Article

# Checklists and their importance for recording freshwater vascular plants: the British experience

Raymond Goulder

*Department of Biological Sciences, University of Hull, Hull, HU6 7RX, UK. Email: r.goulder@hull.ac.uk*

Received 17 April 2008; accepted 18 July 2008; published 10 December 2008

## Abstract

The value of a checklist when recording the species composition of freshwater macrophyte communities has been recognised for over 30 years, yet studies are still published that fail to refer to a specific checklist. This review demonstrates how the recording of British freshwater vascular plants has been enabled and enhanced through the application of checklists. Consideration is given to studies of plants in the context of trophy, pollution, classification, conservation, and spatial and temporal change in freshwater habitats. Twenty-four lists, with diverse origins, were compared using Jaccard similarity coefficients. Similarities tended to be low (mean $S_j = 0.37$) hence there are difficulties in comparing studies that have used different checklists, and a change of checklist should be avoided during long-term studies. It is suggested that long checklists yield comprehensive data but that shorter lists developed for a particular task will produce useful information, perhaps more quickly and with less need for advanced botanical knowledge. It is emphasised that the checklist used should be cited in all new published studies.

Keywords: Aquatic plants; checklists; freshwater macrophytes; lakes; rivers.

## Introduction

There are many reasons for recording the species composition of freshwater vascular plant communities. These reasons often overlap and include:

- assessment of the biological productivity of fresh waters;
- use of aquatic macrophytes as indicators of pollution;
- biological classification of rivers and lakes;
- evaluation of the biological conservation value of freshwater habitats;
- recognition of spatial and temporal change in fresh waters.

This review focuses on studies of freshwater vascular plants (i.e. pteridophytes and angiosperms) in Britain, although some wider European examples are included. Bryophytes and macroscopic algae are generally not addressed and no account is taken of microscopic algae.

An obvious problem when recording plants at freshwater sites is how to define a freshwater plant. Preston & Croft (1997), who provide systematic accounts of British freshwater vascular plants, point out that the boundaries of fresh waters are blurred and change with season and from year to year, and that many plant species are well adapted to boundary zones liable to fluctuations in water level. They recognised as freshwater aquatic plants those species

DOI: 10.1608/FRJ-1.2.5

which they regarded as characteristically growing with at least their basal parts permanently in water throughout the year. Species that tend to be in water for only part of the year, or that tend to be rooted in waterlogged but not flooded soils, were excluded. This approach was both conservative in excluding many wetland species, and pragmatic in that it produced a manageable list of 200 taxa including naturalised species, subspecies and many hybrids (List 1 in Table 1). Inevitably, this approach was also somewhat arbitrary, as the distinction between aquatic and wetland/terrestrial species is often unclear. This problem is faced by anyone attempting to record aquatic plants, as opposed to the potentially much more difficult and time-consuming process of recording all plant species present, such as undertaken by Merry et al. (1981) along the River Wye in the Welsh–English borders.

The difficulty in precisely defining aquatic plants is likely to lead to different recorders adopting (sometimes widely) differing views on what constitutes an aquatic plant. This highlights the need to use a published checklist when recording freshwater plants, otherwise it is not certain whether the absence of a species at a particular site indicates its likely absence from that site, or whether it is simply not on the list of plants being recorded. For this reason, the need for a checklist when recording freshwater plants has long been recognised. For example, Holmes & Whitton (1977a) when describing the distribution of macrophytes along the River Tees, north-east England, and Holmes (1978) when reviewing approaches to the survey of macrophytes in rivers, stressed that one drawback of most river vegetation surveys available at the time was the lack of reference to a checklist. Holmes & Whitton (1977a) used a checklist of their own compiled from Clapham et al. (1962), which included most vascular plants found in and around rivers, streams and lakes. This checklist is not included in the published paper, but these authors published a comprehensive checklist in the following year (List 2) including 523 taxa of vascular plants (Holmes et al., 1978). Likewise, Harding (1987) gave instructions for the survey of plants in rivers, which stressed the need for a checklist; a field checklist for river macrophytes (List 3) was included.

Although the importance of checklists has been recognised for more than 30 years, and current European standards for surveying freshwater macrophytes include a recommendation to use a checklist when possible (British Standards Institution, 2003, 2007), reports of the species composition of freshwater plant communities subsequently published do not always include or refer to a checklist. This review acknowledges that many of these reports are valuable despite the lack of reference to an explicit checklist. The aim of this review, however, is to catalogue and evaluate the use of checklists in diverse studies of British freshwater plant communities that have been carried out for a variety of reasons. The composition of some published lists of British freshwater vascular plants is compared and contrasted and their usefulness is evaluated and discussed.

## The use of checklists in studies of freshwater vascular plants

### Aquatic plants as reflectors of biological productivity

The concept of using river plants as indicators of the trophic status of their habitat was proposed by Haslam (1978, 2006), who listed 45 taxa useful in determining the trophic status of rivers (dystrophic, oligotrophic, mesotrophic, or eutrophic) (List 4). This allowed rivers to be typed based on the predominance of taxa associated with one of these trophic categories. This approach needs no checklist beyond the listed indicator species, although it has the disadvantage that information that might be provided by species not on the list, and therefore not recorded, is lost. In addition, a wide range of species may be recorded, with no predominance of taxa that are representative of a specific trophic category.

These disadvantages were overcome by the parallel development of a numeric approach by Newbold & Palmer (1979), which is applicable to fresh waters in general rather than solely to rivers. These authors listed 150 taxa (List 5) that they regarded as open water freshwater plants, from plants found only in oligotrophic waters, through plants mostly found in mesotrophic and eutrophic conditions,

 DOI: 10.1608/FRJ-1.2.5

***Table 1.*** Summary of lists of British freshwater vascular plants arranged in order of appearance in the text

| List no. | Source | *n* of vascular plant taxa* | Notes |
|---|---|---|---|
| 1 | Preston & Croft (1997) | 200 | The list of taxa for which systematic accounts of distribution, habitats and reproductive biology are given in Preston & Croft's *Aquatic Plants in Britain and Ireland*. Plants selected are herbs that characteristically grow in permanent water, both flowing and standing. The list includes 19 hybrids, including eight *Potamogeton* hybrids. Nomenclature follows Stace (1991). |
| 2 | Holmes et al. (1978), coded list of species (vascular cryptogams, dicotyledons and monocotyledons) | 523 (506) | A comprehensive, numerically coded checklist that aimed to include all 'truly aquatic' freshwater macrophytes and also the majority of those that are associated with very moist or frequently submerged terrestrial habitats. The list is subdivided into 21 pteridophyte, 280 dicotyledon, and 222 monocotyledon taxa (there are additional subdivisions for lichens and bryophytes). Includes 17 trees of which 13 taxa are *Salix*. Lists 100 hybrids, including 25 *Potamogeton*, 13 *Carex* and 12 *Ranunculus*. Nomenclature follows Clapham et al. (1962) plus other contemporary authors for complex genera. |
| 3 | Harding (1987), Table B2 | 108 | A field checklist for recording plants in river habitats for the purpose of water quality monitoring. Separately lists three pteridophytes, 46 dicotyledons and 59 monocotyledons; there are also short lists of nine macro-algae and 17 bryophytes. The list comprises herbs that are common or widespread in British rivers; rare species and bankside species are omitted. No hybrids are included; nomenclature follows Clapham et al. (1962). |
| 4 | Haslam (1978, 2006), Chapter 1 | 45 | Aquatic herbs that are listed in Haslam's *River Plants* as useful indicators of the trophic/nutrient status of river habitats; they are designated 'Group 1' indicators. Nomenclature follows Clapham et al. (1962) and Haslam et al. (1975). |
| 5 | Newbold & Palmer (1979), Table 2 | 150 | A list of herbs (pteridophytes and angiosperms) largely found in open fresh waters. Each species is given a unique trophic ranking number (TRN) between 1 and 150; species associated with richer waters have higher TRN. No hybrids are included; nomenclature follows Clapham et al. (1962). This list with TRN values was further developed, specifically for use in rivers, by Holmes & Newbold (1984). |
| 6 | Palmer (1992), Addendum; Palmer et al. (1992), Tables 2 & 3 | 109 | Vascular herbaceous plants recorded in standing waters; 55 taxa of submerged and floating-leaved plants and 54 taxa of emergent plants. These are taxa that are allocated a trophic ranking score (TRS) between 2.5 and 10, with higher scores given to plants associated with more eutrophic conditions. Hybrids are not included. Also listed are two bryophyte and two macro-alga categories. Nomenclature appears to follow Clapham et al. (1962). |
| 7 | Holmes et al. (1999b) Appendix 5, Table A1 | 88 (86) | A checklist of mostly common river macrophytes (including 3 pteridophytes, 44 dicotyledons and 41 monocotyledons) that are allocated a species trophic rank (STR) between 1 and 10, reflecting their preference for nutrient-rich or -poor waters. Species associated with richer waters have lower STR values. Also lists seven macro-algae and 30 bryophytes, with STR values. Hybrids are not listed separately and are to be recorded with their parents. Nomenclature follows Jermy et al. (1982), Stace (1991) and Kent (1992). |
| 8 | Hill et al. (1999); Hill et al. (2004) | 153 | A list compiled from Hill et al. (1999) and Hill et al. (2004) of those British vascular plants that have been given Ellenberg moisture values of 10–12 (i.e. 10 = plants indicative of shallow-water sites liable to dry out, 11 = plants rooted underwater or free-floating, 12 = plants more or less permanently submerged). No tree species fall into these categories; only three hybrids are included. Nomenclature follows Stace (1997). |

