Ocean & Coastal Management 54 (2011) 241–249

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Spatial analysis of recreational boating as a first key step for marine spatial planning in Mallorca (Balearic Islands, Spain)

P. Balaguer [a,*], A. Diedrich [a], R. Sardá [b], M. Fuster [c], B. Cañellas [c], J. Tintoré [a,c]

[a] Sistema d'Observació i Predicció Costanera de les Illes Balears (SOCIB), Edifici Naorte, Bloc A, 2on n°3, ParcBit. Carretera de Valledemossa km 7.4, 07021 Palma de Mallorca, Mallorca, Spain

[b] Centre d'Estudis Avançats de Blanes, CEAB (CSIC), Accés a la Cala Sant Francesc, 14, 17300 Blanes, Girona, Spain

[c] Institut Mediterrani d'Estudis Avançats, IMEDEA (CSIC-UIB), Miquel Marquès 21, 07190 Esporles, Mallorca, Spain

ARTICLE INFO

Article history:
Available online 13 December 2010

ABSTRACT

Recreational boating is an important, growing leisure activity on the island of Mallorca, Balearic Islands, Spain. This spatial analysis of anchoring of recreational boating along the coast of Mallorca is intended to generate new data to contribute to the achievement of a comprehensive marine and coastal spatial planning on the island in addition to providing important information related to the pressure of increasing demand for anchoring space that, if not properly managed, could jeopardize the coastal and marine environments. The study combines data from the natural (habitats, geology), physical (wave patterns), and social sciences (survey interviews), using Geographic Information Systems (GIS) as the main analytical tool. The final result is an estimate of the average amount of seabed available for anchoring during the highest levels of boating activity in Mallorca (i.e. summer high season) based on a number of different sustainability scenarios (i.e. average distance between boats, weather conditions). In addition to being applicable to any location wishing to manage recreational boating activity, the methodology presented in this study represents an integrated, multidisciplinary approach which could be applied to a number of management scenarios with a spatial dimension in marine environments.

1. Introduction

Recreational boating is a growing sector of the leisure industry which, in the absence of appropriate management measures, can result in a number of negative environmental and social impacts in the coastal zone (Davenport and Davenport, 2006; Hall, 2001; Roig-Munar, 2003). Marine areas (caves and bays) close to the coast tend to be sheltered from wind and waves, making them ideal anchoring locations for recreational boaters. Sensitive marine habitats near the coasts may be threatened by structural damage from anchors (Milazzo et al., 2004) and, in this context, measures should be implemented to regulate and manage this activity appropriately, and to avoid potential conflicts among environmental, social, and economic goals.

In general terms, human activities in marine environments are regulated on a sectoral basis without much consideration of how these activities may conflict with others that are sharing the same space (Douvere, 2008; Ehler, 2008). In the Balearic Islands, Spain, which are located in the Western Mediterranean, similar to many coastal areas, there is no clearly defined spatial vision of marine areas, which means that the distribution and prevalence of some activities such as anchoring are not well-known (Douvere, 2008). Spatial studies about human activities in marine environments will contribute to improving future planning and decision making in marine and coastal environments.

One of the most prevalent and destructive effects of recreational boating is the destabilization of the seabed due to anchoring (Davenport and Davenport, 2006; Lloret et al., 2008; Roig-Munar, 2003; West et al., 2002; Widmer and Underwood, 2004), particularly the degradation of seagrass habitats, which are particularly sensitive to structural damage from dragging anchors (Backhurst and Cole, 2000; Bishop, 2008; Davenport and Davenport, 2006; Duarte, 2002; Walken et al., 1989; West et al., 2002; Widmer and Underwood, 2004). Recreational boating can also contribute to the transmission of invasive species which can compete with local seagrass or other fauna, causing irreversible changes or decline of the ecosystem (Davenport and Davenport, 2006; Klein and Velarque, 2008; West et al., 2002; Williams, 2007), lead to pollution from anti-fouling paints (Cu) and waste waters (N) (Leon and Warnken, 2008; Saphier and Hoffmann, 2005; Warnken et al.,

* Corresponding author.
E-mail address: vdctpbh4@uib.es (P. Balaguer).

