4. SITES OF CONSERVATION IMPORTANCE

In order to place available information on the effects of phosphorus into the context of river stretches of particular conservation importance, a knowledge of the species occurring at important sites is desirable. This said, the information reviewed is as relevant to riverine habitats in general, since sensitive species/communities will occur both inside and outside of designated areas.

4.1 Macrophyte species and communities

Standards defined under the Special Ecosystem UC need to adequately protect macrophyte communities in SSSI sites, including the rare species within these communities. Since SSSI sites should reflect the range of communities existing in England and Wales, this means that they should be capable of protecting all community types and, within these communities, all species under particular threat.

Palmer and Newbold (1983) provided an assessment of the rarity of aquatic plant species. Croft *et al.* (1991) presented a more up-to-date list of nationally scarce and rare submerged and floating aquatic plants. Indeed, eutrophication has been cited as a threat to a number of aquatic macrophyte species in the Nature Conservancy Council's proposed programme for the recovery of Britain's protected species (Whitten 1990), eg Ribbon-leaved water plantain *Alisma gramineum*, Starfruit *Damasonium alisma*, and Water Germander *Teucrium scordium*. Of these, *Alisma gramineum* and *Teucrium scordium* occur in riverine situations. The citations of riverine SSSIs and proposed SSSIs contain descriptions of the species making up plant communities (see Appendix A). However, these lists are not definitive and the presence of these species is not necessarily a key factor in the designation of sites.

The site citations include few notably rare species and, besides, data on phosphorus tolerance are not available for most rarer species. Information on the nutrient requirements (or tolerance range) of rarer species is restricted to general descriptors in publications such as floras. For example, Haslam *et al.* (1975) use descriptors of "oligotrophic", "mesotrophic" and "eutrophic' to describe the combined nutrient status of water and sediment that is important for growth of different species. There is therefore currently little information upon which to support standards to protect rare species. However, some information is available in the literature for the more common species, eg species of *Ranunculus*, *Pectinatus*, *Myriophyllum*, that can dominate SSSI communities.

4.2 Phosphorus concentrations

In an analysis of phosphorus concentrations in a range of 39 designated and proposed riverine SSSIs in England for 1989/91, it was found that annual mean water column levels fell between <0.01 and 1.5 mg l^{-1} SRP (Newbold 1992). However, it should be noted that the highest mean concentrations may be higher than typical due to measurements in drought years. The annual mean in 7 rivers was found to be below 0.02 mg l^{-1} SRP , whilst that of a futher 7 rivers fell between 0.02 and 0.06 mg l^{-1} SRP. The remaining 25 rivers were considered to have phosphorus concentrations that would stress the flora present, with either excessive growths of individual species and/or the extinction of some higher plants. Further analysis of water quality data at SSSIs, pSSSIs and other rivers has been undertaken in this project, aimed at relating phosphorus levels to macrophyte status, and is described in Section 5.

5. ANALYSIS OF HISTORICAL DATA

5.1 Introduction

The main aim of this data analysis was to identify changes in phosphorus levels that could be linked to changes in macrophyte community status. The work sought to provide evidence of community change at phosphorus concentrations similar to the SRP target levels proposed by English Nature for the protection of sites designated under the Special Ecosystem Use Class (see Section 1). It was requested by English Nature that emphasis be placed upon rivers where temporal or spatial changes have been recorded. Identification of sites where further macrophyte surveying might provide valuable information was also seen as a priority by English Nature.

A large amount of historical data on riverine phosphorus levels and macrophyte communities is potentially available. The main sources of data used in the current analysis were:

a) The water quality database on 90 UK rivers collated from NRA archives by Garland (1991), on behalf of English Nature, covering the period 1981-90. Rivers were chosen to be representative of the range of river types in Britain, as classified using macrophyte communities according to the revised NCC scheme. The database consists of 176 separate sites, with water quality data being held on 334 ASCII datafiles in a range of formats that varies between NRA regions. The information on each site is held on between 1 and 4 data files. Phosphorus data are mainly in the form of SRP, although there is some Total Phosphorus data for two regions.

b) The English Nature database of macrophyte surveys, which covers a wide range of rivers throughout England and Wales. Information comprises a species listing with relative abundance categories, as well as observations on habitat. Since surveys are conducted over one or two 0.5km stretches of river, it can be concluded that the species list produced is a reasonable representation of the existing community within a river stretch. Most sites in the database have only been surveyed once, although there are a few which have recently been resurveyed.

Paper files of water quality data on SSSI sites were also available from English Nature for the years 1991 and 1992, but these were not amenable to the type of computerised analysis of data necessary and could not be prepared for such analysis in the time available.

5.2 Limitations of historical data

Archive material is commonly used for purposes other than those for which it was originally collected. This leads to a variety of constraints that need to be stated prior to interpreting any results.

Site selection

Data are rarely readily available at those sites where it is most desired. In the current context, the most useful sites for comparison in a spatial analysis would be located upstream and downstream of pure phosphorus sources, which would minimise the influence of confounding factors. In reality, routine water quality monitoring is undertaken to gain an impression of background quality, so sites tend to be distant and out of the immediate influence of discharges. Macrophyte surveying by English Nature is also aimed at gaining an overall impression of macrophyte communities, rather than determining the impact of specific pollutant sources; sites, therefore, also tend to be spread thinly along the river. When assessing spatial changes, the greater the distance between macrophyte sites being compared, the greater the probability of community change due to natural habitat change, which confounds relationships with phosphorus.

