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The ecofunctional quality index (EQI): a new tool for assessing lagoonal ecosystem impairment

E.A. Fano*, M. Mistri, R. Rossi

Department of Biology, University of Ferrara, Via L. Borsari 46, 44100 Ferrara, Italy

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Abstract

A multimetric index for the evaluation of environmental quality (the ecofunctional quality index, EQI) has been developed using biotic data from three Italian coastal lagoons. Sampling programs were conducted between 1998 and 2000, on a yearly basis, with seasonal frequency at diverse sites in each lagoon. The rationale of the index is that certain attributes, selected on the basis of established principles of benthic ecology, are fundamental for lagoon ecosystem function. The chosen attributes were primary productivity, expressed as phytoplankton, seaweed and seagrass biomasses; structure and productivity of the benthic community, expressed as numerical abundance, biomass density, number of species, and taxonomic diversity of macrozoobenthos; and finally, trophic complexity, expressed as macrozoobenthic functional diversity. The EQI is constituted by the sum of weights given to these eight attributes, each transformed onto a dimensionless 0–100 quality scale. In this way, the use of EQI can derive a series of values yielding a 'functional classification' of sites within a lagoon or between different lagoons. The proposed index is a low cost, flexible and robust routine indicator of lagoon ecosystem impairment and could be of particular benefit to environmental managers and policymakers who require tools capable of expressing the degree of degradation or environmental quality of different lagoon habitats. The process of developing and the initial testing of EQI reported in this paper is intended as preliminary, and until validation of this index is accomplished by incorporating data from a wider range of lagoon environments, we caution the use of this index in anything other than an exploratory manner.

Keywords: environmental quality; biotic indices; benthic macrofauna; coastal lagoons

1. Introduction

Over recent decades, there has been considerable interest in the development of meaningful indices to express, evaluate and monitor the 'health' and/or environmental quality of aquatic ecosystems. Initial efforts were usually chemically based and generally parameter specific (Karr, 1991), or utilised selected sentinel organisms (e.g. Mussel Watch; O'Connor, 1992). However, while these approaches may provide some indications of potential impacts or information on specific effects, they give little information on overall environmental quality or on the potential impacts of forcing factors at the community and ecosystem levels. In contrast, an integrated ecological approach based on structural and functional indices at the community level would be expected to provide more general indications on overall ecosystem health and alterations.

Numerous studies have demonstrated that benthic invertebrate communities respond in a predictable manner to many kinds of natural and anthropogenic stresses (Gray & Mirza, 1979; Gray & Pearson, 1982; Pearson, 1975; Pearson & Rosenberg, 1978; Warwick, 1986, 1993). Therefore, these communities could provide valuable information on ecosystem health since: (a) being relatively sedentary, the organisms are unable to avoid deterioration in water and sediment conditions; (b) being relatively long-lived they may integrate water and sediment quality conditions with time and register both point and chronic stresses; and (c) they are constituted

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* Corresponding author.
E-mail address: fne@unife.it (E.A. Fano).

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by diverse species exhibiting a range of tolerance levels to stress and pollution (Dauer, 1993; Gray, 1979). The potential of faunal communities to serve as environmental quality indicators has long been recognised by freshwater biologists and particularly fluvial ecologists have a long tradition in application of biotic indices based on benthic macrofaunal community characteristics (Cairns, Douglas, Busey, & Chaney, 1968; Chandler, 1970; Woodiwiss, 1964). More recently, similar biocriteria, based on changes in benthic faunal community structure compared to predefined reference conditions, have been developed for the evaluation of estuarine and coastal environments (Borja, Franco, & Perez, 2000; Engle & Summers, 1999; Grall & Glemarec, 1997; Majeed, 1987; Weisberg et al., 1997). Similarly, in shallow water marine environments, the structure of the primary producer community (seagrasses, perenial and ephermeral macroalgae and phytoplankton) is sensitive to environmental conditions and especially to nutrient and light availability, i.e. nutrient and suspended matter loads (see Duarte, 1995; Sand-Jensen & Borum, 1991 for reviews), and thus could also provide potential environmental quality indices.

The political need for the development of biological criteria for the evaluation, classification and management of aquatic environments has also been recognised (Simon, 2000) and European legislation (Directive Proposal 1999/C 343/01) emphasises the importance of biotic indicators for the assessment of the environmental quality of coastal habitats. However, although functional descriptors of aquatic ecosystem integrity have been identified, only indices based on abiotic measures have been officially recognised by the Italian Government, in the framework of the Italian Act 152/99 (paragraphs 3.4 and 3.5). In this act, the classification of environments is based on the TRIX index (Vollenweider, Giovanardi, Montanari, & Rinaldi, 1998). This index relates chl-*a*, inorganic nitrogen and phosphorus and dissolved oxygen concentrations, but is inadequate for the evaluation of shallow water lagoon and coastal environments, since in these systems primary production is dominated by benthic seagrass, macro- and microalgal communities. However, the same Italian Act also recognises the need for more integrated indices, since the legislator foresees the future definition of ecological criteria for the assessment of the trophic status and environmental quality, particularly with respect to lagoon habitats.

