Animal-sediment relationships: Evaluating the 'Pearson-Rosenberg paradigm' in Mediterranean coastal lagoons

P. Magni [a,e,*], D. Tagliapietra [b], C. Lardicci [c], L. Balthis [d], A. Castelli [c], S. Como [e], G.

5 Frangipane [b], G. Giordani [f], J. Hyland [d], F. Maltagliati [c], G. Pessa [g], A. Rismondo [g], M.

Tataranni [c], P. Tomassetti [h], P. Viaroli [f]

[a] CNR-IAMC, Consiglio Nazionale delle Ricerche, Istituto per l'Ambiente Marino Costiero,

Località Sa Mardini, Torregrande, 09072 Oristano, Italy

10 [b] CNR-ISMAR, Consiglio Nazionale delle Ricerche, Istituto di Scienze Marine, Sistemi Marini e

Costieri, Riva Sette Martiri 1364/a, 30122 Venice, Italy

[c] Università di Pisa, Dipartimento di Biologia, Via Derna 1, 56126 Pisa, Italy

[d] National Oceanic and Atmospheric Administration (NOAA), National Ocean Service, 219 Ft.

Johnson Rd., 29412 Charleston SC, USA

15 [e] IMC, International Marine Centre, Località Sa Mardini, Torregrande, 09072 Oristano, Italy

[f] Università di Parma, Dipartimento di Scienze Ambientali, Via Usberti 33/A Campus, 43100

Parma, Italy

[g] SELC Società Cooperativa, Via dell'Elettricità 3/d, 30175 Venice-Marghera, Italy

[h] ISPRA, Istituto Superiore per la Protezione e la Ricerca Ambientale, Via di Casalotti 300, Rome,

20 Italy

* Corresponding author email: <paolo.magni@cnr.it>.

Abstract

In the present study, we investigated the applicability of the Pearson-Rosenberg (P-R) conceptual model describing a generalized pattern of response of benthic communities in relation to organic enrichment to a specific typology of marine systems, i.e. coastal lagoons. The study was performed with independent matching data on the structure of macrobenthic communities and total organic carbon (TOC) content of sediments obtained from 349 stations representing three of the most ecologically and economically relevant coastal lagoons in the Mediterranean Sea, i.e. the lagoons of Cabras, Orbetello, and Venice (Italy). Consistent with P-R model predictions, we found two different peaks in benthic diversity and abundance at low (> 2.5-5 mg g^{-1}) and high (> 25-30 mg g^{-1}) TOC ranges, respectively. We identified TOC thresholds indicating that risks of reduced benthic diversity from organic loading and other associated stressors in sediments should be relatively low at TOC values < about 10 mg g^{-1}, high at TOC values > about 28 mg g^{-1}, and intermediate at values in-between. Predictive ability within these ranges was high based on results of re-sampling simulation. Our results validate and support a prior independent study that identified similar TOC thresholds for assessing risks of benthic impacts in samples from seven coastal regions of the world. While not a measure of causality, it is anticipated that these TOC thresholds should serve as a general screening-level indicator for evaluating the likelihood of reduced sediment quality and associated bioeffects in such eutrophic systems of the Mediterranean Sea, which also are exposed to a variety of stressors from multiple human uses.

Keywords: Macrobenthos; Total organic carbon (TOC); Benthic-TOC relationships; Ecological indicators; Pollution impacts; Eutrophication; Benthic diversity; Coastal lagoons; Mediterranean Sea

1. Introduction

Coastal marine ecosystems are increasingly affected by environmental stress and degradation due to pollution and other anthropogenic factors. A large number of research programmes worldwide have addressed these problems within various coastal regions and have produced highly useful comprehensive datasets on environmental and biotic conditions within each system. A growing number of new tools, methods, and models for assessing the health of these systems have emerged as well, along with the recognition that a wide suite of approaches would be best for such purposes rather than any one single indicator (Magni et al., 2005a; Dauvin, 2007; Borja and Dauer, 2008). Furthermore, it has been recognized that there would be a tremendous advantage in bringing such information and resources together through collaborative efforts in order to provide consistent and comprehensive sets of indicators and related data for future global comparisons (Costello and Vanden Berghe, 2006). At the same time, while consistent and globally-applicable approaches are important, there also is need for adopting monitoring and analytical approaches that recognize and account for natural variations among various regions and unique properties of specific systems (e.g. oligotrophic vs. eutrophic systems, coastal sites vs. estuaries). The final aim is to develop recommendations and indicators that hopefully will provide useful guidance for future coastal research and management applications.

The use of ecological indicators is central to such an approach. While there are many qualities of a good indicator (e.g., see reviews by Cairns et al., 1993; Fisher et al., 2001; European Environment Agency, 2005; Magni et al., 2005a; Rees et al., 2006; UNESCO, 2006; ICES, 2008), a particularly important feature is the presence of a strong stressor-response relationship with quantifiable thresholds to allow one to convey the current status of condition relative to some optimal environmental quality target either to maintain (if the system is already in a healthy state) or to achieve (if the system is disturbed and in need of restoration). As an example, abiotic environmental attributes, such as measures of organic enrichment or chemical contamination and toxicity in sediments, might be the stressor component while measures of key biological

attributes, such as benthic species richness, abundance, or biomass would represent response variables. A classic example of such a stressor-response relationship is provided in the graphical model by Pearson & Rosenberg (P-R, 1978), describing a generalized pattern of benthic

75   community response along a gradient of organic enrichment. Hyland et al. (2005) recently expanded upon the P-R model by using it as a conceptual basis for defining lower and upper thresholds in total organic carbon (TOC) concentrations corresponding to low vs. high levels of benthic species richness in samples from seven coastal regions of the world. Specifically, it was shown that risks of reduced macrobenthic species richness from organic loading and other

80   associated stressors in sediments should be relatively low at TOC values < about 10 mg g^{-1}, high at values > about 35 mg g^{-1}, and intermediate at values in-between. While not a measure of causality (i.e. to imply that the observed bioeffect was caused by TOC itself), it was anticipated that these TOC thresholds may serve as a general screening-level indicator, or symptom, of ecological stress in the benthos from related factors. Such factors may include high levels of

85   ammonia and sulfide or low levels of dissolved oxygen associated with the decomposition of organic matter, or the presence of chemical contaminants co-varying with TOC in relation to a common controlling factor such as sediment particle size.

