Article

The feasibility of developing multi-taxa indicators for landscape scale assessment of freshwater systems

Mark Everard[1], Melanie S. Fletcher[2*], Anne Powell[2] and Michael K. Dobson[2]

[1] *Environment Agency, Block 1 Government Buildings, Burghill Road, Westbury-on-Trym, Bristol, BS10 6BF, UK.*

[2] *Freshwater Biological Association, The Ferry Landing, Far Sawrey, Ambleside, Cumbria, LA22 0LP, UK.*

* *Corresponding author: mfletcher@fba.org.uk*

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Abstract

The use of bird assemblages as wetland indicators is now well established in the UK. An indicator based on a single taxonomic group can, however, have limitations. Conversely, a multi-taxa approach can potentially provide a more robust reflection of the health of fresh waters. In this paper, we consider the *inherent* suitability of different taxonomic groups for inclusion in a multi-taxa indicator, based upon taxon characteristics, species richness and prevalence across a range of freshwater habitats, and their *practical* suitability, based upon quality and quantity of available data. We conclude that, in addition to birds, there are six candidate groups of taxa throughout the world that are currently suitable for inclusion in a multi-taxa indicator. These are: mammals, amphibians and reptiles, fish, dragonflies and damselflies (based on adult recording), benthic macroinvertebrates and macrophytes. Of these taxa, all but amphibians and reptiles and fish are suitable for inclusion in a UK indicator. The types and limitations of currently available datasets are reviewed. We provide recommendations for advancing this approach in the assessment of freshwater systems.

Keywords: Freshwater; indicator; landscape-scale; multiple taxa; ecosystem services; aquatic taxa.

Introduction

The use of living organisms as indicators of the ecological quality of fresh waters is long established (e.g. Metcalfe, 1989). Historically, indicator taxa have been used successfully to assess discrete and often fragmented pressures such as pollution status, habitat modifications or changes in hydrological regime, in both rapid assessment and monitoring programmes. We are, however, increasingly realising the need to understand and manage general ecological health, integrity, resilience and ecosystem functions at a landscape scale (as reviewed by Sweeting, in press). This requirement is driven by a need to develop a system-wide understanding of the interdependencies and pressures operating upon the range of interconnected habitats comprising a freshwater landscape, for example as required to assess Good Ecological Status under the European Union (EU) Water Framework Directive (WFD) (European Commission, 2003) and Favourable Status under the EU Habitats Directive (European Commission, 1992). Looking at appropriate landscape-scale measures, rather than deriving conclusions from indices developed

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to reflect ecological response to single pressures, will allow better assessment of the general vitality and integrity of fresh waters (Everard, 2008). This in turn will enhance our understanding of ecosystem integrity and resilience, and of the capacity for fresh waters to provide beneficial ecosystem services, and will also assist with the setting of priorities for sustainable catchment management (Everard & Powell, 2002; Feld et al., 2009).

The use of multiple taxa indicators allows monitoring programmes to overcome problems associated with species-specific responses to the environment that are unrelated to the stressor of interest; the less closely related the taxa are, the less likely they will show similar responses to stressors such as pathogenic organisms. Multiple taxa can include large numbers of closely-related species, but the 'multi-taxa' approach, as defined here, incorporates taxa from two or more higher taxonomic levels (kingdom, phylum or class).

The multi-taxa approach is well established, particularly through the use of biomonitoring methods based upon benthic macroinvertebrates in running waters, the indicator organisms being drawn from several phyla. Such systems are, however, mainly designed to register responses to specific stressors, such as organic inputs (e.g. BMWP (Biological Monitoring Working Party; Hawkes, 1997), SASS (South African Scoring System; Dallas, 2007)) or acidification (e.g. AWIC (Acid Waters Indicator Community; Davy-Bowker, 2005). Various studies have demonstrated that different taxonomic groups respond to the environment in different ways (e.g. Santi et al., 2010), and therefore there is potential to design monitoring programmes based upon multiple taxa that provide assessment of a range of different aquatic habitats and responses to a variety of stressors (e.g. Lovell et al., 2007; Johnston et al., 2008; Mawdsley & O'Malley, 2009). At least one currently operating monitoring system, the PSYM approach (Predictive SYstem for Multimetrics) to assessing the quality of ponds, specifically incorporates both macroinvertebrates and macrophytes (Pond Conservation, 2002).

The currently existing multi-taxa approaches have mainly been developed as indicators for single habitats. There is, however, potential for further incorporation of data or different taxonomic groups to enable a wider landscape application of indicators to be developed. Here, we explore this potential, primarily from a UK perspective with corresponding examples and conclusions. The paper refers to the species diversity and data collection schemes currently in operation in the UK for different taxonomic groups. However, the principles, addressed here in relation to a multi-taxa approach, are more globally applicable.

Incorporating multiple taxa into a landscape-scale indicator

An early development in landscape-scale indicators in the UK was the Farmland Birds Indicator. This reveals significant and cumulative change in national biodiversity since the 1970s, and has consequently been adopted as a national sustainability indicator used to inform management targets by the UK Government (Gregory et al., 2004; Defra, 2007a). In view of the success of the Farmland Birds Indicator, a Wetland Birds Indicator was developed to achieve similar goals for freshwater wetlands (Noble et al., 2008). Population trend data for wetland birds, when used in this way, currently provide the most comprehensive coverage of environmental quality across different freshwater habitat types, reflecting both the characteristics of birds, their social valuation, and investment in methods for data capture and interpretation (Everard, 2008). Noble et al. (2008) conclude that existing data holdings for birds associated with wetlands provide a valuable and resource-effective means to monitor environmental quality on a systematic basis, better to reflect overall ecosystem health and to inform the need for management and policy responses.

However, Everard (2008) concludes that existing breeding bird survey data present a far from perfect method of monitoring all attributes of freshwater wetland ecosystems. For example, existing survey methods under-represent habitats such as small still water bodies (Collier et al., 2005). Additionally, they are not helpful in informing us about the level of connectivity between aquatic systems.

