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The use of macroalgal species richness and composition on intertidal rocky seashores in the assessment of ecological quality under the European Water Framework Directive

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Abstract

The EC Water Framework Directive (WFD) suggests using abundance and species composition of intertidal seaweed communities for ecological quality classification of rocky seashores. There are two difficulties with this. According to WFD all sensitive species should be present on a shore. There is no accepted list of sensitive seaweed species and those which may be sensitive in one location may not be so in another. Second, natural successions can result in very large abundance changes of common species, e.g. from almost completely fucoid-dominated shores to almost totally barnacle-dominated shores, without any change in ecological quality. Studies have shown that numerical species richness, not the list of actual species present, is broadly constant in the absence of disturbance. The ephemeral species, possibly the sensitive members of the community, change regularly in such a way as to conserve species richness. It is proposed that species richness on a defined length of shore be used as a criterion of ecological quality. A database of species found on over 300 shores in the British Isles, under strictly controlled sampling conditions, has given ranges of values of species richness to be expected and has allowed for variations in these values due to sub-habitat variability, wave exposure and turbidity to be factored in. A major problem in applying such a tool is the lack of expertise of many workers in critical identification of seaweed species. A reduced species list has been extracted from the database using species commonly present and identifiable with reasonable certainty. A numerical index of ecological quality is proposed based on scores for various aspects of the physical nature of the habitat combined with a score for species richness which may be based on the reduced species list. The scoring system also uses further aspects of community structure, such as ecological status groups and the proportions of rhodophyta, chlorophyta and opportunist species. For this system to be effective there has to be close control of the way in which sampling is carried out to ensure a uniform level of thoroughness.

Keywords: Macroalgae; Seaweed; Species richness; Water framework directive; Ecological quality assessment

1. Introduction

The Water Framework Directive (WFD) states that macroalgae are a *biological quality element* to be used in defining the ecological status of a transitional or coastal water body. These intertidal macroalgae communities respond to changes in nutrient status and problems of eutrophication, toxic substances and most importantly to habitat modification and general stress. Specifically, the WFD 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.

Regarding the composition of macroalgae the WFD states that for high quality 'all sensitive taxa should be

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present'. The requirements stipulated for reference and high quality conditions by the WFD create two main problems: (1) it is not known which species are the sensitive ones in any particular situation, and as sensitive species tend to be less abundant members of the community, or such they will not be constantly present even under good water quality conditions: (2) species composition can be naturally highly variable.

There are two main components of variability experienced by rocky shore communities. First, records of species composition differ as a consequence of sampling variability. This was shown by Wells (2002) when studies of sampling effort revealed only 70% of the species were consistently recorded over three consecutive days on the same area of shore. There is also a natural turnover of ephemeral algae resulting in variable species composition between months, seasons and over several years. This lack of consistency makes species composition an undesirable measure of ecological change. However, less detailed aspects of macroalgae composition such as functional form and algal division are useful for studying changes in general community structure. In contrast species richness remains broadly constant in the absence of environmental alteration, over days, months, seasons and years. This was originally suggested by Wilkinson and Tittley (1979) for various shores in the Firth of Forth, Scotland, and proposed as a better measure of seaweed community stability than the detailed listing of actual species present. These findings were later supported by Wells and Wilkinson (2003) with a study of species richness and composition at two sites in Orkney, Scotland, over 4 years. Annual records of species composition indicated a large turnover of ephemeral species resulting in a continual increase in the cumulative number of species recorded but the total species richness remained stable in consecutive years despite seasonal fluctuations (Fig. 1).

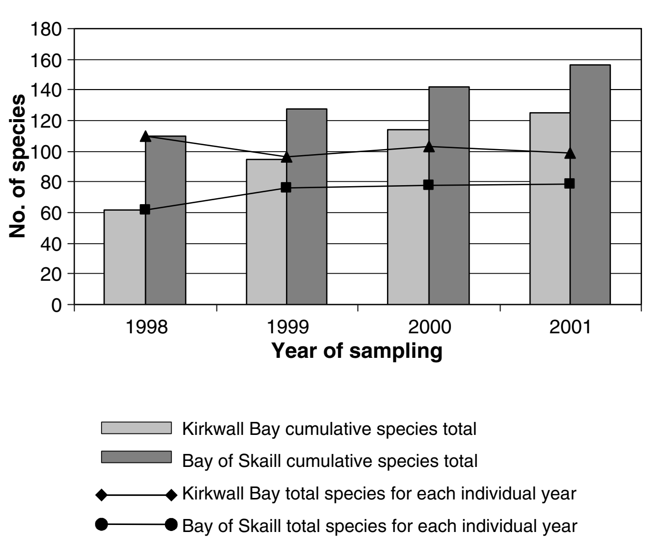

Fig. 1. Trend in total species richness and cumulative species richness over 4 years at Kirkwall Bay and Bay of Skaill, Orkney Islands.

Detailed records have also shown increases in species richness with recovery from severe pollution. Two sites within the Firth of Forth, Scotland, experienced a large reduction in species richness accompanied by a shift in the community structure in response to chronic pollution by domestic effluent (Wilkinson et al., 1987). The algal dominated shore at Joppa was replaced with a high biomass of mussels and barnacles. Similarly, the algal community at Granton was replaced by extensive cover of polychaete mats thought to result from sediment deposition (Wilkinson et al., 1987). The transition to a long sea outfall has since resulted in a return of many algal species with a corresponding shift in the algal community structure although not with the original level of biomass or cover (Wells, 2002).

