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LAGOONS AND COASTAL WETLANDS

Index of size distribution (ISD): a method of quality assessment for coastal lagoons

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Abstract A new index was developed as a tool for quantifying the degree of disturbance in lagoons in order to meet the objective of Ecological Quality Status (EcoQ), using the zoobenthos quality element. The Index of Size distribution (ISD) is proposed to assess the ecological quality status of coastal lagoons. It represents the skewness of the distribution of individuals of a benthic community in geometric size (biomass) classes. The ISD was applied in three coastal lagoons with different levels of disturbance and classified them as of good, moderate and poor ecological quality. A scheme for the classification of EcoQ in lagoonal systems is presented. The index showed a strong relationship with the percentage of organic carbon in the sediment, as well as with the dissolved oxygen concentrations. ISD having the advantage of good discriminating power and not demanding high taxonomic resolution, could be a simple and promising tool to be further applied and tested in Mediterranean lagoons.

Keywords Lagoons · Benthos · Pollution assessment · Indices · Ecological quality status

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Lagoons and Coastal Wetlands in the Global Change Context: Impacts and Management Issues

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Introduction

Coastal lagoons are shallow, relatively enclosed water bodies. They can be considered as harsh, naturally stressed environments, characterised by frequent fluctuations of environmental parameters on a daily and seasonal basis. This natural instability discourages the settlement of many species, resulting in a low number of species and low diversity. On the other hand, they are organically enriched areas, both as a result of the riverine inputs and the recycling of materials within the system, thus a large number of individuals, summing high biomass values, is attained.

The above characteristics of the lagoons would be rather indicative of a polluted situation in the marine environment, especially in the oligotrophic Eastern Mediterranean, which is generally characterised by low abundance and high diversity (Bellan-Santini, 1985). Therefore methods used to assess pollution in the marine environment may not be applicable to the lagoons (Reizopoulou et al., 1996).

European Union Water Framework Directive (2000/60/EC) requires that the member states establish ecological quality classification systems for all surface waters, including transitional waters. The recently developed biotic indices of ecological quality AMBI (Borja et al., 2000; 2003) and BENTIX (Simboura & Zenetos, 2002), are based on the concept of indicator species and are suitable for assessing EcoQ in coastal waters. However, since these indices use ecological groups of species according to their sensitivity to stress, they should be used with caution in lagoons, which are ecosystems naturally inhabited by species able to tolerate stressed conditions.

The application of body-size distribution is an alternative method to investigate benthic community structure. Changes of benthic community biomass under disturbed conditions are well documented in benthic ecology (Pearson & Rosenberg, 1978; Warwick, 1986). The increasing organic pollution results in loss of the larger long-lived species (k-strategists) from the community in favour of more tolerant short-lived opportunists (r-strategists) (Pearson & Rosenberg, 1978). The former dominate in terms of biomass, the latter in terms of abundance.

In the present study, an index (Index of Size Distribution – ISD) was applied to the macroinvertebrates of three Greek coastal lagoons with different degrees of pollution. ISD is an alternative taxonomic free method, developed for lagoons, based on the distribution of individuals of benthic communities in biomass size classes. The skewness of the distribution was used as a measure of disturbance and a classification scheme of environmental quality is proposed

Materials and methods

Sampling sites

Samplings were performed in three Greek brackish water lagoons, with different degrees of disturbance (Fig. 1). Tsopeli lagoon, is situated at the mouth of River Louros in Amvrakikos Gulf (Ionian Sea) and has no obvious source of pollution. On the other end of the pollution scale is Papas lagoon in SW Peloponnisos, communicating with both the Patraikos Gulf and the

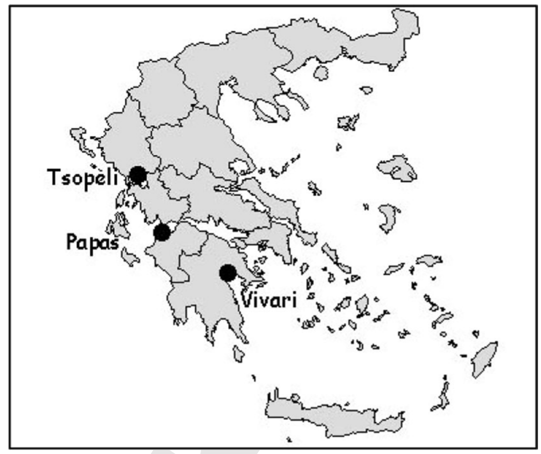

Fig 1. Sampling sites

Ionian Sea. It is an organically polluted ecosystem where anoxic crises are known to occur. The organic carbon, sulphur and phosphorus concentrations were found significantly elevated in the surface sediments of the Papas lagoon. Also heavy metals presented high values compared to other lagoons (Kaberi et al., 2000).

