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Definition of Homogeneous Environmental Management Units for the Catalan Coast

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Abstract Geographical areas constitute the basic implementation locus for integrated coastal zone management strategies and activities. Because the definition of territorial planning objectives may be affected by socioeconomic and environmental characteristics, one of the main steps in the process involves dividing the coast into homogeneous environmental management units (HEMUs). This article presents a general and simple method for regionalizing the landside of a coastal zone into HEMUs and illustrates it through application to the Catalan coast. Socioeconomic and natural (biophysical) subsystems were selected as the most appropriate dimensions of the regionalization process. Dimensions were described using 11 spatial themes, which were managed in a geographic information system environment that proved to be an adequate tool for the purpose. A final coastal zone map of four classes of HEMUs connected to local administrative units was obtained, and because it reflects the current natural and socioeconomic dynamics, it can be considered as an initial step in the planning process for the Catalan coast. Although the proposed method was developed based on the characteristics of the Catalan coast, it is general enough to be adapted and applied to most developed or developing coastal areas.

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Introduction

Management of coastal areas under the sustainable regional development mandate is a complex process. Difficulties arise from the need to strike a balance between socioeconomic development and coastal conservation. This balance may vary due to the high variability of the primary components of the coastal system, i.e., the natural and socioeconomic subsystems (Van der Weide 1993). The aim of integrated coastal management is to maintain a sustainable relationship between the resources of these two subsystems and their exploitation, preventing (or mitigating) potential conflicts and reducing the uncertainties associated with planning and decision making. However, to manage a coastal region properly, a clear picture should already have been obtained of the expectations of stakeholders and/or society regarding each specific unit of territory, as well as the legal framework into which it fits and the existing property rights (Mee 2005). When this vision is shared and accepted, specific criteria can be developed to accommodate uses of coastal areas, to resolve potential conflicts, and to facilitate the decision-making process. In Spain, the coastal zone is administratively defined in the Coastal Law (BOE 1989) in terms of a marine and terrestrial zone that falls within the public domain. It is a very narrow fringe of territory delimited on the land side by the innermost high-water level. Inland there is a conservation easement fringe of variable width with different restrictions. Although this implies some kind of management or regulation of activities, there is an overlap with the responsibilities of the regional and local administrations. These factors generate a relatively poorly defined area in terms of planning and management.

Integrated coastal zone management (ICZM) is a tool to help achieve sustainable regional development in coastal areas. The main purpose of all ICZM initiatives is to maintain, restore, or improve specific aspects of coastal zone systems and their associated human societies. An important feature of ICZM initiatives is that they address the needs of both socioeconomic development and natural conservation in geographically specific planning activities at multiple administrative levels. Thus, geographic areas constitute the basic implementation locus of ICZM strategies and activities. Many authors have emphasized the role of appropriate territorial information and organized, coherent databases as essential for decision making in the coastal zone (e.g., Shupeng 1988, Bartlett 2000). The coastal zone is characterized by a high degree of natural and socioeconomic heterogeneity because of the existence of multiple resources and uses, and its highly dynamic nature (McLaughlin and others 2002). The spatial heterogeneity of the coastal zone can be rationalized by selecting homogeneous environmental management units (HEMUs), discrete homogeneous areas, or units with similar characteristics (for a description of similar approaches, see Christian 1958, Amir 1987, UNESCO 1997). These territorial units should then be linked to a strategic territorial plan, and thus, to active management units (Mee 2005). These units form the basis for research and data collection, and subsequently become the boundaries defining areas with similar land attributes selected as decision criteria for planning and evaluation (Baja and others 2002). This process of reducing spatial complexity is a way of linking management decisions to the biophysical and socioeconomic properties of a territory, and thus, meets the need of policy makers to access quantitative information on physical areas. To be an efficient management tool, these should also be integrated within the existing administrative framework. To properly define a HEMU, natural and socioeconomic properties must represent the coastal system as closely as possible (Zonneveld 1994), and if they are implemented in a geospatial management framework, all the elements of the system (natural, socioeconomic, administrative, etc.) must be spatially coherent.

The definition of HEMUs is a common task when one is dealing with systems with different environmental properties that support significant human activity. Several analytical approaches have been used, such as multivariate classifications/clustering, factor analysis, fuzzy logic, multicriteria analysis, and spatial overlapping (Fricker and Forbes 1988, Gornitz 1990, Bartley and others 2001, Baja and others 2002, Escofet 2002, Maxwell and Buddemeier 2002, Henocque and Andral 2003, Vafeidis and others 2004, Yáñez-Arancibia and Day 2004). The most common HEMU definitions have been based on biophysical characteristics such as geomorphology, climate, vegetation, and biodiversity. However, in order to develop an integrated vision of the coastal zone, the socioeconomic dimension needs to be incorporated into the process (Sardá and others 2005).

As a starting point, typologies constitute repeatable homogeneous units that are the basis for division or classification into geographical units. Usually, development of a typology for geospatial data takes either a top-down or a bottom-up approach (Maxwell and Buddemeier 2002). The top-down approach to classification is based on a decision tree containing predefined environmental characteristics that is specifically developed for a given environment (e.g., Finkl 2004). In the bottom-up approach, a clustering method is used to identify groups with similar environmental characteristics. A variation on bottom-up classification is the regionalization approach, which locates spatially contiguous class members after clustering without attention to spatial location (Harff and Davis 1990). Regions, which constitute a unique discrete system, become planning units and can be identified by a specific valuable quantifiable phenomenon. A combination of structural and functional typologies can determine the specific processes that constitute individual management regions. A review of the biophysical characteristics used for the classification of coastal and marine environments can be found in Finkl (2004). The analytical process leading to regionalization can be divided into two discretization strategies: hierarchical unit grouping and segmenting (Yáñez-Arancibia and Day 2004). These two approaches tend to give rise to regions based on a hierarchical criterion of belonging to a higher scale unit; thus, units can be identified as either belonging to a higher region or forming one (Escofet 2002). The interactions between the individual regions should determine the territorial planning schema that management needs for the process of reconciling the natural and socioeconomic subsystems. Because of the difficulties associated with this data-driven process, most planning instruments, such as assessment and evaluation, lack this framework.

