Water Framework Directive development of classification tools for ecological assessment

Opportunistic Macroalgae Blooming

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Water Framework Directive – United Kingdom Technical Advisory Group (WFD-UKTAG)

Contents

List of Tables

List of Figures

1. Summary

This report details the development of the Water Framework Directive (WFD) opportunistic macroalgal blooming tool. The report consists of a general background to the WFD, the management groups, normative definitions and reference conditions.

The provenance of the tool is discussed emphasising that macroalgae blooms are generally considered to be undesirable, so for any reference conditions macroalgae blooms should be absent or limited to small non-persistent patches. Blooms are considered to be problems of relatively sheltered, sedimentary shores and more frequently found within transitional waters. In contrast species diversity is limited in such conditions, due to lack of firm substratum for attachment, and within estuaries due to salinity reduction and fluctuation. Elevated abundance of opportunistic macroalgae to nuisance proportions is generally considered to be indicative of anthropogenically elevated nutrient levels.

For the foregoing reason the tool does not consider taxonomic composition as a classification criterion and merely focuses on the presence of opportunist algae only. These include *Enteromorpha, Ulva, Cladophora, Chaetomorpha, Pylaiella, Ectocarpus* and *Porphyra.* (*Enteromorpha* is now re-classified as *Ulva* but the old name is used to distinguish tubular from laminar forms). It is the abundance and persistence of such species that is considered a problem. Macroalgae abundance is defined in the tool as a combination of *spatial cover* (considered as both a percentage and total area cover) **and** *biomass*. Combined with the presence of algal entrainment, these aspects of abundance and persistence form the basis of this tool.

The development of the database, reference conditions and threshold setting are discussed, together with the need to take account of other aspects of undesirable disturbance and the response to pressure. The primary pressure considered is elevated nutrient concentrations..

Consideration is also given to calculating the final EQR using worked examples and of calculating the confidence of classification.

2. Background to WFD

The European Water Framework Directive 2000/60/EC governs the protection, improvement and sustainable use of inland surface waters, transitional waters (TW), coastal waters (CW) and groundwaters. The directive, which came into effect on 22nd December 2000, updates previous water legislation and establishes a new integrated water management system based on river basin planning. The key aims of the Water Framework Directive (WFD) are outlined below:

- To prevent further deterioration and protect and enhance the status of aquatic ecosystems and associated wetlands;

- To promote sustainable use of water; and provide sufficient supply of good quality surface water and groundwater.
- To reduce pollution of waters from priority substances
- To prevent deterioration in the status and to progressively reduce pollution of groundwater; and
- To contribute to mitigating the effects of floods and droughts.

The main purpose under WFD guidelines is to develop robust ecological quality objectives (EQOs) for assessment of anthropogenic / human induced pressures in TWs and CWs by looking beyond the drivers of change and linking physical and chemical conditions with a measurable biological response in the community.

The Water Framework Directive requires that defined areas of waters (i.e. water bodies) “achieve good ecological and good chemical status” by 2015 unless there are grounds for derogation. Annex V of the Water Framework Directive 2000/60/EC specifies the quality elements and normative definitions on which the classification of ecological and chemical status is based. Normative definitions outline what aspects of the biological quality elements (BQEs) should be assessed and form the main drivers behind the development of assessment tools.

The Directive’s requirements include ecological status and chemical status classification schemes for surface water bodies which will differ for rivers, lakes, transitional waters and coastal waters. Heavily modified and artificial water bodies will be assessed in relation to their ecological potential and chemical status classification schemes. The quality elements addressed in Annex V of the Directive for assessing ecological status and ecological potential are:

- biological quality elements;
- general physico-chemical quality elements;
- Environmental Quality Standards (EQSs) for synthetic and non-synthetic pollutants; and
- hydromorphological quality elements.

The specific biological requirements for transitional waters are the composition and abundance of:

- composition and abundance of phytoplankton
- macroalgae
- marine angiosperms
- benthic invertebrate fauna
- fish

For coastal waters the biological elements are the composition and abundance of:

- composition and abundance of phytoplankton,
- aquatic flora (macroalgae and marine angiosperms)
- benthic invertebrate fauna

For the ecological status and ecological potential classification schemes, the Directive provides detailed normative definitions of the degree of human disturbance to each relevant quality element that is consistent with each of the ecological status/potential classes. These definitions have been expanded and used in the development of classification tools and appropriate numeric class boundaries for each BQE. The results of applying these classification tools are used to determine the status of each water body or group of water bodies.

The UK was required by 2006 to identify water bodies at risk of not meeting WFD objectives. This risk assessment exercise was supported by the establishment of national monitoring frameworks and classification schemes. All WFD national monitoring tools are subject to a Europe wide Intercalibration process, in order to ensure all member states assess and classify their waters in a manner consistent with each other and with the Directive.

The WFD is implemented within the UK by the relevant competent authorities, namely the various environment agencies.

This report outlines the development of the UK macroalgal blooming classification tool, within transitional and coastal waters, to support assessment of the biological quality elements.

3. UK Process of WFD Development

3.1 UK TAG

The WFD UKTAG is the United Kingdom Technical Advisory Group supporting the implementation of the European Community (EC) Water Framework Directive (Directive 2000/60/EC). It is a partnership of experts from the UK conservation and environment agencies and the Department of Environment and Local Government for the Republic of Ireland. Its main function is to provide coordinated advice on technical aspects of the implementation of the Water Framework Directive (WFD). This includes a coordinated approached to the identification and characterisation of water bodies based on their physical attributes and the assessment of the risk of such water bodies failing to achieve the WFD's environmental objectives. It works alongside various experts, and government and stakeholder groups, to develop common approaches to WFD implementation. It also has oversight of the UK’s efforts on methods intercalibration within the European Intercalibration framework. WFD requirements have legally binding timetables for completion, enabling a framework for general WFD implementation. This includes tool development and monitoring, which commenced in December 2006, and the setting of environmental objectives under the WFD within the UK and Europe.

Overall the UK TAG group initially provided guidance on;

- Development of **typology of surface waters** (describing water bodies into common types) and the establishment of **type specific reference conditions** for the classification of UK waters;

- The definition and subsequent analysis of **pressures and impacts** for the assignment of water bodies to risk categories;

- The development of **classification tools and methods** that will support monitoring of ecological status.

- Development of an overall **monitoring framework** that supports meeting the different requirements of the Directives and future Programmes of Measures. This includes **operational and surveillance monitoring** designed to assess changes from base-line status of UK water bodies as well as **compliance monitoring**.

- Production of initial **reports for the European Commission** on characterisation and pressures and impacts analysis.

- Assistance with the **European intercalibration process** that will support defining the thresholds between the five status classes of water bodies under the WFD (high, good, moderate, poor, bad).

The UKTAG has initiated the development of the classification tools, during the 2003/04 period, with lakes, rivers and marine task teams formed and tasked to: *'coordinate the adaptation and development of suitable surface water classification tools for the biological quality elements'* under the compliance of the European Common Implementation Strategy (CIS). Some of these elements are part historically of UK classification systems whilst others pose new requirements to support assessment of ecological status. To help implement its work programme, UKTAG has established a number of specialist groups:

- Task teams and steering groups comprising experts from the environment and conservation agencies. These are focused on specific themes or actions (eg lakes, rivers, river basin planning etc). These groups may initiate new research programs.

- Drafting Groups - Small short-lived groups of experts charged with producing specific advice (eg. drinking water guidance).

The Marine Task Team (MTT) leads the development of classification systems within Transitional and Coastal waters (TraC), providing further guidance to the relevant subgroups including the Marine Plants Task Team (MPTT).

3.2 MPTT

The Marine Plants Task Team consists of a number of representatives from various government agencies to provide expertise on the translation, development and implementation of the WFD. It met initially every 4-6 months to discuss progress within the phytoplankton, macroalgae and marine angiosperm classification tools as directed by the MTT and UK TAG. The Marine Plant Task Team’s role has been to translate the WFD legislative report into practical ecological and scientific classification methods for marine plants, and in so doing it has developed a number of classification tools to comply with the requirements of the WFD.

Within this group the UK and Republic of Ireland (RoI) representatives have had to ensure harmonisation of ecological classification systems to ensure a coherent approach by both member states. The tools have been, or are being, developed both 'in house' and by consultants, with funding from a number of sources including the environment agencies, SNIFFER, and the Irish North South (SHARE) project, which is INTERREG funded and managed jointly between authorities in Northern Ireland and the Republic of Ireland. The approach includes the:

- review and adaptation of existing methods for potential to support classification schemes under the WFD;
- development of new tools for elements not previously monitored in the UK and RoI;
- assessing which parameters have the best correlation for assessing pressures and impacts;
- development of reference conditions from which to base boundary criteria;
- trialling such tools in the assessment of ecological quality status; and
- the review, comparison and agreement of methods with other EU Member States to comply with intercalibration requirements

This document describes the process involved in the development stages of the macroalgae (macroalgal blooming) tool, considering both its theoretical and practical elements, subsequent implementation and inclusion in the European Intercalibration process. The tools are grounded in scientific knowledge and published and unpublished research, but wherever there is uncertainty or a scarcity of quantitative scientific evidence the precautionary principle has been invoked.

4. WFD Normative definitions & Reference conditions

The criteria by which ecological status should be evaluated are detailed in the normative definitions in Annex V(1.2) of the Water Framework Directive. Normative definitions provide definitions of ecological quality and the values for the quality elements of ecological status for coastal and transitional waters. They describe the various aspects of macroalgae that must be used in the ecological status assessment of a water body. Assessment tools composed of a variety of metrics have been developed to address these aspects of the normative definitions for each of the five status classes. The WFD normative definitions specify which aspects of each biological quality element must be assessed, and the plants tools have been developed accordingly.

The normative definitions relating to macroalgae for transitional and coastal waters are outlined in Table 1 a) and b).

Table 1 a) and b): Description of WFD Normative Definitions for TraC waters

a) Coastal Waters

HIGH	All disturbance-sensitive macroalgae associated with undisturbed conditions present. The levels of macroalgal cover are consistent with undisturbed conditions.
GOOD	Most disturbance-sensitive macroalgae associated with undisturbed conditions are present. The level of macroalgal cover shows slight signs of disturbance.
MODERATE	Macroalgal cover is moderately disturbed and may be such as to result in an undesirable disturbance in the balance of organisms present in the water body.
POOR	Major alterations to the values of the biological quality elements for the surface water body type. Relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions.
BAD	Severe alterations to the values of the biological quality elements for the surface water body type. Large portions of the relevant biological communities normally associated with the surface water body under undisturbed conditions are absent.

b) Transitional Waters

HIGH	The composition of macroalgal taxa is consistent with undisturbed conditions. There are no detectable changes in macroalgal cover due To anthropogenic activities.
GOOD	There are slight changes in the compostition and abundance of macroalgal taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of phytobenthos or higher forms of plant life resulting in undesirable disturbance to the balance of organisms present in the water body or to the physico-chemical quality of the water.
MODERATE	The composition of macroalgal taxa differs moderately from type-specific conditions and is significantly more distorted than at good quality. Moderate changes in the average macroalgal abundance are Evident, and may be such as to result in an undesirable disturbance to the balance of organisms present in the water bpdy.
POOR	Major alterations to the values of the biological quality elements for the surface water body type. Relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions.
BAD	Severe alterations to the values of the biological quality elements for the surface water body type. Large portions of the relevant biological communities normally associated with the surface water body under undisturbed conditions are absent.

4.1 Evolution of Expanded Normative Definitions

These Normative definitions have been expanded by the MPTT (Dublin 2004) to provide examples of how they apply directly to the abundance of macroalgae within Transitional and Coastal waters, including their structural and functional relevance (Table 2). These descriptions form the basis for the development of the opportunistic macroalgae blooming tool currently being used for WFD ecological assessment and apply to intertidal sedimentary shores. Normative definitions have been combined for coastal and transitional waters due to the similar way in which they respond to increasing pressures with regards to opportunist macroalgae growth.

Table 2: Description of the characteristics of opportunistic macroalgae blooms at each WFD status class in accordance with the normative definitions (WFD Annex V) and expanded normative definitions (detailed national interpretation).

Reference Conditions **HIGH**	*All disturbance-sensitive macroalgae associated with undisturbed conditions are present. The levels of macroalgal cover are consistent with undisturbed conditions*	Algal cover <5% and low density. Area and % cover is representative of or close to reference conditions with cover at its minimum accounting for seasonal fluctuations and variations in growth. Macroalgae show no persistence including lack of entrained algae. The taxonomic composition corresponds totally or nearly totally with undisturbed conditions.
GOOD	*Most disturbance-sensitive macroalgae associated with undisturbed conditions are present. The level of macroalgal cover shows slight signs of disturbance.*	Limited cover (<15%) and low biomass (<500gm^{-2}) of opportunistic macroalgal blooms and with limited growth of algae in the underlying sediment. Macroalgae cover shows slights signs of disturbance with slight deviation from reference conditions. Macroalgae shows no persistence with little entrainment of algae.
MODERATE	*A moderate number of disturbance-sensitive macroalgae associated with undisturbed conditions are absent. Macroalgal cover is moderately disturbed and may be such as to result in an undesirable disturbance in the balance of organisms present in the water body.*	Increased cover (>15%) and/or biomass (>500gm^{2}) of opportunistic macroalgal blooms; may have algae growing in the underlying sediment. Macroalgae growth shows moderate deviation from reference conditions and is slightly detrimental to the surrounding environment with some signs of persistence.

4.2 Reference Conditions

Reference conditions represent, as far as possible, undisturbed conditions for the BQE, and class boundaries are set in relation to these. The Water Framework Directive states type-specific biological reference conditions may be spatially based, based on modelling, or derived using a combination of these methods. For spatially based type-specific biological reference conditions, Member States are developing a reference network for each surface water body type. Predictive models or hindcasting methods should use historical, palaeological and other available data. Where it is not possible to use these methods, expert judgement may be used to establish such conditions (Annex II 1.3).