Spatial compatibility of data

Routine data on water quality are always collected, and usually stored, separately from data on riverine biota. In attempting to use this data, water quality sites have to be paired with biological sites and differences in site location have to be assessed for acceptability. It is important that the distance between sites is kept to a minimum, so that the water quality data collected is most likely to reflect the water quality prevailing at the biological site. Changes in water quality between sites may occur through self-purification processes within the river, effluent discharges or diluting influences such as tributaries.

In the current analysis, decisions need to be made concerning the acceptibility of spatial incompatibilities between macrophyte survey sites and water quality monitoring sites.

Temporal compatibility of sampling

Routine biological and chemical data are collected at different times from each other, creating the potential for incompatibility on both short (within-year) and long (between-year) timescales. In the current analysis, temporal incompatibilities also operate within the biological dataset alone, in that macrophyte surveys may have taken place at different times of the year. Owing to seasonal succession within riverine macrophyte communities, discrepancies in the timing of surveys can lead to difficulties in data interpretation. Again, decisions concerning the acceptability of such incompatibilities need to be made.

Monitoring techniques

Where time series of data are analysed, alterations to analytical techniques may occur that result in changes to data accuracy or limits of detection. In the present analysis, the Limit of Detection for SRP has been reduced considerably, significantly affecting the results obtained for oligotrophic rivers.

Similar data from different sources may be collected using different techniques, possibly resulting in incompatible results. An example in the present context are macrophyte data collected by English Nature and the NRA. The aim of English Nature surveys is to identify all species present wherever possible, in contrast to the NRA objective of essentially describing habitats whilst noting important macrophyte species. This means that comparison of species lists collected by the two organisations is not valid, as the reason for the absence of a species from an NRA list may simply be due to a lack of recording. For this reason, NRA river corridor survey information was not considered in the present analysis. Even when considering English Nature surveys alone, the list of species to be recorded is not completely fixed, so results can still vary.

Worker variability

The level of expertise inevitably varies between recorders and adds a further source of variability to historical data. Interpretation of results therefore needs to be cautious, with a knowledge of the recorder of each survey undertaken.

Confounding environmental factors

Consideration of confounding factors is essential if biological effects are to be related to specific water quality parameters with any certainty. In designing a survey for a specific task, many of these (eg substrate type, flow conditions, level of shading) can be controlled by careful site selection that holds them constant between impacted and reference sites (or before and after impact in the case of temporal changes). Those that cannot be so easily controlled (eg water quality parameters intercorrelated with the parameter(s) of interest) need to be quantified so that their likely influence can be judged. Using historical data, there is often little scope for selecting sites where confounding factors are relatively constant, owing to limited data availability. In addition, factors that are known to have significant influences (particularly habitat factors) on the effect under study are often not monitored for routine purposes.

Another way of accounting for confounding factors is to ignore them through randomisation of sites across the full range of conditions encountered. This reduces the statistical power of detecting effects, since confounding factors are left as a large source of unexplained variability, but the approach is useful in many situations. In the present context, however, the large influence of many confounding factors would swamp any effects due to phosphorus.

5.3 <u>Methods</u>

5.3.1 General

The most cost-effective way of addressing the main aim of the analysis was to focus attention on sites where differences (spatial or temporal) were evident. This approach reduced to a minimum the time-consuming process of assessing the temporal and spatial compatibility of water quality and macrophyte sites. It was decided that the best approach would be to minimise the influence of confounding variables rather than to quantify it. This was achieved by the comparison of adjacent sites (ie on the same river) for spatial analysis and the use of temporal analysis at fixed sites.

The use of multivariate techniques, as an alternative approach to the pairwise comparison of sites adopted, was considered. Whilst the use of methods such as multiple regression are useful in quantifying and accounting for the effects of confounding factors, such an approach would have required a great deal of effort in assessing compatibility between water quality and macrophyte data, and would have further required a better database of information on confounding factors than was available. Computer-intensive techniques, such as cluster analysis, would have suffer from the same logistical problems and, in addition, would produce results that are difficult to interpret in the context of phosphorus target levels.

Two main ways of selecting sites for further consideration were identified:

a) Sites with statistically significant differences in phosphorus levels (both temporal or spatial) could be identified and related to macrophyte information.

b) Sites with significantly different macrophyte communities (both temporal or spatial) could be identified and related to phosphorus information.

Since no effect of phosphorus can possibly be detected unless differences in concentration occur, Approach (a) is the most direct way of producing positive results. In statistical terms, phosphorus is the independent variable and macrophyte status is the dependent variable, with no effect on the latter being observable unless a change occurs in the former. Approach (b) is likely to identify many sites where macrophyte status changes for a variety of other reasons not related to phosphorus; these sites would not provide useful information in the current context and would take time to eliminate from the analysis.

In logistical terms, Approach (a) was also preferred, since the water quality database is relatively amenable (after suitable datafile preparation) to identifying spatial and temporal differences in phosphorus. In contrast, the English Nature database is not amenable to the automated detection of changes in macrophyte status that could be attributable to phosphorus. Furthermore, few repeat macrophyte surveys have been undertaken by English Nature, largely eliminating the possibility of identifying temporal changes.

For these reasons, it was decided that the analysis should concentrate on Approach (a). To focus effort still further, a stepped approach to data analysis was adopted:

1. Water quality sites with statistically significant spatial or temporal changes in phosphorus were identified.

2. For sites from (1), attempts were made to link to macrophyte survey sites in the English Nature database.

3. Where water quality and macrophyte survey sites were adequately matched, macrophyte data were analysed for noticeable changes/differences that could be attributable to phosphorus.

4. Where macrophyte changes were identified, ancillary data on habitat were requested from the English Nature macrophyte database to discern whether the physical environment was likely to be responsible.

5. Where habitat was not thought to be a major influence, key water quality parameters were analysed to assess whether they were likely to be having a confounding influence.