| | | | |
|---|---|---|---|
| 9 | Palmer & Newbold (1983), Table 2 | 184 | A list of freshwater and brackish vascular plants found in England and Wales that are regarded as 'fully aquatic'. All are herbs; hybrids are omitted. The conservation status/degree of protection required in Wales and the English regions is indicated. There is a separate list of 114 taxa of threatened riparian and non-aquatic wetland plants with information about their status in Wales and each of the English regions. Nomenclature follows Clapham et al. (1981). |
| 10 | Holmes (1983), survey card; Holmes et al. (1999a), Annex G | 170 (169) | A field survey card that lists 169 selected taxa of herbaceous freshwater vascular plants used for macrophyte-based classification of rivers plus *Salix* spp. treated as a single taxon; 'trees' and 'ferns' are also included as two additional categories. Three hybrids are included. The survey card also lists 51 macro-algae, lichens and bryophytes. The source of nomenclature is not defined but apparently follows Clapham et al. (1962) with updating in the later version. |
| 11 | Seddon (1972), Tables 2 & 3 | 91 | Vascular herbaceous plants recorded from about 70 Welsh lakes and used as indicators for the classification of the lakes. Lists 41 submersed and natant species and 50 emergent. Hybrids are not included; nomenclature follows Dandy (1958). |
| 12 | Duigan et al. (2006), Chapter 10, Annex A | 93 (92) | Vascular plants from a list of submerged and floating macrophytes used for a revised classification of British lakes. Also used were four taxa of macro-algae and two bryophyte taxa. Seven hybrids, six of them *Potamogeton*, are included. Nomenclature follows Stace (1991) and Preston (1995). |
| 13 | Nature Conservancy Council (undated), list of submerged, floating and emergent plants | 180 | A field survey card originating from the NCC Chief Scientist's Team; anonymous and undated but credited to C. Newbold and M.A. Palmer with a 1979 date by Holmes (1980). A list of 180 taxa of herbaceous submerged, floating and emergent vascular plants is included. The catch-all category '*Potamogeton* hybrids' is included; there are no other hybrids. Also included are three macro-algae, one lichen and 11 bryophyte categories. There is a separate list of 213 wetland and riparian plants. The nomenclature used is not defined. |
| 14 | Palmer & Newbold (1983), Table 3 | 157 | A list of freshwater and brackish vascular plants found in Scotland that are regarded as 'fully aquatic'. All are herbs; hybrids are omitted. The conservation status/degree of protection required in each of the Scottish regions is indicated. There is a separate list of 68 taxa of threatened riparian and non-aquatic wetland plants with information about their status in the Scottish regions. Nomenclature follows Clapham et al. (1981). |
| 15 | Biggs et al. (1998), field recording sheet 6 | 365 | A field recording sheet for use with the National Pond Survey methodology, for classifying ponds and establishing their nature conservation value. Lists 361 herbaceous vascular plants (81 submerged, 18 floating-leaved, and 262 emergent). Four tree taxa are also included. The catch-all category '*Potamogeton* hybrids' is included; there are no other hybrids. Also listed are six macro-algae and four bryophyte categories. The nomenclature used is not defined but appears to follow Stace (1991). |
| 16 | National Rivers Authority (1992), Appendix 4 | 133 | A coded list of plants for River Corridor Surveys for recording the wildlife conservation status of rivers. Includes 106 taxa of vascular herbaceous plants (these are largely native comprising 51 dicotyledons, 47 monocotyledons, and one *Equisetum*; there are also seven selected alien species). Also listed are 27 potentially riparian trees and shrubs. No hybrids are included. The nomenclature used is not defined but Clapham et al. (1987) and Stace (1991) are cited as sources for taxonomy, identification and distribution. |


DOI: 10.1608/FRJ-1.2.5

| | | | |
|---|---|---|---|
| 17 | Boon et al. (1996), Table SR 1.1 | 131 | A checklist of aquatic plants used by the System for Evaluating Rivers for Conservation (SERCON). Lists 131 native vascular herbaceous plants; hybrids are not included. Separately lists seven micro-algae, three lichens and 46 bryophytes. There is also a separate list of 23 alien river and river-edge vascular plants. Nomenclature appears to follow Stace (1991). |
| 18 | Joint Nature Conservation Committee (2005a), Table 1 | 186 (185) | A field survey card of river macrophytes in *Common Standards Monitoring Guidance for Rivers*, a methods manual for monitoring rivers for conservation purposes. This list has evolved from List 10 (Holmes et al., 1999). Lists 183 taxa of herbaceous vascular plants (five pteridophytes, 91 dicotyledons, and 87 monocotyledons); these include two *Potamogeton* hybrids. Also lists three tree genera/species. Additionally there are 11 macro-alga, three lichen and 40 bryophyte categories. Nomenclature largely appears to follow Stace (1997). |
| 19 | Hatton-Ellis et al. (2003), Appendix A | 57 | A list of macrophytes used for the classification of high conservation value CB ('*Ranunculion fluitantis* and *Callitricho-Batrachion*') vegetation in rivers. Lists 57 herbaceous vascular plants; emphasis is on *Callitriche*, *Ranunculus* and *Potamogeton*, and four *Potamogeton* hybrids are included. Also listed are two macro-algae (*Chara* spp.) and 32 bryophytes. Nomenclature largely appears to follow Stace (1997). |
| 20 | Joint Nature Conservation Committee (2005b), Appendices 2 & 3 | 149 | A checklist of aquatic plants associated with ditches (i.e. artificial land-drainage channels that include main drains and can be 10 m or more in width); in *Common Standards Monitoring Guidance for Ditches*, a methods manual for surveying ditches for conservation purposes. Lists 137 native vascular herbaceous taxa plus 12 non-native vascular plant taxa. There is a single category for *Potamogeton* hybrids. Three macro-alga and four bryophyte taxa are also included. Nomenclature appears to follow Stace (1997). |
| 21 | Joint Nature Conservation Committee (2005c), Appendices 2 & 3 | 156 | A checklist of aquatic plants recorded from or possibly occurring in UK navigation canals; in *Common Standards Monitoring Guidance for Canals*, a methods manual for surveying canals for wildlife conservation purposes. Lists 139 native and 17 non-native vascular herbaceous taxa. No hybrids are included; three macro-alga and four bryophyte taxa are included. Nomenclature appears to follow Stace (1997). |
| 22 | Hill et al. (2004) | 173 | A list compiled from Hill et al. (2004) of taxa associated with the UK Biodiversity Action Plan Broad Habitat 13 (Jackson, 2000); standing open water and canals. Lists 169 herbaceous taxa and four trees/shrubs; one *Potamogeton* hybrid is included. Nomenclature follows Stace (1997). |
| 23 | Hill et al. (2004) | 149 | A list compiled from Hill et al. (2004) of taxa associated with the UK Biodiversity Action Plan Broad Habitat 14 (Jackson, 2000); rivers and streams. Lists 137 herbaceous taxa and 12 trees/shrubs; two *Potamogeton* and three other hybrids are included. Nomenclature follows Stace (1997). |
| 24 | Holmes (1975), Chapter 4.16 | 65 (64) | Aquatic vascular plants in a checklist for the River Tweed; four *Potamogeton* hybrids and one other are included. Separately listed are 10 lichen taxa and 83 bryophytes. Nomenclature follows Clapham et al. (1962). |

*Numbers in brackets indicate *n* of taxa used for calculation of similarity coefficients if less than the number of vascular plant taxa on the original list.

to those found in hypertrophic waters. Each taxon was given a unique trophic ranking number (TRN) from *Drosera rotundifolia* (TRN = 1) to *Zannichellia palustris* (TRN = 150). The authors suggested that if the taxa recorded at a freshwater site fall within a defined range then the site can be allocated to a trophic category. For example, if all species recorded have a TRN < 10 the site is oligotrophic; if TRN values are in the range 22–103 the site is mesotrophic; and if TRN values are in the range 147–150 the site is hypertrophic. This method has the advantage that all species to which a TRN has been allocated will be recorded when present, forming an intrinsic checklist of 150 taxa.

In practice, plants may be found with a TRN that is apparently anomalous for the site at which they are found, prompting further development in the method. For example, the mean TRN for a site may be calculated (i.e. the sum of TRN values divided by the number of taxa recorded). Thus, Rimes & Goulder (1986) obtained mean TRN values for four calcareous, high-conductivity streams in the Yorkshire Wolds in north-east England that ranged from 68 to 78 compared with values of 23–32 for four low-conductivity streams on granite and greywacke in Galloway, south-west Scotland. The difference in trophic status indicated by the aquatic macrophytes was paralleled by the microbiology of the streams; the concentration of directly counted planktonic bacteria and their heterotrophic activity, measured as turnover rate for glucose assimilation, were greater in the more nutrient-rich Wolds streams.

Holmes & Newbold (1984) suggested improvements to the use of mean trophic score (mean TRN) at river sites. These included the omission of 11 or more generalist species, the inclusion and assignment of trophic ranks to five taxa of common river macro-algae and 10 common river bryophytes, and the amendment of about five of the original TRN values. A revised list of taxa with their trophic ranks (Table 6 of Holmes & Newbold, 1984) contains the vascular plant taxa originally listed by Newbold & Palmer (1979), with some non-river taxa omitted, plus the additional algae and bryophytes. Thiebaut et al. (2002) used the revised list to demonstrate significant relationships between mean trophic score and concentration of $PO_4$-P and $NH_4$-N in streams of north-east France.

The approach used to determine trophic scores for macrophytes of standing fresh waters has been thoroughly revised by Palmer (1989, 1992) and Palmer et al. (1992). These authors drew upon records collected by or for the then Nature Conservancy Council (NCC) of species of aquatic plants and their abundance at 1124 standing water sites throughout England, Scotland and Wales. These data were subjected to ordination analysis (two-way indicator species analysis – TWINSPAN). The analysis of the data for submerged and floating-leaved plants identified ten site types that were found to be broadly aligned to site richness. This allowed species to be allocated a trophic ranking score (TRS) dependent upon the richness of the sites with which they were most strongly associated. These scores ranged from low values for species associated with dystrophic waters, for example, 2.5 for *Eriophorum angustifolium* and 3.0 for *Potamogeton polygonifolius* and *Sparganium angustifolium*, to a maximum of 10.0 awarded to 32 species that were associated with the most eutrophic waters. Scores were allocated to 109 taxa of vascular plants (55 submerged and floating species and 54 emergent species) (List 6) and also to several bryophytes and charophytes (Palmer, 1992; Palmer et al., 1992). A trophic score was not allocated to species that were most associated with site types that were not aligned to trophic richness, to species that reflected brackish conditions, or to those for which there were insufficient records. The use of these lists should, therefore, represent a good basis for assessing the trophic status of standing fresh waters, although information on species that are poor indicators or occur infrequently might be lost.

Linton & Goulder (1998) have provided an example of the application of the new trophic ranking scores. Macrophytes in 57 ponds in East Yorkshire, north-east England, were surveyed and mean tropic ranks calculated, ranging from 7.4 to 9.5. Parallel bioassays were also carried out in which *Lemna minor* and the micro-alga *Selenastrum capricornutum* were separately cultured in sterilised pond water. For these relatively nutrient-rich sites, no relationship was found between mean trophic ranking score and the bioassays of pond water richness. In contrast, Murphy & Wallace (2004) surveyed the mesotrophic Loch of Boardhouse, Orkney, where they found a


DOI: 10.1608/FRJ-1.2.5

decrease in mean trophic rank from 7.8 to 7.4 between 1986 and 2003; this was accompanied by a decrease in total $PO_4$-P in the lake water from 45 µg $l^{-1}$ to 8 µg $l^{-1}$.

