Environment Agency

Evidence

Variability components for macrophyte communities in rivers

Report: SC070051/R2

Integrated catchment science programme

Evidence Directorate

NATURAL ENGLAND

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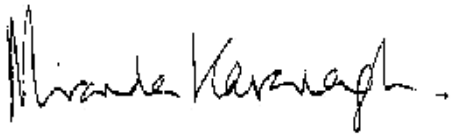


Miranda Kavanagh

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 that are 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 the 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 (within and between reach); (ii) temporal variability (seasonal and annual); and (iii) measurement error (surveyor variability). The analysis focused on three community indicators – Ecological Quality Ratio (EQR), total percentage cover and number of taxa – and also considered spatial variability of two common macrophyte taxa. These aims were addressed using a combination of three data sources: the LEAFPACS development database, a SEPA database and a smaller Countryside Council for Wales (CCW) database.

Results and Conclusions

- Spatial variation in macrophyte communities within a water body appears to be driven predominantly by small-scale 'local' variation among sites within a reach, with relatively little additional, systematic variation among reaches. This means that surveys performed within a three-km reach will have a similar level of variability to surveys performed in different reaches. In other words, a single reach will often be representative of conditions in the water body as a whole.

- Spatial variation is lowest for EQR and highest for total cover, meaning that EQR, out of the analysed indicators, provides the most precise estimate of the average water body status for a given sample size. Typical within-water body standard deviations for the overall EQR are between 0.086 and 0.122.

- The level of spatial variation within the water body varies greatly from one water body to another, and this swamps any differences between different river types. The fact that individual water bodies show contrasting levels of spatial variation means that generic variability estimates may not be suitable for all water bodies.

- The percentage cover of individual taxa, as expected, shows much higher spatial variation than total percentage cover because the latter smoothes out variation across all taxa. Thus, the abundance of individual taxa is much more spatially variable than community indicators. Individual taxa have different sensitivities to impacts. Community metrics that consider the cover of sensitive species will be more useful than overall total cover of macrophytes.

- The analysis suggested that surveying a 200-m stretch of the water body will identify around 30 per cent more individual taxa than a 100-m survey, while a 300-m survey will identify up to 50 per cent more individual taxa than a 100-m survey. However, these values can vary greatly from reach to

reach. It was not possible to determine what survey length would be required to sample all taxa within a water body.

- Based on a small dataset, there was little evidence for significant variation in macrophyte communities between successive years. The level of inter-annual variation was lowest for EQR and highest for total cover and number of taxa. This suggests that surveys need not be performed every year to gain an accurate representation of the water body.
- An analysis of monthly variation found some statistically significant differences between months (May to September) but there was no consistent or systematic pattern to this variation. However, the data used to determine this was not ideal and this variation may be partly the result of differences in water body type and quality. Of the three community indicators, EQR had the lowest monthly variation. There is therefore no reason to believe that conducting macrophyte surveys in just one month will give a biased estimate of conditions throughout the summer.
- Plots of within-water body EQR standard deviation against mean EQR for that water body showed little evidence for a relationship, or had too few low EQR water bodies for a meaningful analysis.

Some aspects of variation could not be analysed fully because of issues relating to data availability.

- Inter-operator variability could not be studied because of the lack of suitable data. Only one of the datasets recorded the operator and no surveys in this dataset were performed at the same site, on the same date and using the same method by different operators.
- Local variability was analysed using three-km reaches. The use of shorter reaches could be considered for some water bodies where local variation is particularly high. The use of shorter reaches was not feasible with this dataset.
- Although the effect of survey length was investigated over lengths ranging from 100 to 300 m, the 500 m JNCC (Joint Nature Conservation Committee) surveys were found not to be comparable with the 100-m Mean Trophic Rank (MTR) surveys. A larger number of adjacent surveys would help to clarify the pattern of increasing taxa number found.
- The analysis suggested that variation between two successive years was low. However, this was based on a small number of water bodies. A larger number of water bodies with surveys performed in successive years would allow annual temporal variation to be analysed more thoroughly. If a longer time-series of data spanning three or more successive years was available, conclusions could perhaps be drawn on a preferred interval between surveys.
- The lack of survey data for the same water body from different months in the year prevented a conclusive analysis of monthly variation to be performed. Ideally data from surveys at the same locations over a number of months would be required for this analysis.

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). Macrophytes are one of two primary response parameters used to assess the trophic status of rivers designated as Sensitive Areas under the UWWTD, and one of five biological quality elements used to assess the ecological status of river water bodies under the 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.

At present, three macrophyte sampling methods are used widely in the UK.

1. The JNCC (Joint Nature Conservation Committee) method (DoE 1987) used by the UK conservation agencies for baseline survey and condition assessment of sites of special scientific interest (SSSI) and special areas of conservation (SAC) rivers uses a 500-m long sampling unit, records all macrophyte species present, and uses a relatively simple three- or five-point cover score. It was designed primarily to survey river reaches to record the maximum number of species present and is inefficient for detecting changes over time.

2. The Mean Trophic Rank (MTR – Holmes *et al.* 1999) method used by the Environment Agency was originally designed to assess changes following phosphorus removal from sewage treatment work effluents and is typically used to survey paired sites upstream and downstream of a potential pollution source. It records only a subset of the macrophyte species present over a relatively short sample length (one 100 or 500-m; the choice is left to the surveyor, 100-m is normally chosen by the Environment Agency), and estimates species cover values on a five- or nine-point scale. Each species is assigned a number between one and 10 on the basis of its sensitivity to nutrient enrichment. These values are multiplied by the respective cover scores for each taxon and then averaged to give the MTR score.

3. The LEAFPACS method (Willby 2006) is a new technique developed specifically to meet the requirements of the WFD. Its purpose is primarily to identify the status of a river water body on the basis of the macrophyte assemblages. The LEAFPACS method follows the MTR method, except that LEAFPACS records all macrophytes (including bryophytes) to species level where possible. Observed values for four metrics (the River Macrophyte Nutrient Index (RMNI), River Macrophyte Hydraulic Index (RMHI), number of aquatic taxa (N_ATAXA) and number of functional groups (N_FG)) are determined. The observed score is then divided by an expected score, which uses measured local physical and chemical conditions to predict the macrophyte community under minimally impacted reference conditions. The resulting multi-metric Ecological Quality Ratio (EQR) ranges from zero to 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

[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.

status by assigning a numerical value to each of the boundaries between the classes. SEPA adopted LEAFPACS in 2006 and requires five x100-m surveys to be carried out in each water body to produce a meaningful classification.

Macrophyte communities vary spatially and temporally. A 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, the UK conservation agencies need to understand variability in 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 effectively 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, the GB environmental protection and conservation agencies formed a project group to investigate variability and uncertainty in river macrophyte communities. The aim of this project is to explore and quantify the sources of variability inherent in measurements of river macrophyte communities. The three sources of variability considered are:

1. Spatial variability (within- and between-reach variability).
2. Temporal variability (seasonal and annual variability).
3. Measurement error (surveyor variability).

The three indicators considered are:

1. Overall EQR.
2. Total percentage cover.
3. Number of taxa.

Percentage cover and number of taxa are individual metrics and the overall EQR is a multi-metric score derived as explained above.

The number of taxa indicator is used as a measure of absolute taxonomic richness rather than a measure of similarity in community composition. Therefore, the absolute number of taxa observed, and not the specific taxa that comprise that number, is of interest. The aim of this project was to measure variability in the chosen indicators and not similarity.

An EQR value is calculated for each of the observed metrics and, from these, an overall EQR value for the water body is calculated. The use of the term EQR throughout this report refers to the overall EQR.

The remainder of this report is divided in to 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 statistical analysis of the data, Section 5 presents the results of analysis, 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: among water bodies, among reaches within a water body, and among sites within a reach (termed 'local' spatial variation in this report).
2. *Temporal variation* – at any given point in space, the macrophyte community will change over time. This temporal variation includes long-term trends, random changes from year to year, systematic seasonal changes (changes from month to month that are consistent from one year to the next), and random within-year variation (changes from month to month that are not consistent from one year to the next).
3. *Spatial-temporal interaction* – whereby a particular temporal effect operates differently in some locations than others. Temporal variation may be greater at some locations within a water body 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 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.

An ecological assessment usually focuses on a defined spatial and temporal '*population*' of macrophyte communities. For example, SEPA assesses the mean EQR per water body over a three-year period. Almost invariably, it is not possible to survey the entire population of interest; it would clearly be unfeasible, for example, to survey macrophyte communities throughout a water body continuously for three years. Ecological assessments must therefore be made using metrics or scores estimated from a limited number of surveys located through space and collected over time. The difference between the true metric or score value (such as the mean EQR in the water body over the three-year period) and the estimated value is termed '*sampling error*', and arises from variability in the data. Sampling error is therefore a consequence rather than a source of variation and acts as a measure of the uncertainty in the estimated metric or score.

For instance, if sampling were to be carried out on just one date, allowance would need to be made for the possibility that quality was unusually good or poor on that occasion, and that would require information on the temporal components of variation. Similarly, if sampling were to be carried out in just one location, allowance would need to be made for the possibility that quality was unusually good or poor in that particular place, and that would require information on the spatial components of variation. Even if quality were spatially and temporally constant, measurement error could still produce a misleadingly optimistic or pessimistic estimate of quality, so some allowance needs to be made for the level of measurement error.

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 were to vary greatly from year to year, then it would be important to conduct surveys annually to quantify and average out that temporal variability. Similarly, if macrophyte communities varied greatly from reach to reach within a water body, it would be necessary to conduct surveys at a number of reaches to quantify and average out that spatial variability.

2.3 Estimating components of variation

The surest way to gain an understanding of the components of variation affecting any given indicator is to carry out a purpose-built monitoring programme designed according to sound statistical principles (Ellis and Adriaenssens 2006). Unfortunately this is rarely done in practice, and components of variation must instead be estimated using datasets collected for other purposes. This can make it difficult to separate out and quantify certain components of variation, but it is nevertheless often possible to derive at least the main components of variation using such datasets.

Current sampling strategies and variability studies for aquatic macrophytes across the EU were reviewed by Pentecost *et al* (2008). The report observed that spatio-temporal variation of aquatic macrophytes is notoriously high but that very few studies have attempted to identify and quantify the main components of variation in either primary metrics (species richness or total cover) or derived indicators (MTR or EQR). The main findings of the report are summarised below.

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 studies have investigated variation in macrophyte communities at hierarchical spatial scales to put this local-scale spatial variation in context. Large-scale geographic factors such as ecoregion and latitude appear to account for only a small proportion of total variation, but the variation at intermediate spatial scales (such as between reaches) has yet to be properly quantified.

Within-year variation has been little studied but there is some evidence that derived indicators of macrophyte community structure show systematic seasonal variation. Results from Polish rivers suggest that between-year variability is greater than within-year variability or measurement error.

Measurement error appears to have been slightly better studied than spatial or temporal variation. Misidentification of taxa appears to be a more significant source of error in MTR scores than misestimation of cover, and inter-operator variability can lead to differences of greater than 15 per cent in metric scores. Other studies suggest that inter-operator variability may be low relative to yearly and seasonal variation.

Overall, there is a lack of well-designed and analysed hierarchical studies with good replication to tease apart spatial and temporal variability and measurement error.

3. Data

Three separate datasets were made available for this study: the LEAFPACS development database, a SEPA database and a smaller CCW database. The following sections describe the origin, structure and content of these datasets and how they were organised and processed prior to analysis.

3.1 LEAFPACS and SEPA databases

The LEAFPACS development database is the result of extensive work to collate existing data on river macrophytes from a range of sources across England, Wales, Scotland and Northern Ireland. Data from around 6,500 surveys of 4,000 unique sites were assembled and used to develop and test the LEAFPACS tool.

The LEAFPACS database was combined with separate SEPA survey database for this study. The combined database is hereafter referred to as the LEAFPACS database in this report.

Macrophyte survey data collated by the Project Manager was received by WRc at the end of February 2008. Following discussions, a revised set of data was received on 20 March. Additions and updates to the SEPA data were received in April and May, so that the data collection was complete by the end of May 2008.

The key fields in the LEAFPACS database are listed in Table 3.1. Notably, two different schemes are used to classify river type. The first of these, a macrophyte-specific classification based upon the alkalinity and gradient of the water body, was developed by Nigel Willby. It is termed River Classification 1 in this report. The second classification is a generic WFD classification system based upon the altitude, geology and size of the water body. It is referred to as River Classification 2 in this report. A summary of the two classification systems is given in Appendix A.

Numerous checks were carried to ensure data quality and consistency. The checks included: survey dates, river name spelling and consistency of River Classification 2 with the altitude, geology and size data. A small number of surveys with no plausible date were removed from the dataset.

Table 3.1 Key data fields in LEAFPACS database.

Field	Description (Values)	Checks
Survey method	1 = 100-m survey; 2 = back-to-back 500-m surveys	
Date of survey	Date (dd/mm/yyyy)	Samples with dates such as 01/01/1901 removed
Data source	Consvn Rivs = JNCC; Nigel Willby = Stirling University; MTR = Environment Agency Mean Trophic Rank; SEPA = Scottish Environment Protection Agency	
River name		Spelling and consistency checks
Water body ID	Environment Agency ID, starting with GB or SEPA ID, four to five digits	
Country	England & Wales; Scotland	Created
River Classification 1	Based on alkalinity (low, moderate, high, very high) and gradient (very low, low, moderate, high)	
Altitude	WFD catchment altitude type (low; mid)	
Geology	WFD catchment geology type (CA = calcareous; OR= Organic; SI = siliceous)	
Size	WFD catchment size type (small; medium; large)	
River Classification 2	Based on altitude, geology and size	Check for consistency with altitude, geology and size data
Distance from source	In km	
Overall EQR	Determines class from bad to high (0-1)	Revised values provided by EA
Total number of taxa	Taxa list based on LEAFPACS protocol (not SEPA additional species list)	
Total cover	Sum of estimated percentages (%)	

Records within the LEAFPACS database were classified as MTR or non-MTR.

MTR surveys used a 100-m survey length and were almost entirely done in England. It is understood that many of the MTR surveys were carried out to compare river quality upstream and downstream of a discharge point. Although the MTR dataset contained many pairs of surveys carried out on the same day and within a short distance, it was decided not to use this data because the non-random location of MTR sites would likely give an exaggerated measure of local spatial variability.

Non-MTR surveys included the SEPA, JNCC and Stirling University data (Table 3.2). Because these surveys are not strategically positioned to measure the impact of point sources discharges they should give an unbiased measure of natural spatial and temporal variability. This dataset is referred to in this report as the Analysis dataset.

The Analysis dataset is provided in MS Excel format with this report. The following were analysed separately:

- the 100-m and paired 500-m (one km total) surveys (survey methods 1 and 2);
- Scotland and England & Wales (E&W).

This resulted in three separate sets of data for analysis; the fourth – 100-m surveys in England & Wales – contained too few surveys for a meaningful analysis.

Table 3.2 Summary of SEPA, JNCC and Stirling University data.

Data source	Survey method	Total no. of surveys	No. in Scotland	No. in E&W	No. with blank Water body ID
JNCC	2 (500m)	1747	401	1198	148
Stirling University	1 (100m)	108	45	59	4
SEPA	1 (100m)	210	210	0	0
Total	**-**	**2065**	**656**	**1257**	**152**

The Analysis dataset was used to investigate spatial and temporal variation in macrophyte communities. Unfortunately, the identity of the operator was not recorded in this dataset. Inter-operator variability could therefore not be measured and measurement error was instead included in estimates of spatial and temporal variation.

The Analysis dataset included for each survey estimates of EQR, total cover and number of taxa. Figure 3.1 to Figure 3.6 show the overall standard deviation of these three variables (expressed as a percentage of the mean values), broken down by location (Scotland or England & Wales), method (1 or 2) and classification scheme (1 or 2). Overall, EQR consistently had the lowest relative standard deviation and total cover had the highest.

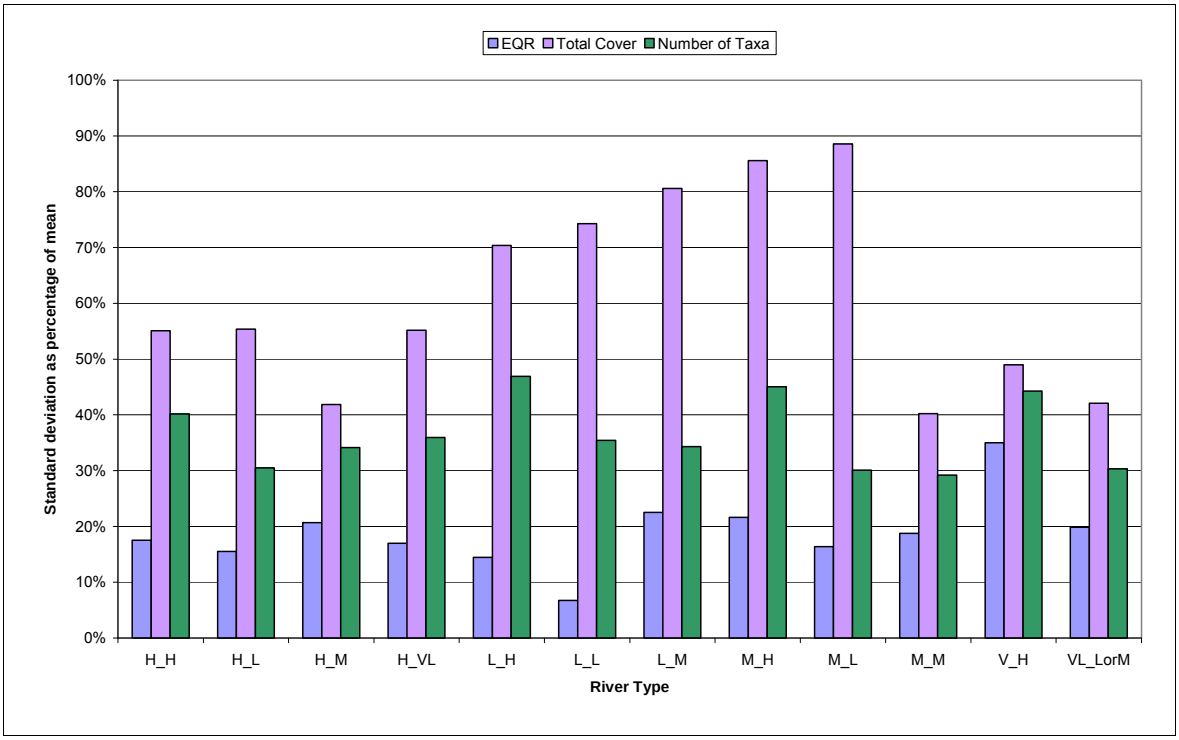


Figure 3.1 Relative standard deviations in Scotland using River Classification 1 and Method 1 (100m).

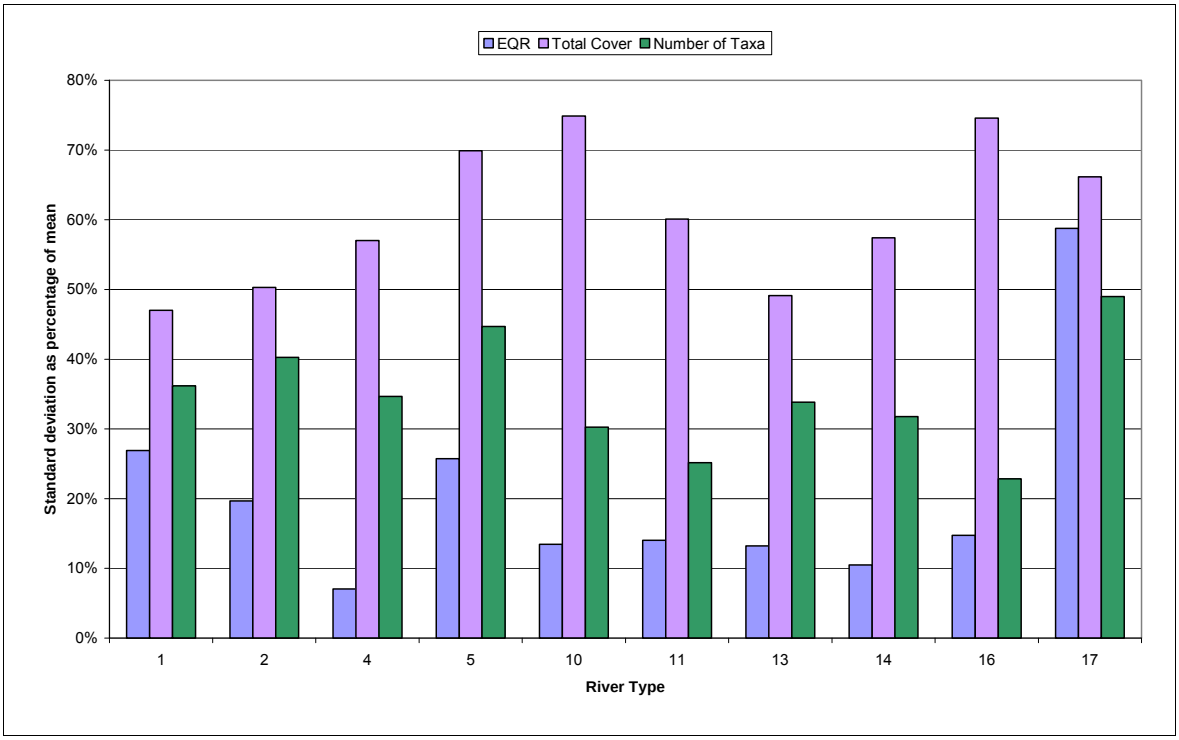


Figure 3.2 Relative standard deviations in Scotland using River Classification 2 and Method 1 (100m).

