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Integration of ecosystem-based tools to support coastal zone management

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ABSTRACT

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Over the past decades policy makers have defined new legislative and policy instruments to address coastal ecosystem degradation. It is important to provide coastal managers with scientifically based information with which they may evaluate the performance of previously adopted responses as well future management policies. This implies the use of scientific applications that enable (i) the understanding of ecosystem biogeochemical processes, (ii) interaction of ecosystem's ecological and socio-economic components, and (iii) synthesis and communication of complex outputs to managers. The integration of tools, such as geographic information systems, ecological modeling (of both catchment and coastal systems), economic valuation methods and integrated environmental assessment, can empower coastal managers with a scientific framework for sound decision making. We present a case study reviewing the application of such a set of tools to support management of a coastal lagoon located in the South of Portugal. This ecosystem and its catchment were chosen given the considerable interaction between the ecological and socio-economic systems: on the one hand this coastal zone includes sites of environmental importance recognized by several international conventions and directives and on the other hand it supports several economic activities that represent the main source of employment and income in the region.

ADITIONAL INDEX WORDS: *Integrated coastal management (ICM), Ecosystem-based management tools, Integration of science and management.*

INTRODUCTION

Coastal zones exhibit complex interactions at different levels: (i) they are under influence of a great variety of pressures at the interface between land and sea, (ii) they are subject to feedback effects between natural and human systems (TURNER et al. 2003), (iii) they exhibit complex relationships between the physical and biological processes – in particular estuaries are characterized by complex ecological feedbacks (BERGAMASCO et al., 2003). Coastal zones are highly productive and provide significant direct and indirect socio-economic benefits, e.g. food, biodiversity, nutrient cycling, climate regulation, recreation, culture and amenity (MA, 2005). As a result coastal zones concentrate 40% of the world population and 61% of world's total GNP (MA, 2005). However, their misuse is causing degradation and consequently decreases of the services that these coastal ecosystems deliver (MA, 2005). The Millennium Assessment (MA, 2005) also indicates impact on human health: of the annual cost due to coastal water pollution (16 billion USD) a large proportion is related to human health.

To address coastal zone problems, ecosystem-based management (EBM) and integrated coastal management (ICM) are required (BROWMAN and STERGIOU, 2005; MURAWSKI et al., 2008). ICM is a well established approach (GESAMP, 1996; CICIN-SAIN and KNECHT, 1998) defined as a dynamic process for the management of the use, development and protection of the coastal zone (MURAWSKI et al., 2008). It consists of an integrated approach from different perspectives (GESAMP, 1996). EBM is an emerging scientific consensus (MURAWSKI et al., 2008), defined as the use of the best available knowledge about the ecosystem to manage marine resources (FLUHARTY, 2005). The integration of (i) science with management and (ii) natural with social sciences, is critical for effective governance of coastal zones (CHEONG, 2008).

The role of science is to provide the insights and information required to support managers and decision makers (GESAMP, 1996; BROWMAN and STERGIOU, 2005). This implies the use of scientific applications that enable (i) the understanding of biogeochemical processes, (ii) interaction of ecological and socio-economic components, and (iii) synthesis and communication of complex outputs to managers. The integration of tools, such as geographic information systems (GIS), ecological modeling of catchment and coastal systems, economic valuation methods and integrated environmental assessment (IEA), can empower coastal managers with a scientific framework for sound decision making.

The objective of this paper is to review the most used tools for coastal ecosystem research and how they can empower coastal managers for (i) performance evaluation of previously adopted responses and (ii) definition of policies. We provide examples, where possible, of the application of these tools for management of Ria Formosa, a coastal lagoon in the South of Portugal.