The use of species trophic scores to indicate the richness of river habitats was again revised by Holmes et al. (1999b). These authors provided a checklist of indicator species comprising 88 taxa of vascular plants that occur in rivers (List 7) plus seven taxa of macro-algae and 30 bryophyte taxa. These are each assigned a species trophic rank (STR) ranging from 1 to 10 and it is important to note that this system assigns low values to plants that are associated with eutrophic conditions (e.g. *Potamogeton pectinatus*, STR = 1) and high values to species indicative of oligotrophic conditions (e.g. *Potamogeton polygonifolius*, STR = 10). The use of macrophytes to monitor rivers was therefore aligned with widely used numerical schemes for monitoring rivers based on macro-invertebrates, which allocate low scores to taxa that are associated with enriched and organically polluted rivers, such as the Biological Monitoring Working Party (BMWP) score system (Hawkes, 1998).

The value of mean trophic rank (MTR) that is calculated for a river site of 100 m length is weighted to take into account both the abundance of the indicator plant species that are present and their STR values, and is within the range 10–100. For example, mean MTR for lowland rivers mainly in south and east England was found to be 34 (n = 49 samples) compared with a mean MTR of 83 (n = 327) for ultra-oligotrophic mountain streams. This revised approach has been shown to be broadly successful when applied to rivers in the UK (Dawson et al., 1999), Poland (Szoszkiewicz et al., 2002, 2007) and across mainland Europe (Szoszkiewicz et al., 2006). Although the information gathered is potentially limited by the relatively small number of indicator species on the checklist, Holmes et al. (1999b) anticipated that non-scoring species might be recorded although not used in calculation of MTR, while Szoszkiewicz et al. (2006) suggested the inclusion of more scoring species to enable the use of MTR throughout Europe.

An alternative metric that potentially indicates the trophic richness of vascular plant habitats is the Ellenberg nitrogen indicator value. Nitrogen indicator values for British vascular plants ranging from 1 to 9, modified for application in Britain, are given by Hill et al. (1999) and Hill et al. (2004). Their application to freshwater sites requires the use of a checklist of aquatic plants to ensure that the taxa to be recorded are the same at all sites. An obvious approach is to define aquatic plants using the Ellenberg moisture values, although this introduces the problem of where aquatic plants fall on the moisture scale of 1–12; the 153 taxa with moisture values of 10–12 might reasonably be regarded as aquatic (List 8). Alternatively, an independent checklist may be used; for example, Goulder (2003) used a checklist of 184 aquatic plants that occur in England and Wales, taken from Palmer & Newbold (1983) (List 9) but with additional *Juncus* species added, and found that mean Ellenberg N values in 0.5 km lengths of the Pocklington Canal, East Yorkshire, were not necessarily related to phosphate enrichment but were negatively related to species richness.

## Aquatic plants as indicators of pollution

The use of aquatic plants as pollution indicators clearly overlaps with their use as reflectors of biological productivity; there is often no meaningful distinction between sources of pollution and artificial nutrient enrichment. Discharges from sewage treatment works, for example, are associated both with inorganic nutrient enrichment and with other forms of pollution such as organic residues, toxic compounds and suspended solids (Hynes, 1960; Mason, 2002). Haslam (1994) regarded river plants as good indicators of pollution by sewage, herbicides, pesticides and other toxic organic compounds at low concentrations. Plants were considered to be especially useful bio-indicators because they are non-motile and liable to reflect long-term conditions in their habitat, they need only be recorded once a year in summer, they can be rapidly surveyed, and they are relatively easy to identify. Haslam (1978, 2006) listed 14 taxa of freshwater macrophytes (including 12 vascular plants) as being resistant to sewage and industrial pollution in British rivers. These taxa tend to persist when more susceptible species are lost and therefore are useful indicators of pollution. On this list *Potamogeton pectinatus* was considered to be very tolerant of pollution, six other taxa were regarded as tolerant and seven taxa as fairly tolerant. Maps were used to demonstrate how the species composition of aquatic macrophytes revealed the effects of sewage effluent along diverse English rivers.

Harding (1987), Haslam (1987) and Spence (1987) described methods by which the species composition of aquatic plants might be used to assess pollution in British rivers and lakes. Haslam (1987) and Spence (1987) recommended use of the comprehensive checklist of Holmes et al. (1978) (List 2) although Haslam suggested that beginners can obtain useful information by recording only the more common species of river plants. Some information may be lost but meaningful between-site comparisons are still possible. Harding (1987) included a separate checklist (List 3) of selected British river macrophytes that included 108 taxa of vascular plants plus 9 macro-algae and 17 bryophytes. Harding also provided pollution tolerance scores for 82 river macrophytes. Fifty-six of these are vascular plants and the scores range from 1 (most tolerant), such as *Potamogeton pectinatus* and *Agrostis stolonifera*, to 10 (least tolerant), such as M*yriophyllum alterniflorum* and *Ranunculus omiophyllus*. It was recommended that the results be expressed per 0.5 km of river surveyed as either:

1. the sum of the scores for the taxa recorded, in which case a high score might reflect both the presence of sensitive species and high species richness, or
2. the averaged score (i.e. the sum of the scores divided by the number of taxa), which was regarded as a better pollution indicator.

Harding et al. (1981) used the Holmes et al. (1978) checklist (List 2) when recording vascular plants, bryophytes and macro-algae along the River Etherow, north-west England, at a time when it was recovering from severe pollution by zinc seepage and organic-rich industrial discharges. The authors found a pronounced pollution-related change in plant species composition along the river. Other comparable studies have not explicitly referred to a checklist. Onaindia et al. (1996) investigated the impact of urban and industrial discharges on vascular plant communities along 18 rivers that flow into the Bay of Biscay, northern Spain. These authors suggested that low species richness was associated with toxicity of waste-derived ammonium, although critical evaluation of this hypothesis was beyond the scope of their study. Daniel et al. (2005) recorded all aquatic macrophytes present on the river bed (vascular plants, bryophytes and macro-algae) along 50 m lengths of the Elorn and Scorff Rivers in Brittany, north-west France. These authors found perturbation of plant communities, with species richness and diversity (Shannon index) being greater downstream of fish farm discharges.

Studies such as these that have successfully related river plant communities to water quality without explicit reference to a checklist (Onaindia et al., 1996; Daniel et al., 2005) presumably each used a constant but unrecorded checklist. This approach will work within a comparative study of vegetation at different sites provided that there is a single recorder, or several recorders all using the same implicit checklist. Comparison between such studies may, however, be hampered.

Haury et al. (2006) proposed a macrophyte-based index (Macrophyte Biological Index for Rivers; IBMR) to assess organic pollution in rivers. Vascular plants, bryophytes, and macro-algae were given a species score (CSi) from 0–20, with low scores indicating tolerance to gross organic pollution. Calculation of IBMR makes use of the CSi of the taxa recorded in 50 m–100 m river lengths, a value of their ecological amplitude (tolerance range) and their percentage cover. This study is exemplary in that the checklist used is readily available as supplementary electronic material. The application of IBMR along rivers in Brittany demonstrated marked impacts on macrophyte communities by effluents from sewage works and fish farms.

## Aquatic plants for the biological classification of rivers and lakes

The use of aquatic macrophytes in the classification of fresh waters in Britain is long established. The species composition and abundance of macrophytes were used by Pearsall (1921) in his ordering of the Cumbrian lakes, and by Butcher (1933) for the typing of rivers.

A comprehensive macrophyte-based classification of British rivers was undertaken by Holmes (1983, 1989). Plant species, with abundance scores, were recorded for

 DOI: 10.1608/FRJ-1.2.5

1055 sites (1012 were 1.0 km river lengths and 43 were 0.5 km lengths) in the channel and on the river banks. The objective allocation of sites to river types was achieved using TWINSPAN. The sites were grouped into two principal river types: 656 broadly lowland, rich sites and 399 upland, poorer sites. These principal types were subdivided into four main types and 56 meaningful end groups. A field survey card, which is included as an appendix in Holmes (1983), served as a checklist (List 10). This list has 223 selected taxa: 169 herbaceous vascular plants; three catch-all categories for *Salix* spp., trees and ferns; and 51 bryophytes and macro-algae. The importance of its use, to ensure consistency in future surveys, was stressed. There is an interesting development in that Holmes (1980), in a preliminary account of the first two years of his 1978–1982 survey, describes the recording of all plants that are visible to the naked eye; 412 species were recorded, many of which are not usually regarded as aquatic plants. The later (Holmes, 1983) record card provided an effective checklist (List 10) with considerably fewer taxa. This record card was recommended by Holmes (1994) in his contribution on river plants to a standard methods manual for wildlife surveys of British rivers (Ward et al., 1994) and its use is demonstrated by Life in UK Rivers (2003) through the reproduction of a completed record card from a survey of a 0.5 km length of the River Teme in the English midlands.

The Holmes (1983) macrophyte-based classification of rivers was reworked by Holmes et al. (1998, 1999a) with the geographical basis of the survey extended and the database increased to 1514 sites. New analysis, again using TWINSPAN, suggested that there are four major river groups in Britain, which were designated as: 'Lowland rivers with shallow gradients and rich geology'; 'Meso-eutrophic rivers flowing predominantly over sandstone and hard limestone'; 'Mesotrophic and oligo-mesotrophic rivers'; and 'Acid and nutrient-poor rivers'. These were subdivided into 10 river types and 38 subtypes. The new surveys employed the same field checklist as Holmes (1983) (List 10) and it was included as Annex G in Holmes et al. (1999a). It was emphasised by Holmes et al. (1999a) that the absence of a checklist species at a site is a significant record. Some more rare species that were not on the checklist were also recorded but not used for classification.

The use of vascular aquatic macrophytes as limnological indicators in Welsh lakes is described by Seddon (1972). The records used were for presence or absence of macrophyte species and were made by over 30 recorders in the 1960s. A duplicated checklist was issued to recorders which was stated to include all submerged and natant species liable to be encountered plus the most frequent emergent and waterside species. This list was not included by Seddon (1972), but lists of the 41 taxa of submerged and floating-leaved plants that were recorded in 70 lakes and of the 50 taxa of emergent plants found at 72 lakes, are included and are potentially the basis of a checklist for Welsh lakes (List 11). Application of principal component analysis to the data for submerged and floating-leaved plants allowed floristic assemblages from 70 lakes to be positioned along ordination axes that roughly delineated gradients from lowland, biologically productive lakes with high species diversity to upland, unproductive lakes with low diversity, and also from hard to soft water. Since each floristic assemblage represented a single lake the procedure essentially classified lakes, along continua and by reference to each other, on the basis of aquatic plants.

