AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS

Aquatic Conserv: Mar. Freshw. Ecosyst. **18**: S135–S142 (2008)

Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/aqc.950

ElNet: The Greek biodiversity transitional waters information system. An exemplar for the development of distributed information networks in Europe

SARAH FAULWETTER[a], PANAYIOTIS GOTSIS[a], SOFIA REIZOPOULOU[b], SOTIRIS ORFANIDIS[c], THEODOROS KEVREKIDIS[d], ARTEMIS NICOLAIDOU[e], NOMIKI SIMBOURA[b], PARASKEVI MALEA[f], COSTAS DOUNAS[a], ATHANASIOS MOGIAS[d], VASILIS VALAVANIS[g] and CHRISTOS ARVANITIDIS[a,*]

[a] *Institute of Marine Biology and Genetics, Hellenic Centre for Marine Research, Former American Base of Gournes, 71003, Heraklion, Crete, Greece*

[b] *Institute of Oceanography, Hellenic Centre for Marine Research, 19013, Anavyssos Attiki, Greece*

[c] *Fisheries Research Institute, 64007, Nea Peramos, Kavala, Greece*

[d] *Laboratory of Environmental Research and Education, Democritus University of Thrace, 68100, Alexandroupolis, Greece*

[e] *Department of Zoology-Marine Biology, Faculty of Biology, National and Kapodestrian University of Athens, Panepistimiopolis, 15784, Athens, Greece*

[f] *Department of Botany, School of Biology, Aristotelian University of Thessaloniki, 54124, Thessaloniki, Greece*

[g] *Institute of Marine Biological Resources, Hellenic Centre for Marine Research, Former American Base of Gournes, 71003, Heraklion, Crete, Greece*

ABSTRACT

1. Transitional waters are ecosystems of special importance for a number of reasons and require effective management. In Greece, biodiversity and environmental data that help to manage these ecosystems do exist, although they are scattered and not easily accessible. An overarching, publicly accessible system combining all kinds of information has not been available until now.

2. The ElNet system was developed to serve these requirements. The system is a functional application consisting of a comprehensive database and an online interface with an interactive map, and search capabilities for biological and environmental data on Greek transitional waters. Nine datasets have already been integrated and are available online. Data and their metadata are documented and checked for quality to allow comparisons and reduce bias in resulting analyses.

3. The data assembled cover a broad geographical and temporal range, allowing large-scale analyses of transitional waters. These in turn produce new scientific knowledge and provide a sound basis of information for scientists, environmental managers and policy-makers.

4. Examination of the data revealed an overall insufficient quality control practice during data acquisition and digitization. A good data management and archive system can significantly improve the quality of data. To

*Correspondence to: Christos D. Arvanitidis, Institute of Marine Biology and Genetics, Hellenic Centre for Marine Research, Former American Base of Gournes, 71003, Heraklion, Crete, Greece. E-mail: arvanitidis@her.hcmr.gr

encourage scientists to submit their data to a data management centre, a clear data policy document regulating rights and duties could form an incentive for data sharing.

5. Results from a case study carried out on the macrobenthic inventories of the lagoonal systems included in the system demonstrate the potential use of this simple type of information by environmental managers and scientists.

6. The system, still in its initial phase, will be improved by integrating new datasets and developing tools for data retrieval and analyses. The database will be linked to other biodiversity databases to participate in a distributed information network and disseminate the information through other global biodiversity portals.

Received 11 September 2007; Accepted 31 December 2007

KEY WORDS: transitional waters; biodiversity; information system; data management; quality control; taxonomic distinctness index

INTRODUCTION

Transitional waters are water bodies in the vicinity of coastal waters; they are saline but influenced by freshwater inflow. Examples of transitional waters are lagoons, estuaries, brackish wetlands or coastal lakes. They show wide ranges of temperatures and salinities (euryhaline and eurythermic) and high natural biological productivity which improves local economies (e.g. sectors of fisheries and aquaculture, education, recreation). This particular habitat frequently experiences anthropogenic pressure from urban, agricultural or industrial activities. The ecological and socio-economic importance has intensified research interest, and large amounts of data are being produced by many institutions. The resulting analyses provide valuable information towards understanding different aspects of the ecosystem, but this can be taken even a step further: by assembling survey data from different sources, localities and time periods, new patterns on larger temporal and spatial scales can be derived. Data which otherwise might disappear after the first publication can be used for new analyses and can continue to contribute to the understanding of the biodiversity of transitional waters.