As a useful working concept, the ecosystem approach has been defined to help in the process of setting environmental management boundaries (CBD 1999). Large-scale applications of this approach can be found in the different global proposals for environmental regionalization, such as the large marine ecosystems of the world (Sherman and Alexander 1986) and the environmental land units of the European ecological regions proposals (EEA 2003). This approach recognizes the dynamics and complexity of ecosystems in order to provide an analytical framework for the development of managerial strategies (Rappaport 1999). An example of regionalization is the use of river basins to define management units for use in a variety of approaches (e.g., Yáñez-Arancibia and Day 2004). This approach is used in the European Union (EU) to apply the European Directive on Water Policy (EC 2000). Although this approach is logical for the management of continental waters, its application to the coastal zone is more limited because it lacks a corresponding geographical structure in the marine domain. For example, in Catalonia the presence of only two large river basins means that this approach would not fully reflect the spatial variability of coastal properties. Consequently, it has to be reduced to smaller units to be a viable framework through which to develop management plans (DMAH 2004). When active administrative management units already exist in the coastal zone, an alternative approach is the inclusion of the environmental values in the existing structure to provide an integrated model (Walpole 1998, Barragán 2004, Sardá and others 2005). The need for a detailed identification of management units on a larger scale has led to the development of regional initiatives based on detailed analysis and maps. Few studies have used a combination of the two scales to perform a HEMU regionalization, because of the difficulty of integration in the ecosystem approach (Yáñez-Arancibia and Day 2004).

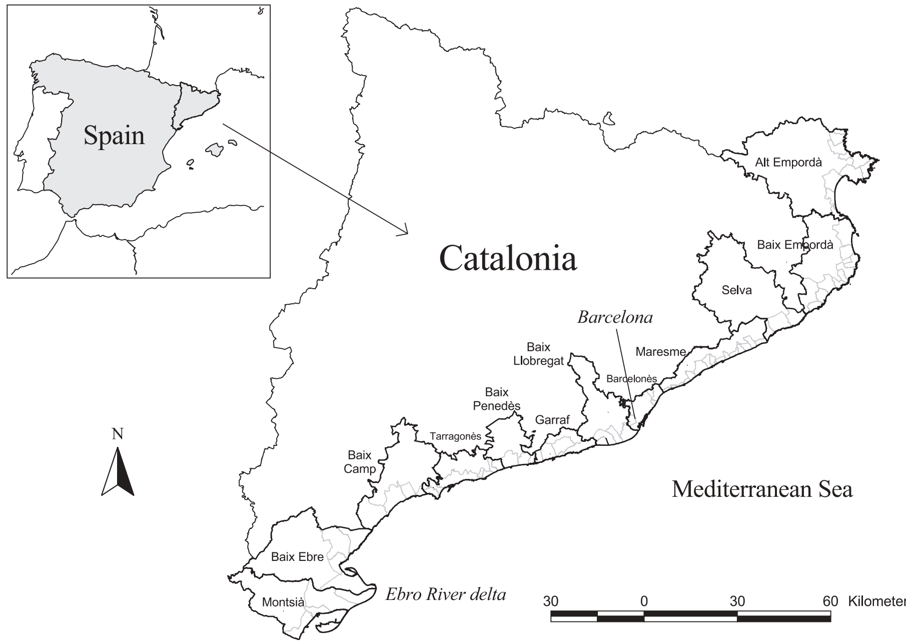
Indicator-based assessment and evaluation has commonly been used to track the performance and progress of ICZM plans and programs from a local to a national scale (Burbridge 1997, Belfiore 2003, Henocque 2003, and references therein). Several methods that incorporate multidimensional analysis have been used in the development of coastal classifications and indices. As an example, Gornitz (1990) used a combination of methods ranging from geometric means to factor analysis for classification of vulnerability and generation of indices. For coastal indicators to be effective in ICZM, it is necessary to demonstrate progress and results in a comparable manner across spatial scales and management levels (Belfiore 2003). Several issues related to the scale problem have been identified in previous research, the modifiable aerial unit problem (MAUP) being one of the most notable. MAUP appears in spatially averaged studies when units are subdivided into smaller nonoverlapping units such that intrinsic geographical meaning is absent (Openshaw 1984). It has major implications in two areas: (1) the number of aerial divisions of a unit that can be performed, and (2) the data aggregation at different resolutions (Bian 1997, Cao and Lam 1997). Although several solutions have been proposed, the main uncertainty arises when geospatial data are scale dependent (Cao and Lam 1997, Marceau 1999). Its importance increases with increasing spatial and temporal heterogeneity of the coast, and the difficulty of combining natural and socioeconomic subsystem indicators in the assessment process further complicates the final situation. Consequently, methodological difficulties are presented for the implementation of regional or national strategies at a local level.