GENERAL APPROACH

Integration of ecosystem-based tools

Integrated approaches for environmental management including of coastal ecosystems, have in common (i) the integration of the environmental and socio-economic systems, and (ii) the communication between the scientific, management and local communities (HARRIS, 2002; GREINER, 2004; CHANG et al., 2008; TOMPKINS et al., 2008). Figure 1 synthesizes most common tools used for integrated coastal research and management and the links that are normally established among them. These tools can be used isolated or combined. The inclusion of "System monitoring" in the diagram, highlights the fact that all the tools require data to be

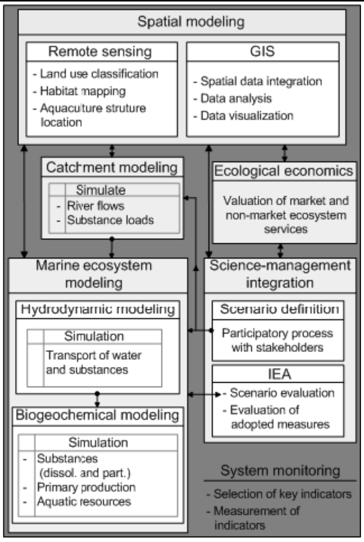

Figure 1. Integration of tools for coastal ecosystem management.

applied. The components of the integrated approach (depicted in Figure 1) are detailed herein in separate sections. For each tool the relevance for coastal ecosystem management was described and illustrated using the same ecosystem. Whenever possible the integration among tools is exemplified.

Case study

Ria Formosa was chosen as a case study due to the considerable interaction between the ecological and the socio-economic systems of this coastal zone: (i) on the one hand this ecosystem has an environmental importance recognized by several international conventions and directives (e.g. RAMSAR, Birds and Habitats EU Directives) and is classified as a Natural Park by the Portuguese legislation, on the other hand (ii) Ria Formosa and its catchment support several economic activities that represent the main source of employment and income in the region. The main economic activities include extensive bivalve aquaculture, tourism, agriculture and livestock, manufacturing industry, fish aquaculture and salt production.

REMOTE SENSING

Understanding the upstream processes that exert a pressure on coastal zones is a very important component. Remote sensing (RS) can provide valuable information, namely for: land use mapping, altimetry, drainage network and other watershed data required for hydrological modeling (PANDEY et al., 2005). RS can also be particularly useful for mapping habitats within coastal systems, e.g. wetlands and mangroves (GREEN et al., 1999) as well as to monitor key surface water quality variables (CHEN et al., 2004). GREEN et al. (1999) and CHEN et al. (2004) provide detailed guidance about the use of RS for ICM. The major strength of RS is that it allows (i) spatially extensive surveys, (ii) monitoring of past situations and (iii) multitemporal sensing of e.g., habitat coverage and condition (LILLESAND and KIEFER, 2000). Such information forms the basis for evaluation of ecosystem services, resource conservation status or pressure evolution over time.

In the Ria Formosa, RS was used to classify the catchment land cover (Figure 2). The enhanced nearest neighbor algorithm was used for supervised classification of a Landsat-7 TM scene (30m resolution). Statistical validation of the supervised classification was carried out by computing a confusion matrix (LILLESAND and KIEFER, 2000) using surveyed test zones. The Khat statistic, which provides an indication of classification performance (LILLESAND and KIEFER, 2000), indicates that classification obtained is 84% better than one resulting from chance.