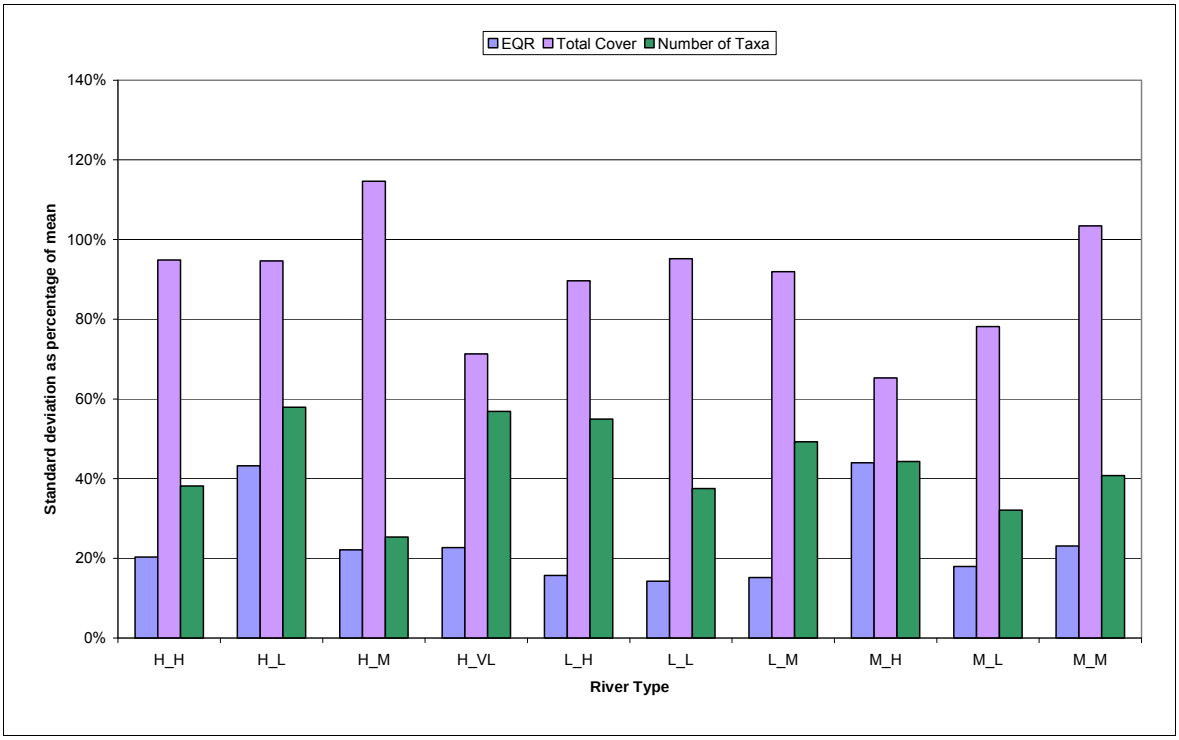


Figure 3.3 Relative standard deviations in Scotland using River Classification 1 and Method 2 (paired 500m).

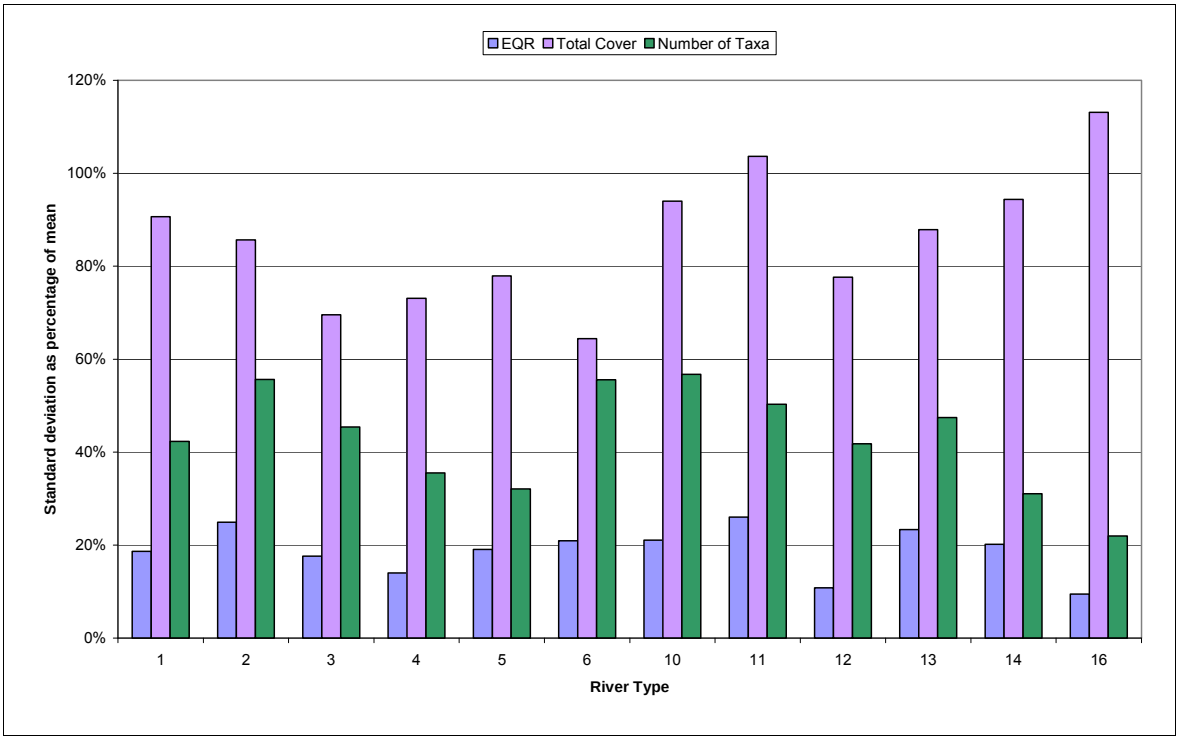


Figure 3.4 Relative standard deviations in Scotland using river classification 2 and method 2 (paired 500m).

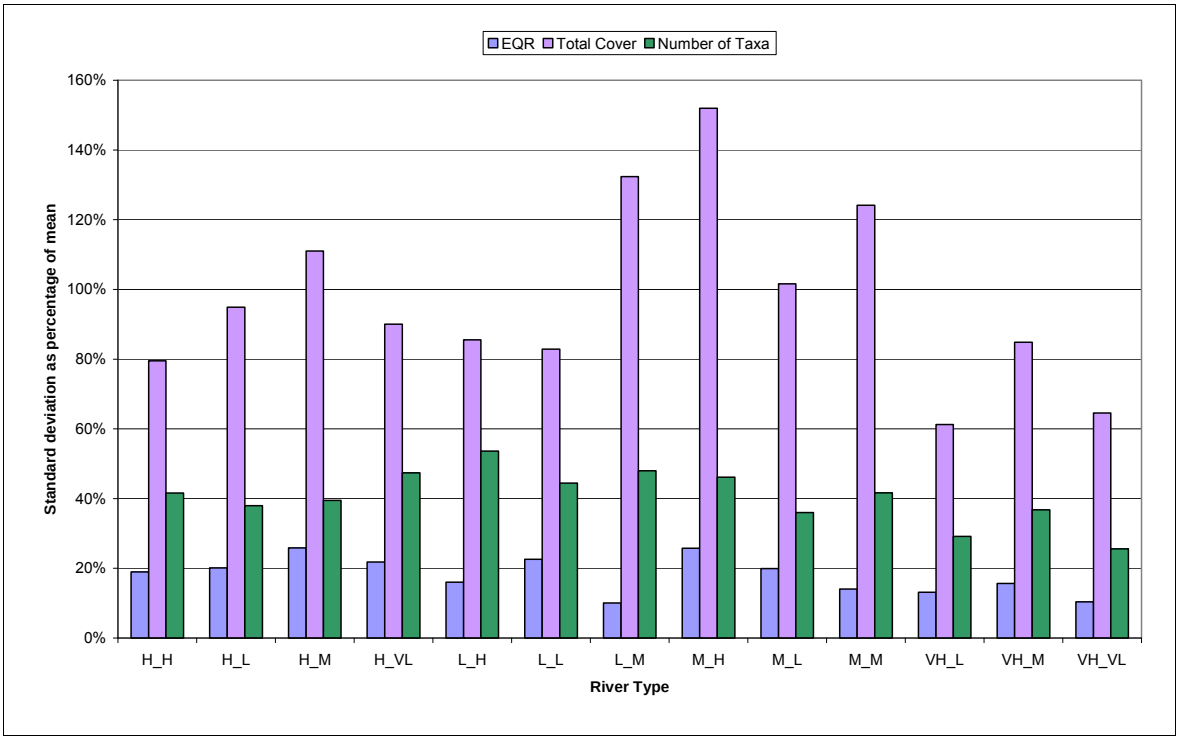


Figure 3.5 Relative standard deviations in England and Wales using River Classification 1 and Method 2 (paired 500m).

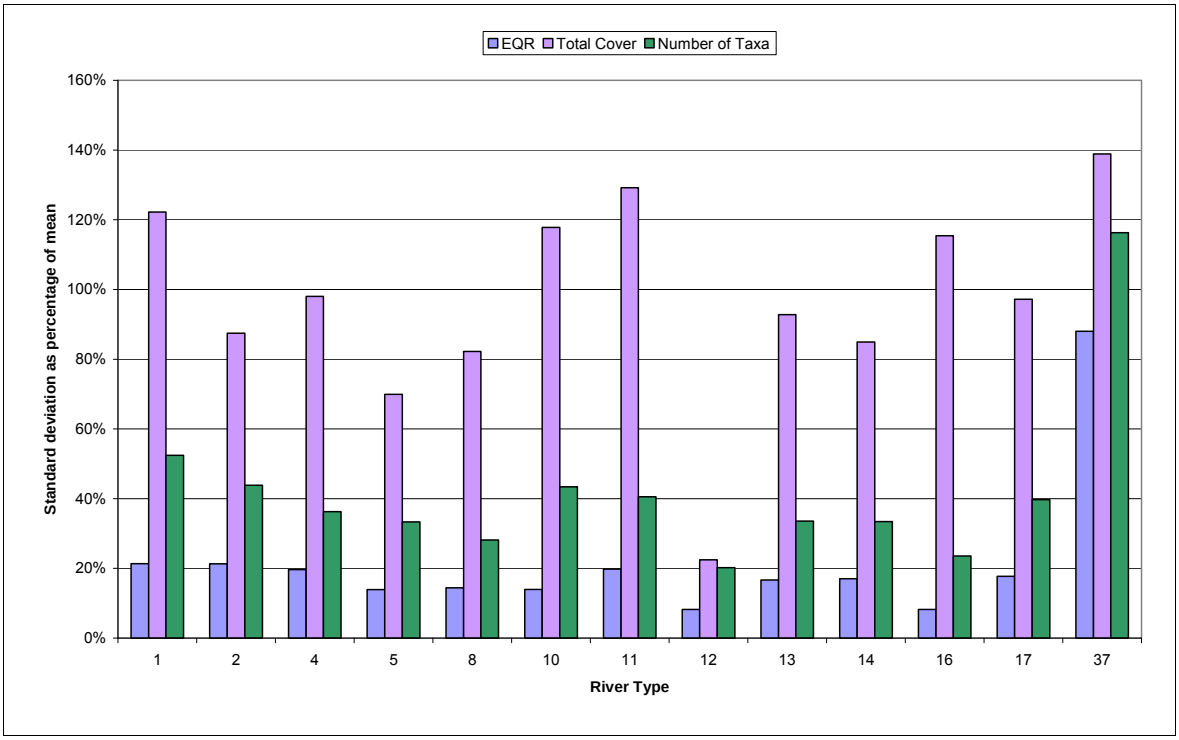


Figure 3.6 Relative standard deviations in England and Wales using River Classification 2 and Method 2 (paired 500m).

3.2 CCW database

The CCW database consisted of 70 MTR and JNCC surveys carried out in Wales between 1999 and 2007. The key fields in the dataset are listed in Table 3.3.

Table 3.3 Key data fields in CCW dataset.

Field	Description (Values)	Checks
WBID	WFD water body ID	
Catchment_Name	Name of the catchment	
Site_Name	Name of the site	Combined with method and year to give site ID
NGR	Two-letter, six-digit UK grid reference, usually upstream end of survey	MTR surveys can have identical NGR, these are regarded as adjacent surveys
Altitude Type	WFD catchment altitude type (MID)	
Geology Type	WFD catchment geology type (CA = calcareous; SI = siliceous)	
Size Type	WFD catchment size type (small; medium; large)	
Surveyor	Name of surveyor	
Year	Year of survey	
Month	Month of survey (August; September)	
Method	Method used for survey (JNCC; MTR)	
Length	Length of survey (500-m = JNCC method, 100-m = MTR method)	
Macrophyte_Name	Name of plant species	Only aquatic species used in analyses
Cover_AQ_R	JNCC aquatic cover value, relative to total plant cover (1-3)	
Cover_AQ_Ab	JNCC aquatic cover value, relative to survey length (1-3)	This field was used to find aquatic species for JNCC surveys
Cover_BA_R	JNCC bank cover value, relative to total plant cover (1-3)	Species only found on banks were excluded from the analyses
Cover_BA_Ab	JNCC bank cover, relative to survey length (1-3)	Species only found on banks were excluded from the analyses
MTR_Cover	Cover value for MTR surveys (1-9)	This field was used to find aquatic species for MTR surveys
Site_ID	ID composed of site name, method & year	Created

EQR values were not available, but the number of taxa was recorded for each survey and estimates of total percentage cover were provided for the MTR surveys.

Although much smaller than the LEAFPACS database, the CCW database had two unique features. First, it included operator identity, which was used to estimate the magnitude of inter-operator variability (see Section 4.3). Second, two or three replicate MTR surveys were sometimes conducted at contiguous 100-m sites by the same operator in the same month, which were used to investigate the effect of survey length on number of taxa observed. The CCW dataset is provided with this report in MS Excel format.

4. Methods

4.1 Spatial variability

4.1.1 Definitions

Figure 4.1 shows the different spatial scales considered in this study. An individual *water body* can be split into a number of contiguous *reaches*, which are defined as being three km long. Each reach can be divided into a number of *sites*, which are specific locations where an individual survey is carried out. At any one site, a number of individual *survey events* may be conducted over time. Variation within a water body can therefore be split into variation among-reaches within a water body and variation among-sites within a reach ('local' spatial variation).

Although the use of shorter reaches for some water bodies might allow a better understanding of local (within-reach) spatial variation, this was not practical in this study as it would greatly reduce the number of reaches containing more than one site or survey event and thus prevent a meaningful analysis of within-reach variability. The definition of a reach as a three-km length of river was therefore a compromise between providing a sufficient number of data while preserving an acceptable spatial resolution.

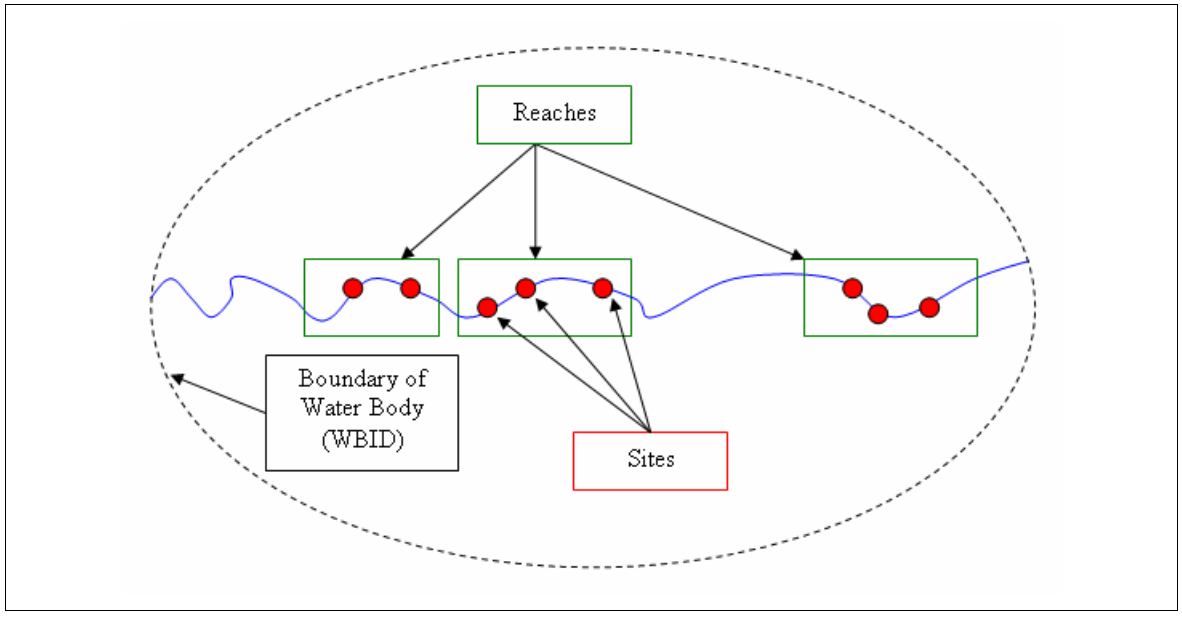


Figure 4.1 Hierarchical spatial scales considered in this report.

4.1.2 Within-water body variation: community indicators

Analyses of within-water body spatial variation were carried out using the LEAFPACS Analysis dataset.

In order to isolate and quantify spatial variability in the overall EQR, number of taxa and total cover, subsets of the data were identified that met the following criteria:

- surveys conducted in the same water body;
- distance from source differs by less than or equal to three km;
- surveys conducted in same month and year (no temporal variation).

A nested analysis of variance (ANOVA) model was used to compare the among-reach and among-site (within-reach) variation. The amount of variation was quantified as a standard deviation.[2] If there was no significant difference between the two standard deviations this was taken as evidence that the distance between sites did not impact upon the variation found in the survey results (i.e. there was no additional among-reach variation over and above the among-site variation).

The Analysis dataset was split by method (1 or 2) and country (Scotland or England & Wales) and separate ANOVA tests were performed on each of the three datasets:

- Method 1 (100m) Scotland
- Method 2 (paired 500m) Scotland.
- Method 2 (paired 500m) England & Wales.

There was not enough data for survey method 1 (100m) in England & Wales to analyse.

The three datasets were then split further by river type and ANOVA tests were performed on each river type where sufficient data existed. Both river classification schemes were used in turn.

To get a better handle on 'local' spatial variation, the relative standard deviation in total cover was also calculated for sets of two or three adjacent MTR surveys in the CCW dataset. These results were compared with those for within-water body variation derived from the LEAFPACS dataset.

4.1.3 Within-water body variation: individual taxa

Following the analysis of spatial variability in community indicators, a similar analysis was undertaken on the abundance of two individual taxa. A shortlist of the five most common (percentage occurrence) and abundant (average percent cover) macrophyte taxa was compiled using the Analysis LEAFPACS dataset, and two taxa – *Ranunculus penicillatus ssp pseudofluitans* and *Rhynchostegium riparioides* – were then selected by Nigel Willby for analysis on the grounds of being widely distributed, covering a range of growth forms and can range from very rare to very abundant in the rivers in which they occur.

ANOVA tests were performed to quantify within-water body and within-reach variation in the percentage cover of these taxa. The analysis was restricted to those water bodies where the taxa were present. The results were broken down by survey method (1 or 2) and country (Scotland or England & Wales), and also for those river types where there was sufficient data for analysis.

[2] i.e. the square root of the variance

4.1.4 Effect of survey length on number of taxa

The length of a survey will affect how representative the survey results are of the macrophyte community in the water body as a whole. The CCW dataset was analysed to investigate specifically how the number of taxa recorded changes with survey length.

Surveys in this dataset were performed using the MTR and JNCC methods. A standard MTR survey is 100-m in length, while a JNCC survey is 500-m in length. There were seven instances where sets of two or three MTR surveys were conducted at contiguous 100-m sites by the same operator in the same month. These sets of surveys all share the same grid reference and were combined to simulate 200-m and 300-m long surveys.

At locations where two or more surveys were performed back to back, the number of different taxa found in each survey was compared with the combined number found in two or three surveys at the same site. If a taxon occurred in each of the surveys being combined, then it was only recorded once as the analysis was comparing the number of unique taxa. This gave the number of different taxa found for surveys of 100-m, 200-m and 300-m in length. The numbers of taxa recorded for 200-m and 300-m surveys were represented as a percentage of the number of taxa found for a 100-m survey to allow direct comparison between different sites and water bodies.

On three occasions where a JNCC and a MTR survey had been performed at the same site, the numbers of taxa found in each survey were compared. However, the two survey methods are not directly comparable due to differences in the survey methods.

4.2 Temporal variability

The analyses of temporal variation were carried out using the LEAFPACS Analysis dataset. Temporal variability may reflect environmental changes over time, which the survey method should detect. For a programme of surveying to accurately reflect the current and changing status of a water body, the period of time between surveys is dependant upon the level of temporal variation and the rate of environmental change.

4.2.1 Annual variation

An analysis of annual variation was performed by isolating those sites where surveys were carried out in two or more successive years. To provide enough data to allow for analysis, surveys in the same water body in successive years were used even if they had been carried out on different reaches within the water body. This means that some spatial variation may be bound up in the measurement of annual variation. Only three water bodies had sufficient levels of data for an ANOVA.

The decision to focus on surveys in successive years was based on the fact that the WFD assessment period is typically three years (at least in Scotland).

Although some surveys were conducted at the same site five, 10 or even 15 years apart, there were too few instances to test whether the level of year-to-year variation increased with the duration between surveys.

4.2.2 Monthly variation

The effect of month could not be estimated separately from other factors because there were no water body that had been sampled in different months in the same year (or

even in successive years). The best that could be done was to examine the change from month to month across all water bodies, recognising that the variation among water bodies may mask or exaggerate the level of monthly variation.

4.3 Inter-operator variability

To quantify inter-operator variation an ideal dataset would comprise the results of several different operators performing identical surveys (same site, same method, same date). Under these conditions, variation in the results between surveys would be entirely due to the different operators. However, performing the same survey several times with different operators is not an efficient method of surveying and such a dataset is unlikely to exist, unless the surveys were performed for the sole purpose of determining inter-operator variability.

The dataset of CCW surveys was the only available dataset which provided details of survey operators, allowing different operators to be compared. A study of this dataset concluded that although there were twelve occasions of two different operators surveying on the same site and date, each operator used a different method of surveying, either MTR or JNCC, and so the results were not comparable.

There were also surveys with the same water body and date, using the same method, by different operators. However, the grid-references of the survey locations showed that these were a significant difference apart and so any variability in the results would be the result of both spatial and inter-operator variability. Therefore, inter-operator variability could not be isolated and quantified from this dataset.

Although the JNCC data from the Analysis dataset records a surveyor ID, this information was not provided with the dataset. The low number of surveys occurring at the same site on the same date suggests that there would be little value in trying to find the inter-operator variation using this dataset.

4.4 Fitting power curves to EQR standard deviations

The analyses of spatial and temporal variability described above assume that the level of variability is independent of water body quality – that is, that the level of variability is the same in water bodies of high, moderate and bad status. There are good reasons, however, to believe that overall variability in EQR will be low in water bodies of high and bad status (because very high and very low EQR scores can be achieved only if the water body is of uniformly high or bad status) and at a maximum in water bodies of moderate status. If this is the case, it may be better to use in confidence of class calculations as a measure of variability that is a function of the mean EQR value.

To investigate how spatial variation changes with water body status, overall within-water body standard deviations for EQR were plotted against the mean EQR for that water body. A polynomial curve was then fitted to the data using the method described in Ellis and Adriaenssens (2006). Separate plots were produced by breaking the data down by method, country and river type.

5. Results

5.1 Spatial variability

5.1.1 Within-water body variation: community indicators

Table 5.1 gives the ratio of among-reach to among-site variances. A ratio significantly greater than one indicates that there is an appreciable variation among reaches over and above any variation from site to site. Overall, the nested ANOVA tests showed no significant difference between the among-reach variation and the among-site variation for the majority of the datasets tested. Similar patterns were found for all three indicators examined: EQR, total cover and number of taxa. This result means that spatial variation in macrophyte communities arises mainly at a local spatial scale, and that there is relatively little systematic variation among reaches. This is not entirely surprising because factors such as water depth, water velocity and shading are known to exert a considerable influence on macrophyte communities at fine spatial scales. This result suggests that a larger distance between survey locations does not increase the level of variation found in the results for surveys within a water body.

