Environmental RTDI Programme 2000–2006

WATER FRAMEWORK DIRECTIVE – Characterisation of Reference Conditions and Testing of Typology of Rivers

(2002-W-LS-7)

Final Report

Prepared for the Environmental Protection Agency

by

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ENVIRONMENTAL RTDI PROGRAMME 2000–2006

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Executive Summary

To fulfil the obligations of the Water Framework Directive, a river typology within Ecoregion 17 had to be produced. The objective of this study was to survey 50 sites within the Republic of Ireland that had been previously classified as high quality by the Irish EPA, to determine whether they were of high ecological status (and thus could be used as reference conditions) and to use these spatial reference sites to develop the river typology.

The biological elements (macroinvertebrates, phytobenthos and macrophytes) were surveyed at all 50 sites during 2002/2003. Chemistry (ammonia, phosphate, nitrate, nitrite, hardness, alkalinity, dissolved oxygen, pH, temperature, calcium, magnesium, potassium, chloride and sulphate) and basic hydromorphological variables (sediment, bank slope, etc.) were measured during the same period to ensure reference status. Q-values, TDI and MTR scores were applied to the biological elements to judge reference status, although it was acknowledged that these methods may not be appropriate since different river types cannot be directly compared using these measures.

Potential deviations from reference status were identified by the biological elements, chemistry and hydromorphology at 23 sites, although coincidence of impact indication from the different elements only occurred at six sites. Agreement of a biological response with chemistry only occurred at one site (MOY2). Despite potential minor impacts, it was considered that the development of the typology would suffer more from the omission of river types than from the effect of the potential impacts. Thus, no sites were excluded, though the status of MOY2 and OGLIN1 should be reviewed in future developments.

Several typologies were developed from this dataset: Expert based, Canonical Correspondence Analysis (CCA) based, the WFD System A Typology, and typologies developed from permutations of different environmental variables and variable boundaries. The permutation-based typologies best segregated the biological elements across all groups, and with combined biological data. A 12-category permutation-based typology was recommended as the best typology, and has now been accepted by the EPA. Categorisation of the 50 sites, indicator species, and the frequency of different species are shown for the 12 different river types within this typology.
1 Introduction

The Water Framework Directive (WFD) requires Member States to measure the ecological status of surface waters by comparison of monitoring sites with unimpacted reference conditions specific to that river or lake type. Reference conditions must be of high ecological status and thus show “no, or only very minor, evidence of distortion” (Council of the European Communities, 2000). Ecological status for biological quality elements is to be a measure of “changes in the composition and abundance” of different taxonomic groups.

The RIVTYPE project addressed the development of reference conditions and a typology for rivers within the Republic of Ireland (part of Ecoregion 17). The specific objectives were:

1. To describe the composition and abundance of the macroinvertebrate, macrophyte and phytobenthos communities of 50 potential reference river sites, which were designated by the EPA.

2. To verify that these sites are of high biological, chemical and hydromorphological status and thereby could be used as reference conditions.

3. To determine and validate a river typology. River types should have distinct biological communities and a range of environmental variables which would be expected under unimpacted conditions.

1.1 Sites Surveyed

Fifty potential reference sites, which were likely to be of high ecological status, were selected by the EPA for macroinvertebrate, phytobenthos and macrophyte surveys. The locations of these sites are shown in Fig. 1.1 and Table 1.1 provides the Irish grid references.

![Figure 1.1. Location of the 50 potential reference sites chosen by the EPA.](image-url)
Table 1.1. Irish Grid References (IGR) of the 50 potential reference sites.

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<td>38C060100</td>
<td>Cronan (Finow)</td>
<td>Ford u/s Dunlewy Lough</td>
<td>CBURN1</td>
<td>B92899 19863</td>
</tr>
<tr>
<td>38G020100</td>
<td>Gweebarra</td>
<td>Pollglass Br.</td>
<td>GWBAR1</td>
<td>B94839 13968</td>
</tr>
<tr>
<td>40B010200</td>
<td>Ballyhallan</td>
<td>Bridge u/s Clonmany River</td>
<td>BHALL1</td>
<td>C36887 46019</td>
</tr>
</tbody>
</table>
2 Sampling Procedures

2.1 Macroinvertebrates

2.1.1 Sampling method
Macroinvertebrate samples were taken at each of the 50 sites in autumn (9 October 2002 to 29 November 2002), spring (10 February 2003 to 19 March 2003) and summer (3 June 2003 to 3 July 2003). Due to flooding in the autumn of 2002, additional samples were taken in the following autumn (7 and 8 October 2003).

Macroinvertebrates were collected using a 3-min, multi-habitat kick-sampling technique (Wright, 1995). This involved surveying a 50-m reach for different habitat types — riffle, glide, pool, backwater, vegetated area and margin. The time allotted to sampling each habitat type depended upon the percentage representation of each in the 50-m reach. Habitats contributing less than 5% of the stable habitat in the reach were generally not sampled (Barbour et al., 1997). Three replicate samples were collected, labelled and preserved in 70% alcohol. Hand searches were also undertaken to provide intact specimens for species confirmation.

2.1.2 Laboratory procedures
In the laboratory, samples were sieved through an 850-µm sieve and transferred to a white tray. All macroinvertebrates were removed and stored in labelled glass tubes containing 70% alcohol. The macroinvertebrates were counted and identified to the lowest possible taxon using standard Freshwater Biological Association (FBA) identification keys. Species/genus-level identification was achieved for all groups with the exception of some dipteran larvae and immature Oligochaeta.

2.2 Phytobenthos
Benthic diatoms were sampled and analysed following draft CEN methodologies (EN 13946, 2002; prEN 14407, 2003). Macroalgal sampling also followed draft CEN guidelines (CEN/TC230/WG2/TG3, 2003). All three draft guidelines have since been updated (but not yet accepted) (EN 13946, 2003; CEN/TC230/WG2/TG3, 2004; EN 14407, 2004).

2.2.1 Sampling method
Diatoms
Diatoms were sampled from cobbles which were free from sediments and filamentous algal growths. Benthic diatoms were removed from approximately five cobbles at each site by brushing with a toothbrush and washing with distilled water into a plastic tray. Up to ten cobbles were sampled on some occasions when the sample appeared to be too dilute. The bulk sample from each site was stored in a plastic tube. Each sample was oxidised in the laboratory with concentrated sulphuric acid, oxalic acid and potassium permanganate. The resulting diatom solutions were mounted onto glass microscope slides using Naphrax® (RI = 1.7, Northern Biological Supplies, UK).

The guidance standard on the identification, enumeration and pre-treatment of benthic diatoms (prEN 14407, 2003) recommends that 300–500 diatom units (valves in this case) are enumerated for diatom surveys. It was decided after preliminary examination of the diatom component to enumerate 500 diatom valves due to the dominance of one particular taxon. This ensured that the chance of encountering rarer species would be increased. One permanent diatom slide was prepared for each river site sampled in each season. Identifications of prepared diatoms were made primarily with the monographs of Krammer and Lange-Bertalot (1986, 1988, 1991a,b).

Counting also followed the draft CEN standard (prEN 14407, 2003):

1. Random fields of view were chosen using the vernier scales on the microscope and counted in traverses. Diatoms valves that were more than half in view at the edges of a field of view were counted, while those with less than half the valve in view were not counted. Broken valves were included if approximately three-quarters of the valve were present.

2. Treatment of unidentifiable diatoms: a diatom may be difficult to identify for a number of reasons, including orientation in girdle view, and the presence of obscuring material and overlapping valves. If many valves were obscured, more dilute
suspensions were prepared, or the sample was re-oxidised. Unidentified girdle views were recorded at the lowest taxonomic level to which they could be assigned with confidence (e.g. ‘Achnanthes sp. 1’ or ‘unidentified, pennate girdle view’).

3. Photographs of identified and unidentified species were also taken and recorded for future reference. Characteristics such as shape and dimensions of the diatom, striae density and arrangement (at centre and poles), shape and size of central area, number and position of punctae and arrangement of raphe endings were recorded. Taxonomic verification was sought for a number of diatom slides (see Acknowledgements).

Macraalgae
All visible algae in a 20-m stretch at each site were collected and preserved in Lugol’s iodine in plastic tubes. Algae from both depositing and eroding habitats were included. The recent draft standard recommends that samples be collected from the permanently submerged zone in the main flow of the river and that the flood zone should be avoided. A visual estimate of the percentage abundance of visible macroalgae was made in the field using a six-point scale (Table 2.1) and detailed notes on the appearance, colour and abundance of the visible macroalgae were made at each site. The composition of the macroalgal assemblage, primarily to genus level, was determined by microscopic examination of preserved samples in the laboratory using manuals by John et al. (2002), Whiston et al. (2002, 2003) and Wehr and Sheath (2003). In the laboratory, a semi-quantitative estimate of the abundance of phytobenthos (minus the diatoms) was also carried out based on the six-point scale. Filamentous algae are well known as being difficult to identify to species level. As a result, operational taxa were employed in this study, identifying taxa to genus level and also defining filament width. A similar approach has been adopted in other studies (Kinross et al., 1993).

<table>
<thead>
<tr>
<th>Scale</th>
<th>Abundance</th>
<th>% Cover in the field</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Occasional</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>2</td>
<td>Rare</td>
<td>1–5%</td>
</tr>
<tr>
<td>3</td>
<td>Common</td>
<td>5.01–10%</td>
</tr>
<tr>
<td>4</td>
<td>Abundant</td>
<td>10.01–25%</td>
</tr>
<tr>
<td>5</td>
<td>Very abundant</td>
<td>25.01–50%</td>
</tr>
<tr>
<td>6</td>
<td>Dominating</td>
<td>&gt;50%</td>
</tr>
</tbody>
</table>

### Table 2.1. Abundance scale estimates for macroalgae (CEN, 2003b).

2.3 Macrophytes

2.3.1 Sampling method

Macrophyte surveying followed the draft CEN standard (CEN, 2002), which has now been accepted (CEN, 2003a). The survey included all aquatic vascular plants, bryophytes, Characeae and macroalgae. They were surveyed at all locations at or below the normal water level. Also, bank species which are strongly influenced by the river channel were separately recorded. Cover was recorded as categories in accordance with CEN guidelines (Table 2.2).