A landscape-scale indicator based on breeding birds may therefore benefit from incorporation of other taxa

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which better reflect different aspects of freshwater quality, as well as specific pressures to which other taxa are differentially sensitive. For example, amphibians are good indicators of the quality of those small still water bodies that the wetland bird indicators under-represent, and may be appropriate indicators of freshwater quality in other habitats (Welsh & Ollivier, 1998). Biggs et al. (1994) and Williams et al. (1998) make the same observation for a wide range of specialist taxa including scarce aquatic beetle species and molluscs.

The following sections of this paper consider those taxa that are likely to provide the best overall view of ecological health at a landscape scale. The inclusion of taxa into a potential suite of multi-taxa indicators would rest upon two primary attributes: 1. the *inherent* ecological attributes of selected species or taxonomic groups (see below); and 2. the *practical* suitability based on the currently available data.

Inherent ecological attributes of taxa as a means for selecting potential groups

The inherent suitability of different taxonomic groups to support indicator development for a range of freshwater wetland types can be assessed on the basis of their diversity, geographical distribution and ecology. In addition to the existence of a substantial body of biological knowledge about the taxonomic group, it is assumed for the purposes of this paper that, to be useful as an indicator, a taxon or group should:

a. be present in a broad spectrum of freshwater habitats;
b. exhibit appropriate species diversity in those habitats – ideally, there should be a number of species or taxa, each of which responds to a single or narrow range of pressures so that collectively they provide an indicator of total ecosystem health;
c. have appropriate ecological attributes; and
d. be present as a sustainable population.

a. Taxa present in a broad spectrum of freshwater habitats

Table 1 provides a summary of the occurrence of different taxa across a range of freshwater habitats, based on the habitat categories identified by Everard & Noble (2008). Most freshwater taxa are widely distributed across a range of habitats, and those that are restricted, such as Plecoptera (stoneflies), can provide valuable information about the habitat types in which they specialise.

b. Taxa presenting appropriate species diversity in freshwater habitats

Most of the taxonomic groups listed in Table 1 achieve an appropriate level of diversity in freshwater habitats, when measured at a landscape scale, to be of potential value. This attribute does, however, show some variation with location; some potentially valuable groups show a strong decline in species richness with increasing latitude (e.g. amphibians), while those with poor dispersal abilities may be of restricted value on islands (e.g. mammals).

c. Taxa with ecological attributes that are appropriate for their use as an indicator

A few taxa are inappropriate because of their ecological attributes. For example, the role of trees as indicators is compromised by their long life spans, as a result of which their community response to environmental change is too slow to allow assessment at the time scales required. In addition, they have low diversity associated with most aquatic habitats. However, some valuable supplementary information is available, for example that collected as part of the UK River Habitat Survey (RHS) which also records the alder (*Alnus* spp.) disease (*Phytophthora alni*) (Environment Agency, 2003).

d. Taxa with sustainable populations

A taxon which exists in small numbers on the edge of its optimal range or is present only as mature individuals, would not be suitable as an indicator. For example some UK rivers support only 'senile populations' of freshwater pearl mussels (*Margaritifera margaritifera*) in which the stock is made up of a remnant population of elderly individuals,

Table 1. Inherent suitability of major groups of freshwater organisms for inclusion in multi-taxa indicators. This assessment is based upon both formal (mainly peer-reviewed literature) and informal sources (including grey literature, special interest groups and expert input). The outcomes of this evaluation were refined through dialogue and consensus-building with a network of 96 participating and corresponding members with interests in wetland indicators and/or selected taxonomic groups. The results give a British perspective on distribution of organisms, but the general pattern is applicable elsewhere in the world.

Habitat	Streams	Rivers	Still Fresh Waters		Reed-beds	Wet Grass-land	Wet wood-land	Wet moor-land	Canals	Other AWBs**	Sub-surface waters	Ephemeral waters	Sources of distributional data for UK
Taxon			Large	Small									
Mammals: bats													Catto et al., 2003; Bat Conservation Trust, 2006b
Mammals: otters													Crawford, 2003; Jones & Jones, 2004
Mammals: voles													Crawford, 2003; Jones & Jones, 2004; Strachan et al., 2003
Mammals: other													Carter & Churchfield, 2006; Tracking Mammal Partnership, 2006
Amphibians and reptiles													National Amphibian and reptile recording Scheme (NARRS)
Fish: salmonids													Davies et al., 2004
Fish: coarse													Davies et al., 2004
Fish: small e.g. sticklebacks													Davies et al., 2004
Zooplankton													Scattered
Benthic macroinver-tebrates*													BIOSYS (EA)
• Ephemeroptera (mayflies)													National Ephemeroptera Recording Scheme
• Plecoptera (stoneflies)													National Plecoptera Recording Scheme
• Odonata (damselflies and dragonflies)													British Dragonfly Society (BDS)
• Trichoptera (caddisflies)													National Trichoptera Recording Scheme
• Diptera (true flies)													Wichard et al., 2002
• Coleoptera (beetles)													Balfour-Browne Club
• Crustacea													Hypogean Crustacea Recording Scheme; Biological Records Centre; Kinchin, 1994

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Habitat / Taxon	Streams	Rivers	Still fresh waters: Large	Still fresh waters: Small	Reed-beds	Wet grass-land	Wet wood-land	Wet moor-land	Canals	Other AWBs**	Sub-surface waters	Ephemeral waters	Sources of distibutional data for UK
• Mollusca	■	■	■	■	■	□	□	□	■	■	□	□	Kerney, 1999
Arachnida (spiders and mites)	▒	▒	▒	▒	■	■	■	■	▒	▒	■	□	British Arachnological Society; Spider Recording Scheme; Harvey et al., 2002
Meiofauna* e.g. microcrustacea, tardigrades and rotifers	■	■	■	■	■	▒	▒	▒	■	■	■	▒	Scattered
Hypogean fauna*	□	□	□	□	□	□	□	□	□	□	■	□	Hypogean Crustacea Recording Scheme; Knight, 2007; Scattered
Parasites*	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	Scattered
Cyanobacteria (blue-green algae)	□	□	■	■	■	□	□	□	■	■	□	□	Scattered
Wetland macrophytes* (emergents)	▒	▒	▒	▒	■	■	■	■	▒	▒	□	▒	Botanical Society of the British Isles (BSBI)
True aquatic macrophytes*	■	■	■	■	□	□	□	□	■	■	□	□	BSBI
Diatoms	■	■	■	■	▒	▒	▒	▒	■	■	□	□	Scattered
Chrysophytes	□	□	■	■	□	□	□	□	▒	▒	□	□	Scattered
Other algae	■	■	■	■	□	□	□	□	■	■	□	▒	Scattered
Bryophytes	▒	▒	▒	▒	▒	■	■	■	□	▒	□	▒	British Bryological Society
Trees*	□	□	□	□	□	▒	■	□	□	□	□	□	BSBI

* Ecological group containing species from a range of taxonomic groups

** Artificial water bodies

Key

■ Taxa well represented in these habitats

▒ Taxa may be represented in these habitats

□ Taxa not well represented in these habitats with no younger specimens and no active recruitment, making it an unsuitable indicator taxon.

