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The use of environmental integrative indicators to assess seabed disturbance in estuaries and coasts: Application to the Humber Estuary, UK

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Abstract

The coastal zone is subject to many and varied changes resulting from human activities and natural processes. Existing or emerging agreements and legislation acknowledge the relevance of indicators for monitoring these. In the UK, following a series of recent workshops, potential indicators of nearshore disturbance have been identified and grouped into three broad indices: 'Coastline Morphological Change', 'Resource Use Change' and 'Environmental Quality and its Perception'. The present study developed these indicators further and tested their use by applying them to 18 sections in the Humber Estuary, Eastern England. The results obtained reflect the current knowledge of the state of the Humber environment and show the potential of integrative indicators but indicate that further studies are required to assess the relative importance of the indicators and their value in reflecting the ability of the ecosystems to sustain natural habitats and populations at a good conservation status.

Keywords: Humber Estuary; Integrative indicator; Environment; Seabed disturbance; Classification; DPSIR; Water Framework Directive

1. Introduction

Indicators are increasingly being developed and used as management tools to address environmental issues (e.g. see OECD, 1994; EEA, 1999; Belfiore, 2003). An environmental indicator is a qualitative or quantitative parameter characterising the current condition of an element of the environment (e.g. tonnage of material dredged) or its change over time (e.g. loss of saltmarshes). Such environmental indicators have three basic functions:

To simplify: Amongst the diverse components of an ecosystem, a few indicators are selected according to their perceived relevance for characterising the overall state of the ecosystem.

To quantify: The value of the indicator is compared with reference values considered to be characteristic of 'pristine' or heavily impacted ecosystems. For example, the ecological status of water bodies assigned under the European Union Water Framework Directive (Elliott et al., 1999) relates to the determination of changes from reference or expected conditions.

To communicate: The use of indicators facilitates communication on environmental issues to stakeholders and policy makers, by promoting information exchange and comparison of spatial and temporal patterns.

National state of the environment reports are widely produced using indicators to illustrate the conditions and trends of varied features such as fish stocks or the emissions of greenhouse gases (e.g. see EA, 2000; ANZECC, 2000; Lehane et al., 2002). In addition, the UK and other countries use classification schemes to assess the water quality for rivers, estuaries and coasts (e.g. see EA, 1998; SEPA, 1995). Indicators can also be used to assess the effectiveness of the actions and policies implemented, by measuring progress towards environmental targets (e.g. see OECD, 1994; DEFRA, 2003). As a recent development, many EU Member States intend to use indicators when implementing the

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Water Framework Directive. In particular, the Directive requires Member States to classify water bodies according to their ecological status and to identify Heavily Modified Water Bodies (HMWBs) for which less stringent environmental objectives can be assigned under specific circumstances laid out in Article 4 of the Directive (CIS, 2003a). The designation process of HMWBs requires investigating and describing the significant anthropogenic pressures and the resulting impacts on an area's physical characteristics and hydromorphology (CIS, 2003b).

Several case studies have suggested possible approaches using indicators. In Belgium, Vandaele et al. (2002) presented a method of detailed assessment of river alterations and the intensity of modification was recorded for several indicators. For example, the amount of alteration for the indicator *dredging operations* was expressed as the percentage of the length of river section affected by dredging. A given water body may then be classified as Heavily Modified if the sum of the degrees of modification for each indicator is higher than a particular threshold.

In order to represent the relations between the environment and the human system, indicators can be structured following the Driver-Pressure-State Change-Impact-Response (DPSIR) framework adopted by the European Environment Agency (EEA, 1999; Elliott, 2002; Elliott and Cutts, 2004). Social and economic developments (as Driving forces, e.g. industries) create a set of Pressures on the environment (e.g. by producing effluent discharges). Consequently, the State Change of the environment (e.g. to the benthic or water column system) undergoes Impacts affecting human uses (e.g. degraded habitats, human health problems or barriers to fish migration). The latter then requires to be addressed by a human Response (e.g. legal control and administrative arrangements) that feeds back to the driving forces, the state or the impacts, through adaptation or curative action, through mitigation and/or compensation (EEA, 1999; Elliott, 2002; Elliott and Cutts, 2004).

On both national and European scales, there is a need for a more coherent approach to the management of the marine environment, including a better and regular reporting (DEFRA, 2002). To do so, a possible approach is to agree a set of indicators and provide guidance to aid their interpretation. For example, the UK Marine Environment Management Group (MEMG) is developing marine indicators for issues such as eutrophication or marine litter and consequently a workshop held in 2002 (CEFAS, 2002) identified potential indicators for nearshore seabed disturbance. These have been grouped by the present authors into three Environmental Integrative Indicators (EIIs): EII 1 'Coastline Morphological Change', EII 2 'Resource Use Change' and EII 3 'Environmental Quality and its Perception'.