0964-5691/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ocecoaman.2010.12.002

2004), noise pollution (Davenport and Davenport, 2006; Lloret et al., 2008) and disturb the natural behaviour of birds, cetaceans and species that move along the surface (eg. sea turtles) (Leon and Warnken, 2008). High concentrations of some pollutants from anti-fouling paints can also accumulate up food chain, resulting in potential negative impacts on the health of humans and other organisms (Leon and Warnken, 2008; Lloret et al., 2008). From a socio-economic perspective, the negative effects of overcrowding of recreational boats on the wellbeing and safety of visitors to anchoring areas have also been documented (Ashton and Chubb, 1972; Tseng et al., 2009).

This spatial analysis of anchoring of recreational boating along the coast of Mallorca, the largest of the Balearic Islands (see next section), is intended to generate new data to contribute to the achievement of a comprehensive marine and coastal spatial planning on the island. It will provide important information related to the pressure of increasing demand for anchoring space that, if not properly managed, could jeopardize the coastal and marine environments (Douvere, 2008) and affect the wellbeing and safety of users if spaces become overcrowded. Specifically, this study will measure the space available for anchoring around the island of Mallorca (resource base), taking into account environmental, physical, and social dimensions, and estimate the pressure exerted upon this space by the recreational boating sector (pressure). In methodological terms, the main objectives of this study were to (a) determine the available seabed for anchoring (resource) in order to estimate the total area of the anchoring zones around Mallorca, based on two types of seabed: seagrass and sandy, (b) estimate the pressure upon this resource from the recreational boating sector, (c) establish spatial scenarios for estimate the maximum number of boats that can anchor along the coast of Mallorca using three spatial anchoring scenarios and (d) use wave climate characterization to estimate the total number of days suitable for anchoring based on wave climate characterization models. The study combines data from the natural (habitats, geology), physical (wave patterns), and social sciences (survey interviews), using Geographic Information Systems (GIS) as the main analytical tool.

2. Study zone

The Balearic Islands constitute an archipelago of Spain made up of four main islands. Mallorca is the most extensive island with an area of 3640 km^2 and a coastline of 722 km (1:5000 scale). The island has a rhomboid shape, with the vertex directed towards the four cardinal points, and has four well defined coastal zones (NW, SW, SE and NE) (Fig. 1), with the largest bays located in the NE and SW. According with a 1:5000 scale topographic map, the North-western coast (between sa Dragonera and Formentor Cape) has a coastline of 170 km, the Northern coast (between Formentor Cape and Capdepera Cape) has a coastline of 151 km, the Eastern coast