Practical suitability of taxa as indicators on basis of available data

Most of the taxa whose distribution and diversity makes them potentially suitable for incorporation into a multi-taxa indicator are simply too poorly known to be of practical use. For example, meiofauna and hypogean fauna offer a potentially large species diversity and their importance to ecosystem function is increasingly being recognised (Knight, 2007), but their diversity and species assemblage structure is still poorly known and as yet we are unable accurately to judge their inherent value as indicators. As our understanding of these groups of organisms improves in the future, they may become valuable additions to freshwater assessment systems. Similarly, parasites are currently too poorly understood, but may be of value because they exhibit a wide phyletic diversity and offer a unique opportunity to integrate environmental pressures as a consequence of their indirect life cycles which utilise different hosts for different life stages (Williams et al., 1992).

Combining inherent properties with data adequacy

On the basis of the criteria considered above, we have identified seven taxa with potential for incorporation into multi-taxa aquatic indicators. Of these, five are useful throughout most of the world, while two are of restricted use in some areas, including the UK.

1. Mammals

Mammals are amongst the best known organisms taxonomically and in terms of distributional and habitat information. They achieve high diversity in freshwater habitats, particularly in the tropics, and there are over 100 freshwater dependant or associated species (Veron et al., 2008), plus many others that frequent the edges of aquatic habitats.

Almost all freshwater mammal species are also active in the surrounding terrestrial environment, and so they provide an important mechanism for monitoring both aquatic and associated terrestrial systems and the linkages between them. Furthermore, most are susceptible to direct human disturbance.

Even where mammal diversity is low, they are valuable as supplementary indicators, as surveys of some individual species are regularly undertaken. In the UK, for example, water voles (*Arvicola terrestris*) and otters (*Lutra lutra*) are routinely surveyed every seven years by the Environment Agency (EA) (Crawford, 2003; Jones & Jones, 2004), and there are a number of locality-specific surveys throughout the UK undertaken by the Wildlife Trusts and others (Strachan & Moorhouse, 2006). Other mammals are recorded incidentally as part of the Breeding Birds Survey or are the subject of specific surveys such as the Mammal Society's water shrew (*Neomys fodiens*) survey (Carter & Churchfield, 2006). An EA-commissioned study (Catto et al., 2003) explored the use of bats as indicators of environmental quality, with the Daubenton's Bat (*Myotis daubentonii*) Waterway Survey particularly recommended.

2. Birds

Birds have the same advantages as mammals in terms of our understanding of their diversity and distribution. However, they are in many ways superior because they are generally better known and more diverse, the high diversity extending throughout most of the world and including high alpha (within-site) diversity (e.g. Everard & Noble, 2008). In the UK, different groups of birds, such as wintering waterbirds, farmland birds and seabirds, show a variety of responses to changing environmental circumstances (Eaton et al., 2010).

3. Amphibians and reptiles

Amphibians and aquatic reptiles are valuable indicators due to their high diversity, particularly in the tropics (Pauwels et al., 2008; Vences & Köhler, 2008), their links with the terrestrial environment and their often clear responses to perturbation (Welsh & Ollivier, 1998). They have been successfully used for rapid bioassessment even

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in parts of the world which have been little studied (e.g. Rödel & Bangoura, 2004). The potential for amphibians and reptiles as wetland indicators in the UK has been reviewed by Sewell & Griffiths (Sewell & Griffiths, 2009 and personal communication), who conclude that, although considerable data exist, many necessary criteria for use as an indicator are not fulfilled. In particular, diversity is low, with only seven native amphibians of which two are restricted in distribution, and only one native reptile associated with water (grass snake: *Natrix natrix*). Nevertheless, most of the native amphibians and reptiles found in the UK have been subject to national monitoring programmes under the National Amphibian and Reptile Recording Scheme (NARRS), which commenced in 2007 following some pilot surveys in 2006 (NARRS, 2006). In addition to these more recent data, long-term records exist for natterjack toads (*Bufo calamita*) and other species of particular (national and local) interest, although, in the past, there has been little consistency in methods and patchy coverage nationally.

4. Fish

A fish-based index (Index of Biotic Integrity, IBI) has been used as a measure of freshwater condition in North America, some parts of Europe, Africa, Asia and Australia (Maitland, 2004a). In the UK, a Fish Classification System (FCS) has been developed as a river assessment method for WFD monitoring in England and Wales. Characteristic groups of freshwater fish exist on each continent (Lévêque et al., 2008). However, the fauna of the UK is depauperate compared with that of the rest of Europe due to the elimination of stocks during the last Ice Age. Furthermore, the interventions of anglers, river managers and others over the last several hundred years have modified stocks to a considerable extent (Maitland, 2004b). Fish populations across the UK and elsewhere in Europe have been, and continue to be, heavily manipulated (Copp et al., 2005), which confounds interpretation of any environmental 'signals' to which they may respond. These factors render this group unlikely candidates as specific indicators in the UK, although they may be of value in bioassessment where natural diversity is high and human introductions or population manipulations relatively unimportant (e.g. in West Africa – Kouamélan et al., 2003).