The present study aimed to develop these indicators further and to produce a classification scheme to characterise the state of and pressures on coastal and estuarine environments, for a general application to coastal zone management in the UK. This also involved developing a method for integrating heterogeneous indicators into single value 'integrative' indicators. The latter approach assigned a value and a weighting for each 'component' indicator in order to obtain the three EII mentioned above. Specifically, this study focused on a case-study of seabed disturbance in an estuarine and nearshore zone, the Humber Estuary, Eastern England, to enable the testing of the indicators' relevance. The Humber is a coastal plain estuary, whose catchment is the largest in the British Isles, draining over one fifth of England (IECS, 1994). It has many uses and users and is one of the most important estuaries for commerce in the UK with an expanding port complex and extensive industries. Despite this, the Estuary is a potential European Marine Site because of its conservation importance. It is a well-studied area and thus provides adequate data to test the indicators; it is expected that if an indicator is unsuitable for use in the Humber Estuary because of limited data then it will also be unsuitable for other areas.

2. Methods

This study developed a classification scheme using EII which requires (i) the selection of appropriate indicators, (ii) the description of the indicators following a consistent framework, (iii) the definition of classification criteria against which the observed values are evaluated, (iv) the production of individual weightings for each indicator, and (v) the choice of the combination rule to obtain the three EIIs. The initial list of possible indicators selected according to the following criteria:

Criterion 1: Relevance with nearshore seabed disturbance.
Criterion 2: Practical to measure.
Criterion 3: Relevance to the current legislation and management.
Criterion 4: Fully and easily understood.
Criterion 5: Practical to measure in the Humber Estuary.

If the indicator did not fulfil the requirements for one or more criteria, it was either discarded or modified in order to be more relevant. In order be more complete, indicators not originally defined by the workshop have also been suggested.

Decisions were based on literature and expert judgment to define the Component Indicators, followed by establishing the criteria against which the observed values of the indicators were evaluated and classified. The comparison of quantitative and qualitative indicators expressed in different units of measure (e.g. km^2, km, number...) is facilitated if the classification criteria (also referred to as 'classes') are expressed using a common scale for all the indicators. The classification criteria used in the present study are based on a perceived level of disturbance (or perceived quality for the indicator EII 3) for each Component Indicator, which still usually relies on a subjective judgment, but with no a priori consideration of whether these

Table 1
Classification criteria for EII 1

EII 1: Coastline morphological change		Degree of change					
Code	Indicator	No change (0)	Very low (1)	Low (3)	Medium (5)	High (7)	Very high (9)
1.1	Intertidal area lost	Increase	Status quo	<1% lost over the last few decades	*⩾1% and <5% lost*	⩾5% and <10% lost	⩾10% lost
1.2	Re-alignment schemes	*0 ha*	<5 ha created over the last few decades	⩾5 ha and <50 ha	⩾50 ha and <300 ha	⩾300 ha and <500 ha	⩾500 ha
1.3	Land claim	0 ha	<1 % of the current intertidal area	⩾1% and <5%	⩾5% and <15%	*⩾15% and <30%*	⩾30%
1.4	Gross change in the bathymetry and topography	Not applicable	No significant modification of the subtidal and intertidal area	<5% of the intertidal and subtidal area modified	⩾5% and <10%	*⩾10% and <30%*	⩾30%
1.5	Interference with the hydrographic regime	*No construction*	<5% of the intertidal and subtidal area affected	⩾5% and <10%	⩾10% and <20%	⩾20% and <40%	⩾40%
1.6	Gross change in coastline shape	No coastal defences	<5% of the length of coast with coastal defences	⩾5% and <20%	⩾20% and <50%	⩾50% and <80%	*⩾80%*
1.7	Relative Sea Level Rise	Decrease	Stable situation AND similar or upward projection	Increase less than 0.5 mm per year AND similar or downward projected change	(i) Increase less than 0.5 mm per year AND greater projected rise OR (ii) between 0.5 and 2 mm per year AND similar projected change	*(i) between 0.5 and 2 mm per year AND greater projected rise OR (ii) between 2 and 5 mm per year AND similar projected change*	(i) Between 2 and 5 mm per year AND greater projected rise OR (ii) more than 5 mm per year

