therefore provide ecosystem services (Rapport *et al.* 1998). Accordingly, the capacity of ecosystems to provide services constitutes a relevant measurable proxy of the overall social-ecological system's sustainability. Furthermore, the provision of ecosystem services to humans depends on the flow of healthy ecosystem functions. Spatial analysis is fundamental to ecosystem services valuation because both the production of biophysical functions and social determinants of service benefits depend upon the landscape context in which those functions and services arise (Bockstael 1996).

Joint models of ecosystems and of economic activity have played an important role in environmental policy since the seminal work of Kneese and Bower (1968). Separately, ecology and economics have advanced much faster that the integrated methods necessary for real integrated descriptive and power. The construction of an indicator of provision capacity of ecosystem services would have three fundamental challenges. First, ecological services must be measured in standardized units. Second, given the lack of markets, service's price will have to be obtained via individual preferences. Third, ecosystem services flow depends on biophysical stocks, and thus commonly influenced by human activities.

Other carrying capacity type composite indicators have been used before in ecological and economic sciences as sustainability proxies. The indicator of impact on the environment resulting from consumption developed by Ehrlich and Holdren (1971) is another way of stating the carrying capacity equation for humans that substitutes impact for resource depletion and adds the technology term to cover different living standards. In this approach money affects carrying capacity, but it is too general a term for accurate carrying capacity calculation. The concept of ecological footprint was also developed to examine differential consumption by humans (Rees 1992). By calculating the average consumption of humans over a small area, projections can be made for that type of population's impact on the environment (Wackernagel and Yount 2004). The ecological footprint index is calculated every year on per hectare basis. However, these measures allow the possibility to use resource substitutes through either technology or unfair distribution which is not compatible with nature conservation and thus ecosystem services science as developed in this study.

In the last three decades economic growth has opened new opportunities in Catalonia; however it has also caused a series of negative ecological dysfunctions (Marull 2003). Recently, several local and regional initiatives have demonstrated the regional interest on assessing the environmental value of the coastal zone and its performance towards sustainability (*i.e.* WWF 2000, Vicente 2004, CADS 2005, DMAH 2005b, DMAH 2006b, EEA 2006b, OSE 2006). In parallel, the ecosystem approach guidelines proposed by the Convention on Biological Diversity urge for a novel research that facilitates integration of data from biological, physical, social and economic disciplines into an Ecosystem-Based Management (EBM) schema. The ecosystem approach seeks for a "strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way" (CBD 1999). The approach must be able to incorporate data that span multiple spatiotemporal scales, matching the scale of the science to the scale of the system, and the scales of management to those of natural processes (Hilborn *et al.* 2005).

The objective of this study is to present an integrated ecological and economic value assessment of the economic benefits provided by the Catalan coast natural environment. The study identified valuable ecological predictors that when used in conjunction with human influence predictors would further the accuracy of the economic valuation process by integrating ecosystems' capacity to deliver services. The integrated assessment uses the best available ecological and economic data sources, and analytical techniques to generate value estimates that can be integrated into EBM decision-making in the study area.

4.4.2 Methodological approach

To perform the above mentioned integrated assessment, the Ecosystem Services' Provision Capacity Index (ESPCI) has been developed. This index aggregates information on the ecological value of habitats (positive characteristics) and how they are influenced by humans and their fragility (negative characteristics). This ESPCI will later be used to modulate the economic ESV estimated in previous Section 4.3 and provide an integrated value of the Catalan coast ecosystem services. Due to the lack of adequate information concerning the marine dimension of the coastal zone in Catalonia, this study presents results only for the terrestrial domain of this area. Components of the ESPCI are: (i) Ecological Index, (ii) Human Footprint Index, and (iii) Fragility Index, described below in Figure 4.4.1.

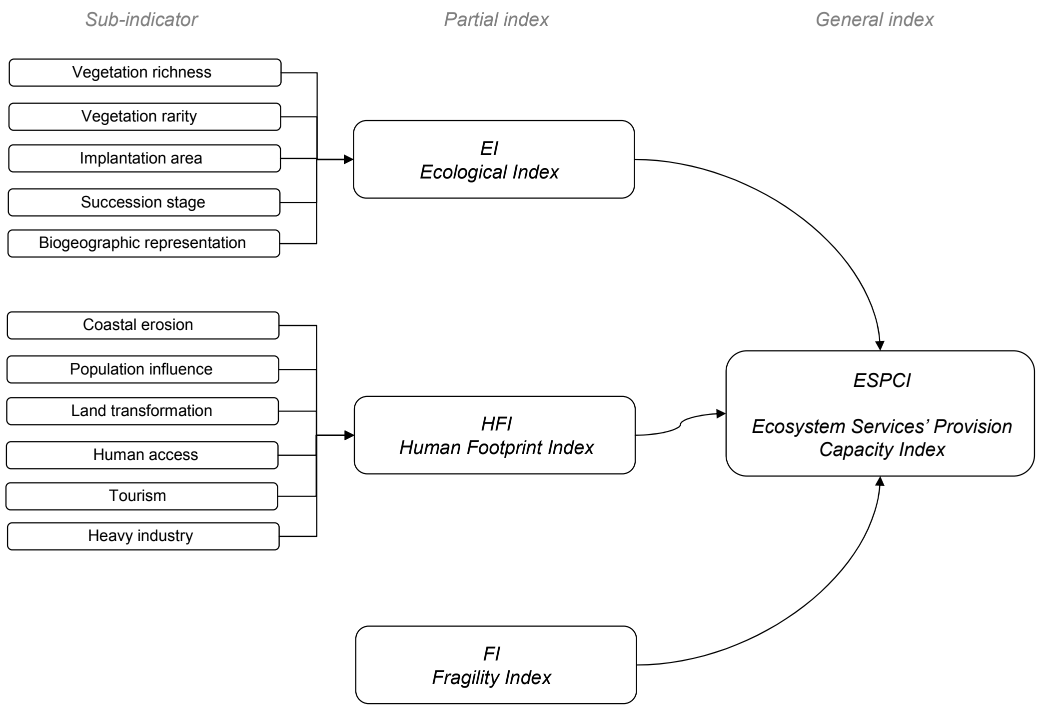


Figure 4.4.1. Elements included in the development of the Ecosystem Services' Provision Capacity Index of the Catalan coast.

4.4.3 Ecological Index (EI)

The EI measures the ecological value of the Catalan coast natural and semi-natural areas. The valuation goal here constitutes the contribution of ecosystems to its services' provision capacity. Thereafter, for the purposes of this section the definition of ecological value of the coast refers as follows: the value of coastal ecosystems without reference to anthropogenic use. This definition is similar to the definition used by Smith and Theberge (1986): the assessment of ecosystem qualities *per se*, regardless of social interests (*i.e.* non-use value). Although by ecosystem qualities the authors of the latter paper covered all levels of biodiversity, from genetic diversity to ecosystem functions. Since habitat constituted the larger flow of ESV provided annually by the Catalan coast (40.9 % estimated in Section 4.3), in this section, ecological values will be assessed at the habitat level which represents the ecological structure that an assemblage that many species use to provide ecosystem services.

The capacity of a given ecosystem to perform functions depends on many environmental characteristics (components and processes). Biological and ecological valuation assessments have been developed primarily for terrestrial species and environments (de Blust *et al.* 1994). However, several international initiatives to select coastal-marine ecological criteria already exist in the literature (see comprehensive discussion on parameter in de Groot 1992, Derous *et al.* submitted). Likewise, relevant ecological criteria needed to develop environmental plans and natural capital conservation has been identified in Catalonia (*i.e.* Mallarach 1999, Germain and Mallarach 2004, Sardá *et al.* 2005, Marull 2005, MMA 2005b, Toldra 2005).

The valuation criteria used were developed based in part on the Natural Heritage Value Index (NHVI) framework developed for future Strategic Environmental Valuation processes in Catalonia (Marull *et al.* 2004). The selected criteria have also significant similarities with other ecological valuation processes of the coastal-marine environment (*i.e.* DFO 2004, Derous *et al.* submitted). The proposed method represents a synthesis of ecological and biogeographically characteristics of the coastal zone. It assumes that vegetation constitutes a good indicator of ecosystems in the terrestrial domain. Thereafter communities and associations are considered as reliable biodiversity proxies (see de Groot 1992 and Marull *et al.* 2004 for an explanation on vascular vegetation as ecological indicator).

As presented in Figure 4.4.1, the ecological value was assessed using a set of five spatial sub-indicators which represent Catalonia coast's ecological relevance, being: vegetation species richness, vegetation rarity, implantation area, succession stage and biogeographic representation. Sub-indicators were chosen on the basis of data availability and their independent capacity to represent main ecological characteristics of the coast. It is expected that this reduced number of variables is capable if predicting the ecological value (Meentemeyer and Box 1987).

To map the sub-indicators, the terrestrial habitats of Catalonia vector GIS layer at a cartographic scale of 1:50,000 was used (DMAH 2006c). The habitats layer which is based on vascular vegetation polygons, was used in this study due to the relevance of vascular vegetation communities in ecosystem functioning and as a first approach to ecosystem dynamics understanding (de Groot 1992, Kiester *et al.* 1996). Each sub-indicator constitutes a vector spatial layer that was transformed into a discrete variable with a four value range for each polygon (1 low, 2 medium, 3 high, 4 very high). Values were extracted directly from the habitat layer and populated the NHVI database and integrated in this study (Marull *et al.* 2004). Ecological properties in the database correspond to analysis conducted between 1998 and 2003.

Sub-indicators of each habitat polygon were summed and re-scaled between one (low value) and 10 (very high value) scores to integrate the EI following the equation:

$$EI = 1 + [\, 9\,(\alpha_i - \alpha_{min}) / (\alpha_{max} - \alpha_{min})\,]$$

where α_i represents the sum of all five values in each habitat polygon and, α_{max} and α_{min} correspond to the minimum (five) and maximum (20) values of the sum respectively. Table 4.4.1 shows a synthesis of discrete sub-indicator values. Relevant information on construction of each sub-indicator is described next. Descriptive statistics of sub-indicators can be reviewed in Annex XI.

Table 4.4.1. Sub-indicators included in the Ecological Index of the Catalan coast.

	Values			
Sub-indicator	**1**	**2**	**3**	**4**
Vegetation richness	< 10 spp	10-20 spp	20-30 spp	> 30 spp
Vegetation rarity	0 spp	1-2 spp	3-7 spp	> 7 spp
Implantation area	> 250 ha	50-250 ha	10-50 ha	< 10 ha
Succession stage	Initial	Low maturity	Interm. maturity	High maturity
Biogeographic representation	Large region	Interm. region	Small region	Endemic

Species richness constitutes a basic indicator of natural areas (Gotelli and Colwell 2001). In this study, species richness was defined as habitats' mean vascular flora species, without integrating the relative frequency of species present. Value discretization has been done by expert knowledge using inventory data from BIOCAT database (http://biodiver.bio.ub.es/biocat/homepage.html) (see Table 4.4.1). Vegetation associations from BIOCAT and the list of species of Catalonia were reconciled with the habitat layer legend. In the case of habitats with only one association, the statistical mode was used as a reliable indicator of association's richness. Species richness for each polygon constitutes the sum of each habitat value weighted by its extent.

Vegetation rarity was used as a modulator of possible negative effects integrated by the lack of species richness specificity (Lyons *et al.* 2005). In this case, rarity was measured as the presence of endemic species and rare communities in the habitats of Catalonia. It was calculated as the maximum value on each habitat polygon. Rare species were obtained from the list of Rare, Threatened and Endemic Plants of Catalonia (Sáez and Soriano 2000). A total of 276 species and subspecies are considered endemic or sub-endemic in Catalonia.