<table>
<thead>
<tr>
<th>Value</th>
<th>Visual cover estimate (% of channel or bank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>&lt;0.1</td>
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<tr>
<td>2</td>
<td>0.1–1</td>
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<td>3</td>
<td>1–5</td>
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<tr>
<td>4</td>
<td>5–10</td>
</tr>
<tr>
<td>5</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

The sites were assessed by surveying two 50-m lengths along representative sections of the channel. One stretch, where possible, coincided with the invertebrate sampling location and one was nearby, but at a section which appeared to have a different character. Often these two stretches covered each of a pool/riffle or an open/shaded reach. Sites where physical impact was evident were avoided and sections with a more natural character located up or downstream were selected (although the distance between the stretches was short enough to ensure that they were of similar altitude, had similar chemistry and did not have interceding tributaries).

All sites permitted wading, although this was restricted to shallow areas near the bank for a few deep-water sites. The sampling season was from June to August (inclusive) although there was a minor overrun into September. River flows tended to decrease throughout this period. Reduced visibility due to heavy rainfall and subsequent high flows was not a problem during this survey period. Low flows permitted high visibility, especially of mosses in large rivers, where they are usually less obvious.

A species survey sheet, organised by habitat type, was used to record species although additional aquatic macrophytes were recorded. Vouchers were retained for laboratory identification on the rare occasions where field
identification was not possible, particularly with *Ranunculus* spp. Taxonomic confirmations were sought for certain species (see Acknowledgements).

Macrophyte data for channel and bank species were combined for subsequent analyses. Bank species cover was estimated as a percentage of the bank to be regularly (more than annually) flooded and it was believed that certain bank species could aid with the identification of hydromorphological impacts if their low reliability is down-weighted, e.g. in methods such as CBAS (Dodkins et al., 2005). Bank species were also considered to be an important aspect of the riverine ecology.

2.4 Hydrochemistry

2.4.1 Sampling method

In order to validate the chemical and pollution status of each site it was decided that at least two sets of chemical analyses would be completed per site. Physico-chemical measurements such as water temperature, dissolved oxygen, % oxygen saturation, pH and conductivity were recorded in the field using automatic probes.

Water was collected in 1-litre polyethylene bottles, which were pre-rinsed with water from the site prior to sample collection. Two separate snap-cap vials were filled with water for anion and cation analyses. In the laboratory, analyses for alkalinity, total hardness, cations: sodium (Na⁺), magnesium (Mg²⁺), calcium (Ca²⁺) and potassium (K⁺), anions: sulphate (SO₄²⁻), chloride (Cl⁻) and nitrate (NO₃⁻) and nutrients: orthophosphate, ammonia, nitrite and nitrate were carried out using the methodologies listed in Table 2.3.

2.5 Hydromorphology

2.5.1 Sampling method

Hydromorphological survey methods were not developed in time so instead simple hydromorphological observations were recorded in the field. All variables were estimated by eye and therefore accuracy may be low. The hydromorphological survey locations coincided with the macrophyte monitoring locations, and therefore were also conducted along two representative 50-m stretches at each site. Physically impacted stretches were avoided. The data collected in the field included shade (four categories), connection with bank (bank slope; five categories), estimated stream power (nine categories) and mean substrate diameter (phi scale). Additional hydromorphological and geographical data were derived from Geographical Information Systems and provided by the EPA and Compass Informatics. These included slope, distance from source, altitude, catchment area, stream order and valley slope.

<table>
<thead>
<tr>
<th>Table 2.3. Standard methods used for chemical analysis.</th>
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<tbody>
<tr>
<td><strong>Parameter</strong></td>
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<tr>
<td>Temperature</td>
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<td>Conductivity</td>
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<tr>
<td>Dissolved oxygen</td>
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<tr>
<td>Oxygen saturation</td>
</tr>
<tr>
<td>pH</td>
</tr>
<tr>
<td>Alkalinity</td>
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<tr>
<td>Total hardness</td>
</tr>
<tr>
<td>Total ammonia</td>
</tr>
<tr>
<td>Nitrate</td>
</tr>
<tr>
<td>Nitrite</td>
</tr>
<tr>
<td>Orthophosphate</td>
</tr>
<tr>
<td>Chlorinity</td>
</tr>
<tr>
<td>Sulphate</td>
</tr>
<tr>
<td>Calcium</td>
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<tr>
<td>Magnesium</td>
</tr>
<tr>
<td>Sodium</td>
</tr>
<tr>
<td>Potassium</td>
</tr>
</tbody>
</table>

Note: all samples for Dionex analyses were filtered.
3 Verification of Ecological Status

3.1 Macroinvertebrates

Q-values were assigned to all sites for each season (Tables 3.1, 3.2 and 3.3). The majority of sites scored a Q5 value indicating that these sites were of good or excellent quality. Seasonal differences were obvious at some sites.

In autumn, the number of Class A scoring taxa (genus level) ranged from three (AILLE1, CARAG1) to 11 (GGARF1). Only one Class A taxon was observed at OGLIN1 in autumn 2003, whereas four taxa were observed at this site in the previous autumn but in low numbers (eight). Sites BLKWA1 and OWDAL1 both had ten Class A taxa. The percentage abundance of Class A taxa varied between the sites, ranging from 0.11% (OGLIN1) to >60% abundance at sites such as CAMCO1, FUNSH1 and DODDE1. Class A abundance at 18 of the 50 sites was less than 20% of the total fauna, while ten of those sites had less than 10% Class A representatives.

As expected, the number of Class A taxa increased in spring at most sites, due mainly to the Ephemeroptera. The number of taxa ranged from five (AILLE1) to 12 (MOY1). Forty-three of the sites had at least six Class A taxa. Five sites, including FLESK1, GOWLA1, KEERG1, OWGAR1 and MOY1, had at least ten Class A scoring taxa. The percentage abundance of Class A taxa ranged from 0.80% (AILLE1) to >50% (FUNSH1 and DODDE1). Thirteen of the sites had less than 10% total Class A taxa representation.

In the summer, the total Class A taxa recorded ranged from two (EANYM1, EANYW1) to ten (DODDE1). Only one Class A taxon was again observed at OGLIN1. Furthermore, a lower percentage abundance of Class A taxa was recorded, ranging from 0.17% (AILLE1) to 38% (BROAD1). Thirty-three of the 50 sites had less than 10% Class A abundance, while 20 of these sites had less than 5% representation of Class A taxa.

In summary, the majority of sites scored a Q5 value indicating that these sites were of good quality. Several sites deviated slightly from the expected Q5 status during some sampling seasons. Site AILLE1 always exhibited a low percentage abundance of Class A taxa, although at least three taxa were observed in each season (five in spring) resulting in a Q4–5 score. Five sites (CARAG1, EANYM1, EANYW1, FINOW1 and OREAG1) were given a Q4–5 in the summer season due to low percentage abundances of Class A taxa and/or in some sites where less than three Class A taxa occurred. The status of the biological community at the OGLIN1 site remains questionable. Here, the Q-values ranged from Q4–5 (autumn 2002) to Q5 in spring 2003, failing to Q4 in the summer and to the lowest value (Q3–4) in autumn 2003. The difficulty associated with taking kick-samples at this site may have contributed in part to the low scores. However, additional information obtained from discussions with Martin McGarrigle, EPA, and Fiona Kelly, Central Fisheries Board, lead to the conclusion that this site may be deviating from reference condition.

3.2 Phytobenthos

To assess ecological status the Trophic Diatom Index (TDI) (Kelly and Whilton, 1995; Kelly et al., 2001) was used. There are three drawbacks to this method: (i) it utilises only the diatom component of the phytobenthos, (ii) it was designed for the purposes of the Urban Waste Water Treatment Directive and may not be valid in less nutrient-rich rivers, and (iii) it was developed in the UK and may not be applicable to Ireland. However, as there are no complete phytobenthos methods available in Europe and there is no equivalent to the TDI in Ireland, this was the best available method for indicating departure from reference status.

The DARES project (Diatom Assessment of River Ecological Status – Environment Agency (England and Wales), the Scottish Environmental Protection Agency, Bowburn Consultancy, the Natural History Museum, and the Universities of Bristol, Newcastle and Ulster) is evaluating past diatom collections on the basis of the TDI and has so far agreed that good status sites have a TDI score between 0 and 50 and impacted sites have a TDI score between 50 and 100 (Dr Martyn Kelly, Bowburn Consultancy, personal communication).

The TDI was applied to the combined spring and summer diatom data set. Results are presented in Table 3.4. Five sites had low diatom species richness and density,
### Table 3.1. Autumn EPA Q-value ratings at the potential reference sites (Q-value scores less than Q5 are highlighted in bold).

<table>
<thead>
<tr>
<th>Site</th>
<th>% of scoring taxa in each class (zero decimal places)</th>
<th>Number of Class A: Species</th>
<th>Q-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>AILLE1</td>
<td>0</td>
<td>2</td>
<td>93</td>
</tr>
<tr>
<td>BEHYM1</td>
<td>22</td>
<td>2</td>
<td>73</td>
</tr>
<tr>
<td>BHALL1</td>
<td>12</td>
<td>14</td>
<td>71</td>
</tr>
<tr>
<td>BILBO1</td>
<td>25</td>
<td>4</td>
<td>69</td>
</tr>
<tr>
<td>BLKWA1</td>
<td>19</td>
<td>9</td>
<td>49</td>
</tr>
<tr>
<td>BOLND1</td>
<td>26</td>
<td>8</td>
<td>64</td>
</tr>
<tr>
<td>BONET1</td>
<td>37</td>
<td>6</td>
<td>55</td>
</tr>
<tr>
<td>BOW1</td>
<td>38</td>
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<td>56</td>
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<td>CLYDA1</td>
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<td>44</td>
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</tr>
</tbody>
</table>

*Indicates the scores for the additional autumn sample at this site.
Table 3.2. Spring EPA Q-value ratings at the potential reference sites (Q-value scores less than Q5 are highlighted in bold).

<table>
<thead>
<tr>
<th>Site</th>
<th>% of scoring taxa in each class (zero decimal places)</th>
<th>Number of Class A:</th>
<th>Q-value</th>
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</thead>
<tbody>
<tr>
<td></td>
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Table 3.4. Results for the Trophic Diatom Index.

