Environment Agency

Evidence

Variability components for macrophyte communities in rivers: 2008 survey

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Integrated catchment science programme

Evidence Directorate

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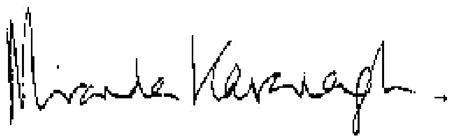

Miranda Kavanagh

Director of Evidence

Executive summary

The Water Framework Directive requires sources of uncertainty in the monitoring programmes of Member States to be quantified. Specifically, estimates of the level of confidence and precision of the results provided by the monitoring programmes must be stated in the river basin management plan, and will be used to guide the development of cost-effective programmes of measures. For riverine macrophytes - water plants visible to the naked eye, this requires a quantitative understanding of how macrophyte communities vary in space and time, as well as an estimate of the magnitude of measurement error.

The aim of this project was to improve our understanding of the components of variation in riverine macrophyte communities to help refine survey methods and sampling strategies used by UK environmental protection and conservation agencies. The objectives were to examine and quantify three sources of variability: (i) spatial variability; (ii) temporal (among-month) variability; and (iii) measurement error (operator variability). The analysis focused on four community indicators – Ecological Quality Ratio (EQR), River Macrophyte Nutrient Index (RMNI), number of taxa (NTAXA) and total percentage cover (%Cover). The project built upon earlier work by analysing a UK-wide dataset of surveys conducted in summer 2008.

Results

1. Measures of ecological status such as EQR, and measures of community composition such as RMNI, show less variability than 'absolute' indicators such as NTAXA and %Cover.

2. For all four indicators, variation appears to be driven predominantly by larger scale spatial variation among rivers and among reaches.

3. Variation among 100-m sites in a reach is low relative to the variation among reaches.

4. Monthly variation is typically very low.

5. Operator variability is a considerable source of variation for all four indicators, accounting for between four and 38 per cent of total variation in the data examined.

6. Operator variability is most important for NTAXA, which suggests that missing and misidentification of taxa can be an important source of error, and also high for %Cover, which may reflect the fact that this indicator is not routinely recorded in LEAFPACS surveys. Operator variability is least important for EQR and RMNI, which suggests these metrics are less sensitive to inaccurate survey data.

7. Operator variability is consistently larger than among-site variation by at least a factor of two, and in some cases comparable with among-reach variation. This means that assessments of ecological status as a water body level may be prone to a higher degree of uncertainty.

8. It is unclear whether teams of operators produce less variable results than lone operators.

9. The number of taxa recorded increases with survey length, but at a diminishing rate. The number of taxa found in a five x 100-m LEAFPACS surveys is, on average, 87 per cent higher than the number of taxa found in a one x 100-m survey. In other words, a 100-m survey on average yields 47

per cent fewer taxa than a 500-m survey. However, a 100-m survey can be sufficient to judge the relative level of taxonomic diversity in a 500-m reach.

10. RMNI scores from 100-m surveys are unbiased, but less precise than scores from longer surveys. One x 100-m survey can estimate the RMNI of a 500-m reach with a precision of ±17 per cent.

11. Comparison of the number of taxa recorded using one x 500-m JNCC survey and five x 100-m LEAFPACS surveys showed that neither method consistently recorded more taxa than the other. However, the two methods are not directly comparable because of the differences between the taxa lists used.

Conclusions and recommendations

1. Low among-site variation means that a single 100-m survey will often be representative of the conditions within a 500-m reach.
2. Significant among-reach variation means that replicate surveys in different reaches will be required to characterise the whole river (or water body).
3. Low among-month variation means that surveying in a single month each year should be sufficient to represent conditions within the river.
4. Relatively high operator variability indicates that there is scope for greater consistency in identification of taxa and recording of plant cover.
5. Further research should be undertaken to test whether measurement error is reduced when operators work in teams.

Contents

1 Introduction

In the UK, statutory agencies are required to survey river macrophyte[1] communities for several reasons. The environmental protection agencies – Environment Agency in England and Wales and Scottish Environment Protection Agency (SEPA) in Scotland – monitor macrophytes for the Urban Waste Water Treatment Directive (UWWTD) and the Water Framework Directive (WFD). The conservation agencies – Countryside Council for Wales (CCW), Natural England and Scottish Natural Heritage (SNH) – survey and monitor river macrophyte communities as part of their work to select, designate and assess the condition of rivers of conservation importance in their duties under the Wildlife and Countryside Act 1981 and the Habitats Directive. Future monitoring needs are likely to be driven mainly by the Habitats Directive and WFD.

Macrophyte communities vary spatially and temporally. Good understanding of these sources of variability is required to optimise macrophyte survey methods and sampling strategies used by UK environmental protection and conservation agencies. The WFD requires sources of uncertainty in the monitoring programmes of Member States to be quantified. Specifically, estimates of the level of confidence and precision of the results provided by the monitoring programmes must be stated in the river basin management plan, and will be used to guide the development of cost-effective programmes of measures. This requires an understanding of how macrophyte communities vary in space and time, as well as an estimate of the magnitude of measurement error. In addition, UK conservation agencies need to understand variability of macrophyte communities and the uncertainty of resulting metrics, in order to refine guidance on common standards monitoring of SSSI and SAC rivers. In particular, there is a need to establish the minimum survey length required to gauge the conservation status of a river. Ultimately, there is a desire to move towards a common survey method for macrophyte monitoring across the UK.

In response to these issues, UK environmental protection and conservation agencies have formed a project steering group (PSG) to investigate variability and uncertainty in river macrophyte communities. A previous project (Davey *et al*., 2008) examined a dataset composed of historical survey data and produced preliminary estimates of spatial and temporal variability in macrophyte communities. However, it was not possible to quantify small-scale ‘local’ spatial variability, within-year and operator variability because the historical data had not been collected in way that allowed all sources of variation to be partitioned and enumerated separately.

Both Davey *et al*. (2008) and an earlier review of macrophyte variability studies (Pentecost 2008) identified the need for a dedicated and properly designed hierarchical study with good replication to tease apart spatial and temporal variability and measurement error. In response to this need, a co-ordinated macrophyte survey programme was organised by the PSG and carried out by the various agencies over the summer of 2008. This sampling exercise was designed to obtain representative survey data from across the UK using a standard survey method and reporting approach (LEAFPACS), to quantify the following sources of variability in river macrophyte communities:

1. Spatial variability (variability among rivers, among reaches and among sites).
2. Temporal variability (variability among months).
3. Measurement error (inter-operator and within-operator variability).

[1] Macrophytes are larger plants of freshwater which are easily seen with the naked eye, including all aquatic vascular plants, bryophytes, stoneworts (Characeae) and macro-algal growths.

This report describes the outcome of this project and considers four indicators of macrophyte community status:

1. Ecological Quality Ratio (EQR).
2. River Macrophyte Nutrient Index (RMNI).
3. Total percentage cover.
4. Number of aquatic taxa.

The remainder of this report is divided into five sections. Section 2 provides background information on the various components of variation and their relevance to ecological assessment; Section 3 describes the datasets used in this study; Section 4 details the approach taken in the statistical analysis of the data; Section 5 presents the results of the analyses; and Section 6 discusses the implications of the results for future macrophyte monitoring strategy.

2 Background

2.1 Components of variation

Any environmental metric is subject to four broadly different types of variation:

1. *Spatial variation* – at any given point in time, macrophyte communities vary from place to place, and this spatial variation can be considered at a number of hierarchical scales. The spatial scales considered in this project are river, reach and site.

2. *Temporal variation* – at any given point in space, the macrophyte community will change over time. This project considers the variability arising from different months within a single year.

3. *Spatial-temporal interaction* – whereby a temporal effect operates differently in some locations than others. Temporal variation may be greater at some locations within a river than others. It can be distinguished from measurement error only if replicate surveys are undertaken at a number of locations on a number of occasions.

4. *Measurement error* – relates not to actual variation in the macrophyte community itself, but to variation generated by the measurement process. Measurement error is the difference between the true metric value and that recorded on a particular sampling occasion. It comprises both inter-operator variability, whereby different operators may produce different results for the same survey, and within-operator variability, whereby the same operator may produce different results when repeating the exact same survey.

2.2 Definitions of spatial variation

This study considers spatial variation at three hierarchical scales (Figure 2.1). An individual *river* can be split into a number of *reaches*. Each reach is divided into a number of adjacent *sites*, which are specific locations where a survey is carried out. At any one site, a number of individual *survey events* may be conducted over time or by different operators. Variation within a river can therefore be split into variation among reaches within a river and variation among sites within a reach ('local' spatial variation).

These definitions differ from those used in the previous project (Davey *et al*., 2008) since the structure of the data has altered. In the previous project, a *reach* was defined as a three-km long stretch of a water body containing two or more surveys at different sites. Therefore, sites within a reach were located at varying distances from one another (between 100-m and 3-km), making it difficult to interpret the meaning of among-site variation.

This project makes a clearer and more consistent distinction between reaches and sites. For the LEAFPACS surveys, a reach is typically 500-m in length and split into five adjacent 100-m sites. The exception is the data provided by Natural England, where only a single 100-m site was surveyed in each 500-m reach, making it impossible to distinguish among-reach variation from among-site variation.

For the JNCC (Joint Nature Conservation Committee) surveys, each 500-m reach is recorded as a single survey so it is only possible to measure variation at a 500-m scale.

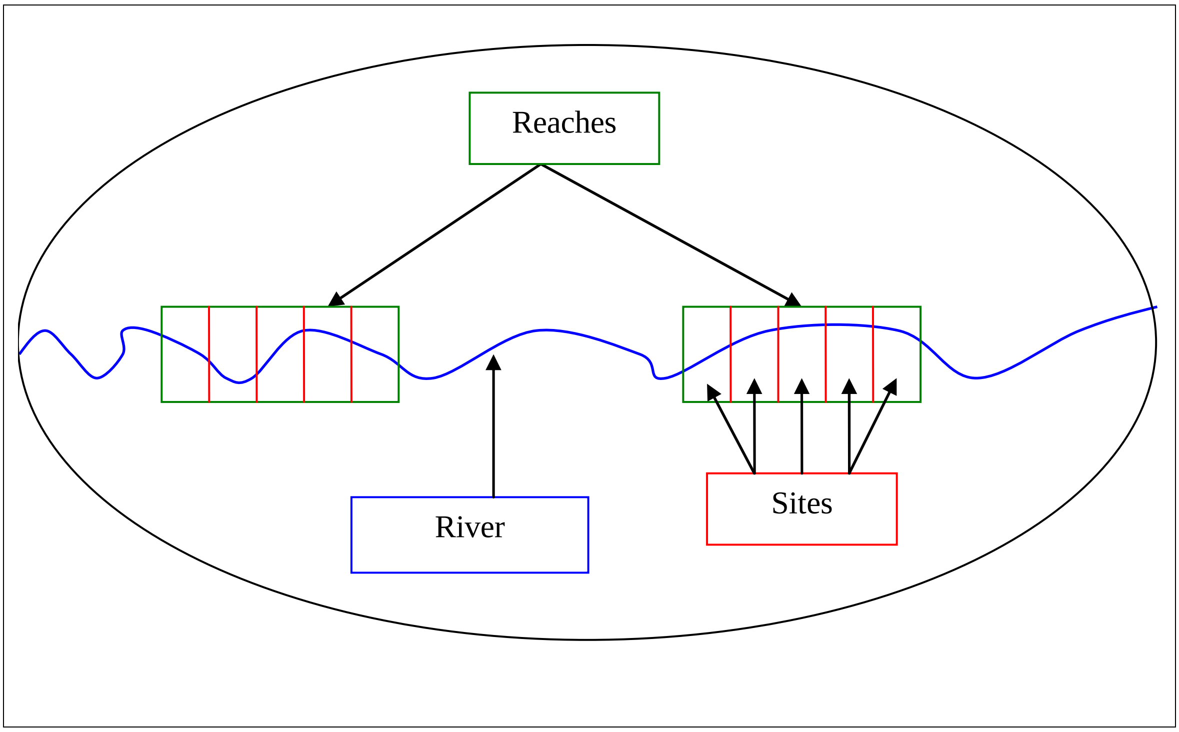

Figure 2.1 Spatial hierarchy of data.

2.3 Relevance to ecological assessment

The four components of variation listed in Section 2.1 combine to produce variation in the environmental metric being measured, which in turn leads to uncertainty in the assessment of ecological status.

