

Editorial Synthesis and Highlights

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Overall Synthesis and Some Unifying Concepts

The workshop brought together scientists and coastal managers from different areas of the world involved in the development and application of environmental indicators for assessing and predicting the health of coastal ecosystems. Presentations and follow-up discussions focused on three general themes: development of new indicators and their implications for addressing critical coastal-research and management needs; review of relevant measurement, data-analysis, or modelling approaches; and overview of ongoing programmes related to the topic of “Indicators of Stress in the Marine Benthos,” a major emphasis of the workshop. The forum, which included two days of informal and lively round-table discussions, provided an opportunity to discuss ongoing initiatives in related fields from local to international perspectives and to exchange ideas on future directions regarding the use of environmental indicators.

One important theme that emerged was the recognition that a wide suite of tools, methods, and models would be best for such purposes rather than any one single indicator. It was also recognized that there is a wealth of existing biological and environmental observations originating from specific places and research programmes worldwide, and 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 regional to global comparisons. However, while consistent and globally applicable approaches are important, there also is a call for good regional models that provide a basis for understanding the natural states and unique properties of specific systems. Thus, there is also a need for adopting monitoring approaches that recognize and account for natural variations among various regions and ecosystem types.

The following is a list of these and other important unifying concepts that emerged from the meeting:

- Promote the use of weight-of-evidence approaches that bring together information from multiple indicators (e.g., including multiple biological endpoints as well as additional data on chemical, biogeochemical, toxicological, physical, and hydrographic conditions)
- Need for collaborative programmes to help develop consistent and comprehensive sets of indicators and processes for broad applications and comparisons (but at the same time

realizing that there are often major differences among various regions and ecosystem types, and thus that any single indicator may not work consistently across all scenarios)

- Need for better regional models of ecosystem health to help in evaluating status and trends in ecological conditions within the region and understanding whether observed changes are due to natural or human-induced sources
- Need for reliable and accurate taxonomy as a starting foundation for many benthic indicators
- Borrowing from models of freshwater ecology may serve as a useful analogue for marine applications
- Although the benthos was a major emphasis of the workshop, it is also important to think about other biological receptors that are easy to measure and may be more directly linked to public perception.

Several presentations also addressed the topic of what an ideal ecological indicator should be, with the term indicator in this case being a measure of some important attribute of the ecosystem (either biological, physical, geological, or chemical). There was general consensus that a good indicator in this context might be one that consisted of as many of the following features as possible (also see Fisher *et al.* 2001, Cairns *et al.* 1993):

- Conveys information that is meaningful and useful in decision-making with respect to the risk of concern
- Linkage to a conceptual stressor-response framework with corresponding thresholds signally the onset of conditions that may result in significant ecosystem degradation and thus require management action
- Amenable to measurement and preferably easy to measure
- High predictive ability (indicative of stress where stress should be occurring)
- Applicable over broad regions and environmental conditions
- Capable of surviving legal interrogation.

Other types of indicators were discussed and embraced including the use of various data-analysis techniques to assess change (e.g., basic statistical approaches; graphical methods; multivariate methods of classification and ordination; and diagnostic indices); the use of biological and oceanographic models that characterize the natural state and properties of a system, and thus provide a basis for detection of adverse change; and weight-of-evidence approaches (such as BENTIX, AMBI, and the Sediment Quality Triad) that combine suites of complimentary measurements as a basis for assessing current status and potential changes in environmental quality. Further highlights are summarized below.

