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PRIMARY RESEARCH PAPER

Critical influence of seasonal sampling on the ecological quality assessment of small headwater streams

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Abstract Variability in the ecological quality assessment of reference sites was tested on small headwater streams in Ireland. Although headwater streams constitute a large portion of the river channel network, they are not routinely monitored for water quality. Various metrics were used including the Irish Q-value and the newly developed Small Streams Risk Score (SSRS), and metrics applied elsewhere in the Atlantic biogeographic region in Europe, including the Biological Monitoring Working Party score (BMWP), the Average Score per Taxon (ASPT), the Ephemeroptera, Plecoptera and Trichoptera taxa (EPT), the Belgium Biotic Index (BBI) and the Danish Stream Fauna Index (DSFI). The AQEM (version 2.5a) assessment software was used to apply some of these metrics. The spring and summer datasets are used to test the performance of biotic metrics with respect to season, and the applicability of their use to assess the ecological quality of wadeable streams. The quality status of most sites assigned by the various metrics was high using the spring invertebrate data, and an apparent considerable deviation in quality status occurred when the summer data was applied. Seasonal differences were noted using all the biotic indices and are attributed to the absence of pollution-sensitive groups in summer. Seasonal variability in the water quality status was particularly evident in acidic streams draining non-calcareous geologies with peaty soils that had relatively lower numbers of taxa. Some indices applied reflect a greater seasonal difference in the quality category assigned. The least amount of variability between seasons was obtained using the ASPT and the SSRS risk assessment system. Results suggest that reference status is reliably reflected in spring when more pollution-sensitive taxa were present, and that a new ecological quality assessment tool is required for application in summer when impacts may be most severe. This highly heterogeneous freshwater habitat seems to have too few taxa present in the summer to reliably determine the ecological quality of the stream using the available indices.

Keywords Water quality · Biological monitoring · Benthic macroinvertebrates · Seasonal variation · Pollution

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Introduction

Small watercourses, including first and second-order streams, form over 77% of the river channel network in Ireland (Kavanagh et al., 2006) and a significant proportion in most other countries. These headwaters, defined as a watercourse within the first 2.5 km of its furthest source (Furse, 2000), occur over a range of climate, geology, hydrology and biogeographical settings (Meyer et al., 2007). As the drainage catchments are small, local conditions often determine their characteristics and they tend to be dominated by rapid longitudinal changes in the physical and biological components contributing to high habitat heterogeneity. Headwaters are intricately linked to the landscape (Cummins, 1992; Ventura & Harper, 1996), and their relatively small discharge makes them highly susceptible to localized anthropogenic pressures. Upland headwaters for example are under an increasing risk of forest-mediated acidification (Tierney et al., 1998; Ormerod et al., 1993). Due to longitudinal linkages with the entire river network, organic and toxic pollution and habitat degradation in headwaters transfer pressures further downstream to larger river channels. The concept of ecological connectivity of the entire river catchment emphasises the need to include headwater streams to achieve the protection of the whole aquatic ecosystem as required by the Water Framework Directive (WFD; CEC, 2000), although small streams of a catchment size <10 km^2 are excluded from the monitoring requirements of the WFD.

