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A comparison of biotic groups as dry-phase indicators of ecological quality in intermittent rivers and ephemeral streams

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ABSTRACT

Intermittent rivers and ephemeral streams (IRES) are dynamic ecosystems that shift between aquatic and terrestrial states. IRES are widespread, abundant and increasing in extent, but developing biomonitoring programmes to determine their ecological quality is challenging. To date, quality assessments have focused on the aquatic organisms present during wet phases, whereas dry-phase communities remain poorly characterized. We examined multiple biotic groups present in dry IRES channels, to compare assemblages at sites impacted and unimpacted by human activity and to evaluate the potential of each group as an ecological quality indicator. We explored existing, unpublished data for three biotic groups: an aquatic microflora (diatoms), an aquatic fauna (the invertebrate 'seedbank'), and a mixed flora (aquatic and terrestrial plants); notably, we did not source data for terrestrial assemblages with high potential to act as indicators. Diatom and plant assemblage composition differed between impacted and unimpacted sites, and the latter assemblages were more diverse and included more indicator taxa. Invertebrate seedbank taxa richness was higher at unimpacted sites but compositional differences were not detected, probably due to the coarse taxonomic resolution to which abundant taxa were identified. Performance of standard indices of ecological quality was variable, but differences were identified between impacted and unimpacted conditions for all biotic groups. Our results can inform the enhancement of biomonitoring programmes designed to characterize IRES ecological quality in relation to legislative targets. We highlight the need to integrate wet- and dry-phase survey data in holistic quality assessments. Although we suggest diatoms, aquatic plants and the aquatic invertebrate seedbank as having the potential to inform assessment of dry-phase ecological quality, we highlight the need for research to further characterize these aquatic groups and, crucially, to explore terrestrial assemblages with high potential to act as dry-phase quality indicators.

1. Introduction

Intermittent rivers and ephemeral streams (IRES) are defined by freshwater ecologists as lotic ecosystems in which water sometimes stop flowing, and many systems also experience partial or complete loss of surface water (Datry et al., 2017a). IRES encompass a diverse range of ecosystems, from rivers that stop flowing only during severe droughts, through to headwater channels that are usually dry and flow only occasionally after heavy rain. As such, IRES are not only aquatic ecosystems that sometimes lose all flowing surface water, but are also transition zones in which aquatic and terrestrial habitats can occur both successively and simultaneously (Datry et al., 2016). Depending on the extent and pattern of drying, IRES may also be conceptualized as linear terrestrial habitats that experience periodic inundation (Stubbington

Abbreviations: IRES, Intermittent rivers and ephemeral streams

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et al., 2017). These coupled aquatic-terrestrial ecosystems can dominate dendritic networks in drylands, are common in temperate regions, and are increasing in global extent in response to water resource demands, land use change and climatic drivers (Datry et al., 2017a; Stubbington et al., 2017).

The communities present in IRES during flowing phases are relatively well-studied, and include vertebrates, invertebrates, microorganisms and aquatic plants (i.e. macrophytes), with spatial and temporal variation in community composition promoting high beta-diversity (Schriever and Lytle, 2016; Stubbington et al., 2017). Dry channels can also support high terrestrial biodiversity including invertebrates, diatoms and plants. These communities are far less well-known, but terrestrial invertebrates include both generalists and dry-channel specialists (Steward et al., 2011; Corti and Datry, 2015) that may have adaptations such as inundation tolerance (Adis and Junk, 2002). Some desiccation-tolerant aquatic invertebrate life stages also persist as a 'seedbank' within the drying sediments (Stubbington and Datry, 2013), and other biotas include diatom-rich biofilms (Barthès et al., 2015) and plant communities in which the dominance of terrestrial taxa increases over time (Holmes, 1999; Westwood et al., 2006).

International legislation such as the EU Water Framework Directive (WFD) and the US Clean Water Act require biomonitoring to assess ecological quality. Although it encompasses IRES, this biomonitoring has to date relied almost exclusively on aquatic biota present during flowing phases (Sheldon, 2005; Stubbington et al., 2018a; but see Steward et al., 2018). This activity includes recent evaluation of indices developed for perennial systems in IRES (Mazor et al., 2014; Prat et al., 2014) and development of IRES-specific indices to characterize the responses of flowing-phase biota to ecological quality (Munné and Prat, 2011). However, difficulties in timing sampling to coincide with peak aquatic diversity in systems with short, unpredictable flowing phases (Sheldon, 2005) and inappropriate calculation of IRES ecological quality using indices designed for perennial ecosystems (Wilding et al., 2018) may both prevent accurate assessment of ecological quality (Stubbington et al., 2018a). Elsewhere, if channels are dry no samples are collected, and absent samples often compromise quality assessments in drylands and during droughts (Steward et al., 2012). A robust suite of aquatic *and* terrestrial indicators that collectively reflect the physicochemical determinants of ecological quality during both wet *and* dry phases therefore requires development (Steward et al., 2012).