The relative magnitudes of the components of variation determine how sampling effort should be deployed to give the best possible ecological assessment. For example, if macrophyte communities varied greatly from month to month, it would be important to conduct surveys in different months to quantify and average out within-year temporal variability. Similarly, if macrophyte communities varied greatly from reach to reach within a river, it would be necessary to conduct surveys at a number of reaches to quantify and average out spatial variability among reaches.

3 Data

3.1 Data sources

The dataset used in this project was composed of surveys carried out throughout the summer and autumn of 2008 by the Environment Agency, Scottish Environment Protection Agency, Countryside Council for Wales and Natural England. The four separate datasets were combined into a single dataset for analysis. The analysis dataset, split into JNCC and LEAFPACS surveys, is supplied with this report in MS Excel format.

The majority of surveys were conducted using the LEAFPACS methodology (Willby, 2006) to ensure data from different agencies were comparable. LEAFPACS surveys yielded four indicators for analysis:

1. Ecological Quality Ratio (EQR).
2. River Macrophyte Nutrient Index (RMNI).
3. Total percentage cover (%Cover).
4. Number of aquatic taxa (NTAXA).

Total percentage cover is recorded directly by the operator during the survey.

NTAXA and RMNI are sub-metrics calculated from the survey data. NTAXA is simply the number of non-helophyte taxa listed in LEAFPACS that are recorded in the survey. RMNI is determined from the taxa found in the river. Each taxon on the survey list has a nutrient index score. The associated RMNI for the survey site is calculated using the equation:

$$RMNI = \frac{\sum_{j=1}^{n}\left(C_j \times R_j\right)}{\sum_{j=1}^{n} C_j}$$

where:

RMNI = River Macrophyte Nutrient Index value for survey site.

R_j = River macrophyte nutrient index score for the j^{th} taxon.

C_j = Cover value for the j^{th} taxon, measured on a scale of 1 to 9.

n = number of LEAFPACS taxa observed in survey site.

EQR is a summary metric that combines the four separate sub-metrics: NTAXA, RMNI, River Macrophyte Hydraulic Index (RMHI) and the number of functional groups of macrophyte taxa which are not helophytes (NFG). Each observed sub-metric score is divided by an expected score, which uses measured local physical and chemical conditions to predict the macrophyte community under minimally impacted reference conditions. The sub-metric EQRs are then combined to give an overall EQR between zero and one, with high ecological status represented by values close to one and bad ecological status by values close to zero. The EQR scale is divided into five classes ranging from high to bad ecological status.

In addition, a smaller number of surveys were conducted using the JNCC methodology (JNCC 2005), which surveys a single stretch of 500-m.

3.2 Data structure

Tables summarising the datasets used in this analysis can be found in Appendix A.

3.2.1 EA data

The Environment Agency conducted a total of 79 LEAFPACS surveys during July and August 2008 on five rivers (Dee, Erewash, Tern, Welland and Eden). Replicate 500-m reaches were surveyed in each river. Each 500-m reach was split into five contiguous 100-m sites. The exception to this was the Ingheads reach on the River Eden, which had only four 100-m sites.

Most sites were surveyed once by a team of two operators. However, one reach, Coldhatton on the River Tern, was surveyed by two different teams of operators. Although these surveys were conducted about a week apart, it is expected that the temporal variability between surveys was small enough to allow some study of inter-operator variability to be made for this reach.

All four indicators were recorded for each survey, with the exception of a single survey conducted on the Eden river, for which %Cover was not recorded.

3.2.2 SEPA data

SEPA conducted a total of 64 LEAFPACS surveys during August and September 2008 on five rivers (Leader Water, Shiel, Stinchar, Teith and White Cart). Replicate 500-m reaches were surveyed in each river. Each 500m reach was split into five contiguous 100-m sites. Most sites were surveyed once by a team of two operators.

The exception to this was the River White Cart, where a single 100-m site in a single 500-m reach was surveyed in four different months between June and October 2008.

EQR, RMNI and NTAXA were recorded for each survey, but %Cover values were not recorded for the SEPA data.

3.2.3 CCW data

CCW conducted a total of 88 LEAFPACS surveys between July and September 2008 on a single river, the River Dee. Six replicate 500-m reaches were surveyed, with each reach split into five contiguous 100-m sites. All surveys were conducted by a lone operator.

Each site was surveyed twice – once in July and once in September; the same operator performed both the June and September surveys. In addition, Reaches 1 and 4 were surveyed by different operators in July over the period of a week. It is expected that any temporal variability between these surveys was small enough to allow some study of inter-operator variability to be made for these two reaches.

All four indicators were recorded for each survey, except in September when %Cover was not recorded.

At one reach on the Dee, both CCW and the Environment Agency performed surveys. This is referred to as the Rhewl reach in the Environment Agency data and Reach 4 in the CCW data. Surveys at this reach were given the same reach and site references.

CCW also conducted 18 JNCC surveys. These surveys were conducted at the same reaches as the LEAFPACS surveys, by the same surveyors, in the same months and within a week of the LEAFPACS surveys, allowing a comparison between the two methods to be made.

3.2.4 NE data

Natural England conducted a total of 28 LEAFPACS surveys during August and September 2008 on six rivers (Avon, Bourne, Dochens, Nadder, Till and Wylye). A number of replicate reaches were surveyed on each river, but a single 100-m site was surveyed in each reach. Each site was surveyed by a lone operator.

All four indicators were recorded for each survey.

Natural England also conducted 28 JNCC surveys. These surveys were conducted at the same sites as the LEAFPACS surveys. Most of the JNCC surveys also had matching operators and dates with the LEAFPACS surveys. However, two surveys were performed at different times, one in a different month, and a single reach was surveyed by a different operator using the JNCC method.

4 Methodology

4.1 Summary statistics

The overall level of variability in each indicator was quantified by computing its relative standard deviation (RSD = standard deviation/mean) across all surveys.

4.2 Analysis of variance components

Restricted Maximum Likelihood (REML) models[2] were used to partition the variation in the LEAFPACS survey data into its component parts. Specifically, REML models calculate the level of variation each component contributes to the overall variation in the dataset. This allows the relative importance of each component to be assessed.

The variation in the data was represented as a series of four hierarchical levels: (i) among rivers, (ii) among reaches within a river, (iii) among sites within a reach, and (iv) among months at a given site (Table 4.1). Because the dataset was collected in 2008 only, it was not possible to measure variation among years (inter-annual variation).

The remaining 'residual' variation is the variation among replicate surveys of the same site undertaken by different operators. This comprises inter-operator variability and intra-operator variability (true measurement error – variation among replicate surveys undertaken by the same operator at the same site on the same day). It was not possible to distinguish between inter- and intra-operator variability because no sites were repeatedly surveyed by the same operator on the same day.

Table 4.1 Components of variation.

Component	Definition
River	Variation among rivers
Reach	Variation among replicate 500-m reaches in a river
Site	Variation among replicate 100-m sites in a reach ('local' spatial variability)
Month	Variation among months at a given site
Residual	(Within-month variation) + inter-operator variability + intra-operator variability

Interpretation of the residual variation is complicated by the fact that replicate surveys of the same site undertaken by different operators were sometimes conducted a week or more apart. This means that the residual term includes some among-day (within-month) variation. For example, differences in flow between the two survey events may affect the ability of the operators to identify species and assess their coverage, which would lead to additional variation in the survey results. However, two lines of evidence suggest that within-month variation contributes very little to the residual variation.

[2] REML models can be thought of as analysis of variance (ANOVA) models that can deal with unbalanced data (datasets that have unequal numbers of observations at various points in space and time).

First, the REML results showed generally very low among-month variation in macrophyte indicators (Section 5.2), so it is likely that within-month variation is even smaller.

Second, flow data from the River Dee (where the effect of inter-operator variability can be best examined) was examined to see whether flow changed much around the time that replicate surveys were undertaken. The location of the two flow gauges and the survey reaches are shown in Figure 4.1.

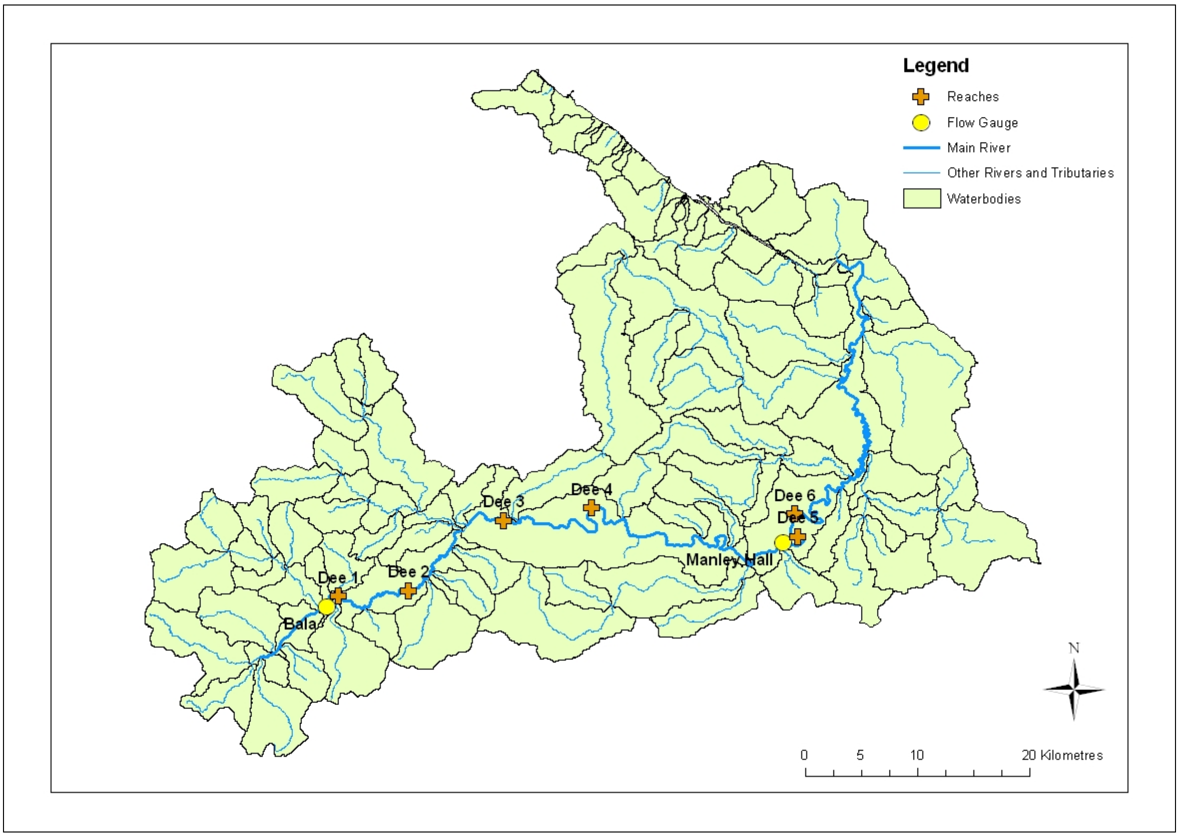

Figure 4.1 Locations of flow gauges and survey reaches on Dee.

There is a system of flow regulation in operation on the Dee, with sluice gates upstream of the surveyed areas used to control water levels; this produces a more stable flow regime than is usual for similar rivers. Figure 4.2 shows that flows were relatively stable around the time of the surveys in July, with the exception of a noticeable rise and fall in the measured flow between the surveys on 18/07/2009 and 23/07/2009. All but two of the surveys on the 23 July 2009 were performed by operator D. The surveys carried out by this operator were compared to those of the operators and do not show an obvious deviation from the other operators (see Section 5.3 for details). Therefore, it is believed that variability arising from flow levels will have no noticeable impact upon the residual component of variability. The lines in the chart are not complete because flow data was only recorded for the weeks in which surveying occurred. The surveys in September were all performed by operator A, thus the more variable flow levels in this month will not affect the residual component of variability. The days on which surveys were performed are shown by arrows.

For these reasons, the residual component from the REML models is interpreted as mainly representing operator variability, although there may be some slight impact from short-term environmental changes.

