Using plant communities to characterise biotic response to drying in chalk stream headwaters

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Chalk streams are internationally important for their biodiversity. In their headwaters chalk streams shift between flowing, ponded and dry phases as ground water levels fluctuate (Figure 1), with characteristic winterbournes flowing only during winter. These changing conditions influence biotic community composition, richness and abundance, and habitat time-sharing by aquatic and terrestrial species enhance biodiversity in space and time. However, ground water abstraction is altering patterns of intermittence, and we need to better understand biological responses to these changes to inform the management of these rivers. In particular, variation in plant communities provides a useful bio-indicator of biotic responses to changing environmental conditions. Here, we outline the development of approaches to summarise plant community responses to drying and how these can inform better management of these biodiverse, but impacted ecosystems.

Characterising community responses to drying

Initial research describing vegetational responses to antecedent instream conditions, including drying, characterised community composition and identified indicator taxa. Holmes (1999) used a 3-year plant dataset surveyed in spring, summer and autumn from 118 sites across 24 southern English chalk streams, to develop a classification system. He recognised 13 distinct community types based primarily on flow intermittence and physical habitat characteristics, divided into four main groups: perennial, winterbourne, ditch and intermittent. Lesser water-parsnip (*Berula erecta*), Water starwort (*Callitriche obtusangula*) and Whorl grass (*Catabrosa aquatica*) were classified as characteristic of perennial reaches; Pond water crowfoot (*Ranunculus peltatus*) and Watercress (*Rorippa nasturtium-aquaticum*) dominated winterbourne reaches. Reed canary grass (*Phalaris arundinacea*) and Sweet grass (*Glyceria* spp.) were characteristic of more extensive drying within ditch communities; and Marsh foxtail (*Alopecurus geniculatus*) and terrestrial taxa were indicators of intermittent reaches that regularly dried for up to and beyond 6 months per year.

Figure 1: Hertfordshire chalk stream, River Ver, in flowing and dry phases.

Table 1: Generalised descriptions of the 10 community types within the Winterbourne Classification (Westwood et al. 2020a, 2020b) with indicative photos.

Perennial and transitional © C. Westwood, winterbourne © Environment Agency, and intermittent and ditch © N Holmes.

Plant community type		Description	Typical annual dry period
Perennial	P1-3	 River Water-crowfoot (*Ranunculus pseudofluitans*) dominated. Typical of fast to medium flowing sites with gravel/pebble substrates and accumulations of silt in the margins which support emergent herbs.	0-5% (mostly flowing with some sites drying in very severe droughts)
Transitional	T4-5	 Plant coverage is higher than for the Perennial groups and often includes non-aquatic grasses. Pond water crowfoot (*Ranunculus peltatus*) Water starwort (*Callitriche* spp.) and Sweet grass (*Glyceria* spp) often have high coverage.	0-10% (low flows but only dry in moderate or severe droughts)

Winterbourne	W6 & W7	 Typically with high proportions of Watercress (*Rorippa nasturtium aquaticum*), Fool's Watercress (*Apium nodiflorum*) and sweet grass (*Glyceria* spp.). Brooklime (*Veronica beccabunga*) is characteristic.	0-40% (very low flows and drying in moderate droughts)
Ditch	D8	 Characteristic of ponding and regular drying, dominated by Reed canary grass (*Phalaris arundinacea*). Water mint (*Mentha aquatica*), Willowherb (*Epilobium hirsutum*) and non-aquatic taxa regularly occur.	30-90% (regular intermittence, some drying)
Intermittent	I9	 Characterized by the occurrence of the wetland grass Marsh foxtail (*Alopecurus geniculatus*), Typically with a high coverage of non-aquatic taxa.	50-100% (regular intermittence, dry channels)

Westwood et al. (2006a) further developed our understanding of plant community responses to drying by using a 10-year study of sites within the Thames basin to quantify the influence of antecedent flow on the composition of in-channel plant communities. The community types classified by Holmes (1999) were thus formally linked to hydrological variation, allowing for the prediction and hindcasting of site-specific community types at the study sites. A parallel study (Westwood et al. 2006b) examined how physical habitat characteristics alter relationships between flow and community composition. These two studies formed the basis of a larger investigation encompassing 29 sites across 6 rivers, which developed an approach to setting hydroecological thresholds to support various stages of community development (Westwood et al. 2017). More recently, Westwood et al. (2020a) revised Holmes' classification using data collected by Holmes between 1992 and 2013 and water company data collected between 2015 and 2018. This revealed that the prolonged drought of 1989–1992 reset the 'ecological clock', promoting a high diversity of plant life as water returned and species colonised the wide range of newly available habitats. Since 1996 however, communities have become increasingly simplified with only 10 of the 13 community types found by Holmes (1999) occurring in 2018 (Westwood et al. 2020a).