The main aim of this article is to present a method for classification of the coastal zone into regions by defining HEMUs. One of the characteristics of the approach is that these units are integrated within the administrative framework and can therefore be used as management units for implementing ICZM initiatives. The method is applied to the Catalan coast of Spain to identify management units in which specific planning strategies such as the Coastal Zone Management Strategic Plan (PEGICZ; DMAH 2004) and activities can be implemented according to the socioeconomic and natural characteristics of the territory.

Area of Study

The Catalan coast is one of the richest and most rapidly developing regions in Spain. Of the total population of Catalonia, 44% (2.79 million in 2001) lives in just 7% (70 municipalities) of the total surface area (IDESCAT 2005). The coastline is 699 km long and includes a wide variety of temperate coastal systems. This results in considerable geomorphological and biological diversity. Figure 1 shows the administrative regions of the Catalan coastal area. Past and present human settlements reflect the organization of socioeconomic activities. The Mediterranean climate helped to configure the current structure based on typical coastal activities such as tourism, commerce, agriculture, and more recently, residential developments. Industrial and commercial activities are strongly associated with the metropolitan areas of Barcelona (Central) and Tarragona (South) but are less significant along the rest of the coast, where other economic activities (mainly tourism) dominate (Sardá and others 2005).

Fig. 1 Catalan coastal zone. *Comarcas* and municipalities administrative division



The Spanish coast is not only a complex area from a physical, demographic, and economic point of view, but also because of the way it is regulated. There are three administrative levels in terms of institutions and legislation: the central government of Spain, the regional government of Catalonia, and the municipalities. Within those levels, the Catalan coast is governed through two main legal instruments. First, the Spanish National Coastal Law constitutes the jurisdictional framework through which coastal zones are organized, specifically in terms of coastal public property (BOE 1989). Despite the fact that this does not define management attributions to the Catalan coastal zone, it does offer a general coastal zoning schema, as mentioned previously. The second instrument, the Statute of the Autonomous Community of Catalonia, sets out the limited competencies of the Generalitat (regional government) with respect to the Catalan coast and its marine environment (BOE 1979). Although in general the Spanish government manages most activities related to the marine domain (as set out in the Coastal Law), some of the activities (mainly seasonal services such as upkeep and cleaning of beaches) that influence the structure and dynamics of the shoreline (plus interior waters from base line) are managed by the local municipalities, which constitute the minimum administrative and management implementation unit. Following the EU recommendation on the implementation of integrated coastal zone management in Europe (COM/00/545), the Generalitat has already launched PEGIZC (DMAH 2004). This strategic plan constitutes a first step in a long-term move toward a much more rational management of the coast. However, because of the diversity of the biophysical and socioeconomic dimensions of the Catalan coast, it is difficult to implement without a HEMU schema. Although the importance of discrete planning units was stated in the objectives of the Catalan Agenda 21, the existing division of legal and administrative responsibilities may account for the lack of an effective HEMU framework.

There is a mismatch between the administrative units in the terrestrial and marine domains of the coastal zone. In the terrestrial part there is a clear spatial structure based on municipalities, whereas no equivalent division exists in the marine domain. Furthermore, data with which to characterize the status of the marine portion are scarce and heterogeneously distributed in comparison with a well-monitored terrestrial system. Moreover, most of the environmental status of the coastal zone is affected and/or controlled by activities that take place in the terrestrial domain, such as urban development and tourism (Nunneri and others 2005). Consequently, the scope of the present study is to identify inland territorial units with homogeneous characteristics in which coastal managers have responsibilities and in which they can develop a planning schema of priorities and implement strategies.

Specific typologies developed by scientific and management communities have been used in previous planning efforts. Such classifications are commonly based on a single characteristic and have linear features. The Master Ports Plan of the Generalitat is the most comprehensive coastal study undertaken in Catalonia. It proposed a division of the coast into 21 continuous sectors based on homogeneous coastline typologies, later classified into six geomorphological coastal types (DPTOP 1983). A more recent initiative is the Oil Spill Prevention Plan, which assessed the vulnerability of the previous 21 coastal sectors based on the composition of their benthic communities. The criteria of the plan are (1) exposure to marine hydrodynamics, (2) functional value *per se* for the ecosystem, (3) rarity, and (4) ecological resilience (CAMCAT; DMAH 2003). Other landscape units have been identified through a region-specific analysis, e.g., the environmental transformation of the northern Catalan coast or Costa Brava. Although units were defined using an aggregation criterion of the geomorphology matrix based on current human perception of such landscapes (Nogué 2004), classifications were restricted to one dimension (e.g., the natural environment) and lacked aspects of integration with socioeconomic activities. In the neighboring French Mediterranean, the coast has been divided into 50 homogeneous zones within the context of the Master Plan for the Development and Management of Water (SDAGE; RCM-Comite de Bassin 1995, Henocque and Andral 2003). Although the divisions are based on coastal geomorphology, they have been used by the regional water agency for more than 10 years to monitor water quality.

Methodological Approach

The Geographic Information System

In order to develop a HEMU-based regionalization, the terrestrial coastal subsystem was divided into natural (biophysical) and socioeconomic dimensions according to the generally accepted ICZM framework. Because of the heterogeneity of this area and the need to incorporate the environmental structure and function effectively, a regional, subnational cartographic scale between 1:25,000 and 1:50,000 was chosen for the purpose of the study according to UNEP (1995) recommendations.

The complex nature of the coast presents a challenge for the determination of appropriate structures for use when analytical and information frameworks are needed. This multidimensional spatial complexity can be addressed more efficiently with the aid of geographic information systems (GIS; Shupeng 1988, Bartlett 2000, among others). Because the representation of a system's elements is an important factor for the organization of databases, GIS have been widely used to integrate topological terrestrial and marine data models for studies of coastal zones. However, GIS also face problems in effectively representing the coast (Mueller and others 2002), and data model and structure have been identified by Bartlett (2000) as the two major concerns in the development of a coastal information system.

