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# A methodological framework for multi-hazard risk assessment in beaches

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ABSTRACT

Beach management has traditionally concentrated on recreational uses and geomorphologic processes, overlooking environmental values. Traditional risk analysis also overlooks environmental services focusing on socio-economic damages and only accounting for a part of the total risk. To overcome this situation, a systemic approach dealing with ecological and social dimensions is required. This paper proposes a risk analysis framework in which coastal hazards and beach ecosystem services are jointly considered. The first phase consists of the definition of the risk profile. This is done by building the beach Pathway of Effect, where links between coastal hazards and ecosystem services are identified following the DPSIR approach. The second phase, risk assessment, includes risk valuation and hazard prioritization, which will help managers to decide where to allocate resources to cope with hazards affecting beach functionality. The methodology was validated at S'Abanell beach (Spanish Mediterranean coast), which provides several ecosystem services and is subjected to a variety of hazards.



## 1. Introduction

Caused by natural factors or induced by human activities, natural hazards could be seen as a function of a specific natural process and a human activity (WEF, 2009), leading to strong impacts on societies (i.e. economic damages, loss of human lives) (Pérez-Maqueo et al., 2007; Raschky, 2008). Natural disasters should be understood as the outcome of a development process whereby human societies have generated vulnerabilities and risks (Taubenböck et al., 2008). However, though they are common features that have long concerned the international community, humans have yet to fully learn how to cope with them (Pérez-Maqueo et al., 2007).

Coastal environments are transitional areas where intense physical, ecological and social interaction occurs (Hildebrand and Norrena, 1992). They are exposed to multiple aquatic and terrestrial hazards, whose impacts are often exacerbated by the fact that they occur in areas with high economic and social vulnerabilities (Fleischhauer et al., 2005). In coastal zones, damage due to natural hazards has been significant, mainly because of the high concentration of population and the amount of infrastructure susceptible to being damaged (Martínez et al., 2007). Global warming and rising sea levels could also increase the severity and frequency of coastal storms and add to the intensity of coastal risk impacts (Roca et al., 2008). However, the design and placement of infrastructure without planning to safeguard ecosystem services and protect natural capital resources is probably the most important cause of damage (Costanza and Farley, 2007).

Since 1995, concern about the state of European coastlines has led to the development of several EU initiatives based on

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the concept of integrated coastal zone management (ICZM) (EEA, 2006a,b; Douvere and Ehler, 2009). ICZM is a strategy for an integrated approach to planning and management, considering all interests (i.e. policies, sectors, individuals) and all coastal stakeholders in a participative way, in the full range of temporal and spatial scales. It attempts to balance development needs with the protection of the resources that sustain coastal economics, addressing the three dimensions of sustainability (i.e. socio-cultural, economic and environmental) with good communication between authorities (EEA, 2006a). Recognizing this urgent need, the Council of the EU recently approved the signing of the Protocol on ICZM in the Mediterranean by the signatories to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (2009/89/EC).

Due to the extreme variability of coastal areas, the highly diverse nature of these systems and their social-ecological value, appropriate study units need to be selected from the very beginning to guide ICZM initiatives (Balaguer et al., 2008). Beaches are one of the most important shoreline units requiring management, and, as in other coastal areas, resources and activities have been traditionally managed by sectorial approaches dealing with specific resources in isolation (Hildebrand and Norrena, 1992).

Beach management has traditionally concentrated on geomorphic hazards and the recreational human use of beaches but has largely ignored their ecological and broader environmental values (James, 2000). Beaches are usually viewed as natural places supporting hedonic socio-cultural activities. However, they are very complex social-ecological systems that have many other functions (e.g. Regulation, Habitat, Production and Information; de Groot, 1992). A broader conception of beaches must be incorporated, recognizing these ecosystems as multidimensional environmental systems rather than one-dimensional physical or recreational sites (James, 2000). Beach management must be integrated, well-coordinated and based on interdisciplinary approaches (Ariza et al., 2008; Forst, 2009).

The growing need for solutions to complex environmental problems has led to an upsurge in interdisciplinary work, encouraging synergies between academics and practitioners and blurring boundaries between social and natural sciences (Cheong, 2008; Roca et al., 2008; Hills et al., 2009; Zou and Wei, 2010; Innocenti and Albrito, in press). Natural ecosystems and the services they provide for human well-being have occasionally been considered in coastal management and risk reduction programmes (Pérez-Maqueo et al., 2007). However, the usual practice of risk analysis overlooks the other functions of beaches and mainly deals with damages to assets, which means that risk management frequently only manages a part of the total risk (Meyer et al., 2009).

Risk analysis is internationally recognized as an approach to assist decision-making. It is a systematic way of gathering, evaluating, and disseminating information leading to recommendations in response to an identified risk. It is a tool intended to provide decision-makers with an objective, repeatable and documented assessment of the risks posed by a particular action. A risk-based approach also helps managers to prioritize issues and focus efforts when they are regulating the activities that are considered to have the greatest potential impact (Hardy and Cormier, 2008).

The objective of this paper is to propose a framework for beach multi-hazard risk assessment considering beaches as social-ecological systems in which the consequences of the existing hazards are assessed according to their effects on environmental services provided by the beach. The proposed methodology consists of two phases: (i) the definition of the risk profile, in which links between hazards and ecosystem services are identified and formalized in the beach Pathway of Effect (PoE), and (ii) risk assessment, in which risks associated with each hazard are assessed and prioritized from a risk manager's perspective. Both phases are intended to propose the best decision in the subsequent risk analysis steps (i.e. risk management and risk communication).

The methodology was validated at a beach on the Spanish Mediterranean coast where several hazards (natural and anthropogenic) and environmental services coexist. It can therefore be considered as representative of a large part of the Mediterranean coastline. The description of the proposed methodology is introduced using the case study as follows: (i) a general description of the study area is presented, (ii) the risk analysis framework is applied, and (iii) policy implications and conclusions are provided.