For the most part substratum dictates the potential macroalgae assemblage likely to colonise a waterbody. Defining type-specific reference conditions is problematic because for transitional waters substratum characteristics only partially inform the typology and in coastal waters the substratum is not a defining characteristic at all. This means reference conditions are not type-specific; rather they may vary within a type or may be common across types. Three macroalgae tools have been developed for transitional and coastal waters largely depending on substratum.

For macroalgae on soft sedimentary shores predictive models of macroalgae abundance under varying environmental conditions are limited; consequently this is not currently a viable approach for establishing reference conditions. Reference conditions have been established using a combination of expert judgement and data from sites considered to be pristine and those considered to be highly affected with distinct visual deviation from natural conditions. Macroalgae blooms are generally considered to be undesirable, so for any reference conditions blooms should either be absent or restricted to small patches and with limited persistence. At reference conditions the % cover and total areal cover of macroalgae within a defined water body is minimal. For UK and RoI waterbodies reference conditions were established using historical and existing data and reports along with expert judgement where possible. Expert judgement was then used to refine recommended levels of macroalgae to correspond to desired reference conditions of minimal cover and extent of opportunist growth within natural and undisturbed water bodies.

4.3 Ecological Quality Status

Once reference conditions are established for high ecological status, the departure from these can be measured. The degree of deviation sets boundaries for each of the ecological status classes. The boundaries between each of the status classes need to be described and criteria established which reflect the normative definitions.

Annex V 1.4.1 of the Directive states *"the results of the (classification) system shall be expressed as ecological quality ratios for the purposes of classification of ecological status. These ratios shall represent the relationship between the values of the biological parameters observed for a given body of surface water and the values for these parameters in the reference conditions applicable to that body. The ratio shall be expressed as a numerical value between zero and one, with high ecological status represented by values close to one and bad ecological status by values close to zero."*

Figure 1 illustrates this concept.

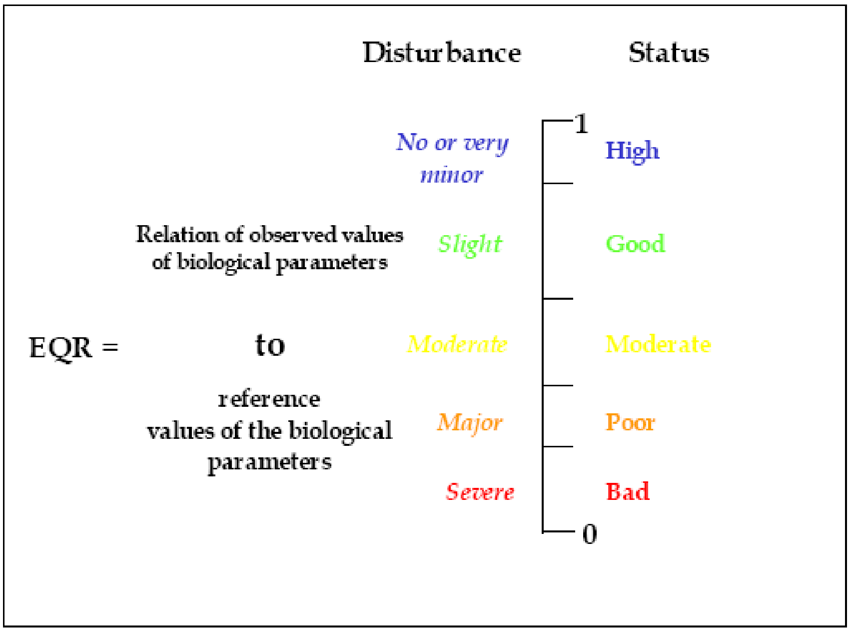

Figure 1: Suggested Ecological Quality Ratio; Annex V, 1.4.1 (From COAST Guidance, Vincent *et al*., 2002).

EQRs are derived by comparing monitoring results with the reference conditions. The values of the EQR then set for each ecological status class must ensure that the water body meets the normative definition for that status class given in Annex V (Tables 1.2, 1.2.3. or 1.2.4). As such the reference conditions form the anchor for the whole ecological assessment. Ecological status classes will be defined by their deviation from reference.

4.3.1 Classification

The outcome of any one assessment tool will be combined with the assessments of other WFD quality elements to inform the overall classification of a water body.

5. Opportunistic Macroalgae Monitoring Tool

Annex V of the Water Framework Directive (WFD) states macroalgae are a *biological quality element* to be used in defining ecological status of a transitional or coastal water body. Specifically it outlines the criteria that need to be related to type-specific reference conditions for macroalgae:

- *Taxonomic composition corresponds totally or nearly totally with undisturbed conditions.*
- *There are no detectable changes in macroalgae abundance due to anthropogenic activities.*

A number of tools have been developed within the UK and Republic of Ireland to encompass the requirements of the WFD. Taxonomic composition is an appropriate criterion for shores of a hard, rocky nature. For sedimentary shores, however, a different approach has been taken, as macroalgae species richness is hindered on such substratum due to the lack of hard surface for secure attachment. In such circumstances the formation of opportunist macroalgal blooms has been considered to be more appropriate, as they may attain nuisance proportions as a result of anthropogenically elevated nutrient levels. As a relatively small number of opportunistic taxa form blooms, they may be considered to fulfil the taxonomic composition criterion of the WFD. Detecting changes in macroalgae abundance is considered a more appropriate and robust criterion for sedimentary shores.

All potential bloom-forming species are a natural component of shore ecosystems (Abbott & Hollenberg, 1976), which, under certain conditions, may become a nuisance. On rocky shores macroalgal opportunists like *Enteromorpha* may be abundant in the upper shore as they are euryhaline and able to cope with elevated salinity in top shore pools, and also with reduced salinity adjacent to freshwater inflows. They may also be abundant in areas of sand scour. In such cases their presence may be neither anthropogenic in origin nor deleterious (Wilkinson & Wood, 2003). However, in soft sediment environments such as estuaries or lagoons their presence as bloom-forming mats may be of nuisance proportions for which the ecological impacts can be highly variable. As a rule, in the UK and RoI, blooms of opportunist macroalgae are generally considered to be problems of relatively sheltered, sedimentary shores most often found within Transitional waters or sheltered coastal embayments. They may also be dependent upon the slope of the shore which can affect their deposition.

Macroalgae communities are able to provide a good means of measuring ecological quality. Such communities are quick to respond to changes in the environment often providing visible responses. Changes in species abundance are often indicative of anthropogenic effects, with pressures often causing a shift from larger long lived perennial species to fast growing, opportunist species, which are able to take advantage of the adverse conditions and lack of competition. More specifically, changes in the levels of opportunist algae have been proved to be linked with elevated nutrient levels (eutrophication problems).

5.1 Background to Macroalgae Blooms

Macroalgae are natural components of shallow-water marine and transitional soft-sediment communities (Abbott & Hollenberg, 1976). However, excessive growth of opportunistic species can occur under certain conditions, altering the natural balance not only of the algal community, but also of associated faunal communities. An opportunist is considered a species that is able to take advantage of conditions in which other species often struggle to survive and, due to characteristically high rates of mineral nutrient uptake and enhanced reproductive capability, can prevent or stunt growth of perennial algae by excessive abundance and competition for space (Wallentinus, 1984; Hoffmann & Ugarte, 1985; Vogt & Schramm, 1991; Kruk-Dowgiallo, 1991). Blooms form principally of species of *Enteromorpha, Ulva, Chaetomorpha* or *Cladophora*, although other green, red (e.g.

Ceramium, Porphyra) and brown algae (e.g. *Ectocarpus, Pylaiella*) may also reach nuisance proportions (Vogt & Schramm, 1991; Fletcher, 1996a, 1996b).

Macroalgae can play an important functional role in structuring benthic faunal assemblages. However, the presence of particular laminar forms of macroalgae such as *Ulva*, can have a mixed effect on the density of benthic fauna (Everett, 1994). Species of *Enteromorpha*, *Ulva*, *Chaetomorpha* and *Cladophora* are able to out-compete other seaweeds as well as seagrasses and sometimes phytoplankton, but high biomass may provide a refuge for small fish, crustaceans and gastropods (e.g. Rafaelli *et al*., 1998). Mobile sediment-water interface feeding species can have greater densities, while the densities of sedentary species, especially bivalves and tube-dwellers, can be much lower with algal cover (Everett, 1994). However, nuisance blooms of rapidly growing macroalgae can have deleterious effects on intertidal communities and an undesirable imbalance (Soulsby *et al*., 1982; Tubbs & Tubbs, 1983; den Hartog, 1994). The main effects are listed below with examples of blooms shown in Figures 2 and 3 (Raffaelli *et al*, 1999; Gamenick *et al*, 1996, Norkko *et al*, 2000, Tubbs, 1977; Tubbs & Tubbs, 1983, Raffaelli *et al.*, 1989, den Hartog, 1994, Montgomery *et al.*, 1985, Jeffrey *et al.,* 1992);

- blanketing of the surface causing a hostile physico-chemical environment in the underlying sediment,
- sulphide poisoning of infaunal species,
- anoxic gradient at the water sediment interface,
- effects on birds including changes in the feeding behaviour of waders,
- smothering of seagrass beds,
- interference with water use activities by rafts of floating, detached weed,
- aesthetic effects such as odour nuisance and deposition on sites such as bathing waters.

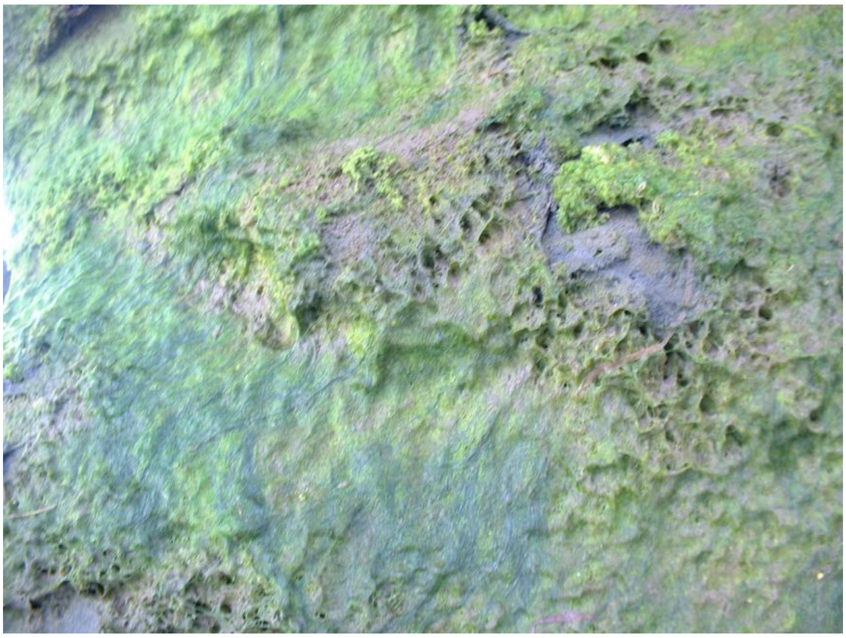

Figure 2: Mat of opportunist macroalgae with high percent cover resulting in distinct anoxic layer within the surface sediment shown as a black layer.

Figure 3: Macroalgae bloom consisting of several green, brown and red opportunist species forming a dense blanket over the substratum

Evidence also suggests that factors such as nutrient supply, temperature, turbidity, hydrography, light and bed stability and the total surface area of the intertidal region suitable for algal growth are important limiting factors where macroalgal blooms are concerned (Lowthion *et al.,* 1985, Poole & Raven, 1997; Rees-Jones, unpubl.; CEFAS, 2004 unpubl.).

It is clear that the occurrence, persistence and impacts of macroalgal blooms are governed by a number of physical, chemical and biological factors, which may interact in a complex fashion, and are often difficult to characterise and understand fully. Therefore, as opportunistic macroalgae such as *Ulva* sp. and *Enteromorpha* spp. cannot exist above the high tide limit nor grow at depths where turbidity levels limit light intensity (Josselyn, 1985), so the standing stock in an estuary must be limited by the total available intertidal area. Given these pre-conditions, the biomass density will primarily be controlled by nutrient concentrations (up to a physically controlled maximum density).

In some situations it is also possible for the algae to grow within the underlying sediment or continue growth after cover by sedimentary deposits. This can have further deleterious impacts on the surrounding organisms with underlying fauna unable to resurface also restricting bird feeding activity. Entrained algae can also promote new algal growth by causing nutrient enrichment within the sediment through decomposing plant material, and overwintering of algal spores. Large entangled mats of algal blooms may also break loose and become mobile which may cause the problem to spread or may cause mats to deposit on sensitive areas such as saltmarsh.

Blooms are a world-wide phenomenon (e.g. McComb & Humphries, 1992; Reise & Siebert, 1994; Sfriso *et al*., 1992; Raffaelli *et al.*, 1989; den Hartog, 1994; Soulsby *et al*, 1982, Fletcher, 1996a), and most often occur in areas of restricted flushing (Lotze *et al*, 1999), and considered to be the result of nutrient enrichment (Ryther & Dunstan, 1971; Kruk-Dowgiallo, 1991; Schramm & Nienhuis, 1996, Wilkes, 2005), with a concomitant shift from long-lived algal species to short-lived opportunists. Species of *Enteromorpha*, *Ulva*, *Chaetomorpha* and *Cladophora* are able to out-compete other seaweeds as well as seagrasses and sometimes phytoplankton. Although some research has established a direct link between nutrient loading and the growth of macroalgae (Lotze & Worm, 2002), evidence to support a direct causative link between effluent discharge and community structure is less clear (Lowthion *et al*., 1985; Everett, 1994; Trimmer *et al*., 2000).

Heavy growth of macroalgae in the presence of elevated nutrients may in part be due to their position in the littoral zone, shelter from tidal action, light penetration and seasonal temperature. Because of the attenuation of surface irradiance by blooms of phytoplankton and epiphytic growth, macroalgal abundance has also been shown to decline under high nutrient regimes (Twilley *et al*., 1985). External inputs of nutrients to southern UK harbours may support the growth of macroalgae at the start of a growing season, but phytoplankton could subsequently restrict this supply and intense recycling of nitrogen within the sediments is the more likely explanation for continued macroalgal growth (Trimmer *et al*., 2000). If sediments are consistently anoxic, de-nitrification processes will break down and the system may become self-sustaining. Figure 4, based on work by Mark Trimmer (University of Essex), summarises the change in sediment chemistry in the presence of excessive weed growth.