The use of Nature Conservancy Council (NCC) records of incidence and abundance of aquatic plants from 1124 standing fresh waters in Britain (Palmer, 1989, 1992; Palmer et al., 1992) has been described above in the context of allocating trophic ranking scores to indicator species for use in the numeric description of the biological richness of lakes. These studies were extended by Duigan et al. (2006, 2007). The database was much increased to 3447 lakes recorded in the period 1975–2001, the geographical coverage was broadened to be less biased towards northern Scotland and Cumbria, and the application of TWINSPAN to records of floating-leaved and submerged plants separated the sites into 11 distinct lake types. The 99 taxa of submerged and floating macrophytes, comprising 93 vascular plants (List 12), four macro-algae and two bryophytes, which were used in this new analysis are listed by Duigan et al. (2006). Valuable methodological information provided by Duigan et al. (2007) is that records were made using a standard recording sheet developed by the NCC. Duigan (personal communication) indicates that this was a checklist from an NCC field recording card (Nature Conservancy Council, undated). This card lists 195 taxa of submerged, floating and emergent macrophytes of which 180 are vascular plants (List 13). The card anticipates that additional species will be added and, in the lake surveys, additional taxa (e.g. several *Potamogeton* hybrids) were recorded. The card also has a separate longer list of wetland and riparian plants.

In the wider context of European lakes, a checklist of 97 aquatic vascular plants that have been recorded in fresh waters in Scandinavia is given by Rørslett (1991). The plants listed were considered to be those species that normally occur below median water level and it was stressed that the use of the predefined list will avoid problems caused by inconsistency in recording semi-aquatic species. The study suggested that intermediate lakes support greater species richness than either oligotrophic or highly eutrophic lakes. The typing of lake vegetation in the widespread softwater lakes of northern Europe, on the basis of the species occurrence of submerged and natant vascular plants, was reviewed by Murphy (2002). That review includes a list, compiled from the literature, of 104 species of vascular euhydrophytes (i.e. plants that are wholly or mostly submerged for much of the year) that have been recorded from softwater lakes in Scandinavia, Britain and the North European Plain. This is potentially a useful checklist for vegetation recording in softwater lakes across northern Europe.

## Aquatic plants for evaluation of biological conservation value

When plants are used for evaluation of the conservation value of habitats the criteria that may be taken into account include species diversity and the rarity and naturalness of the species present (Margules & Usher, 1981). It is desirable that checklists are used to facilitate a uniform approach to recording and to allow comparisons between sites and studies.

Lists of vascular aquatic plants found in Britain were published by Palmer & Newbold (1983) with the aim of helping the then Regional Water Authorities in England and Wales and the Scottish River Purification Boards with their statutory responsibilities towards nature conservation. There were 184 species regarded as fully aquatic plants listed for England and Wales (List 9), and a separate list of 157 species for Scotland (List 14). An indication of the frequency and likely need for protection was given for each species in each of the Water Authority and River Purification Board areas. Palmer & Newbold (1983) also provided lists of scarce (i.e. recorded in 100 or fewer 10 km × 10 km squares in Britain) riparian and semi-aquatic wetland plants for England and Wales and for Scotland, which also indicated the regional status of each species.

The Palmer & Newbold (1983) list of aquatic plants found in England and Wales has been much used as a checklist for the recording of aquatic vegetation in conservation-related studies. Examples include: Linton & Goulder (1997, 2000) for surveying vascular plants in ponds of different origin in East Yorkshire, north-east England; Folkard et al. (1998) in assessment of the conservation value of the ditch flora of the Nene Washes RSPB reserve in Cambridgeshire, eastern England; Linton & Goulder (2003) in relating species richness of aquatic macrophytes in East Yorkshire ponds to the number of species in surrounding water bodies; Goulder (2001a) in demonstrating increased plant species richness in East Yorkshire ponds in response to habitat disturbance by anglers; and Goulder (2003, 2006) in evaluation of the botanical conservation value of disused and little-used navigation canals in East Yorkshire. Linton & Goulder (1997, 2000) also included information from Palmer & Newbold (1983) on the conservation status of aquatic plants in the former Yorkshire Water Authority area in their calculation of a numeric conservation index for the diverse ponds surveyed; gravel pits, clay pits, and borrow pits excavated alongside railway embankments were found to have higher conservation indices and species richness than ancient moats, village ponds and ponds of miscellaneous origin. The listing by Palmer & Newbold (1983) of aquatic plants in need of special protection in the area of the then Welsh Water Authority was used by Wilkinson (1998) along with the datasets from Seddon (1972) for submerged and floating-leaved plants in 70 Welsh lakes


DOI: 10.1608/FRJ-1.2.5

and for emergent plants at 72 Welsh Lakes – data referred to above in discussion of the use of aquatic plants for the biological classification of lakes. The Wilkinson (1998) analysis showed that, for both morphological groups, the lakes with greater species richness tended to have more rare species, although species richness was, at best, an imprecise guide in selection of sites for conservation.

Standard methods for the survey of ponds in Britain, including collection of wildlife information for conservation management, have been developed for the National Pond Survey (e.g. Biggs et al., 1993, 1998). These publications each included a comprehensive checklist for field recording of submerged, floating, and emergent and other wetland plants. Thus the Biggs et al. (1998) list (List 15) comprises 81 taxa of submerged vascular plants, 18 taxa of floating vascular plants, 262 species of emergent herbaceous plants, and four pondside trees; also listed are six macro-algae and four bryophytes. The National Pond Survey methods were used, for example, by Jeffries (1991) who surveyed forestry ponds throughout Scotland and showed how pond restoration and excavation by the Forestry Commission provided valuable wildlife habitat, and by Williams et al. (2003) who applied them to rivers, streams, ditches and ponds in southern England and demonstrated that ponds, although often neglected in national monitoring programmes, are important contributors to floristic diversity.

The NCC record card (Nature Conservancy Council, undated) (List 13), used for survey of lake vegetation (Duigan et al., 2006, 2007), has been used for other conservation-related recording. It was compiled for use in all NCC surveys of aquatic vegetation (Holmes, 1980) and was credited by Holmes to C. Newbold and M.A. Palmer and dated 1979. The checklist of submerged, floating and emergent plants on this card was evaluated by Holmes (1980) who showed that when applied to diverse rivers in Britain it assigned greater species richness to the more biologically rich rivers of the south and east. This contrasted with an initial, counter-intuitive, conclusion that the more biologically poor rivers of the north and west were more species rich. This initial conclusion, based on survey of the same rivers (Holmes, 1980), was reached chiefly because many bryophytes were recorded; the list on the NCC record card is largely of vascular plants (180 taxa) while only 11 taxa of, often conspicuous, bryophytes are included. The NCC record card also appears to have been used by Helliwell (1983) to demonstrate that larger ponds and lakes in Worcestershire, central England, were more species rich than smaller water bodies, although the list used was credited to the Biological Records Centre (Monks Wood, Huntingdon).

The statutory responsibility of the (former) National Rivers Authority for wildlife conservation led to the adoption of a standard approach (River Corridor Surveys) by the authority and its contractors to recording the fine structure of aquatic plant distribution along rivers (National Rivers Authority, 1992). This approach required the cover of individual species of aquatic plants to be mapped at a large scale (1:2 500 or 1:10 000) along 500 m stretches of river. A list of 106 river-associated herbaceous plants and 27 trees and shrubs (List 16) was given with codes for use on the maps, and it was anticipated that any additional species would be included. The lists in Palmer & Newbold (1983) were to be used for recognition of plants of conservation significance; these were to be highlighted on the river corridor maps. Such maps are, however, time-intensive to prepare (Ducros & Joyce, 2003) and they do not readily yield quantitative data for statistical analysis.

The System for Evaluating Rivers for Conservation (SERCON) was developed under the aegis of Scottish Natural Heritage (SNH) to allow the recognition of river lengths that are of importance to biological conservation (Boon et al., 1996, 2002). The system relies upon the recording of a wide range of physical, water quality and biological characteristics of rivers. This includes aquatic plants, and a checklist of 131 native vascular plants (List 17) plus 46 bryophyte taxa and seven macro-algae, was published in Boon et al. (1996). A separate list of 23 taxa of alien aquatic and marginal vascular plants was also provided.

Building upon the SERCON approach, the JNCC (Joint Nature Conservation Committee, 2005a) sought to establish uniform standards for the assessment of the condition of rivers that are of conservation value, specifically Sites of Special Scientific Interest (SSSIs) and Special Areas of Conservation (SACs). The recommended procedures included macrophyte recording and use of a checklist for river survey that includes 183 taxa of herbaceous vascular plants, three genera/species of trees and shrubs (List 18), and many bryophytes (12 liverworts and 28 mosses). Additionally, 11 taxa of macro-algae are included. This checklist (List 18) is similar to and has evolved from that of Holmes (1983) and Holmes et al. (1999a) (List 10). It is included in Life in UK Rivers (2003) for use in surveys to recognise river lengths that have vegetation dominated by species of *Callitriche* and batrachian *Ranunculus* and are of nature conservation value. Related characterisation of the '*Ranunculion fluitantis* and *Callitricho–Batrachion*' vegetation in UK rivers into six conservation-significant community types by Hatton-Ellis et al. (2003), however, was achieved using a shorter list of 91 key taxa comprising 57 vascular plants (List 19), 32 bryophytes and two stoneworts (*Chara* spp.). Within the vascular plants the emphasis was on submerged taxa, especially species of *Callitriche*, *Potamogeton*, and *Ranunculus*.

The JNCC has also recommended standard methods for monitoring the condition of freshwater and brackish ditches (Joint Nature Conservation Committee, 2005b); here ditches are artificial land-drainage channels including 'main drains', which may be 10 m or more in width. Checklists are provided of submerged, floating and emergent plants that are found in ditches in the UK; 137 native and 12 non-native vascular plants are included (List 20). There are also four bryophyte taxa and three macro-algae. Similarly, standard methods are recommended for monitoring UK navigation canals (Joint Nature Conservation Committee, 2005c); checklists are provided of 139 native and 17 alien vascular plants liable to be found in canals (List 21). Additionally four bryophyte and three macro-alga taxa are listed.

Lists of aquatic vascular plants that are associated with broad UK freshwater habitats, and that are potentially useful as checklists, can also be compiled from Hill et al. (2004). UK vegetation has been classified into broad habitats within the UK Biodiversity Action Plan (Jackson, 2000) as an aid to the monitoring and conservation of biodiversity. Broad habitats in the UK include standing open water and canals (designated as Broad Habitat Type 13) and rivers and streams (Broad Habitat Type 14). The lists, compiled from Hill et al. (2004), have 169 herbaceous taxa plus four tree/shrub species that are associated with standing open water and canals (List 22), and 137 herbaceous taxa plus 12 tree/shrub species associated with rivers and streams (List 23).

## Aquatic plants for recognition of spatial and temporal change in fresh waters

An early survey of aquatic plants along a UK river, and the alignment of their distribution with changes in physical and chemical conditions, was undertaken by Butcher et al. (1937) on the River Tees, north-east England. The treatment of aquatic vascular plants focused on the more conspicuous of the submerged species. Fourteen principal taxa were listed, six of them *Potamogeton* spp.; greater abundance of macrophytes was associated with soft substrata and enrichment by effluent from sewage works.