Most existing studies of coastal area classification use the shoreline as the basic representation unit. In this shoreline-oriented approach, the explicit spatial structure of system properties and dynamics is lost, and only the resulting classification is retained. This is equivalent to assigning the entire properties of the coastal area to a given length of shoreline without maintaining the original spatial reference (DPTOP 1983, Fricker and Forbes 1988, Maxwell and Buddemeier 2002, DMAH 2003, Vafeidis and others 2004). However, linear-feature models are commonly used in coastal mapping and analysis (Shupeng 1988), based on the common perception of the coast as a linear entity, which assumes that its two horizontal dimensions are essentially equivalent (Goodchild 2000). This represents one of the main limitations of the data model, which fails to address problems of variable spatial resolution of coastal data (Vafeidis and others 2004).

The aim of the present study is to develop a framework of geospatial coastal units that can be used in integrated management and that extends beyond the shoreline level. Because of the spatial scale of the relevant elements and the management model that will be implemented in Catalonia, the management units are based on a polygon data model in which discrete units represent subsystems whose processes and functions (including morphometric capabilities) can be subject to assessment, modeling, and monitoring (Bartlett 2000). Few thematic mapping efforts have been undertaken in Catalonia. Although the descriptors were created from the available data (published mainly by the local government), some of the spatial representations were developed by the Coastal Management Area of the LIM-UPC. To incorporate them into the Catalan Coastal GIS (which began to be developed in 2003 using ArcView™ v3.x software from ESRI), spatial data layers obeyed quality standardization processes for format, scale, and metadata.

Environmental Descriptors

It was assumed that variations in the environmental state (or health) of the coastal zone are controlled by spatial and temporal variations in the characteristics and processes of the system. Such changes are the result of interactions between human and biophysical subsystems (UNESCO 1997, DMAH 2004, Vafeidis

Table 1 Theme by dimension used for the Catalan coastal zone HEMU definition

Dimension	Theme	Cartographic scale	Year	Descriptor (s)
Socioeconomic	Population size	50,000	2004	Inhabitants count[1]
	Population growth	50,000	2001	Mean anual rate[1]
	Gross National Product	50,000	1996	Euros at market price[1]
	Accommodation coefficient	50,000	2002	Hotel beds by population[1]
	Impervious surface	50,000	2003	Urban area and Infrastructure[1,2]
Natural	Natural protected area	25,000	2004	Protected areas & wetlands surface[3]
	Geomorphologic relevance	50,000	2002	Areas surface[3]
	Vegetation condition	25,000	2004	Naturalness, diversity, and rarity[4]
	Landscape transformation	50,000	2004	Environmental degradation[3]
	Running water condition	50,000	2003	River flow and quality[3,5]
	Coastal geomorphology	50,000	1983	Coastal geomorphology and dynamics[6]

Source: (1) Catalan Statistics Institute (IDESCAT-GenCat); (2) Blanes Advance Studies Center (CEAB-CSIC); (3) Department of Environment and Housing of the Catalan Government (DMAH-GenCat); (4) Plant Biology Department of the University of Barcelona (UB); (5) Water Catalan Agency (ACA-GenCat); (6) Department of Land Policy and Public Works (DPTOP-GenCat)

and others 2004). These interactions are considered within the Catalan PEGIZC by focusing on five of the seven specific objectives: consolidation of undeveloped land, sustainable land use, land-derived marine pollution, erosion mitigation, and biodiversity conservation (DMAH 2004). Themes were chosen on the basis of their independent capacity to represent the coastal issues and were used to build up a data-driven classification process (bottom-up). As in the case of indicators, a reduced number of variables is desirable for prediction of the environmental state (Meentemeyer and Box 1987). The idea is to reproduce most of the system dynamics with a minimum number of descriptor criteria. Thus, selected themes represent the demographics, economy, geographic and biological diversity, water resources, and coastal geomorphology of the Catalan coast. A total of 11 geospatial themes were selected according to their conceptual, environment-specific contributions as quantifiable phenomena of the dynamic coastal subsystem and the quality of the available data. The quality-control schema was based on the following criteria: (1) 1:50,000 subnational cartographic scale or larger, (2) whether the source was official or not, and (3) data update criteria. Table 1 shows the themes used and their descriptors, the spatial scale and the year the data were gathered.

Within the socioeconomic dimension, the gross national product (GNP) was the most robust indicator, because of its capacity to integrate several elements of economic development, even though it was the least up-to-date dataset. The tourist industry is considered the most significant environmental influence on the Catalan coast (Sardá and others 2005); thus, the accommodation coefficient was included as a relevant socioeconomic factor. The group of themes corresponding to the environmental dimension coincided with the main institutional and governmental environmental concerns in Catalonia (loss of biodiversity, fresh and marine water quality, and habitat condition and transformation).