        In the present study, we aimed to assess the applicability of benthic-TOC relationships and associated thresholds for one particular typology of coastal systems, i.e. Mediterranean coastal

90   lagoons. Our choice was based on the hypothesis that these relationships might be very different or invalid in the case of such eutrophic, organic-enriched systems as are many of the coastal lagoons in the Mediterranean Sea. To this end, matching data on the structure of macrobenthic communities and TOC content of sediments were obtained and analyzed, through the collaborative efforts of several institutions and scientists, from 349 stations representing the three

95   Mediterranean Sea coastal lagoons of Cabras, Orbetello, and Venice (Italy).

2. Materials and methods

2.1 Lagoons investigated

The lagoons of Cabras, Orbetello and Venice are shallow, eutrophic bodies of water geographically belonging to three different marine sub-basins in which the Mediterranean Sea is usually subdivided (UNEP/FAO/WHO/IAEA, 1990; Magni et al., 2008a): the Southwestern Mediterranean Sea, the Tyrrhenian Sea, and the Adriatic Sea, respectively (Fig. 1). They are characterized by nano- (Cabras and Orbetello lagoons) or micro-tidal (Venice lagoon) tides (Tagliapietra and Volpi Ghirardini, 2006). According to the Koeppen-Geiger-Pohl Climatic Classification (e.g. Peel et al., 2007), the Cabras and Orbetello lagoons have a Csa climate (i.e. Mediterranean Mild with dry, hot summer), while the Venice lagoon experiences a Cfa climate (i.e. Humid subtropical Mild with no dry season, hot summer). These lagoons represent three of the most economically and ecologically relevant, as well as widely studied, coastal lagoons in Italy and the Mediterranean Sea. Historically, they have a high economic rating due to fishery activities including both fishes (e.g. *Liza ramado*, *Mugil cephalus*, *Anguilla anguilla*, *Sparus aurata*, *Dicentrarchus labrax*) and shellfish (e.g. *Mytilus galloprovincialis*, *Ruditapes philippinarum*). However, like many other Mediterranean coastal lagoons, they also tend to be subjected, especially during summer and periods of climatic stasis, to dystrophic events causing massive mortalities of benthic macroinvertebrates and fishes. Eutrophication and organic over-enrichment of sediments, resulting in the subsequent release from sediments of toxic hydrogen sulphide, are thought to be major causes of these events (Lardicci et al., 1997; Tagliapietra et al., 1998; Magni et al., 2005b, 2008b). Several studies have been conducted on benthic communities of the Cabras, Orbetello, and Venice lagoons (e.g. see Magni et al. 2004, 2005b, 2008a; Como et al., 2007, for the Cabras lagoon; Lardicci et al., 1993, 1997, 2001; Lardicci and Rossi 1998, for the Orbetello lagoon; Tagliapietra et al., 1998, 2000; Pessa, 2005, for the Venice lagoon) and the reader is referred to these references for more detailed accounts of the individual systems.

2.2 Dataset

Matching data on the structure of macrobenthic communities and organic carbon content of

125 sediments were obtained from 59, 108, and 182 stations from multiple sampling efforts in the

lagoons of Cabras (De Falco et al., 2004; Magni et al. 2004, 2005b), Orbetello (Lardicci et al.,

1997, 2001) and Venice (Tagliapietra et al., 2000; Frangipane, 2005; Pessa, 2005) respectively,

resulting in a total of 349 stations (Table 1). There were some differences in methods used to

generate the data among the various studies (e.g., variations in sieve sizes, surface area of

130 sampling gear, method of organic matter determination). However steps were included in the

present analysis to account for such differences. For example, synoptic data of total organic

carbon (TOC) measured by a CHN analyzer and organic matter (OM) measured by loss on

ignition (LOI) were available for a subset of stations in each lagoon (e.g. Frangipane et al., in

press; Magni et al., 2008a). Where organic carbon was measured only as OM content by LOI,

135 site-specific equations were used to convert to TOC, taking into account the analytical conditions

(i.e. temperature and time of ignition) used in each study for LOI (see also Frangipane 2005;

Magni et al., 2008a). These equations were as follows: Cabras lagoon TOC = 0.30 LOI (500°C x

3 h) (R^2 = 0.75, P < 0.001), Orbetello lagoon TOC = 0.27 LOI (450°C x 4 h) – 0.28 (R^2 = 0.85, P

< 0.001), and Venice lagoon TOC = 0.48 LOI (350°C x 16 h) + 0.1 (R^2 = 0.96, P < 0.001). Figure

140 2 shows the ranges of TOC content of sediments of the three lagoons after standardization.

Salinity values were also available for most stations (333 out of 349). Their ranges are also given

for each lagoon in Fig. 2.

As for macrobenthos, numbers of individuals of each benthic species (or lowest practical

taxon) in a sample were recorded by station and lagoon. Taxonomy consistency across different

145 studies was carefully checked. Taxa were in most cases identified with similar experience levels,

e.g. by similarly trained staff from the same institution in the case of the Cabras and Orbetello

lagoons. Furthermore, when differences in the level of taxonomic resolution were observed in the

raw data, the higher taxonomic level was used consistently across lagoons. This need occurred for

the syllid polychaetes which were classified to the species level in the Orbetello and the Cabras

150   lagoons (17 and one species found, respectively) and to the family level in the Venice lagoon. In

this case, all Syllids in a given sample were grouped as one family. Nevertheless, a comparative

analysis of various diversity measures [e.g. H′ and $E(S_{10})$] calculated for the Orbetello samples

using Syllids as individual species and merged to family showed no significant differences, with

H′ and $E(S_{10})$ averaging 99% ± 2 and 98% ± 3, respectively. This is consistent with the low

155   contribution of Syllids to the total number of taxa in our dataset and their overall limited

occurrence in lagoonal environments as compared to coastal waters (Mistri and Munari, 2008).

Total abundance was also corrected for sample-size differences by standardizing the data to a per-

m^2 basis (i.e. density). Additional methods to account for potential sample-size variations

(resulting from different grab and sieve sizes) were used in the data analysis step as well (see

160   below).