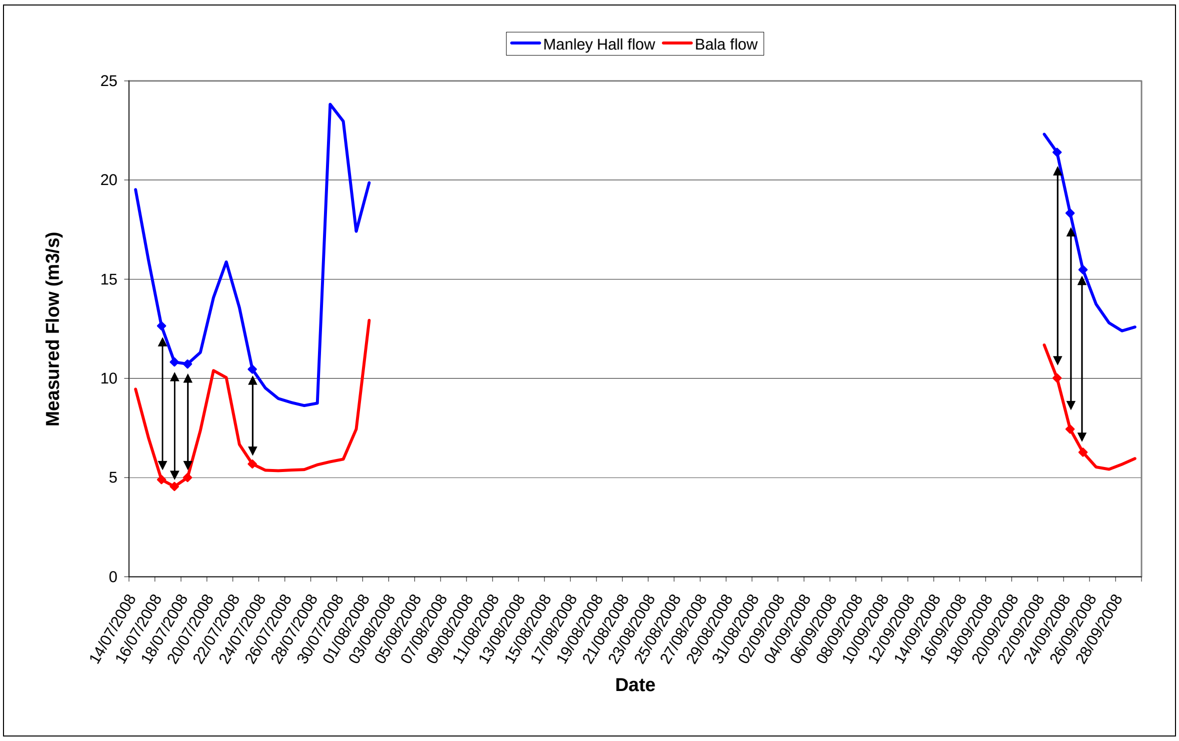

Figure 4.2 Flow data for surveying days on the river Dee.

In addition to the components listed in Table 4.1, organisation was considered as a possible term in the model, representing large-scale regional variation among rivers. However, initial modelling showed that this term was not a significant source of variation and so it was not included in the REML models.

Separate REML models were run for each of the four indicators: EQR, RMNI, NTAXA and %Cover. Unlike the other datasets, the Natural England surveys only had a single site in each reach. For this reason, consideration was given to removing these surveys from the dataset for modelling. Initial modelling, however, showed that the inclusion of this data did not affect the stability of the models or their results so these data were retained.

All the LEAFPACS surveys from SEPA and LEAFPACS surveys carried out by CCW in September lacked %Cover so these data could not be included in the analyses of this indicator. Since these two datasets contained the surveys conducted at the same site in different months, this meant that among-month variation in %Cover could not be quantified.

4.3 Inter-operator comparison

The REML analyses were supplemented by detailed graphical investigation of inter-operator variation in the LEAFPACS surveys. Further investigations were done for the JNCC data at two sites on the River Dee.

Following discussion of the initial results from the inter-operator analysis with the PSG, we set out to improve our understanding of the effect of inter-operator variability on measures of macrophyte community composition, over and above those of EQR, NTAXA and %Cover. The use of a measure that included species abundance was agreed upon. A further analysis was conducted using the squared chord distance (SCD) dissimilarity measure. The SCD is calculated using the following equation:

$$d_{ij} = \sum_{k=1}^{m} \left(\sqrt{p_{ik}} - \sqrt{p_{jk}} \right)^2$$

where:

d_{ij} = SCD between samples i and j;

m = total number of taxa;

p_{ik} = proportion of k^{th} taxon in sample i;

p_{jk} = proportion of k^{th} taxon in sample j.

The SCD is a signal-to-noise metric that emphasises the pattern (‘signal’) within the data, while reducing the impact of the random variation in taxa abundance (‘noise’). Each LEAFPACS survey records a cover score, on a scale of one to nine, for each taxon instead of an absolute percentage. This prevents the exact proportion of each taxa being ascertained, but an approximation was made by taking the mid-point of each score band to represent the percentage cover. The cover bands and associated cover values are shown in Table 4.2.

Table 4.2 Cover bands and associated percentage cover values.

Cover Band	Percentage Cover Range	Mid-Point
1	<0.1	0.05
2	0.1 < 1	0.55
3	1 < 2.5	1.75
4	2.5 < 5	3.75
5	5 < 10	7.5
6	10 < 25	17.5
7	25 < 50	37.5
8	50 < 75	62.5
9	>=75	87.5

The SCD was calculated for all pairs of surveys conducted by different operators at the same site in the same month.

4.4 Effect of survey length

The LEAFPACS survey data from Environment Agency, CCW and SEPA all have a number of contiguous 100-m sites within each 500-m reach. This allows an analysis of the effect of survey length upon the number of aquatic taxa recorded to be carried out. The first site in each reach was taken as a reference level, then the number of unique taxa found in Sites 1 and 2 combined was determined. This combined survey can be considered as a single survey of length 200-m. Therefore, the number of taxa found in a 200m survey at the associated reach is now known. The same process was conducted for a 300-m (Sites 1 to 3), 400-m (Sites 1 to 4) and 500-m (Sites 1 to 5) survey.

The numbers of taxa found using this method were plotted as a percentage of the number found in 100 m to quantify the increase in taxa found as the length of survey increases.

4.5 Comparison of JNCC and LEAFPACS methods

The one x 500-m JNCC surveys from CCW were compared with the five x100-m LEAFPACS surveys conducted at the same. JNCC surveys were also provided by Natural England but could not be compared to LEAFPACS surveys at the same locations because only a single LEAFPACS survey was conducted at each reach.

5 Results

5.1 Summary statistics

The relative standard deviations (RSDs) of the four indicators are shown in Table 5.1. EQR and RMNI were the least variable and %Cover was the most variable.

Table 5.1 Relative standard deviations of the four indicators.

Indicator	RSD
EQR	0.26
RMNI	0.22
NTAXA	0.49
%Cover	0.86

EQR is expected to show low variability because it is a ratio that takes into account the natural, expected variation in macrophyte communities caused by large-scale physico-chemical factors such as altitude and alkalinity. It also integrates four separate sub-metrics, which will tend to balance out the variation within each sub-metric.

RMNI is an observed indicator that is computed directly from the survey data and does not control for expected conditions, so it is perhaps surprising that it shows less variability than EQR. Unlike NTAXA and %Cover, however, it measures the *composition* of the macrophyte community, and is designed to reflect the nutrient status of the river, which is likely to change relatively little spatially unless there is a large point source input of nutrients or a major tributary.

The high variability of NTAXA and %Cover probably reflects in part the natural spatial and temporal variation in macrophyte communities. But because these indicators provide an *absolute* measure of macrophyte diversity and abundance, respectively, they may be particularly sensitive inter-operator variability. For example, different operators may differ in their ability to identify macrophyte taxa, and some operators use a snorkel and mask, which allows them to gain a clearer view of the bed than is possible using just chest waders. Furthermore, %Cover is not routinely recorded in LEAFPACS surveys, so operators may be less practiced in recording this indicator accurately.

5.2 Analysis of variance components

The components of variance estimated by the REML models are shown in Table 5.2, with the percentage of total variance attributed to each level shown in Table 5.3. Because the SEPA dataset and September surveys from CCW did not record %Cover, among-month variation could not be quantified for this indicator. A negative variance in Table 5.2 means that the variation associated with that component is less than expected given the variation in the components below it; these are assumed to be zero for the purposes of calculating the percentages in Table 5.3. The raw outputs from the modelling can be found in Appendix B.

Table 5.2 Components of variance (variances).

Component of variation	EQR	RMNI	NTAXA	%Cover
River	0.0182	1.849	3.951	450.5
Reach	0.0083	0.196	4.058	289.2
Site	0.0028	0.038	1.595	-209.6
Month	0.0014	0.041	-0.76	NA
Residual	0.0052	0.086	5.937	229.4
Total	**0.0359**	**2.210**	**14.781**	**759.5**

Table 5.3 Components of variation (as % of total).

Component of variation	EQR	RMNI	NTAXA	%Cover
River	50.7	83.6	25.4	46.5
Reach	23.2	8.9	26.1	29.8
Site	7.7	1.7	10.3	0.0
Month	3.9	1.9	0.0	NA
Residual	14.4	3.9	38.2	23.7
Total	**100.0**	**100.0**	**100.0**	**100.0**

The REML models show at least four important results.

First, most of the variation in three of the four indicators is due to variation among rivers. This is perhaps not surprising given the wide geographic spread of rivers in this study. NTAXA has the lowest percentage variation among rivers at just 25 per cent, which might reflect to some degree the high residual variance (operator variability). By contrast, RMNI has the highest percentage variation among rivers at 84 per cent, which may reflect contrasting levels of eutrophication among rivers.

Second, spatial variation within each river is much greater among reaches than among sites within a reach. This shows that spatial variation increases with the distance between survey locations, as might be expected. This means that replicate surveys in separate reaches will give a better assessment of ecological status than the same number of replicate surveys undertaken in the same reach.

Third, all four indicators show very low variation among months. This suggests that surveying a river in a single month is sufficient to represent the macrophyte community. However, the surveys were conducted over a relatively narrow three-month period (July-September), and monthly variation might well be higher among surveys conducted over a longer time period.

Fourth, operator variability (represented by the residual term) is a considerable source of variation for all four indicators. Operator variability is most important for NTAXA (38 per cent), which suggests that missing and misidentification of taxa can be an important source of error, and also quite high for %Cover (24 per cent), which may reflect the fact that this indicator is not routinely recorded in LEAFPACS surveys. Operator variability is least important for EQR (14 per cent) and RMNI (four per cent), which suggests these metrics are less sensitive to inaccurate survey data. Interestingly, operator variability is consistently larger than among-site variation by at least a factor of two, and in some cases comparable with among-reach variation. This means that assessments of ecological status as a water body level may be prone to a greater uncertainty.

Causes and consequences of operator variability are discussed further in Section 5.3.

5.3 Inter-operator comparison

The REML modelling identified operator variability as an important source of variation for most of the indicators examined. Therefore the REML analyses were supplemented by detailed graphical investigation of inter-operator variation in the LEAFPACS surveys. Further investigations were also done for the JNCC data at two sites on the River Dee.

The sites that were surveyed by different operators within the same month were studied in detail. The LEAFPACS indicator values for each site determined by the different operators were compared and are shown in Figure 5.1 to Figure 5.4. Each operator or team of operators is shown on these charts (identified by letters A-D for lone operators and numbers 1-2 for two-operator teams).

The results are consistent with those produced by the REML analysis. As already noted in Section 5.2, the inter-operator variability for NTAXA is a significant proportion of total variability in this indicator. This is reinforced by Figure 5.3, which shows large differences in the number of taxa recorded at a site by different operators. This may be due to the misidentification or overlooking of individual taxa.

Although there is a very large difference among operators for total cover at several sites (see Figure 5.4), this arises from consistently higher cover values recorded by a single operator. This operator uses a snorkel and mask, enabling better study of the channel bed. The differences between the other operators at these sites, who do not use snorkels or masks, are much less.

Figure 5.1 to Figure 5.4 show that, in general, the results produced by teams of two operators (number 1-2) were less variable than the results produced by lone operators (A-D). This could mean that operators working as a team produce less inter-operator variability (perhaps through conferring) than lone operators. However, the differences could also be explained by the fact that the lone operators worked in the River Tern, which is a smaller river than the Dee, and were Environment Agency staff rather than contractors. It is therefore not possible without further study to conclude that teams of operators produce more consistent results than lone operators. A key to the labels used to identify surveyors in the following figures is shown in Table 5.4.

Table 5.4 Key to operator labels.

