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A methodological approach to be used in integrated coastal zone management processes: the case of the Catalan Coast (Catalonia, Spain)

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Abstract

Since early 1999, we have been working on an environmental information system as a preliminary phase to develop the National Strategy of the Catalan Coast. Using the tourism industry as the main pressuring driver and the municipality as the territorial unit, we have compiled a vast amount of information that has been converted into an information platform for the general public, politicians, and public administrators. Working in close co-operation with the planning authorities of the Generalitat of Catalonia, we developed decision support tools as a methodological approach for coastal management. The decision support system is composed by: (a) the development of an environmental indicator-based report; (b) the use of a geographical information system (GIS); and (c) the incorporation of different types of graphical packages. These tools have been applied to the 70 municipalities of the Catalan Coast and a specific development of the system was carried out in the region of La Selva, municipalities of Blanes, Lloret de Mar, and Tossa de Mar (southern Costa Brava, Girona). The system has been designed to help coastal managers in Catalonia, and it is thought to be used in the process of developing the National Strategy for Integrated Coastal Zone Management (ICZM) of the Catalan Coast following the EC Recommendation (COM/00/545).

Keywords: integrated coastal zone management (ICZM); sustainable development; environmental indicators; geographical information system (GIS); mass tourism

1. Introduction

After the V Environmental Action Programme of the European Union, the sustainable development of the coastal zones is one of the main priorities. In order to achieve this priority, long-term economic, environmental and social considerations have to be considered for designing planning decisions, and an exhaustive amount of environmental information has to be developed and translated into convenient units of information to be useful in the decision-making processes. However, the wide variety of activities, values, and cultures of the different European countries make these efforts extremely difficult and, in many cases, with very different final results and decisions between regions. A joint initiative of several General Directorates of the European Union launched in 1996 the idea of a general framework for the coastal management policy (the integrated coastal zone management, ICZM), as a tool to reach a harmonious and sustainable development of the European coastal zones. The move towards the implementation of ICZM processes "dynamic, continuous and iterative processes designed to promote sustainable management of coastal zones" (European

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Commission, 1999) began in Europe with several demonstration programmes. From all these and related initiatives, it became clear than sustainable development and integrated management of the coastal zones should propose alternatives within current legislation using a global and integrated approach to solve coastal area problems (Dauvin, 2002).

The European Commission has launched recently a proposal for a European Parliament and Council Recommendation concerning the implementation of Integrated Coastal Zone Management in Europe (COM/00/545). The recommendation, adopted by Council and Parliament in May 2002, explains how the Commission will be working to promote ICZM through the use of Community instruments and programmes. The recommendation finally indicates the steps that the member states should conduct to develop national strategies of ICZM. According to this scheme, national strategies are due in Spring 2006 and should involve all the coastal stakeholders operating in their territories. Since the appearance of this regulatory framework, the management of coastal territories and its resources has become an important policy goal for all governments of countries with coastlines in Europe (Turner, 2000). Nevertheless, the management of the coastal zone is complex. This fringe of territory is characterized by its extreme variability, the highly diverse nature of their systems, and their variable multifunctionality (von Bodungen and Turner, 2001). Even if it is necessary to have an overall framework and some homogenous instruments to deal with its management, whatever approach applied will require some adaptation to the particularities of every portion of coast. In addition, in order to develop ICZM processes, an essential requisite would be the obtention of exhaustive environmental information and its analysis through these appropriate management tools.

Spain is among the European Countries with the longest coastal zone. Its coastal zone is still suffering the consequences of historical mistakes due to mismanagement of the general public interests in favour of particular interests (Sardá, 2001). In 1988 a new Spanish Coastal Law was enacted to protect the coastal zone and to promote coastal management in a different way according with the new European policies. Besides the introduction of this new regulation, coastal erosion in the Spanish littoral (including the alarming process of beach regression) and the increased pressure of the built environment (urban development, tourism activities, and construction) are still acute problems, obscuring others such as pollution connected problems or losses in biodiversity. These problems need to be quickly addressed if Spain wants to move towards sustainable development in the coastal zone. However, the concurrence of many different administrations on coastal issues, each one addressing different managerial aspects related with the coastline and often with confronted objectives and strategies, together with the administrative division in autonomous communities in which Spain is presently organized, make it fairly complicated to find general solutions (Sardá, 2001). It becomes necessary to design specific coastal plans to set the main principles from which administrative daily decisions can be formulated, and to design specific tools to support the performance of these plans, in order to improve the regulation of coastal uses that may deplete the ecological services that coastal ecosystems provide.

Besides the problems of coordination, efforts to move towards sustainable development of the coastal zone by the introduction of regional programs of action have been done in several autonomous communities of Spain (the coastal management program of the Basque country, the Ordination Littoral Plan of Cantabria, the Sustainable Development of Tourism in the Canary Islands, …). Recently, Catalonia has initiated several actions to develop as soon as possible an ICZM process in its territory: "Catalunya i la gestió integrada de les zones litorals". The main objectives of this process are: (a) to express an integrated and clear answer to the main environmental problems of the Catalan Coastal zone; (b) to define actions of immediate intervention to protect the natural heritage and to restore environmentally degraded littoral sites; and (c) to establish baseline information in order to develop the National Strategy of the Catalan Coast. An administrative managing office, the General Directorate of Environmental Planning (Generalitat, Autonomous Government, of Catalonia), is the main office in charge of the coordination of the work. From the very beginning, the involvement of science in these efforts was done following conceptual frameworks suggested elsewhere (Cairns et al., 1994; Bretón, 1996; Salomons et al., 1999; von Bodungen and Turner, 2001; Dauvin, 2002).

The Catalonian coastline is 699.3 km long. It is composed of a large variability of coastal systems, from large flat areas with long sandy beaches to abrupt rocky shores with high cliffs. This coastal structure yields a highly diverse geomorphology associated with a highly diverse biodiversity. Past human accommodation, socio economic activities, and related land-uses responded mostly on the relief, the climate, the geographical situation, and the available resources that were needed. Traditionally, flat areas, lower reaches and deltas of rivers, as well as low mountains comprised a territory whose mild Mediterranean climate, diversity of natural environments, and agriculture and industrial activities encouraged its occupation by people. Other areas, far from rivers and with difficult access were less occupied. The present distribution of social and natural environments in the coast reflects this former process of occupation, and yields a territory with a high level of multifunctionality.