## 2. Study area

The methodology presented was validated at S'Abanell beach, located in the Bay of Blanes (NW Mediterranean Catalan coast, Spain) (Fig. 1). S'Abanell is an urban and touristic beach that is intensively used during the bathing season and managed so as to guarantee this industry. Tourism represents almost 10% of the Catalan GNP and is the main economic activity in the area (Valdemoro and Jiménez, 2006). However, this beach is subject to increasing pressure due to intensive development, already identified as one of the main factors inducing coastal degradation (Sardá and Fluvià, 1999).

In the last decade S'Abanell beach has suffered significant erosive processes that have accelerated its retreat (Valdemoro and Jiménez, 2006). This trend has been associated with a drastic decrease in sediment supplies from the Tordera River, caused by increasing urbanization in its watershed, major dredging operations on the river bed and decreasing river liquid discharge due to intensive human use (Martí and Pintó, 2004). This retreat has contributed to the failure of S'Abanell beach as a supplier of several ecosystem services, especially *disturbance regulation* and *recreation and aesthetic*. In 2008, Blanes endured several coastal storms causing considerable damage to the sea front, resulting in the failure of S'Abanell beach and thus compromising protection and tourism activities. Three nourishment processes were necessary to guarantee these services, but by 2009 S'Abanell almost failed again.

Valdemoro and Jiménez (2006) identified two different zones in S'Abanell beach in terms of frequentation, beach use, hinterland, morpho-dynamics and management. The southern part (900 m from the river mouth) is not intensively used, even during the summer, and has natural areas, camping sites and crop lands in its hinterland. In the north, the beach hinterland is urban and beach frequentation is clearly greater,


**Fig. 1 – Picture of S'Abanell beach, including northern and southern zones (GoogleEarth™2007). The effects of beach nourishment can be seen in the southern zone.**

especially during the bathing season. Differences were also observed in both hazards (intensities and consequences) and ecosystem services (existence and degree of delivery), which made this beach more interesting and increased the potential of this methodology for generalization.

## 3. Risk analysis

### 3.1. *General characteristics*

The proposed methodology goes through two phases: risk profile and risk assessment. The main objective of the risk profile is to define the beach PoE, which describes the links between main hazards and principal ecosystem services provided by the beach. The analysis follows the DPSIR approach, described as a ''causal framework for describing the interactions between society and the environment'' (EEA, 2006b). Within this frame, social and economic developments (Drivers, D) generate Pressures (P) on the environment, and modify its State (S), leading to Impacts (I) on ecosystems, human health, and society. Related to decision making, Responses (R) feeds back on Drivers, on State or on Impacts through mitigation, adaptation or curative actions (Maxim et al., 2009). The main objectives of risk assessment are hazard prioritization and risk valuation, based on hazard intensities and, economic valuation and exposure of the affected ecosystem services (Fig. 2).

### 3.2. *Risk profile*

In order to obtain the beach PoE the risk profile starts with the identification and characterization of main hazards and ecosystem services.

#### 3.2.1. *Hazard characterization*

Two main groups of coastal hazards were defined for this characterization. The first group, *natural hazards*, includes those affecting the physical environment (physical hazards, e.g. storms, erosion) and those involving organisms and their effects (biological hazards, e.g. dangerous marine life). The second group, *anthropogenic hazards*, includes those resulting from human activities and policies, specific events (e.g. major accidents), spread processes (e.g. pollution, land use, tourism overuse), and legal aspects (e.g. land reclamation).

For each of the identified hazards, the PoE were constructed within a DPSIR framework. Since PoE are visual representations of relationships between human activities, the pressures they generate and their impacts on ecosystem components (Hardy and Cormier, 2008), they become a tool to assist in the understanding and communication of links between hazards and beach ecosystem services.

Six hazards were identified and classified as the most important stressors affecting S'Abanell beach. We found three physical hazards (*coastal storms*, *long-term erosion* and *river floods*) and one biological hazard (*jellyfish*). Among anthropogenic hazards we identified *pollution* and *human uses*, the latter combining the two main human drivers of change at S'Abanell: *tourism overuse* and *hinterland urbanization*. Based on these hazards, we identified two PoE with two main drivers (*anthropogenic*, and *natural and climate-related*) and two main impacts (*surface area reduction* and *quality reduction*) (Fig. 3).

As for anthropogenic activities, *alteration of natural land-sea fluxes* was one of the negative pressures, causing the increase in litter and waste discharges (state), with the corresponding reduction in beach quality (impact). *Urbanization and land cover transformation* was also a negative pressure, causing a decrease in sediment supply from land to sea, an increase in waste pipe

