CHAPTER 1. Introduction

1.1 Background

Coastal areas contain a striking concentration of human settlement and economic activity. At the global level, nearly half of major cities are located within 50 km of the coast, and population densities are on average more than two and a half times higher than those of inland areas (Millennium Ecosystem Assessment 2005a). In Catalonia, coastal municipalities support 44 % of the total population and mean densities of 1,324 hab/km^2 (IDESCAT 2006); which can triple in some municipalities during the summer season. Additionally, this zone also comprises areas with highly productive ecosystems that in most of the cases concentrate high natural values. As an example, Figure 1.1.1 shows the distribution of wetlands in Catalonia where it can be seen that the majority and largest are located in the coastal zone. Without knowing their values, it should be expected that the human influence on this part of the territory can affect their health and, in consequence, would alter the natural value of the coastal zone.

Figure 1.1.1. Distribution of wetlands in Catalonia (Data source: DMAH 2001).

Traditionally, benefits from natural resources' use have not been fully taken into account in environmental planning and decision-making. Thus, ecologically productive, multifunction ecosystems continue to be converted into simple, single function land-use types (*e.g.* croplands, urban developments). One reason to continue underestimating the benefits of natural and semi-natural ecosystems is the difficulty to express the overall importance of its functions in monetary terms that can capture the conventional market-based economies. From an economic perspective, coastal ecosystems should be treated and counted as other elements of development infrastructure, *i.e.* as a stock of facilities, services and equipment which are needed for the economy and society to function properly. However, to ensure the availability of the ecosystem goods and services, their use should be limited to a social-ecological system sustainable use levels.

Ecological economic valuation can be considered as a powerful tool for placing coastal ecosystems on the agenda of integrated planning processes decision-making, as in Integrated Coastal Zone Management (ICZM). Its basic aim is to determine people's preferences: how much better or worse they would consider themselves to be as a result of changes in the supply of ecosystem goods and services. By expressing these preferences, and relating them to measures of human well-being, valuation aims to make natural ecosystems comparable with other sectors of the economy when investments are appraised, activities are planned, policies are formulated, or land and resource use decisions are made.

Although most of the final demand for ecosystem services value comes from policy-makers and public agencies, a number of factors have limited the use of ecosystem services non-market value as a major justification for environmental decisions. Limited people's perceptions, on which non-market assets valuation is based on, constitutes a common limitation to the reliability of valuation studies. However, it has been suggested that besides assessing value from the subjective point of view of individuals, the objective point of view of what we may know from other sources about the connection should be included (Costanza 2000).

This study presents how recent advances in ecological economic concepts and methods provide an opportunity to make better informed decisions in ICZM, and can be used to strengthen sustainable development in coastal areas. The study argues that a shift in the way in which development and conservation trade-offs are calculated is required, moving from approaches which fail to factor in ecosystem costs and benefits, to those which recognise, count and invest in natural ecosystems as an economic part of coastal infrastructure.

The proposed approach is expected to have the largest impact in ecologists, economists and especially in ICZM decision-making. In consequence, they will have a clear way to integrate the concept of ecosystem services as well as a transparent and consistent ways to value its services. Making the contribution of ecosystem services to human well-being and the ecosystem functions that underlie those services more explicit, should help motivate policy towards integrated sustainability.

1.2 Objectives

This study departs from the hypothesis that ecosystem benefits or services are becoming scarce by experiencing serious degradation in regard to their capability to provide services efficiently in the Catalan coast. Thereafter, the general objective of the study was to ***"assess the non-market value of ecosystem services provided in the Catalan coastal zone, in monetary terms."***

To achieve the general objective four specific objectives were identified:

- **Regionalize the coastal zone to provide a consistent structure for assessing value.**
- **Estimate the human preference-based value of ecosystem services delivered annually using a benefit transfer approach.**
- **Determine the social-ecological capacity of ecosystems to provide services in the coastal zone.**
- **Develop an integrated ecological and socio-economic valuation of ecosystem services based on its provision capacity.**

To achieve these objectives the steps in Figure 1.2.2 were followed.

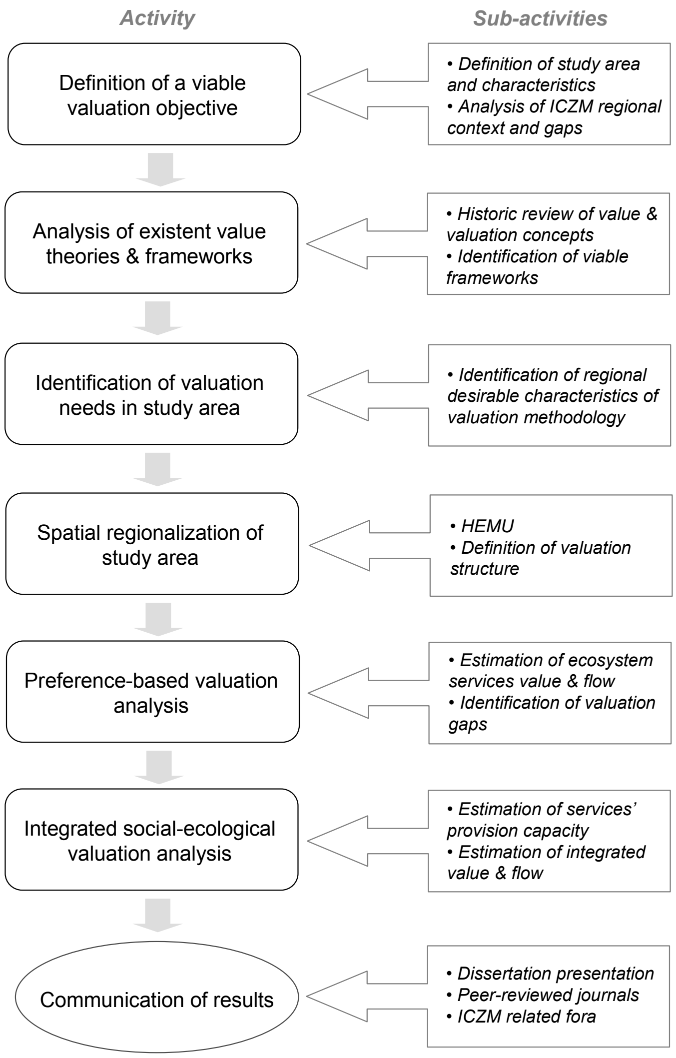


Figure 1.2.2. Overview of main conceptual steps involved in the study.

1.3 Structure of the document

All this work has been included in this document according to the following structure. Chapter two introduces the study area of the Catalan coast. It provides a description of three main dimensions relevant to Integrated Coastal Zone Management: socio-economic, natural and administrative dimensions.

Chapter three provides the conceptual framework for this study. It identifies ecosystem functions as key elements of ecosystem's health. The analysis focuses on natural and semi-natural terrestrial and marine functions and services which are not counted in the economic markets, therefore marketed goods, such as fisheries, were not part of the scope of this study. The chapter provides an outlook to ecological functions and services provided by the Catalan coast and available data on its value.

Results of analytical developments are presented in chapter four. In the first section, study area was regionalized into discrete homogeneous environmental management units by using socio-economic and natural spatial indicators. The valuation of the coastal ecosystem services was conducted in the second section. Here, monetary value was assessed using a value transfer approach. After that, an integrated ecological and socio-economic valuation was conducted in the third section. Integrated value was derived using each ecosystem's capacity to provide services, which was conceived as a function of the non-use ecological value of ecosystems and the human influence.

Chapter five presents the conclusions of this work and identify the relevance of the work for strategic planning and decision-making processes for the management of the Catalan coast. Moreover, a list of management related questions is presented.

References to the literature used in the study are cited in chapter six and complementary materials are provided in annexes on chapter seven.

CHAPTER 2. The Catalan coast

2.1 Introduction

Catalonia is located at the North-eastern Spanish Mediterranean coast. It occupies 32,105 km^2, with a coastline of 699 km long, of which 270 km are beaches (CADS 2005). Its coast has a NE → SW orientation and has a considerable geodiversity and biodiversity, represented in their cliffs, rocky coasts, sand beaches, low coastlands, river deltas, and estuaries.

The Catalan coast comprises 70 municipalities which comprise the 7 % of the surface of Catalonia, grouped into 12 *comarcas* (similar to a county) included in three provinces that from North to South are Girona, Barcelona, and Tarragona (see Figure 2.1.1). Among the 53 commercial and leisure ports (marinas) plus a number of boat ramps along the coast, the Ports of Barcelona and Tarragona constitute its major infrastructures along the coastline (DPTOP 2001). Other relevant physical-cultural features associated to the coastline are the El Prat International Airport in Barcelona and the Vandellos II nuclear plant in Tarragona.

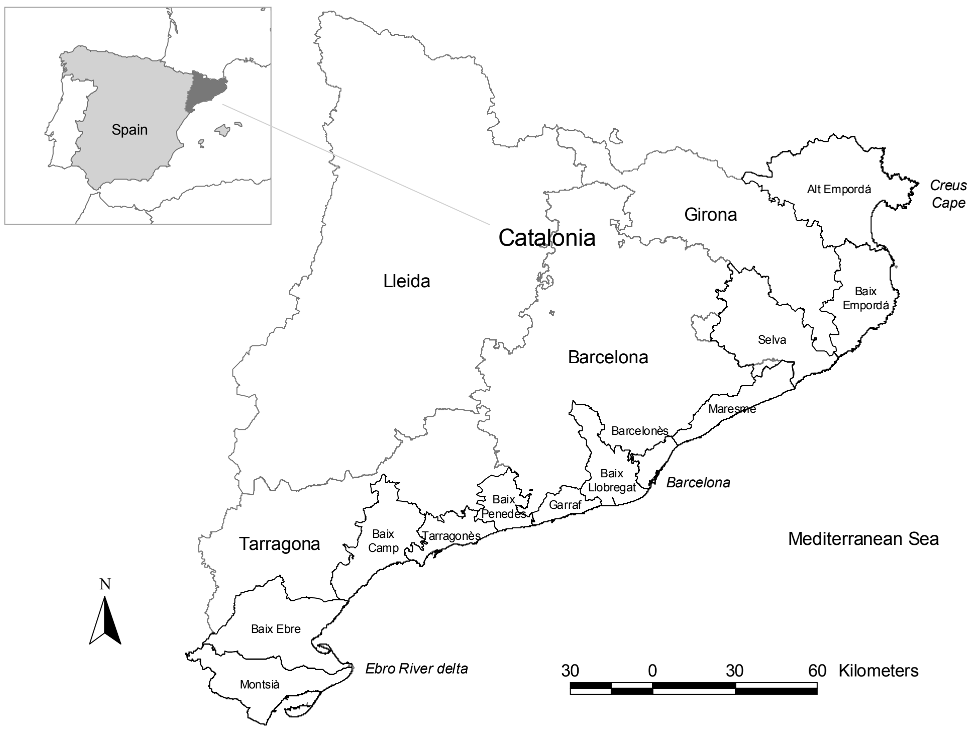


Figure 2.1.1. Provinces and coastal *comarcas* of Catalonia.

Past and present human settlements reflect the organisation of socio-economic 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 *et al.* 2005). Catalonia occupies an important socio-economic and environmental role in Spain, European Union (EU) and at the global level; examples of such contribution can be seen in Table 2.1.1. The following sections contain detailed descriptions of the socio-economic, natural and administrative dimensions of the coastal system, as well as the coastal zone working definition used in this study. A list of common sources of data and information of the Catalan coastal zone can be found in Annex I.

Table 2.1.1. Catalonia in Spain, the European Union and the world.

	Descriptor	Dimension	Global	EU	Spain	Catalonia	Notes
Territory	Coastline length	km	1,634,701	89,000	8,267	699	*1,2,1,3*
Population	Population	hab	6,525,170,264	456,953,258	40,397,842	6,813,319	*4,4,5,6*
	Coastal population	% of total	37	50	62	44	*7,2,7,8*
Macroeconomic	Gross Domestic Product	USD/per capita	9,300	28,100	25,200	26,942	*9,9,9,10*
Environment	Natural protected area	ha	1,800,000,000	76,635,536	4,400,000	648,065	*11,16,12,13*
	Ecological footprint	ha/hab	2.2	4.9	4.8	3.9	*14,14,14,15*

Source:
(1) Data from 2000; Burke et al. 2001
(2) EU-25; DMAH 2005a
(3) CADS 2005
(4) Data estimated for 2006; CIA 2006
(5) Data from 2005; INE 2006a
(6) Data from 2005; IDESCAT 2006
(7) Data from 1999; Singh et al. 2001
(8) Data from 2001, municipalities; IDESCAT 2006
(9) Data estimated for 2005; CIA 2006
(10) Data estimated for 2003; IDESCAT 2006
(11) Data from 2003; Chape et al. 2003
(12) Data from 2003; MMA 2005a
(13) Data from 2004; DMAH 2005a
(14) Data from 2001; EU-25; WWF 2005
(15) Data from 2003; Mayor et al. 2003
(16)Data from 2004; EEA 2006a.

2.2 Coastal system dimensions

2.2.1 Socio-economic dimension

One of the most relevant issues of the Catalan coast is its complex demographic dynamics. The coastal municipalities support 44 % of the total population of Catalonia (2.79 million in 2001; IDESCAT 2006). The coast supports mean densities of 1,324 hab/km^2, but this value can triple in some municipalities during the summer season. As shown in Table 2.2.2, during the 1996–2002 period the coastal *comarcas* experienced the highest increment in population density in Catalonia 32.6 %, while the rest experienced a 7.3 % increment. However, the coastline (municipalities) experienced even a higher increment of 42.7 %, which reflects how crowded is the coastal zone (CADS 2005, Vicente and Gutiérrez 2004).

Table 2.2.2. Evolution of the population density in Catalonia during the 1996–2002 period (hab/km^2; data source: CADS 2005).

	Population density		Density increment in period
	1996	*2002*	*1996-2002*
Coastal *comarcas*	545.4	587.0	32.6 %
Non coastal *comarcas*	86.6	93.9	7.3 %
Catalonia	190.9	204.0	13.1 %
Coastal municipalities	1,281.7	1,324.4	42.7 %

The seasonal population can reach more than 13 million visitor per year, while the beaches having less than 1 % of the total Catalonia surface can host more than 1.5 million people per day (during August). Therefore the coast has the highest density of secondary residences in Catalonia reaching 50 % in some towns, and 85 % of the hotel rooms. In the municipalities North to Barcelona metropolitan area, temporal visitors versus local inhabitants ratio can be of 6.8 to one, and those to the South of 3.1 (CADS 2005).

The coastal fringe is affected by several socio-economic activities, being most relevant industrial and urban development, services and agriculture. Having a small diverse economy, tourism represents one of the most important activities in the coastline and it accounts for 10.8 % of the Gross National Product (GNP) in Catalonia (DCTC 2002). The resulting tourism and secondary residence urbanization processes have contributed substantially to the artificialization of the coastline, with a consequence in the reduction of natural areas along the coast. Among the total coastal land, 46 % is urban, 5.7 % is protected against urbanization (but not for other used such as agriculture), 8.2 % is non urban, and 39.6 % is protected under the regional Plan of the Spaces of Natural Interest in Catalonia (PEIN; see Figure 2.2.3; DMAH 2002, DPTOP 2005, Vicente and Gutiérrez 2004).

The percentage of coastal population in Catalonia is 44 % that added to a higher than the Spanish mean per capita Gross Domestic Product (GDP) are representative of a high developed, populated and energy consumer country (see Table 2.1.1). With a contribution of 18.3 % of the Spanish GNP it constitutes the richest and most rapidly developing regions in Spain (in 2003; INE 2006a). The *per* sector contribution to its GNP corroborates that tourism has a major participation in its economy, being its distribution: services 63.2 %, industry 26.6 %, construction 8.5 %, and agriculture 1.57 % (in 2003; IDESCAT 2006).

2.2.2 Natural dimension

The terrestrial environment of the coastal *comarcas* comprises 450,901 ha of coastal plains and 280,507 ha of coastal mountains, which configure the distribution of terrestrial biodiversity. Among the several classifications of the Catalan coastline it can be grouped based on morphostructural basis on: (1) rocky and highly abrupt coast; (2) rocky and moderate abrupt coast; (3) rocky substrate, linear and with high sedimentary depressions; (4) deltas; (5) alluvial deltas; and (6) human highly modified coast (see Figure 2.2.2; DPTOP 1983). The continental shelf has an extension of 888,589 ha

(DARP 2000) and It drops around 20 km from the coastline at about 160 to 180 m deep, although in front of the Ebro River delta has its maximum amplitude at 60 km.