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<td>G. olivaceum 29% (1 season only)</td>
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<td>GOURN1</td>
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<td>Navicula gregaria 16%. A. minutissimum 10% (1 season only)</td>
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<td>G. olivaceum 20%. A. minutissimum 13% (1 season only)</td>
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*Indicates river samples with low diatom density such that quantitative counts could not be made and TDI could not be calculated. Underlined sites indicate rivers with questionable high quality status.
precluding the calculation of a TDI value. Rivers with TDI scores of 50 or less were presumed to be of ‘good’ quality. Rivers with TDI scores greater than 50, and therefore of questionable quality, were BILBO1, BOLND1, BOW1, CLYDA1, DUNNE1, GCREE1, GOURN1, GRANE1 and SLANY1. Sites underlined had TDI scores only slightly above 50, and therefore were considered acceptable. BOW1 scored above 50 in spring but not in summer. For all the other sites, the TDI could not be calculated in summer due to the low density of diatom valves, making a quantitative count impossible. It may be possible that these rivers would score within the acceptable limits in future surveys. All sites were included in the data analysis and the determination of typology, but it is recommended that the status of the sites listed above be reviewed as part of future monitoring.

Little work has been carried out on the use of macroalgae for water quality monitoring. An exception is Cladophora, which is tolerant of high nutrient concentrations, and thus an increase in abundance has often been considered to signal eutrophication (Whitton, 1970; Bolas and Lund, 1974), although at lower population densities, it is a natural component of many water systems (Whitton, 1970). Cladophora glomerata was abundant at DUNNE1 during the summer, and attained a high abundance at DUNIR1 in both spring and summer, indicating that both of these sites may be of questionable quality. DUNEN1 also scored above 50 in the TDI. The status of both these sites should be further reviewed.

Filamentous algae including Spirogyra spp., Mougeotia spp., Oedogonium spp. and Zygnema spp. did reach high abundance at some of these sites, but there is little evidence of their relationship with water quality. They are commonly found at the littoral edges of rivers and are favoured by the lower flows and higher water temperatures that prevail during the summer.

The diatom Didymosphenia geminata, which forms visible brownish mats, was found in a number of rivers in Donegal, Mayo and Sligo, particularly during summer sampling, but rarely reached over 5% abundance. Although this species thrives in clear, warm, shallow and nutrient-poor water, an increase in its abundance may reduce rearing habitats for salmonids due to changes in invertebrate communities, physical impacts such as gill irritations and clogging, and displacement of fish species (Ministry of Water, Land and Air, British Columbia, 2004).

3.3 Macrophytes

Within Ecoregion 17 (specifically N. Ireland), the Mean Trophic Rank (MTR) (Holmes et al., 1999) has been shown to have only a weak relationship with phosphate: \( r^2 = 0.239 \) with a significance of \( P = 0.1 \) (Dawson et al., 1999). Also, macrophytes are strongly affected by the physical environment (Haury, 1996; Wilby et al., 1998), which is why the MTR is not recommended when comparing sites that are physically dissimilar (Dawson et al., 1999). In addition, MTR scores would naturally be lower for lowland rivers, and thus cannot be directly compared between different river types. Despite this, MTR values are presented in Table 3.5. The five sites identified in this table as likely to be affected by eutrophication (i.e. having an MTR score below 45) are all lowland sites, below an altitude of 55 m with slopes less than 0.016 m/m (mean slope for the 50 sites being 0.03 m/m). High silt cover in the channel can falsely suggest eutrophication within the MTR, which is likely to be the case with BROAD1 (100% silt) and SHILL1 (38% silt).

Table 3.5. MTR scores for the 50 sites. Sites in bold have an MTR score below 45 and “are likely to be affected by eutrophication” (Holmes et al., 1999).

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<th>MTR</th>
<th>Site</th>
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<td>BONE1</td>
<td>65</td>
<td>DUNNE1</td>
<td>62</td>
<td>GGARF1</td>
<td>67</td>
<td>MOY1</td>
<td>66</td>
<td>SLANY1</td>
<td>73</td>
</tr>
<tr>
<td>BOW1</td>
<td>70</td>
<td>DUNNE2</td>
<td>53</td>
<td>GNEAL1</td>
<td>81</td>
<td>MOY2</td>
<td>44</td>
<td>SULLA1</td>
<td>59</td>
</tr>
<tr>
<td>BROAD1</td>
<td>30</td>
<td>EANYM1</td>
<td>71</td>
<td>GOURN1</td>
<td>57</td>
<td>NPORT1</td>
<td>53</td>
<td>SWAN1</td>
<td>83</td>
</tr>
<tr>
<td>CAHER1</td>
<td>62</td>
<td>EANYM2</td>
<td>57</td>
<td>GOWL1</td>
<td>59</td>
<td>OGLIN1</td>
<td>44</td>
<td>URRN1</td>
<td>76</td>
</tr>
</tbody>
</table>
Sites MOY2, OGLIN1a and BEHYM1 recorded MTR scores only slightly below 45, and despite being lowland sites they may have minor nutrient impacts and should be considered for review in future studies.

Due to the shortcomings of evaluating the sites with MTR, a site-by-site ecological assessment was also undertaken. It was apparent that Fuchsia and Crocosmia (Montbretia) were invasive species along many river banks, including many of the reference sites, throughout Ireland. Finding spatial reference sites without these species would be difficult; however, the species were not considered to have had a large effect on the cover of naturally occurring species. These species together with the invasive aliens Impatiens glandulifera and Reynoutria japonica were removed from the survey data (Table 3.6).

Access to the river channel by cattle and sheep was also evident at many sites (from faeces and hoof prints), and, although attempts were made to avoid these areas, it was not always possible. These sites included GGARF1, GOWL1A, KEERG1, LIFFY1, MOY2 and OWEBEG1. The growth of Fontinalis antipyretica at some sites may suggest that some local and mild eutrophication may be occurring (AILLE 1 and OWDAL1). Although some sites had species that may be indicative of eutrophication, this was not supported by the water chemistry data, suggesting that either low summer flows or a localised event resulted in their growth. Despite invasive species and local enrichment, it was considered that all of the chosen sites had only very minor anthropogenic alterations and should be retained within subsequent analyses.

### 3.3.1 Representativeness of sites

A total of 114 aquatic macrophyte species (not including invasive aliens) were found during this survey and are used in the analyses. To determine whether a sufficient range of species was detected, species from this survey were compared with species lists previously surveyed in Northern Ireland by the Environment and Heritage Service (EHS) and also by Dodkins (2003). Species missing from this survey and suggested reasons why they were missing are listed in Table 3.7.

The absence of several species suggests that the extreme ranges of habitat have not been represented. Nardia compressa, characteristic of very acidic areas, did not occur. Rumex hydrolapathum and Potamogeton lucens, which are both found in lowland calcareous rivers, were also not found. In addition, species that occur in rivers with associated wetlands were not found, i.e. Menyanthes trifoliata and Veronica anagallis-aquatica. The relatively low number of reference sites may have reduced the chance of finding less common species.

Agrostis stolonifera, Barbarea vulgaris, Cardamine spp., Cirsium palustre, Epilobium hirsutum, Epilobium palustre, Galium palustre and Rhytidiodendrus were not considered sufficiently associated with waterbodies for this survey and were not recorded. Riparian trees (e.g. alder and willow) were also ignored during surveying.

### 3.4 Hydrochemistry

In order to determine whether these 50 sites represent reference conditions, the chemical status of each was assessed paying particular attention to the level of nutrients: ammonia, nitrite, nitrate and phosphate (McGarrigle et al., 2002).

#### 3.4.1 Ammonia

Total ammonia levels were generally below 0.01 mg/l N for the majority of sites. Nine sites had higher ammonia values ranging from 0.0014 (CAMC01) to 0.126 mg/l N (EANYW1) mostly occurring on single occasions (Table 3.8). The MOY2 site, however, recorded ammonia values ranging from 0.017 to 0.037 mg/l N on three of the four sampling occasions. However, all of the sites contained less than 0.025 mg/l N as unionised ammonia.

#### 3.4.2 Nitrite and nitrate

Nitrite levels in unpolluted waters are normally low, below 0.01 mg/l N (Flanagan, 1992). Concentrations were below this value at the majority of the sites (Table 3.8) except for

---

**Table 3.6. Impacts on reference sites indicated from the macrophytes; (a) and (b) are each of the two 50-m stretches surveyed at the sites.**

<table>
<thead>
<tr>
<th>Site</th>
<th>Invasive species*</th>
</tr>
</thead>
<tbody>
<tr>
<td>BILBO1a</td>
<td>&lt;0.1% I. glandulifera</td>
</tr>
<tr>
<td>BILBO1b</td>
<td>0.1–1% I. glandulifera; 1–5% R. japonica</td>
</tr>
<tr>
<td>BOW1a</td>
<td>&lt;0.1% R. japonica</td>
</tr>
<tr>
<td>BOW1b</td>
<td>&lt;0.1% R. japonica</td>
</tr>
<tr>
<td>BROAD1b</td>
<td>0.1–1% R. japonica</td>
</tr>
<tr>
<td>DUNNE2a</td>
<td>Fuchsia</td>
</tr>
<tr>
<td>OGLIN1a</td>
<td>Fuchsia. Crocosmia</td>
</tr>
<tr>
<td>OGLIN1b</td>
<td>0.1–1% I. glandulifera</td>
</tr>
<tr>
<td>OMORE1b</td>
<td>Crocosmia</td>
</tr>
</tbody>
</table>

*Removed from survey data prior to data analysis.*
13

Table 3.7. Species found in N. Ireland surveys but not found within the RIVTYPE survey, with suggested reasons for differences.