The natural dimension themes were incorporated at the municipality level. However, the natural protected area and the geomorphological relevance themes were incorporated at the landward 200-m fringe. This approach tried to capture the functional processes that comprise the strip 200-m inland from the shoreline in order to capture the coastal dynamics; this characteristic guards against overestimation of real conservation and the condition of coastal resources. The 200-m strip constitutes the coastal conservation easement zone indicated in the Spanish Coastal Law (BOE 1989). The natural geospatial features were incorporated into the GIS using the original minimal mapping unit (as provided by the source, e.g., raw polygons), be they polygons, lines, or points, and were later aggregated at the municipality level. Municipalities are the smallest official geographical management unit, and they constitute the highest administrative implementation level, and therefore, the most effective planning unit for ICZM (Sardá and others 2005). In contrast, the themes corresponding to the socioeconomic dimension were georeferenced to the *comarca* (a territorial unit comparable to a county), because this constitutes the highest administrative level for which there is complete and official statistical data, and because *comarcas* are recognized as a real and practical administrative territorial unit in Catalonia, as well as in the rest of Spain, thereby providing an accepted spatial framework. *Comarcas* are groups of municipalities (cluster), and they were selected because a large part of the socioeconomic data available is only complete for 68.5% of municipalities (those with more than 5000 residents).

Themes were spatially combined using the GIS to produce an ordinal pseudo-indicator of a specific desirable condition of each theme. The resulting continuous real number scale for each theme was numerically aggregated into an arbitrary four-way classification, whether or not it was originally on an ordinal scale. Gornitz (1990) and Gornitz and others (1994) used a similar approach to develop indices of several coastal characteristics that were aggregated into a vulnerability index using a linear model. The classification method used the Jenks optimization, which identifies break points between classes by minimizing the sum of the variance within each of the classes (Jenks 1967). This method identifies groupings and patterns inherent in the data and produces a more objective aggregate representation of spatial variability, thus providing a valuable tool with which to explore and represent data by minimizing its natural variation (Smith 1986).

Data Aggregation Method

The natural themes considered in the analysis (Table 1) were aggregated at the level of the *comarca* to be spatially coherent and consistent with the socioeconomic data scale. An aggregation method based on a weighted average was used to represent the contribution of the surface area of coastal municipalities to the *comarca* level for the natural dimension themes (see Gornitz 1990 for a discussion of data aggregation methods). This met the requirement to establish a common spatial framework and prevented inferences from higher to lower levels of analysis that are associated with the ecological fallacy (Alker 1969, Cao and Lam 1997). *Comarcas* constitute true physical management units, because they are based on the common historical, cultural, and administrative characteristics of their constituent municipalities. They are therefore important in ICZM planning and monitoring of the Spanish coast (Barragán 2004).

Regionalization Process

Theme typologies were used to develop a specific regionalization map for each dimension. The algebraic sum of individual themes represented the contribution of the individual natural and socioeconomic regionalization of the Catalan coast. The thematic map of each dimension represents an independent view of the territory, and together they constitute the main input for the integrated regionalization process. The following criteria form the basis of the HEMU definitions:

- They should follow the principles proposed in the EU recommendation concerning the implementation of integrated coastal zone management in Europe (EC 2002).
- They should constitute local administrative (management) units.
- They should be based on real, natural, biophysical data.
- They should integrate and reflect the principal existing structure and functional processes of the coastal environment.
- They should be derived from a combination of independent characteristics that remain constant over time (wherever possible).

The natural and socioeconomic rationalizations were aggregated to form the final HEMU map. The aggregation process obeyed certain algebraic combination rules. The final regional HEMU map was produced using four category units for the 12 *comarcas* of the Catalan coast. An additional analytical phase defined spatial modeling rules to determine criteria for a proposed natural coastal resources conservation scenario.

Results

The implementation of the Catalan ICZM strategic plan requires a territory-based spatial framework, which in this case is based on the definition of HEMUs. Although the coastal system consists of several different dimensions that determine its stability and health, only two are used in this study: the socioeconomic and natural dimensions. It was assumed that the Catalan coastal zone could be defined for management purposes in terms of these two dimensions, consisting of five and six themes respectively that were incorporated in the GIS at cartographic scales of 1:25,000 to 1:50,000 (Table 1).

Table 2 shows the values generated by classifying Catalan coastal *comarcas* using the Jenks method for each theme and dimension. This classification is based on results given in terms of ordinal classes, where the maximum value (four) indicates the highest relevance of the characteristic and the minimum (one) indicates the lowest relevance. Table 2 also shows the surface area (in hectares) of the *comarcas* and provinces to indicate the relative geographical contribution of the themes in the regionalization process.

Figure 2 shows the results of the socioeconomic and the natural thematic rationalizations. There is a clear relationship between the two: in general, higher values for the socioeconomic component are accompanied by lower values for the natural component. This pattern

Table 2 Theme classification values by *comarca* of the Catalan coastal zone

Comarca	Province	Has	Socioeconomic					Natural					
			A	B	C	D	E	F	G	H	I	J	K
Alt Empordà	Girona	135,697	1	2	1	3	1	3	3	4	4	2	1
Baix Empordà	Girona	70,016	1	2	1	3	2	2	2	3	3	2	1
Selva	Girona	99,5374	1	3	1	4	1	2	1	3	3	2	1
Maresme	Barcelona	40,049	2	3	2	2	2	1	2	3	3	2	3
Barcelonès	Barcelona	14,463	4	1	4	I	4	1	2	2	1	2	2
Baix Llobregat	Barcelona	48,664	3	2	3	1	3	2	2	3	2	2	4
Garraf	Barcelona	18,503	1	4	1	2	2	2	2	3	3	2	3
Baix Penedés	Tarragona	29,618	1	4	1	2	2	1	1	3	2	1	3
Tarragonès	Tarragona	31,931	1	2	2	3	3	2	2	3	2	2	2
Baix Camp	Tarragona	69,633	1	2	1	2	1	2	1	4	3	1	3
Baix Ebre	Tarragona	100,212	1	2	1	1	1	3	2	4	4	3	4
Montsià	Tarragona	73,741	1	2	1	1		3	3	3	4	3	4

