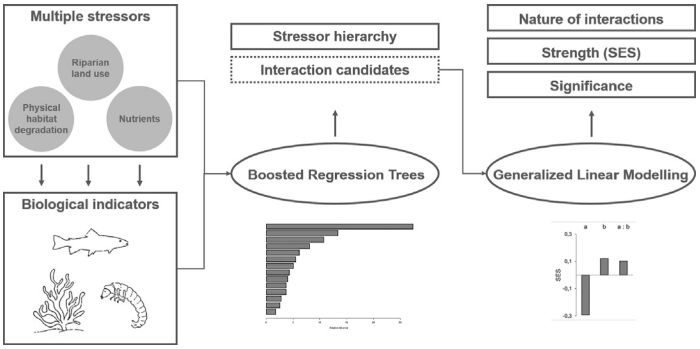
Alexander Gieswein *, Daniel Hering, Christian K. Feld

Department of Aquatic Ecology, Faculty of Biology, University of Duisburg-Essen, Universitätsstrasse 5, D-45141 Essen, Germany

HIGHLIGHTS

- Multiple stressors have serious negative effects on river biota, particularly if stressors interact.
- Quantified stressor effects and interactions can help river basin managers to derive suitable management actions.
- Biological and abiotic data resulting from monitoring schemes provide a solid basis to disentangle multiple-stressor effects.
- We investigated the hierarchy and interactions of anthropogenic stressors using standard WFD monitoring data.
- Stressor interactions were rare and weak, thus implying independently-acting stressors.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 19 January 2017
Received in revised form 10 March 2017
Accepted 11 March 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Multiple stressors
Interactions
Monitoring data
Riverine ecosystems
Boosted Regression Trees
Generalised Linear Modelling

ABSTRACT

Freshwater ecosystems are impacted by a range of stressors arising from diverse human-caused land and water uses. Identifying the relative importance of single stressors and understanding how multiple stressors interact and jointly affect biology is crucial for River Basin Management.

This study addressed multiple human-induced stressors and their effects on the aquatic flora and fauna based on data from standard WFD monitoring schemes. For altogether 1095 sites within a mountainous catchment, we used 12 stressor variables covering three different stressor groups: riparian land use, physical habitat quality and nutrient enrichment. Twenty-one biological metrics calculated from taxa lists of three organism groups (fish, benthic invertebrates and aquatic macrophytes) served as response variables. Stressor and response variables were subjected to Boosted Regression Tree (BRT) analysis to identify stressor hierarchy and stressor interactions and subsequently to Generalised Linear Regression Modelling (GLM) to quantify the stressors standardised effect size.

Our results show that riverine habitat degradation was the dominant stressor group for the river fauna, notably the bed physical habitat structure. Overall, the explained variation in benthic invertebrate metrics was higher than it was in fish and macrophyte metrics. In particular, general integrative (aggregate) metrics such as % Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa performed better than ecological traits (e.g. % feeding types). Overall, additive stressor effects dominated, while significant and meaningful stressor interactions were generally rare and weak.

We concluded that given the type of stressor and ecological response variables addressed in this study, river basin managers do not need to bother much about complex stressor interactions, but can focus on the prevailing stressors according to the hierarchy identified.

---

* Corresponding author.
E-mail address: alexander.gieswein@uni-due.de (A. Gieswein).

http://dx.doi.org/10.1016/j.scitotenv.2017.03.116

1. Introduction

Worldwide, freshwater ecosystems are increasingly exposed to multiple human induced stressors arising from various land and water uses (Allan, 2004; Ormerod et al., 2010; Tockner et al., 2010; Schinegger et al., 2012, 2016; Hering et al., 2015). There is increasing evidence of the prevalence and biological effects of multiple stressors from marine ecosystems (Crain et al., 2008; Darling and Côté, 2008; Ban et al., 2014; Côté et al., 2016) and freshwater ecosystems (see Jackson et al., 2016, for a recent review). Understanding the biological response to multiple stressors, however, is not straightforward (Townsend et al., 2008) and constitutes one of the main challenges for aquatic ecosystem managers at present (Hering et al., 2015).

When acting in concert, multiple stressors literally form a “cocktail” of stressors, with often serious adverse effects on ecosystems integrity and biological diversity (Townsend et al., 2008; Ormerod et al., 2010). Besides the stressors additive (i.e. individual) effects, it is their potential interaction that bothers ecosystem managers and conservationists. Multiple stressors can interact in unexpected ways (Folt et al., 1999), either reducing (antagonism) or amplifying (synergism) the individual effects of each stressor (Crain et al., 2008; Piggott et al., 2015b), which may lead to unexpected results after management (Townsend et al., 2008).

Multiple stressors vary in their intensities and exhibit different impacts on the aquatic biota (e.g. Feld, 2013). For example, water quality deterioration in course of organic pollution directly affects the freshwater fauna, but not the flora, through oxygen depletion following bacterial decay of organic waste. In contrast, nutrient enhancement directly promotes biomass production (flora), but only indirectly affect the fauna through secondary saprobity following the aerobic decay of the biomass by bacteria (Johnson and Hering, 2009). Consequently, multiple stressor interactions are conditional on the individual stressors selected, the stress level of each stressor and the biological response indicator (Côté et al., 2016; Jackson et al., 2016).