The implantation area indicator, value inversely the mean habitat extent. It suggests that the smaller the area of implantation, the larger the effect of anthropogenic impacts in the association. Values were assigned based on expert knowledge and the mean surface of habitats in each polygon (see Table 4.4.1; Marull *et al.* 2004). The final value assigned to each polygon in the habitat layer corresponds to the maximum of all habitats inside the polygon.

The sub-indicator of ecosystem's succession stage measures the vegetation proximity to its potential climax state or maturity. It was discretized in four levels (1) initial: instable but with high evolutionary capacity (*i.e.* agricultural land, reforested areas, riparian areas), (2) low maturity: areas related to human pressures in general (*i.e.* logging, fires, ranging), (3) intermediate maturity: areas closer to the potential habitat (*i.e.* deciduous forest, secondary pine forest with understory integrated by potential habitat species), and (4) high maturity: composed of a permanent or climax community.

The biogeographic representation values the habitats based on its distribution area's singularity according to Carrillo *et al.* (2003) and Ferré *et al.* (2004). Habitats were classified using expert knowledge and integrated the following criteria (1) its extension, being cosmopolitan habitats of less value; (2) its relationship to biogeographic limits, *i.e.* latitudinal, altitudinal, therefore habitats with restricted distributions and on their limits will be highly valued (*i.e.* Northern limit of Iberian xerantic scrubs), and (3) special situations as littoral habitats. The maximum value of all habitats inside the polygon was assigned to each habitat layer polygon. The biogeographic representation sub-indicator is of particular relevance to biodiversity conservation, since it represents the valuable populations and habitats of a taxon distribution's center at local and regional scales.

A relevant issue related to parameter aggregation in ecological composite indicators is the redundancy between the sub-indicators selected (Andrearsen *et al.* 2001). Bivariate comparisons were performed to EI ordinal sub-indicators using the Kendall's Tau-b statistic; see Table 4.4.2 (Agresti 1984). The largest correlation was found among succession stage and biogeographic representation with an r^2 of 0.502. However, they were considered as independent variables due to the observed capacity to independently value different aspects of the ecological value of the coastal zone (including the spatial representation).

Table 4.4.2. Bivariate comparisons of sub-indicators of the Ecological Index of the Catalan coast. All Kendall's Tau-b correlations were significant ($p < 0.01$).

	Vegetation richness	Vegetation rarity	Implantation area	Succession stage	Biogeographic rep.
Veg. richness					
Veg. rarity	0.086				
Implantation area	-0.103	0.035			
Succession stage	0.289	0.019	-0.419		
Biogeographic rep.	0.367	0.072	-0.366	0.709	

Figure 4.4.2 shows the EI map. The average EI score along the Catalan coast was five ($\sigma = 2$). Higher EI scores (10) were found in natural temperate forest communities due to a combination of biological and biogeographic values; while lowest scores (1) correspond to urban areas, timber plantations and open freshwater flows or water bodies associated to municipal or industrial areas.

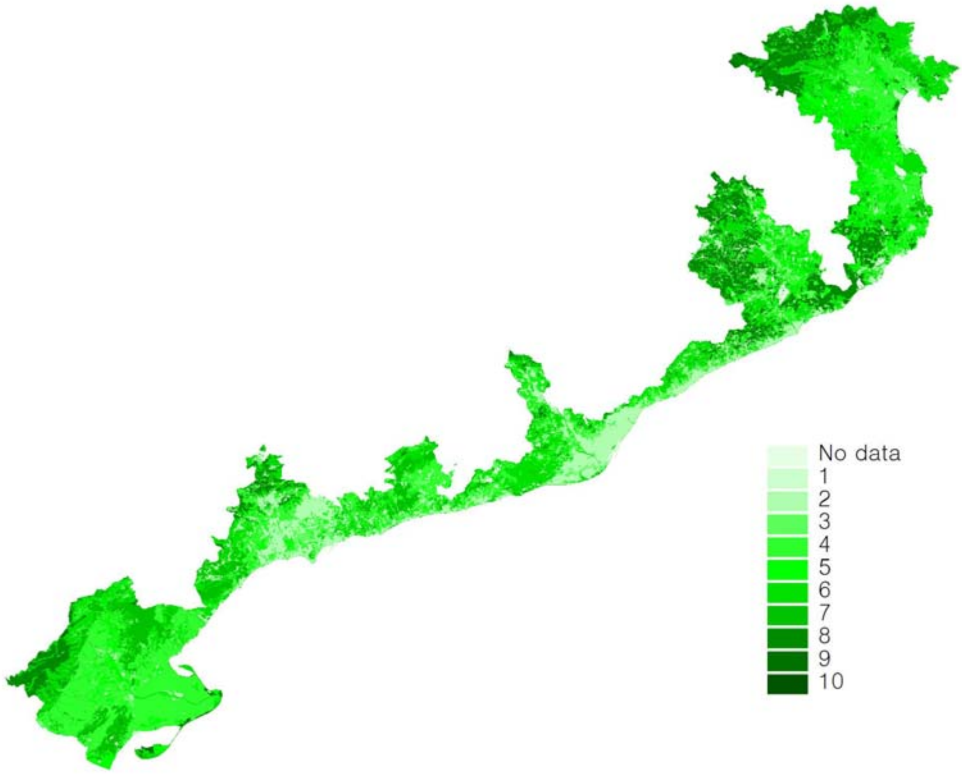


Figure 4.4.2. Distribution of the ecological Index of the Catalan coast. Scale represents higher (10) and lower (1) ecological value.

Figure 4.4.3 shows the relationship between the average EI and ESV of the different land covers of the coast. It was determined from Figure 4.4.3 that land covers with higher EI scores in average were beach or dune (6.1), temperate forest (6.1) and freshwater wetlands (6.0), while lower values were obtained by urban greenspace (2.0) and riparian buffer (2.9). Although both curves share similar patterns, there are differences among land covers with higher and lower scores. Similarities on beach or dune, saltwater wetland and freshwater wetland enhance the relevance of the shoreline of the entire coastal zone from both, the ecology and economics disciplines. Therefore, differences might correspond to those of the essential concepts behind the two valuation methods, *i.e.* value of services provided by nature to us versus *per se* value of nature regardless of any social interests.

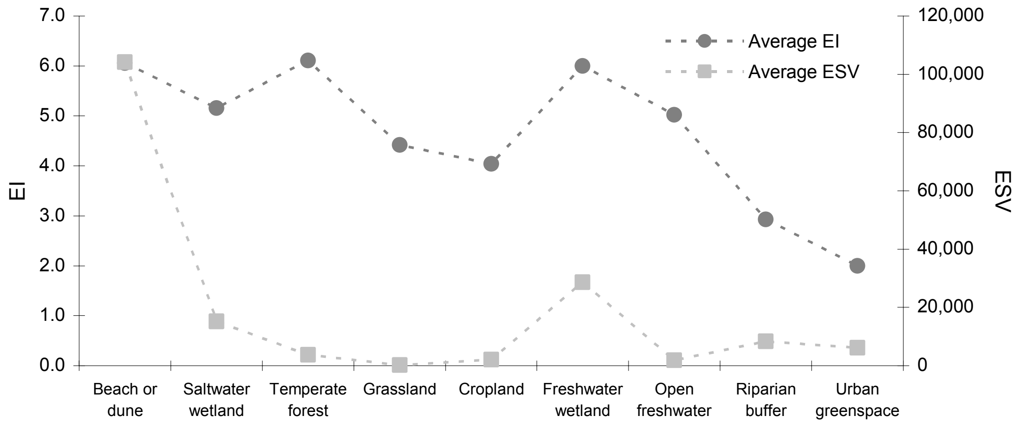


Figure 4.4.3. Average Ecological Index and ecosystem services value flow (2004 USD/ha·yr) by land cover of the Catalan coast.

More complex composite indicators related to the ecosystem services provisioning capacity estimation goal have been reported in the literature (*i.e.* biotic integrity index and habitat suitability index). However, few of them have been widely accepted in ecology (Banzhaf and Boyd 2005). The EI constitutes a composite indicator which has been developed based on ecological characteristics of Catalonia and due to this, it can not be directly applied to other ecoregion or biogeographic region without being adapted. The relative homogeneity of the EI scores compared to those in ESV could be interpreted as the result of the use of EI criteria in this assessment. EI sub-indicators provide a specific view of the non-use value and therefore can be used independently to investigate the particular conditions across areas (*i.e. comarcas*) and land covers (*i.e.* as a complementary analysis to that presented in Figure 4.4.3). The quantitative nature of the EI provides practical advantages in communicating results to managers and technicians, thereafter in coastal zone planning.

4.4.4 Human Footprint Index (HFI)

HFI measures the relative human influence in each land cover of the study area. Changes in the environmental state of the coast are the result of interactions between human and biophysical sub-systems (UNESCO 1997, DMAH 2004, Vafeidis *et al.* 2004). HFI was used in present study due to the relevance of human influence in the Catalan coastal zone (DMAH 2004) and the need to understand its effects in ecosystem services provisioning.

As presented in Figure 4.4.1, human influence was assessed using a set of spatial sub-indicators which represented six Catalan coast's drivers of change: population activities, industrial and energy development, food production, resource extraction, recreational activities, and transportation. Thereafter, sub-indicators of such drivers were chosen on the basis of their independent capacity to represent their influence in natural and semi-natural areas, being: (1) population influence (2005), (2) land transformation (2003), (3) coastal erosion (2004), (4) tourism activities (2003), (5) heavy industry (2004), and (6) human access (1997) (year of data in parenthesis). Similarly to the case of EI, a reduced number of variables is desirable for prediction of the human influence. As a result, this analysis focuses on proxies of population, its activities and infrastructure that have the most immediate impacts on ecosystem services provisioning and for which spatial data were readily available.

Table 4.4.3 shows sub-indicators of human influence used, along with their pressure factor, impact factor and value range. Values were based on pressure factors derived from each selected driver and converted into spatial impact using published scientific studies and consultation with coastal zone experts. Therefore, some variables were considered to be more relevant in terms of influence that others and thus different values were assigned.

Table 4.4.3. Sub-indicators integrated in the Human Influence Index of the Catalan coast.

Driver(s)	Sub-indicator	Pressure factor(s)	Impact factor(s)	Value	Source
Coastal alteration for tourism & protection	Coastal erosion	Confirmed and prob. erosion	100 m	0, 4, 8	1
Change induced by population activities	Population influence	Population density	Municipality	1 to 10	2
Change induced by human uses	Land transformation	Land cover & roads	Land cover / 600 m	0 to 18	3,4
Resources extraction, hunting & disposal	Human access	Rivers, roads & coastline	300 / 600 / 1000 m	0,4	4
Recreational activities	Tourism	Seasonal population	*Comarca*	1 to 3	2
Economic and energy development	Heavy industry	Chemical plant / other	1 / 13 km	0,1,8	5

Source: (1) Eurosion 2005, (2) IDESCAT 2006, (3) DMAH 2006c, (4) DMAH 1997, (5) GenCat 2004.

Coastal erosion is one of the most used (if not the most) variables to characterize the status of the coastal zone from the physical stand point. The main reason is that determines the decrease in available coastal emerged surface that could affect existing uses and resources. In the case of Catalonia a large part of the coastline is experiencing long term erosion mainly due to human-induced factors such as ports that interrupt littoral dynamics and decrease in sediment supply from rivers (Jiménez 1995). In this sense, the Eurosion project (2005) proposed a classification of the European coast according to coast stability and its probability to be eroded. The information compiled in that study was used to characterize the coastline stability in Catalonia. Using a fixed impact factor of 100 m landwards of the coastline, a score of eight was associated to confirmed eroded coast, four to probable eroded coast and zero to prograding or stable coasts.