Towards biotic metrics that characterise responses to drying

The extensive research characterising plant community response to environmental conditions has been useful in describing temporal and spatial changes. However, biotic metrics summarising these changes would enable modelling of community response to changes in flow and hydrological state. Previous metrics summarising plant community responses to flow - the mean flow rank index (Soley et al., 2002) and the river macrophyte hydraulic index (Wilby et al., 2012) were not widely adopted, nor were they designed for use in rivers that dry. What is needed are approaches specifically designed for intermittent rivers.

Ellenberg Abundance Score

In the early 1970s, reflecting concerns about the environmental impact of ground water abstractions in the Upper Wylye catchment, the Avon and Dorset River Authority (1973) initiated a photographic survey of the River Wylye and its winterbourne tributaries, the Chitterne Brook and Heytesbury Bourne. Two photographs – a panoramic view of the reach and a close-up of the bed – were taken each month at 28 sites in the Wylye catchment (11, 15 and two sites on the Wylye, Chitterne and Heytesbury, respectively), from August 1971 to August 1976. From February 1992 until March 1994, the same sites were again photographed, by the then National Rivers Authority, with additional photographs taken in August and December 1994 (Walls, 1998).

Walls (1998) analysed the photographs by, using Ellenberg F values to objectively summarise the species present at each site in each year. The Ellenberg system encompasses moisture indicator (F) values which reflect the species-specific affinities of higher plants to moisture (Hill et al. 1999). Walls (1998) compared the mean Ellenberg F values (based on all recorded plants) to the estimated length of the dry period before the photograph was taken. The mean Ellenberg F and dry period were highly correlated (Kendal coefficient of rank correlation, $r = 0.560$, $p = <0.001$), indicating that the mean wetness score (Ellenberg F) is responsive to drying. Rowell (2006) furthered the work, by assessing the impact of groundwater changes on the winterbourne plant community using Ellenberg F values.

The Ellenberg approach was developed further by Wessex Water ecologists House and