Specific Highlights

An example of efforts to develop and evaluate indicators from a global (multi-regional) perspective was provided through presentations by the UNESCO-sponsored Ad-hoc Study Group on Benthic Indicators (<http://www.ioc.unesco.org/benthicindicators>), formed in December 1999 by the Intergovernmental Oceanographic Commission (IOC) of UNESCO. Following welcoming words by the workshop's co-organizers, P. Magni (IMC representative and member of the IOC Study Group on Benthic Indicators) and O. Vestergaard (IOC/UNESCO representative), the first three presentations were given by members of this international initiative. J. Hyland (NOAA, Charleston,

South Carolina, USA) gave an overview on the scope and activities of the committee, and J. Shine (Harvard University, Boston, Massachusetts, USA) presented results of the committee's recent efforts to look at organic-carbon content of sediment as an indicator of stress in the marine benthos. Macroinfaunal and TOC data from seven different regions of the world were examined to look for patterns of association consistent with conceptual-model predictions and to identify TOC critical points indicative of low to high risks of reductions in benthic species richness. R. Warwick (PML, Plymouth, England), member of the same IOC Study Group, also gave a presentation on the use of taxonomic distinctness (Δ^+) as an additional response variable for evaluating potential changes in the integrity of benthic communities in relation to anthropogenic disturbances. Desirable attributes of this and related measures of biodiversity that would be especially useful in the committee's work, as well as other similar programmes, include high sample-size independence, low sensitivity to "noise" in the data, robustness to influences of natural controlling factors (e.g., changes in salinity), and high sensitivity to detection of pollution impacts.

There were additional presentations and discussions that pertained to the topic of benthic-TOC relationships. D. Tagliapietra (CNR-ISMAR, Venice, Italy) presented the results of a large survey conducted in the Venice lagoon and showed how, and to what extent, the spatial patterns of benthic assemblages can be a function of organic matter. Tagliapietra stressed the importance of considering the degree of lability of organic matter and added that, particularly for transitional systems, the residence time seems to have a major effect on the "physiological" distribution patterns of species diversity. A proposal was then made by S. Guerzoni (CNR-ISMAR, Venice, Italy) to implement international protocols to foster the use of common methodologies (*i.e.*, TOC and organic-matter determination) and thus to help facilitate the comparison of results among different study areas. There was a general agreement on this matter. Besides the need for a better standardization of methodologies, the value of TOC as a screening-level indicator was recognized, in addition to its importance as a fundamental variable in the definition of the trophic state (and anthropogenic impact) of an ecosystem. Such efforts to standardize monitoring approaches should be applied to other variables and endpoints as well (not just the measurement of TOC).

An action plan resulted from this latter discussion. Specifically, P. Viaroli (Parma University, Italy), Tagliapietra, Guerzoni and Magni — who are all members of "LaguNet" (the Italian Network for Ecological Research in coastal lagoons and transitional waters, www.dsa.unipr.it/lagunet) — proposed to test benthic-TOC relationships in samples from relatively similar systems, using historical datasets from coastal lagoons in Italy. The focus of such an exercise on a particular typology of coastal-marine systems might help to reduce variability in the data due to natural factors (e.g. estuaries *vs.* coastal sites, or oligotrophic *vs.* eutrophic systems), which could otherwise mask any potential effects due to anthropogenic factors. It was thus agreed to make such comparisons, based on several existing studies conducted in lagoons around Italy. As a first step, which was already started in December 2004 (Magni, Tagliapietra and Viaroli, pers. com.), each group of investigators will work autonomously on a volunteer basis, using their respective data sets. Following these initial independent analyses, there would then be an *ad-hoc* meeting among the participants to compare individual results and to discuss ways of merging the various datasets in support of a combined integrative analysis. Proper funds should be searched along the way, at both the ministerial and private level. Similarly, regarding other future efforts to coordinate results of individual research and monitoring programmes, it was proposed and agreed to have a data exchange among various participants in order to correct for potential methodological differences (e.g., sample size, sieve size, etc.) and to see whether meaningful patterns can be detected.

Other significant points and recommendations were made as well. With regard to comparing and predicting trends in benthic community structure, M. Scardi ("Tor Vergata" University, Rome, Italy) suggested that marine ecologists should be in touch with the freshwater scientific community

and take into consideration the significant experience they have gathered from these systems. H. Rumohr (IfM-GEOMAR, Kiel, Germany) also pointed out the need for developing and using regional biological models (such as the five-step benthic succession model for the Baltic Sea) as a management tool. Such models would provide a basis for understanding the natural state and properties of a system within a particular region and what to expect under disturbed conditions. À. Borja (AZTI Foundation, Spain) further underlined the need for recognizing and accounting for variations among different regions and systems. Borja, for example, pointed out the major differences that exist between northern and southern Europe. This point was also reinforced by Viaroli who described inherent differences between large and well-flushed estuaries vs. sheltered lagoons with high water retention times.