The number of people is frequently cited as a primary cause of declines in species and ecosystems (Cincotta and Engelman 2000). However, there is little guidance in the literature about how human influence exactly scales with human population density (Forester and Machlis 1996). The consequences of interactions between population density and the environment depend on the nature of the interaction and the particular species, processes and ecosystems in question. In this study a continuum approach was used using municipality data from 2005. In which human influence scores for densities between 1 and 10 persons per hectare increased linearly from 1 to 10 and the score above 10 persons per hectare was maintained constant at 10 as suggested by Sanderson *et al.* (2002). The study assumes that human influence in the coastal zone attributable solely to human population density reaches an asymptote at some level, though at what density that influence even occurs is uncertain. The impact extent was set to the municipality.

Called the single greatest threat to biological diversity, land transformation has resulted in loss and fragmentation of habitat in many different ecosystem types (Vitousek 1997). Human begins transforming land to build settlements, grow food, and produce other economic goods. Different land uses, however, differ in the extent to which they modify ecosystem processes, and affect the quality of habitat for different species (Forman 1995, Goudie 2000). A maximum score of 10 was assigned to built-up areas; lower scores of eight to burned areas, six to cropland, four to beach or dunes and mixed grasslands, and zero to barren areas, forest and all others. Land transformation also includes the direct effects of roads and railways on species and ecosystems. Not all species and ecosystems are equally affected by roads, but overall the presence of roads is highly correlated with changes in species composition, including increases in nonnative invasive species, decreased native species populations through direct and indirect mortality and modification of the hydrological cycle (Trombulak and Frissell 2000). Lalo (1987) estimated that 1 million vertebrates a day are killed on roads in the United States. Likewise, Forman and Deblinger (2000) estimated that the effects of roads in the United States extend over a band approximately of 600 m wide. Thereafter, a buffer of 600 m to each side of roads and railways, and a fixed score of eight were used here.

Roads, major rivers and the coastline provide opportunities for hunting, extracting other resources, polluting, and disruption of natural systems (Gucinski *et al.* 2001). To measure the area affected by human access to natural resources, Sanderson *et al.* (2002) estimated the distance a person can walk in one day in a difficult accessible ecosystem (*i.e.* tropical moist forest), as 15 km. However, due to the larger road coverage in developed countries as the Catalan coast is, this estimate appears to be large enough to cover the entire study area. Therefore, a fixed score of four was assigned to buffers of 300 m for rivers and streams, 600 m for roads and railways and 1000 m for the coastline.

The Catalan coast is dominated by tourist activities (Sardá *et al.* 2005). Although, having a diverse economy, tourism in Catalonia represents one of the most important activities in the coastline and it accounts for 10.8 % of the Gross National Product in Catalonia (DCTC 2002). Therefore, 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. Seasonal population estimates in 2003 were used to determine tourism pressure on *comarcas'* natural environment (IDESCAT 2006). Three classes of seasonal population were used to represent its pressure and scores of one (less seasonal population) to three (larger) were assigned accordingly to each *comarca*.

Chemical and other transformation heavy industry poles constitute a major pressure factor along coastal natural environment (*i.e.* energy plants, oil refineries). Impacts from these economic development activities are derived from a variety of emissions, wastes disposal, and ultimately from the landscape transformation they originate. Although emissions are commonly quantified on environmental accounting and impact studies, pressure over surrounding natural areas is normally not monitored, nor mitigated (Power *et al.* 2006). In Catalonia, using the Chemical Industry of Tarragona Emergency Plan approved by the Generalitat, it was estimates that maximum impact could extent over an area of 13 km around the plants (GenCat 2004). Although, this is considered to be a very conservative estimate no other impact data was found for the study area. Thereafter, due to more constant pressures on areas closer to the plants a score of eight was assigned to an impact buffer of one kilometre from main industrial areas along the coastal zone. Similarly a score of one was assigned to less frequent impacted areas within a butter pf 13 km from industrial areas. Although in the case of a nuclear event from the Vandellos II plant near Tarragona a much larger catastrophic effect at a global scale would take place, due to the difficulty to estimate these impacts in an objective way, only its normal functioning impacts were taken into account in this study (*i.e.* water cooling).

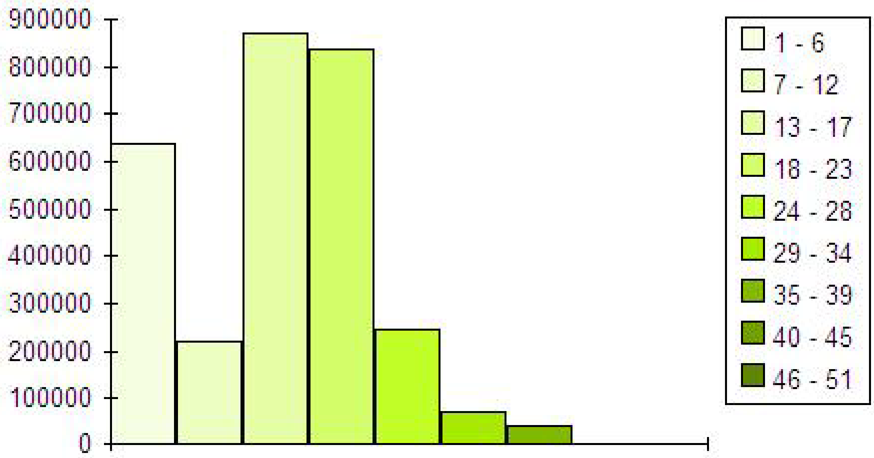
Spatial datasets of the study area were combined in the GIS to integrate the influence sub-indicators, following: (1) geographic projection standardization to UTM 31 and European Datum 1950, (2) converting them as overlying grids at a square cell resolution of 50 x 50 m, and (3) attributing each sub-indicator dataset into values that reflect their estimated contribution to human influence using an ordinal scale (being zero lowest influence). The quality-control scheme was based on the following criteria: (1) a 1:50,000 sub-national cartographic scale or larger, (2) whether the source was official (confirmed sources) or not, and (3) data update criteria (recent). Descriptive statistics of sub-indicators can be reviewed in Annex XII.

Human influence scores for each sub-indicator were summed in each cell to create the Human Influence Index (HII) in the GIS, as preliminary step in calculating the HFI. The HII constitutes a direct aggregation of human influence in each land cover of the study area and have a maximum score of 51 and a minimum score of one. Table 4.4.4 shows the redundancy analysis conducted to the influence sub-indicators using the Kendall's Tau-b statistic. All bivariate comparisons resulted statistical significant and below a 50 % of variance explanation. This result was expected due to conceptual differences in selected proxies and large number of cells on grids. The largest correlation among sub-indicators was found between the access and land transformation (r^2 = 0.483). This result was expected beause parameters in land transformation sub-indicator includes roads and railways influence.

Table 4.4.4. Bivariate comparisons of sub-indicators of the Human Influence Index of the Catalan coast. All Kendall's Tau-b correlations were significant ($p < 0.001$).

	Tourism	Land transf.	Pop. inf.	Access	Heavy ind.	Erosion
Tourism						
Land transformation	0.080					
Population influence	-0.057	0.284				
Access	0.044	0.695	0.226			
Heavy industry	0.150	0.203	0.375	0.123		
Erosion	-0.020	0.019	0.059	0.033	0.024	

An average HII of 14.5 (σ = 8.3), maximum (51) and a minimum of one (1) were reported in the Catalan coast. Thereafter, the entire Catalan coast was found to be subject of human influence to some extent. From HII histogram in Figure 4.4.4 can be interpreted that most cells in the grid were part of the 13 to 23 score classes which are part of the lower influence side of the graph. Furthermore, a large number of cells were within the 1 to 6 score class were influence is at its lowest level. Annex XIII shows the summary of the Human Influence Index scores by ecosystem and dimension. As expected, largest influences were reported on the urban (average = 27.9 and overall maximum score = 51) and urban greenspace (average = 23.6) land covers. While lowest average score corresponded to temperate forest (9.2). Therefore, due to land cover surface representation in the coastal zone, higher influenced areas correspond to 8.7 % (urban, burned, barren and mining), while 37.6 % to the less influenced areas (forest).



Note: last two class groups (40-45 & 46-51) are not shown due to scale.

Figure 4.4.4. Histogram of Human Influence Index of the Catalan coast.

The HII, like the GLOBIO methodology (UNEP 2001), treats the land surface as if it were a blank slate on which human influence is written. However, since this is not the case, the distribution of major ecosystems modifies the biological outcomes of human influence (Chapin *et al.* 2000). For example, an absolute value of 40 in urban greenspace has a definitively different effect, and biological context, in coastal wetlands. Similarly to Sanderson *et al.* (2002) and since this study is interested in understanding the interaction between human influence and the natural environment in the coastal zone, HII values were normalized within land covers in the Catalan coast. As a result, a zero score was assigned to the grid cell with minimum HII value in each land cover and a score of 100 to the cell with maximum value. This method stretches the intermediate values linearly between those extremes. The result is the HFI which expresses as a percentage the relative human influence in every land cover of the Catalan coastal zone. Therefore, a score of 10 in a coastal wetland indicates that the grid cell is part of the 10 % least influenced or wildest are in its land cover, although the absolute influence value may be quite different. Due to this, the HFI comprises a relevant biodiversity conservation tool to identify those areas were protection actions could have the higher impact on the coastal zone (Sanderson *et al.* 2002).

Average HFI score was 41 (σ = 8.0). Although urban and urban greenspace accounted for a score of 49, beach or dunes obtained the largest footprint score, 50 (both followed closely by freshwater wetlands = 48). This can be the result of the urban and tourist development that the Catalan coast has been subject in the last three decades (Marull 2003). In fact there is considerable variation in levels of mean human influence and mean HII between land covers, as shown in Figure 4.4.5. More evident difference corresponds to cropland among the coast.

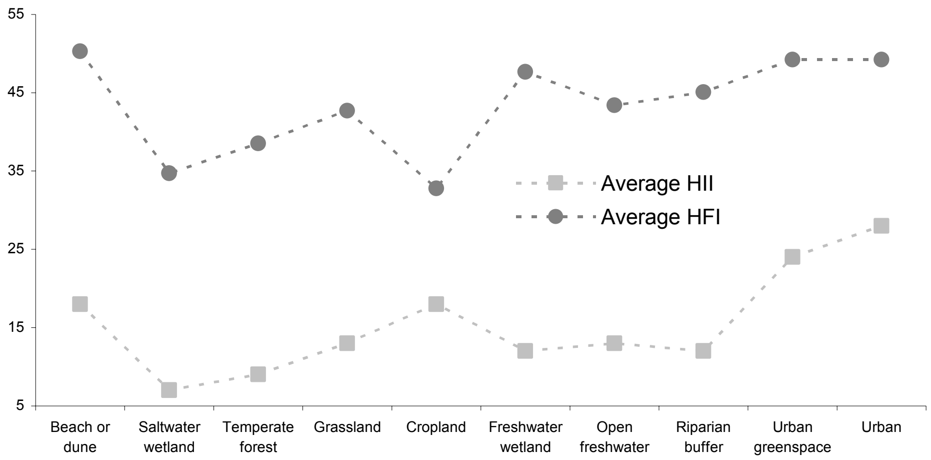


Figure 4.4.5. Average Human Influence Index and Human Footprint Index by land cover of the Catalan coast.

Figure 4.4.6 shows the resulting HFI map. The map constitutes the spatial distribution of less and higher influenced coastal ecosystems by human activities and infrastructure. The map clearly shows that areas closer to the shoreline are subject of higher human footprint, while those in the hinterland are more natural. Similarly, map shows that HFI keeps a fare relationship with higher developed and less natural HEMU. It can be interpreted in general, that the Barcelona area represents the larger human footprint along the coast (including metropolitan area of the Baix Llobregat *comarca*). To some extent the HFI also represents artificial versus natural areas, since it is based on man-made infrastructure as cities, industrial areas, roads, etc. This characteristic is also relevant when the identification of wildest areas for conservation purposes is the goal.