The Catalonian coast contains 70 municipalities along its shoreline. These municipalities are included in 12 main administrative regional divisions or "comarcas". Almost half of the Catalan population (44%) lives in these municipalities (2.8 million, 1996 census). This population is enlarged every year by foreign tourists and day trippers (12.9 and 7.6 million, respectively) as well as by another 4.7 million of hispaniards travelling from other autonomous communities (data from 2001) (Catalunya Turisme, 2003; Sardá et al., 2003a). Catalonia accounted in 2001 for 27% of the foreign tourist visitors of Spain, being the most visited region of the country. Besides the metropolitan area of Barcelona and the municipality of Tarragona, where industrial and logistic activities became very important, the most important driver producing regional environmental change in this coastal zone today is the tourism industry and its associated activities of commerce, residential development and construction, and mobility. Other economic activities such as agriculture and fisheries are less important on this coast.

Tourism's relationship with the environment is complex. In order to evaluate all these interactions it became necessary to develop a complete information system of territorial environmental indicators together with the main socio-economic aspects of population, urban structure, and economic structure in the territory, and to analyse the condition of their natural systems. Beginning in 1999, we started two research projects in connection with the planning authorities of the Generalitat of Catalonia. These projects focused on the search for the best protocols to assure an Environmental Sustainable Tourism Development and the development of new management tools to assess environmental changes in this coastal region. In parallel with these projects, yearly contracts were signed during the period 1999–2003 with the Generalitat to work in close cooperation with this administration in: (a) the characterization and analysis of the present status of the Catalan Coast, and (b) the development of an environmental information system as a decision support system for coastal managers (Sardá, 2003).

The purpose of this paper is to describe the conceptual framework and the methodological approach used for the development of an environmental information system thought to be useful as a decision support system for coastal managers in Catalonia. The general intention behind this work was to provide a set of guidelines and recommendations for organizing and expressing the complexities found in our move towards the sustainable development of our coastal fringe. During the work, we generated a vast amount of information. In order to see an example of how this information system works, we present in this paper the application of the system to one of the 13 "comarcas" of the Catalan Coast (La Selva, Girona) following a preliminary paper (Sardá and Fluvià, 1999). This example is intended merely as a means of illustration of how the overall system works but at the same time it provides a comprehensive picture of the main problems faced by the Catalonian coast today.

2. Methodological approach and results

2.1. Criteria used

The need for a National Strategy towards the Sustainable Development of the Spanish Coast (Sardá, 2001) was strongly supported when the EC Recommendation COM/00/545 was formulated 4 years ago. In accordance with the singularities of Spain, divided into autonomous communities with competencies in many important issues (Sardá, 2001) its national strategy should be formulated by the harmonization of different strategic regional coastal plans. While seeking the best procedures to optimize the long-term contribution of the coast to the social welfare, we analysed the actual and future trade-offs between different economic activities and the use of coastal resources. The overall objective is to maintain and/or to obtain a good ecological status of the coastal zone while keeping human activities on it. To reach this objective a holistic methodological approach was established. We initially compiled and analysed a vast amount of existing information producing two big data sets: one entailing socioenvironmental data and the other scientific-technical data. The two large databases created were an essential need for further planning applications. Then, we developed information-based instruments to make information useful for taking managerial decisions. As a final product of this work a set of recommendations (Sardá, 2003) were translated to the national authorities with competences in the coastal zone. These recommendations included: (a) the development of sustainable plans for sectoral organizations, mainly from the tourism industry; (b) the establishment of criteria for the evaluation of new activities pressuring coastal ecosystems; and (c) the promotion of the protection of the natural heritage and the restoration of degraded sites.

The information compiled into the databases was converted into more convenient units of information and introduced into a more formal information system (indicator panel and visualization tools). The following criteria are at the basis of this work:

(a) The municipality was selected as the main administrative regional unit, and the tourism industry as the main pressuring economic driver in the region.
(b) Although tourism was selected as the main economic driver pressuring the coast, recommendations for

management should be cross sectoral with other human pressuring activities.

(c) To work with a large data set of towns and to introduce the variability associated with different coastal geomorphologies, the information was grouped into two main categories: (1) a common information system that works for all towns and coastal typologies; and (2) indicators that may vary according to the heterogeneity of these coastal areas. During the analysis of this second group, a pilot plan was carried out in the region of La Selva (southern Costa Brava).

(d) When possible, the information of indicators should be collected from existing organizations, and should be of easy access, quantifiable, reliable, and collected periodically.

(e) It would be necessary to develop a friendly user indicator report that allows us to analyse tendencies and to benchmark data.

2.2. Tools developed

A conscious effort was made to use a consistent format during the development of the information system. For every coastal municipality the same range of information was obtained and ordered in homogenous files. The units of information selected (indicators) were thought to be the basis for decision making in general as well as the system of measurement of tendencies and scenarios. As the data appended to the indicators become truly significant when related to a geographical area, it was clear that a geographical information system (GIS) environment would allow us to develop the applications to manage geo-related information in a much more friendly format.

We recognized the necessity for a clear framework for organising the information contained in the databases. The framework employed evolved from a driving force–state–response approach (D-PSIR) following similar experiences adopted elsewhere (UN, 1996; Turner et al., 1998). With this conceptual scheme, the territorial information was separated into two large groups. The socioenvironmental database was used to obtain the territorial indicators of environmental management, compiling all information related to model and flux indicators following the European Environmental Agency (EEA) scheme. The compilation and analysis of the historical information by means of the study of the scientific and technical information was, on the other hand, the only way to study the evolution of the indicators of environmental condition, which are very often lacking reference situations, especially in the marine domain. Finally, the information generated from the main driving force, the tourism industry, was compiled as sectoral information. All this information was hierarchically organized in a panel as indicated in Fig. 1.