Many countries in Europe routinely implement biomonitoring methods using macroinvertebrates to assess the ecological quality of streams and rivers (McGarrigle & Lucey, 1983; Rosenberg & Resh, 1993; Buffagni et al., 2001; Bonada et al., 2006). These national monitoring programmes are usually country specific (Armitage et al., 1983; De Pauw & Vanhooren, 1983; McGarrigle & Lucey, 1983; Alba-Tercedor & Pujante, 2000; Hering et al., 2003) and despite the necessity to harmonize the national classification schemes with regard to quality status boundaries (Birk & Hering, 2006) there are significant correlations among values assigned using the different metrics (Friberg et al., 2006). As a result national metrics implemented in each country remain applicable, although central to defining the high quality classifications in each country is the use of ecosystems in a reference state for appropriate comparative and predictive purposes (Hughes, 1995; Gibson et al., 1996; Reynoldson & Wright, 2000; Buffagni et al., 2001; Nijboer et al., 2004; Kelly-Quinn et al., 2005). These undisturbed ecological units should provide a representative benchmark or 'reference condition' with the capacity for extrapolation. Although it is unlikely that pristine headwaters still exist in Ireland and similarly in most parts of Europe, streams that are 'minimally impacted' can be used as surrogates and formed the basis of this study. Only a small proportion of sites achieving good ecological status in Ireland (rating $>$ Q4) are considered to have the potential to represent reference condition (Anonymous, 2006). The assessment programmes in Europe have incorporated the typology-based approach, although the small streams are not routinely included in national monitoring programmes, emphasising the need for the appropriate application of current assessment systems for the use on headwaters.

From a conservation perspective, the diversity of habitats found in headwaters provide suitable conditions for unique species and communities, and increased attention to these habitats provides many new records and new species (Blackburn & Forest, 1995; Blackburn et al., 1998). Small streams are shown to have a unique invertebrate fauna including near-source species (Dowling et al., 1981; Clenaghan et al., 1998; Furse, 1998) and contribute to the total catchment biodiversity (Furse, 2000; Meyer et al., 2007).

This study assesses the use of various commonly applied metrics, the majority of which were developed to assess wadeable streams, to determine the ecological quality of headwaters in Ireland. The performance of the metrics is assessed using data from 50 headwater streams considered to fulfil the requirements of reference condition and represent good ecological quality. This study reports on the performance of these biotic metrics with respect to season, and their applicability to assess the ecological quality of small streams in Ireland in the future.

Materials and methods

Site selection

Fifty streams were selected throughout the country, spanning environmental gradients from acidic upland to nutrient-rich lowland streams. Site selection was based on the reference condition approach stipulated in the WFD (2000/60/EC), and sites were only included if the criteria for reference condition were met (Nijboer et al., 2004) including hydrochemistry and following guidelines outlined in the AQEM project (Hering et al., 2003). Although the hydrochemistry was taken into account it was only a brief snapshot as to the chemical state of the stream and was only taken once during each season. The watershed of each site had little or no human habitation and no intrusive agriculture or forestry. The watercourses were either first or second-order streams, which were fed by seepage or springs, and streams that were lake-fed were not included. Only streams falling within the first 2 km of its furthest source were selected, as marked by a blue line on the Ordnance Survey Ireland maps as defined by Furse (2000) as headwaters.

Sampling protocol

Macroinvertebrate samples were taken at each site during the field surveys conducted in spring (April to May) and summer (July to August) 2004. Five replicate one-minute kick-samples were taken using a standard pond net (1000 μm mesh) at each site using a multi-habitat sampling procedure with time in each habitat spent proportional to the frequency of its occurrence at the site (Wright, 1995; Baars et al., 2004). The standard 3-min sample used in other studies (Wright, 1995; Kelly-Quinn et al., 2005) was scaled down to one-minute due to the small size of these streams. Samples were preserved in 70% Industrial Mentholated Spirits (IMS), and were processed and sorted in the laboratory using standard procedures. Individuals smaller than 1000 μm may have been lost through this process but this is the standard methodology used in routine bioassessment. Wherever possible, specimens were identified to the lowest taxonomic level, usually to species or genus with the exception of Chironomidae and Oligochaeta which were identified to subfamily and order, respectively. Water samples were taken during the two sampling periods and were analysed to characterize the stream and validate its reference status.

