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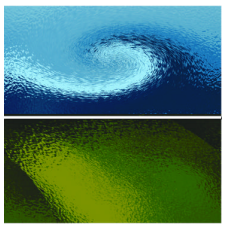

RESEARCH ARTICLE

Benthic macrophyte communities as bioindicators of transitional and coastal waters: relevant approaches and tools

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Abstract

1 - In order to use benthic macrophyte communities as bioindicators of transitional and coastal waters an understanding of main community organization mechanisms along water quality gradients is necessary.

2 - Four different approaches are presented briefly: (a) scale-based variation of biotic indices in lagoon macrophyte communities, (b) multivariate analysis of community at species and functional group levels, (c) scale-based variation of body size descriptors of angiosperms, (d) eco-toxicological tests of mechanistic stressor-response relationships.

3 - Since growth of benthic macrophytes seems to be related to species' ability to exploit the most abundant resources they can be successfully used as bioindicators of eutrophication in transitional and coastal waters.

Introduction

Bioindicators are readily measured components or metrics of the biota that are used to provide long-term ecologically relevant information about the ecosystem status or trends (Anderson, 1999). They effectively distinguish responses of human impact from natural variability, when supported by predictive modelling and sound ecological theory.

The effects of human induced stressors on aquatic ecosystems involve a series of hierarchical responses of different biological organizational levels with the most ecologically relevant ones to occur at population, community or higher levels (Addison, 1996). Population changes due to life history feature responses as of growth and reproduction will result in alteration of intra- and inter-specific relationships at community level, leading ultimately to changes in the functional integrity of ecosystem. Therefore, population responses due to environmental stress could be regarded as an early warning signal of the community and ecosystem impairment.

Marine benthic macrophytes (seaweed and seagrasses) are key structural and functional components of some of the most productive ecosystems of the world, including coastal waters and lagoons. As photosynthetic sessile organisms being at the base of food web are vulnerable and adaptive to human and environmental stress of water and sediment (especially for seagrasses). They respond to aquatic environment representing reliable indicators of its changes. Extensive field and laboratory experimentation have provided mechanistic explanations of their community-environment interactions. For example, the excess of nutrients in shallow marine ecosystems shift the species composition from the angiosperms/late-succesional seaweeds to the dominance of opportunistic and often bloom forming seaweeds due to rapid growth and/or colonization ability of latter under abundant

nutrient conditions. Hydrographic changes, grazing etc. could also contribute in this switch.
Usage of macrophyte community changes as an indicator of ecosystem status or trends necessities understanding of the main ecological processes or mechanisms responsible for those changes. Therefore, experimental science using quantitative data for precision and accuracy, recognition of spatial and temporal heterogeneity of communities, and stressor-response relationships are needed (Niemi *et al*., 2004). Within TWReferenceNET, a project on conservation and sustainable management of transitional water ecosystems, different field and laboratory tests of benthic macrophytes of transitional and coastal waters were applied in order to develop relevant water quality bioindicators.

Methods

Four different approaches to understand the role of major underlying mechanisms of benthic macrophyte community organization along water quality gradients were used:
a) Scale-based variation of structural and functional metrics in different eastern Mediterranean lagoon macrophyte communities (analysis of random nested quantitative destructive samples),
b) Multivariate analysis of key abiotic factors along with benthic macrophytes identified at species and functional group levels, e.g. *sensu* Orfanidis *et al*. (2001, 2003),
c) Scale-based variation of body size descriptors of angiosperms at a population level, e.g. skewness of *Cymodocea nodosa* leaf length,
d) Eco-toxicological tests to study stressor-response relationships (laboratory factorial experiments using as response variable photosynthesis and/or growth).

Results and discussions

A) Scale-based variation of biotic indices in lagoon macrophyte communities
The variation of marine benthic macrophyte community indices was studied in two different habitats (mud with submerged angiosperms, mud with macroalgae) of three eastern Mediterranean coastal lagoons: one from Greece (Agiasma, Nestos Delta) and two from Italy (Cesine and Margherita of Savoia, Apulian region).
The variation (Fig. 1) of different indices related to community structure (species number, Shannon-Weaver index) and function (Ecological Evaluation Index-EEI) was analyzed on a hierarchy of different scales (habitat x time x site) using nested parametric and non-parametric ANOVA. The results indicated that species diversity indices values of macrophyte communities seems to be in general low, showing highest heterogeneity at a local, site specific scale. Therefore, they appear not appropriate to be used as indicators of water quality status. Nutrient excess alone or in combination with hydrographical changes often shifts the habitat from angiosperms to the dominance of opportunistic macroalgae. Such a community switch is better indicated by functional indices, especially the EEI, which is designed in accordance to sound ecological theory to evaluate water quality status.