2.3 Data Analysis

        Three benthic variables were selected to examine in relation to the TOC data: total

macrobenthic density (number of individuals m^{-2} for all species combined), and two diversity

165   measures, Shannon index, *H′,* calculated with base-2 logarithms (Shannon and Weaver, 1949) and

Hurlbert's $E(S_n)$ (Hurlbert, 1971). $E(S_n)$ is the expected number of species present in an

increasingly rarefied sample of *n* individuals randomly selected (without replacement) from a

finite collection of *N* individuals and *S* species. With this measure, meaningful comparisons of

species richness among collections of different sizes can be made by adjusting the collections to a

170   common size (*n*). Such a feature was particularly suitable for the present study in which we

sought to examine benthic diversity in relation to TOC among samples collected with varying

types of sampling gear. While $E(S_n)$ is generally unaffected by sample-size variability, it is not

sample-size independent when $N < n$. Nevertheless, a low value of *n* (*n* = 10) was chosen in order

7

that low-abundance samples could be included in the analysis. H' also was used as an example of a highly sample-size dependent diversity measure to evaluate possible deviations in the patterns generated by different indices along a gradient of organic enrichment.

The analysis of the merged dataset was conducted following the approach used by Hyland et al. (2005). Simple *X-Y* plots of macrobenthic density, richness, and diversity versus TOC content were generated as a tool for examining basic patterns in the data and comparing them against the conceptual model. TOC content (mg g^{-1}, plotted on the X axis) was divided initially into 10 discrete intervals as follows: ≤ 2.5, > 2.5-5, > 5-10, > 10-15, > 15-20, > 20-25, > 25-30, > 30-35, > 35-40, and > 40. Mean density and diversity measures among stations within a specific TOC interval, and the 95% confidence intervals, were plotted across each of the TOC intervals. The resulting curves were examined to look for their consistency with the P-R model and main breakpoints in the data.

Two quantitative methods were used to determine the location of TOC thresholds associated with the largest changes in benthic measures. These were identified as a lower TOC critical point at which diversity starts to decline and an upper TOC critical point at which the decline starts to level out. In the first approach, we used ANOVA as an exploratory tool to identify TOC thresholds that maximized differences in diversity among the three TOC ranges resulting from various combinations of upper and lower TOC values. Upper and lower TOC thresholds were derived by selecting the two values that produced the highest *F*-statistic (Sokal and Rohlf, 1981). In the second approach, a standard sigmoid dose-response curve was fitted to the data using non-linear least-squares regression (Bates and Watts, 1988). The function was of the form:

$$f(x) = a_0 + a_1 / (1 + e^{a_2 + a_3 x}) \qquad [1]$$

where x = TOC (mg g^{-1}) and a_0, a_1, a_2, and a_3 are parameters selected by the regression procedure to minimize the sum of squared deviations from the fitted curve. Upper and lower TOC thresholds were calculated by determining minima and maxima of the second derivatives.

The two TOC thresholds determined from each analysis were used to separate samples into

200   three groups of low, medium, and high levels of TOC. To evaluate the predictive ability of these

thresholds as indicators of change in benthic diversity, a re-sampling simulation (Lunneborg,

1999) was used to estimate the probability of observing reduced diversity with increasing TOC

across these three ranges. Simulations consisted of 10 iterations of 250 pair-wise comparisons of

randomly selected samples (with replacement) from each group. Probabilities of reduced diversity

205   were computed for the following combinations: $E(S_{10})$ or $H´$ in Low TOC range > $E(S_{10})$ or $H´$ in

Medium TOC range; $E(S_{10})$ or $H´$ in Low TOC range > $E(S_{10})$ or $H´$ in High TOC range; $E(S_{10})$ or

$H´$ in Medium TOC range > $E(S_{10})$ or $H´$ in High TOC range. These probabilities, which can range

from 0.5 to 1.0, are a measure of the power of a threshold in separating samples with higher and

lower diversity. Probabilities closer to 1.0 are indicative of thresholds with higher discriminatory

210   power, while probabilities close to 0.5 indicate that TOC alone has no explanatory power with

respect to reductions in diversity. Type I error probabilities were computed as a basis for testing

the null hypothesis that when comparing samples taken from two groups, the probability of

observing reduced diversity in the higher TOC range is equal to 0.5 based on one-sided t-tests.

All statistical tests were conducted using either SAS (SAS Institute, USA) or S-Plus (Math

215   Soft, Inc., USA).

3. Results

3.1 Density and diversity patterns in relation to TOC

Patterns of benthic density and diversity in relation to increasing TOC content are illustrated

220   in Fig. 3. Density largely fluctuated at low TOC (< 5 mg g^{-1}) and showed a moderate increase

over a wide TOC range, with a peak at 25-30 mg g^{-1}, followed by a decline (Fig. 3a). In contrast,

the two diversity measures peaked at TOC between about 2.5-5 mg g^{-1}, began declining between

5-10 mg g^{-1}, and then reached a minimum around 35-40 mg g^{-1} (Fig. 3b, c).

225   *3.2 TOC thresholds for assessing reductions in diversity*

As described in Section 2.3, two different quantitative methods were used to help pinpoint the lower and upper TOC thresholds: selecting the two values that produced the highest *F*-statistic from a series of ANOVAs performed on various combinations of upper and lower TOC values (Method 1); and calculating inflection points of a sigmoid dose-response function fitted to the

230   original data (Method 2). A plot of the *F*-values (Method 1) and the fitted curves (Method 2) are shown in Figs. 4 and 5, respectively.

The two methods produced very similar TOC thresholds for both diversity measures, each with a highly significant *F*-statistic. The main exception was the low TOC threshold for *H´* using Method 1 (maximum *F*-statistic), which differed the most from the others (Table 2). In particular,

235   lower and upper thresholds produced by Method 1 were 11 and 29 mg g^{-1} for $E(S_{10})$, and 15 and 30 mg g^{-1} for *H´*, respectively. This discrepancy could be related to a lower suitability of *H´*, as a highly sample-size dependent diversity measure, for analyzing our merged dataset. Lower and upper thresholds produced by Method 2 (dose-response function) for $E(S_{10})$ and *H´* were identical, i.e. 10 and 28 mg g^{-1}. Given these patterns, TOC concentrations of 10 and 28 mg g^{-1} were selected

240   as lower and upper thresholds for further analysis. Thus, the likelihood of observing a decline in benthic diversity in relation to increasing TOC is expected to be relatively low at concentrations < about 10 mg g^{-1}, high at concentrations > about 28 mg g^{-1}, and intermediate at concentrations in-between. On a related note, differences in mean values of both diversity measures among the three TOC ranges (low, moderate, high), tested using ANOVA, were highly significant, with Type I

245   error probabilities near zero, regardless of which set of thresholds (11 and 29, or 10 and 28) were used to define these ranges. This is true even after applying a Bonferroni correction to account for the multiple-comparisons issue associated with the Method 1 (maximum *F*-statistic) procedure.

