Ecological Indicators 77 (2017) 293–303

Contents lists available at ScienceDirect

Ecological Indicators

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

Decomposing multiple pressure effects on invertebrate assemblages of boreal streams

Richard K. Johnson[a,*], David G. Angeler[a], Simon Hallstan[a], Leonard Sandin[b], Brendan G. McKie[a]

[a] Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, P.O. Box 7050, SE-750 07, Uppsala, Sweden
[b] Department of Aquatic Resources, Swedish University of Agricultural Sciences, Stångholmsvägen 2, SE-17893 Drottningholm, Sweden

ARTICLE INFO

Article history:
Received 8 August 2016
Received in revised form 25 October 2016
Accepted 14 February 2017
Available online 28 February 2017

Keywords:
Multiple pressures
Macroinvertebrates
Streams
Land use
Disturbance

ABSTRACT

Land use often results in multiple pressures affecting the structure and function of aquatic ecosystems. Understanding how pressures interact to affect the biology of aquatic ecosystems is therefore a major challenge for freshwater management. Using a field survey approach, we studied individual and combined effects of impacts arising from agricultural land use and alteration of hydrology and geomorphology (HYMO) on benthic invertebrate assemblages in boreal streams. Variation partitioning of species and trait composition to pressures characterizing agriculture and HYMO revealed significant joint effects on the biota. Changes in species composition were significantly and uniquely related to agricultural pressures, whilst the variance component characterizing HYMO effects was not significant, confounding separation of unique pressure effects. In line with our predictions, the effects of HYMO on species and trait composition were largely negative. However, in contrast to predictions, ranking pressure variables showed that agricultural impacts explained more of the variability in species composition than HYMO impacts. Disturbance of riparian habitats was a strong predictor of shifts in species and trait composition. Interestingly, community responses were less pronounced at sites affected by both loss of riparian integrity and elevated nutrients, suggesting that HYMO effects were mitigated by moderate levels of elevated nutrients. Collectively, our results showed ecologically realistic, impact-specific changes on biodiversity of riverine environments. This knowledge allows managers to rank the importance of individual and combined pressure impacts when designing rehabilitation strategies.

1. Introduction

Freshwaters are arguably amongst the most heavily degraded habitats on Earth, with pollution, elevated nutrients, habitat degradation and invasive species considered to be the main pressures affecting their biodiversity (e.g. Dudgeon et al., 2006). For effective management of aquatic habitats a multidisciplinary approach is often needed to identify and resolve conflicts associated with land use (Young et al., 2005). Fundamental to ecosystem management is the identification of cause-effect relationships to underpin decisions when managing aquatic resources (Verdonschot et al., 2013). To date, monitoring programmes have largely focused on single impacts on biodiversity and function, such as elevated nutrients and alterations of hydrology and geomorphology. However, there is now a growing concern that chemical, physical and biological stressors can interact synergistically or antagonistically to produce biological responses that cannot be predicted from individual stressors alone (Townsend et al., 2008; Matthaei et al., 2010). This awareness has resulted in an increase in the use of manipulative experiments to disentangle the effects that combinations of stressors may have on stream assemblages (Townsend et al., 2008; McKie et al., 2009; Ormerod et al., 2010). Although laboratory and field experiments are useful for quantifying relatively strong, small-scale effects, they often lack ecological realism and consequently may underestimate persistent, subtle effects (Angeler et al., 2016). To fill this knowledge gap, our study addressed the use of spatially comprehensive monitoring data for separating and ranking the importance of individual and multiple impacts on boreal stream ecosystems.

Agricultural land use is one of the most pervasive pressures affecting the integrity of streams worldwide. Elevated nutrient concentrations result in increased productivity and decreased oxygen

* Corresponding author.
E-mail address: richard.johnson@slu.se (R.K. Johnson).

http://dx.doi.org/10.1016/j.ecolind.2017.02.020
1470-160X/

concentrations (Hynes, 1970; Tonkin and Death, 2012), inputs of fine sediment result in loss of in-stream habitat (Piggott et al., 2012) and water abstraction alters hydrology and connectivity (Lange et al., 2014). A number of recent studies have quantified multiple stressor effects on aquatic ecosystems. For example, manipulating three stressors commonly associated with agricultural land use, Matthaei et al. (2010) found that sediment addition and reduced flow negatively affected algal biomass and community composition of benthic invertebrates, while conversely elevated nutrients resulted in increased abundance of invertebrates, algal biomass and leaf litter decomposition. Besides altering in-stream habitat heterogeneity and food resources, agricultural land use often results in loss of riparian vegetation causing increased water temperature and shifts in community composition (e.g. Johnson and Almlöf, 2016); effects that are expected to worsen in the warmer future (e.g. Woznicki et al., 2016). For example, studying interactions between temperature and other stressors (nutrients, sediments), Piggott et al. (2015) showed that temperature exacerbated the negative effects of sediment on benthic invertebrate assemblages. Collectively, studies have shown that interactions between stressors are common and complex (non additive) and therefore should be considered in riverine management.