Numerical species richness is a very basic measure of intertidal algal biodiversity and recent studies have shown small degrees of variation in species richness can occur as a result of natural as well as anthropogenically induced variables between sites. Although different ecological communities do not contain the same number of species (Krebs, 1978), there is a particular range of species richness which can be expected within intertidal communities (Wells, 2002). These expected ranges of algal species richness have been proposed as a means of discriminating between the five WFD quality classes measured by their deviation from reference or high conditions.

These ranges of species richness were ascertained through the development of an extensive database incorporating a variety of sites from around the UK and Republic of Ireland and consisting of species records from a number of known sources which fitted set criteria. This data consisted of both current species records and historical records. These sources of data were restricted to a shore sample taken on a single low tide only and comprehensive species lists compiled by authoritative workers including:

- Recent surveys conducted by the Marine Plants Task Team for the WFD.
- Published papers from the British Phycological Society field meetings and other field surveys from 1956 to 1994 (Burrows, 1963; Burrows et al., 1956; Dixon, 1963; Farnham, 1994; Jones, 1960; McAllister et al., 1967; Norton, 1970, 1972, 1976; Norton et al., 1969; Powell, 1956; Wilkinson, 1975, 1979, 1980, 1982).
- The Northern Ireland Littoral Survey (Wilkinson et al., 1988).
- Unpublished surveys for assessing the impacts of the Channel Tunnel construction on the surrounding coastline carried out by one of the present authors (Wilkinson 1985–1991, pers comm) and
- Recent Ph.D. surveys (Wells, 2002).

2. Development of a macroalgae composition tool

Intertidal rocky shore environments vary in their physical nature due to natural abiotic influences which can affect the level of species richness found. Intertidal algal communities often display zonation patterns from high to low water mark producing distinct bands (Lewis, 1961, 1964). These different zones can vary both their height and extent on the shore primarily as a result of wave exposure (Hawkins and Jones, 1992). Sheltered shores are often characterised by a dense abundance of fucoids with a distinct transition from upper to lower shore. This presence of fucoids becomes less apparent as shores become more exposed, initially forming a more mosaic pattern of faunal and floral species and later becoming highly dominated by barnacles and mussels. Despite wave exposure appearing to contribute to the abundance and zonation patterns of algae in the intertidal there is no significant impact on the levels of species richness (Wells and Wilkinson, 2002). Further studies of the overall shore structure, using data for 122 rocky shores in Northern Ireland (Wilkinson et al., 1988), have indicated a link between species richness of macroalgae and localised intertidal variables (Wells and Wilkinson, 2002) as explained below.

The physical type of shore is broadly described by the most dominant substrate type or structure present such as rock platforms, boulders and pebbles; this is referred to as the dominant shore type. This has been shown to significantly contribute to the levels of species richness with certain substrates more habitable due to their stability and attachment properties. Statistical comparisons were made of average species richness between different shore types using one way analysis of variance with Tukey's test (with family error rate of 5%). The results indicated rock ridges, outcrops and platforms have significantly higher species richness than shores consisting predominantly of boulders, pebbles and vertical rock. Therefore the following shore types are listed in descending order of their contribution to the level of species richness: Rock ridges/outcrops/platforms > irregular rock and boulders > steep/vertical rock > pebbles, stones and small rocks > shingle and gravel.

Subhabitat type and number have a similar effect to shore type with statistical analysis indicating the presence of particular subhabitat types resulting in higher levels of species richness. Large, wide rockpools provide very favourable habitats by limiting the effects of desiccation providing a more tolerable environment than is experienced on open rock. The following subhabitat types are given in descending order of their contribution to the level of species richness: wide shallow/large/deep rockpools > basic rockpools and crevices > overhangs > caves. Equally, with increasing number of subhabitat types there is a significant increase in the levels of algal species richness recorded, as higher subhabitat diversity results in higher species diversity. The presence of naturally occurring turbidity and sand scour can also result in reduced numbers of perennial taxa and domination by opportunist annuals such as *Enteromorpha* and *Ulva* (Mathieson et al., 1991; Chapman, 1943; Daly and Mathieson, 1997; Sousa, 1979, 1984) which may similarly be experienced by unstable chalk shores located in the south east of England (Tittley and Price, 1978) and can therefore decrease species richness further.

These variables need to be considered when establishing levels of species richness to be expected on shores of different ecological quality status. The use of shore descriptions within the development of a rocky intertidal macroalgal

Table 1
Field sampling sheet to record basic shore descriptions with scores indicating the weighting of each of the shore characteristics to be used in the final scoring system

General information							
Shore name			Date				
Water body			Tidal height				
Grid ref.			Time of low tide				
Shore descriptions							
Presence of turbidity (known to be non-anthropogenic)	Yes	=0	Sand scour	Yes	=0	No	=2
	No	=2	Chalk shore	Yes	=0	No	=2
Dominant shore type			*Subhabitats*				
Rock ridges/outcrops/platforms		=4	Wide shallow rock pools (>3 m wide and <50 cm deep)				=4
Irregular rock		=3					
Boulders large, medium and small		=3	Large rockpools (>6 m long)				=4
Steep/vertical rock		=2	Deep rockpools (50% >100 cm deep)				=4
Non-specific hard substrate		=2	Basic rockpools				=3
Pebbles/stones/smallrocks		=1	Large crevices				=3
Shingle/gravel		=0	Large overhangs and vertical rock				=2
Dominant biota			Others habitats (please specify)				=2
Ascophyllum							
Fucoid							
Rhodophyta mosaics			Caves				=1
Chlorophyta			None				=0
Mussels			*Total number of subhabitats*				
Barnacles			>4	3	2	1	0
Limpets							
Periwinkles							
General comments							

tool acts as a type of ‘correction factor’ whereby shores that have high species richness due to favourable environmental conditions can be equally compared with shores of low species richness due to unfavourable natural conditions.