Table 5.1 Ratios of among-reach to among-site variance.

Survey method	Country	River Classification 1	River Classification 2	EQR	No. of taxa	Total cover
1	Scotland	All	All	1.78 S	NS	NS
1	Scotland	H_H		NS	NS	NS
1	Scotland	H_M		NS	7.43 HS	2.47 S
1	Scotland		2	NS	NS	NS
2	E&W	All	All	NS	NS	NS
2	E&W	H_H		NS	NS	NS
2	E&W	H_L		NS	NS	NS
2	E&W	H_M		NS	NS	NS
2	E&W	H_VL		5.75 S	NS	NS
2	E&W	VH_L		4.03 HS	NS	NS
2	E&W	VH_VL		NS	NS	NS
2	E&W		2	NS	NS	NS
2	E&W		4	NS	NS	NS
2	E&W		5	NS	NS	NS
2	E&W		8	NS	NS	NS
2	E&W		10	5.46 S	NS	8.80 S
2	E&W		11	NS	NS	6.79 S
2	Scotland	All	All	NS	NS	1.75 S
2	Scotland	L_H		2.37 S	NS	NS
2	Scotland		10	3.77 S	4.26 S	3.84 S
2	Scotland		13	NS	NS	NS
2	Scotland		1	NS	NS	NS
2	Scotland		10	NS	NS	NS

Note: Only variance ratios significantly greater than one are shown. HS = highly significant ($p < 0.01$), S = significant ($p < 0.05$), NS = not significant.

Figure 5.1 shows the standard deviation in EQR values for all surveys within a reach and for all surveys within a water body, broken down by country and survey method (method 1 = 100m, method 2 = paired 500m). The actual standard deviations are tabulated in Appendix B. In general, the level of variation among all surveys within a water body is similar to the level of variation among all surveys in a reach, which is consistent with the ANOVA results in Table 5.1. Similar results were obtained for total cover and number of taxa. Together, these results suggest that performing several surveys within a single three-km reach will produce a level of variation similar to that produced by the same number of surveys spread across the whole water body. Effectively, the variation between surveys in different reaches is driven by the variation among-sites rather than any additional systematic variation among-reaches. This suggests spatial variation at larger spatial scales is driven primarily by local variation in macrophyte communities.

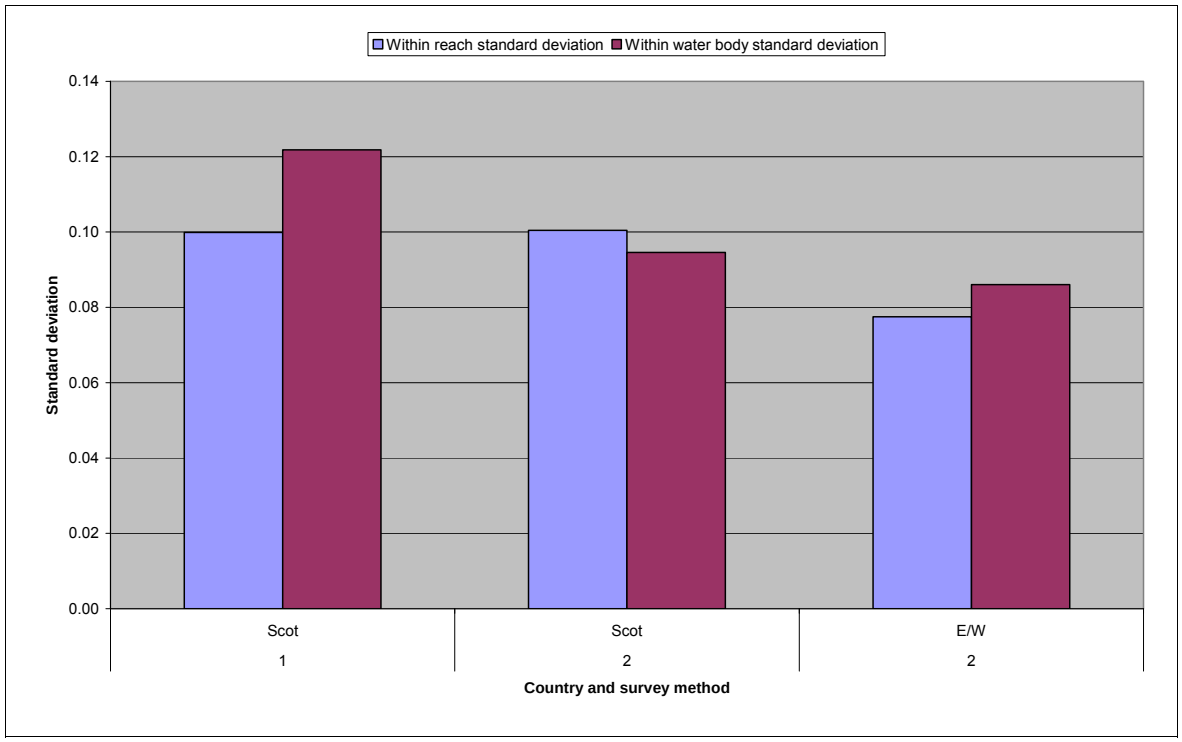


Figure 5.1 Standard deviations for EQR.

Figure 5.2 and Figure 5.3 show within-reach and within-water body standard deviations in EQR values broken down by country, survey method (method 1 = 100m, method 2 = paired 500m) and river type. These results show that there is a greater difference between the standard deviations for several of the river types when classified using the River Classification 1 system.

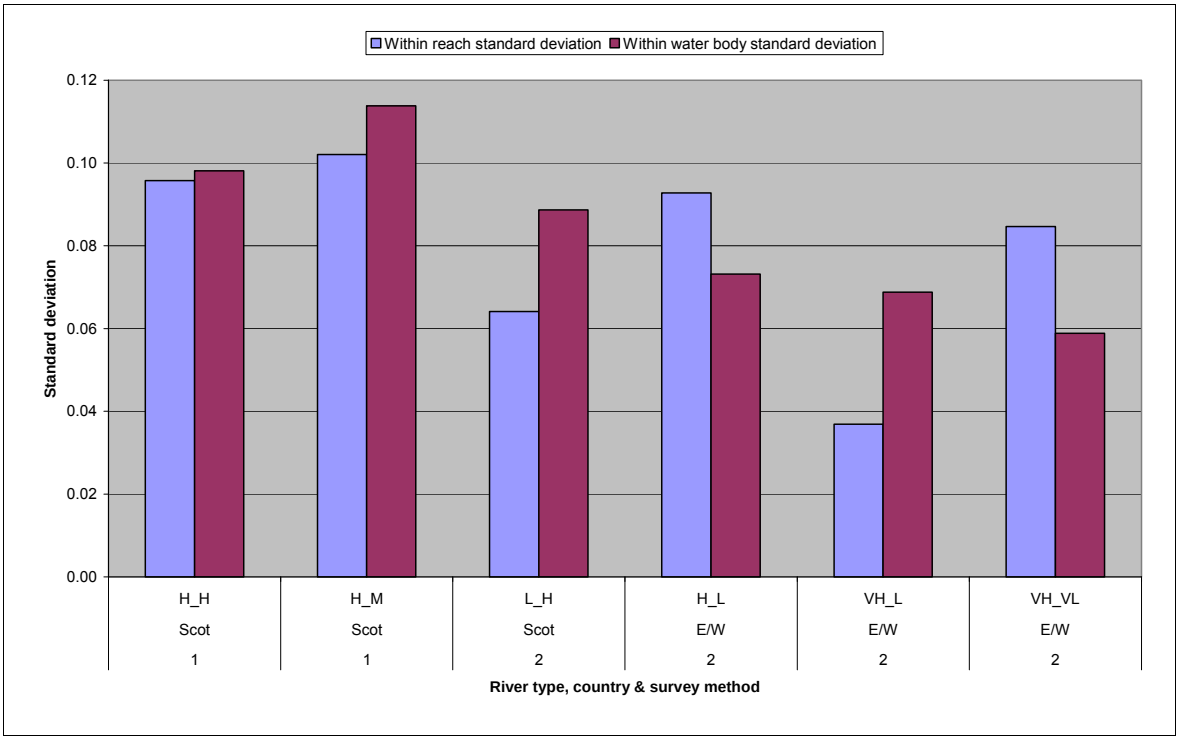


Figure 5.2 Standard deviations for EQR by River Classification 1.

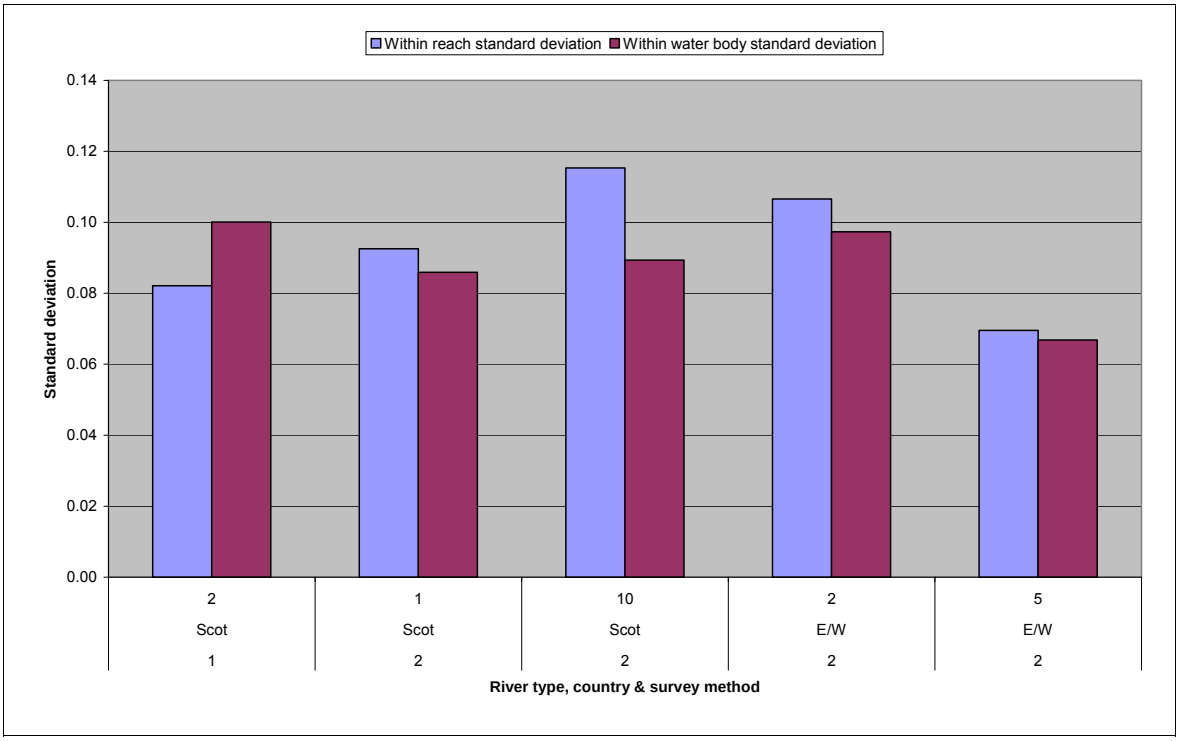


Figure 5.3 Standard deviations for EQR by River Classification 2.

The magnitude of total within-water body variation in EQR scores is highly variable from water body to water body, as shown in Figure 5.4 to Figure 5.7. These box plots show the median, quartiles, maximum and minimum values of within water body standard deviations and are for survey method 2 (paired 500m) unless otherwise stated. In most cases, the magnitude of spatial variation is similar for the majority of

water bodies, but there are a small number of water bodies where macrophyte communities show an unusually high or unusually low level of spatial variation. This result shows that generic measures of within-water body spatial variability will not necessarily apply to all water bodies. There is no obvious pattern in the level of variability among river types.

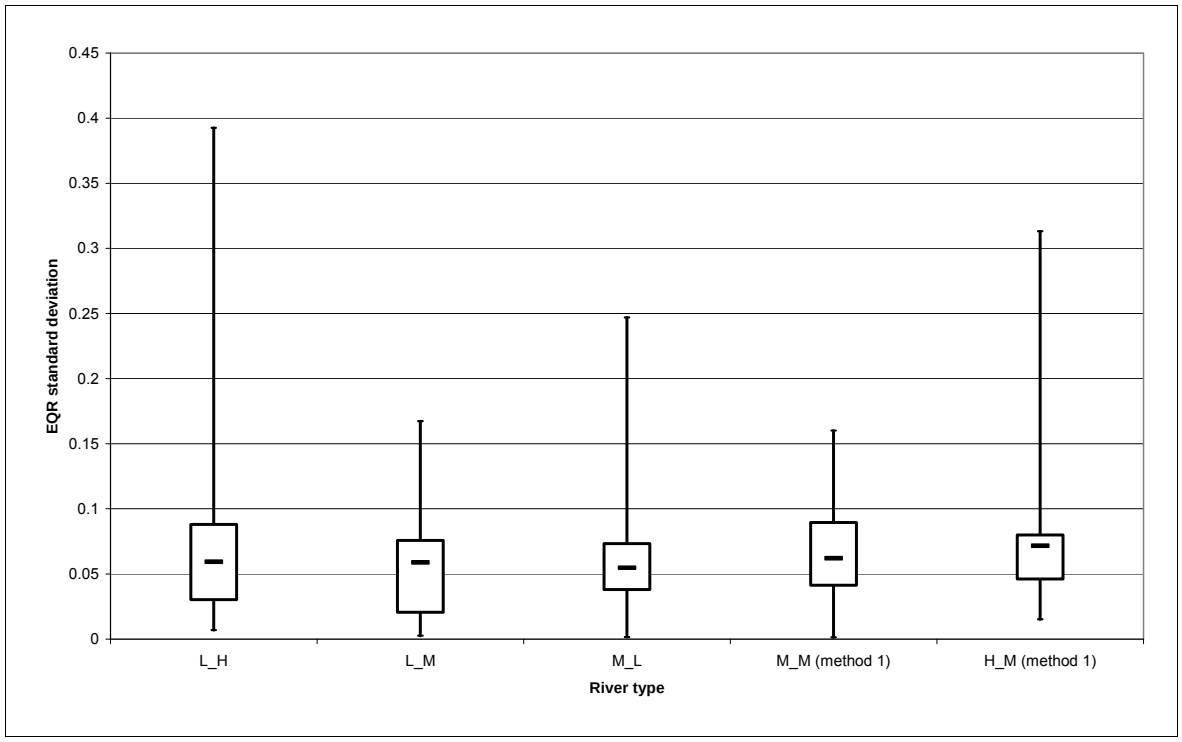


Figure 5.4 Box plots of EQR standard deviations for water bodies in Scotland classified using River Classification 1.

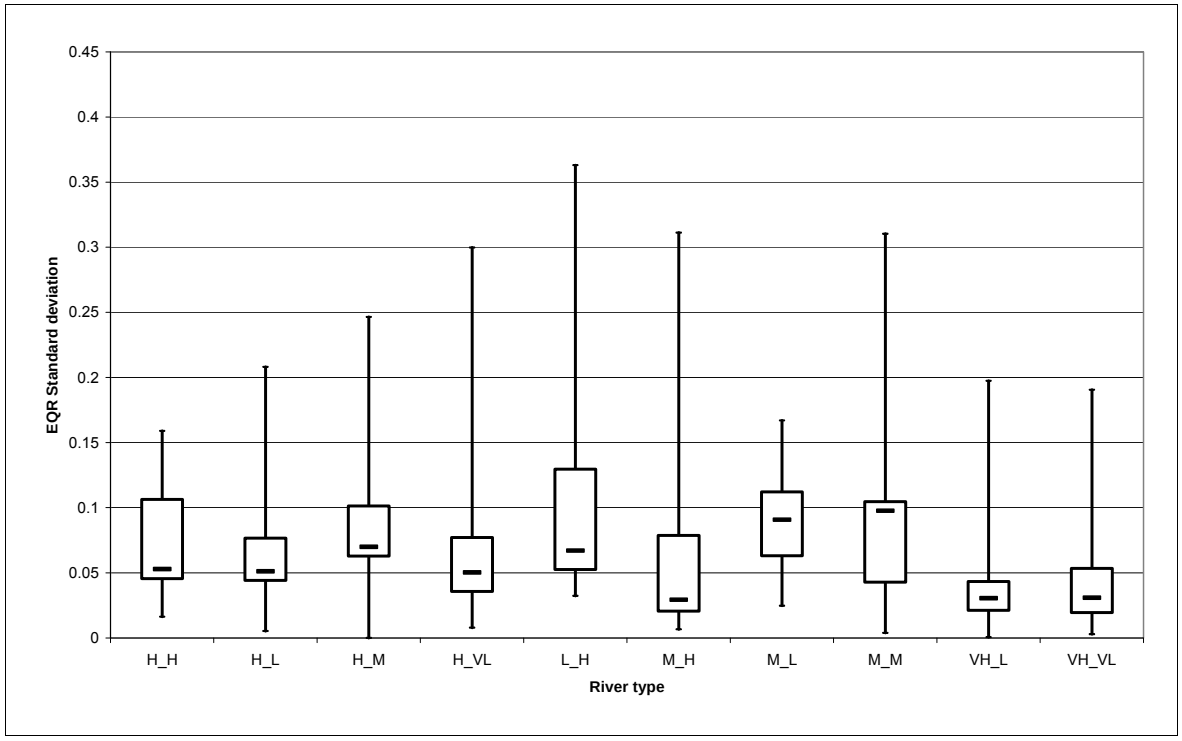


Figure 5.5 Box plots of EQR standard deviations for water bodies in England and Wales classified using River Classification 1.

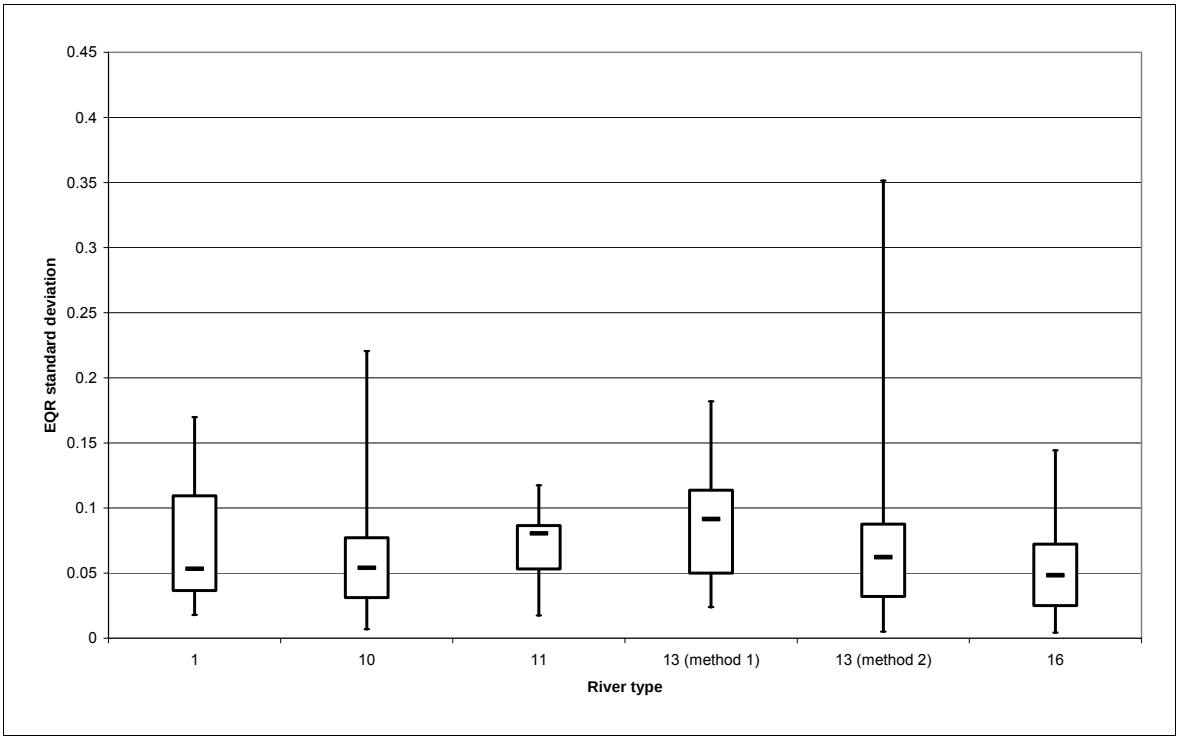


Figure 5.6 Box plots of EQR standard deviations for water bodies in Scotland classified using River Classification 2.

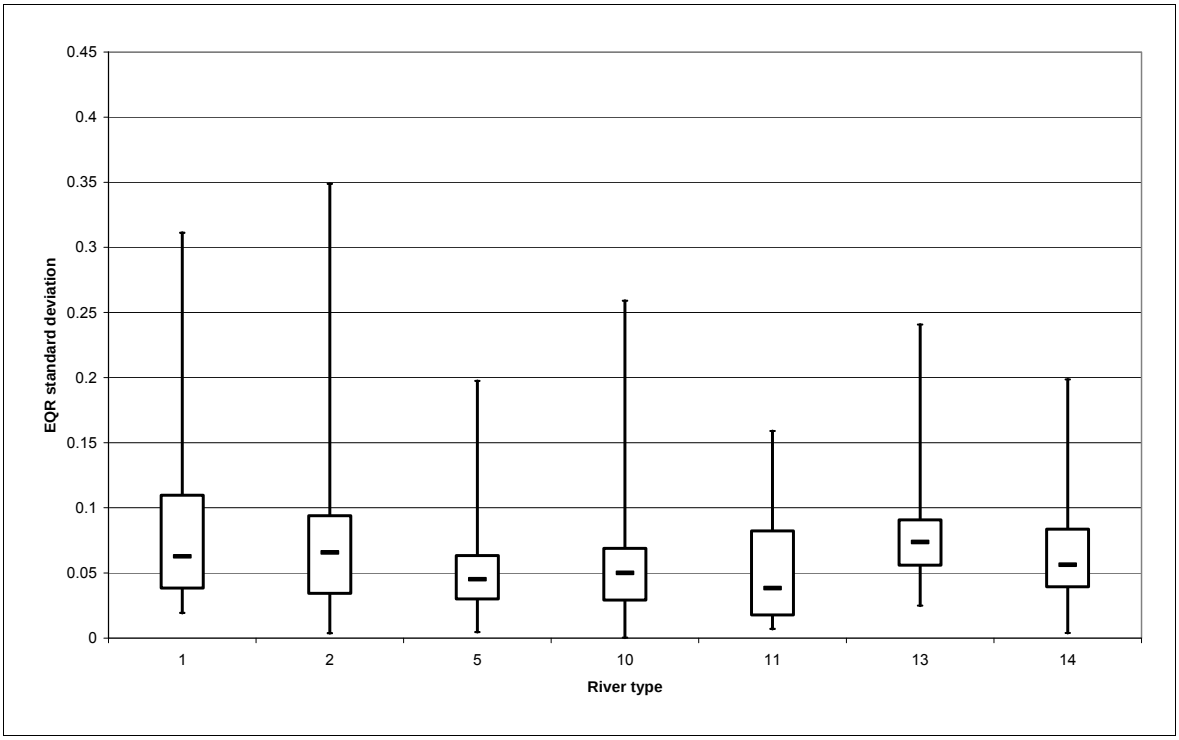


Figure 5.7 Box plots of EQR standard deviations for water bodies in England and Wales classified using River Classification 2.