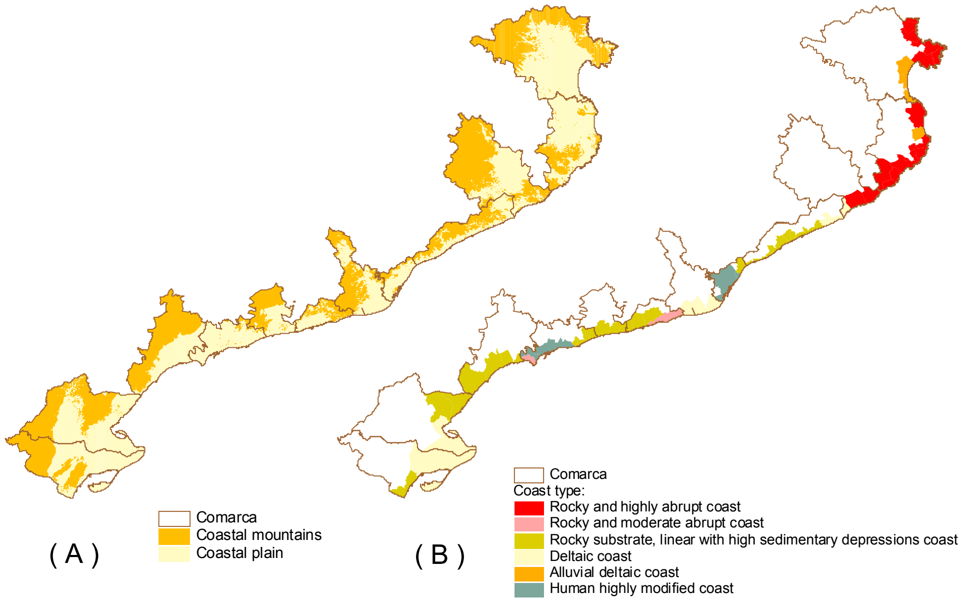


Figure 2.2.2. Coastal plains and mountains (A), and coast type (B). Coastal mountains were defined as slope >= 6.31 % or altitude > 200 m. Coast type is represented using municipalities (Data source: DPTOP 1983).

The marine coastal dynamics are governed by the Linguro-Provenzal-Catalan current which has a NE → SO circulation pattern. Therefore the Catalan coastal circulation is a continuation of that of the Gulf of Lyon (Pereira 1996), which constitutes the main dynamic agent of the coastal-marine ecosystem (Font 1986). The coastline presents river discharge and storm-associated longitudinal and transversal sediment variability as a result of these dynamic processes. 59 % of the total storms and the most energetic ones that help shape the coast have an East direction, followed by the Northwest and South directions. The storm-associated mean climatic year can be defined by two distinctive seasons, being October-April the storm season and May-September the calm season (Jiménez *et al.* 1997, Mendoza and Jiménez 2004).

The terrestrial environment of the Catalan coast is part of the Northern Spain and Southern France Mediterranean ecoregion, which also includes parts of Valencia and France (EEA 2003). Most representative terrestrial ecosystems of the coastal zone are temperate forest and scrub, crops, prairies, sand dunes and beaches. Table 2.2.3 shows the relative representation of main land covers in the coastal *comarcas*, being agriculture the largest surface but the lowest contribution to the local GNP and the opposite with beaches (under the Natural areas with few or no vegetation habitat type; DMAH 2006a). Several ecological relevant areas along the coast have been identified by the Master Ports Plan of the Generalitat. They haven't been incorporated into any of the existing conservation instrument at present and therefore relevant to this study: the Rosas Bay and Pals Bay in Girona, the Tordera-Arenys de Mar system and Llobregat system in Barcelona, the Vilanova-Tarragona system, Salou Cape, and external coast of the Ebro River delta in Tarragona (DPTOP 2001). Marine ecological communities correspond to those of the Atlantic-Mediterranean Province. Major marine communities along the coast are the infralittoral hard and soft bottom benthic habitats (Ros *et al.* 1985). Among the relevant communities are the seagrass *Posidonia oceanica*, which constitute one of the most productive environments in the Mediterranean. There is small geographic variability on the pelagic communities but benthic hard bottom communities show a clear gradient North of Blanes (Girona) and South of the Salou Cape (Tarragona; Margalef 1985). The marine environment accounts for a higher productivity level than the Mediterranean Sea annual mean (70 gC/m^2/yr), which is most possibly due to the land and river inputs, especially at the Ebro River delta area.

Table 2.2.3. Main land covers of the coastal *comarcas* and the marine environment. Percentages by environment (Data source: DARP 2000, DARP 2002, DMAH 2006a).

Environment	Habitat	Surface (ha)	%
Terrestrial	Agriculture lands	247,033	33.78
	Temperate forest	237,077	32.41
	Scrubs	113,755	15.55
	Urban areas	73,482	10.05
	Prairies	39,198	5.36
	Natural areas with few or no vegetation	6,523	0.89
	Lakes, rivers and wetlands	5,253	0.72
	Rocks	3,628	0.50
	Burned areas	2,778	0.38
	Mining grounds	2,681	0.37
Marine	Continental shelf (≤ 200 m)	888,589	99.04
	Posidonia oceanica beds	8,568	0.95

Costal uses constitute the main source of negative impacts on the coastal natural and semi-natural environment as well as the major drivers of ecosystem structure and functioning deterioration. The local government of the Generalitat has identified that the most important environmental aspects of the coastal zone are the impact by the urban development industry, the hydrologic system alteration, the pollution of marine waters, the coastal erosion, and the biodiversity loss (DMAH 2004). These impacts are reflected in the ecological footprint indicator, which with a value of 3.9 ha per inhabitant it almost doubles the global mean of 2.2 ha/hab. However, Catalonia remains below the Spanish and EU values as can be seen in Table 2.1.1. The ecological footprint indicator represents the land surface amount that a territory (and its population) need in order to maintain its present development model (CADS 2005). This can also be interpreted as energy and materials consumption-disposal in terms of human impact over the environment. It more practical interpretation reflects that a 6.8 million population overextends 8.2 times the total surface and 23.3 times the coastal surface (coastal *comarcas* in 2004; IDESCAT 2006).

With 648,065 ha protected under the PEIN and other instruments (*i.e.* seagrasses and wetlands with not up to date extension) the nature conservation strategy in Catalonia contributes with 14.7 % of the total natural protected areas surface in Spain and with 0.03 % to the global scenario (see Figure 2.2.3 and Table 2.1.1). However, it represents the Autonomous Community with larger invests in nature protection in Spain. Catalonia contributes to 18 % of the total Spanish investment and during the 1995-2001 period it has experienced even a larger than Spain investment increment of 48.6 % (in 2001; INE 2006a). In the other hand, only 0.7 % of the surface corresponds to marine protected areas and consequently just 0.5 % to the continental shelf surface is protected. Since 2002, 99 % of the beach waters are compliant with the EU Quality of Bathing Water Directive (COM(2002)581; ACA 2006). Major conservation efforts have been paid to some key species, especially to the high productive seagrass beds of *Posidonia oceanica,* which have been declining progressively in the last decades (DMAH 2004).

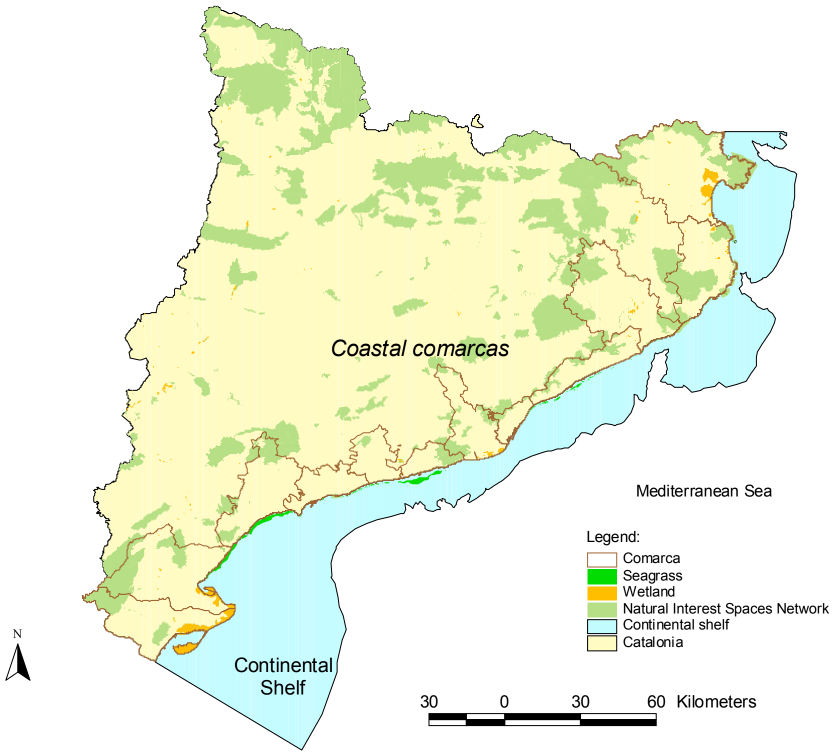


Figure 2.2.3. Natural interest spaces network, coastal wetlands and seagrasses of Catalonia (Data source: DARP 2002, DMAH 2002).

2.2.3 Administrative dimension

The Spanish coast is not only a complex area from the demographic, economic and biophysical points of view, but also because of the way it is regulated. There are three main administrative levels in terms of institutions and legislation relevant to coastal zone management: the central government of the Spanish State, the Autonomous Government of Catalonia (Generalitat), and the Municipalities. Within those levels, the Catalan coast is governed through two main legal instruments.

Firstly, 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 with three main fringes, terrestrial domain, public terrestrial-marine domain, and marine domain (see Figure 2.2.4). The marine domain constitutes also public domain and it is integrated by four zones: interior waters that constitute marine waters between coastal capes that establish the measurement base line, the territorial sea which extends offshore 12 miles from the base line, the contiguous zone which extends between the

12 and the 24 miles from the base line, and the economic exclusive zone which extends up to 200 miles from the base line.

The Public Terrestrial-Marine Domain (PTMD) represents the area between the mean lowest tide and the line where the highest storm waves reach in the beach or riviera, or the highest tides level. It could include inland areas with sand dunes, vegetation that directly influenced by the marine environment. In the terrestrial domain where the land can be private owned have been established easement zones: protection in the first 100 m inland where urban and transportation infrastructure and use is forbidden. The first six meters of the former, represent public transit easement (especially for surveillance and rescue activities). In general the terrestrial part forms a 500 m influence (buffer) zone that ranges from the inland limit of the sea riviera where uses are regulated. This zoning schema can be implemented whenever there is no previous infrastructure since several coastal developments are previous to the Coastal Law implementation in 1989.

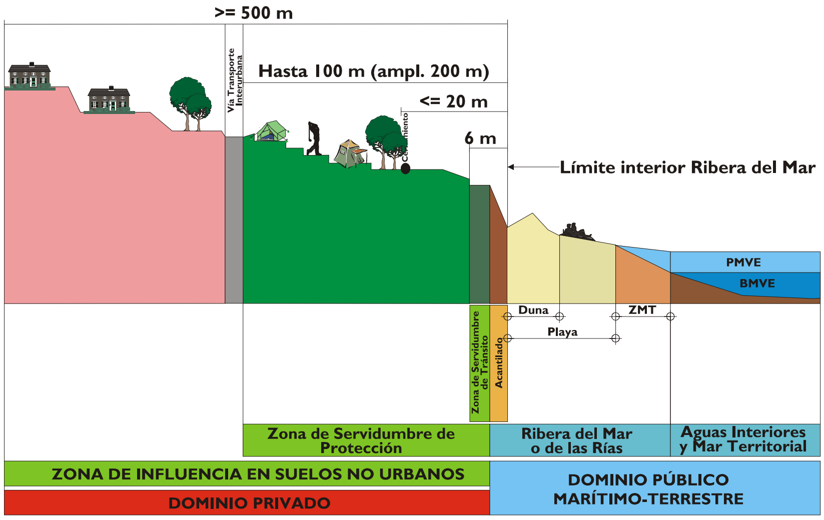


Figure 2.2.4. Coastal zone delimitation according to the Spanish Coastal Law (MMA 2006).

The second instrument, the Statute of the Autonomous Community of Catalonia, sets out the limited competencies of the Generalitat 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 that influence the structure and dynamics of the shoreline (plus interior waters from base line) are managed by the local municipalities (mainly seasonal services such as upkeep and cleaning of beaches). Municipalities constitute the minimum administrative unit in Spain, and therefore the real structure for coastal management implementation. As a complement to Coastal Law, the Generalitat got underway the Coastal System Urbanization Plan (PDUSC) whose main objective is to zone the coastal territory under sustainable development basis (DPTOP 2005). It can be also considered a coastal conservation instrument by setting the growth limits to seafront urbanization. Although it lacks of management competences in the PTMD (reserved to the Spanish State), it does in the 500 m buffer zone where uses are regulated and therefore influencing the territorial zoning.

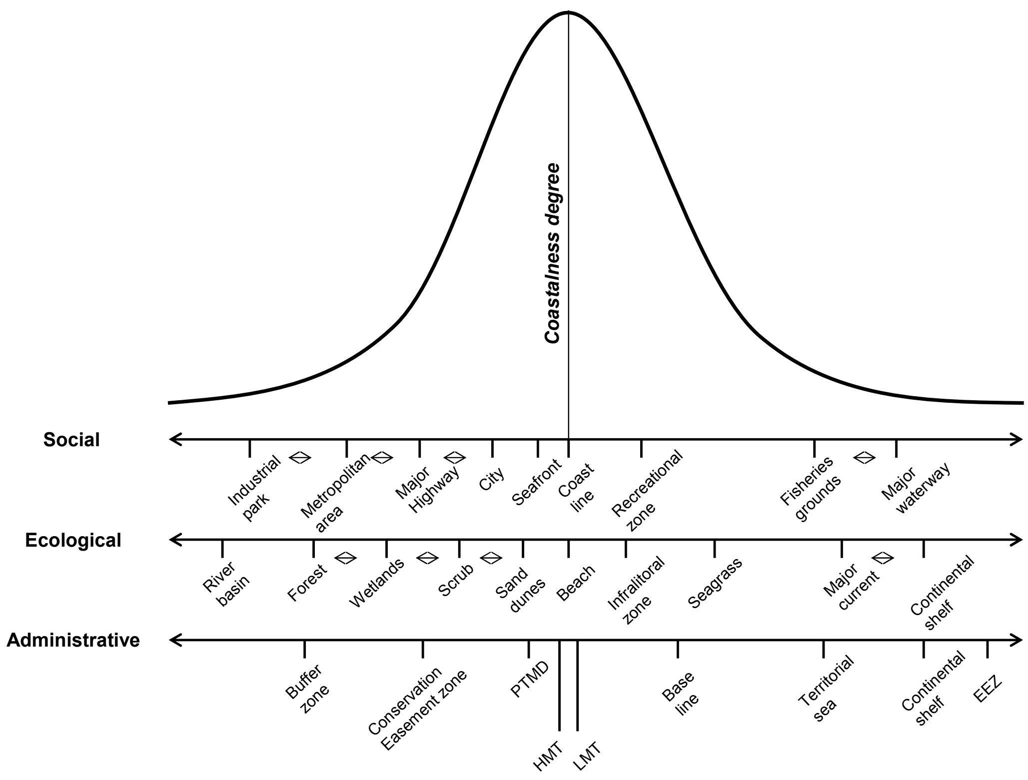
Following the EU recommendation on the implementation of integrated coastal zone management in Europe (COM/00/545), the Generalitat has launched its Integrated

Coastal Zone Management Strategic Plan (PEGIZC; DMAH 2004). The strategic plan constitutes a first step in a long-term move towards a much more rational management of the coast. The main objectives of this process are to express and integrated and clear answer to the main environmental problems (above mentioned); to define actions of immediate intervention to protect the natural heritage and to restore environmentally degraded areas; and to establish an information baseline in order to develop the national strategy of the Catalan coast. The PEGIZ implementation work is coordinated from the General Directorate of Environmental Planning of the Environmental Department of the Generalitat.

2.3 Operational coastal zone definition

The coast is the transitional zone between the continental mass terrestrial environment and the surrounding marine environment. Its morphology is considered to be the result of dynamic and integrated processes, being the most relevant waves, currents, tides, river basins and discharges, and air circulation. Nevertheless, human action and uses constitute the major drivers of coastal physical configuration and ecological condition. Most definitions of the coastal zone agree in that it should include both, the terrestrial and marine portions of the coast (see a revision in Kay and Alder 2000). Furthermore, most concur in that it should be defined by the biological, physical and chemical process of each environment that has influence in its counterpart. However, with half of the global population living in the coastal zone, only a few definitions integrate explicitly human societies dynamic into an operational definition of the coastal zone (*i.e.* the European Environmental Agency definition includes "…and where human activities occur…"; EEA (2002a).

The term operational is used in this study as the feature, or group of, that provides a fit advantage for proper functioning (The American Heritage Dictionary of the English Language 2006). Then an operational definition would mean here the definition of an area that can be useful for assessing coastal functioning and managing its dynamic behavior and links as a single coastal system. This approach is believed to provide the management advantage of incorporating the key social, economic, policy and cultural dimensions of the human subsystem to the coastal system value assessment. Figure 2.3.5 shows the coastalness degree of some elements of such dimensions, according to Kay and Ader (2000) original model.



Notes: Elements are not shown at scale. The coastline is represented as part of the social subsystem, since it is not always as clear from the ecological or administrative perspective. ←→ indicates that a change of order might occur. HMT = high mean tide; LMT = low mean tide; EEZ = economic exclusive zone.

Figure 2.3.5. Coastalness degree of some elements of the social and ecological subsystems (Adapted from Kay and Alder 2000).

Although it has been reviewed that municipalities constitute the highest scale management implementation level in Spain, having 70 municipalities in the Catalan coast makes no practical assessment and management possible. Such complexes geographic and administrative levels are not expected to provide practical advantages to the general view of the Catalan coast value assessment. Furthermore, the assessment of the environmental value at such geographic scale should require a more on site, field, and empirical-based evaluation of system characteristics, which is not the objective of present study. However, data at this level will be considered as desirable when ever existing since it continues to be the more detailed and natural basic mapping/aggregation unit.