Table 2
Classification criteria for EII 2

EII 2: Resource use change		Intensity of resource use					
Code	Indicator	No resource use (0)	Very low (1)	Low (3)	Medium (5)	High (7)	Very high (9)
2.1	Anthropogenically affected coastline	No development	<5% of the coastline mainly impacted by industrial or urban developments	≥5% and <30%	*≥30% and <60%*	≥60% and <90%	≥90%
2.2	Construction licences	0 licence	1 licence for the last 2 years	1 licence per year for the last 2 years	2 or 3 licences per year	4 or 5 licences per year	>5 licences per year
2.3	Direct discharges	0 discharge	<0.1 point source discharge per km of coastline	*≥0.1 and <0.4*	≥0.4 and <0.8	≥0.8 and <2	≥2
2.4	Maintenance dredging-Dredging area	*No dredging*	<1% of subtidal area dredged	≥1% and <10%	≥10% and <30%	≥30% and <50%	≥50%
2.5a	Maintenance dredging-Disposal area	No disposal	<1% of subtidal area designated for disposal	*≥1% and <10%*	≥10% and <30%	≥30% and <50%	≥50%
2.5b	Maintenance dredging-Disposal amount	No disposal	<5000 tons deposited annually	≥5000 and <100,000 tons	≥100,000 and <1 million tons	*≥1 and <4 million tons*	≥4 million tons
2.6	Capital dredging	No disposal	<5000 tons deposited for the last 10 years	≥5000 and <100,000 tons deposited	≥100,000 and <1 million tons deposited	*≥1 and <4 million tons deposited*	≥4 million tons deposited
2.7	Beneficial use	No disposal	*<10% of material going for sea disposal*	≥10% and <30% of material going for sea disposal OR ≥30 and <60%, and increase in the number of licences	≥30% and <60% of material going for sea disposal OR ≥60% and <90%, and increase in the number of licences	≥60% and <90% of material going for sea disposal OR ≥90%, and increase in the number of licences	≥90% of material going for sea disposal
2.8	Intensity of wind farm development	*No wind farm*	<1% of the subtidal area restricted due to wind farm developments	≥1% and <10%	≥10% and <30%	≥30% and <50%	≥50%
2.9	Aquaculture	No aquaculture	<1% of the intertidal and subtidal area covered by the developments	≥1% and <10%	≥10% and <30%	≥30% and <50%	≥50%
2.10	Other fisheries activities causing nearshore seabed disturbance	Not applicable	<10% of the length of coast affected by the activities	*≥10% and <30%*	≥30% and <60%	≥60% and <90%	≥90%
2.11	Intensity of marina developments	*No marina*	<100 berths in marinas	≥100 and <150 berths	≥150 and <300 berths	≥300 and <500 berths	≥500 berths
2.12	Intensity of port developments	No harbour	<500 m of quays	≥500 m and <2 km of quays	*≥2 km and <5 km of quays*	≥5 km and <10 km of quays	≥10 km of quays
2.13	Area covered by pipelines and cables	No pipeline or cable	<1% of the intertidal and subtidal area restricted to fishing and anchoring	≥1% and <10%	*≥10% and <30%*	≥30% and <50%	≥50%
2.14	Oil and gas exploration and production	*No activity*	<1% of the subtidal area	≥1% and <10%	≥10% and <30%	≥30% and <50%	≥50%
2.15	Water pollution incidents	Not applicable	No incidents reported	≥1 and <50 incidents reported	*≥50 and <100 incidents reported*	≥100 and <200 incidents reported	≥200 incidents reported
2.16	Tourism and recreation	Not applicable	*<10% of the coastline affected by the activities*	≥10% and <30%	≥30% and <60%	≥60% and <90%	≥90%

Table 3
Classification criteria for EII 3

EII 3: Environmental Quality and its Perception		Quality				
Code	Indicator	Very high (1)	High (3)	Medium (5)	Low (7)	Very low (9)
3.1	Water chemical quality	*100% compliance of samples with EQSs for all substances*	One List II substance fails to comply with EQS AND no significant increase in the concentration of this substance	(i) One List II substance fails to comply with EQS AND significant increase in the concentration of this substance OR (ii) More than one List II substances fail to comply with EQSs AND no significant increase in the concentration of these substances failing the EQS	(i) One or more List II substances fail to comply with EQSs AND Significant increase in the concentration of these substances failing the EQS OR (ii) one List I substance fails to comply with EQSs	More than one List I substances fail to comply with EQSs
3.2	Sediment chemical quality	The concentration for all metals is <Threshold Effect Level (TEL)	The concentration for one metal is ⩾TEL and <Probable Effect Level (PEL)	*The concentration for more than one metal is ⩾TEL and <PEL*	The concentration for one metal is ⩾PEL	The concentration for more than one metal is ⩾PEL
3.3	Water quality—biological effect e.g. (i) Bioaccumulation and (ii) Oyster embryo bioassay	(i) Low concentration for all metals (<2X National background level)	(i) The concentration for one or more metals is ⩾2X National background level and <substantially elevated level	*(i) The concentration for one or more metals is ⩾substantially elevated level and <Grossly elevated level*	(i) The concentration of one metal is ⩾grossly elevated level	(i) The concentration of more than one metal is >grossly elevated level
		(ii) PNR = 0	(ii) PNR between 1 and 20	*(ii) PNR between 21 and 49*	(ii) PNR between 50 and 99	(ii) PNR = 100
3.4	Water quality—microbial assay	Grade *Excellent* for all designated waters	Grade *Excellent* for more than 40% of designated waters AND No grade *Poor*	Grade *Excellent* for less than 40% of designated waters AND No grade *Poor*	Grade *Poor* for less than 60% of designated waters	Grade *Poor* for more than 60% of designated waters
3.5	Benthos	Normal	*Normal*	Recovering or deteriorating	Modified	Severely modified
3.6	Shellfish quality	(i) 100 compliance with standards for growth AND/OR (ii) Class A for all designated harvesting areas	(i) 100% compliance AND/OR (ii) Class A for more than 40% of the designated areas AND No class C	(i) >40% compliance AND/OR (ii) Class A for less than 40% AND No class C	(i) >0 and ⩽40% compliance AND/OR (ii) Class C for less than 60%	(i) 0% compliance AND/OR (ii) Class C for more than 60%
3.7	Loss of habitats	*Increase in the habitats extent or equal status*	Equal status for all habitats	Loss for one habitat type AND equal status (or increase) for the other habitats	Loss for more than one habitat type	Loss for all the habitat types
3.8	Aesthetic pollution	Grade A for all beaches under the Beach Aesthetic Quality Assessment	Grade A for more than 40% of beaches AND no grade C or D	Grade C for less than 40% of beaches AND No grade D	Grade C for more than 40% of beaches OR Grade D for less than 60% of beaches	Grade D for more than 60% of beaches
3.9	Interference with fish migration routes—Physical barriers (only for estuaries)	Percentage of natural drains and rivers affected by a physical barrier: <5%	⩾5% and <30%	⩾30% and <60%	*⩾60% and <90%*	⩾90%
3.10	Interference with fish migration routes—Chemical barrier (only for estuaries)	DO saturation > 80% for 95% of the time	DO saturation ⩽80% and >70% for 95% of the time	*DO saturation ⩽70% and >50% for 95% of the time*	DO saturation ⩽50% and >20% for 95% of the time	DO saturation ⩽20% for 95% of the time