As a second step, we developed some management tools to monitor and to analyse the regional development of the coastal zone. These tools followed a holistic approach. We worked mainly with three developmental tools:

(a) a panel of indicators following the above conceptual framework;
(b) the use of a geographical information system (GIS); and
(c) a set of different graphic presentations (including conventional graphs, GIS applications, and the use of the AMOEBA model (Ten Brink et al., 1991).

The panel (Fig. 1) was the basic tool in the quantification of pressures. The information that it contains is then used for the evaluation of future scenarios based on included indicators of tendencies and seasonality. The panel also allows us to identify environmental producer impacts and environmental receiver impacts on the coastal zone by pooling together the indicators of environmental management and the indicators of environmental condition. The use of the GIS allowed us to geo-reference most of the elements obtained in the panel. It enables the construction of plausible future scenarios when tendency indicators are included, and allows the modelization of our visions on the coast. Finally, the graphic modelization builds very potent visual tools for the managers.

2.3. The indicator panel

Our panel includes three different typologies of indicators (Fig. 1). The *sectoral indicators* were obtained in co-operation with the Patronage of Tourism Costa Brava-Girona, in the case of the Costa Brava, and with the General Directorate of Tourism of the Generalitat of Catalonia, for the rest of the Catalan coast. We compiled detailed information from administrative

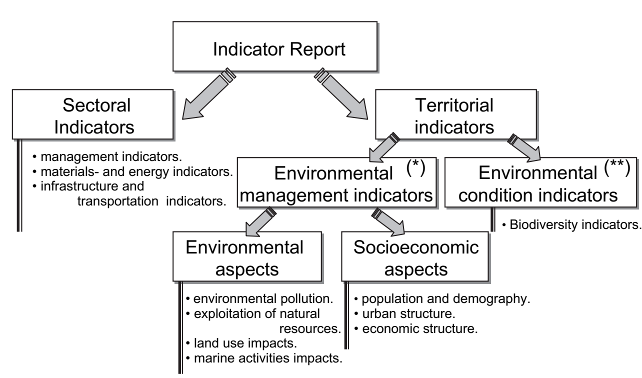

Fig. 1. Structure of the panel of indicators.

sources and we carried out a questionnaire to the 338 hotel resorts established in the Costa Brava as an example to illustrate the environmental achievements that this industry is obtaining today (Sardá et al., 2003a).

We divided the territorial indicators into managing indicators and condition indicators following above commented factors. The *territorial indicators* of environmental management totalled 43 groups of indicators (for a total of 128 indicators). In choosing and producing groups of indicators, considerable weight was placed on the selection of the main economic forces working in the territory, as well as on the natural resources currently available. Thirty of these groups were obtained for the 70 municipal towns presented in the Catalan Coast (the common information system), the other 13 were measured only in the pilot plan carried out in the "comarca" of La Selva (the specific information system). For each group we selected a primary indicator (the metric is to be found in Table 1) and several secondary indicators (absolute and/or relative indicators, tendency indicators, and seasonal indicators if possible). The selected groups of indicators were classified into five classes depending on the source of the information used:

(a) indicators obtained from the autonomic (Generalitat of Catalonia) or central (Spanish Government) administration;
(b) indicators obtained from municipal administrative offices;
(c) merely cartographical indicators;
(d) indicators that contain aggregate information coming from different sources; and
(e) indicators obtained from our own studies (mainly the ones developed in the pilot plan).

Due to the difficulties in managing such a large group of indicators, we selected some strategic indicators by using multivariate statistical techniques. We used principal component analysis (PCA) as an effective ordination technique to reduce the number of indicators and to obtain these strategic indicators. Therefore, we identified a final set of indicators that when pooled together provided a classification of the information comparable to the total information obtained from all the indicators used. The strategic indicators were selected to accomplish a series of criteria and to allow further management and planning: (a) being available for all the municipalities along the coast; (b) avoiding duplication of information; (c) being easy to obtain; (d) compiling information from the main economic sectors implicated (tourism, construction, and mobility); and (e) being easily understood. The 12 indicators already established are listed below (the metrics is to be found in Table 2). We are working to incorporate two more (see * in the list) due to their importance for shoreline developmental issues. We believe that the data we are getting today from administrative offices about these two later indicators are not the most appropriate for the purposes of the panel, and that it is necessary to develop better indicators related to beach quality and water depuration. The strategic indicators are:

- resident population density
- population seasonality (base population/resident population)
- impervious soil
- construction coefficient
- unemployment rate
- accommodation coefficient
- hotel ratio quality/price
- waste production intensity
- protected area index
- coastal protection index
- motorization coefficient
- coastal fringe artificialization
- beach quality (*)
- water depuration intensity (*)

The territorial indicators of *environmental condition* aimed to describe the quality and health status of the natural systems. Usually, when these indicators are obtained, they are based on monitoring programs. Monitoring programs alone often depend on a small number of indicators and, as a consequence, fail to consider the full complexity of the ecological and/or territorial system (Dale and Beyeler, 2001). By selecting few indicators, the focus of the program becomes narrow and this simplification often leads to poorly informed managerial decisions. We developed a wider approach carrying out initially an inventory of biodiversity. The inventory was made using the three-dimensional projection of the GIS, and allowed us to quantify in detail the natural systems presented in a geographical area. Then, we analysed the status of these systems by the selection of appropriate bioindicators. To relate environmental management and environmental condition indicators we developed a matricial approach. We used a habitat–impact matrix to select a series of species and/or indexes, selecting those that allow us to follow the status of the natural systems in a particular territory. The AMOEBA approach (Ten Brink et al., 1991) could be used here as the graphical output of the data in the matrix to see the evolution of these indicators through time. Since most of the data obtained in this work cannot be compared with "optimal" or historical values, the AMOEBA approach is intended to be used for the future when repeated measures of the selected indicators of environmental condition would be again demanded. In the case of the territorial indicators of environmental management, the