Recently, many initiatives have focused on the collection of an increasing number of biological and environmental data which are made available online. Initiatives such as the Ocean Biogeographic Information System (OBIS, http://www.iobis.org), the Dynamic Atlas of the Gulf of Maine (http://gmbis.iris.usm.maine.edu/), Reefbase (http://reefgis.reefbase.org/mapper.asp), the Marine Life Information Network (MarLIN, http://www.marlin.ac.uk/) or the UN Geo Data Portal (http://geodata.grid.unep.ch/) have developed facilities to assemble distributed biological and environmental data and make them available through internet portals. Within the context of the European Network of Excellence MarBEF, two large-scale databases have been compiled: (1) the Macroben database (http://www.marbef.org/data/dataset.php?dasid=631) contains pan-European data on soft-bottom macrobenthos including abiotic readings (Claus *et al.*, 2006); (2) the MANUELA database (http://www.marbef.org/projects/Manuela/index.php) is assembling meiobenthic data for the same region (Arctic to Mediterranean). The knowledge derived from such kinds of assembled data will enrich our understanding of the large-scale marine biodiversity structure and functioning.

Some attempts have been made to manage the information on transitional waters in the Mediterranean and other parts of the world. Table 1 summarizes the features of various information systems on transitional waters. It can be observed that the projects from which the systems have emerged, often have a hydrological background and focus on physico–chemical variables or provide descriptive information about the water bodies without giving species distribution information. Gaps can be identified where an overarching system focusing on biotic and abiotic variables and assembling long-term and large-scale data is concerned. However, to better understand and hence manage ecosystems, comprehensive information is required. Temporal, spatial, chemical, physical and biological components are closely interrelated and affect the structure and functioning of any system; this component complexity results in manifold information that has to be managed (Maurer, 2003).

The effective management of this information demands the following basic elements: (1) a system that is capable of storing all kinds of data (biological, chemical, physical, temporal, spatial and of a generally descriptive type); (2) a data management process that documents and controls the quality of the legacy data and accompanying metadata, thus allowing for comparisons; (3) a medium to make these data publicly accessible. Fulfilment of these requirements has resulted in the development of the ElNet system.

ElNet is part of the Southern European Arc lagoon observation Network (SeaNet-L), membership consisting of national lagoon observation networks. The networks developed are the French (PNEC: http://www.cnrs.fr/cw/dossiers/dosclim/biblio/pigb13/04_chantier.htm), Italian (LaguNet: http://www.dsa.unipr.it/lagunet), Greek (ElNet: http://www.elnet-

DOI: 10.1002/aqc

Table 1. Summary of the available information provided by the information systems existing on transitional waters

Project	Content	Information on water bodies	Species distribution data	Physico–chemical data	Availability of information
California Wetlands Information System: http://www.ceres.ca.gov/wetlands/	Maps, environmental documents, agency roles in wetlands management, restoration and mitigation activities, regulatory permitting, and wetland policies for California	Yes	No	No	Through reports and third parties
OzEstuaries: http://www.ozcoasts.org.au/	Geomorphic type, condition status, political boundaries, geometric and physical measurements (including availability of water & sediment data) of Australian Coasts and Wetlands	Yes	No	Yes	Online database
MedOBIS: http://www.medobis.org/; Arvanitidis *et al*., 2006	Marine species distribution data of the Eastern Mediterranean and Black Sea	No	Yes	Not structured, only free text	Online database
LaguNet: http://www.dsa.unipr.it/lagunet; Viaroli *et al*., 2004	Observational network studying the fluxes of nutrients and other contaminants from lagoon catchments to the near coastal environment of the Italian coast; biogeochemical models	No	No	Yes	Biogeochemical models online, no raw data available
Banca Dati Ambientale sulla Laguna di Venezia; Marani *et al*., 1999	Atmosphere, Hydrosphere, Geosphere and Biosphere of the Venetian Lagoon, Italy	Yes	No	Yes	Online database
GIS for Kotychi lagoon: Kalivas *et al*., 2003	Spatial features of Kotychi Lagoon, Greece	No	No	No	Offline
Database for the northern Greek littoral lake: Shttp://balwois.mpl.ird.fr/balwois/administration/full_paper/ffp-766.pdf	Information on physiochemical parameters, flora and fauna, fishery production, human interventions, land uses, protection level, characteristics of the water bodies, management plan and measures for the protection, rehabilitation and sustainable development of the Northern Greek littoral lakes	Yes	No	No	Offline
BALWOIS: http://www.balwois.net/	Hydrographic information on Balkan Inland waters	Not accessible	No	Yes	Only for project members
TWReferenceNET: http://www.twreferencenet.com	Scientific environmental meta-data and socio-economic information for 22 transitional ecosystems located in Italy, Greece, Romania, Bulgaria and Albania	Yes	Yes	Yes	Only for project members