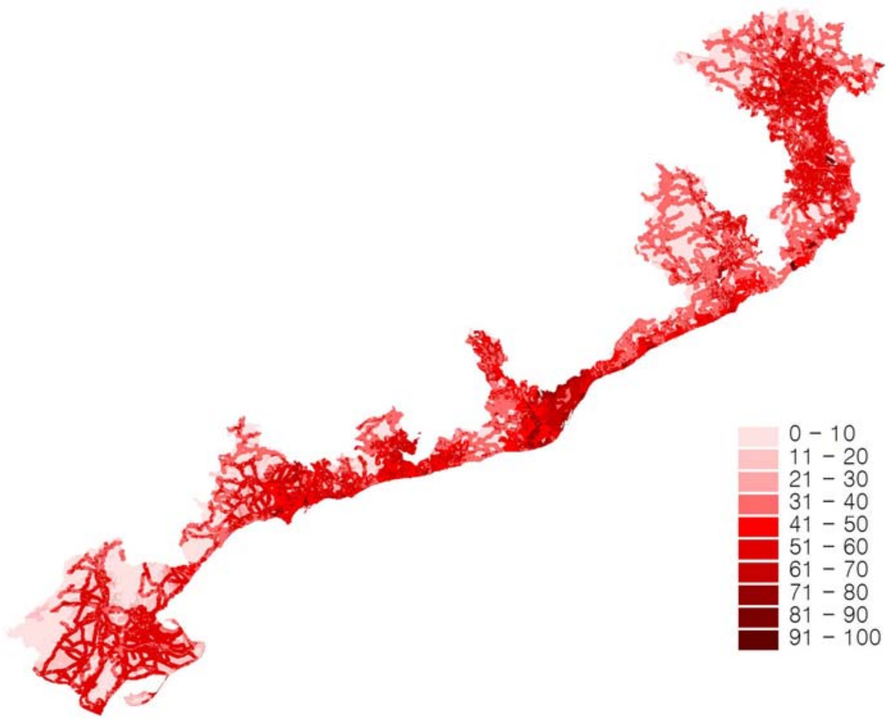


Figure 4.4.6. Distribution of the Human Footprint Index of the Catalan coast. Scale represents higher (100) and lower (0) human influence as percentage.

This geography of human influence represents roughly the inverse of the geography of natural processes and patterns in the Catalan coast. Given what we know about the effects of the input factors on nature, we expect that where human influence is highest, ecosystems will be most modified and species under the most pressure from human activity. Where the human footprint scores are lower, we expect more intact and functional natural communities. The exact consequences of human influence in any given location are complicated, however, and depend of the history of the place, the types of the current influence, and the parts of nature that we are concerned with (Redford and Richter 1999).

4.4.5 Fragility Index (FI)

FI represents the vascular vegetation sensitivity to land cover change in Catalonia. The concept as used here is opposed to stability and could be used as a proxy for integrated vulnerability, due to the relatedness of ecosystem's structure constituents, *i.e.* soil and vegetation. FI values have been extracted from the NHVI database. According to Marull *et al.* (2004) have been determined using land cover simulations based on four aspects related to ecosystems, (1) disappearance probability due to landscape change, (2) ecological resilience, (3) disappearance due to habitat dependence on specific ecological conditions, and (4) extreme events in Catalonia. FI values are associated to the habitat layer and were transformed into a discrete variable with a four value range for each polygon (1 low, 2 medium, 3 high, 4 very high). Similarly to data that integrates the EI, fragility data correspond to analysis conducted between 1998 and 2003.

Figure 4.4.7 represents the spatial distribution of ecological fragility across ecosystems in the coastal zone. High scores in map reflect that there is a combination of productivity and structure properties but no resilience in ecosystems. Resilience is enhanced by nature variation and prevents systems from reaching a brittle state (Rapport *et al.* 1998). Fragile habitats are associated to urban and infrastructure development in the Catalan coast. Thereafter, areas associated to high fragility scores constitute those with higher probabilities to suffer severe degradation or even disappear due to land transformation processes.

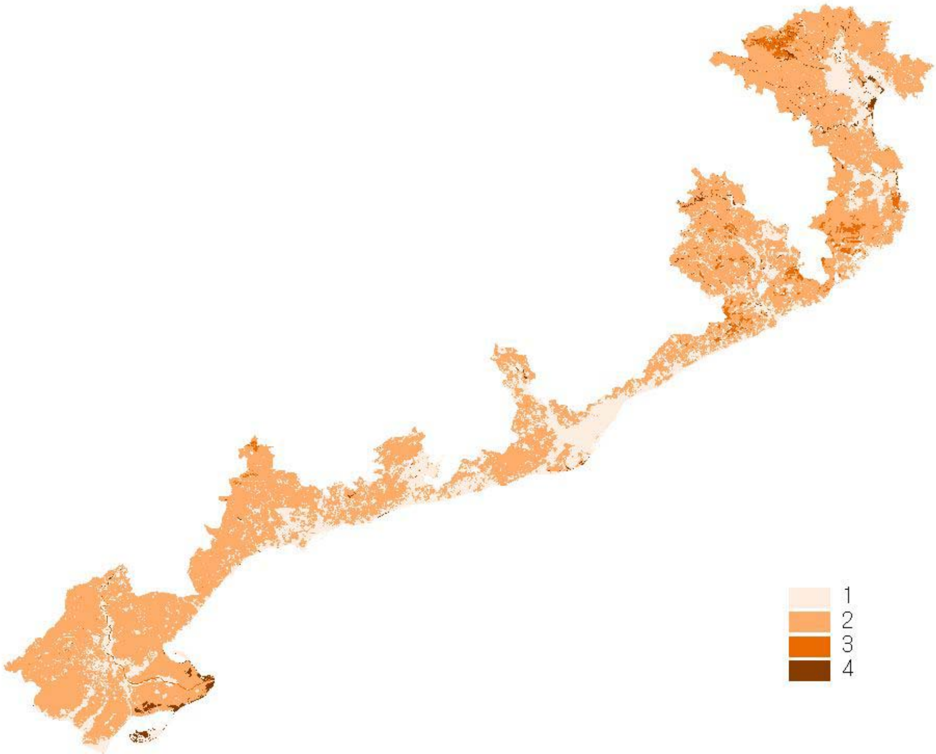


Figure 4.4.7. Distribution of the Fragility Index of the Catalan coast. Scale represents higher (4) and lower (1) fragility values.

Average FI along the study area equals 1.7. Although fragility in this study was estimated using vegetation associations, it was assumed that being the matrix for most ecosystem processes fragile vegetation lead to unhealthy habitats with low capacity to provide services at the ecosystem level. Patterns interpreted from Figure 4.4.8 show that in general littoral-related ecosystems account for higher fragility (*i.e.* freshwater wetlands, 4; saltwater wetlands, 3.1; and beaches or dunes, 1.9), while terrestrial ones were found to have lower scores. The lower score of open freshwater systems is considered to be the effect of accounting water bodies and flow's vegetation into riparian systems and not into them itself (see a description of methods used in Marull *et al.* 2004).

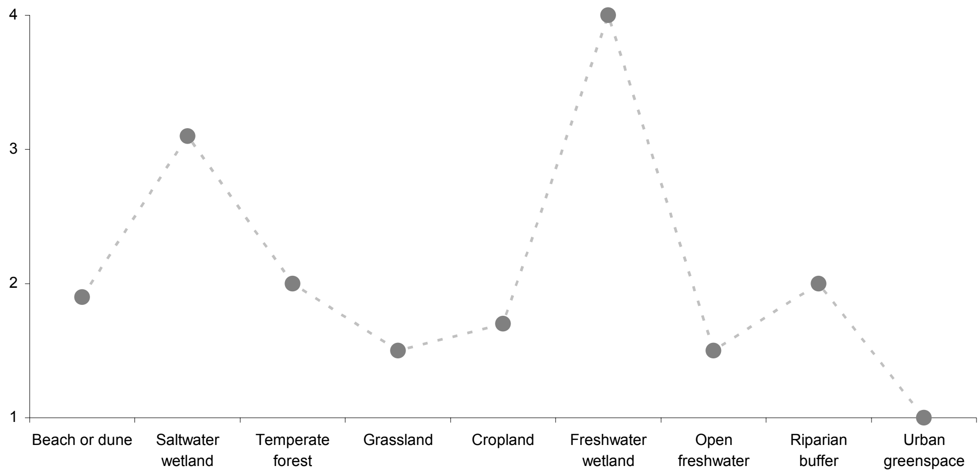


Figure 4.4.8. Average Fragility Index by land cover of the Catalan coast.

4.4.6 Ecosystem Services' Provision Capacity Index (ESPCI)

The provision of ecosystem services to humans depends on the flow of healthy ecosystem functions (Rapport *et al.* 1998). However, the lack of clear understanding of how the functioning of an ecosystem translates into a flow of ecosystem services from that ecosystem is a serious obstacle (de Groot 2002). Therefore the estimation of the capacity of ecosystems to provide its services is not straight forward, and ideally measurements should integrate thresholds to different feedbacks and minimum extent to support functions of each relevant function and service. Consequently, a methodology to determine ecosystem services' provision capacity has not been found in the literature.

Ecosystem functioning is influenced by both environmental and human-originated feedbacks. In this study, predictors of the health of ecosystem functioning will be used to estimate its provisioning capacity, and thus incorporate the SES dynamics and feedbacks. Since ESV estimated in Section 4.3 has been obtained entirely based on human preferences (using basically CV), ESPCI will influence ecosystem services value by merging ecology and economics in an integrated valuation. Predictors in Figure 4.4.1 were integrated into the ESPCI following the next equation which is divided in two main groups:

$$ESPCI = EI - (HFI \cdot FI)$$

The first group corresponds to the *per se* value of ecosystems and is represented by the Ecological Index which is expected to enhance functioning and thus ESV flow. Alternatively, the second group corresponds to the combined measurement of the Human Footprint Index and the ecological Fragility Index of ecosystems, which is expected to limit ecosystems' efficiency and thus reduce ESV flow. Together the two groups constitute in a mathematical practical way the integration of two relevant views that determine the provisioning of ecosystem services and that are not commonly integrated into the valuation processes. Furthermore, the assessed state of the selected components is what will be proposed to predict the sustainability of the coastal SES.

Individual indexes were mapped in the GIS using the terrestrial habitats of Catalonia (DMAH 2006c). The HFI (0 to 100 scores) and FI (1 to 4) indexes of each habitat polygon were linearly aggregated and re-scaled between 0 (lowest fragility and influence) and 10 (highest fragility and influence) scale using the same equation to calculate the EI (see Section 4.4.3). The resulting scores were then subtracted to the EI (1 to 10 scores) and represented in final -9 to 10 scores. The scale represents positive and negative service provisioning fluctuations of coastal ecosystems in Catalonia. Thus, fluctuations constitute the result of properties increasing and decreasing ESV flow. In the absence of human influence ESV flow is linearly increased by its EI. However in presence of influence, it will be reduced by the combined effect of FI and HFI on its EI.