In the middle of the scale, Vivari lagoon, in Argolikos Gulf, receives a small intermittent flow of fresh water from a runnel and no obvious source of pollution was observed at the time of sampling. However, a sudden disappearance of vegetation was reported 1 year earlier.

All the lagoons are shallow systems with depths around 0.5 m, reaching 1.5 m only locally. Narrow barriers isolate them from the sea, communicating through small openings. They are used for extensive (Tsopeli and Vivari) and semi-intensive (Papas) fish farming.

Tsopeli lagoon is characterized by the presence of angiosperms (*Zostera noltii*), while in Papas lagoon enormous amounts of decomposing *Ulva rigida* are responsible for dystrophic crises. The prolonged anoxic events in the southern part of the lagoon, often lead to release of hydrogen sulphide, with consequent massive mortality of fishes and clams.

Sampling and laboratory methods

A dense grid of stations was sampled for abiotic parameters in order to acquire a detailed picture

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of the physicochemical conditions in the studied lagoons. Salinity, temperature and dissolved oxygen were measured in situ, using Yellowspring probes.

Macrozoobenthos was sampled seasonally: five times in Tsopeli and Vivari lagoons in 1990–1991, and five times in Papas lagoon in 1998–1999. Six stations were visited in Tsopeli, four in Vivari and three in Papas lagoon. The biomass data of benthic communities were available only for four stations in Tsopeli and three in Vivari.

Macrofaunal samples were collected using a Ponnar grab (0.05 m^2) and three replicate samples were collected from each site. The samples were sieved through a 1-mm mesh, stained with Rose Bengal and preserved in 4% formalin. In the laboratory, the macrofauna was sorted, identified at species level and counted.

A sub-sample of sediment was used for granulometry and organic carbon analysis. Organic carbon analysis was carried out according to Gaudette et al. (1974) for Tsopeli and Vivari and according to Verardo et al. (1990) in Papas lagoon.

For the determination of the ISD the individual body size was expressed as body weight (m g). Individual body weight of the animals was obtained after drying at 60°C for 48 h and weighing at the 0.0001 g level. The polychaetes were removed from their tubes and mollusc shells were dissolved with dilute hydrochloric acid prior to biomass determination.

To examine the distribution of individuals per geometric size classes (class I = 0.1 mg, class II = 0.2–0.3 mg, class III = 0.4–0.7 mg,... class XII = 204.8–409.5 mg), histograms were plotted presenting the percentage of individuals belonging to each geometric size class for each station. For every size-distribution set, a skewness value was calculated and the ISD classification scheme was produced, by plotting the whole series of skewness values obtained.

Multivariate and univariate analyses were performed using the program PRIMER-E 2000.

Results

Environmental variables

The ranges of abiotic variables for each lagoon are shown in Table 1. Salinity and temperature showed a wide range of values as a result of the lagoon shallowness and the degree of confinement (Table 1). Smaller ranges were observed in Vivari, which had the highest degree of communication with the sea.

In Tsopeli oxygen concentrations were enhanced by the presence of phanerogam meadows, whilst the sedimentary organic carbon presented the lowest values (Table 1). The Vivari lagoon had a bare sediment with an high organic carbon content. In the Papas lagoon the sedimentary organic carbon was also high. Moreover, in the southern part persistent summer anoxic events occurred, due to the mass development and further decomposition of *U. rigida* bimasses.

Community attributes

The differences in environmental characteristics of the lagoons were reflected in their benthic communities. The MDS of Fig. 2 grouped the stations of each lagoon according to their faunal similarities.

Tsopeli was characterised by species typical of brackish water lagoons, the most dominant of which were *Abra ovata, Cerastoderma glaucum, Mytilaster minimus* and larvae of Chironomidae insects. The abundance of the polychaetes *Nephtys hombergi* and *Heteromastus filiformis* was also high, while the crustaceans *Gammarus insensibilis* and *Idotea baltica* were found within the vegetation stands.