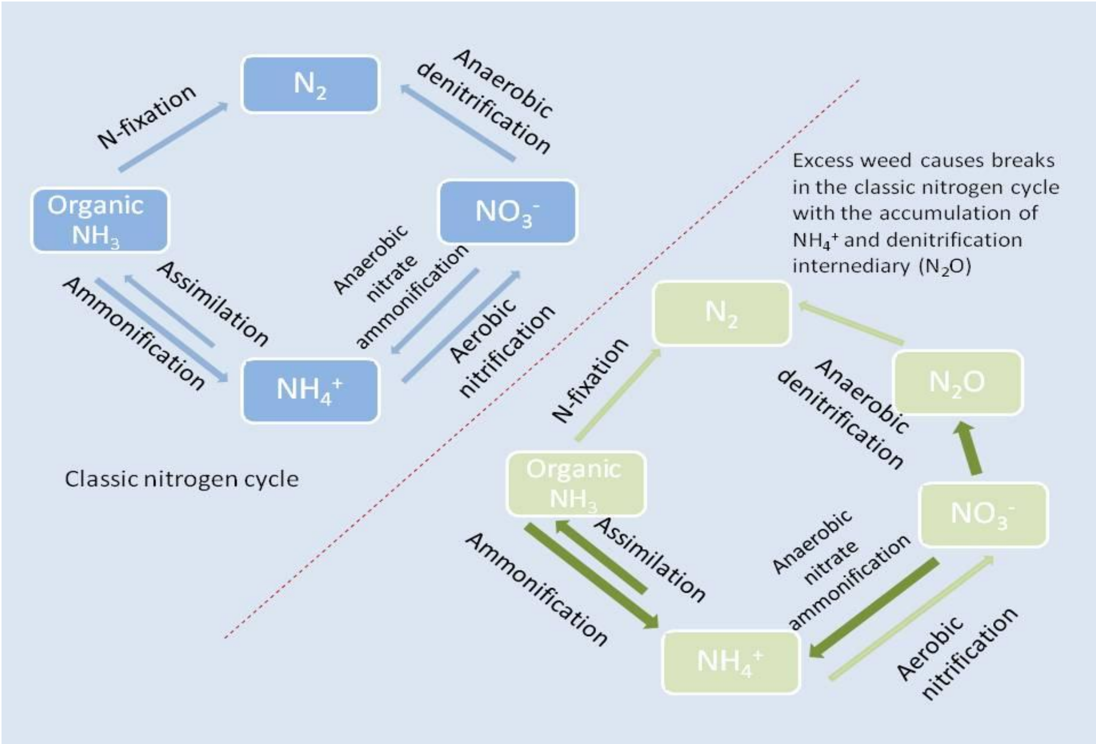

Figure 4: Changes in sediment chemistry with excess weed growth (Trimmer).

Functional form, i.e. whether the plant is filamentous or foliose, may affect its relationship with underlying sediments and interactions with fauna, but evidence for this is not entirely clear (Everett, 1994; Raffaelli *et al.*, 1998). *Chaetomorpha* (fine, unbranched single filament), *Enteromorpha* (filiform to robust tubes), *Cladophora* (fine, branched filaments) are intimately bound into sediments (Raffaelli, *et al,* 1998). In depositing environments *Ulva* (laminar thallus) too may be closely bound to sediments (Raffaelli, *et al,* 1998), but can also be more loosely associated, lifting off the mud surface with the tide (Raffaelli, 2000). Mats may be mono-specific, but are frequently composed of more than one taxon. Even where a mat is mono-generic, e.g. *Enteromorpha* only, there may be several species present, whose growth peaks at different times (Raffaelli, 2000), thus potentially affecting the time span or areal distribution of a bloom.

5.2 Links between the WFD and other EU directives

Various European Union Directives besides the WFD consider the assessment of eutrophication, principally the Urban Waste Water Treatment (UWWTD, 1991), Nitrates (Nitrates Directive, 1991) and Habitats (Habitats Directive, 1992) Directives, and also OSPAR (the Oslo and Paris Convention). Unlike the WFD, the UWWT and Nitrates Directives each define eutrophication in relation to sources, i.e. phosphorous from discharges and nitrates from agricultural activities respectively. OSPAR considers not only the area covered by WFD but trans-boundary transport across maritime areas. Its *Strategy to Combat Eutrophication* (OSPAR, 2003) aims “to achieve and maintain a healthy marine environment where eutrophication does not occur”, and is developing ecological quality objectives for eutrophication as part of a wider framework that is the basis for an ecosystem approach to management of human activities. OSPAR has a common procedure for the identification of eutrophication within OSPAR areas and has considered synergies with other assessment regimes (OSPAR 2005a,b,c,d). The UWWT and Nitrates Directives not only provide definitions of eutrophication, but measures to combat it through designations as Sensitive Areas (SAs) and Nitrate Vulnerable Zones (NVZs) respectively. Existing designations under these directives will remain unchanged by WFD independent of the ecological status of the water bodies concerned. “Sensitive areas” and “NVZs” will become protected areas under Article 6 and Annex IV of the WFD. UWWT and the Nitrates Directives designations may also be a result of non-eutrophication criteria such as high nitrate concentrations in ground and surface waters for the protection of drinking water.

The possibility of the different definitions of eutrophication, criteria used and different monitoring regimes of the several directives producing differing assessments of an area, and the implications of this for programmes of measures to combat pollution, has been the subject of much discussion. There is no direct exchange between the directives, but the need to normalise definitions of eutrophication and have monitoring schemes to produce robust assessment satisfying all relevant criteria has now been recognised (COAST, 2002; Leaf, 2006; CIS, 2005). Table 3 demonstrates the differing approach to assessment methods between directives (CIS, 2005).

The Environment Agency (EA) for England and Wales has developed internal guidance (Wither, 2003) for assessing the risk to Natura 2000 sites for the Habitats Directive, and has set guidelines for triggering appropriate assessments under the Directive in relation to the extent and density of macroalgal blooms. There is also internal guidance on monitoring algal blooms in relation to the UWWTD. The EA guidelines were derived from the outcome of internal agency discussions using monitoring experience and following a DETR (U.K. Department of the Environment, Trade and the Regions) workshop attended by leading U.K. experts (DETR, 2001, unpubl.). This workshop derived tentative criteria for reference levels for algal cover and biomass, based largely on expert opinion.

Table 3: Comparison of assessment results under various policies for waters responding to nutrient enrichment (based on the assumption that WFD is the starting point and that the different sources of pollution are relevant).

Ecological status	WFD normative definition	UWWTD Directive	Nitrates Directive	OSPAR
Assessment of current status				
High	Nearly undisturbed conditions	Non-eutrophic, designation of sensitive area is not required	Non-eutrophic, not a polluted water, designation of NVZ is not required	Non-problem area
Good	Slight change in composition and biomass	Non-eutrophic, designation of sensitive area is not required	Non-eutrophic, not a polluted Water, designation of NVZ is not required	Non-problem area
Moderate	Moderate changes in composition and biomass	Eutrophic or may become eutrophic in the near future, designation as sensitive areas is required	Eutrophic or may become eutrophic in the near future, polluted water, designation as NVZ is required	Problem area
Poor	Major changes in biological communities	Eutrophic, designation of sensitive area is required	Polluted water, designation as NVZ is required	Problem area
Bad	Severe changes in biological communities	Eutrophic, designation of sensitive area is required	Polluted water, designation as NVZ is required	Problem area

6. Development of a macroalgae blooming tool

6.1 Dataset

Although all environment agencies and other workers have looked at the same basic parameters of macroalgal blooms, they have done so in different ways, often for different purposes. There was therefore no one established, generally accepted method of assessing blooms. Consideration had to be given to these various approaches and the data generated from them when trying to arrive at a scientifically robust and environmentally relevant monitoring tool. Published and unpublished literature were used in an attempt to derive critical threshold values suitable for defining quality status classes. Evidence from well-studied UK sites demonstrated considerable inter-annual variation in the extent and location of spatial cover (Withers {EA}, 2003) and often results were presented in different formats. Some did not provide sufficient levels of detail, while others did not relate directly to levels of nutrients or eutrophication within the area of impact. It was considered that the effects of weed cover would be greatest on those sites which are consistently covered by blooms; sites which are affected only intermittently have greater opportunity to recover, and those with patchy cover have refugia for invetebrates. Short-term data sets were more variable and would contribute less confidence to the establishment of boundary values. Expert opinion was also used where standard published levels of effects did not exist.

Macroalgal blooms in littoral soft sediment environments have been a cause of concern under Directives that pre-date the WFD, as discussed previously. For many water bodies a historic baseline can be established using various forms of data collected under these directives; such as direct *in situ* macroalgae surveys, aerial photographs, water quality data, information on sediments and the general extent of the available habitats. The Environment Agency is the authority responsible for such surveys in England and Wales, and the following have provided data; David Lowthion, Southern Region, Waterlooville; Sian Davis, Anglian Region, Ipswich; Ginny Swaile, NE Region; Bob Davison, Agency Technology Group, Twerton. The Countryside Council for Wales (CCW) and the Scottish Environment Protection Area (SEPA) are further sources of recent and historic data that have been used for tool development.

6.2 Approach

The monitoring tools need to discriminate between the five WFD quality classes, measuring anthropogenically induced deviation from reference/high conditions. The normative definitions for high, good and moderate ecological status have been provided in section 4.1 and form part of the criteria for the tool development. The WFD also states that the features of macroalgal communities to be used for the assessment of ecological quality should include taxonomic composition and macroalgae abundance.

6.2.1 Taxonomic composition

Various genera of opportunistic macroalgae are implicated in blooms worldwide. The majority of algal mats encountered in UK locations are composed principally of *Enteromorpha* or *Ulva* and known as ‘green tides’. Other green species of algae such as *Cladophora and Chaetomorpha* have also been reported along with the brown algae *Ectocarpus* and *Pylaiella,* and the red algae *Porphyra* which may also reach nuisance proportions. Other fast-growing taxa such as the red algal *Ceramium* can contribute to blooms, and are found less commonly in the UK.

To aid general understanding of any site of study, the dominant alga(e) within mats should be identified to at least genus level, However, it is inappropriate and impractical to use taxonomic composition of mats as a classification criterion for various reasons: presence alone of any of the potential nuisance species does not imply deterioration in quality, as they are natural members of the coastal and estuarine soft sediment communities (Abbott & Hollenberg, 1976), and the number of species in areas of fluctuating salinity is generally reduced and does not provide sufficient discrimination to classify on number of species (Wilkinson & Wood, 2003). The presence of opportunistic macroalgal species is not a problem *per se* and thus not an appropriate measure. The absence of other taxa is equally not a reliable, quantifiable criterion. Disturbance sensitive taxa such as seagrasses may occupy the same habit as macroalgae, and are sensitive to high nutrient regimes and smothering by algal blooms (e.g. den Hartog, 1994), but their absence does not necessarily denote poor quality status (for example seeds may not have reached the site). Tools for monitoring seagrasses and other macroalgae taxa are being developed under separate monitoring activities. Due to the reduced number of taxa which form algal blooms, and which are also characteristic of estuaries, taxonomic composition was deemed an inappropriate criterion. The WFD specifies that taxonomic composition should be considered, and this approach does conform to Annex 5, section 1.4.1 (i) of the Directive (WFD, 2000), as opportunistic blooming species can be considered as a representative group for the quality element in areas of soft sediment and in transitional waters in particular.

6.2.2 Macroalgae abundance

This is defined as a combination of *spatial cover* (considered as both percentage cover (%) and total areal cover (ha)) **and** *biomass*. These two aspects of abundance form the basis of this tool. Many studies have assessed these in a variety of ways, but for the purposes of future WFD monitoring it will be necessary to adopt a standard approach.

6.2.3 Supporting information

Other aspects of undesirable disturbance that should be considered, alongside macroalgae abundance and composition, as supporting evidence of anthropogenic impact include: invertebrate fauna reduced; wading bird feeding distribution modified; cockle numbers reduced; deposited weed smothers other salt marsh vegetation; public complaints about odour; floating rafts of weed impacting on boating activity; and anoxia in surface sediment layer (e.g. top 2 cm). Such information is not used within the tool, but may be used alongside it to better understand local impacts.

6.3 Determination of metrics and development of WFD Classification Boundaries

For blooms of opportunistic macroalgae the original proposal for the WFD was to use abundance, estimated by a combination of spatial coverage and biomass. This is in line with OSPAR and the Habitat Directive approaches whereby *excessive* biomass of opportunist foliose and filamentous macroalgae, giving rise to adverse environmental effects (Wilkinson & Wood, 2003), would be considered as moderate, poor or bad status. Criteria for determining threshold levels for macroalgae blooms were discussed by the Comprehensive Studies Task Team (CSTT), but never finalised or implemented within the comprehensive studies guidance (CSTT, 1997). A DETR workshop held in 2001 also set some tentative criteria for spatial cover and biomass based on expert opinion resulting from extensive experience, but these were not subsequently validated. These values have been used as starting points by MPTT. Some of the values were later adopted by the Environment Agency (England and Wales) for guidance on when to conduct appropriate assessments of areas under the Habitats Directive.

Based on current assessment methods the main criteria used in the development of thresholds within the opportunist tool are percentage cover, biomass and presence of entrained algae. The derivation of boundaries for the various metrics is discussed and the boundaries are summarised in Table 4. A full worked example is given later in this document in Section 7.6.

