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A synthesis of the biological quality elements for the implementation of the European Water Framework Directive in the Mediterranean ecoregion: The case of Saronikos Gulf

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Abstract

Benthic macroinvertebrates, macroalgae and phytoplankton constitute the biological quality elements proposed in the Water Framework Directive (WFD, 2000/60/EC) to be used for the classification of the ecological status of a water body. In the context of the preparation for the implementation of WFD, classification schemes for all three elements have been developed and tested for all the European ecoregions. In the present work, the classification schemes, with the corresponding metric tools and the interpretations of the class boundaries according to the normative definitions of WFD, are presented for each biological element in Saronikos Gulf, as case study in the Mediterranean ecoregion. The combination of the three biological elements into an integrated classification for coastal water bodies has been one of the major issues addressed in the context of WFD guidelines. Results are interpreted and validated, through an ecological viewpoint, on the basis of relevant environmental data. Moreover, this work presents a way to combine the EUNIS system to the typology of water bodies in the Mediterranean ecoregion.

Keywords: Water Framework Directive; Macroinvertebrates; Macroalgae; Coastal waters; Ecological status; Biotic index

1. Introduction

The European Water Framework Directive (WFD, 2000/60/EC) introduced the concepts of typology, classification and reference conditions of water bodies (EC, 2000). Recent research activity on these issues led to the development of new tools and methodologies meeting the requirements of the Directive (Borja et al., 2003; EC, 2003a; Orfanidis et al., 2001, 2003; Simboura and Zenetos, 2002). Parallel to this process, the issue of inter-comparability of methods or inter-calibration has emerged as an obligation to the Directive but also as an occasion to test and validate classification tools (EC, 2003b). This work attempts to offer some links among biology and the typological scheme proposed for the Mediterranean ecoregion and demonstrate the combined use of the biological quality elements (macroinvertebrates, phytobenthos and phytoplankton) for the classification of coastal water bodies. A case study from Greek coastal waters gives the opportunity to inter-compare available tools using a

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test-set of data. The inter-comparison among the different tools has challenged a fruitful debate (Simboura, 2004; Borja et al., 2004) which is hopefully the essence of the intercalibration.

2. Mediterranean typology of coastal water bodies

The typological definition of a water body is the first step towards the classification of the ecological quality in a given ecoregion. The need to simplify and harmonize the process has led to suggest the use of an already existing scheme as a basis, on which to build the reference conditions and then the classification.

Therefore, the COAST group of experts (CIS Working Group 2.4: http://europa.eu.int/comm/environment/water/water-framework/implementation.html) of the WFD, has recommended that the description of water body types for coastal and transitional waters should include basic information from the EUNIS habitat classification system, as described by Davies and Connor (2003). This information will act as a 'common currency' to define reference conditions on the biological elements zoobenthos and phytobenthos. The habitat types refer to the level 3 of the EUNIS system which involves the substratum. One or more community types are incorporated in each of these habitats. The community types correspond to the classical benthic bionomy of the Mediterranean (Pérès and Picard, 1964).

According to a preliminary harmonized typological classification scheme for the Mediterranean ecoregion, five types are likely to be identified and described among which four types are registered as common intercalibration sites for the Mediterranean ecoregion (EC, 2003c).

Table 1, based on the acquired knowledge of the Mediterranean ecosystems and the EUNIS scheme, compiles the information pertaining to habitat and communities types linking them to the main Mediterranean ecoregion coastal water body types.

This comprehensive approach may serve as a basis for describing the reference conditions in each water body type and for each of the main biological elements of phyto- and zoo-benthos. The information for each community type may be extended into a description in terms of species composition and in terms of species abundance, using existing or newly collected data from selected reference sites.

3. Classification and intercalibration

According to the classification and the intercalibration guidance, the boundary values between classes rendered by any classification tool must be consistent with the normative definitions of the class boundaries given in Annex V of the WFD (EC, 2000, 2003b). This will ensure comparability of the classification results derived by various monitoring systems and will also ensure reliability of the results produced by each classification tool. Therefore, an explanation of the values rendered by the classification tools for each ecological quality class is required for each biological quality element (BQE) in relation with the normative definitions of the WFD.

A description of the quality classes and class boundaries, based on specific metrics used for the different biological elements, is given below. The metrics proposed for the macroinvertebrates and macroalgae have been included in the guidance documents produced by the COAST group of experts working for the WFD implementation (EC, 2003a). These tools will be considered for the intercalibration process (EC, 2003c) driven by the new WFD Working Group "WG 2.A. Ecological Status" ECOSTAT in cooperation with the geographical intercalibration groups (GIGs): http://forum.europa.eu.int/Members/irc/env/wfd/library?1=/workinggroups/ecologicalstatus.

3.1. Macroinvertebrates

The BENTIX index (Simboura and Zenetos, 2002) was designed to fit the Mediterranean benthic ecosystem and to render a five step numerical scheme for the classification of benthic communities. It is a biotic index based on the concept of indicator groups and uses the relative contribution of tolerant and sensitive taxa weighting the percentages in an ecologically relevant way. The developed formula $[6 \times \%GI + 2 \times (\%GII + \%GIII)]/100$ assigns the numerical factor '6' for the sensitive taxa group GI and the factor '2' for the tolerant taxa groups GII and GIII. The selection of the factors is not random and it is based on the realization that the probability of a