Table 1 Range of abiotic variables in each lagoon

Lagoon	Depth (m)	*S* (psu)	*T* (°C)	O_2 (mg l^{-1})	Coarse material (%)	Organic C (%)
Tsopeli	0.2–1.5	21.0–38.0	8.0–29.0	2.8–9.8	6.7–66.3	1.1–5.3
Vivari	0.6–1.5	28.5–40.0	12.0–34.0	4.2–8.4	16.4–35.1	3.1–6.7
Papas	0.2–1.5	20.0–42.5	10.0–32.0	0.8–9.3	23.0–98.0	2.9–5.6

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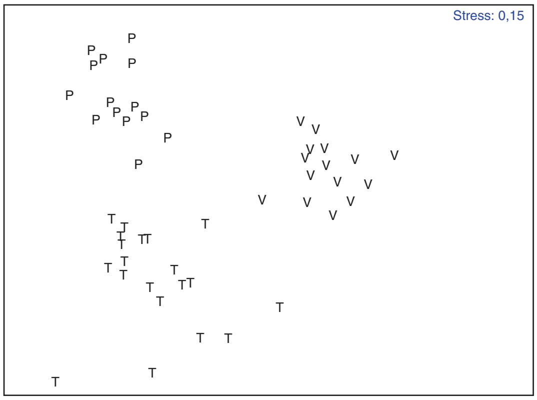

Fig 2. Multidimensional scaling based on the species abundances [log $(x + 1)$]

In Vivari two species, *Abra ovata* and *Heteromastus filiformis* alternated in dominance. In autumn *Abra ovata* decreased in favour of *Hediste diversicolor*. Other species of molluscs and crustaceans were almost absent. Finally, in Papas lagoon the bivalve *Abra ovata* and the serpulid *Hydroides dianthus* were very abundant. High densities of amphipods (*Corophium insidiosum, Microdeutopus gryllotalpa*) and opportunistic polychaetes (*Capitella capitata*, *Heteromastus filiformis*) were observed seasonally. In summer, the southern part of the lagoon became azoic due to the anoxia, while in the northern part clam populations (*Tapes decussatus*) disappeared.

The variations of macrobenthic community characteristics, namely number of species (*S*), diversity (*H′*), evenness (*J*) and abundance (*N*) of each lagoon are shown in Table 2 The highest number of species was found in Tsopeli (84) and the lowest in Vivari (64). The diversity neither varied according to the degree of disturbance in the lagoons, nor showed a statistically significant correlation with dissolved oxygen concentrations in the water column and organic carbon in the sediment. The lowest diversity value was found in Vivari, characterised by total absence of vegetation, while the highest number of individuals was noted in Papas, the most eutrophicated lagoon.

The index of size distribution

The frequency distribution of geometric size (biomass) classes was plotted for all stations and seasons in the three lagoons. Examples of the distributions are shown in Fig. 3. It is evident that the undisturbed conditions correspond to more even distribution of smaller and larger size classes, while under disturbed conditions an uneven distribution of the size classes is obvious, with the smaller ones being the most abundant. This can be expressed numerically by the skewness of distribution (the novel feature of this index).

The differences in size distribution were not only due to the presence of small opportunistic species in Vivari and Papas. Some of the most abundant species attained a larger size in the less disturbed Tsopeli, as indicated by the mean individual size of *Abra ovata*, *Cerastoderma glaucum*, *Tapes decussatus* and *Hediste diversicolor* in Fig. 4.

The plot of Fig. 5 illustrates the range of the skewness values over the lagoons studied. As with the environmental parameters and the fauna, the ISD values varied in each lagoon. In Tsopeli the index ranged from high (–0.34) to moderate (2.51), in Vivari from good (1.85) to poor (3.28) and in Papas the ISD was even higher ranging from moderate (2.26) to poor (3.45). Figure 6 shows the mean ISD for each lagoon. Overall, Tsopeli showed the lowest mean ISD value, classifying it as belonging to 'good' ecological class, while ecological quality in Vivari and Papas was characterised as 'moderate' and 'poor', respectively.