Table 1
Indicator report for Selva Marítima

				Blanes	Lloret	Tossa
Population structure	♣	Resident population (Pr)	Inhabitants (1999)	30653.00	20086.00	4407.00
	♣	Base population (Pb, resident plus average seasonal population)	Inhabitants (1999)	50438.00	48954.00	18120.00
		Increment by day visitors (seasonal peak)	Number of people (August 2000)	2470.00	−1042.00	756.00
Urban structure	♣	Impervious soil	Percentage over total soil (1997)	26.12	27.03	8.99
	♣	Home construction (construction coefficient) (Pr)	Houses (1996–2000) by 100 inhabitants	6.96	7.38	5.99
	♣	Forced mobility	Vehicles exiting by day (1996)	1976.00	−1058.00	85.00
	♣	Population density (Pb)	Inhabitants km^{-2} (1999)	2833.60	1022.00	474.40
Economic structure	♣	IBI evolution (private-owner tax)	Millions of euros (1999)	5.21	6.08	2.18
	♣	IAE evolution (economic activity tax)	Millions of euros (1997)	0.56	0.69	0.09
	♣	RBFD evolution (income rent per family)	Euros per inhabitant (1996)	9706.62	13139.81	n.c.
	♣	Unemployment rate	Percentage over active population (1996)	12.48	13.01	15.33
	♣	Tourist offer	Total bed accommodation (1999)	13837.00	34635.00	13989.00
	♣	Tourist bed quality	Average stars by hotel bed (1999)	2.28	2.49	2.07
	♣	Tourist bed price (maximum at seasonal peak)	Euros by hotel bed (1999)	49.75	69.21	67.60
Environmental pollution	♣	Air quality (ICQA)	Institutional index (*) (1999)	n.c.	n.c.	n.c.
		Water consumption (Pb)	m^3 day^{-1} $person^{-1}$ (1999)	0.21	0.30	0.20
	♣	Water depuration (Pb)	m^3 day^{-1} $person^{-1}$ (1999)	0.24	0.21	0.12
	♣	River water quality (ISQA)	Institutional index (*) (1999)	68.37	–	–
	♣	Aquifer situation	Piezometric level (m) (1997)	−3.1	–	–
	♣	Generation of household waste (Pb)	kg day^{-1} $person^{-1}$ (1999)	1.16	1.54	0.95
	♣	Waste valorization (Pb)	kg day^{-1} $person^{-1}$ (1999)	0.04	0.06	0.03
	♣	Generation of industrial wastes (Pb)	kg day^{-1} $person^{-1}$ (1999)	0.37	0.30	0.20
		Energy consumption (electricity) (Pb)	kw day^{-1} $person^{-1}$ (1999)	n.c.	8.03	n.c.
		Gas emissions	tons contaminant km^{-2}	n.c.	n.c.	n.c.
Resource exploitation	♣	Fisheries landings	Tons (1999)	1899.80	–	–
		Beach frequentation (urban zones) (between 12.00-18.00 h)	m^2 per $person^{-1}$ (August 2000)	16.00	5.00	8.50
		Beach frequentation (non-urban zones) (between 12.00 and 18.00 h)	m^2 per $person^{-1}$ (August 2000)	14.00	19.00	13.00
		Beach utilization (S'Abanell-BL/Lloret Centro-LL/Platja Gran-TS)	Daily percentage population (August 2000)	36.01	29.37	26.48
	♣	Beach quality	Institutional index (*) (1999)	9.00	7.00	9.00
	♣	Natural area in the municipality	Percentage over total soil (1997)	34.10	60.26	81.71
	♣	Protected area in the municipality	Percentage over total soil (1997)	0.00	3.37	68.56
Marine occupation	♣	Recreational fleet in marinas	Number of boats (2000)	525.00	132.00	–
		Marina and harbour utilization	Percentage of total boats (August 2000)	36.30	27.00	–
	♣	Beach nourishment	Millions of euros invested up to 1997	0.15	–	0.36
		Boat transit (from 11.00 to 12.00 h and from 17.00 to 18.00 h)	Boats (August 2000)	89.00	94.00	233.00
Land-use occupation	♣	Coefficient of motorization	Vehicles per 1000 inhabitants (1999)	641.57	801.79	806.27
		Traffic mobility inside population	Minutes to move 1 urban km (August 2000)	3.35	4.00	3.24
		Public transport	People travels	n.c.	n.c.	n.c.
		Bus circulation	Number of day buses (August 2000)	708.00	679.00	203.00
		Traffic congestion (morning/afternoon)	Percentage of time blocked August (2000)	5.31/9.18	3.38/0.00	0.00/0.00
	♣	Coastal protection index	Institutional index (*) (1999)	2.54	2.00	1.79
	♣	Mosaic index (land-use index)	Without units (1997)	0.76	0.85	0.84
	♣	Coastal fringe artificialization	Percentage of total coast (1999)	84.50	67.00	39.30

BL, Blanes; LL, Lloret de Mar; TS, Tossa de Mar. Primary indicators of the 43 groups of analysed indicators. The year 1999 is used as the basis for this work (other years used depend on official data). (*) Institutional indexes: ISQA runs between 0 (the worst) and 100 (the best); the beach quality index runs between 1 (the worst) and 9 (the best); and coastal protection index runs between 1 (the best) and 4 (the worst). (♣) is used when the indicator was measured for the 70 coastal towns in the Catalan coast; the rest of indicators were only computed in the pilot plan of La Selva Marítima. (n.c., not computed; no infrastructure, activity or natural system to be measured).