<table>
<thead>
<tr>
<th>Species missing from survey</th>
<th>Suggested reason for omission</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Azolla filiformis</em></td>
<td>Invasive alien and characteristic of eutrophic waters</td>
</tr>
<tr>
<td><em>Barbarea vulgaris</em></td>
<td>Not considered sufficiently associated with waterbodies for this survey</td>
</tr>
<tr>
<td><em>Cicuta virosa</em></td>
<td>Characteristic of eutrophic waters</td>
</tr>
<tr>
<td><em>Elodea nuttallii</em></td>
<td>Characteristic of eutrophic waters</td>
</tr>
<tr>
<td><em>Glyceria maxima</em></td>
<td>Often on nutrient-rich substrates</td>
</tr>
<tr>
<td><em>Heracleum mantagazzianum</em></td>
<td>Invasive alien</td>
</tr>
<tr>
<td><em>Hydrocharis morsus-ranae</em></td>
<td>Tends to exist in ponds</td>
</tr>
<tr>
<td><em>Lemna gibba</em></td>
<td>Characteristic of eutrophic waters</td>
</tr>
<tr>
<td><em>Lemna polyrhiza</em></td>
<td>Base-rich lowlands, often eutrophic, not common in the Republic of Ireland</td>
</tr>
<tr>
<td><em>Menyanthes trifoliata</em></td>
<td>At fringes of slow rivers/lakes</td>
</tr>
<tr>
<td><em>Nardia compressa</em></td>
<td>Liverwort associated with very acidic conditions</td>
</tr>
<tr>
<td><em>Orthotrichum rivulare</em></td>
<td>Quite a rare upland moss</td>
</tr>
<tr>
<td><em>Phragmites australis</em></td>
<td>Associated with slow-flowing lowland areas which don’t have a fluctuating water level. Unusual that it wasn’t found</td>
</tr>
<tr>
<td><em>Potamogeton gramineus</em></td>
<td>Found in slow-flowing meso–eutrophic base-rich sites, though not ubiquitous</td>
</tr>
<tr>
<td><em>Potamogeton lucens</em></td>
<td>Calcareous slow-flowing locations</td>
</tr>
<tr>
<td><em>Ranunculus aquatilis</em></td>
<td>Still or slow-flowing marginal. Not common in Ireland</td>
</tr>
<tr>
<td><em>Rumex hydrolapathum</em></td>
<td>Calcareous, slow-flowing locations, though not common in Ireland</td>
</tr>
<tr>
<td><em>Sagittaria sagittifolia</em></td>
<td>Associated with eutrophic waters</td>
</tr>
<tr>
<td><em>Schistidium alpicola</em></td>
<td>Moss of basic rocks</td>
</tr>
<tr>
<td><em>Sium latifolium</em></td>
<td>Lowland, rare in Ireland</td>
</tr>
<tr>
<td><em>Solanum dulcamara</em></td>
<td>Marginal plant whose omission unlikely to be important</td>
</tr>
<tr>
<td><em>Symphytum officinale</em></td>
<td>Marginal plant whose omission unlikely to be important</td>
</tr>
<tr>
<td><em>Veronica anagallis-aquatica</em></td>
<td>Lowland plant of shallow margins</td>
</tr>
</tbody>
</table>

EANYW1 (0.0258 mg/l N) where the recommended limit of 0.015 mg/l N set in the Freshwater Fish Directive (78/659/EEC) for Salmonid Waters was exceeded on a single occasion. All readings were, however, below the newly proposed limit of 0.061 mg/l N (EPA, 1997). Nitrate is a plant growth promoter and therefore can contribute to eutrophication. Nitrate levels were low, ranging from 1.04 mg/l N (GGARF1) to a moderate 9.08 mg/l N (which was maximum concentration recorded at MOY2).

3.4.3 Phosphate

Phosphate concentrations generally remained below the 0.01 mg/l P detection level at the majority of sites on most occasions (Table 3.8). Twelve sites had phosphate values greater than the Q5 – 0.015 mg/l P limit (EPA, 1997). Seven of these sites (AILLE1, BOLND1, DODDE1, DUNNE1, GDINE1, GOURN1 and OWGAR1) had phosphate values greater than 0.02 mg/l P on single occasions.

3.4.4 Chemical status of the 50 sites

The majority of sites exhibited a low nutrient content and therefore a high quality chemical status. Most of the higher nutrient readings occurred on single occasions in the summer or autumn 2003 sampling period. Three sites (GDINE1, OWGAR1 and MOY2) in particular may warrant further investigation. The phosphate value at GDINE1 ranged from 0.0409 mg/l P in the summer to 0.0281 mg/l P in the autumn. At the OWGAR1 site, the phosphate value was elevated at 0.0516 mg/l P in the summer while the ammonia value (0.0280 mg/l N) was also high in the autumn 2003 period. Finally, the MOY2 site had high ammonia (0.0333 mg/l N), nitrate (9.08 mg/l N) and phosphate (0.0165 mg/l P) values in the summer sampling period in comparison to the remaining sites. As
Table 3.8. Summary results of nutrients: ammonia, nitrite, nitrate and phosphate$^a$.

<table>
<thead>
<tr>
<th>Site</th>
<th>Ammonia</th>
<th>Nitrite</th>
<th>Nitrate</th>
<th>Phosphate</th>
<th>Site</th>
<th>Ammonia</th>
<th>Nitrite</th>
<th>Nitrate</th>
<th>Phosphate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/l N</td>
<td>mg/l N</td>
<td>mg/l N</td>
<td>mg/l P</td>
<td></td>
<td>mg/l N</td>
<td>mg/l N</td>
<td>mg/l N</td>
<td>mg/l P</td>
</tr>
<tr>
<td>AILLE1</td>
<td>Mean</td>
<td>0.0031</td>
<td>0.0059</td>
<td>1.77</td>
<td>DUNNE1</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>0.0005</td>
<td>0.002</td>
<td>1.32</td>
<td>Max</td>
<td>0.0083</td>
<td>0.0121</td>
<td>2.32</td>
<td>0.0453</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>0.0144</td>
<td>0.0011</td>
<td>4.82</td>
<td>Max</td>
<td>7.85</td>
<td>0.0017</td>
<td>&lt;0.01</td>
<td>Max</td>
</tr>
<tr>
<td>BEHYM1</td>
<td>Mean</td>
<td>6.33</td>
<td>0.0008</td>
<td>0.001</td>
<td>DUNNE2</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0054</td>
<td>0.0258</td>
<td>0.013</td>
</tr>
<tr>
<td>BHALL1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>EANYM1</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0049</td>
<td>0.0041</td>
<td>0.0117</td>
</tr>
<tr>
<td>BILBO1</td>
<td>Mean</td>
<td>2.69</td>
<td>0.0007</td>
<td>0.0313</td>
<td>EANYM2</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>0.0053</td>
<td>0.0166</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0044</td>
<td>&lt;0.001</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BLKWA1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>EANYV1</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0054</td>
<td>0.0258</td>
<td>0.013</td>
</tr>
<tr>
<td>BOLND1</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>0.0074</td>
<td>0.0313</td>
<td>FINOW1</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>0.0053</td>
<td>0.0166</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0044</td>
<td>&lt;0.001</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BONET1</td>
<td>Mean</td>
<td>1.92</td>
<td>0.0008</td>
<td>0.001</td>
<td>FLESK1</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>0.0002</td>
<td>0.0062</td>
</tr>
<tr>
<td></td>
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<td>&lt;0.01</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0093</td>
<td>&lt;0.001</td>
<td>0.013</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>FUNKH1</td>
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<td>&lt;0.001</td>
<td>&lt;5</td>
</tr>
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<td>&lt;0.001</td>
<td>&lt;5</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0044</td>
<td>&lt;0.001</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BROAD1</td>
<td>Mean</td>
<td>3.83</td>
<td>0.0011</td>
<td>4.24</td>
<td>GREE1</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>0.0032</td>
<td>0.0141</td>
</tr>
<tr>
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<td>n/r</td>
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<td>3.42</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0018</td>
<td>1.68</td>
<td>0.0054</td>
</tr>
<tr>
<td></td>
<td>Max</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAHER1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>GDINE1</td>
<td>Mean</td>
<td>0.0036</td>
<td>0.0069</td>
<td>1.59</td>
</tr>
<tr>
<td></td>
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<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
<td>Max</td>
<td>0.0218</td>
<td>0.0008</td>
<td>0.001</td>
<td>1.21</td>
</tr>
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<td>0.0008</td>
<td>0.001</td>
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<td></td>
<td>0.0063</td>
<td>0.0082</td>
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</tr>
<tr>
<td>CAMCO1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>GEARF1</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0093</td>
<td>&lt;0.001</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>CARAG1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>GNEAL1</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0044</td>
<td>&lt;0.001</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Max</td>
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<td>0.0141</td>
<td>0.008</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CBURN1</td>
<td>Mean</td>
<td>0.0012</td>
<td>0.0003</td>
<td>0.0047</td>
<td>GOURN1</td>
<td>Mean</td>
<td>0.0206</td>
<td>0.0032</td>
<td>0.0072</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
<td>Max</td>
<td>0.0002</td>
<td>0.0101</td>
<td>&lt;0.01</td>
<td>0.0188</td>
</tr>
<tr>
<td>CLYDA1</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>0.0014</td>
<td>0.004</td>
<td>GOWLA1</td>
<td>Mean</td>
<td>0.1258</td>
<td>0.0052</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>0.001</td>
<td>&lt;5</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0092</td>
<td>0.0043</td>
<td>&lt;5</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>0.0002</td>
<td>0.0101</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td>0.1258</td>
<td>0.0052</td>
<td>0.014</td>
</tr>
<tr>
<td>DODDE1</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>0.0028</td>
<td>&lt;5</td>
<td>GRANE1</td>
<td>Mean</td>
<td>0.0206</td>
<td>0.0032</td>
<td>0.0072</td>
</tr>
<tr>
<td></td>
<td>Min</td>
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<td>0.001</td>
<td>&lt;5</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0015</td>
<td>0.0032</td>
<td>1.52</td>
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<tr>
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<td>Max</td>
<td>0.0014</td>
<td>0.004</td>
<td>0.0002</td>
<td></td>
<td></td>
<td>0.1258</td>
<td>0.0052</td>
<td>0.014</td>
</tr>
<tr>
<td>DUNIR1</td>
<td>Mean</td>
<td>&lt;0.01</td>
<td>0.0018</td>
<td>1.59</td>
<td>GWBAR1</td>
<td>Mean</td>
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<td>0.002</td>
<td>0.0051</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>0.0018</td>
<td>1.59</td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.002</td>
<td>0.0051</td>
<td>1.59</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>0.0018</td>
<td>1.59</td>
<td>0.0036</td>
<td></td>
<td></td>
<td>0.1258</td>
<td>0.0052</td>
<td>0.014</td>
</tr>
</tbody>
</table>
most of the sites exhibiting the higher nutrient values did so only on single occasions and our sampling protocol only allowed two to four sampling periods, it was decided that no sites should be omitted from the analysis unless impact was also indicated by the biological status. From these sites only MOY2 may have a biological impact (for macrophytes) (see Section 3.6).