A minimum value has been imposed to avoid the existence of a zero value to any piece of the territory because it was assumed that even the most degraded area will play a residual role in ecosystem functioning. This residual value has been set equal to the 10 % (arbitrary) of the habitat with lowest ESV. Since the lowest value corresponded to grassland with an ESV of \$ 230 USD/yr the residual value in this study was \$ 23 USD/yr. This is based in the assumption that the information available at a cartographic scale of 1:50,000 do not provide an adequate level of analysis, and thus a minimum capacity of 10 % was assigned. Therefore ESPCI was calculated as follows:

if $EI - (HFI \cdot FI) \geq 0$ then $ESPCI = 1 + [(EI - (HFI \cdot FI)) / 10]$

if $EI - (HFI \cdot FI) < 0$ then

$$Rv = 0.1 \cdot ESV_{min}$$

$$\beta = 1 - (Rv / ESV)$$

$$ESPCI = 1 + [((EI - (HFI \cdot FI)) / 10) \cdot (\beta / 0.9)]$$

where, Rv = residual value, ESV_{min} = land cover with lowest ESV in USD/yr calculated in Section 4.3, β = negative slope, ESV = ecosystem services value in USD/yr calculated in Section 4.3.

Figure 4.4.9 shows that if index product (aggregation) is positive or zero then it constitutes ESPCI directly. In contrary, if index product is negative then ESPCI is a function of the negative slope of residual value. Figure shows how direct aggregation method recalculates value in a linear way and ESPCI scores increment habitat value linearly up to the double (100 %).

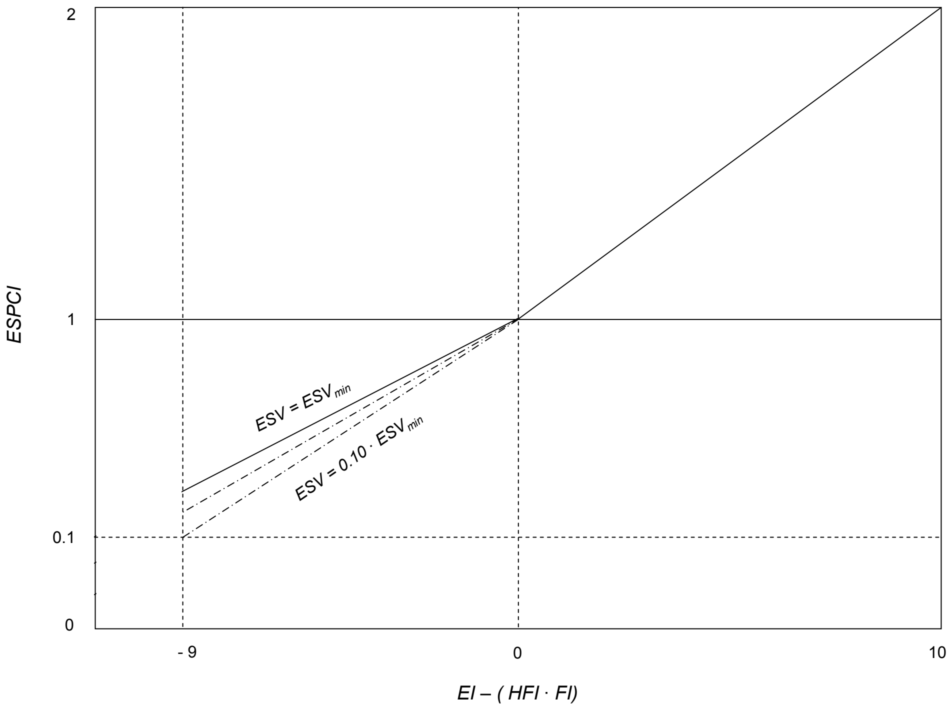


Figure 4.4.9. Calculation of the Ecosystem Services' Provision Capacity Index.

Catalan coast's ESV flow following an efficient allocation goal has been calculated in previous Section 4.3. The estimated ESV flow of 3.2 billion USD/ha·yr was based on stated-preferences by humans and followed a value transfer approach. In this section, ESV flow estimate will be based on an integrated ecological and economic approach and pursuing the same valuation goal. Thereafter, integrated flow value was calculated as a linear function of the ecosystem's capacity to provide services, as follows:

I-ESV flow = ESV flow · ESPCI

where, I-ESV = integrated ESV flow in USD/ha·yr, ESV = ESV flow in USD/ha·yr calculated in Section 4.3.

4.4.7 Application of the ESPCI

In Section 4.3, preference-based ESV was attached to specific land covers, while in this new integrated approach the flow of ESV was considered a function of ecological properties and human influence of ecosystem's infrastructure that provide services. Therefore, ecological characteristics (EI) and human influence (HFI & FI) on ecosystems were included in the ESPCI, which represents the capacity of ecosystems to provide a flow of ecosystem services. Therefore, the capacity to supply services by a given ecosystem depends on the relationship between its properties and the indirect environmental state of such, measured by the human influence.

Similar to the carrying capacity concept used in ecology and economics, the ESPCI represents the services' supply level not only given the productivity, but its efficiency and resilience (*i.e.* measured by communities' richness, ecological maturity, fragility). In the other hand, ESPCI constitutes a range of provision levels that increases or decreases stated-preference value. Thereafter, ecosystem's value increases by having more and rare species and being in a mature stage; and decreases by having a larger fragility and human footprint (*i.e.* closer to the coast, roads and to urban areas). Zero ESPCI score represents no change in value. Frequently valuable ecological properties measured and the negative influence provided by humans resulted in a zero score, meaning that healthy ecosystems' properties (*i.e. per se* value) provide essential life infrastructure to maintain functions even in the event of a similar magnitude human influence.

Due to its spatially explicit nature ESPCI can be assessed at practically any desired ecological or management unit, while carrying capacity type indicators tend to average the ability to sustain a population either at larger ecoregions or at national basis. Furthermore, carrying capacity type indicators integrate the possibility to use resource substitutes through either technology or unfair distribution, *i.e.* in Catalonia with an ecological footprint of 3.9 hectares per person exceeds 8.2 times its total surface (CADS 2005); while the flow of ecosystem services has no market price and there will therefore be no price signal to policy makers that substitutes are needed before total depletion. Although a measurement of flow sustainability was considered initially in this work, the resulting measurement constitutes a conservative estimate of such capacity due to the data available for the analysis.

The map in Figure 4.4.10 represents the distribution of habitats' capacity to provide a flow of ecosystem services. Map shows that larger areas with higher provisioning capacity are in the hinterland of the Catalan coast. Similarly, distribution shows that those areas are associated to more natural spaces and not close to urban or impervious zones. In general, Barcelona metropolitan area, Tarragona and littoral areas, account for lower provisioning capacity that the rest of the studied area. This was found especially relevant with scores around zero, since intermediate scores represent more complex combinations of parameters. Scores at the extremes of the scale represent basically peak contributions of either EI or HFI. However, in order to develop a comprehensive integrated valuation of ecosystem services in the Catalan coast, this gap is recommended to be filled.

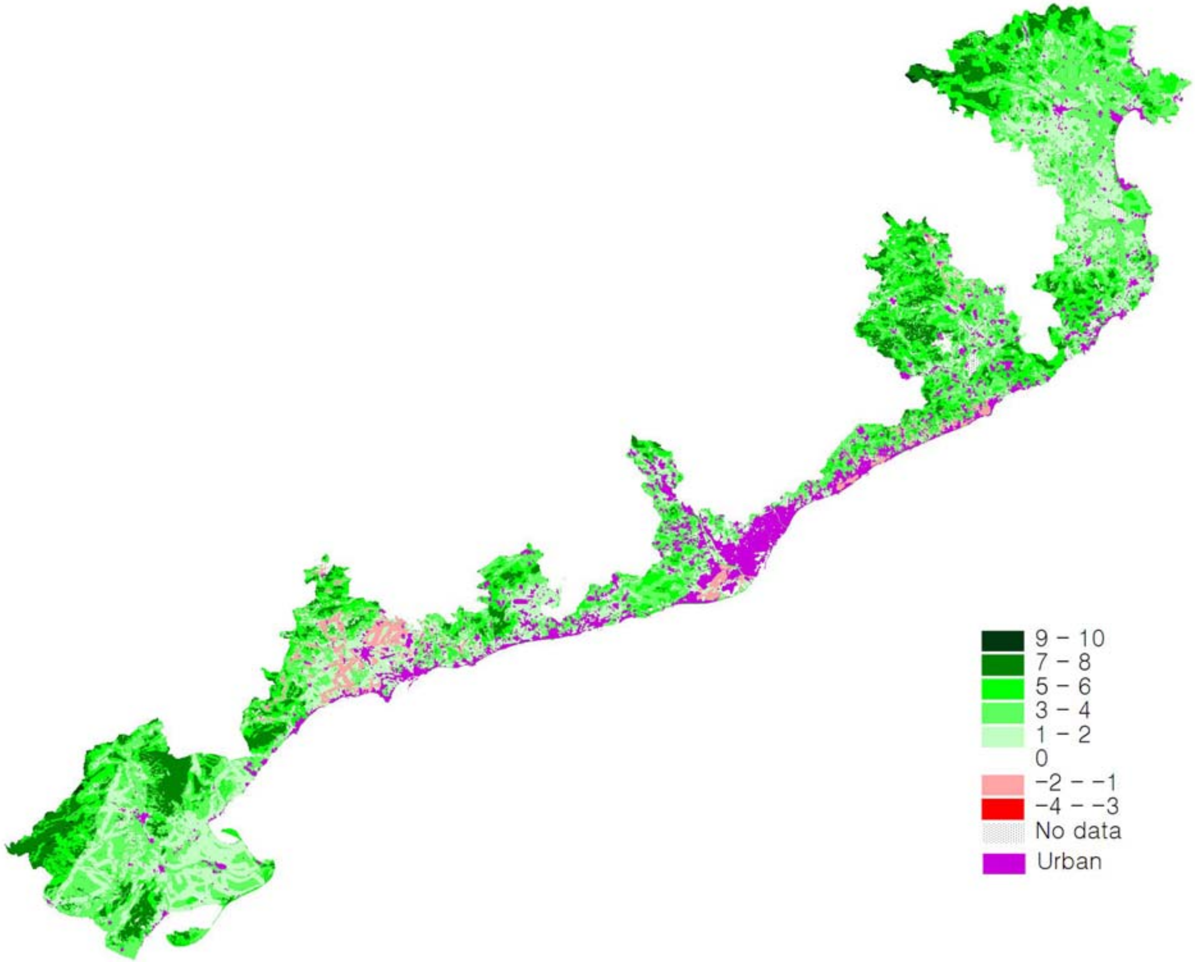


Figure 4.4.10. Distribution of the Ecosystem Services' Provisioning Capacity Index of the Catalan coast. Scale represents positive-higher (10) and negative-lower (-4) provisioning capacity of ecosystems. Urban areas were not assessed.

All land covers had positive mean values (Figure 4.4.11), with an average capacity of 2.50 (σ = 1.50). This represents that ecosystems in the Catalan coast maintains a positive capacity to deliver services to citizens. Highest score was obtained in barren areas (6.26) which constitute coastal cliffs and rocky mountainous areas. However, it was not included in the integrated valuation since no stated-preference value of its ecosystem services was available. Larger average provisioning capacities greater than four were found in beaches and dunes (4.23), temperate forest (4.16) and open freshwater (4.07); while the minimum values were associated to freshwater wetlands (1.15), urban greenspaces (0.70) and riparian buffers (0.38).