6. Following steps 1-5, a reasoned judgement was made as to whether the observed differences in macrophyte communities are likely to be due to the influence of phosphorus levels.

Water quality and macrophyte sites were paired using the following pragmatic criteria:

1. Sites must lie within 4km of each other.

2. There should be no known discharges entering between the two sites.

3. There should be no major diluting influences between the two sites.

These criteria attempted to ensure that the water quality prevaling at each macrophyte site was reflected in the values recorded at the paired water quality site. Criterion 2 was judged by the presence of sewage treatment works on 1:50,000 Ordnance Survey maps, and criterion 3 was judged by the presence of significant confluences falling between the two sites.

5.3.2 Temporal analysis

Analysis of changes through time at fixed sites has the advantage of eliminating, or at least minimising, the effects of many potential confounding factors, particularly relating to habitat type. However, there is still plenty of scope for changes in environmental conditions over time, due to activities such as channel dredging, bank reprofiling, the management of riparian trees and natural channel meandering (ie erosion/deposition processes), and these possibilities have to be borne in mind when interpreting data.

A temporal analysis of the database was previously conducted by Garland (1991), but significance testing of changes in phosphorus concentrations was restricted to a linear regression of the whole time series. Such an analysis gives no indication of the presence of any significant non-linear behaviour within the time series, which may be important when considering temporal compatibility with available macrophyte information. A linear regression analysis may be strongly influenced by extreme phosphorus concentrations in one part of a time series, whilst macrophyte data may only be available for other times. In such a case, a significant linear trend in phosphorus levels may be indicated without any possibility of relating this to effects on macrophytes.

In the present analysis, a software programme developed by WRc (SAD - Steps Automatically Detected) was used to identify statistically significant "steps" in phosphorus concentrations within the time series data from each site. Only those sites considered by Garland to have a reasonable time series (75 sites in all) were selected for the analysis. Sites exhibiting at least one significant step, with "step intervals" (ie the time interval between steps or between a step and the end of the time series) of at least two years duration, were paired with macrophyte survey sites. The timing of macrophyte surveys within the time series was then related to the time period of each step interval. The requirement was for macrophyte surveys that were undertaken during different step intervals within the time series and at least two years after the start of each interval (in order to allow at least some time for a response in the community).

Since very few sites have so far been surveyed twice by English Nature, the main emphasis in the temporal analysis was to produce a list of sites where a repeat survey in the near future would provide data to coincide with different steps in phosphorus concentrations.

5.3.3 Spatial analysis

As with the temporal analysis, a single comparison of phosphorus concentrations between sites using the complete dataset available (ie 1981-90) may obscure variability in between-site differences through the time series. This is important when comparing differences in phosphorus to macrophyte data taken at specific points along the phosphorus time series. The need for dividing the dataset into smaller time periods has to be weighed against the loss of statistical power in detecting differences in phosphorus, due to the smaller numbers of observations involved in each comparison.

A computer program was designed, using GENSTAT V software, to run on the water quality database and compare phosphorus levels at pairs of sites on the same river in each year of the time series (ie 1981-90). Concentrations were compared using a non-parametric technique, the Mann-Whitney U-Test. Pairs of sites with at least three years of significant differences within the time series were considered to be of sufficient interest to link to macrophyte survey sites. The timing of macrophyte surveys was then assessed in relation to the years in which significant phosphorus differences occurred. The requirement was for macrophyte surveys to be preceded by at least two years of significant differences in phosphorus.

5.4 Results

5.4.1 Temporal analysis

Appendix B lists sites with significant "steps" in SRP within the time series of the water quality database. Some sites with steps have been omitted from the list since they showed an inconsistent or variable pattern in phosphorus levels. A high level of statistical significance ($p=0.01$) was used in order to highlight the most significant differences. Ten sites complied with the requirement for at least two time steps of at least two years duration. A further 5 sites were found to have two or more time steps which are potentially long enough, but more data would be required in order to confirm this; these sites were included in the analysis. The phosphorus data in all 15 cases is in the form of SRP.

Since so few steps were highlighted at the 99% level of significance (ie $p=0.01$), the analysis was repeated at the 95% level in order to identify new sites worthy of further investigation. This produced another 5 sites with potential (see Appendix B), although the steps identified were generally of smaller amplitude than those identified in the original analysis. In most instances, sites with significant steps in the 99% significance analysis exhibited identical steps in the 95% analysis, indicating that the SRP concentration within each step interval was relatively consistent.

Seven of the 20 sites identified are located within SSSI river stretches, and a further site lies on an SSSI river but downstream of the designated stretch. The sites exhibited a range of changes in SRP concentrations, mostly corresponding to reductions in the English Nature SRP target value achieved. Target values breached include all but the lowest value, Class 5 (1.50 mg l^{-1}). This result compares to 29 sites found by Garland (1991) to show significant linear trends in SRP, at a significance level of $p<0.05$ (see Appendix C). 16 of the 20 sites are included in Garland's list of 29 sites.

When the selected water quality sites were compared with macrophyte survey sites (see Appendix D), 14 were rejected using the criteria stated in Section 5.3.1. Macrophyte surveys have not been conducted on 6 of the rivers under consideration, and the remaining water quality sites are separated from the nearest macrophyte sites by distances greater than 4km and/or significant confluences and/or sewage discharges.