With this aim in mind, we have developed a multimetric index, the ecofunctional quality index (EQI) which is based on the characteristics of the primary producer and benthic faunal communities and is intended to overcome the above cited problems, and to provide a tool for environmental managers and policymakers who require simple, manageable methodologies for the classification, evaluation and monitoring of the ecological condition of natural and/or degraded lagoon habitats. This note reports the development and preliminary testing of the EQI.

2. Materials and methods

2.1. The model

We propose a system constituted by a number (seven or eight, dependent if macroalgae are present or not) of ecological attributes, which are integrated to generate a single index to express the environmental quality of lagoon habitats, EQI. Estuarine and coastal lagoon ecosystems are subjected to varying degrees to chronic natural and anthropogenic disturbances of different typologies, and are constituted by a mosaic of patches at different levels of impairment and successional phases. These environments generally are also highly productive and therefore we felt that production should be included amongst the metrics assessed. However, productivity determinations are an expensive, technically demanding and time consuming task to perform and thus are not ideally suited for inclusion in an assessment model such as the EQI. In contrast, attributes such as the biomass of different primary producers present within a habitat can be easily and rapidly estimated, and may give an adequate assessment of potential productivity.

The sum of yearly mean values of a series of attributes which are known to play primary roles in the functioning of estuarine and lagoon ecosystems gives rise to a more general measure of ecosystem functioning which, in turn, provides an index of the health of the environment. EQI combines a complex suite of attributes, such as total biomass of primary producers (divided into phytoplankton, macrophytes and macroalgae when present), total biomass and abundance of secondary producers, community measures such as the number of taxa and taxonomic diversity of the macrofauna, and trophic measures such as the functional diversity of the macrofauna, into an ecologically meaningful index. Each of these attributes, which are expressed by heterogeneous units, is then transformed onto a dimensionless quality scale of 0–100, simply by assigning 100 to the highest value, and by normalising to 100 all the other values. Once all attributes are expressed by means of this scale, they are combined to obtain the integrated index, whose maximum theoretical value will vary from 700 to 800, depending on whether macroalgae are present in the particular habitat. These values would correspond to the optimum condition of the index, irrespective of the units and magnitudes used to measure the different individual attributes; obviously, the closer the actual values are to, say, 800, the better the condition of the environment. EQI also allows comparisons to be made between sites from different lagoons (nEQI). Data sets from the different lagoons are merged into a worksheet so that the value of each attribute can be rescaled, using the same quality scale of 0–100, on the complete data set. Finally, scores are summed and divided by the number of attributes measured in each different lagoon. In this way, the use of EQI can derive a series of continuous values, from 0 to 800 (nEQI: from 0 to 100): the result obtained is a 'functional classification' of the sites within a lagoon or between different lagoons.

2.2. Data collection

Data sets were gathered in three coastal lagoons located in the Po River Delta (Fig. 1), namely the Sacca di Goro, Valle Fattibello and Valli di Comacchio; a total of 16 sampling sites (Goro, 7; Fattibello, 5; Comacchio, 4) were chosen as representative of the different lagoon habitats on the basis of historical data sets, local expertise and best judgment (Bencivelli & Castaldi, 1991; Bencivelli, Castaldi, & Finessi, 1994; Dallocchio, Ghion, Milan, & Viaroli, 1998; VV.A.A., 1999). Valle Fattibello geographically belongs to the wider Valli di Comacchio lagoonal system, but its characteristics are so different from those of Comacchio (Mistri, Fano, Rossi, Caselli, & Rossi, 2000) that we considered it as an independent water body. Each lagoon was sampled with a seasonal frequency over a 1-year period (Fattibello, 1998–1999; Goro, 1998–1999; Comacchio, 1999–2000). At each site, within each individual lagoon, three replicate benthic samples were collected for the analysis of the macrofaunal community using a Van Veen grab; fauna retained on a 0.5 mm screen were identified to the lowest practical taxonomic level (usually species) and counted. Macroalgae, whenever present, were harvested in triplicate from a known area of sediment using a benthic drag. Macrophytes, when present, were collected by cutting the leaves contained within triplicate plexiglas cylinders haphazardly settled onto the sediment. Phytoplanktonic biomass was assumed to be proportional to the chl-*a* concentration (Environmental Protection Agency, 2000) and was directly read in the water column using a Idronaut© Ocean Seven 316 CTD probe. The biomasses of fauna, algae and macrophytes were obtained by oven-drying to constant weight, following standard methods (Crisp, 1984). For macrofauna, taxonomic diversity was traditionally computed as the Shannon–Wiener index, while functional diversity was calculated by applying the Shannon–Wiener formula to abundance data for the major functional groups (i.e. grazers, scrapers, suspension-feeders, surface deposit-feeders, subsurface deposit-feeders and predators; Gaston & Nasci, 1988).