Table 1
Coastal water body types, habitat types and community types

Water body types	Habitat types (EUNIS)
Rocky deep exposed	A3.2: infralittoral rock moderately exposed to wave action and/or currents and tidal streams (communities of infralittoral algae moderately exposed to wave action, association with *Cystoseira* spp., association with *Peyssonnelia* spp.) A4.5: shallow sublittoral sediments dominated by angiosperms (*Cymodocea*, *Halophila*, *Posidonia*) A4.2: sublittoral sands and muddy sands (DE) A4.4: sublittoral combination sediments (DC) A4.3: sublittoral muds (VTC) A4.7: deep shelf sediment habitats (animal communities of deep circalittoral bottoms, DL)
Rocky shallow sheltered	A3.3: infralittoral rock sheltered from wave action and currents and tidal streams (communities of infralittoral algae sheltered from wave action, association with *Cystoseira* spp.) A4.2: sublittoral sands and muddy sands (DE) A4.4: sublittoral combination sediments (animal communities in shallow water mixed sediments)
Sedimentary deep exposed	A4.2: sublittoral sands and muddy sands (SFHN, SFBC) A4.4: sublittoral combination sediments (DC) A4.6: biogenic structures over sublittoral sediments (association with rhodolithes in coarse sands and fine gravels under the influence of bottom currents-SGCF) A4.5: shallow sublittoral sediments dominated by angiosperms (*Cymodocea*, *Halophila*, *Posidonia*) A4.7: deep shelf sediment habitats (animal communities of deep circalittoral bottoms, DL)
Sedimentary shallow sheltered	A4.2: sublittoral sands and muddy sands (DE) A4.4: sublittoral combination sediments (animal communities in shallow water mixed sediments, DC) A4.5: shallow sublittoral sediments dominated by angiosperms (*Halophila*, *Cymodocea*, *Posidonia*, *Zostera*) A4.3: sublittoral muds (VTC)
Very sheltered bays	A4.3: sublittoral muds (SVMC, association with *Caulerpa prolifera* on superficial muddy sands in sheltered waters, VTC) A4.5: shallow sublittoral sediments dominated by angiosperms (*Halophila*, *Cymodocea*, *Zostera*) A4.2: sublittoral sands and muddy sands (SFHN)

Abbreviations after Pérès and Picard (1964) used for communities—VTC: of the Coastal Terrigenous muds; SFBC: Fine well-sorted sands; SFHN: of fine surface sands; SGCF: coarse sands and fine gravels under the influence of bottom currents; SVMC: calm water muddy sands; AP: photophilous algae; DC: coastal detritus bottoms; DE: muddy detritus bottoms; DL: shelf edge detritic bottoms.

benthic species picked up randomly, to be tolerant to stress is 3:1.

This realization is based on the concept of Hily (1984) and Glémarec (1986) that have recognized five taxa groups according to their sensitivity to an increasing stress gradient: the sensitive group (GI), the indifferent group (GII), the tolerant group (GIII), the second-order opportunists (GIV), and the first-order opportunists (GV). Among them, the first two maybe regarded as non tolerant and as such could be grouped under a single 'sensitive' group represented as GI in the formula. The other three groups are considered as 'tolerant' and are represented in the formula as GII (tolerant and second-order opportunistic) and GIII (first-order opportunistic). Thus, the probability ratio among 'tolerant' and 'non tolerant' groups is 3:1. This ratio is multiplied by 2 to create a scale ranging from 2 to 6. The 'sensitive' group GI is weighted by 6 to correspond highest status with highest value of the index and the groups GII and GIII, which could be actually regarded as a single 'tolerant' group are weighted by 2. The absence of any 'sensitive' species (GI = 0) results to an index value of 2 (poor status) and the absence of any one species (azoic state) corresponds to a 0 value of the index (bad status).

Based on the above rationale, the BENTIX index is an ecologically relevant biotic index taking into account the species composition in a balanced way in order not to underestimate or overestimate the relative role of the two general groups. The boundary limits among classes were set after multiple tests with real data rendering a five-step scale with equal distances among the three central boundary limits.

Table 2
The BENTIX index classification scheme (Simboura and Zenetos, 2002)

Ecological status class	Range of BENTIX	Boundary limits	EQR
High	$4.5 \leq$ BENTIX < 6	6	1
Good	$3.5 \leq$ BENTIX < 4.5	4.5	0.75
Moderate	$2.5 \leq$ BENTIX < 3.5	3.5	0.58
Poor	$2.0 \leq$ BENTIX < 2.5	2.5	0.42
Bad	0	0	0

In a diverse and rich benthic environment, as that of the Mediterranean ecoregion, the index successes into designating the most relevant ecological status in a five step scale. The index has been validated in Saronikos gulf using chemical parameters such as organic carbon in sediments (OC), dissolved oxygen in the near bottom layer (DO) and particulate organic carbon in seawater (POC) and was compared with other biological indices. Table 2 presents the range of the BENTIX index for each Ecological Quality Status (EcoQ), the boundary limits of the BENTIX scale and the respective ecological quality ratios (EQR) as is defined the ratio of the observed value versus the value of the same metric under reference conditions (EC, 2003a).

Fig. 1 presents the degradation model of the percentage contribution of the three main ecological groups GI, GII, GIII in the benthic fauna in relation with the values of the BENTIX index. The sequence of quality classes and class boundaries are interpreted in terms of shifts of ecological group percentages.

3.1.1. High status ($6 < \text{BENTIX} \leq 4.5$)

According to the normative definition of WFD for the macroinvertebrates at high status: "The level of diversity and abundance of invertebrate taxa is within the range normally associated with undisturbed conditions. All the disturbance-sensitive taxa associated with undisturbed conditions are present". This condition corresponds with unpolluted sites (normal and impoverished). As it is shown in the degradation model of the three ecological groups involved in the BENTIX index formula, in the high status the sensitive taxa represented by the ecological group GI account for more than 61% of the fauna reaching potentially to 100% percentage in cases where reference conditions are met (BENTIX = 6). The tolerant taxa represented by the groups GII (tolerant-second-order opportunistic) and GIII (first-order opportunistic) account for less than 31% and less than 9% of the fauna, respectively.