Important subsequent surveys of aquatic vascular plants (and also bryophytes and macro-algae) were carried out along rivers in southern Scotland and north-east England; the Tweed (Holmes & Whitton, 1975a, 1975b), Tees (Holmes & Whitton, 1977a), Swale (Holmes & Whitton, 1977b), Wear (Holmes & Whitton, 1977c) and Tyne (Holmes & Whitton, 1981). Successive 0.5 km lengths of river were surveyed and the approach was innovative in that a checklist of the taxa liable to be encountered was used. In addition, it was made clear that records within each 0.5 km length include the presence or absence of each of the taxa on the checklist. The checklist used for the Tweed is included by Holmes (1975) in his PhD thesis. It has 65 vascular plant taxa (List 24) plus 11 liverworts and 72 mosses. These studies demonstrated downstream change in vegetation, with a general tendency for bryophytes to decrease while submerged angiosperms became more important. They also represented significant methodological development in that they facilitated reliable comparisons between rivers. Thus, for example, Holmes & Whitton (1977b) showed that the Tweed and Tyne were richer in *Potamogeton* species and their hybrids than the Tees and Swale, and were able to draw attention to the likelihood of between-river transfer of angiosperm species in the context of a proposed scheme to transfer water from the Tyne to the Wear, Tees and Swale.

 DOI: 10.1608/FRJ-1.2.5

The Palmer & Newbold (1983) checklist of aquatic plants that occur in England and Wales (List 9) has also been used in studies that compare vascular plant communities within and between watercourses. For example, Goulder (2003) recorded the checklist species and their abundance in 0.5 km lengths of navigation canals in East Yorkshire, north-east England. Detrended correspondence analysis (DECORANA) separated the vegetation of the occasionally navigated and phosphate-enriched lower Pocklington Canal from that of the non-navigated and less enriched upper canal; while the Driffield Canal, also phosphate enriched, tended to resemble the lower Pocklington Canal. The same methodology applied to disused or little used navigation canals and major land drainage channels, also in East Yorkshire, showed substantial overlap of plants in canals and drains (42 out of 66 taxa recorded were found in both) and did not identify separate distinct vegetation types in canals and drains (Goulder, 2008). Comparison of the species richness of aquatic plants in drainage dykes in East Yorkshire with other areas of eastern England was addressed by Goulder (2000). Reliable comparison with drainage channels of the Nene Washes (Folkard et al., 1998) was possible because the Palmer & Newbold (1983) list was used in both areas; the ditches of the Nene Washes were found to be more species rich. Comparison with studies of Norfolk dykes (Driscoll, 1983, 1986) was less straightforward in the absence of a defined checklist for the Norfolk sites.

The use of checklists has also facilitated the recognition of long-term changes in river vegetation. Surveys of aquatic vegetation in 0.5 km lengths along the River Wear in 1996 (Whitton et al., 1998), 1986 (Birch et al., 1989) and 1976 (Holmes & Whitton, 1977c) were easily compared because the same checklist was used, whereas comparison with a 1966 survey (Whitton & Buckmaster, 1970) was less straightforward because only a limited range of macrophytes had been recorded. These studies showed substantial change in the vegetation of the river over 30 years in response to both long-term recovery from pollution and irregular year-to-year variation in flow regime (Whitton et al., 1998); for example, in the upper river the macroscopic alga *Cladophora glomerata* appeared and increased in abundance, while further downstream *Myriophyllum spicatum*, *Ranunculus fluitans*, *Elodea canadensis*, *Potamogeton pectinatus* and *Sparganium erectum* increased while *Zannichellia palustris* decreased.

The Palmer & Newbold (1983) checklist (List 9) was used in a study of long-term drought-related changes in aquatic plants in an intermittent calcareous headwater stream in East Yorkshire (Goulder, 1992, 1993, 2001b). Mill Beck usually flows from about January to September and has luxuriant submerged and emergent vegetation close to its source, predominantly *Rorippa nasturtium-aquaticum* and *Apium nodiflorum*. In the drought year of 1992 the stream remained dry and aquatic macrophytes over the first 50 m downstream of the source were represented by only six species, all emergent, compared to 13 in 1983 (Goulder, 1992). In 1993, however, the stream flowed again and nine species were recorded (Goulder, 1993); in the subsequent years, 1994–1999, the recovery was maintained with 9–12 species recorded in each year (Goulder, 2001b). The Palmer & Newbold (1983) checklist was also used for survey of aquatic plants in the Rivers Test and Itchen, chalk streams in southern England, between 1991 and 1996 (Wilby et al., 1998). River flow was found to be the most significant variable in controlling macrophyte abundance, and in low-flow years batrachian *Ranunculus* species tended to be replaced by filamentous algae.

Aquatic vegetation of the River Torne, in the East Midlands of England, was assessed five years after engineering work that transformed a trapezoidal channel to include berms, shallow bays and linear ponds (Clarke & Wharton, 2000). A survey of 50 m lengths of improved channel and non-improved trapezoidal channel was carried out and the methods of Harding (1987), and implicitly his associated checklist (List 3), were used. It was demonstrated that the engineering works to enhance the channel had led to floristically distinct and more diverse vegetation.

Protocols for the long-term monitoring of vegetation in rivers and lakes have been developed by the UK Environmental Change Network (ECN) (Parr et al., 1999). The presence and abundance or the absence of species in 10 m lengths along a marked 100 m of river or lake margin is recorded between July and August, annually in rivers and every two years in lakes. The checklist to be used is the macrophyte list of Holmes et al. (1978) (List 2) plus 39 species of macroscopic algae, 33 of them charophytes (Lane, 1999). The results of a pilot evaluation of ECN methodology on five UK rivers demonstrated between-river diversity that was largely related to physical characteristics of the rivers (Scott et al., 2002), although the checklist used (not included or referenced) comprised only the more abundant aquatic macrophytes found in the UK.

## Checklists compared and contrasted

The lists of British aquatic vascular plants that are referred to above are summarised in Table 1, arranged in the order in which they appear in the text. To allow comparison of the lists a similarity matrix was prepared (Table 2). This matrix was calculated using the Community Analysis Package (Pisces Conservation Ltd, Lymington, England) from a meta-list that comprised 24 columns (lists) and 671 rows (taxa), with the presence or absence of a taxon in each cell indicated by 1 (3792 cells) or 0 (12 312 cells). A common nomenclature (Stace, 1997) was used in preparation of the meta-list. This led to a small reduction in the number of taxa in some of the lists (as indicated in Table 1) because some of the plant names on the original lists are combined with other taxa by Stace, or because names could not be reconciled with Stace; only vascular plants were included. The meta-list is available as a supplementary file to the electronic version of this paper (Appendix 1). This appendix is potentially useful because some of the original lists are now difficult to obtain. Note, however, that the few taxa that were not reconcilable with Stace (1997) are not included.

The similarity values in Table 2 are Jaccard coefficients ($S_J$), which are calculated when two lists, e.g. 1 and 2, are compared; $S_J = a/(a+b+c)$ where a = $n$ of taxa common to both lists, b = $n$ of taxa on List 1 only, and c = $n$ of taxa on List 2 only. Therefore the absence of a taxon from both lists does not enhance their perceived similarity.

Table 2 emphasises the low degree of similarity between the lists summarised in Table 1; mean $S_J$ = 0.37. Some of the low similarity values are unexpected; for example, List 23 (taxa associated with the Biodiversity Action Plan Broad Habitat of rivers and streams) has low similarity with any of the other river-associated lists; its maximum similarity with any other list for rivers is $S_J$ = 0.28 with List 18 (the JNCC Common Standards field survey card for river macrophytes). The generally low $S_J$ values in Table 2 emphasise the difficulties that are liable to be encountered in comparing published studies that have used different checklists. The low values also indicate that problems are likely if there is a change of checklist during an ongoing long-term recording programme.

Only 13 out of 276 values of $S_J$ were greater than 0.70 (i.e. > 70 % of the total taxa on two lists being compared were common to both lists); three $S_J$ values exceeded 0.80 (Table 2). The lists with highest similarities (e.g. List 5 and List 13, $S_J$ = 0.83; List 9 and List 13, $S_J$ = 0.83; List 9 and List 14, $S_J$ = 0.81) have broadly common origins; i.e. those from the NCC and M.A. Palmer and C. Newbold (Lists 5, 9, 13 and 14). These are concise lists of 150–184 submerged, floating and emergent aquatic taxa, with the more marginal and wetland plants largely not included. Also notably similar to these lists is List 17 (the SERCON list), which is expected because SERCON procedures were based on those of the NCC (Boon et al., 1996).

The information about each list, given in Table 1, generally includes the number of taxa, the purpose of the list, the inclusion or exclusion of hybrids, the extent to which macrophytes additional to vascular plants are included, and the source of nomenclature that is followed. Some of the lists were compiled specifically for use as checklists for recording freshwater plant communities (e.g. Lists 2, 3, 10, 13, 15, 18, 20, 21); others have different origins but have the potential to be used as checklists in appropriate circumstances (e.g. Lists 1, 5, 8, 9, 11, 14, 22, 23). Some are applicable to the full range of freshwater habitats, i.e. both flowing and standing waters (Lists 1, 2, 5, 8, 9, 13, 14); others have more restricted relevance, such as to rivers and streams (Lists 3, 4, 7, 10, 16, 17, 18, 19, 23), a specific river – the Tweed (List 24), ditches (List 20), navigation canals (List 21), or standing waters (Lists 6, 11, 12, 15, 22).