6.3.1 Percentage (%) cover

While nutrient availability may be a major factor in the increasing dominance of opportunistic algae in shallow coastal environments, their reported physiological responses to a spectrum of light and salinity conditions show that the area of shore covered is often limited only by the availability of suitable substratum on which to grow (e.g. Poole & Raven, 1997). It is therefore important to define the area of intertidal that may be suitable for macroalgal growth, as stressed by various authors (e.g. Lowthion *et al.*, 1985; CEFAS, 2004). Some areas, e.g. channel edges subject to constant scouring, may never be suitable for algal blooms and may thus be excluded from calculations of area. Based on various published literature, suitable areas are considered to consist of mud, muddy sand, sandy mud, sand, stony mud and mussel spat. Workers on individual sites must determine the available area based on local knowledge; alternatively the intertidal area as delineated on Ordnance Survey maps could be used. Total available intertidal habitat (AIH) is thus the total area available for growth when any known unsuitable areas are excluded.

The preliminary CSTT criteria stated that a symptom of eutrophication is when more than 25% of the available intertidal area is covered with green macroalgae of greater than 25% cover. The DETR workshop held in 2001 made the following recommendations:

- The preliminary reference level = 5% cover.
- A problem area is one with > 15% cover of intertidal area on soft sediments.

Although the criterion suggested by the CSTT implies 6.25% (25% of 25%) cover can represent a problem area, in reality affected zones may typically have ca. 60% cover. This is consistent with the suggestion from the DETR (25% of 60% = 15%).

The DETR expert workshop (DETR, 2001) suggested reference levels of <5% cover of AIH of climax and opportunist species for high quality sites (DETR, 2001). This figure was derived from various studies, (e.g. Lowthion *et al*. 1985), as one that adequately represents relatively unaffected areas. DETR (2001) also proposed >15% cover of AIH represented a problem area and could therefore be used for % cover at the next critical level. However, it was also suggested that greater than 25% cover was considered an indicator of harm. Wither (2003) stated that problem areas often have 60% cover within the affected area therefore 25% x 60% equals 15% cover of the AIH.

Some regions of the Environment Agency have utilised % cover bands, e.g. 0, 1-25%, 26-50%, 51-75%, 76-100% for UWWTD and Nitrates Directive monitoring. While very useful in investigations, 25% cover bands were considered to be too broad for setting classification boundary thresholds for WFD. In practical terms, it is considered preferable to estimate percentage cover as accurately as possible, i.e. to the nearest 5%, to maintain sensitivity. In line with the DETR/EA approach, the MPTT has adopted <5% cover of opportunistic macroalgae as a reference level (equivalent to High quality status) and proposed <15% (5-15%) cover of opportunistic macroalgae as a threshold level for acceptable cover. The EA has considered >75% cover as seriously affecting an area, and this could possibly form a threshold for Bad status. The final % cover thresholds for the levels of ecological quality status are given in Table 4 and described generically in Table 5.

Percentage cover alone will not indicate the level of risk to a water body, and biomass must also be considered. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna, yet it still represents a significant deviation from reference conditions. Therefore, the WFD has adopted an approach whereby a combination of spatial cover and biomass are necessary to achieve a classification.

In very large water bodies with relatively small patches of macroalgal coverage there was concern that despite the total % cover remaining below the threshold, the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities. This would not be picked up with % cover if the total available intertidal habitat within the water body was excessively large. Therefore an additional parameter was added into the metric to help compensate for this factor. This parameter calculates the total affected area in hectares within the AIH. With very little information available to support the development of boundary conditions for this parameter, tentative boundaries have been established by expert judgment within the MPTT (Tables 4, 5) and shall be tested using existing data. These shall be refined as WFD-specific data are collected. The lower value ONLY of the two metrics total Affected Area and AA/AIH% should be used.

6.3.2 Biomass

DETR (2001) suggested a tentative reference level of <100gm^{-2} wet weight, but stated that <500 gm^{-2} wet weight was acceptable. The former could therefore form a reference threshold for the High/Good quality status boundary. In Good status only slight deviation from High status is permitted. 500 gm^{-2} would then become the lower limit of the Good class, i.e. the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500 gm^{-2} but less than 1,000 gm^{-2} would lead to a classification of Moderate quality status at best (Table 4), but would depend on the percentage of the AIH covered. Consideration was given to whether figures for biomass should be calculated as a mean for the whole of the AIH or just those affected areas. A further alternative was to use maximum biomass figures. This latter was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Mean biomass in affected areas is important, as these may form discrete areas within a larger water body, but for classification of the water body as a whole it was considered that the figures expressed in Table 4 should be mean figures for the whole water body or the AIH. Classification for the WFD is achieved on a water body basis and not on localised impacts. While this could under-represent problems in sub-areas, where higher densities could cause impacts on other parts of the biota or on sediments, data from the sub-areas would be available and would prompt investigative monitoring.

DETR (2001) and others (Lowthion *et al.*,1985; Hull, 1987, Wither, 2003) have identified $1kgm^{-2}$ wet weight as a level of biomass at, or above, which significant harmful effects on biota have been observed. Mixed effects have been observed at lower and higher biomasses, presenting a difficulty with establishing a categorical level of effect. Not all studies have shown harmful impacts at or above $1kgm^{-2}$ (e.g. Rees-Jones, 2006) due to local conditions, but there seems reasonable evidence to support the DETR expert committee’s view that this level of biomass is unacceptable.

Note: The proposed threshold values are expressed as wet rather than dry weight per square metre. For practical reasons it is much easier and less time-consuming to use wet weight, and measurements could even be performed in the field. Various studies have shown good correlations between wet and dry weights (Tindall & Morton, 1998; Lawrence et al., 2000, Pye, 2000; Vila et al., 2001).

Table 4: Metric system for the assessment of opportunist macroalgae blooms

Quality Status	High	Good	Moderate	Poor	Bad
EQR	**≥0.8 - 1.0**	**≥0.6 - 0.8**	**≥0.4 - 0.6**	**≥0.2 - 0.4**	**≥0.0 - 0.2**
% cover of AIH	0 - 5	5 - 15	15 -25	25 - 75	75 - 100
Average biomass (gm^{-2}) of AIH	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000 (- 6,000)
Average biomass (gm^{-2}) of Affected Area	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000 (- 6,000)
Affected area (AA) (hectares)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250 (- 6,000)
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
% entrained algae	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

Note: Only the lower of the two asterisked criteria is used in calculating the final overall WB EQR

Table 5: Interpretation of the parameters for the metric system

Measurement	Definition
% cover of AIH	The % cover is estimated as an average over the whole of the available intertidal habitat for the waterbody
Total affected area [AA] (hectares)*	The total extent of the bloom, measured in hectares and based on the external perimeter of the bloom
AA/AIH (%)*	The affected area (ha) as a percentage of the total available intertidal habitat (ha)
Biomass (gm^{-2}) of Affected Area (AA)	This is the average biomass per square metre over the affected area only
Biomass (gm^{-2}) of AIH	This is the average biomass per square metre over the whole of the available intertidal habitat
Presence of entrained algae (%)	The percentage of quadrats where algae are seen to be growing ≥3cm into the underlying sediment, indicating the likelihood of regeneration of a bloom

Note: Only the lower of the two asterisked criteria is used in calculating the final overall WB EQR

6.3.3 Entrained Algae

Various workers have also noted that persistence of algae within sediments provides both a means for over-wintering of algal spores and a source of nutrients within the sediments (e.g. Raffaelli *et al.*, 1998). In the United States Thiel & Watling (1998), in following long-term effects of small-scale experiments, found that effects on infaunal colonisers were most severe and long-lasting where decaying algal mats finally became incorporated into the sediment. Build-up of weed within sediments therefore implies that blooms can become self-regenerating given the right conditions (Raffaelli *et al*, 1998). Absence of weed within the sediments therefore lessens the likelihood of bloom persistence, while its presence gives greater opportunity for nutrient exchange with sediments. Incorporation of algal biomass into the sediments in Good status water bodies, leading to an increase in the sediment nutrient pool, could potentially lead to deterioration within class, contrary to the aims of the Directive. Consequently, this forms a valid metric within the multi-metric tool. The values in Table 4 were arrived at following refinement of early tentative values revised in the light of actual data collection and trial classifications.

To summarise, the final multi-metric system therefore is composed of five metrics:

1. % cover of AIH – The average % cover of algae in the available intertidal habitat.

2. Biomass (g m^{-2}) per m^2 AIH – The average biomass of algae per square metre in the available intertidal habitat.

3. Presence of entrained algae – The % of quadrats where algae is seen to be growing deeper than 3cm into the underlying sediment indicating the likelihood of regeneration.

4. Total affected area (ha) – The total extent of the algal bloom, measured in hectares and based on the external perimeter of the bloom.

5. Biomass (g m^{-2}) per m^2 affected area – The average biomass of algae per square metre over the affected area.

:

6.4 Calculation of Ecological Quality Ratios (EQRs)

In trying to arrive at a scientifically sound and environmentally relevant monitoring tool and classification system, we have considered the preceding approaches and guidelines. Using published and unpublished literature along with expert opinion we have attempted to derive critical threshold values suitable for defining quality status classes.

In order to combine the various parameters discussed previously, including % cover, biomass, area covered and presence of entrained algae a metric approach was proposed. Data can therefore be collected for individual affected patches, giving an indication of impact in these areas, but then be aggregated to the whole water body level to represent overall quality status. This multi-metric system requires the calculation of an ecological quality ratio (EQR) for each individual metric; an average of these is then taken to assign a final classification to the WB overall. The final metric system works on a sliding scale to enable an accurate EQR value to be calculated for each of the different metrics. Figure 7 demonstrates the process of sampling through to quality classification.

Calculation of the ecological quality ratio for each metric

The ecological quality ratio (EQR) for the metric should be calculated using the following equation whereby "value" signifies the observed value. The same equation is used for all metrics.

$$\textbf{EQR} = \textbf{upper EQR parameter range} - \left\{ \left[\frac{\textbf{value} - \textbf{lower class range}}{\textbf{class width}} \right] \times \textbf{EQR band width} \right\}$$

An example is:

Example For % cover, using a value of 17% for %cover, consult Table 4: 17 lies between 15-25 and with an EQR between 0.4-0.6, therefore:

Score = 0.6 - {(17 – 15)/10 x 0.2}

Score = 0.6 – 0.04 = 0.56

These calculations may also be performed within the CAPTAIN confidence of class tool (see later)

6.4.1 Long Term Data

Inter-annual variation in spatial coverage and biomass is well documented and to be expected (Soulsby *et al.*, 1978; Lowthion *et al.*, 1985; Raffaelli, Hull & Milne, 1989; Raffaelli *et al.*, 1999). Though the controlling factors are not always clear, Lowthion *et al.* (1985), Jeffrey *et al.* (1992) and Raffaelli *et al.* (1999) have all drawn attention to the importance of climatic factors in influencing the magnitude of blooms from year to year. To account for this inter-annual variation, it may be appropriate to use rolling means to assess a water body over a period of time, e.g. five years, or however many year's worth of data exist, preferably a minimum of three. This again harmonises with the OSPAR approach. A single year could in theory give a misleading picture if there had been an unusually low growth of algae for whatever reason. However, where a single year's data show high levels, this should trigger further investigation automatically, and annual and longer-term means should both be used in assessing a water body over a reporting cycle (see 8.1).

There is still a requirement for baseline data or historical data to be used where possible to establish if there is a long standing problem, if it is a natural bloom not induced by anthropogenic influences or whether it is the occurrence of a natural cyclical event. However this tool is able to detect both localised and wider spread changes in ecological health.

6.5 Application of the macroalgae blooming multi-metric tool

This tool is specifically geared towards the monitoring of intertidal sedimentary shores which may be either coastal or transitional. The exact monitoring methods used may vary considerably depending on the extent of the algal bed but, for a survey to take place, there must also be evidence of some opportunist algal cover. Therefore, the ideal methods developed for the macroalgae blooming tool have been based on a tiered approach although it is understood that such methods may not always be achievable.

6.5.1 Preliminary Assessment

The first stage of this process requires a preliminary risk assessment in the form of a desk based data collation exercise. This aims to assess the potential or current pressures faced by a particular water body such as sewage inputs, agricultural diffuse pollution and the designation of specific areas e.g. as Nitrate Vulnerable Zones or UWWTD sensitive areas. This process will also highlight any drivers related to these risks such as Nitrates Directive, OSPAR, UWWTD and the Habitats directive. Finally it aims to produce an historical baseline, where possible, using various forms of data such as previous surveys, aerial photos, water quality data, information on sediments and the general extent of the available habitats. This enables a picture to be established of the general area of concern. If there is no available intertidal area, or if light penetration and nutrient concentrations are known to be limited, there is little chance of an estuary being at risk. Those estuaries thought to be at risk, or historically known to have high levels of opportunist macroalgal growth will require a preliminary site visit.

It is also likely that a general visual assessment of the area of concern would be conducted to establish semi-quantitatively if percentage cover of the total available intertidal area is >5%, with this being the reference level. If the level of cover is <5% no further action is required. Further investigation should be conducted if there is >5% cover.

6.5.2 Survey Methods

An assessment of the available habitats suitable for growth of opportunist macroalgae is required, so that areas which could never support algal blooms can be excluded. Inclusion of such areas would skew the data and lead to a false classification. Surveyors may conduct an initial mapping of the external perimeter of algal beds using hand-held GPS recording a rough percentage cover e.g. 5-25%, 25-50%, 50-75% and 75-100%. Only those areas >5% require mapping. During this initial survey additional points of observation should be recorded such as the dominant algal genera, the sediment condition, visual estimation of anoxic layer depth, presence of *Arenicola* casts, presence of *Corophium*/*Hydrobia*, and cockles, and the presence of heaps or rolled mats of algae. Photographs should also be taken of areas with and without algal cover to enable future comparison. Where it is considered unsafe or impractical to map extensive areas of mudflat, it may be necessary to use an alternative method such as aerial photography or telescope survey.

Subsequent to the initial survey, detailed and concise information on the extent and density of the algal beds can be used to establish a level of ecological quality status.