Table 2 Total number of species and variations of community features in each lagoon

Lagoon	Total no. of species *S*	Variations of no. of species *S*	Diversity *H′*	Evenness *J*	Abundance *N*
Tsopeli	84	5–45	1.3–3.7	0.48–0.89	508–5827
Vivari	64	7–21	0.7–3.4	0.21–0.78	753–8820
Papas	76	0–44	1.7–3.7	0.45–0.79	0–44108

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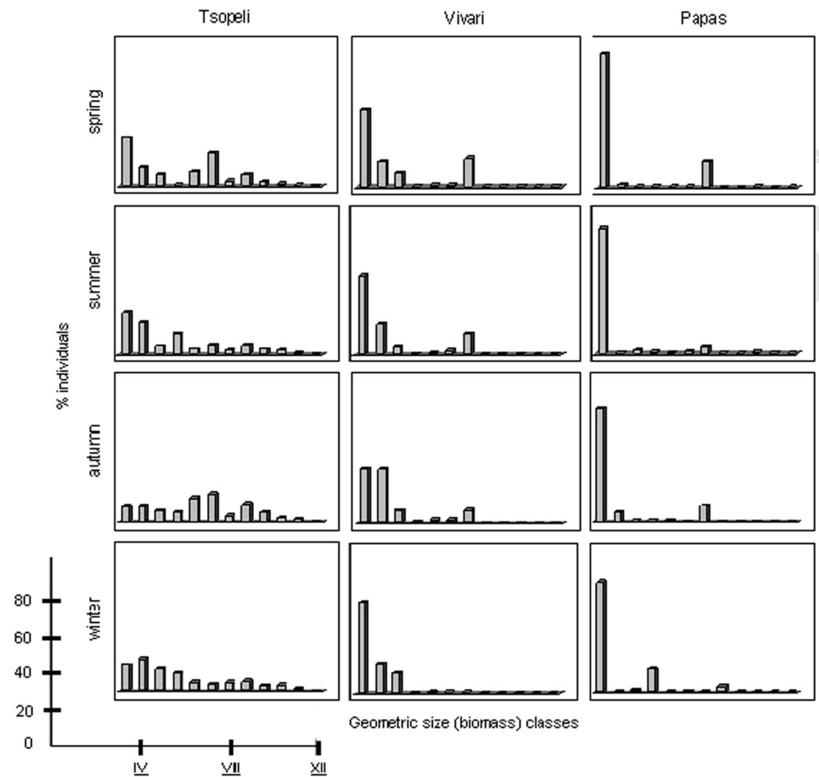

Fig 3. Examples of size distributions of benthic communities in the studied lagoons

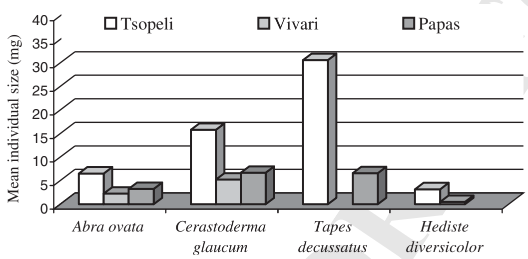

Fig 4. Mean individual size of some abundant species in the three lagoons

A scheme for the classification of Ecological Quality Status in lagoonal systems is presented in Table 3.The boundary limits among classes were set following a linear scale and according to the plot. The respective Ecological Quality Ratio (EQR), defined as the ratio of the observed value versus the value of the metric under reference conditions (EC, 2003) is also given in Table 3. The EQR values are standardized to fit the 0–1 range.

Validation of the method

Figure 7 shows the regression between the ISD and the percentage of the organic carbon in the sediment. The significant correlation (r = 0.63, p = 0.0000) indicates that the ISD co-varies with the organic pollution gradient in the lagoons. The ISD was significantly correlated with dissolved oxygen concentrations (r = –0.35, p = 0.0001), which is also a measure of environmental health.

Figure 8 shows the mean ISD values within each ecological class against the corresponding mean organic values. There is a strong correspondence between ISD and organic carbon values along the ecological classes defined by the metric.

Discussion

The most common and serious anthropogenic impact in Mediterranean coastal lagoons is nutri-

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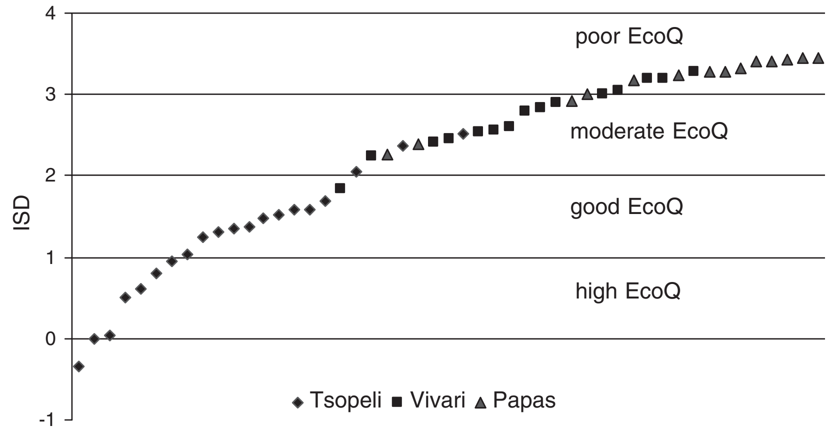