Figure 5.8 to Figure 5.11 show the within-water body standard deviation in EQR, total cover and number of taxa, expressed as a percentage of the mean value. The results are presented separately for Scotland and England & Wales, and broken down by river

type using both classification systems. As before, the box plots show the median, quartiles, maximum and minimum values across all water bodies and are for survey method 2 (paired 500m) unless otherwise stated. It is apparent that the relative standard deviation is much lower for EQR than for total cover or number of taxa.

To get a better handle on 'local' spatial variability, the relative standard deviation in total cover (%) was calculated for sets of two or three adjacent MTR surveys in the CCW dataset. Figure 5.12 shows the results for six reaches in the Wye catchment. The relative standard deviations ranged from 12 to 53 per cent of the mean and were generally lower than the within-water body variation in total cover for England & Wales reported in Figure 5.11. This suggests that there may be some reach-to-reach variation, but it is difficult to make a direct comparison between the CCW and LEAFPACS datasets.

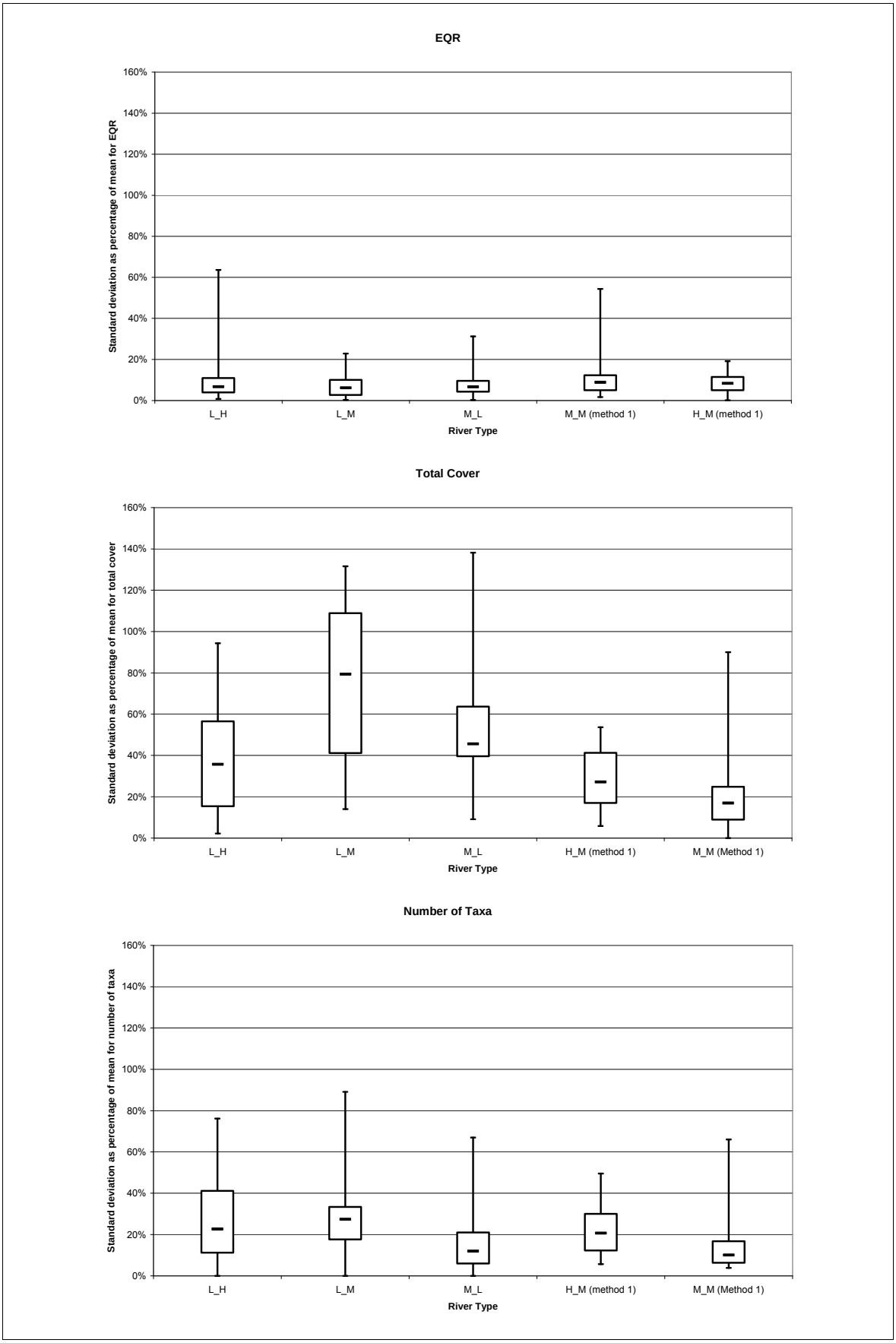


Figure 5.8 Box plots of relative standard deviations for within-water body spatial variation for Scotland using River Classification 1.

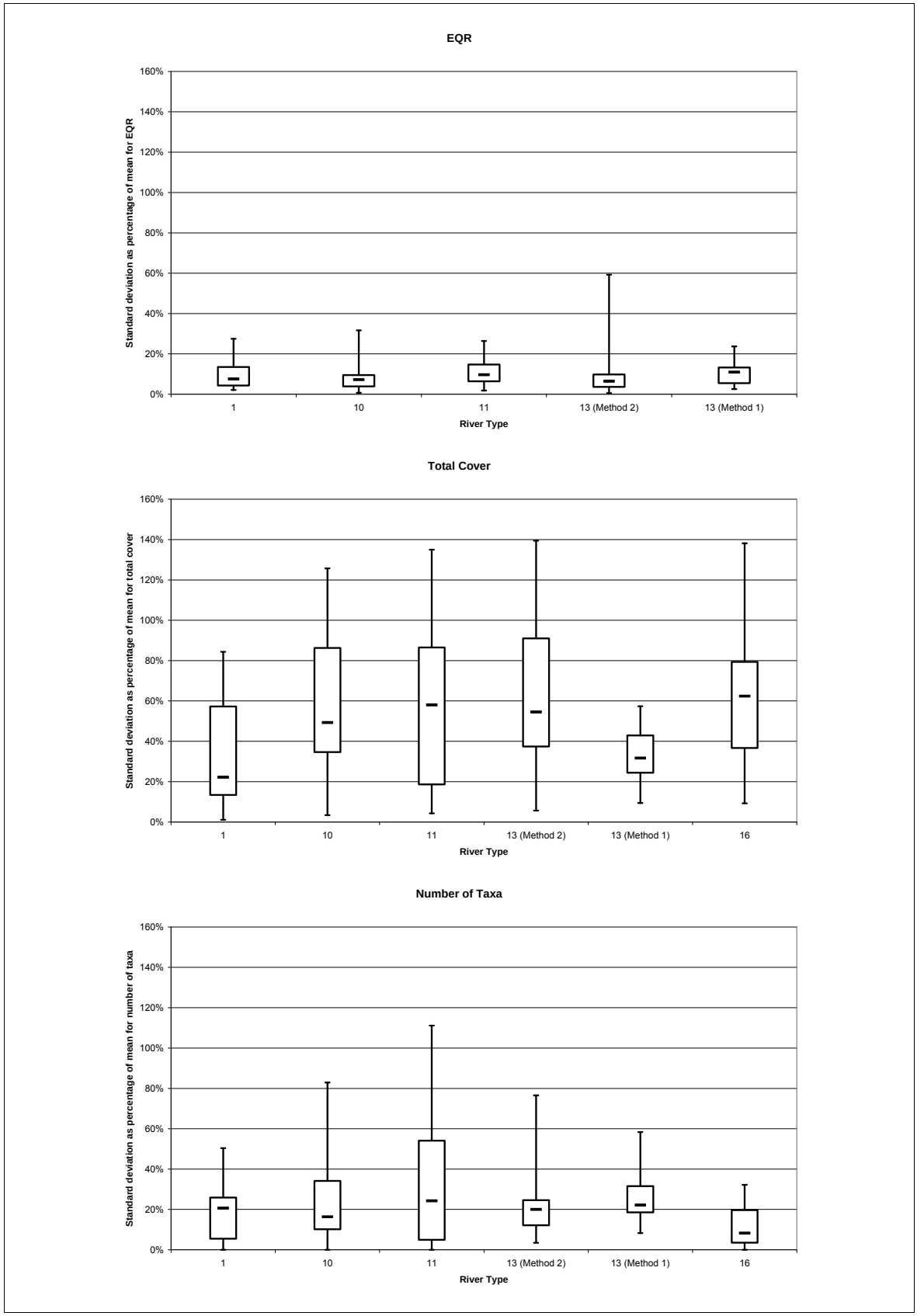


Figure 5.9 Box plots of relative standard deviations for within-water body spatial variation for Scotland using River Classification 2.

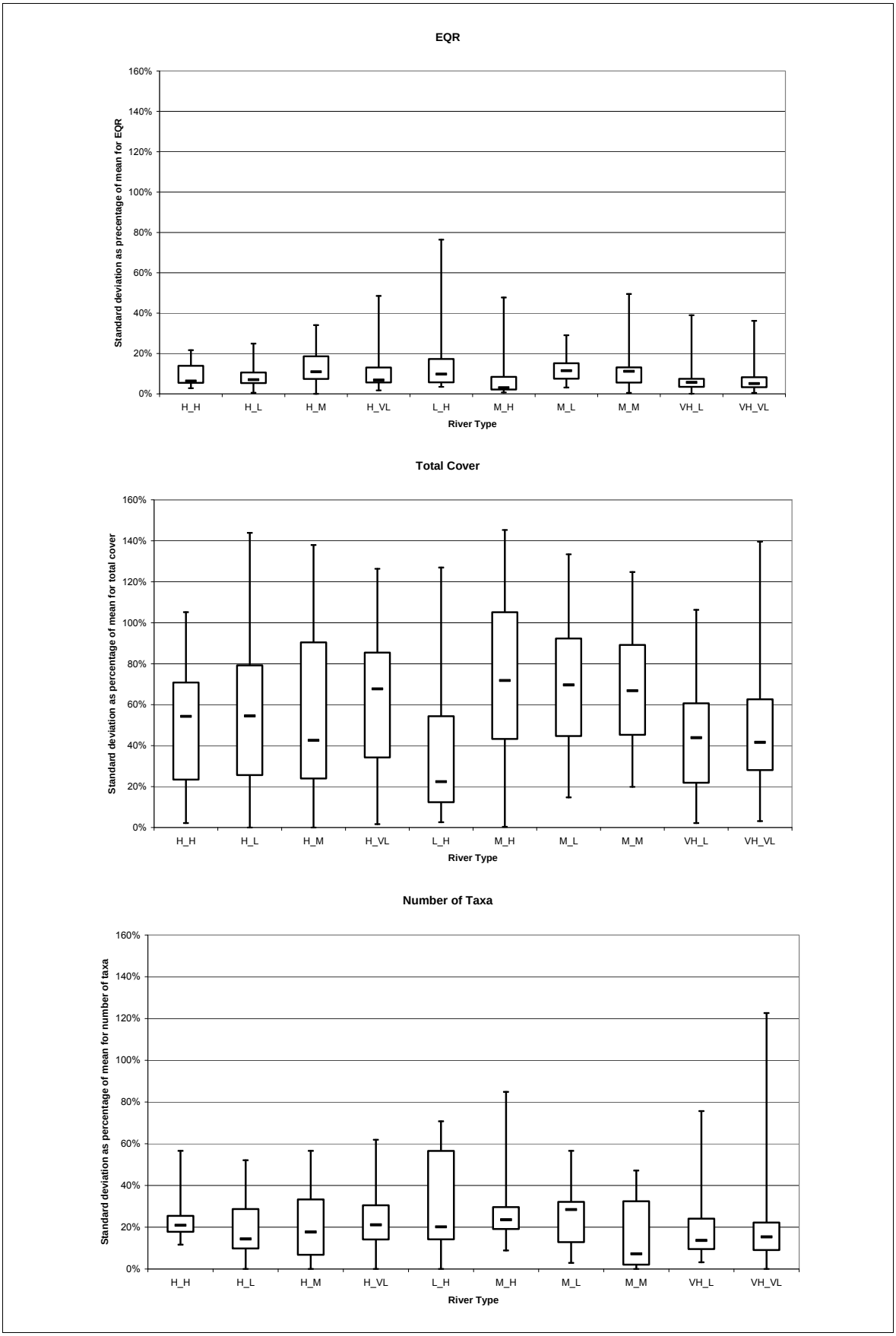


Figure 5.10 Box plots of relative standard deviations for within-water body spatial variation for England and Wales using River Classification 1.

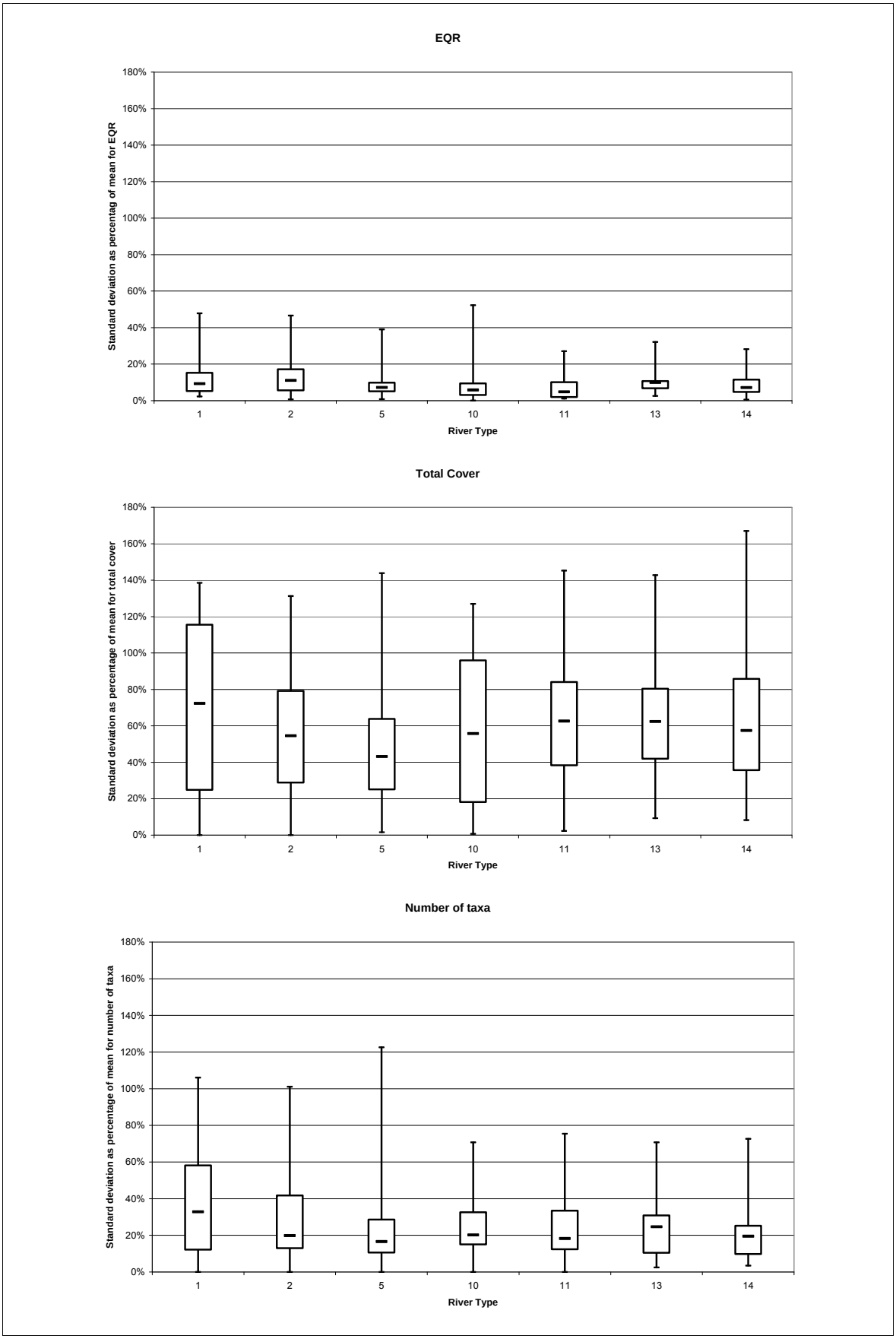


Figure 5.11 Box plots of relative standard deviations for within-water body spatial variation for England and Wales using River Classification 2.

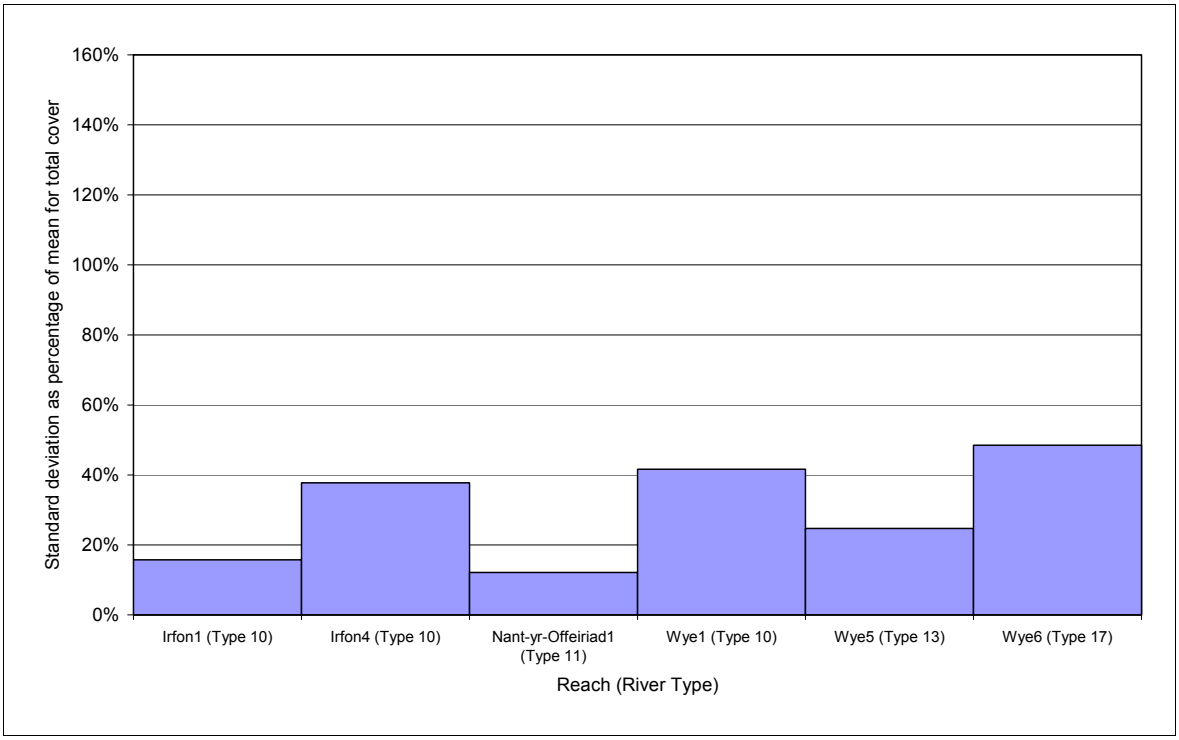


Figure 5.12 Relative standard deviation in total cover for adjacent MTR surveys in six reaches.

5.1.2 Within-water body variation: individual taxa

ANOVA tests were performed to quantify within-water body and within-reach variation in percentage cover of two taxa - *Ranunculus penicillatus ssp pseudofluitans* and *Rhynchostegium riparioides*. The ANOVA results revealed no significant difference between the within-water body and within-reach variation in all the datasets tested. This is the same result as was observed when all taxa were analysed and reinforces the observation that spatial variation in macrophyte communities arises mainly at a local spatial scale, and that there is relatively little systematic variation among reaches.

Box and whisker plots of within-water body relative standard deviations (standard deviations expressed as a percentage of the mean) for each taxon were created to show how spatial variability in the percentage cover of individual taxa can itself vary from water body to water body.

Figure 5.13 shows the results at a national level. The plots are all for method 2 (paired 500m). There were not enough water bodies with *Ranunculus penicillatus ssp pseudofluitans* present in Scotland to create a plot. Therefore, this taxon was only considered at an overall (Great Britain) level. The relative standard deviation for both species was around 140 per cent, and there was little difference between Scotland and England & Wales for *Rhynchostegium riparioides.*

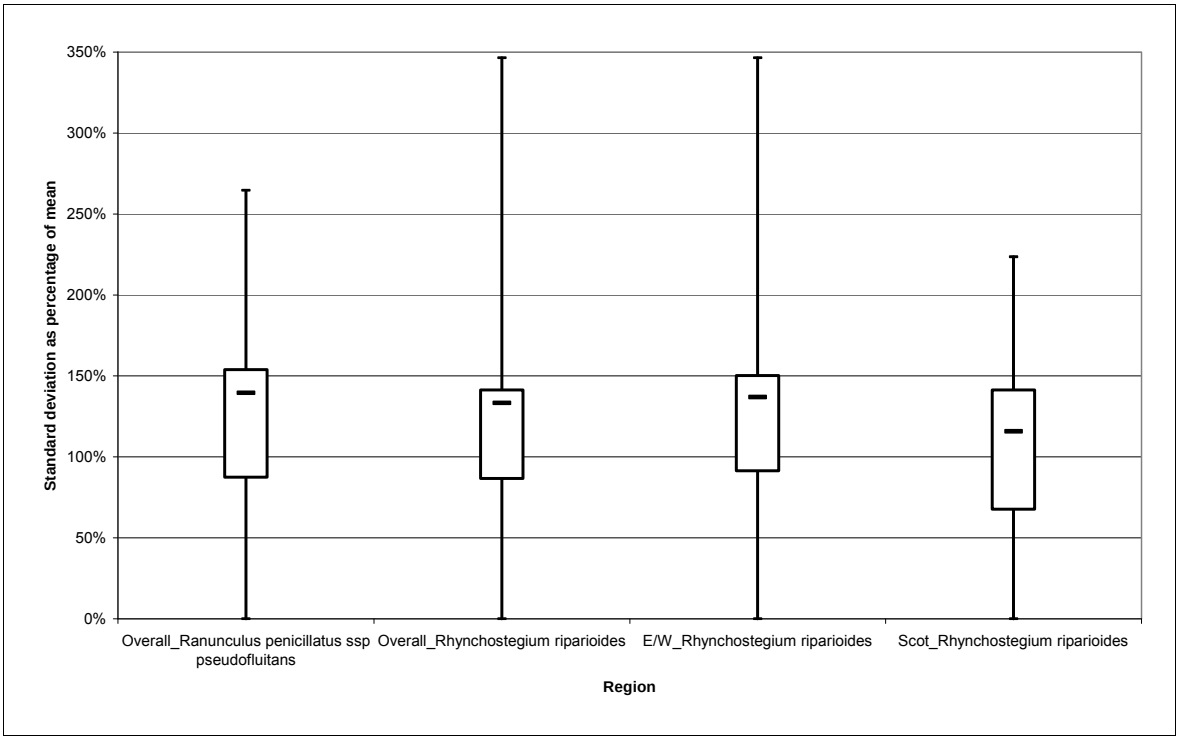


Figure 5.13 Box plots of relative standard deviation for within-water body spatial variation in cover values for two taxa at national level.

