A DECISION SUPPORT SYSTEM IN ICZM FOR PROTECTING THE ECOSYSTEMS: INTEGRATION WITH THE HABITAT DIRECTIVE

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Abstract

The integrated coastal zone management (ICZM) and Habitat directives have the common task, among others, to develop a strategy for the conservation of biodiversity and the protection of the ecosystems in coastal regions. Multiple criteria are needed for management purposes, given that this task entails the following aspects: investigation, assessment and comparison of a range of options for managing human use of coastal resources; collection of these options into feasible portfolios for regional scenarios; assessment and comparison of these scenarios in order to determine the most appropriate regional balance between conservation and other factors; establishment of a follow-up system (including monitoring) for ICZM; creation of an off-set system for biodiversity. The use of a coastal decision support system to assess the various scenarios, build appropriate ecosystem management plans, and carry out simulation analyses will help stakeholders to visualize the long-term outcomes of their decisions and help to build a consensus. Examples derived from coastal systems in the Adriatic Sea (Italy) are presented.

1 Introduction

In the emerging research field of *integrated coastal zone management* (ICZM), sustainability is sought for a complex system on different levels. Important initiatives involving ICZM and Habitat (92/43/EEC) directives study how components, ecosystems and geosystems interact with multiple actors dealing with coastal governance (e.g., state, province, town). The process can be described by an integrated set of indices involving the geo-ecological component, the modelling earth processes, the socio-economic aspect, and the coastal uses at multiple scales [Vallega, 1999], as shown in the model of Figure 1.

ICZM generally needs some software, which can be of different degrees of sophistication. Artificial intelligence (AI) techniques have been applied to environmental problems for a long period of time with good results [Wright *et al.*, 1993; Sazonova *et al.*, 1999; Ceccaroni *et al.*, 2004]. In ICZM, *environmental decision support systems* (EDSSs) are a key support tool for governance and policy making [van Kouwen *et al.*, 2008], and they are based on indices, indicators, models, scenarios and *multicriteria assessment* (MCA). In this paper, systems capable of integrating highly sophisticated software are considered.

2 Materials and Methods

The EDSS is centred in particular on the integration of *rule-based expert systems* (RBESs) and *case based reasoning* (CBR) systems. RBESs possess a fact base or ontology, a knowledge-base of rules, and some inference and search process. The problems addressed through RBESs are very complex and related to specific domains, and they would usually need a human expert (i.e., a large amount of knowledge) to be solved. The central idea of CBR systems is that a solution found for some past case is reused to solve the current problem. By recalling old solutions given to similar problems and adapting them to fit the new problems, CBR systems can improve their performance, becoming more efficient. Furthermore, they do not have to solve new problems from scratch. The memorization of past problems or episodes is integrated with the problem-solving process, which thus requires the access to past experience to improve the system performance. Additionally, case-based reasoners, becoming more competent during their functioning over time, can develop better solutions when faced with equally familiar situations because they do not repeat the same mistakes (learning process).