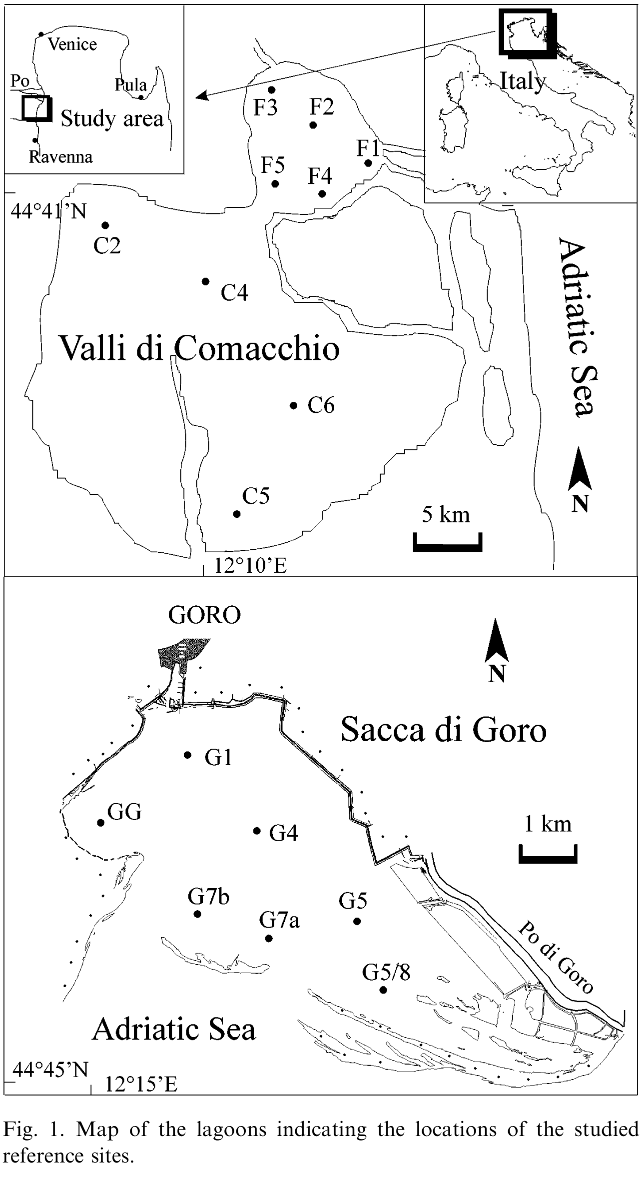

Fig. 1. Map of the lagoons indicating the locations of the studied reference sites.

3. Results

Based on historical data sets (Bencivelli & Castaldi, 1991; Bencivelli et al., 1994; Dallocchio et al., 1998; Regione Emilia Romagna, 1999), the opinions of local experts and best judgement, the 16 studied sampling sites were roughly classified a priori, as disturbed Goro (sites G1, G4 and GG), Fattibello (sites F3 and F4), Comacchio (site C6); moderately disturbed Goro (site G5/8), Fattibello (sites F1 and F2), Comacchio (sites C2 and C4); and minimally disturbed Goro (sites G5, G7a and G7b), Fattibello (site F5) and Comacchio (site C5). In both the Goro and Fattibello lagoons seagrass meadows are completely absent, whilst macroalgal blooms have never been observed in the Valli di Comacchio and some residual seagrass meadows persist (Piccoli, 1998), for example, at site C5.

Table 1
Average annual values of ecological attributes at reference sites

	Comacchio				Goro							Fattibello				
	C2	C4	C5	C6	G1	G4	G5	G5/8	G7a	G7b	GG	F1	F2	F3	F4	F5
Macrofaunal abundance	1282.0	7886.1	2287.4	1322.1	2311	3124	7542	6185	6239	5633	20106	2172.27	8998.33	3264	1238.9	5117.7
Number of taxa	19.75	19.25	22.25	16.50	14	15	20	14	24	20	17	14	17	16	12	17
Taxonomic diversity	1.99	1.16	1.53	1.21	1.81	1.32	1.54	1.74	2	1.9	0.86	1.6708	0.9561	1.1115	1.3261	1.0332
Functional diversity	1.10	0.64	0.81	0.78	1.15	0.91	1.05	1.35	1.276	1.278	0.41	0.7527	0.4752	0.4533	0.6136	0.7245
Macrofaunal biomass	0.540	1.184	0.655	0.762	1.94	3.55	10.22	4.48	3.35	7.14	1.82	0.711	0.8612	1.8043	15.084	14.533
Macroalgal biomass	np	np	np	np	6.47	5.63	22.02	13.83	19.28	19.75	0	24.281	15.938	0	1.1841	11.103
Phytoplankton biomass	25.58	15.88	17.75	31.58	10.11	6.19	14.38	4.91	5.06	3.62	10.59	7.211	12.095	14.29	9.1579	18.448
Macrophytal biomass	0	0	5	0	np	np	np	np	np	np	np	np	np	np	np	np

np, attribute not present in the lagoon.