GEOGRAPHIC INFORMATION SYSTEMS

GIS can be used for spatial data integration (e.g. bathymetry, sampling stations, habitat area, catchment land use), data analysis (e.g. calculation of waterbody volume and area, thematic mapping such as interpolation of sampling station data, zoning) and data visualization (e.g., of the generated thematic maps). These capabilities make it a useful tool for ICM (DOUVEN et al., 2003; TOLVANEN and KALLIOLA, 2008) either as a data generator (if used to extract data for other tools, e.g. setup ecological models) or as an 'end in itself' (if used for communicating information to managers). GIS can integrate with other applications as e.g., ecological models, by offline coupling, whereby the model receives some of its input data from the GIS, or using a tighter integration whereby both the model and GIS share a common interface and communicate directly (FEDRA, 1996). SARDÁ et al. (2005), illustrates the integration of data into GIS, and its use for data processing and visualization targeted to managers. The use of embedded GIS basic functions into Decision Support Systems (DSS) can empower managers by enabling to manipulate, display and analyze spatial data and models (FEDRA, 1996). Another example of GIS use for ICM is to support marine spatial planning for the implementation of relevant legislation (GILLILAND and LAFFOLEY, 2008; MAES, 2008). Examples are provided by (i) CHEONG (2008) for the delineation of Exclusive Economic Zones required by the Law of the Sea Convention of 1982, (ii) FERREIRA et al. (2006) for the division of transitional and coastal waters into waterbodies as determined by the Water Framework Directive (WFD, 2000/60/CE) and (iii) BOYES et al. (2007) for zoning based on legislation applicable within the Irish Sea.

For Ria Formosa there are several examples of the use of GIS for ICM, namely (i) zoning of Ria Formosa for the application of WFD as described by FERREIRA et al. (2006) and (ii) identification of conflicting uses by the Natural Park authority (ICN, 2005). Existing spatially distributed data (either produced by research institutes, universities or local managers) could be compiled for the development of a DSS to support local managers to implement existing and develop future plans.

CATCHMENT MODELING

Integrated land use catchment modeling emerged as a requirement from policy makers and managers to understand the feedback between changing land use and changing environmental conditions (VELDKAMP and VERBURG, 2004). Several studies were developed to understand the effects of land use policy on the environmental and socio-economic systems (VELDKAMP and VERBURG, 2004; MACLEOD et al., 2007). Furthermore, information about catchment pressures is of paramount importance to simulate

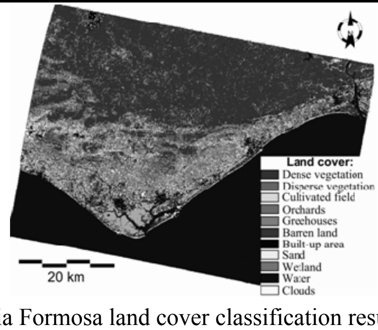

Figure 2. Ria Formosa land cover classification results.

the downstream coastal ecosystems (NEAL et al., 2003). In particular, estimates of substance loads entering from the catchment are required to simulate the biogeochemical conditions of the coastal water bodies. Depending on objectives and available data simpler or more complex approaches can be used: direct estimation techniques, simple export coefficient methods or more complex catchment models (MCGUCKIN et al., 1999; LETCHER et al., 2002; ENDRENY and WOOD, 2003; PANDEY et al., 2005; WADE et al., 2005). The advantage of catchment models is that they allow for scenario simulation of catchment land use. This can be integrated with coastal ecosystem models to determine the impact of the catchment loads.

In the case of Ria Formosa, the runoff is concentrated in the winter months (ca. 71%). Loads entering into this coastal system have been calculated based on river water quality and flow data together with waste water discharge data (MAOT, 2000; Ferreira et al., 2003). However, it is desirable to apply catchment models to determine daily nutrient and sediment loads as well to test relevant management scenarios and respective impacts.

COASTAL ECOSYSTEM MODELING

For the simulation of estuarine and coastal ecosystems there are a large number of models of varying complexity, regarding spatial and temporal scales, components of the ecosystem and processes included (FULTON et al., 2003). Model development normally depends on the research objectives. Recently the use of ecosystem modeling to assist ICM became an emerging requirement (FULTON et al., 2003; NOBRE et al., 2005). In particular modeling can be useful to overcome data limitations and to simulate scenarios. For instance ecological modeling can play an important role for the implementation of the WFD (DE JONGE, 2007). The development of ecological models usually implies integration with some of the other tools in review, at least for the model setup and forcing with boundary conditions (FEDRA, 1996; NEAL et al., 2003).