DOI: 10.1002/aqc

Table 2. Summary of the information stored in the ElNet information system

Content	Value
Number of datasets	9
Area covered	Greek lagoons of Rodia, Tsopeli, Logarou and Tsoukalio in the Amvrakikos Gulf, (Northern Ionian Sea); Monolimni and Laki in the Evros Delta, (North-Eastern Aegean Sea); Papas, (Southern Ionian Sea) and Vivari (Western Aegean Sea)
Number of taxa (incl. higher classification)	836
Number of species distribution records	1125
Time period covered	June 1990–July 2005
Number of abiotic readings	300
Number of lagoons with abiotic readings	7
Number of sampling stations	13

net.gr), Portuguese (PlaNet), the Baltic (Balloon: http://www.balticlagoons.net) and the newly founded Spanish network (RedMarisma) as well as the European Union projects DITTY (http://www.dittyproject.org) and TWReferenceNET (http://www.twreferencenet.com). These networks offer a significant scientific contribution by networking transitional ecosystems through functional links of monitoring, conservation and management strategies.

Potential user groups have been involved during the development phase of the system. The developers have contacted scientists, environmental managers (e.g. authorities in the Greek Ministry of Agriculture and in the Ministry of the Environment and Public Works), fishermen's associations and non-governmental organizations (NGOs) in the vicinity of the Amvrakikos Gulf (Western Greece), and individuals involved in higher education. Their needs have been recorded, and, as far as possible, addressed by the system. As an example, a 'case study' has been attempted in the course of this initial phase, by using only lagoonal species inventories and their taxonomic classification, in order to calculate sample-size, sample-effort free biodiversity measures (taxonomic distinctness, Warwick and Clarke, 1998). This example clearly demonstrates the usability of the system for many of the afore-mentioned user groups, even by including this simple form of information.

MATERIAL AND METHODS — DESCRIPTION OF THE SYSTEM

Overview of the system

The basis of the ElNet system is formed by a relational database capable of storing different types of data and measurements — from geographical, physico-chemical to biological data — as well as documenting the underlying sampling process. Given that future types of data which might be integrated into the system cannot be predicted, the database has been structured in such a way in order to allow enough flexibility to incorporate all types of measurements. The database can be accessed through various tools on a web interface that provides different modes of search functions, allowing the user to focus on limited subsets of data by taking into account various aspects of time, space, environmental parameters or taxonomic groups.

Raw data

Setting up a data management structure for environmental and biological legacy datasets is not a straightforward task owing to the problematic aspects of these types of data (Koschel *et al*., 1996; Günther, 1997). During the storage processing it has to be considered that the data: (1) have come from different sources; (2) have been collected for different purposes; (3) are very heterogeneous in structure and format; (4) have very different contents (e.g. different parameters measured); (5) are complex (geographical, temporal, taxonomic, environmental coverage); (6) have been collected under different circumstances; (7) are often insufficiently documented and consequently of variable quality. Similar problems were encountered during the development of the ElNet system and the integration of the datasets.

Currently the system comprises nine different datasets from Greek lagoons and estuaries, including information on species distribution and taxonomy, sampling information, abiotic readings and descriptions of the water bodies. All information is geo-referenced, meaning that it can be related to a certain location — either a sampling station with given coordinates of latitude and longitude or a whole lagoon; in the latter case the information is linked to a large but well-defined area. A summary of the database contents can be found in Table 2.

Metadata

The ElNet information system stores not only real data but also metadata. Metadata are defined as those data describing

DOI: 10.1002/aqc

the 'what', 'who', 'where', 'when' and 'why' component of the actual data, and enable the user to judge the 'fitness' of the stored data for a certain purpose and to compare the data with that obtained in another research context. This meta-information has to be presented along with the actual data in order to reduce the chance of wasted scientific effort and of false conclusions.

The data in the ElNet database are described by different metadata categories that summarize and describe the content of the individual datasets: (1) general, which includes dataset name, version, date of release, dataset description, keywords, restrictions; (2) involved persons and institutions and their role (data owner, custodian, manager, etc.); (3) description of included information (geographical, environmental, biological, etc.); (4) description of temporal and geographical coverage and resolution; (5) description of taxonomic coverage and resolution (taxonomic groups, level of identification, number of taxa, number of distribution records); (6) publications, links, images and other media related to the dataset.