The requirement to encompass the natural variations that occur over the coastline of the British Isles, such as physical shore descriptions, has led to the development of a field sampling sheet (Table 1) and scoring system which then contributes to the overall quality classification. The numbers in the sampling sheet attached to each of the shore types/habitat types are based on how much they contribute to the overall species richness, for example rock ridges/platforms/outcrops have a high value of 4 where as shingle/gravel only scores 0 because this substrate type does not lend itself to high numbers of algal species. The sampling sheet also leaves space for brief shore descriptions as well as basic details on the site name, times of sampling etc. The dominant biota information does not contribute to the overall scoring system but may be useful in subsequent years to explain any ecological change and may help to identify shifts in the benthic invertebrate community.

The scores from each of the categories in the field sampling sheet are added together, ranges of which equate to a quality status score and contributes to the final classification. For those factors, such as shore type and habitat type, where more than one description may be recorded on the sampling sheet, only the highest score is used in the final scoring system.

Species richness provides an excellent tool for using macroalgae communities as a measure of ecological quality; however, this does not incorporate any measure of composition as required by the WFD. Individual species vary considerably due to the constant turn over of ephemeral species but general measures of composition may be used as an alternative means of indicating a shift in the community structure. In order to identify the potential occurrence of correlations between community composition and quality status, members of the marine plants task team tentatively assigned each site within the marine benthic algal database a level of quality; high, good, moderate, poor and bad. This was based on expert knowledge of each of the sites irrespective of their species number and considering the proximity and magnitude of direct and indirect effluent discharges. Unfortunately there was limited corresponding data for nutrients loads and concentration with which to supplement this assessment of ecological quality. These subjected levels of classification status for each site were later used to establish the boundary levels for each quality status class for each of the community measures. Such measures of community structure include the proportions of rhodophyta and chlorophyta calculated as the number of species within these divisions as a percent of the total species richness.

The rhodophyta constitute a high proportion of small filamentous and delicate species and show an increase in species numbers with increasing environmental quality. The chlorophyta species although small and often filamentous are able to adapt more readily to changes in the environment whereby proportions increase with decreasing quality status. In contrast many phaeophyta species are large, cartilaginous and relatively hardy and are more likely to stay constant. Consequently the changes in proportion of rhodophyta and chlorophyta species have been considered to be indicative of anthropogenic influences and shifts in quality status.

Other alternative measures of species composition include the ratio of ecological status groups (ESG’s) and proportion of opportunist species. ESG’s can be used to indicate shifts in the ecosystem from a pristine state (ESG 1 – late successionals or perennials) to a degraded state (ESG 2 – opportunists or annuals). This is achieved by using the following ratio ESG 1/ESG 2 (Orfanidis et al., 2001). The allocation of each species into one of the two ESG groups is also broadly based on a functional group system devised primarily by Littler et al. (1983) and later adapted by Wells (2002) (Table 2).

The opportunists include *Blidingia* spp., *Chaetomorpha linum*, *Chaetomorpha mediterranea*, *Enteromorpha* spp., *Ulva lactuca*, *Ectocarpus* spp., *Pilayella littoralis*, *Porphyra* spp. Nuisance blooms of these particularly rapidly growing macroalgae can have deleterious effects on intertidal communities (Soulsby et al., 1982; Tubbs and Tubbs, 1983; Den Hartog, 1994) whereby excessive biomass would be considered as moderate, poor or bad quality status (Wilkinson and Wood, 2003).

Although it may be considered that the proportion of green species, the proportion of opportunist species and the ESG ratio are similar measures they are all required so as to incorporate different aspects of community composition. It is likely that the different community measures will respond differently to the various environmental stresses; the rate of response may vary as well as the degree to which various groups of species are affected. Therefore it is important to consider all variables as it is unlikely that all

Table 2
Descriptions of the different functional groups used in placing species into the two ecological status groups indicating functional groups as modified by Wells (2002) from Littler et al. (1983)

	Functional groups
ESG 1	Late successionals or perennials including • Coarsely branched and highly corticated forms • Thick, leathery and corticated forms • Jointed calcareous forms • Crustose forms including those microscopic forms found epiphytically or endophytically
ESG 2	Opportunists or annuals including • Unicellular and epiphytic, endophytic, epizoic and endozoic microscopic forms • Foliose, thin, membranous and sheet-like forms • Uniseriate filamentous forms • Multiseriate and/or corticated filamentous forms

situations will respond to environmental stress in the same manner.

Each of the species richness and composition attributes was compared with the subjective quality status to ensure they followed the expected trends. Figs. 2–6 show the correlation between the measures of algal community and quality status. All community measures show a distinct trend either increasing or decreasing with quality status.

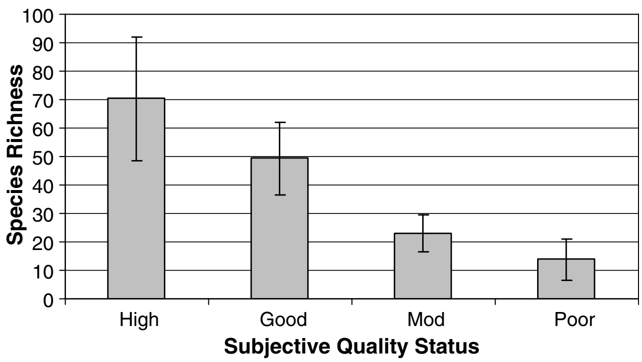

Fig. 2. Trend of average species richness recorded for each of the predicted ecological quality status classes from the benthic marine algae database with error bars signifying standard deviation.