Themes: (A) Population size; (B) Population growth; (C) Gross National Product; (D) Accommodation coefficient; (E) Impervious surface; (F) Natural protected area; (G) Geomorphologic relevance; (H) Vegetation condition; (I) Landscape transformation; (J) Running water condition; (K) Coastal geomorphology

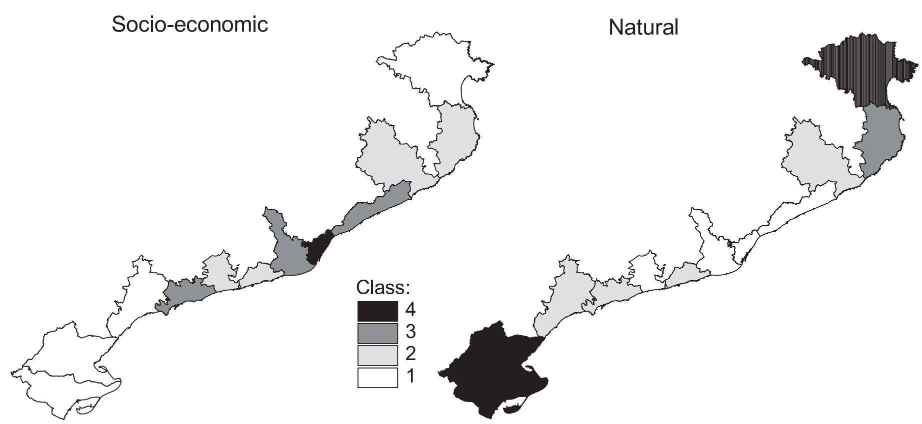


Fig. 2 Socio-economic and natural regionalizations of the Catalan coast

clearly reflects the central role of the metropolitan areas of Barcelona (Barcelonès) and Tarragona (Tarragonès) in the socioeconomic development of Catalonia. The least developed areas in socioeconomic terms correspond to those with the highest environmental values and are located in the northern (Alt Empordà) and southern (Montsià) ends of the region, where the most important protected natural coastal areas are located (Cap de Creus and the Ebre delta, respectively; see Figure 1).

Once these two independent rationalizations were performed, they were combined to define the map of the HEMUs. Figure 3 shows the HEMUs obtained by applying a method designed to retain the attribute homogeneity of units after aggregation. By applying a direct averaging of the two dimensions, the numerical values attached to each *comarca* in Figure 3 should be obtained. This value, which we will refer to as ''total wealth,'' is obtained by averaging natural and socioeconomic values, and it can be considered an integrated measurement of the two dimensions. However, this method of aggregation can introduce interpretation errors, because zones with very different characteristics can have similar numerical values. Thus, Barcelonès and Alt Empordà have an equal total wealth value which in the first case is due to a high socioeconomic value and in the second is due to a high natural one.

To prevent this, we used an integrative model in which the natural component was combined with the socioeconomic component, but in which they were inverse scaled (i.e., an original value of four is substituted by a value of one) and averaged. The resulting values were obtained from the algebraic mean of both the regionalization of the dimensions and re-aggregating them to their class type (i.e., values ranging from 2.000 to 2.999 indicate class 2). Reclassified values were assigned to a nonordinal nominal four-class scheme to avoid misinterpretation of results. The final results indicate units (*comarcas*) with similar socioeconomic

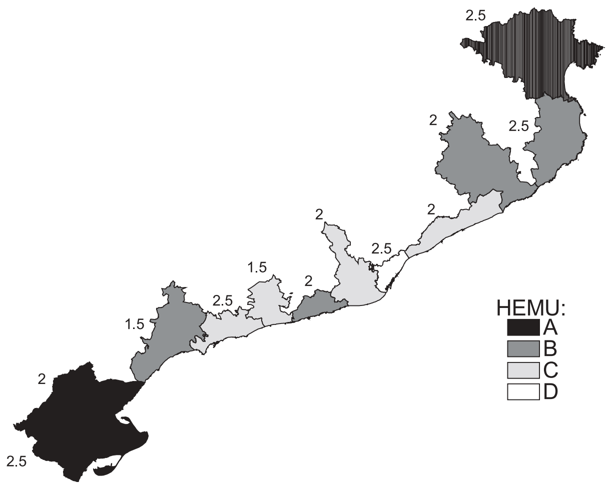


Fig. 3 Homogeneous Environmental Management Units of the Catalan coast. Numbers indicate total socio-economic and natural total richness by unit

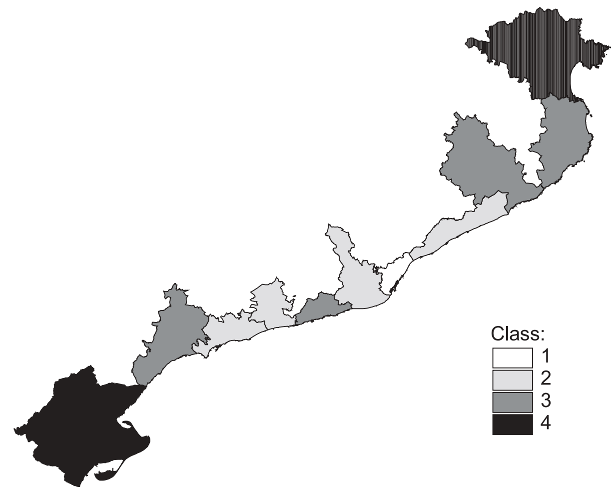


Fig. 4 Conservation HEMU regionalization scenario of the Catalan coast

and natural properties but without showing any priority indication.