Figure 5.14 to Figure 5.17 show box plots for individual river types for which enough data exist. All surveys are method 2 (paired 500m) because there were not enough sites recording these taxa using method 1 (100m). All plots are for England and Wales unless otherwise stated. There are three important points to note. First, some water bodies have very high within-water body spatial variability while others have very low spatial variability. Second, the level of within-water body spatial variability is broadly similar among different river types. Third, the relative standard deviation observed for individual taxa (typically 100-150 per cent of the mean) is much greater than that observed for total percentage cover (typically 20-80 per cent - see Figure 5.8 to Figure 5.11), because the latter smoothes out variation across all taxa. Thus, the abundance of individual taxa is much more spatially variable than community indicators.

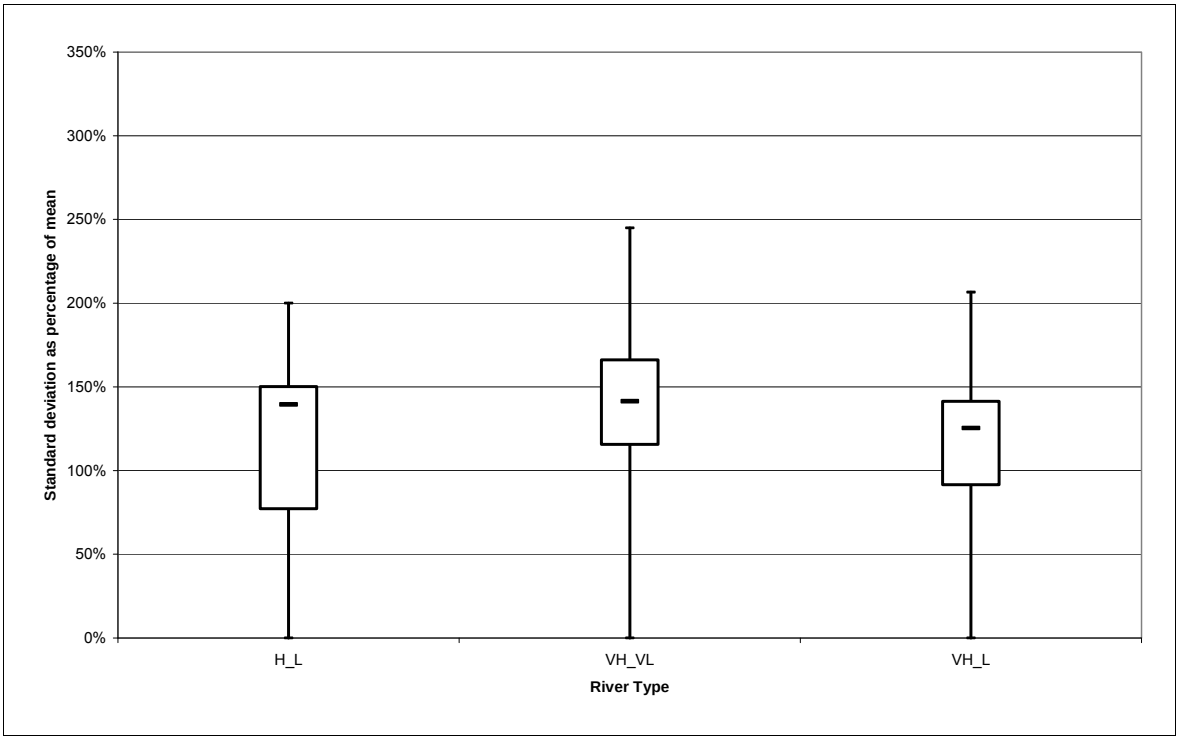


Figure 5.14 Box plots of relative standard deviations for within-water body spatial variation in cover of *Ranunculus penicillatus ssp pseudofluitans* using River Classification 1.

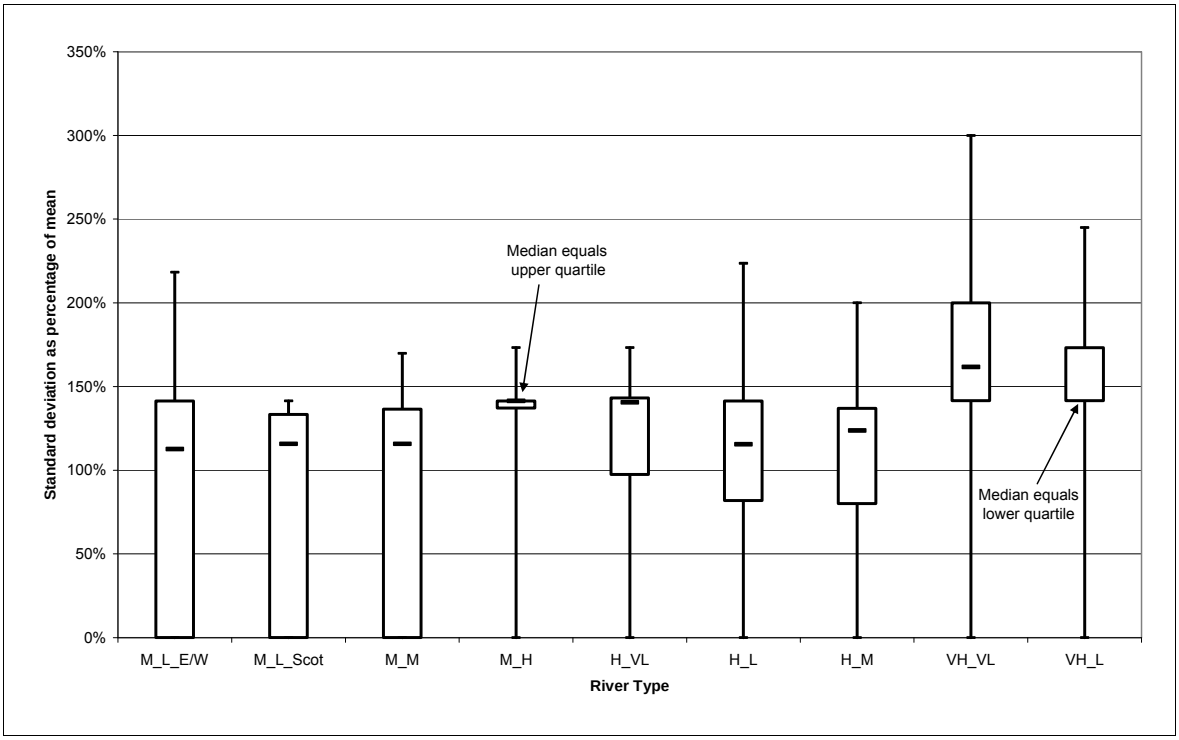


Figure 5.15 Box plots of relative standard deviations for within-water body spatial variation in cover of *Rhynchostegium riparioides* using River Classification 1.

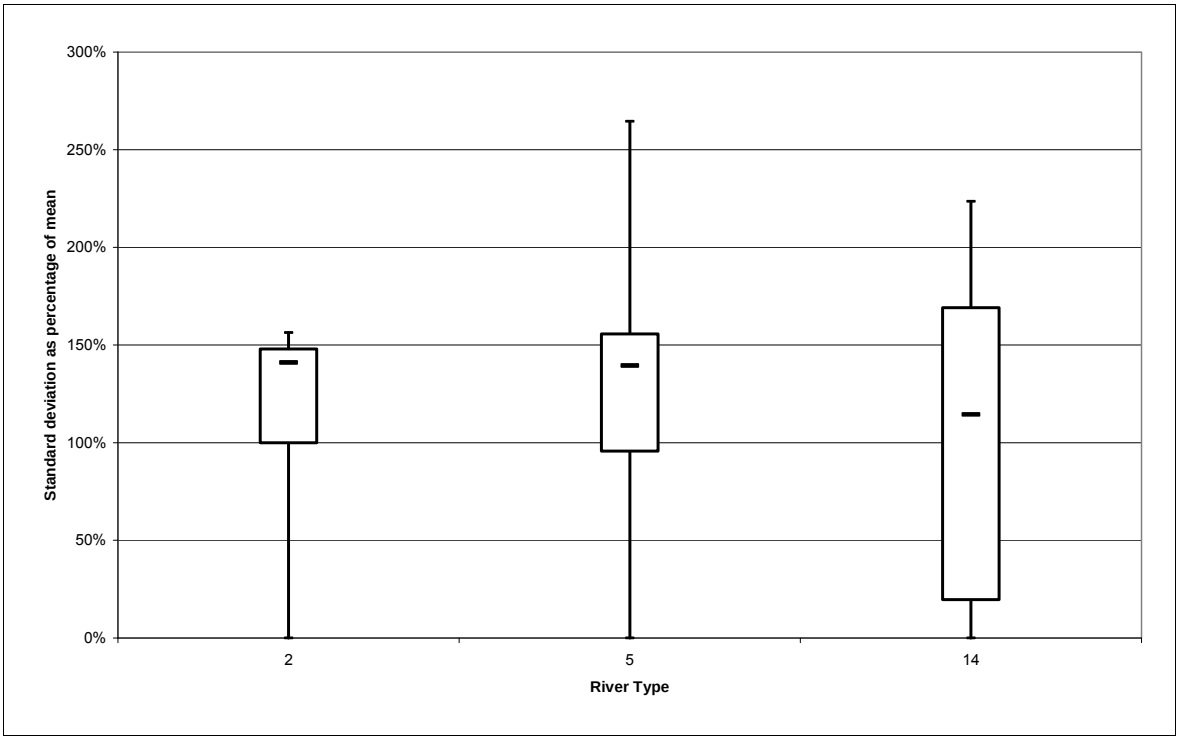


Figure 5.16 Box plots of relative standard deviations for within-water body spatial variation in cover of *Ranunculus penicillatus ssp pseudofluitans* using River Classification 2.

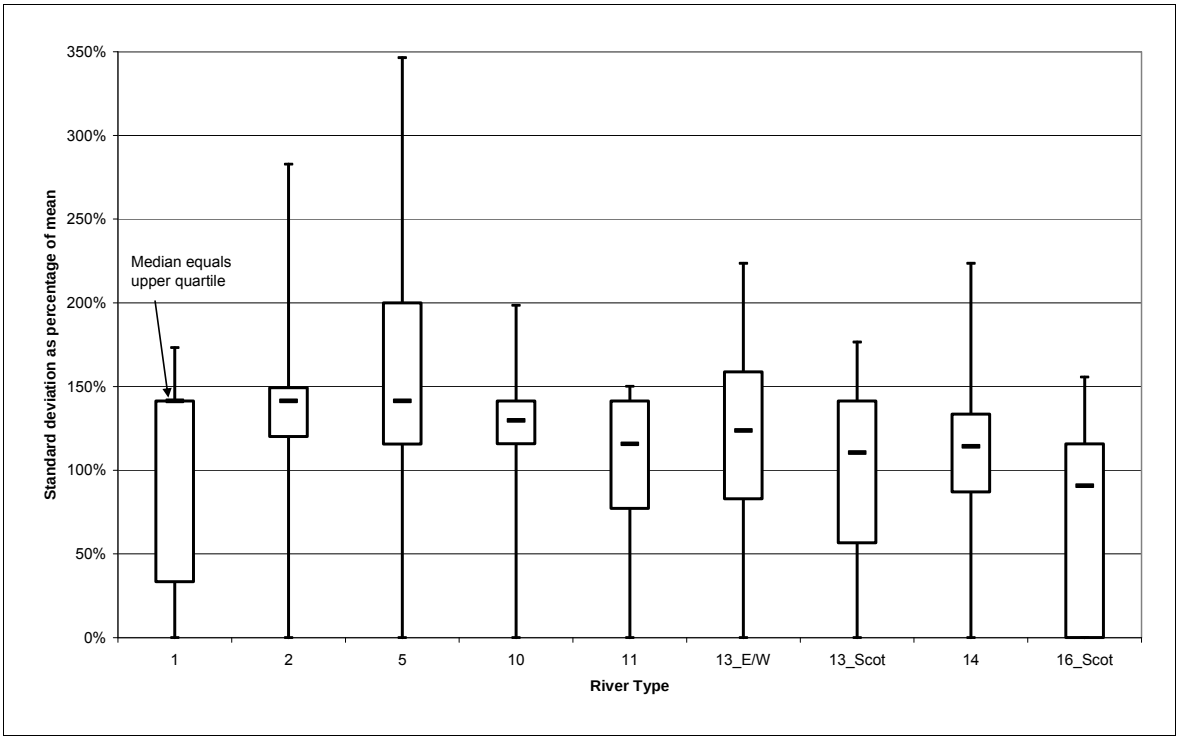


Figure 5.17 Box plots of relative standard deviations for within-water body spatial variation in cover of *Rhynchostegium riparioides* using River Classification 2.

5.1.3 Variation due to survey length

Figure 5.18 shows the relationship between the number of taxa recorded in CCW MTR surveys and total survey length. The analysis found that surveying 200 m of river recorded, on average, 31 per cent more taxa than were recorded in either of the 100-m surveys forming the 200-m length. Surveying 300 m of river recorded an average of 49 per cent more taxa than a 100-m survey. However, there is a relatively high variability in these results from water body to water body. The increase in the number of taxa recorded ranged from seven to 43 per cent for a 200-m survey and from 35 to 59 per cent for a 300-m survey.

As no more than three replicate surveys were conducted in any one reach, it was not possible to determine the asymptotic species richness, nor the length of survey that would be required to record, say, 95 per cent of all taxa. However, the number of taxa recorded is expected to gradually level off with increasing survey length and it is clear that a large number of contiguous 100-m MTR surveys would be required to record all the taxa present in a water body.

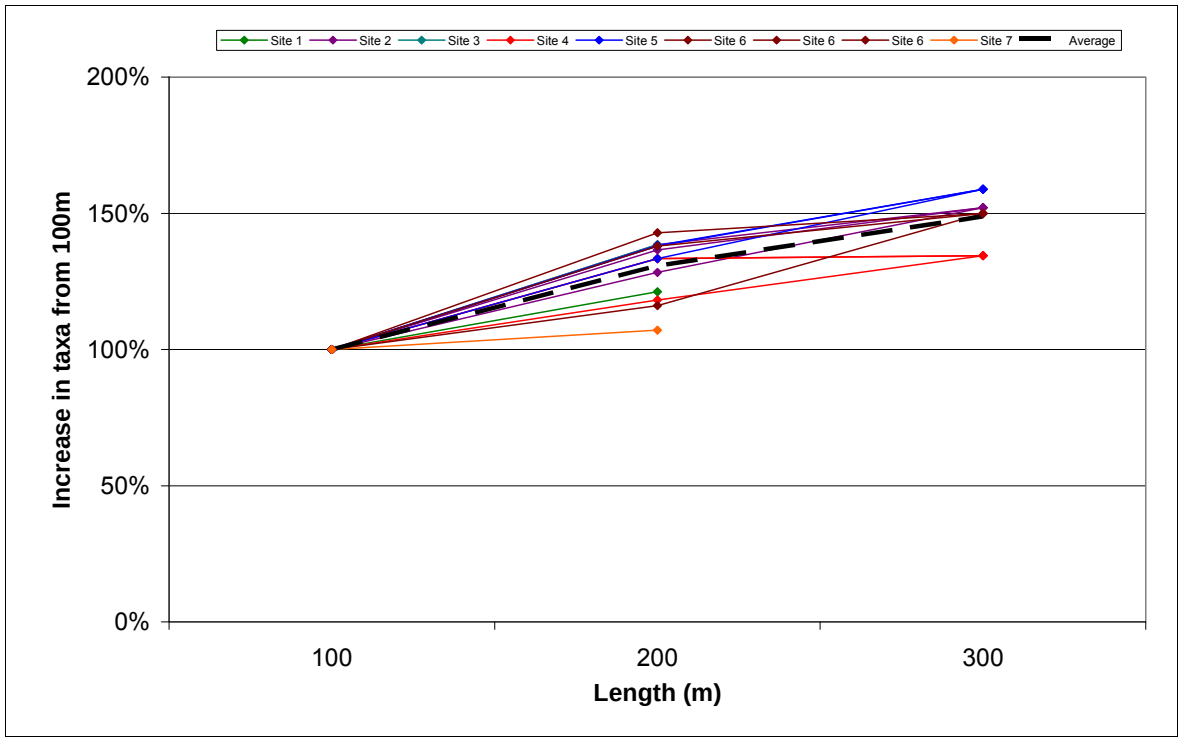


Figure 5.18 Increase in taxa recorded for different survey lengths.

The percentage increases from 100 m for each site for different lengths are shown in Table 5.2. This also includes the 500-m JNCC results for sites where such a survey was performed at the same time as an MTR survey. The results suggest that the MTR and JNCC methods are not directly comparable; at three sites where a JNCC and MTR survey had been performed together, the number of species recorded by the JNCC survey was lower than the total recorded in the three x 100-m MTR surveys. At one site the 500-m JNCC survey actually recorded fewer taxa than an individual 100-m MTR survey. Thus, the survey method appears to have a greater impact on the number of taxa recorded than the length of the survey.

Table 5.2 Number of individual taxa found for different surveys lengths as a percentage of that found in an average 100-m survey length.

Site	1st 200m (%)	2nd 200m (%)	3rd 200m (%)	300m (%)	JNCC (500m) (%)
1	21.2	-	-	-	-
2	38.5	36.6	28.3	52.1	-
3	38.5	-	-	-	-
4	18.2	33.3	33.3	34.5	-
5	33.3	37.9	38.2	58.8	-
6	16.1	37.9	42.9	50.0	-
7	7.1	-	-	-	-
8	-	-	-	-	30.0
9	-	-	-	-	-16.7
10	-	-	-	-	33.3

Clearly, a 100-m survey will record only a proportion of the taxa present in a reach, and an even smaller proportion of the taxa present in the water body. This reinforces the importance of local spatial variability noted in Section 5.1.1, and means that shorter length surveys will be subject to a higher level of variability between surveys than those of longer length. Ultimately, small-scale variation in microhabitat availability is likely to drive the positive relationship between survey length and number of taxa; longer surveys are more likely to sample a larger number of microhabitats and therefore have a larger number of unique taxa than shorter surveys.

5.2 Temporal variability

5.2.1 Annual variation

The results of the surveys performed in successive years for the three highlighted water bodies are shown in Figure 5.19 to Figure 5.21. There was relatively little variation in EQR from year to year, but greater variation for number of taxa and total cover. The results from the ANOVA tests confirmed that random variability between successive years was generally low as the majority of the tests found no significant differences between the years.

To quantify the level of annual variation, the average value of each indicator was calculated for each year and the standard deviation of these annual averages was computed. Absolute and relative standard deviations for the three selected water bodies are presented in Table 5.3 and Table 5.4, respectively. Again, EQR showed the lowest annual variation and number of taxa showed the greatest variation. However, it should be remembered that some of the variation shown in these values may result from local spatial variation as these values were calculated at water body level.

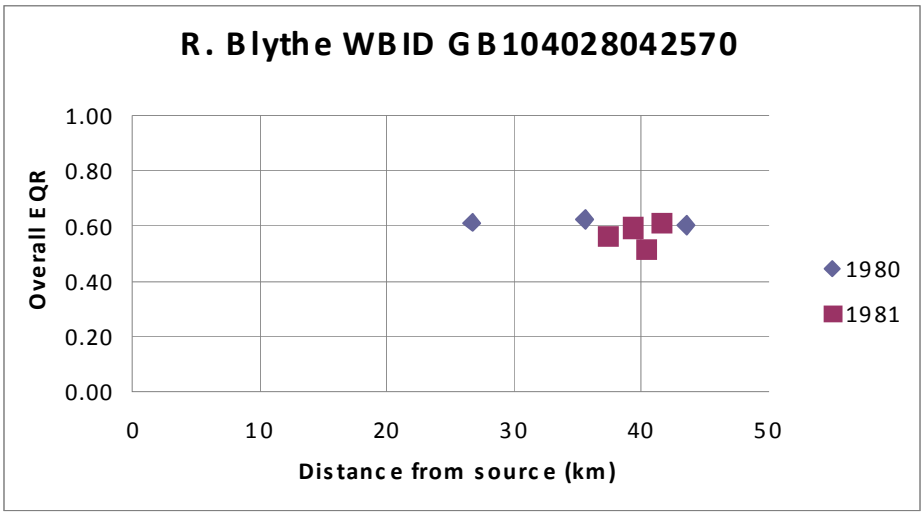
Table 5.3 Standard deviations for average indicator values for successive years.

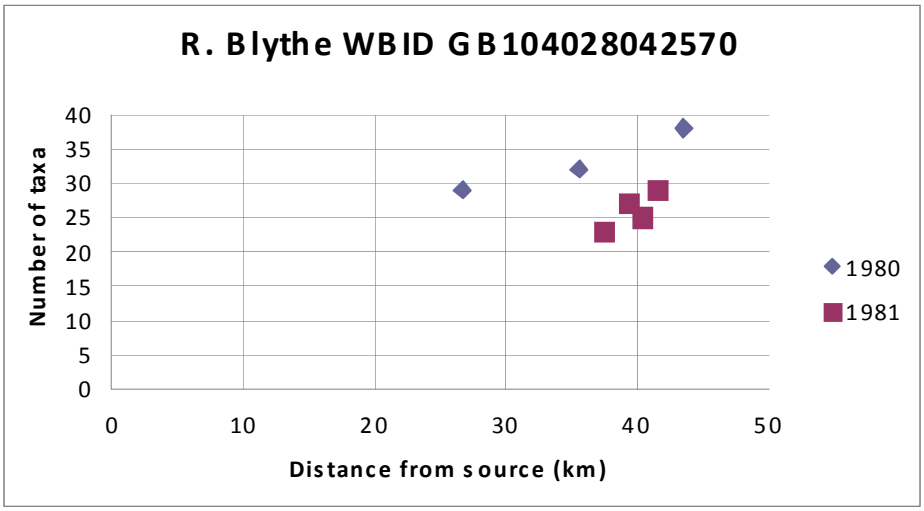
WBID	EQR	Number of taxa	Total cover
GB104028042570	0.028	4.950	2.790
GB105033047921	0.021	5.382	3.135
GB112071065610	0.017	4.302	1.847

Table 5.4 Relative standard deviations for annual variation (as %).