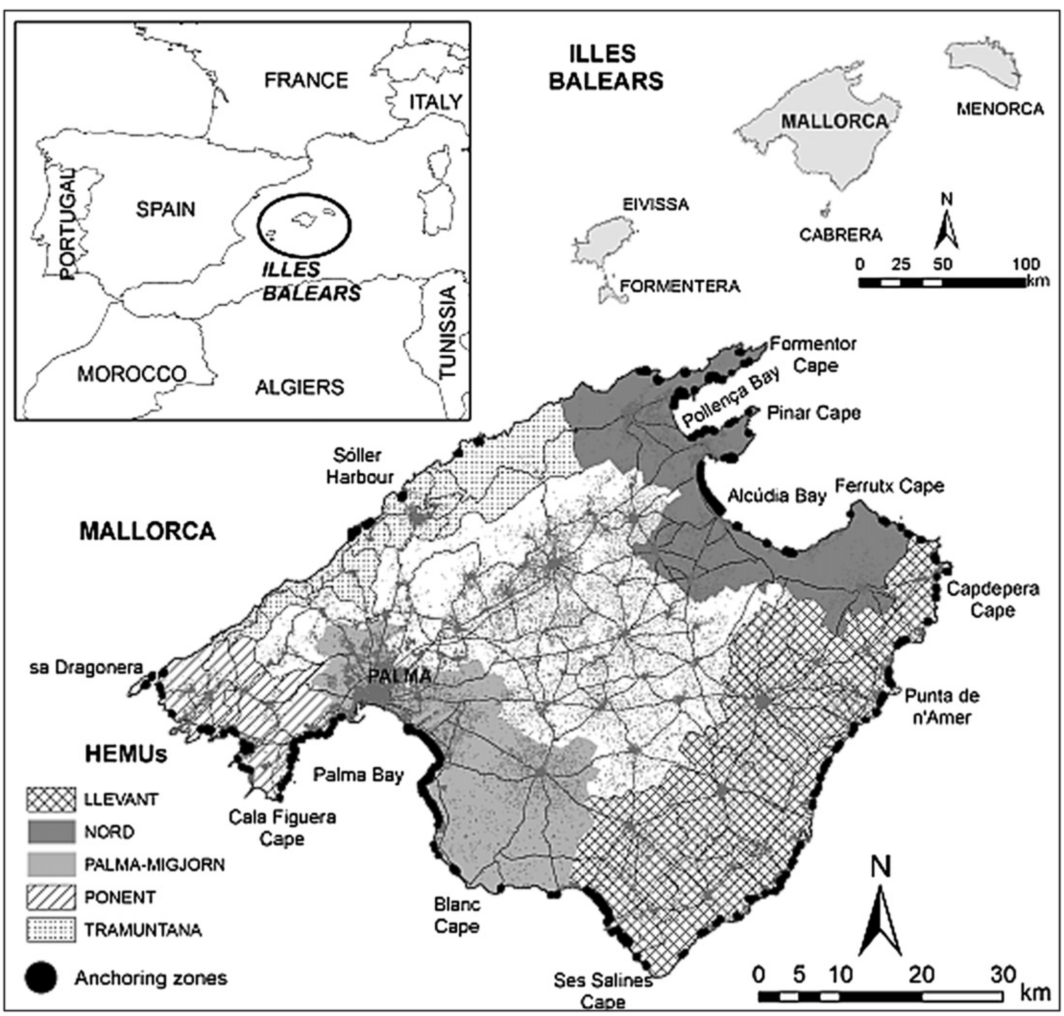

Fig. 1. Location of the Balearic Islands, Mallorca island and the anchoring zones of HEMUs (Homogeneous Environmental Units) of Mallorca identified for the study of recreational boating.

(between Capdepera Cape and Salines Cape) also has a coastline of 148 km, and the southern coast has a coastline of 253 km (Fig. 1). The island has 862,397 inhabitants, with the majority (401,270) residing in the municipality of Palma, which borders the Bay of Palma (population register, 2009). Fifty-one percent of the surface of the island remains in a natural state, and the remaining forty-nine percent can be considered to be artificial or modified coasts, built or transformed by man (Balaguer et al., 2008).

The majority of the marinas on the island (43 of 45 (CITTIB, 2009)) are located along the SW, SE and NE coastal zones (Fig. 2), providing relatively easy access to the majority of the island. The two remaining marinas are located within Sóller Habour on the NW coast. This side of the island is characterized by high coasts with few natural refuges from swell and strong onshore winds (Fig. 2). The SE coast has the highest relative concentration of suitable anchoring zones (Fig. 1).

The Balearic Islands, particularly the Bay of Palma in Mallorca, are a globally significant hub for recreational boating. In 2008, the industry generated over 537 million € and the number of recreational boaters to the Islands was 324,522 (CITTIB, 2009). In addition to being one of the most lucrative sectors of the tourism industry, recreational boating is a popular activity for the resident population. Although social considerations associated with crowding and safety are also important, impact studies in the Mediterranean, including the Balearic Islands, are often directed towards the negative effects of anchoring and propellers on *Posidonia oceanica*, an endemic, endangered seagrass which is prevalent in many anchoring zones (Ceccherelli et al., 2007; Francour et al., 1999; Marbà et al., 2002; Montefalcone et al., 2006; Lloret et al., 2008; Roig-Munar, 2003). Seagrass meadows are one of the most significant elements of the benthic natural environment of Balearic coasts, the majority of them growing on carbonate sediments of biogenic origin (Marbà et al., 2005). There are extensive and dense meadows around the archipelago up to depths of 40 m, and many of them have been degraded as a result of anchoring and pollution from recreational boating, which is largely unregulated around the islands (Procaccini et al., 2003; Sánchez-Camacho, 2003). In addition, some areas have been affected by the invasive seaweed *Caulerpa taxifolia* and *Caulerpa racemosa*, an impact which has also been attributed to anchor activity (Mas et al., 1993).