Table 2
Strategic indicators for the region of La Selva (Blanes, Lloret de Mar, and Tossa de Mar)

			Blanes	Lloret	Tossa
1	Resident population density	Inhabitants per km^2 (1999)	1722.00	419.30	115.40
2	Base population (Pb)/resident population (Pr)	Index (1999)	1.65	2.44	4.11
3	Impervious soil	Percentage over total soil (1997)	26.12	27.03	8.99
4	Construction coefficient (Pb)	Built houses per 100 inhabitants last 5 years (1999)	4.23	3.03	1.46
5	Unemployment rate	Percentage over active population (1996)	12.48	13.01	15.33
6	Accommodation coefficient (Pr)	Hotel beds per 100 inhabitants (1999)	14.88	155.41	168.73
7	Hotel ratio quality/price	Average price by star at the peak season (1999)	21.82	27.80	32.65
8	Waste production intensity	Household and industrial wastes/GDP in millions euros (1996)	68.61	50.74	64.87
9	Protected area index	Percentage over total natural area (1999)	0.00	5.59	83.91
10	Coastal protection index	Institutional index (1999)	2.54	2.00	1.79
11	Motorization coefficient (Pr)	Vehicles per 1000 inhabitants (1999)	641.57	801.79	806.27
12	Coastal fringe artificialization	Percentage of coast artificialized over total (1999)	84.50	67.00	39.30
13	Beach quality (*)				
14	Water depuration intensity (*)				

The year 1999 is used as basis for this work (other years used depend on official data). (*) These two indicators have not yet been included in the present analysis although we are in the process of modifying the current ones for this purpose.

work was done at a reduced spatial scale (the "comarca" of La Selva) due to the difficulties of the task and to the need to use marine GIS, which we had to create in the frame of this study.

For the selection and use of bioindicators in these processes, we consider bioindicators species which fit within these groups: rare species, endemic species, endangered species or under great pressure, species which form specific habitats, or key species in trophic or functional webs following recommendations developed by the EC-BIOMARE network (http://www.biomareweb.org). For some cases, indexes or complex of species were also used. The selection of these species was carried out using an application similar to the Leopold matrices, commonly used in environmental impact assessments. This matricial approach allows us to relate the environmental impact producers (which can be measured from the indicators generated in the environmental management section) to the environmental impact receivers of such impacts (which in this case will be the different natural communities of the area). These matrices therefore, allowed us to select useful species for our purposes. Standard protocols were established for the obtention of data of the selected bioindicators in the matrix. When possible, we used data from existing monitoring programs in the region, such as the seawater quality monitoring program and the monitoring of *Caulerpa taxifolia* actually done by the Water Agency of the Generalitat of Catalonia.

2.4. GIS visualizations

As a method for synthesizing the obtained information we transferred it to a digital geographical information system, GIS (Harper and Curtis, 1993; Costello and Mills, 1996; Neilson and Costello, 1999). We introduced the exhaustive information generated during the project in an Arc View 8.1 GIS environment. Besides the graphic capabilities that the GIS provided, these systems also allowed us to develop applications to manage geo-referenced information, both for the localization of particular elements and for the identification and function of these elements in the terrestrial or marine surface. The elements of the system consisted of a general cartography of reference, thematic cartographical layers of support (environmental management, spatial planning, infrastructures), and the specific layers generated in the frame of these projects (land-use occupation, natural system cartography, protected areas, …). In addition, with the help of the GIS, we could predict future scenarios for territorial planning by introducing the observed tendencies for the territorial indicators of environmental management, we could delimitate the number of Ha per each natural system, being also a convenient tool for the comparison between the different layers of uses (cross analyses), and in the visualization of the scientific and technical information databases that were generated during the development of these projects.

2.5. Application to the Costa Brava South region: the pilot plan of La Selva

The Costa Brava (Fig. 2, upper-right graph) comprises the NW Mediterranean coast in Catalonia (Fig. 2, upper-left graph), which extends from the Spanish–French border (Portbou) to the mouth of the Tordera river (Blanes). The coast is administratively composed of three regions (L'Alt Empordà, Baix Empordà, and La Selva) and 22 towns. La Selva is the southeast region in the Costa Brava and it includes three coastal municipalities, Blanes, Lloret de Mar, and Tossa de Mar. Blanes