3.3 Predictive ability of TOC thresholds

250   Results of re-sampling simulation (Table 3) indicated that there is a very high probability of having high, medium, and low mean diversity within low, medium, and high ranges of TOC, respectively. The values for all group comparisons in Table 3 are significantly different from a probability of 0.5 (all $P < 0.0001$). These are the Type I error probabilities associated with rejecting the null hypothesis that when comparing samples taken from two groups, the probability

255   of observing reduced diversity in the higher TOC range is equal to 0.5 based on one-sided t-tests. Based on these results, it appears that there is high predictive ability across the TOC ranges defined by these thresholds. On a related note, an analysis of stations with TOC in the low range (i.e. ≤ 10 mg g^{-1}) and benthic diversity in the high range (restricted to stations with $E(S_{10})$ values above the mean high range of the original lagoon) revealed that 78% of them (39 out of 50

260   stations) are in more "vivified" (unsecluded) areas of the lagoons (e.g. seaward –with a higher water renewal) removed from major anthropogenic influences, and thus reflecting relatively undisturbed conditions. In contrast, 88.5% of the stations (54 out of 61) in the high TOC range (i.e. > 28 mg g^{-1}) and with lower diversity were closer to point sources of human-induced stress (e.g. Orbetello and Cabras stations) or in secluded areas (e.g. Venice stations, located far from the

265   sea inlets), and thus reflecting, directly or indirectly, more disturbed conditions. Whereas this analysis was based on our personal, yet extensive, knowledge of the studied lagoons and the location of sampling stations (i.e. "expert-judgements"), this analysis helps to illustrate that the identified thresholds appear to be realistic and predictive of disturbed condition where clear evidence of disturbance exists.

270

4. Discussion

4.1 Animal-stressor relationships and the Pearson-Rosenberg model in Mediterranean coastal lagoons

        The need to develope appropriate tools or indicators for assessing the ecological quality of

275   coastal marine and transitional waters in a regulatory framework has sparked considerable

discussion among the scientific community worldwide (e.g. Dauvin, 2007; Borja and Dauer, 2008; Rees et al., 2008). Within the European Water Framework Directive (WFD; 2000/60/EC), descriptive approaches and expert judgments are used for different biological components and reference conditions (e.g. Ballesteros et al., 2007; Muxika et al., 2007). Yet, also recognized is the

280 importance of quantitative data for precision and accuracy, stressor-response relationships, predictive modeling, and sound ecological theory (Magni et al., 2005a; Orfanidis, 2007; Josefson et al., 2008; Lyche Solheim et al., 2008). A significant challenge in assessing stressor-response relationship in transitional waters, such as estuaries and coastal lagoons, is that they are under the influence of multiple factors and have a great internal patchiness and heterogeneity, which can

285 often bias the application of the most common indicators and indices of environmental quality and health status (Dauvin, 2007; Elliott and Quintino, 2007; Ruellet and Dauvin 2007). An example of such a complexity and uncertainty in ecological-quality assessment is provided by Mediterranean coastal lagoons. These usually are shallow, highly productive ecosystems where benthic components and processes play an important regulatory function for the whole system (Viaroli et

290 al., 2004; Marinov et al., 2007). Yet, most common benthic indices have shown limits in defining their ecological status (Munari and Mistri, 2008). Under these circumstances, one should identify a set of basic benthic/sedimentary variables or ecological attributes indicative of operative ecosystem properties and functions that could be integrated and used for classification and quality-assessment purposes (e.g. Viaroli et al., 2004; Magni et al., 2008a).

295 The P-R model (1978) has been widely used over the past three decades to describe distributional and spatial changes of marine benthic communities along a gradient of organic enrichment. This conceptual model can be associated with a stressor-response relationship where the organic enrichment of sediments is the stressor component and the measures of macrobenthic attributes, i.e. number of species, abundance and biomass, are the response variable. In this study,

300 we evaluated the applicability of the P-R model and the robustness of TOC thresholds for assessing the likelihood of benthic community impairment in Mediterranean coastal lagoons, as

generally eutrophic ecosystems. Our results indicate that abundance and diversity patterns in lagoon ecosystems (Fig. 3) are consistent with the P-R model predictions. For example, there may be a co-existence of species with varying life-history strategies and levels of tolerance to stress

305   throughout the intermediate TOC range. As TOC increases within this range, heartier opportunistic species are able to maintain high abundances even though other more sensitive species may be dropping off. In the present study, this is indicated by the highest abundances at a high ($> 25\text{-}30$ mg g^{-1}) TOC range, where benthic diversity had markedly declined (Fig. 3). Yet, abundance does not appear to be a good variable to use for deriving both lower- and upper-range

310   TOC thresholds, because there is no lower-end inflection point at which the curve begins to show a gradual decline. In contrast, diversity measures show a maximum in the low TOC range, a gradual decline over the intermediate TOC range, and a minimum in the high TOC range (Fig. 3b, c). This pattern was similar to that described by Hyland et al. (2005) and suitable for identifying ranges in TOC that could be used to assess low, moderate, and high risks of an impaired benthos

315   (i.e. reduced diversity) along a gradient of organic enrichment in Mediterranean coastal lagoons.

4.2 Organic enrichment, TOC thresholds and data uncertainty

It is recognized that Mediterranean coastal lagoons generally are organically enriched systems, increasingly receiving sources of anthropogenic disturbance from multiple human uses

320   (Como et al., 2007; Magni et al., 2008a; Munari and Mistri, 2008). Yet, the term "organic enrichment" is often used in a relative or conceptual manner, while there is an increasing need for a quantitative and broadly applicable classification of organic enrichment in marine sediments in order to assess changes in the benthos (Hargrave et al., 2008). This study now provides a quantitative framework for evaluating the biological significance of "organic enrichment" in

325   Mediterranean coastal lagoons, as related to an increasing risk of benthic impact. In particular, our results showed that the probability of having a reduced diversity from organic loading and other associated stressors in sediments should be relatively low in the low TOC range (<10 mg g^{-1}) and

high in the upper TOC range (>28 mg g^{-1}), being the latter threshold indicative of excessive

organic enrichment. For the same reason, TOC values within the intermediate group (>10-28 mg

330   g^{-1}) should comprise stations with moderate to high organic enrichment, which in some cases may

also have a naturally low benthic diversity (Fig. 5), as is typical of lagoon ecosystems. The largest

variation of benthic diversity (Fig. 5) and the highest numbers of individuals (Fig. 3a) found

within the intermediate group consistently suggest the occurrence here of fewer tolerant and

opportunistic species.