In the Ria Formosa several models have been applied at different levels, namely a detailed hydrodynamic model and an ecosystem box model that simulate transport, nutrient cycling, primary production and secondary production (bivalves) (NOBRE et al. 2005). The ecosystem model was run to simulate different scenarios relevant for eutrophication management.

ECONOMIC VALUATION

Ecosystem valuation aims to estimate the total and marginal value of the ecosystem services (both the market and the non-market components). There are several difficulties in placing an economic value on natural assets and specially of calculating an absolute economic value of ecosystems (COSTANZA et al., 1997; LEDOUX and TURNER, 2002). Nevertheless, it is of crucial importance that an effort is made to calculate the changes caused on human welfare due to the changes that affect ecosystem functioning (COSTANZA et al., 1997). Valuation can be regarded as a policy tool in the sense that it enables an accounting of ecosystem goods and services, together with the market services, in decision-making and management of coastal systems (BARBIER et al., 1996; COSTANZA et al., 1997; LEDOUX and TURNER, 2002). There is a variety of economic valuation methods broadly categorized either as revealed preference methods (such as hedonic pricing, travel cost or replacement cost) or as stated preference methods (such as contingent valuation and choice experiment), each with advantages and limitations depending on the application. LEDOUX and TURNER (2002) and BIROL et al. (2006) provide a review of the application of such methods for water resources management.

Given the ecological importance of the Ria Formosa and the benefits it generates, it would be appropriate to conduct such a valuation exercise. Considering the economic activities that depend on this ecosystem (aquaculture, fisheries, tourism and salt production) an average benefit of 338 million Euros yr^{-1} (2000 prices) is estimated. This value corresponds to the average net profit generated by these activities for the period between 1980 and 1999 (NOBRE, 2009). Updated and more detailed studies are required to capture other direct and indirect use values. Particularly important is to estimate the values associated with the wetland area (ca. 17 % of Ria Formosa Natural Park area) given the range of benefits this type of ecosystem provides, i.e. food resources, flood water retention, groundwater recharge/discharge and nutrient abatement (ACHARYA, 2000). Detailed guidelines to carry out such studies are provided by BARBIER et al. (1996). In order to estimate an approximate range, the wetlands potential value was evaluated using values provided by GHERMANDI et al. (2008), ca. 100 to 10,000 USD (2003) ha^{-1} yr^{-1}, based on an extensive review of economic value estimates of wetlands worldwide. The estimated value of wetlands in Ria Formosa ranges between 0.30 and 29.54 million Euro yr^{-1} (2000 prices) (USD conversion to Euros was based on the Consumer Price Index rate from the Bureau of Labor Statistics and currency conversion from the IMF).

ASSESSMENT METHODOLOGIES

Integrated Environmental Assessment (IEA) methodologies can be broadly defined as interdisciplinary approaches targeted to guide decision-makers and managers about environmental problems, and in more general terms for natural resources management (TOTH and HIZSNYIK, 1998). IEA methodologies are by themselves integrative tools (CHEONG, 2008) that promote the interaction of ecological and socio-economic disciplines or simply the synthesis of complex information to managers. The Drivers-Pressure-State-Impact-Response (DPSIR) is one such tool that has been widely applied to synthesize natural and socio-economic sciences for marine policy formulation (CHEONG, 2008) and for ICM (LEDOUX and TURNER, 2002). For the application of assessment approaches the selection of key indicators is critical (HÅKANSON and BLENCKNER, 2008). BORJA et al. (2008) reviews existing methodologies to assess ecosystem ecological status in order to address legislation adopted worldwide for management of ecological quality or integrity.