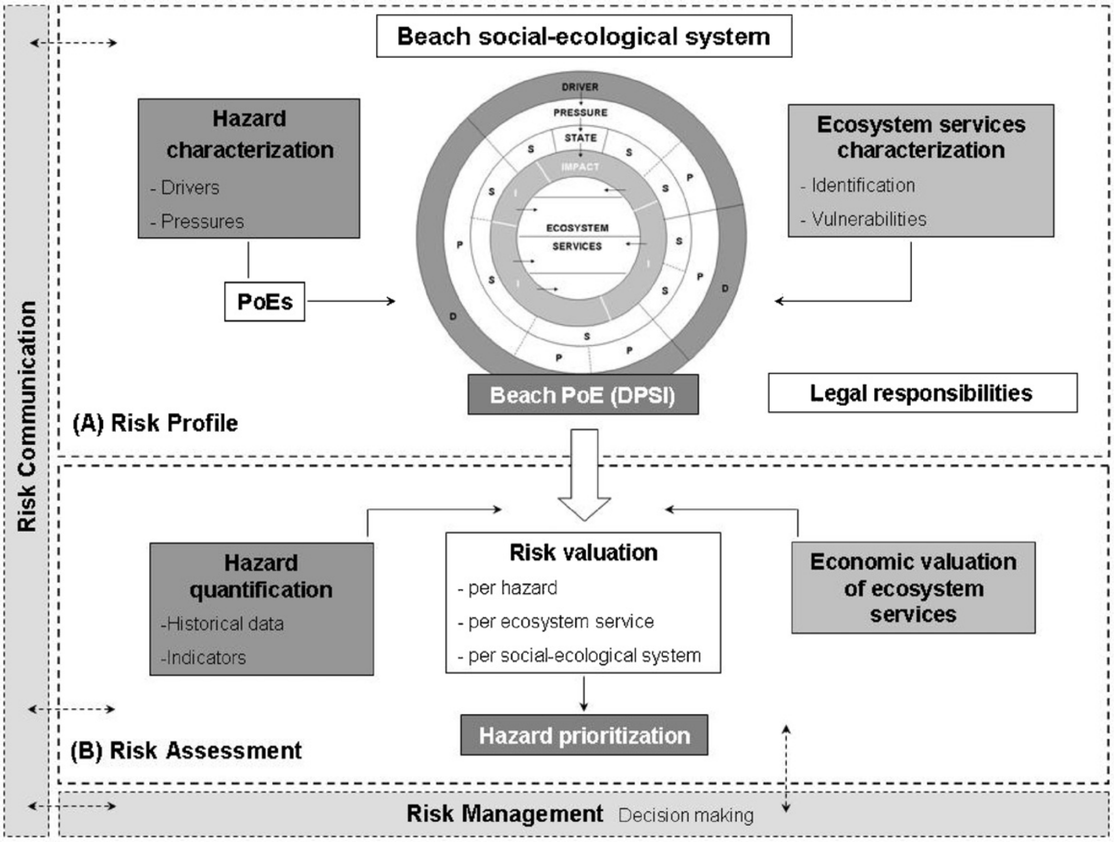


**Fig. 2 – Diagram of the multi-hazard risk assessment of the beach presenting the main steps of the proposed methodology.**

discharge and a reduction in the distance between infrastructure and the sea (states). All of these activities reduce both beach quality and beach surface area (impacts). *Tourist population increase* was the third negative pressure identified, causing higher litter and waste discharges and increased beach crowding (states), both of which reduce beach quality (impact) (Fig. 3a).

The main negative pressures identified for the second driver (natural and climate-related) were alteration of natural beach sand transport, alteration of sea level, alteration of river bed and natural water transport patterns and alteration of species distribution patterns. The first implies a decrease in beach sediment supply, while the second also causes an increase in sea level. Alteration of river bed and natural water transport patterns increases the river level (state), while alteration of species distribution patterns increases the occurrence of dangerous marine life (state). The latter was the only pressure which causes a reduction in beach quality, while the other three only reduce beach surface area (Fig. 3b).

### 3.2.2. *Ecosystem services characterization*

Several ecosystem functions and services categorizations have been developed concerning biodiversity conservation, integral environmental assessments and economic valuation (e.g. de Groot, 1992; Costanza et al., 1997; MEA, 2003; Farber et al., 2006). Within these categories, several ecosystem services have been described for coastal ecosystems and beaches (e.g. nutrient cycling, habitat, climate regulation, disturbance regulation, water supply, recreation) (de Groot, 1992; MEA, 2003; Beaumont et al., 2007; Brenner et al., 2010). However, ecosystem services must be characterized by considering the features of the region under study and their main activities (Turner, 2000). Accordingly, the identification of services' vulnerabilities was included in the characterization, thus improving the understanding of the types of risks which could have a significant impact on services.

Considering the characteristic of S'Abanell beach and its main activities, six ecosystem services were examined in this assessment:

*Habitat*: defined as the physical place where organisms reside and the habitat that they provide. At S'Abanell beach, this service is primarily linked to the Tordera river delta which is included in the Natura 2000 network, an EU network of nature protection areas which is the centrepiece of the EU nature and biodiversity policy (Council Directive 92/43/EEC). Any non-natural event causing the loss of surface or an environmental perturbation directly (e.g. beach surface losses, pollution) or indirectly (e.g. reducing sediment supply) could be affecting this service

*Disturbance regulation*: with a valuable role in the defence of coastal regions, this service is mainly determined by hinterland infrastructures and concerns the dampening of environmental fluctuations. As it is probably one of the most important services provided by S'Abanell beach, it will be affected by any direct (e.g. coastal erosion) or indirect (e.g. reducing sediment supply) beach surface loss.