Label	Definition
A	Operator ‘A’, individual surveyor for CCW
B	Operator ‘B’, individual surveyor for CCW
C	Operator ‘C’, individual surveyor for CCW
D	Operator ‘D’, individual surveyor for CCW
1	Operator team ‘1’, pair of surveyors for EA
2	Operator team ‘2’, pair of surveyors for EA

At one reach (Reach 4 on the River Dee), surveys were carried out within the same month by two different organisations (CCW and Environment Agency). Although the site grid references are slightly different it is believed that the sites are the same. Therefore this reach has four different operators from CCW and a single team of operators from the Environment Agency shown on the charts. In general, the results produced by the two organisations were similar, suggesting that the LEAFPACS sampling protocol is being used in a consistent manner.

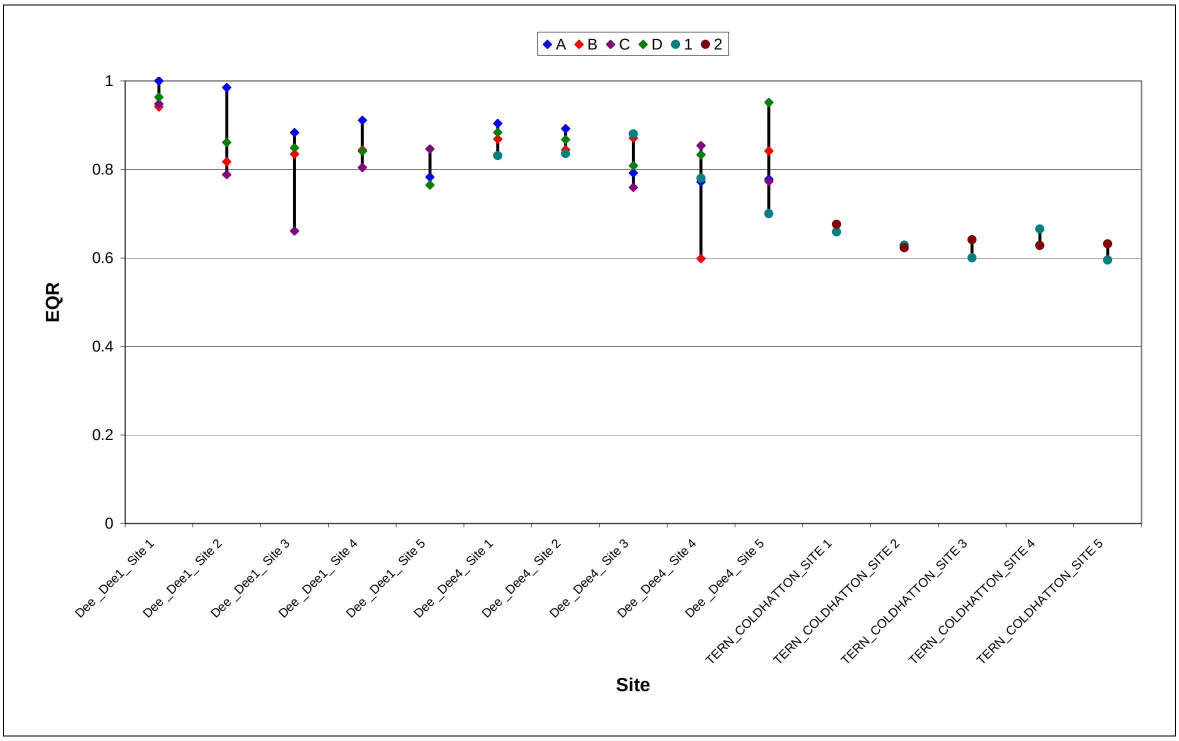

Figure 5.1 EQR results recorded by different operators at the same site in the same month.

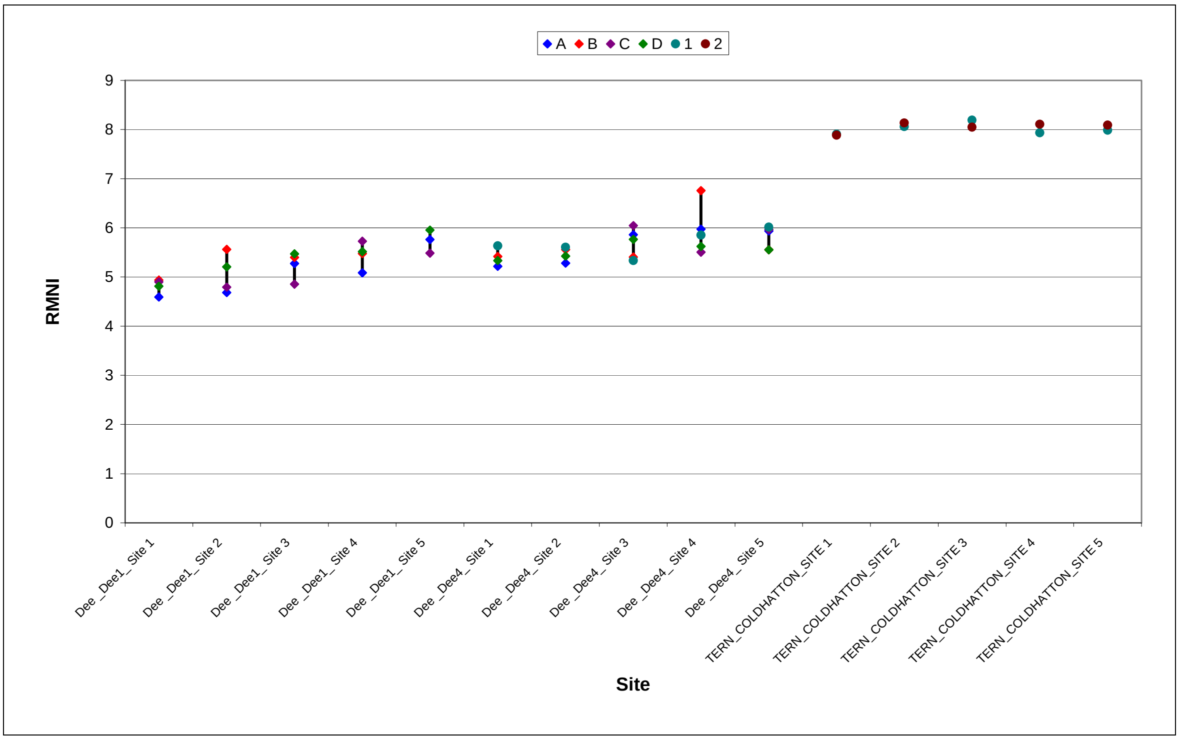

Figure 5.2 RMNI results recorded by different operators at the same site in the same month.

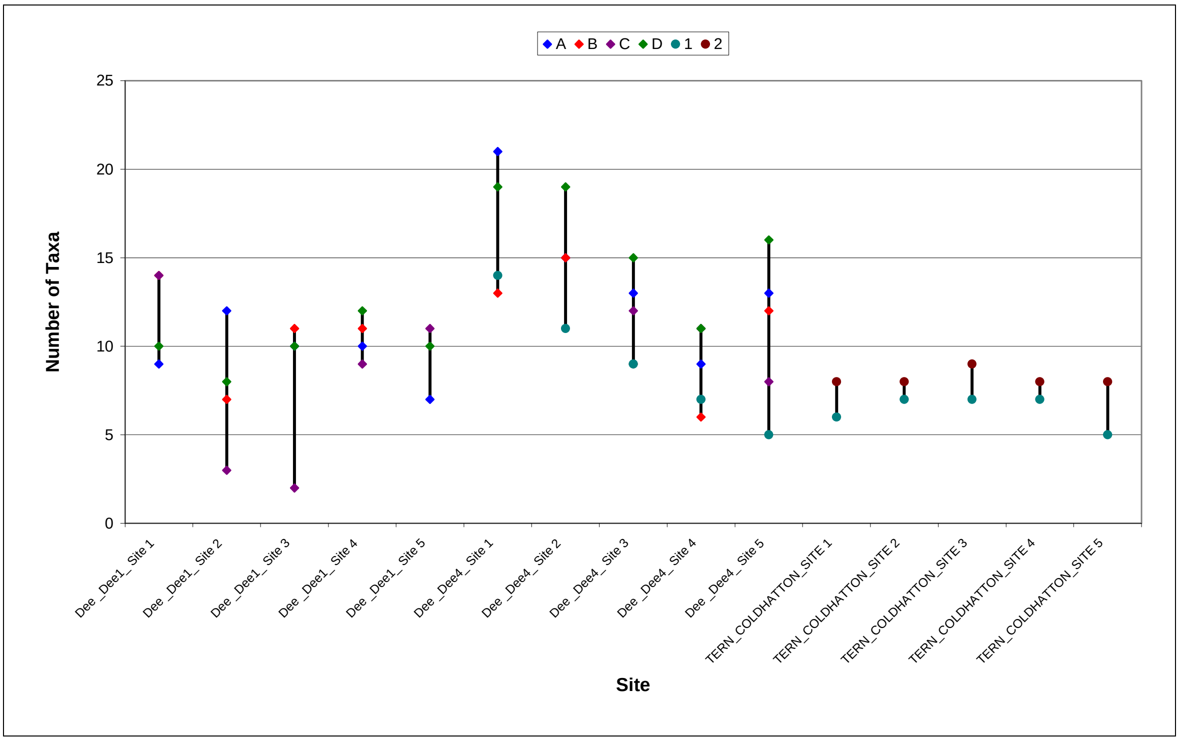

Figure 5.3 NTAXA results recorded by different operators at the same site in the same month.

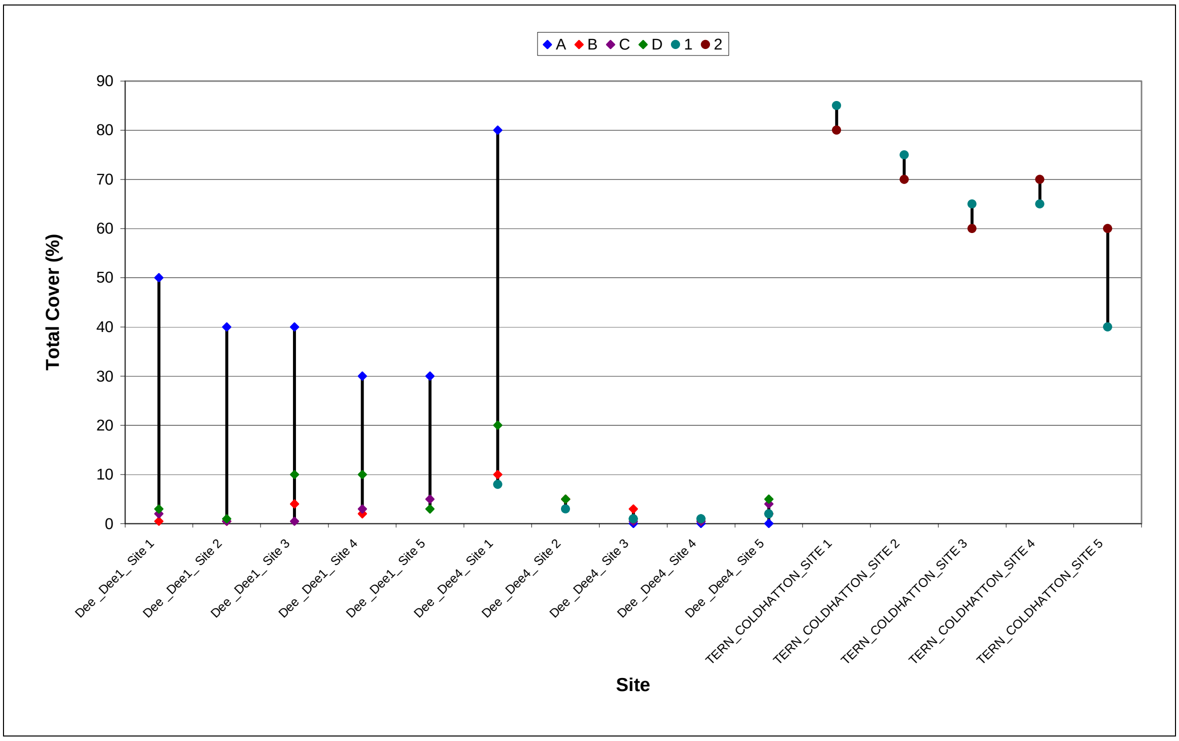

Figure 5.4 %Cover results recorded by different operators at the same site in the same month.