335   Predictive ability within these TOC ranges was high based on results of re-sampling

simulation (Table 3), suggesting that these particular breakpoints in the data provide a reasonable

framework for assessing effect of organic enrichment on lagoonal benthic diversity. We

acknowledge that predictive ability of TOC thresholds is not free of uncertainty. We still found

much scatter in the raw data, as can be seen by the wide range in diversity values at discrete levels

340   of TOC (Fig. 5). Among the possible reasons for such variability in the data are the effects of key

environmental factors. For instance, salinity below 18-20 PSU is considered to be a threshold

affecting the structure of the benthic assemblages in lagoon habitats (Giangrande et al., 1984;

Gravina et al., 1988; Lardicci et al., 1993, 1997, 2001). In our dataset, salinity below this

threshold was mainly found in Cabras (Fig. 2b), which also was the lagoon with fewer stations

345   (17% of the total). However, an analysis of stations at salinity <20 PSU showed varying TOC

contents and $E(S_{10})$ and H' values, and no correlation between salinity and diversity measures.

Other major factors, which can influence both salinity gradients and diversity levels in

Mediterranean coastal lagoons, include the water residence times (WRTs) and the confinement of

the stations (Remane, 1934; Guélorget and Perthuisot, 1992). As an example, in the Cabras

350   lagoon impoverished benthic communities occur in areas characterized by accumulation of

cohesive sediments (< 8 µm grain size particles), capable of binding organic carbon, which is

related to the highest WRTs (Magni et al., 2008a, in press). Moreover, differences in the size of

the lagoon (Abele and Walters, 1979) and its degree of connection with the sea (the "island

theory"; McArthur and Wilson, 1967), as well as the number of habitats within each lagoon

355   (Tagliapietra and Volpi Ghirardini, 2006), can influence benthic diversity and thus also serve as a

source variability in our merged dataset. Finally, we should not rule out methodological and

analytical differences between the various studies that produced data for the present analysis, even

though there was an effort to account for such differences where possible (see Sections 2.2 and

2.3).

360   The TOC thresholds found in this study matched (10 mg g^{-1}) or approximated relatively well

(28 vs. 35 mg g^{-1}) those reported by Hyland et al. (2005). The difference in the upper TOC

threshold, i.e. a more restricted intermediate range in this study (i.e. TOC from about 10-28 mg g^{-1}), may have various explanations. For instance, in contrast to macrotidal estuaries which

represented about one third of the stations in Hyland et al. (2005), the present lagoons are

365   enclosed systems characterized by reduced hydrodynamics and low water exchange (Tagliapietra

and Volpi Ghirardini, 2006; Como et al., 2007; Magni et al., in press). The latter conditions may

increase the risk of hypoxic/anoxic conditions, sulphide development and massive kills of benthos

and fish (Gray et al., 2002; Lardicci et al., 1997; Magni et al., 2008b). For this reason, it seems

reasonable to think that a relatively lower value for the upper TOC threshold is because the

370   stations with high TOC in these lagoons also have co-occurring high levels of other stressors (due

to the long history of human activities in these systems) which are knocking out a larger

percentages of even some of the heartier species. As an example in the Cabras lagoon, Magni et

al. (2005b) showed that peaks in acid volatile sulphide concentrations in summer corresponded to

a major impoverishment of macrobenthos irrespective of seasonal change in sedimentary organic

375   matter concentration, highest between the end of summer and autumn. We also acknowledge that

differences in the composition and bioavailability of organic matter can play an important role in

the derivation of TOC thresholds for assessing risks of benthic impacts. For instance, Pusceddu et

al. (in press) suggested that the biopolymeric carbon fraction (BPC, i.e. protein, carbohydrate and

lipid pools) of sediment organic matter, positively correlated with TOC, is a more sensitive proxy

380   of benthic trophic status than the total carbon pool, due to its higher systematic variability and

different bioavailability along a gradient of organic enrichment. In particular, the authors

identified a critical threshold in BPC concentrations in the sediment of > 2.5 mg C g^{-1}, being

associated with a bioavailable fraction $< 10\%$, at which benthic consumers may experience mostly

refractory organic carbon. This knowledge was unattainable in the present study because our

385   dataset did not include such measurements. However, if we assume a bioavailable fraction less

than about 10% in eutrophic sediments, as proposed by Pusceddu et al. (in press), our upper TOC

threshold of 28 mg C g^{-1}, being mostly refractory but still indicative of high risks of benthic

impact, would be then rather consistent with a BPC value of about 2.5 mg C g^{-1}. On a related note,

it seems to be of minor importance which of the two lower (10 or 11 mg g^{-1}) and upper (28 or 29

390   mg g^{-1}) thresholds identified in our study were used to define the three TOC ranges (see Section

3.2 and Table 2). Thus, the present results demonstrate the robustness and global applicability of

the TOC thresholds identified originally by Hyland et al. (2005) and confirms TOC as a good

proxy indicator for the rapid assessment of environmental conditions potentially harmful to the

benthos. However, it is important to note that these thresholds should not be considered as

395   absolute values, nor that we are assuming a causal relationship between TOC content itself and

diversity reduction. In fact, the premise of such an approach is that because TOC tends to

correlate with factors causing ecological stress (e.g. low dissolved oxygen, high ammonia and

dissolved sulphide, chemical contamination of sediments; Gray et al., 2002; and review by

Hargrave et al., 2008), then TOC, in turn, may serve as a simple screening-level indicator, or

400   symptom, of such stress (Hyland et al., 2005).