Table 2
Matrices of rescaled values of ecological attributes at each lagoon; the sum of each column gives EQI

	Comacchio				Goro							Fattibello				
	C2	C4	C5	C6	G1	G4	G5	G5/8	G7a	G7b	GG	F1	F2	F3	F4	F5
Macrofaunal abundance	16.3	100	29.0	16.8	11.5	15.5	37.5	30.8	31.0	28.0	100	24.1	100	36.3	13.8	56.9
Number of taxa	88.8	86.5	100	74.2	58.3	62.5	83.3	58.3	100	83.3	70.8	82.4	100	94.1	70.6	100
Taxonomic diversity	100	58.3	76.5	60.7	90.5	66.0	77.0	87.0	100	95.0	43.0	100	57.2	66.5	79.4	61.8
Functional diversity	100	57.7	73.8	70.5	85.2	67.4	77.8	100	94.5	94.7	30.4	100	63.1	60.2	81.5	96.3
Macrofaunal biomass	45.6	100	55.3	64.4	19.0	34.7	100	43.8	32.8	69.9	17.8	4.7	5.7	12.0	100	96.4
Macroalgal biomass	np	np	np	np	29.4	25.6	100	62.8	87.6	89.7	—	100	65.6	—	4.9	45.7
Phytoplankton biomass	81.0	50.3	56.2	100	70.3	43.0	100	34.1	35.2	25.2	73.6	39.1	65.6	77.5	49.6	100
Macrophytal biomass	0	0	100	0		np	np	np	np	np	np	np	np	np	np	np
EQI	431.6	452.8	490.8	386.6	364.2	314.8	575.6	416.9	481.1	485.7	335.7	450.3	457.3	346.6	399.8	557.0

np, attribute not present in the lagoon.

Table 3
Matrix of rescaled values of ecological attributes on the whole data set; the sum of each column divided by the number of attributes gives nEQI

	Comacchio				Goro							Fattibello				
	C2	C4	C5	C6	G1	G4	G5	G5/8	G7a	G7b	GG	F1	F2	F3	F4	F5
Macrofaunal abundance	6.4	39	11.4	6.6	11.5	15.5	37.5	30.8	31.0	28.0	100	10.8	45	16.2	6.2	25.5
Number of taxa	82.3	80.2	93	68.8	58.3	62.5	83.3	58.3	100	83.3	70.8	58.3	71	66.7	50.0	71
Taxonomic diversity	100	58.1	76.3	60.5	90.5	66.0	77.0	87.0	100	95.0	43.0	84	47.8	55.6	66.3	51.7
Functional diversity	82	47.2	60.4	57.7	85.2	67.4	77.8	100	94.5	94.7	30.4	56	35.2	33.6	45.5	53.7
Macrofaunal biomass	3.6	8	4.3	5.1	12.9	23.5	68	29.7	22.2	47.3	12.1	4.7	5.7	12.0	100	96.4
Macroalgal biomass	np	np	np	np	26.6	23.2	91	57.0	79.4	81.3	—	100	65.6	—	4.9	45.7
Phytoplankton biomass	81.0	50.3	56.2	100	32.0	19.6	46	15.6	16.0	11.5	33.5	22.8	38.3	45.3	29.0	58
Macrophytal biomass	0	0	100	0	np	np	np	np	np	np	np	np	np	np	np	np
nEQI	50.7	40.4	57.3	42.7	45.3	39.7	68.5	54.0	63.3	63.0	48.3	48.0	44.0	38.2	43.1	57.4

np, attribute not present in the lagoon.

For each lagoon, seasonal values for each of the single attributes were averaged in order to damp seasonal fluctuations. The mean annual values at each individual site, for each of the attributes considered in the model are reported in Table 1. A matrix with the attributes listed by row and the sampling sites by column was then constructed for each of the considered lagoons, in which, in each row, a score of 100 was assigned to the highest value for each attribute, and all the other values in the row were rescaled relative to this value as described in Section 2. The values in each column were then summed, to give the EQI at each site in each lagoon (Table 2). Highest scores were obtained by sites G5, G7a and G7b of the Sacca di Goro, site F5 in Fattibello and site C5 in Comacchio, i.e. the minimally impaired reference sites. Whereas, the lowest scores corresponded with sites G1, G4 and GG of the Sacca di Goro, sites F3 and F4 in Fattibello and site C6 in Comacchio, i.e. the most disturbed reference sites.

An inter-lagoon comparison (nEQI, Table 3) was performed by merging matrices for the different lagoons into a single matrix, with lagoons and sites in columns, mean values of attributes in rows and by repeating the scaling procedure by assigning 100 to the highest attribute value in whole data set and recalculating the individual values relative to this scale. Finally, to give the nEQI the sum of each column was divided by the total number of entries in rows, i.e. the number of attributes measured at that site. According to this inter-lagoon quality scale, the best sites were again G5, G7a, G7b, F5 and C5, while the most impaired sites were F3, G4, C4 and C6, thus reflecting the a priori quality assignment of each site, with the exception being GG and C4 sites, that were classified a priori as a highly and moderately disturbed sites, respectively, but which scored as a moderately and a highly disturbed site by nEQI in the inter-lagoon comparison.