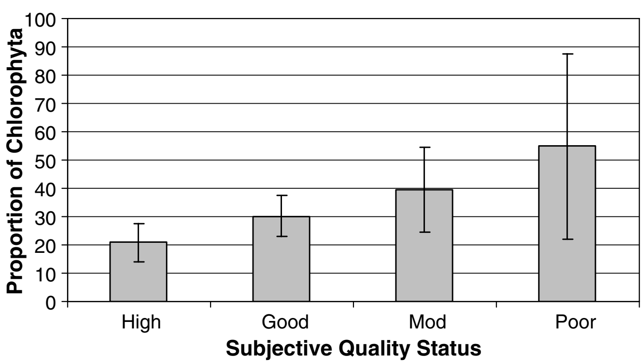

Fig. 3. Trend of average proportion of green species recorded for each of the predicted ecological quality status classes from the benthic marine algae database with error bars signifying standard deviation.

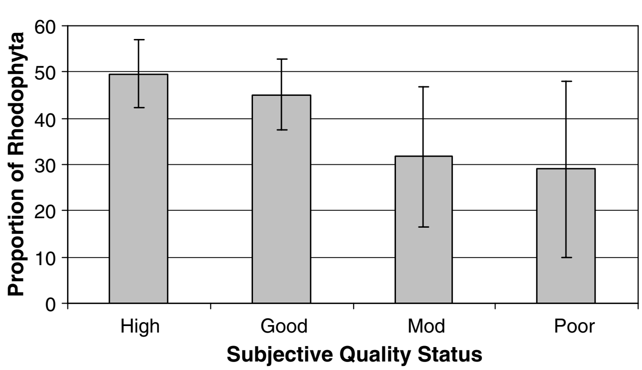

Fig. 4. Trend of average proportion of red species recorded for each of the predicted ecological quality status classes from the benthic marine algae database with error bars signifying standard deviation.

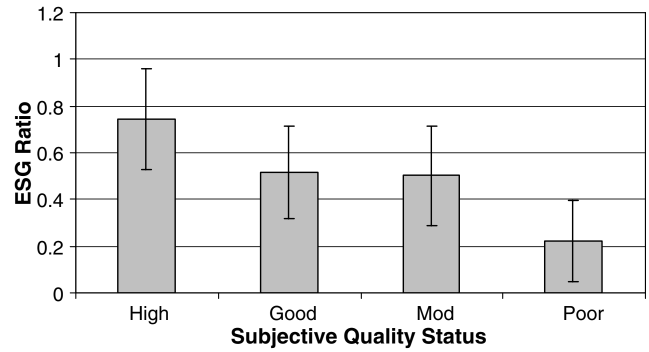

Fig. 5. Trend of average ESG ratio recorded for each of the predicted ecological quality status classes from the benthic marine algae database with error bars signifying standard deviation.

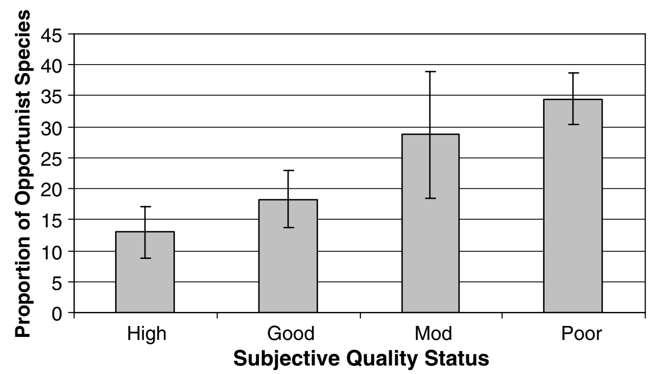

Fig. 6. Trend of average proportion of opportunist species recorded for each of the predicted ecological quality status classes from the benthic marine algae database with error bars signifying standard deviation.

The most significant boundary is that which lies between good and moderate status as this distinguishes between an acceptable and unacceptable level of quality requiring mitigation according to the WFD. In most cases this boundary is clear, however, for ESG ratio there is little different between the two classes despite the overlying trend. It is possible that this is due to the misclassification of species into the two ESG groups and this area may need some refining to ensure two clear cut groups. Further statistical analyses were then run on the results to establish a level of significant difference between quality status groups.

All datasets were tested for normality (Kolmogorov–Smirnov test) and homogeneity of variance (Levene's test) to see if a one-way Analysis of Variance (ANOVA) could be used. All datasets failed at least one of these tests so a non-parametric equivalent, Kruskal–Wallis test was used whereby there is a statistically significant difference ($p = <0.001$) when the differences in the median values among the treatment groups are greater than would be expected by chance.

Each of the species parameters showed a significant difference between groups with $p = < 0.001$. The high and poor quality status contributed most to this significant difference with the moderate class showing less difference with

Table 3
The metric scoring system with classification status ranges for macroalgae species richness, chlorophyta, rhodophyta and opportunist proportions, ESG ratios and shore descriptions as described and calculated from the field sampling sheet in Table 1

Quality EQR	Bad 0–0.2	Poor 0.2–0.4	Moderate 0.4–0.6	Good 0.6–0.8	High 0.8–1.0
Species richness	⩽5	6–19	20–31	32–54	⩾55
Proportion of chlorophyta	61–100	46–60	36–45	26–35	⩽25
Proportion of rhodophyta	0–15	15–24	25–34	35–44	⩾45
ESG ratio	0–0.1	0.1–0.29	0.3–0.39	0.4–0.64	⩾0.65
Proportion of opportunists	41–100	31–40	21–30	16–20	⩽15
Shore descriptions	N/A	15–18	12–14	8–11	1–7

the other groups. The less distinguishable boundary around the moderate quality class may be attributed in part to the low number of shores represented within this class and the high level of variability within each group, represented by the error bars of standard deviation. Further data would be required to clarify some of these trends and refine the boundaries.