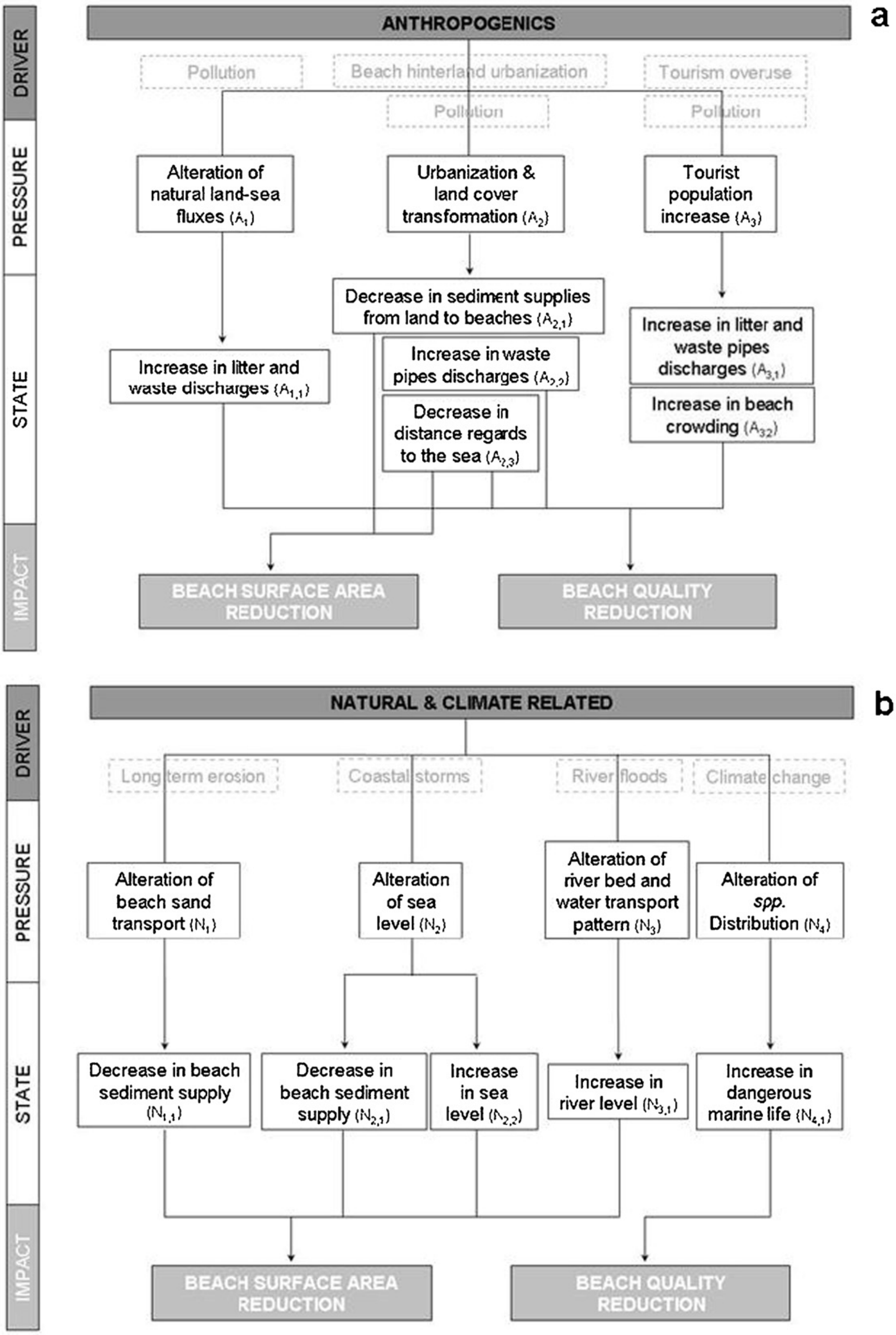


**Fig. 3 – Following DPSIR model, the Pathway of Effect (PoE) of the two main drivers in S'Abanell beach (a) Anthropogenic and (b) natural and climate-related activities are presented. The main hazards are suggested.**

*Water supply*: defined as the retention, filtering and storage of fresh water, including fresh water for drinking, irrigation or transportation. In this case, the southern zone of S'Abanell beach supports a water pump from a desalinization plant (Catalan Water Agency, ACA), which provides drinking water for several towns along the coast. Any reduction in beach width that could affect these infrastructures or any considerable reduction in water quality could affect this service.

*Recreation*: defined as the opportunities for rest, refreshment and stimulation of the human body and mind based on ecosystems. This ecosystem service is one of the most important at S'Abanell beach. Reductions in beach surface area and beach quality are the main vulnerabilities of this service.

*Aesthetic*: The attractive landscape features based on the sensory enjoyment of functioning ecological systems. Although S'Abanell is an urban beach, its aesthetic value is not negligible because of the beauty of the Costa Brava landscape. As in the previous case, reductions in beach surface area and beach quality are the main vulnerabilities of this service.

*Spiritual and Historic*: defined as spiritual or historic information provided by natural features of the ecosystem, this value is intimately associated with the beach itself and the fishing history of the town of Blanes. Reductions in both beach quality and surface are also the main vulnerabilities.

Because of the aforementioned differences between the two zones of the beach, not all ecosystem services were considered equally. The southern zone offered all the services described above, while the northern zone simply offered *disturbance regulation*, *recreation*, *aesthetic*, and *spiritual and historic services*. *Water supply* was strictly related to the infrastructures of the desalinization plant, and *habitat* was linked to the Tordera River, both in the southern zone. In order to improve risk assessment, and economic valuation in particular, *recreational* and *aesthetic services* were then considered as one service (*recreational and aesthetic*).

### 3.2.3. Beach pathway of effect

The aim of this step, and the main result of the risk profile is to obtain the beach PoE (Fig. 4), based on the PoEs obtained in hazard characterization, and the vulnerabilities identified in ecosystem services characterization.

Fig. 4 shows for the two main drivers, their main pressures ($A_n$ and $N_n$), the corresponding states ($A_{n,m}$ and $N_{n,m}$) and the impacts. Since the vulnerability of beach ecosystem services was already characterized, the link between the impacts and the ecosystem services considered for S'Abanell beach can be established.

### 3.2.4. Legal responsibilities

In this step, an overview of key legal responsibilities related to the hazards and the ecosystem services provided by the beach helps to identify the appropriate jurisdictions which may be affected in a risk assessment.

In Spain, several public administrations are responsible for coastal management. With various laws and regulations, they are spread over three administrative levels (i.e. national, regional and local). The central government has the main responsibility for coastal management. The Shores Act 22/1988 is the main jurisdictional framework, defining the coastal zone as public property according to the Spanish Constitution. This is the Spanish regulation that most resembles a coastal management law, even though it was created for the Maritime-Terrestrial Public Domain (DPMT) and not for the entire littoral zone. It defines the DPMT limits, and competencies and responsibilities related to DPMT management (Barragán, 2003; Suarez de Vivero and Rodriguez Mateos, 2005; Ariza et al., 2008).

Where S'Abanell beach is concerned, any mitigation or reduction measures proposed in a risk management process will entail coordination between departments and agencies at three administrative levels: the Spanish government, the Autonomous Government of Catalonia and the Municipality of Blanes.

## 3.3. Risk assessment

The main objectives of this phase are risk valuation and prioritization, in order to assist and facilitate risk management. Both objectives were based on hazard quantification (i.e. intensities) and economic valuation and exposure of ecosystem services.

### 3.3.1. Hazard quantification

Hazards were quantified according to intensity, based on frequency (e.g. extreme probability distributions) and consequences (e.g. reduction in beach width, erosion rate), in accordance with a previously defined return period or temporal scale. In order to normalize these intensities, an ordinal scale of relative intensities (i.e. 0–1) was applied.