5. Dragonflies and damselflies

Dragonflies and damselflies (order Odonata) are part of the aquatic macroinvertebrate fauna as larvae, but as adults they are also very suitable as candidates for inclusion in a multi-taxa indicator, as they are easy to see and distinguishable in the field, and provide information about the status of the terrestrial shoreline of habitats as well as the underwater component. Most are also highly mobile, and they will rapidly colonise new or restored sites and abandon impacted sites. Worldwide, the dragonfly and damselfly fauna is relatively well known (Kalkman et al., 2008), and their conspicuous nature and often high alpha diversity makes them an attractive option for biomonitoring. Adult dragonflies and damselflies are the most thoroughly recorded emergent aquatic invertebrates in the UK. The Dragonfly Recording Network (DRN) is co-ordinated by the British Dragonfly Society and operates within guidelines based upon recommendations given by the National Biodiversity Network (NBN). However, the quantity and spread of data is not currently adequate to be considered a robust national monitoring programme.

6. Macroinvertebrates

Benthic aquatic macroinvertebrate indices have been adapted for biomonitoring purposes in many parts of the world (Wright et al., 2000), albeit often only at family level. A substantial EA dataset for benthic macroinvertebrates covers England and Wales (see below). However, despite some specific interrogations of this dataset to determine selected environmental signals (for example riverine hydromorphology, Vaughan et al., 2007), general trends within the dataset, other than for the statutory reporting purposes for which the monitoring programme was developed, remain largely to be explored. The RIVPACS dataset (River InVertebrate Prediction And Classification System) is also of great value in providing species level coverage from semi-natural rivers throughout the UK (Wright et al., 2000).

7. Macrophytes

Macrophytes are often the primary factor in determining the structure and function of aquatic ecosystems (Chambers et al., 2008). They have been used to assess the biological productivity of fresh waters, as indicators of pollution, biological conservation value and change over time. Apart from difficulties with what is actually classed as an 'aquatic' plant, what constitutes a 'macrophyte', and the lack of an agreed pan-European species checklist, there are also problems with variability in local plant names and morphological variation in the plants themselves in different locations (Goulder, 2008). This makes inter-country intercalibration for the WFD very difficult.

In the UK, aquatic macrophyte data are collected at river sites by Natural England (NE) (and formerly its predecessor body English Nature (EN)), the Countryside Council for Wales (CCW), the EA, Scottish Natural Heritage (SNH), Scottish Environment Protection Agency (SEPA), some County Wildlife Trusts, the Botanical Society of the British Isles (BSBI) and other voluntary bodies and individuals. Much of this information is collated by the Biological Records Centre (BRC) and NBN. Some aquatic macrophyte data have been collected for discrete water quality purposes, such as derivation of Mean Trophic Rank (MTR) scores indicating nutrient status of linear waterways (Holmes et al., 1999) or the Wildlife Trusts' *River Plants for River Quality Surveys* (Wildlife Trusts, 2005). In lakes, macrophyte data have primarily been collected for conservation assessment or inventory purposes, for example as part of work undertaken for the EU Habitats Directive to select Special Areas of Conservation (SACs). Currently, various methods, such as River and Lake LEAFPACS (UKTAG, 2008a, 2009; Willby et al., 2009) and the FREE index (UKTAG, 2008b) have been developed to undertake WFD monitoring in the UK. Habitats and wetland vegetation assessment is undertaken periodically under the Countryside Survey (Defra, 2006). Some of these data are used to inform the UK Government's 'quality of life counts' sustainability indicators (DETR, 1999). The BRC database and the flowering plant distribution recorded by the BSBI provide data coverage across the UK, but the lack of routine stratified methods for collating vegetation data make them less appropriate as a routine indicator of river and freshwater wetland quality.

The quality of data currently available – the UK example

Ecologically-based indicators must be founded upon groups of organisms for which reliable and appropriate survey data are available. Consequently, it would be unsafe to assume that today's bioindicators are based on optimal taxa for different freshwater habitat types. The availability of appropriate data for other taxa could therefore support development of more robust indicators in the future.

Data collection for the various taxa present in fresh waters, gathered at species level or higher, depends upon reliable taxonomic skills supported by clear, unambiguous identification guides and suitably skilled practitioners. Some groups of organisms which fulfil the ecological criteria outlined above, making them candidates for consideration within a multi-taxa indicator, are in practice difficult to identify. There is, for example, no UK key for aquatic beetle larvae, and coverage for aquatic dipteran larvae is incomplete. Of those keys that are available, some can be difficult to use. Furthermore, few Higher Education courses now include training in identification skills or taxonomy. Although some organisations undertake relevant training, it can take a long time for individuals to become proficient.

In addition to reliability of identification, a number of other practical factors inhibit the gathering of data sufficient to inform an indicator. These include the necessity for comprehensive habitat sampling, geographic coverage, temporal coverage, the need for quality control, taxonomic resolution, and the potential for continued collection of data in the future. The accessibility and availability of past data for comparative purposes may also be important both for setting baselines from which to interpret trends and to maintain the interest and attention of recorders.

The freshwater taxa listed in Table 1 receive different amounts of attention in the laboratory and in the field. For example, whereas family-level data on benthic macroinvertebrates are available for much of the major river network across England and Wales, distributional

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information is lacking for zooplankton in lakes. This is despite considerable biological understanding of the relationship between zooplankton assemblages and various pressures (e.g. Gliwicz, 1969, 1986; Hilbricht-Ilkowska, 1977; Irvine et al., 1990; Beklioglu & Moss, 1996; Duncan, 1997; Elliott et al., 2005; 2006). These organisms are not routinely sampled in the UK, nor do they feature as quality indicators in implementation of the WFD.

The aim of the WFD is to achieve 'good ecological status' for all natural surface waters, based on the management of 'River Basin Districts'. Many current monitoring programmes in the UK focus on the objectives of the WFD. A network of sites across the UK are used to undertake surveillance, operational and investigative monitoring to assess the ecological and chemical status of surface waters and the chemical and quantitative status of groundwater. The focus of the WFD is overall assessment of ecological status rather than a diagnostic approach for specific pressures, representing a change in policy to previous monitoring efforts. This may affect the types of data now collected.

Survey data available for taxa that are inherently suitable for inclusion in a multi-taxa approach can be divided into three main categories: coordinated collection programmes; reactive sampling/monitoring; and *ad hoc* data collection.