4. Discussion

The recognition that chemical water quality analyses alone are inadequate to predict or reflect the condition of all aquatic resources has led to the development of measures of biological integrity, expressed by biological indicators. The identification of such routine indicators, which should be easily measurable, inexpensive and robust, is a relatively difficult task. The majority of quality indices developed so far (Borja et al., 2000; Cairns et al., 1968; Chandler, 1970; Engle & Summers, 1999; Grall & Glemarec, 1997; Majeed, 1987; Weisberg et al., 1997; Woodiwiss, 1964) were designed to differentiate between impacted and reference sites. However, environmental managers and policymakers also require tools capable of distinguishing the degree of degradation to the biotic community. The advantage of the biocriteria presented here, the EQI and nEQI indices, is that areas of intermediate impact can be clearly identified along an environmental quality scale. Thus, these indices provide a greater degree of sensitivity to degradation in habitat quality, compared to other currently available methods. Moreover, EQI and nEQI were designed specifically for the evaluation of lagoon ecosystems and consider specifically attributes, which are known to play major roles in lagoon ecosystem functioning, while other biocriteria have been calibrated mostly for marine or freshwater habitats. EQI and nEQI have several further advantages over other methods: there is no need for a deep taxonomic expertise or the painstakingly detailed analysis of species, since, for the use of these techniques, instead of identifying and counting, say, *Gammarus aequicauda*, *Gammarus insensibilis*, *Echinogammarus veneris* and *Neogammarus adriaticus*, one can count as Gammaridae sp. 1, sp. 2, sp. 3 and sp. 4, simply on the basis of gross morphological differences, since for these indices, it is the number of species and not their names which is important. This is also true for assigning animals to broad functional categories, since with a few exceptions (e.g. the detritivorous amphipod *Corophium insidiosum*), species belonging to the same lower taxonomic level (e.g. family) usually feed in the same manner (Gambi & Giangrande, 1985; Scipione, 1989). Similarly, there is no need for complex or expensive analytical equipment, and moreover, since the proposed procedure is independent of the units or magnitudes used to measure the various ecological attributes, one can choose the most practical technique depending on the available expertise and laboratory facilities (e.g. phytoplanktonic biomass can be estimated by measuring chl-*a* concentration, cell counting, etc.).

Many of the biocriteria so far developed for environmental evaluations are based on the paradigm of Pearson and Rosenberg (1978), which stated that benthic communities respond to improvements in habitat quality in three progressive steps: the abundance increases, species diversity increases, and dominant species change from *r*-selected pollution tolerant to *k*-selected pollution sensitive organisms. Thus the development of EQI was based upon established principles of benthic ecology, not by developing new ones. However, the EQI places no fixed artificial limits on any of the measured attributes and simply reflects the relative difference in parameters between sites or lagoons, i.e. no values are imposed as representing high or low environmental quality. This characteristic, along with the inclusion of several community-based attributes, allows inclusion of attributes which alone would provide only equivocal information. For example, high macrofaunal abundance may indicate high environmental quality (e.g. a seagrass meadow with abundant epifauna) or a chronically eutrophied environment where the macrozoobenthos is dominated by numerous, small sized, tolerant surface deposit-feeders (Pearson & Rosenberg, 1978). Thus macrofaunal abundance alone is a poor indicator, but using an integrated index such as EQI distinguishes these two cases, as both sites would score highly for macrofaunal abundance, the eutrophied site would score poorly for macrofaunal biomass, number of species, biodiversity and functional diversity compared to a pristine site (Pearson & Rosenberg, 1978) and thus would have a lower overall EQI score. Moreover, the attributes on which EQI is computed are of major importance to the functioning of lagoon ecosystems. Estuaries and lagoons are extremely dynamic systems (McLusky, 1971), and are among the most productive ecosystems known to man (Barnes, 1984). In such environments, phytoplankton is the base of most food webs, and fish production is linked to phytoplankton primary production (Day, Hall, Kemp, & Yanez-Aranciba, 1989), therefore phytoplankton abundance is included as EQI attribute. Similarly, the beneficial role to estuarine and lagoon functioning played by seagrass meadows is universally recognised (Edgar, 1990; Lewis, 1984), therefore seagrass biomass is classed as a positive attribute and sites without seagrass score a zero. In contrast, the role of macroalgal mats is controversial, since macroalgal blooms can have both positive and negative effects depending on the scale of the bloom (Raffaelli, Raven, & Poole, 1998). On the one hand, seasonal mats of ephemeral macroalgae are a natural component of many estuarine habitats, they can contribute significantly to overall primary and secondary production and the maintenance of discrete patterns of faunal distribution (Everett, 1991), by enhancing food availability, increasing habitat complexity, providing physical protection from predators and the possibility for coexistence between species (Hull, 1987; Norkko & Bonsdorff, 1996a,b; Norkko, Bonsdorff, & Norkko, 2000; Parker, Duffy, & Orth, 2001; Thiel & Watling, 1998). Indeed, macrofaunal abundances and secondary production within algal mats can greatly exceed those in the underlying or adjacent macroalgae-free sediments (Norkko et al., 2000; Österling & Pihl, 2001; Vetter, 1994, 1998). On the other hand, negative influences on seagrass and macrofaunal communities dominate when the macroalgae occur at high densities, covering large areas for prolonged periods of time (Norkko & Bonsdorff, 1996a,b). However, since the negative impacts on macrofaunal communities are mediated largely by the hypoxia, anoxia or dystrophy induced when the macroalgal biomasses collapse and are degraded (Castel, Caumette, & Herbert, 1996; Caumette, 1986; Izzo & Hull, 1991; Viaroli, Azzoni, Bartoli, Giordani, & Tajé, 1995; Viaroli, Bartoli, Bondavalli, & Naldi, 2001), the threshold biomass at which these negative impacts occur is highly dependent upon local characteristics, such as the degree of confinement or hydrodynamism of the site. Therefore, within the EQI instead of arbitrarily imposing a macroalgal biomass density at which impacts switch from being net positive to net negative, we count macroalgal biomass as a positive attribute to reflect the potentially positive influences of macroalgae and allow the effects of excessive macroalagal biomasses to manifest themselves through their negative impacts on the other EQI attributes, e.g. seagrass communities which are shaded out and macrofaunal communities which are impoverished through loss of sensitive species during hypoxic, anoxic and dystrophic events. However, in contrast to the seagrass case, where absence of seagrasses resulted in a zero score to reflect the absence of a positive influence, in the case of macroalgae, where the community influences are highly variable, the absence of macroalgae is considered to be environmentally neutral, no score is ascribed and the EQI or nEQI is calculated based solely on the remaining seven attributes.

