Confidence of class for the WFD seagrass classification tool

Introduction

The Water Framework Directive 2000/60/EC states that angiosperms are a biological quality element to be used in defining the ecological status of transitional and coastal water bodies. Seagrasses are the only true marine angiosperms and are useful for monitoring purposes as they are sensitive to human disturbance that can cause eutrophication, habitat degradation and loss of species. Their presence is generally regarded as indicative of a healthy environment.

The Environment Agency has developed an approach to assess the health of seagrass beds for the purposes of classifying the status of transitional and coastal water bodies. The purpose of this study is to develop a statistical methodology to estimate the precision and confidence of the classification results. The specific objectives are to:

- propose a potential methodology;
- identify any statistical issues presented by the monitoring strategy; and
- assess how much data is required to adequately implement the methodology.

Background

The ecological status of seagrasses within a water body is measured by an Ecological Quality Ratio (EQR) comprising three metrics:

1. taxonomic composition (presence of disturbance sensitive taxa);
2. abundance, determined by seagrass shoot density; and
3. abundance, measured by seagrass bed spatial extent.

An EQR is calculated for each metric and their average of these EQRs gives a final EQR, which is used to determine an overall face value class using the class boundaries detailed in Table 1.

Table 1 Ecological status classes for seagrass

Ecological Status	Mean score ranges
High	0.80-1.00
Good	0.60-0.79
Moderate	0.40-0.59
Poor	0.20-0.39
Bad	0.00-0.19

Seagrasses are surveyed annually during the peak bloom period (July to September). Within each water body, discrete patches of seagrasses are identified and located and sampling is undertaken in patches chosen to be representative of both disturbed and undisturbed areas within the water body.

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Like other biological quality elements, it is not possible to survey seagrass communities across a whole water body continuously throughout the whole reporting period. This means there will always be some sampling error, which will lead to uncertainty in the estimate of the EQR. This uncertainty can be quantified as the expected difference between the observed EQR and the true underlying EQR, which can then be used to calculate the probability of the water body being in each of the five status classes (termed a confidence of class (CofC) assessment). From this it is possible to determine the most probable class (the one with the highest probability) and to estimate the risk of mis-classification and the confidence of being worse than Good status.

An approach to assessing the precision of the results is represented below for each metric in turn, and then consideration is given to how this information can be combined to estimate the precision of the final EQR.

Taxonomic composition

UK seagrasses include three species of *Zostera* (*Z. noltii, Z. marina and Z. angustifolia*). *Ruppia* is often grouped with *Zostera* as a seagrass and is also monitored. The presence or absence of these four species is determined visually at each sampling site. As the number of potential species in a water body is low and seagrasses often occur in mono-specific or two-species stands, reference conditions for the metric EQR are based on historical records and the classification is based on the percentage loss of species from the reference conditions. The metrics used for different conditions are shown in Table 2 (Wells, 2010) and range from 0.1 to 0.9.

Table 2 Metric system for taxonomic composition

Status class	Level of disturbance	Change in composition from reference conditions	EQR
High	No detectable change	All reference species present	0.9
Good	Slight signs of disturbance	Loss of 25%-33% of species	0.7
Moderate	Moderate distortions	Loss of 50% of species	0.5
Poor	Major distortions	Loss of 66%-75% of species	0.3
Bad	Severe distortions	Loss of all species	0.1

Uncertainty in the EQR for this metric could arise from error in assessing which species are present; a species may either go undetected (a false negative) or mis-identification may lead to the mistaken belief that a species is present when it is not (a false positive). The risk of a false positive is believed to be very small (staff are well trained and have a high level of taxonomic expertise), but the risk of a false negative is considered to be higher because small, isolated patches of a species could be overlooked by the monitoring programme. Thus, the taxonomic composition metric is more likely to be under-estimated than over-estimated.

It is very difficult to estimate directly the probability of a false negative and a false positive without doing a very detailed study comparing the performance of different survey teams in the same water body. However, it is possible to use expert judgment to derive an estimate for each type of error and to use these as default values in a confidence of class tool.

Let:
S = the true number of species actually present;
O = the number of taxa observed; and
U = the probability of each species going undetected (by default we assume a 10% chance of each species going undetected, i.e. a probability of 0.1, and assume that a species can never be observed if it is not present, i.e. a false positive).