With regard to management applications, H. Rees (CEFAS, UK) gave an overview of criteria for evaluating scientific and management effectiveness of benthic indicators, which he presented as one of the current initiatives being addressed by the International Council for the Exploration of the Sea (ICES). Key criteria used in a preliminary ranking of several existing indicators are included in the list above. Rumohr presented a five-step succession conceptual model applied to the southern Baltic (as mentioned above) and highlighted the benefits of combining routine benthic sampling with sediment-imaging techniques. Rumohr, as a member of ICES and Chair of the Benthos Ecology Working Group (BEWG) of ICES, also introduced briefly the work of ICES and BEWG. ICES is the oldest organization that coordinates and promotes marine research in the north Atlantic. It acts as a focal point for a community of more than 1600 marine scientists from 19 countries around the north Atlantic. ICES plans and coordinates marine research through a system of committees, including more than 100 working groups, that cover most aspects of the marine ecosystem. The Benthos Ecology Working Group, a group of 20-25 scientists, is planning to hold a symposium on Marine Environmental Indicators in connection with the ICES "Study Group on the North Sea Benthos" in 2007. Hyland, Chair of the UNESCO/IOC *Ad-hoc* Study Group on Benthic Indicators, proposed that the 2007 ICES symposium be a forum for the presentation of any data and collaborations that may result from the present Sardinia workshop. Rees, co-convenor of the 2007 ICES symposium, also agreed to include any such developments in the symposium agenda. This idea was unanimously accepted by the workshop participants.

Presentations by À. Borja (AZTI, Spain) on the use of the AMBI Biotic Index, and by A. Zenetos (HCMR, Greece) on the use of the BENTIX index, were discussed in the context of the European Water Framework Directive (WFD 2000/60/EC), with this latter programme being described in more detail by C. Silvestri (APAT, Rome). AZTI and BENTIX were further compared in the presentation by G. Forni (Pavia University, Italy) who tested both approaches on benthic communities in the northern Adriatic Sea. Results showed that the two newly developed indices, based on the same principle (ecological identity of benthic species according to their response to pollution) produce somewhat similar results. However, there are discrepancies observed in the scoring of species and further restrictions to their use in certain environments. It was agreed that the differences should be resolved by collaboration of the two groups (AZTI and HCMR) and, if possible, that the two indices be integrated into a common tool in efforts to minimize confusion among scientists working in the Mediterranean area.

A. Marchini (Pavia University, Italy), using data on the distribution of hard-bottom assemblages in the Lagoon of Venice, described a new and innovative approach, the "fuzzy logic" model, as a potentially powerful tool for classifying different ecological sectors in such dynamic systems that are controlled by a complexity of natural factors and human influences. Furthermore, I. Karakassis (University of Crete, Greece) proposed new tools and prospects for environmental impact assessments in areas of fish farming in the eastern Mediterranean. Viaroli also proposed a biogeochemical approach to evaluate ecosystem functions and properties in coastal lagoons. Additional approaches included the use of thermodynamic and network-oriented indicators by P.

Vassallo (Genoa University, Italy) and community-structure models by E. Fresi and M. Scardi ("Tor Vergata" University, Rome, Italy). M. Zavatarelli (Bologna University, Italy) gave an overview of the Adriatic Sea ecosystem-modelling initiative, and discussed the application of a coupled physical/biogeochemical ecosystem model as a preliminary step to operational forecasting and climate-change studies of the Mediterranean Sea ecosystem.