Figure 5.5 shows the relative standard deviations (RSDs = standard deviation divided by the mean) of the LEAFPACS results at each of the sites on the River Dee. %Cover is shown both with and without the inclusion of operator A, who appears to record very different values to the other operators. The surveys carried out on the River Tern are not shown because there were only two comparable surveys at each site.

Figure 5.5 confirms the REML results that EQR and RMNI have a lower level of inter-operator variability than NTAXA and %Cover.

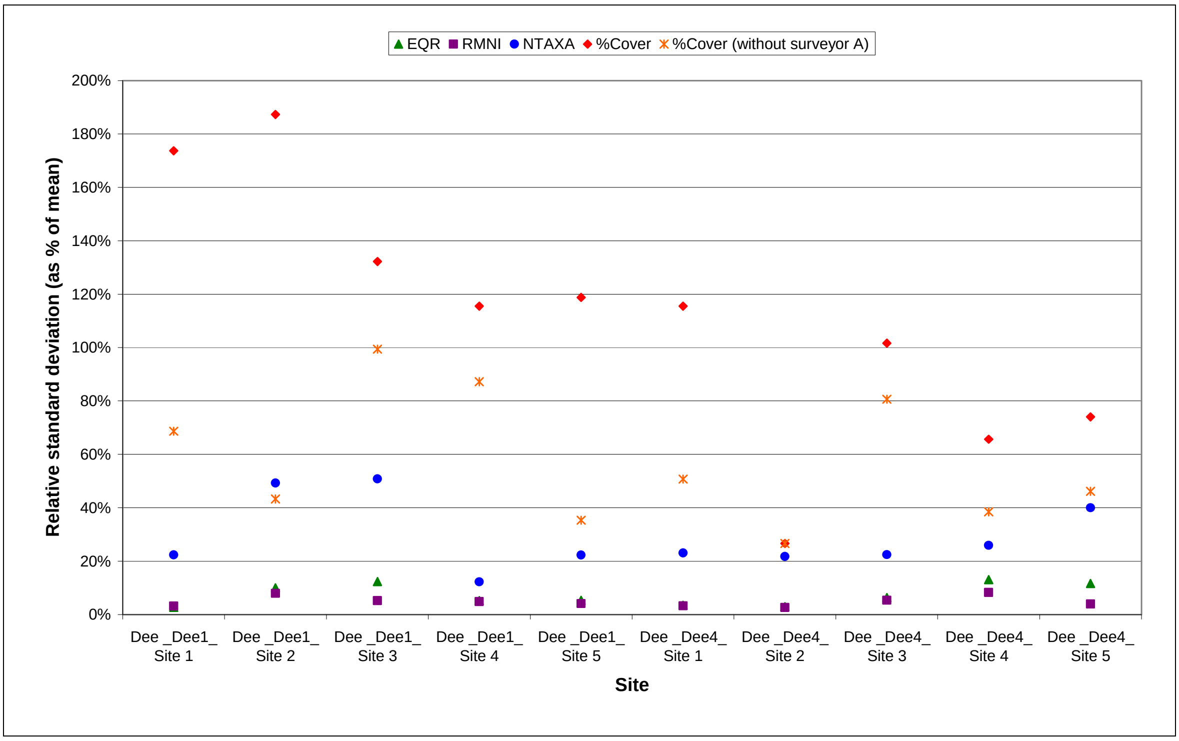

Figure 5.5 Relative standard deviation of results from surveys by different operators at individual sites in the same month.

Figure 5.6 shows the same analysis conducted for the JNCC data. The sites used in the JNCC analysis are equivalent to the 500-m reaches from the LEAFPACS dataset. The number of taxa found is very similar for one of the sites, but quite different for the other. There are no other sites where more than one operator carried out surveying. Without other indicators to consider for this data, no further analyses can be conducted using the JNCC surveys.

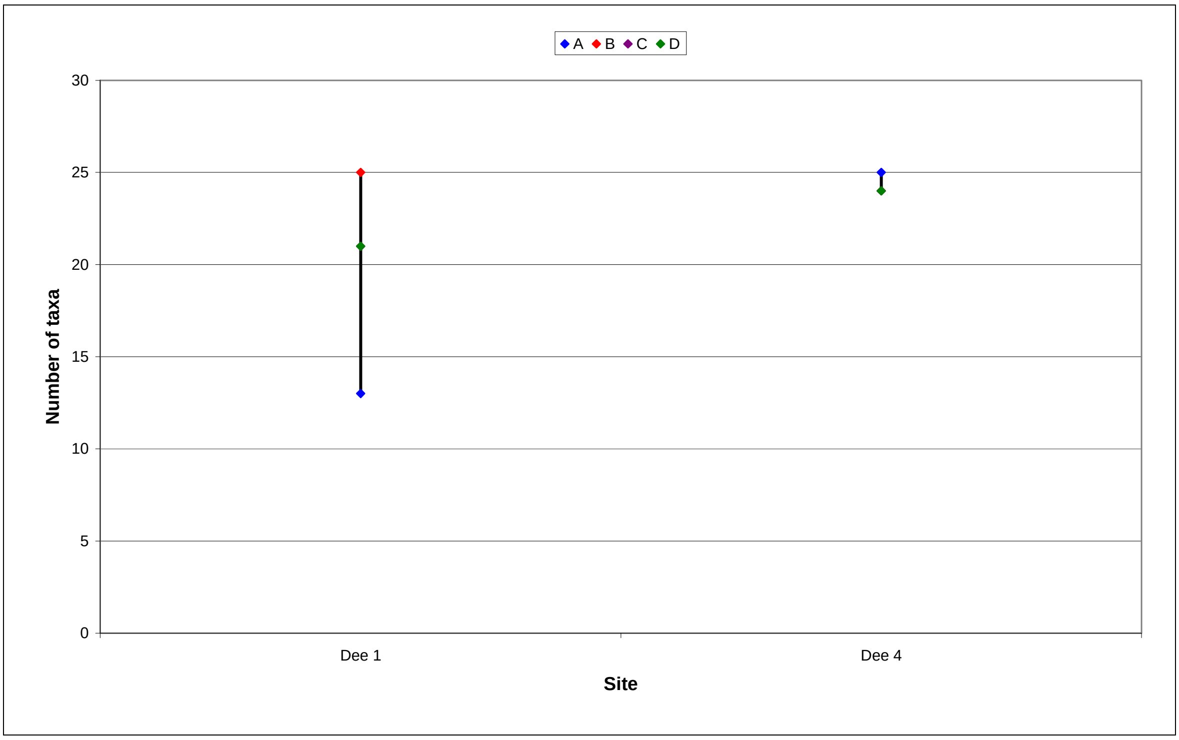

Figure 5.6 Number of taxa recorded by different operators at individual survey sites within the same month (JNCC surveys).

An analysis of the squared chord distance (SCD) for pairs of surveys conducted by different operators at the same site in the same month was undertaken. Figure 5.7 shows the SCD values for all possible pairs of surveys at the identified sites. Larger values indicate a higher level of dissimilarity between the results.

Figure 5.7 shows there is a wide variation in the SCD values obtained at individual sites with large values observed at several sites, suggesting that the identified taxa and their abundance varies from operator to operator. Inter-operator variability would appear to be quite significant based upon this analysis.

In general, values for the surveys on the Dee are higher than those found on the Tern. This suggests that results from two teams of two operators are likely to be more similar than those of two lone operators. However, this could also result from differences among the rivers.

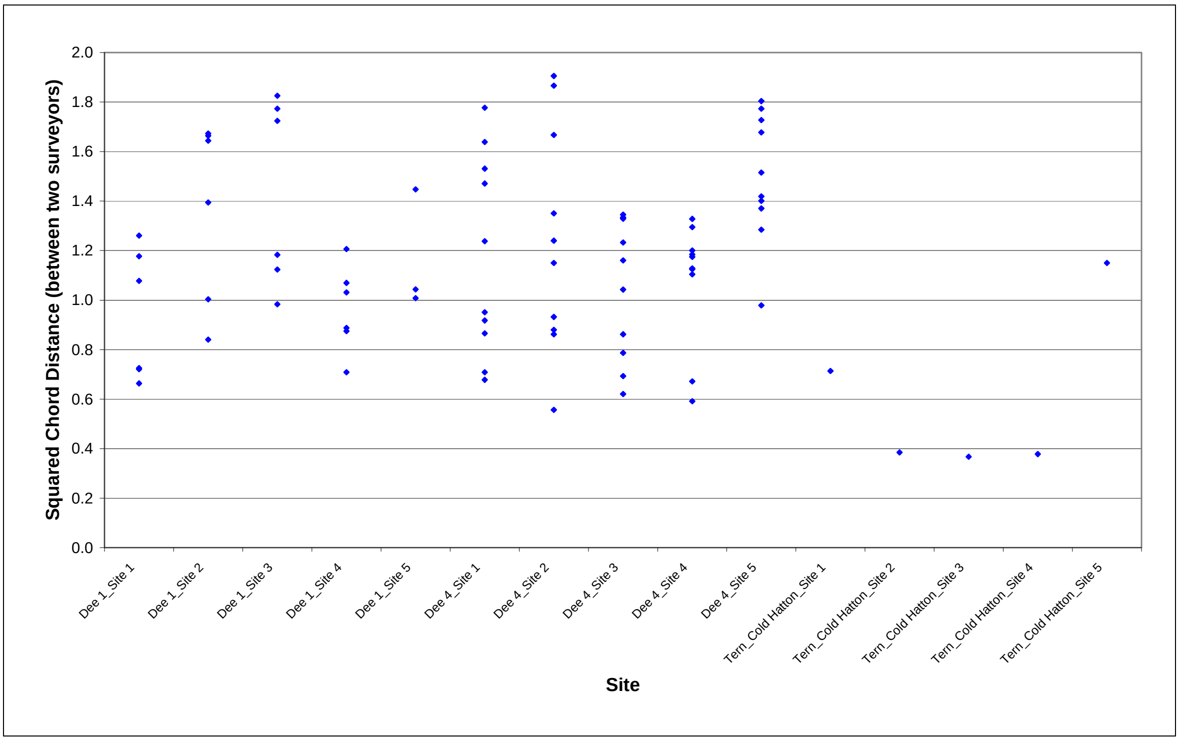

Figure 5.7 Squared chord distances for surveys conducted by different operators.

The high SCD values observed at most sites on the River Dee do not appear to depend on any single operator, such as might arise from different methods of surveying, as can be seen in Figure 5.8. This chart shows the maximum, minimum, median and quartiles of the SCD values between each pair of operators. It shows that high SCD values can be found for nearly every pair of operators. As noted above, the lowest SCD values observed are between the two pairs of operators (1 and 2 in the chart).

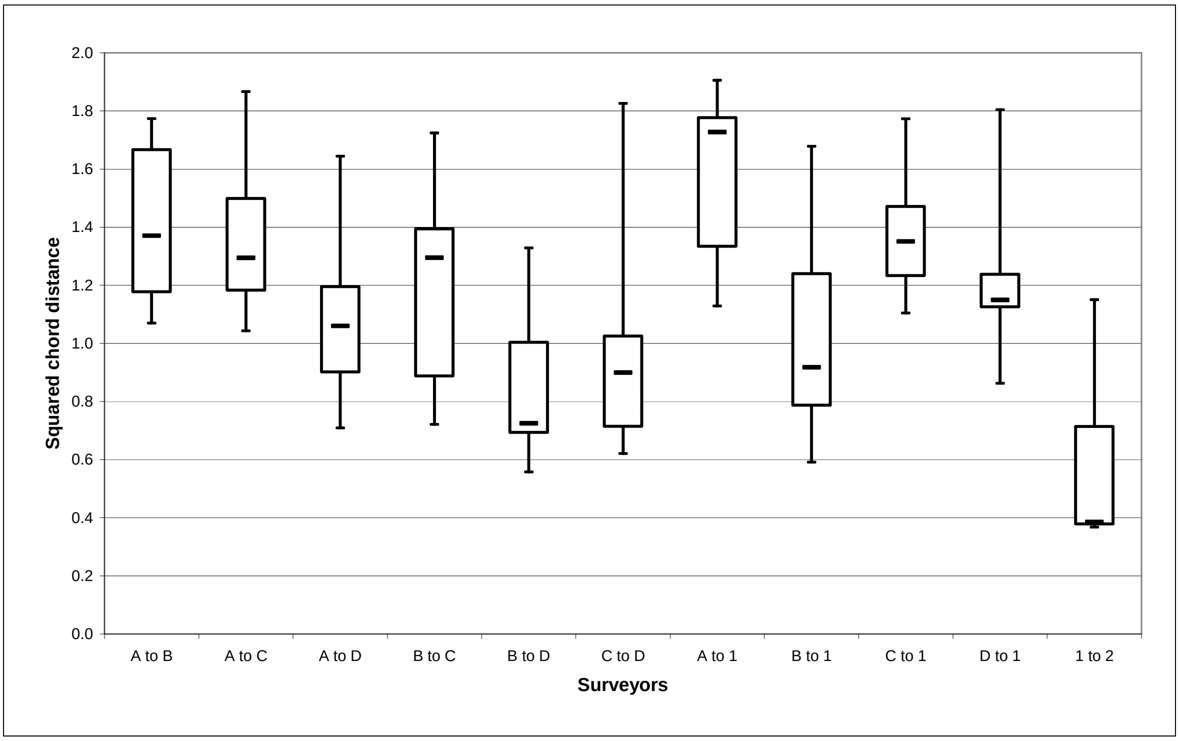

Figure 5.8 Box plot of squared chord distance between operators.