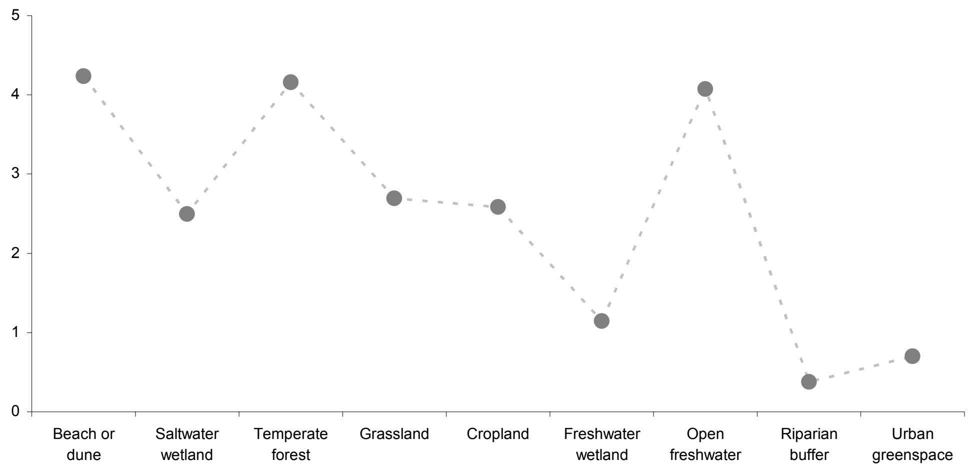


Figure 4.4.11. Average Ecosystem Services' Provisioning Capacity Index by land cover of the Catalan coast.

Although highly human-influenced by humans beaches constitute the land cover with highest provisioning capacity (max. = 7, min. = -4, σ = 1), due to the combination of the highest ecological value (6.1) and relative low fragility (see Figure 4.4.8). Due to the interface nature of the shoreline in the coastal zone, the resulting high provisioning capacity of beaches and dunes becomes relevant in maintaining vital services that support humans in this area (*i.e.* living and transportation infrastructure, recreational activities, among others). Opposite, low ESPCI scores from saltwater (2.50) and freshwater wetlands (1.15) are the result of high fragility which increments the effect of human footprint, especially in the large wetlands of the Baix Ebre and Montsià *comarcas*. Less evident constitute the low average score of riparian buffer that might be the effect of miss representation of its ecological value in the habitat's database (see Figure 4.4.3).

Similarly to sub-indexes that integrate the ESPCI, this geography of capacity to provide ecosystem services represents that of natural processes and patterns in the Catalan coast. Therefore, an analysis of such functioning patterns lead to the understanding of the ability to provide services by ecosystems (de Groot 2006). Given what we know about ecosystem structure and functioning, we expect that where supply capacity is highest ecosystem services value will be higher than estimated using stated human preferences. Consequently, where supply capacity scores are lower we expect flow value will be lower due to reduced natural infrastructure to support essential ecological processes. The exact consequences of the three studied components on the capacity to provide services by a given ecosystem cannot be determined at this geographical scale and will depend on local measurements of productivity, efficiency and resilience properties (Costanza *et al.* 2006). If this is the case EI, HII and thus HFI can be constructed using specific local ecological properties and human pressures at larger cartographic scales (*i.e.* 1:5,000 to 1:25,000), if available. Moreover, ecosystem health proxies such as structure (organization) and resilience can be incorporated into the ecological index as they relate to ecosystem functioning, and land transformation dynamic models (*i.e.* Costanza *et al.* 2002) to identify threats and how they influence in ecosystem services provisioning capacity.

It has been argued that conserving biodiversity is necessary for maintaining ecosystem functioning (see Section 3.2.2). Literature reflects that there is substantial evidence that diversity is able to affect function in the ecological network of interrelations, particularly for plant communities due to their role as carries of ecological functions in the ecosystem (*e.g.* Loreau *et al.* 2002, Srivastava and Vellend 2005). Therefore, it can be also interpreted that biodiversity acts against underprovision of ecosystem services (see Figure 4.4.11; *i.e.* control of water run-off by forest and wetlands, control of pests and diseases by biodiversity, protection of storm effects by shoreline in the Catalan coast). Consequently it can be said that biodiversity has an insurance value, which represents an additional component to those values used here, *i.e.* non-use. This insurance value should be taken into account when deciding upon how much to invest into biodiversity conservation (Baumgartner in press). Additionally, Chan *et al.* (2006) proposed that conservation strategies should also reflect the understanding of spatial and temporal relevance of physical landscapes. Therefore beaches and dunes would be highly valuable due to their unique supportive and regulating services that make life possible along the coastline.

Natural processes representation through ESPCI provides a unique opportunity to guide conservation efforts in the Catalan coast. Newest version of the Plan of the Spaces of Natural Interest in Catalonia (PEIN) integrates the most representative natural areas in Catalonia (DMAH 2006a). Natural areas have been included in the PEIN based on their regional biodiversity and landscape relevance; as well larger national parks (*e.g.* Ebro River delta). Moreover, areas included in the PEIN constitute a network of conservation elements that complement a regional strategy along Catalonia, which are managed individually (*i.e.* management plans) and as a whole (*e.g.* indicator system developed by Germain and Mallarach 2004). PEIN network ecosystem services provisioning capacity was investigated in order to determine network's contribution to maintain functional landscapes in the coast.

Fifty two PEIN areas are included totally or partially in the study area. Protected area inside coastal *comarcas* represents 23.4 % (171,293 ha). These areas have an average ecological value of 5.7, an average human footprint of 37 and an average fragility of 2 (see Annex XIV for individual area estimates). Results show that with an average 3.7 ESPCI PEIN areas contribute to a 25.8 % of total preference-based ESV flow in the study area (estimated in Section 4.3). However, if compared to integrated ESV flow its contribution represents 37.5 % of total terrestrial value. Therefore, PEIN network constitutes a relevant ecosystem conservation mechanism which is responsible for more than one fourth of total services valued by citizens. In the other hand, 62.5 % of value is provided by unprotected areas that correspond to 66.7 % of coastal *comarcas* (not including urban areas). Figure 4.4.12 shows the distribution of PEIN areas and its average ESPCI. Among the 52 areas only the Gaià River mouth area accounted for a negative provision capacity. Gaià River mouth area is located near Tarragona and between two large urban areas which leaded to the largest HFI score. Spatial pattern shows that although areas near coastline account for relevant provision capacity, those with larger capacity tend to be in the hinterland of the coastal zone. Heal *et al.* (2001) proposed that the identification and establishment of ecosystem services districts will improve significantly the efficiency of provision necessary for human well-being. Thereafter, due to their present conservation status PEIN areas constitute seed sites in the development of such districts, whose role in the provision of services should be taken seriously into account in future coastal sustainability strategies and plans.

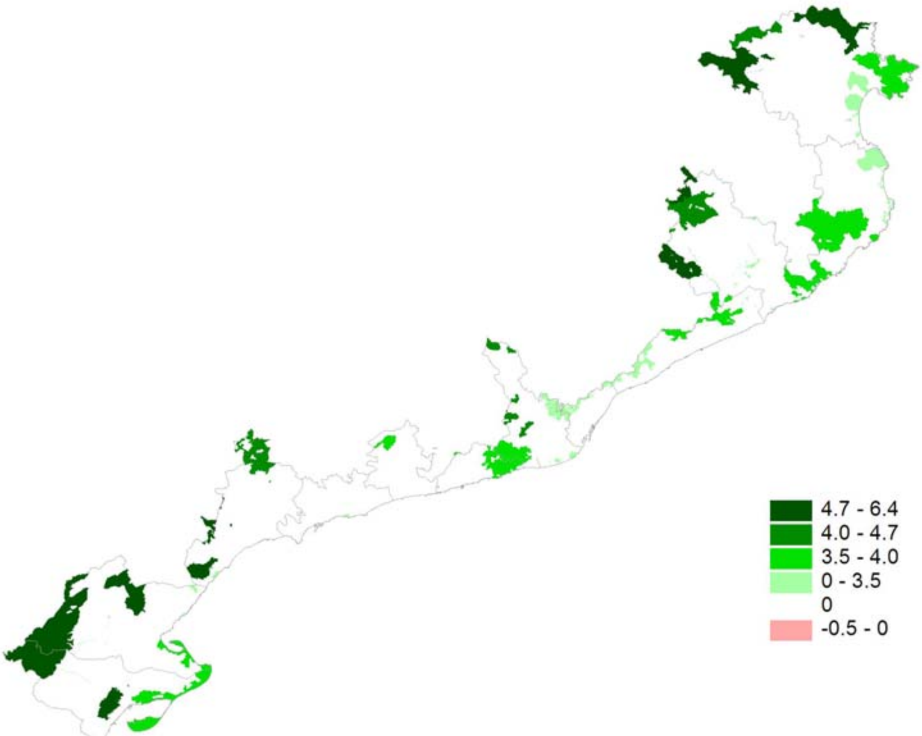


Figure 4.4.12. Average ecosystem services provisioning capacity by PEIN area in the Catalan coast.

Complementarily to PEIN areas the less influenced areas along the coastal zone were analyzed. It follows that from mapping the human footprint that it is also possible to map the least influenced areas in each land cover. There are many ways of using the human influence and/or human footprint to define areas of interest for conservation depending on specific conservation goals (see Sanderson *et al.* 2002 for a more detailed description on assessing the last of the wild areas for conservation purposes). In present study, wildest areas were described as the 10 % least influenced areas, *i.e.* 10 % cutoff on the HII. Although an arbitrary threshold, these relative intact and undisturbed ecosystems were considered of particularly important for conserving biodiversity in the Catalan coast. Results show that the last of the wild add an additional 8 % (73,947 ha) surface to that of PEIN areas (map in Annex XV shows the 10 % last of the wild distribution). If those areas were conserved then these resulting ecosystem services districts will improve significantly the efficiency of provision necessary for human well-being (Heal *et al.* 2001).

The map in Figure 4.4.13 shows the average ecosystem services' provisioning capacity by *comarca* of the Catalan coast. The distribution of estimated ESPCI, in general, follows that of HEMU along the coastal zone. Alt Empordà and Baix Ebre accounted for higher provisioning capacities; while as expected Barcelonès obtained the lowest score. Major differences were found in Garraf and Montsià. Garraf constitutes the second smallest *comarca,* 20.7 % of its territory constitutes urban area and accounts for 5.3 % of the total ESV flow in the coastal zone. However, just 21.3 % of such value is provided by terrestrial ecosystems, which represents the second lowest ESV flow along the coast. Thereafter, a combination of low ESV flow, average EI of 3.5, average human footprint of 48 and low fragility of resulted in a low provisioning capacity. For consistency purposes, map was created using the same method and number of classes that the HEMU map (see Section 4.2). Thereafter, the map can vary depending on the specified number of classes and thus ESPCI at land cover level constitutes the relevant information for management and decision-making processes.

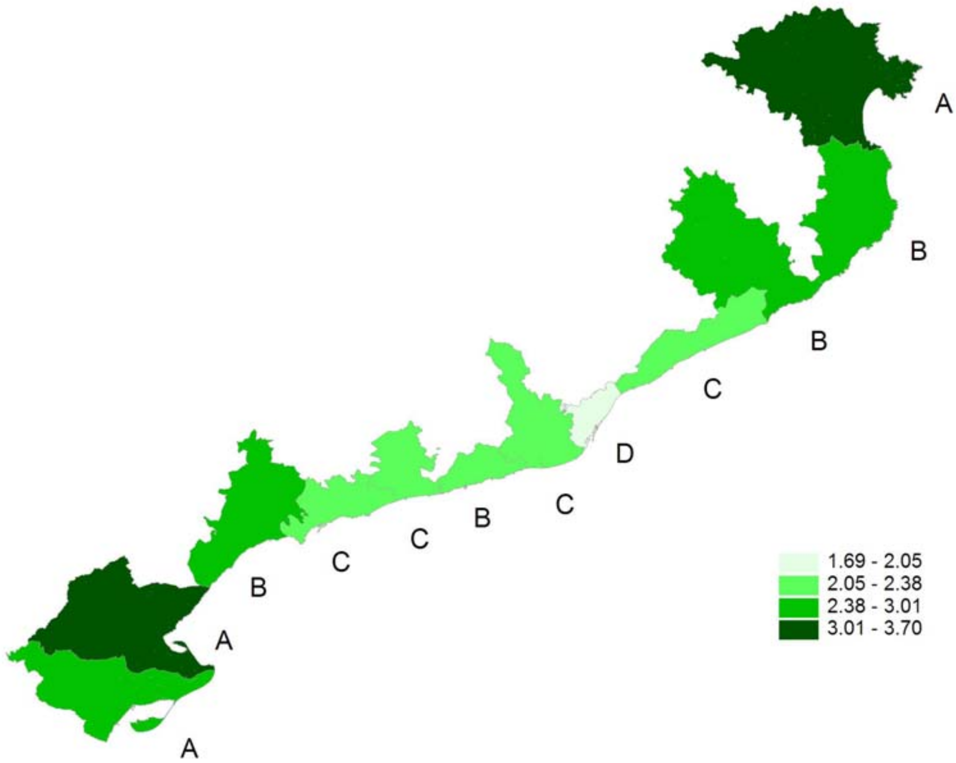


Figure 4.4.13. Distribution of average ecosystem services' provisioning capacity by *comarca* of the Catalan coast. Letters indicate HEMU class.