The number of vascular plant taxa on the lists ranges from 45 (List 4) to 523 (List 2); the mean is 159 taxa. An advantage in the use of a checklist with

 DOI: 10.1608/FRJ-1.2.5

***Table 2.*** Similarities between lists of British freshwater vascular plants. Values are Jaccard coefficients(Sj); values > 0.7 are in **bold**.

| List no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.34 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 0.36 | 0.19 | | | | | | | | | | | | | | | | | | | | | |
| 4 | 0.20 | 0.09 | 0.32 | | | | | | | | | | | | | | | | | | | | |
| 5 | 0.60 | 0.29 | 0.52 | 0.25 | | | | | | | | | | | | | | | | | | | |
| 6 | 0.43 | 0.21 | 0.51 | 0.26 | 0.69 | | | | | | | | | | | | | | | | | | |
| 7 | 0.35 | 0.16 | 0.58 | 0.37 | 0.47 | 0.43 | | | | | | | | | | | | | | | | | |
| 8 | 0.64 | 0.27 | 0.37 | 0.24 | 0.64 | 0.46 | 0.39 | | | | | | | | | | | | | | | | |
| 9 | 0.61 | 0.33 | 0.44 | 0.21 | **0.77** | 0.58 | 0.40 | 0.63 | | | | | | | | | | | | | | | |
| 10 | 0.33 | 0.31 | 0.53 | 0.22 | 0.44 | 0.40 | 0.43 | 0.31 | 0.39 | | | | | | | | | | | | | | |
| 11 | 0.34 | 0.18 | 0.40 | 0.26 | 0.49 | 0.63 | 0.37 | 0.36 | 0.42 | 0.36 | | | | | | | | | | | | | |
| 12 | 0.44 | 0.17 | 0.30 | 0.29 | 0.47 | 0.38 | 0.33 | 0.55 | 0.42 | 0.23 | 0.31 | | | | | | | | | | | | |
| 13 | 0.66 | 0.34 | 0.46 | 0.22 | **0.83** | 0.58 | 0.40 | 0.64 | **0.83** | 0.40 | 0.41 | 0.44 | | | | | | | | | | | |
| 14 | 0.53 | 0.29 | 0.45 | 0.22 | **0.74** | 0.64 | 0.41 | 0.57 | **0.81** | 0.39 | 0.47 | 0.41 | **0.74** | | | | | | | | | | |
| 15 | 0.39 | 0.53 | 0.25 | 0.12 | 0.39 | 0.29 | 0.22 | 0.35 | 0.43 | 0.38 | 0.25 | 0.21 | 0.44 | 0.37 | | | | | | | | | |
| 16 | 0.21 | 0.20 | 0.33 | 0.19 | 0.29 | 0.27 | 0.27 | 0.21 | 0.26 | 0.43 | 0.26 | 0.14 | 0.26 | 0.26 | 0.24 | | | | | | | | |
| 17 | 0.49 | 0.25 | 0.52 | 0.26 | **0.71** | 0.61 | 0.49 | 0.50 | 0.67 | 0.44 | 0.48 | 0.37 | 0.64 | **0.73** | 0.34 | 0.31 | | | | | | | |
| 18 | 0.36 | 0.30 | 0.50 | 0.20 | 0.45 | 0.39 | 0.42 | 0.34 | 0.41 | **0.76** | 0.35 | 0.23 | 0.42 | 0.40 | 0.39 | 0.43 | 0.46 | | | | | | |
| 19 | 0.27 | 0.10 | 0.35 | 0.38 | 0.30 | 0.30 | 0.39 | 0.30 | 0.24 | 0.24 | 0.23 | 0.36 | 0.27 | 0.25 | 0.13 | 0.13 | 0.33 | 0.24 | | | | | |
| 20 | 0.62 | 0.25 | 0.48 | 0.24 | 0.64 | 0.53 | 0.44 | 0.66 | 0.62 | 0.37 | 0.40 | 0.45 | 0.66 | 0.59 | 0.35 | 0.25 | 0.59 | 0.42 | 0.27 | | | | |
| 21 | 0.59 | 0.29 | 0.49 | 0.23 | **0.74** | 0.58 | 0.45 | 0.59 | **0.72** | 0.44 | 0.42 | 0.41 | **0.75** | 0.64 | 0.40 | 0.29 | 0.66 | 0.48 | 0.27 | **0.74** | | | |
| 22 | 0.41 | 0.27 | 0.25 | 0.17 | 0.42 | 0.30 | 0.26 | 0.52 | 0.41 | 0.24 | 0.23 | 0.41 | 0.45 | 0.37 | 0.35 | 0.16 | 0.33 | 0.26 | 0.20 | 0.43 | 0.39 | | |
| 23 | 0.22 | 0.21 | 0.19 | 0.15 | 0.22 | 0.17 | 0.21 | 0.25 | 0.22 | 0.26 | 0.15 | 0.17 | 0.22 | 0.21 | 0.23 | 0.23 | 0.23 | 0.28 | 0.16 | 0.24 | 0.25 | 0.31 | |
| 24 | 0.22 | 0.12 | 0.37 | 0.24 | 0.28 | 0.34 | 0.29 | 0.21 | 0.23 | 0.33 | 0.33 | 0.18 | 0.26 | 0.26 | 0.14 | 0.28 | 0.31 | 0.30 | 0.29 | 0.27 | 0.28 | 0.14 | 0.13 |

DOI: 10.1608/FRJ-1.2.5

a high number of taxa (e.g. List 2 with 523 taxa, or List 15 with 365 taxa) is that more comprehensive records are obtained. Potential disadvantages are:

1. recording takes longer and greater botanical expertise is required, with greater potential for misidentifications – during evaluation of methodology for the UK Environmental Change Network, Scott & Hallam (2002) found that 5.9 % of a range of plant specimens were wrongly identified at species level;
2. longer lists tend to include many taxa that are only marginally aquatic, hence if multivariate (e.g. ordination) analysis is used to describe temporal or between-site variation, small but significant change among the more aquatic taxa is liable to be masked by stability amongst less-aquatic taxa. Conversely, inclusion of the less-aquatic taxa in the analysis might reveal change that does not reflect significant change amongst the more aquatic community.

More focused checklists that include fewer taxa and are compiled for a specific purpose are likely to be valuable. Support for this suggestion is given by, for example:

1. the success of Lists 5 (150 taxa), 6 (109 taxa) and 7 (88 taxa) in recording the trophic status of fresh waters;
2. the fact that Lists 11 (91 taxa) and 12 (93 taxa) contain sufficient taxa to allow the classification of lakes;
3. the value of Lists 9 (184 taxa), 14 (157 taxa), 16 (133 taxa), 17 (131 taxa) and 18 (186 taxa) for evaluating the botanical conservation value of lakes or rivers.

The treatment of hybrids varies greatly. There is substantial coverage in List 1 (19 hybrids) and List 2 (100 hybrids), with emphasis on hybrids of *Potamogeton*, *Ranunculus* and *Carex*, while other lists have few or no hybrids. Their inclusion adds to the comprehensiveness of records but demands more extensive botanical experience. Some of the lists that relate to a specific task make significant use of hybrids. For example, List 12 demonstrates the value of *Potamogeton* hybrids (especially *P.* × *nitens* and *P.* × *zizii*) in the classification of lakes; others, such as Lists 5, 6 and 7, which were compiled to assess the richness of fresh waters, do not require the separate recording of hybrids.

The lists that are summarised in Table 1, as used for calculation of similarity values (Table 2), comprise vascular plants only. Some have their origin in sources that deal solely with vascular plants (e.g. Lists 1, 4, 5, 8, 9, 11, 14, 22 and 23); others are derived from sources that include extensive coverage of bryophytes (e.g. Lists 2, 7, 17, 18, 19 and 24) or from sources that include macro-algae and/or lichens. From the habitat perspective the exclusion of non-vascular macrophytes might be reasonable in the context of lowland British fresh waters, where most macrophytes are vascular plants. It is less reasonable, however, for upland waters where bryophytes are often responsible for much of the macrophyte diversity and biomass. The exclusion of non-vascular macrophytes in calculation of similarity values (Table 2) allows better comparison of the lists in terms of vascular plants, but the original lists should not be truncated by omission of non-vascular plants when they are used for survey of freshwater habitats. This is especially important where lists have been compiled for a specific task; for example, in the evaluation of the trophic status of rivers (List 7) or in the classification of rivers for conservation purposes (Lists 10, 17, 18, 19).

The lists summarised in Table 1 are very variable in their treatment of trees and shrubs, although tree shading can profoundly influence the distribution of aquatic vegetation in rivers and lake margins. List 2 includes 17 trees, List 16 includes 27 trees/shrubs, and List 23 includes 12 trees/shrubs. No other list has more than four tree/shrub taxa and most have none. Some of the lists, however, are designed for use as part of wider surveys within which trees might be recorded separately; for example List 17 is used in assessing the conservation value of rivers within SERCON (Boon et al., 1996), a process that anticipates recording of the terrestrial vegetation alongside rivers.

The nomenclature of vascular plants in the lists summarised in Table 1 reflects their date of publication. The earlier lists generally followed Clapham et al. (1962, 1981); more recent lists follow Stace (1991, 1997). Because Stace (1997) includes synonyms for names that have been changed since Clapham et al. (1962) it was usually straightforward to reconcile the nomenclature of earlier lists with that of Stace (1997) during preparation of the meta-list used for calculation of the between-list similarities. Some problems were encountered with, for example, hybrids of *Carex*

 DOI: 10.1608/FRJ-1.2.5

*viridula* ssp. *oedocarpa* (formerly *C. demissa* Hornem.) (List 2) that could not be reconciled with either Stace (1997) or Jermy et al. (2007), and with varieties of *Ranunculus penicillatus* ssp. *pseudofluitans* that are not recognised by Stace (Lists 7, 18) – a problem that is addressed by Lansdown (2007).

## Conclusion

This review has described and evaluated the use of diverse lists of vascular plants in the context of recording freshwater plant communities for a wide range of purposes. It has been shown that there is much dissimilarity between many of the lists, often more than might be anticipated.

Comparative studies are needed to evaluate the effects of using different checklists. Descriptions of plant communities that largely consist of a core of relatively common, fully aquatic species are likely to be relatively constant when different checklists are used. However, if there are many species associated with aquatic–terrestrial transitional habitats, or rare species or hybrids are present, then different checklists are more likely to yield markedly different results.

Care should be taken when comparing studies that have used different checklists, or where no checklist has been cited. Furthermore, any change of checklist during long-term work should be undertaken with caution. Focused lists, with relatively few taxa, may be appropriate for specific purposes.

This author does not recommend the use of a specific checklist, but suggests that the above should be taken into account when selecting an appropriate checklist for a new study. It is especially important that the checklist used should be cited in ensuing publications. Moreover, if an established checklist is used but additional taxa are written in, then this information should also be included.

## References

Biggs, J., Corfield, A., Walker, D., Whitfield, M. & Williams, P. (1993). *National Pond Survey Methods Booklet.* Pond Action, Oxford Brookes University, Oxford. 28 pp.

Biggs, J., Fox, G., Nicolet, P., Walker, D., Whitfield, M. & Williams, P. (1998). *A Guide to the Methods of the National Pond Survey.* Pond Action, Oxford Brookes University, Oxford. 23 pp.

Birch, S.P., Kelly, M.G. & Whitton, B.A. (1989). Macrophytes of the River Wear: 1966, 1976, 1986. *Transactions of the Botanical Society of Edinburgh* **45**, 203-212.

Boon, P.J., Holmes, N.T.H., Maitland, P.S. & Rowell, T.A. (1996). *SERCON: System for Evaluating Rivers for Conservation: Version 1 Manual.* Scottish Natural Heritage Research, Survey and Monitoring Report No. 61. Edinburgh.

Boon, P.J., Holmes, N.T.H., Maitland, P.S. & Fozzard, I.R. (2002). Developing a new version of SERCON (System for Evaluating Rivers for Conservation). *Aquatic Conservation: Marine and Freshwater Ecosystems* **12**, 439-455.

British Standards Institution (2003). *Water Quality – Guidance Standard for the Surveying of Aquatic Macrophytes in Running Waters.* BS EN 14184. British Standards Institution, London. 14 pp.