4.3 Lagoon comparison and implications for benthic monitoring and ecological quality

assessment of Mediterranean coastal lagoons

       A comparison among lagoons showed that there was a general pattern of decreasing

405   diversity from low to high TOC ranges (Table 4). $E(S_{10})$ and H' for all lagoons combined

averaged 5.0 and 2.8 in the low TOC range, 4.3 and 2.3 in the intermediate range, and 3.3 and 1.7 in the high range, respectively. This general pattern was consistent across most individual datasets, though there were some differences among lagoons. For example, there were a few Orbetello stations with low diversity and very low TOC values (<4 mg g^{-1}) and some Venice stations with a high diversity and very high TOC values (>40 mg g^{-1}) (Fig. 5). Such cases may be due to inherent data uncertainty as discussed above (Section 4.2), while the latter stations were consistently found to contain a large fraction of refractory organic carbon (Frangipane, 2005). Besides this inconsistency, however, the Venice lagoon showed an overall decreasing diversity from low to high TOC ranges (Table 4). Also the Cabras lagoon, which had the least number of stations and was not represented by stations in the low TOC range, showed a decreasing mean diversity from the intermediate to the high TOC range (Table 4). The main exception to this general pattern was Orbetello, which showed similar mean diversity values at low and intermediate TOC ranges. It should be mentioned here that the Orbetello lagoon experienced an alternate series of dystrophic impacts (Lardicci et al., 1997) and recoveries of the benthic communities (Lardicci et al., 2001) over the past fifteen years. While in this study we did not account for temporal changes, a separate analysis of the 1994 (dystrophy) and 1999 (recovery) Orbetello datasets showed a tendency toward higher diversity values of the latter dataset across the whole TOC range (not shown). Thus, the merging of the two datasets may have hidden any separately consistent pattern within the Orbetello lagoon study. However, also in the case of Orbetello, an analysis of the merged dataset showed again the lowest diversity in the high TOC range.

Overall, this study provides a good example from a relatively large dataset of the levels and ranges of benthic diversity which can be encountered in Mediterranean coastal lagoons. The popular *H´* diversity index has been used for direct comparisons (e.g. Zettler et al., 2007; Bigot et al., 2008; Blanchet et al., 2008) and recently integrated with other biotic indices (Muxika et al., 2007) as tools for assessing ecosystem condition within the framework of the European Water

Framework Directive (WFD; 2000/60/EC). As an example in a Baltic Sea study, $H´$ was given an absolute scale composed of five classes associated with the different ecological quality (EcoQ) status categories proposed for the WFD, and ranging from $H´ > 4$ to $H´ < 1$ for "high" and "bad"

435   EcoQ status, respectively (Zettler et al., 2007). The authors showed significant positive correlations between $H´$ and salinity, resulting in a decreased EcoQ with decreasing salinities, thus making this index inappropriate to assess the EcoQ in systems with strong salinity gradients. According to the above scale, 7.4%, 33.2%, and 37.8% of our stations would be classified as "bad", "moderate," and "poor", respectively (in total: 274 out of 349 stations), while only 19.2%

440   and 2.3% of the stations would be classified as "good" and "high" respectively (in total: 75 out of 349 stations). Since the WFD requires that both coastal and transitional waters should achieve the 'Good EcoQ' status by 2015, up to 78.5% of our stations, simply based on $H´$, would be classified below this threshold, thus in the need of remediation measures. However, these results could be related to the inherently reduced (low) number of species occurring in these highly variable and

445   eutrophic systems, which also are exposed to a variety of stressors from multiple human uses. Thus it is suggested that the use of diversity measures alone may be not appropriate to assess the ecological quality of Mediterranean coastal lagoons (see also Munari and Mistri, 2008), unless different thresholds are defined (Chainho et al., 2008). We demonstrate the utility of diversity measures in the context of a conceptual stressor-response framework, such as the P-R model for

450   organic enrichment, with corresponding thresholds for assessing the biological significance of increasing organic enrichment of sediments and associated stressors. While not a measure of causality, the TOC thresholds developed here should serve as a general screening-level tool for evaluating the likelihood of reduced benthic diversity within different ranges of TOC in these eutrophic lagoonal systems.

455   This study also reinforces the importance of reliable and accurate taxonomy as a starting foundation for the integration of diversity measures and other benthic indicators into comprehensive data sets for large-scale management purposes (Magni et al., 2005a). It also

highlights the value of collaborative regional programmes to help develop consistent and comprehensive sets of indicators and processes that provide a basis for understanding the unique

460   properties of specific ecosystems, such as Mediterranean coastal lagoons (Magni, 2003; Draredja et al., 2006; Cognetti and Maltagliati, 2008; Magni et al., 2008a). This initiative, which began in October 2004 (Magni et al., 2005a), is an important step in this direction and provides a valuable assessment and validation of previously published TOC thresholds (Hyland et al., 2005) as a general screening-level indicator for evaluating the likelihood of reduced sediment quality and

465   associated bioeffects in these systems.

475   **References**

Abele, L.G., Walters, K., 1979. Marine benthic diversity: a critique and alternative explanation. Journal of Biogeography 6, 115-126.

Ballesteros, E., Torras, X., Pinedo, García, M., Mangialajo, L., de Torres, M., 2007. A new methodology based on littoral community cartography dominated by macroalgae for the

480   implementation of the European Water Framework Directive. Marine Pollution Bulletin 55, 172-180.

Bates, D.M., Watts, D.G., 1988. Nonlinear regression analysis and its applications. John Wiley & Sons, New York.

Bigot, L., Grémare, A., Amouroux, J.-M., Frouin, P., Maire, O., Gaertner, J.C., 2008. Assessment

485   of the ecological quality status of soft-bottoms in Reunion Island (tropical Southwest Indian

Ocean) using AZTI marine biotic indices. Marine Pollution Bulletin 56, 704-722.

Blanchet, H., Lavesque, N., Ruellet, T., Dauvin, J.C., Sauriau, P.G., Desroy, N., Desclaux, C.,

Leconte, M., Bachelet, G. Janson, A.-L., Bessineton, C., Duhamel, S., Jourde, J., Mayot, S.,

Simon, S., de Montaudouin X., 2008. Use of biotic indices in semi-enclosed coastal

490   ecosystems and transitional waters habitats - Implications for the implementation of the

European Water Framework Directive. Ecological Indicators 8, 360-372.

Borja, A., Dauer, D.M., 2008. Assessing the environmental quality status in estuarine coastal

systems: comparing methodologies and indices. Ecological Indicators 8, 331-337.

Cairns, J. Jr., McCormick, P.V., Niederlehner, B.R., 1993. A proposed framework for developing

495   indicators of ecosystem health. Hydrobiologia 263, 1-44.

Chainho, P., Chaves, M.L., Costa, J.L., Costa, M.J., Dauer, D.M., 2008. Use of multimetric

indices to classify estuaries with different hydromorphological characteristics and different

levels of human pressure. Marine Pollution Bulletin 56, 1128-1137.