Those sites for which a match was found (six sites in all) were assessed for temporal compatibility between SRP step intervals and macrophyte surveys (Table 5.1). At only one of the sites have two macrophyte surveys been undertaken (River Lugg at Mordiford Bridge); neither fall within the time series of the database, so extra water quality data would need to be requested to assess whether SRP concentrations were consistent over longer time periods. For three sites (on the Axe, Tarnbeck and Ure), no macrophyte surveys were undertaken during the first step interval, so no comparison of communities would be possible even if a further survey were undertaken in the future. At the remaining two sites (on the Teme and Rye), macrophyte surveys have been undertaken during the first step interval, which could act as baselines for

Table 5.1 Temporal compatibility between data at water quality and macrophyte sites, as selected by temporal analysis.

Values are the mean (in mgl^{-1}) of each step interval, which are all statistically different at the 99% level of significance (p=0.01) except where indicated.

REGION (River)	SITE	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
SEVERN-TRENT												
Teme	Tenbury*		----	----	----	----	---0.086---	----	----	----	---|---	---0.181---
	Macrophyte survey		Sep									
SOUTHWEST												
Axe	A358 Bridge @ Weycroft		----	----	---0.210---	----	|----	----	----	---0.305---	----	----
	Macrophyte survey							Jan				
WELSH												
Lugg+	Mordiford Bridge		----	---0.140---	----	---|---	----	----	---0.200---	----	----	----
	Macrophyte survey	Jul										1991
YORKSHIRE												
Rye+	Nunnington Bridge		----	----	---0.027---	----	----	---|---	----	---0.045---	----	----
	Macrophyte survey	Jun										
Tarnbeck	entry to Malham Tarn			----	----	---0.007---	---|	--0.018--|	----	----	---0.044---	----
	Macrophyte survey											Jun
Ure	West Tanfield*		---0.009---	|----	----	----	----	---0.029---	----	----	----	----
	Macrophyte survey				Jul							

* Sites that do not have two time steps of at least two years duration using the available time series, but may have if the time series were extended.

+ Steps significant at the 95% significance level (p=0.05) repeat surveys. However, pre-1980 SRP data would be required in order to assess the consistency of SRP concentrations prior to the initial macrophyte surveys. Post-1990 data would then be required to assess SRP levels prior to any repeat macrophyte survey.

<u>Summary</u>

Of the 75 sites with sufficient data to undertake a time series analysis, only 3 have been identified as being worthy of further temporal investigation, these being:

1. **River Lugg at Mordiford Bridge**, moving from a mean SRP of 0.140 mg l^{-1} (English Nature Class 4 Target Level) to 0.200 mg l^{-1} (borderline Class 4).

2. **River Teme at Tenbury**, moving from 0.086 mg l^{-1} (Class 3) to 0.181 mg l^{-1} (Class 4).

3. **River Rye at Nunnington Bridge**, moving from 0.027 mg l^{-1} (Class 3) to 0.045 mg l^{-1} (Class 3).

Expansion of the time series would be required at all three sites to confirm the consistency of SRP concentrations prior to macrophyte surveys, and repeat macrophyte surveys would be necessary on the Teme and Rye.

This is a disappointing result, considering the amount of data analysed, but is not unusual when seeking compatibility between independently collected datasets.

5.4.2 Spatial analysis

<u>Selection process</u>

Sites on the same river showing at least three years of significant differences in phosphorus levels are listed in Appendix E. Out of 133 pairs of sites analysed (ie all possible pairs on the same river within the database), 38 pairs on 22 different rivers were selected for further consideration, involving 54 individual sites. Eighteen of the 36 site pairs are distributed across 2 SSSI and 7 pSSSI rivers, although some sites lay outside of the designated stretches. In only two site pairings was there a significant difference in Total Phosphorus levels, due largely to the lack of data within the database. Phosphorus data for all other selected site pairs were in the form of SRP. The number of years where significant differences in phosphorus occurred varied greatly, from the minimum of 3 years up to 9 years. For some selected pairs, lack of statistical significance in certain years seemed to be largely due to insufficient samples being taken, rather than a real lack of difference in phosphorus levels. In other rivers, phosphorus data were only available for a handful of years within the time series, thereby reducing the chances of temporal compatibility with macrophyte survey data.

Appendix F shows the closest match of each selected water quality site with sites in the macrophyte database. Using the selection criteria outlined in Section 5.3, 21 sites had to be eliminated from the analysis, leaving 15 site pairs for further consideration. Appendix G shows the temporal compatibility between macrophyte surveys and significant annual differences in SRP. This indicates that, for each site pair, there is one set of macrophyte surveys that was undertaken in the same month of the same year. However, for 8 site pairs, these surveys fall outside of the water quality time series, being undertaken either one or two years earlier (1978 or 1979). At other site pairs, compatible macrophyte surveys have been undertaken within the time series, but no SRP samples were taken near the survey time. This is true of all pairs in NRA Wessex Region, where SRP monitoring commenced in 1985 or 1986 but macrophyte surveys were undertaken in 1980 or 1982.

Since, using the data available, no site pair fulfilled the requirement of compatible macrophyte surveys being preceded by at least two years of significant differences in SRP, further water quality data were requested from NRA regions. Data requests were made for those site pairs where macrophyte surveys had been undertaken in 1978 or 1979 and significant differences in SRP were apparent in 1980 (ie the first year of the original water quality time series). The extended time series of SRP data for these site pairs is given in Table 5.2.