levels reflect acceptable or desirable conditions from society's point of view. Five classes have been defined here ranging from a 'Very high' level of disturbance (or quality) to a 'Very low' level of disturbance (or quality). These five classes are commonly used to categorize values or features of a particular set of indicators (e.g. see Hwang and Yoon, 1981; Mendoza and Prabhu, 2003; Vandaele et al., 2002). A 'Nil' class corresponds to cases where there is sufficient evidence to assert that the parameter reflected by the indicator is absent or does not apply to the particular area under consideration (e.g. if there is no dredging in the area). Tables 1–3 present the classification criteria. They are based on expert judgment or perspectives gained from the literature, in particular from the classification scheme adopted by SEPA (1995), as well as the ongoing research providing guidance over the links between morphological modifications and the classification status of water bodies under the Water Framework Directive (EA, 2003; CIS, 2003b).

The Component Indicators within each EII represent impacts and changes which differ in their nature and severity. Hence, it is considered here that there is a need to assign weightings to the Component Indicators to reflect their relative importance and thus the outcome of the overall assessment (i.e. the EII) is in proportion to their importance (Silvert, 1997). The weightings were derived using 'expert judgement' created by sending a questionnaire to the 50 participants of the seabed disturbance indicators workshop (CEFAS, 2002) and asking them to rank the indicators depending on their perceived relative importance, following a 9-point scale (1, very low importance; 3, low; 5, moderate; 7, high and 9, very high). The weightings used here were based on 13 respondents to the questionnaire. In their case study on the development of indicators for supporting the sustainable management of a forest unit in Indonesia, Mendoza and Prabhu (2000) followed a similar approach. However, since in some instances one expert did not provide a rank for all the Component Indicators, the following average procedure was suggested to obtain the relative weights:

$$w_i = \frac{100 \times \text{mean of the ranks given to the indicator } i}{\text{sum of the } n \text{ mean values of the ranks given to each of the } n \text{ indicators}}$$

where n is the number of indicators, w_i is the relative weight (or importance) of the indicator i.

Once classes were obtained for each Component Indicator, there was a need to choose the integration rule that would be used to derive the class of the three EIIs. Although a common approach is to have a default system in which an area is classified according to the lowest (i.e. worst) class for any individual indicator (e.g. SEPA, 1995), with indicators of different relative importance the following method was suggested: classes were defined using a 9-point scale (1—very high to 9—very low), and the EII was calculated as the weighted arithmetic mean.

3. Results

Tables 1–3 present the classification criteria. The indicators 1.3, 2.3, 2.10, 2.12, 2.14, 2.15, 2.16 and 3.10 were not initially suggested at the workshop (CEFAS, 2002) and have been proposed in the present study. The criteria in italics correspond to the values obtained for the three sections highlighted in Fig. 1 (grey hatched areas): section 14 in the outer Estuary for EII 1, section 7w in the middle Estuary for EII 2 and section 3 in the inner Estuary for EII 3.

EII 1 provides an indication of the nature in which the coastline has been modified by anthropogenic activities or natural processes. It concentrates on the morphological change, using predominantly physical characteristics. EII 2 details the amount of the main activities responsible for coastal disturbance. It is therefore the primary indicator of the drivers and pressures causing change. EII 3 aims to give the status of the natural environment and assess the impacts of the environmental change represented in EII 1 and EII 2. Some Component Indicators of EII 3 relate to the 'quality' of the water and sediments (concentration of pollutants), whereas others relate to the conditions of the habitats and their ability to maintain viable populations. This Integrative Indicator includes both quantitative and qualitative data.

The classification criteria of the indicators *Water chemical quality* (3.1) and *Sediment chemical quality* (3.2) are based on the classification scheme adopted by SEPA (1995) in which four classification criteria are defined for each indicator. The indicators *Land claim* (1.3), *Interference with the hydrographic regime* (1.5), *Gross change in coastline shape* (1.6), *Anthropogenically affected coastline* (2.1), and *Maintenance dredging* (2.4 and 2.5a) are also being investigated for the designation process of Heavily Modified Water Bodies (EA, 2003; CIS, 2003b). However, the percentages used in the present study to define the classification criteria usually differ from the ones suggested in the works mentioned above. This is because the indicators are usually not applied to areas of similar sizes. It must be borne in mind that the percentages used in the present classification scheme are only valid for sections delimited by ca. 10 km of coastline.