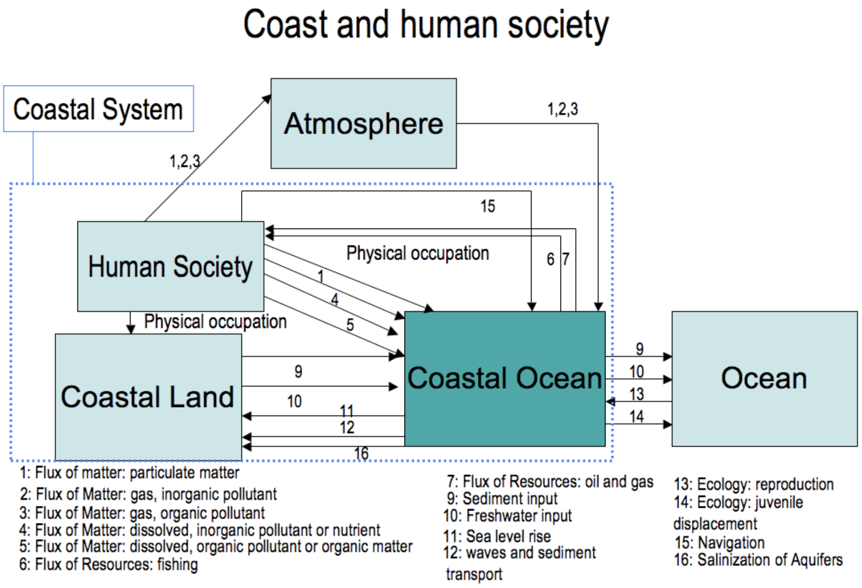


Fig. 1. Conceptual model of coastal system and coastal interactions

The method developed can be divided into several steps, as presented in Figure 2. MCA provides planning solutions (scenarios); Gap analysis assesses the implication for biodiversity and evaluates planning interventions for maintaining (or improving) ecosystem/landscape health. The sustainability indices give the threshold limits between sustainability and un-sustainability. There are two phases of interaction (for both policy makers and stakeholders) in the process: the identification of weights in MCA and the selection of sustainability thresholds.

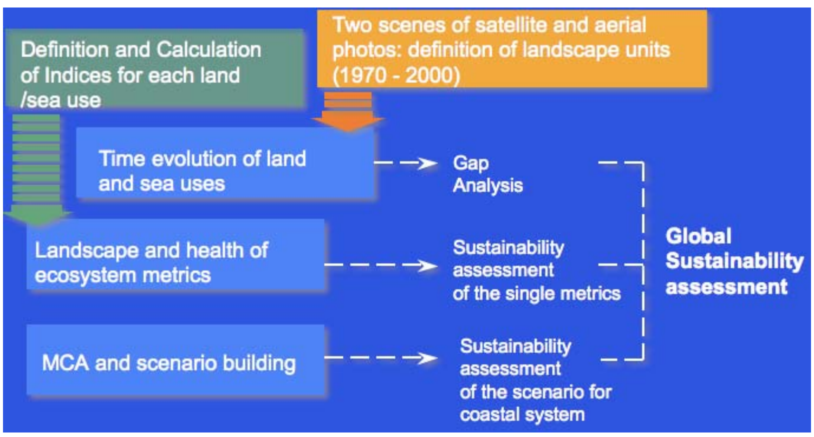
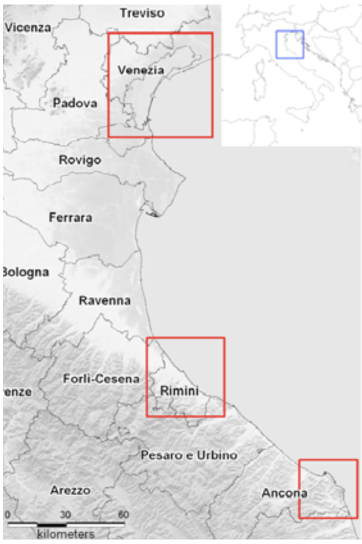


Fig. 2. The general framework developed as a method.

2.1 *Data-processing, landscape ecology, health of ecosystem*

The analysis was carried out in 3 study areas. Lagoon of Venice is characterized by an extraordinary combination of activities: tourism, fishing and industry (petrochemical plants). Rimini area is one of the most important mass tourism areas in the Mediterranean sea. Conero is a wild mountain with a cliff coast, it is a park and Marine Protected Area with important ecosystems and geosites. Close to Conero area, in its northern part, there are an important port (Ancona) and a petrochemical plant (API at Falconara). The areas are examined following the landscape ecology principles. Landscape ecology investigates the complexity of ecological hierarchy, the effect of the spatial arrangement of patches and corridors and the related processes into a geographic area [Farina, 2006]. Among the important applications of landscape ecology to coastal management there are the definition of Homogeneous Environmental Management Units [Brenner *et al.*, 2006], the analysis of spatial and temporal structure, hierarchy and dynamics over multiple scales [Marotta, 2006] and the assessment of cumulative impacts and habitat loss in coastal ecotones [Thrush *et al.,* 2008]. For the landscape analysis and individuation, two Landsat satellite scenes are used for each study area (see Fig. 3). Images are processed into landscape patches units; the classification is carried out by photo-interpretation and ground control. These data are used in order to calculate landscape metrics (fractal dimension and landscape diversity), and sustainability indices and indicators.