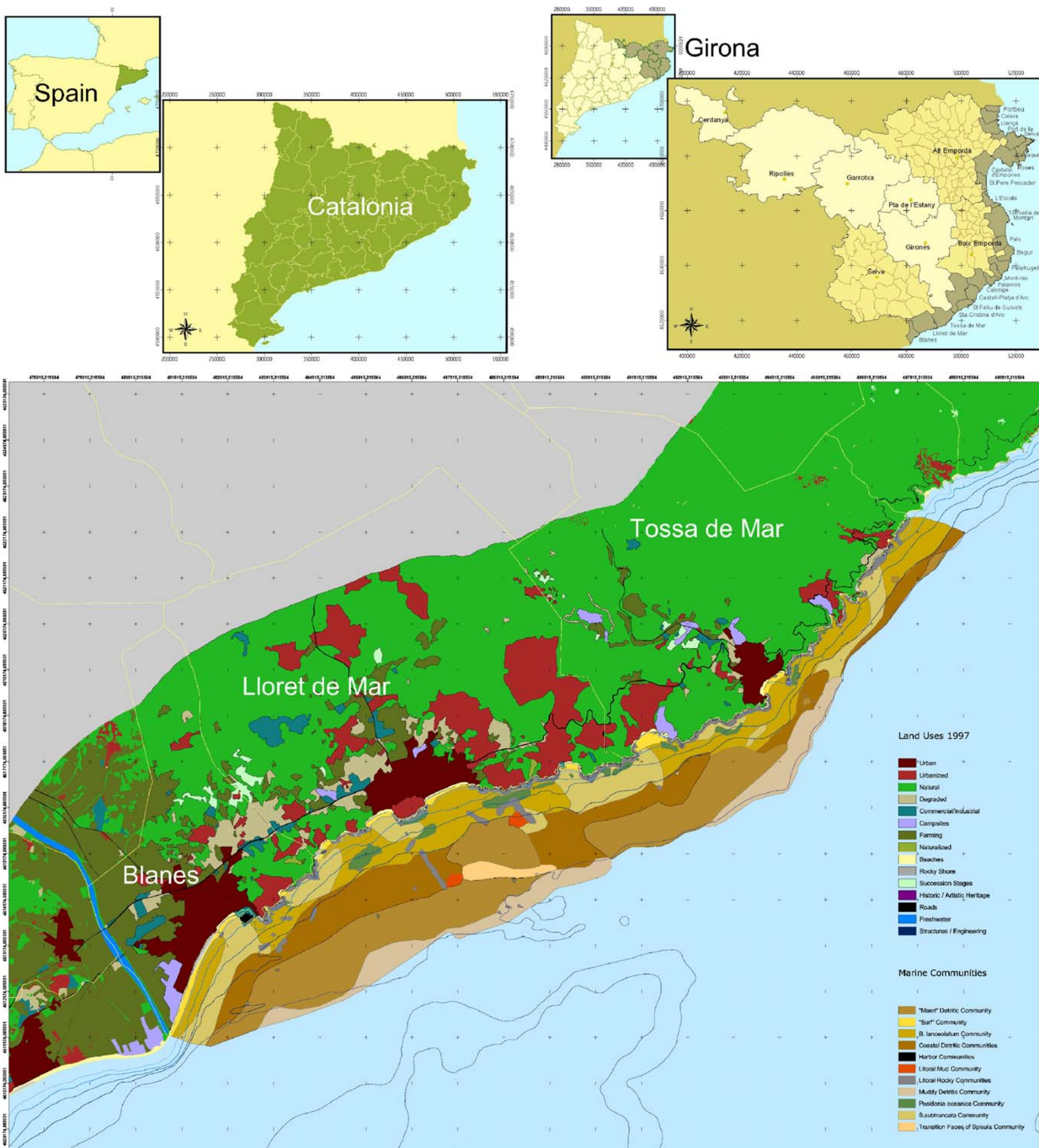

Fig. 2. Upper graphs: close-up of the Costa Brava region showing the "comarcas" of Girona province and the 22 coastal municipalities of the area. Bottom graph: GIS visualization of the three coastal towns of La Selva; the map shows the land use structure and the marine benthic communities inhabiting the marine environment up to 50 m depth.

marks the southern start of the Costa Brava, Lloret de Mar with its more than 35,000 accommodation beds is one of the main tourist resorts in Catalunya, and Tossa de Mar is recognised as one of the most famous towns of the entire coast by its walled quarter, its beaches, and its natural and cultural surroundings. These three towns have together a terrestrial surface of 101.9 km^2, and a marine surface, up to 50 m depth, of 37 km^2.

The primary indicators of the 43 indicator groups established in the panel are reported in Table 1. The table divides these indicators into two main groups: the common ones which where obtained for the 70 coastal

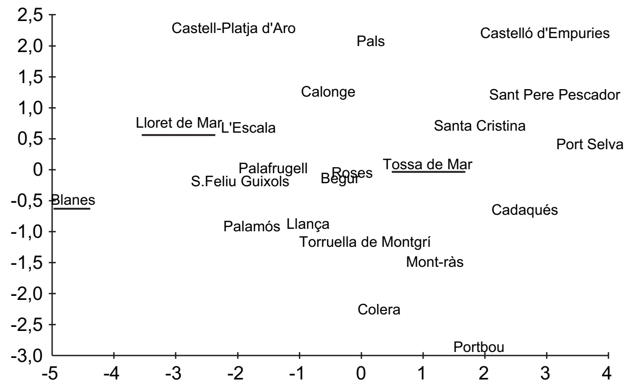

Fig. 3. Bidimensional PCA ordination of the 22 towns of the Costa Brava according to the strategic indicators. Coastal municipalities of La Selva are underlined.

municipalities in the Catalan Coast (common indicators, see the trefoil symbol in the table), and the specific ones, which were only obtained during the pilot plan carried out in the particular region of La Selva. The entire panel of indicators (128) included therefore, a total of 85 common indicators compiled in 30 indicator groups, and 43 specific indicators compiled into 13 indicator groups. From the panel, the strategic indicators of the region are shown in Table 2. Using these data in a principal component analysis, Fig. 3 shows the bidimensional ordination plane of the 22 towns of the Costa Brava, representing their similarity related to these 12 strategic indicators. The ordination of towns showed that human density is the main factor explaining differences. Less populated areas tend to be clustered together and the town of Blanes, the one with the highest density, comes clearly separated in the analysis. The second axis explaining the associated variance is more difficult to interpret and it seems to be related to the patterns of activities that have been carried out on it. The two first axes in the analysis explained 54% of the associated variance.

Indicators are useful in judging if we are making progress towards a goal, in this case advancing to a sustainable development of the coast. By using the tendency indicators associated with the strategic ones we could benchmark the evolution of these three towns in comparison with the other towns of the Costa Brava and/or the averages obtained for the rest of the Catalan Coast. (Table 3). Annual resident population growth increased by 3% during the period 1996–2001. The increase is considerably larger than that observed for the entire Catalan Coast, with annual increases of around 1%. On the other hand, the income rent per family (RBFD) increased at a lower rate (around 2%) than the rate observed for the entire coast. Concerning human activities, traditional tourism activities has been stagnated (a reduction of 2.3% in accommodation beds and a very small increase in quality, 3.7% during the studied period, 1996–2001) where not replaced by a tourist model based on secondary residences and with the construction as the main economic activity (Sardá et al., 2004). Annual rates for housing construction were measured around 3%. In relation to that, the need for transportation also increased sharply during these years. The motorization coefficient, an indicator that measures the number of vehicles of resident people, increased 10.5% in this period. All these socio-economic indicators could be confronted with those who gave information on environmental issues such us land uses, natural resource consumption, and/or conservational measures adopted. The annual water consumption and the annual household and industrial waste production increased by 4% and 5.5% respectively. No additional areas were devoted for conservation at that time, and the fisheries catches declined by 21% in the harbour of Blanes. Conversely, water depuration decreased by 15%

Table 3
Tendency indicators for the region of La Selva (Blanes, Lloret de Mar, and Tossa de Mar)