Coordinated collection programmes

These are programmes carried out using standardised methods, with the aim of generating geographically broad-scale information. They are generally carried out by statutory bodies or coordinated volunteer programmes and often incorporate a temporal element, involving return to fixed survey sites. The most extensive and comprehensive programme of this type is that carried out by the EA to collect macroinvertebrate data from running waters in England and Wales. The EA and SEPA network of macroinvertebrate sampling sites covers a range of locations across England, Wales and Scotland. The RIVPACS approach has been updated and incorporated into the River Invertebrate Classification Tool (RICT) for WFD monitoring in parts of the UK. Other tools for assessing the condition of both running and still waters across the UK are the Chironomid Pupal Exuviae Technique (CPET), the Lake Acidification Macroinvertebrate Metric (LAMM) and the Scottish Acid Water Indicator Community (SAWIC). The EA, SEPA and the Northern Ireland Environment Agency (NIEA) also carry out RHS throughout the UK, primarily focused on hydromorphological information but including mapping the distribution of three invasive riparian plant species: Himalayan balsam (*Impatiens glandifera*); Japanese knotweed (*Fallopia japonica*) and giant hogweed (*Heracleum mantegazzianum*) (Environment Agency, 2003). The National Pond Survey (NPS) and the PSYM approach provide a small but high-quality dataset of macrophyte and benthic invertebrate information for small standing waters (Pond Conservation, 2008). The Countryside Survey, repeated every 6 to10 years, is an intensive monitoring of sites throughout the UK. In fresh waters, it covers macroinvertebrates and macrophytes in headwater streams, along with macrophytes in representative ponds (Carey et al., 2008; Dunbar et al., 2010; Williams et al., 2010). It is designed to allow statistically robust comparisons across seven broad environmental areas, rather than at a River Basin District or finer scale, and it is limited to around 600 one-kilometre squares, of which many contain no open water habitat. The value of the Countryside Survey dataset as a contribution to an indicator lies therefore not in its spatial coverage of freshwater wetland types but in its temporal compatibility and its potential for assessing the quality of data collected by other methods.

Reactive sampling/monitoring

This is a form of coordinated sampling carried out in response to a specific trigger, and not routinely. An example of this is algal data collected by the EA in response to reports received that a bloom is occurring (Fig. 1). This type of sampling is extremely important when there are still significant concerns about land use and impacts of runoff on lakes and their continuing eutrophication.

Ad hoc data collection

Ad hoc data collection is the development of datasets through the activities of disparate groups and individuals, often over a long period of time. The effort is not coordinated, and often involves different sampling techniques. The national recording schemes in the UK illustrate this well, one example being the scheme coordinated by the BSBI, which provides information on vascular plant distribution collected usually by individual enthusiasts; the resulting dataset includes no indication of abundance, but can give a good indication of temporal trends and general spatial distribution at national scale (Fig. 2).

Limitations to current datasets

Each of the datasets described above has limitations. Within a single taxonomic group, data are often collected in a number of different ways, and collating datasets can be difficult. For example, our knowledge of the macrophyte flora of British lakes derives from a large number of published and unpublished studies often associated with Sites of Special Scientific Interest (SSSI) designations or condition surveys, along with individual recorders' records. Although this fusion approach can give a good overall picture, it is clearly *ad hoc* data collection and highlights the fact that until the advent of the WFD, even large, obvious freshwater habitats such as lakes had not been consistently or routinely monitored/surveyed, and that data holdings were therefore likely to be incompatible. Furthermore, practical sampling difficulties may mean that we know rather more about easily accessible habitats, such as shallow rivers and the riparian and shallow littoral zones of lakes, than we do about the places that are more difficult to survey, such as deep rivers and lake beds. Collection from different sites at different times can further distort the true picture of current distributions, particularly for a habitat and/or taxonomic group prone to the effects of alien species invasion (Dawson & Holland, 1999; Manchester & Bullock, 2000), one which exhibits pronounced seasonality such

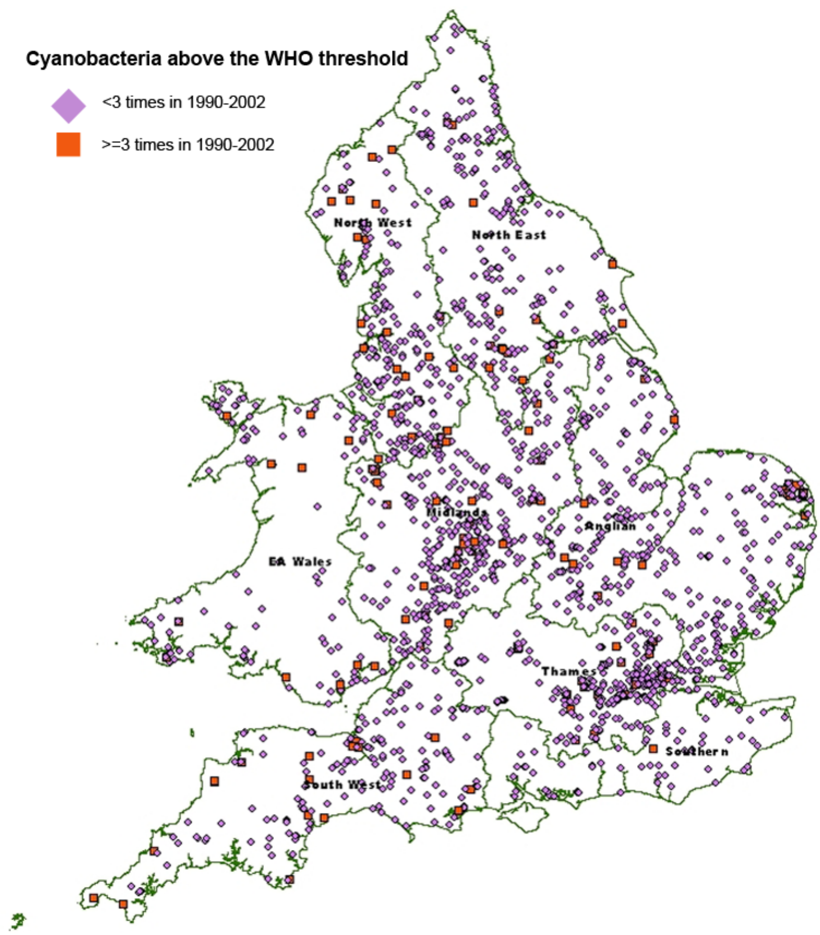

Fig. 1. An example of reactive monitoring data. Coverage of algal blooms recorded in England and Wales following reports from members of the public. This illustrates a reactive dataset, the records being derived from reported incidents rather than an active survey. The purple diamonds indicate that the WHO (World Health Organization) threshold for Cyanobacteria was breached fewer than three times for the period 1990–2002. The red squares indicate that the WHO threshold for Cyanobacteria was breached three times or over for the period 1990–2002. Source: Environment Agency.