From these predicted levels of ecological quality, boundary levels were established for the levels of species richness to be expected. This was achieved by taking the mid point between the upper and lower error bars (calculated from standard deviation) of adjacent quality status classes. The same was achieved for the proportions of chlorophyta, rhodophyta, the ratio of ESG's and the proportion of opportunist species. Each of the parameters has a range of values which equates to a quality status of high, good, moderate, poor and bad which in turn corresponds to an ecological quality ratio on a scale of 0.0–1.0. The final metric system works by establishing the ranges for which each parameter lies and finding its associated quality status and score. These individual scores, including those of the shore descriptions, are averaged to produce a final EQR score and associated quality status. Table 3 shows the class ranges for each parameter but the final product will be based on a sliding scale so as to minimise potential misclassification when measures fall on or close to boundary values. Although the scoring system has already been devised it is likely that this will require some refinement with each of the community measures weighted accordingly.

3. Development of a reduced species list

Unfortunately, the identification of intertidal seaweed species, necessary to record an accurate level of species richness, requires high levels of taxonomic expertise. An alternative means of recording qualitative species data is the implementation of a reduced species list (RSL) whereby the number of species from the RSL is in proportion to the total species richness. The list is composed of species (approximately 70) that contribute most significantly to the overall species composition of rocky shores of a particular type within a geographical area, and this would act as a surrogate to the production of a full species list. The benefits of this approach are the requirement of a lower level of taxonomic experience and familiarisation with fewer algal species.

Marine algae, like other organisms show geographical distributions, whereby imaginary boundaries are recognised by the changes in composition of the coastal flora and fauna and surface seawater isotherms. Water temperature was thought to be the main factor governing the geographical distribution of species (Lüning, 1990). However, Prescott (1969) suggested that the north–south distribution patterns are determined by temperature and east–west distributions are related to a greater number of factors such as water currents and ancient inter-ocean connections. Often restrictions on algal growth are due to high or low survival limitations including lethal limits set by the tolerance of the hardiest life-history stage, reproductive limits and growth limits (Lüning, 1990; Lobban and Harrison, 1994).

It was suggested by Maggs (1986) that many algae consist of geographical ecotypes with regards to environmental responses. In any one site the algal composition represents a complex mixture of species in different parts of their geographical ranges, regarded in the British Isles as northern, southern and widespread species (Maggs, 1986).

As a consequence the variable species composition of different areas around the British Isles should be incorporated into the establishment of a reduced species list in order to account for these geographical variations. It is likely that many of the species will be common to most areas, but it is also anticipated that some species may be

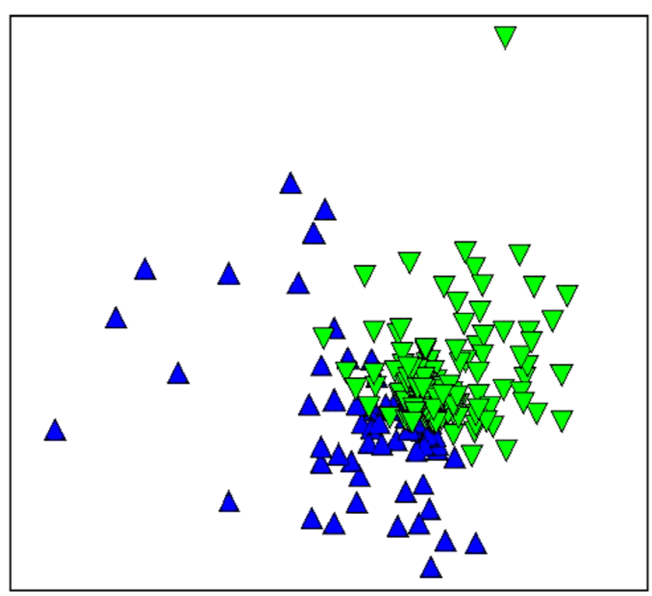

Fig. 7. Multidimensional scaling showing the two of the main geographic areas of northern England and Scotland (green inverted triangles) and Southern England, Wales and Republic of Ireland (blue triangles) with a 2d minimum stress of 0.19.

more frequently recorded on southern or northern shores as a consequence of their distribution limits.

The coastline was broadly split into 10 different geographic areas based on the sites for which species records were present within the database. These areas consisted of Northern Ireland (177 sites), Republic of Ireland (16), West Scotland (37), Orkney (44), Sheltand (18), East of Scotland (62), Northern England (26), Southern England (59) and Wales (17). An analysis of similarity (ANOSIM) was calculated to determine the level of similarity or dissimilarity between the sample groups. ANOSIM calculates a sample statistic R of between 0 and 1, where $R = 1$ represents a strong difference between groups.

The greatest degree of significant difference was found between Northern Ireland and all other areas with $R > 0.5$ for all comparisons. Although there was a greater affinity between some areas than others the rest of the results appeared relatively inconclusive. Data from Northern Ireland were subsequently removed from the analysis and a second ANOSIM calculation was run. The results of the second test showed some significant similarities between Wales and southern England and Republic of Ireland. The northern areas of Scotland, Shetland, Orkney and Northern England also showed a similar affinity towards each other. These areas have been plotted on a multi dimensional scaling diagram (Fig. 7). The northern regions appear to clump together, however the southern regions show a broad degree of scatter. Some of these more dispersed sites are located on the Island of Lundy, off the coast of Southern Wales where slightly more unusual species have been recorded. With few site records for such a large geographic area it is difficult to establish any significant boundaries for the southern half of England, Wales and the Republic of Ireland.