In order to efficiently integrate the dynamic of the terrestrial coastal subsystem, the *comarca* administrative level will be selected to form the proposed operational definition. It provides several advantages over the municipalities, by representing a reduced number of management units, by forming historical clusters of municipalities with coherent natural and socio-economic characteristics, and by corresponding to actual administrative units. This view which is shared with other authors (*i.e.* Barragán 2004), integrates the coastal dynamics into 12 discrete units with a terrestrial surface of 731,408 ha and a mean surface of 61,005 ha. Finally, the use of *comarcas* in the assessment assures the completeness of the information, since socio-economic data it is only available for 68.5 % of municipalities (those with more than 5,000 residents).

The shallow near-coastal environment has been commonly referred as the most productive marine environment, due to the proximity to from-land inputs, processes in the photic zone, and diversity of submerged habitats (Thurman 1983). It is responsible for approximately 80 % of the total marine environment in Catalonia (CADS 2005). This zone ranges from a few meters depth to the extent of the continental shelf (commonly defined as up to 200 m), depending on oceanographic conditions (light, suspended sediments, currents, among others). Although this fringe includes the world renowned coral reefs, mangroves and seagrass habitats, which are not present in Catalan waters, it does include the relevant rocky infralitoral habitats present along the coast (ACA 2004). Due to the local characteristics, the 50 m isobathic line will be selected to complement the proposed coastal zone operational definition. It is expected that most relevant coastal marine processes (*i.e.* nutrient cycling, primary production) and biodiversity (*i.e.* 56.6 % of fish diversity in the continental shelf; Froese and Pauly 2006) are included in this fringe that will provide a specific coastline relevant processes and functions view to the study. The selected area has a total surface of 191,484 ha and a maximum linear extent of 20.5 km.

Together, both areas provide the coastal system structure needed for the assessment of coastal zone environmental value. These areas were selected to constitute a systemic model of the natural and semi-natural processes and functions of the Catalan coast. Therefore, with a combined area of 922,892 ha the operational definition of the Catalan coastal zone used in present study consists on the interacting natural (biophysical) and socio-economic subsystem' elements and processes of the area comprised between the seafront *comarcas* and the marine water extent to a depth of 50 m, see its geographic extent in Figure 2.3.6. This definition will be implemented in the present study by the characterization of coastal-terrestrial homogeneous environmental management units that will function as basic assessment and valuation units in the next chapters. This pre-defined structure will constitute the assessment universe and thus main input in the process, however external elements and processes will be considered based on their direct or indirect influence to the studied ones (*i.e.* commercial-industrial fisheries operate on depths greater than 50 m and hence only indirectly considered based on its links/feedbacks to subsystems).

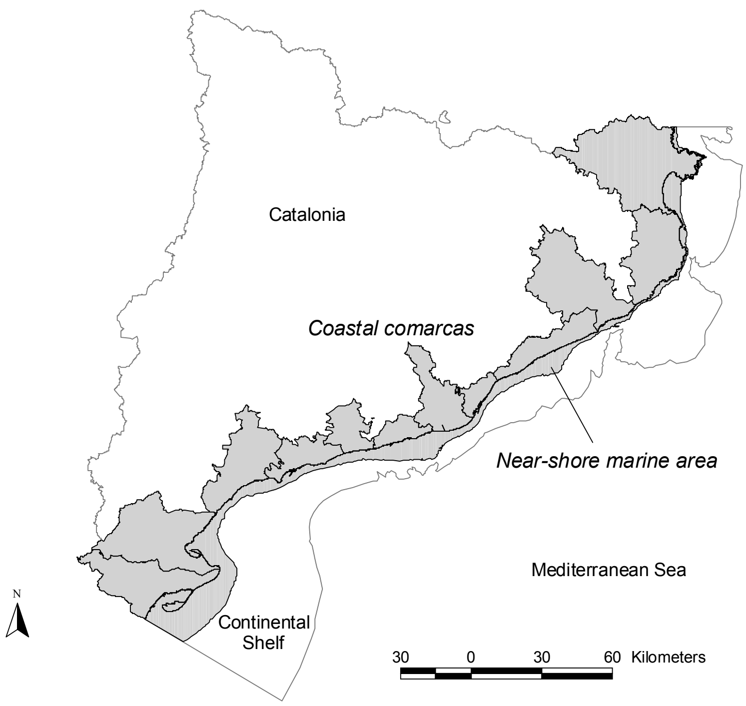


Figure 2.3.6. Geographic extent of the operational definition of the Catalan coastal zone: coastal *comarcas* and near-shore marine area (≤ 50 m depth).

CHAPTER 3. Ecosystem functions and services

3.1 Introduction

Coastal communities must often choose between competing uses of the environment and a number of goods and services provided by healthy, functioning systems. By choosing from among the competing options, it is important to know that not only ecosystem goods and services will be affected but also that society's well-being will be impacted. Ecosystem services, by definition, contains all "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Daily 1997). Without efforts to assess and quantify all the benefits associated with coastal ecosystem goods and services, policy and managerial decisions will continue to be biased in favor of environmentally degrading practices. Thus, it is suggested that integrated assessment frameworks of the coastal zone must include considerations of its ecological structure, processes, land use decisions, human welfare and the feedbacks between them. If this is the case, then ecosystem goods and services form the pivotal conceptual link between social and ecological systems needed in coastal zone management (Wilson *et al.* 2002).

The concept of ecosystem service value can be a useful guide when distinguishing and measuring where trade-offs between society and the rest of nature are possible and where they can be made to enhance human welfare in a sustainable manner. Thereafter, the main objective of this chapter consists in translating the ecological complexity into a set of ecosystem functions that provide services to the social and ecological subsystems of the coastal system. Thus ecosystem services will be used as essential and valuable elements of coastal ecosystems in the following chapters. Two specific objectives will be addressed here in order to provide the general valuation framework to be used in the Catalan coast. The first will review the relevant ecosystem function and service concepts and its role in the scientific literature. The second objective will present a general view of the ecosystem functions and services identified in the Catalan coast.

3.2 Review of concepts

3.2.1 Functional view of ecosystems

According to the Millennium Ecosystem Assessment (UNEP 2006, p. 1) "an ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit." Ecosystems are commonly referred as the smallest level of organization in nature. Levin (1998) also defined ecosystems as natural Complex Adaptive Systems (CAS), being systems in which properties and patterns at higher levels emerge from localized interactions and selection processes acting at lower scales and may feedback to influence the subsequent development of those interactions.

Ecosystem functions have been subject of different and sometimes contradictory interpretations in the ecological/environmental literature (see Jax 2005 for an entire discussion on this issue). The concept has been used to describe the internal functioning of the ecosystem (*e.g.* energy fluxes, nutrient recycling, food-web interactions), as well as to describe the benefits derived by humans from the ecosystem processes (*e.g.* food production, waste treatment). From a management perspective and according to de Groot (1992) ecosystem functions can be defined as "the capacity of natural process and components to provide goods and services that satisfy human needs, directly or indirectly." While, ecosystem goods and services constitute the observed functions that are re-conceptualized as human values. Daily (1997) define ecosystem services as the "conditions and processes through which natural ecosystems, and species that make them up, sustain and fulfill human life." Commonly, ecosystem functions and services do not show a one-to-one correspondence, and a function can provide one to several services. Therefore, the ecological structure and processes need to be addressed from a complex system approach (Limburg *et al.* 2002). Furthermore, the analysis of functions and services generally involves different scales, being the physical scale of the ecosystem itself and the scale at which humans value the correspondent goods and services, thus these inter-linkages issues should be make clear in a case-by-case basis.

Ecosystem functions provide benefits to the ecosystem itself, to other ecosystems and to human societies (Green *et al.* 1994). In a holistic approach, ecosystems provide a multitude of functions which are subject to many possible uses. However, there is still a considerable lack of the many functions and values of natural and semi-natural ecosystems, and humans continue to take decisions and tradeoffs between different land-use options based on incomplete information. In the past decades, the ecological economic discipline has rise the concern of valuation of ecosystem functions, goods and services. For this reason, ecologists, social scientists and environmental managers are increasingly interested in assessing the economic values associated with ecosystem functions and services associated with coastal systems (Farber *et al.* 2002, Wilson *et al.* 2002).

The ecosystem function concept as proposed by de Groot (1992) and used in this chapter, provides the empirical basis for the potential classification of natural and semi-natural ecosystems. Several ecosystem function classifications have been developed for biodiversity conservation, integral environmental assessments and ecosystem services economic valuations purposes (de Groot 1992, Costanza *et al.* 1997, Daily *et al.* 2000, de Groot *et al.* 2000, de Groot *et al.* 2002, Millennium Ecosystem Assessment 2005, de Groot 2006). Among those, de Groot (2006) has translated the ecological complexity into five useful functional categories: (1) regulation, (2) habitat, (3) production, (4) information, and (5) carrier. This classification schema seems to be appropriate whenever an ecological and/or economic value approach is the objective, as is the case of present study.

3.2.2 Biodiversity's role in ecosystem functioning

Beyond their functions within the interdependencies of species diversity, the ecological importance of species results from their role as carries of ecological functions in the ecosystem (Loreau *et al.* 2002). Species and their interconnections are, in this context, biotic elements of the ecosystem structure, which, in combination with abiotic elements, provide the basis of ecological functions of ecosystems. The biotic elements are, therefore, attributed a central importance for the maintenance of the full range of ecosystem services. In ecology, it is assumed that not all species are of the same relevance in this context, and the general hypothesis relies on that a relative small number of dominant species is sufficient to maintain most processes. However, Lyons *et al.* (2005) provide good insights where less common and rare species are demonstrated to make significant contributions to ecosystem functioning. Holling *et al.* (1995) consider that seemingly less relevant may possibly conduct subtle, unforeseeable functions in the ecological network of interrelations. Figure 3.2.1 shows two hypothetical relationships between biodiversity and ecosystem function where a positive correlation of the two exists.

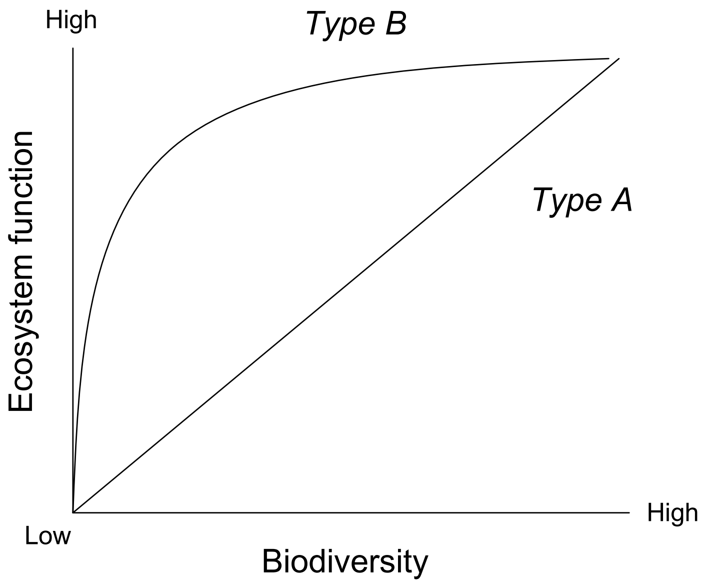


Figure 3.2.1. Hypothetical relationships between biodiversity and ecosystem function where a positive correlation between the two exists (Schwartz *et al.* 2000). Type A relationship shows a linear dependence, where even relatively rare species contribute to ecosystem functioning. Type B relationship shows how ecosystem function is effectively maximized by a relatively low proportion of total biodiversity, and rare species do not contribute to the maintenance of a function.

“Although there are many unanswered questions the ability of ecosystems to provide a sustainable flow of goods and services to humans is likely to be highly dependent on biodiversity” (Tilman 1997, p. 94). The importance of species diversity in ecosystems is, therefore, based on the fact that species that seem redundant under certain environmental conditions become “keystone species” under different conditions (Schulze and Mooney 1994, Perrings 1995). This mean that a loss of species in an ecosystem or alterations on the mix of species makes the ecosystem more susceptible to exogenous alterations and rises the probability that the system changes discontinuously form one stable to another (*i.e.* from one ecosystem type to another). Thus, the loss of one or several species can result in the loss of one to several ecosystem functions.

3.2.3 Ecosystem services

There is explicit evidence that ecosystems around the world are declining in terms of species and services that they provide to humans (Daily 1997, Millennium Ecosystem Assessment 2005a). Thus in many cases their capacity to provide necessary goods and services has been either overwhelmed or eroded (Palmer *et al.* 2004). The World Resource Institute concluded in 2000 that that within a few decades virtually all the world’s ecosystems will have suffered significant negative impacts from human activities (World Resource Institute 2000). There are many immediate causes of this trend, but underlying these causes is the fact that humans give relatively low value to ecosystems compared with the value given to activities that potentially degrade them. The literature gives several reasons for this trend:

- People generally are not well informed about the benefits that come from ecosystems and the potential to lose those benefits under some management regimes (Daily 1997);
- People assume ecosystem services to be endlessly regenerating;
- Many of the components of ecosystems are publicly rather than privately owned, meaning that private markets that might give price signals when resources decline do not emerge and that decline of ecosystems due to other economic activity is not factored into costs in those markets (Heal 2000);
- The economic systems used in most countries emphasize values and preferences of individuals (consumer sovereignty) more than values of communities (Costanza and Folke 1997);
- Many ecosystem services are not approaching critical rarity, so marginal looses are not given high importance;
- Many changes in ecosystems have long lead times, meaning that symptoms of decline are not apparent until years or decades after critical thresholds are passed (Resilience Alliance and Santa Fe Institute 2004);
- There is a widespread assumption that ecosystem services can be replaced cost-effectively by technological alternatives (Daily 1997);
- There are few mechanisms or incentives for investment in ecosystem services (Heal 2000; see an example: Ecosystem Marketplace http://www.ecosystemmarketplace.com/).

Hereafter in present study ecosystem goods and services will be just referred as ecosystem services. There is still little detailed ecological understanding of the underlying ecosystem's structure and functions that sustain ecological services, however, there are impeding progress in their conservation and management (Balmford *et al.* 2003, Palmer *et al.* 2004). Several works describe and categorizes ecosystem services, identifies methods for economic valuation, maps the supply and demand for services, assess threats to them, and estimates economic values (Daily 1997, Daily *et al.* 2000, Heal 2000, Farber *et al.* 2002, Biggs *et al.* 2004, Millennium Ecosystem Assessment 2005a). Together, ecosystem services meet most of the fundamental needs that humans have, including subsistence, protection, understanding, leisure, creation, identity and freedom (Max-Neef 1991). However, management of ecosystem services is as complicated as managing ecosystems; past attempts to manage even single components of ecosystems such as fisheries have demonstrated the complexity and difficulty of this task (Walters and Holling 1990).

In addition to the production of goods, ecosystem services constitute the actual life-support functions (such as cleansing, recycling, and intangible aesthetic and cultural benefits). According to Farnworth *et al.* (1981), ecosystem services are inherently connected to the integrity of natural systems and embody the totality of structure and functioning of the system. In an effort to merge there two elements, Kremen (2005) proposed a functional unit concept, which refers to the unit of study for assessing functional contributions of ecosystem services (article shows a list of functional units and spatial scales for several services provided by biodiversity).

According to Green *et al.* (1994) the ecosystem services can be divided into tree categories: services for the development and maintenance of functionality of the system itself, services for other ecosystems, and services that human use. The services first mentioned describe the self-organizing capacity of the system, including the evolutionary processes and the capability to absorb external disturbances (stability). The second, therefore refer to the continuous maintenance of the ecosystem health among interconnected systems. This later concept will be used as key element in the ecological valuation.

Farnworth *et al.* (1981) suggested that ecological systems posses non-use values. Thereby, Farnworth *et al.* for the first time draw attention to ecological functions, which in the first place provide the basis for those services then directly used and valued by individuals. They are, therefore, in a complementary relationship. Accordingly, the concept of ecosystem services is useful for coastal zone science and management for two reasons. First, it helps us synthesize essential ecological and economic concepts, allowing us to link human and ecological systems in a viable and policy relevant manner. Second, scientists and policy makers can use the concept to evaluate social and political tradeoffs between coastal land use development and conservation alternatives (Wilson *et al.* 2002).

As relevant examples, Costanza *et al.* (1997) found that the mean value of services provided by functions is 33 trillion USD/yr, and among those the marine environment accounts for 20.9 trillion USD/yr (63.3 % of the total). Recently Alcamo *et al.* (2005) at a global scale, and Schröter *et al.* (2005) at an European scale, have developed a multiple quantitative scenario approach to focus on major global change drivers and to estimate the future supply of worldwide ecosystem services. Their findings arise that although at the global scale services consumption substantially increases up to 2050, the scenarios show a positive balance of increasing services and a negative balance of increasing risks and tradeoffs of services. While at the European scale, most changes might increase the vulnerability as a result of a decreasing supply of ecosystem services (*e.g.* declining of soil fertility and water availability; and increasing risk of forest fires), especially in the Mediterranean region.

One of the most relevant developments at the global scope is the framework proposed by UNEP as the Millennium Ecosystem Assessment (MEA; Millennium Ecosystem Assessment 2005a). Although the MEA places human well-being as central focus for the assessment, it integrates an ecosystem function-service approach to human condition and how these are affected by feedbacks. The findings of the MEA show that 14 out of 24 identified ecosystem services are in decline. Only four services are increasing globaly: production from crops, livestock and aquaculture, and carbon sequestration in terrestrial ecosystems. Adverse changes are reported to coincide with an increasing demand for ecosystem services by humans. However, the MEA offers hope by identifying characteristics of coupled social and ecological systems that seem to be resilient and capable of ongoing renewal. Figure 3.2.2 shows the relationship between the four type ecosystem services classification and the five type constituents of well-being classification used by the MEA.