5.4 Effect of survey length

The standard survey length for a LEAFPACS survey is 100 m. The surveying programme carried out by the Environment Agency, CCW and SEPA involved several contiguous five x 100-m surveys at various reaches within a river. Therefore, two adjacent 100-m surveys can be considered as a single 200-m survey for determining the number of taxa present in the reach.

Figure 5.9 shows the average number of taxa found in surveys of differing lengths, measured as a percentage of the number found in the first 100-m survey. The number of taxa found in a 500-m survey is, on average, 87 per cent higher than the number of taxa found in a 100-m survey. In other words, a 100-m survey on average yields 47 per cent fewer taxa than a 500-m survey.

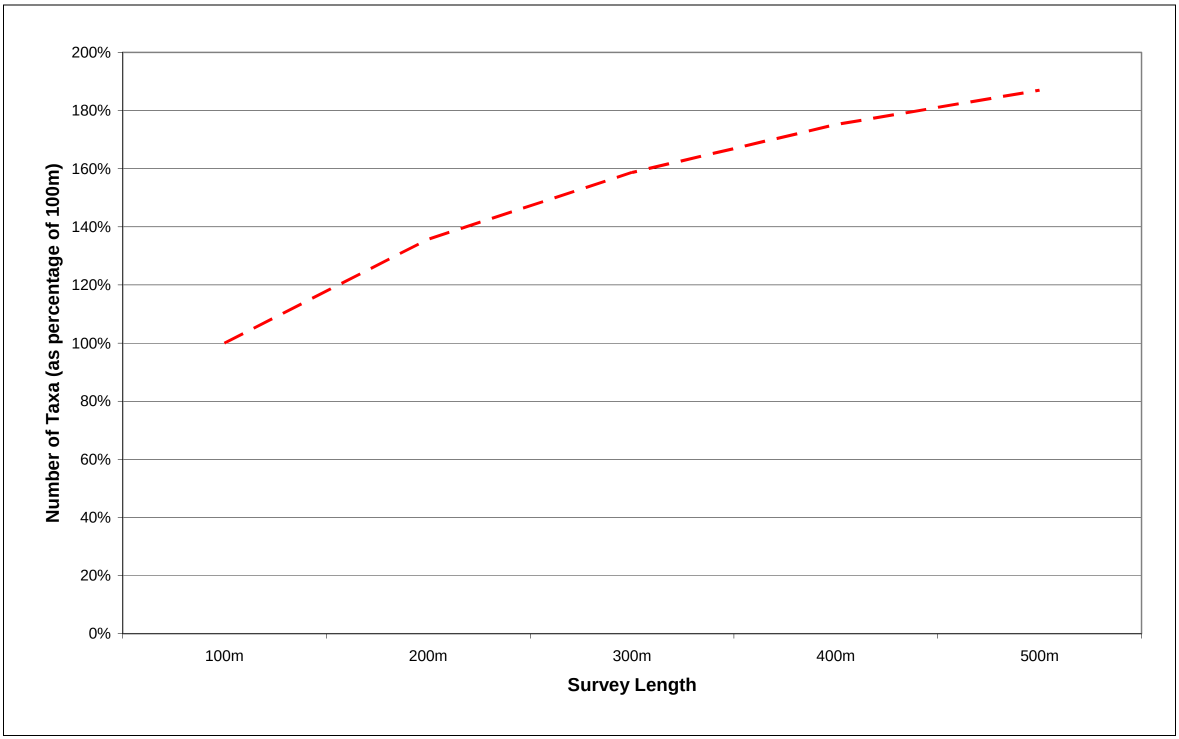

Figure 5.9 Average number of taxa found in LEAFPACS surveys of differing lengths.

Figure 5.9 shows that the number of taxa recorded increases with survey length, but at a diminishing rate. This is to be expected as many taxa will be found in more than one 100-m site. This effect may also be influenced by intra-operator factors. For example, it may prove difficult for an operator to treat each 100-m survey within a reach as completely independent of other surveys in the same reach. Operators may subconsciously search for taxa they have already observed at nearby sites within the reach, or record taxa they do not directly observe because they are sure the taxa must exist within the survey section. It is difficult to quantify the impact of such influences.

Figure 5.10 shows that the increase in the number of taxa found with increasing survey length varies greatly among reaches. However, the relatively small range between the first and third quartiles (represented by the boxes) shows the majority of reaches to have a consistent pattern.

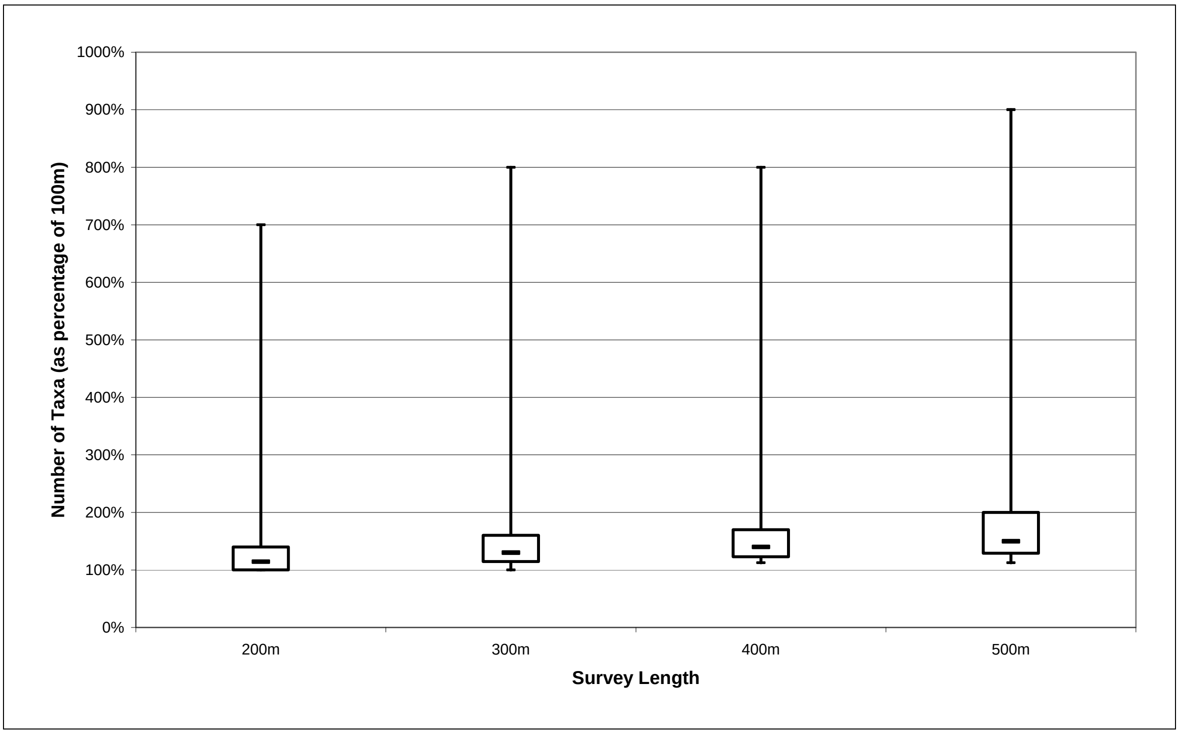

Figure 5.10 Box-plot of number of taxa found in different LEAFPACS survey lengths.

Figure 5.11 shows the NTAXA for 500-m against the NTAXA for 100-m at each site. The trendline has a similar gradient to the line of perfect match between 100-m and 500-m NTAXA, which suggests that a 500-m long survey will on average record five more taxa than a 100-m long survey, regardless of the number of taxa found in the 100-m survey. The relationship is reasonably strong (80 per cent of variation is explained by the trendline), which implies that a 100-m survey is sufficient to gauge the level of taxonomic diversity within a 500-m reach.

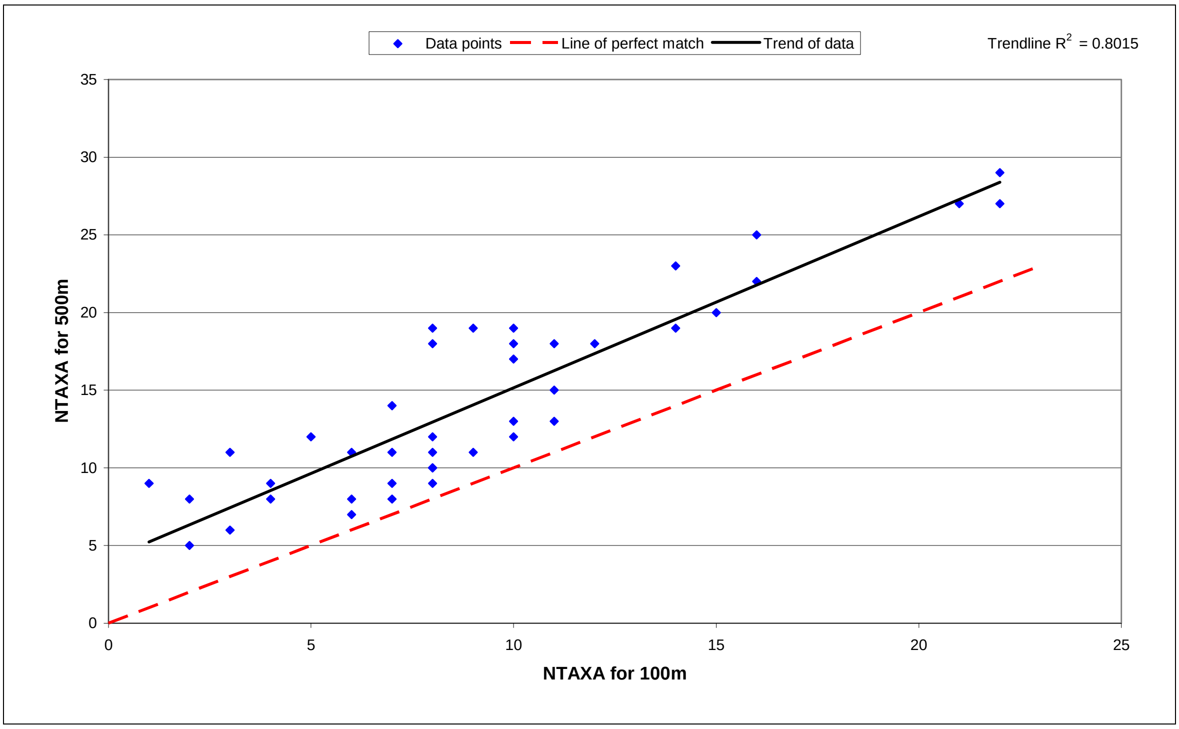

Figure 5.11 Number of taxa found in 100-m LEAFPACS survey against number found in 500-m LEAFPACS survey.

RMNI values were also used to analyse the effect of increasing survey length. RMNI values were calculated for survey lengths of 200-500 m using average cover values across the individual 100-m surveys. The RMNI values for surveys of 100-400 m were then expressed as a percentage of the RMNI value calculated for the 500-m reach (Table 5.5).

Table 5.5 RMNI values for different LEAFPACS survey lengths.