3.1.2. Good status ($3.5 \leq \text{BENTIX} < 4.5$)

"The level of diversity and abundance of invertebrate taxa is slightly outside the range associated with undisturbed conditions. Most of the sensitive taxa of the type specific communities are present". This condition corresponds with slightly polluted sites (unbalanced). At the good status, as is indicated by the degradation model, the sensitive group may range from 38 to 57% of the fauna, while the tolerant-second-order opportunistic group GII from 37 to 60% and the first-order opportunistic group GIII from 2 to 15% accounting as a whole for a percentage of 40–60% of generally tolerant taxa. At the border of good to high status, the sensitive group accounts roughly for more than 60% or more than two-third of the fauna, while the tolerant group as a whole (tolerant plus opportunists) accounts for less than 40% or less than one-third of the fauna. It is important to stress here that for purely muddy habitats where the benthic fauna is normally dominated by some tolerant species, and only in this class border among high and

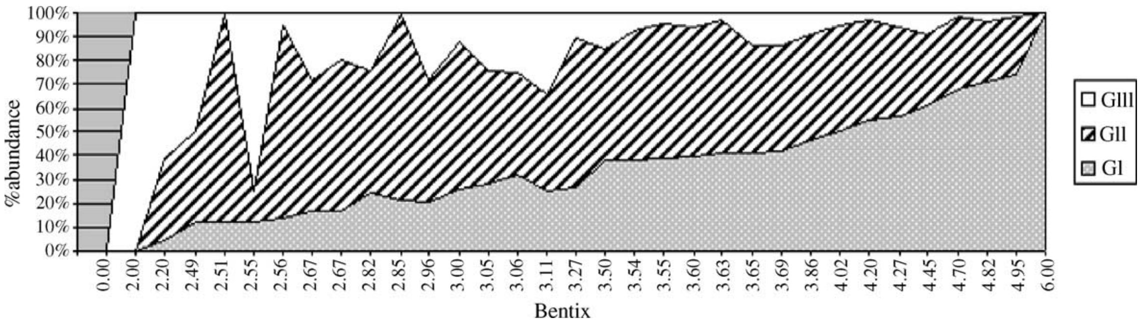

Fig. 1. Degradation model of benthic fauna composition in terms of ecological groups percentages from heavily polluted to undisturbed communities in relation to the BENTIX index tools.

good, a possible refinement of the boundary limit would change the value 4.5 to 4.

3.1.3. Moderate status (2.5 ≤ BENTIX < 3.5)

"The level of diversity and abundance of invertebrate taxa is moderately outside the range associated with undisturbed conditions. Most of the sensitive taxa of the type specific communities are absent". This condition corresponds with meanly polluted sites (transitional to pollution and polluted). At the moderate status, as is indicated by the degradation model, the sensitive group may range from 12 to 32% of the fauna, while the tolerant-second-order opportunistic group GII from 38 to 81% and the first-order opportunistic group GIII from 1 to 50% accounting as a whole for a percentage of 70–90% of generally tolerant taxa. At the border of good to moderate status, the sensitive group accounts roughly for less than 40% or less than one-third of the fauna, while the tolerant group as a whole (tolerant plus opportunists) accounts for more than 60% or more than two-third of the fauna.

3.1.4. Poor status (2 ≤ BENTIX < 2.5)

"Water showing evidence of major alterations to the values of the biological quality elements for the surface water body type, in which the relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions". This condition corresponds with heavily polluted sites (transitional to heavy pollution to heavily polluted sites). At the poor status, as is indicated by the degradation model, the sensitive group accounts for less than 12% of the fauna, while the tolerant taxa in general account for a percentage of 88–100%.

3.1.5. Bad status (BENTIX = 0)

"Water showing evidence of severe alterations in which large portions of the relevant biological communities normally associated with the surface water body type under undisturbed conditions are absent". This condition corresponds with extremely polluted sites (azoic sediments).

3.2. Macroalgae

The Ecological Evaluation Index (EEI), proposed by Orfanidis et al. (2001,2003) is based on the concept of indicator groups (morphological and functional). Highly stressed or disturbed marine environments are inhabited by annual species with high growth rates and reproductive potential, while undisturbed marine environments by perrenial species with low growth rates and reproductive potential. Macroalgal taxa are divided in two ecological status groups or ESG: in the ESG I are grouped the thick leathery, the articulate upright calcareous and the crustose calcareous species which are mostly *k*-selected species. In the ESG II are grouped the foliose, the filamentous and the coarsely branched upright species. Most of them are *r*-selected species. The evaluation of ecological status into five categories from high to bad includes a cross comparison of the ESGs coverage value on a matrix, and a numerical scoring system to express the category of ESG to a number ranging from 2 to 10. The methodology includes a technique for spatial integration of the results for assessing the ecological status of the whole area delimited by sampling stations. An insight to the structure and ecological relevance of the ecological evaluation index is presented in Orfanidis et al. (2003) and its use in implementing the European WFD is demonstrated in Panayotidis et al. (2004). The scale of the EEI is linear and the EQR values are standardized to fit the 0–1 range (Table 3). It is noteworthy that according to the theoretical model of the EEI method, the two functional groups ESGI and ESGII may appear in up to three different combinations of relative abundance in each ecological quality class:

3.2.1. High status (10 ≤ EEI < 8)

"The composition of macroalgal taxa is consistent with undisturbed conditions. There are no detectable changes in macroalgal cover due to anthropogenic activities". This condition corresponds with unpol-

Table 3
The EEI index classification scheme (Orfanidis et al., 2001)

Ecological status	EEI range	Boundary limits	EQR (1.25 × (EEI/10)−0.25)
High	10 ≤ EEI < 8	10	1
Good	8 ≤ EEI < 6	8	0.75
Moderate	6 ≤ EEI < 4	6	0.5
Poor	4 ≤ EEI < 2	4	0.25
Bad	2	2	0

luted sites. As it is shown in the matrix of EEI method (Orfanidis et al., 2001), in the high status the sensitive taxa represented by the ecological group ESGI account for more than 60% of the mean macroalgae abundance-coverage and the tolerant taxa represented by the groups ESGII account for 0–30% of the macroalgae coverage.