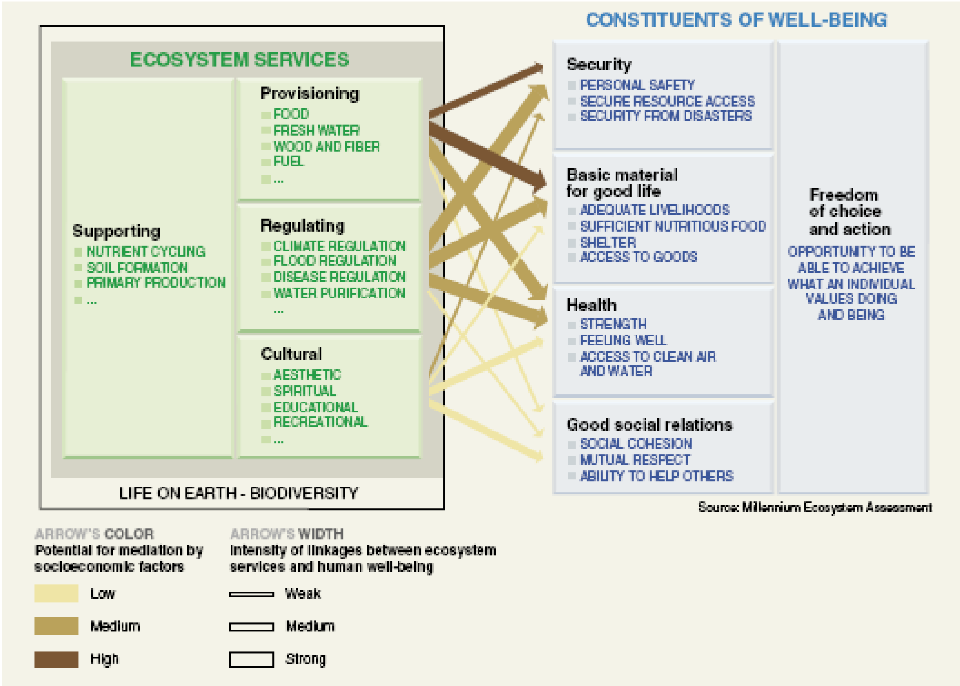


Figure 3.2.2. Linkages between ecosystem services and human well-being (Millennium Ecosystem Assessment 2005a).

As referred by the MEA itself, “this Figure depicts the strength of linkages between categories of ecosystem services and components of human well-being that are commonly encountered, and includes indications of the extent to which it is possible for socio-economic factors to mediate the linkage. (For example, if it is possible to purchase a substitute for a degraded ecosystem service, then there is a high potential for mediation.) The strength of the linkages and the potential for mediation differ in different ecosystems and regions. In addition to the influence of ecosystem services on human well-being depicted here, other factors including other environmental factors as well as economic, social, technological, and cultural factors influence human well-being, and ecosystems are in turn affected by changes in human well-being” (Millennium Ecosystem Assessment 2005a).

3.2.4 The integrated social-ecological system

Much of the development in environmental resource management sciences since the 1970s has sought to deal with the ecological and social problems, represented by resource mismanagement and depletion (*e.g.* maximizing of unsustainable yields). New approaches have been reformist in nature, seeking to alleviate these excesses. Although some have been more radical (*e.g.* deep ecology, Næss 1989), others as the previously mentioned holistic/systemic-based and adaptive management-based approaches are replacing the view that resources can be treated as discrete entities from the rest of the ecological, social and economic systems (Holling 1978, Walters 1986). In practice depending on the author’s discipline either social systems or ecological systems tends to be taken as a given. As a result, a newer goal in most emergent natural resource management systems is to relate the management practices based on ecological understanding, to the social mechanisms behind these practices. In this approach the social and ecological systems are in fact linked and the delineation between them is artificial and arbitrary. Although this view is not completely accepted in conventional ecology and social science, when one wish to emphasize the concept of humans-in nature, the term Social-Ecological System (SES) should be used (Berkes and Folke 1998). As defined by the Resilience Alliance (2005), SES are complex adaptive systems in which humans are part of nature, and the dynamics of both dimensions are strongly linked at equal weight.

Unlike common ecological theory which tends to view humans as external to ecosystems, SES explicitly include the social systems into its analysis and synthesis. This relative new concept is consistent to previous classical contributions of human ecology (Park 1936) and urban ecology (Collins *et al.* 2000). However, mere economic science has put emphasis on the sustainable use of natural capital, SES approach focus on the ability of the management system to respond to feedbacks from the environment. According to this approach, the three levels of services referred by Green *et al.* (1994) will be integrated into the dynamics of the SES. This vision is also consistent with the way many traditional societies see their relationships with the environment. Several pre-scientific ecosystem concepts are known from Europe, North America and Asia as well as throughout Oceania where they have well documented (Gadgil and Berkes 1991). Berkes and Folke (1998) have proposed a framework to help identify the characteristics of ecosystems, people and technology, local knowledge, and property rights that characterize the SES.

New views and tools have helped us to envision SES, assembling models of coupled human and natural systems requires of information on processes (function) over time. In addition, there needs to be a logical connection (structure) between these two systems reflected in the available data. McPeak *et al.* (2006) points out that the question "is there enough information to adequately model a dynamic human system, a dynamic natural system, and their linkages in a way that captures essential elements of reality?, is often the most problematic in the SES integration and modeling from a practical standpoint (among six other issues related to human and natural system coupling).

The SES constitutes coupled, complex and evolving integrated models, which by definition focus on the ability of the management system to respond to feedbacks from the environment. As a result, a SES sustainable approach implies the understanding of system's heterogeneous functions and its capacity to provide such and its maintenance processes.

3.3 Concepts in the scientific literature

The ecosystems function and services role in the literature in order to gain insight of the different environmental approaches that have been developed around the concept and its application to the coastal zone has been investigated. By this, this work also expects to identify the relevant attributes of this ecological property that need to be taken into account in present study. The performed literature review followed two approaches. First a thematic search in scientific periodic publications from the past ten years. Second the review of the meaning of both concepts and how they have changed over time.

3.3.1 Representation of the concepts in the scientific literature

The thematic revision of periodic publications indexed in the Science Citation Index and from the ecological and environmental sciences themes of the Journal Citation Reports (JCR; Thomson 2005a) being, (1) ecology, (2) environmental sciences, and (3) marine and freshwater biology. A search was performed using the online ISI Web of Science databases (Thomson 2005b) and followed the criteria of, (1) time span 1995-2004; (2) first quartile of top ranked publications by impact factor of the JCR (the last report includes data up to 2004; Thomson 2005a); (3) in title, abstract and/or key words: [coast] AND [ecology OR ecosystem OR environmental] AND [function OR service] (including variations of words in plural and main variations (*e.g.* coast, coasts, coastal). The impact factor is calculated by dividing the number of citations in the JCR year by the total number of articles published in the two previous years. It constitutes the most used indicator of periodic publications relevance.

Search results show that among a maximum of 494 potential articles (gross search result, without detailed review) that integrate to some extent the concept(s) of ecosystem or ecological or environmental functions and/or services (out of a greater total of 17,498 globally) the investigated themes contribute to a maximum of 17 %. Figure 3.3.3 illustrate that marine and freshwater biology journals contain a larger number of published articles on coastal ecosystem functions and services, followed by the ecology theme publications. While the environmental sciences theme journals have a considerable lower productivity on these issue. From the search we can also conclude that the ecosystem functions and services do not constitute article's main objective during the past 10 years since most do not include such words in their title.

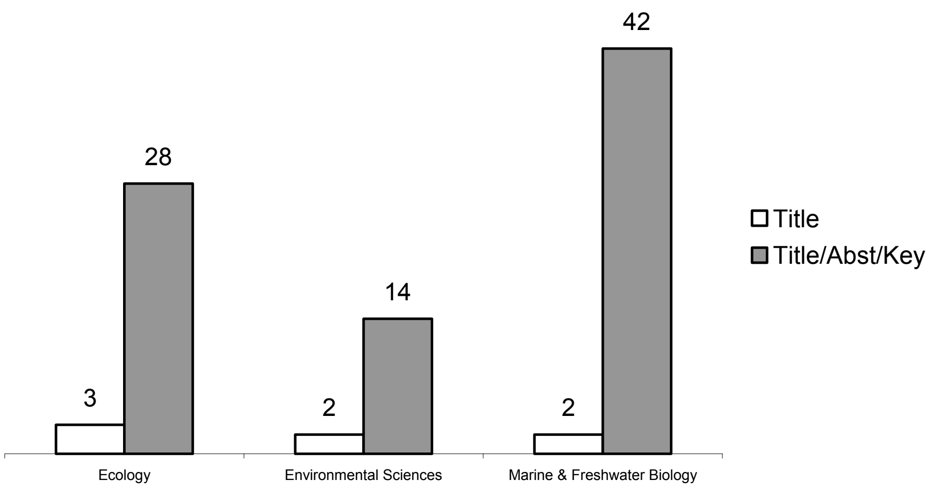


Figure 3.3.3. Number of articles on coastal ecosystem functions and services published from 1995 to 2004. Search performed using the fist quartile by impact factor of the Journal Citation Reports themes: Ecology, Environmental Sciences, and Marine and Freshwater Biology (Thomson 2005a).

From Table 3.3.1 can be observed that the Marine Ecological Progress Series journal of the marine and freshwater biology theme has published the larger number of articles in this topic with 15 in total and two in title. Being the second and third larger number of articles has appeared in the Ecological Applications, and Estuarine, Coastal and Shelf Science journals. This can be the result of the shared transdisciplinary and applied view of these publications. The inverse logic can be applied to the rest of the publications analyzed, being more specific to a particular scientific discipline/field or specific environment (such as pollution, microbiology, freshwater, atmosphere). However, it is not as clear the reason behind the small number of articles in the environmental sciences theme and the more ecology fundamental publications that could appear to be the proper place to discuss these topics (*i.e.* Conservation Biology, Journal of Ecology, Ecosystems).

Table 3.3.1. First three publications or classes on coastal ecosystem functions and services by number of articles published, impact factor and theme from 1995 to 2004. Title abbreviations from the Journal Citation Reports (Thomson 2005a).

Theme	Journal Title	Impact Factor (2004)	Title	Title/Abst/Key
Ecology	Ecol Appl	3.287	1	6
	Ecology	4.104	0	5
	Ecosystems	3.455	0	3
	J Ecol	3.397	1	2
Environmental Sciences	Sci Total Environ	2.224	2	2
	Global Change Biol	4.333	0	2
	Conserv Biol	3.672	0	2
	Environ Pollut	2.205	0	2
Marine & Freshwater Biology	Mar Ecol-Proc Ser	2.052	2	15
	Estuar Coast Shelf S	1.633	0	8
	Aquat Microb Ecol	2.255	0	5

Table 3.3.2 shows the search results on periodic publications of special interest due to their relevance to this study. The search was performed using the same criteria as above and only years changed, since it was completed from 1995 and up to date (June 2006). Publications included in the search where those that either weren't part of the groups or the first quartile used. Results confirm the interest on such issues from the coastal and marine management and research disciplines, while most general publications, although with the highest impact factor, have not focused on such (*i.e.* Nature and Science). This is relevant when compared to the publications published on the two top academic science journals on the terrestrial environment. The search revealed that 18 articles with reference to ecosystem services were published since 1991, which is considerable higher to those on the coastal-marine environment.

Table 3.3.2. Other publications on coastal ecosystem functions and services by number of articles published and impact factor from 1995 to 2006 (June). Title abbreviations from the Journal Citation Reports (Thomson 2005a).

Journal Title	Impact Factor (2005)	Title	Title/Abst/Key
J Coastal Res	0.861	2	19
Ocean Coast Manage	0.520	1	14
Ambio	1.403	1	10
Environ Manage	0.914	2	9
Ecol Econ	1.179	1	8
Nature	32.182	1	5
Coast Manage	0.943	1	5
Bioscience	3.041	0	3
Landscape Ecol	2.092	0	2
Science	31.853	0	1

Although the specific definition of ecological functions was not addressed in the publication search due to the more in deep examination needed, the analysis resulted useful in determining the low participation of this concept in the actual ecological and environmental research. It also provided insights in identifying the type of publications and thus scientific fields that are contributing to this issue. However the reasons of such low productivity remain obscures and it is more evident and surprising that environmental sciences theme which should constitute the more applied vision of these key topics as conservation biology and global change. These results are coherent with other authors' visions on the need of integration of this dimension into global change earth system models and the more anthropocentric definition of coastal ecosystem functions and services used by the emergent ecological economics field in recent years (*i.e.* Wilson *et al.* 2002).

3.3.2 Meaning and evolution of the concepts

A revision of the ecosystems function-service state-of-the-art should investigate what is their meaning of such concepts and how it has evolved over time. Two main steps have been identified in the lifetime of the ecosystem function concept as relevant to the ecological and environmental sciences. The concept has been applied extensible in biology and any other dimensions at its most basic definition, *to perform*. Early references to the concept of ecosystem functions and their economic value date back to mid-1960s (*e.g.* King 1966, Odum and Odum 1972). Jax (2005) provides a complete analysis of the function concept meaning and characterizes it into four main classes which also reflect its evolution over time: functions as processes, functioning of a system, functions as roles, and functions as services. Thereafter, there is a clear an exponential growth in publications on the benefits of ecosystems to human societies (*e.g.* de Groot 1992, Turner 1993, Costanza *et al.* 1997, Daily 1997, Daily 1999, de Groot *et al.* 2002). In a first step, ecosystem functions were referred as the performance action or processes that are necessary for self maintenance in ecology (Margalef 1974, Müller 1997). In this sense, functions were helpful in describing the internal processes of organisms, communities and ecosystem (*e.g.* inter/intra energy and material fluxes from species to metaecosystems). According to Likens (1985), an ecosystem is so complex that is not possible to capture all its properties by one approach. Therefore the utility of this definition in ecology is clear from a thermodynamic point of view, but of limited use in its integration into the SES schema.

The second step constituted a switch from the thermodynamic concept to a CAS perspective applied to SES. Thus the system is extended even more by taking relations of an ecological system to humans into focus. These functions mostly relate to the whole system and they determine the capacity of natural and semi-natural processes to provide goods and services that satisfy human needs (de Groot 1992). Since dynamic linkages govern complex ecosystem processes, thus functions benefit the social subsystem directly and indirectly. Odum (1953) is largely responsible for developing this process-functional approach, which has dominated ecology during the last few decades. Since complexity is a relative concept dependent on the observer Kay (1984) distinguishes between structural and functional complexity, being the later the number of functions carried out by the system. This concept has been used to describe the number of benefits provided from different ecosystem and thus its ecological value (as distinguished from its economic and social values).

On the other hand, the ecosystem service concept was defined by Daily (1997) three decades after (see Functional View of Ecosystems section). Mooney and Ehrlich (1997) have traced the development of the concept. Ecosystem function, as it pertains to service delivery for humans, was first described in a 1970 report (Study of Critical Environmental Problems), which coined the term environmental services. Holdren and Ehrlich later refined the list of services, using the terminology public service functions of the global environment. Westman, in 1977, simplified this to nature's services which was finally refined to ecosystem services by Ehrlich *et al.* in 1981. Recently, the term has been used extensible from the monetary valuation perspective (*e.g.* Costanza *et al.* 1997, Farber *et al.* 2002, Wilson *et al.* 2002, Farber *et al.* 2006).

Several research lines of action have appeared from this point of view. This vision is shared by several global organizations as The Nature Conservancy (Poiani *et al.* 2000), The World Conservation Union (IUCN 2005), and the MEA (Millennium Ecosystem Assessment 2005a); which focus on the intrinsic value of biodiversity and ecosystems in human well-being at the global scale. An additional relevant and complementary issue is the emerging study of the role of biodiversity in the ecosystem functioning. Holling (1992) and Holling *et al.* (1995) suggested that the diversity of ecosystems can be traced to a relatively small number of biotic and abiotic variables, and therefore a relatively few species, or groups of species, run these processes and contribute to the functional performance of the ecosystem. Based on the hypothesis that species diversity enhances community and ecosystem functioning and resilience a number of authors have developed good insightful synthesis of lessons learned, in general (*e.g.* Mooney *et al.* 1996, Loreau *et al.* 2002, Millennium Ecosystem Assessment 2005b), and in aquatic ecosystems (*e.g.* Emmerson *et al.* 2001, Gessner *et al.* 2004).

Coastal subsystems such as estuaries, rivers, wetlands, beaches, etc. support several functions and thus provide different services to human societies. For this reason, ecologists, social scientists, economists, and environmental managers are increasingly interested in assessing the value of such functions and services associated with coastal systems (*e.g.* Bingham *et al.* 1995, Costanza *et al.* 1997, Daily 1997, Gilbert and Janssen 1998, Farber *et al.* 2002, Wilson *et al.* 2002, Fano *et al.* 2003, Moberg and Rönnbäck 2003, UNEP-WCMC 2006). The review suggests that the concepts of ecosystem functions and services are useful for coastal zone science and managers for three fundamental reasons. First, it helps to synthesize the essential ecological concepts, allowing researchers and managers to link SES in a viable policy manner. Second, it draws upon the latest available developments in ecosystem and social sciences. Third, scientists and managers can use the concept to evaluate the SES tradeoffs between coastal use and conservation alternatives. A review on information resources for ecological benefits assessment can be found in van Houtven and McVey (2003).