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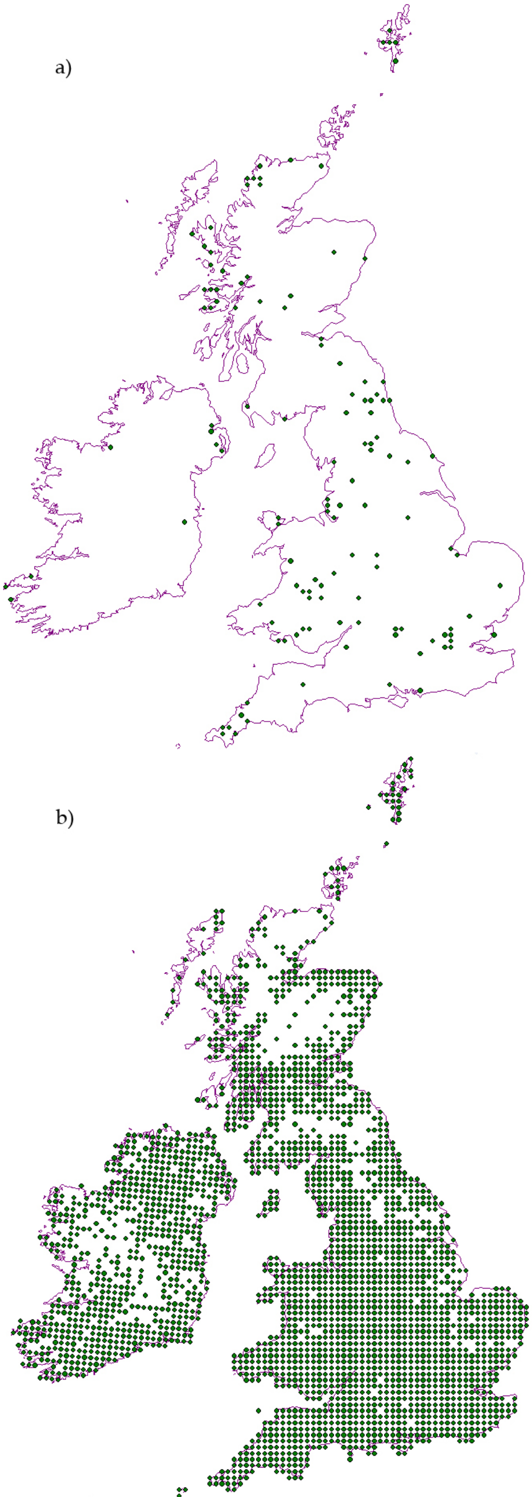

Fig. 2. An example of *ad hoc* collection data. Japanese knotweed distribution as derived from the Botanical Society of the British Isles (BSBI) records: (a) records from before 1930; (b) all records up to 2008. Source: BSBI.

as response to annual succession (e.g. Glenn-Lewin et al., 1992), or in response to intermittent influences (such as winterbourne flow (Holmes, 1996)).

Even when the data themselves are comparable, collection by different programmes can result in data held in different locations and in incompatible formats. Higher plants once again provide an example of this, with data having to be extracted from the BSBI's presence/absence maps on a 10 km grid, bespoke site-level surveys to support Environmental Impact Assessments (EIAs), the RHS, MTR assessment of eutrophication impacts from sewage effluent outfalls qualifying under the EU Urban Wastewater Treatment Directive, and the Countryside Survey (Holmes et al., 1999; Environment Agency, 2000).

All of these datasets can be subject to geographical bias. This is often allied with recorder bias, where *ad hoc* data collection is heavily influenced by the activities of an individual or small group of recorders. This results in our understanding of the distribution of a group of organisms, which might otherwise be highly suitable for inclusion in an indicator, being based on data gathered from very few geographical locations or time scales (Fig. 3). Taxa that suffer from this bias include wetland arachnids and hypogean Crustacea; data for both these groups in the UK is primarily collected by a handful of expert volunteers.

From the above considerations, it is clear that the datasets that are likely to have the fewest limitations are those nationally collected as part of coordinated programmes. The EA river macroinvertebrate data benefits from standardised field collecting techniques, although subsequent processing of these data is variable. All EA regions routinely identify organisms to family level, but identification to species is less common. When examining the data, this disparity can give a skewed picture of distributions. For example, species level data is routinely collected in Anglian Region, but species-level identification is more patchy in South West Region. When comparing results of surveys for two hydropsychid caddis species in these regions, the maps appear to show a greater abundance of *Hydropsyche angustipennis* in Anglian Region (Fig. 4a). Comparison of records for *Hydropsyche instabilis* shows a similar abundance in both regions. The first result may be interpreted as an accurate reflection as *Hydropsyche angustipennis* can tolerate high temperatures, low oxygen concentrations and slow flow (Edington & Hildrew, 1995), conditions more typical of the low-gradient rivers of Anglian Region than the higher-gradient and often more turbulent rivers of South West Region. However, the second result may be an artefact of the less consistent amount of species level identification being carried out in the South West Region, as *Hydropsyche instabilis* would be expected to be more abundant in that region as it is indicative of high gradient rivers.