3.2.2. Good status ($8 \leq EEI < 6$)

There are slight changes in the composition and abundance of macroalgal taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of phytobenthos or higher forms of plant life resulting in undesirable disturbance to the balance of organisms present in the water body or to the physicochemical quality of the water. This condition corresponds with slightly polluted sites (unbalanced). At the good status, as is indicated by the EEI matrix, the ESGI group may range from 30 to 60%, while the ESGII from 0 to 30% of the macroalgae coverage, or the combination may be that ESGI accounts for over 60% and ESGII between 30 and 60% of the total macroalgae coverage.

3.2.3. Moderate status ($6 \leq EEI < 4$)

The composition of macroalgae taxa differs moderately from type-specific conditions and is significantly more distorted than at good quality. Moderate changes in the average macroalgal abundance are evident and may be such as to result in an undesirable disturbance to the balance of organisms present in the water body. This condition corresponds with meanly polluted sites. At the moderate status, as is indicated by the EEI matrix, the two groups may equally share the macroalgae coverage accounting for equally low, moderate or high percentages.

3.2.4. Poor status ($4 \leq EEI < 2$)

At the poor status, as is indicated by the EEI matrix, the sensitive group ESGI may account for 0–30% and the tolerant group for 30–60% or the sensitive group may represent a coverage among 30 and 60%, while the tolerant group may account for over 60%.

3.2.5. Bad status ($EEI = 2$)

At the bad status, the sensitive group ESGI accounts for 0–30% and the tolerant group ESGII represents over 60% of the total macroalgae coverage.

3.3. Phytoplankton

An eutrophication scale was developed specified for the Greek seas and based on the nutrient concentration ranges including phosphates, nitrates and ammonium as well as phytoplankton parameters including phytoplankton cell density and chlorophyll-a concentration (Ignatiades et al., 1992; Karydis, 1999; Pagou, 2000; Siokou and Pagou, 2000). The original scale included four levels of eutrophication: eutrophic, higher mesotrophic, lower mesotrophic and oligotrophic. In order to fit the five step ecological status scale of WFD, chlorophyll-α values were modified by splitting the lower mesotrophic range into two using the median value of the two boundary limits (0.1–0.6) resulting into the good quality class (0.1–0.4) and the moderate quality class (0.4–0.6) (Table 4). The intergration of eutrophication scales and ecological status classification is the task of another WFD Working Group—the WG 2.A ‘‘Eutrophication Activity’’ http://forum.europa.eu.int/Members/irc/env/wfd/library?1=/workinggroups/ecologicalstatus. However, the above-modified scale for the chlorophyll-a concentration is provisionally used here to express an attribute of the phytoplankton quality element.

Thus, for the biological quality element of phytoplankton the WFD normative definitions of high, good and moderate classes are as follows.

3.3.1. High status (Chl.-a < 0.1 μg/l)

The composition and abundance of the phytoplanktonic taxa are consistent with undisturbed conditions. The average phytoplankton biomass is consistent with the type-specific physicochemical conditions and is not such as to significantly alter the type specific transparency conditions. Planktonic blooms occur at a frequency and intensity which is consistent with the

Table 4
Eutrophication scale based on chlorophyll-a concentration (modified after Karydis, 1999 and Pagou et al., 2002)

Eutrophication scale	Chlorophyll-a (μg/l)	Ecological Quality Status
Oligotrophic	<0.1	High
Lower mesotrophic	0.1–0.4	Good
	0.4–0.6	Moderate
Higher mesotrophic	0.6–2.21	Poor
Eutrophic	>2.21	Bad

type specific physicochemical conditions. The trophic status corresponds with the oligotrophic level characterizing non sensitive areas.

3.3.2. Good status ($0.1 < Chl.\text{-}a < 0.4\ \mu g/l$)

The composition and abundance of planktonic taxa show slight signs of disturbance. There are slight changes in biomass compared to the type-specific conditions. Such changes do not indicate any accelerated growth of algae resulting in undesirable disturbance to the balance of organisms present in the water body or to the quality of the water. A slight increase in the frequency and intensity of the type specific planktonic blooms may occur. The trophic status corresponds with the lower mesotrophic level characterizing non sensitive areas.

3.3.3. Moderate status ($0.4 < Chl.\text{-}a < 0.6\ \mu g/l$)

The composition and abundance of planktonic taxa show signs of moderate disturbance. Algal biomass is substantially outside the range associated with type-specific conditions, and is such as to impact upon other biological quality elements. A moderate increase in the frequency and intensity of planktonic blooms may occur. Persistent blooms may occur during summer months.

3.3.4. Poor status ($0.6 < Chl.\text{-}a < 2.21\ \mu g/l$)

In this class, the trophic status corresponds with the higher mesotrophic eutrophication conditions which indicate 'sensitive' ecosystems that can be eutrophic in the future, if an increasing trend in eutrophication parameters is detected (Pagou et al., 2002). Concentrations characterizing higher mesotrophic conditions can serve as 'red flags' for ecosystems potentially threatened by future human impacts.