There is an urgent need for the development of environmental indicators and indices for the assessment of environmental quality/change. Such tools must be able to simultaneously evaluate interactions between, and the cumulative impacts on environmental media and resources of different types of forcing. Additionally, investigations of environmental change require detailed analysis of the processes involved, in order to facilitate the prediction of environmental response(s) over a wide range of spatial and temporal scales, as well as the capacity to translate these predictions into a format upon which informed decisions can be made (Malkina-Pykh, Pykh, & Lenz, 1999). We feel that EQI fully satisfies all these requirements. EQI implies a comprehensive description not only of the single elements of the ecosystem, but also of the principal processes that characterise lagoon ecosystem function, as has been recommended by the International Committee on Environmental Indices (Malkina-Pykh et al., 1999). EQI is composed of eight ecosystem attributes each of which has ecological relevance for lagoon ecosystems. Individually, all these attributes are themselves useful indicators of environmental conditions. However, the combination of these attributes into a single index, provides a more robust, overall indicator of the response of the natural communities to environmental perturbations and avoids misleading or ambiguous results, as unequivocal indicators, such as the previously discussed examples of macrofaunal abundance or macroalgae, are corrected or compensated for by their effects on or interactions with the other EQI attributes. The EQI is also a flexible indicator and could easily be extended to include other physical (e.g. hydrodynamic), chemical (e.g. oxygen concentration) or biogeochemical (e.g. sediment oxygen demand or respiratory quotient) indicators directly, rather than indirectly through their effects on the macrofaunal and primary producer communities. Indeed, increasing the number of considered attributes could further increase the robustness of this analysis by decreasing the overall weighting of the individual attributes to the final result. Although, the benefits of such extensions must be balanced against the increased material, time, personnel and financial costs involved.

In this study, we carried out an EQI analysis of sites in three Northern Adriatic coastal lagoons and obtained a classification of these sites which corresponded well with a subjective a priori classification of the same sites based on the results of previous environmental studies, the opinions of local experts and best judgement. Thus our results indicate that EQI analysis is able to give an accurate evaluation of the environmental quality of lagoon environments. However, while encouraging, these data must be considered as being preliminary and the general applicability of EQI for the evaluation of lagoon habitats still needs to be validated. Most of our sites belong to a long-term monitoring program, and in subsequent years we intend to revisit these sites and to acquire data on sites in geographically distant areas in order to validate and, if necessary modify the EQI index. Therefore, until such a validation process has been completed we recommend that the EQI should only be used with caution.

References

Barnes, R. S. K. (1984). *Estuarine biology* (76 pp.). London: Edward Arnold Ltd.

Bencivelli, S., & Castaldi, N. (1991). *Studio integrato sull'ecologia della Sacca di Goro* (263 pp.). Milano: Franco Angeli srl.

Bencivelli, S., Castaldi, N., & Finessi, D. (1994). *Sacca di Goro: Studio integrato sull'ecologia* (303 pp.). Milano: Franco Angeli srl.