3.4 Framework for analysis of ecosystem functions and services

The flow of functions and services depends on how well the ecosystems are functioning and will be functioning under global change. Presently, the relationship between ecosystem functions and services provisioning has not been fully investigated. Most notably, global change scenarios have not formally analyzed the functioning-provision relationship. Although there are well-established measures of ecosystem functions, such as mineralization rates of organic matter production, these are difficult to translate to provision and thus efficiently integrated into the SES model. Since ecosystem performance needs to be measured at a specific one-to-one basis, this is most probably due to the difficulty in achieving a functioning metric or base system. Moreover, functions and services do not match one-to-one. As an example, annual net primary production contribute to most ecosystem services because it measures the production of plants or algal biomass that forms the foundation of terrestrial and aquatic systems. Such links and mutual dependencies need to be addressed carefully in order to value the services provided by nature to the SES, and to understand the provision dynamics under different environmental states (*e.g.* stress).

3.4.1 Functional approach

Present study used the function-analysis framework proposed by de Groot (2006) in the valuation of the Catalan coast environment. The original framework proposed by de Groot intents to provide a land use tool that integrates the functions into the human valuation process needed to analyze various planning and management alternatives for multi-functional landscapes. However, in present study the main purpose of using it constitutes the rationalization of ecosystem functions into ecosystem services whose ecological and economic value for the Catalan coast SES will be assessed. Therefore, function-analysis provides the advantage of translating the ecological complexity into a limited number of ecosystem functions, which consecutively provide a range of valuable ecosystem services. It is also expected to be helpful in the identification of their dependencies by establishing a theoretical framework for modeling such relationships. The maximization of such dependencies through adaptive management leads to more viable environments; also the resulting baseline could help guide similar approaches in different geographical areas.

Although Jax (2005) reported that there are problems related to the operationalization of the different concepts of functions and their normative assumptions, the function-analysis constitutes a true operationalizable framework whenever functions are correlated to services as in this study (fourth definition according to the author). It allows unambiguously distinguishing between those phenomena which are to be called functions and those which are not. However, other problems with this approach arise when trying to couple the social and ecological subsystems in a practical manner. In SES both subsystems are linked at equal weight by definition, however in practice social and ecological processes do not occur at the same time and spatial frames.

Hence, the first step in the valuation process consists in the translation of the ecological complexity into discrete ecosystem functions and services.

The framework follows the functions classification schema proposed by de Groot (2006) due to its services provision capacity vision to the SES, and wide application in other natural resource assessments. Functions are classified into five useful functional categories: regulation, habitat, production, information, and carrier. In this schema, regulation functions relates to the capacity of ecosystems to regulate essential ecological processes and life support systems through biogeochemical cycles and other biospheric processes. These functions provide the necessary preconditions for other functions, and thus are responsible for maintaining a healthy ecosystem at different scales and levels. The habitat functions relate to the spatial conditions needed to maintain biodiversity and evolutionary processes. The availability or condition of this function is based on the physical aspects of the ecological niche within the biosphere, and can be described in terms of minimum critical ecosystem size. Production functions constitute the biomass provided by ecosystems in many ways, ranging from food and raw materials to energy resources. Information functions provide an essential reference function and contribute to the maintenance of human health by providing opportunities for reflection, spiritual enrichment, cognitive development, recreation and aesthetic experience. Finally, carrier functions are related to the human need of suitable substrate (*e.g.* soil) or medium (*e.g.* water, air) to support the associated infrastructure. This function involves the conversion of the original ecosystem, thus the capacity of ecosystems to provide carrier functions on a sustainable basis is usually limited. A larger description of the ecosystem functions included in the framework can be found in de Groot *et al.* (2002).

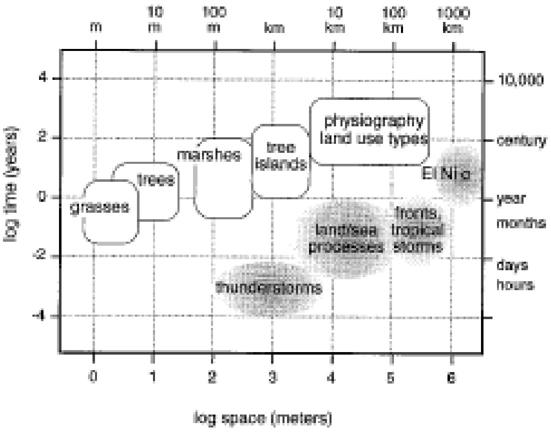
The framework uses the ecosystem services classification proposed by Farber *et al.* (2006). The schema integrates the general view of services developed by previous works on ecosystem services valuation (*i.e.* Costanza *et al.* 1997, Daily *et al.* 2000). The schema provides the advantage of integrating specific services into the four major classes proposed by the Millennium Ecosystem Assessment: supporting services, regulating services, provisioning services, and cultural services (Millennium Ecosystem Assessment 2005a). This characteristic will allow the value comparison and assimilation with other frameworks/models from other studies. Table 3.4.3 shows the global status, human use trend and monetary value of several ecosystem services by functional class to which they belong (de Groot 2006). The function class attribute relates the original function group (as provided by de Groot) that has produced the current and observable service. Results show that although the majority of ecosystem services are declining, their use continues to increment.

Table 3.4.3. Ecosystem services of the coastal SES by class (Adapted from Farber *et al.* 2006). Relation to function group, and global status, use and monetary value is shown. Global status and human use are indicated by arrows to increase (▲), decrease (▼) or remain stable (±; Millennium Ecosystem Assessment 2005a). Global monetary value is expressed in 1994 USD/yr x 10^9 (Costanza *et al.* 1997).

Service class	Ecosystem service	Functional class [1]	Global status [2]	Human use [3]	Global value [4]
Supportive functions and structures	Nutrient cycling	R			17,075
	Net primary production	P			
	Pollination & seed dispersal	R	▼ a	▲	117
	Habitat	H			124
	Hydrological cycle	R			
	Soil formation	R			53
Regulating services	Gas regulation	R	▼ b	▲	1,341
	Climate regulation	R	▲	▲	684
	Disturbance regulation	R	▼	▲	1,779
	Biological regulation	R	± c	▲	417
	Water regulation	R	±	▲	1,115
	Soil retention	R	▼	▲	576
	Waste regulation	R	▼	▲	2,277
	Nutrient regulation	R			
Provisioning services	Water supply	R	▼	▲	1,692
	Food	P	▲ d	▲	1,386
	Raw materials	P	▼ e	±	721
	Genetic resources	P	▼	▲	79
	Medicinal resources	P	▼	▲	
	Ornamental resources	P			
Cultural services	Recreation	I	±	▲	815
	Aesthetic	I	▼	▲	
	Science & education	I			3,015 f
	Spiritual & holistic	I	▼	▲	

Notes: [1] R = regulation, H = habitat, P = production, I = information; [2] Supporting services are not included here as they are not used directly by people. Status indicates whether the condition of the service has been globally enhanced (i.e. if the productive capacity has been increased) or degraded in the recent past. All trends are medium to high certainty or otherwise state; [3] For provisioning services, human use increases if the human consumption of service increases. For regulating and cultural services human use increases if the number of people affected by the service increases. The time frame in general is 50 years; [4] Estimated global total value is 33.26 trillion per year; a = low to medium certainty; b = air quality; c = decease regulation, but pest regulation decreases; d = but fisheries & wild foods decreases; e = wood fuel; f = aggregated cultural services value.

All ecological services are the consequence of supporting processes working at various spatial and temporal scales (Farber *et al.* 2006). For example, carbon dioxide (CO_2) gas regulatory cycles (function) work at small and rapidly changing local scales, but carbon (C) sequestration services have value at global and long-term scales. Hierarchy is the name that semi-autonomous levels of a subsystem receive when formed from the interactions among a set of variables that share similar speeds (Simon 1974). Ideally, elements of the hierarchy transport a limited amount if information or material to the next level in order to develop more stable and resilient elements and structure. Not overlapping subsystems in time and space make difficult to develop an integrated baseline. As an example, Figure 3.4.4 shows how physiographic type's development takes over a century to evolve while human policy and laws can compromise its integrity in just a year timeline. Thus, the variation of subsystem integrity (transfer interrupted or slowed) can lead to structural and processes malfunctioning. Although not simple, to be effective, management must focus on the health of appropriate scaled ecosystems, and on integrating knowledge about the SES across scales.



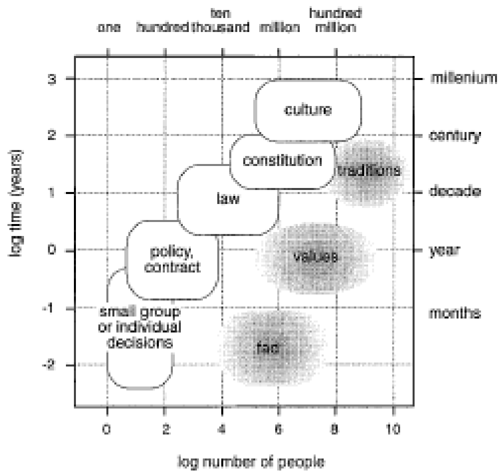


Figure 3.4.4 (A) Time and space scales of levels of a hierarchy in the Everglades. (B) Institutional hierarchy of rule sets. In contrast to ecological hierarchies, this is structured along dimensions of the number of people involved in rule sets and approximate turnover times (Holling 2001).

3.5 Ecosystem functions and services of the Catalan coast

3.5.1 Ecosystem functions

The study used de Groot's (2006) function-analysis approach to determine ecosystem functions, processes and services of the Catalan coast SES. Results of the analysis are presented in Table 3.5.4. Due to the antrophic nature of the Catalan coast, the function classification schema was modified to also include other semi-natural aspects. Only those services that can be managed or used on a sustainable basis were included, to maintain the ecosystem functions and associated structure and processes de Groot (2006). This sustainability criterion excludes the integration of some production and carrier functions in natural and semi-natural systems, since they may involve the conversion of original ecosystems into other unsustainable land-use type. Therefore uses such as, agriculture, fisheries and material use and transfer in our analysis refer to subsistence, small scale, or low impact sustainable activities. Two other aspects were included in the Catalan coast analysis, the functions maintenance geographic scale and the main domain at which they occur.

The function's maintenance geographic scale is that which determines function's performance in this particular coastal system and can be considered homologous to Kremen's (2005) spatial scale proposal. This attribute of the function is considered essential in order to derive any further conservation and management strategy and action. It was expected to vary from other perspectives but it intends to serve as a general guideline in this approach (since earth system elements are commonly referred as meta-linked at the regional scale). The main domain attribute directs the analysis to focus on a particular function that is best represented either in the terrestrial, marine or integral dimensions of the coastal system. As in the geographic scale case, it is considered useful in the investigation of particular elements and processes that determine the overall function group and system. Although service list is not exhaustive, examples provided are intended to represent major environmental issues of the Catalan coast.

Table 3.5.4. Natural and semi-natural ecosystem functions and services of the Catalan coast.

General function	Specific function	Ecosystem processes	Maintenance geographic scale *	Main domain +	Services & examples
Regulation					
	Gas regulation	Essential ecological processes & life support systems; role of ecosystems in biogeochemical cycles (*e.g.* CO2/O2 balance)	Regional	Both	UV protection by O3 (preventing disease); influence on Mediterranean climate (& specific Catalan-Balear Sea); maintenance of good air/water quality (hyperventilated zone)
	Climate regulation	Influence of ecosystem structure	Regional	Both	Maintenance of favorable climate (*e.g.* human health, food, DMS production)
	Disturbance prevention	Influence of ecosystem structure on dampening env. disturbances	Coarse	Both	Storm protection (*e.g.* natural beaches, dunes, small bays or *calas*); flood protection (*e.g.* wetlands, forest, *rieras*)
	Water regulation	Role of land cover in regulating runoff & river discharge	Coarse	Terrestrial	Drainage and natural irrigation (*e.g.* Ebro river delta)
	Water supply	Filtering, retention & storage of fresh water (*e.g.* aquifers)	Coarse	Terrestrial	Provision of water for consumptive use (*e.g.* drinking, irrigation, industrial) (*e.g.* Besos, Llobregat, Ebro rivers)
	Soil retention	Role of vegetation root matrix, soil biota in soil retention & fine sedimentation	Intermediate	Terrestrial	Maintenance of arable land (*e.g.* Ebro, Llobregat river deltas); prevention of damage from erosion/siltation/sedimentation by healthy water systems
	Soil formation	Weathering of rock, organic matter accumulation	Intermediate	Terrestrial	Maintenance of productivity of arable land & natural productive soils (*e.g.* river deltas along the coast)
	Nutrient regulation	Role of biota in storage & recycling of nutrients	Intermediate	Both	Maintenance of healthy soils & water quality; & productive ecosystems; large influence on river/delta discharge CZ
	Waste management	Role of vegetation & biota in removal of xenic compounds	Intermediate	Both	Pollution control, detoxification, decomposition, filtering of particles by bacteria and other organisms; beneficial trophic dynamics; abatement of noise pollution
	Pollination	Role of biota in movement of	Intermediate	Both	Pollination of wild organisms, crops; advantages of aquatic

		gametes			organisms by continuous media diffusion (*e.g.* mollusk larvae in aquaculture)
	Biological control	Population control through trophic-dynamic relations	Intermediate	Both	Control of invasives, pests (*e.g.* jellyfish-sea urchin bottom-up dynamics) & diseases; reduction of herbivory (crop damage)
Habitat	Refugium function	Suitable living space for wild species	Intermediate	Both	Maintenance of biological & genetic diversity; thus the basis of most other functions (*e.g.* community structure of sea grass meadows)
	Nursery functions	Suitable reproduction/grow habitat	Intermediate	Both	Maintenance of wild/commercially harvested species (*e.g.* sea grass meadows, coraligen & littoral rock for fish juveniles)
Production	Food	Conversion of solar energy into edible organisms	Intermediate	Both	Food production by: agriculture, aquaculture, fisheries, hunting, recollection
	Raw materials	Conversion of solar energy into biomass for human construction & other uses	Local	Both	Building and manufacturing (*e.g.* lumber, decorative rocks, sand for beach nourishment); fuel and energy (*e.g.* fuel wood, thermoelectric plants & wind and wave generators possibilities); fertilizer (*e.g.* algae to fertilize crops)
	Genetic resources	Genetic materials & evolution in wild organisms	Intermediate	Both	Improve organisms resilience to environment, pathogens & pests; other applications (*e.g.* health care, algae); high circulation area of genetic material due to the number of ecosystems in CZ
	Medicinal resources	Biochemical substances & other medicinal uses	Local	Both	Drugs & pharmaceuticals (*e.g.* FarmaMar organismal screening, other algae); chemical models & tools; test & essay organisms (*e.g.* bioassays)
	Ornamental resources	Biota in natural ecosystems with ornamental use	Local	Both	Resources for fashion, handicraft, pets, worship, decoration & souvenirs (*e.g.* red coral in Costa Brava)
Information	Aesthetic information	Attractive land/seascape features	Local	Both	Enjoyment of scenery (*e.g.* scenic roads, housing, coastal/seascape)
	Re-creation	Land/seascapes with recreational uses	Local	Both	Travel to natural ecosystems for eco-tourism, rural-tourism & nature study/enjoy; coast related cultural & sports events
	Cultural and artistic information	Natural features with cultural & artistic value	Local	Both	Use of nature as motive in books, films, painting, folklore, architecture, marketing
	Spiritual and historic information	Natural features with spiritual & historic value	Local	Both	Use of nature for religious or historic purposes (*e.g.* heritage value of natural ecosystems & features, small fisherman *ermitas*)

	Science and education	Nature with scientific & educational value	Local	Both	Use of natural systems for school excursions; for scientific research (*e.g.* Marine Science Inst.-CSIC, el Far Consortium, Seaman Schools)
Carrier	Habitation	Depending on the specific land use type, different requirements are placed on env. conditions	Local	Terrestrial	Living space (ranging from small settlements to urban areas)
	Food cultivation and extraction		Local	Both	Food & raw materials from cultivated land, fisheries & aquaculture
	Energy-conversion		Local	Both	Energy-facilities (solar, wind, water, nuclear, etc.)
	Mining		Local	Both	Construction materials, sand for beach nourishment, etc.
	Waste disposal		Local	Both	Space for solid waste disposal in land and sea (*e.g.* submarine outfalls)
	Transportation		Local	Both	Transportation by land & water (*e.g.* ports, roads, trails, etc.)
	Tourism-facilities		Local	Both	Tourism-activities (outdoor sports, beach-tourism, marinas, etc.)

*Notes: * Maintenance geographic scale corresponds to that of occurrence at the Catalan coast; + Main domain corresponds to the principal environmental domain to which a specific function occurs. Spanish terms used: Cala, small rocky bay or cove; Ermita, small oratory site, usually contains an image or statue (not a church); Riera, natural drainage cause or creek.*

The schema included 30 functions aggregated into the five classes. Although the rank order of the function classes is arbitrary, the first two classes (regulation and habitat) are essential to the maintenance of natural elements and processes, and therefore conditional to the maintenance and availability of the other three classes (de Groot *et al.* 2002). However, all of them are recognized as necessary for the SES sustainability. Therefore the hierarchy proposed should not be interpreted too strictly.

Ecosystems play an essential role in the regulation and maintenance of the ecological processes and functions whose performance determine the viability of the environmental life support systems on the coastal system. The table has been compiled with a metaecosystemic view, thus processes have been integrated at a Catalan coast regional spatial and time scale (which is not the same as the maintenance geographic scale). As an example, a local coastal plain of a few hundred hectares could integrate shoreline, wetland, and crop dynamics in time frame of several months (seasonal dynamics). Therefore, this ecosystem model allows the conceptual coupling of both dimensions into a single coastal vision. The reconciliation of the two dimensions has the potential to provide fundamental insights on ecosystem functioning at the system's scale. Although explicit differences among terrestrial and marine environments were reported, most functions are performed in both domains, and only some regulation functions main contribution appeared to be exclusive of the terrestrial dimension.