4.4.8 Integrated valuation of ecosystem services

An integrated ecosystem services valuation approach based on the ESPCI was conducted for the Catalan coast. By being based on the ESPCI, integrated valuation incorporates objective ecological properties and human influences in ecosystems across the coastal zone. Therefore, the effect of human induced bias stated on preferences should be reduced and thus provide a more accurate estimate of value. The new estimate constitutes the linear aggregation of each habitat's subjective preference-based value obtained in previous Section 4.3 and its objective capacity to provide services. This method combines three major aspects on which ecosystem functioning depends on (EI, HFI and FI) and constitutes a way to standardize ecosystem services valuation processes. It provides the advantage of translating the three dimensions that affect value into a direct measurement of services flow supply.

The assessment of integrated value followed a direct aggregation method which recalculates value in a linear way. Positive ESPCI scores increment habitat value linearly up to 100 % (double) and negative scores up to a residual value which prevent from overestimating totally influenced habitats to have a larger value than a less influenced. More complex relationships than those proposed here and empirical studies could be used in the future to define limits to value in a more precise way, *e.g.* using weights to individual indicators or indexes or developing decision rules for local conditions based on resource supply and demand or its absolute scarcity. Therefore, integrated values were truncated to their double in order to set a limit and do not produce unreal and unviable ESV estimates. These results constitutes a first initiative on ecosystem services valuation of the Catalan coast and therefore future developments could integrate new and better components into this research area.

The integrated ESV of studied land covers correspond to a flow of 3.37 billions USD/ha·yr in the Catalan coast. However, this should be considered as a conservative estimate of the entire Catalan coast value since the contribution of the continental shelf and seagrass beds have not been included. New estimate represents an absolute 42.3 % increment to that of nine out of 11 land covers calculated in Section 4.3. Thereafter, new estimate reflects SES characteristics in a more systemic view and not only based on human preferences. As an example, if the average ESPCI could be applied to shelf and seagrasses the resulting estimate would constitute an overall 70 % increment in flow.

Results show that integrated value represents 2.9 % of the total GDP and 4.5 % of available family income of the studied area. Although new contributions obtained do not seem to have a considerable absolute increment (compared those obtained directly from individual preferences), the study concludes that any increment in income will represent a significant improvement in human well-being on the coastal zone. While most contribution to natural value is provided by terrestrial land covers (80.5 %), coastal land covers (beach, dune and saltwater wetland) contribute to a significant 18.5 % to total ESV flow. This is especially relevant by looking to the 18 % contribution by beaches and dunes to total value.

Figure 4.4.14 shows change percentages in flow of each of the studies land covers' integrated ecosystem services value. All land covers accounted for value increments. In consequence to original ESV and its provision capacity, forest, beach and dune, open freshwater and saltwater wetlands accounted for the largest ESV flows. From Figure 4.4.14 can be also interpreted that the spatial dimension of economic value resulted highly important as one look at land cover in the context of ecosystem services.

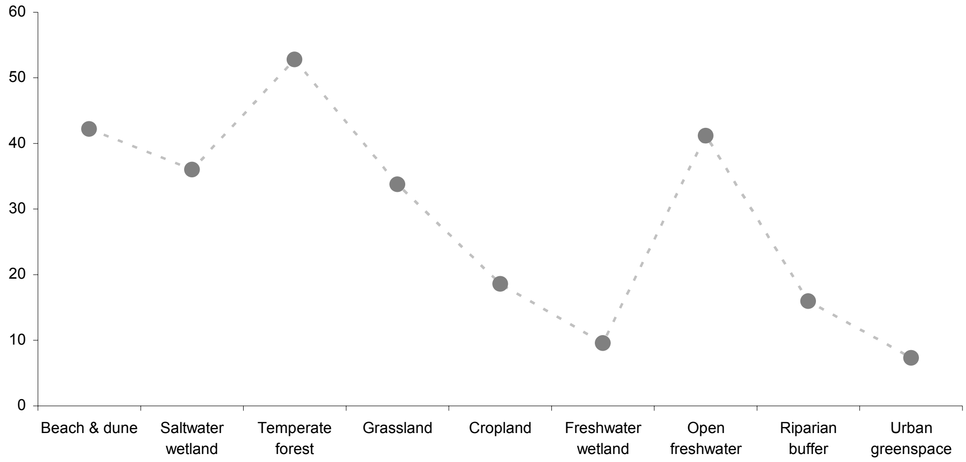


Figure 4.4.14. Change in flow of ecosystem services value as a function of ecosystem services' provisioning capacity by land cover of the Catalan coast. Change expressed as percentage of preference-based flow of ESV.

4.4.9 Conclusions

An integrated valuation of the non-market ecosystem services was conducted in order to incorporate ecosystem-based management goals into future ICZM plans. The integrated valuation challenged current methodologies and called for the integration of ecological properties in economic valuations. Thereafter, methodology incorporated ecological as well as socio-economic predictors of the capacity of ecosystems to provide services on which human well-being depends on.

The resulting geography of capacity to provide ecosystem services represents a proxy of natural structure and processes of the Catalan coast. Therefore, the analysis of such functioning patterns leaded to the understanding of the ability to provide services by ecosystems. The resulting ESPCI constituted a range of provision abilities that increased or decreased the stated-preference value estimated in Section 4.3 and constituted the integrated valuation.

The highest provisioning capacity areas were associated to the hinterland of the study area. The lowest values were found in large urban areas as Barcelona and Tarragona, and in the shoreline where large human influences are present. The Catalan coast maintains a positive capacity to provide services and larger average provisioning capacities were found in beaches and dunes, temperate forest and open freshwater land covers. Due to the interface nature of the shoreline in the coastal zone, the resulting high provisioning capacity of beaches and dunes becomes highly relevant in maintaining vital services that support humans in this area.

The relevance of physical landscape features should be also integrated into the costs and benefits in conservation efforts, *i.e.* beaches and dunes are highly valuable due to their supportive and regulating services. Moreover, PEIN protected areas network constitute a relevant ecosystem conservation mechanism which is at present responsible for more than one fourth of total services valued by citizens. Therefore, PEIN network constitutes an efficient site selection from the ecosystem services perspective even it wasn't its primary goal.

Results found are in concordance with the HEMU regionalisation developed in Section 4.2. Therefore, we conclude that HEMU regionalisation reflects ESV flow in an adequate manner. Alt Empordà and Baix Ebre accounted for higher provisioning capacities; while as expected Barcelonès obtained the lowest score. Major differences were found in Garraf due to a combination of low ESV, EI, HFI and fragility that resulted in a low capacity to provide ecosystem services. It is recommended that ESPCI at land cover level (habitat polygons) constitutes the more relevant information for managers.

The nine land covers assessed resulted in an ***integrated ESV flow of 3.37 billions USD/ha·yr in the Catalan coast***. This estimate was considered as a conservative estimate since any the continental shelf and seagrass beds have not been included due to lack of reliable data. The integrated ESV flow represents a 42.3 % increment to stated-preference value used in Section 4.3, as well as a 2.9 % of GDP and 4.5 % of the income of the Catalan coast. All land covers studied but freshwater wetlands accounted for value increments. Similarly, forest, beach and dune, open freshwater and saltwater wetlands accounted for the largest ESV flows. It was also interpreted that the spatial dimension of economic value resulted highly important as one look at land cover in the context of ecosystem services.

We can't ignore that individual perceptions are the basis for any discussion on value (Costanza 2000). However, economic valuations should not be a function of solely land cover and individual preferences but also the underlying functioning and pressures on ecosystem. Therefore, we envision the role of ecologists at identifying objective criteria for the optimization of integrated valuation assessments. This will reduce human-induced bias (via stated-preferences) and thus provide a more accurate estimate of ESV flow in the future. However, here proposed method, by combining two major aspects on which ecosystem functioning depends (EI and HFI) constitutes a way to standardize ecosystem services valuation processes across different spatial sites.

This study proposes a methodology that assumes that the more efficient is an ecosystem in providing a service (more natural and less influenced), the more valuable the ecosystem will be to the society. From this standpoint, the value of a flow of ecosystem services cannot be viewed as independent of the efficient functioning of the system. In consequence, results present a clear understanding why the same ecosystem services provided by the same land cover vary substantially in its economic value.

Real prices of ecosystem services in the Catalan coast would be almost certainly greater than estimated in this work. This is due to the lack of marine and several other ecosystem services value at present. However, if one were to try to replace currently studied services, at least an annual increment in GDP of 2.9 % should take place and will most likely to economic wealth deterioration (plus the contribution by the continental shelf and seagrass beds).

The study suggests the need for future research relevant for additional developments on integrated valuation of ecosystem services:

- Improve the availability and quality of ecological properties and human influence over ecosystems in empirical peer-reviewed literature.

- Identify other measurable ecological processes that can be correlated to ecosystem services provisioning.

- Map more complex linkages among ecosystem functioning and the services it provides.

- Conduct empirical assessments in order to identify thresholds and weights for individual indicators.

- Establish theoretical baseline for modeling the relationship to ecosystem services provision.

- Develop decision rules for local conditions based on resource supply and demand and the effect absolute scarcity of ecosystem services.

- Determine the effect of ESPCI in sustaining human well-being efficiently.

CHAPTER 5. Conclusions

This study constitutes a contribution to the analysis of non-market natural capital in the Catalan coastal zone from an efficient allocation perspective. It provides a set of three methodologies which contribute to estimating the ecosystem services value that should be considered relevant in coastal and environmental management. First, it proposes a method to identify the social-ecological spatial heterogeneity of the coast, which leaded to the identification of homogeneous management units on which valuation was carried out. Secondly, a benefit transfer spatial function was used in order to estimate the annual contribution of ecosystem services value to citizens' well-being. Furthermore, it was assumed that the more efficient is an ecosystem in providing a service, the more valuable will be to the society, and thus valuable ecological and human influence predictors were incorporated in an integrated value assessment of the economic benefits provided by the Catalan coast natural environment. By estimating the economic value of ecosystem services not traded in the marketplace, social costs or benefits that otherwise would remain hidden or unappreciated are revealed. Therefore, this work can be useful in evaluating tradeoffs between economic development and conservation in the coastal zone.

The study area (coastal zone) in present work was defined integrating Social-Ecological System (SES) processes at the *comarca* level. Therefore, biophysical, socio-economic and administrative dimensions were integrated in a single model which can be useful in integrated coastal management. The 12 littoral *comarcas* and their marine water extent to a depth of 50 m constituted the operational definition of the Catalan coast.