The principal methods of assessing spatial cover are listed in Table 6. While no method is recommended over another, the pros and cons, as well as costs, should be considered carefully. In the Republic of Ireland estimation of coverage by *in situ* survey has been shown to give a 10% lower figure than aerial methods, probably due to the different scales used (Wilkes, 2005). *In situ* measurements may be more accurate than aerial survey methods because of better resolution, but have been estimated as being 10 times slower and more labour-intensive (Berglund, 2003 in Wilkes, 2005). With *in situ* surveys there may be variation between field operators, so suitable training and quality control measures are essential. Raffaelli (1999) found that densities below $1kgm^{-2}$ wet weight (a biomass showing impacts on invertebrates in the Ythan estuary) were not visible as clear mats on aerial photographs for the aircraft height and scale used at that time. Remote sensing methods such as CASI are being refined constantly to better discriminate between vegetation types, and other forms of aerial survey are being developed. It is important to determine a suitable degree of ground-truthing for whichever methodology is selected. *In situ* estimation of percentage cover can be quality controlled by use of graduated quadrats or the super-position of grids on photographs of quadrats, assessment by more than one operator and by auditing. With any field assessment or remote sensing method it is essential to have some form of quality assurance to ensure year on year consistency and precision.

Table 6: Methods for surveying opportunistic macroalgae

Method	Comments	Cost
Conventional transects	Application of well understood technique, but labour intensive. Does not provide overall % cover	Low cost, labour intensive
Systematic coverage using hovercraft etc	Labour intensive but capable of giving high quality data on both cover and biomass. May conflict with conservation interests	Medium/ High
Aerial survey using standard or digital camera	Simple technique; important to ensure adequate resolution is achieved	Low/Medium
Oblique aerial photography	Technique well suited to coverage of smaller locations	Medium
Infra-red false colour (IRFC) stereo pairs	Capable of giving high quality data if undertaken in conjunction with appropriate ground truthing. Requires expert interpretation	High
Compact Airborne Spectral Imager (CASI)	Some early problems with interpretation, but a method undergoing continuing development	Medium/High, if combined with LIDAR
Satellite, e.g., Quickbird, IKONOS	Good spatial resolution (0.6 - 4 m); swath width <30 km	Low/Medium
Telescopic surveys	Rapid assessment of sites where access is restricted	Low

Certain issues affect all remote methods, e.g. cloud cover, must be minimised to allow correct interpretation of images. Ground-truthing requirements for all methods require quadrats to be taken incorporating measures of both abundance and biomass.

Some areas show a spring bloom of algae, followed by a summer dip and then another rise in density in late summer, while other areas may be characterised by one peak and other areas by rolling of mats under certain weather conditions. If these local patterns are severe it may be necessary to monitor in spring and summer, but peak density is most often found in July/August, so this is the recommended time for monitoring to take place. Peak density refers to both biomass and % cover. Historical data or local knowledge may be used to clarify the peak time of the bloom and this is recommended where available, although it is recognised that this is difficult to predict with certainty. In cases where no previous data have been collected, ideally it may be necessary to check the bloom status every couple of weeks in order to establish the approximate peak time of algal density. In practice it is recognised that agencies may not have sufficient resource to do this, and that surveys may need to be pre-programmed to fit in with aerial survey/remote sensing contracts and with staff availability. Rolling of algal mats into ropes can start to occur during late summer as weather conditions become more unsettled. To obtain the most representative estimates of cover, surveys should ideally be carried out before this happens. It is also important that comparisons between years are based on samples collected at the same time of year to ensure consistency between results unless the peak time for the bloom shifts significantly.

6.5.3 In-situ field sampling

Surveys are conducted using a stratified random sampling approach, whereby the waterbody is divided into one or more discrete patches with differing levels of macroalgae and three or more replicate quadrats are randomly positioned in each patch. (Areas of the waterbody with no algae effectively form a separate stratum or patch which is not surveyed and where %cover and biomass are assumed to be zero.)

In-situ field monitoring should commence at the lowest possible tide to ensure the full extent of the bloom is captured. During the initial skilled eye survey of the site, if the area of available intertidal habitat (AIH) appears to have no or <5% algal cover there is no need to proceed with any further with a detailed survey as at this level the area is generally considered to be of high quality and it is highly unlikely that biomass would measure greater than 100g m^{-2}. For areas of >5% cover measurements should include the total area covered by the algal bloom, the average % cover within the affected areas and the average biomass within the affected areas. For this particular tool monitoring should be targeted at the areas of AIH which are being described as those areas of soft sediment consisting of mud, muddy sand, sandy mud, sand, stony mud and mussel beds. Areas of hard substratum such as jetties and piers should be excluded. The total AIH can be calculated using Ordnance Survey maps or other maps, photographs or images that can detail the substratum type adequately. The total AIH is subsequently used to estimate the average % cover and biomass for the whole water body. The dominant genera should be recorded along with other opportunistic species that may be present in smaller abundance.

Area Coverage (Total affected area in hectares)

This refers to the total extent of the bloom measured in hectares and based on the external perimeter of the bloom. However, the edge of a bloom is often very patchy or indistinct with % cover varying considerably and it is therefore hard to establish an accurate boundary for the external perimeter. In some sites the whole area may be covered by algae, though with varying densities, while in others there may be discrete patches of algae throughout the water body. Patches should be measured and their areas added together to give the total areal coverage for the waterbody. The good/moderate boundary for % cover of algae lies at 15%. Therefore the external perimeter of a macroalgae bloom should be measured at 15% (see Figure 5 and example at Section 5.7). The area of >15% cover can be obtained either from aerial imagery or from mapping the bed with a hand held GPS. A second perimeter (or perimeters, depending on the nature of algal occurrence) may be established to encompass all remaining patches of algae at <15% cover, this may be necessary to obtain a designated sampling area which incorporates all areas of algal cover. The external perimeter of the less dense growth would then be treated separately to enable a more accurate estimate of the total cover and area affected of the patchier sections of macroalgal growth. Although the external perimeter of the patchier sections is likely to be less defined, by splitting the affected sample area into two distinct areas this would help produce a more accurate overall result. Additionally, the blooms may be distributed throughout the water body in discrete patches, where this occurs it will be necessary to establish the external perimeter and subsequent area (ha) for each bloom/patch.

The presence of macroalgae cover is often described as an area, patch or bed. Although there is no discrete definition for the three they can be broadly explained using the following description:

Area – this is the total amount of substratum covered by bloom within a waterbody

Bed – this refers to a discrete area of algal coverage often lacking distinct boundaries; it may account for all algal coverage within the water body or a portion of it, but it often has a distinct geographic boundary. % cover can range from 15 – 100%

Patch – this refers to a very distinct, usually smaller, area of algal growth usually with fairly distinct boundaries with potentially several patches per bed. % cover is usually >15%

Examples of a bed and patch can be seen in Figure 6 which shows a number of dense patches within a less defined bed.

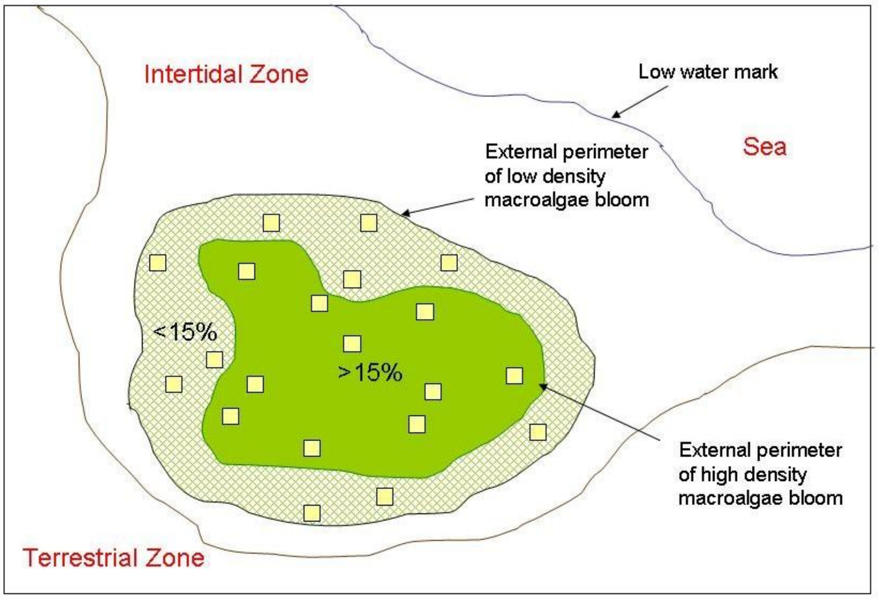

Figure 5: Example of collection of quadrat data from bed with areas of differing algal density

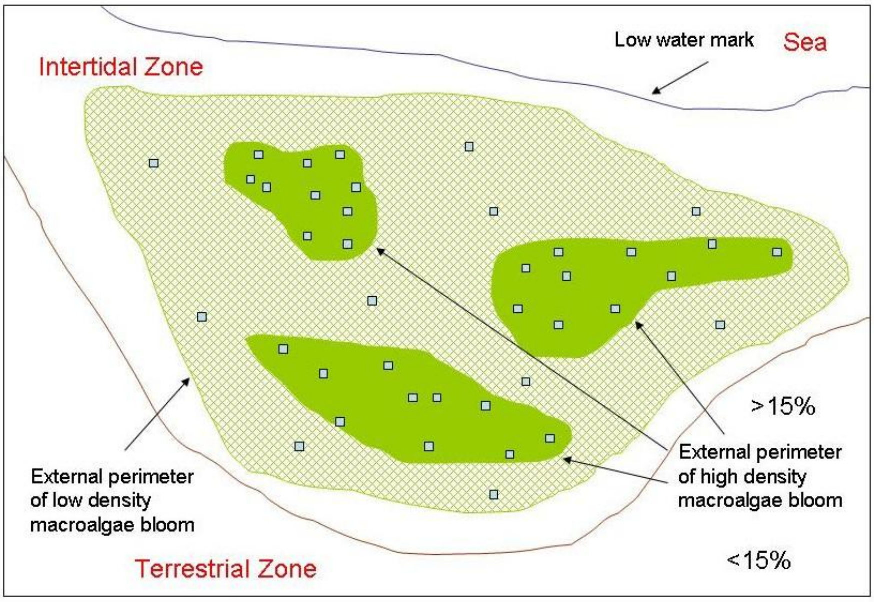

Figure 6: Example of collection of quadrat data within areas of differing algae density and discrete patches

% Cover (% cover of AIH)

The % cover estimated is achieved through stratified random quadrat sampling within the areas of >15% cover (high density area) and <15% cover (low density area). These areas are considered separately to ensure accurate % cover is achieved for the high density areas and so as not to underestimate the cover of the bloom. Within the high density areas of >15% a minimum of 10 quadrats for each discrete patch of algal bloom should be recorded in the appropriate field recording sheets. This should also be repeated for the less dense areas of <15%. Within each quadrat the total % cover should be estimated as accurately as possible to the nearest 5%. This can be achieved using a variety of methods;

1. Open quadrat - this method allows the analyst to estimate the percent cover in a 0.25m^2 quadrat without visual obstruction or assistance from gridlines. A general estimation is conducted looking solely at the total area within the quadrat that is clearly covered by opportunist macroalgae.

2. 4 x 4 gridded quadrat - this method spits the 0.25m^2 quadrat into 25 squares with each square representing 4% of the total quadrat. The percent cover is estimated by counting the number of squares covered by macroalgae to the nearest half square. The number of squares is divided by 25 and then multiplied by 100 to give a percentage.

3. 9 x 9 gridded quadrat - this method splits the quadrat into 100 squares. The crosshair refers to the point at which the lines cross and within a 9 x 9 grid amounts to a total of 81 crosshairs. The method of cover estimation is achieved by recording the presence or absence of algae under each of the crosshair points. Where algae is present under the crosshair this is recorded as 1 and absence is recorded as 0. The number of cross

hairs with algae present is divided by 81, and then multiplied by 100 to give a percentage.

For quality assurance of cover, when more than one ecologist is present on site, two independent readings of cover should be within +/- 5%. If this cannot be agreed, then the samples should be referred to the photographic QA method. Where competence can be shown, it may be possible to assess % cover from photographs.

The taxon/taxa of alga(e) should also be recorded to genus level only unless species is known, and the approximate relative proportions of taxa present. In addition any obvious signs of invertebrate life e.g. number of worm casts or presence of cockle/mussel shells should also be fully noted.

A minimum of 3 samples should be collected for each algal patch. The number of quadrats will be dependent on patch size and the variability of cover and density.

Biomass (Biomass of Affected Area & Biomass of AIH)

The collection of algal samples for biomass estimation is inherently inexact, as there is no clearly defined point at which all algae may be collected. Some workers have derived biomass data from wet weight surface samples (e.g. Hull, 1987, 1988; Raffaelli, 1999), while other workers have taken samples to a depth of one (Pye, 2000) or several centimetres (EA, unpubl.). The MPTT proposes that the surface layer only should be collected, as this is easier to determine once mud is disturbed than one or two centimetres in depth, and is also likely to correlate more closely with what is visible on remotely collected images.

Algal biomass is achieved through stratified random sampling within both the high and low density areas. Biomass is calculated within each of the quadrats sampled for % cover. The algae within the quadrat are removed at the surface layer only. Where algal density is very thick it may be necessary to cut, using scissors or a knife, around the inside of the quadrat so as not to pull in any algae from outside the quadrat. The algae should be lifted from the surface of the mud. Where algae are entrained it may be also be necessary to cut the algae at the surface so as not to pull up any deeply embedded algae and over estimate the surface biomass. If the algae are easily removed from the underlying sediment this would suggest they are not properly entrained and may therefore be used for the calculation of biomass. If the algae are harder to remove they should be cut at the surface. The algae should then be thoroughly rinsed to remove all sediment and hand squeezed until water stops running. The remaining wet weight of algae can either be weighed in situ on appropriate, calibrated field scales or retained in plastic bags, clearly labelled and weighed later in the laboratory. At this stage in the field the presence of entrained algae within the high density areas only should also be noted.

Two fictional examples of how to sample for a discrete macroalgae bloom are shown in order to demonstrate the mapping of algal beds and use of quadrats for estimating average cover and biomass (Figures 5 & 6). Distinguishing the patches into low and high density enables the boundaries set at 15% to be established with a second boundary of substantially more patchy and thin growth of algae to be roughly mapped. As long as all variations of cover density are incorporated into the quadrat sampling the outcome should be reasonably accurate.