3. Legal framework

There is currently no legislation regarding the total number of boats that can access the anchoring areas around the island. Limitations to boat anchoring are generally associated with the legislation related to the delimitation of bathing areas. In Spain, the management of bathing zones is complex (Yepes and Cardona, 2001) due to the coexistence of several regulations from different administrations. The Spanish Coastal Law 22/1988 (BOE, 1988) is compulsory throughout the country and establishes the dimensions and distances for the shoreline bathing area. This law forbids the use and navigation all boats in bathing areas, only allowing some of them to navigate to shore in clearly marked channels. When bathing areas are not marked by buoys, they should extend 200 m when beaches are present on the coast, and 50 m for other types of coasts. At the regional level, Decree 72/1994 of May 26th is compulsory in the Balearic Islands (Yepes and Cardona, 2001). This decree includes the Coastal Law (BOE, 1988) and also states that, in the case of coves where the distance between the outer capes is less then 200 m, the entire area should be classified as a bathing area.

Despite the restrictions stipulated by these laws for anchoring zones without physically delimited bathing areas (i.e. buoys), oblique aerial photographs from 2006 to 2007 (photographs taken for this study by *Surveillance and Cleaning Service* (SCS) of the *Department of Environmental Quality and Coastal Affairs* of *Council of Environment* of the *Balearic Government*) indicate that many boats disregard or are unaware of them and anchor in shallower, restricted waters closer to shore. In addition to these national and regional laws there are a number of additional regulations that limit spatial use of recreational boating zones. These include Order 1964 of the Ministry of Commerce (Yepes and Cardona, 2001) that notes that bathing zones without marks (buoys) are prohibited to crafts with propeller and Presidential Order of 1972 (Yepes and

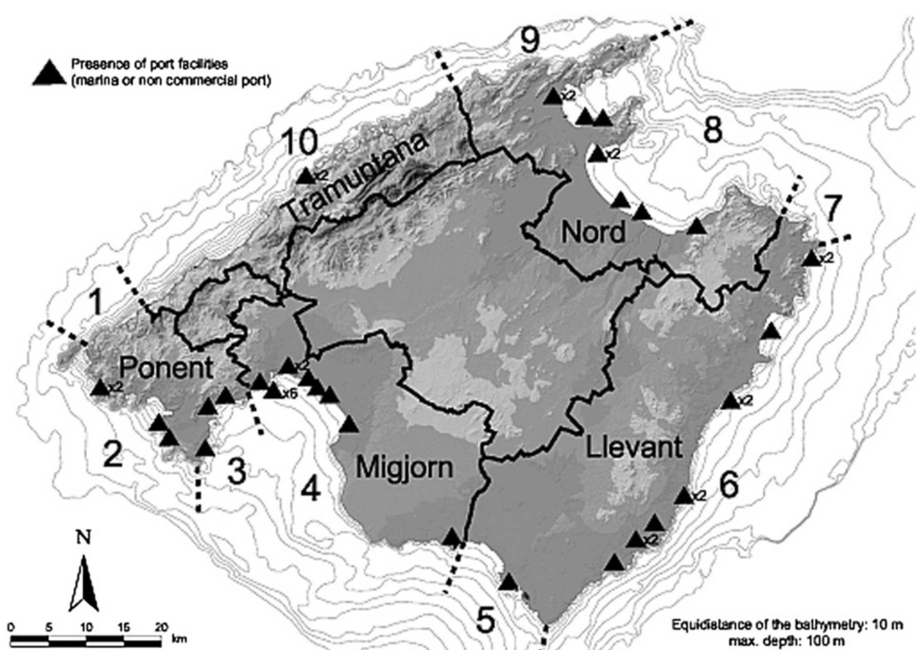

Fig. 2. Boundary delimitation of the coastal exposure zones (1–10) used for the study of wave climate (determining the maximum Hs for anchoring), location of port facilities where marinas and non commercial ports are located. Triangles with a number indicate the number of marinas that are located within a port facility.

Cardona, 2001) lists the rules for the people's safety in bathing areas, preventing the presence of motorboats and water skiing.

With respect to *P. Oceanica*, the species is included on the Red List of threatened marine species, is considered a priority natural habitat in Annex 1 of the EC Directive 92/43/EC (ECC 1992), and is also protected by the Spanish National Law 42/2007 of Natural Heritage and Biodiversity. There are currently four anchoring areas around the island that are *Marine Special Areas of Conservation* (SAC) of the Natura 2000 Network (Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora). These sites have ecological buoys, installed in order to preserve seagrass meadows as part of the *LIFE Posidonia Project*, established at the end of 2006 (http://www.balearslifeposidonia.eu/index.php, accessed 22.01.10). Although for stability reasons users generally prefer to anchor in sandy areas rather than on seagrass, anchoring in the other areas around the island is largely unregulated and many boats continue to anchor in these habitats (according to oblique aerial photographs taken in the summers of 2006 and 2007 by SCS of the Balearic Government).