With the SRP data for 1976-79, only two site pairs were found to have two years of significant differences in SRP preceding macrophyte surveys. These were:

1. River Eden (a pSSSI): upstream of Kirkby Stephen and at Warwick Bridge

2. River Windrush: at the intake at Worsham and at Newbridge gauging station

On the Eden, there were insufficient data in the year of the macrophyte survey (1978) to determine whether significant differences in SRP existed, but differences were evident in the two years preceding this. In 1976, the upstream (ie u/s Kirkby Stephen) median SRP concentration was 0.030 mg l^{-1}, compared to 0.080 mg l^{-1} downstream (ie Warwick Bridge); in 1977, the median value increased from 0.015 mg l^{-1} upstream to 0.060 mg l^{-1} downstream. On the Windrush, differences in SRP occurred in the year of the macrophyte survey (1979) and the preceding year; no SRP monitoring was undertaken in 1976 and 1977. In 1978, the upstream site (intake @ Worsham) exhibited a median SRP of 0.100 mg l^{-1}, whilst the downstream (Newbridge G/S) median was 0.200 mg l^{-1}; in 1979, the median values were 0.100 mg l^{-1} upstream and 0.185 mg l^{-1} downstream.

The macrophyte species lists for the site pairs on the Rivers Eden and Windrush are given in Tables 5.3 and 5.4. It is clear from the "other species" entries that no list is complete, but since, on each river, the same worker undertook both surveys at the same time, it is a fair assumption that the absence of a species at one site, when it is present at the other, is a good indication of true absence. It should also be noted that some of the species recorded are only tenuously linked with the aquatic environment, and are therefore not likely to be affected by changes in riverine phosphorus levels.

Table 5.2 Temporal compatibility between data at selected water quality and macrophyte sites, as selected by spatial analysis, (including extended SRP time series).

Values given are annual medians, with associated level of probability of significance for the difference between sites (using the non-parametric Mann-Whitney U-Test). Values in bold indicate significant differences at the 95% level of significance (p<0.05).

REGION (River)	SITE	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	TOTAL
NORTHWEST																
Derwent	1. Ouse Bridge	-	0.010	0.020	0.010	0.020	0.010	0.010	0.010	0.010	0.020	0.010	0.020	0.005	-	0.010
	2. Workington	-	0.010	0.014	0.015	0.030	0.020	0.035	0.030	0.040	0.020	0.030	0.025	0.015	-	0.025
	Probability (p)	-	>0.10	>0.10	>0.10	0.060	**0.001**	**0.004**	**0.000**	**0.002**	0.068	**0.037**	**0.020**	**0.009**	-	**0.000**
	1. Macrophyte survey				June											
	2. Macrophyte survey				June											
Eden	1. u/s Kirkby Stephen	0.030	0.015	0.005	0.010	0.020	0.015	0.020	0.010	0.020	0.020	0.007	-	-	-	0.020
	2. Warwick Bridge	0.080	0.060	0.050	0.030	0.080	0.050	0.090	0.065	0.115	0.090	0.075	-	-	-	0.070
	Probability (p)	**0.001**	**0.014**	*	0.060	**0.010**	**0.012**	*	**0.000**	**0.008**	**0.002**	**0.003**	-	-	-	**0.000**
	1. Macrophyte survey			July												
	2. Macrophyte survey			July												
Eden	1. Appleby	0.030	0.040	0.030	0.010	0.020	0.025	0.010	0.040	0.025	0.020	0.017	0.005	-	-	0.022
	2. Warwick Bridge	0.080	0.060	0.050	0.030	0.080	0.050	0.090	0.065	0.115	0.090	0.075	0.040	-	-	0.070
	Probability (p)	*	>0.10	*	**0.031**	**0.010**	0.052	*	**0.002**	**0.018**	0.078	**0.008**	*	-	-	**0.000**
	1. Macrophyte survey			July												
	2. Macrophyte survey			July												
THAMES																
Windrush	1. New Br below Dikler	-	-	-	-	0.105	0.100	0.065	0.080	-	-	-	-	-	-	0.095
	2. Newbridge G/S	-	-	0.200	0.185	0.205	0.210	0.300	0.160	-	-	-	-	-	-	0.200
	Probability (p)	-	-	*	*	**0.003**	**0.032**	**0.000**	**0.000**	-	-	-	-	-	-	**0.000**
	1. Macrophyte survey				June											
	2. Macrophyte survey				June											

Table 5.2 continued

REGION (River)	SITE	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	TOTAL
Windrush	1. Intake @ Worsham	-	-	0.100	0.100	0.045	0.070	0.075	0.110	0.060	0.090	0.090	-	-	-	0.090
	2. Newbridge G/S	-	-	0.200	0.185	0.205	0.210	0.300	0.160	0.250	0.250	0.150	-	-	-	0.200
	Probability (p)	-	-	**0.031**	**0.001**	**0.000**	**0.000**	**0.000**	**0.000**	**0.002**	**0.002**	**0.041**	-	-	-	**0.000**
	1. Macrophyte survey				June											
	2. Macrophyte survey				June											
YORKSHIRE																
Rye	1. Nunnington Bridge	-	<0.10	<0.10	0.06	0.030	0.030	0.060	0.040	0.040	0.049	0.056	0.060	0.040	0.015	0.040
	2. Ryton Bridge	-	<0.10	<0.10	0.09	0.060	0.070	0.080	0.080	0.075	0.057	0.075	0.070	0.090	0.015	0.070
	Probability (p)	-	>0.10	>0.10	>0.10	**0.042**	**0.003**	0.098	**0.042**	**0.042**	0.139	0.204	0.181	0.214	0.163	**0.000**
	1. Macrophyte survey				June											
	2. Macrophyte survey				June											

* Significance level is not quoted because the sample size is too small, with 4 or less observations at one or both sites.

Table 5.3 Macrophyte taxa at sites on the River Eden.