Fig 5. Values of ISD, as calculated for the three lagoons and the corresponding proposed EcoQ classification

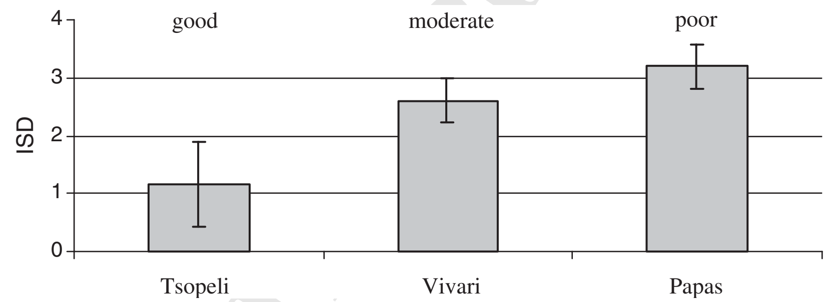

Fig 6. Mean values and standard deviation of ISD in each lagoon

Table 3 Classification scale of Ecological Quality Classes based on ISD

EcoQ	ISD	EQR
High	–1 ≤ ISD < 1	1
Good	1 ≤ ISD < 2	0.60
Moderate	2 ≤ ISD < 3	0.39
Poor	3 ≤ ISD < 4	0.20
Bad	Azoic conditions	0

ent enrichment, which often leads to a replacement of sea-grasses by opportunistic green macroalgae (Valiela et al., 1997; Orfanidis et al., 2001) and leads to oxygen depletion known as 'dystrophic crises' (Sfriso et al., 1992; Viaroli et al., 1996). Temporal variations in benthic communities associated with such eutrophication phenomena have been the subject of numerous studies (e.g., Lardicci et al., 1997, 2001; Tagliapietra et al., 1998; Koutsoubas et al., 2000). According to most of the above authors, increased organic disturbance results in an increase of opportunistic and tolerant lagoonal species, in an increase of densities, and in a decline of suspension feeders and carnivores in favour of sub-surface deposit feeders. Pearson & Rosenberg (1978) suggested that the average individual size decreases in polluted areas. Under disturbed conditions the larger, long-lived species are the first to disappear and the communities are dominated, by smaller, short-lived opportunistic species.

The results of the present investigation are in accordance with the abovementioned comments. Biomass profile may highlight alterations on benthic ecosystem along a pollution gradient, through intense changes on community size structure. Small-bodied invertebrates may characterize environments with high instability and small body size could be a consequence of the environmental/anthropogenic pressures imposed on the organisms. The small size classes of the studied communities, were dominated by tolerant and opportunistic deposit feeders, while the larger size classes were mostly dominated by filter feeding bivalves and carnivorous polychaetes. Algal blooms, anoxic events and sulphide production in Papas lagoon depleted the abundant filter feeders, lowered the abundance of

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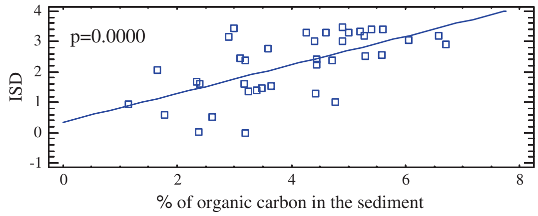

Fig 7. ISD against percentage of organic carbon in the sediment

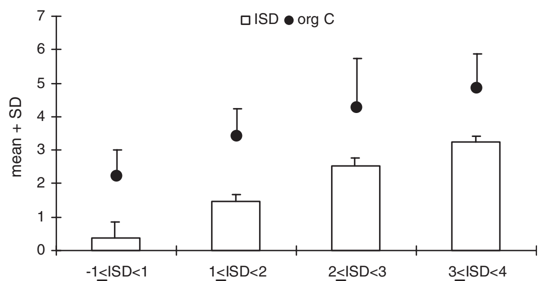

Fig 8. Mean and standard deviation of ISD and organic carbon values within each ecological class

many sedentary species, and, at the same time, allowed a stronger representation of mobile small bodied grazers (crustaceans) able to withstand the constantly disturbed environment. The dominance of tolerant species in lagoons mainly indicates the natural instability of the environment, while the disappearance of populations of large filter feeding bivalves such as *Tapes decussatus* in Papas Lagoon, should raise concern for the community health.