The analysis arose that most theoretical functions are performed by the Catalan coastal system (and are evident), probably due to its large diversity of ecosystems. Being one of the most rapidly developing regions in Spain, with 44 % (2.79 million in 2001) of the total population lives in just 7 % (70 coastal municipalities) of the total surface area, it is also subject of several environmental stresses (IDESCAT 2005, Nunneri *et al.* 2005). Although theoretically all systems have the potential to perform all the functions in the schema, the perception (socio-economic values) and the specific objective of the study will determine their relevance. From the SES perspective all functions compared at equally weights, however bias can be induced in the study either by the over-representation or contribution of specific functions (*e.g.* basic regulation, habitat and production functions in more natural ecosystems), or the inherent observation difficulty of some of them (cryptic functions such as pollination).

The Catalan coast, a natural confluent area, posses a heterogeneous character capable of balancing the representation of ecosystem functions along its natural and semi-natural habitats. Relevant regulation functions include the transformation of energy into biomass (primary productivity mainly from solar radiation); storage and transfer of minerals and energy in food chains (secondary productivity); biogeochemical cycles (such as C, N, and P); mineralization of organic matter in soils and sediments; and the regulation of physical climate. These processes are regulated by abiotic factors together with biodiversity through control and evolution. Therefore they provide the necessary preconditions for other functions, and thus are responsible for maintaining a healthy ecosystem. The coastal system provides a variety of reproductive, feeding and living substrata for biodiversity. As introduced before, species and their role from local to global systems are responsible for most of the functions represented in this analysis (Holling *et al.* 1995, Loreau *et al.* 2002, Gessner *et al.* 2004). The maintenance of healthy habitats is a necessary precondition for the provision of most goods and services derived directly or indirectly form biodiversity.

Natural and semi-natural resource production is by large the most tangible property of ecosystems. The coastal system production function or productivity ranges from basic elements oxygen, water; to biodiversity information (genetic resources); to energy and materials for building. From a management perspective a fundamental distinction should be made between biotic and abiotic resources. The implication of such deals with biotic resources renewability versus abiotic resources quasi-static characteristic (commonly referred as in human time span). Although humans tend to manipulate biotic system productivity, biotic resources exploitation should be limited to the portion of the Gross Primary Production (GPP) that can be sustainable harvested. According to Odum (1953) as a general rule-of-thumb maximum sustainable use levels should not be more than 50 % of the GPP (or 10 % of Net PP) to maintain the integrity of ecosystems.

Coastal zone’s information functions provide almost unlimited and essential opportunities for reflection, spiritual enrichment, cognitive development, recreation and aesthetic experience. By being a vital source for science and society inspiration these functions contribute to the present maintenance of human health and future cultural heritage. Carrier functions in the coastal zone are probably more evident that any other area, since the water fluid considerable expands transportation capacity. With two large combined international ports and several marinas, it is obvious the established and growing capacity of water transportation infrastructure a long the Catalan coast. However, the increase of this function’s capacity commonly involves the transformation of original ecosystems. Thus, the capacity of ecosystems to provide carrier functions on a sustainable basis is usually limited.

3.5.2 Ecosystem services

The ecological related concept of ecosystem functions was translated into the more socio-economic concept of ecosystem services. This process potentially allows services to be included into people's everyday life. The analysis used the ecosystem services classification proposed by Farber *et al.* (2006). Due to its value-driven nature, it is expected to be useful in the economic and ecological valuations of the Catalan coast. Specific services were also aggregated into four major classes which corresponded to those proposed by the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005a). The relevance of this classification relies on its multi-scale approach and demonstrated utility at global, regional and local scale assessment.

In order to achieve the level of ecosystem services provision needed by society we need to identify what functions determine what services. By being based on a provision capacity viewpoint, in this framework is possible to relate both function and service concepts in a dependencies model. Figure 3.5.5 shows major and direct relationships between both classification systems used. Function class attribute in Table 3.4.3 was derived from this relationship model. The model illustrates the more evident dependencies of human-valued ecosystem services on functions derived from ecosystem structure and processes. Dependencies were obtained by theoretically and explicit relationships found in both typologies' description (de Groot 2006, Farber *et al.* 2006). Supporting services are the result of the basic regulation and habitat functions. As shown in the figure, they are also responsible of the performance of the rest of the services provided by ecosystems, thus represent relevant elements to be included in the valuation process. Since everything is connected at some level, it is also valid to understand that that several other non-obvious links could apply between functions and services. The model provides the capacity of mapping dependencies in both directions, which also constitutes a further goal derived from this study, the capacity to determine the health of the underlined functioning of coastal ecosystems. Consequently, the role of ecologists would then be that if identifying specific rules for the efficiency optimization in different ecosystems. Accordingly, the model is expected to be useful in communicating managers what functions should work in order for a system to provide a valuable service to society. In addition, current approach is expected to be helpful in the assimilation of services value into other frameworks and models (future developments by the author and colleagues).

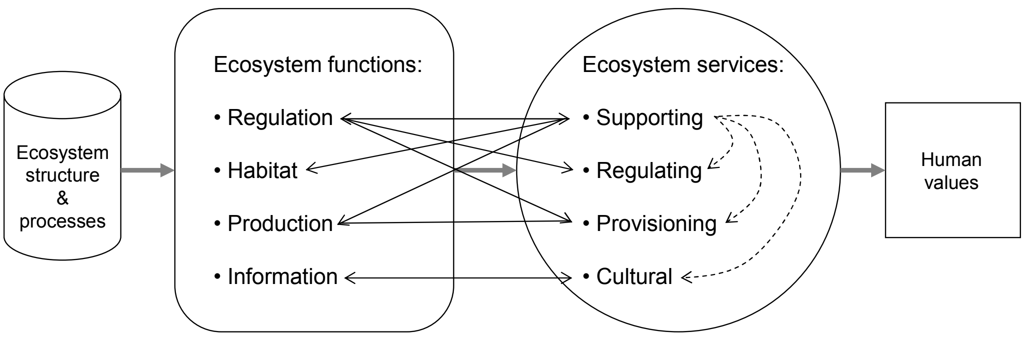


Figure 3.5.5. Major direct relationships between ecosystem functions and services. Supporting services are necessary for production of other services.

In order to operationalize the proposed framework, specific coastal habitat and ecosystems are identified under the synthetic typologies. For example, hard rock on cliffed coast is most likely represented as sea cliffs. Once the landscape features are identified, it is possible to associate ecological habitats and ecosystem types with them. Table 3.5.5 presents the results from cross-referencing ecosystem services against some of the coastal ecosystems and habitats found in the Catalan coast. A scientific literature review was performed between 1978 and 2005 publications. An accurate land cover classification needs to be able to delineate whether or not ecosystem services are derived from habitats or ecosystems to prevent the danger of doubling accounting (Wilson *et al.* 2002). Additionally, Kremen (2005) proposes a functional unit concept that refers to the unit of study for assessing functional contributions of ecosystem services providers. The concept is easily operationalized when accounting for services provided by biodiversity (*i.e.* species, populations, communities, functional groups).

Table 3.5.5. Coastal zone habitat and ecosystem services identified in the literature (1978-2005).

Feature	*Supportive functions and structures*						*Regulating services*								*Provisioning services*						*Cultural services*				Notes
	Nutrient cycling	Net primary production	Pollination & seed dispersal	Habitat	Hydrological cycle	Soil formation	Gas regulation	Climate regulation	Disturbance regulation	Biological regulation	Water regulation	Soil retention	Waste regulation	Nutrient regulation	Water supply	Food	Raw materials	Genetic resources	Medicinal resources	Ornamental resources	Recreation	Aesthetic	Science & education	Spiritual & holistic	
Forest	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	1,2
Grassland			●			●	●	●		●	●	●	●			●		●			●				1,3
Cropland			●							●						●									1,4
Rock/cliff				●					●								●			●	●	●	●		5
Rivers & lakes	●			●	●						●		●	●	●	●					●	●	●	●	1,6
Wetland	●			●	●	●	●	●	●	●	●	●	●	●	●	●					●	●	●		1,5,7
Delta	●			●	●	●	●	●	●		●		●	●	●	●	●				●	●	●	●	5
Beach				●					●			●									●	●		●	5
Soft bottom	●	●		●									●	●		●	●			●	●		●		8,9
Rocky bottom	●	●		●									●	●		●					●		●		9
Posidonia spp	●	●		●			●		●			●		●		●	●		●			●	●	●	1,5,10,11

Notes: Service description available in peer-reviewed literature: (1) Costanza et al. 1997; (2) Myers 1997; (3) Sala and Paruelo 1997; (4) Naylor and Ehrlich 1997; (5) Wilson et al. 2002; (6) Postel and Carpenter 1997; (7) Brouwer et al. 1999; (8) Troell et al. 2005; (9) Peterson and Lubchenco 1997; (10) Duarte 2000; (11) de la Torre-Castro and Rönnbäck 2004. Blanks indicate no data available.

Information in Table 3.5.5 shows that ecosystem services can be associated with either habitat or ecosystem features. Dots represent potential ecosystem goods and services provided by the feature, while blanks represent no available data found in literature. A good representation of services by group was found in the as metadata in the literature review, especially in Daily (1997). Table also shows how some features apparently provide a larger number of services when compared to others (*i.e.* cliff *versus* wetland). However, all features are relevant elements of the entire coastal system by performing specific and valued services. Functional metaecosystems may account for aggregated multi-feature values, besides the un-obvious non-use values that all features integrate from a holistic viewpoint.

Features shown on table will input both economic and ecological valuation in next chapters. Economic (monetary) and ecological (*i.e.* human influence, ecological indicators) values will be used to develop an integrated valuation method of the Catalan coast.

Probably the most practical method to illustrate and communicate the ecosystem functioning concept is through the expression of the services to humans that they provide. It has been suggested before that observing ecosystem's structure is easier than processes and that the structure is the result of the operation of processes, thus can be used as a surrogate (such as depth) (*e.g.* Zacharias and Roff 2000).

3.6 Conclusions

The conceptual framework presented in this chapter provides an ecological-based approach to understand the relationship and dependences of ecosystem services provision based on ecosystem functioning of the SES. It has been used to translate ecosystem's structure and processes into identifiable functions and services to be included in coastal management plans. The approach provides a qualitative framework which identifies the elements responsible for human well-being on the coastal zone.

Results suggested that the concepts of ecosystem function and service are useful for coastal zone science since it synthesizes the essential ecological theory that scientists and managers can use to evaluate the SES tradeoffs between coastal use and conservation alternatives. The framework also shows how ecosystem functions constitute the pivotal conceptual link between ecological and social subsystems. This allows the conceptual coupling of both dimensions into a single coastal vision which will be assessed in the next chapter.

Although the schema included five general classes, regulation and habitat were considered essential to the maintenance of natural elements and processes, and therefore conditional to the maintenance and availability of the other three classes. Since supporting services are the result of the basic regulation and habitat functions they were also found responsible of the performance of most of the services provided by ecosystems. The capacity of mapping dependencies in both directions will provide the opportunity to assess the health of the underlined functioning of coastal ecosystems in a further step. Results in Table 3.5.5 showed that due to present knowledge some land covers provide a larger number of services when compared to others. However, all land covers were considered relevant by performing specific and valued services in the coastal zone.

CHAPTER 4. Analysis of the coastal social-ecological system

An emergent goal in natural resource management is to relate the management practices based on ecological understanding, to the social mechanisms behind these practices. In this approach the social-ecological systems are in fact linked and the delineation between them is artificial and arbitrary (Berkes and Folke 1998). Unlike common ecological theory which tends to view humans as external to ecosystems, SES explicitly include the social systems into its analysis and synthesis. As a result, a SES sustainable approach implies the understanding of system's heterogeneous functions, services and their capacity to provide those on which human well-being depends on. A way to assess the contribution to well-being of such benefits or services provided by ecosystems is through valuation. While measuring good's exchange values simply requires monitoring market data for observable trades, non-market values of goods and services are more difficult to measure.

4.1 Introduction

4.1.1 Ecosystem services valuation

One reason for the persistent under-valuation of coastal ecosystems is that, concepts of economic value have been based on a very narrow definition of benefits. Economists have tended to see the value of natural ecosystems only in terms of the raw materials and physical products they generate for human production and consumption (especially focusing on commercial activities and profits). These direct uses however represent only a small proportion of the total value of coastal ecosystems, which generate economic benefits far in excess of just physical products or marketed commodities. Confining concepts of ecosystem value to these benefits alone would constitute a huge underestimation, and covers only the tip of the total value.

In discussing values, several underlying concepts need to be defined. The following definitions are based on Farber *et al.* (2002). <u>Value system</u> refers to group of norms and precepts that guide human judgment and action. It constitutes the normative and moral framework people use to assign importance and necessity to their beliefs and actions. By framing how people assign importance to things and activities, it also implies internal objectives. <u>Value</u> refers to the contribution of an object or action to specific goals, objectives or conditions (Costanza 2000). The value of an object or action may be tightly coupled with an individual's value system, because the latter determines the relative importance to the individual of an action or object relative to other actions or objects within the perceived world. The value of an object or action therefore needs to be assessed both from the subjective point of view of individuals and their internal value systems, and also from the objective point of view of what we may know from other sources about the connection. Finally, <u>valuation</u> is the process of assessing the contribution of a particular object or action to meeting a particular goal, whether or not that contribution is fully perceived by the individual.

Traditionally, the goal of ecosystem services valuation is efficient allocation, *i.e.* to allocate scarce ecosystem services among competing uses such as development and conservation. But other goals have been identified (Daly 1992): (i) assessing and insuring that the scale or magnitude of human activities within the biosphere are ecologically sustainable; (ii) distributing resources and property rights fairly, both within the current generation of humans and between this and future generations, and also between humans and other species; and (iii) efficiently allocating resources as constrained and defined by i and ii above, and including both market and non-market resources, especially ecosystem services. Because of these multiple goals, valuation must be conducted from multiple perspectives, using multiple methods (including both subjective and objective), against multiple goals (Costanza 2000).

A range of economic valuation techniques used to establish values when market values do not exist have been identified (Bingham *et al.* 1995, Farber *et al.* 2002, de Groot *et al.* 2002, Freeman 2003). However, each valuation methodology has its own limitations, often limiting its use to a select range of ecosystem services. For example, the economic value generated by a naturally functioning ecological system can be estimated using the Replacement Cost method which is based on the price of the cheapest alternative way of obtaining that service, *e.g.* the value of a wetland in the treatment of wastewater might be estimated using the cost of chemical or mechanical alternatives. A related method, Avoided Cost, can be used to estimate economic value based on the cost of damages due to lost services. Travel Cost is primarily used for estimating recreation values while Hedonic Pricing for estimating property values associated with aesthetic qualities of natural ecosystems. On the other hand, Contingent Valuation surveys are often employed in the absence of actual environmental use to estimate the economic value of less tangible services like critical wildlife habitat or recreational values. Marginal Product Estimation has generally been used in a dynamic modeling context and represents a helpful way to examine how ecosystem service values change over time. Finally, Group Valuation is a more recent addition to the valuation literature and directly addresses the need to measure social values directly in a group context. In many applications, the full suite of ecosystem valuation techniques will be required to account for the economic value of goods and services provided by a natural landscape (see Annex II for a description of methods).

Over the last decade or so, the concept of Total Economic Value (TEV) has become one of the most widely-used frameworks for identifying and categorising ecosystem benefits or services (Costanza and Folke 1997). Figure 4.1.1 shows components of TEV of a given landscape might be estimated by linking different ecosystem structures and processes with the output of specific goods and services, which can then be assigned monetary values using the range of valuation techniques described. Key linkages are made between the diverse structures and processes associated with the landscape and habitat features that created them and the goods and services that result. Once delineated, values for these goods and services can then be assessed by measuring the contribution they make to supporting human well-being. In economic terms, the natural assets of the landscape can thus yield direct (fishing) and indirect (nutrient regulation) use values as well as non-use (conservation) values of the system. Once accounted for, these economic values can then be aggregated to estimate TEV of the landscape.

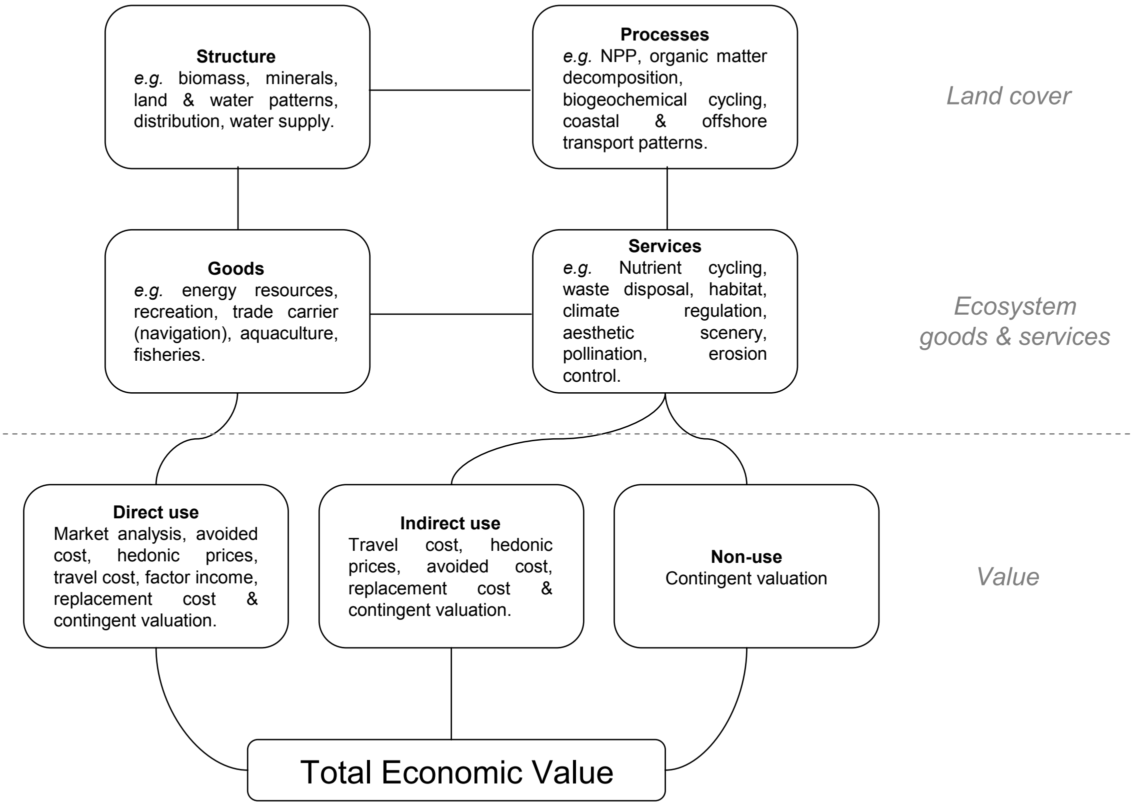


Figure 4.1.1. Total economic value of coastal ecosystems.