WBID	EQR	Number of taxa	Total cover
GB104028042570	4.79	17.07	5.47
GB105033047921	3.47	17.21	10.37
GB112071065610	2.22	18.03	6.41

It should also be remembered that the analysis focuses only on surveys conducted in successive years; to test whether the magnitude of annual variation increases with duration between surveys and whether there is a long-term temporal trend would require a more comprehensive dataset with surveys performed on the same water body over several successive years.





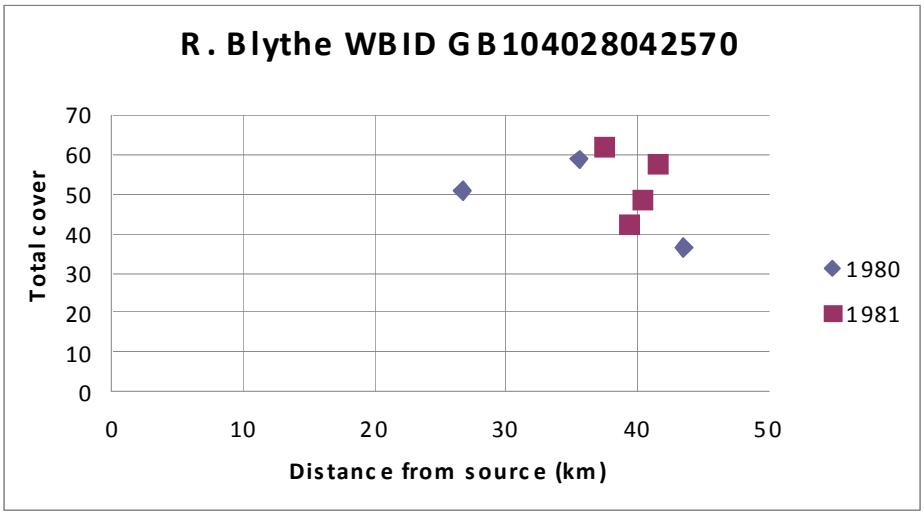
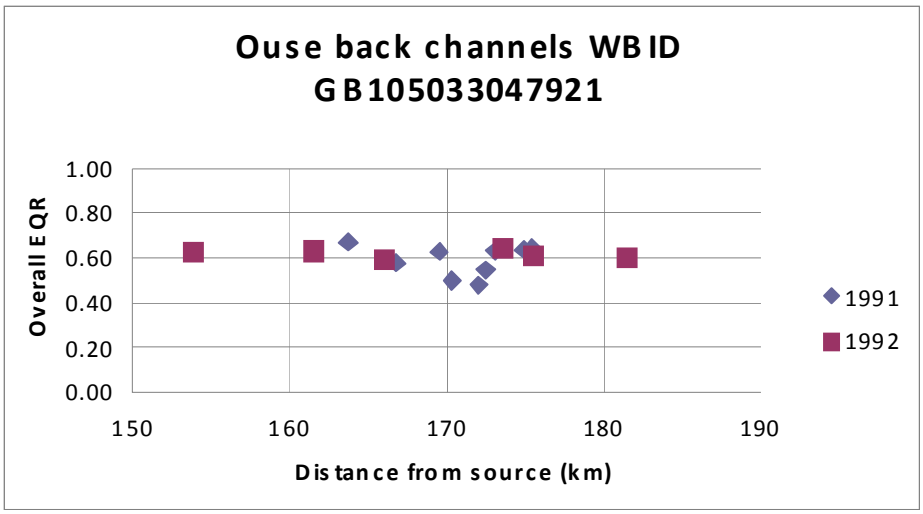
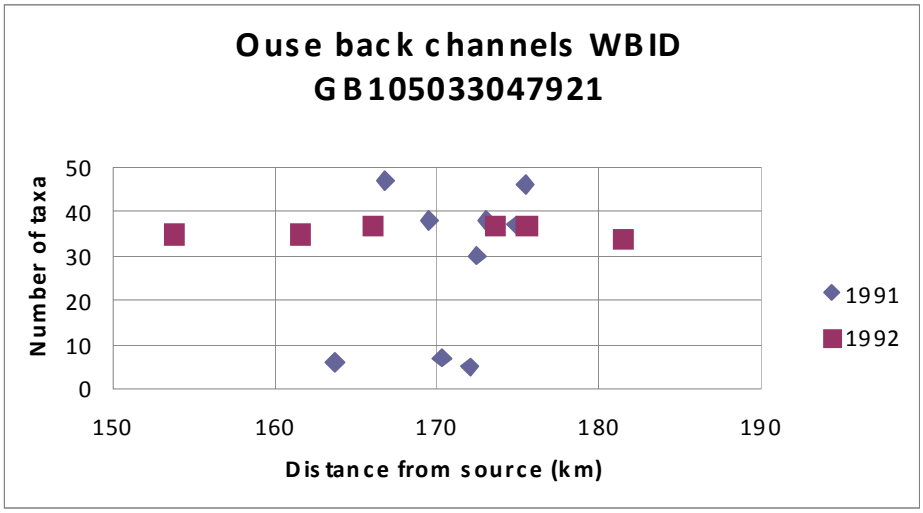


Figure 5.19 Results of surveys performed in successive years GB104028042570.





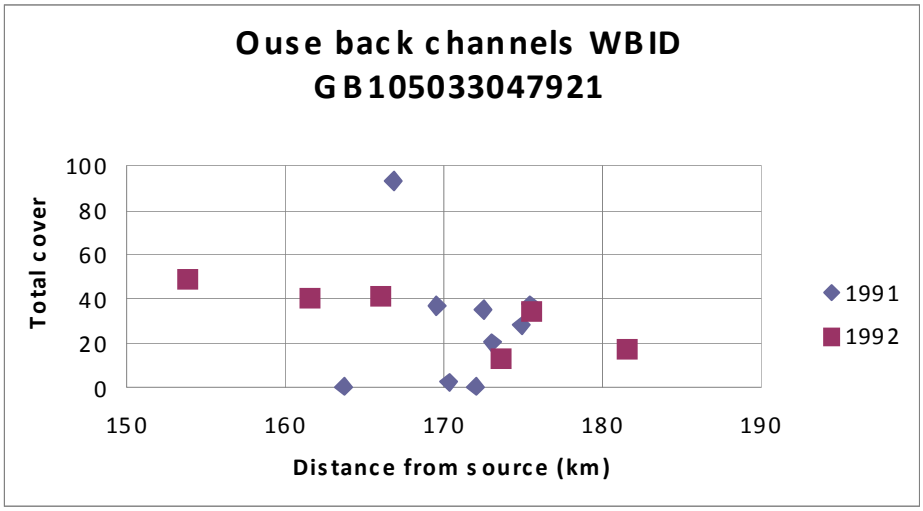


Figure 5.20 Results of surveys performed in successive years GB105033047921.

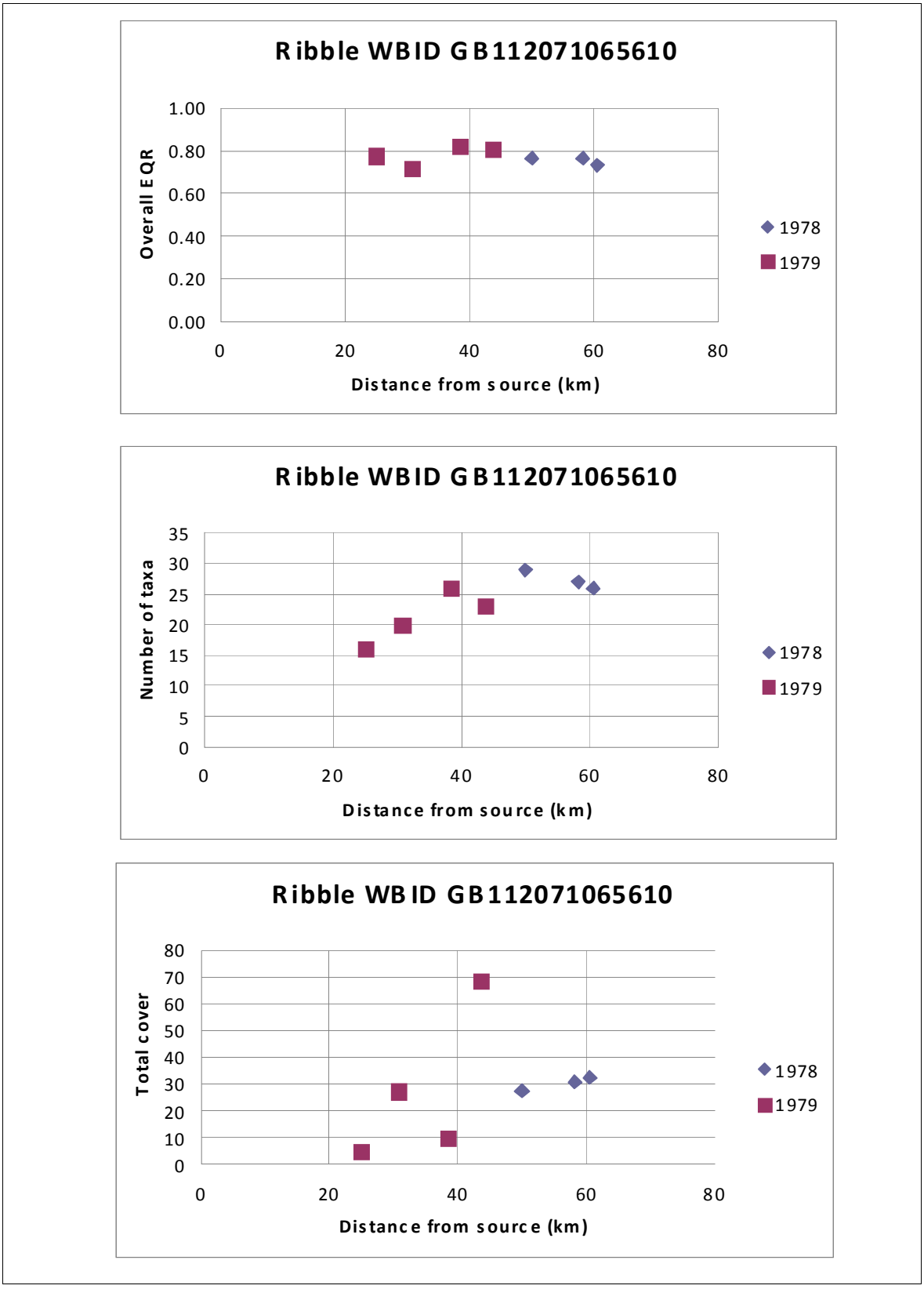


Figure 5.21 Results of surveys performed in successive years GB112071065610.

5.2.2 Monthly variation

An examination of the changes from month to month across a range of water bodies was undertaken. As explained in Section 4.2 the type and quality of the different water bodies may influence the results of this analysis.

The analysis found statistically significant differences between months for overall EQR, number of taxa and total cover (Figure 5.22 to Figure 5.24). EQR was the least variable indicator; total cover was the most variable. There was, however, no consistent seasonal pattern among the three groups of water bodies (survey method 1 (100m) , mostly Scotland; survey method 2 (paired 500m), England and Wales; and survey method 2, Scotland), suggesting that any variation from month to month was not systematic and predictable, but rather driven by other random sources of variation.

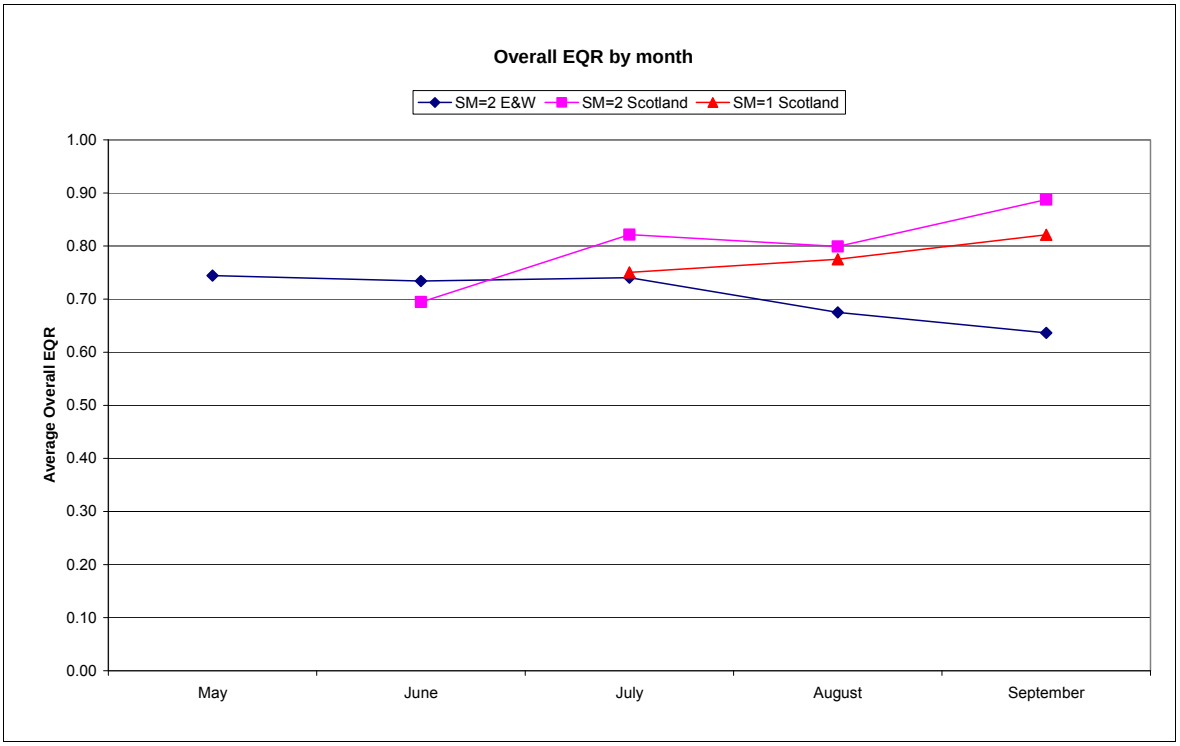


Figure 5.22 Overall EQR by month.

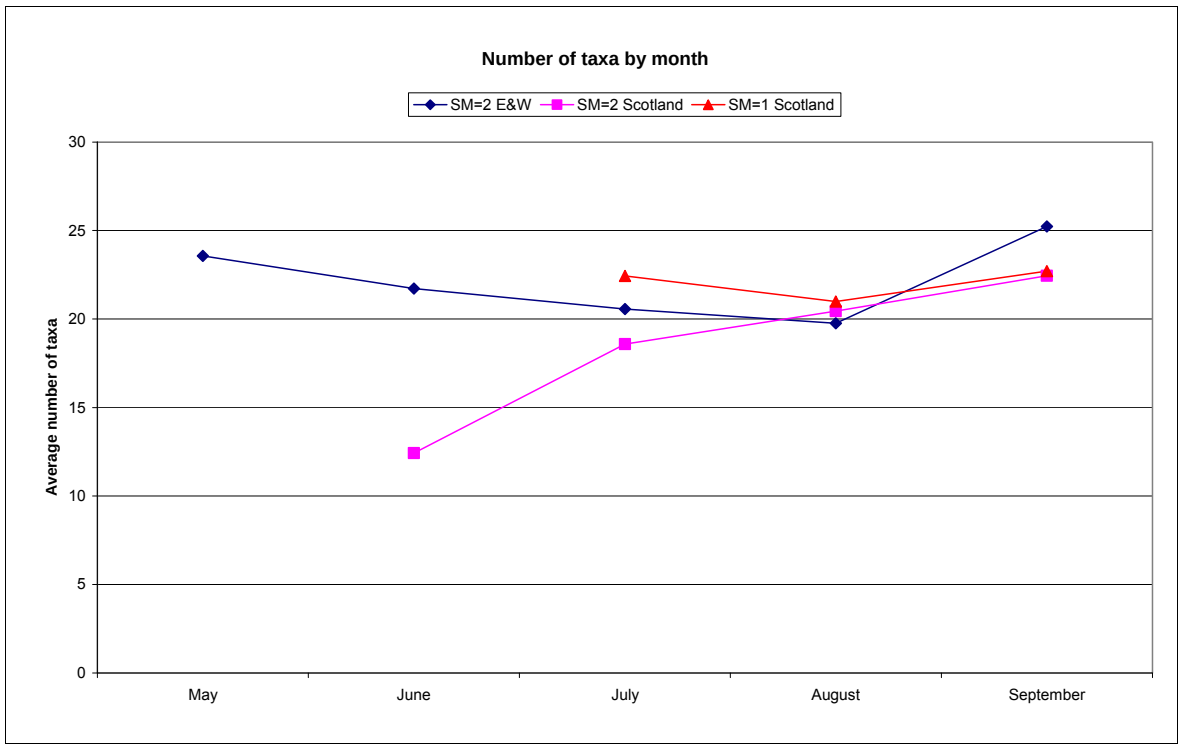


Figure 5.23 Average number of taxa by month.

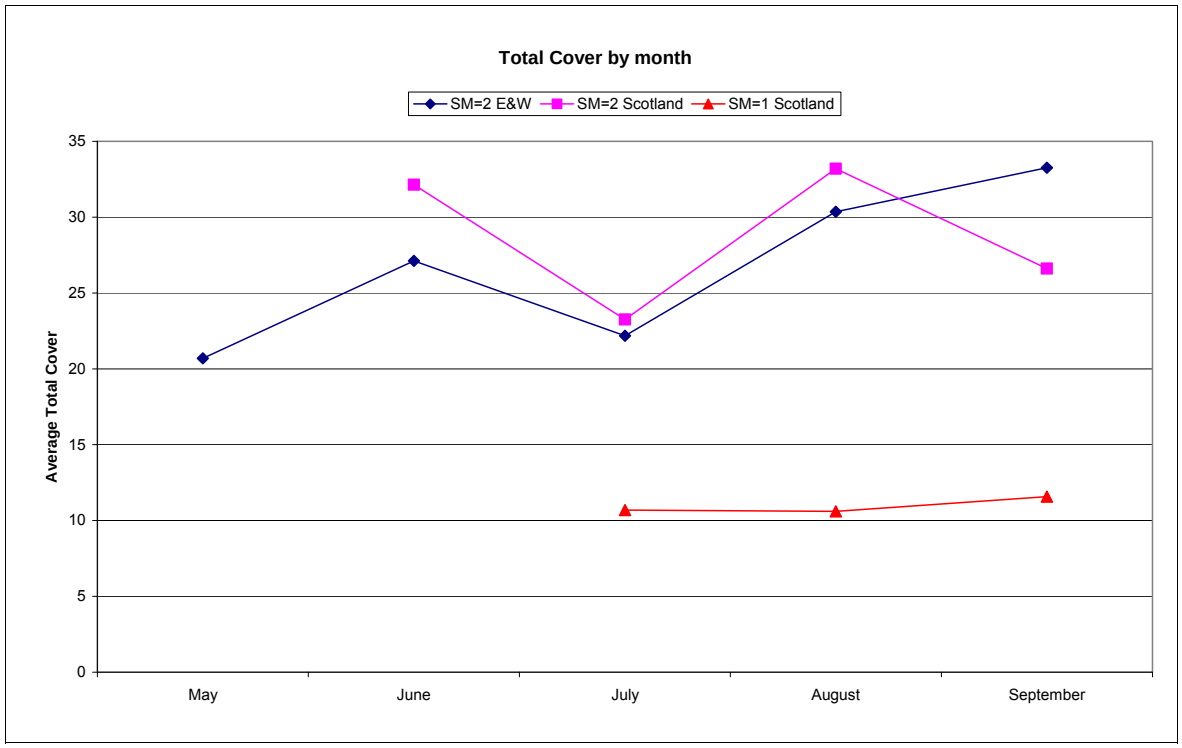


Figure 5.24 Average total cover by month.

5.3 Fitting power curves to EQR standard deviations

Figure 5.25 to Figure 5.38 show the overall within water body EQR standard deviation plotted against the mean EQR for that water body. Separate plots are given according to method, country and river type. Polynomial curves describing the 'upturned wok' shape of the relationships are shown in red.

The important point to note is that most water bodies have a mean EQR greater than 0.5 (only five per cent have an EQR of less than 0.47). As the polynomial curves are anchored at both ends, this causes difficulties in fitting reliable and meaningful curves. In some cases, for example Figure 5.26, the curve is skewed to the left, suggesting that maximum variability occurs in water bodies with an EQR of around 0.8. In other cases, for example Figure 5.25, where a single water body with a low mean EQR happens to have a very high within-water body standard deviation, the curve is skewed strongly to the right.

Thus, although it is possible to fit a polynomial curve, in most cases there is either limited evidence that the within-water body standard deviation is related to mean EQR, or insufficient data to produce a reliable curve. For these reasons, it was considered that producing similar curves using water bodies classified using River Classification 2 was unlikely to add much new information.

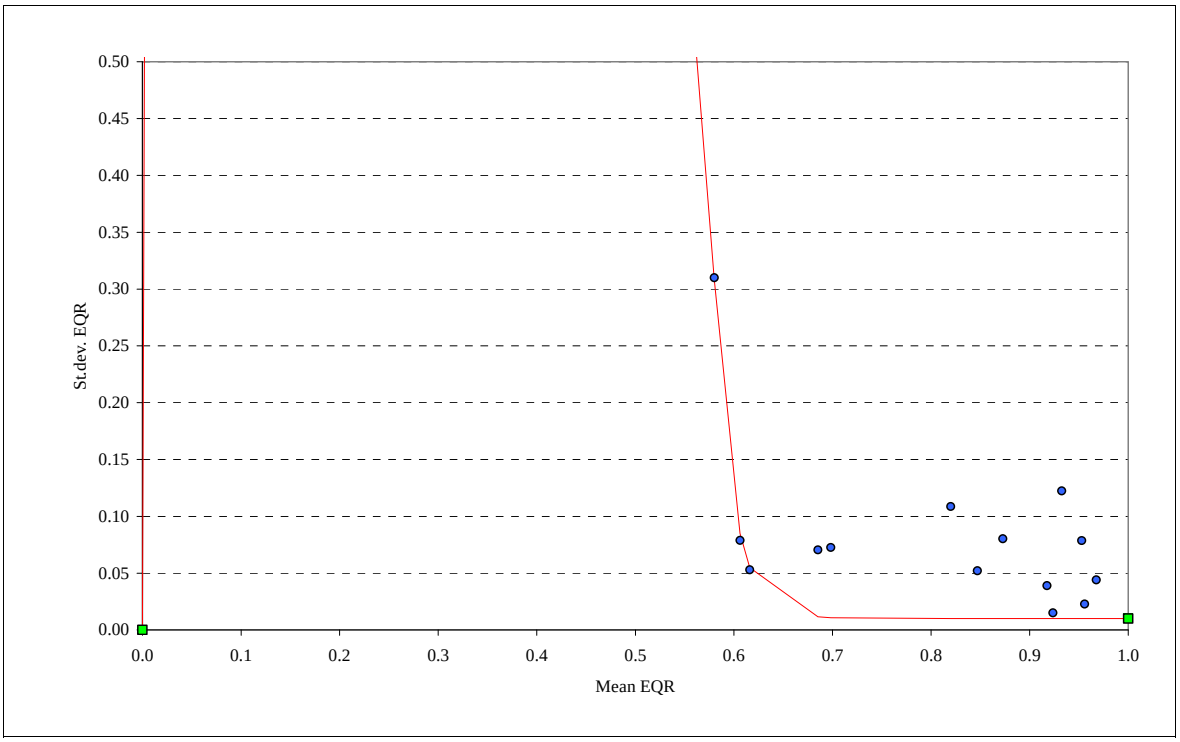


Figure 5.25 EQR within-water body variation for river type H_M in Scotland using method 1 (100m).