Consequently the British Isles has been broadly segregated into three main areas (Fig. 8) based on the

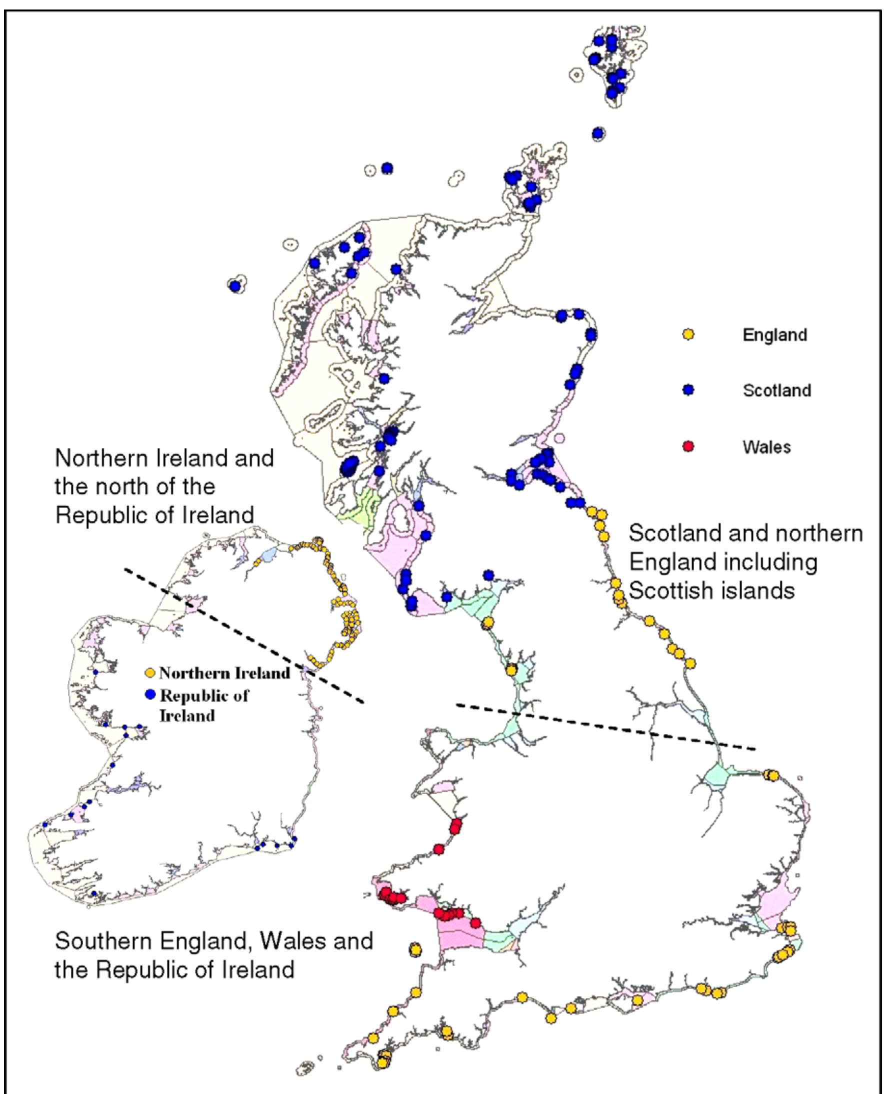

Fig. 8. Map of the UK and Republic of Ireland indicating the boundaries used for the compilation of the three reduced species lists whereby spots represent those sites for which species records are available and have been used in the algal database.

Table 4
Reduced species lists for each of the defined geographic areas of Northern Ireland, Scotland and Northern England, and Southern England, Republic of Ireland and Wales

Species list	S. Eng RoI Wales	NI	Scot N. Eng
Greens			
Blidingia sp.	1	1	1
Bryopsis plumosa	1		
Chaetomorpha linum	1	1	1
Chaetomorpha mediterranea	1	1	
Chaetomorpha melagonium	1		1
Cladophora albida		1	
Cladophora rupestris	1	1	1
Cladophora sericea	1	1	1
Enteromorpha sp.	1	1	1
Monostroma grevillei		1	
Rhizoclonium tortuosum		1	
Spongomorpha arcta		1	
Sykidion moorei			1
Ulothrix sp.		1	
Ulva lactuca	1	1	1
	9	12	8
Browns			
Alaria esculenta		1	1
Ascophyllum nodosum	1	1	1
Asperococcus fistulosus		1	1
Chorda filum	1		1
Chordaria flagelliformis			1
Cladostephus spongious	1	1	1
Desmarestia aculeata			1
Dictyosiphon foeniculaceus			1
Dictyota dichotoma	1	1	1
Ectocarpus sp.	1	1	1
Elachista fucicola	1	1	1
Fucus serratus	1	1	1
Fucus spiralis	1	1	1
Fucus vesiculosus	1	1	1
Halidrys siliquosa	1	1	1
Himanthalia elongata	1	1	1
Laminaria digitata	1	1	1
Laminaria hyperborea	1		1
Laminaria saccharina	1	1	1
Leathesia difformis	1	1	1
Litosiphon laminariae			1
Pelvetia canaliculata	1	1	1
Petalonia fascia		1	
Pilayella littoralis	1	1	1
Ralfsia sp.	1	1	1
Saccorhiza polyschides	1		
Scytosiphon lomentaria	1	1	1
Sphacelaria sp.		1	
Spongonema tomentosum		1	1
	20	22	26
Reds			
Aglaothamnion/Callithamnion	1	1	1
Ahnfeltia plicata	1	1	1
Audouinella purpurea		1	
Audouinella sp.		1	
Calcareous encrusters	1	1	1
Callophyllis laciniata			1
Catenella caespitosa	1	1	
Ceramium nodulosum	1	1	1
Ceramium shuttleworthanium	1	1	1
Ceramium sp.	1		
Chondrus crispus	1	1	1
Corallina officinalis	1	1	1