Presence of entrained algae

The presence of algae growing 3cm or more down into sediments should be assessed per quadrat. Where algae are hard to remove and even require to be cut to facilitate removal (see above), the depth of entrainment may be measured, e.g. with a ruler to help determine entrainment.

6.5.4 Data collection and handling

Data collected in the field or the laboratory should be stored appropriately, according to the organisation's normal practice. Examples of data sheets are shown below (Table 7 & 8). Data might also be collected in the field on GPS data dictionaries and downloaded later; this saves time and also reduces the potential for transcription errors.

Table 7: Example Field Recording sheet – Manual method

Water Body		**Algal Patch code**	**Overall area of Patch Hectares**	**Transect no.**	**Quadrat no.**	**Quadrat GPS**	**% Cover in quadrat**	***Entero-morpha***	***Ulva***	***Chaeto-morpha***	***Pilayella***	***Ecto-carpus***	***Porphyra***	**Biomass per quadrat gm2**	**Entrained algae Y/N?**	**Entrain-ment Depth**	**Comments**
Water body 1		a		1	1.1		5	5						5	n		
Water body 1		a		1	1.3		25	20	5					100	n		
Water body 1		a		2	2.1		10	10						10	n		
Water body 1		a		2	2.2		20	10	5			5		50	n		
Water body 1		a		2	2.3		20	20						100	n		
Water body 1	Sub-totals		**10**				**15**							**45**	N		
Water body 1		b		1			20	10	10					50	n		
Water body 1		b		1			15		15					100	y	< 5mm	
Water body 1		b		2			20	5	5	5		5		35	n		
Water body 1		b		2			20	10	10					30	n		
Water body 1		b		2			20	15	5					50	n		
Water body 1		b		2			15	10	5					45	n		
Water body 1		b		2			25	5	15			5		75	y	<5mm	
	Sub-totals		**90**				**20**							**50**	Y		
	Totals		**100**				**19.5**							**49.5**			
Water body 2																	
Water body 2																	

Table 8: Example Recording sheet - Aerial method

Water Body	**Date/ Time**	**Site/ Waypoint/ quadrat number**	**Quadrat GPS position (Easting/Northing)**	**Distance North (m)**	**Distance East (m)**	**Distance South (m)**	**Distance West (m)**	**Square Area of patch (m^2)**	**Class (eg. green weed/Fucus/Zostera/ Saltmarsh etc)**	**Photo number**	**Total Green weed (% Cover in quadrat)**	***Entero-morpha (% cover)***	***Ulva (% Cover)***	***Chaeto-morpha (% cover***	***Other relavent macroalgal speices***	***Mud/Sand/Gravel (% cover)***	***Zostera (% cover)#***	***Relavent Salmarsh Species****	**Total Green weed Biomass per quadrat gm2**	**Entrained algae Y/N?**	**Entrain-ment Depth (mm)**	**Comments**
Water body 1		1		2	5	2	10	60	GrWe		5	5				95			5	n		
Water body 1		2		10	3	3	10	169	GrWe		10	10				90			5	n		
Water body 1		3		10	8	8	10	324	Fucus		25	20	5		15	75			50	n		
Water body 1		4		4	2	10	2	56	GrWe		10	10				90			10	n		
Water body 1		5		3	3	3	3	36	GrWe		15	10	5			80	5		50	n		
Water body 1		6		5	5	5	5	100	GrWe		20	20				80			100	n		
Water body 1		7		2	10	2	10	80	GrWe		**15**	**15**				**85**			**45**	n		
Water body 1		8		4	10	5	5	135	GrWe		20	10	10			80			50	n		
Water body 1		9		10	10	30	10	800	GrWe		100	80	20						357	y	< 5mm	small amount of entrainment
Water body 1		10		10	5	5	3	120	GrWe		20	5	15			80			15	n		
Water body 1		11		5	5	15	15	400	GrWe		60	50	10			40			210	n		
Water body 1		12		7	7	7	7	196	GrWe		35	30	5			65			155	n		
Water body 1		16 etc		10	10	5	5	225	GrWe		40	5	35			60	5		189	y	<5mm	
Information to be collated at the end of each survey day. In order to estimate if enough ground truthing for each class has been collected (Target for CASI methods is 400m2 per class)																						
Total area of polygon ground truthed (m^2)								$400m^2$	Green weed													
Total area of polygon ground truthed								$250m^2$	Fucus													
Total area of polygon ground truthed								$345m^2$	Zostera													

6.6 Summary of classification process

The full assessment process can be more clearly understood following the flow chart below (Figure 7).

Work Area	*Considerations*
Monitoring Design	• Is opportunistic macroalgae an appropriate assessment? (Consider suitable AIH) • Establish peak growth period for monitoring • Consider aerial imagery for bed extent measurements
Sample collection	• Does preliminary survey show <5% cover in water body? If yes, full survey not required – High class • If full survey required, use standardised methods • Measure bed extent by aerial imagery or ground assessment using handheld GPS • Measure % cover in quadrats (no. defined by algal coverage) • Collect macroalgae for biomass measurement from quadrats • Record entrainment (growth ≥ 3cm in sediment) • Record taxa and supporting observations
Sample analysis	• Quality assurance procedures • Wet weight (biomass) of algae • Calculate AIH (refine with local knowledge)
Calculation: Face value	• Total affected Area • Total % algal cover of Available Intertidal Habitat (AIH) • Average Biomass of Available Intertidal Habitat (AIH) • Average Biomass of affected area • Presence of entrained algae (% of quadrats) • AA as a percentage of AIH (AA/AIH%)
EQR calculation	• Normalise and rescale values to equidistant 0-1 range *Final Equidistant metric score = Upper Equidistant Class range value – ((Face Value - Upper Face value range) * (Equidistant class range / Face Value Class Range))*
Water body classification	• Derive WB EQR • Assign Class Status (use defined class boundaries) • Calculate Confidence of Class and Risk of Misclassification

Figure 7: Flow chart summarising the main stages involved in undertaking an assessment of macroalgal blooms

6.7 Worked Example

This shows the process of how to calculate the individual metrics and then the final waterbody level EQR.

6.7.1 Case Study of Langstone Harbour

Langstone Harbour is recognised as having high levels of opportunistic macroalgal growth in most years. Therefore this area was ideal for preliminary studies on the effectiveness of the assessment tool and metric scoring system.

In a study of eutrophication in Langstone Harbour, Pye (2000) established permanent quadrats (PQ) of 10m x 10m marked with white stakes visible 15 cm above the mud surface. Random quadrats (RQ) of 50cm x 50 cm (0.25m^2) were taken from the area adjacent to the edges of the PQs as representative samples. The results are given in the tables below for each of the algal patches (Tables 9, 10 &11).

Table 9: Biomass and % cover data for Langstone Harbour

Patch 1 5-25%		**% cover**	**Weight**	**Size of patch**
	1	15	36	
	2	10	96	
	3	10	52	
	4	5	32	
	5	15	68	
Average		11	56.8	
Actual cover (ha) and weight (g) per patch		10.197	5265.36	92.7

Patch 2 25-50%		**% cover**	**Weight**	**Size of patch**
	1	60	92	
	2	60	296	
	3	70	740	
Average		63.333333	376	
Actual cover (ha) and weight (g) per patch		61.623333	36584.8	97.3

Patch 3 50-75%		**% cover**	**Weight**	**Size of patch**
	1	70	156	
	2	75	188	
	3	55	280	
	4	100	416	

5	75	216	
6	80	616	
7	50	412	
8	70	240	
9	60	180	
10	70	317.52	
Average	70.5	302.152	
Actual cover (ha) and weight (g) per patch	108.3585	46440.7624	153.7

Patch 4 75-100%	% cover	Weight	Size of patch
1	100	2776	
2	95	308	
3	95	1164	
4	100	4200	
5	100	2140	
6	90	324	
7	90	808	
8	100	1020	
9	100	1212	
10	90	1000	
11	100	648	
12	90	1612	
13	100	1380	
14	60	368	
15	70	224.2	
Average	92	1278.946667	
Actual cover (ha) and weight (g) per patch	95.864	133266.2427	104.2

Table 10: Final results for the analysis of opportunistic macroalgae cover, biomass and entrainment in Langstone harbour.

Totals	
Cover of algae (ha)	276.04
Biomass of algae (gm^{-2})	221557.2
Affected intertidal area (ha)	447.9
Available intertidal habitat (ha)	1481.8

Table 11: Final classification and quality status for Langstone Harbour

	Value	EQR
% cover of macroalgae within the AIH	18.629	0.527

Average biomass of algae per quadrat within the AIH	149.519	0.775
Average biomass within the affected area only	494.658	0.603
Total size of affected area	447.900	0.193
Entrained algae	0.000	1.000
Average EQR		0.620
		Good

The final EQR from the 5 metrics is 0.620 equating to Good status and with the lower and upper confidence intervals ranging between 0.602 and 0.640. Applying the calculation for confidence of class discussed in section 7 the confidence of survey for the single year of data shows that it lies within the Good status with a confidence of 95.187% and 4.183% within Moderate status. Assuming a 20% chance of sampling error, the classification has a reduced confidence of Good status classification at 83.513% and 16.487% chance of Moderate status classification.

7. Response to Pressure

The WFD requires the characteristics used in the assessment of water bodies to show evidence of response to changes in the natural environment through both direct and indirect pressures such as;

- toxic substances
- morphological pressures & alterations more specifically habitat modification,
- point source discharges or general pollution,
- increased nutrients leading to eutrophication,
- abstraction & flow regulation,
- presence of alien species, and
- general stress

The primary pressures thought to cause a shift in the balance of intertidal macroalgae communities are toxic substances, habitat modification or degradation and point source discharge which may in turn lead to problems of eutrophication through increased nutrients. Blooms of opportunist macroalgae are primarily considered an indicator of eutrophication. Despite the rich nutrient load, hydrodynamic and climatic conditions as well as biotic factors are controlling algal growth. For this reason, and due to the lack of spatially/temporally properly linked datasets of algal cover and nutrient concentrations in the field, a significant correlation between the two variables cannot be shown. However there are documented effects of environmental impacts that can be well described.

Increased Nutrients and Eutrophication

Marine plants are a key component of the ecology of shallow coastal and transitional water environments. In healthy shallow coastal waters with a balanced nutrient regime the dominant primary producers are perennial benthic macrophytes such as seagrass or long-lived seaweeds, with seasonal opportunistic macroalgae or phytoplankton playing a lesser role in biomass and production (Schramm & Nienhuis, 1996).

Increased nutrient inputs from both direct and indirect sources such as sewage outfalls and land run-off contribute to eutrophication problems and increased suspended sediment levels. These may exacerbate the growth of opportunist species or extend their peak growth season. Increasing nutrient loading increases blooms of 'nutrient opportunists', in particular fast-growing epiphytic macroalgae and bloom-forming phytoplankton taxa; macrophytes and perennial macroalgae decline and finally disappear. The changes in benthic vegetation due to increased nutrients are a series of direct and indirect affects that can feedback and self-accelerate, and are difficult to control once initiated (Schramm & Nienhuis, 1996).

The increasing nutrients and excessive algal growth smother the diverse understorey causing decreased species richness and transition in species composition from long lived perennial algae to fast-growing ephemeral algae restricting the abundance of sensitive species. Additional responses may be an undesirable shallow anoxic level as well as excess suspended particulate matter resulting from increased nutrients and runoff leading to light limitation. This impact can result in a community transition from algal dominated to animal dominated due to an increase in filter feeders and an overall change in environmental conditions.
Increased nutrients inputs from both direct and indirect sources such as sewage outfalls and land run-off contribute to eutrophication problems.

Habitat Modification

Habitat loss or degradation may be through coastal morphological change including construction of flood defences, harbours or slipways, dredging activity causing removal of habitats, increased deposition of sediments. Increased morphological pressure can lead to loss or complete removal of coastal habitats with a change or loss of algal communities, and a shift in community structure from long lived perennial species to ephemeral, opportunist species, which can dominate the community and restrict continued growth of other faunal and floral species.

Degradation through coastal morphological change or increased pressure, specifically dredging activity also causes increased sedimentation and excess deposition. This can lead to smothering and light limitation causing a dominance of tolerant macroalgae species and restricting growth of less tolerant species resulting in a community transition from algal dominated to animal dominated due to an increase in filter feeders and an overall change in environmental conditions.

Toxic Substances

Toxic substances present in intertidal areas through industrial run-off and trickle streams can produce seriously undesirable conditions, with the presence of sulphur reducing bacteria and a general decrease in species richness and abundance. Freshwater run-off or outflows reducing salinity can also lead to a dominance of more tolerant species such as the opportunist macroalgae whereby less tolerant species may be restricted in both richness and abundance. Some shores are known to have mine water draining through, and this can often cause discoloration of the substrate and algae.

In summary, algal blooms can contribute to the decline of the natural community in a variety of ways:

- Increasing nutrients lead to excess algal growth and the production of opportunist macroalgae blooms, which may smother the underlying sediments and modify bird feeding behavious due to restricted access to benthic fauna and cause anoxia in sediments.
- Increased and persistent growth of opportunist macroalgae can eventually lead to the complete anoxia of underlying sediment with rotting algal causing pungent odours and causing general disruption to the natural environment.
- Rafts of detached algae may interfere with saltmarsh, and with recreational use of waters, e.g. canoeing.
- Increased hydromorphological pressure leading to loss or complete removal of coastal habitats can cause a shift in community structure from long lived perennial species to ephemeral, opportunist species which can dominate the community and restricted continued growth of other faunal and floral species.
- Reduction in salinity can lead to the removal of sensitive species and promote the growth of tolerant opportunist species especially in the vicinity of freshwater run-off.

8. Levels of Confidence

The WFD requires programmes of measures to be implemented in areas of less than Good status, to allow those waterbodies to achieve at least Good status by defined target dates. Therefore the outcomes of the tools being developed will govern the actions, if any, to be taken in a particular area. Consequently, there needs to be a high level of confidence in the sampling strategy, methods used and data collected, and in the tools' ability to classify accurately the ecological status of a water body.