3.3.5. Bad status ($Chl.\text{-}a > 2.21\ \mu g/l$)

In the bad category, the trophic status corresponds with the eutrophic level characterizing sensitive eutrophic areas.

4. Synthesis of the biological quality elements: a case study

4.1. Ecological status in Saronikos Gulf (Aegean Sea, Greece)

Saronikos Gulf, surrounding the Athens metropolitan area (Fig. 2), is one of the sites registered among the common intercalibration sites for the WFD implementation in the Mediterranean ecoregion and belongs to the rocky deep exposed coastal water body

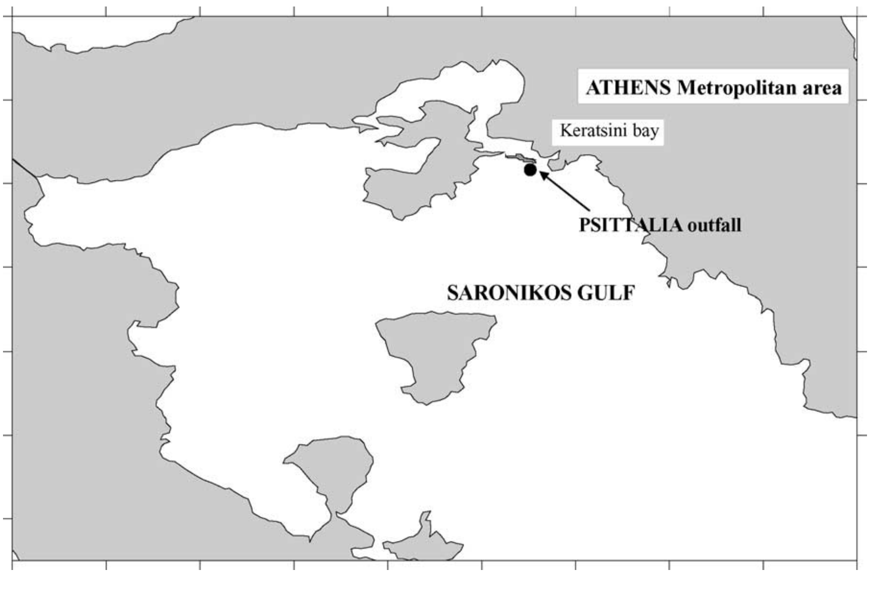

Fig. 2. Map of Saronikos gulf.

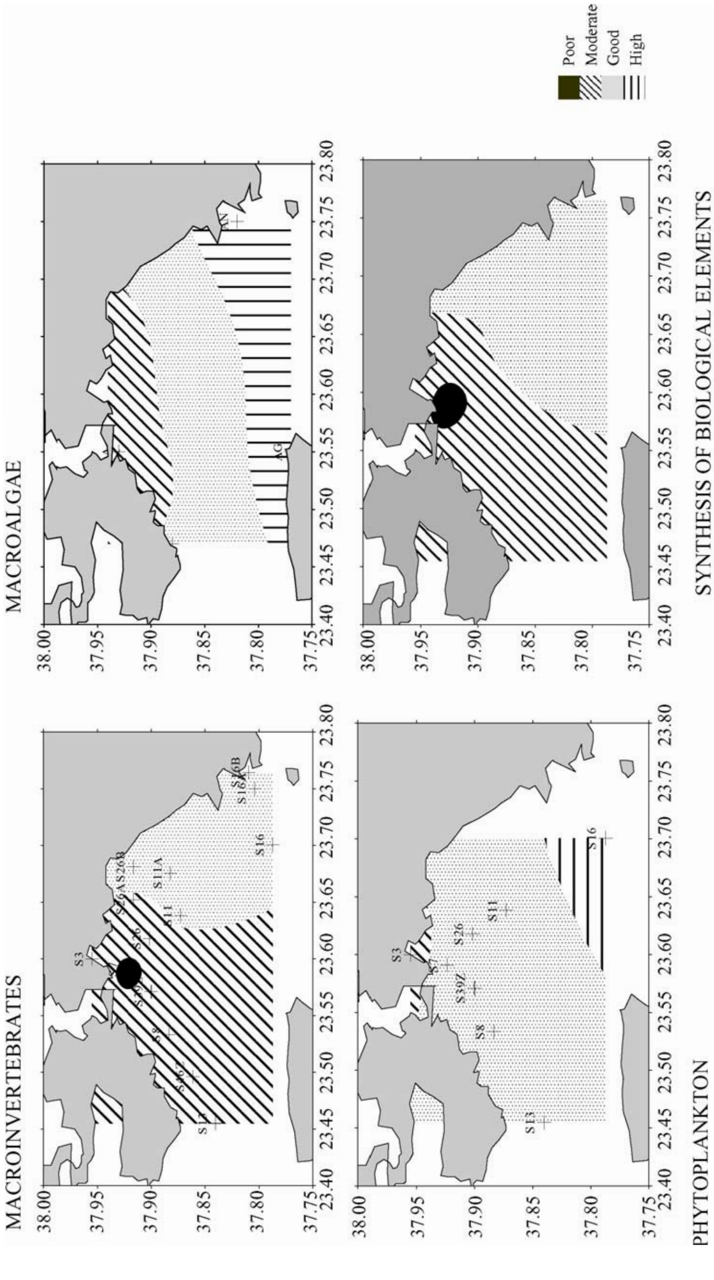

Fig. 3. Synthesis of the biological elements classification results.

type (Table 1). The gulf receives the sewage effluents of the central sewage outfall of Athens through a deep underwater outlet situated on Psittalia Island, at the inner part of Saronikos Gulf, discharging primarily treated urban sewage. The sewage treatment plant has started functioning in 1994 and since then the effects of the Psittalia sea outfalls on the ecosystem have been monitored regularly by the Hellenic Centre for Marine Research (HCMR) (Siokou-Fragou et al., 1999, 2003). The site had served as a pilot area for the application of the newly developed tools for the purposes of the WFD implementation. A synthesis of the biological elements classification results based on the available synchronic data sets is presented below.