Table 2 (*continued*)

Species list	S. Eng RoI Wales	NI	Scot N. Eng
Cryptopleura ramosa	1	1	1
Cystoclonium purpureum	1	1	1
Delesseria sanguinea			1
Dilsea carnosa	1	1	1
Dumontia contorta	1	1	1
Erythrotrichia carnea	1		1
Furcellaria lumbricalis	1	1	1
Gastroclonium ovatum	1		
Gelidium sp.	1	1	
Gracilaria gracilis	1		
Halurus equisetifolius	1		
Halurus flosculosus	1		
Heterosiphonia plumosa	1		
Hildenbrandia rubra	1	1	
Hypoglossum hypoglossoides	1		
Lomentaria articulata	1	1	1
Lomentaria clavellosa			1
Mastocarpus stellatus	1	1	1
Melobesia membranacea		1	
Membranoptera alata	1	1	1
Nemalion helminthoides	1		
Odonthalia dentata		1	1
Osmundea hybrida	1	1	1
Osmundea pinnatifida	1	1	1
Palmaria palmata	1	1	1
Phycodrys rubens			1
Phyllophora sp.	1	1	1
Plocamium cartilagineum	1	1	1
Plumaria plumosa	1	1	1
Polyides rotundus	1		1
Polysiphonia fucoides	1	1	1
Polysiphonia lanosa	1	1	1
Polysiphonia sp.	1	1	1
Porphyra leucosticta			1
Porphyra umbilicalis	1	1	1
Ptilota gunneri			1
Rhodomela confervoides	1	1	1
Rhodothamniella floridula	1	1	1
	40	34	36
Total	69	68	70

geographic distribution of site records and the results these have produced. The exact boundary between northern and southern England has been partly driven by the physical nature of the dividing areas. The Wash, north Norfolk, Merseyside and Lancashire are primarily sedimentary areas with little or no algal growth therefore provide a natural break in the rocky shore coastline. It is likely that with time and increasing data sources the boundaries of these three geographic areas may shift but these are the current geographic boundaries used for the compilation of the three reduced species lists.

From the marine benthic algal database the species records from those sites deemed as ‘high quality’ were used to extract a reduced species list. This decision was taken as the final reduced species lists should ideally be representative of high quality shores with which other shores will be compared and therefore act as a reference condition.

The species list was compiled by selecting those species which occurred most frequently throughout the range of shore types on high quality shores. The minimum frequency of occurrence of each species depended on the total number of sites available for analysis. There are approximately 885 species of seaweed recorded in the algal database based on the Marine Conservation Society checklist compiled by Guiry (1997), although some of these species may currently only have records for northern France. This tool aims to reduce the number of species required for identification to approximately 70 algal species. The frequency of the top 70 species varied according to the geographic area. For Northern Ireland species that occurred on >55 high quality shores out of a possible 142 were included, for Scotland and Northern England the frequency was a minimum of 36 out of 86 and for southern England, Wales and the Republic of Ireland species occurring on >17 out of 55 were included.

It was further decided that a number of species would be difficult to identify to species level or locate on the shore, even for many trained algal taxonomists. Therefore, for a select few species, identification has been limited to the level of genus only, although microscopic identification would still be required. These genera include *Blidingia*, *Enteromorpha*, *Ulothrix*, *Ectocarpus*, *Ralfsia*, *Gelidium*, *Audouinella*, *Calcareous encrusters*, *Ceramium* except for *C. nodulosum* and *C. shuttleworthianum* and *Polysiphonia* species except for *P. lanosa* and *P. fucoides,* as it was thought that these species of *Polysiphonia* and *Ceramium* would be comparatively easy to distinguish. The final species to be used within the three reduced species lists are given in Table 4.

Quality boundaries were then established by applying each of the relevant reduced species lists to each of the shores within the database and using the predicted quality status for each shore. For each of the defined areas alternate ranges within the metric system were devised to incorporate the geographical variations and boundary values were tentatively assigned to each of the quality classes in the same way as for the full species list.

4. Case study – the firth of forth

The coastline of the Firth of Forth in Edinburgh, Scotland is an ideal setting for testing the tool for its response to anthropogenic influences. Joppa and Granton were two site locations of former crude sewage outfall pipes showing definite effects of pollution stress, apparent through the absence of macroalgae and macroinvertebrate species as well as the presence of indicator species (Read et al., 1983). After an improved sewerage system was introduced in 1978, marked changes in the flora and fauna were observed with dramatically improved water quality (Read et al., 1983).