Cognetti, G., Maltagliati, F., 2008. Perspectives on the ecological assessment of transitional

500   waters. Marine Pollution Bulletin 56, 607-608.

Como, S., Magni, P., Baroli, M., Casu, D., Floris, A., De Falco, G., 2008. Comparative analysis of

macrofaunal species richness and composition in *Posidonia oceanica*, *Cymodocea nodosa*

and leaf litter beds. Marine Biology 153, 1087-1101.

Como, S., Magni, P., Casu, D., Floris, A., Giordani, G., Fenzi, G.A., Signa, G., Giordani, G., De

505   Falco G., 2007. Sediment characteristics and macrofauna distribution along a human-

modified inlet in the Gulf of Oristano (Sardinia, Italy). Marine Pollution Bulletin 54, 733-

744.

Costello, M.J., Vanden Berghe, E., 2006. 'Ocean biodiversity informatics': a new era in marine

biology research and management. Marine Ecology Progress Series 316, 203-214.

510   Dauvin, J.-C., 2007. Paradox of estuarine quality: benthic indicators and indices, consensus or debate for the future. Marine Pollution Bulletin 55, 271-281.

De Falco, G., Magni, P., Teräsvuori, L.M.H., Matteucci, G., 2004. Sediment grain size and organic carbon distribution in the Cabras lagoon (Sardinia, western Mediterranean). Chemistry and Ecology 20 (Suppl.1), S367-S377.

515   Draredja, B., Como, S., Magni, P. 2006. Regional cooperation in the Mediterranean Sea: joint analysis of macrobenthic assemblages in the lagoons of Mellah (Algeria) and Cabras (Italy). Biologia Marina Mediterranea 13(2), 50-51.

Elliott, M., Quintino, V., 2007. The estuarine quality paradox, environmental homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas. Marine Pollution
520   Bulletin 54, 640-645.

European Environment Agency, 2005. EEA core set of indicators – guide. EEA Technical Report No. 1/2005. Office for Official Publications of the European Communities, Luxembourg, 38 pp.

Fisher, W.S., Jackson, L.E., Suter, G.W.II, Bertram, P., 2001. Indicators for human and ecological
525   risk assessment: a U.S. EPA perspective. Human and Ecological Risk Assessment 7, 961-970.

Frangipane, G., 2005. Distribuzione spaziale della sostanza organica nei sedimenti lagunari e suoi rapporti con morfologia e biota. Ph.D. thesis, University of Cà Foscari, Venice, Italy.

Frangipane, G., Pistolato, M., Molinaroli, E., Guerzoni, S., Tagliapietra, D., in press. Comparison
530   of loss on ignition and thermal analysis stepwise methods for determination of sedimentary organic matter. Aquatic Conservation: Marine and Freshwater Ecosystems, DOI: 10.1002/aqc.970.

Giangrande, A., Gravina, M.F., Gambi, M.C., Fresi, E., Ardizzone, G., 1984. Soft bottom polychaetes of sheltered coastal areas: factors of selection in brackish water. Nova Thalassia
535   6 (Suppl.), 155-163.

Gravina, M.F., Ardizzone, G.D., Giangrande, A., 1988. Selecting factors in polychaete communities of central Mediterranean coastal lagoons. Internationale Revue der gesamten Hydrobiologie 73(4), 463-476.

Gray, J.S., Wu, R.S., Or, Y.Y., 2002. Effects of hypoxia and organic enrichment on the coastal environment. Marine Ecology Progress Series 238, 249-279.

Guélorget, O., Perthuisot, J.P., 1992. Paralic ecosystems - Biological organization and functioning. Vie Milieu 42, 215-251.

Hargrave, B.T., Holmer, M., Newcombe, C.P., 2008. Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. Marine Pollution Bulletin 56, 810-824.

Hurlbert, S.H., 1971. The nonconcept of species diversity: a critique and alternative parameters. Ecology 52, 577-586.

Hyland, J., Balthis L., Karakassis I., Magni P., Petrov A., Shine J., Vestergaard O., Warwick R., 2005. Organic carbon content of sediments as an indicator of stress in the marine benthos. Marine Ecology Progress Series 295, 91-103.

ICES, 2008. Report of the Workshop on Benthos Related Environment Metrics (WKBEMET), 11-14 February 2008, Oostende, Belgium. ICES CM 2008/MHC:01. 53 pp.

Josefson, A.B., Hansen, J.L.S., Asmund, G., Johansen, P., 2008. Threshold response of benthic macrofauna integrity to metal contamination in West Greenland. Marine Pollution Bulletin 56, 1265-1274.

Lardicci, C., Rossi F., 1998. Detection of stress on macrozoobenthos: Evaluation of some methods in a coastal Mediterranean lagoon. Marine Environmental Research 45, 367-386.

Lardicci, C., Abbiati, M., Crema, R., Morri, C., Bianchi, C.N., Castelli, A., 1993. The distribution of polychaetes along environmental gradient: an example from the Orbetello lagoon, Italy. P.S.Z.N.I.: Marine Ecology 14(1), 35-52.

Lardicci, C., Rossi, F., Castelli, A., 1997. Analysis of macrozoobenthic community structure after severe dystrophic crises in a Mediterranean coastal lagoon. Marine Pollution Bulletin 34, 536-547.

Lardicci, C., Como, S., Corti S., Rossi, F., 2001. Recovery of the macrozoobenthic community

565   after sever dystrophic crises in a Mediterranean coastal lagoon (Orbetello, Italy). Marine Pollution Bulletin 42, 202-214.

Lunneborg, C.E., 1999. Data analysis by resampling: concepts and applications. Brooks/Cole Publishing, Pacific Grove, CA.

Lyche Solheim, A., Rekolainen, S., Moe, S.J., Carvalho, L., Phillips, G., Ptacnik, R., Penning,

570   W.E., Toth, L.G., O'Toole, C., Schartau, A.-K.L., Hesthagen, T., 2008. Ecological threshold responses in European lakes and their applicability for the Water Framework Directive (WFD) implementation: synthesis of lakes results from the REBECCA project. Aquatic Ecology 42, 317-334.

Magni, P., 2003. Biological benthic tools as indicators of coastal marine ecosystems health.

575   Chemistry and Ecology 19, 363-372.

Magni, P., Micheletti, S., Casu, D., Floris, A., De Falco, G., Castelli, A., 2004. Macrofaunal community structure and distribution in a muddy coastal lagoon. Chemistry and Ecology 20 (Suppl. 1), S397- S409.