We evaluated the potential of multiple biotic groups present in dry IRES channels to act as indicators of ecological quality, potentially of the quality of an IRES in general (i.e. also representing wet phases) and/or of dry phases in particular. We sought dry-phase data from participants in a European research network (Datry et al., 2017b), acquiring data for the aquatic invertebrate seedbank, diatoms, and aquatic and terrestrial plants. We evaluated each group's response to specific human impacts i.e. its ability to distinguish between sites of contrasting ecological quality, with 'quality' defined in relation to the geomorphological, hydrological and/or physicochemical conditions at sites impacted and unimpacted (or minimally impacted) by human activity. We identify biotic groups warranting further study, with the long-term goal of establishing robust dry-phase indicators of IRES quality.

2. Materials and methods

2.1. Data collection

We gathered existing data from 69 members representing 24 countries in a European research network (COST Action *CA15113 Science and Management of IRES*; Datry et al., 2017b). We requested data comprising samples or surveys of one taxonomic group collected from multiple sites within one river type during dry phases. River types could be classified using official typologies (for example under the WFD; EC, (2000)) or comparable descriptions (e.g. UK chalk rivers, which fall within the *lowland, small, calcareous* WFD river type; EC, 2000). Within a river type, sites had to vary in specific aspects of ecological quality, with: at least two states characterized (i.e. unimpacted and impacted); the driver(s) responsible for deviations from unimpacted conditions determined by legislation-driven regulatory monitoring or academic research projects; and each state represented by at least three replicate samples per site / date. Differences in quality could be among multiple sites sampled at one time and/or at repeatedly sampled individual sites. Taxonomic identification was required to a sufficient resolution to infer environmental preferences, preferably genus or species level, with some exceptions made for taxonomically challenging groups.

Data meeting most or all of our criteria were acquired for each of three groups: an aquatic microflora (diatoms; Bacillariophyceae), an aquatic fauna (the invertebrate seedbank), and a mixed flora (aquatic and terrestrial plants; Appendix A, Supplementary Material).

2.1.1. Diatoms

The diatom data comprised 12 biofilm samples collected on 1–3 dates from six sites across five rivers in the temperate (oceanic-mediterranean climate) Adour-Garonne catchment, France, during single, continuous dry phases of 4–30 weeks (Appendix B, Supplementary Material; A. Barthès, unpublished data). Field sampling and laboratory processing methods followed the French national standard (AFNOR, 2007; Appendix B, Supplementary Material). Ecological quality was categorized using WFD *status* classes and spanned *high* (i.e. unimpacted conditions, $n = 8$), *good* (i.e. slight deviation from unimpacted conditions; $n = 2$) and *moderate* (i.e. moderate deviation; $n = 2$) classes. Deviations from high status reflected elevated phosphate concentrations (mean ± SE, 0.15 ± 0.04 mg L^{-1} compared to $\leq 0.10 \pm 0.01$ mg L^{-1}). Low replication was a notable limitation of this data set.

2.1.2. Aquatic invertebrate seedbank

In total, 19 dry sediment samples were collected across three rivers in a semi-arid region of Bolivia (Figs. S1–S2) to examine the aquatic macroinvertebrate and meiofauna taxa persisting within the seedbank (Appendix B, Supplementary Material; T. Datry, unpublished data). In each river, 3–5 replicate sediment samples were taken at unimpacted sites ($n = 11$) and 2–3 replicates were collected from sites impacted by sediment mining ($n = 8$), following methods described by Datry et al. (2017c; Appendix B, Supplementary Material). Data set limitations were covariation of ecological quality and intermittence, i.e. ten of 11 unimpacted sites had longer flowing phases (> 8 months $year^{-1}$) than impacted sites (< 6 months $year^{-1}$), and the coarse taxonomic resolution to which three abundant taxa (Chironomidae [Diptera], Hydrachnidia, Oligochaeta) were identified (Appendix B, Supplementary Material).

2.1.3. Macrophytes and terrestrial plants

The plant data reported 137 surveys conducted during dry phases in 15 headwater sites across six chalk rivers in two catchments in temperate (oceanic climate) England, between 1992 and 2013 (Fig. S3, Appendix B, Supplementary Material). These surveys represent a subset of the data set reported by Holmes (1999) and Westwood et al. (2006), with our dry-phase focus complementing these previous explorations of community responses across wet and dry phases. Dry-phase durations prior to sampling varied between 3 months and 4 years, but were otherwise unknown. Surveys followed Holmes (1999), with aquatic and semi-aquatic macrophytes identified to species or genus, and terrestrial plants recorded as *non-aquatic grasses* and *non-aquatic herbs*. Data collected by regulatory agencies informed characterization of environmental variables influencing ecological quality at spatiotemporally relevant scales: sediment heterogeneity, shading by riparian vegetation, bank slope, livestock poaching (i.e. physical disturbance of bank and bed sediments by hooves), and water quality. Additional information regarding the extent of habitat modification and instream habitat quality was also available (Appendix B, Supplementary Material).