B) Multivariate analysis of community at species and functional group levels
Canonical Correspondence Analysis (CCA) ordination was used to identify the best set of environmental variables explaining the variance in macrophyte data (CANOCO software). This technique is often based on species composition assessment. However, by using functional groups one could reduce the complexity, compare non overlapping communities, and develop user friendly and cost-effective protocols. A functional group is here regarded a non-phylogenetic classification leading to a grouping of organisms that respond in a similar way to certain environmental factors.
Ordination diagram showed (Fig. 2) that functional groups ESG I, II were completely separated and occupied opposite positions. ESG II showed its optimum where salinity, nitrite, nitrate, temperature and dissolved oxygen were high, while ESG I showed its optimum where depth, silicate and phosphate were high. This result might shows that these groups are natural

and could be used to understand macrophyte patterns across quality gradients

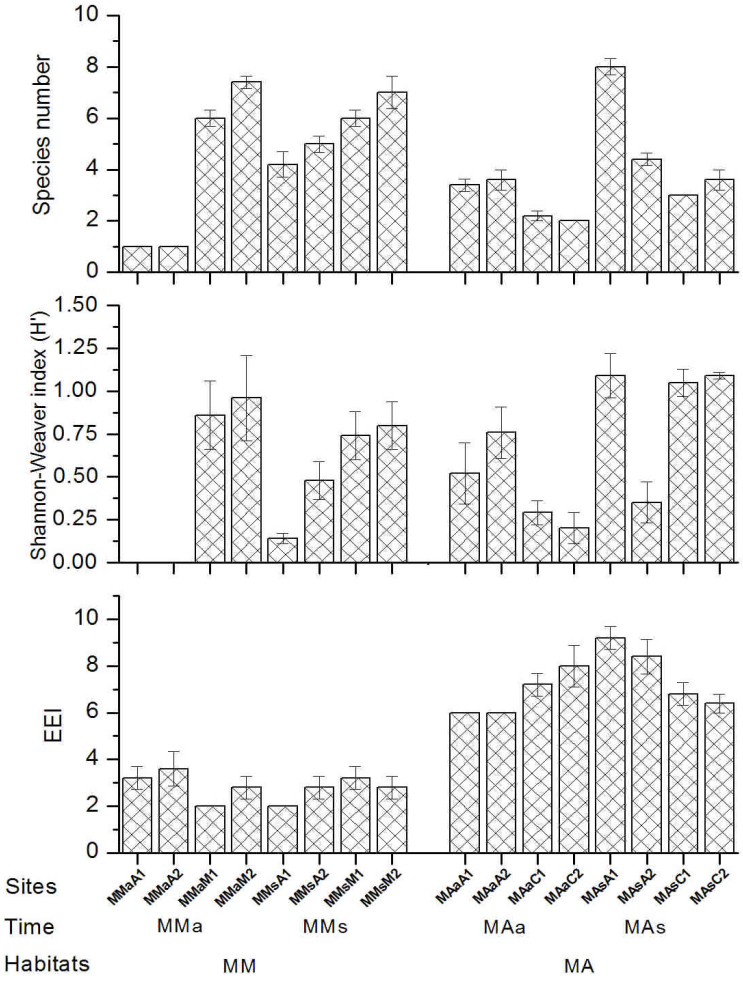

Figure 1. Mean values (± SE) of species number, Shannon-Weaver index and EEItrend indices. MM=mud with macroalgae, MA=mud with angiosperms, a=autumn-winter sampling period, s=spring-summer sampling period, A=Agiasma lagoon, M=Margherita of Savoia lagoon, C=Cesine lagoon, 1=Site 1, 2=Site 2.