Tables 4–6 indicate the ranks given by each respondent for each Component Indicator. The standard deviation (SD, see bottom row of Tables 4–6) calculated for each respondent is usually high (between 1 and 3), indicating

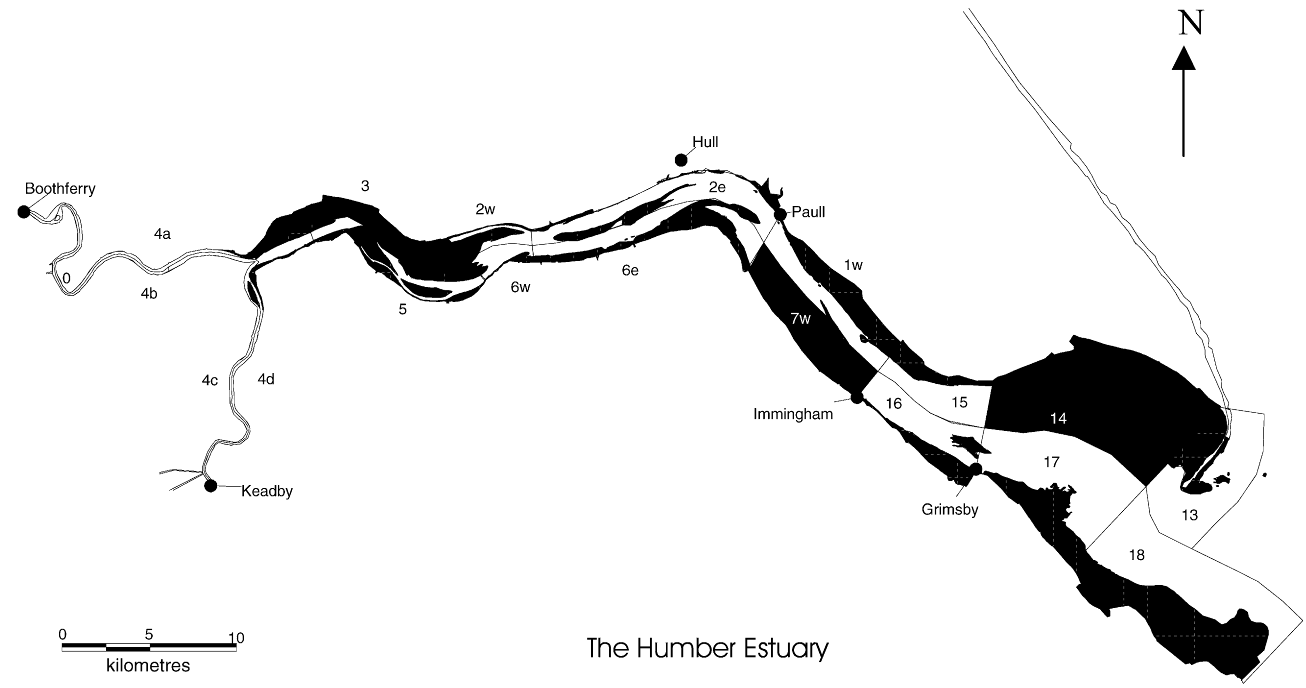

Fig. 1. Geographical sections for the case study of the Humber Estuary, Eastern England.

Table 4
Relative weights for the Component Indicators of EII 1

EII 1	Respondents													Range	Average	SD	Weight
	1	2	3	4	5	6	7	8	9	10	11	12	13				
1.1	5	7	6	3	5	9	5	5	[a]	7	7	9	7	6	6.3	1.8	16
1.2	1	3	7	7	3	7	1	3	3	5	5	7	5	6	4.4	2.2	11
1.3	7	9	8	5	5	7	7	5	9	5	7	9	3	6	6.6	1.9	17
1.4	3	5	6	3	4	7	5	7	7	9	5	9	7	6	5.9	2.0	15
1.5	7	3	7	5	5	9	9	3	7	5	3	5	7	6	5.8	2.1	15
1.6	9	3	5	5	9	5	5	5	7	5	5	7	5	6	5.8	1.7	15
1.7	3	5	7	1	1	4	7	3	7	3	3	9	5	8	4.5	2.5	11
Average	5.0	5.0	6.6	4.1	4.6	6.9	5.6	4.4	6.7	5.6	5.0	7.9	5.6		*39.2*		*100*
SD	2.8	2.3	1.0	2.0	2.4	1.9	2.5	1.5	2.0	1.9	1.6	1.6	1.5				

[a] Missing data.

that most of the respondents consider that one or more indicators are significantly less (or more) important than others. It should also be noted that the average values for some respondents (in particular respondents 6, 10 and 12) are always among the highest, possibly indicating that they consider that all the Component Indicators are important and should not be discarded from the classification scheme. Tables 4–6 also indicate the averages and relative weights obtained for each Component Indicator. As an example of the calculation of weightings, relative weight for the Component Indicator 1.2 is obtained by applying the equation mentioned earlier and thus equals $(100 \times 4.4)/39.2 \cong 11.2$, approximated to 11 in Table 4.

The range and standard deviation obtained for most of the Component Indicators are relatively high (SD is often greater than 2), indicating diverging opinions among respondents. This is particularly the case for the indicators *Re-alignment schemes* (1.2), *Relative sea level rise* (1.7), *Anthropogenically affected coastline* (2.1), *Biological effect* (3.3), Water quality—microbial assay (3.4), *Shellfish quality* (3.6), *Aesthetic pollution* (3.8), and *Interference with fish migration routes—chemical barriers* (3.10). On the contrary, the standard deviation for the indicators *Maintenance dredging* (2.4 and 2.5a), *Fisheries activities* (2.10), *Intensity of marina developments* (2.11), and *Loss of habitats* (3.7) seems relatively low and thus it appears justified to consider the mean value as the relative weight for these particular indicators since there is broad agreement among the respondents.