Survey length (m)	RMNI as percentage of RMNI in first 100-m
100	99.20
200	99.95
300	99.49
400	99.91

Table 5.5 shows that increasing the survey length has minimal impact upon the average RMNI value calculated for the reach. On average, a 100-m survey gives a nearly identical RMNI value to that of a 500-m survey, indicating that shorter surveys do not give biased estimates. Figure 5.12 shows the variation in RMNI values produced by surveys of different lengths. As expected, a 400-m survey tends to give a result very similar to that from a 500-m reach (generally within ± four per cent), but shorter surveys tend to become increasingly variable. A 100-m survey, for example, will typically give a result within ±17 per cent of that from a 500-m survey. Thus, a longer survey length will produce more precise estimates of RMNI.

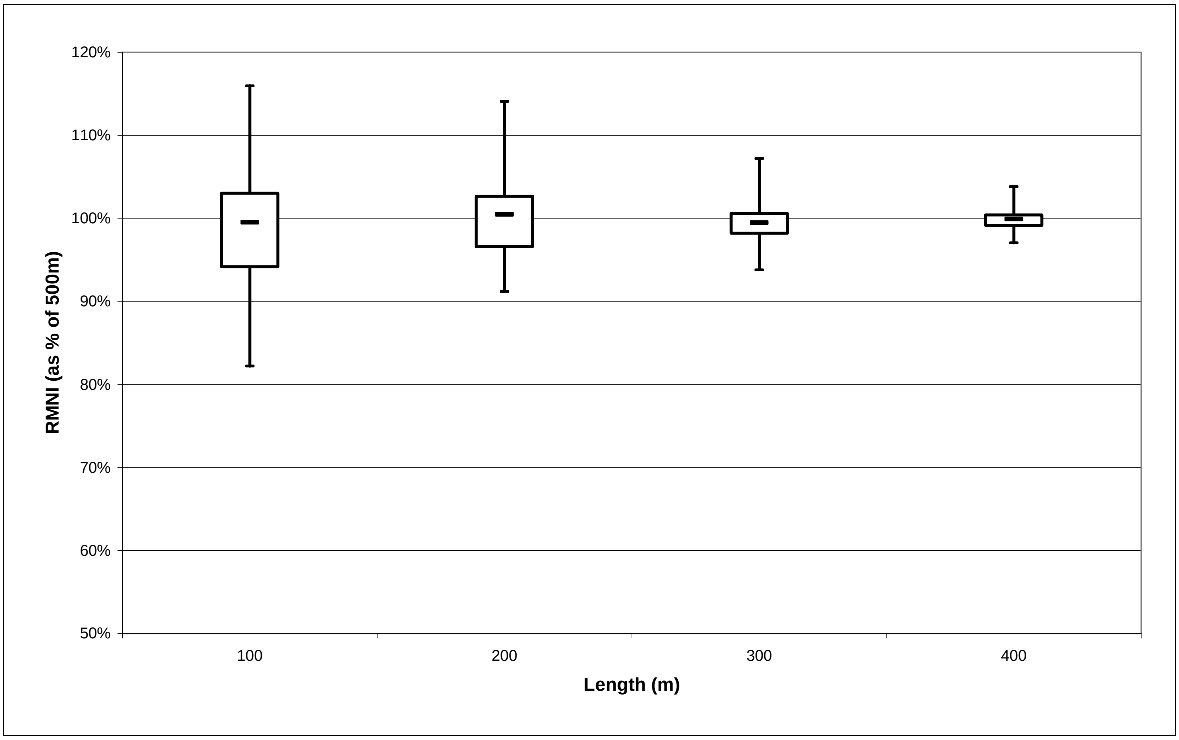

Figure 5.12 Box plot of RMNI values for different LEAFPACS survey lengths.

5.5 Comparison of JNCC and LEAFPACS methods

CCW surveyed 18 reaches on the River Dee using both the LEAFPACS (five x 100-m surveys) and JNCC (one x 500-m survey) methods. Figure 5.13 compares the total number of taxa recorded by the two methods over the whole 500-m reach.

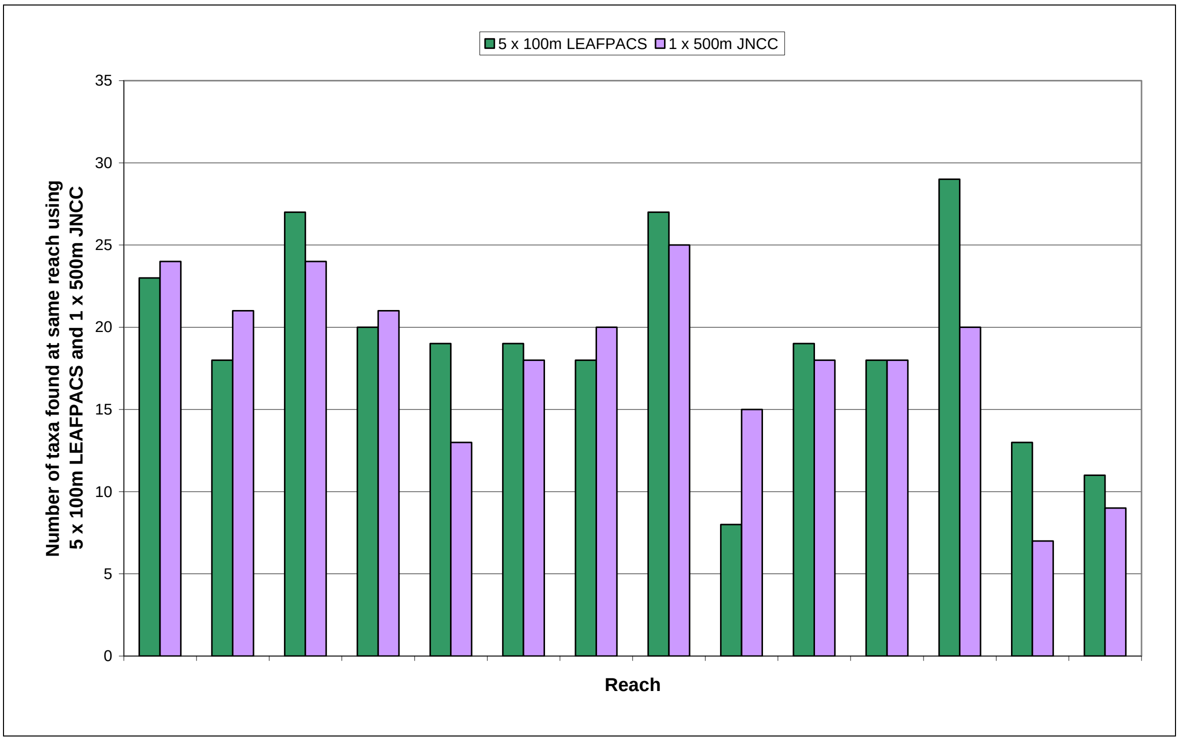

Figure 5.13 Total number of taxa found in 500-m reaches using LEAFPACS and JNCC methods.

At some reaches, the LEAFPACS and JNCC methods recorded similar numbers of taxa, but at other reaches the number of taxa recorded differed by up to nine. Overall, neither method consistently recorded more taxa, which is surprising given that the two methods use different taxa lists.

6 Conclusions

This study analysed an extensive dataset of LEAFPACS and JNCC macrophyte surveys carried out by different agencies across the UK, to examine and quantify variation in macrophyte communities arising from spatial and temporal variability and measurement error (operator variability). This section assesses the progress made in this project, summarises the key findings, and discusses the implications of these results for future monitoring of macrophyte communities in the UK.

6.1 Progress in assessing variability

A previous project (Davey *et al*., 2008) examined a dataset composed of historical survey data and produced preliminary estimates of spatial and temporal variability in macrophyte communities. However, it was not possible to quantify among-site (small-scale 'local' spatial) variability, among-month and operator variability because the historical data had not been collected in way that allowed all sources of variation to be partitioned and quantified separately.

This project has demonstrated how a carefully designed programme of sampling can yield far more information about components of variation in macrophyte communities than a large quantity of historical data collected for other purposes. By quantifying among-reach, among-site, among-month and operator variability in selected indicators, this study has successfully filled the gaps identified by Davey *et al.* (2008).

The only downside of a small, focused study is that the results are based on a smaller selection of rivers and it has therefore not been possible to produce variance estimates for rivers of different types, or to investigate how the level of variability changes with ecological status.

6.2 Summary of results

The main results of this study are as follows:

1. Measures of ecological status such as EQR, and measures of community composition such as RMNI, show less variability than 'absolute' indicators such as NTAXA and %Cover.
2. For all four indicators, variation appears to be driven predominantly by larger scale spatial variation among rivers and among reaches.
3. Variation among 100-m sites in a reach is low relative to the variation among reaches.
4. Monthly variation is typically very low.
5. Operator variability is a considerable source of variation for all four indicators, accounting for between four and 38 per cent of total variation in the data examined.
6. Operator variability is most important for NTAXA, which suggests that missing and misidentification of taxa can be an important source of error, and also high for %Cover, which may reflect the fact that this indicator is

not routinely recorded in LEAFPACS surveys. Operator variability is least important for EQR and RMNI, which suggests these metrics are less sensitive to inaccurate survey data.

7. Operator variability is consistently larger than among-site variation by at least a factor of two, and in some cases comparable with among-reach variation. This means that assessments of ecological status at a water body level may be prone to a higher degree of uncertainty.
8. It is unclear whether teams of operators produce less variable results than lone operators.
9. The number of taxa recorded increases with survey length, but at a diminishing rate. The number of taxa found in a five x100-m LEAFPACS surveys is, on average, 87 per cent higher than the number of taxa found in a one x 100-m survey. In other words, a 100-m survey on average yields 47 per cent fewer taxa than a 500-m survey. However, a 100-m survey can be sufficient to judge the relative level of taxonomic diversity in a 500-m reach.
10. RMNI scores from 100-m surveys are unbiased, but less precise than scores from longer surveys. A one x 100-m survey can estimate the RMNI of a 500-m reach with a precision of ±17 per cent.
11. A comparison of the number of taxa recorded using a one x 500-m JNCC survey and a five x 100-m LEAFPACS surveys showed that neither method consistently recorded more taxa. However, the two methods are not directly comparable because of the differences between the taxa lists used.

6.3 Results in context

Pentecost *et al* (2008) reviewed previous studies on macrophyte variability and noted that macrophyte communities can vary greatly at a fine spatial scale. In particular, considerable variation in species richness among contiguous 100-m sites has been reported in several studies. Unfortunately, few previous studies have investigated variation in macrophyte communities at hierarchical spatial scales in order to put this local-scale spatial variation in context.

Our study suggests that measurement error may contribute significantly to high variation in survey results among sites. When viewed in context, small-scale ‘local’ spatial variability appears to be insignificant compared with the variation among reaches and among rivers.

Pentecost *et al* (2008) also noted that large-scale geographic factors such as ecoregion and latitude appear to account for only a small proportion of total variation. This is supported by our study, which found no significant variation among the survey results from different parts of the UK.

Pentecost’s *et al* (2008) review showed that among-month variation has been little studied but noted some evidence that derived indicators of macrophyte community structure show systematic seasonal variation. Results from Polish rivers suggest that among-year variability is greater than either among-month variability or measurement error.

Among-year variation could not be examined in this study because the data was restricted to a single year, and there was very low among-month variation.

Pentecost’s *et al* (2008) observed that measurement error has been better studied than either spatial or temporal variation. Misidentification of taxa appears to be a more significant source of error in Mean Trophic Rank (a surveying method similar to LEAFPACS which uses the same cover value scale) scores than misestimation of cover, and inter-operator variability can lead to differences of greater than 15 per cent in metric scores. Other studies, however, suggest that inter-operator variability is low relative to yearly and seasonal variation.

Our study shows that operator variability can contribute significantly to variability in estimates of taxonomic richness and plant cover, and to a lesser extent to variability in community metrics such as EQR and RMNI. Surveys of the same site in the same month by different operators have confirmed that operator variability can lead to differences of ±20 per cent in EQR scores.

6.4 Implications of results for macrophyte monitoring

The results of this study have a number of clear implications for the design and operation of future macrophyte monitoring programmes.

1. Low among-site variation means that a single 100-m survey will often be representative of the conditions within a 500-m reach.
2. Significant among-reach variation means that replicate surveys in different reaches will be required to characterise the whole river (or water body).
3. Low among-month variation means that surveying in a single month each year should be sufficient to represent conditions within the river.
4. Relatively high operator variability indicates that there is scope for greater consistency in identification of taxa and recording of plant cover.
5. Further research should be undertaken to test whether measurement error is reduced when operators work in teams.

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Appendix A

Table A.1 Summary of indicators recorded in LEAFPACS dataset.