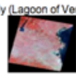
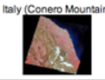
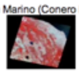
[WRS: P/R]	[Acq. Date]	Dataset	Location (Study Area)
1: 207/029	12-08-1972	MSS	Italy (Lagoon of Venice) 
2: 192/028	26-08-2001	ETM+	Austria, Italy (Lagoon of Venice) 
1: 206/029	28-04-1975	MSS	Croatia,Italy, San Marino (Rimini Province) 
2: 191/029	16-08-2000	ETM+	Croatia, Italy, San Marino (Rimini Province) 
1: 205/030	3-04-1976	MSS	Italy (Conero Mountain) 
2: 191/030	3-08-2001	ETM+	Italy, San Marino (Conero Mountain) 

Fig. 3. The study areas and data used: Landsat satellite images.

The used indices and indicators for sustainability/health metrics are as follows. *Emergy* is defined as all the available energy that was used in the work of making a product and expressed in units of energy [Odum, 1996]. The *exergy* of a system is the maximum work possible during a process that brings the system into equilibrium with a heat reservoir. When the surroundings are the reservoirs, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. Exergy is then the energy that is available to be used. After the system and surroundings reach equilibrium, the exergy is zero [Jørgensen, 2006]. Using land-use data and development-intensity measures derived from energy use per unit area, an index of landscape development intensity (LDI) can be calculated for the coastal zones to estimate the potential impacts from human-dominated activities. The intended use of the LDI is as an index of the human disturbance gradient [Brown and Vivas, 2005]. The ecosystem function is measured using the biological capacity potential (BCT) [Ingegnoli and Pignatti, 2007], based on resistance stability, vegetation type, and metabolic data of vegetation. Ecosystem services are based on the values calculated by Costanza *et al.* [1997].

2.2 Multicriteria methods for decision support

A *geographic information system* (GIS), and a *geographic resources analysis support system* (IDRISI™, Andes version) were used. IDRISI™ was used for the analysis of coastal changes , Gap Analysis for ecological sustainability and MCA [Eastman, 2006].

The *ecological footprint* is a sustainability indicator, which provides a metric with a threshold (the biocapacity). It has been proposed by Wackernagel and Rees [1996] in order to quantify the intensity of the resources used and the waste discharge activity (in a specified area) in relation to the (area's) biocapacity to be provided for that activity.

The biodiversity conservation at landscape and habitat scale during time is analysed trough Land Change Modeller for Ecological Sustainability, a tool for GAP Analysis [Eastman, 2006]. In this case threshold came from the assessment of unprotected areas and corridors (Gap analysis), identifying the areas that need protection for biodiversity sustainability.

A coastal Urban and Infrastructure Sprawl density and a Coastal Urban and Infrastructure Sprawl Index UI_{sp_c} were calculated following (1), where u are the areas changed from non urban/infrastructure to urban/infrastructure, n is the number of years of analysis (land cover change), A is the total area of analysis.

$$UI_{sp\_c} = 10 - \log_{10}\left(\frac{1}{A}\sum_{i=1}^{n}\frac{(u_i)}{n}\right) \qquad (1)$$

3 Results

The resulting values are presented in Figure 4.

	Lagoon of Venice	Rimini province	Conero area	Error
Non renewable Emergy (sej/yr) per ha	9.3E+16	5.5E+16	7.3E+16	20%
Renewable Emergy (sej/yr) per ha	2.6E+11	1.0E+10	1.0E+10	20%
LDI per ha	4.86	7,12	3.95	30%
Ecosystem value (euro) per ha	3.4E+03	9,2E+02	1.9E+03	10%
Human Value (euro) per ha	5.0E+05	7.9E+05	6.6E+05	30%
CO_2 absorption (tonn) per ha	3.8E+03	1.3E+03	3.6E+03	20%
BTC (J/yr) per ha	3.8E+10	0.9E+10	3.6E+10	15%
Exergy (J) per ha	5.8E+09	1.9E+09	6.0E+09	20%
Percolation (in total area)	0.93	0.86	0.91	5%
Percolation in coastal area (5km)	0.71	0.39	0.89	5%
Percolation in coastal area (1km)	0.68	0.17	0.68	5%
Natural habitat Loss in total area (1970-2001*)	2.29E+3	4.11E+3	1.87E+4	5%
Total Area (ha)	255512	15988	89848	>0,1%
Sea Area (ha)	94520	71770	37890	>0,1%
Coastal Urban and Infrastructure in total area Sprawl Index (1970-2001*)	7.8	7.5	7.6	10%
Coastal use conflicts	0.85	0.41	0.53	5%
Ecological footprint (global hectares)	6.6	10.4	4.9	20%
Threshold: biocapacity (global ha)	1.6	0.44	2.1	20%
GDP (total per year, 2004), euro/ha	8.7E+4	1.8E+5	7.2E+5	10%