Borja, A., Franco, J., & Perez, V. (2000). A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. *Marine Pollution Bulletin 40*, 1100–1114.

Cairns, J., Douglas, W. A., Busey, F., & Chaney, M. D. (1968). The sequential comparison index—a simplified method for non-biologists to estimate relative differences in biological diversity in stream pollution studies. *Journal of Water Pollution Control Federation 40*, 1607–1613.

Castel, J., Caumette, P., & Herbert, R. A. (1996). Eutrophication gradients in coastal lagoons as exemplified by the Bassin d'Arcachon and the Etang du Prévost. *Hydrobiologia 329*, ix–xxviii.

Caumette, P. (1986). Phototrophic sulfur bacteria and sulfate-reducing bacteria causing red waters in a shallow brackish lagoon. *FEMS Microbiology Ecology 38*, 113–124.

Chandler, J. R. (1970). A biological approach to water quality management. *Water Pollution Control 69*, 415–422.

Crisp, D. J. (1984). Energy flow measurements. In N. A. Holme, & A. D. McIntyre (Eds.), *Methods for the study of marine benthos* (pp. 284–372). Oxford: Blackwell Scientific Publications.

Dallocchio, F., Ghion, F., Milan, C., & Viaroli, P. (1998). Variazioni temporali delle caratteristiche chimico-fisiche delle acque delle Valli di Comacchio. *Laguna 5/98*, 4–15.

Dauer, D. M. (1993). Biological criteria, environmental health and estuarine macrobenthic community structure. *Marine Pollution Bulletin 26*, 249–257.

Day, J. W., Hall, C. A. S., Kemp, W. M., & Yanez-Aranciba, A. (1989). *Estuarine ecology* (558 pp.). New York: Wiley.

Duarte, C. M. (1995). Submerged aquatic vegetation in relation to different nutrient regimes. *Ophelia 41*, 87–112.

Edgar, G. J. (1990). The influence of plant structure on the species richness, biomass and secondary production of macrofaunal assemblages associated with Western Australian seagrass beds. *Journal of Experimental Marine Biology and Ecology 137*, 215–240.

Engle, V. D., & Summers, J. K. (1999). Refinement, validation, and application of a benthic condition index for Northern Gulf of Mexico estuaries. *Estuaries 22*, 624–635.

Environmental Protection Agency. (2000). Estuarine and coastal marine waters: Bioassessment and biocriteria technical guidance. EPA 822-B-00-024.

Everett, R. A. (1991). Intertidal distribution of infauna in a central California lagoon: the role of seasonal blooms of macroalgae. *Journal of Experimental Marine Biology and Ecology 150*, 223–247.

Gambi, M. C., & Giangrande, A. (1985). Caratterizzazione e distribuzione delle categorie dei policheti nei fondi mobili del Golfo di Salerno. *Oebalia 11*, 223–240.

Gaston, G. R., & Nasci, J. C. (1988). Trophic structure of macrobenthic communities in Calcasieu Estuary, Louisiana. *Estuaries 11*, 201–211.

Grall, J., & Glemarec, M. (1997). Using biotic indices to estimate macrobenthic community perturbations in the Bay of Brest. *Estuarine, Coastal and Shelf Science 44*, 43–53.

Gray, J. S. (1979). Pollution-induced changes in populations. *Transactions of the Royal Philosophical Society of London 286*, 545–561.

Gray, J. S., & Mirza, F. B. (1979). A possible method for the detection of pollution-induced disturbance on marine benthic communities. *Marine Pollution Bulletin 10*, 142–146.

Gray, J. S., & Pearson, T. H. (1982). Objective selection of sensitive species indicative of pollution-induced changes in benthic communities. *Marine Ecology Progress Series 9*, 11–21.

Hull, S. C. (1987). Macroalgal mats and species abundances: a field experiment. *Estuarine, Coastal and Shelf Science 25*, 519–532.

Izzo, G., & Hull, V. (1991). The anoxic crises in dystrophic processes of coastal lagoons: an energetic explanation. In C. Rossi, & E. Tiezzi (Eds.), *Ecological physical chemistry* (pp. 559–572). Amsterdam: Elsevier.

Karr, J. R. (1991). Biological integrity: a long-neglected aspect of water resource management. *Ecological Applications 1*, 66–84.

Lewis, F. G. (1984). Distribution of macrobenthic crustaceans associated with Thalassia, Halodule and bare sand substrata. *Marine Ecology Progress Series 19*, 101–113.

Majeed, S. A. (1987). Organic matter and biotic indices on the beaches of North Brittany. *Marine Pollution Bulletin 18*, 490–495.

Malkina-Pykh, I. G., Pykh, Y. A., & Lenz, R. J. M. (1999). Environmental indices: theoretical background and systems analysis approach. In A. Farina (Ed.), *Perspectives in ecology* (pp. 209–217). Leiden: Backhuys Publishers.

McLusky, D. S. (1971). *Ecology of estuaries* (144 pp.). London: Heinemann.