Number of municipalities	Blanes	Lloret	Tossa	Comarca La Selva	Costa Brava	Catalan Coast
	1	1	1	3	22	70
Resident population	10.75	20.73	13.31	14.59	9.24	4.45
House construction	14.28	10.46	4.44	13.03	9.10	9.78
Income rent per family (RBFD, constant currency) (*)	14.52	1.86	–	9.51	7.77	14.88
Unemployment rate	−42.96	−19.88	−13.48	−32.30	−36.24	−44.13
Accommodation beds (1996–2000)	−7.69	0.48	−4.24	−2.39	−2.89	−1.64
Hotel bed quality (1996–2000)	1.36	4.56	3.90	3.70	7.24	6.72
Water consumption (1996–1999)	10.60	13.73	9.98	12.10	–	–
Water depuration	−28.55	−7.20	2.57	−15.73	–	–
Household and industrial waste production	37.32	24.00	9.04	30.21	32.86	20.63
Protected area	0.00	0.00	0.00	0.00	–	–
Fisheries landings	−21.46	–	–	−21.46	−21.58	−15.50
Motorization coefficient	14.46	5.50	6.08	10.53	11.90	13.67

Data are given in percentage of increase in a 5 year period (1996–2001). (*) data are given for the period 1991–1996 because the 2001 data have not yet been released by the Generalitat of Catalonia.

Table 4
Evaluation of the environmental condition indicators for the region of La Selva

Inventoried communities	Surface (Ha)
Viburno-Quercetum subass. *suberetosum*	603.1
Reichardio-Crithmetum maritimi	45.1
Cistion Mediomediterraneum	367.6
Sand communities in the surf zone	77.1
Communities of the rocky Mediolittoral zone	3.1
Communities of the rocky Infralittoral zone	155.1
Communities of the rocky Circalittoral zone	56.7
Community of *Posidonia oceanica*	84.3
The community of medium to fine sand with *Spisula subtruncata*	535.2
The community of large sand with *Branchiostoma lanceolatum*	816.4
Sandy detritic communities	802.3
"Maerl" Communities	1146.7

Bioindicators	Data	
1. *Quercus suber* and *Pinus* spp.	Percentage trees per Ha	28.9
2. *Pinna nobilis*	Individuals 100 m^{-2}	1.3
3. *Cystoseira* spp	g C m^{-2} year	284.6
4. *Ulva/Enteromorpha*	Percentage of coverage	6.2
5. *Capitella capitata*	Individuals m^{-2}	0.0
6. *Actinia equina*	Individuals m^{-2}	0.3
7. *Patella* spp.	Individuals m^{-2}	52.2
8. *Mytilus galloprovincialis*	Percentage of coverage	11.4
9. Tellinoidea	g dry weight m^{-2}	0.016
10. *Merluccius merluccius*	Tons $year^{-1}$	81.5
11. *Aristeus antennatus*	Tons $year^{-1}$	84.2
12. *Callista chione*	g dry weight m^2	0.9
13. *Gymnammodytes cicerelus*	Tons $year^{-1}$	265.1
14. *Paracentrotus lividus*	Individuals m^{-2}	6.9
15. *Posidonia oceanica* (*)	Leaves m^{-2}	559.0
16. *Carici-Salicetum catalaunicae*	Index (0–10)	2.8
17. *Eunicella* spp.	Individuals m^{-2}	3.4
18. *Ditrupa arietina*	Individuals m^{-2}	24.8
19. *Reichardio Crithmetum maritimi*	Coverage aloctonous species	–
20. *Caulerpa taxifolia*	Coverage m^{-2}	0.0
21. *Phalacrocorax* spp.	Total individuals	70.0

Upper part: inventoried communities; bottom part; bioindicators. (*) data from Alcoverro, T., (–) data being evaluated.

in this period as a consequence of different measures such as reutilization and/or the improvements in water use efficiency.

We also carried out a complete digital inventory of the biodiversity of the region. The digital outline of the mainland of Catalonia was obtained from the Environmental Department of the Generalitat of Catalonia. All the digital layers established for the marine environment were developed during this project, as previous digital data for the region were conducted at a scale that was not useful for our purposes. Three separate marine layers were obtained: (a) a bathymetric layer, obtained using a sonar recorder; (b) a sedimentological layer, analysing through a LS Particle size analysis Counter more than 2000 samples obtained with a Van Veen grab (carbonate content and the organic matter of the samples was also measured and digitalized); and (c) a mapping layer of the marine communities, which was done using historical data as well as through the classification of the organisms extracted from the sieving of grabs (Fig. 2, bottom graph). The above data were combined with existing information from different sources that we compiled in the large scientific-technical information database produced at the beginning of this project. The marine information transferred into the GIS was then pooled with digitalized information on terrestrial communities. The natural ecosystems of the region were digitalized from data obtained from administrative offices (MAPA, 1990) and the land-use layer carried out during this work. The surface of all the communities presented in the marine and the terrestrial environment were quantified in a three-dimensional GIS environment. As an example, Table 4, upper part, shows the area of the inventoried communities for the region of La Selva and its associated marine environment up to 50 m depth.

Once the inventory was established, we constructed a matrix to relate the producers of impacts (specific types of impacts in the coastal zone) with the receivers of impacts (the different communities found in the

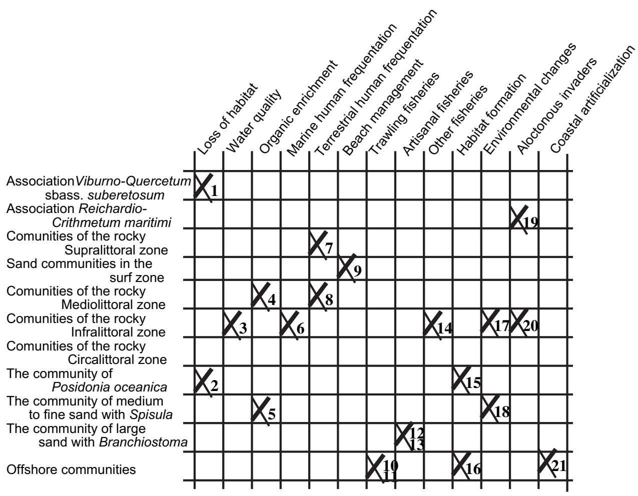

Fig. 4. Habitat–impact matrix for the selection of the appropriate bioindicators in the region of La Selva.

inventory). The used matrix (Fig. 4) serves us for the selection of 21 selected variables that are the indicators of environmental condition. In Table 4, bottom part, the values obtained for these indicators of environmental condition are shown. The idea behind this would be to follow this approach in the future on a periodical basis and to use the current data as reference values following the typical ''radar diagram'' of the AMOEBA model (Ten Brink et al., 1991).