The classification result of each element (value of the respective tool or measurement) was expressed as a score ranging from 1 to 5 (5, high; 4, good; 3, moderate; 2, poor; 1, bad). For the final Ecological Quality Status classification, the one-out–all-out principle suggested in the WFD classification guidelines (EC, 2003a) was respected. Given that the tools described above are non type-specific, the same methodology can apply to every site. Table 5 summarizes the results of the classification (values of biotic indices or chlorophyll concentration, EcoQ and EQR) of the three biological elements and the intergrated EcoQ results for each water body. The surface plots in Fig. 3 illustrate the intergrated classification results for the whole study area. The data set consisted of 14 sampling stations.

Results showed that the classification based on the BQE macroinvertebrates gives the lowest quality class, thus determining the final intergrated classification by following the principle of one-out–all-out.

In this work is presented the extended horizontal differentiation pattern of the intergrated EcoQ of the area and will be validated with chemical data and inter-compared with the results rendered by other methods of classification as demonstrated in the following paragraphs and illustrations (Fig. 7).

Results showed that the inner Saronikos gulf presents a clear gradient from poor quality in the Psittalia (outfall) station to moderate in the southwest of Psittalia stations, and good in the southeast of Psittalia stations. Results are consistent with previous monitoring results based on macrozoobenthos in a less extended network of stations (Zenetos et al., 1994; Simboura et al., 1995).

The EcoQ of the inner Saronikos gulf is justified by the distribution patterns of the chemical parameters and is largely attributed to the hydrological regime of the area and the sewage effluent pressures (Siokou-Fragou et al., 2003). Intra-annual variations in the ecological quality are related to meteorological variations and changes in the sewage quality. In fact, the cyclonic hydrological regime of the area results into the dispersion of the organic load towards the

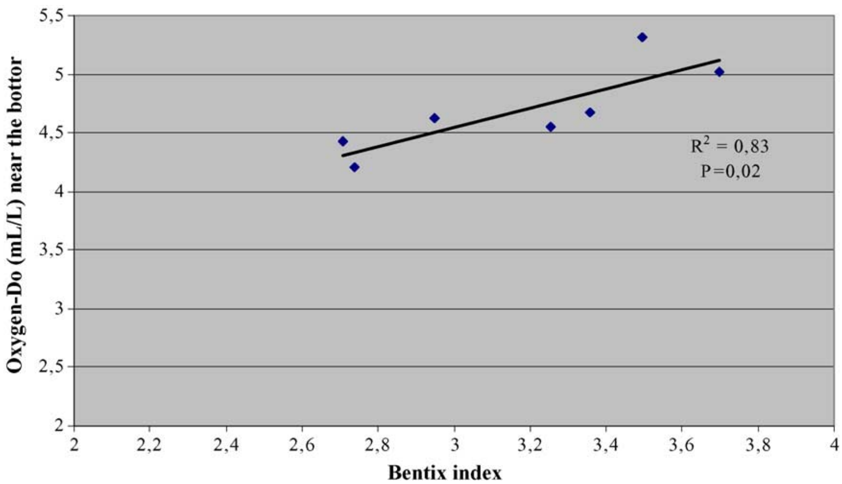

Fig. 4. Linear correlation of the dissolved oxygen near the bottom (mean annual values) and the EcoQ of the benthic communities as illustrated by the BENTIX index.

Table 5
Classification results for the biological elements and synthesis of the final EcoQ

Stations	BENTIX	EQR	EcoQ zoobenthos	Chlorophyll-a (μg/l)	EcoQ phytoplankton	Stations	EEI	EQR (1.25 × (EEI/10)−0.25)	EcoQ macroalgae	EcoQ water body
S3	3.36	0.56	3	0.46	3					3
S7	2.20	0.37	2	0.28	4					2
S39Z	2.74	0.46	3	0.291	4	A	5.3	0.41	3	3
S8	2.71	0.45	3	0.332	4	KV	4.5	0.31	3	3
S46Z	3.04	0.51	3			PS	6.5	0.56	4	3
S13	3.25	0.54	3	0.207	4					3
S26	2.95	0.49	3	0.11	4					3
S26A	3.25	0.54	3			P	5	0.38	3	3
S26B	4.37	0.73	4							4
S11	3.70	0.62	4	0.096	4					4
S11A	3.87	0.65	4							4
S16	3.49	0.58	4	0.056	5	AG	9	0.88	5	4
S16A	3.48	0.58	4							4
S16B	4.21	0.70	4			AN	9	0.88	5	4

EcoQ: Ecological Quality Status; EQR: ecological quality ratio.

southwest of Psittalia as evidenced in an overview of the results of the long-term monitoring of Saronikos gulf (2000–2004) presented for the period 2002–2003 (Kontoyiannis, 2003; Siokou-Fragou et al., 2003).

This spatial differentiation is reflected to the mean annual horizontal distribution pattern of the dissolved oxygen, presenting lower mean annual values in the stations southwest of Psittalia (S39Z, S8, S13) than in the southeast stations (S11, S16). Besides, during the year-round monitoring, dissolved oxygen concentrations at the depth of the sewage effluents were often found significantly low (lower than 4ml/l) in the southwest of Psittalia stations and also at station S26 which is among the southeast stations most close to Psittalia (Pavlidou and Psyllidou-Giouranovits, 2003).