Quality control

Every step in the information management chain, from data collection to the final use of the data can be a possible source of errors. Errors include imprecise and inaccurate data that devalue the overall quality of the data if they are not detected and documented (Chapman, 2005). During the data management validation, processes are undertaken to detect inaccurate, incomplete or invalid data and documents and, where applicable, to correct these errors.

Various tools and standards are available to detect errors in data. Taxonomic names can be compared with species registers such as the European Register of Marine Species (ERMS; http://www.marbef.org/data/erms.php), the Integrated Taxonomic Information System (ITIS; http://www.itis.gov/) or the Catalogue of Life Species2000 (http://www.catalogueoflife.org). These registers cannot be regarded as the ultimate correct source, but they do attempt to establish a high standard by involving taxonomic experts to review those lists. Geographic data can be checked for outliers in latitude and longitude by a local GIS application: suspect records (e.g. marine records falling on land) can be detected easily by superimposing the sampling stations on a map.

The data in the ElNet database are controlled for possible errors by first checking all taxonomic names against ERMS: if taxon names cannot be found in ERMS, other registers such as the afore-mentioned, or scientific literature and expert opinion can also be employed. The source and date of the 'validation' of the taxonomic name are documented along with the name. Unaccepted names, at least as in those cases described by the International Code of Zoological Nomenclature (ICZN) and the International Code of Botanical Nomenclature (ICBN) (e.g. synonymy, misspelling) are not corrected but directed to the correct name and the reason for the decision is given. Secondly, geographic records are checked for outliers by visualization through a local GIS application. Thirdly, plausibility checks are performed through database queries (e.g. comparison of start date and end date of sampling (end date should be after start date), abundance and biomass should have positive values), as recommended by Chapman (2005).

The rate of newly-generated errors by the data management (during data entry, correction etc.) is kept as low as possible, by virtue of the following precautions: (1) use of a relational database with foreign key constraints (referential integrity, ensures the accuracy of entries); (2) use of a data entry interface that provides: (i) pull-down menus, (ii) domain checks, (iii) controlled vocabulary, (iv) automatic completion and calculation of fields, (v) validation rules during entry, and (vi) programmed plausibility checks (all the previously mentioned features contribute significantly to reducing errors during the data entry); (3) documentation of any entries or changes by an automated audit log, so that changes can be traced and in cases of uncertainty the audit log can help to determine when a record has been created or modified, by whom and what the previous value had been; (4) automated data import — large parts of the data can be imported automatically to the database through the user interface if they are present as comma separated value (csv) files.

Case study

To demonstrate a possible use of the ElNet system for environmental assessment and decision-making, a simple case study has been carried out based on the simplest form of data available through the system. Biodiversity patterns have been explored in a study of eight Greek lagoons by the calculation of the taxonomic distinctness indices (Warwick and Clarke, 1998). Average Taxonomic Distinctness (AvTD) was used to assess macrofaunal biodiversity of the Greek lagoons included in the system. This index was applied to the total macrofaunal list as well as to the list of polychaete species. To calculate the index, a presence/absence matrix consisting of 127 macrofaunal species from eight Greek lagoons was assembled along with an additional aggregation matrix, which included information on their taxonomic/phylogenetic classification. The 95% confidence limits funnel showing the estimated distribution of the average taxonomic distinctness values was constructed from a random subset of the species inventory of 20 Mediterranean lagoons (using a list comprising 14 lagoons, by Arvanitidis *et al.* (2005a), amended with data from the ElNet database). This list contains 353 macrofaunal species. The estimated $\Delta+$ values calculated from the lagoonal species inventories were superimposed on the funnel. Values

DOI: 10.1002/aqc

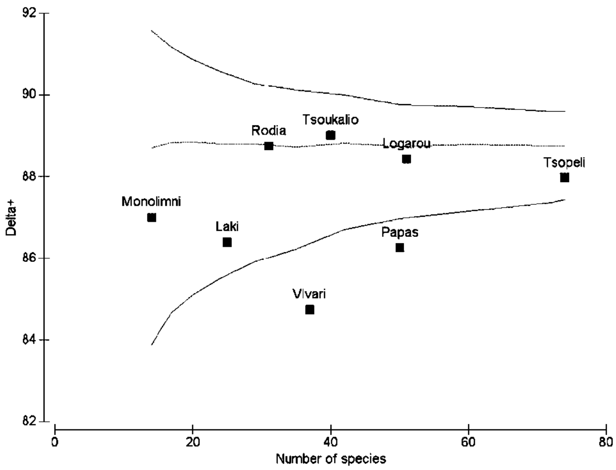

Figure 1. 95% funnels for the Average Taxonomic Distinctness Index, calculated for the macrobenthic species inventory from eight Greek lagoons.

falling outside the funnel show a significant divergence from the expected taxonomic spread.