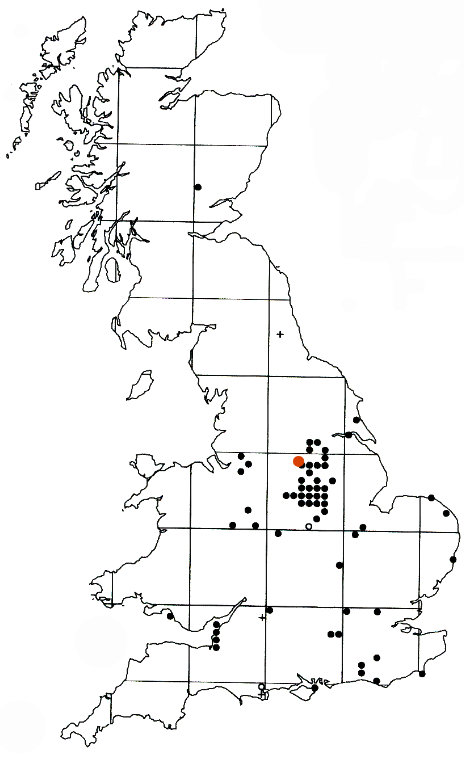

Fig. 3. An example of recorder bias data. Distribution of the spider *Tetragnatha striata* in the UK. This is a dataset heavily skewed by a single recorder, in this case an individual based in the Sheffield area. The species is probably common in suitable habitats elsewhere but, because it lives in poorly accessible flooded reedbeds, few people are actively recording its presence. Number of 10 km² occurrences: 1900–1949 +, 1950–1979 °, 1980 onwards ●. Red circle shows location of Sheffield. Source: Harvey et al. (2002).

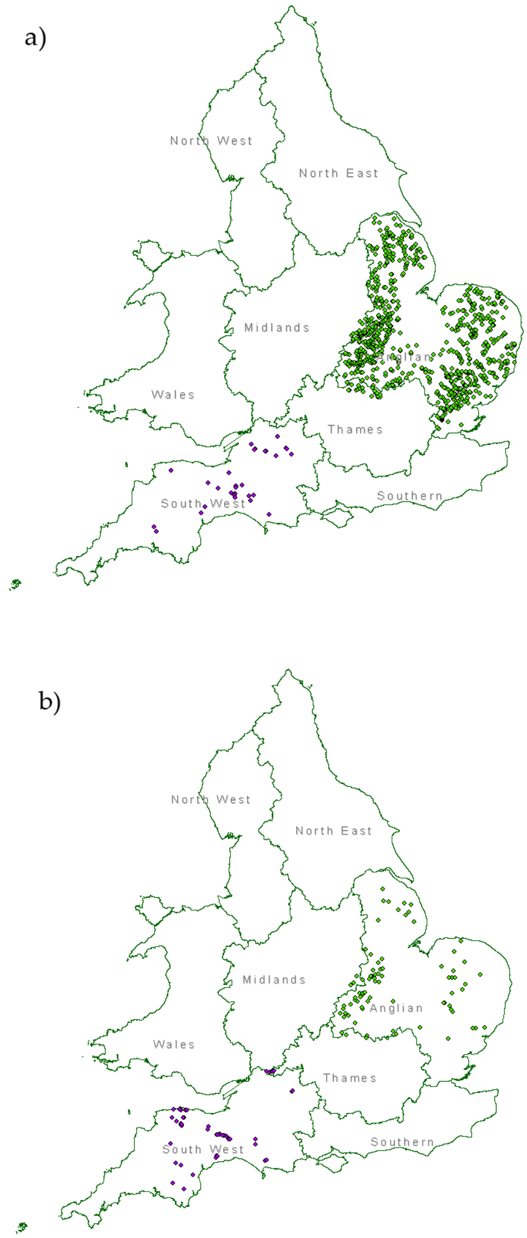

Fig. 4. An example of coordinated collection data. The figure highlights inconsistencies in taxonomic determination levels between Environment Agency (EA) regions, in this case Anglian Region (illustrated with green dots) and South West Region (illustrated with purple dots). It shows distribution records of two hydropsychid caddis species in these regions: (a) *Hydropsyche angustipennis*; (b) *Hydropsyche instabilis*. See text for more details. Source: Environment Agency.

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As a consequence of these limitations, the *practical* suitability of survey data for many taxa in indicator development often falls substantially short of the suite of ideal attributes of such datasets. Consideration of these examples would suggest that the multi-taxa approach is valuable, but only if appropriate and sufficient data are available.

Conclusions and recommendations for multi-taxa wetland indicator development

There are three principal conclusions of this review of the feasibility of developing multi-taxa indicators for freshwater wetland systems:

1. we know enough about a small number of groups in order to use them;
2. we need to find out more information about those groups for which there is a current lack of data, as these may be better indicators;
3. existing data collection needs to be improved for all groups, although it is adequate for some taxonomic groups; consideration needs to be given to how readily it can be combined with other datasets, before collection programmes are implemented, thus making the combination of data in the future more straightforward.

These conclusions in turn lead to a set of recommendations on how to make progress towards a proposed set of multi-taxa indicators. These proposals are illustrated with examples of good practice from the UK; their adoption elsewhere would benefit from equivalent initiatives.

Maintain long-term data collection

Existing data collection programmes should continue in a consistent way to become the long term datasets of the future. New collection programmes also need to be initiated to cater for specific monitoring requirements. That survey methods and data interpretation can be modified to reflect changing needs is reflected in the continued evolution of bird census schemes collated by the British Trust for Ornithology (such as the Breeding Bird Survey, Risely et al., 2009). A further example is the recent inclusion of butterfly and bat population trend assessment into the suite of sustainable development indicators reported by the UK Government (Defra, 2006, 2007b), based on volunteer-collected survey data collated by Butterfly Conservation (Botham et al., 2008) and the Bat Conservation Trust (Bat Conservation Trust, 2006a).

Develop robust methods for integrating datasets

We need to address the practicalities of combining different datasets collected in different ways, with different methodologies at different taxonomic resolutions and different geographic scales, as well as those collected in different formats. This process will present some difficulties, in view of the disparate types of data available and their variability in terms of collection methods, temporal scale, taxonomic resolution, replicability and quality control. There are examples where it has been achieved even though it is difficult, such as the derivation of the LEAFPACS tool for assessing ecological status based upon macrophyte assemblages from a number of pre-existing macrophyte datasets (Willby et al., 2009), the NBN Gateway, and the development of a marine data archive (Data Archive for Seabed Species and Habitats (DASSH)). Development of robust methods for integrating datasets will now allow new taxonomic groups to be added using data collection that is fully compatible with the data analysis and interpretation procedure of a multi-taxa indicator.