British Standards Institution (2007). *Water Quality – Guidance Standard for the Surveying of Macrophytes in Lakes.* BS EN 15460. British Standards Institution, London. 20 pp.

Butcher, R.W. (1933). Studies on the ecology of rivers I. On the distribution of macrophytic vegetation in the rivers of Britain. *Journal of Ecology* **21**, 58-91.

Butcher, R.W., Longwell, J. & Pentelow, F.T.K. (1937). *Survey of the River Tees, Part III – the non-tidal reaches – chemical and biological.* Department of Scientific and Industrial Research, Water Pollution Research Technical Paper No. 6. HMSO, London.

Clapham, A.R., Tutin, T.G. & Warburg, E.F. (1962). *Flora of the British Isles.* 2nd edition. Cambridge University Press, Cambridge. 1269 pp.

Clapham, A.R., Tutin, T.G. & Warburg, E.F. (1981). *Excursion Flora of the British Isles.* 3rd edition. Cambridge University Press, Cambridge. 499 pp.

Clapham, A.R., Tutin, T.G. & Moore, D.M. (1987). *Flora of the British Isles.* 3rd edition. Cambridge University Press, Cambridge. 688 pp.

Clarke, S.J. & Wharton, G. (2000). An investigation of marginal habitat and macrophyte community enhancement on the River Torne, UK. *Regulated Rivers: Research and Management* **16**, 225-244.

Dandy, J.E. (1958). *List of British Vascular Plants.* British Museum, London. 176 pp.

Daniel, H., Bernez, I., Haury, J. & Le Coeur, D. (2005). The ability of aquatic macrophytes to assess fish farm pollution in two salmon rivers. *Hydrobiologia* **551**, 183-191.

Dawson, F.H., Newman, J.R., Gravelle, M.J., Rouen, K.J. & Henville, P. (1999). *Assessment of the Trophic Status of Rivers using Macrophytes. Evaluation of the Mean Trophic Rank.* R&D Technical Report E39. Environment Agency, Bristol. 178 pp.

Driscoll, R.J. (1983). Improvements in land management: their effects on aquatic plants in Broadland. *Watsonia* **14**, 276-277.

Driscoll, R.J. (1986). The dyke vegetation at Holkham National Nature Reserve, Norfolk. *Transactions of the Norfolk and Norwich Naturalists' Society* **27**, 183-190.

Ducros, C.M.J. & Joyce, C.B. (2003). Field-based evaluation tool for riparian buffer zones in agricultural catchments. *Environmental Management* **32**, 252-267.

Duigan, C.A., Kovach, W.L. & Palmer, M.A. (2006). *Vegetation communities of British lakes: a revised classification.* Joint Nature Conservation Council, Peterborough. 106 pp. Retrieved from http://www.jncc.gov.uk/PDF/pub06_Vegcommunities_of_British_Lakesa.pdf, April 2008.

Duigan, C.A., Kovach, W.L. & Palmer, M.A. (2007). Vegetation communities of British lakes: a revised classification scheme for conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems* **17**, 147-173.

Folkard, N., Ausden, M. & Kitchin, C. (1998). *Conservation Management of the Nene Washes RSPB Reserve.* Royal Society for the Protection of Birds, Sandy. 40 pp.

Goulder, R. (1992). Loss of aquatic vegetation in a Wolds winterbourne during perennial dryness. *Naturalist* **117**, 127-131.

Goulder, R. (1993). Aquatic vegetation and resumption of flow after drought in a Wolds winterbourne. *Naturalist* **118**, 85-87.

Goulder, R. (2000). Aquatic macrophytes and conservation in the drains of the Hull Valley. *Naturalist* **125**, 17-28.

Goulder, R. (2001a). Angling and species richness of aquatic macrophytes in ponds. *Freshwater Forum* **15**, 71-76.

Goulder, R. (2001b). Recovery by aquatic vegetation in a Wolds headstream subsequent to the 1988–1992 drought. *Naturalist* **126**, 127-131.

Goulder, R. (2003). Aquatic plants in the Pocklington and Driffield canals with regard to the potential extension of navigation. *Naturalist* **128**, 129-146.

Goulder, R. (2006). Aquatic plants in the Leven Canal, East Yorkshire: does the waterway continue to be an important site for botanical conservation? *Naturalist* **131**, 77-82.

Goulder, R. (2008). Conservation of aquatic plants in artificial watercourses: are main drains a substitute for vulnerable navigation canals? *Aquatic Conservation: Marine and Freshwater Ecosystems* **18**, 163-174.

Harding, J.P.C. (1987). The survey and assessment of macrophytes in watercourses. In: *Methods for the Use of Aquatic Macrophytes for Assessing Water Quality 1985–1986*, Section B, pp. 34-53. Standing Committee of Analysts, Methods for the examination of waters and associated materials. HMSO, London.

Harding, J.P.C., Say, P.J. & Whitton, B.A. (1981). River Etherow: plants and animals of a river recovering from pollution. *Naturalist* **106**, 15-31.

Haslam, S.M. (1978). *River Plants: the Macrophytic Vegetation of Watercourses.* Cambridge University Press, Cambridge. 396 pp.

Haslam, S.M. (1987). The surveying of macrophytes in watercourses. In: *Methods for the Use of Aquatic Macrophytes for Assessing Water Quality 1985–1986. Section A, pp. 9-33.* Standing Committee of Analysts, Methods for the examination of waters and associated materials. HMSO, London.

Haslam, S.M. (1994). *River Pollution: an Ecological Perspective.* Wiley, Chichester. 253 pp.

Haslam, S.M. (2006). *River Plants: the Macrophytic Vegetation of Watercourses.* 2nd edition. Forrest Text, Cardigan. 438 pp.

Haslam, S.M., Sinker, C.A. & Wolseley, P.A. (1975). British water plants. *Field Studies* **4**, 243-351.

Hatton-Ellis, T.W., Grieve, N. & Newman, J. (2003). *Ecology of Watercourses Characterised by* Ranunculion fluitantis *and* Callitricho-Batrachion *Vegetation.* Conserving Natura 2000 Rivers Ecology Series No. 11. English Nature, Peterborough. 64 pp.

Haury, J., Peltre, M.-C., Trémolières, M., Barbe, J., Thiébaut, G., Bernez, I., Daniel, H., Chatenet, P., Haan-Archipof, G., Muller, S., Dutartre, A., Laplace-Treyture, C., Cazaubon, A. & Lambert-Servien, E. (2006). A new method to assess water trophy and organic pollution – the Macrophyte Biological Index for Rivers (IBMR): its application to different types of river and pollution. *Hydrobiologia* **570**, 153-158.

Hawkes, H.A. (1998). Origin and development of the Biological Monitoring Working Party score system. *Water Research* **32**, 964-968.

Helliwell, D.R. (1983). The conservation value of areas of different size: Worcestershire ponds. *Journal of Environmental Management* **17**, 179-184.

Hill, M.O., Mountford, J.O., Roy, D.B. & Bunce, R.G.H. (1999). *Ellenberg's Indicator Values for British Plants. ECOFACT Volume 2 Technical Annex.* Institute of Terrestrial Ecology, Huntingdon. 46 pp.

Hill, M.O., Preston, C.D. & Roy, D.B. (2004). *PLANTATT. Attributes of British and Irish Plants: Status, Size, Life History, Geography and Habitats.* NERC Centre for Ecology and Hydrology, Huntingdon. 73 pp.

Holmes, N.T.H. (1975). The vegetation of the River Tweed. PhD

 DOI: 10.1608/FRJ-1.2.5

thesis, University of Durham, UK (unpublished).

Holmes, N.T.H. (1978). *Macrophyte Surveys of Rivers.* Chief Scientist's Team Notes No. 7. Nature Conservancy Council, London. 54 pp.

Holmes, N.T.H. (1980). *Preliminary Results from River Macrophyte Survey and Implications for Conservation.* Chief Scientist's Team Notes No. 24, Nature Conservancy Council, London. 68 pp.

Holmes, N.T.H. (1983). *Typing British Rivers According to their Flora*. Focus on Nature Conservation No. 4. Nature Conservancy Council, Shrewsbury. 174 pp.

Holmes, N.T.H. (1989). British rivers: a working classification. *British Wildlife* **1**, 20-36.

Holmes, N.T.H. (1994). Plant surveys. In: *The New Rivers and Wildlife Handbook* (eds D. Ward, N.T.H. Holmes & P. José), pp. 119-124. Royal Society for the Protection of Birds, Sandy.

Holmes, N.T.H. & Newbold, C. (1984). *River Plant Communities – Reflectors of Water and Substrate Chemistry.* Focus on Nature Conservation No. 9. Nature Conservancy Council, Shrewsbury. 73 pp.

Holmes, N.T.H. & Whitton, B.A. (1975a). Macrophytes of the River Tweed. *Transactions of the Botanical Society of Edinburgh* **42**, 369-381.

Holmes, N.T.H. & Whitton, B.A. (1975b). Submerged bryophytes and angiosperms of the River Tweed and its tributaries. *Transactions of the Botanical Society of Edinburgh* **42**, 383-395.

Holmes, N.T.H. & Whitton, B.A. (1977a). The macrophytic vegetation of the River Tees in 1975: observed and predicted changes. *Freshwater Biology* **7**, 43-60.

Holmes, N.T.H. & Whitton, B.A. (1977b). Macrophytic vegetation of the River Swale, Yorkshire. *Freshwater Biology* **7**, 545-558.

Holmes, N.T.H. & Whitton, B.A. (1977c). Macrophytes of the River Wear: 1966–1976. *Naturalist* **102**, 53-73.

Holmes, N.T.H. & Whitton, B.A. (1981). Plants of the River Tyne system before the Kielder Water scheme. *Naturalist* **106**, 97-107.

Holmes, N.T.H., Whitton, B.A. & Hargreaves, J.W. (1978). *A Coded List of Freshwater Macrophytes of the British Isles: Lichens-Bryophytes-Vascular Plants.* Water Archive Manual Series No. 4. Water Data Unit, Department of the Environment, Reading. 201 pp.

Holmes, N.T.H., Boon, P.J. & Rowell, T.A. (1998). A revised classification system for British rivers based on their aquatic plant communities. *Aquatic Conservation: Marine and Freshwater Ecosystems* **8**, 555-578.

Holmes, N.T.H., Boon, P.J. & Rowell, T.A. (1999a). *Vegetation Communities of British Rivers: a Revised Classification.* Joint Nature Conservation Committee, Peterborough. 114 pp.

Holmes, N.T.H., Newman, J.R., Chadd, S., Rouen, K.J., Saint, L. & Dawson, F.H. (1999b). *Mean Trophic Rank: a User's Manual.* R&D Technical Report E38. Environment Agency, Bristol. 145 pp.