Looking at the TEV of a coastal ecosystem essentially involves considering its full range of characteristics as an integrated system, *i.e.* its resource stocks or assets, flows of environmental services, and the attributes of the system as a whole. Broadly defined, the total economic value of coastal ecosystems includes:

Use values:

- *Direct values*. The raw materials and physical products that are used directly for production, consumption and sale at both subsistence and commercial levels. Examples include fish, crustaceans and other marine species; firewood; construction materials; medicines; fodder; tourism and recreational resources.

- *Indirect values.* The ecological functions which maintain and protect natural and human systems and provide essential life support. These obviously vary for different types of coastal ecosystems, but include services such as protecting shorelines from storms, waves and tidal surges; guarding against coastal erosion; cycling nutrients; attenuating floods; sequestering carbon; regulating micro-climate; and providing nursery, breeding sites and shelter to various animal species.

- *Option values.* The premium placed on maintaining a pool of landscapes, species and genetic resources for future possible uses which have economic value. By definition, many future use options for coastal ecosystems cannot be known now, because they have not yet been identified, discovered or developed. Examples include new industrial, pharmaceutical or agricultural applications of wild species; future tourism developments; or novel possibilities for resource utilisation.

Non-use values:

- *Existence values.* The value of ecosystems and their component parts, regardless of current or future possibilities to use them. Coastal ecosystems provide sites and landscapes, and contain a range of plant and animal species, which people value simply because they exist — not just because of the products and services they generate. Examples include historical or cultural sites and artefacts; aesthetic appeal; considerations of local, national or global heritage; or perceptions of legacy for future generations.

Many ecosystem goods and services (particularly subsistence-level benefits, indirect, option and existence values) are however never traded, are undervalued by the market, are subject to prices which are highly distorted, or have characteristics of public goods which mean that they are not adequately allocated or priced by the economic market. For these reasons, their value cannot be expressed accurately via market prices. Taking this concept of TEV, which essentially defines and categorises the different benefits of natural ecosystems, we can in turn articulate the economic contribution of ecosystem services to various elements of human well-being.

The ability to transfer economic valuations from one context to another may be critical to the cost-effective use of services-based valuations (Farber *et al.* 2006). Some ecosystem services may be provided at scales at which benefits are easily transferable (*e.g.* carbon sequestration). Other services are available only at local scales but so general that valuation in one context may be meaningful transferred to another (*e.g.* value of fish yields). Other local-scale services may have limited transferability, such as flood control value. Table 4.1.1 provides guidance on ecosystem services, valuation methods and transferability of values from one context to another. Markets for ecosystem services are therefore likely to increase demand for ecological information and drive improvements in technology for ecosystem measurements (Carpenter and Folke 2006)

Table 4.1.1. Categories of ecosystem services, economic methods for valuation and transferability across sites (Farber *et al.* 2006).

Ecosystem service	Amenability to economic valuation	Most appropriate method for valuation	Transferability across sites
Gas regulation	Medium	CV,AC,RC	High
Climate regulation	Low	CV	High
Disturbance regulation	High	AC	Medium
Biological regulation	Medium	AC,P	High
Water regulation	High	M,AC,RC,H,P,CV	Medium
Soil retention	Medium	AC,RC,H	Medium
Waste regulation	High	RC,AC,CV	Medium to high
Nutrient regulation	Medium	AC,CV	Medium
Water supply	High	AC,RC,M,TC	Medium
Food	High	M,P	High
Raw materials	High	M,P	High
Genetic resources	Low	M,AC	Low
Medicinal resources	High	AC,RC,P	High
Ornamental resources	High	AC,RC,H	Medium
Recreation	High	TC,CV	Low
Aesthetics	High	H,CV,TC	Low
Science & education	Low	Ranking	High
Spiritual & historic	Low	CV	Low

Notes: AC = avoided cost; CV = contingent valuation; H = hedonic pricing; M = market pricing; P = production approach; RC = replacement cost; TC = travel cost.

Figure 4.1.2 shows the integrated framework for ecosystem services proposed by de Groot *et al.* (2002) and which has been adapted to fulfill the purpose of integrated value in this study. Framework shows how ecosystem goods and services form a central link between the social and the ecological systems. Ecosystem structures and processes are influenced by biophysical drivers (*e.g.* weather patterns, solar energy) which in turn create the necessary functions for providing the ecosystem goods and services that support human welfare. Non-marketed ecosystem goods and services are assessed by stakeholders through the development of ecological (objective) and social (subjective) integrated valuation process. Which through laws, land use management and policy decisions, individuals and social groups make tradeoffs will be included in cost-benefit analysis and improve environmental decision-making. In turn and as a result of a close dynamic interaction, these land use decisions directly modify the ecological structures and processes by engineering and construction activities and/or indirectly by modifying the physical, biological and chemical structures and processes of the landscape. However, if a sustainable goal is established by consensus, these effects could be set to sustainable levels by adaptive planning mechanisms.

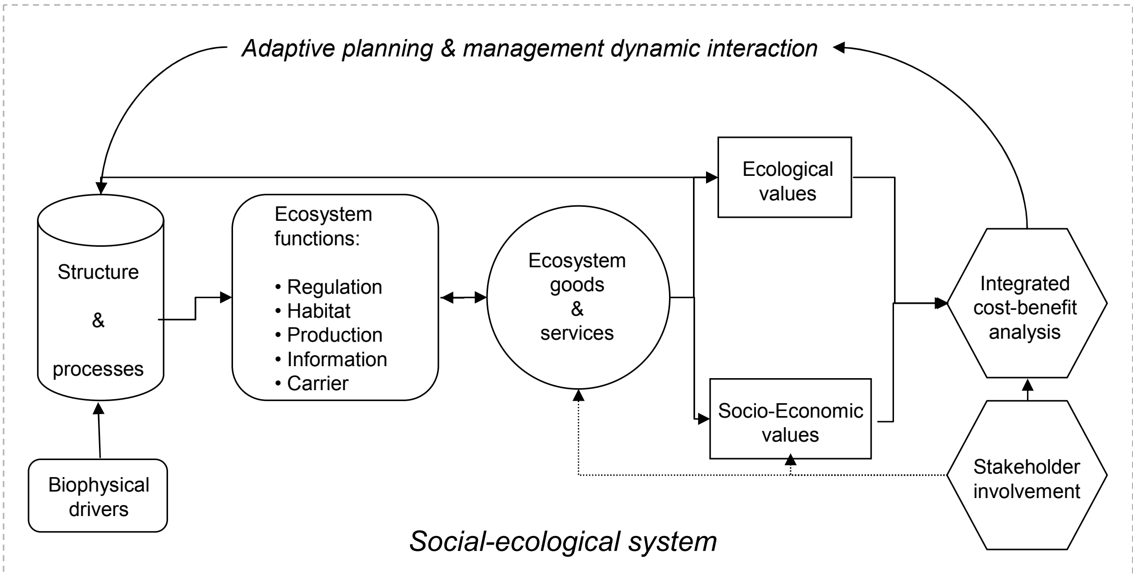


Figure 4.1.2. Framework for valuation of ecosystem services and integrated assessment of the social-ecological system (Adapted from de Groot *et al.* 2002).

Another way of looking at environmental benefits has been gaining favour over the last decade among scientists and economists. It is the natural capital framework. Natural capital is a metaphor for the mineral, plant, and animal formations of the Earth's biosphere when viewed as a means of production of oxygen, water filter, erosion prevention, thus provider of ecosystem services. This concept sees natural environment as a capital asset (an asset that provides a flow of benefits over an extended period) (Costanza and Daly 1992). In this framework the emphasis is on the benefits provided by the living environment, usually viewed in terms of whole ecosystems. It is one approach to ecosystem valuation, an alternative to the traditional view of all non-human life as passive natural resources, and to the idea of ecological health.

Two interdisciplinary publications have drawn widespread attention to ecosystem service valuation and stimulated a continuing controversy between ecological economists and traditional "neoclassical" economists. First, Costanza and his colleagues (ecologists and economists) published a paper on valuing the services provided by global ecosystems (Costanza *et al.* 1997). They estimated that the annual value of 17 ecosystem services for the entire biosphere was 33 trillion USD. The paper has inspired the development of the ecological economics field and journal of Ecological Economics contributed a special issue in 1998, which included a series of 13 commentaries on this article. After a decade, discussions on this article continue to arise and just recently articles have been published in the journal Nature (2006, 443: 749-750). Second, the first book dedicated to ecosystem services was also published in 1997 (Daily *et al.* 1997). Nature's Services brings together world-renowned scientists from a variety of disciplines to examine the character and value of ecosystem services, the damage that has been done to them, and the consequent implications for human society. The book presents a detailed synthesis of the latest understanding of a suite of ecosystem services and a preliminary assessment of their economic value.

4.1.2 Valuation needs of the Catalan coast

Over the last decade or so, the concept of ecosystem services value has become one of the most widely-used frameworks for identifying and categorising ecosystem benefits (Costanza and Folke 1997). Instead of counting only easily observable commercial values, it also encompasses subsistence and non-market values, ecological functions and non-use benefits. As well as presenting a more complete picture of the economic importance of ecosystems, it can be used to demonstrate the high and wide-ranging costs associated with their degradation, which extend beyond the loss of direct values.

The recent finalized Millennium Ecosystem Assessment Project was designed to meet the needs of decision-makers for scientific information on the consequences of ecosystem change for human well-being (Millennium Ecosystem Assessment 2005a). Although conducted at global and regional scale, the MEA constitutes the most comprehensive assessment of ecosystem services to date. It recommends improving our knowledge and technical capabilities in six main issues, being: (1) improve theoretical basis for linking ecological diversity to ecosystem dynamics and thus services, (2) develop robust frameworks for analyzing ecosystem services at multiple scales, (3) develop indicators of ecosystem services performance, (4) understand the cost and benefits of alternative management approaches for the entire range of ecosystem services, (5) linking social to ecosystem change, and (6) develop economic incentives to improve ecosystem management. It concluded that, although attempted to provide a systematic accounting of ecosystem services value, was limited in its ability to do so since too often ecological and economic studies are carried out separately and as a result, the most reliable ecological and economic information cannot be brought together (Carpenter *et al.* 2006).

Consequently, this study contributes to the above needs by developing an analytical framework and methods for evaluating the success of management interventions in the SES. Based in recommendations from MEA, present study raises three main questions relevant to its management in order to understand the relationship between the natural and socio-economic dimensions of the Catalan coastal zone:

- What are the implications of natural and socio-economic spatial heterogeneity in coastal management?,
- What is the value of coastal ecosystem services not captured by economic markets?, and
- What characteristics of the coastal zone can predict the capacity to provide ecosystem services?

Thereafter, present study proposes three environmental assessments to address the questions raised. First, based in *comarcas* the ***homogeneous environmental management units*** will provide a discrete but integrated spatial structure to understand ecosystem services value; second, the ***ecosystem services value*** will estimate non-market and preference-based contribution to TEV in the coast; and third the ***integrated social-ecological ecosystem services value flow*** will incorporate the ecological production functions to the provision of ecosystem services. Results of these applications are present in the following sub-sections of present chapter.

A survey was conducted to identify the desirable characteristics of a social-ecological valuation method. Survey was performed using a questionnaire which was sent by postal mail to investigate the main needs on coastal zone assessment in Catalonia in 2004. Ten out of 30 surveyed policy-makers, coastal managers and technicians answered the questionnaire.

According to the preferences established in the survey, all answered affirmative to the necessity to value the coast in Catalonia environmentally, and 9 answered that the necessity is high. The majority responded that coastal environment has gotten worse (7), and that the time scale in which it has happened varies between a lustrum to a decade in both sectors. The reasons exposed about the worsening of environment were also coincident mainly and the causes were by order: direct use and urbanization; ports and direct spills; overflows of water collectors and streams; erosion, canalization and aquaculture byproducts. Table 4.1.2 summarizes results on the desirable characteristics of a valuation method. However, there is no practical way to implement all characteristics in a personal project as a dissertation due to time and economic constrains.

Table 4.1.2. Desirable characteristics of an environmental valuation system of the Catalan coast.

Theme	Characteristics
Objective	To value the environmental and measure the impact of coastal programmes and policies
Scale	Autonomous Community but with capability to be up-scaled to local level
Analytical capabilities	Science-based, inter and intra system complex dynamics assessment, spatially explicit, geo-modelling capabilities, based on species to ecosystem
Monitoring capabilities	Environmental value analysis at different temporal and spatial resolutions, performance and success assessment
Operational capabilities	User/manager oriented, modular and fare up-scaling system
Outreach capabilities	Communicate results in practical manner and key concepts
Valuation type	Ecological and economic (monetary)

The rational behind the proposed studies is to translate the geographic, ecological and socio-economic complexity into a set of management units and ecosystem services to provide a methodological framework to value the natural capital flow in the coastal zone. To the author’s knowledge, present study constitutes the first monetary approach to the value of coastal ecosystem services in Catalonia. The proposed tools can be further analyzed in more detail once a better understanding of the general concepts is achieved by coastal managers. By integrating these two sides of the SES in a single toolkit for the coast (geographic heterogeneity and ecosystem services value), the proposed ecosystem services value estimation constitutes a practical approach to fulfilling the gap between the socio-economic and the ecological disciplines.

4.2 Definition of homogeneous environmental management units for the Catalan Coast

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4.2.1 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 socio-economic 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 socio-economic 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 socio-economic 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 emphasised the role of appropriate territorial information and organized, coherent databases as essential for decision making in the coastal zone (*i.e.* Shupeng 1988, Bartlett 2000). The coastal zone is characterized by a high degree of natural and socio-economic heterogeneity due to the existence of multiple resources and uses, and its highly dynamic nature (McLaughlin *et al.* 2002). The spatial heterogeneity of the coastal zone can be rationalised by selecting Homogeneous Environmental Management Units (HEMU), 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 *et al.* 2002). This process of reducing spatial complexity is a way of linking management decisions to the biophysical and socio-economic 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, they should also be integrated within the existing administrative framework. To properly define an HEMU, natural and socio-economic 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, socio-economic, administrative, etc.) must be spatially coherent.

The definition of HEMU 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 (see Fricker and Forbes 1988, Gornitz 1990, Bartley *et al.* 2001, Baja *et al.* 2002, Escofet 2002, Maxwell and Buddemeier 2002, Henocque and Andral 2003, Vafeidis *et al.* 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 socio-economic dimension needs to be incorporated into the process (Sardá *et al.* 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 (*i.e.* 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 regionalisation 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 regionalisation 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 socio-economic subsystems. Due to 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 regionalisation, 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 recognises the dynamics and complexity of ecosystems in order to provide an analytical framework for the development of managerial strategies (Rappaport 1999). An example of regionalisation is the use of river basins to define management units for use in a variety of approaches (*i.e.* 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 since 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 *et al.* 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 an HEMU regionalisation, due to 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 programmes 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 non-overlapping 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 is 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 socio-economic 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 paper is to present a method for classification of the coastal zone into regions by defining HEMU. 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 Integrated Coastal Zone Management Strategic Plan (PEGIZC; DMAH 2004) and activities can be implemented according to the socio-economic and natural characteristics of the territory.

4.2.2 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 4.2.1 shows the administrative regions of the Catalan coastal area. Past and present human settlements reflect the organisation of socio-economic 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 *et al.* 2005).