The EIIs were then obtained by calculating the weighted arithmetic mean using the relative weights presented in Tables 4–6. As an example of the calculation of EIIs, the Component Indicators of EII 1 for section 14 have the classes as shown in italics in Table 1. Each class corresponds to

Table 5
Relative weights for the Component Indicators of EII 2

EII 2	Respondents													Range	Average	SD	Weight
	1	2	3	4	5	6	7	8	9	10	11	12	13				
2.1	9	7	6	3	3	9	3	7	9	9	5	9	5	6	6.5	2.5	8
2.2	3	3	7	7	5	5	3	5	5	5	5	7	5	4	5.0	1.4	6
2.3	7	3	5	7	3	7	3	3	7	7	5	3	3	4	4.8	1.9	6
2.4	[a]	[a]	[a]	[a]	[a]	[a]	[a]	5	5	3	5	7	5	4	5.0	1.3	6
2.5a	3.5	2.5	2	2.5	2.5	3.5	1.5	2.5	2.5	1.5	2.5	3.5	1	3	2.4	0.8	3
2.5.b	1.75	1.25	1	1.25	1.25	1.75	1.5	1.25	1.25	0.75	1.25	1.75	7	6	1.8	1.6	2
2.6	3	9	8	9	5	7	7	5	5	5	5	7	5	6	6.2	1.8	8
2.7	1	1	5	5	1	5	1	5	3	7	3	5	1	6	3.3	2.1	4
2.8	1	3	5	5	1	5	5	3	5	5	7	7	3	6	4.2	1.9	5
2.9	3	1	4	7	7	5	5	7	5	5	5	7	3	6	4.9	1.8	6
2.10	7	7	7	7	4	5	7	5	5	5	5	7	7	3	6.0	1.2	7
2.11	7	9	5	5	7	5	7	5	7	7	5	7	5	4	6.2	1.3	8
2.12	7	9	5	5	7	5	7	7	7	7	7	7	5	4	6.5	1.2	8
2.13	1	3	3	5	3	5	5	3	3	5	7	5	3	6	3.9	1.6	5
2.14	5	1	4	3	1	5	5	5	5	5	5	7	3	6	4.2	1.7	5
2.15	5	5	4	5	6	8	3	7	5	7	5	3	5	5	5.2	1.5	6
2.16	3	1	5	3	7	3	7	5	5	7	7	7	3	6	4.8	2.1	6
Average	4.2	4.1	4.8	5.0	4.0	5.3	4.4	4.8	5.0	5.4	5.0	5.9	4.1		*81.0*		*100*
SD	2.6	3.1	1.8	2.1	2.3	1.8	2.2	1.7	1.9	2.1	1.6	2.0	1.7				

[a] Missing data.

Table 6
Relative weights for the Component Indicators of EII 3

EII 3	Respondents													Range	Average	SD	Weight
	1	2	3	4	5	6	7	8	9	10	11	12	13				
3.1	3	7	7	5	7	7	9	5	5	5	7	9	5	6	6.2	1.7	10
3.2	7	7	7	7	5	7	9	5	5	5	9	7	5	4	6.5	1.5	11
3.3	5	5	8	7	3	9	7	3	7	5	7	7	1	8	5.7	2.3	9
3.4	3	5	6	5	4	7	7	3	5	7	9	9	1	8	5.5	2.4	9
3.5	5	9	5	9	3	7	9	7	7	7	9	7	5	6	6.8	1.9	11
3.6	3	7	5	3	7	7	9	5	5	5	9	9	3	6	5.9	2.3	10
3.7	9	9	7	5	7	9	7	7	9	7	7	9	9	4	7.8	1.3	13
3.8	1	3	6	5	5	5	7	5	7	7	3	9	3	8	5.1	2.2	8
3.9	7	5	5	5	5	9	5	5	5	3	7	7	3	6	5.5	1.7	9
310	[a]	[a]	[a]	[a]	[a]	[a]	[a]	5	3	9	7	9	3	6	6.0	2.8	10
Average	4.8	6.3	6.2	5.7	5.1	7.4	7.7	5.0	5.8	6.0	7.4	8.2	3.8		*61.0*		*100*
SD	2.5	2.0	1.1	1.7	1.6	1.3	1.4	1.3	1.7	1.7	1.8	1.0	2.3				

[a] Missing data.

a numerical value (e.g. value 5 for the class 'Medium'). Thus the weighted mean for this section equals $[(5\times16)+(0\times11)+(7\times17)+(7\times15)+(0\times15)+(9\times15)+(7\times11)]/100\cong5.2=\text{EII 1}$. Considering the intervals presented in Table 7, the corresponding class for the value 5.2 is 'Medium'.