In many situations any attempts to assess pollution effects is faced with lack of baseline data from which to work, such as the absence of accurate records of the presence and status of individual species in a given area at a given time (Johnston, 1972). The benefits of using an area such as the Firth of Forth are the extensive algal records dating back to the 19th century. At Granton algal species have been recorded by Greville (1824), Lindsay (1886),

Table 5
Basic shore descriptions for Granton and Joppa, Scotland, with scoring for each of the characteristics as taken from Table 1

Characteristic	Description	Score
Site name	Granton	
Shore type	Two small rock outcrops surrounding a shingle bay with some artificial boulders	4
Subhabitat type	Mainly crevices with a couple of small	3
No. subhabitats	2	2
Other factors	Quite highly turbid	4
Total score		13
Site name	Joppa	
Shore type	Predominantly large rock ridges and outcrops	4
Subhabitat type	Consisting of some basic rockpools, crevices and overhangs	3
No. subhabitats	3	3
Other factors	None	6
Total score		16

Table 6
The Macroalgal reduced species list for tool applied to long term species records from Granton and Joppa in the Firth of Forth

Site name	RSL	ESG	% Chloro	% Rhodo	% Oppor	Shore description
Granton						
19th Century total	30	1.31	6.67	56.67	13.33	13
Wilkinson, Scanlan 1986–1987	33	0.74	21.21	36.36	21.21	13
Wells, 1999–2001	34	0.70	23.53	38.24	23.53	13
Joppa						
Traill 1881–1886	55	0.96	9.09	50.91	12.73	16
Wilkinson, Scanlan 1986–1987	37	0.61	18.92	51.35	21.62	16
Wells, 1999–2001	36	0.64	19.44	50.00	22.22	16

Table 7
Boundaries values for RSL, ESG, green, red and opportunist proportions for Scotland/Northern England area

Scotland and Northern England score system					
	0	1	2	3	4
	Bad	Poor	Moderate	Good	High
RSL	0	<17	17–19	20–29	>30
ESG	0	<0.6	0.6–0.69	0.7–0.89	⩾0.9
Greens	100	>26	>21.0–26.0	16.0–21.0	⩽15.0
Reds	0	<37.0	N/A	38.0–44.0	⩾45.0
Opportunist	100		>15		⩽15
Shore description	N/A	15–18	12–14	8–11	1–7

Table 8
Final scores for each time period at Joppa and Granton for each of the characteristics of RSL, ESG, proportion of Chlorophyta, Rhodophyta and opportunist species

Site name	RSL	ESG	% Chloro	% Rhodo	% Oppor	Shore description	Final score	Quality status
Granton								
19th Century total	4	4	4	4	4	2	22	High
Wilkinson, Scanlan 1986–1987	4	3	2	1	2	2	14	Good
Wells, 1999–2001	4	3	2	3	2	2	16	Good
Joppa								
Traill 1881–1886	4	4	4	4	4	1	21	High
Wilkinson, Scanlan 1986–1987	4	2	3	4	2	1	16	Good
Wells, 1999–2001	4	2	3	4	2	1	16	Good

Rattray (1886), Trail (1880–1882), unpublished records by Wilkinson and Scanlan (1986–1987, pers comm) and Wells (2002). Similar records exist for Joppa by Trail (1880–1882), unpublished records by Wilkinson and Scanlan (1986–1987, pers comm) and Wells from 1999 to 2001 (Wells, 2002). However, problems start to arise with such lists due to unsystematic collecting. Traill's work includes general species lists often incorporating records from other field workers. Such data are valuable when looking at pollution assessment and long term trends but it is dangerous to place too much emphasis on past records. Results from different surveys, especially those from past centuries, will harbour discrepancies from not only nomenclature and taxonomic interpretation but also differences in field technique. Despite this, algal records from Joppa and Granton have enabled community composition to be observed over long term time scales, indicating any changes following the abatement of sewage pollution and providing ideal data for testing the macroalgae composition tool.

The basic shore descriptions for the two sites are given in Table 5 from which a final score could be derived and input to the species richness metric system. The reduced species list for Scotland and Northern England was applied to the cumulative lists for both sites for each sampling period. From these reduced lists the proportion of Rhodophyta and Chlorophyta, ESG ratio and proportion of opportunist species could be calculated. These results are given in Table 6. The scoring system for Scotland and Northern England (Table 7) could then be applied to the results of the RSL whereby the result could be compared with each of the quality ranges. From this it was possible to establish a final quality score and classification status for both Granton and Joppa (Table 8).

The tool clearly responds to the change in water quality over the two centuries at Granton and Joppa. There is a drop in quality from high conditions in the 19th century, during which the flora had been described as luxuriant, to only good conditions in the 20th and 21st centuries. Granton was also at the lower end of good between 1986 and 1987 showing a slight improvement in the quality of the site during the latter period of sampling. Data obtained during the period of sewage pollution would have been useful to establish if the quality status dropped to moderate which would be more consistent with the reports from Read et al. (1983). Although the data consists of cumulative records of species lists, data taken from a single date only during 1999–2001 from the two sites only shows slight variation within each individual parameter with the overall score remaining constant.

This tool is aimed to be used in coastal areas of rocky intertidal and where substrate permits, it may also be used for the outer reaches or mouth of transitional waters. The most desired method of this tool is the application of the full species list which requires a full and detailed shore search. However, it has been anticipated that this may not always be achievable. In such instances the RSL tool should be used with a full list completed at least every 6 years as this is the definitive quality criterion, the reduced list merely acts as a link between the quality status and the species richness. However the levels of species richness of macroalgae communities need to equate to a defined level of ecological quality status. This has been achieved by developing the scoring system to incorporate both physical and biological aspects of intertidal algal communities.

The establishment of a classification system using characteristics of rocky intertidal algal community composition and levels of species richness is a relatively new concept but extensive testing of the tool have shown a response to known changes in environmental conditions. The geographical gaps that currently exist within the algal database have slightly hindered the establishment of tight quality status boundaries and it is likely that these will need further refinement as additional data is collected from a variety of known quality status shores.

However, it is likely that the shore descriptions will only acts as a 'correction factor' for levels of species richness. It is likely that this tool will under go continued refinement over the next few years to ensure confidence in classification. Final scoring system will be based on a sliding scale.

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