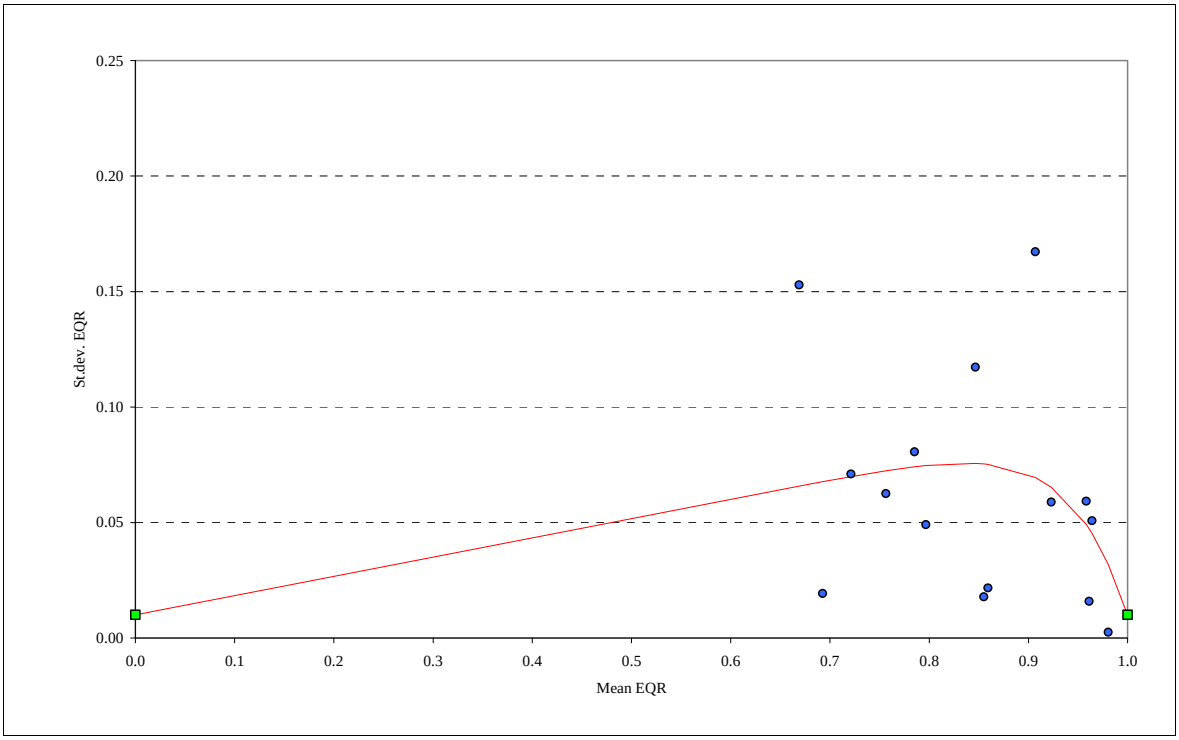


Figure 5.26 EQR within-water body variation for river type L_M in Scotland using method 2 (paired 500m).

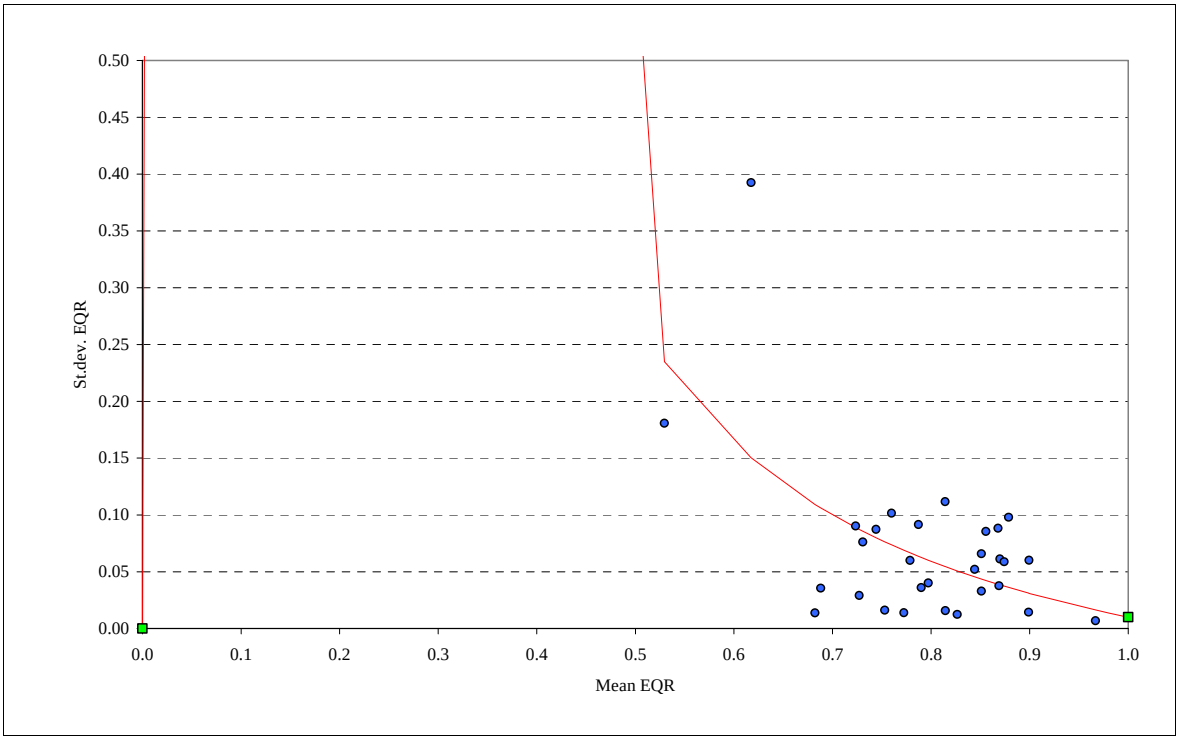


Figure 5.27 EQR within-water body variation for river type L_H in Scotland using method 2 (paired 500m).

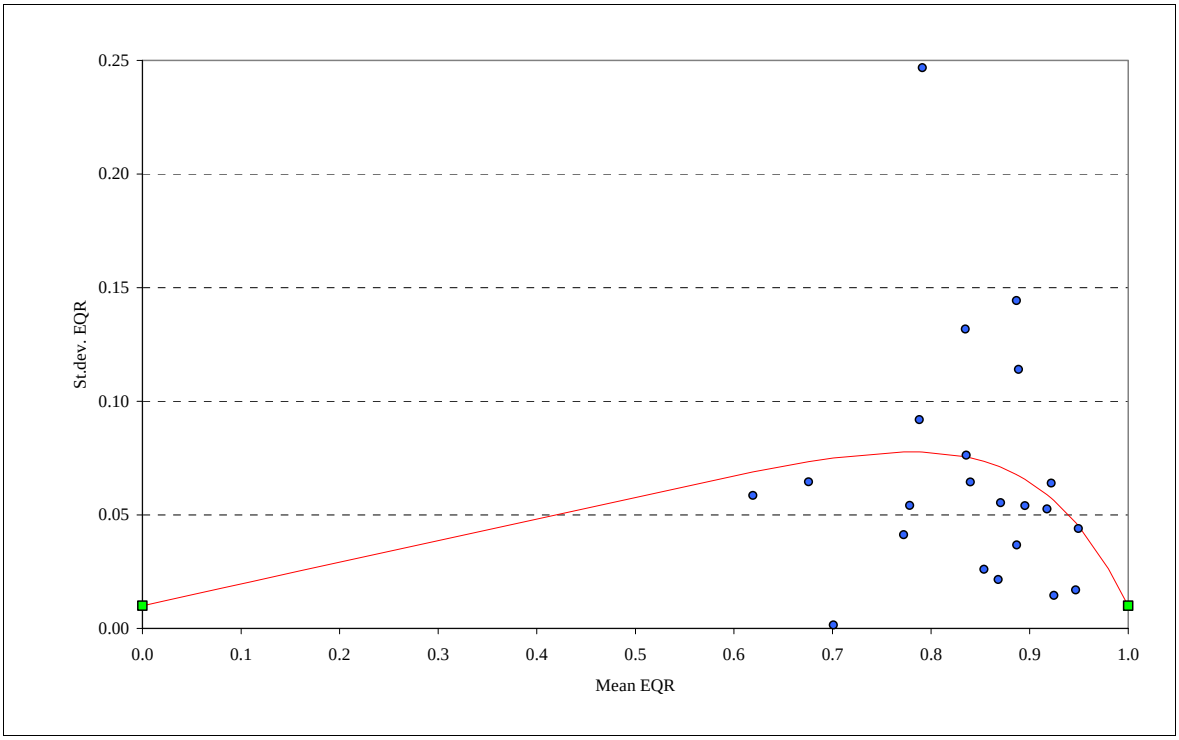


Figure 5.28 EQR within-water body variation for river type M_L in Scotland using method 2 (paired 500m).

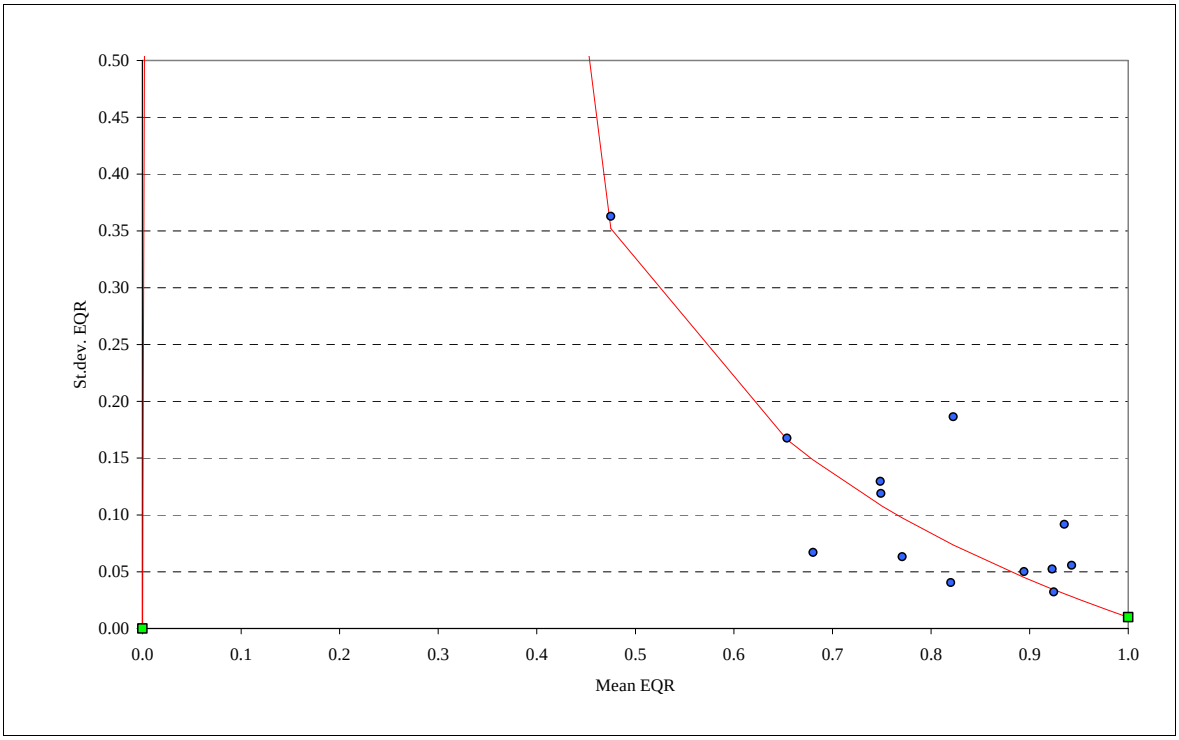


Figure 5.29 EQR within-water body variation for river type L_H in England and Wales using method 2 (paired 500m).

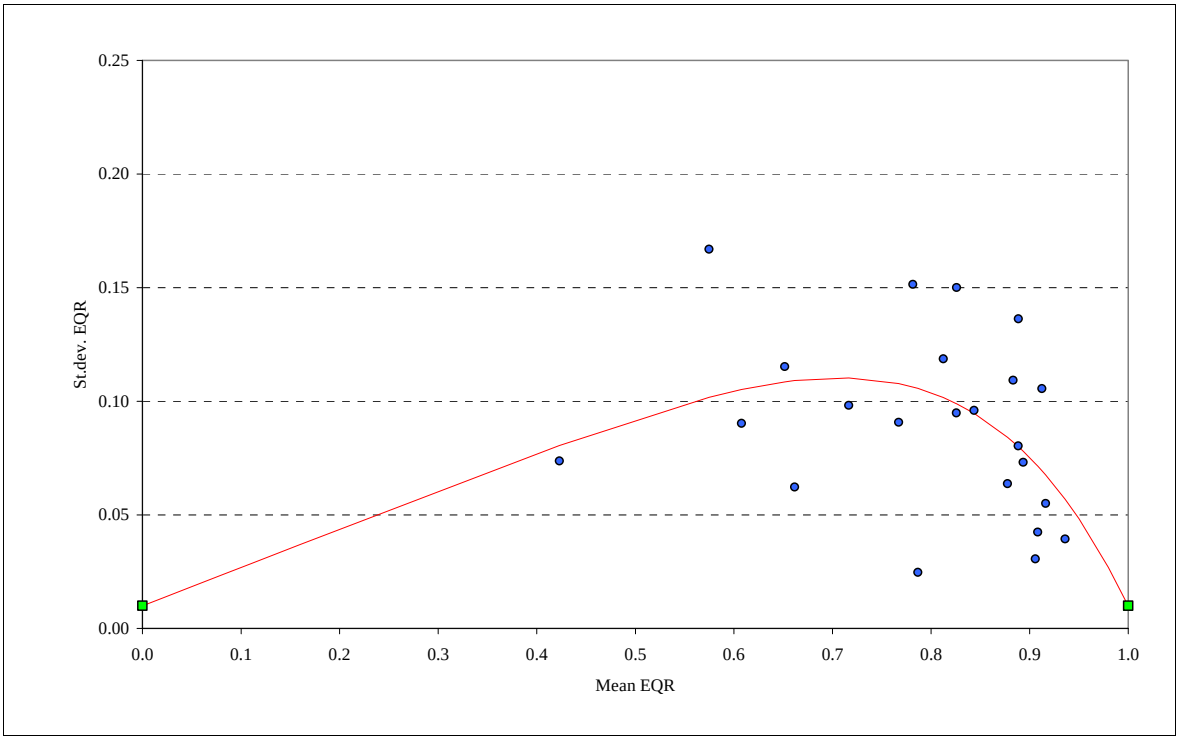


Figure 5.30 EQR within-water body variation for river type M_L in England and Wales using method 2 (paired 500m).

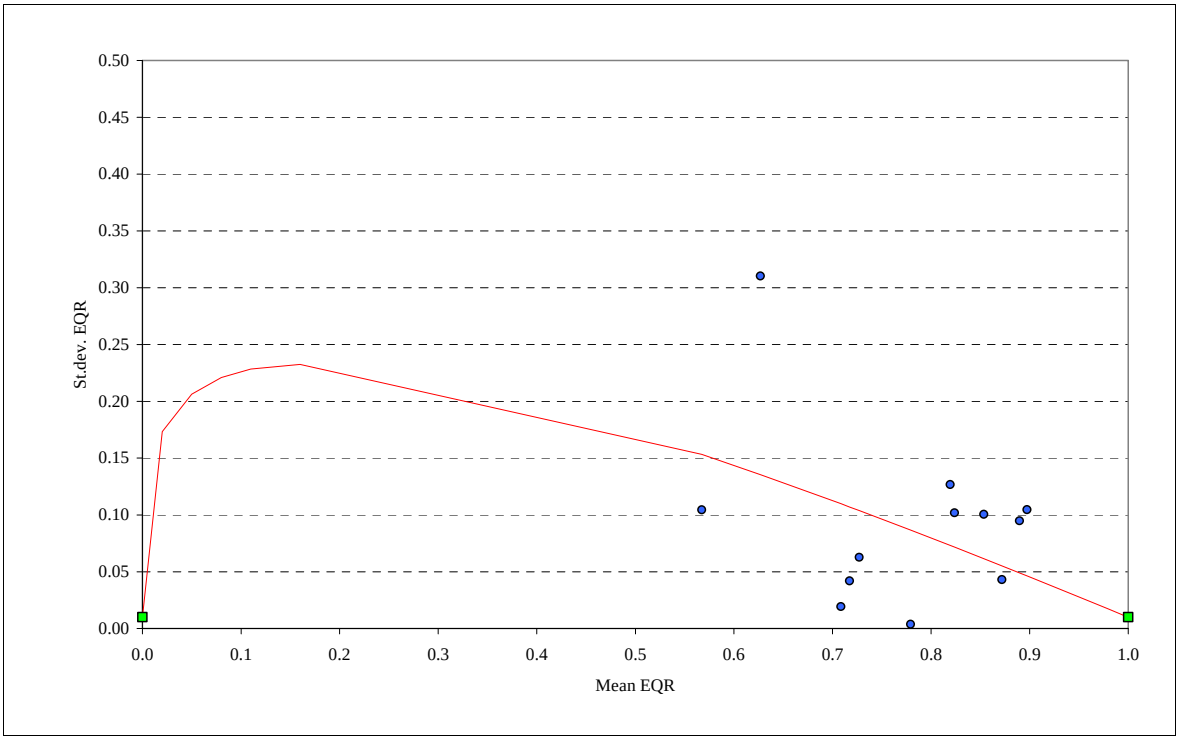


Figure 5.31 EQR within-water body variation for river type M_M in England and Wales using method 2 (paired 500m).

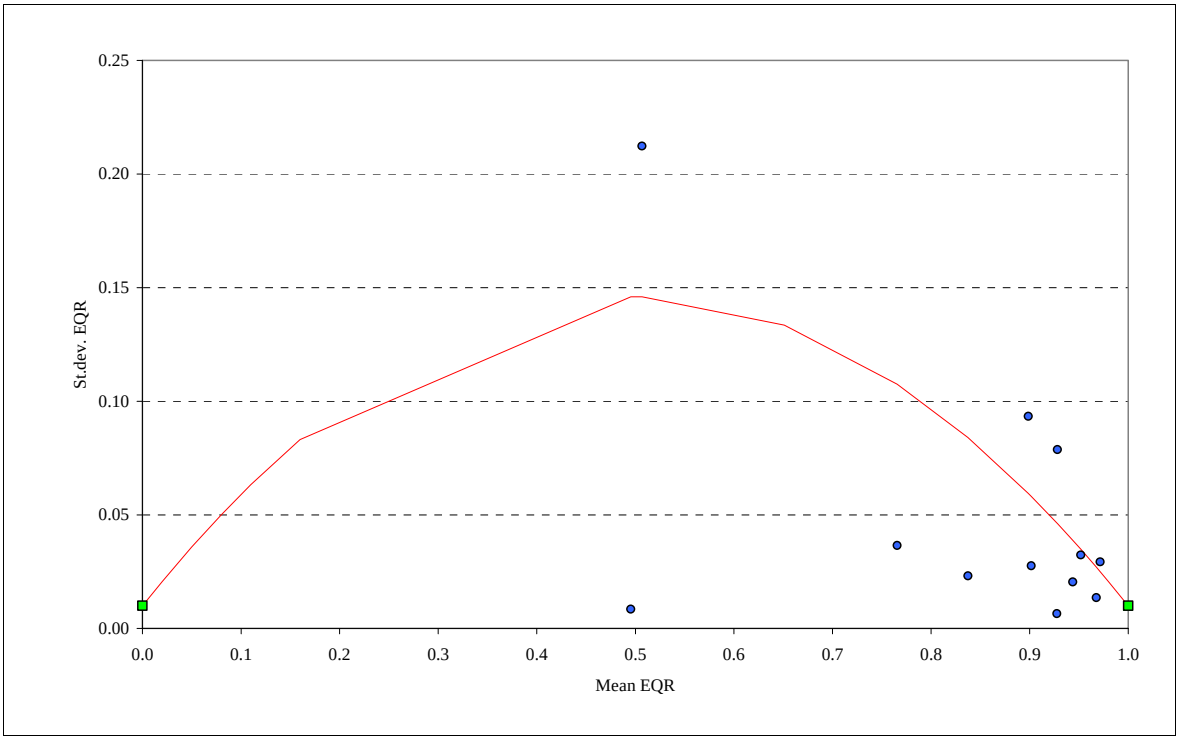


Figure 5.32 EQR within-water body variation for river type M_H in England and Wales using method 2 (paired 500m).