Biotic indices applied

Each site was assessed using the eight metrics listed in Table 1. The Q-value system implemented by the Environmental Protection Agency (Flanagan & Toner, 1972; McGarrigle et al., 2002) is a biological quality rating system developed for Irish rivers and streams, and has been in operation since 1971 (McGarrigle & Lucey, 1983). Sites are assigned to a five-point scale with intermediate classes, from Q1 indicating a seriously polluted condition to Q5 representing unpolluted conditions. The Small Streams Risk Score (SSRS) on headwaters was recently developed as a rapid assessment system and implemented in Ireland (Anonymous, 2005). The SSRS system assigns sites to three risk categories, 'at risk', 'probably at risk' and 'probably not at risk', based on the presence and absence of five macroinvertebrate groups. These include the Ephemeroptera (Group 1), the Plecoptera (Group 2), the Trichoptera (Group 3), the Gastropoda, Oligochaeta and Dipteran larvae (GOLD—Group 4) and *Asellus* species (Group 5).

The Biological Monitoring Working Party score (BMWP) developed by the National Water Council is widely used in the United Kingdom since 1981. In

Table 1 List of water quality metrics applied to the invertebrate data from headwater sites and level of taxonomic resolution required for each metric

Water quality metric	Taxonomic level	Reference
EPA Q-value system	Family, Genus & Species	Flanagan & Toner, 1972; Lucey et al., 1999
Small Stream Risk Score (SSRS)	Genus/Species	EPA (Anonymous, 2005)
Biological Monitoring Working Party (BMWP)	Family	National Water Council, 1981
Average Score per Taxon (ASPT)	Family	Armitage et al., 1983
Emphereroptera, Plecoptera, Trichoptera (EPT) Taxa richness	Species	Resh & Jackson, 1993; Lenat & Penrose, 1996
Belgium Biotic Index (BBI)	Family	De Pauw & Vanhooren, 1983
Danish Stream Fauna Index (DSFI)	Family & Genus	Skriver et al., 2000

this metric, each 'taxon' present at a site is assigned a score ranging from 1 to 10 according to its tolerance to organic pollution (1 = most tolerant & 10 = least tolerant). The individual scores are added together to give the BMWP score. The BMWP score is divided by the number of scoring taxa to give the Average Score Per Taxon (ASPT) (Armitage et al., 1983). The Ephemeroptera, Plecoptera, and Trichoptera are combined into the EPT taxa (STAR-AQEM project, www.eu-star.at; Plafkin et al., 1989) representing the more pollution-sensitive taxa. The relative proportion of EPT taxa is presented to indicate the composition of the overall community in relation to pollution-sensitivity. The Belgium Biotic Index (BBI) and the Danish Stream Fauna Index (DSFI) were also applied to the data using the AQEM assessment software (version 2.5a) (Hering et al., 2004). The BBI was developed by De Pauw & Vanhooren (1983) to apply to different types of rivers. This metric ranges from 0 to 10, the highest '10' indicating 'good' water quality or absence of pollution and '0' being very heavily polluted. Water quality decreases as the BBI score decreases, and De Pauw & Vanhooren (1983) indicate that with a decrease from 10 to 7 the receiving water is affected by a pollution pressure. The DSFI was introduced as the official method for biological assessment of running water in Denmark in 1998 (Skriver et. al., 2000). The metric values range from 1 to 7, with seven representing the best ecological quality. As with the BBI, water quality decreases as the DSFI score decreases.

Results

A total of 141 and 127 taxa were recorded in the spring and summer samples, respectively. On average 45 taxa were recorded at each site for spring (range 26–61) and 32 taxa for summer (range 20–46) (Fig. 1). Representatives of most of the invertebrate groups were recorded in the samples.

Q-value

The spring Q-value system indicated that most of the sites were in good ecological status achieving a Q-value of Q4 to Q5 (Fig. 2), with the majority of the sites (30) assigned a Q5. When the summer data were assigned Q-values, a notable shift in the apparent water quality was indicated. The quality status assigned to most sites using the summer data resulted in a drop of at least one category. A number of sites (41%) still maintained good quality status, ranging between Q4 and Q5, although the majority (28 sites) were rated as slightly (Q3–Q4) or moderately (Q3) polluted despite no apparent source of impact.