Fig. 4. Table of Coastal sustainability indices and constraints for the case studies. The values of indices and indicators are linked to the land/sea use. (*) First year of analysis for Venice is 1972, for Rimini is 1975, for the Conero area is 1976.

Indices (Fig.4) are calculated in the 5 km of coastal fringe (4km land and 1km sea, for Venice lagoon is calculated whit the entire Lagoon and 4 km Landward and 1 km seaward) when is not differently described. The thresholds of biodiversity and habitat sustainability came from the Gap analysis, identifying the areas that need protection for biodiversity sustainability (see Fig.5). The analysis was carried out through a change analysis process. This compares the earlier and the later land-cover maps and measures the nature of change. The habitat assessment produced primary and secondary habitats, primary and secondary corridors, and unsuitable areas. All those categories are protected or unprotected. The unprotected areas show a Conservation Gap and indicate an unsustainability level.

The Gap analysis shows the important landscape patches (high value habitat and key areas for the species) where species or habitat are threaded. As a main result of the analysis, unprotected areas are proposed for reserve areas, along which actions towards conservation are needed.

	Lagoon of Venice	**Rimini province**	**Conero area**	**Error**
Gap, unprotected areas	ha	ha	ha	
Primary potential corridor	4.9E+2	67	22	10%
Secondary potential corridor	1.2E+2	98	35	10%
Primary habitat	73	0	12	10%
Secondary habitat	1.0E+4	6.8E+2	5.2E+2	10%

Figure 5. Table of the conservation constraints for ecological sustainability of the case studies.

The MCA calculated with data reported in Figure 4 provides three different scenarios (maximizing different objectives of the policy: Conservation, Tourism, Agriculture and fishing, Industrial and port development) per each area (Fig. 6). Suitability maps result from multicriteria analysis. Once the multicriteria suitability maps have been created for each objective, the multicriteria decision problem has been approached. For each area a Multiobjective scenario is obtained (using objectives and weight assigned each). These Multiobjective scenarios, using the sustainability constraints, give a final decision scenario: a map that gives a spatial definition and balance of the actions.

Those scenarios are characterised by the parameters presented in the following Table (Fig. 6). Gap and Coastal use conflicts are imposed as constraints for the scenarios.

Scenario at 2015	**Lagoon of Venice**	**Rimini province**	**Conero area**	**Error**
Ecological footprint (global hectares) (at the actual level of consumption)	7.2	7.9	6.6	>20%
Threshold: biocapacity (global hectares)	1.8	0.91	2.1	>20%
Gap, unprotected areas	0	0	0	5%
Coastal Urban and Infrastructure Sprawl Index	3.2	3.1	3.1	>20%
LDI per ha	5.12	7.63	4.23	30%
Percolation in coastal area (5km)	0.68	0.32	0.85	5%
Coastal use conflicts	0.10	0.10	0.10	5%

Fig. 6. Table of results for final decision scenario. the parameters used as constraints are underlined In light yellow.

Results show that although the conflicts and the gap are managed, some unsustainability persists (Biocapacity is lower than Ecological footprint, Urbanization Sprawl index is higher than zero, LDI is increasing, and percolation is lower than the threshold limit in Rimini province).