4. Methods

The focus of this study is on sections of the coast that are sheltered from prevailing winds and swells which is where recreational boats tend to be anchored. The methods, described in the following subsections, were designed to estimate (a) the resource (seabed) available for recreational boating in Mallorca and (b) the pressure (demand) for that space. Additional analyses were conducted to estimate (c) the number and relative proportion of boats that can anchor around the island based on three spatial scenarios (i.e. the distance between anchored boats) and (d) the number of days suitable for anchoring based on wave climate characterization.

4.1. Resource (seabed) available for recreational boating in Mallorca

Anchoring zones in Mallorca have been identified using georeferenced oblique aerial photographs, taken during the summers of 2006 and 2007 (June–September) (SCS of the Balearic Government). One hundred and sixty-three anchor areas have been identified along the coast of Mallorca (Fig. 1), based on the presence of anchored boats in the photographs.

The main types of anchoring zones identified include sheltered coasts (e.g. natural harbours, bays, coves), exposed coasts such as open beaches, popular due to their aesthetic and natural characteristics, and areas within close proximity to urban areas and/or ports, which tend to be frequented despite having a high degree of exposure to swell and onshore winds. In order to simplify the subsequent analysis, the anchoring zones have been grouped according to five HEMUs (Homogeneous Environmental Management Units) of Mallorca (Balaguer et al., 2008) (Fig. 1). The heterogeneity of the coastal zone has been rationalized by the adoption of HEMUs defined by (Brenner et al. 2006) as areas with similar land attributes (natural, socio-economic, administrative, etc.). The use of coastal HEMUs, has been proposed in Mallorca as a potential higher order spatial scale for defining boundaries for ICZM initiatives (Balaguer et al., 2008). The HEMUs correspond with the major tourism zones and municipal boundaries of the Island (defined by *Council of Tourism* of the *Balearic Government*). They also correspond with four main coastal exposure zones (i.e. NE, NW, SE, SW) of the island. In this context, they are also a relevant spatial category for this study. It is important to note that the boundaries of coastal zones and HEMUS can overlap (Figs. 1 and 2).

The total seabed available for anchoring, understood as sensitive seabed (presence of seagrass) and non-sensitive (sandy seabed), has been mapped for all the identified anchoring zones using GIS (ArcGIS 9.1) and digital aerial orthophotographs taken in 2002 and 2006, provided by the *Territorial Information Service of the Balearic Islands* (SITIBSA) and the *National Plan of Aerial Orthophotography* (PNOA) respectively. Orthophotographs taken in 2002 have a maximum resolution of 40 cm per pixel, and othophotographs taken in 2006 have a maximum resolution of 50 cm. Both collections of orthophotos are suitable for working on a 1/5000 scale, but on a 1/2000 scale maintain a good image resolution. It was necessary to use aerial photographs from two different flights and years (2002 and 2006) because specular reflections produced by the angle of incidence of sunlight did not always permit a clear view of the seabed. The use of aerial photographs from different years for defining the types of seabed is feasible because the growth of seagrass is a very slow process (Hemminga and Duarte, 2000; Infantes et al., 2009; Marbà et al., 2005). For example, Sánchez-Camacho (2003) observed a decrease in total *Posidonia oceanica* coverage in Mallorca of between 11 and 18% for the period between 1956 and 2001. These studies tell us that the changes in cover of seabeds are difficult to perceive through aerial photos separated by a period of 4 years.

Bathymetric maps for Mallorca and for most coastal areas normally begin at a depth of 5 m. The survey of coastal waters is difficult because survey boats equipped with acoustic echo sounders cannot operate in shallow waters (Muirhead and Cracknell, 1986; Pillai and Antonion, 2000). Due to the absence of detailed bathymetric data close to the coastline, demarcation of the landward boundary of anchoring areas was based on the presence of boats seen in the oblique aerial photographs (over 4000 photographs) taken during the summers of 2006 and 2007, for the SCS of the Balearic Government.