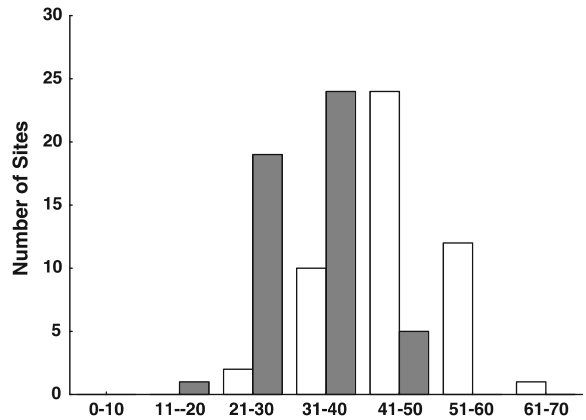


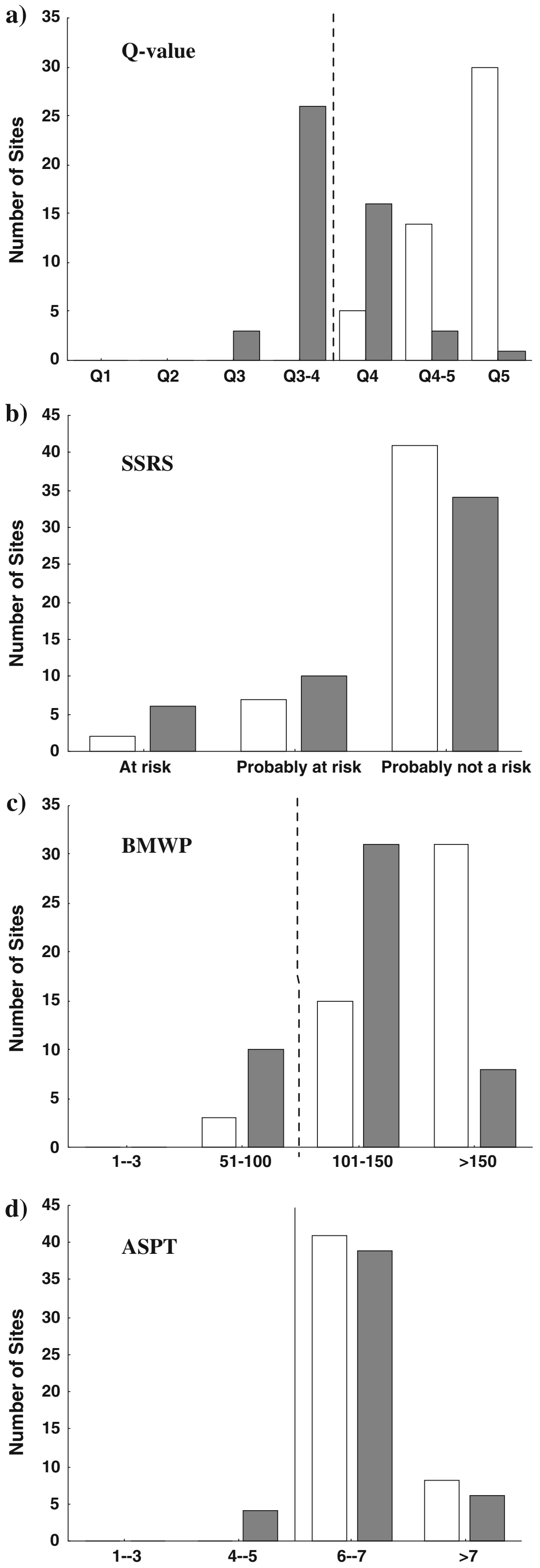
Fig. 1 The frequency of taxa showing the spread of taxa per site from spring (open bars) and summer (shaded bars)

Small streams risk score (SSRS)

When the newly developed SSRS system was applied to the data, the shift in risk status between seasons was minor (Fig. 2). A proportion (26%) of the sites was shifted to one of the three categories. Most of the sites in spring, 41 sites achieved a 'probably not a risk' status in comparison to only 34 sites in summer. The most noteworthy change between seasons was the increase in the number of sites 'at risk'.