Due to their high sensitivity and stress-specific responses to environmental stressors, benthic invertebrate assemblages are commonly used to assess the ecological status of aquatic ecosystems (e.g. Rosenberg and Resh, 1993; Johnson et al., 2007). Moreover, as benthic invertebrate assemblages respond predictably to changes in basal resources and habitat (two common stressors associated with agricultural land use) they are often used in biomonitoring. Traditionally, taxonomic-based approaches using species composition, diversity and biotic indices have been used to gauge anthropogenic impacts (Johnson et al., 1993; Bonada et al., 2006; Johnson and Angeler, 2014). However, in the last decade use of trait-based approaches has increased markedly (Statzner and Beche, 2010); chiefly due to the understanding that species traits more accurately reflect functional patterns and processes than taxonomic metrics (Truchy et al., 2015). Advocates of trait-based approaches for assessing ecological impacts argue that use of trait variables related to life history, mobility, reproduction and feeding: (i) condense community data into more manageable and easily interpretable information for managers (Verberk et al., 2013), (ii) provide a mechanistic understanding of the species-environment relationships underpinning impairment (Culp et al., 2011), (iii) can assist in assessing linkages and disconnections between ecosystem structure and functioning along human pressure gradients (Frainer and McKie, 2015) and (iv) provide information about the resilience of aquatic ecosystems to mounting human pressures (Angeler et al., 2014).

Aquatic ecosystems in the North Baltic Water Basin are affected by multiple pressures related to land use, including agriculture, forestry and urbanization. Using correlative analyses (variation partitioning) we quantified and ranked responses in species and trait composition of benthic invertebrate assemblages to impacts commonly associated with land use in this basin. Based on earlier work, we predicted that the individual effects of altered hydrology on species richness and diversity would generally be negative, whereas elevated nutrients would largely be positive (e.g. Matthaei et al., 2010; Lange et al., 2011; Wagenhoff et al., 2012). Furthermore, in agreement with previous studies showing pervasive effects of sediments on invertebrates, we predicted that alterations of riparian vegetation would negatively affect community composition, e.g. through an increase in sediment from runoff. Specifically, altered hydrology and geomorphology putatively affect habitat stability and quality which is then predicted to result in an increase in disturbance-related traits such as an increase in species with shorter generation times and with diapause. At the same time, changes in basal resources were predicted to result in an increase of scrapers in response to increased benthic algae production with increased nutrient levels and a decrease of shredders and xylophages in response to lower inputs of terrestrial organic matter with loss of riparian vegetation (Statzner and Beche, 2010). The effects of multiple impacts were difficult to predict. However, from the stressors discussed above we predicated that loss of riparian vegetation would result in multiple stressors (loss of habitat heterogeneity, shifts in basal resources, increased water temperature) that would counter and probably override positive effects of nutrients. Furthermore, as eutrophication and increased loadings of fine sediments can result in altered oxygen concentrations, we predicted that relative abundance of invertebrates with tegument respiration would decrease.

2. Methods

2.1. Study sites

In addition to selecting degraded sites within the North Baltic Water Basin, an important criterion for selecting this study basin was that minimally disturbed systems (*sensu* Stoddard et al., 2006) could be identified and used as reference sites in this study. Regional and national monitoring data between 2008 and 2013 were screened to identify stream systems where standardized measures of benthic invertebrates and physicochemical data were available. This initial screening resulted in a total of 77 streams with standardized data. The 77 lowland streams (altitude 51 ± 54 m a.s.l.) are circumneutral (pH 7.0 ± 0.36), cover substantial gradients in nutrient concentration (9.3–120 μg TP/L, 10–90 percentiles) and alterations of hydrology and geomorphology (e.g. 29% of the sites were classified as having poor status due to alterations of hydrological regimes) (see below).

2.2. Sampling and data

Invertebrates were sampled from hard-bottom, riffle habitats in spring (36 sites) or autumn (41 sites). Five standardized kick samples were taken using a hand net (mesh size 0.5 mm) according to standardized sampling protocols (Fölster et al., 2014). Sampling consisted of disturbing the substratum along a 1-m-long stream reach for 60 s. Samples were immediately preserved in 70% ethanol and later processed in the laboratory by sorting using $\times 10$ magnification and identified to the lowest feasible taxonomic unit and counted using light and dissecting microscopes.

Water samples were taken in the middle of each stream and analysed for electric conductivity (EC, mS/m), pH, nutrients (total phosphorus, total nitrogen, μg/L) and water colour (absorbance 420 nm of filtered water). Water temperature (°C) was recorded at the time when water samples were collected. All physicochemical analyses followed international (ISO) or European (EN) standards (Fölster et al., 2014). Altitude (m a.s.l.), catchment size (km^2) and stream length (length of the water body, km) were obtained using GIS.

2.3. Classifying pressures and impacts

Two pressures commonly associated with land use in riverine catchments were studied using a number of putatively important impact variables. Five hydrological and geomorphological variables, obtained from the regional monitoring boards database (Water Information System Sweden, http://www.viss.lansstyrelsen.se/), were used to characterize land use effects on hydrology and geomorphology (hereafter referred to as hydrogeomorphology or HYMO): hydrologic regime, deviation in discharge (Δ discharge) from minimally disturbed conditions, morphological