Macrophyte site:			NY781040	NY469567
Date of survey:			July 1978	July 1978
Surveyor:			Holmes	Holmes
Water quality site:			u/s Kirkby Stephen	Warwick Bridge
Taxa list	**Trophic Rank[1]**	**Plant Score[2]**		
ALGAE				
Enteromorpha	X136	3		*
Cladophora glomerata agg	112	3	*	*
Cladophora aegagropila	-	3		*
Didymosphenia geminata	-	-	*	
Hildenbrandia rivularis	55	7		*
Lemanea fluviatilis	-	8	*	*
Leptogium (with *Collema*)	-	-	*	*
Lyngbia vanderberghenii	-	-	*	*
Nostoc parmelioides	-	-		*
Phormidium sp(p)	-	-	*	
Sigeoclonium tenue	-	1		*
Vaucheria sessilis agg	135	2		*
Verrucaria spp	-	-	*	*
Other filamentous greens	-	-	*	
MOSSES/LIVERWORTS				
Pellia endiviifolia	-	6		*
Amblystegium fluviatile	-	6	*	
Anomobryum filiforme	-	10	*	
Barbula cylindrica	-	10	*	
Brachythecium rutabulum	-	10		*
Brachythecium plumosum	-	10	*	
Brachythecium rivulare	-	10	*	
Bryum argentum	-	10	*	
Bryum alpinum	-	10	*	
Bryum biclor	-	10	*	
Bryum pseudotriquetum	-	10	*	
Chiloscyphus polyanthos	-	10		*
Cinclidotus fontinaloides	-	7	*	*
Cratoneuron filicinum	-	10	*	*
Dichodontium flavescens	-	10	*	
Dichodontium pellucidum	-	10	*	
Fissidens crassipes	-	10		*
Fissidens rufulus	-	10	*	
Fissidens viridulus	-	10		*
Fontinalis antipyretica	X56	4	*	
Fontinalis squamosa	40	10		*
Funaria hygrometrica	-	10	*	
Gymnostomum auruginosum	-	10	*	
Hygrohypnum luridum	-	10	*	
Orthotrichum affine	-	10	*	

Table 5.3 continued

Macrophyte site:			NY781040	NY469567
Date of survey:			July 1978	July 1978
Surveyor:			Holmes	Holmes
Water quality site:			u/s Kirkby Stephen	Warwick Bridge
Taxa list	**Trophic Rank**[1]	**Plant Score**[2]		
Orthotrichum rivulare	-	10	*	
Philonotis fontana	-	10	*	
Racomitrium aciculare	-	10	*	
Rhynchostegium lusitanicum	-	10	*	*
Schistidium alpicola	-	10	*	
Thamnobryum alopecurum	-	10		*
Conocephalum conicum	-	-		*
Marchantia polymorpha	-	-	*	
HORSETAILS				
Equisetum arvense	-	-	*	*
DICOTYLEDONS				
Angelica sylvestris	-	-		*
Callitriche stagnalis	-	6	*	
Caltha palustre	X54	6	*	*
Cardamine amara	30	-	*	
Epilobium hirsutum	-	-		*
Epilobium sp(p)	-	-	*	*
Eupatorum cannabinum	-	-		*
Impatiens glandulifera	-	-		*
Lysimachia vulgaris	-	-		*
Mentha aquatica	X77	6	*	*
Mimulus guttatus	-	-	*	*
Myosotis scorpioides	62	5	*	*
Myriophyllum spicatum	148	3		*
Nasturtium officinale agg	97	7	*	
Oenanthe crocata	-	3		*
Petasites hybridus	-	-		*
Polygonum sp(p)	-	-		*
Ranunculus flammula	26	6	*	
Ranunculus fluitans	45	5		*
Ranunculus penicillatus var *peni*	69	6		*
Ranunculus penicillatus var *calc*	99	6		*
Ranunculus trichophyllus	75	6	*	
Rorippa sylvestris	-	-		*
Sagina procumbens	-	-	*	
Solanum dulcamara	-	2		*
Stachys palustris	-	-		*
Stellaria alsine	-	-	*	*
Tussilago farfara	-	-	*	
Veronica beccabunga	76	5	*	*
Salix sp	-	-		*

Table 5.3 continued

Macrophyte site:			NY781040	NY469567
Date of survey:			July 1978	July 1978
Surveyor:			Holmes	Holmes
Water quality site:			u/s Kirkby Stephen	Warwick Bridge
Taxa list	**Trophic Rank**[1]	**Plant Score**[2]		
Other tree genera	-	-	*	*
Other dicotyledons	-	-	*	*
MONOCOTYLEDONS				
Agrostis stolonifera	X53	1	*	*
Anthoxanthum odoratum	-	-	*	
Alopecurus geniculatus	-	-		*
Butomus umbellatus	82	-		*
Carex acuta	40	8		*
Carex demissa	-	8	*	
Carex nigra	14	8	*	
Cochlearia officinalis	-	-	*	
Deschampsia cespitosa	-	-	•	
Eleocharis palustris	56	-		*
Elodea canadensis	71	5		*
Glyceria fluitans	X47	4	*	
Iris pseudacorus	60	3		*
Juncus acutiflorus	-	6	*	*
Juncus bufonius	-	6		*
Juncus bulbosus	44	6		*
Juncus effusus	X51	4	*	
Juncus inflexus	-	4	*	
Lemna minor	X139	4		•
Molinia caerulea	-	-	*	
Phalaris arundinacea	X78	2		*
Potamogeton crispus	137	4		*
Potamogeton pectinatus	149	1		*
Potamogeton perfoliatus	135	7		*
Sparganium erectum	X103	2		*
Zannichellia palustris	150	5		*
Other monocotyledons	-	-	*	*
TOTAL NUMBER OF TAXA			**62**	**66**
PLANT SCORE[2]			**312**	**224**
AVERAGE PLANT SCORE PER TAXON[2]			**7.8**	**5.6**
TROPHIC INDEX[3]			**61**	**88**

[1] Assigned by Newbold and Palmer (1979) and Newbold and Holmes (1987)
[2] After Standing Committee of Analysts (1987)
[3] After Newbold and Holmes (1987)

Table 5.4 Macrophyte taxa at sites on the River Windrush.