Mistri, M., Fano, E. A., Rossi, R., Caselli, K., & Rossi, R. (2000). Variability in macrobenthos communities in the Valli di Comacchio, northern Italy, a hypereutrophized lagoonal ecosystem. *Estuarine, Coastal and Shelf Science 51*, 599–611.

Norkko, A., & Bonsdorff, R. (1996). Rapid zoobenthic community responses to accumulation of drifting algae. *Marine Ecology Progress Series 131*, 143–157.

Norkko, A., & Bonsdorff, R. (1996). Population responses of coastal zoobenthos to stress induced by drifting algal mats. *Marine Ecology Progress Series 140*, 141–151.

Norkko, A., Bonsdorff, E., & Norkko, A. (2000). Drifting algal mats as an alternative habitat for benthic invertibrates: species specific responses to a transient resource. *Journal of Experimental Marine Biology and Ecology 248*, 79–104.

O'Connor, T. P. (1992). Recent trends in coastal environmental quality: Results from the first five years of NOAA Mussel Watch Project (45 pp.). Rockville: US Department of Commerce, NOAA.

Österling, M., & Pihl, L. (2001). Effects of filamentous green algal mats on benthic macrofaunal functional feeding groups. *Journal of Experimental Marine Biology Ecology 263*, 159–183.

Parker, J. D., Duffy, J. E., & Orth, R. J. (2001). Plant species diversity and composition: experimental effects on marine epifaunal assemblages. *Marine Ecology Progress Series 224*, 55–67.

Pearson, T. H. (1975). The benthic ecology of Loch Linhe and Loch Eil, a sea-loch system on the west coast of Scotland IV. Changes in the benthic fauna attributable to organic enrichment. *Journal of Experimental Marine Biology and Ecology 20*, 1–41.

Pearson, T. H., & Rosenberg, R. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology: An Annual Review 16*, 229–311.

Piccoli, F. (1998). Passato e presente della vegetazione delle Valli di Comacchio. *Laguna 5/98*, 24–27.

Raffaelli, D. G., Raven, J. A., & Poole, L. J. (1998). Ecological impact of green macroalgal blooms. *Oceanography and Marine Biology: An Annual Review 36*, 97–125.

Sand-Jensen, K., & Borum, J. (1991). Interactions among phytoplankton, periphyton and macrophytes in temperate freshwater and estuaries. *Aquatic Botany 41*, 137–175.

Simon, T. P. (2000). The use of biological criteria as a tool for water resource management. *Environmental Science and Policy 3*, S43–S49.

Scipione, M. B. (1989). Comportamento trofico dei Crostacei Anfipodi in alcuni sistemi bentonici costieri. *Oebalia 15*, 249–260.

Thiel, M., & Watling, L. (1998). Effects of green algal mats on infaunal colonization of a New England mud flat—long-lasting but highly localized effects. *Hydrobiologia 375/376*, 177–189.

Viaroli, P., Azzoni, R., Bartoli, M., Giordani, G., & Tajé, L. (2001). Evolution of the trophic conditions and dystrophic outbreaks in the Sacca di Goro lagoon (Northern Adriatic Sea). In F. M. Guglielmo, L. Guglielmo, & G. Spezie (Eds.), *Structure and processes in Mediterranean ecosystems* (pp. 467–475). Berlin: Springer.

Viaroli, P., Bartoli, M., Bondavalli, C., & Naldi, M. (1995). Oxygen fluxes and dystrophy in a coastal lagoon colonised by Ulva rigida (Sacca di Goro, Po River Delta, Northern Italy). *Frenius Environmental Bulletin 4*, 381–386.

Vollenweider, R. A., Giovanardi, F., Montanari, G., & Rinaldi, A. (1998). Characterization of the trophic condition of marine coastal waters with special reference to the NW Adriatic Sea: proposal for a trophic scale, turbidity and generalized water quality index. *Environmetrics 9*, 329–357.

Vetter, E. W. (1994). Hotspots of benthic production. *Nature 372*, 47.

Vetter, E. W. (1998). Population dynamics of a dense assemblage of marine detritivores. *Journal of Experimental Marine Biology and Ecology 226*, 131–161.

Regione Emilia Romagna (1999). Nuove progettualità per la gestione di un ambiente Ramsar: Valle Fattibello-Spavola. *Laguna Suppl. 5/99*, 81.

Warwick, R. M. (1986). A new method for detecting pollution effects on marine macrobenthic communities. *Marine Biology 92*, 557–562.

Warwick, R. M. (1993). Environmental impact studies on marine communities: pragmatical considerations. *Australian Journal of Ecology 18*, 63–80.

Weisberg, S. B., Ranasinghe, J. A., Dauer, D. M., Schaffner, L. C., Diaz, R. J., & Frithsen, J. B. (1997). An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries 20*, 149–158.

Woodiwiss, F. S. (1964). The biological system of stream classification used by the Trent River Board. *Chemistry Industries 11*, 443–447.