Using these parameters, the relative probability of each possible value of S is given by:

$(1-U)^{O} * U^{(S-O)} * (S!/(O! * (S-O)!)$

where ! = factorial function (e.g., 3! = 3*2*1 = 6; 4! = 4*3*2*1 = 24; and so on…).

The only constraint in these calculations is that S can never exceed the reference number of species (i.e. Probability(S > Reference) = 0).

If more species are observed than the reference number, then the reference should be revised up to match the observed and the probability of High status would then be 100%.

As an example, consider a water body in which the reference condition is three species, and two are observed by the survey (O=2). The true number of species in the water body (S) must can either be 2 or 3. If the probability of a false negative is assumed to be 0.1 for each species then we can calculate the relative probability of there being 2 or 3 species in the water body:

Number of species in water body (Status)	**Calculation**	**Relative probability**	**Adjusted probability**
4	NA because this exceeds the reference	0.000	0.000
3 (High)	$0.9^{2} * 0.1^{(3-2)} * 3!/(2! * (3-2)!)$	0.243	0.231
2 (Good)	$0.9^{2} * 0.1^{(2-2)} * 2!/(2! * (2-2)!)$	0.810	0.769
1	NA because we have already observed 2 taxa	0.000	0.000
Sum		**1.053**	**1.000**

The relative probabilities are all divided by the sum of the relative probabilities; this ensures that the adjusted probabilities sum to 1.000

Thus, there is 23.1% confidence that one species was missed and that status is High, and 76.9% confidence that no species were missed and that status is Good. In all of these calculations it is assumed that the reference condition is known without error.

There is no way to reliably estimate a standard error for the metric EQR as it can take just one of five possible EQR values. An approximate standard error can be estimated, however, by calculating a weighted mean and standard deviation using the confidence of class results. Continuing the above example, if the confidence of class assessment gives 77% confidence of Good (EQR = 0.7), 23% confidence of High (EQR = 0.9), then the weighted EQR result is:

Metric EQR = (0.769 * 0.7) + (0.231 * 0.9) = 0.746

and the associated standard error is:

$SE = SQRT \{ 0.769 * (0.7 - 0.746)^{2} + 0.231 * (0.9 - 0.746)^{2} \} = 0.084$

Shoot density

Shoot density is a measure of either leaf density or shoot counts (depending on the species present) and, is variable across different geographic regions. As with taxonomic composition, density is compared with reference conditions based on historic data representing the bed's healthiest previously recorded condition (E). At least three stratified randomized quadrats are used in each discrete seagrass bed (provided the bed is bigger than the area of three quadrats). Ideally the number of quadrats used in each bed reflects the size and density of the patch, but this is sometimes constrained by the time available and the accessibility of the site. The fractional spatial cover by seagrass is estimated for each quadrat and the water body density is estimated as the average fractional spatial cover of the quadrats (O). If 5-6 years of data is available then mean is calculated using all quadrats surveyed in that time period.

The %loss from reference conditions is calculated as: (E-O)/E. A sliding scale is then used to convert this score into an EQR:

$$MetricEQR = upperEQRparametervalue - \frac{score - lowerclassrange}{classwidth} \times EQRbandwidth \tag{1}$$

The metric EQR class boundaries are shown in Table 3.

Table 3 Metric system for shoot density

Status class	Level of disturbance	% loss of density from reference conditions (annual change)	% loss of density from reference conditions (5-6 year rolling mean)	Metric EQR
High	No detectable change	0-10% density loss	0-5% density loss	0.8-1.0
Good	Slight signs of disturbance	11-30% density loss	6-15% density loss	0.6-0.8
Moderate	Moderate distortions	31-50% density loss	16-25% density loss	0.4-0.6
Poor	Major distortions	51-70% density loss	26-35% density loss	0.2-0.4
Bad	Severe distortions	71-100% density loss	36-100% density loss	0.0-0.2

Uncertainty in the metric EQR can be calculated as follows:

1. calculate the standard deviation of the shoot density recorded for individual quadrats;
2. calculate the standard error of the mean shoot density (SE_O) by dividing the standard deviation by the square root of the number of quadrats;
3. calculate the standard error of the % loss as $SE_{\%loss} = SE_O/E$;
4. calculate a 95% confidence interval for %loss;
5. convert the upper and lower 95% confidence limits to an EQR;
6. subtract the lower 95% EQR confidence limit from the upper confidence limit and divide by (2*1.96) to derive an approximate standard error for the metric EQR.

