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Research paper

The influence of flow permanence and drying pattern on macroinvertebrate biomonitoring tools used in the assessment of riverine ecosystems

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ABSTRACT

Temporary rivers comprise a significant proportion of river networks globally and their prevalence is expected to increase as a result of future climate change and anthropogenic water resource pressures. Despite this, the influence of drying events on freshwater biomonitoring tools within temporary rivers has received limited research attention within temperate environments. This study examines the effects of flow permanence and longitudinal drying patterns on selected biomonitoring indices used within the United Kingdom to assess the ecological status of waterbodies within the context of the Water Framework Directive. These indices are based on faunal tolerances and preferences to nutrient enrichment (BMWP, ASPT and Ntaxa) and flow velocity (Family LIFE). Long-term biomonitoring data from four rivers within southern England were examined, two of which dry longitudinally from the headwaters and two that dry within the mid-reaches. The results demonstrate that all of the biomonitoring indices examined differed significantly between each 'hydrological class' (i.e. temporary versus perennial reaches), with those based on absolute scores (BMWP and Ntaxa) displaying greater differences compared to those derived using scores standardized by the number of taxa recorded (ASPT and Family LIFE). The individual influence of drying pattern did not have a significant effect on any biomonitoring index. However, the interaction between the hydrological class and drying pattern significantly influenced all biomonitoring indices, indicating that the effect of flow intermittency on the metrics examined differed between drying patterns. Flow permanence explained a greater amount of statistical variation compared to the hydrological class and highlights the importance of the duration of flowing conditions on biomonitoring indices. The results indicate that flow intermittency has a significant effect on freshwater biomonitoring tools and highlights the need to incorporate this knowledge into existing management and environmental policy frameworks to prevent the misclassification of the ecological status of temporary streams.

1. Introduction

Temporary rivers, also referred to as intermittent, non-perennial, or ephemeral, are lotic ecosystems that experience the cessation of surface flows partially or completely for a period of time (Leigh et al., 2016). Temporary rivers are widely distributed across drainage basins spanning all climatic zones, where they make a substantial contribution to the total channel length and discharge volume of the global river network (Larned et al., 2010; Datry et al., 2014b). The total channel length of temporary streams within river networks is predicted to increase in response to rising volumes of water abstraction and future climate change, resulting in a greater frequency and duration of channel drying events (Palmer et al., 2008; Acuña et al., 2014). However, temporary streams are often not specifically recognised or incorporated within environmental policy frameworks and there remains a need to examine the influence of flow intermittency on the biomonitoring indices currently employed in the implementation of environmental legislation (Leigh et al., 2016; Acuña et al., 2017).

The flora and fauna supported by temporary streams display a range of adaptions to the variations between wet and dry periods (Stanley et al., 1994; Boersma et al., 2014). The duration of flowing conditions will govern the survival of temporary water specialists as this will dictate whether taxa can complete their life-cycle (Bogan et al., 2013; Garcia et al., 2017). In addition, catchment-wide longitudinal drying

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patterns (*sensu* Lake, 2003) potentially regulate fauna being able to colonize and persist within temporary streams. For example, rivers that dry within the mid-reaches possess upstream and downstream perennial sources from which taxa can migrate (aquatically or aerially) into temporary reaches once flows resume (Storey and Quinn, 2008; Arscott et al., 2010). In contrast, the (re)colonization of taxa from permanent waterbodies may require longer periods of time within rivers that dry from the headwaters as fauna are forced to migrate aquatically upstream or aerially disperse (Wright et al., 1984; Wood et al., 2005; White et al., 2018).

Although temporary and perennial rivers support distinct faunal assemblages, the ecological status of most lotic systems is characterised by the same biomonitoring indices as those employed in perennial systems internationally (Dallas, 2013; Leigh et al., 2016). Macroinvertebrates are one of the most widely utilized freshwater biomonitoring indicator group globally, with a large number of biotic indices and tools available based on faunal tolerances and preferences in relation to specific pressures (Rosenberg and Resh 1993; Buss et al., 2015). Within Europe, the majority of macroinvertebrate biomonitoring indices used in the implementation of the Water Framework Directive (European Union, 2000) are largely based on the sensitivity of taxa to nutrient enrichment (Birk et al., 2012) and have been predominantly guided by evidence from perennial environments (Reyjol et al., 2014). The inappropriate use of such metrics within temporary streams could lead to such systems being ecologically misclassified (Acuña et al., In Press). Although the utilization of biomonitoring indices within temporary waterbodies has been researched within Mediterranean climates (e.g. Morais et al., 2004; Munné and Prat, 2011; Mazor et al., 2014), it has not been explored within temperate regions, despite the widespread geographical distribution of temporary streams within these environments (see Stubbington et al., 2017).