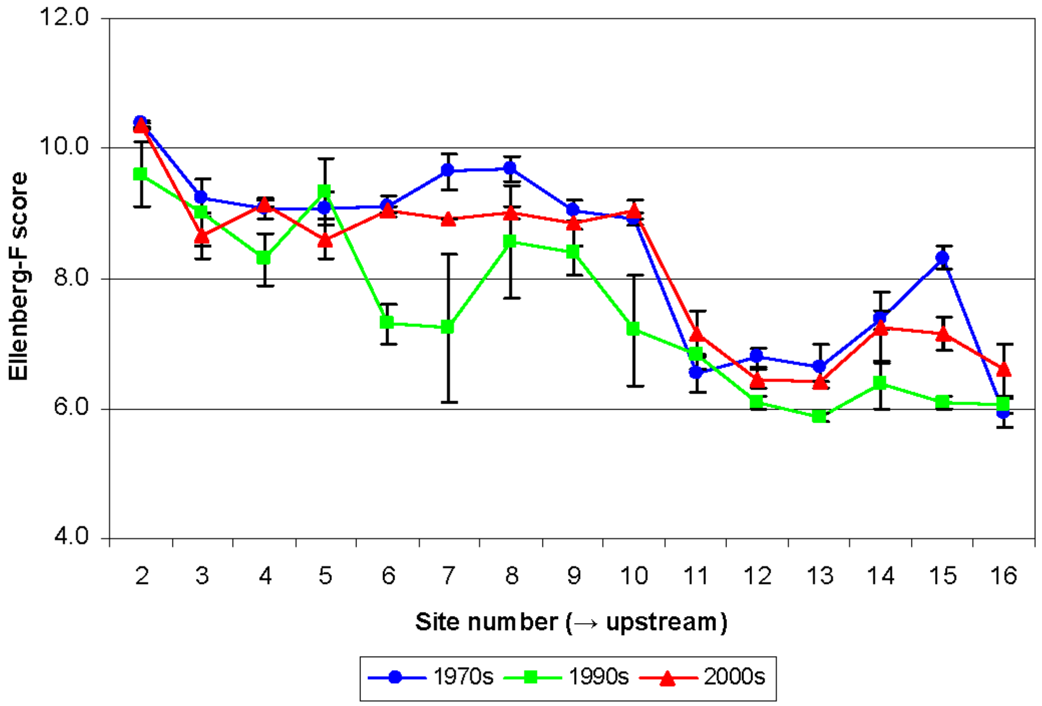

Figure 2: Spatial and temporal changes in mean Ellenberg-F scores along the Chitterne winterbourne (House and Punchard, 2007).

Punchard (2007) for their company's abstraction impact assessment, required for the Environment Agency's review of consents under the European Habitats Directive. For each river of concern they assessed temporal and spatial changes in plant communities. For example surveys in the Chitterne winterbourne demonstrate a consistent spatial change, with mean Ellenberg F values decreasing with distance downstream (Figure 2). However, the pattern varied between the 1970s, 1990s and 2000s, with lower scores observed in the 1990s.

In addition to using presence/absence data House and Punchard (2007) also developed an abundance-weighted Ellenberg scoring system (Table 2) to take the percentage cover of each species into account. The relationship between the summer Ellenberg Abundance Score (EAS) and channel drying was analysed by examining 'the winterbourne signature' flow patterns (produced by monthly observations of each winterbourne) and calculating the dry period experienced in the preceding 12, 24 and 36 months at each survey site. The 24-month flow period was most closely correlated with EAS. The relationship allowed the calculation of a 'naturalised' Ellenberg score (i.e. the score expected under a natural intermittence) using the modelled dry period of the winterbourne sites.

Since trialling the 24-month EAS in 2007, Wessex Water ecologists have reverted to using the mean Ellenberg F score derived from presence/absence data and its relationship with the preceding 12 months dry period. This showed a slightly stronger relationship than the EAS though the reasons behind this are still under investigation.

Most recently, Wessex Water ecologists have used mean Ellenberg values to characterise dry period related variability among winterbourne plant communities and thus predict community change in response to abstraction. By indicating

Table 2. The matrix used to assign scores based on Ellenberg F scores and species cover values (House and Punchard, 2007).

	Species Cover Value								
Ellenberg (F) Score	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
12	12	12.5	13	13.5	14	14.5	15	15.5	16
11	11	11.5	12	12.5	13	13.5	14	14.5	15
10	10	10.5	11	11.5	12	12.5	13	13.5	14
9	9	9	9	9	9	9	9	9	9
8	8	7.5	7	6.5	6	5.5	5	4.5	4
7	7	6.5	6	5.5	5	4.5	4	3.5	3
<7	6	5.5	5	4.5	4	3.5	3	2.5	2

whether or not the lower Ellenberg score resulting from abstraction accounted for the absence of key species such as pond water crowfoot (R. peltatus), this approach made it possible to inform the protection of plant communities listed in a site's conservation designation under the Habtiats Directive e.g. the Ranunculus community of the River Till.

Plant Flow Index

A new index, the Plant Flow Index (PFI; Westwood, 2020b), has been developed to assess community change in response to drying in chalk streams. The index is based on relationships between the occurrence and abundance of 34 common aquatic, semi-aquatic and terrestrial taxa and the proportion of time the channel was dry within the antecedent 12 months. Taxon-specific PFI codes (assigned mainly at species level) reflect each taxon's modal association with drying (% of time with zero flow; %ZF). A weighting is applied based on each taxon's percentage cover (CWC), following Holmes et al. (1999): <0.1% (1), 0.1–1% (2), >1–2.5% (3), >2.5–5% (4), >5–10% (5), >10–25% (6), >25–50% (7), >50–75% (8) and >75% (9). To derive the score for a surveyed assemblage, each PFI taxon code is multiplied by its CWC, summed and divided by the sum of the CWCs. The result is multiplied by 10 to give scores on a scale comparable with %ZF assessments:

$$\mathrm{PFI} = \frac{\sum (\text{PFI taxon code} \times \text{CWC})}{\sum \text{CWC}} \times 10$$

The PFI score can be used to track plant community change in response to drying. Long-term monitoring of the River Ver (Figure 1) shows lower PFI scores corresponding with increased drying, as indicated by increased %ZF (Figure 3)

Both the EAS and PFI approaches show the potential of using plant community change to track response to intermittence in chalk stream headwaters. However, winterbournes are just one of many types of 'temporary' river, and further testing and development is needed to see whether they can be applied more widely.