8.1 Confidence in Sampling Frequency

Ideally sampling should take place during all periods of excess algal growth, however, with limited resources this is not possible, so it is proposed that monitoring for macroalgae blooms should take place during the peak growth season. As this time is not always known and can be variable, historical data are desirable where possible to help establish the time of peak growth. Confidence in sampling can be increased by improving the frequency of sampling. Inter-annual variation in both biomass and percentage cover of macroalgal blooms can occur as a result of a number of factors such as changes in temperature, river flows (affecting nutrient loads) and sediment scouring as a result of extreme weather events. Ideally there would be annual sampling, as least for a number of years, but this is not always possible with limited resources. Therefore sampling should be completed at least every 2-3 years enabling at least 2-3 datasets per reporting cycle, or until there is a good understanding of inter-annual variability. In order to smooth any annual fluctuations in class resulting from inter-annual variation, the annual water body EQRs can be averaged once several sets of data have been collected. More frequent monitoring to begin with will give some idea of inter-annual variation and, once a degree of confidence is reached, sampling frequency may be reduced.

8.2 Confidence in Data

The confidence here lies with the field surveyors' ability to collect all the required data to a set standard following precise methodologies. This can be dealt with both internally within each of the relevant monitoring organisations, and externally as part of a quality assurance scheme. Organisations should utilise quality systems incorporating auditing. An external proficiency testing scheme is run by the National Marine Biological Analytical Quality Control (NMBAQC) with ring tests requiring estimations of % cover and the assessment of biomass samples. The participating laboratories are able to test their levels of consistency and accuracy in their methods. This process can also help identify areas requiring additional training. Where field skills and consistency between workers is lacking there will be limited confidence in the data collected. Sample numbers should be sufficient to encompass the variation in percentage cover and biomass occurring throughout the water body.

8.3 Confidence of Classification

Providing an estimate of the statistical uncertainty of water body assessments is a statutory requirement of the WFD (Annex V, 1.3). In an ideal world of comprehensive monitoring data containing no errors, water bodies would always be assigned to their true class with 100% confidence. However, estimates of the truth based on monitoring are subject to error because monitoring is not done everywhere and all the time, and because monitoring systems, equipment and people are less than perfect. Understanding and managing the risk of misclassification as a result of uncertainties in the results of monitoring is important on two counts; first, because of the potential to fail to act in cases where a water body has been wrongly classified as being of better status than it is, and secondly because of the risk of wasting resources on water bodies that have been wrongly classified as worse than they are.

A methodology for calculating a measure of the confidence of class (CofC) for the Opportunistic Macroalgal Blooming tool, 'Confidence And Precision Tool AIds aNalysis' (CAPTAIN), was developed by WRc (Davey, 2009).

CAPTAIN calculates confidence of class (CofC) at three levels: metric, survey (single sampling event) and water body over the reporting period (potentially several surveys):

- The CofC for each metric in each survey is based on the metric EQR and takes account of sampling error plus any error in the measurement. This aspect describes how each metric score is derived, and its corresponding standard error is calculated to give a metric CofC.
- The CofC for each survey is based on the Survey EQR and takes account of combined uncertainty in the five metrics. This part of the system considers how the metric scores are combined to yield an EQR and CofC for each survey.
- The CofC for the water body is based on the Final EQR and takes account of the temporal variation among the EQR results from replicate surveys. This part of the CofC assessment is performed for the water body as a whole.

For the CofC of each of the five metric scores and metric EQRs the level of standard error can be calculated incorporating all variables including measurement error. This can be converted to a confidence of class using a normal distribution approach. The confidence of class for the survey EQR is calculated using the average of the five metric EQRs. As the standard errors of the five metrics cannot be assumed to be independent because they are based on data from the same quadrats, they will share any errors in the measurement of patch area and AIH. Therefore the system calculates a further standard error of the whole survey EQR which is also converted to a confidence of class following the same normal distribution approach.

When there is more than one patch, the sub-metrics are calculated by weighting the result for each patch by the area of each patch.

Further information on the development of the confidence in class approach is given in Appendix 1.

9. European Intercalibration

The main aims of the European intercalibration exercise are to establish class boundary values for high-good and good-moderate status, which must in turn be consistent with the normative definitions for those class boundaries, and to ensure the various Members States (MS) are making equivalent assessments. The former is achieved by monitoring the degree of deviation from reference conditions by use of monitoring tools currently developed by the member states and incorporating various parameters, methodologies and assessment measures. The intercalibration process entails discussions between member states to agree a common means of quality assessment incorporating all biological quality elements, all waterbody types and all pressures.

The intercalibration process deals with the development of reference conditions, and the setting of specific class boundaries for those metrics of the biological quality element macroalgae. It also deals specifically with macroalgae blooming problems primarily present on sedimentary intertidal areas, for which suitable assessment methods and comparable data are available within the NEA GIG areas NEA 1, 26 and NEA 11 in the UK, RoI, and Germany at this stage of the intercalibration exercise. Portugal is currently in the process of collecting data with the possibility of adopting this particular metric system. Within the UK, RoI and Germany this tool is being adopted for sedimentary shores.

A number of quality assessment tools have been developed by different member states incorporating various aspects of macroalgae composition and abundance. Discussions have been held throughout Europe to review the feasibility of such tools and how they may be adapted to include the variable habitat types and environmental factors experienced across the member states. It was agreed that this aspect of the plant community required a multi-metric system approach, rather than a full tool, combining elements of different assessment methods. This was decided as the NEAGIG types could not all be covered within a single tool due to tidal restrictions, substrate type and data availability.

Note: The following discusses Phase 1 of the Intercalibration process. Initial Intercalibration was agreed in Phase 1 (European Commission, 2008), then taken forward into Phase 2 of the Intercalibration process. It has not yet (at the time of this update) been intercalibrated successfully according to Phase 2 criteria.

9.1 Discussion of Data Availability and Analysis

The monitoring of macroalgal blooms appears to be quite common between member states. However, the methodologies used tend to vary considerably even within the UK there are disparate forms of data collected for various purposes, using various methodologies. It also seems that different member states are subjected to different types of macroalgal growth:

- The UK and Republic of Ireland experience large mats of opportunist species with rapid growth covering vast areas of the intertidal, these mats are not always persistent and their levels of disturbance vary primarily as a result of biomass, overall density and depth penetration into the sediment. Much of this data has been collected by transect, estimating overall cover, usually 0-25% 25-50%, 50-75% and 75-100%, and measuring the outer extent of the algal mats and total available intertidal for opportunist growth.

- In contrast the Netherlands are subjected to loose rolls of algae that tend to be seasonal and appear to have no long term effects. These mats are often very mobile forming heaps in the intertidal; it is these heaps that are measured but not routinely.

- Areas of France have opportunistic macroalgae freely growing in the water column and this is deposited on the shore, unfortunately these mats do not behave in the same way as sediment based mats and so the Uk tool could not be intercalibrated with France at this stage.

- The coastline of Sweden appears to be more prone to drifting mats of macroalgae with data collected at 5, 10 and 15m depths.

- Germany have some aerial coverage data for green opportunistic algae, however this has not been ground-truthed, therefore there is no abundance or biomass data. Germany have also stressed that they have different ranges and boundary conditions.

- Spain (Basque region) also has some coverage data.

- France has a similar problem with drifting blooms of Ulva particularly around Brittany where the waters are very clear resulting in a visible response to eutrophication. These blooms also vary seasonally and the biomass can be subtidal. The blooms accumulate where the residual currents are low and the Ulva are kept in the system. High levels can be detected in April or May due to the winter residual stock of green algae but if the winter residual stock is low then the bloom will occur later in the year. The phenomenon is an irregular occurrence. Data is collected as cover on the shore and in the water at low tide and is calculated in hectares.

9.2 Tool Development

The general problem is that there seems to be a limited amount of data, the quality of which varies considerably across member states, so the common approach needs to be fairly simple and applicable to the various data sets. Initially it was thought that the best indicator would be measures of biomass as it is often the shear density of the algal mats that create the greatest degree of disturbance and disruption to the natural environment. However, this is known to be much more labour intensive and consequently many member states do not possess vast amounts of this type of data. Equally with some dense mats of algal growth in the Netherlands and Sweden appearing more mobile their impacts may be very short lived despite high biomass measurements. Further discussion highlighted the potential use of % cover of algal mats for which many member states possess spatial coverage in some form, either as aerial photography, remote sensor and ground truthing or general field transects. Another benefit of using coverage data is that there are already existing guidelines on where to draw up potential classification status boundaries from current reports and studies including OSPAR common assessment criteria.

It was suggested that it may be necessary to measure the duration of the offending bloom, a measurement often adopted within measures of phytoplankton blooms. However, with little knowledge of the natural annual persistence of opportunistic growth it would be difficult to incorporate this metric into a tool. This would also require more intensive field surveys adding to the cost and frequency of sampling. Denmark and the UK also highlighted the importance of considering the hydromorphology of the affected area and the incorporation of this into the model, but this was also dismissed as overly complicated and was considered a general problem of the WFD that would not be easily overcome.

9.3 Development of Boundary Values

Many member states do not have existing boundaries from which to develop. Where class boundaries have been developed these have been part of a more complex metric system. Denmark suggested it was important to consider the accuracy of the metric when setting the boundary values. If the good/moderate boundary is, for example, 1% cover then measurement error must be considerably smaller. France suggested that reference conditions should be 0-1% cover of the intertidal but there needed to be more clarity on the total survey area; was it to include a small area of intertidal such as a single beach or bay or was this to be calculated from the whole water body. The UK calculates total % coverage from the available intertidal habitat for potential growth. This has been briefly addressed in but needs to be fully documented and agreed between member states. Thresholds still need to be full agreed between member states.

These class boundaries developed by the UK and RoI have been discussed within the intercalibration process and are being developed further to allow for geographical variations and slight differences in scale. Germany has tested its data against this metric, initially the classification appeared to be skewed towards high status but the incorporation of a scale for the total number of hectares covered this appears to have corrected this problem, however, this still needs more testing to substantiate these results and test with a variety of datasets. Geographic differences in environmental conditions and the sizes of water bodies indicated the requirement for a revision of the metric and its boundary values. Tentative boundaries has seen been compiled but these are yet to be fully tested against the existing data from the UK, RoI, Germany and Portugal (Tables 12 & 13).

The classification metric to initially undergoing testing is detailed in the tables below (Tables 14 & 15), these values should ideally be based on a 5-6 year rolling mean where possible. They have so far been applied to data from the UK and Germany.

Table 12: Boundary values for % cover of opportunist within available intertidal for intercalibration metric.

	High	Good	Moderate	Poor	Bad
% cover of opportunist algae within available intertidal	<5%	5 - 15%	15 - 25%	25 - 75%	> 75%

The table above provides an initial classification status but does not account for the overall size of the patch within the water body. Where there is a large algal bloom but % cover is relatively small due to the large size of the water body the table below allows for this to be taken into account. Therefore for those areas where there is an extensive bloom of algae they cannot achieve high status.

Table 13: Boundary values for areal coverage of opportunist algae for the intercalibration metric.

	High	Good	Moderate	Poor	Bad
Total area covered by opportunist algae (hectares)	<100	100-500	500-1000	1000-2500	>2500
Effect on quality status class	No change	No change	-1 class	-2 classes	-3 classes

However, a major issue with this initial metric system is that it does not incorporate any aspect of biomass which is a critical parameter to assure accurate quality status

Table 14: Testing metric with UK data using mean data

	Year	Total % cover of intertidal	Quality status	Total number of hectares	effect on quality status	Final Classification
Chichester harbour	1994-1999	19.95	Moderate	91.85	No change	Moderate
Langstone Harbour	1994-1999	19.49	Moderate	577.13	minus 1 class	Poor
Newtown	2001-2003	12.01	Good	66.34	No change	Good
Pagham	1999-2000	9.67	Good	76.05	No change	Good
Portsmouth	1998-2000	26.54	Poor	533.21	minus 1 class	Bad

Table 15: Testing metric with German data using annual data only from 1990.

	N2 Untere Ems		**N4 Untere Ems**		**N2 Jade**		**N4 Wes Weser**		**N4 Ost Weser**		**N4 West Elbe**	
Year	% cover macroalgae	Total no. hectares	% cover macroalgae	Total no. hectares	% cover macroalgae	Total no. hectares	% cover macroalgae	Total no. hectares	% cover macroalgae	Total no. hectares	% cover macroalgae	Total no. hectares
1990	6.851	1335.8	6.940	2369.4	1.485	375.9	0.504	26.4	0.757	126.7	0.042	4.2
Initial Class status	Good	Minus 2 classes	Good	Minus 2 classes	High	No change	High	No change	High	No change	High	No change
Final Classification	**Poor**		**Poor**		**High**		**High**		**High**		**HIgh**	

An alternative metric that has been developed in the UK (Table 16) has been agreed if only by the UK and Ireland and may show better potential for subsequent intercalibration with additional members states and other countries are considering if this tool could be used in their waters. Denmark will consider intercalibration at a later date, post June 2007.

Table 16: Metric system that has been developed for intercalibration for the UK and RoI

Quality status	High	Good	Moderate	Poor	Bad
EQR	**0.8 - 1.0**	**0.6 - 0.8**	**0.4 - 0.6**	**0.2 - 0.4**	**0.0 - 0.2**
% cover of AIH	0 - 5	5 - 15	15 - 25	25 - 75	75 - 100
Area (ha)	0 - 100	100 - 500	500 - 1000	1000 - 2500	>2500 (- 6000)
Biomass (g m^{-2}) of AIH	0 - 100	100 - 500	500 - 1000	1000 - 3000	>3000 (- 6000)
Biomass (g m^{-2}) of Affected Area	0 - 100	100 - 500	500 - 1000	1000 - 3000	>3000 (- 6000)
Presence of entrained algae (%)	0 - 5	5 - 20	20 - 50	50 - 75	75 - 100

The tool is a combination of percent cover by opportunistic green algae, the density of growth with a defined area and the presence of entrained algae.