Macrophyte site:			SP273117	SP403013
Date of survey:			June 1979	June 1979
Surveyor:			Holmes	Holmes
Water quality site:			Intake @ Worsham	Newbridge G/S
Taxa list	**Trophic Rank[1]**	**Plant Score[2]**		
ALGAE				
Enteromorpha	X136	3		*
Cladophora glomerata agg	112	3		*
Lunularia cruciata	-	-	*	
Vaucheria sessilis agg	135	2	*	*
MOSSES/LIVERWORTS				
Pellia epiphylla	25	6	*	
Amblystegium fluviatile	-	6	*	
Amblystegium riparium	126	2		*
Brachythecium rutabulum	-	10	*	*
Cratoneuron filicinum	-	10	*	*
Fissidens crassipes	-	10	*	
Fontinalis antipyretica	X56	4	*	*
Pohlia carnea	-	10	*	
Rhynchostegium lusitanicum	-	6	*	*
HORSETAILS				
Equisetum arvense	-	-	*	
DICOTYLEDONS				
Bidens cernua	-	-		•
Epilobium hirsutum	-	-	*	*
Eupatorum cannabinum	-	-	*	*
Filipendula ulmaria	-	-	*	
Lycopus europaeus	-	-	*	*
Lythrum salicaria	-	-	*	*
Mentha aquatica	X77	6	*	*
Myosotis scorpioides	62	5	*	*
Myriophyllum spicatum	148	3	*	*
Nasturtium officinale	97	7	*	
Nuphar lutea	138	6	*	
Petasites hybridus	-	-	*	
Petasites japponicus	-	-	*	
Polygonum amphibia	141	3		*
Polygonum sp(p)	-	-		*
Ranunculus circinatus	98	6		*
Ranunculus fluitans	45	5	*	*
Ranunculus penicillatus var *calc*	99	6	*	*
Rorippa palustris	-	-	*	
Rorippa amphibia	112	4		*
Rumex hydrolapathum	100	-	*	*
Rumex sp(p)	-	-	*	*
Scrophularia auriculata	-	-	*	*

Table 5.4 continued

Macrophyte site:			SP273117	SP403013
Date of survey:			June 1979	June 1979
Surveyor:			Holmes	Holmes
Water quality site:			Intake @ Worsham	Newbridge G/S
Taxa list	**Trophic Rank[1]**	**Plant Score[2]**		
Solanum dulcamara	-	2	*	*
Symphytum officinale	-	-	*	
Veronica anagallis-aquatica	66	-	•	*
Veronica beccabunga	76	5	*	*
Salix sp	-	-	*	*
Other tree genera	-	-	*	
Other dicotyledons	-	-	*	*
MONOCOTYLEDONS				
Agrostis stolonifera	X53	1	*	*
Alisma plantago-aquatica	X109	3		*
Carex acutiformis	110	8	*	*
Carex hirta	-	8	*	
Carex riparia	114	8	•	*
Elodea canadensis	71	5		*
Glyceria maxima	116	3	*	*
Iris pseudacorus	60	3	*	
Juncus inflexus	-	4	*	*
Phalaris arundinacea	X78	2	*	*
Potamogeton crispus	137	4		*
Potamogeton pectinatus	149	1		*
Potamogeton perfoliatus	135	7		*
Schoenoplectus lacustris	142	5	*	*
Sparganium erectum	X103	2	*	*
Typha latifolia	146	4	*	
Zannichellia palustris	150	5		*
Other monocotyledons	-	-	*	*
TOTAL NUMBER OF TAXA			**48**	**45**
PLANT SCORE[2]			**141**	**135**
AVERAGE PLANT SCORE PER TAXON[2]			**5.2**	**4.3**
TROPHIC INDEX[3]			**99**	**111**

[1] After Newbold and Palmer (1979), revised by Newbold and Holmes (1987)
[2] After Standing Committee of Analysts (1987)
[3] After Newbold and Holmes (1987)

A broad indication of the trophic tolerances of many aquatic species is given by the Trophic Rank (Newbold and Palmer 1979, Newbold and Holmes 1987) and the Plant Score (Standing Committee of Analysts 1987). However, these should both be treated with caution, as they are largely based upon field observations of plant communities without reference to nutrient data, and refer to trophy in general terms (ie water column and sediment). Also, in the case of the Plant Score, taxa scores were designated on the basis of field observations over a limited area (North West England), but tolerances may vary across the UK. The sum of taxa scores yields the Plant Score, which is divided by the number of scoring taxa present to give the Average Score Per Taxon. These parameters are analogous to the BMWP score and ASPT used in invertebrate monitoring; in the same way, reduced scores indicate an increase in nutrient/organic status and a shift towards a more tolerant community. The Trophic Index (Newbold and Holmes 1987) is the average Trophic Rank of scoring species present, omitting some of the species with a wide trophic range. An increase in the Trophic Index is intended to indicate a shift towards a community indicative of higher nutrient levels.