				Number of surveys with indicator recorded			
Agency	**River**	**Reach**	**Length**	**EQR**	**RMNI**	**%Cover**	**NTAXA**
EA	Dee	Rhewl (Dee4)	5 x 100m	5	5	5	5
EA	Eden	Ingheads	4 x 100m	4	4	4	4
EA	Eden	Outhgill	5 x 100m	5	5	4	5
EA	Erewash	Ilkeston	5 x 100m	5	5	5	5
EA	Erewash	Stanton Gate	5 x 100m	5	5	5	5
EA	Erewash	Toton	5 x 100m	5	5	5	5
EA	Erewash	Trowell	5 x 100m	5	5	5	5
EA	Tern	Cold Hatton	5 x 100m	10	10	10	10
EA	Tern	Peplow	5 x 100m	5	5	5	5
EA	Tern	Stoke on Tern	5 x 100m	5	5	5	5
EA	Tern	Wollerton	5 x 100m	5	5	5	5
EA	Welland	Duddington	5 x 100m	5	5	5	5
EA	Welland	Medbourne	5 x 100m	5	5	5	5
EA	Welland	Rockingham	5 x 100m	5	5	5	5
EA	Welland	Stamford Meadows	5 x 100m	5	5	5	5
SEPA	Leader Water	Foot	5 x 100m	5	5	0	5
SEPA	Leader Water	Newmills Farm upstr rd br	5 x 100m	5	5	0	5
SEPA	Leader Water	opp The Roan	5 x 100m	5	5	0	5
SEPA	Shiel	d/s Allt Mhalagain	5 x 100m	5	5	0	5
SEPA	Shiel	u/s A87 Roadbridge	5 x 100m	5	5	0	5
SEPA	Shiel	u/s Allt Coire	5 x 100m	5	5	0	5
SEPA	Stincher	Ballantrae	5 x 100m	5	5	0	5
SEPA	Stincher	Belhamie	5 x 100m	5	5	0	5
SEPA	Stincher	near Craighouse	5 x 100m	5	5	0	5
SEPA	Teith	Bridge of Teith	5 x 100m	5	5	0	5
SEPA	Teith	Heathershot	5 x 100m	5	5	0	5
SEPA	Teith	u/s Gart House	5 x 100m	5	5	0	5
SEPA	White Cart	Stoneside	1 x 100m	4	4	0	4
CCW	Dee	Dee1	5 x 100m	24	24	19	24
CCW	Dee	Dee2	5 x 100m	10	10	5	10
CCW	Dee	Dee3	5 x 100m	10	10	4	10
CCW	Dee	Dee4	5 x 100m	25	25	19	25
CCW	Dee	Dee5	5 x 100m	9	9	4	9
CCW	Dee	Dee6	5 x 100m	10	10	5	10
NE	Avon	A100	1 x 100m	1	1	1	1
NE	Avon	A116	1 x 100m	1	1	1	1
NE	Avon	A12W	1 x 100m	1	1	1	1
NE	Avon	A145	1 x 100m	1	1	1	1
NE	Avon	A157	1 x 100m	1	1	1	1
NE	Avon	A163	1 x 100m	1	1	1	1
NE	Avon	A196	1 x 100m	1	1	1	1
NE	Avon	A2	1 x 100m	1	1	1	1
NE	Avon	A28	1 x 100m	1	1	1	1
NE	Avon	A5W	1 x 100m	1	1	1	1
NE	Avon	A60	1 x 100m	1	1	1	1
NE	Avon	A62	1 x 100m	1	1	1	1
NE	Avon	A83	1 x 100m	1	1	1	1
NE	Bourne	B10	1 x 100m	1	1	1	1
NE	Bourne	B2	1 x 100m	1	1	1	1
NE	Dochens	D1	1 x 100m	1	1	1	1
NE	Dochens	D2	1 x 100m	1	1	1	1
NE	Nadder	N18	1 x 100m	1	1	1	1
NE	Nadder	N32	1 x 100m	1	1	1	1
NE	Till	T5	1 x 100m	1	1	1	1
NE	Till	T8	1 x 100m	1	1	1	1
NE	Till	TILL	1 x 100m	1	1	1	1
NE	Wylye	W21	1 x 100m	1	1	1	1
NE	Wylye	W31	1 x 100m	1	1	1	1
NE	Wylye	W37	1 x 100m	1	1	1	1
NE	Wylye	W50	1 x 100m	1	1	1	1
NE	Wylye	W62	1 x 100m	1	1	1	1
NE	Wylye	W65	1 x 100m	1	1	1	1

Table A.2 Summary of variability components analysed in LEAFPACS dataset.

Agency	River	Reach	Spatial	Inter-operator	Monthly	Survey Length
EA	Dee	Rhewl (Dee4)	✓	✓		✓
EA	Eden	Ingheads	✓			
EA	Eden	Outhgill	✓			✓
EA	Erewash	Ilkeston	✓			✓
EA	Erewash	Stanton Gate	✓			✓
EA	Erewash	Toton	✓			✓
EA	Erewash	Trowell	✓			✓
EA	Tern	Cold Hatton	✓	✓		✓
EA	Tern	Peplow	✓			✓
EA	Tern	Stoke on Tern	✓			✓
EA	Tern	Wollerton	✓			✓
EA	Welland	Duddington	✓			✓
EA	Welland	Medbourne	✓			✓
EA	Welland	Rockingham	✓			✓
EA	Welland	Stamford Meadows	✓			✓
SEPA	Leader Water	Foot	✓			✓
SEPA	Leader Water	Newmills Farm upstr rd br	✓			✓
SEPA	Leader Water	opp The Roan	✓			✓
SEPA	Shiel	d/s Allt Mhalagain	✓			✓
SEPA	Shiel	u/s A87 Roadbridge	✓			✓
SEPA	Shiel	u/s Allt Coire	✓			✓
SEPA	Stincher	Ballantrae	✓			✓
SEPA	Stincher	Belhamie	✓			✓
SEPA	Stincher	near Craighouse	✓			✓
SEPA	Teith	Bridge of Teith	✓			✓
SEPA	Teith	Heathershot	✓			✓
SEPA	Teith	u/s Gart House	✓			✓
SEPA	White Cart	Stoneside	✓		✓	
CCW	Dee	Dee1	✓	✓	✓	✓
CCW	Dee	Dee2	✓		✓	✓
CCW	Dee	Dee3	✓		✓	✓
CCW	Dee	Dee4	✓	✓	✓	✓
CCW	Dee	Dee5	✓		✓	✓
CCW	Dee	Dee6	✓		✓	✓
NE	Avon	A100	✓			
NE	Avon	A116	✓			
NE	Avon	A12W	✓			
NE	Avon	A145	✓			
NE	Avon	A157	✓			
NE	Avon	A163	✓			
NE	Avon	A196	✓			
NE	Avon	A2	✓			
NE	Avon	A28	✓			
NE	Avon	A5W	✓			
NE	Avon	A60	✓			
NE	Avon	A62	✓			
NE	Avon	A83	✓			
NE	Bourne	B10	✓			
NE	Bourne	B2	✓			
NE	Dochens	D1	✓			
NE	Dochens	D2	✓			
NE	Nadder	N18	✓			
NE	Nadder	N32	✓			
NE	Till	T5	✓			
NE	Till	T8	✓			
NE	Till	TILL	✓			
NE	Wylye	W21	✓			
NE	Wylye	W31	✓			
NE	Wylye	W37	✓			
NE	Wylye	W50	✓			
NE	Wylye	W62	✓			
NE	Wylye	W65	✓			

Table A.3 Summary of variability components analysed in JNCC dataset.

Agency	River	Reach	Length	Surveys	Inter-operator	Survey length
CCW	Dee	Dee1	1 x 500m	5	✓	✓
CCW	Dee	Dee2	1 x 500m	2		✓
CCW	Dee	Dee3	1 x 500m	2		✓
CCW	Dee	Dee4	1 x 500m	5	✓	✓
CCW	Dee	Dee5	1 x 500m	2		✓
CCW	Dee	Dee6	1 x 500m	2		✓
NE	Avon	A100	1 x 500m	1		
NE	Avon	A116	1 x 500m	1		
NE	Avon	A12W	1 x 500m	1		
NE	Avon	A145	1 x 500m	1		
NE	Avon	A157	1 x 500m	1		
NE	Avon	A163	1 x 500m	1		
NE	Avon	A196	1 x 500m	1		
NE	Avon	A2	1 x 500m	1		
NE	Avon	A28	1 x 500m	1		
NE	Avon	A5W	1 x 500m	1		
NE	Avon	A60	1 x 500m	1		
NE	Avon	A62	1 x 500m	1		
NE	Avon	A83	1 x 500m	1		
NE	Bourne	B10	1 x 500m	1		
NE	Bourne	B2	1 x 500m	1		
NE	Dochens	D1	1 x 500m	1		
NE	Dochens	D2	1 x 500m	1		
NE	Nadder	N18	1 x 500m	1		
NE	Nadder	N32	1 x 500m	1		
NE	Till	T5	1 x 500m	1		
NE	Till	T8	1 x 500m	1		
NE	Till	Till	1 x 500m	1		
NE	Wylye	W21	1 x 500m	1		
NE	Wylye	W31	1 x 500m	1		
NE	Wylye	W37	1 x 500m	1		
NE	Wylye	W50	1 x 500m	1		
NE	Wylye	W62	1 x 500m	1		
NE	Wylye	W65	1 x 500m	1		

Appendix B

The raw outputs from the REML modelling are shown below.

EQR:

REML variance components analysis

Response variate: Overall_EQR
Fixed model: Constant
Random model: River + River.Reach_2 + River.Reach_2.Station_No_Name2 + River.Reach_2.Station_No_Name2.Month
Number of units: 256 (3 units excluded due to zero weights or missing values)

Residual term has been added to model

Sparse algorithm with AI optimisation

Estimated variance components

Random term	component	s.e.
River	0.018204	0.008336
River.Reach_2	0.008325	0.002490
River.Reach_2.Station_No_Name2	0.002769	0.001264
River.Reach_2.Station_No_Name2.Month	0.001415	0.001731

Residual variance model

Term	Model(order)	Parameter	Estimate	s.e.
Residual	Identity	Sigma2	0.00516	0.001286

RMNI:

REML variance components analysis

Response variate: RMNI
Fixed model: Constant
Random model: River + River.Reach_2 + River.Reach_2.Station_No_Name2 + River.Reach_2.Station_No_Name2.Month
Number of units: 256 (3 units excluded due to zero weights or missing values)

Residual term has been added to model

Sparse algorithm with AI optimisation

Estimated variance components

Random term	component	s.e.
River	1.84944	0.71080
River.Reach_2	0.19592	0.05601
River.Reach_2.Station_No_Name2	0.03833	0.02224
River.Reach_2.Station_No_Name2.Month	0.04114	0.03047

Residual variance model

Term	Model(order)	Parameter	Estimate	s.e.
Residual	Identity	Sigma2	0.0863	0.02070

NTAXA:

REML variance components analysis

Response variate: N_ATAXA
Fixed model: Constant
Random model: River + River.Reach_2 + River.Reach_2.Station_No_Name2 + River.Reach_2.Station_No_Name2.Month
Number of units: 256 (3 units excluded due to zero weights or missing values)

Residual term has been added to model

Sparse algorithm with AI optimisation

Estimated variance components

Random term	component	s.e.
River	3.951	2.293
River.Reach_2	4.058	1.388
River.Reach_2.Station_No_Name2	1.595	0.661
River.Reach_2.Station_No_Name2.Month	-0.760	0.800

Residual variance model

Term	Model(order)	Parameter	Estimate	s.e.
Residual	Identity	Sigma2	5.937	0.860

%Cover:

REML variance components analysis

Response variate: Total_%_cover_of_macrophytes
Fixed model: Constant
Random model: River + River.Reach_2 + River.Reach_2.Station_No_Name2 + River.Reach_2.Station_No_Name2.Month
Number of units: 159 (100 units excluded due to zero weights or missing values)

Residual term has been added to model

Sparse algorithm with AI optimisation

Estimated variance components

Random term	component	s.e.
River	450.5	263.0
River.Reach_2	289.2	103.2
River.Reach_2.Station_No_Name2	-209.6	72.3
River.Reach_2.Station_No_Name2.Month	229.4	aliased

Residual variance model

Term	Model(order)	Parameter	Estimate	s.e.
Residual	Identity	Sigma2	229.4	43.4

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