Portugal has a long time series of data for one particular estuary and tested the metrics of total area, percentage and biomass in different combinations. The results are very comparable and comply with the expert judgement of Portuguese scientists

Currently Germany only has data for the areal cover of opportunistic macroalgal growth on soft sediments in the intertidal. A recent report has tried to compare this metric to part of the UK/RoI tool (see below). (Classification tools for biomass and for taxonomic composition might be designed after further investigations in the field.)

However, a recent German report considered that "UK intercalibration tool on the whole cannot be applied to the German dataset. Moreover model calculations already show that the class boundaries of the UK proposal do not reflect the heavy disturbances in algal growth that have been reported from the German water bodies in the 1990s (ADOLPH 2007)." Therefore, Germany is still in the process of intercalibrating their data.

As noted at the beginning of this section, the intercalibration process is continuing, with greater emphasis on the ability of tool to identify a relationship between pressures and impacts.

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11. Appendices

Appendix 1: Background to the development of CAPTAIN confidence of class assessment

Surveys are conducted using a stratified random sampling approach, whereby the waterbody is divided into one or more discrete patches with differing levels of macroalgae and three or more replicate quadrats are randomly positioned in each patch. (Areas of the waterbody with no algae effectively form a separate stratum or patch which is not surveyed and where %cover and biomass are assumed to be zero.) The metric system is composed of five submetrics (Figure 8 demonstrates the process of sampling through to quality classification):

1. % cover of AIH – The average % cover of algae in the available intertidal habitat.

2. Biomass (g m^{-2}) per m^2 AIH – The average biomass of algae per m^2 in the available intertidal habitat.

3. Presence of entrained algae – The % of quadrats where algae is seen to be growing deeper than 3cm into the underlying sediment indicating the likelihood of regeneration.

4. Total affected area (ha) – The total extent of the algal bloom, measured in hectares and based on the external perimeter of the bloom.

5. Biomass (g m^{-2}) per m^2 affected area – The average biomass of algae per meter squared over the affected area only.

When there is more than one patch, the sub-metrics are calculated by weighting the result for each patch by the area of each patch.

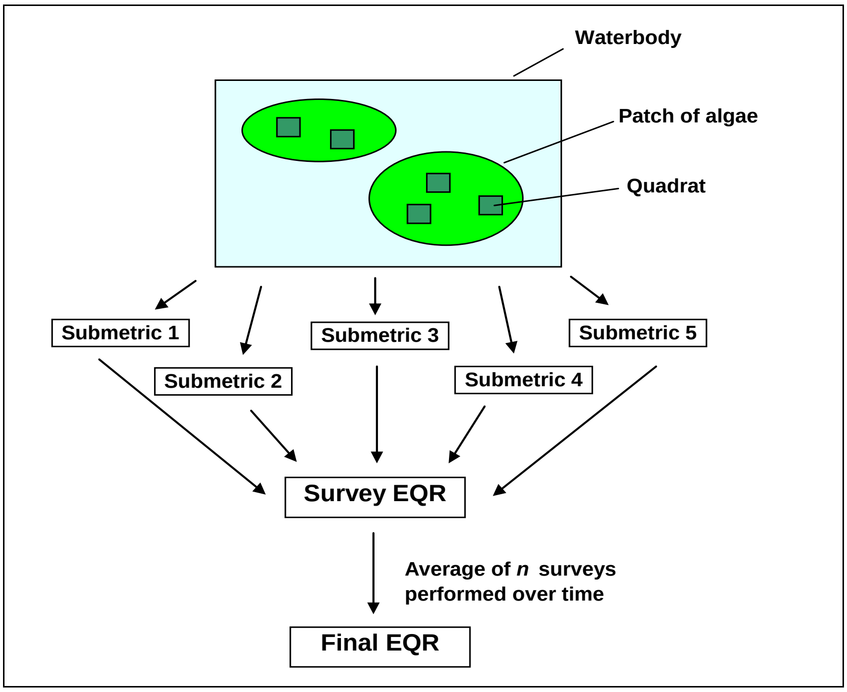

Figure 8 Sampling scheme for opportunistic macroalgae tool

CAPTAIN is able to perform confidence of class calculations at three levels: sub-metric, survey and waterbody:

1. The confidence of class for each sub-metric in each survey is based on the sub-metric EQR and takes account of sampling error plus any error in the measurement of patch area. This aspect describes how each sub-metric score is derived, and its corresponding standard error is calculated to give a sub-metric CofC.

2. The confidence of class for each survey is based on the Survey EQR and takes account of combined uncertainty in the five sub-metrics. This part of the system considers how the sub-metric scores are combined to yield an EQR and CofC for each survey.

3. The confidence of class for the waterbody is based on the Final EQR and takes account of the temporal variation among the EQR results from replicate surveys. This part of the CofC assessment is performed for the waterbody as a whole.

The process of equations used to calculate the confidence of class are fully described in the draft report from WRc; confidence of class for WFD marine plant tools.

In summary for the confidence of class of each of the five sub-metric scores and sub-metric EQR's the level of standard error can be calculated incorporating all variables including measurement error. This can later be converted to a confidence of class using a normal distribution approach. The confidence of class for the survey EQR is calculated using the average of the five submetric EQR's. As the standard errors of the five sub-metrics cannot be assumed to be independent because they are based on data from the same quadrats, they will share any errors in the measurement of patch area and AIH. Therefore the system calculates a further standard error of the whole survey EQR which is also converted to a confidence of class following the same normal distribution approach.

However, each of the sub-metrics have been normalised on a scale of 0-1 as shown in Figure 9. This process creates problems when attempting to calculate the standard error associated with each sub-metric EQR. Although it is relatively straightforward to calculate the standard error of the sub-metric *score*, there is no easy way to then normalise the standard error onto an equal-width EQR scale. Therefore the solution adopted was to estimate a 95% confidence interval around each sub-metric score, normalise the upper and lower confidence limits, and then to derive an approximate standard error on the normalised EQR scale.

step 1 **step 2**

Class	Sub-metric score	Non-equidistant EQR	Equi-distant EQR
High	0--10	0.67 - 1.00	0.8 - 1.0
Good	10--15	0.44 - 0.67	0.6 - 0.8
Moderate	15--20	0.34 - 0.44	0.4 - 0.6
Poor	20--25	0.27 - 0.34	0.2 - 0.4
Bad	>25	0.00 - 0.27	0.0 - 0.2

Combined steps

EXAMPLES			
High	5.00	0.84	0.90
Good	13.00	0.53	0.68
Moderate	19.00	0.36	0.44
Poor	25.00	0.27	0.20
Bad	26.00	0.26	0.19

Figure 9: Normalisation of sub-metric scores to produce an EQR

Finally the standard error of the final EQR measures the uncertainty in the final status assessment. However, here lie further problems. Where only one survey is undertaken with a single EQR result, the variability cannot be measured directly, it has to be estimated indirectly using data from other waterbodies. Therefore, the standard deviation is instead estimated from the mean EQR using an approach developed by Ellis & Adriaenssens (2006) to estimate the likely spatio-temporal variability in Survey EQR as a function of the mean Survey EQR in a waterbody. Variability is expected to be greatest in waterbodies of moderate status (EQR ≈ 0.5), and to get progressively smaller as the mean EQR tends towards 0 or 1e.g. to have a mean EQR of exactly 0 (or 1), all surveys must yield EQR values of 0 (or 1) – i.e. there must be no variation among surveys. The Final EQR and its standard error are then converted to a confidence of class following the t-distribution approach

This process is better described using a worked example from data collected from the Medway as part of the WFD classification process. This survey was conducted using a stratified random sampling scheme, whereby the waterbody was divided into one or more patches with differing levels of macroalgae and two or more replicate quadrats are randomly positioned in each patch.
This water body had patches of algal growth, from patches 1-4 a total of 9, 12, 10 and 12 quadrats were sampled respectively. Table 17 provides the results from each of the patches. From these results the confidence intervals can be calculated (Table 18) to provide a standard error.

The final CAPTAIN spreadsheet (Table 19) calculates both the face value class (based on the mean EQR) and probability of the waterbody being in each of the five status classes. Occasionally the face value class may not be the same as the most probable class given by the CofC assessment. This is perfectly correct, and arises because the EQR is constrained to take values between 0 and 1. It typically occurs when the mean EQR is close to a boundary between two classes. For example, consider a waterbody with a Final EQR of 0.78, just below the High/Good boundary - the face value class will be Good, but the CofC may say 50% High, 40% Good and 10% Moderate, which 'averages out' at Good. Thus, there is no contradiction between the face value result, which relates to the long-term expected EQR value, and the CofC, which presents the distribution of outcomes that are expected to arise due to random variation.

Table 17: Basic data collected from 4 patches of opportunist algae in the Medway including the first round of calculations.

	Patch No.	%cover	Biomass (g/m2)	%entrained	Affected area (ha)
No. of quadrats	**1**	9	9	9	
	2	12	12	12	
	3	10	10	10	
	4	12	12	12	
Mean	**1**	17.89	136.00	11.1	
	2	38.92	229.00	0.00	
	3	64.80	418.80	10.0	
	4	93.33	1251.67	0.00	
SD	**1**	6.31	176.73	33.0	
	2	6.19	107.14	0.00	
	3	6.76	316.21	32.0	
	4	9.40	1248.82	0.00	
RSE(Mean)	**1**	0.12	0.43	1.00	
	2	0.05	0.14	0.00	
	3	0.03	0.24	1.00	
	4	0.03	0.29	0.00	
Subtotals	**1**	40.61	30872.00	25.22	227.00
	2	43.16	25396.10	0.00	110.90
	3	131.54	85016.40	20.30	203.00
	4	275.80	369867.50	0.00	295.50
Totals		491.11	511152.00	45.52	836.4
Number of patches					4
Total available intertidal habitat (AIH) in ha					2930.9

Table 18: Confidence intervals and standard error for patches both with and without error assumption

		Sub-metrics					
		%cover in AIH	Biomass per m2 AIH	%entrained in AA	AA (ha)	Biomass per m2 AA	Final EQR
Sub-metric Score (Q)		16.756	174.401	5.443	836.400	611.133	
Best estimate EQR		0.565	0.763	0.594	0.180	0.556	0.531
Face Value Class		Moderate	Good	Moderate	Bad	Moderate	Moderate
		ASSUMING NO ERROR IN MEASURMENTS OF PATCH AREA OR AIH					
SE(Q)		0.358	37.299	3.659	0.000	130.703	
Lower 90% CI for Q		16.166	112.857	-0.594	836.400	395.473	
Upper 90% CI for Q		17.347	235.945	11.479	836.400	826.794	
Upper 90%CI for EQR		0.577	0.794	1.000	0.180	0.642	0.557
Lower 90% CI for EQR		0.553	0.732	0.514	0.180	0.469	0.505
Confidence of Class (%) for survey	**High**	0.000	2.304	11.232	0.000	0.005	0.000
	Good	0.000	97.696	33.953	0.000	19.754	0.000
	Moderate	100.000	0.000	54.811	0.000	80.095	100.000
	Poor	0.000	0.000	0.003	0.000	0.146	0.000
	Bad	0.000	0.000	0.000	100.000	0.000	0.000
		WITH ERROR IN MEASURMENTS OF PATCH AREA AND/OR AIH					
RSD of each patch area measurement					**0.10**		
RSD of AIH measurement					**0.10**		
SE(Q)		2.016	43.185	3.690	43.859	142.099	
Lower 90% CI for Q		13.430	103.146	-0.646	764.033	376.671	
Upper 90% CI for Q		20.082	245.656	11.531	908.767	845.596	
Upper 90%CI for EQR		0.631	0.798	1.000	0.182	0.649	0.572
Lower 90% CI for EQR		0.498	0.727	0.513	0.177	0.462	0.490
Confidence of Class (%) for survey	**High**	0.000	4.246	11.430	0.000	0.016	0.000
	Good	19.181	95.754	33.796	0.000	21.692	0.250
	Moderate	80.817	0.000	54.770	0.000	77.981	99.750
	Poor	0.002	0.000	0.004	0.000	0.310	0.000
	Bad	0.000	0.000	0.000	100.000	0.000	0.000

Table 19: Final classification results providing mean EQR's along with confidence of classification within each of the five status classes

WaterBody Name	No. of surveys	Mean EQR	SD - observed	SD - predicted	SE of mean	Face Value Class	High	Good	Moderate	Poor	Bad	GoodOrBetter	ModerateOrWorse
WB001	1	0.801		0.038	0.038	High	50.8	41.6	3.3	1.5	2.7	92.5	7.5
WB002	1	0.821		0.034	0.034	High	66.8	26.6	2.7	1.3	2.5	93.5	6.5
WB003	2	0.804	0.081		0.057	High	52.4	42.1	3.6	1.1	0.8	94.5	5.5
WB004	1	0.746		0.050	0.050	Good	22.5	65.6	6.3	2.2	3.4	88.2	11.8
WB005	1	0.543		0.135	0.135	Moderate	13.4	23.8	38.8	13.3	10.7	37.2	62.8
WB006	2	0.743	0.008		0.006	Good	0.4	99.5	0.1	0.0	0.0	99.9	0.1
WB007	4	0.632	0.116		0.058	Good	1.4	67.7	29.9	0.9	0.1	69.1	30.9
WB008	2	0.827	0.044		0.031	High	75.0	23.3	1.1	0.3	0.3	98.3	1.7
WB009	2	0.757	0.002		0.001	Good	0.0	99.9	0.0	0.0	0.0	100.0	0.0
WB010	3	0.797	0.031		0.018	Good	44.2	55.6	0.1	0.0	0.0	99.8	0.2
WB011	4	0.740	0.038		0.019	Good	1.4	98.5	0.1	0.0	0.0	99.9	0.1
WB012	2	0.800	0.009		0.006	Good	49.9	50.0	0.1	0.0	0.0	99.9	0.1
WB013	4	0.794	0.047		0.024	Good	39.8	60.0	0.1	0.0	0.0	99.9	0.1
WB014	2	0.587	0.126		0.089	Moderate	5.3	39.6	46.3	6.7	2.1	45.0	55.0