River Eden

Large differences between the two macrophyte communities are immediately evident, with 41 out of 62 taxa at the upstream site not present at the downstream site, and 45 out of 66 at the downstream site not present at the upstream site (a large number of these species at both sites are not aquatic). Plant Scores are high (312 upstream and 224 downstream) due largely to the presence of diverse moss floras, particularly at the upstream site. This is reflected in the Plant ASPT, with the upstream site scoring 7.8 compared to 5.6 downstream. The Trophic Index suggests a shift downstream towards a community associated with higher nutrient levels. The NCC river type changes from Type 8 upstream (predominantly upland oligo-mesotrophic rivers) to Type 6 downstream (large rivers on sandstone, mudstone and hard limestone), indicating a major change in community type.

Regarding habitat, the two site pairs are approximately 50 km apart and are considerably different in a number of respects. From ancillary habitat data obtained from the Macrophyte Database (see Table 5.5), the overall picture is one of an upstream site with strong upland character, with fast shallow waters overlying a very coarse substrate, and a downstream site in the floodplain with decidedly slacker water and depositional areas.

Table 5.5 Habitat characteristics of sites on the Eden.

Parameter	Upstream	Downstream
Altitude (m)	229	30
Gradient (m km^{-1})	15	1.0
Flow class (m^3 s^{-1})	0.31-0.62	20-40
Current velocity	Fast	Moderate
Modal depth (m)	<0.25	0.5-1.0
Dominant substrate	Cobbles/boulders	Cobbl/bould/pebbl/grav
Width (m)	5-10	>20
Dominant land use	Permanent grass	Permanent grass

It is evident that there is plenty of scope for differences in the macrophyte communities of the two sites from habitat considerations alone, without recourse to phosphorus data. Mosses species are generally thought to be intolerant of elevated phosphorus levels, but are also likely to fair better in the upland environment of the upstream site, with fast, clear and shallow water. A number of aquatic plants tolerant of higher trophic status appear at the downstream site, such as *Sparganium*, *Zannichellia*, *Myriophyllum*, *Phalaris*, and three *Potamogetons*, but these rooted species would be expected to appear as water velocities slacken and finer substrates are deposited. *Ranunculus flammula* is intolerant of elevated nutrient levels and is present upstream whilst absent downstream; it is possible that phosphorus is playing a role in the distribution of this rooted macrophyte. However, in summary, if phosphorus is causing some of the observed differences in macrophyte communities, it is difficult to separate them from differences due to changing habitat from the upstream to the downstream site.

River Windrush

Although both sites on the River Windrush have similar numbers of taxa recorded (48 upstream as opposed to 45 downstream), 17 species are unique to the upstream site and 14 are unique to the downstream site. There is therefore a considerable change in species composition between the two communities. This is reflected in the NCC river type designations, the upstream site being Type 3 (lowland chalk and oolite rivers with generally stable flow regimes) and the downstream site Type 2 (lowland clay rivers, or rivers from predominantly clay catchments). The Trophic Index increases from 99 at the upstream site to 111 downstream, implying that the community changes downstream towards one associated with a higher nutrient status. The Plant Scores are similar for the two sites, but the Plant ASPT is somewhat higher upstream, suggesting a more sensitive community.

In terms of habitat, the two sites are approximately 22 km apart and are broadly similar (see Table 5.6), although the downstream section is generally faster and shallower, resulting in coarser substrates. The geology is described in identical terms (soft limestone); however, the NCC river type designations suggest no limestone influence at the upstream site, but subsequent intrusion into river flow at the downstream site.

Table 5.6 Habitat characteristics of sites on the Windrush.

Parameter	Intake @ Worsham (Upstream)	Newbridge G/S (Downstream)
Geology	Other soft limestone	Other soft limestone
Altitude (m)	95	70
Gradient (m km^{-1})	1.15	1.07
Flow class (m^3 s^{-1})	1.25-2.5	2.5-5.0
Current velocity	Moderate	Moderate/fast
Modal depth (m)	0.5-1.0	<0.25
Substrate	mainly clay	gravel/sand
Width (m)	5-20	10-20
Land use	-	Permanent grass

Comparisons of general water quality at the two sites are given in Table 5.7. No significant differences were found in parameters relating to organic pollution (ie Total Oxidised Nitrogen, Ammoniacal Nitrogen, Biochemical Oxygen Demand and Suspended Solids) in any of the 3 years preceding macrophyte surveying. Similarly, pH showed no significant differences between sites. Hardness was significantly higher at the downstream site, indicating greater limestone influence; it is unlikely, however, that the increase (of around 13% in 1978 and 8% in 1989) would be ecologically significant. N:P ratios are greater than 70:1 at the upstream site and greater than 35:1 at the downstream site, indicating that nitrogen is not limiting growth.

Table 5.7 Comparison of general water quality at sites on the Windrush.

Values given are annual medians, with associated level of probability of significance for the difference between sites (using the non-parametric Mann-Whitney U-Test). Values in bold indicate significant differences at the 95% level of significance (p<0.05).

Year	Site location	TON (mg l^{-1})	NH_4N (mg l^{-1})	BOD (ATU) (mg l^{-1})	ALK (mg l^{-1} as $CaCO_3$)	HARD (mg l^{-1} as $CaCO_3$)	pH	SOLIDS (mg l^{-1})
1977	Upstream	7.4	0.01	1.0	-	-	8.14	13.8
	Downstream	6.9	0.04	1.0	-	-	8.20	12.8
	Probability	0.686	0.133	0.561			0.060	0.954
1978	Upstream	7.4	0.05	1.5	185	258	8.06	14.0
	Downstream	7.9	0.06	1.3	188	292	8.10	7.8
	Probability	0.805	0.536	0.167	0.432	**0.002**	0.157	0.237
1979	Upstream	8.1	0.01	1.4	182	270	8.13	29.5
	Downstream	8.1	0.05	1.5	189	291	8.14	26.8
	Probability	0.827	0.098	0.367	0.092	**0.039**	0.342	0.860