The output of the process is presented also by GIS representation as reported for the Venice Lagoon (Fig. 7). In the conflicts map (Fig. 7a) the coastal conflicts increase from zero (blue) to one (red). Higher conflicts areas are obviously outside the higher impact zones (for example zones were the LDI is maximum), but generally on their boundaries. The results of Gap Analysis highlight unprotected areas that are proposed as reserve areas, along which actions towards conservation are needed (Fig. 7b). In order to represent the MCA results, suitability maps were created for each objective chosen (e.g. map in Fig. 7c). As a final results, Figure 7d shows the suitability of space planning in Lagoon of Venice, integrating the actual socio-economic activity whit conflicts management and conservation, without reduction of space areas for economy.

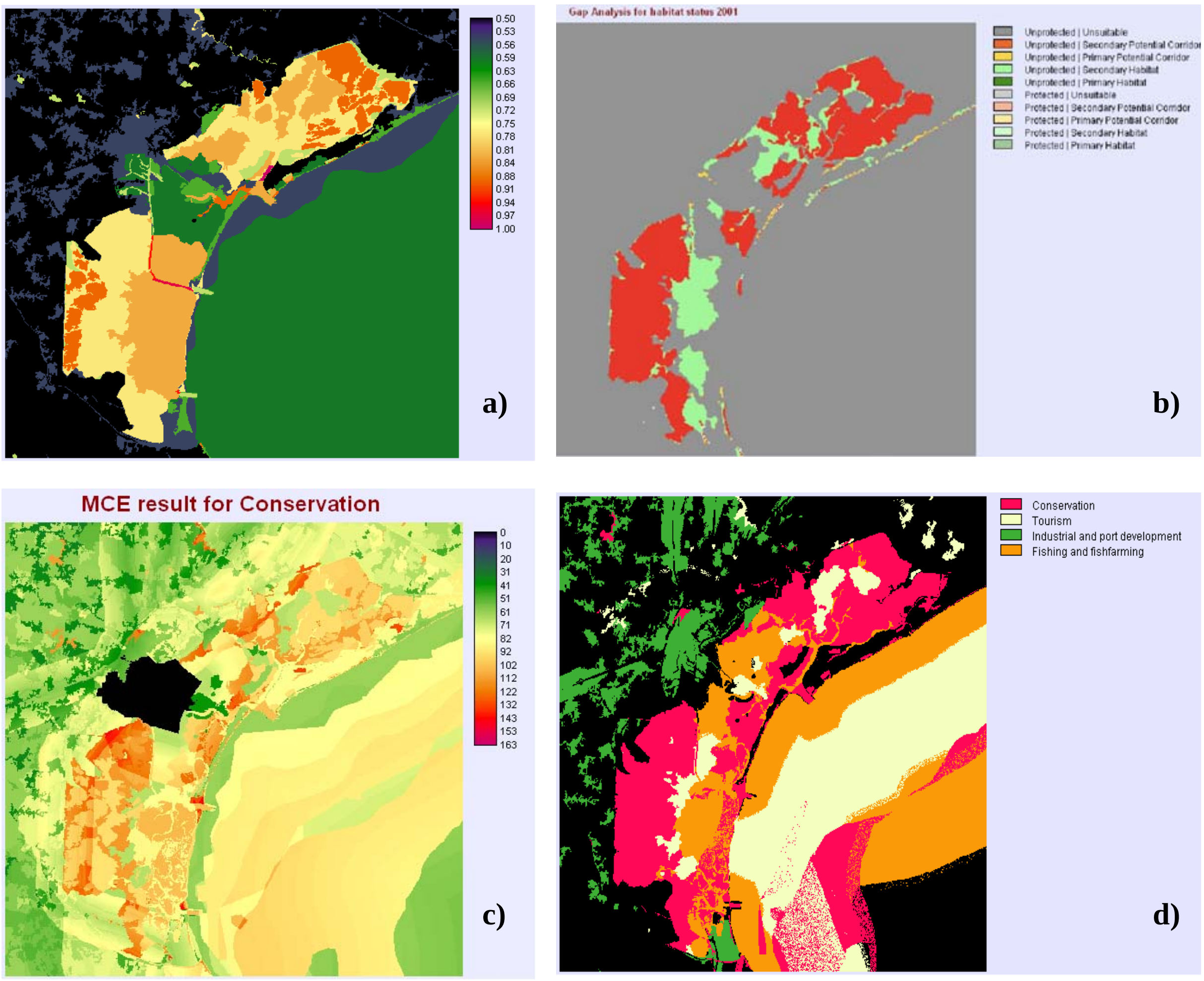


Figure 7. Costal conflicts (a); Gap Analysis for ecological sustainability (b); Mutricriteria analysis results (c); integration suitability of space planning, integrating the actual socio-economic activity *(d).*