The episodic events identified (i.e. storm-induced erosion, storm-induced floods and river floods) were analyzed in probabilistic terms through a probability of occurrence expressed as a return period (Tr). These hazards were considered in the analysis as *frequent* and their Tr were 50 years, based on the European Flood Risk Directive (2007/60/EC-FRD). Other events not associated with extreme conditions were quantified based on a probability distribution obtained from historical local data. For these hazards, which present a defined time trend, a temporal scale of 5 years was used in order to ensure enough time for managers to consider risk assessment, policy and decision-making, and implementation.

The six hazards identified at S'Abanell beach were quantified as follows:

A coastal storm causes two processes that were quantified independently: (*a*) *Storm-induced erosion*: due to the stochastic nature of this process, quantification was based on the extreme probability distribution of beach induced retreats ($\Delta x$). This distribution was built through a numerical model based on local beach geomorphology and wave climate, which calculates the expected shoreline retreats for a given probability. With this distribution, the intensity of this hazard (0–1) was calculated following Jiménez et al. (2011) from the ratio between the actual beach width (BW), the beach retreat ($\Delta x$) associated with the target return period (Tr = 50 yr) and the minimum beach width necessary for any recuperation activity (MBW):

$$\beta = \frac{1}{(\mathrm{BW} - \Delta x)/\mathrm{MBW}} \tag{4}$$

The relative intensities for the northern and southern zones of S'Abanell beach were 0 and 1, respectively (Fig. 5).

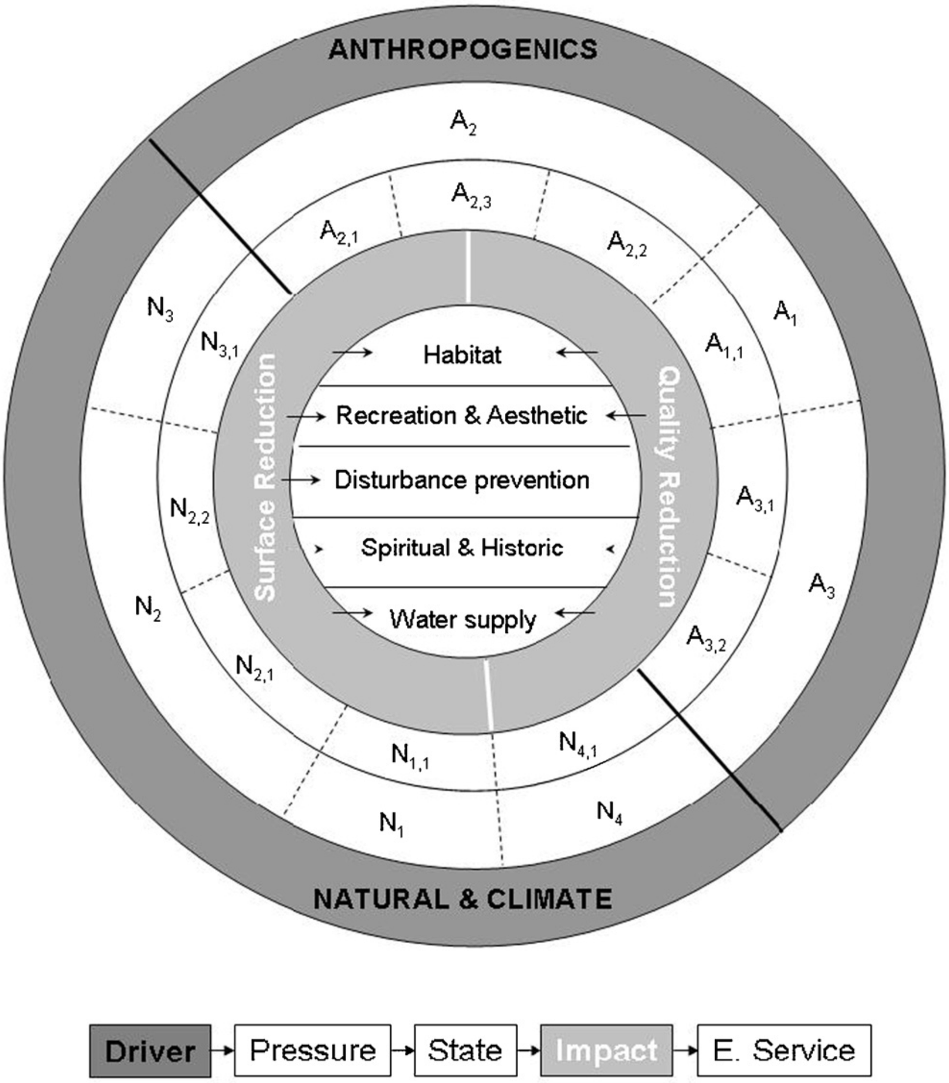


**Fig. 4 – PoE obtained for S'Abanell beach, showing the two main drivers, their main pressures, and the corresponding states and impacts (see codes in Fig. 3). Links between Impacts and ecosystem services considered for S'Abanell beach are also presented.**

(*b*) *Storm-induced flood*: this quantification was also based on extreme probability distribution, using the expected water level increase (runup). The intensity was determined from the ratio between the expected runup and the sea front height (SFH) of the beach, where the runup was calculated according to Stockdon et al. (2006). The relative intensities (Tr = 50 years) were 0.8 and 1 for the northern and southern zones, respectively (Fig. 5).

*Long-term erosion*: this quantification was achieved from an erosion rate for a period of 5 years, calculated with historical data and assuming that the system remains constant (Jiménez et al., 2011). The erosion rates ($\Delta x$) were −0.8 for the northern and −2.2 for the southern zones, and the relative intensity calculated with Eq. (4) was 0 for both zones (Fig. 5)

*River floods*: an extreme probability distribution of Tordera river floods was used in this quantification, comparing the water level increase and the topography (Generalitat de Catalunya, 2010). Fixing the return period at Tr = 50 years, we analyzed the expected percentage of flood surface against total beach surface. For both zones the relative intensity was 1 (Fig. 5)

*Jellyfish*: this biological hazard was quantified based on historical organism concentration data from the Catalan Water Agency (ACA) monitoring programme (2000–2009). The intensities were calculated from the frequency (% of weeks) of *low concentration* (<1 ind 10 $m^{-2}$, ACA) during the bathing season. The relative intensities were 0 and 0.2 for the northern and southern zones, respectively (Fig. 5).