RESULTS AND DISCUSSION

The ElNet, an online biodiversity information system on Greek transitional waters has been set up and so far, a database integrating biological and environmental data on Greek lagoons and a functional and easy-to-use web interface have been developed and released (http://www.medobis.org/dbase-elnet/). This application forms a source of information that has not existed until now: an overall system able to unify all available data on Greek transitional waters over a broad geographical and temporal range. The continuously growing assemblage of data on transitional waters opens the way for unique analyses and provides new knowledge on the state of these particular ecosystems over time and space. These efforts help the scientific community as well as environmental managers and policy makers by providing a solid basis of information on which analyses and decisions can be based.

Quality issues

During development of the system and population of the database several problems concerning data quality became apparent. Quality control and quality assurance is an aspect that becomes more and more important when datasets from different sources are merged; however, the scientific community has only recently started to acknowledge this fact (Dalcin, 2004). Taxonomic data are noticeably error-prone, or at least errors are relatively easy to detect in this domain. To give an example—of the 294 different taxonomic names submitted to the ElNet database, only 53 are error-free (error-free in this case is defined as taxonomic name, including author and year of publication, can be found in an authoritative source such as an online species register or recent taxonomic literature). Most of these inconsistencies result in a missing reference for the author and year of publication, sometimes the genus is abbreviated, misspellings or synonyms occur and many records include multiple errors. The inconsistencies in taxonomic data are shown in Figure 2. This figure shows that misspellings and synonymies are very common but could be avoided by carefully checking the nomenclature against an approved species register or the taxonomic literature. In this context, the further extension, improvement and validation of online species registers is encouraged. ITIS, for example, still contains about 33% legacy data that have not yet been approved by taxonomic editors.

Validating species names against a register, however, cannot prevent errors that occur during identification. These mis-identifications remain hidden from the data manager, and without documentation of the person performing the identification (taxonomic expert, trained ecologist/ biologist, student) the data manager and/or the end user can only rarely evaluate the quality of the data. Samples identified by a taxonomic expert are likely to have a lower rate of mis-identifications than samples identified by a student, but these circumstances remain hidden from the user, who receives only a species list on the screen. Scientists should therefore be encouraged to document their data and provide a good description of methods (including any quality assurance procedures followed), persons involved and other descriptive data, such as identification keys and literature employed (Olson and McCord, 1997). Datasets should always be submitted with the supporting metadata, in order to assess the quality of the dataset.

Results from the case study

The calculation of the average taxonomic distinctness values for the eight Greek lagoons included in the system showed that all but the Papas and Vivari lagoons fall within the expected 95% funnel (Figure 1). The Papas lagoon, opening to the Patraikos Gulf and the Ionian Sea, is strongly affected by eutrophication phenomena and characterized by prolonged seasonal hypoxia and frequent anoxic events (Reizopoulou and Nicolaidou, 2004). The Vivari lagoon, located in the eastern part of Peloponnese (Argolikos Gulf), has been proved to be moderately disturbed, according to the Size Distribution Index proposed by Reizopoulou and Nicolaidou (2007). Here, although no obvious sources of pollution are documented, a sudden disappearance of vegetation has been reported. All of