4 Conclusions

In this paper a structure of indices and sustainability thresholds for integrated coastal zone management is presented. A decision support system integrates the indices and the preferences of agents, taking into account the limits of growth for coastal zones.

The results presented here in this paper highlight that other policies must be adopted in order to reduce the energy and matter consumptions and control the Ecological Footprint and LDI. Even though absolute sustainability of Rimini and Venice coastal zones is a difficult goal to reach in the short term, a sustainable path for coast and inland for those areas could be a possible aim of strategic choices. The Lagoon of Venice mitigates and compensates the impacts of the inland area and the port, fishing, and tourism activity, and for this reason it must be protected and when necessary restored. Rimini shows the worst indices (scenario), with high footprint and LDI and low biocapacity and percolation. Conero area can reach a sustainability level because the natural coastal space can balance, if adequately protected, the Ancona Port and industrial activities and the Falconara Refinery.

References

Brown M.T. and M. B. Vivas, 2005. Landscape Development Intensity Index, Environmental Monitoring and Assessment, 101, 1-3, 289 – 309.

Brenner, J., J. Jimenez and R. Sarda, 2006. Definition of Homogeneous Environmental Management Units for the Catalan Coast, Environmental Management, 38, 993–1005

Ceccaroni, L., U. Cortés, and M. Sànchez-Marrè, 2004. OntoWEDSS: augmenting environmental decision-support systems with ontologies. Environmental Modelling and Software, 19(9):785–797.

Costanza R., R. D'arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton and M. van den Belt, 1997. "The value of the world's ecosystem services and natural capital", Nature, Vol. 387, pp. 253-260.

Eastman J.R., 2006. IDRISI Andes. Guide to GIS and Image processing. Clark University, Worcester, 327 p.

Farina A. 2006. Principles and Methods in Landscape Ecology. Towards a Science of Landscape, Springer-Verlag, New York: 448 pp.

Ingegnoli V. and S. Pignatti, 2007. The impact of wined landscape ecology on vegetation science: towards a new paradigm, Rend. Fis. Acc. Lincei, 9, 18, 89 -122.

Jørgensen S. E., 2006. Eco-Exergy as Sustainability. Wit Press, Southampton, 207 p.

Marotta, L., 2006. Unità di paesaggio in Laguna. In S. Guerzoni, D. Tagliapietra, Atlante della Laguna. Venezia tra terra e mare. Comune di Venezia, CNR-ISMAR di Venezia, Marsilio editore, Venezia. pp. 200 - 201.

Odum, H.T. 1996. Environmental accounting: Energy and environmental decision making, Wiley, New York, 370 p.

Sazonova, L., G. Osipov, and M. Godovnikov, 1999. Intelligent system for fish stock prediction and allowable catch evaluation. Environmental Modelling and Software, 14(5): 391–399.

Thrush, S.F., J. Halliday, J. E. Hevit, and A. M. Lohrer, 2008. The effects of habitat loss, fragmentation, and community homogenization on resilience in estuaries, Ecological Applications, 18, 1, 12–21

Vallega A., 1999. Fundamental of coastal zone management, Kluwer, Dordrecht, 263 p.

Van Kouwen, F., C. Dieperink, P. Schot, M Wassen, 2008. Applicability of decision support systems for integrated coastal zone management. Coastal Management, 36, 19 -34.

Wright, J.R., Wiggins, L.L., and Ravinder, K.J. (editor), 1993. Expert systems in environmental planning. Berlin; New York: Springer-Verlag.

Wackernagel, M., W.E., Rees, 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. New Society, Gabriola Island, 176 p.