*Pollution*: this quantification was based on water quality history (ACA monitoring programme, 2000–2009), and the intensities were calculated from the frequency (% of weeks) of *good water quality* (ACA) during the bathing season. The relative intensities were 0.2 and 0 for the northern and southern zones, respectively (Fig. 5).

*Human uses*: this hazard was quantified by combining *tourism overuse* and *hinterland urbanization*: (*a*) *Tourism overuse* was

***STORM-INDUCED EROSION***

| | | | | | |
|---|---|---|---|---|---|
| **cale** | | | | | |
| β | >0.83 | >0.90 | >0.99 | >1.24 | >1.66 |
| Intensity | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
| **Data Analysis** | | | | | |
| Tr (yr) | 5 | 10 | 25 | **50** | 100 |
| Δx (m) | 10 | 12 | 15 | **16** | 21 |
| | *North* | | | *South* | |
| MBW (m) | 5 | | | 5 | |
| BW (m) | 27 | | | 19 | |
| β | 0.45 | | | 1.67 | |
| **Intensity** | **0** | | | **1** | |

MBW: Minimum Beach Width; BW: Beach Width; Δx: Beach retreat

***STORM-INDUCED FLOOD***

| | | | | | |
|---|---|---|---|---|---|
| **Scale** | | | | | |
| Run up/SFH (%) | >80% | >90% | >100% | >120% | >150% |
| Intensity | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
| **Data Analysis** | | | | | |
| Tr (yr) | 5 | 10 | 25 | **50** | 100 |
| Run up (m) | 3.4 | 3.7 | 4.1 | **4.4** | 4.7 |
| | *North* | | | *South* | |
| SFH (m) | 3 | | | 2 | |
| Run up/SFH (%) | 147% | | | 220% | |
| **Intensity** | **0.8** | | | **1** | |

SFH: Sea Front Height

***LONG TERM EROSION***

| | | | | | |
|---|---|---|---|---|---|
| **Scale** | | | | | |
| β | >0.83 | >0.90 | >0.99 | >1.24 | >1.66 |
| Intensity | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
| **Data Analysis** | | | | | |
| Δx (m/yr) | *North*: **0.8** | | | *South*: **2.2** | |
| | *North* | | | *South* | |
| MBW (m) | 5 | | | 5 | |
| BW (m) | 27 | | | 19 | |
| β | 0.22 | | | 0.63 | |
| **Intensity** | **0** | | | **0** | |

MBW: Minimum Beach Width; BW: Beach Width; Δx: Beach retreat

***RIVER FLOOD***

| | | | | | |
|---|---|---|---|---|---|
| **Scale** | | | | | |
| In flood/BS (%) | >40% | >50% | >60% | >70% | >80% |
| Intensity | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
| **Data Analysis** | | | | | |
| Tr (yr) | 10 | **50** | 100 | 500 | |
| In flood/BS (%) | >80% | **>80%** | >80% | >80% | |
| | *North* | | | *South* | |
| In flood/BS | >80% | | | >80% | |
| **Intensity** | **1** | | | **1** | |

BS: Beach surface

***JELLYFISH***

| | | | | | |
|---|---|---|---|---|---|
| **Scale** | | | | | |
| Frequency (% weeks) | >10% | >20% | >30% | >40% | >50% |
| Intensity | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
| **Data Analysis** | | | | | |
| | *North* | | | *South* | |
| Low concentration (*) frequency (% weeks) | 6% | | | 19% | |
| **Intensity** | **0** | | | **0.2** | |

(*) Absent: no ind; Low: <1ind·10m$^{-2}$; Moderate: >1ind·10m$^{-2}$ and High: >1ind·1m$^{-2}$ (sensu ACA)

***POLLUTION***

| | | | | | |
|---|---|---|---|---|---|
| **Scale** | | | | | |
| Frequency (% weeks) | >10% | >20% | >30% | >40% | >50% |
| Intensity | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
| **Data Analysis** | | | | | |
| | *North* | | | *South* | |
| Good quality (**) frequency (% weeks) | 12% | | | 5% | |
| **Intensity** | **0.2** | | | **0** | |

(**) Very good, Good, Moderate, Bad and Deficient (sensu ACA)

***HUMAN USES***

| | | | | | |
|---|---|---|---|---|---|
| **Scale** | | | | | |
| Hinterland urbanization | Natural | Crop | Camping | Urban | |
| Scores | 0 | 1 | 2 | 3 | |
| **Data Analysis** | | | | | |
| Surface (0 to 1) | | | | | Scores |
| *North* | 0 | 0.09 | 0.18 | 0.73 | **3** |
| *South* | 0.18 | 0.52 | 0.29 | 0.01 | **1** |
| **Scale** | | | | | |
| Beach crowding (m$^2$/user) | >18 | <18 | <9 | <4.5 | |
| Scores | 0 | 1 | 2 | 3 | |
| **Data Analysis** | | | | | |
| | *North* | | | *South* | |
| Scores | **1** (15m$^2$/user) | | | **0** (74m$^2$/user) | |
| **Intensity** | **0.6** | | | **0.2** | |

**Fig. 5 – Quantification of main hazards at S'Abanell beach: storm-induced erosion, storm-induced floods, long-term erosion, river floods, jellyfish, pollution and human uses. Quantification scales, data analysis and relative intensities are presented.**

estimated using beach crowding data (i.e. sand availability per user, S) obtained from MeVaPlaya project, applying four scores: '3' if $S < 4.5\ m^2\ user^{-1}$, '2' if $4.5\ m^2\ user^{-1} < S < 9\ m^2\ user^{-1}$, '1' if $9\ m^2\ user^{-1} < S < 18\ m^2\ user^{-1}$ and '0' if $S > 18\ m^2\ user^{-1}$.