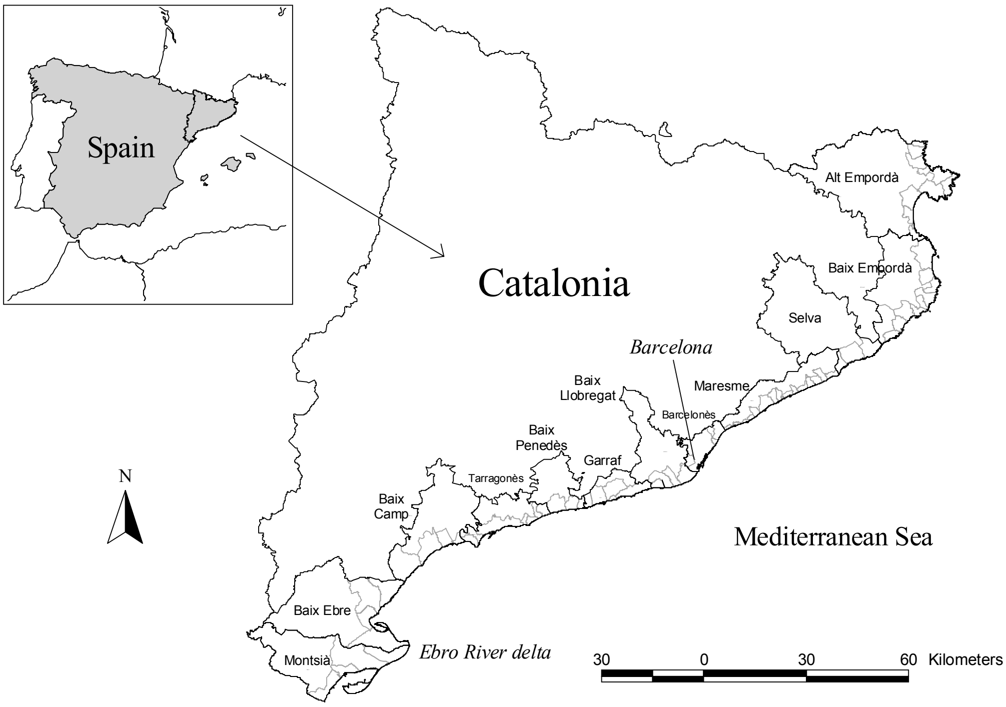

Figure 4.2.1. Catalan coastal zone. *Comarcas* and municipalities administrative division.

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. Firstly, 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 towards a much more rational management of the coast. However, due to the diversity of the biophysical and socio-economic dimensions of the Catalan coast, it is difficult to implement without an 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. Whereas in the terrestrial part there is a clear spatial structure based on municipalities, 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 *et al.* 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, *i.e.* 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 (*i.e.* the natural environment) and lacked aspects of integration with socio-economic activities. In the neighbouring 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.

4.2.3 Methodological approach

The Geographic Information System

In order to develop an HEMU-based regionalisation, the terrestrial coastal subsystem was divided into natural (biophysical) and socio-economic dimensions according to the generally accepted ICZM framework. Due to the heterogeneity of this area and the need to incorporate the environmental structure and function effectively, a regional, sub-national 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). Since 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 *et al.* 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 (see DPTOP 1983, Fricker and Forbes 1988, Maxwell and Buddemeier 2002, DMAH 2003, Vafeidis *et al.* 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 *et al.* 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. Due to 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, modelling, 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 standardisation 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 sub-systems (UNESCO 1997, DMAH 2004, Vafeidis *et al.* 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 eleven geospatial themes were selected according to their conceptual, environment-specific contributions as quantifiable phenomena of the dynamic coastal sub-system and the quality of the available data. The quality-control schema was based on the following criteria: (1) 1:50,000 sub-national cartographic scale or larger, (2) whether the source was official or not, and (3) data update criteria. Table 4.2.1 shows the themes used and their descriptors, the spatial scale and the year the data were gathered.

Table 4.2.1. Themes by dimension used for the Catalan coastal zone HEMU definition.

Dimension	Theme	Cartographic Scale	Year	Descriptor (s)
Socio-economic	Population size	50,000	2004	Inhabitants count [1]
	Populationon 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 & 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 & 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).

Within the socio-economic dimension, the gross national product (GNP) was the most robust indicator, due to 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 an others 2005); thus, the accommodation coefficient was included as a relevant socio-economic 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, *i.e.* 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 *et al.* 2005). In contrast, the themes corresponding to the socio-economic dimension were georeferenced to the *comarca* (a territorial unit comparable to a county), since this constitutes the highest administrative level for which there is complete and official statistical data, and because *comarcas* are recognised 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 socio-economic data available is only complete for 68.5% of municipalities (those with more than 5,000 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 *et al.* (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 optimisation, which identifies break points between classes by minimising 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 minimising its natural variation (Smith 1986).

Data aggregation method

The natural themes considered in the analysis (Table 4.2.1) were aggregated at the level of the *comarca* to be spatially coherent and consistent with the socio-economic 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, since 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).

Regionalisation process

Theme typologies were used to develop a specific regionalisation map for each dimension. The algebraic sum of individual themes represented the contribution of the individual natural and socio-economic regionalisation 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 regionalisation 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 socio-economic 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 twelve *comarcas* of the Catalan coast. An additional analytical phase defined spatial modelling rules to determine criteria for a proposed natural coastal resources conservation scenario.

4.2.4 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 HEMU. Although the coastal system consists of several different dimensions that determine its stability and health, only two are used in this study: the socio-economic 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 (see Table 4.2.1).

Table 4.2.2 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 4.2.2 also shows the surface area (in hectares) of the *comarcas* and provinces to indicate the relative geographical contribution of the themes in the regionalisation process.

Table 4.2.2. Theme classification values by *comarca* of the Catalan coastal zone.

			Socio-economic					Natural					
Comarca	**Province**	**Has**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Alt Empordà	Girona	135697	1	2	1	3	1	3	3	4	4	2	1
Baix Empordà	Girona	70016	1	2	1	3	2	2	2	3	3	2	1
Selva	Girona	99537	1	3	1	4	1	2	1	3	3	2	1
Maresme	Barcelona	40049	2	3	2	2	2	1	2	3	3	2	3
Barcelonès	Barcelona	14463	4	1	4	1	4	1	2	2	1	2	2
Baix Llobregat	Barcelona	48664	3	2	3	1	3	2	2	3	2	2	4
Garraf	Barcelona	18503	1	4	1	2	2	2	2	3	3	2	3
Baix Penedès	Tarragona	29618	1	4	1	2	2	1	1	3	2	1	3
Tarragonès	Tarragona	31931	1	2	2	3	3	2	2	3	2	2	2
Baix Camp	Tarragona	69633	1	2	1	2	1	2	1	4	3	1	3
Baix Ebre	Tarragona	100212	1	2	1	1	1	3	2	4	4	3	4
Montsià	Tarragona	73741	1	2	1	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.

Figure 4.2.2 shows the results of the socio-economic and the natural thematic rationalisations. There is a clear relationship between the two: in general, higher values for the socio-economic component are accompanied by lower values for the natural component. This pattern clearly reflects the central role of the metropolitan areas of Barcelona (Barcelonès) and Tarragona (Tarragonès) in the socio-economic development of Catalonia. The least developed areas in socio-economic 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 4.2.1).

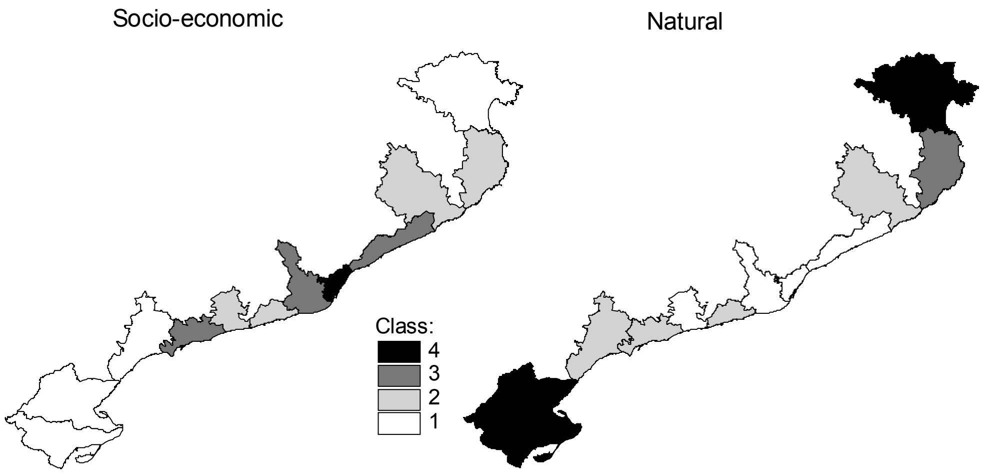

Figure 4.2.2. Socio-economic and natural regionalisations of the Catalan coast.

Once these two independent rationalisations were performed, they were combined to define the map of the HEMU. Figure 4.2.3 shows the HEMU 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 4.2.3 should be obtained. This value, which we will refer to as "total wealth," is obtained by averaging natural and socio-economic values, and it can be considered an integrated measurement of the two dimensions. However, this method of aggregation can introduce interpretation errors, since 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 socio-economic value and in the second is due to a high natural one.

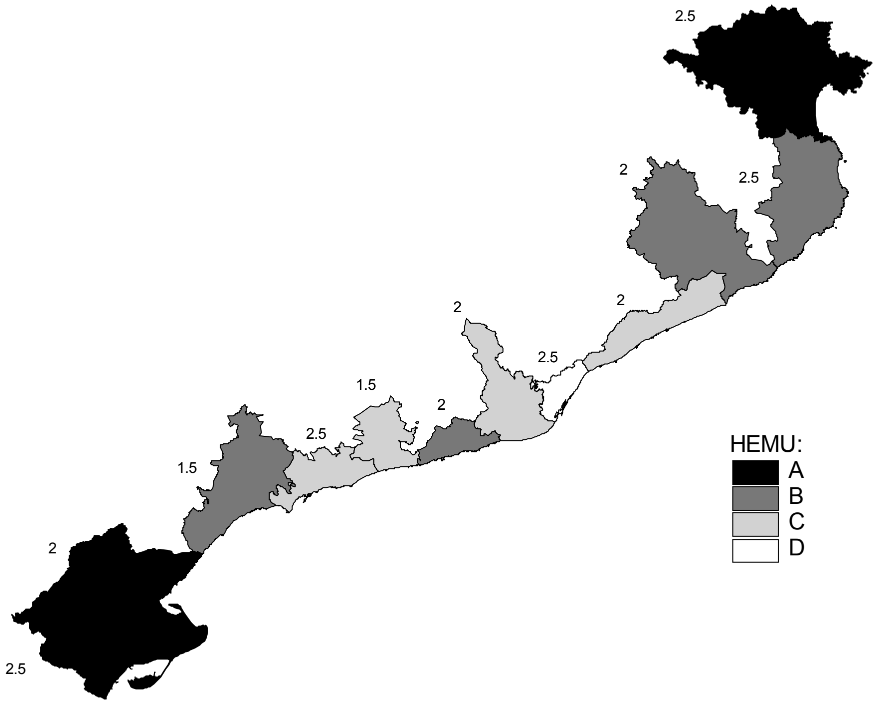

Figure 4.2.3. Homogeneous Environmental Management Units of the Catalan coast. Numbers indicate total socio-economic and natural total richness by unit.

To prevent this, we used an integrative model in which the natural component was combined with the socio-economic 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 regionalisation 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 non-ordinal nominal four-class scheme to avoid misinterpretation of results. The final results indicate units (*comarcas*) with similar socio-economic and natural properties but without showing any priority indication.

The four-class *comarca* map obtained represents a reliable management regionalisation 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 HEMU classify the *comarcas* into highly natural areas (A), semi-natural areas (B), semi-urban areas (C), and areas with high socio-economic development (D). Geographically, each of these classes (units) should be managed under a desired "vision" that fulfils 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 socio-economic values.

Figure 4.2.4 shows the resulting map of HEMU 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.

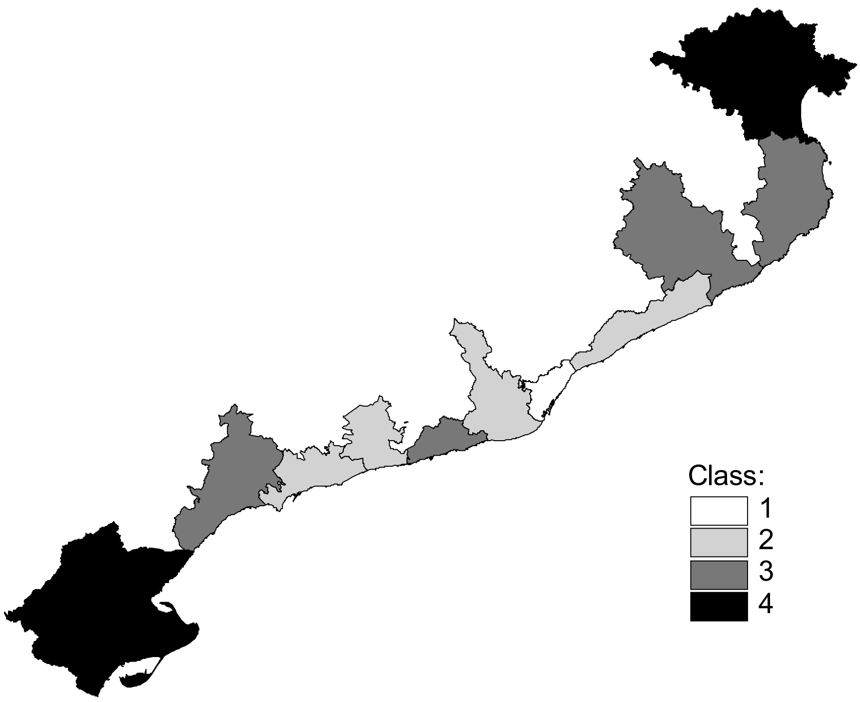

Figure 4.2.4. Conservation HEMU regionalisation scenario of the Catalan coastal.

4.2.5 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 modelling 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 *et al.* 2004), we also found that there is no straight forward system to define an aerial model that efficiently manages the dynamics of the two coastal dimensions studied (Mueller *et al.* 2002). However, in this study we used the mean-based aggregation model proposed by Gornitz (1990), since 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 multi-source database appropriate integration at a sub-national cartographic scale (1:25,000 to 1:50,000), as recommended by UNEP (1995) (see Table 4.2.1). The themes are relevant to most developed and developing coastal zones, and only a few were specific to the coast analysed. 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 socio-economic 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 analysed.

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 socio-economic 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 since data was up-scaled 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 socio-economic components are frequently accompanied by low values for the natural components (see Figure 4.2.2). This also seems to confirm a global tendency in coastal areas for socio-economic 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 socio-economic terms, they were the greatest contributors to the geographic and biological diversity of the Catalan coast. If a river sub-basin 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 socio-economic dimensions have to be integrated in order to characterise 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 socio-economic and natural values of developed coastal areas mentioned above. Thus, two units with different characteristics (one with high socio-economic 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 the components before adding them together and prevented from the socio-economic data interval ranking problems experienced by McLaughlin *et al.* (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 socio-economic and natural values mentioned above.

The bottom-up approach used here provided a data-driven environmental regionalisation of the coast that could not have been obtained with a pre-determined 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 4.2.3 by comparing the difference in HEMU class (four classes) with the total wealth values obtained (almost constant throughout the entire territory). However, HEMU 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 regionalisation developed here (see Figure 4.2.4) 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 socio-economic 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 regionalisation of the Catalonia coastal zone based on HEMU performed here does not correspond to any other existing *comarca*-based regionalisation of the area. Most existing regionalisations 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 regionalisation (DCTC 2002) is based on the major economic driving force for the coastal zone, *i.e.* the tourist industry. In spite of the relative weight of this factor in the socio-economic structure, using it as the only regionalisation parameter for the territory fails to reflect the actual socio-economic and natural variability and complexity of the coastal zone. This generates five regions (Figure 4.2.5) that, despite being currently managed and exploited as homogeneous units, are composed of *comarcas* with dissimilar socio-economic and natural values (Figures 4.2.2 and 4.2.3). The method proposed here to define a multidimensional HEMU-based regionalisation 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.

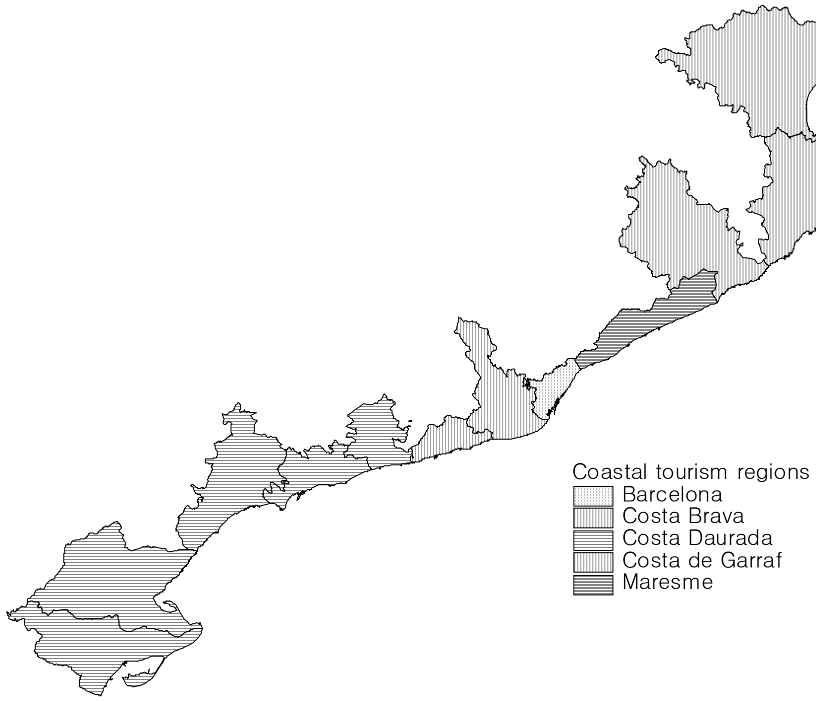

Figure 4.2.5. Touristic regionalisation of the Catalan coast (DCTC 2002).

In summary, the regionalisation process performed here for the Catalan coastal zone generated four different classes of HEMU, for which socio-economic 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 regionalisation 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 multi-component spatial vision of the coastal system. The proposed HEMU regionalisation, 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.