Correlation between mean annual (June 2002–May 2003) dissolved oxygen values near the bottom and the BENTIX index values (Fig. 4) was found to be statistically significant ($R = 0.83$ with $P = 0.02$). This pattern is also reflected (Fig. 5) in the mean annual (June 2002–May 2003) phosphate values (Pavlidou and Psyllidou-Giouranovits, 2003) (Fig. 7), the

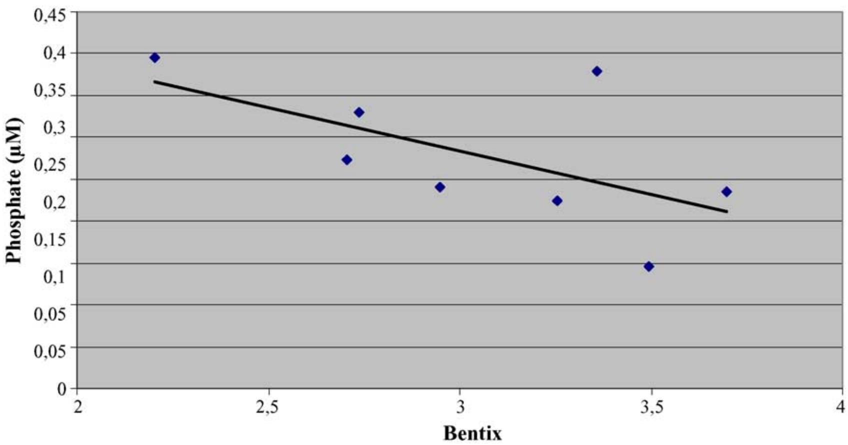

Fig. 5. Negative correlation between the Phosphate mean intergrated values in the water column and the EcoQ of the benthic communities as illustrated by the BENTIX index.

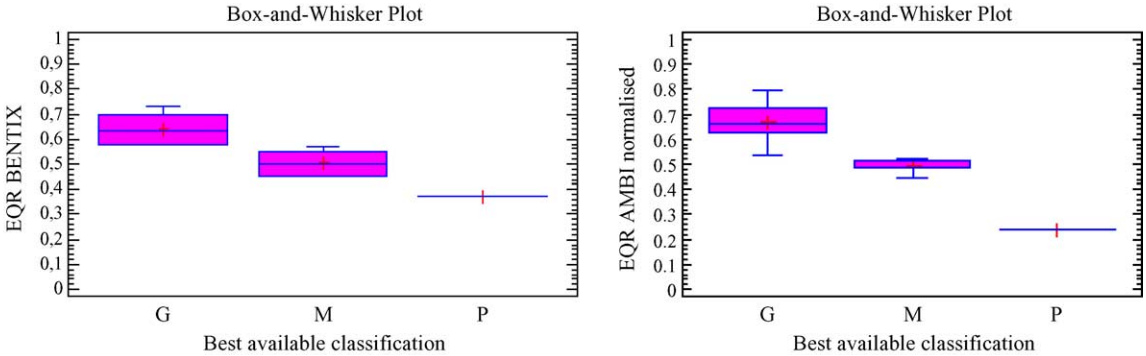

Fig. 6. Box-and-Whisker plots of the compared indices illustrating differences of the best available classification rendered.

particulate organic carbon (Krasakopoulou, 2003) and the coprostanole measured in the suspended particulate matter (Hatzianestis and Sklivagou, 2003). All these parameters presented higher mean annual values in the southwest stations as compared to the values in the southeast ones.

Fig. 7 illustrates the spatial gradation of the dissolved oxygen near the bottom and the phosphates, showing that these abiotic stress factors follow the same differentiation pattern with the gradient of ecological status as is demonstrated by the BENTIX index for the macroinvertebrates which is the biological element determining the integrated EcoQ of the area.

It is noteworthy that the poor–moderate–good gradation of EcoQ is demonstrated by the macrozoobenthos quality element, while the macroalgae and most strikingly the phytoplankton reflected the high ecological potential of the outer Saronikos Gulf. The results rendered by the macroalgae are close to the macroinvertebrates results, classifying Saronikos gulf in sub-regional scales from moderate and good to high ecological status (inner Saronikos and outer Saronikos, respectively). This implies that the benthic quality elements for the evaluation of the ecological status of coastal waters are reliable (Panayotidis et al., 2004).

The macrozoobenthos is expected to give the lowest EcoQ results, as it is the biological element that receives the accumulated effect of organic and other types of pollution due to the perennial character of the benthic communities and its end position at the sea bottom. In this case, the macroinvertebrates quality element acted as a threshold criterion for estimating the global EcoQ of the coastal ecosystem. In fact, it is well established that the benthic communities are good and reliable indicators of the ecosystem health (Grall and Glémarec, 1997).

4.2. Comparison between the BENTIX and the AMBI index classification results

Table 6 presents the outcome of the classification of Saronikos Gulf based on the use of the two indices: the AZTI Marine Biotic Index (AMBI) developed by Borja et al. (2003) and the BENTIX. Results are similar for the southeast stations S11, S11A, S16, S16A, S16B and S26B designating these stations to the good EcoQ. Results are also consistent for the Psittalia outfall station S7 and station S8 in the southwest of the outfall, classifying the two stations to the poor and moderate EcoQ, respectively.

Discrepancies among the two indices involve the region southwest of the outfall (S39Z, S46Z and S13) where the BENTIX classifies these stations to the moderate class, while the AMBI index classifies all the above stations as belonging to the good class. Furthermore, the closer to the outfall stations S26 and S26A have been classified by the BENTIX to the moderate class, while by the AMBI have been classified to the good. The same result was produced for station S3.

The differences in the classification results rendered are demonstrated in Fig. 6 where the Box-and-Whisker plots were constructed for both indices plotting normalized EQRs against the classification rendered. The AMBI method assigned most stations to the good class.