(*b*) *Hinterland urbanization* was estimated using Geographic Information Systems (GIS) and aerial photographs, applying scores to four categories of hinterland urbanization in a 500 m buffer zone from shoreline: natural (0), crop land (1), camping (2) and urban (3). This sub-indicator was quantified by applying the corresponding score to the percentage (from 0 to 1) of each category in the buffer zone, which gave an urbanization score from 0 to 3 in each zone of the beach. Assuming equal relative importance, *human uses* intensity (from 0 to 1) was obtained adding both sub-indicators, being 0.8 in the northern and 0.2 in the southern zone (Fig. 5).

*Storm-induced erosion*, *storm-induced floods* and *river floods* were the most intense hazards in the south, while in the north *river floods* showed the highest intensity.

### 3.3.2. *Economic valuation of ecosystem services*

Economic valuation is one of the critical steps. Although it is a criticized methodology, it enables the comparison of dissimilar ecosystem services, giving a more complete picture of their economic importance, and is therefore highly relevant to managers; it can be used to estimate monetary values of ecosystem services related to human welfare and to demonstrate the high costs associated with their degradation (Brenner et al., 2010). In this case, existing economic estimations, gathered empirically at an original study site, were applied (i.e. value transfer assessment) in order to obtain estimates of ecosystem services values (ESV) at the beach under study. Despite known limitations (i.e. biophysical and socio-economic sensitivity), this method has become very useful when primary data collection is limited (Troy and Wilson, 2006; Brenner et al., 2010).

Annual estimates of ecosystem services values (ESV) for S'Abanell beach were obtained from scientific literature review, updating the values obtained by Brenner et al. (2010)

**Table 1 – Non-market values (ESV: € ha$^{-1}$ yr$^{-1}$ in 2009) of the ecosystem services considered in the validation case. These estimations were obtained based on values calculated by Brenner et al. (2010), Rabadán and Suárez (2008), Machado and Mourato (2002), Leeworthy and Bowker (1997) and Falk et al. (1994). Annual flow of non-market values (€ yr$^{-1}$ in 2009) of each ecosystem service, in both northern and southern zones and the entire beach, and their contribution (%) to the total value of S'Abanell beach are also shown.**

| Ecosystem services | ESV (€ ha$^{-1}$ yr$^{-1}$) | Annual flow North (€ yr$^{-1}$) | Annual flow South (€ yr$^{-1}$) | Annual flow S'Abanell (€ yr$^{-1}$) | Annual flow (%) |
|---|---|---|---|---|---|
| Habitat | 106 | – | 318 | 318 | 0.06 |
| Disturbance regulation | 95,165 | 380,660 | 234,106 | 614,766 | 49.86 |
| Water supply | 25,920 | – | 77,760 | 77,760 | 13.58 |
| Recreation and aesthetic | 69,577 | 278,308 | 31,310 | 309,618 | 36.46 |
| Spiritual and historic | 83 | 332 | 249 | 581 | 0.04 |
| Total | 190,851 | 659,300 | 343,743 | 1,003,043 | 100 |

(Table 1). These results are the statistical mean of individual estimates for each ESV, standardized to the average 2009 euro (€) equivalents per hectare and per year. Values were standardized using the annual Consumer Price Index variation for Catalonia and the annual mean fixed exchange rate (http://www.ine.es; http://www.bde.es).

*Disturbance regulation* and *recreation and aesthetic* were the most valuable services, while *habitat* and *spiritual and historic* were the least valuable, with two and three orders of magnitude less.

Nevertheless, the differences described above between the two zones of S'Abanell beach were considered in the economic valuation. A different number of ecosystem services were delivered by each zone, and *disturbance regulation* and *recreation and aesthetic* services were not equally delivered. A percentage of supplied service was defined for each service in each zone, and the ESVs obtained were corrected according to these percentages. *Disturbance regulation* is mainly determined by hinterland infrastructures, and the northern zone has a higher concentration of settlement than the southern one (18% of natural hinterland). Based on this, the ESV for this service in the south was reduced by 18% (€78,035/ha yr). Mean recreational use during summer in the south (568 users/day) was 85% lower than in the north (3753 users/day). The ESV of the *recreation and aesthetic* services was thus reduced by 85% in the southern zone (€10,436/ha yr). Considering the whole beach, the total annual flow of ecosystem services delivered to citizens was €1,003,043/yr, of which almost 50% corresponded to *disturbance regulation* (Table 1).

### 3.3.3. *Risk valuation and prioritization*

Risk valuation was based on the definition proposed by Morrow (2009), in which risk was defined as the product of hazard, exposure and consequence or a combination of probability and severity of consequences. The exposure of all ecosystem services along S'Abanell beach was assumed to be maximum and constant, and the risk was calculated as the product of hazard intensities (H) and ecosystem services values (ESV), according to the links defined in the beach PoE.

Considering subsequent interactions with risk managers and stakeholders, the proposed methodology allows for a risk valuation per hazard, considering all the services affected by each hazard ($H_a$ hazard intensity, $ESV_A$ the value of the ecosystem service affected and $TR_a$ the risk caused by the hazard):

$$TR_a = \sum_{A=1}^{A=n} (H_a \times ESV_A)$$

per ecosystem service, considering all the hazards affecting a particular ecosystem service ($R_A$ being the risk for the ecosystem service):