The four-class *comarca* map obtained represents a reliable management regionalization of the Catalan coast, while being a data-based and user-oriented product. Based on the spatial aggregation method developed, it was possible to account for the functional homogeneity of the coastal zone. The HEMUs classify the *comarcas* into highly natural areas (A), seminatural areas (B), semiurban areas (C), and areas with high socioeconomic development (D). Geographically, each of these classes (units) should be managed under a desired ''vision'' that fulfills the expectations of the population living in the area and obeys the established legal framework.

Finally, the need to incorporate a stronger plan for the conservation of natural resources in current and future coastal zone management strategies has been stressed previously by several authors (Sherman and Alexander 1986, Van der Weide 1993, EC 2002, DMAH 2004). A management scenario involving environmental conservation was defined to conserve the natural role of the coast and provide a tool for managers that could contribute to the target set for 2010 by the Convention on Biological Diversity (CBD 1999). The scenario was defined by applying an arbitrary relative weighting of 80% to the natural dimension values and 20% to the socioeconomic values.

Figure 4 shows the resulting map of HEMUs in terms of ordinal values. In this case, the map represents conservation priorities for the Catalan coast. The regions are clearly similar to those obtained from the equally weighted averaging map, with the differences between them arising from the existence of priority indications for management purposes. As in previous cases, the maximum value for the criteria selected is four; in this case, the highest environmental values. Management plans for these units should be properly considered.

Discussion and Conclusions

The GIS provided an appropriate geospatial structure through which to develop an efficient classification of coastal management units (Shupeng 1988). As suggested by Bartlett (2000), GIS also played a key role in database construction, theme modeling, and visualization of results. Although the selected polygon data model does not account for the dimensional problems implicit in the line representation of the coast (Vafeidis and others 2004), we also found that there is no straightforward system to define an aerial model that efficiently manages the dynamics of the two coastal dimensions studied (Mueller and others 2002). However, in this study we used the mean-based aggregation model proposed by Gornitz (1990), because it has been demonstrated to be less sensitive to data errors, omissions, and misclassifications.

In order to use a method that is general enough to be applicable to most coastal zones, themes describing each component were selected on the basis that they were relevant, georeferenced, and could be either easily measured or obtained from existing official data. Although it might be desirable to integrate data at a larger cartographic scale, positive results were observed in the spatial patterns obtained at the Catalan coast geographic scale. This is clearly the result of the multisource database appropriate integration at a subnational cartographic scale (1:25,000–1:50,000), as recommended by UNEP (1995) (Table 1). The themes are relevant to most developed and developing coastal zones, and only a few were specific to the coast analyzed. This approach differs from data-intensive studies requiring a large number of descriptors for each theme that in many cases prevent its practical application (see an example in Cendrero and Fischer 1997). An example of an area-specific variable is the accommodation coefficient (number of hotel beds per inhabitant), which is only relevant to areas in which tourism is an important economic activity. This is clearly the case for the Catalan coast, where tourism accounted for about 10.8% of GNP in 2002 (DCTC 2002). If this analysis were to be performed for a coastal zone with different major economic sectors, the corresponding representative indicator would need to be properly selected to reflect the most important socioeconomic component.

In this study, two parameters in the natural dimension were calculated for the 200-m-wide fringe along the coast using the GIS, instead of using municipalities as spatial units. This was done to accurately reflect coastal environmental resources and not environmental resources in coastal administrative units (municipalities) in a specifically adapted ecosystem approach (Rappaport 1999). This width corresponds to the official conservation easement zone based on the administrative regulations for the Spanish coast (Spanish Coastal Law, BOE 1989) and must therefore be adjusted to the specific regulations of the coast to be analyzed.

The natural data layers at the level of the municipality were aggregated at a higher administrative level—the *comarca*—by considering values corresponding to the number of coastal municipalities included in it. Thus, the use of *comarcas*, made up of municipalities with similar characteristics, leads to a degree of uniformity that is most likely to be due to the common natural and socioeconomic environment that is implicit inside the boundaries, reflected in a unification effect within the *comarca.* This final geographic scale was found to be useful for reducing the high variability found at the level of municipalities, which would have complicated the design of an effective ICZM strategic plan for Catalonia (or probably anywhere else). This scale still retained the major sources of variability along the coast, and because data were upscaled and no aerial subdivisions were made, it did not show significant MAUP symptoms (Marceau 1999). Likewise, no scale-dependent problems were addressed in the classification process because several themes were compiled from the beginning at the *comarca* level and not aggregated at a different resolution. Similar results concerning the use of *comarcas* as aggregation planning units in Spain can be found in Barragán (2004).

The integrated description of themes selected for the Catalan coastal zone can be considered representative of developed coastal areas, where high values for the socioeconomic components are frequently accompanied by low values for the natural components (Figure 2) This also seems to confirm a global tendency in coastal areas for socioeconomic activities to generate significant pressures on coastal systems, leading to an inherent reduction in or degradation of natural resources. A similar pattern was found in *comarcas* with high values for natural resources (the northern and southernmost *comarcas*); although these are the least developed in socioeconomic terms, they were the greatest contributors to the geographic and biological diversity of the Catalan coast. If a river subbasin schema existed for this area, the present results could be complemented in the future with similar approaches to those used by Escofet (2002) and Yánez-Arancibia and Day (2004).