Future development

Going beyond assessing only aquatic taxa

Assessments of the plant communities within chalk stream headwaters have, to date, concentrated on aquatic plant species, with terrestrial plants categorised only as non-aquatic grasses or herbs. Identifying both aquatic and

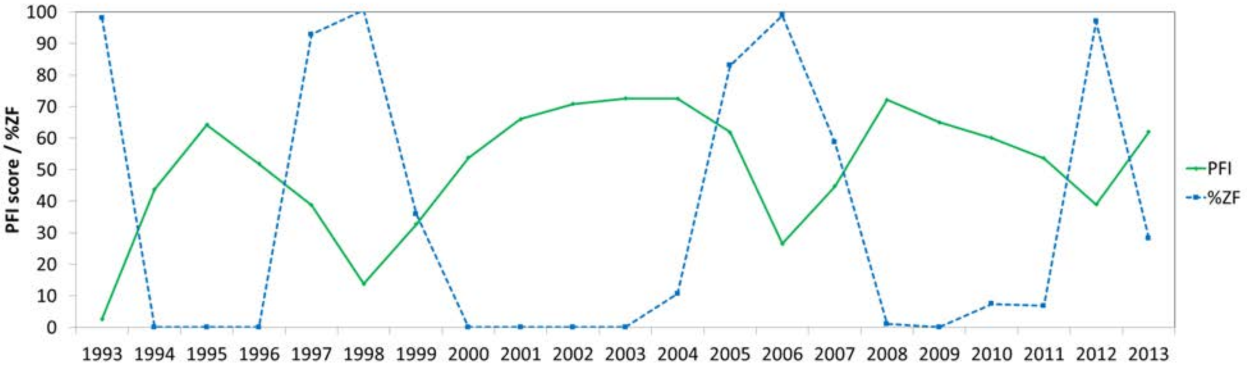

Figure 3: Temporal changes in PFI and percentage of time with zero-flow for the River Ver – Figure 1.

terrestrial plants has considerable potential to advance our understanding of how communities change as river channels transition between flowing, ponded and dry phases (Westwood et al., 2020a,b). The PFI is a flexible index and could be modified to include terrestrial taxa, as more information of their tolerance to wetter conditions (% zero flow) becomes available. This flexibility could also enable PFI to be adapted for use in other temporary river types within and beyond the UK.

Ecological quality assessments

Ground water abstraction is not the only stressor affecting chalk stream headwaters. Many channels are also affected by diffuse nutrient and silt pollution, physical modification, realignment and invasive species. To effectively protect and restore these valuable ecosystems, we need to assess their quality despite their intermittence.

The Mean Trophic Rank (MTR; Holmes et al., 1999) is a well-established index that uses plant communities to assess nutrient status. A modified version of the MTR index (with additional scoring of non-aquatic herbs and grasses) had been applied to assess the responses of plant assemblages in chalk stream headwaters to abiotic conditions indicative of specific human impacts: bank slope, livestock poaching, sediment heterogeneity, shade and water quality (Stubbington et al., 2019). Distinct assemblages were associated with different impacts, with higher species richness and diversity indicative of less impacted sites. Overall, plants were judged to be high-potential indicators of dry-phase ecological quality, but community responses could be characterised more effectively if terrestrial plants were also identified to a finer taxonomic level. Research is needed to devise a method to assess biological quality based upon the whole plant assemblage, encompassing species from fully aquatic to fully terrestrial.

Preliminary research, by Chloe Hayes at Nottingham Trent University, suggests that soil/sediment moisture may be the primary determinant of aquatic–terrestrial plant communities. However, within streams with comparable moisture levels, plants are potential biomonitors for aspects of ecological quality such as land use, sediment complexity and inorganic nutrient concentrations.

Research done in the winterbourne streams of south England has dominated global efforts to better characterise plant community responses to changing conditions in dynamic, wet-dry river channels. With aquatic community responses to hydrological change now well-described, we are taking the first steps towards a better understanding of aquatic-terrestrial community responses to human impacts. As river drying increases in space and time, these ongoing research efforts will support better protection of biodiversity within dynamic river ecosystems as they respond to global change.

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