FERREIRA et al. (2003) exemplifies the use of an IEA methodology to inform managers about eutrophication status in Ria Formosa. The work carried out concluded that there is a moderate low eutrophic condition, for which the main symptom identified is periodic blooms of macroalgae in some locations of Ria Formosa (FERREIRA et al., 2003). Further research investigated the effects of nutrient loading scenarios on the eutrophic state of Ria Formosa by coupling the eutrophication assessment methodology with the ecosystem ecological model (NOBRE et al. 2005). The eutrophication assessment methodology used was the USA National Estuarine Eutrophication Assessment (NEEA) method and its successor the ASSETS screening model (BRICKER et al., 2003).

The case study presented by NOBRE (2009) exemplifies how an IEA approach could support the strategic management of Ria Formosa natural resources from both ecological and socio-economic perspectives: The comparison of drivers, pressures and ecosystem state in two different periods (1980/85 and 1995/99) indicates that although there was a significant management response (namely the construction of waste water treatment plants), the negative economic impacts represented 80% to 220% of the response cost (NOBRE, 2009). The decrease of the economic benefits was mainly due to the decrease of bivalve production, which is believed to be related to the appearance of a parasite

(CAMPOS AND CACHOLA, 2006). Aquaculture production in Ria Formosa presently accounts for 47% of the Portuguese mariculture products and it is estimated that bivalve aquaculture alone is responsible for the direct employment of 4,500 people (ICN, 2005) or up to 10,000 according with unofficial estimates (CAMPOS AND CACHOLA, 2006). *Ruditapes decussatus* is the local clam species and its production in Ria Formosa is highly significant (ca. 90% of Portuguese production, in 2001). This species is highly priced (MATIAS et al., 2008), however, it is being displaced by the Manila clam *Ruditapes philippinarum* (CAMPOS AND CACHOLA, 2006). Notwithstanding the incentives for conservation of local clam, the stipulated activities in Ria Formosa Natural Park Management Plan preview for bivalve related management an amount that represents 1.9% of planned total budget (ICN, 2005). Results and information synthesized herein, suggest that is advisable to invest in the proper management of bivalve aquaculture and natural beds with a special emphasis on the seeding procurement or development of local hatcheries, which might have a positive effect on (i) mitigating disease introduction (NOBRE, 2009), (ii) limiting the introduction of alien species (CAMPOS AND CACHOLA, 2006) and (iii) on *Ruditapes decussatus* seed availability (MATIAS et al., 2008).

It is advisable that the relevant authorities should define a set of indicators to monitor effectiveness of the goals established in the several management plans that exist for this ecosystem, the most important being: (i) Management Plan of Coastal Zone between Vilamoura e Vila Real de Santo António approved through Resolution No. 103/2005 of 27 June 2005, focus on the strip of land 500m wide from the seawater baseline and on the marine area limited by the 30m bathymetric line, (ii) Ria Formosa Natural Park Management Plan approved through Regulatory Decree No. 2/91 of 24 January 1991 and currently is under revision, focus on Ria Formosa lagoon ecosystem, and (iii) Hidrographic basin plans of the Algarve streams approved through Regulatory Decree No. 12/2002 of 9 March 2002, focus on the drainage basin of several streams encompassing Ria Formosa catchment area.

CONCLUDING REMARKS

This paper describes a range of tools that can be used to provide coastal managers with scientifically based information for performance evaluation of previously adopted responses as well as future management policies. In order to capitalize on the use of these tools and their integration a tighter iterative collaboration at the ecosystem level between managers and scientists is required, whereby the former should provide the latter with specific management objectives or goals for conservation of a given ecosystem and the services it delivers (ROSENBERG and MCLEOD, 2005). This approach asks scientists for: (i) suggestions about how to achieve those objectives within budget and timeframe constraints, and (ii) monitoring tools to assess the performance of policies adopted. Scientists engaged in this process should focus on addressing the management needs and communicating the information in an understandable and accessible away (TRIBBIA and MOSER, 2008). Nevertheless there are always uncertainties associated with scientific knowledge and predictions. These should be acknowledged, particularly with respect to accuracy, but without holding the ecosystem-based management process.

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