Whenever the natural and socioeconomic dimensions have to be integrated in order to characterize the properties of discrete planning units, results can be unclear or susceptible to misinterpretation by managers. This is due to the inverse relationship between the socioeconomic and natural values of developed coastal areas mentioned above. Thus, two units with different characteristics (one with high socioeconomic and low natural values, and the other with the reverse situation) could give the same overall integrated value if they were directly combined. Although the value obtained in this way could be interpreted as a measure of the total wealth (considering both themes) of the territorial unit, it is clear that the two units could not be managed in the same way. This problem was overcome by reclassifying one of the components before adding them together and prevented the socioeconomic data interval ranking problems experienced by McLaughlin and others (2002). The implicit result of this operation should be equivalent to only considering one of the two components, and it can only be used for coasts that display the inverse relationship between socioeconomic and natural values mentioned above.

The bottom-up approach used here provided a data-driven environmental regionalization of the coast that could not have been obtained with a predetermined planning structure (Harff and Davis 1990). Thus, the results obtained are not intended to provide *a priori* management priorities, but rather to identify classes of truly homogeneous units that managers can use for future planning, policy implementations, and monitoring initiatives. This can be seen clearly in Figure 3 by comparing the difference in HEMU class (four classes) with the total wealth values obtained (almost constant throughout the entire territory). However, HEMUs with the lowest total wealth values (La Selva, Maresme, Baix Penedès, and Baix Camp) should be identified as critical hot spots in the ICZM strategic plan. Compared with the rest of the territory, these hot spots do not seem to have a dominant value or resource. As suggested by Burbridge (1997), a special plan would have to be designed to improve their situation and to reach the average value throughout the territory.

Following the recommendations of the Sixth Environmental Action Programme of the European Community (EC), the conservation of natural resources has been defined as a central objective of the Catalonia ICZM strategic plan to maintain and/or improve the environmental quality of the system and its associated human societies (DMAH 2004). The specific conservation regionalization developed here (Figure 4) provides a spatial vision based on the natural quality of the coastal zone and at the same time serves to identify priority conservation areas, a process that has been proposed as relevant to coastal management by EC (2002). According to the pattern observed, the areas with the highest environmental values are the northernmost and southernmost *comarcas*, and consequently, under the present management scenario, those are the areas with the lowest priority. For the *comarcas* with the lowest natural values, two different management options could be selected: defining immediate actions for the improvement of environmental values (condition) or abandoning them and converting them into sacrificed areas in terms of natural wealth. The final choice will depend on the level of transformation shown by these areas, as well as local institutional capacity. In any case, to build a management-oriented scenario, the selection of weights for the socioeconomic and natural components should be based on real policy objectives as part of a more systemic view (Van der Weide 1993). Thus, this study only represents a proposal for managers to consider in relation to such issues.

Although based on the *comarca* administrative units, the regionalization of the Catalonia coastal zone based on HEMUs performed here does not correspond to any other existing *comarca*-based regionalization of the area. Most existing regionalizations are based on a single theme (typology) and consequently fail to capture the integrated structure and functioning of the coastal system. As an example, the Catalan coastal tourism regionalization (DCTC 2002) is based on the major economic driving force for the coastal zone, e.g., the tourist industry. In spite of the relative weight of this factor in the socioeconomic structure, using it as the only regionalization parameter for the territory

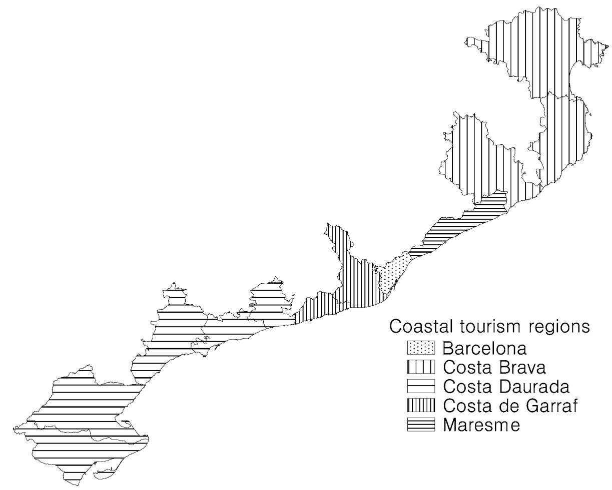


Fig. 5 Touristic regionalization of the Catalan coast (DCTC 2002)

fails to reflect the actual socioeconomic and natural variability and complexity of the coastal zone. This generates five regions (Figure 5) that, despite being currently managed and exploited as homogeneous units, are composed of *comarcas* with dissimilar socioeconomic and natural values (Figures 2 and 3). The method proposed here to define a multidimensional HEMU-based regionalization of the coastal zone using GIS overcomes these problems and can be used to define a more integrated management plan. However, the present proposal represents the result of a data-driven analysis, and the process should be complemented by a more social vision that considers the goals and interests of managers, stakeholders, and end users.

In summary, the regionalization process performed here for the Catalan coastal zone generated four different classes of HEMUs, for which socioeconomic and natural characteristics were combined in a GIS to give an overall integrated value. The GIS proved to be an efficient tool for data management, analysis, and visualization in the overall process of defining coastal management units. This HEMU-based regionalization of the territory is a way to rationalize the definition of the Catalan ICZM strategic plan. This geospatial approach could also be adapted and applied to other coastal regions. Finally, the relevance of the process will ultimately depend on specific management goals and objectives, and must be considered in the context of the need for a multicomponent spatial vision of the coastal system. The proposed HEMU regionalization, based on the *comarca* as the administrative/management unit, is expected to be an important tool for the future implementation of the recent ICZM strategic plan for Catalonia.

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