### 3.4.5 Representativeness of the sites

Various other chemical parameters were measured to characterise the sites. The frequency distribution of key measurements across the 50 sites is illustrated in Fig. 3.1.

#### Temperature and pH

The temperature readings were typical of the sampling season ranging from 3.0°C (OWGAR1) in the spring to 17.9°C (OREAG1) in the summer. The pH values ranged from 4.80 (URRN1) to 8.78 (CAHRE1), both recorded in autumn 2002. The majority of the sites studied had pH values >7 (Fig. 3.1).

#### Dissolved oxygen

The dissolved oxygen concentrations were satisfactory at all sites, ranging from 9.26 mg/l O$_2$ (OREAG1) in the summer to 17.6 mg/l O$_2$ at OWDAL1 in the spring. Each of the sites had oxygen saturation readings above the 9 mg/l level required for salmonid waters (Salmonid Water Regulations, 1988). Values ranged from 90% (BHALL1) in the autumn to 139% (OWDAL1) in the spring. The high values at OWDAL1 are indicative of eutrophication.

#### Conductivity

Conductivity values ranged from 24 µS/cm at GNEAL1, which is influenced by hard geology and nutrient-poor peaty soils, to high values of 489 µS/cm at SHILL1, which is influenced by underlying limestone and fertile soils. The majority of sites had a mean conductivity value below

---

**Table 3.8. Contd**

<table>
<thead>
<tr>
<th>Site</th>
<th>Ammonia mg/l N</th>
<th>Nitrite mg/l N</th>
<th>Nitrate mg/l N</th>
<th>Phosphate mg/l P</th>
<th>Site</th>
<th>Ammonia mg/l N</th>
<th>Nitrite mg/l N</th>
<th>Nitrate mg/l N</th>
<th>Phosphate mg/l P</th>
</tr>
</thead>
<tbody>
<tr>
<td>KEERG1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>OREAG1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0068</td>
<td>0.009</td>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>LIFFY1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>OWBEG1</td>
<td>Mean</td>
<td></td>
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<td>Min</td>
<td>&lt;0.01</td>
<td>0.0027</td>
<td>2.52</td>
<td></td>
<td>Min</td>
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<td>&lt;5</td>
<td>&lt;0.01</td>
</tr>
<tr>
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<td>Max</td>
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<td></td>
<td>Max</td>
<td>&lt;0.01</td>
<td>0.0022</td>
<td>&lt;0.01</td>
</tr>
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<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>OWDAL1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>Min</td>
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<td>Min</td>
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<td>&lt;5</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0028</td>
<td></td>
<td></td>
<td>&lt;0.01</td>
<td>0.0165</td>
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</tr>
<tr>
<td>LSLAN2</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>OWGAR1</td>
<td>Mean</td>
<td>0.0121</td>
<td>0.0071</td>
<td>0.297</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>0.0044</td>
<td>2.26</td>
<td></td>
<td>Min</td>
<td>0.0003</td>
<td>&lt;0.001</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0175</td>
<td></td>
<td></td>
<td>&lt;0.01</td>
<td>0.0077</td>
<td></td>
</tr>
<tr>
<td>MOY1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>SHILL1</td>
<td>Mean</td>
<td>0.0156</td>
<td>4.75</td>
<td></td>
</tr>
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<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>2.18</td>
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<td>0.005</td>
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<td>2.39</td>
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<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOY2</td>
<td>Mean</td>
<td>0.0188</td>
<td>0.0058</td>
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<td>0.0125</td>
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<td>1.89</td>
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</tr>
<tr>
<td>NPORT1</td>
<td>Mean</td>
<td></td>
<td>1.5</td>
<td></td>
<td>SULLA1</td>
<td>Mean</td>
<td></td>
<td></td>
<td>4.79</td>
</tr>
<tr>
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<td>&lt;0.001</td>
<td>1.3</td>
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<td>Min</td>
<td>0.0003</td>
<td>0.0018</td>
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<td></td>
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<td>&lt;0.01</td>
<td>0.0054</td>
<td></td>
</tr>
<tr>
<td>OGLIN1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>SWANL1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>0.0015</td>
<td>&lt;5</td>
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<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>2.62</td>
</tr>
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<td>0.0022</td>
<td></td>
<td></td>
<td>&lt;0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OMORE1</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>URRN1</td>
<td>Mean</td>
<td></td>
<td></td>
<td>2.88</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;5</td>
<td></td>
<td>Min</td>
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<td>&lt;0.001</td>
<td>2.11</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>&lt;0.01</td>
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<td></td>
<td></td>
<td>&lt;0.01</td>
<td>0.0074</td>
<td></td>
</tr>
</tbody>
</table>

*a*Where only a minimum value is reported, only one sample was available for that particular analysis; otherwise two or three samples were analysed to produce the mean value.
Table 3.9. Potential hydromorphological impacts at potential reference sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Potential hydromorphological impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>DUNIR1a</td>
<td>Over-widened?</td>
</tr>
<tr>
<td>DUNIR1b</td>
<td>Over-widened?</td>
</tr>
<tr>
<td>EANYM1b</td>
<td>Disturbed bank; may be cause of Petasites occurrence</td>
</tr>
<tr>
<td>LIFFY1a</td>
<td>Banks altered/eroded?</td>
</tr>
<tr>
<td>LIFFY1b</td>
<td>Banks altered/eroded?</td>
</tr>
<tr>
<td>OGLIN1a</td>
<td>Old wall forms part of bank</td>
</tr>
<tr>
<td>OGLIN1b</td>
<td>Evidence of management for fisheries (boulders across channel to create pools)</td>
</tr>
<tr>
<td>MOY2</td>
<td>Arterial drainage – spoil heaps on banks</td>
</tr>
</tbody>
</table>

200 µS/cm. The low representation of high conductivity waters is apparent in Fig. 3.1.

**Alkalinity**

The mean alkalinity values ranged from below 1 mg/l CaCO₃, at sites such as GWBAR1 (~0.19 mg/l CaCO₃) and CBURN (0.17 mg/l CaCO₃) where there is a low buffering capacity, to values above 200 mg/l CaCO₃ at sites such as DUNNE1 (247.5 mg/l CaCO₃), BEHYM1, CAHRE1, MOY2 and SHILL1. The majority of the sites (43) had mean alkalinity values below 100 mg/l CaCO₃, with 34 of these sites having mean alkalinity values below 50 mg/l CaCO₃ (Fig. 3.1). Eleven of these sites had alkalinity values of 10 mg/l or less. These sites were all influenced by peat deposits in their catchments and included CBURN1, DODDE1, FINOW1, GNEAL1, GWBAR1, LSLAN1, URRN1 (flowing over siliceous rock formations), BLKWA1, CARAG1, GGARF1 and OREAG1 (with calcareous formations in their catchments).

**Total hardness**

The total hardness values ranged from 3.24 mg/l CaCO₃ (DODDE1) to 427 mg/l CaCO₃ (MOY2). The majority of sites (46) sampled were soft waters with total hardness values below 100 mg/l CaCO₃ (Fig. 3.1).

The calcium, magnesium, potassium, sodium and chloride values for all the sites sampled fell within the ranges expected given the geological and geographical conditions. Limestone sites with high alkalinity and total hardness values were however under-represented in the study.

### 3.5 Hydromorphology

Each of the two stretches at the 50 sites was visually assessed for suitability as reference conditions based on their hydromorphology. Major alterations (weirs, bridges, channelised sections) were avoided but some minor bank and channel modifications could not be avoided. It was considered that anything greater than a minor alteration would also affect the biology. The sites listed in Table 3.9 were determined as potentially having hydromorphological impacts.

It was difficult to determine whether the DUNIR1 has been affected by over-widening. OGLIN1a was considered to have only a very minor alteration. OGLIN1b had pools that had been formed by boulders being placed across the channel, presumably for fisheries. However, it was also possible to survey a riffle section (OGLIN1a) and therefore, despite the exact location having a different character to that which would normally be expected, the two sections were still representative of a pool/riffle sequence which would be characteristic within this type of river. Natural boulders were also evident at the banks, and therefore the substrate was not artificial, even though its arrangement was. Impacts were considered to be very minor at these sites and therefore none was rejected.

The LIFFY stretches were probably the most impacted in this survey. Flood flows appeared to have eroded the banks on the outside of the river bends. Although the flood flows may have been natural, the level of erosion could be from destabilisation of the bank due to removal of the natural riparian vegetation. Apart from these areas, the river seemed to possess a natural character that may be unlikely to be replicated by other cobble rivers of this size. Therefore, the retention of this site as a potential reference site is recommended, although future development on the reference network may suggest its removal at a later date. Silt cover may have been elevated in these sections, but at the locations surveyed the hydromorphological impact could be considered minor.
3.6 Reference Site Validation Summary

Sites can only be accepted for reference conditions if they have “no or only very minor anthropogenic alteration” for all of the biological elements, and for chemistry and hydromorphology (WFD, Annex V, Table 1.2). Several sites were identified as potentially having minor impacts within the surveys (Table 3.10). It was considered that the spatial reference network would suffer more from the removal of sites representative of different river types than from the effects of the possible minor impacts occurring at these sites. There was agreement of potential impacts between two different elements at six sites (AILLE1, DUNIR1, EANYM1, EANYM2, OGLIN1 and MOY2) and agreement between three elements at only two sites (OGLIN1 and MOY2).

Table 3.10. A summary of sites which potentially have minor impacts within this survey (suggested impacts indicated by □).