3. Discussion

The need to find management practices to guarantee the sustainable management of the coastal zones (Turner and Bower, 1999) and the implication of the scientific community for developing such methodologies and providing high quality data (Schwarzer et al., 2001) is today widely recognized. As a general recommendation there is a need to introduce integrated coastal zone management processes, to co-ordinate public and private interests under a clear and transparent framework using the best possible techniques and tools for the daily managerial decisions. It is assumed that this is the way in which we can advance towards the sustainable development of the coastal zone. However, although the incorporation of sustainability criteria into management plans has gained importance as a societal objective, paradoxically the development of environmental statistical information systems to relate environmental and human ecological management is still in its early stages. The use of environmental information systems in which we combine the use of indicators to quantify information by aggregating different and multiple data, with the analytical capabilities of the GIS becomes a useful toolbox in this process. However, the developed toolbox has to be friendly and easy to use and to understand, since policy makers require high level of acceptance for indicators, scientists require very specific indicators to avoid uncertainties, and the general public understands social and cultural contexts but not yet the ecological one.

Catalonia is an autonomous community of Spain, which used to be a pioneer in the introduction of the regulatory policies of the European Community. Concerning environmental issues, the compromise of the region with the international mandatory requirements is high and it is included in its sustainable development model. This model is defined by four condition aspects: (a) its sociopolitical structure derived to the fact to be included inside Spain as an autonomous community; (b) its regional model based on the subsidiarity; (c) its Mediterranean style; and (d) its own identity which established a clear link between its culture and natural diversity (Martí, 2003). Although Catalonia is a territory with a diversified economy, for some special regions, mainly the coastal ones, this economy is highly dependent on the income generated by the tourism industry. Since tourism and recreation can threaten the environment if not well managed, and at the same time be affected by the environment, there is an urgent need for a better understanding of regional environmental change processes as a consequence of such human intervention, and for a better management of this extremely fragile environment. In this context, the environmental information system presented in this paper has been developed as a toolbox to implement the National Strategy of the Catalan Coast, and to advance towards the sustainable development of a coast in which tourist activities have been extremely important for decades (Sardá et al., 2004).

Our methodological approach combines the use of socio-economic and environmental indicators to assess pressures and impacts derived of human activities in the shoreline, using bioindicators in order to assess the condition of the environment. This methodology also allows the adaptability of this procedure to the variability of the coastal zone by using a common group of strategic indicators but, at the same time, to having specific indicators and using a habitat-impact matrix that can vary according to the different territorial units under analysis.

In the measurement of sustainable development, considerable effort needs to be addressed in the aggregation of data. The role of human development in causing environmental deterioration was summarized in the $I = P \times A \times T$ equation, the so-called fundamental equation developed by Ehrlich and Holdren (1971). By using this equation, we could assess through the collective system of indicators generated in the decision support system if we are maintaining a good ecological status of the coastal zone while keeping human activities on it. In the equation the impact (I) of any territory on the environment can be viewed as the product of its population size (P) multiplied by per-capita affluence (A) as measured for example by consumption or by GDP per capita, in turn multiplied by a measure of the damage done by the technologies (T) employed in supplying each unit of that consumption or unit of GDP. This latter term cannot only be directly related to technological issues, but to behavioural ones too. The $I = P \times A \times T$ equation, although it is a large simplification of real issues, can be used for the argumentation in the conflicts raised when we tried to incorporate sustainable development concepts into the regional development

In the region of La Selva, at the time of the analysis, resident population increased by 14.6% and the rent income per family by 9.5% during the period from 1996 to 2001. In order to equalize the equation, the "T" term of the $I = P \times A \times T$ equation should be reduced by 20.6%. Those values are indicating to us the great effort that the civil society needs to do through technology and behaviour to not increment the environmental impact we are producing on the territory. This simple equation, linked to an environmental information system, may argue future objectives and criteria for planning decisions such as the need to reduce water consumption and to increase waste valorization, as well as to raise environmental conservational measures.

Finally, recommendations for coastal managers were postulated based on the predictions, tendencies and scenarios that were developed through the analysis of the data collected in our decision support system (Sardá, 2003; Sardá et al., 2003b). The concluding recommendations are a challenge for all of the stakeholders involved, to find a balance between the encouragement of tourist activities and the preservation and correct management of the natural environment under the guidelines given by the international authorities. To achieve this challenge some values were clearly suggested: (a) it was necessary to give an answer to the environmental problems facing the coast and to include the responses in a longer-term perspective for policy-makers as sustainable tourism is a goal which cannot be reached immediately; (b) it was necessary to recognize the interdependence of economic and environmental systems and to determine the limits within human activities that need to stay in a particular coastal areas; and (c) it was necessary to protect the remaining natural and cultural heritage and to restore environmental degraded sites. The pooled information and the concluding recommendations provide managers with a powerful tool to do a better land-use management and planning activities in this conflictive coastal zone under a sustainable development vision. The work that we were carrying out in Catalonia is also a preliminary step to incorporate new regulatory amendments such as the Strategic Environmental Assessment Directive (COM/96/511) and to fulfil the EC-Recommendation on ICZM (COM/00/547).

4. Final note

At the time of sending this paper for printing (2004), the Generalitat of Catalonia launched a new and innovative legislative instrument for the protection of the Catalonian coast. This Catalan Order protects some areas from development, rescues others, and establishes criteria for further protection and restoration. In 2003, the Generalitat protected by Law (Law 25/2003) the natural space of Pinya de Rosa, a 60 ha shoreline area between Lloret de Mar and Blanes. We recommend that you visit this place as well as our institution located in the vicinity.

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