Regarding broad-scale indicator testing at the European level, it was expressed that in spite of efforts of the European Environment Agency (EEA), various countries may not be ready yet to deliver large sets of data to EEA for such purposes. Consequently, pertinent results to date are based largely on smaller-scale case studies (e.g., Greek and Norwegian data sets). At the regional level, Zenetos on behalf of UNEP/MAP (United Nations Environment Programme, Mediterranean Action Plan) indicated that a current task of UNEP/MAP is the preparation of fact sheets on biological indicators, so as to issue guidelines on EQS to be used by Mediterranean countries. Initial results of the testing were presented with data from Greece, Turkey, Syria, Italy and Spain. A major future task will focus on additional validation with other data sets, which will require further collaboration among countries throughout the entire Mediterranean region.

There is also a need for a common set of indicators and monitoring approaches for use in shallow transitional waters (e.g., wetlands and coastal lagoons) that account for some of the unique properties of these systems. For example, one of the major goals of the EU Framework Water Directive (2000/60/EC) is to promote an agreed-upon and common approach to studies of biogeochemical processes as support for management and policy applications. Within this context, Viaroli made a brief presentation of the LaguNet network (also see above). LaguNet provides a forum for discussion and cooperation between researchers who are studying biogeochemical processes in lagoons, wetlands, and salt marshes along the Italian coasts. Key goals of LaguNet include conducting assessments of the quality of these systems, interacting with important stakeholders, and developing EU project-proposals either in Italy or in Europe (with Mediterranean EU partners as well as eventually eastern Europe and North Africa). An overarching goal of LaguNet is aimed at promoting common approaches to the study of biogeochemical processes in these ecosystems that can provide support to management or policy applications.

The LaguNet approach was also developed in Greece and Portugal, is in progress now in the Black Sea region, and will be further implemented in Spain. Overall, a product of this bottom-up networking would be a regional network federation, covering the Southern European Arc (SEANet). The LaguNet approach also has been used within the implementation plan of the Coastal module of the Global Terrestrial Observing System (C-GTOS). The goal here has been to characterize the basic stressor delivery system, namely the release of organic matter, phosphorous (P), nitrogen (N) and chemicals from watersheds into the adjacent ocean systems. A significant challenge is that shallow transitional waters and coastal lagoons are under the influence of multiple factors and have a great internal patchiness and heterogeneity, which can often bias the application of the most common indicator and indices of environmental quality and health status. Here, water-quality criteria that are suited for deep lakes and marine ecosystems cannot be used due to the shallow depth. Overall, the water-volume/surface-area ratio is of paramount importance in determining levels of ecosystem metabolism throughout benthic communities. Issues to be analysed cannot be resolved by considering only simple variables and linear relationships. Usually, the conventional trophic-status parameters and thresholds developed for deeper systems do not apply to coastal lagoons, the pelagic components being quantitatively less important than the benthic subsystem, especially when macrophytes become dominant. Under these circumstances, one should identify a set of basic benthic/sedimentary variables indicative of operative ecosystem properties and functions and that could be used for classification and quality-assessment purposes.

The approach of these latter networks at present is based mainly on the assessment of biogeochemical budgets of C, N, and P and does not consider benthic-community features. Viaroli proposed to start collaboration between LaguNet and IOC in environmental-assessment and data-exchange issues, in order to help fill some of these critical gaps. O. Vestergaard (UNESCO/IOC) indicated that the collaboration between IOC and LaguNet could help to increase methods of assessment. On behalf of UNESCO/IOC, Vestergaard also pointed out that one of the roles of IOC is to give support for data systems to developing countries. The importance of regional models was again stressed. The need for the development of a rapid-assessment programme also was expressed.

The workshop was a testimony of the importance of bringing scientists and coastal managers together in an international forum to promote open information exchange; to develop a better appreciation of the range in coastal environmental issues and corresponding approaches to addressing them in different parts of the world; and to reach consensus on solutions to some common problems, as well as the need to work collaboratively in the future (e.g., toward the development of consistent sets of indicators and protocols) to provide a stronger basis for understanding and predicting regional to global patterns of coastal-ecosystem health.

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