BMWP and ASPT

The frequency distributions of BMWP scores and ASPT scores are shown in Fig. 2, respectively. The BMWP and ASPT scores are categorized according to ranges considered to indicate good, impacted and poor quality status. The scores assigned to the headwater streams fell between 84 and 192 (BMWP) and 6.00–7.17 (ASPT) using the spring invertebrate data. In contrast, the scores assigned to the sites using the summer data ranged between 70 and 178 (BMWP) and 5.50–7.48 (ASPT). There was a 63% shift in BMWP category between spring and summer



◀**Fig. 2** Graphic representation of (**a**) Q-value (**b**) SSRS (**c**) BMWP (**d**) ASPT assigned to fifty headwater sites for both spring (open bars) and summer (closed bars) invertebrate data. Broken lines indicate good ecological quality boundaries

(Fig. 2). Sites assigned to ASPT categories on the other hand showed little shift between seasons, with only 16% of the sites decreasing in ASPT category in summer (Fig. 2).

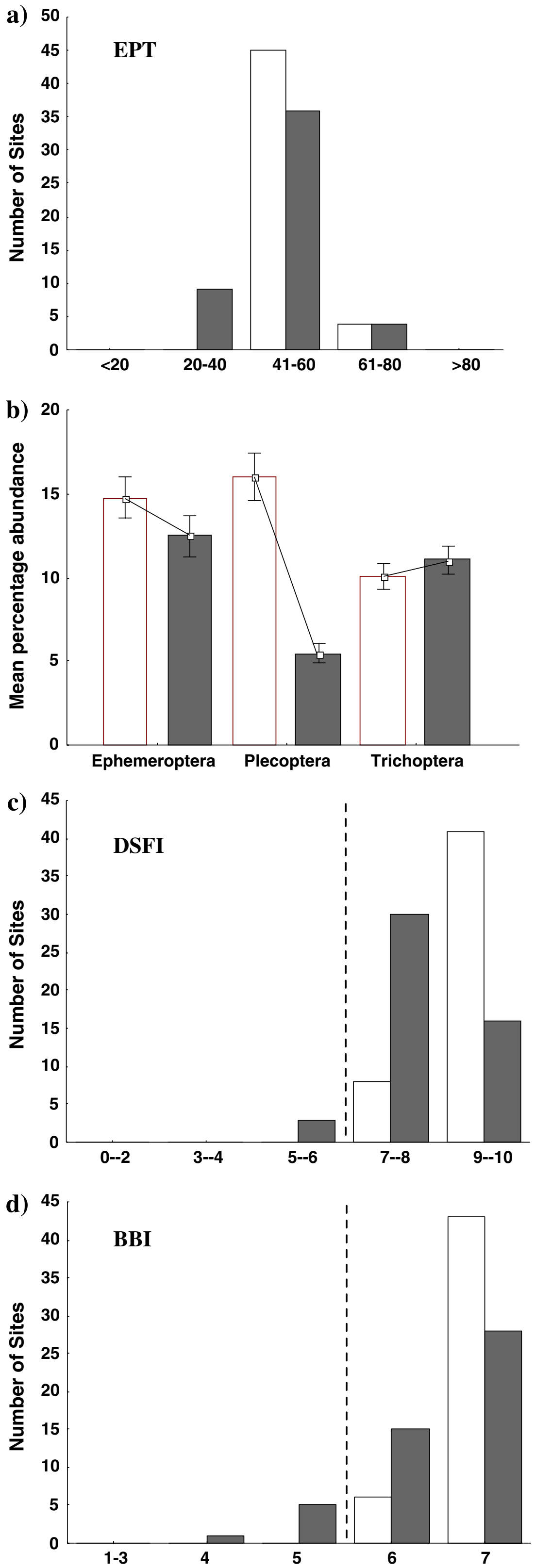
Percentage EPT taxa

The relative proportion of the EPT taxa in Fig. 3 indicates that these headwater streams were largely dominated by the mayflies, stoneflies and caddisflies in both spring and summer. The EPT taxa made up a larger proportion of the invertebrate community in spring when compared to summer, with a range of 41–63% in spring and 28–65% in summer. The mean decrease in the proportion of EPT taxa between the seasons was in excess of 5%, with EPT values above 50% occurring at 38 sites in spring and only 24 sites in summer.

Mean percentage abundance of EPT groups

As expected the percentage abundance of each EPT group varied between spring and summer (Fig. 3). The greatest change in abundance occurred in the Plecoptera with a decrease of 22% from spring to summer. Although to a lesser extent, the abundance of the Ephemeroptera decreased by about 8% from spring to summer. The least change occurred in the Trichoptera with similar proportions occurring in both spring and summer.