<table>
<thead>
<tr>
<th>Site</th>
<th>Macroinvertebrates</th>
<th>Phytothems</th>
<th>Macrophytes</th>
<th>Hydrochemistry</th>
<th>Hydromorphology</th>
</tr>
</thead>
<tbody>
<tr>
<td>AILLE1</td>
<td>□</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEHYM1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BILBO1</td>
<td></td>
<td>□</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOLND1</td>
<td></td>
<td>□</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOW1</td>
<td></td>
<td>□</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CARAG1</td>
<td></td>
<td>□</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLYDA1</td>
<td></td>
<td>□</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUNIR1</td>
<td></td>
<td>□</td>
<td>□</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUNNE1</td>
<td></td>
<td>□</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EANYM1</td>
<td>□</td>
<td></td>
<td></td>
<td>□</td>
<td></td>
</tr>
<tr>
<td>EANYW1</td>
<td></td>
<td>□</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>FINOW1</td>
<td></td>
<td>□</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCREE1</td>
<td></td>
<td></td>
<td>□</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDINE1</td>
<td></td>
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<td>GOURN1</td>
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</tr>
<tr>
<td>MOY2</td>
<td></td>
<td>□</td>
<td>□</td>
<td>□</td>
<td></td>
</tr>
<tr>
<td>OGLIN1</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td></td>
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<td>OREAG1</td>
<td></td>
<td>□</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OWDAL1</td>
<td></td>
<td>□</td>
<td>□</td>
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<td></td>
</tr>
<tr>
<td>OWGAR1</td>
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<td></td>
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</tr>
<tr>
<td>SLANY1</td>
<td></td>
<td>□</td>
<td>□</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.1. Frequency distributions for the mean pH, conductivity, alkalinity and hardness values.
A difficulty with using measures of trophic status such as TDI, Q-values and MTR is that they were not designed for use within a typology, i.e. lowland rivers would normally be expected to be naturally more enriched than upland rivers, and conversely upland rivers which appear to pass the standard may still be relatively impacted. Therefore, direct comparisons cannot be made until a river typology is developed. From the experience with RIVPACS (Reynoldson and Wright, 2000; Wright, 2000) it is evident that any spatial reference network should, over time, be iteratively improved by both removing and including additional sites. RIVTYPE should be no exception, and the sites listed in Table 3.10 in particular should be considered for replacement by higher quality sites within the same river type, if they can be found.

Fifty reference sites were also considered to be a low number for representing the complete biological diversity of high ecological status sites. Some of the chosen survey sites were also quite close together and on the same river system. This could result in pseudo-replication of reference conditions and a lower range of species and habitats being detected. The spatial reference network should be expanded in future to include more sites, particularly more acidic upland rivers and large lowland rivers with adjacent wetlands.

3.7 Artificial Intelligence

Artificial intelligence, specifically MIR-max (O’Connor, 2002), was used to classify the biological data. An attempt was made to produce a River Pollution Diagnostic System (RPDS) model like that produced for the Environment Agency (Walley et al., 2002); however, there were insufficient data to produce an effective model. Classification of biological data with MIR-max tended to be slightly worse than that produced by TWINSPLAN (Hill and Minchin, 1997). A typology based on this classification method was considered to be inappropriate for species prediction, although prediction with any classification method was brought into question, given the limited range of variables available within the WFD and the high temporal variation in species.
4 Typology Production

A System A Typology (based on fixed boundaries of altitude, size and geology) is defined in the WFD, but there is allowance for development of alternative (System B) typologies which can use additional optional factors to delineate river types. If a System B Typology is used, it must achieve “at least the same degree of differentiation as would be achieved using System A” (WFD, Annex II 1.1 (iv)).

Four methods of classifying the sites into river types were evaluated:

1. The System A Typology.
2. Typologies based on expert opinion of the North South Technical Advisory Group (NSTAG) for rivers which included inter alia river biologists from the EPA and EHS (referred to as Expert-64, 32, 16, etc.).
3. A typology developed by examining the most important environmental gradients within the biological data using CCA.
4. Typologies derived from permutation tests; assessment of biological similarities within and between groups of many different typologies.

4.1 Combining Taxonomic Data

As well as assessing the biological differentiation achieved within each biological group, it is important to combine all the biological elements to determine the overall ability of each typology to segregate distinct biological communities.

4.1.1 Method

If the numbers of taxa in one biological element greatly exceed that in the others, analysis following a combination of these elements would unduly weight the analysis towards that group. Therefore, phytobenthos data were reduced to 129 taxa, and macroinvertebrates to 122 taxa, to combine with the 114 macrophyte taxa. The phytobenthos taxa number was reduced by removing all unidentified taxa, only including taxa which occurred in five or more river samples, and including taxa that reached an abundance level of two or more in the combined spring and summer data set. The reduced macroinvertebrate data set contained only spring data, identified predominantly to the genus level.

The abundance data for the different biological elements also had to be at the same scale. This is especially important for CCA as it utilises relative abundances. The abundance values recorded for macrophytes and phytobenthos were already approximately equivalent to a log transformation. A square-root transformation was applied to the macroinvertebrate data since it was desirable to retain the zero values; the phytobenthos and macrophyte data also had zero values. The maximum values for the macrophyte, phytobenthos and invertebrate (square-root transformed) abundance data were 5, 6 and 46, respectively; the minimum was 0. The data for these taxonomic groups were therefore standardised to the same scale by multiplying by 10/5, 10/6 and 10/46, respectively, to ensure that the abundance values for each taxonomic group ranged from 0 to 10.

4.2 Developing the CCA Typology

A site conditional bi-plot with the combined taxonomic group species data was constructed using only those variables which are available within WFD System B and which enable simple visualisation within a typology (Fig. 4.1). Temperature, chloride and substrate were not included since they were considered to be subject to impacts and therefore unsuitable for determining a river typology. Rare species were down-weighted to make the CCA more robust (Cao and Larsen, 2001; Marchant, 2002).

Forward selection was performed on the combined data set to determine the variables that explained the most additional variance, and thus are likely to be the best at structuring the typology. This was only done with the first four variables to ensure that the typology was kept simple. Environmental boundaries were to be determined by visually assessing clusters; however, peat and calcareous variables were the first to be selected, which are already coded as binary categories.

4.2.1 Results

Figure 4.1 shows the site-conditional CCA biplot created from the combined macrophyte, phytobenthos and
invertebrate data and the appropriate WFD variables. Clearly defined clusters cannot be distinguished in the ordination, and therefore distinct river types are not evident.

Alkalinity was most correlated with the biological variance (eigenvalue = 0.136, explaining 5.5% of the variation). However, the combined (binary) categories of peat and calcareousness were selected instead (explaining together 7.5%) since it was difficult within the analysis to determine where appropriate boundaries may lie along an alkalinity gradient. Table 4.1 shows the results of the manual forward selection, following the removal of alkalinity in preference for calcareousness.

Categorical divisions were kept the same as those used in the Expert-64 Typology (Table 4.2). Catchment area boundaries were determined such that they produced a better segregation of the sites than the System A catchment area boundaries. Figure 4.2 shows the allocation of sites to the CCA Typology.

In total, 14.2% variance (out of total species variance) was explained using the variables selected from the CCA Typology.

**4.3 Typologies Derived from Permutation Tests**

Choosing the best category boundaries for a fixed typology is highly subjective. The choice of category boundaries for one variable may influence the best choice of category boundaries for another variable, or even the next choice of variable. The method applied here in developing the Permutation-48 Typology overcomes this by using a large number of permutation tests with different combinations of variables and category boundaries.

<table>
<thead>
<tr>
<th>Eigenvalue (total variance = 2.484)</th>
<th>% of additional variance explained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geology (peat and calcareousness)</td>
<td>0.187</td>
</tr>
<tr>
<td>Slope</td>
<td>0.096</td>
</tr>
<tr>
<td>Area</td>
<td>0.069</td>
</tr>
</tbody>
</table>
Olden and Jackson (2000) found that permutation tests are more likely to select inappropriate variables than forward selection within gradient analysis. However, permutation tests enable different combinations of category boundaries to be assessed simultaneously, which cannot be achieved within gradient analysis.

The BIOENV routine within PRIMER (Clarke and Gorley, 2001) was used to carry out the permutation tests in this method. A similarity matrix for the biological data is first prepared. This is calculated as the similarity between different sites based on the species found at the sites. Data for all the environmental variables that could be associated with the biology are also provided, with corresponding site names. The BIOENV routine produces a similarity matrix based on all the different combinations of the environmental variables, i.e. the similarity between sites based on the environmental variables at the site. Rank correlation coefficients between each environmental similarity matrix and the similarity matrix based on species are calculated. Rank coefficients are appropriate since the environmental and species similarities that are being compared are based on entirely different similarity coefficients (in our case, Bray–Curtis and Euclidean, respectively). The correlation coefficient is reported as a rho ($\rho$) value. Once the $\rho$ values for all the possible combinations of environmental variables have been calculated, the results are ordered and displayed with the highest correlation at the top. The combination of environmental variables with the highest $\rho$ value is that which best explains the similarities in species between sites. Therefore, it is likely that these variables are the most strongly associated with the species distributions.

### 4.3.1 Method

The number of potential variables for producing the typology had to be reduced since the computing power increases exponentially with the number of variables within permutation tests. Therefore, continuous data for the variables listed in Table 4.3 were selected as the environmental data, and the combined biological data were selected as biological data. The BIOENV routine was used to find the combination of variables that best explained the Bray–Curtis similarities between sites. Variables that were repeatedly important in explaining the species similarities between sites were selected for subsequent analysis.

Once the important environmental variables had been determined, each of these variables could be divided into a range of different category types. The category boundaries were selected by considering where ecological changes would occur or enabling an even number of sites in categories. Based on the CCA analysis, it was considered that specific ecological boundary conditions did not exist, except perhaps for alkalinity and hardness. The alkalinity classes were $<25$ mg CaCO$_3$/l and $>100$ mg CaCO$_3$/l boundaries. A scatter plot of alkalinity against hardness for the site data suggested that the equivalent boundaries for hardness are $<35$ mg CaCO$_3$/l and $>100$ mg CaCO$_3$/l. Table 4.4 shows the environmental variables with their category boundaries.

A single BIOENV analysis was applied to the combined biological data (with Bray–Curtis similarity) and the complete set of categorised environmental data (with Euclidean distance similarity). Different categorical classifications of a single variable were not analysed separately; they were all included in this single permutation test. A maximum of four variable combinations was selected for the routine, although two and three variable combinations occurred within the top ten correlations.