A function-based approach to ecosystems was used to help identify the relevant dependences of ecosystem services provision. This approach provided qualitative and quantitative analysis capabilities of elements, processes and services which are responsible for human well-being. Thirty ecosystem services providing regulation, habitat, production, information and carrier functions were identified to be present in the Catalan coast. The approach provided a way to translate the ecological complexity into a structure useful in natural resource management.

Natural capital valuation was proposed as a relevant methodology to be of further use in Integrated Coastal Zone Management (ICZM) processes in Catalonia. Thereafter, three analytical methods were developed to valuate non-market ecosystem services' annual flow. A survey was conducted among coastal managers and technicians to determine the desirable characteristics of an environmental valuation system of the Catalan coast. Preferences determined the necessity to ecologically and economically value the coast due to constant environmentally degradation and the lack of such input to develop sustainable strategies and plans.

The regionalisation process performed to the Catalan coast was based on the 12 littoral *comarcas.* The regionalisation process was based on socio-economic and ecological sub-indicators. Four different classes of Homogeneous Environmental Management Units (HEMU) were obtained, ranging form highly natural and less developed *comarcas* to less natural and highly developed *comarcas*. HEMU-based regionalisation of the coast provided a biophysical and socio-economic coherent management structure to conduct valuation of ecosystem services. Furthermore, it is expected to constitute a useful social-ecological structure in the future implementation of a ICZM Plan.

A value transfer approach of non-market services provided by terrestrial and marine domains of the coast was conducted based on more than 90 peer-reviewed studies. Based on Individual preferences, results indicated that an Ecosystem Services Value (ESV) of at least ***3.2 billion USD was delivered to citizens in 2004 (2,572 x 10^6 Euros)***. The study therefore, makes clear that non-market ecosystem services provide an important contribution to human well-being in the coast. ESV flow is the functional result from a diverse matrix of land cover types that are present in the coastal zone. It was found that ecosystem services when provided by different land cover types vary substantially in its economic value, and this study reflects such variability.

The availability of a larger number of studies measuring ESV and spatial land cover digital data has improved the specificity and reliability of present study. Beaches and dunes were found to provide the largest ESV on per hectare basis and disturbance regulation constituted the most valued ecosystem service. Coastal (beach, dune and saltwater wetland) and marine (shelf and seagrass) land covers provided more than 40 % of the total flow value, but they account for 22 % of valuated surface only. Single largest contribution to ESV flow was provided by forest while larger coastal-marine contribution was provided by the continental shelf. Results were found consistent with the HEMU geography and the Catalan coastal zone accounted for 3,463 USD/ha·yr in average. The Montsià had the largest absolute flow ESV, followed by the Alt Empordà and the Baix Ebre, while the Barcelonès had the lowest contribution among *comarcas*.

Although ecosystem services are not tradable or excludable due to their public nature, results suggest that an amount equivalent to 4.3 % of annual income should be added to total economic wealth of the coastal citizens. Similarly, if one were to try to replace the current ecosystem services, at least an annual increment of 2.7 % in the Gross Domestic Product (GDP) should take place in the study area (since the evaluated services are not captured in GDP). However, one should take into account that many ecosystem services are irreplaceable.

An integrated ecological and economic valuation of the non-market ecosystem services flow was conducted in order to account for the value of natural capital in future ICZM plans. Together, ecological, human footprint and fragility indexes resulted useful in the construction of the Ecosystem Services' Provision Capacity Index (ESPCI). This composite indicator constitutes a production-type proxy of the capacity of ecosystems to deliver services to citizens. Each indicator was integrated by one or several sub-indicators that were considered relevant in previous studies and to the Catalan coast. The methodology proposed is general enough to be implemented at other coastal zones; and sub-indicator selection could vary depending on specific realities and needs of other geographical contexts. The resulting geography of the capacity to provide ecosystem services represents a proxy of natural structure and processes in the Catalan coast. Therefore, the analysis of such functioning patterns leaded to the estimation of and integrated ESV delivered annually in this area.

The Catalan coast accounted for a positive capacity to provide services. Although larger average provisioning capacities were found in beaches, dunes, temperate forest and open freshwater, spatial distribution of ESPCI showed that larger areas with higher provisioning capacity were found in the hinterland of the coastal zone. Due to the interface nature of the shoreline in the coastal zone, the resulting high provisioning capacity of beaches and dunes becomes highly relevant in maintaining vital services that support humans in this area. Similarly to preference-based ESV, the distribution of average ESPCI by *comarca* followed that of HEMU with minor differences. The Alt Empordà and the Baix Ebre accounted for higher provisioning capacities; while as expected the Barcelonès obtained the lowest score. Results suggest that the ESPCI at land cover level constitutes the most relevant information for managers to be taken into account in future valuation functions.

Although it was not possible to include the marine portion of the study area in this analysis due to data heterogeneity and availability, an ***integrated ESV flow of 3.37 billion USD/ha·yr (2,712 x 10^6 Euros)*** was estimated in the Catalan coast. Integrated ESV flow, even though a conservative estimate represents more than a 42 % increment to that of terrestrial stated-preference value (see Section 4.3). This new estimate should be considered a more realistic approximation to ecosystem services value in the Catalan coast, since it combines two major aspects on which ecosystem functioning depends. Furthermore, the proposed method constitutes a way to standardize ecosystem services valuation processes across different spatial sites.

Present Natural Interest Spaces Plan (PEIN) network of protected areas was found to constitute a relevant ecosystem conservation mechanism which is responsible for the maintenance of at least one fourth of total services valued by citizens. The relevance of physical landscape features should be also integrated into the costs and benefits in conservation efforts, *e.g.* beaches and dunes are highly valuable due to their supportive and regulating services. Moreover, since it is based on a dynamic geographic information system, present valuation system can be useful in alerting managers of ecosystem services threats. Areas with negative provision capacity could be identified and analyzed in more detail while outweighing benefits or on project appraisal. This work has identified areas which should be considered as seed for the provision of ecosystem services; and whose performance need to be monitored using an approach like the one is proposed here. In the future, new areas can be identified for the specific purpose of conserving ecosystem services using these or similar criteria.

Both valuation processes kept close spatial relationship to that of HEMU geography. This was the result of the specific development patterns in the Catalan coast. As found, highly developed *comarcas* account also for lower ecological value and higher levels of human influence and *vice versa,* and such pattern prevailed in all results. Differences arose only at those *comarcas* with intermediate levels of economic wealth, ecological value and human activities. Most relevant and atypical patterns were discussed along the study and explained in terms of their variance contribution to value. Furthermore, regionalisation was found essential to understanding major social-ecological process driving coastal ESV, thus HEMU are proposed as a relevant complement to other regional and local valuation studies.

One cannot ignore that individual perceptions are the basis for any discussion on value. However, economic valuations of natural capital should not be a function of solely land cover and individual preferences but also the underlying functioning and pressures on ecosystem. Therefore, proposed integrated valuation method was considered to reduce human induced bias (via stated-preferences) and thus provide a more accurate estimate of ESV flow. By estimating the ESV flow of the coastal zone, the study provides coastal scientists and managers with relevant information for decision-making processes. It also reflects that if we hypothetically had to pay for ecosystem services, the price would be much different from what it is today, since it would be almost certainly greater. The study proposes that if these results are included in future project appraisals, past errors in projects due to undervaluation would be minimized due to nature and socio-economic benefit outweighing.

Given the uncertainties involved in the value transfer approach conducted, a precise estimate of the total ESV may be difficult to achieve. Uncertainties found indicate that estimate represents a minimum value which would increase much likely, if (i) additional effort is paid to integrate a broader range of ecosystem services value, (ii) more realistic representations of ecosystem dynamics are incorporated, and (iii) ecosystem services become scarcer in the future.

Developed methods are expected to provide coastal managers with relevant information for conservation and development purposes. These results intent to better inform coastal managers and technicians, and to provide new insight on the ecological economic dimension of natural resources. Therefore, it is expected that if such methods were implemented, significant advances towards coastal sustainability could be achieved.

If an ICZM strategy were to be implemented in the Catalan coast, it should be consistent with an Ecosystem-Based Management (EBM) (UN 2002). This work could be helpful in guiding such process by answering some management relevant questions. Examples of management questions and how these results can help to answer them are:

A) It is necessary to include the natural component in coastal zone planning and management?

- This study has demonstrated the non-market flow of value of the natural environment.

B) How should be included?

- This study presented a methodology relevant in an EBM approach in which value is assigned to the services provided by ecosystems.

C) What should be included?

- What are the ecosystem functions that the complex coastal components and structure perform?

- What are the ecosystem goods and services that are provided to citizens in the coastal zone?

D) What is the complementarily value of natural capital in the coastal zone not integrated into existing economic indices/accounting?

- What is to-date the available information on ESV to conduct valuations in the Catalan coast?

- What is the contribution of existing land covers (and habitats) and ecosystem services to ESV in the Catalan coast?

- What is the ESV flow contribution to total natural capital of the Catalan coast? and How is spatially distributed along the coast?

- What is the contribution of ESV flow in terms of GDP and income?

E) What is the capacity to provide such services coastal zone?

- What are the ecological non-use value, fragility, human influence and human footprint in the coastal zone?

- What is the capacity to provide ESV of the coastal zone, as a function of land covers?

- What are the implications of provisioning capacity in the estimation of an integrated social-ecological ESV flow?

- What is the ecosystem services provision capacity conserved through the protected areas network (*i.e.* PEIN) in the coast?

F) What are the management-relevant sub-regions into which the Catalan coast can be divided?

- What are the relevant homogeneous environmental spatial units on which strategies and policies can be applied and what are the social-ecological differences among them?

- How do *comarcas* contribute to the total ESV flow and each of the used variables?

Moreover, this study expects to provide complementary information to that to other regional or local initiatives. Relevant examples in the Catalan coast are DEDUCE Project (DMAH 2005b), which will provide an estimate of coastal zone performance towards sustainability; and MEVAPLAYA Project (http://lim050.upc.es/mevaplaya/), which has been developing an environmental state indicator of beaches and related recreational infrastructure along the coast. Therefore, here proposed methods together with other ICZM products will provide in the near future the necessary instruments to improve coastal performance towards a desirable and sustainable future.

Several challenges have been identified in order to improve present methods and results, as well as future developments. Envisioned challenges for ESV are:

- Improve the availability and quality of ecological properties and human influence over ecosystems in empirical peer-reviewed literature, specially in the marine domain.

- Improve the availability and quality of ESV data in empirical peer-reviewed literature, specially in the marine domain.

- Map complex linkages among ecosystem functioning and the services they provide, which can be correlated to provision capacity.

- Improve quality of land cover typology for the coastal zone to test the biophysical similarity of the policy site and the study site.

- Increase the consistency in the use of ecosystem service terminology to communicate better the value of ecosystem services.

- Develop socio-economic functions for function-based value transfer assessments, *e.g.* use alternative indicators as the Genuine Progress Indicator (see Cobb 1995).

- Conduct sensibility analysis to determine provision capacity equation's sub-indicator's contribution (*i.e.* weights).

Since present study constitutes the first approach to ESV on the Catalan coast, results should be considered an initial baseline for the valuation of ecosystem services. However, several scientific opportunities for further development have been identified from present experience. Major areas are shown in the order that the author will address them:

- Identify relevant management criteria to develop scenarios of provision capacity of the Catalan coast.
- Integrate ecological and economic scarcity concepts into valuation approach
- Identify ecosystem services priority areas, based in efficiency and resilience properties, and integrate a conservation portfolio of the Catalan coast (*e.g.* use Spatial Portfolio Optimization Tool (SPOT; http://conserveonline.org/workspaces/spot/base_view).
- Develop a payment strategy for ecosystem services capable of integrating ESV into markets.

CHAPTER 6. References

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