Within the United Kingdom (UK), the sensitivity of macroinvertebrates to nutrient enrichment has underpinned the biotic indices used to characterise the ecological health and status of aquatic environments for the Water Framework Directive (Birk et al., 2012; Paisley et al., 2014). To complement these, some national environmental regulators have developed additional biomonitoring tools to assess specific pressures, such as flow velocity/discharge (Extence et al., 1999) or fine sediment loading (Extence et al., 2013), which may aid in the identification of any underlying causes of failure to achieve the required ecological target (e.g. Clews and Omerod, 2009). However, aquatic biomonitoring indices have traditionally not considered the effects of flow intermittency on lotic communities within the UK (but see Chadd et al., 2017) and compliance with the Water Framework Directive has been historically focussed on biotic communities sampled from sites situated in lower parts of the catchment which possess permanent flow regimes. This study examines how macroinvertebrate community biomonitoring indices routinely employed by environmental regulators and river managers within the UK have been affected by flow intermittency and longitudinal drying patterns over a long-term (> 20 years) time period.

2. Methods

2.1. Study area and data collection

Four streams overlaying chalk geology ($CaCO_3$) in southern England (UK) were examined. The waterbodies display two distinct longitudinal 'drying patterns' (DP; Fig. 1): two rivers which dry longitudinally downstream from the headwaters (River Tarrant and Chitterne Brook) and two that dry outwards from the mid-reaches and possess upstream and downstream sources of perennial water (Devil's Brook and North Winterbourne). Three of the rivers are primarily surrounding by arable agriculture (National River Flow Archive, 2017a, 2017c), although the Chitterne Brook is surrounding by large areas of grassland (National River Flow Archive, 2017b). Temporary streams are widespread across chalk headwaters due to large seasonal fluctuations in the water table (Sear et al., 1999) and are regionally called 'winterbournes'. The strong geological influence of the chalk on the receiving waters produces a highly stable flow regime which does not respond rapidly to rainfall. This typically results in a low stream power which limits the potential sediment transport capacity, leading to shorter riffles often being interspersed by longer stretches of slow-flowing habitats (Sear et al., 1999). The physico-chemical properties of these systems are typically characterized by high alkalinity, conductivity and nutrient levels due to the strong geological influence of the underlying chalk. Chalk streams typically display high dissolved oxygen levels due to abundant macrophyte growths and also typically support diverse macroinvertebrate and fish communities (Sear et al., 1999). All of the study sites are routinely monitored by the Environment Agency (the statutory environmental regulator within England) and all four rivers have been classified as possessing a 'Good' chemical status consistently across recent years and a hydromorphological condition regarded as 'not being artificial or heavily modified' (Environment Agency, 2017). Many chalk stream catchments are subject to groundwater abstraction practices which can potentially influence the hydrological variability within these systems (Soley et al., 2012). However, White et al. (2018) could not detect any ecological implications of such flow alterations across the study region, which indicates that such activity has minimally affected the biotic compositions inhabiting the rivers examined within the present study. In spite of this, the rivers have been classified as ecologically failing in accordance with the Water Framework Directive across multiple years during the study period (Environment Agency, 2017).

Long-term flow intermittency patterns were established along three of the studied rivers, whereby biological sampling locations were visited on a monthly basis for ≥13 years and the presence/absence of surface water flow was recorded. This procedure was also undertaken along the Devil's Brook for two years and hydrological information obtained from this was validated using expert opinion from regional surveyors and consultation of existing literature (e.g. Arnott et al., 2009) to assign biological sites to flow permanence (FP) groups (see below). Macroinvertebrate samples were collected by Wessex Water plc. (the regional water company) and the Environment Agency as part of routine biomonitoring between 1990 and 2014 (n = 326). Comparable numbers of samples were analysed from 'perennial' (n = 160) and 'temporary' (n = 166) sites (termed as the two 'hydrological classes' (HC) herein). These were defined as sites that flow continuously (except possibly during extreme drought events) and sites which dry periodically, respectively. Samples were collected during routine biomonitoring sampling periods of spring (n = 175) and autumn (n = 95), with additional samples being collected during summer (n = 56) often to monitor the ecological effects of low flows. Temporary sites were also subdivided into FP categories based on the available hydrological information, which were adapted from existing hydrological classifications of chalk headwater streams in the study region (see Punchard and House, 2009; White et al., 2018): 'intermittent' (sites typically flowing for less than 4 months each year – n = 13); 'winterbourne' (sites normally flowing for 4–9 months each year and almost always flowing during the winter months – December-February – n = 42) and 'transitional' (sites typically dry for up to 3 months each year but in wetter years may flow continuously – n = 111). These were examined alongside samples from 'perennial' sites, so that four FP categories were investigated in total.

Macroinvertebrate samples were collected following the Environment Agency's sampling protocol for routine biomonitoring assessment, whereby during flowing conditions the surveyor would disturb the river bed *via* a kicking motion for 3 min across all habitats present (e.g. macrophytes, gravels), with the time designated to each habitat being divided proportionally relative to their occupied surface area. Following this, a 1 min hand search of instream material was performed to obtain taxa attached to bed features difficult to disturb *via* kicking (e.g. larger substrates; Murray-Bligh, 1999; ISO, 2012).