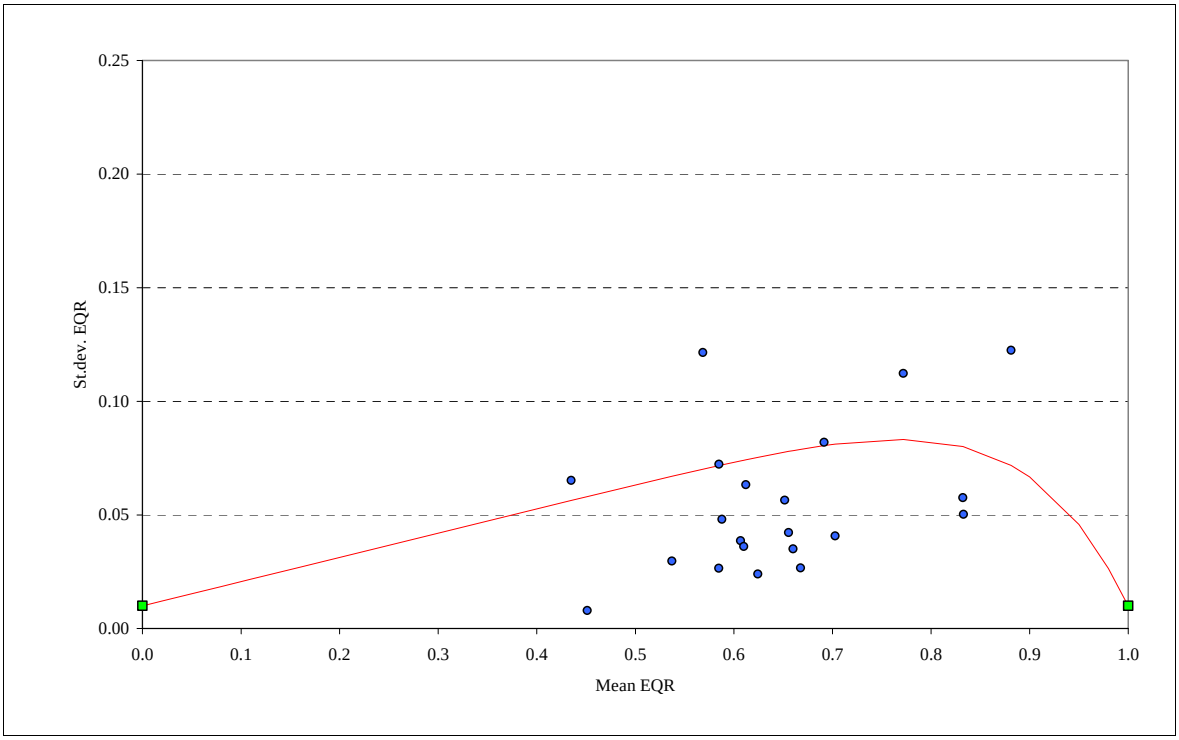


Figure 5.33 EQR within-water body variation for river type H_VL in England and Wales using method 2 (paired 500m).

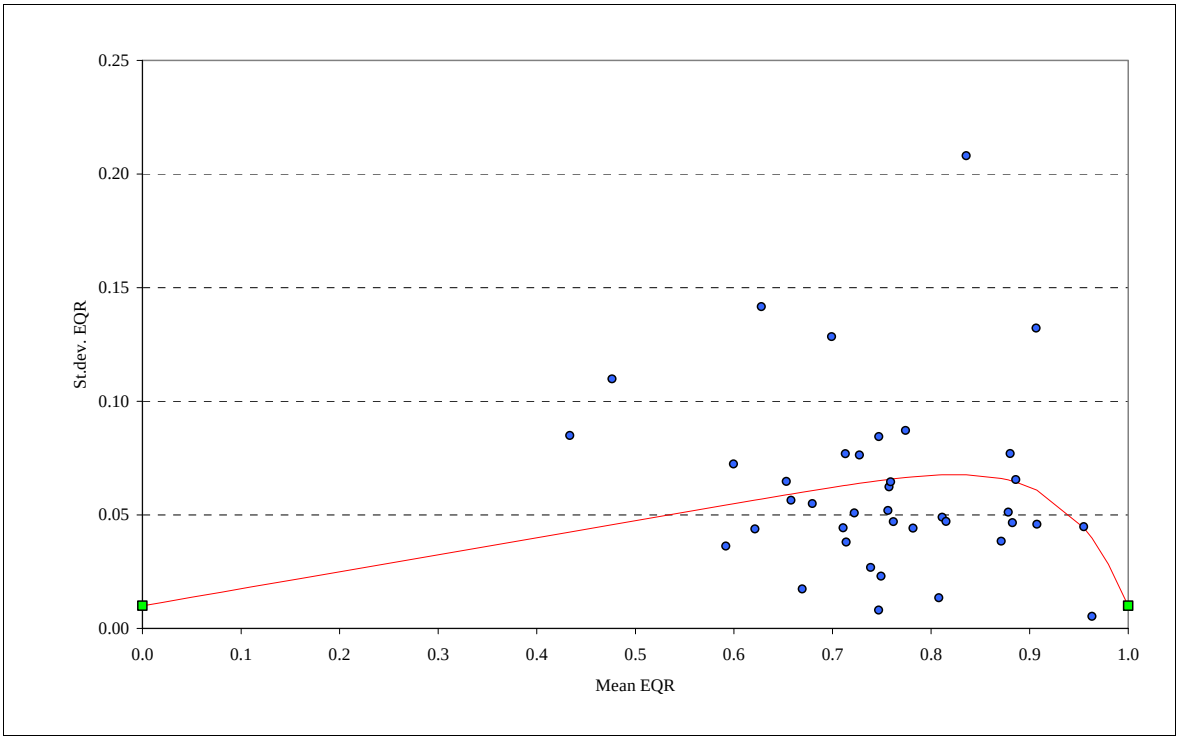


Figure 5.34 EQR within-water body variation for river type H_L in England and Wales using method 2 (paired 500m).

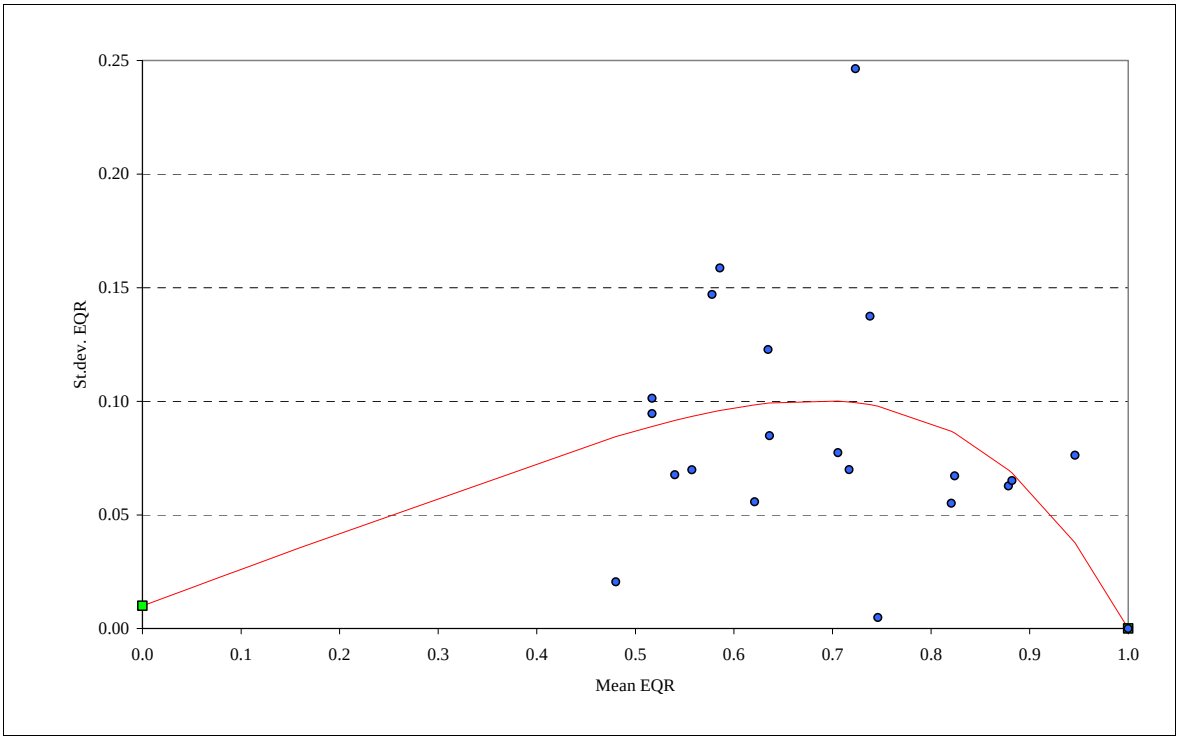


Figure 5.35 EQR within-water body variation for river type H_M in England and Wales using method 2 (paired 500m).

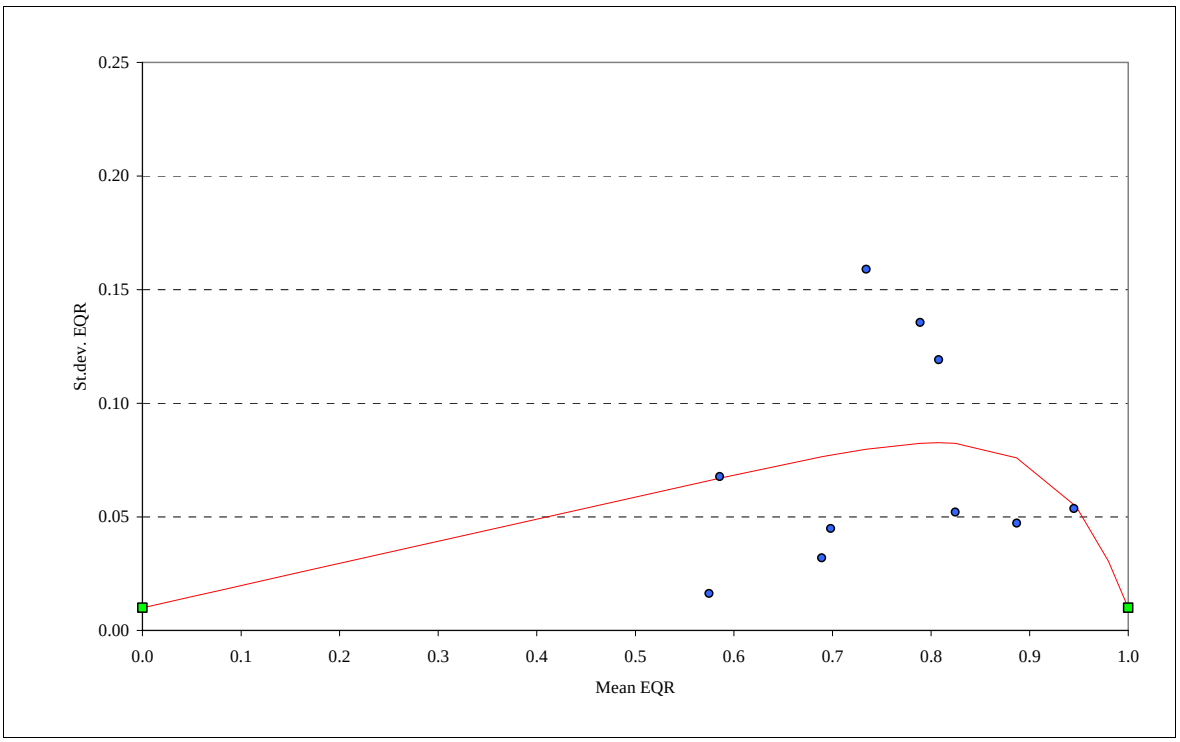


Figure 5.36 EQR within-water body variation for river type H_H in England and Wales using method 2 (paired 500m).

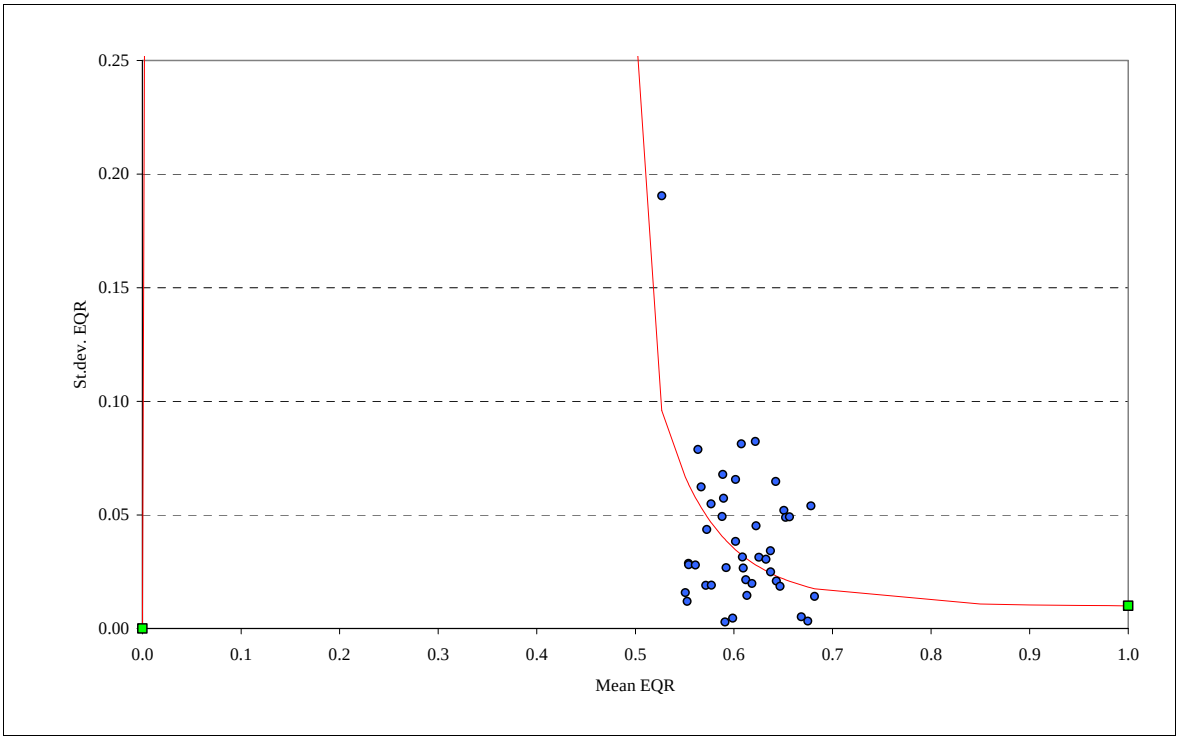


Figure 5.37 EQR within-water variation for river type VH_VL in England and Wales using method 2 (paired 500m).

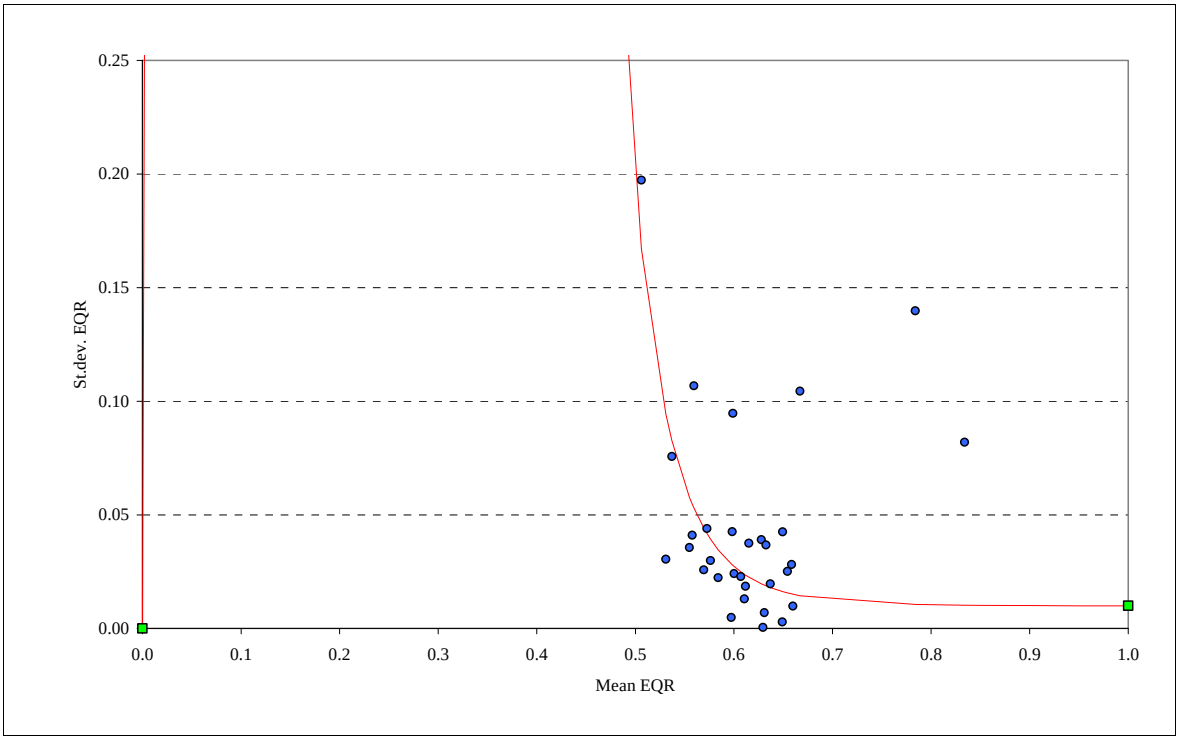


Figure 5.38 EQR within-water body variation for river type VH_L in England and Wales using method 2 (paired 500m).

6. Conclusions

The aim of this project was to improve 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.

This study has analysed an extensive UK-wide dataset to examine and quantify variation in macrophyte communities arising from spatial and temporal variability and measurement error. This section discusses the implications of these results for future monitoring of macrophyte communities in the UK and highlights gaps in understanding which will require further dedicated fieldwork to fill.

The conclusions on the components of variation recorded in this report relate only to the analysed indicators of EQR, number of taxa and percentage cover. Conclusions on other indicators used to assess macrophyte communities can only be made with further study of the indicators in question.

6.1 Implications of results for macrophyte monitoring

- Spatial variation in macrophyte communities within a water body appears to be driven predominantly by small-scale 'local' variation among sites within a reach, with relatively little additional, systematic variation among reaches. This means that surveys performed within a three-km reach will have a similar level of variability to surveys performed in different reaches. In other words, a single reach will often be representative of conditions in the water body as a whole.
- Spatial variation is lowest for EQR and highest for total cover, meaning that EQR, out of the analysed indicators, provides the most precise estimate of the average water body status for a given sample size. Typical within-water body standard deviations for the overall EQR are between 0.086 and 0.122.
- The level of spatial variation within the water body varies greatly from one water body to another, and this swamps any differences between different river types. The fact that individual water bodies show contrasting levels of spatial variation means that generic variability estimates may not be appropriate for all water bodies.
- The percentage cover of individual taxa, as expected, shows much higher spatial variation than total percentage cover because the latter smoothes out variation across all taxa. Thus, the abundance of individual taxa is much more spatially variable than community indicators. Individual taxa have different sensitivities to impacts. Community metrics that consider the cover of sensitive species will be more useful than overall total cover of macrophytes.
- The analysis suggested that surveying a 200-m stretch of the water body will identify around 30 per cent more individual taxa than a 100-m survey, while a 300-m survey will identify up to 50 per cent more individual taxa than a 100-m survey. However, these average values can vary greatly from reach to reach. It was not possible to determine what survey length would be required to sample all taxa within a water body.
- Based on a small dataset, there was little evidence for significant variation in macrophyte communities between successive years. The level of inter-

annual variation was lowest for EQR and highest for total cover and number of taxa. This suggests that surveys need not be performed every year to gain an accurate representation of the water body.

- An analysis of monthly variation found some statistically significant differences between months (May to September) but there no consistent or systematic pattern to this variation. However, the data used to determine this was not ideal and this variation may be partly the result of differences in water body type and quality. Of the three community indicators, EQR had the lowest monthly variation. There is therefore no reason to believe that conducting macrophyte surveys in just one month will give a biased estimate of conditions throughout the summer.
- Plots of within-water body EQR standard deviation against mean EQR for that water body either showed little evidence for a relationship, or had too few low EQR water bodies for a meaningful analysis.

6.2 Future research needs

Some aspects of variation could not be fully analysed because of issues relating to data availability.

- Inter-operator variability could not be studied because of the lack of suitable data. Only one of the datasets recorded the operator and no surveys in this dataset were performed at the same site, on the same date and using the same method by different operators.
- Local variability was analysed using three-km reaches. The use of shorter reaches could be considered for some water bodies where local variation is particularly high. The use of shorter reaches was not feasible with this dataset.
- Although the effect of survey length was investigated over lengths ranging from 100 to 300 m, the 500-m JNCC surveys were found not to be comparable with the 100-m MTR surveys. A larger number of adjacent surveys would help to clarify the pattern of increasing taxa number found.
- The analysis suggested that variation between two successive years was low. However, this was based on a small number of water bodies. A larger number of water bodies with surveys performed in successive years would allow annual temporal variation to be analysed more thoroughly. If a longer time-series of data spanning three or more successive years was available, conclusions could perhaps be drawn on a preferred interval between surveys.
- The lack of survey data for the same water body from different months in the year prevented a conclusive analysis of monthly variation to be performed. Ideally, data from surveys at the same locations over a number of months would be required for this analysis.

Appendix A

Table A1 River Classification 1.

River type	Alkalinity	Gradient
L_L	Low	Low
L_M	Low	Moderate
L_H	Low	High
M_L	Moderate	Low
M_M	Moderate	Moderate
M_H	Moderate	High
H_VL	High	Very low
H_L	High	Low
H_M	High	Moderate
H_H	High	High
VH_VL	Very high	Very low
VH_L	Very high	Low
VH_M	Very high	Moderate

Table A2 River Classification 2.

River type	Altitude	Geology	Size
1	Low	Siliceous	Small
2	Low	Calcareous	Small
3	Low	Organic	Small
4	Low	Siliceous	Medium
5	Low	Calcareous	Medium
6	Low	Organic	Medium
8	Low	Calcareous	Large
10	Mid	Siliceous	Small
11	Mid	Calcareous	Small
12	Mid	Organic	Small
13	Mid	Siliceous	Medium
14	Mid	Calcareous	Medium
16	Mid	Siliceous	Large
17	Mid	Calcareous	Large
28	Low	Siliceous	Small

Appendix B

Table B1 Within-water body standard deviations.

Country	Method	River type	EQR	Total cover	Number of taxa
Scotland	1 (100m)	H_H	0.098	5.1	2.2
Scotland	1 (100m)	H_M	0.114	6.9	2.7
Scotland	1 (100m)	2	0.100	6.7	2.2
Scotland	2 (paired 500m)	L_H	0.089	12.5	3.4
Scotland	2 (paired 500m)	1	0.086	11.8	3.7
Scotland	2 (paired 500m)	10	0.089	14.8	3.6
E&W	2 (paired 500m)	H_L	0.073	17.6	4.2
E&W	2 (paired 500m)	VH_L	0.069	18.9	5.2
E&W	2 (paired 500m)	VH_VL	0.059	24.6	6.9
E&W	2 (paired 500m)	2	0.097	19.4	4.9
E&W	2 (paired 500m)	5	0.067	19.7	5.4

Table B2 Within-reach standard deviations.

Country	Method	River type	EQR	Total cover	Number of taxa
Scotland	1 (100m)	H_H	0.096	5.3	2.6
Scotland	1 (100m)	H_M	0.102	5.3	1.4
Scotland	1 (100m)	2	0.082	5.9	2.7
Scotland	1 (100m)	L_H	0.064	15.6	3.4
Scotland	2 (paired 500m)	1	0.093	11.5	3.4
Scotland	2 (paired 500m)	10	0.115	18.0	3.8
E&W	1 (100m)	H_L	0.093	24.8	5.1
E&W	1 (100m)	VH_L	0.037	18.2	4.6
E&W	1 (100m)	VH_VL	0.085	23.3	7.9
E&W	2 (paired 500m)	2	0.107	22.0	3.6
E&W	2 (paired 500m)	5	0.070	22.1	5.3

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