C) Body size descriptor of benthic angiosperms indicate anthropogenic stress

The metabolic theory of ecology combines organism body size distribution with function and dynamic of ecological systems and provides a new theoretical context to develop new indicators of ecosystem quality (Basset 1995). We studied skewness (asymmetry) of log-transformed relative frequencies of *Cymodocea nodosa*'s leaf length (SkLnRfLL) as an easy measurable indicator of anthropogenic stress in selected biotopes of Eastern Macedonia, North Aegean, Greece. Three *Cymodocea nodosa* biotopes of the eastern Kavala Gulf coasts (Nea Karvali, Erateino, Agiasma), with that of Nea Karvali being the most degraded (close to industrial area), were sampled following a random nested sampling design during the seagrass main growth season in July 2004. Statistical significant variation ($p<0.05$) was estimated on the biotope scale, showing maximum mean value in the most degraded biotope and minimum mean values in the less impacted biotopes (Orfanidis *et al.*, 2007).

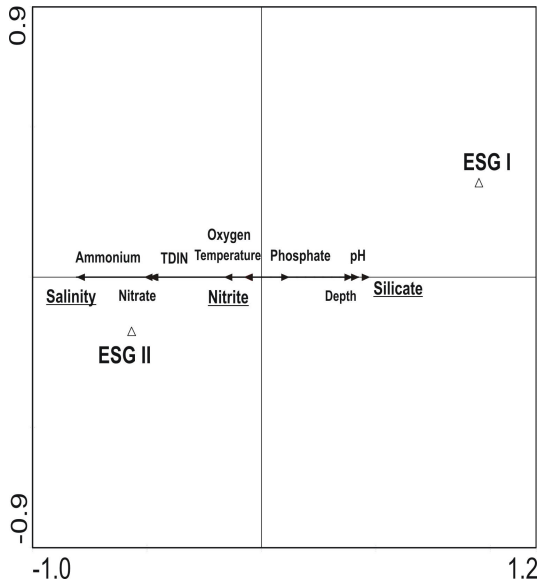

Figure 2. Ordination diagram of samples in relation to abiotic factors analyzed at functional group sensu Orfanidis *et al.* (2001, 2003) levels. ESG=Ecological State Group.

D) Eco-toxicological tests of mechanistic stressor-response relationships

Chemical stressors, e.g. nutrients, heavy metals, have been recognized in conceptual and predictive-assessment models as major underlying determinant of benthic macrophyte community organization along pollution gradients. Two possible relevant mechanisms could be hypothesized: (1) Pollution usually affects the sensitive species and if there is sufficient redundancy, other more tolerant species may fill the functional niche occupied by them; (2) The dominance of a species under certain conditions is related to species' ability to exploit the most abundant resources.

In order to test the above hypotheses the growth responses of the red alga *Grateloupia filicina* to different heavy metals (Cu, Cd) and nutrients (von Stosch synthetic growth medium) concentrations were studied using 4 days factorial batch cultivation eco-toxicological tests. Growth was estimated as relative growth rate using an image analysis system (Image-Pro) (Fig. 3). Statistically significant (ANOVA, $p<0.05$) responses were concluded as follows. By taking into account the synthetic nature of water pollution, e.g. heavy metals, often co-occur with nutrients, and the fact the reported Cu, Cd water concentrations in polluted coastal areas world wide are significant lower than the lethal concentrations identified for *G. filicina*, the results of this study seems to support the second hypotheses.

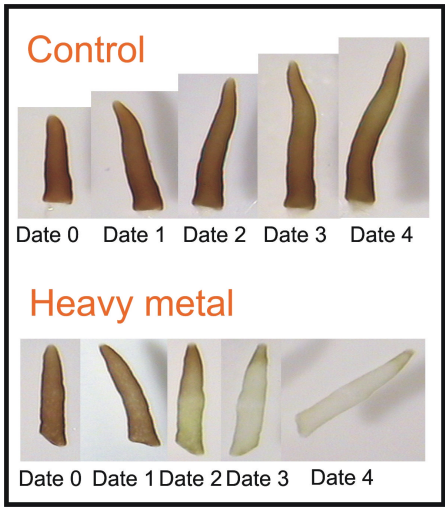

Figure 3. *Grateloupia filicina* tips cultivated in seawater without (control) and with heavy metals.

Conclusions

Benthic macrophyte communities have been successfully used as indicators of eutrophication in transitional waters of Eastern Mediterranean Sea. They provided readable responses with analyses based on a functional group level providing powerful support to traditional species-level analyses. Leaf length asymmetry of angiosperms seems to represent easily measurable early warning indicators of anthropogenic stress in coastal waters. In order to understand macrophyte community organization along pollution gradients laboratory ecotoxicological tests are of paramount importance.

Acknowledgments

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