The numerical values and corresponding classes obtained when calculating the weighted arithmetic mean for all sections are shown in Table 8. EII 1 is usually classified as 'Medium' or 'Low' and EII 3 as 'Medium' or 'High', which would indicate that the Humber Estuary is moderately affected by morphological changes whereas the environmental quality tends to be moderate or high. However, classes usually vary with the geographical section, indicating an important spatial variation in the environmental quality and intensity of pressures exerted on the Humber estuarine environment (Table 8). That Section 2e has the worst observed combination of classes ('Medium', 'Low'

Table 7
Classes and their numerical values

Values of the indicator (v)	$v=0$	$0<v<2$	$2\leqslant v<4$	$4\leqslant v<6$	$6\leqslant v<8$	$8\leqslant v\leqslant9$
Class (pressure or impact)	No disturbance	Very low	Low	Medium	High	Very high
Class (quality)		Very high	High	Medium	Low	Very Low

Table 8
Classes of the EIIs for the Humber Estuary

	Section	EII 1		EII 2		EII 3	
		Weighted mean	Mean	Weighted mean	Mean	Weighted mean	Mean
Outer estuary	13	L *(3.2)*	L *(3.3)*	VL *(1.6)*	VL *(1.5)*	M *(4.0)*	H *(3.8)*
	14	M *(5.2)*	M *(5.0)*	VL *(1.8)*	L *(2.0)*	M *(5.8)*	M *(5.8)*
	17	M *(4.4)*	M *(4.3)*	L *(2.5)*	L *(2.1)*	M*(5.2)*	M *(5.0)*
	18	M *(5.0)*	M *(4.8)*	VL *(1.1)*	VL *(1.0)*	H *(3.5)*	H *(3.3)*
Middle estuary	15	L *(3.5)*	L *(3.6)*	VL *(1.8)*	VL *(1.7)*	H *(3.5)*	H *(3.6)*
	1w	M *(4.7)*	M *(4.9)*	VL *(1.8)*	VL *(1.8)*	H *(3.5)*	H *(3.6)*
	2e	M *(5.5)*	M *(5.3)*	M *(4.1)*	L *(3.8)*	M *(4.4)*	M *(4.6)*
	6e	L *(3.3)*	L *(3.4)*	VL *(1.7)*	VL *(1.6)*	M *(4.2)*	M *(4.4)*
	7w	M *(4.5)*	M *(4.6)*	L *(3.1)*	L *(3.0)*	H *(3.7)*	H *(3.9)*
	16	L *(3.8)*	L *(3.9)*	L *(3.4)*	L *(3.3)*	H *(2.5)*	H *(2.4)*
Inner estuary	2w	L *(2.9)*	L *(3.0)*	VL *(1.6)*	VL *(1.5)*	H *(2.3)*	H *(2.3)*
	3	M *(4.8)*	M *(4.7)*	VL *(1.4)*	VL *(1.3)*	H *(3.7)*	H *(3.9)*
	5	M *(4.7)*	M *(4.6)*	VL *(1.4)*	VL *(1.3)*	H *(3.6)*	H *(3.8)*
	6w	L *(3.6)*	L *(3.7)*	VL *(1.6)*	VL *(1.5)*	H *(3.9)*	M *(4.2)*
River Ouse	4a	M *(4.4)*	M *(4.3)*	L *(2.1)*	L *(2.3)*	M *(4.8)*	M *(4.7)*
	4b	M *(4.1)*	M *(4.0)*	L *(2.3)*	L *(2.4)*	M *(4.1)*	M *(4.0)*
River Trent	4c	M *(4.4)*	M *(4.3)*	VL *(1.4)*	VL *(1.5)*	L *(7.6)*	L *(7.7)*
	4d	M *(4.4)*	M *(4.3)*	VL *(1.1)*	VL *(1.0)*		

and 'Low' for EII 1, EII 2 and EII 3 respectively) is not surprising since this section has been affected by important industrial developments (it contains the city of Hull's waterfront) and morphological changes (in particular through land claim and variations in the bathymetry) compared to other sections. Sections 4a, 4b and 17 are also classified among the poorest sections. Section 7w is characterised by an important morphological change and resource use (in particular dredging and disposal), which is well reflected by the present classification scheme, by assigning the highest observed class for EII 1 ('Medium') and 'Low' for EII 2. However, the environmental quality for this section is among the highest (class 'High' for EII 3), indicating that pressures exerted in this section do not seem to affect its environmental quality, although it may have indirect effects on other sections. Sections 1w, 3 and 5 are rated among the best sections for EII 2 and EII 3, although a relatively important morphological change is attributed to these places (class 'Medium' for EII 1). This is mainly explained by the nature of the inner Estuary (including sections 3 and 5), which is subject to important bathymetric variations and changes in the coastline shape for section 1w.

The results obtained when calculating the arithmetic mean (and therefore not considering the relative weights) are also presented in Table 8. It is of note that classes obtained when including the relative weights (by calculating the weighted mean) are usually the same as the ones obtained without considering them, except for four sections (Table 8). The weighted mean and the simple mean are usually very similar, the maximum difference being only 0.4 for EII 2 of section 17. These findings may indicate that the weights obtained for each Component Indicators are not significantly different since the value obtained for the EIIs is always very similar when using an equal weight for all the Component Indicators (by calculating the arithmetic mean) or when using the relative weights presented in Tables 4–6 (by calculating the weighted arithmetic mean).