Table 6
Comparison between the BENTIX and the AMBI index in Saronikos gulf benthic data

Stations	BENTIX	EcoQ–BENTIX	AMBI	BI	EcoQ–AMBI
S3	3.36	M	2.6	2	G
S7	2.20	P	5.3	5	P
S39Z	2.74	M	3.1	2	G
S8	2.71	M	3.4	3	M
S46Z	3.04	M	2.9	2	G
S13	3.25	M	2.4	2	G
S26	2.95	M	3.3	2	G
S26A	3.25	M	2.5	2	G
S26B	4.37	G	1.4	2	G
S11	3.70	G	2.5	2	G
S11A	3.87	G	1.9	2	G
S16	3.49	G	2	2	G
S16A	3.48	G	1.9	2	G
S16B	4.21	G	1.8	2	G

EcoQ: Ecological Quality Status. Station rows with controversial results are shaded.

The moderate EcoQ of the areas of the outfall and those in the southwest direction was validated using hydrological and chemical evidence (Figs. 4 and 5). At S3, the classification should be no better than moderate, as the high nutrient values suggest. These values are similar to those at the outfall station, while the chlorophyll-α values were even higher.

Fig. 7 shows the spatial gradation patterns of the ecological status rendered by the two indices and the gradients of the dissolved oxygen near the bottom

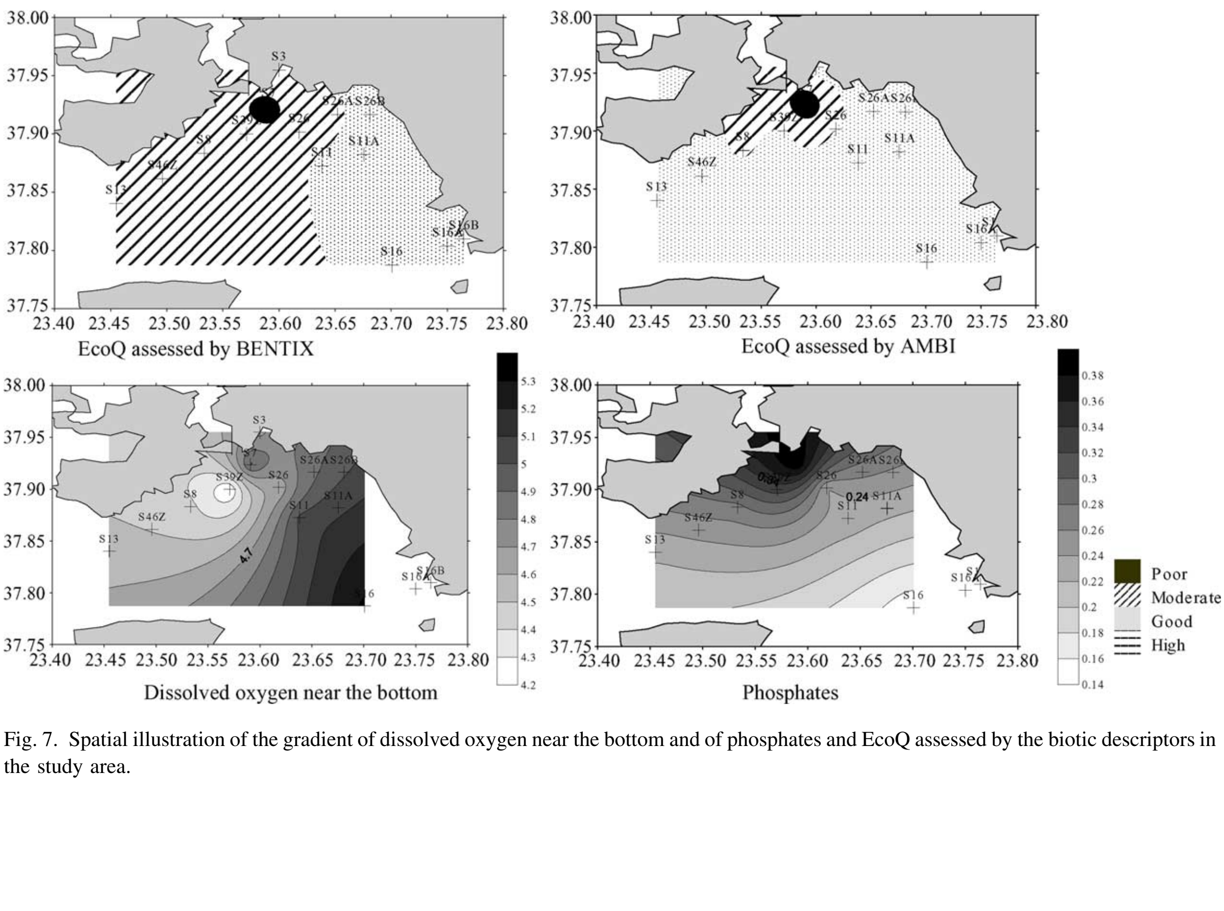

Fig. 7. Spatial illustration of the gradient of dissolved oxygen near the bottom and of phosphates and EcoQ assessed by the biotic descriptors in the study area.

layer and the phosphate values in the case study area. The EcoQ gradient illustrated by the BENTIX index is syntonic with the gradient of the abiotic factors, while the gradient demonstrated by the AMBI is much more limited and weaker.

Conclusively, the AMBI index failed to detect the spatial differentiation of the EcoQ between the southwest and the southeast of the outfall and also to highlight the drop of the ecological quality in S3 and in the southeast stations at a close distance from the outfall. On the other hand, the use of the BENTIX index, in this specific case study, succeeded in producing an ecologically relevant classification reflecting the environmental pressures as expressed in the chemical and biological elements.

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