Magni, P., Hyland, J., Manzella, G., Rumohr, H., Viaroli, P., Zenetos, A., eds., 2005a.

580   Proceedings of the Workshop "Indicators of Stress in the Marine Benthos", Torregrande-Oristano (Italy), 8-9 October 2004. Paris, UNESCO/IOC, IMC, iv + 46 pp. IOC Workshops Reports, 195. Available online: http://unesdoc.unesco.org/images/0013/001397/139719e.pdf

Magni, P., Micheletti, S., Casu, D., Floris, A., Giordani, G., Petrov, A., De Falco, G., Castelli, A., 2005b. Relationships between chemical characteristics of sediments and macrofaunal

585   communities in the Cabras lagoon (Western Mediterranean, Italy). Hydrobiologia 550, 105-119.

Magni, P., De Falco, G., Como, S., Casu, D., Floris, A., Petrov, A.N., Castelli, A., Perilli, A., 2008a. Distribution and ecological relevance of fine sediments in organic-enriched lagoons: The case study of the Cabras lagoon (Sardinia, Italy). Marine Pollution Bulletin 56, 549-

590   564.

Magni, P., Rajagopal, S., van der Velde, G., Fenzi, G., Kassenberg, J., Vizzini, S., Mazzola, A., Giordani, G., 2008b. Sediment features, macrozoobenthic assemblages and trophic relationships (δ^{13}C and δ^{15}N analysis) following a dystrophic event with anoxia and sulphide development in the Santa Giusta lagoon (western Sardinia, Italy). Marine Pollution Bulletin

595   57, 125-136.

Magni, P., Como, S., Cucco, A., De Falco, G,. Domenici, P., Ghezzo, M., Lefrançois, C., Simeone, S., Perilli, A., in press. A multidisciplinary and ecosystemic approach in the Oristano Lagoon-Gulf system (Sardinia, Italy) as a tool in management plans. Transitional Water Bulletin. Available online: xxx

600   Marinov, D., Galbiati, L., Giordani, G., Viaroli, P., Norro, A., Bencivelli, S., Zaldívar, J.-M., 2007. An integrated modelling approach for the management of clam farming in coastal lagoons. Aquaculture 269, 306-320.

McArthur, R.H., Wilson, E.O., 1967. The theory of island biogeography. Princeton University Press, N.J. Princeton.

605   Mistri, M., Munari, C., 2008. BITS: A SMART indicator for soft-bottom, non-tidal lagoons. Marine Pollution Bulletin 56, 587-599.

Munari, C., Mistri, M., 2008. The performance of benthic indicators of ecological change in Adriatic coastal lagoons: Throwing the baby with the water. Marine Pollution Bulletin 56, 95-105.

610   Muxika, I., Borja, Á, Bald, J., 2007. Using historical data, expert judgement and multivariate analysis in assessing reference conditions and benthic ecological status, according to the European Water Framework Directive. Marine Pollution Bulletin 55, 16-29.

Orfanidis, S., 2007. Comments on the development of new macroalgal indices to assess water quality within the Mediterranean Sea. Marine Pollution Bulletin 54, 626-627.

615   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.

Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007. Updated world map of the Koeppen-Geiger climate classification. Hydrology and Earth System Sciences 11, 1633-1644.

620   Pessa, G., 2005. Aspetti metodologici dello studio del macrozoobenthos negli ambienti acquatici di transizione. Ph.D. thesis University of Cà Foscari, Venice, Italy.

Pusceddu, A., Dell'Anno, A., Fabiano, M., Danovaro, R., in press. Quantity and bioavailability of sediment organic matter as signatures of benthic trophic status. Marine Ecology Progress Series.

625   Rees, H.L., Boyd S.E., Schratzberger, M., Murray, L.A., 2006. Role of benthic indicators in regulating human activities at sea. Environmental Science and Policy 9, 496-508.

Rees, H.L., Hyland, J.L., Hylland, K., Mercer Clarke, C.S.L., Roff, J.C., Ware, S., 2008. Environmental indicators: utility in meeting regulatory needs. An overview. ICES Journal of Marine Science 65, 1381-1386.

630   Remane, A., 1934. Die Brackwasserfauna. Verhandlungen der Deutschen Zoologischen Gesellschaft 36, 34-74.

Ruellet, T., Dauvin J.-C., 2007. Benthic indicators: Analysis of the threshold values of ecological quality classifications for transitional waters. Marine Pollution Bulletin 54, 1707-1714.

Shannon, C.E., Weaver, W., 1949. The mathematical theory of communication. University of
635   Illinois Press, Urbana, IL.

Sokal, R.R., Rohlf, F.J., 1981. Biometry, 2nd ed. W.H. Freeman & Co., New York.

Tagliapietra, D., Pavan, M., Wagner, C., 1998. Macrobenthic community changes related to eutrophication in Palude della Rosa (Venetian lagoon, Italy). Estuarine, Coastal and Shelf Science 47, 217-226.

640   Tagliapietra, D., Pavan, M., Wagner, C., 2000. Benthic patterns in a salt marsh basin: a snapshot of Palude della Rosa (Venetian Lagoon, Italy). Wetlands Ecology and Management 8, 287-292.

Tagliapietra, D., Volpi Ghirardini, A., 2006. Notes on coastal lagoon typology in the light of the EU Water Framework Directive: Italy as a case study. Aquatic Conservation: Marine and

645   Freshwater Ecosystems 16, 457-467.

UNEP/FAO/WHO/IAEA, 1990. Assessment of the state of pollution of the Mediterranean sea by organohalogen compounds. UNEP/MAP Technical Report no. 39, Athens, Greece.

UNESCO, 2006. A Handbook for measuring the progress and outcomes of integrated coastal and ocean management. IOC Manual and Guides, 46; ICAM Dossier, 2, Paris.

650   Viaroli, P., Bartoli, M., Giordani, G., Magni, P., Welsh, D.T., 2004. Biogeochemical indicators as tools for assessing sediment quality/vulnerability in transitional aquatic ecosystems. Aquatic Conservation: Marine and Freshwater Ecosystems 14, S19-S29.

Zettler, M.L., Schiedek, D., Bobertz, B., 2007. Benthic biodiversity indices versus salinity gradient in the southern Baltic Sea. Marine Pollution Bulletin 55, 258-270.

655