Seasonal changes in the species abundances were due to the absence of several pollution-sensitive taxa. The only summer representative of the Plecoptera that occurred in high numbers in the headwater streams was *Leuctra fusca* L. (Leuctridae). These stoneflies only in spring included *Brachyptera risi* (Morton), *Leuctra hippopus* (Kempny), *Nemoura cinera* (Retzius), *Leuctra nigra* (Oliver), and *Chloroperla tripunctata* (Scopoli). The Ephemeroptera were represented by several species in both seasons, some like *Ameletus inopinatus* (Eaton), *Leptophlebia vespertina* (L.), *Ecdyonurus venosus* (Fabricus), *Ephemera danica* (Müller) and *Caenis luctuosa* (Burmeister) occurred only in spring and *Seratella ignita* (Poda), *Beatis vernus* Curtis, *Ecdyonurus*



◀**Fig. 3** Graphic representation of (**a**) the relative proportion of EPT taxa (Categories assigned to 20% bands) (**b**) seasonal variation in the mean percentage (%) abundances of taxa in three orders, including Ephemeroptera, Plecoptera and Trichoptera (**c**) the BBI scores (scores assigned following De Pauw & Vanhooren, 1983) (**d**) the DSFI scores (Categories assigned following Skriver et al., 2000) assigned to fifty headwater streams using both spring (open bars) and summer (closed bars) invertebrate data. Broken lines indicate good ecological quality boundaries

dispar (Curtis) and *E. insignis* (Eaton) were present in summer. Although seasonal differences in the mayfly abundances were noted (Fig. 3), a few species like *Siphlonurus lacustris* Eaton, *Baetis rhodani* Pictet., and *Seratella ignita* accounted for high abundances and were relatively high scoring taxa in summer.

BBI

The BBI scores assigned varied from 9 to 10 indicating excellent quality to 5–6 indicating moderate water quality. Scores were assessed using five categories (Fig. 3), and 41 sites in spring were found to have excellent quality (9–10) and 9 sites were of good quality (7–8). In contrast, 16 sites in summer were categorized as having excellent water quality, the majority were of good quality and 3 sites were of moderate water quality.

DSFI

Using the Danish Stream Fauna Index, 43 sites in spring were assigned the highest index score (7) and the other 7 scored a 6, which represented good ecological quality. In comparison, 28 sites in summer had an index score of seven but the remaining sites scored 4–6 indicating only good or moderate ecological quality.