As with the taxonomic composition metric, it is assumed that the reference condition is known without error.

Bed spatial extent

The third metric applies to seagrass beds where shoot density is greater than 5%. It assumes that the spatial extent of the bed will be in equilibrium with the maximum extent expected in line with the local climate, substrate and hydrodynamic regime. If no other data is available, the maximum is assumed to be equal to the previous largest extent (i.e. reference conditions). If the bed's current spatial extent is below this limit, this is assumed to indicate ecological disturbance. The spatial extent of the bed is estimated visually, photographically or by mapped survey.

The %loss from reference conditions is calculated as:

$$\%loss = \frac{E - O}{E} \qquad (2)$$

where E = reference extent and O = observed extent (i.e. the sum of the individual patch areas).

The class boundaries are the same as for annual change in shoot density (Table 4) and equation (1) is used to convert the %loss result into an EQR.

Table 4 Metric system for seagrass bed spatial extent

Status class	Level of disturbance	% loss of area from reference conditions (annual change)	Metric EQR
High	No detectable change	0-10% area loss	0.8-1.0
Good	Slight signs of disturbance	11-30% area loss	0.6-0.8
Moderate	Moderate distortions	31-50% area loss	0.4-0.6
Poor	Major distortions	51-70% area loss	0.2-0.4
Bad	Severe distortions	71-100% area loss	0.0-0.2

As with taxonomic composition, it is not possible to directly estimate the likely error in the measured bed areal extent. The level of error is likely to depend upon the method used, and it is recommended that default values are used to represent the expected degree of error, in the same way as used in the CAPTAIN tool for opportunistic macroalgae. For example, a relative standard deviation (RSDO) of0.1 would equate to 95% confidence that the measured area is within ±20% of the true area

If it can be assumed that the errors in the measurement of each individual seagrass patch are independent (i.e. the tendency to over- or under-estimate one patch bears no relationship to the errors in another patch), then these random errors will increasingly average out as more patches are surveyed. Following the approach used by CAPTAIN, the standard error of the total bed extent is given by:

$$SE_0 = \overline{RSD_0 * \quad a_i^2} \qquad (3)$$

where a_i = the area of the i^{th} patch.

Uncertainty in the metric EQR can then be calculated as follows:

1. calculate the standard error of the %loss as $SE_{\%loss} = SE_O/E$;
2. calculate a 95% confidence interval for %loss;
3. convert the upper and lower 95% confidence limits to an EQR;
4. subtract the lower 95% EQR confidence limit from the upper confidence limit and divide by (2*1.96) to derive an approximate standard error for the metric EQR.

Again, it is assumed that the reference condition is known without error.

Final EQR

The final EQR is calculated as the mean of the metric EQRs. The EQR should be based on three metrics, but if the taxonomic composition assessment shows that all species have been lost, the other metrics cannot be calculated.

To combine the uncertainty associated with each metric EQR, it is necessary to express the uncertainty in a common format – in this case as a standard error. If it can be assumed that the errors of the three metrics are independent, then the standard error of the final EQR is given by:

$$SE_{FinalEQR} = \sqrt{\frac{SE^2_{metricEQR}}{3}}$$

This standard error may then be used to compute a confidence of class for the final EQR using the standard approach used in other TraC tools.

Summary

This paper sets out a proposed methodology for quantifying the confidence of class in estimates of seagrass status in transitional and coastal water bodies. It relies on expert judgement to quantify certain sources of uncertainty and therefore does not require large quantities of data. However, it is recommended that a sensitivity analysis be undertaken to determine how much the confidence of class results are influenced by the default values used to measure (i) the risk of failing to detect species, and (ii) the error in measurements of bed extent. If the sensitivity is high, then consideration should be given to undertaking a short intensive study to estimate empirically these two sources of uncertainty.

References

Wells, E., (2010). Water Framework Directive Development of Classification Tools for Ecological Assessment: Intertidal Seagrass.

WFD-UKTAG (2009) UKTAG Transitional and coastal water assessment methods: Angiosperms: Seagrass (Zostera) Bed Assessment (draft).