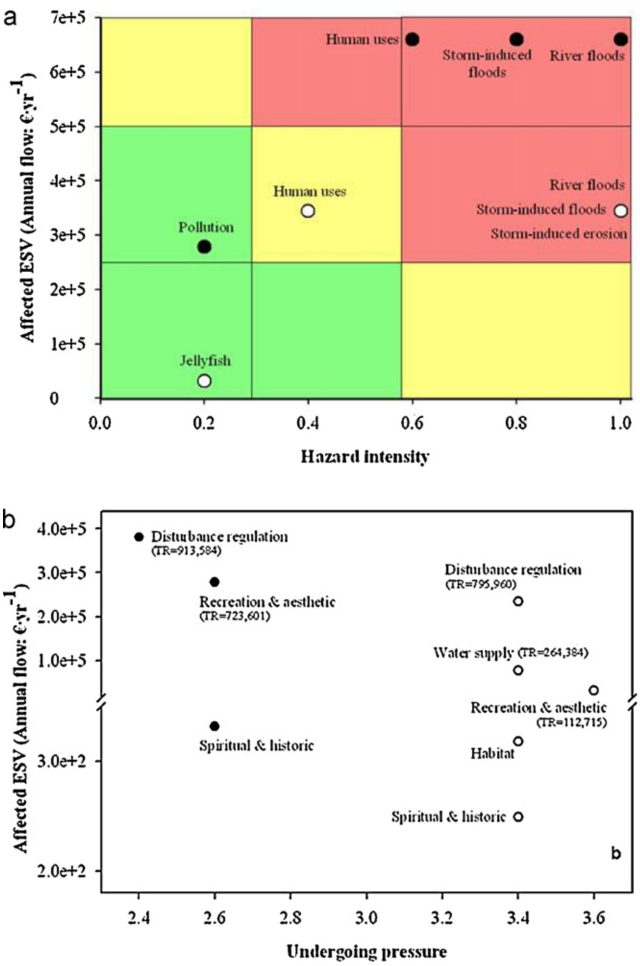


**Fig. 6 – (a) Hazard prioritization based on intensities and affected ecosystem services (ESV). (b) Ecosystem services prioritization based on values (ESV) and supported pressures, with risk values of the most affected ones. Results are for northern (●) and southern (○) zones.**

$$TR_A = \sum_{a=1}^{a=n} (H_a \times ESV_A)$$

and per the entire social-ecological system (TRV being the risk for the entire system):

$$TRV = \sum R_a \text{ or } \sum R_A$$

In order to improve visualization of the riskiest hazards and the most affected ecosystem services and thereby ameliorate risk communication and management, both hazards and ecosystem services were prioritized. Coastal hazards were prioritized according to their intensities and their consequences (i.e. affected ESV) (Fig. 6a). Ecosystem services were prioritized based on their values (ESV) and the supported pressure due to affecting hazards (Undergoing pressure) (Fig. 6b).

Among hazards, *river floods* was the most risky in the north, followed by *storm-induced floods* and *human uses*, while in the south the riskiest events were *river floods*, *storm-induced erosion* and *storm-induced floods*. As for ecosystem services, in both zones *disturbance regulation* was the most affected, followed by *recreation and aesthetic* in the north and by *water supply* in the south. Concerning the entire beach, the north involved a greater risk than the south ($TRV_N$ = 1.638048 and $TRV_S$ = 1.174987).

## 4. Policy implications and conclusions

This paper proposes a multi-hazard risk assessment for beaches in order to assist policy and decision-making in the framework of integrated beach management processes. The need for holistic approaches is undeniable in environmental policies as well as for beach management (Hildebrand and Norrena, 1992; Ariza et al., 2008; Forst, 2009). Moreover, risk reduction processes require a systemic vision, integrating natural and socioeconomic variables (Pérez-Maqueo et al., 2007). Since the concept of ecosystem services could improve this integration, this methodology combines coastal hazards and beach ecosystem services in a risk analysis framework. The identification and prioritization of the highest risk hazards and the most affected ecosystem services allows ad hoc managers' plans and actions, improving risk and coastal management.

Based on the methodology proposed, the riskiest hazards at S'Abanell beach were *river floods*, *storm-induced floods* and *storm-induced erosion* in the south, and *river floods*, *storm-induced floods* and *human uses* in the north (in decreasing order). This prioritization is in accordance with the RISKCAT program (Natural Risks in Catalonia), which describes this area as a high river flood risk area, and a high danger zone related to coastal erosion and coastal flooding (Generalitat de Catalunya, 2008).

For ecosystem services, *disturbance regulation* and *recreation and aesthetic* (especially in the northern zone) were the service more affected, barely ahead of *water supply*, *habitat* and *spiritual and historic*. S'Abanell beach brings at least €1,003,043 each year (in 2009) to Blanes' citizens, from which *disturbance regulation* (€95,165/ha yr) and *recreation and aesthetic* (€69,577/ha yr) were the most valuable services, though *habitat* and *spiritual and historic* services seem to be undervalued due to the limited availability and reliability of the literature. Considering the total risk scores, the northern zone of S'Abanell involved a greater risk than the southern one, mainly due to the great importance of *disturbance regulation* and *recreation and aesthetic* services. This risk-based prioritization is critical for beach management at S'Abanell because it is an important tourist destination, mainly managed to guarantee this industry (Valdemoro and Jiménez, 2006).

Any risk reduction or mitigation measure at S'Abanell beach in an integrated management process should be part of a risk management plan based on effective communication, coordination and cooperation between at least three administrative levels: the Directorate General for Coasts of the Spanish Ministry of the Environment (national government), the Ministry of Environment and Housing and the Ministry of Town and Country Planning and Public Works of the Catalan autonomous government (Generalitat de Catalunya) and the Department of Environment of the Municipality of Blanes (local government). However, although new beach management approaches have been introduced, beach management in Spain is still carried out by various private and public organisms, which lack an organized, regular flow of information, and clear, shared mid-term policies. Responsibilities are widely dispersed and beach management lacks proactive management tools that allow coordination between the different authorities, thus hindering the effective implementation of an integrated beach management process (Barragán, 2003; Ariza et al., 2008; Doménech et al., 2009).

New beach management tools as well as a critical assessment of actual models are needed to ensure an efficient and equitable use of ecological services, minimizing the environmental impacts exerted by human activities. The methodology proposed could contribute to the development of a pathway in order to move away from a competence-based model to integrated management based on processes, applying the ecosystem approach to the sustainable management of beach social-ecological systems. Additional work at other beaches is required for comparative purposes in order to check consistency and to confirm the potential of this approach for generalization. Despite these limitations this methodology should provide a procedure for systemic and spatially explicit coastal risk assessment, thereby improving risk analysis and helping managers make responsible decisions as part of an integrated beach management process.

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