4. Discussion and conclusions

The classification scheme developed in the present study provides an assessment of the environment of the Humber Estuary which agrees with subjective perceptions in comparing classes between sections. However, given the large catchment and estuarial population and the large industrial base and port activity (IECS, 1994; EA, 1998), EII 2 (Resource Use Change) is expected to be classified at high levels of disturbance for most of the sections of the Humber Estuary. However, as shown in Table 8, the class for EII 2 is usually 'Very Low' or 'Low'. This is probably due to the fact that for most sections many indicators have been assigned the 'Nil' class, and therefore the value zero, when the activity or phenomenon represented by the indicator did not occur in the section. When many indicators get the value zero, the value obtained for EII 2 when calculating the weighted arithmetic mean is necessarily low. It seems therefore that the structure of EII 2 needs to be reviewed. It could be suggested to limit the number of indicators classified as 'Nil' to 5 or 6 for instance, and to discard any additional indicator classified as 'Nil', in order to increase the value of EII 2. It may also be necessary to reduce the number of indicators or review the classification criteria for some of them.

The study has demonstrated that experts in the field of estuarine and coastal zone management consider that the different issues covered by the indicators should not be given equal importance when assessing the overall state of the environment (see Tables 4–6), although other studies using indicators usually give them similar weights (e.g. see SEPA, 1995; EA, 2000; DEFRA, 2003). This would justify the need for considering relative weights to the Component Indicators before integrating them into each of the EII. However, there was an important divergence of opinions among experts over the relative importance of many of the indicators. This may explain why the relative weights obtained were not significantly different. It appears therefore that a better consensus is required regarding the relative importance of the indicators, which may then result in weights that would be sufficiently different to affect the EIIs.

Although the present study applied the indicators to an estuary, most of them are also applicable to coastal zones although some modifications would be required. In particular, the classification criteria presented in Tables 1–3 for indicators referring to subtidal areas need to be reviewed, especially if the seaward boundary of coastal waters is likely to be at least three nautical miles from the coastline. This corresponds to the geographical area within which UK legislation on pollution control commonly applies (WRc Swindon, 1999) and so the subtidal area of coastal sections is likely to be wider than for most estuaries. Thus the percentages used to define classes need to be lower than the ones defined for the estuarine areas. The indicators concerned by such a modification are *Gross change in the bathymetry* (1.4), *Interference with the hydrographic regime* (1.5), *Maintenance dredging* (2.4 and 2.5a), *Intensity of wind farm developments* (2.8), *Aquaculture* (2.9), *Area covered by pipelines and cables* (2.13), and *Oil and gas exploration and production* (2.14).

The present study has shown that these indicators can help to set priorities in terms of issues and/or geographical zones perceived not to be in a desirable condition. For instance, management efforts could be targeted towards sites with high values for EII 3, indicating that there are some environmental quality issues. This approach may also be followed when setting environmental objectives, by considering for instance that sites where EII 2 is very high may have less stringent objectives than the other sites, at least in the short term and when the uses of these sites (e.g. navigation, flood defence) would be significantly affected by the measures required to achieve a good environmental status (CIS, 2003a). This approach may prove valuable when defining the environmental objectives for each water bodies under the EU Water Framework Directive, especially for water bodies designated as Heavily Modified.

Implementing the EU Water Framework Directive will require the need to decide nationally which water bodies (and how many) will be monitored to assess long-term changes ('surveillance monitoring' as mentioned in Article 8 of the Directive) within each river basin. The present approach may prove valuable in setting some selection criteria and associating them with indicators. There will also be a need to decide which elements of the water body will need to be monitored when the site does not meet the environmental objectives ('operational monitoring'). The present study may also prove helpful in proposing specific indicators to monitor for assessing the significance of the disturbance.

The scheme developed and applied to the Humber Estuary includes and provides more information than traditional classification schemes, which usually tend to focus only on State Change indicators. In addition, the suggested scheme differs from most of the State of the Environment Reports since each indicator is associated with a set of several classification criteria. There is now a need to further develop the indicators for assessing seabed disturbance in coastal and estuarine environments. In particular, it appears necessary to develop further indicators within EII 3 assessing the ability of the ecosystems to sustain natural habitats and populations at a good conservation status. However, information is often lacking to assess the extent and conditions of many components of natural ecosystems, such as marine mammals or non-indigenous species as noted by the European Commission (CEC, 2002). It is expected that with the further implementation of the EU Habitats and Species Directive, most of the necessary data will soon be available for designated areas, since the Directive requires monitoring the deviation of each designated sites from its favourable conservation status (Elliott et al., 1999; McLusky and Elliott, 2004). However, there is also a need to consider the application of these indicators to non-protected areas, since the EU Water Framework Directive requires a good ecological status for all water bodies.

Some indicators may include an element of double counting or redundancy (e.g. *Interference with the hydrographic regime* (1.15) and *Intensity of port developments* (2.12)). This can lead to the over-weighting of particular pressures (e.g. development of navigation facilities), which introduces bias when integrating the indicators into a single Integrative Indicator. The present scheme did not investigate in detail the redundancy in relationships between indicators and therefore could have misrepresented the complexity of the interdependencies among them. Hence there is the need to study the linkages between the indicators in order to avoid double counting by identifying redundant indicators and to help setting priorities for actions in terms of issues for which improvement is more likely to lead to a better status for the whole system.

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