<table>
<thead>
<tr>
<th>Table 4.2. The CCA Typology variables derived from forward selection of the combined taxonomic group data.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peat</strong></td>
</tr>
<tr>
<td><strong>Calcareous</strong></td>
</tr>
<tr>
<td><strong>Slope (using the same categories as the NSTAG Typology)</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Catchment area (using a spread of categories more appropriate to the 50 sites)</strong></td>
</tr>
</tbody>
</table>
Figure 4.2. The 50 sites classified by the System A, expert-64, CCA and permutation-48 typologies.
It is possible that the same variable is selected twice for a single typology if the boundaries between the categories do not coincide. This suggests that both sets of boundaries are important and a different set of boundary conditions or an increased categorisation of that variable should be used. This occurred with two hardness variables (Nos 3 and 5), but could not occur with any other variables since, even though there were different numbers of categories, they had coincident boundaries. BIOENV analyses using only one of the categorical hardness variables in turn showed the three category hardness variable to repeatedly explain the most variance, so this was retained. Table 4.5 shows the results of the BIOENV analysis.

### 4.3.2 Results

Hardness (var. 4), was the most important variable occurring in every suggested combination. Four-category slope (var. 18), also occurred in all of the top six results, suggesting that this is the next most important variable.

The highest correlation between the species and environment data was found to be with hardness (var. 4), slope (var. 18), peat (var. 7) and discharge (var. 9), producing a 48-category Typology. Coincidentally, the best three-variable combination was the same excluding

<table>
<thead>
<tr>
<th>Variable code</th>
<th>Variable</th>
<th>Categories</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 Alkalinity</td>
<td>&lt;25, 25–100, &gt;100</td>
<td>mg CaCO$_3$/l</td>
</tr>
<tr>
<td>2</td>
<td>2 Alkalinity</td>
<td>&lt;25, 25+</td>
<td>mg CaCO$_3$/l</td>
</tr>
<tr>
<td>3</td>
<td>4 Hardness</td>
<td>&lt;20, 20–50, 50–100, &gt;100</td>
<td>mg CaCO$_3$/l</td>
</tr>
<tr>
<td>4</td>
<td>3 Hardness</td>
<td>&lt;35, 35–100, &gt;100</td>
<td>mg CaCO$_3$/l</td>
</tr>
<tr>
<td>5</td>
<td>2 Hardness</td>
<td>&lt;35, 35+</td>
<td>mg CaCO$_3$/l</td>
</tr>
<tr>
<td>6</td>
<td>2 Geology (calcareous)</td>
<td>Calcareous/non-calcarenous</td>
<td>–</td>
</tr>
<tr>
<td>7</td>
<td>2 Peat</td>
<td>Peaty/non-peaty</td>
<td>–</td>
</tr>
<tr>
<td>8</td>
<td>4 Discharge</td>
<td>&lt;0.25, 0.25–2.5, 2.5–25, &gt;25*</td>
<td>m$^3$/s</td>
</tr>
<tr>
<td>9</td>
<td>2 Discharge</td>
<td>&lt;0.25, 0.25+</td>
<td>m$^3$/s</td>
</tr>
<tr>
<td>10</td>
<td>3 Catchment area</td>
<td>&lt;10, 10–100, &gt;100</td>
<td>km$^2$</td>
</tr>
<tr>
<td>11</td>
<td>3 Altitude</td>
<td>&lt;50, 50–150, 150+</td>
<td>m</td>
</tr>
<tr>
<td>12</td>
<td>2 Altitude</td>
<td>&lt;50, 50+</td>
<td>m</td>
</tr>
<tr>
<td>13</td>
<td>3 Catchment slope</td>
<td>&lt;10, 10–25, &gt;25</td>
<td>m/km</td>
</tr>
<tr>
<td>14</td>
<td>2 Catchment slope</td>
<td>&lt;10, 10+</td>
<td>m/km</td>
</tr>
<tr>
<td>15</td>
<td>4 Drainage density</td>
<td>0, 1, 2, 3</td>
<td>–</td>
</tr>
<tr>
<td>16</td>
<td>3 Distance from source</td>
<td>&lt; 10, 10–30, &gt;30</td>
<td>km</td>
</tr>
<tr>
<td>17</td>
<td>2 Distance from source</td>
<td>&lt;10, 10+</td>
<td>km</td>
</tr>
<tr>
<td>18</td>
<td>4 Slope</td>
<td>&lt;0.005, 0.005–0.02, 0.02–0.04, &gt;0.04</td>
<td>m/m</td>
</tr>
<tr>
<td>19</td>
<td>3 Slope</td>
<td>&lt;0.005, 0.005–0.02, &gt;0.02</td>
<td>m/m</td>
</tr>
<tr>
<td>20</td>
<td>2 Slope</td>
<td>&lt;0.02, 0.02+</td>
<td>m/m</td>
</tr>
</tbody>
</table>

*Only three discharge categories are actually represented by the site data.*
peat, and the best two-variable combination was the same excluding both peat and discharge. Therefore, in order of importance the typology structure (Permutation-48) is:

- 3 hardness categories: <35, 35–100, >100
- 4 slope categories: <0.005, 0.005–0.02, 0.02–0.04, >0.04
- 2 discharge categories: <0.25, 0.25+
- 2 peat categories: 1/0.

Based on the BIOENV results in Table 4.5, a typology with fewer river types is produced by removing the variables consecutively from the bottom of the 48-Typology hierarchy, i.e. a 24-category Typology is formed by removing peat, and a 12-category Typology is formed by removing peat and discharge.

The allocation of sites to the Permutation-48 Typology is shown in Fig. 4.2. The allocation of sites for the 24- and 12-category typologies can also be derived from this figure.

### 4.3.3 Conclusions

Hardness was found to be more important in forming a typology than either alkalinity or geology (calcareousness). Slope was the next most important variable, and requires all four categories to optimise the typology. Discharge, which is estimated from catchment area and rainfall, only required two categories. Possibly this allows differentiation between the small lowland, low-slope streams and the large lowland, low-slope rivers. Peat amount has some use in the typology, but could be ignored if a smaller typology is required.

### Table 4.5. BIOENV results showing correlations of variable combinations with species similarities between sites, using the combined species data set. The variable set was restricted to a maximum of four variables. Variable codes are listed in Table 4.4.

<table>
<thead>
<tr>
<th>Number of variables</th>
<th>Correlation</th>
<th>Selections</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.477</td>
<td>4, 7, 9, 18</td>
</tr>
<tr>
<td>4</td>
<td>0.473</td>
<td>2, 4, 9, 18</td>
</tr>
<tr>
<td>3</td>
<td>0.470</td>
<td>4, 9, 18</td>
</tr>
<tr>
<td>3</td>
<td>0.463</td>
<td>4, 8, 18</td>
</tr>
<tr>
<td>4</td>
<td>0.460</td>
<td>4, 7, 8, 18</td>
</tr>
<tr>
<td>4</td>
<td>0.460</td>
<td>1, 4, 8, 18</td>
</tr>
<tr>
<td>3</td>
<td>0.459</td>
<td>4, 8, 20</td>
</tr>
<tr>
<td>4</td>
<td>0.458</td>
<td>4, 7, 9, 20</td>
</tr>
<tr>
<td>2</td>
<td>0.458</td>
<td>4, 18</td>
</tr>
<tr>
<td>4</td>
<td>0.458</td>
<td>4, 7, 8, 20</td>
</tr>
</tbody>
</table>
5 Assessing Typology Performance

5.1 Introduction

The performance of the typologies was determined by assessing how well they predict type-specific reference conditions. It is important to remember that classifications are subjective since a decision always has to be made on the elements of a community which have to be classified, e.g. changes in ecological integrity could be represented by changes at the family level, changes in ratios of one functional group of species to another or other assessments of the ecological functioning (Angermeier and Karr, 1994) rather than species change. However, species are usually the most sensitive indicators of impact (Angermeier and Karr, 1994) and, within the WFD, measurement of composition and abundance within the taxonomic group is specified. Classifications also depend on a similarity measure for comparing sites or groups of sites. Within TWINSPAN (and ordination methods) this is the chi-squared value, whereas within other traditional classifications the more biologically applicable Bray–Curtis similarity measure is usually used. The MIR-max artificial intelligence classification utilises Mutual Information as a similarity measure. Classifications assessed using the similarity index that was used to create them are inevitably going to appear to perform better and so care must be taken in interpretation.

5.2 Methods

Concordance between the typologies and the biological data can be assessed using the method of Paavola et al. (2003) with ANOSIM (Clarke and Warwick, 1994; Clarke and Gorley, 2001). The hypothesis is that if a classification is imposed on species data the within-group variability should be less than the between-group variability if there is any concordance between the classification and the biological community.

Each typology under test was used to classify the sites and ANOSIM (using Bray–Curtis similarity) was used to determine whether the within-group variability was greater than the between-group variability for each of these typologies. The typologies being tested were the Permutation-48 Typology and the 23 and 12 river type derivatives of this, the Expert-64 Typology, determined by the NSTAG, and the 32 and 16 river type derivatives, the CCA-based Typology (48 potential river types) and the System A Typology from the WFD (24 potential river types in Ecoregion 17) (Fig. 4.2).

5.3 Results

The CCA, expert-32 and expert-16 typologies did not produce a significant classification of the invertebrate biology (Table 5.1). Although the Expert-64 Typology produced good results for combined and individual taxonomic group data, the Permutation-48 Typology and its derivatives out-performed all other typologies. There was not a large decrease in effectiveness between the Permutation-48 and Permutation-12 typologies, except for phytobenthos. The Expert-64 Typology and the Permutation-48, -24 and -12 typologies all performed better than the System A Typology.

Table 5.1. Effectiveness of the typologies in segregating the biological data. Values are Global-R values from ANOSIM. Significance (Sig.) is calculated from 999 permutations. Only spring data were used for the macroinvertebrates. Results are ordered by effectiveness with the combined data.