A large number of methods proposed to assess degradation of the marine environment are based on benthic communities. Originally, these methods were developed using data collected from marine areas, and their applicability in coastal Mediterranean lagoons was first questioned by Reizopoulou et al. (1996). The natural environmental stress precludes the graphical method of Gray & Mirza (1979) based on the distribution of species in geometric abundance classes, since it relies on the fact that unstressed communities host many rare species while a small number of opportunists dominate; on the other hand in stressed environments the rare species are eliminated and many opportunists become extremely abundant. The ABC method (Warwick, 1986) and W statistic (Clarke, 1990) were successful in discriminating among impacted and not impacted lagoons in some occasions (Reizopoulou et al., 1996) but in some others were not (Lardicci & Rossi, 1998).

Regarding the community diversity, used widely as an index of environmental quality (Rosenberg et al., 2004), it should be noted that it cannot be successfully used in lagoons. Here, the natural instability and organic enrichment create extreme conditions where few species can be established and where diversity, depending on species richness and evenness of distribution, remains naturally low. Indeed, Reizopoulou & Nicolaidou (2004) found a strong negative correlation between diversity and confinement (sensu Guelorget & Perthuisot, 1983, 1992), as instability of environmental conditions increases with increasing isolation from the sea. Nevertheless confinement is a natural situation not always associated with environmental health. Arvanitidis et al. (2005) tested the rapid biodiversity assessment techniques on a pan-Mediterranean scale and found that although these techniques can reveal biodiversity patterns they are, nevertheless, inadequate for distinguishing naturally disturbed lagoons from anthropogenically impacted at a regional scale.

Reizopoulou et al. (1996) suggested that methods which use biomass are more reliable than those based on abundance. According to the literature, biomass structure is an important attribute of the community. Edgar (1994) found that size (biomass) structure of macrofaunal communities varied consistently between assemblages associated with macroalgal habitats of different morphology. This author suggested that the existence of relationships between community body size and environmental parameters might provide insight into the functioning of benthic communities. Jennings et al. (2002) demonstrated that there is a significant relationship between body weight and trophic level and suggested that analysis of temporal and spatial changes in size spectra could be used to detect temporal and spatial changes in trophic structure and to assess the impact of disturbance. Finally, Basset et al. (2004) who discussed the advantages and disadvantages of benthic macroinvertebrate body size

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descriptors as a tool for environmental monitoring, suggest that body size abundance distribution is related to disturbance pressure through individual energetics, population dynamics, interspecific interactions and species coexistence responses.

In the present study, the ISD based on biomass showed good correlation with the organic carbon in the sediment and the dissolved oxygen, two parameters related to environmental degradation. The EcoQ gradient illustrated by the ISD index is syntonic with the organic carbon gradient (Fig. 8).

ISD index seems to be a promising approach and a simple and effective tool for the ecological quality assessment of coastal lagoons. The new index has to be applied in other transitional water ecosystems, in order to set the confidence intervals of the boundary limits across the five EcoQ levels. It is important to focus on some points when applying the index. Given the high spatial variability of physical and chemical factors in lagoons, the ecological status may vary significantly. Furthermore, an intense seasonal variation is expected due to reproduction patterns: recruitment, for example, would tend to increase the skewness of the biomass distribution. Thus, in order to define the integrated ecological status for a given lagoon, the mean value of the index at various instances in space and time should be used.

The development of indicators and metrics is highly driven by the obligation of the European countries to meet the WFD requirements to classify the ecological status in coastal and transitional waters. Tools that are simple, practical, robust and cost effective (Rapid Assessment Techniques – RATs) are highly valued under the perspective of establishing monitoring and management plans.

The greatest advantage of the ISD over other indices is that it does not require high taxonomic resolution of the fauna, which is an extremely costly and time consuming process. The animals are weighed individually, independently of the species to which they belong. This makes the ISD a very practical tool for monitoring and management of the harsh, but at the same time fragile lagoonal ecosystems.

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