The evidences of multiple stressor effects in freshwater systems is primarily based on experimental studies (e.g. Townsend et al., 2008; Matthaei et al., 2010; Wagenhoff et al., 2012, 2013; Piggott et al., 2012, 2015a; Jackson et al., 2016). There is no doubt that experiments helped to improve our knowledge about the mechanisms behind multiple stressor interactions. However, owed to the controlled conditions and the limited number of stressors manipulated, experiments do not reflect the real multiple stressor conditions that threaten freshwater ecosystem integrity at the continental scale (e.g. EEA, 2012b). Moreover, the data derived from broad-scale freshwater monitoring schemes (Birk et al., 2012) is different from experimental data with regard to the level of detail and temporal resolution of measurements. Often, stressors at the reach scale (e.g., nutrient concentration) are mixed with broad-scale proxy variables (e.g., % agriculture in the catchment), which also introduces a mismatch of spatial scales. Irrespective of this mismatch of experimental and survey data, the implementation of the Water Framework Directive (WFD, European Commission, 2000) has resulted in data of ~120,000 surface water bodies (EEA, 2012a), which constitutes an unprecedented asset for multiple-stressor analysis in applied aquatic ecology.

Against this background, disentangling multiple stressors using survey data can be considered a challenge, which scientists and practitioners in river basin management need to meet. More knowledge is required in order to set up effective programmes of measures for Europe's waters. For instance, stressors acting additively can be managed hierarchically, i.e. management can address the stressors in order of their adverse effects on ecology (Brown et al., 2013). However, if stressors interact, management options are different and may not simply follow a hierarchical order, but require the joint management of stressors.

The main objective of our study was to test, if data resulting from monitoring schemes can be used to identify multiple stressors and to disentangle their effects on the aquatic flora and fauna. More specifically, we aimed to identify the stressor's hierarchy and interactions, both of which are crucial aspects to identify the hierarchical order and spatial extent of appropriate management options. We used data on fish, benthic invertebrates and aquatic macrophytes to compare the effects of stressors on different assemblage types and we applied traits, ecological metrics and biological indices to test for differences between structural and functional biological response variables. The statistical analyses followed the recently published cookbook on multiple-stressor analysis using survey data (Feld et al., 2016b) and is organised in two analytical steps: (i) investigation of stressor importance in order to determine the stressor hierarchy and (ii) identification of potential pairwise interactions between stressors, to determine the nature (antagonistic or synergistic), strength (standardised effect size) and significance (explained variance, *p*-value) of interactions.

2. Materials and methods

2.1. Study area

The study area comprised the mountainous catchment of the River Ruhr in Western Germany, Europe (Fig. 1). The Ruhr Basin covers a drainage area of 4485 km^2, with a stream network length of about 7000 km (main Ruhr course: 219 km). The entire catchment has a siliceous geology (mainly slate and schist) and is characterized by small to mid-sized fine to coarse substrate-dominated highland streams. Land cover is dominated by non-native coniferous forest and remnants of natural deciduous forest at the upper parts of the Basin, with agriculture and urbanization predominantly occurring in larger valleys (MUNLV, 2005). Even though, the water quality in the Ruhr Basin improved after several decades of heavy pollution (Ruhrverband, 2013), hydromorphology conversely is still degraded in large parts of the catchment. This is mainly due to physical modifications, e.g. operation of hydropower plants withdrawing a substantial portion of the water, bank and bed fixations, straightening, riparian modification and lack of linear connectivity by many barriers (MUNLV, 2005; MKUNLV, 2014).

2.2. Stressor variables

We addressed the impact of 12 environmental predictors belonging to three stressor groups on aquatic biota: (i) riparian land use, (ii) physical habitat quality and (iii) nutrients (Table 1). Biological stressors (e.g., invasive species; Simberloff et al., 2013) were neglected, because invasive species accounted for only 0.6–3% of the total richness of macrophytes, fish and benthic invertebrates, respectively, in our data.

2.2.1. Riparian land use

Riparian land use was evaluated in a 20 m wide (10 m width on either side of the watercourse) and 1000 m long buffer strip upstream of each sampling site. Buffer strips included the main course and its tributaries up to 1000 m, respectively. Sites with buffer lengths <750 m (main course) were excluded from the analyses, because they were too close to the stream source. After spot-checks for quality control, we calculated the percentage of land use (ATKIS®-Basis-DLM, Official Topographical Cartographic Information System, spatial resolution 3 × 3 m) for each buffer using a GIS system. Land use data was grouped into the following categories: arable land, pasture, urban areas, naturally-forested land and non-native coniferous forest. Land use categories with <5% within a buffer were excluded from further analysis to ensure meaningful relationships between land use and biological response variables.

2.2.2. Physical habitat quality

Physical habitat quality data was evaluated according to the North Rhine-Westphalian (West Germany) river habitat survey method (Gellert et al., 2014). The method compares the difference between observed and reference physical habitat conditions and assigns a quality