<table>
<thead>
<tr>
<th>Typology</th>
<th>Biological data</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Combined</td>
<td>Macrophyte</td>
<td>Phytobenthos</td>
<td>Macroinvertebrates</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sig.</td>
<td>Sig.</td>
<td>Sig.</td>
<td>Sig.</td>
<td>Sig.</td>
</tr>
<tr>
<td>Permutation-48</td>
<td>0.489</td>
<td>0.333</td>
<td>0.464</td>
<td>0.365</td>
<td>0.001</td>
</tr>
<tr>
<td>Permutation-24</td>
<td>0.467</td>
<td>0.333</td>
<td>0.384</td>
<td>0.383</td>
<td>0.001</td>
</tr>
<tr>
<td>Permutation-12</td>
<td>0.402</td>
<td>0.276</td>
<td>0.333</td>
<td>0.382</td>
<td>0.001</td>
</tr>
<tr>
<td>Expert-64</td>
<td>0.333</td>
<td>0.224</td>
<td>0.299</td>
<td>0.195</td>
<td>0.015</td>
</tr>
<tr>
<td>System A</td>
<td>0.330</td>
<td>0.173</td>
<td>0.349</td>
<td>0.145</td>
<td>0.042</td>
</tr>
<tr>
<td>Expert-32</td>
<td>0.308</td>
<td>0.185</td>
<td>0.346</td>
<td>0.049</td>
<td>0.265</td>
</tr>
<tr>
<td>CCA</td>
<td>0.304</td>
<td>0.193</td>
<td>0.308</td>
<td>0.111</td>
<td>0.103</td>
</tr>
<tr>
<td>Expert-16</td>
<td>0.251</td>
<td>0.152</td>
<td>0.291</td>
<td>0.059</td>
<td>0.229</td>
</tr>
</tbody>
</table>
5.4 Discussion

Although the Expert-64 Typology performed better than the System A Typology, by far the best were the Permutation-48, -24 and -12 typologies (in that order). The Permutation-24 Typology only had a minor drop in Global-R values compared to the Permutation-48 Typology. The CCA, Expert-32 and Expert-16 typologies performed very poorly in the concordance test with the combined and individual taxonomic data and none of these significantly segregated macroinvertebrate data.

There was only a single site in a large proportion of the river types within the typologies examined. Therefore, the biological range within this river type may not be represented. Also, since there was only one site, statistical analyses will suggest that there is no biological variation within these river types and therefore may overestimate the ability to classify or predict the biology.

The 50 sites may be too few or too unevenly distributed throughout the biological response gradients to represent all the different river types. RIVPACS in Northern Ireland uses 110 reference sites to characterise a much smaller and less diverse area. The typologies have been optimised for the 50 sites, and the reliability of the analyses when extrapolated to the whole of Ireland is highly dependent on the representativeness of this subsample.

5.5 Additional Comments

It is not likely that a typology will lead directly to the derivation of species lists for each river type, but measures of biological condition could be derived. Any single typology is likely to be sub-optimal for species prediction for one or more of the taxonomic groups. Although species are often good early indicators of impacts, more robust predictions could be made by using simpler biological elements such as functional groups of species (Willby et al., 2000), family-level predictions, or the prediction of metrics (Dodkins et al., 2005). If metrics are used, characterisation of the river types by metric values would require far fewer river types. However, in this case the typology would be best optimised by reducing the variance in metric scores for a river type, rather than the variance in species.

The Trophic Diatom Index (Kelly, 1998), Mean Trophic Ranking (Holmes et al., 1999), BMWP scores (Armitage et al., 1983) or other metrics (Dodkins et al., 2005) could be used to produce characteristic scores for each river type within a typology. It is unlikely that a simple typology will be useful in a RIVPACS (Wright et al., 1984) modelling approach, since WFD-required typologies use only a small number of variables, and are fixed rather than probabilistic. Characterisation of metric values for even quite a large number of river types into five ecological status classes seems feasible. Interpolation of reference conditions using the same variables as the accepted (fixed-boundary) typology could improve metric predictions whilst still enabling the submission of ecological status values to the EU within the structure of the (fixed-boundary) typology.

5.6 Conclusions and Recommendations

There is little difference in performance between the best three typologies, which are the permutation-48, 24 and 12 Typologies. These typologies were substantially better than any other environmental typologies in segregating the biological data and they performed equally well with each of the taxonomic groups. The only other typology to perform better than the System A Typology was the Expert-64 Typology.

Typology optimisation was only carried out using 50 sites. Validation with biological data for all the taxonomic groups from additional sites may be required to ensure that the best typologies work well on a larger scale. Some sites, particularly MOY2, GDINE1 and OGLIN1, have questionable status as reference sites. Potentially the typology may have to be expanded for river types that are dissimilar to the 50 reference sites used in this study and additional high status sites should be examined within Ecoregion 17.

Out of the top three performing typologies it is suggested that the Permutation-12 Typology is adopted since (i) there is little difference in performance compared to the Permutation-48 and -24 typologies and (ii) there are far fewer river types than the other typologies. Adopting a low number of river types within a typology also suggests that some form of metric scores will need to be used to assess impact, rather than species predictions.

5.7 Recent Developments

The Permutation-12 Typology was adopted by the EPA for the purposes of the WFD Article 5 Characterisation Report. Table 5.2 presents the assignment of sites in the Permutation-12 Typology based on GIS-derived slope values.
Table 5.2. Assignment of sites in the Permutation-12 Typology based on GIS-derived slope values. Code refers to the two-digit code used to define the river type, the first digit indicating geology and the second digit the river slope (e.g. River Type 23 has a hardness value in the range 35–100 mg/l CaCO$_3$ and a slope of 0.02–0.04 m/m).

<table>
<thead>
<tr>
<th>Hardness code</th>
<th>Code values</th>
<th>1 (\leq 0.005) m/m</th>
<th>2 (0.005–0.02 ) m/m</th>
<th>3 (0.02–0.04 ) m/m</th>
<th>4 (&gt;0.04 ) m/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;35 mg/l</td>
<td>BLKWA1</td>
<td>CARAG1</td>
<td>CBURN1</td>
<td>DODDE1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EANYM1</td>
<td>GGARF1</td>
<td>GWBAR1</td>
<td>LSLAN1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FINOW1</td>
<td>LSLAN2</td>
<td>OMORE1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLESK1</td>
<td>OGLIN1</td>
<td>SWANL1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>GCREE1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>GNEAL1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LIFFY1</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>OREAG1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>35–100 mg/l</td>
<td>AILLE1</td>
<td>BHALL1</td>
<td>BOW1</td>
<td>BONET1</td>
</tr>
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<td></td>
<td></td>
<td>BROAD1</td>
<td>BILBO1</td>
<td>CLYDA1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>DUNIR1</td>
<td>BOLND1</td>
<td>DUNNE1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>EANYW1</td>
<td>CAMCO1</td>
<td>KEERG1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>GOURN1</td>
<td>DUNNE2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>GRANE1</td>
<td>EANYM2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>MOY1</td>
<td>FUNSH1</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>OWGAR1</td>
<td>GDINE1</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>SLANY1</td>
<td>GOWLA1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SULLA1</td>
<td>NPORT1</td>
<td>OWBEG1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OWDAL1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&gt;100 mg/l</td>
<td>MOY2</td>
<td>BEHYM1</td>
<td>CAHER1</td>
<td>SHILL1</td>
</tr>
</tbody>
</table>
6 Composition of Biological Elements within River Types

Species occurring at the 50 sites that characterise river types within the Permutation-12 Typology are summarised in Table 6.1.

INDVAL within PC-ORD (McCune and Mefford, 1999) was used to determine the indicator species associated with the different river types for each biological element (Table 6.1) (based on the new allocation of sites). For each river type, these are ordered as macroinvertebrates, phytobenthos, then macrophytes. Indicator species cannot be derived for river types with zero or one site. Indicator values range from 0 to 100, indicating the strength of the association with the river type (100 being a perfect indicator of that river type). All the species listed are significant indicators at P = 0.05.

Table 6.2 shows the range of chemistry associated with these river types. Ranges are likely to vary less with river types that have fewer sites, and therefore may not reflect the true range of high status sites within the whole of Ireland. Where the sample was below the limit of detection (LoD), a value equal to half the LoD value was used to enable mean values to be generated.

An expected species list is difficult to construct for river types since natural variation (e.g. due to natural disturbance) is likely to result in some species not occurring. Also, perfect indicator species are unlikely to exist since biological communities are not discrete, but more likely to be a patchy continuum (Poole, 2002), and thus an environmental typology with discrete boundaries can never precisely define the communities. Therefore, lists were constructed which show frequency of occurrence of species within each different river type (Appendix).
Table 6.1. Indicator species (from INDVAL) for each river type. Macrophyte species in bold are confined to banks, and are likely to be more indicative of neighbouring landscape and land-use than type-specific river chemistry or hydromorphology.

<table>
<thead>
<tr>
<th>12-Typology group</th>
<th>Indicator species</th>
<th>Indicator value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Phormidium fragile</td>
<td>27</td>
<td>0.032</td>
</tr>
<tr>
<td></td>
<td>Tabellaria flocculosa</td>
<td>32</td>
<td>0.042</td>
</tr>
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= macroinvertebrates
= phytobenthos
= macrophytes
Table 6.2. Chemistry at each of the river types from the Permutation-12 Typology. Mean values are presented, with ranges (minimum to maximum) in parentheses.

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<td>0.005 (&lt;0.01–0.012)</td>
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<td>(4.97–6.64)</td>
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<tr>
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<td>(6.31–8.43)</td>
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References


Hill, M.O. and Minchin, P.R., 1997. TWINSPLAN: Divisive classification program. Centre for Ecology and Hydrology.


Krammer, K. and Lange-Bertalot., 1991b. Süßwasserflora von


O’Connor, M., 2002. Mutual Information and Regression Maximisation (MIR-max) software Version 0.2. e-mail: mo3@staffs.ac.uk, Staffordshire University.


## Appendix  Species Frequencies for Each River Type

### River Type 11 (8 sites).

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<th>Macroinvertebrates contd.</th>
<th>% freq</th>
<th>Macroinvertebrates contd.</th>
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<th>% freq</th>
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## WFD – Characterisation of reference conditions and testing of typology of rivers

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### WFD – Characterisation of reference conditions and testing of typology of rivers

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