DOI: 10.1002/aqc

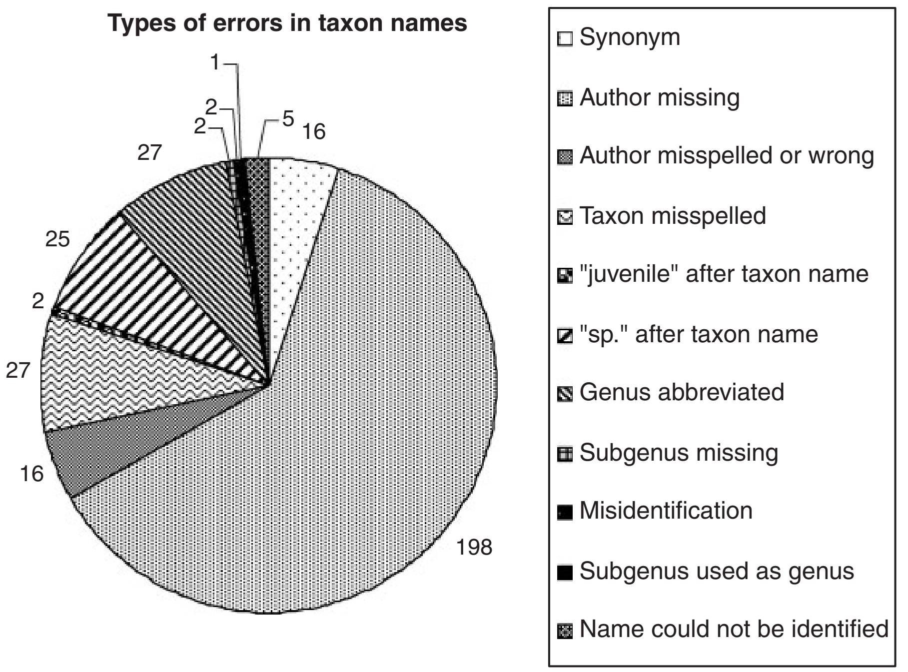

Figure 2. Types of errors (in numbers) in the nomenclature of taxonomic names in the ElNet database.

the remaining lagoons are not considered to be severely affected.

Application of the non-metric MDS ordination revealed the expected zoogeographic gradient, in accordance with that shown by Arvaniditis *et al*. (2005b) for the total of the Greek lagoons (not shown).

The afore-mentioned results show the potential use of the simplest type of information included in the system by: (1) environmental managers looking for data on the ecological status of the lagoons in the cases of environmental impact assessment studies; (2) scientists looking for examples of lagoonal gradients over large scales of observation.

Future data acquisition

Until recently, investigators were reluctant to make their data widely available. Submitting the data to an approved national or international data centre, however, has many benefits if a framework is provided. A clear data policy defining the rights and duties of the individual parties is essential to regulate rights on co-authorship and to prevent misuse of data. An example of such a policy is the Declaration of Mutual Understanding (DMU) for data sharing in the MarBEF Theme 1 Workpackage (http://www.marbef.org/documents/Theme1/DMUDataSharing.doc). If such a legal document about sharing and using the data exists, scientists, data owners (usually the financing body) and end-users may profit from the data management services, resulting in improved quality control, assurance of longevity through proper archiving and free access to data and knowledge (Olson and McCord, 1997). Developments towards this end are also endorsed by the European Directive 2003/04/EC on public access to environmental information (European Parliament and Council, 2003). The creation of a regulation agreement on data sharing in the framework of the ElNet project should be tackled in the near future to encourage more investigators to submit their data to the database, which in turn helps to complete the knowledge about the transitional water systems.

Future improvements of the system

It has already been indicated that the system is still in its infancy phase. The presented solution appears adequate as a prototype introducing the project to the scientific community; however, not all planned features have so far been implemented. Future work will include the acquisition of new datasets and the development of new components that provide: (1) additional customized interaction features for the user; (2) the possibility to link the database to other biogeographic databases for real-time data exchange and

DOI: 10.1002/aqc

comparison; (3) online tools to analyse spatial and survey data. Completing these tasks can turn the system into a very powerful tool to assess the biodiversity and the environmental status of Greek transitional waters.

Value of information systems for conservation issues

A gap analysis has shown that the existing information systems on transitional waters do not entirely cover the needs of conservationists and environmental managers, concerning the availability of data. The ElNet system has been set up as an example for a useful online information system able to store and provide quality-controlled data, through which the defragmentation of the research activities carried out in this habitat can be combated and the continuity of the value of the data to future analyses can be ensured. Assistance for the estimation of biodiversity change, both at smaller and larger temporal and spatial scales, may also be provided by such an information system. All of the above attributes may well lead to a better understanding and consequently to conservation and management of these particular ecosystems.

ACKNOWLEDGEMENTS

This study forms part of the Core Lagoonal Biodiversity Programme of the Institute of the Marine Biology and Genetics and of the Institute of Oceanography (HCMR). The authors acknowledge support by the TWReferenceNet Project (Contract No: 3B073). The authors wish to thank Professor Anastasios Eleftheriou and Mrs Margaret Eleftheriou for the critical reading of the manuscript. The two anonymous reviewers are thanked for their critical comments and suggestions.

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DOI: 10.1002/aqc