Discussion

This study assessed the performance of various ecological quality and risk status metrics applied to macroinvertebrate data collected from clean, headwater sites in Ireland. Such information is essential before the metrics can be used to accurately detect anthropogenic pressures. The metrics assessed are routinely applied in countries in the Atlantic biogeographical region, although variably applied to different freshwater types, these are not largely in use on small streams. The reliable ecological assessment of headwaters is an essential requirement to derive effective management strategies during the implementation of the WFD (CEC, 2000), because of the connectivity of headwater streams with rivers further downstream. The return of similar status values when assessments are made in different seasons on unimpacted freshwater habitats underpin the reliable use of the various metrics applied in this region.

Despite the consideration that the study streams represented near-reference status the headwater streams in this study showed significant changes in water quality ratings between the spring and summer seasons. In most sites, the water quality rating assigned using the spring season data was considerably higher than when the summer season data were used. Although the performance of the metrics varied, the ASPT scores proved to be the most resilient between seasons, resulting in only 16% change between the spring and summer season. The various other metrics applied resulted in notable change in status assigned. The SSRS, a rapid risk assessment protocol was also relatively resilient with a 28% change in category during summer relative to spring. The other metrics were more variable between season, namely EPT taxa (33% change), DSFI (48%), BBI (57%), BMWP (63%) and Q-value (98%). Variation in the performance of metrics has been highlighted by other studies conducted within Europe (Dahl et al., 2004; Lorenz et al., 2004). However, the biotic metrics are routinely applied in summer with the view to determine the ecological quality when organic impacts may be highest. The ASPT, BBI and DSFI scores have been highlighted as performing well across pollution gradients. The ASPT in particular has been shown to be relatively robust in studies in comparison to the other assessment methods (Furse et al., 1984; Lorenz et al., 2004; Sandin & Hering, 2004). The ASPT is also well correlated with stress gradients, and shows relatively slight seasonal variations (Armitage et al., 1983), and was shown to be the most consistent across stream types (Birk & Hering, 2006). Although a Spanish study did find ASPT to be less sensitive than BMWP, Zamora-Muňoz et al. (1995) found a significant relationship between ASPT and temperature which would therefore imply that ASPT is dependent on temperature and as a result seasonal variability. In the application of the various indices most sites changed category between seasons. The highest degree of change occurred using the Q-value system. The Q-value system was derived specifically for larger lotic systems and McGarrigle et al. (2002) discourages its application on small streams including headwaters. Recent implementation of the SSRS is expected to address the need to assess the risk status of small streams (Anonymous, 2005), although more reliable ecological quality rating systems are required to be developed.

In the application of RIVPACS III the stringent ecological quality index (N-Taxa) set as the benchmark to assess biological condition led to the lowering of perceived quality of all headwater sites (Furse, 2000). The relatively diverse species richness inherently associated with larger rivers, make comparisons between these and headwater streams for predictive purposes relatively inaccurate. Headwaters constitute a unique freshwater habitat and as a rule support a naturally low faunal diversity. As supported by the river continuum concept (Vannote et al., 1980), differences in community structure between small streams and freshwater habitats further downstream emphasizes the need to use appropriate indices for assessment purposes. The changes in benthic communities associated with different freshwater habitats are incorporated in some biotic indices, like the application of the Q-value system in either eroding or depositional habitats (McGarrigle et al., 2002). However, ecological quality indices have not been modified for the specific application to small streams.

The environmental gradient which exists in headwaters from intrinsically acidic upland to nutrient-rich lowland streams, has led to the development of a number of headwater typologies (Furse, 2000; Baars et al., 2004). A small number of sites in this study returned consistently low ratings in both spring and summer, even though the water analysis showed no signs of anthropogenic impact, and lack of landscape characteristics associated with organic impacts (see Donohue et al., 2006). These sites were mainly from catchments draining base-poor geology and peaty soils. Most were circum-neutral but could under natural conditions become substantially acidic during high flow. Headwaters which generally support a low faunal diversity due to certain physical variables suggested by Crunkilton & Duchrow (1991), seem under these circumstances to support even lower species diversity. Naturally acidic streams are shown to support lower numbers of species elsewhere (Collier et al., 1990; Renberg et al., 1993; Rapp, 2001; Woodward et al., 2002; Dangles et al., 2004; Petrin et al., 2007). As a result the seasonal changes noted in the ecological assessment are exacerbated under conditions such as natural acidity, high water temperatures or limited productivity due to lack of allochthonous organic input (Crunkilton & Duchrow, 1991).