Hynes, H.B.N. (1960). *The Biology of Polluted Waters.* Liverpool University Press, Liverpool. 202 pp.

Jackson, D.L. (2000). *Guidance on the Interpretation of the Biodiversity Broad Habitat Classification (Terrestrial and Freshwater Types): Definitions and the Relationship with other Classifications.* JNCC Report No. 307. Joint Nature Conservation Council, Peterborough. 73 pp.

Jeffries, M. (1991). The ecology and conservation value of forestry ponds in Scotland, United Kingdom. *Biological Conservation* **58**, 191-211.

Jermy, A.C., Chater, A.O. & David, R.W. (1982). *Sedges of the British Isles.* 2nd edition. Botanical Society of the British Isles, London. 268 pp.

Jermy, A.C., Simpson, D.A., Foley, M.J.Y. & Porter, M.S. (2007). *Sedges of the British Isles.* 3rd edition. Botanical Society of the British Isles, London. 554 pp.

Joint Nature Conservation Committee (2005a). *Common Standards Monitoring Guidance for Rivers.* JNCC, Peterborough. 59 pp. ISSN 1743-8160 (online), retrieved from http://www.jncc.gov.uk/pdf/CSM_rivers_Mar05.pdf, April 2008.

Joint Nature Conservation Committee (2005b). *Common Standards Monitoring Guidance for Ditches.* JNCC, Peterborough. 32 pp. ISSN 1743-8160 (online), retrieved from http://www.jncc.gov.uk/pdf/CSM_ditches_Mar05.pdf, April 2008.

Joint Nature Conservation Committee (2005c). *Common Standards Monitoring Guidance for Canals.* JNCC, Peterborough. 29 pp. ISSN 1743-8160 (online), retrieved from http://www.jncc.gov.uk/pdf/CSM_canals_Mar05.pdf, April 2008.

Kent, D.H. (1992). *List of Vascular Plants of the British Isles.* Botanical Society of the British Isles, London. 384 pp.

Lane, A.M.J. (1999). ENC data reporting. In: *The United Kingdom Environmental Change Network: Protocols for Standard Measurements at Freshwater Sites* (eds J.M. Sykes, A.M.J. Lane & D.G. George), pp. 97-119. Institute of Terrestrial Ecology, Huntingdon.

Lansdown, R.V. (2007). The identity of *Ranunculus* subgenus *Batrachium* in the River Itchen. Ardeola Environmental Services, Stroud (unpublished report for the Environment Agency: Southern Region). 82 pp.

Life in UK Rivers (2003). *Monitoring* Ranunculion fluitantis *and* Callitricho-Batrachion *Vegetation Communities.* Conserving Natura 2000 Rivers Monitoring Series No. 11. English Nature, Peterborough. 32 pp.

Linton, S. & Goulder, R. (1997). Botanical conservation value of East Yorkshire ponds: a comparison of village ponds and clay-pit ponds. In: *British Pond Landscapes: Action for Protection and Enhancement* (ed. J. Boothby), pp. 165-171. Pond Life Project, John Moores University, Liverpool.

Linton, S. & Goulder, R. (1998). The duckweed *Lemna minor* compared with the alga *Selenastrum capricornutum* for bioassay of pond-water richness. *Aquatic Botany* **60**, 27-36.

Linton, S. & Goulder, R. (2000). Botanical conservation value related to origin and management of ponds. *Aquatic Conservation: Marine and Freshwater Ecosystems* **10**, 77-91.

Linton, S. & Goulder, R. (2003). Species richness of aquatic macrophytes in ponds related to number of species in neighbouring water bodies. *Archiv für Hydrobiologie* **157**, 555-565.

Margules, C. & Usher, M.B. (1981). Criteria used in assessing wildlife conservation potential: a review. *Biological Conservation* **21**, 79-109.

Mason, C.F. (2002). *Biology of Freshwater Pollution.* 4th edition. Pearson Education, Harlow. 387 pp.

Merry, D.G., Slater, F.M. & Randerson, P.F. (1981). The riparian and aquatic vegetation of the River Wye. *Journal of Biogeography* **8**, 313-327.

Murphy, K.J. (2002). Plant communities and plant diversity in softwater lakes of northern Europe. *Aquatic Botany* **73**, 287-324.

Murphy, K.J. & Wallace, G. (2004). *Macrophyte Survey of the Loch of Boardhouse, Orkney.* Commissioned Report No. 021 (ROAME No. F03LA10). Scottish Natural Heritage, Edinburgh. 33 pp.

National Rivers Authority (1992). *River Corridor Surveys: Methods and Procedures.* Conservation Technology Handbook No. 1, NRA, Bristol. 37 pp.

Nature Conservancy Council (undated). *Standing and flowing water habitats (freshwater and brackish water excluding estuaries and marshes).* Record card CST OW2. NCC, London (unpublished).

Newbold, C. & Palmer, M.A. (1979). *Trophic Adaptations of Aquatic Plants.* Chief Scientist's Team Notes No. 18. Nature Conservancy Council, London. 12 pp.

Onaindia, M., de Bikuña, B.G. & Benito, I. (1996). Aquatic plants in relation to environmental factors in northern Spain. *Journal of Environmental Management* **47**, 123-137.

Palmer, M.A. (1989). *A Botanical Classification of Standing Waters in Great Britain and a Method for the Use of Macrophyte Flora in Assessing Changes in Water Quality.* Research and Survey in Nature Conservation No. 19. Nature Conservancy Council, Peterborough. 38 pp.

Palmer, M.A. (1992). *A Botanical Classification of Standing Waters in Great Britain and a Method for the Use of Macrophyte Flora in Assessing Changes in Water Quality: Incorporating a Reworking of Data 1992.* Research and Survey in Nature Conservation No. 19. Nature Conservancy Council, Peterborough. 48 pp.

Palmer, M.A. & Newbold, C. (1983). *Wetland and Riparian Plants in Great Britain: an assessment of their status and distribution in relation to water authority, river purification board and Scottish islands areas.* Focus on Nature Conservation No. 1. Nature Conservancy Council, Shrewsbury. 80 pp.

Palmer, M.A., Bell, S.L. & Butterfield, I. (1992). A botanical classification of standing waters in Britain: applications for conservation and monitoring. *Aquatic Conservation: Marine and Freshwater Ecosystems* **2**, 125-143.

Parr, T.W., Monteith, D.T. & Gibson, M. (1999). Aquatic macrophytes. In: *The United Kingdom Environmental Change Network: Protocols for Standard Measurements at Freshwater Sites* (eds J.M. Sykes, A.M.J. Lane & D.G. George), pp. 66-80. Institute of Terrestrial Ecology, Huntingdon.

Pearsall, W.H. (1921). The development of vegetation in the English Lakes, considered in relation to the general evolution of glacial lakes and rock basins. *Proceedings of the Royal Society (B)* **92**, 259-284.

Preston, C.D. (1995). *Pondweeds of Great Britain and Ireland.* Botanical Society of the British Isles, London. 352 pp.

Preston, C.D. & Croft, J.M. (1997). *Aquatic Plants in Britain and Ireland.* Harley Books, Colchester. 365 pp.

Rimes, C.A. & Goulder, R. (1986). Suspended bacteria in calcareous and acid headstreams: abundance, heterotrophic activity and downstream change. *Freshwater Biology* **16**, 633-651.

Rørslett, B. (1991). Principal determinants of aquatic macrophyte richness in northern European lakes. *Aquatic Botany* **39**, 173-193.

Scott, W.A. & Hallam, C.J. (2002). Assessing species misidentification rates through quality assurance of vegetation monitoring. *Plant Ecology* **165**, 101-115.

Scott, W.A., Adamson, J.K., Rollinson, J. & Parr, T.W. (2002). Monitoring of aquatic macrophytes for detection of long-term change in river systems. *Environmental Monitoring and Assessment* **73**, 131-153.

Seddon, B. (1972). Aquatic macrophytes as limnological indicators. *Freshwater Biology* **2**, 107-130.

Spence, D.H.N. (1987). The surveying of macrophytes in standing waters. In: *Methods for the Use of Aquatic Macrophytes for Assessing Water Quality 1985–1986*, Section C, pp. 54-65. Standing Committee of Analysts, Methods for the examination of waters and associated materials. HMSO, London.

Stace, C. (1991). *New Flora of the British Isles.* Cambridge University Press, Cambridge. 1226 pp.

Stace, C. (1997). *New Flora of the British Isles.* 2nd edition. Cambridge University Press, Cambridge. 1130 pp.

Szoszkiewicz, K., Karolewicz, K., Ławniczak, A. & Dawson, F.H. (2002). An assessment of the MTR aquatic plant bioindication system for determining the trophic status of Polish rivers. *Polish Journal of Environmental Studies* **11**, 421-427.

Szoszkiewicz, K., Ferreira, T., Korte, T., Baattrup-Pedersen, A., Davy-Bowker, J. & O'Hare, M. (2006). European river plant communities: the importance of organic pollution and the usefulness of existing macrophyte metrics. *Hydrobiologia* **566**, 211-234.

Szoszkiewicz, K., Jusik, S., Zgola, T., Czechowska, M. & Hryc, B. (2007). Uncertainty of macrophyte-based monitoring for different types of lowland rivers. *Belgian Journal of Botany* **140**, 7-16.

Thiebaut, G., Guérold, F. & Muller, S. (2002). Are trophic and diversity indices based on macrophyte communities pertinent tools to monitor water quality? *Water Research* **36**, 3602-3610.

Ward, D., Holmes, N.T.H. & José, P. (eds) (1994). *The New Rivers and Wildlife Handbook.* Royal Society for the Protection of Birds, Sandy. 426 pp.

Whitton, B.A. & Buckmaster, R.C. (1970). Macrophytes of the River Wear. *Naturalist* **95**, 97-116.

Whitton, B.A., Boulton, P.N.G., Clegg, E.M., Gemmell, J.J., Graham, G.G., Gustar, R. & Moorhouse, T.P. (1998). Long-term changes in macrophytes of British rivers: 1. River Wear. *Science of the Total Environment* **210/211**, 411-426.

Wilby, R.L., Cranston, L.E. & Darby, E.J. (1998). Factors governing macrophyte status in Hampshire chalk streams: implications for catchment management. *Journal of the Chartered Institution of Water and Environmental Management* **12**, 179-187.

Wilkinson, D.M. (1998). Relationship between species richness and rarity in Welsh aquatic floras. *Watsonia* **22**, 29-32.

Williams, P., Whitfield, M., Biggs, J., Bray, S., Fox, G., Nicolet, P. & Sear, D. (2004). Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in southern England. *Biological Conservation* **115**, 329-341.

## Author Profile

Ray Goulder has a longstanding interest in freshwater biology. He teaches freshwater ecology, plant ecology, plant ecophysiology, and organism diversity in the University of Hull and is active in the development of teaching methods.