Involve others

The costs of biological monitoring are significant, and indicator development in future may require an extension to the sampling undertaken at present. In addition to ensuring that maximum value is obtained from the existing large public investment in monitoring, ways need to be found to extend the contribution from others, including the voluntary sector. Additional partnerships need therefore to be developed with independent data providers such as local and national recording schemes, conservation charities and others already carrying out related work which could be extended into national programmes with standardised methodologies, through increased support of existing recorders.

The UK Riverfly Partnership provides a good example of voluntary bodies and statutory agencies working closely together to implement an effective strategy. It is a consortium of volunteers (anglers, conservationists and others) and professional entomologists, scientists, watercourse managers and relevant authorities. Trained groups focus on mayflies, caddisflies and stoneflies in their local rivers using a simple, standardised methodology. They not only record emerging insects but also report changes in larval insect populations which may trigger further investigative work by EA staff.

Assess suitability of current datasets

Data holdings for different taxonomic groups, and the diverse datasets often held for individual taxonomic groups (such as surveys of macrophyte or zooplankton communities as previously noted) are often dispersed, incompatible and poorly collated. Most serve the purpose for which the data were initially gathered, but could have further value if stored and collated centrally. This could enhance ecological understanding, and could in turn lead to evolution of recording methods to address shifting regulatory requirements. This conclusion has already been recognised by Everard (2008), who also reviews the key characteristics of datasets which would optimally suit them to the purpose of reflecting the quality of wetland habitats at a landscape scale. Crucially, data needs to be fit for purpose, to be gathered reliably over the long term, and to be accessible for collation with related data.

Recommendations

The recommendations arising from this study are as follows.

1. The taxa for which adequate datasets have been identified are suitable for incorporation into a multi-taxa indicator, either developed 'from scratch' or supplementing a current indicator such as the Wetland Birds Indicator in the UK. Effort therefore needs to be made to develop an appropriate mechanism for combining multiple datasets in a useable form.
2. The datasets upon which the multi-taxa approach initially depends should continue to be supported.
3. Efforts should be made to organise and mobilise the large numbers of individuals and organisations that are collecting biological information, to ensure that they can contribute consistent, valuable data. Initiatives such as the UK Riverfly Partnership provide useful models for this approach. It is also being developed in the UK by the Open Air Laboratories (OPAL) network (www.opalexplorenature.org).
4. Efforts should be made to collate information about available datasets, to encourage standardisation in surveying and reporting methods, and to standardise the formats in which data are stored. This type of work is now being developed by the Freshwater Biological Association (FBA) and others.
5. Coordinated monitoring programmes should be further developed for taxa that will provide valuable information about freshwater habitat types that are currently neglected (especially fens, mires and small still water bodies). The Million Pond Project, run by Pond Conservation, is currently in the process of creating and monitoring suitable habitats for around 80 UKBAP (UK Biodiversity Action Plan) pond species.

Recommendations 1–3 are immediate priorities, supporting the subsequent development of recommendations 4 and 5 consistent with accepted methodologies. Careful application of this flow of recommendations will result in a sustainable, cost-effective mechanism for generating and interpreting data that will inform a robust and flexible indicator system for monitoring freshwater habitats.

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Relevant websites

Bat Conservation Trust (BCT):
www.bats.org.uk

Botanical Society of the British Isles (BSBI):
www.bsbi.org.uk

British Arachnological Society:
http://wiki.britishspiders.org.uk/index.php5?title=Main_Page

British Bryological Society (BBS):
www.britishbryologicalsociety.org.uk

British Dragonfly Society (BDS):
www.dragonflysoc.org.uk/home.html

British Trust for Ornithology (BTO):
www.bto.org

Butterfly Conservation:
www.butterfly-conservation.org

Data Archive for Seabed Species and Habitats (DASSH):
www.dassh.ac.uk

Herpetological Conservation Trust (HCT):
www.herpconstrust.org.uk

National Amphibian and Reptile Recording Scheme (NARRS):
www.narrs.org.uk

National Biodiversity Network (NBN):
www.nbn.org.uk

Riverfly Partnership:
www.riverflies.org

The Mammal Society:
www.mammal.org.uk

Author Profile

Dr Mark Everard: Dr Mark Everard's interests in various aspects of aquatic environment span basic and applied ecology, sustainable exploitation, economic valuation and their role in development issues across the world. Mark is the author of six books, five of which touch upon aquatic sciences, as well as many scientific papers and technical articles. Today, Mark works for part of his time for the Environment Agency, and is also involved in capacity-building for integrated water resource management in South Africa as the country strives to institute equitable sharing of its limiting water resources.

Dr Melanie Fletcher: Melanie graduated from the University of Glasgow in Aquatic Bioscience. She trained with the Scottish Wildlife Trust in habitat surveying and restoration and later moved to Manchester Metropolitan University where she gained her doctorate in 'Assessing fluctuating asymmetry in stoneflies as a biomonitoring tool' in 2006. Since this time she has worked for the Freshwater Biological Association as a Scientific Officer, with particular responsibilities for freshwater recorders and the design and implementation of identification training courses and materials.

Dr Anne Powell: Anne has many years experience working in the freshwater world. She has served on a wide range of committees including the English Nature Council, the board of the Environment Agency for England and Wales, the Freshwater Biological Association council and the council of Berkshire, Buckinghamshire and Oxfordshire Wildlife Trust. As well as managing Freshwater*Life* she currently sits on the National Trust's conservation panel and is Chairperson for Cumbria Wildlife Trust. She received her OBE in 2001 for services to conservation, and as one of the founders of Freshwater*Life*, has managed the project since its inception.

Dr Michael Dobson: Dr Michael Dobson has worked for over two decades on the ecology and management of upland streams, and has particular interests in the impact of forestry on streams and in tropical freshwaters. He spent fifteen years teaching ecology and biogeography in the university sector, before moving in 2007 to his current position as Director of the Freshwater Biological Association.