Macroinvertebrates are sensitive to change in their physico-chemical environment including flow-rate (Newbury, 1984), stream size and distance to the source (Minshall et al., 1985), substrate (Minshall & Minshall, 1977), vegetation (Dallas & Day, 2007), and temperature and stream discharge (Bournard et al., 1987; Boulton & Lake, 1992). Some of these factors are linked to seasonal variability especially flow-rate, temperature and stream discharge (Bunn et al., 1986). Metrics applied to wadeable freshwaters show little difference between season variability in their performance (Murphy, 1978; Armitage et al., 1983; Furse et al., 1984; Bunn et al., 1986; Boulton & Lake, 1992), although variations occur in the proportion of sensitive taxa in different seasons (Dallas, 2002). Larger rivers are inherently more diverse, and the turn over of species between seasons overcome significant seasonal differences as a good representation of pollution-sensitive taxa are present throughout the year. Headwaters on the other hand have low species diversity and as a result are subject to shifts in species composition due to life history patterns in response to seasonal changes. Due to this seasonal variation some studies encourage the use of bioassessment at certain times of the year (Reece & Richardson, 1999). Stonefly species dominate unimpacted headwater streams and many species occurring in Ireland are absent during the summer months. These include species like *Brachyptera risi* and *Leuctra nigra*, with such life history patterns supported by other studies (Smith et al., 2000). Mayfly species including *Ecdyonurus venosus* Fabricus (Elliott et al., 1988) as well as caddisfly larvae such as *Agapetus fuscipes* Curt. (Mittelstadt et al., 1991; Nijboer 2004; Becker, 2005) show similar life history patterns. In terms of species richness Ireland has a small proportion of species (usually about 70%) of that occurring in the United Kingdom, which in turn is less diverse than mainland Europe (Kelly-Quinn et al., 2002). The apparent lack of species present during the summer in headwaters seems to result in a shift in the ecological quality status assigned using several biotic metrics. Species do not necessarily disappear but may have emerged or due to the sampling method, albeit standard practice, the smaller larvae may be missed. Despite the shift in species presence between seasons some metrics result in a greater change in category than others.

This study indicates that several metrics routinely used in ecological and risk assessments of freshwaters are subject to seasonal changes in apparent status when applied to small streams. Several studies show how temporal changes in macroinvertebrate communities can result in a lower water quality status which can be due to life cycles rather than a result of anthropogenic circumstances (Crunkilton & Duchrow, 1991; Dallas, 2002, 2004; Linke et al., 1999; Reece & Richardson, 1999). This emphasizes the sensitivity of such indices and the need to use appropriate indices interpreting the results with due consideration of the autecology of the invertebrate species present. We consider that small watercourses offer a unique, highly variable habitat which is characterized by an intrinsically low faunal diversity. The turn over of species in headwaters between seasons, particularly the pollution-sensitive groups like the Ephemeroptera and Plecoptera, contribute to the lack of consistency in returning similar status values throughout the year. The sites in this study represent the gradient from acidic upland to nutrient rich lowland streams, and indicate that acidic streams are more susceptible to such seasonal changes when these metrics were applied. Furthermore, we consider that due to the higher number of species, spring assessments in headwaters using the indices applied may reliably reflect the ecological quality. Similar recommendations are made by Reece & Richardson (1999) that assessments should be confined to a particular season. However, the effective use of biotic indices in summer when the impacts may be greatest may not be applicable in headwater streams therefore requiring the redevelopment of ecological quality assessments indices in small streams or standardizing the time at which samples are taken.

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