The demarcation of seaward boundaries of anchoring corresponds with the line that connects the outer capes of the bays, coves or natural harbours, beyond which boats tend to be less protected from the wind and waves, backed up by the presence of anchored boats in the oblique aerial photographs (SCS). Anchoring areas located in open coasts (exposed to onshore winds and waves) the outer (seaward) boundaries have been determined to a depth of 10 m, a limit that is also backed up by the oblique aerial photographs (SCS).

4.2. Pressure (demand) for space: total number of berths in Mallorca and the proportion of these boats that navigate around the island

The number of registered boats (dinghies transported by trailer (little motor – and sailboats, pneumatics) and moored boats) is not necessarily an accurate reflection of the potential demand for anchoring. In Spain there are no taxes associated with maintaining an active registration of a boat and it is not required to cancel the registration when the boat is no longer operational (destroyed, damaged, disappeared, stolen, etc.). Thus, there is a risk associated with determining the potential demand for anchoring from the list of registered boats, since a number of the boats that are accounted for may be non-existent or not active and therefore do not cause any pressure on the marine environment.

The total number of berths in recreational marinas in Mallorca represents the total potential demand for anchoring [data obtained from (CITTIB, 2009)]. However, not all boats located in ports/marinas operate at the same time or with the same frequency, and there is a significant proportion that hardly ever, or never sail. Statistics related to the proportion of boats that navigate out of each marina were non-existent at the time of this research so a survey was conducted in the summer of 2009 to determine this proportion. In the absence of data, techniques like surveys, are often used for studies focused on marine activities within a framework of marine and coastal spatial planning (Dalton and Thompson, 2010; Widmer and Underwood, 2004). Face to face interviews were conducted with representatives of 29 of the 45 marinas (CITTIB, 2009) on the island (which represent 9107 berths, or 64% of the total berths), who were asked to estimate (a) the percentage of boats leaving their marina to navigate on the busiest day of the high season, and (b) the percentage of boats leaving the harbour that remain sailing around Mallorca. The representatives were not included in the survey chose not to participate. These data were extrapolated and used to estimate the potential demand for anchoring space around the island.

4.3. Establishment of spatial scenarios

GIS (ArcGIS 9.1) was used to estimate the capacity of the seabed of Mallorcan coasts to accommodate anchored boats in accordance with three spatial scenarios: 25 m, 50 m or 75 m between anchor points. The scenarios were mapped using digital aerial orthophotography (2002 and 2006 of SITIBSA and PNOA respectively) and digital maps and three raster grids (which cover the entire coastal zone of the island), were created using the Spatial Analyst Tool of ArcGis 9.1. The grids were converted into polygonal shapes and the geographical (X,Y) centroid of each cell was calculated. The centroids were exported as standalone point shapes, which were clipped with the available anchoring zones (sandy and sensitive seabeds) in order to estimate how many boats can anchor in each of the three spatial scenarios (Fig. 3).

4.4. Number of days suitable for anchoring: characterization of the wave climate

It is important to note that all of the anchoring zones identified for this study will not be suitable for anchoring at the same time. Wave climate conditions around the island determine the areas that are suitable for anchoring on any given day in the different coastal exposure zones (Fig. 2). Wave data used in this study is part of the HIPOCAS Project (*Hindcast of Dynamic Processes of the Ocean and Coastal Areas of Europe*). This data base contains a high resolution, spatial and temporal, long term hindcasted data set (Soares, 2008). The HIPOCAS data covers a time period ranging from 1958 to 2001 on an hourly basis, providing 44 years of wave data with high spatial resolution. It is currently the most complete wave data base available for the Mediterranean Sea (Cañellas et al., 2007).

HIPOCAS data was produced by means of dynamical downscaling from the *National Centre for Environmental Prediction* (NCEP) and the *National Centre for Atmospheric Research* (NCAR) global reanalysis using the regional atmospheric model REMO. Hourly wind fields from the REMO (U_{10}) were used as a forcing by the *Ente Publico Puertos del Estado* for the third generation wave model WAM. Data contained in the HIPOCAS node consist of a set of sea states defined hourly by significant wave height (Hs), spectral peak period and direction. An estimation of the long term distribution for the significant wave height was carried out making use of the lognormal probability distribution (Castillo and Hadi, 1997), in order to obtain the mean significant wave height and standard deviation. The long term probability distribution defines the most probable sea state throughout a year and is also suitable for calculating the number of

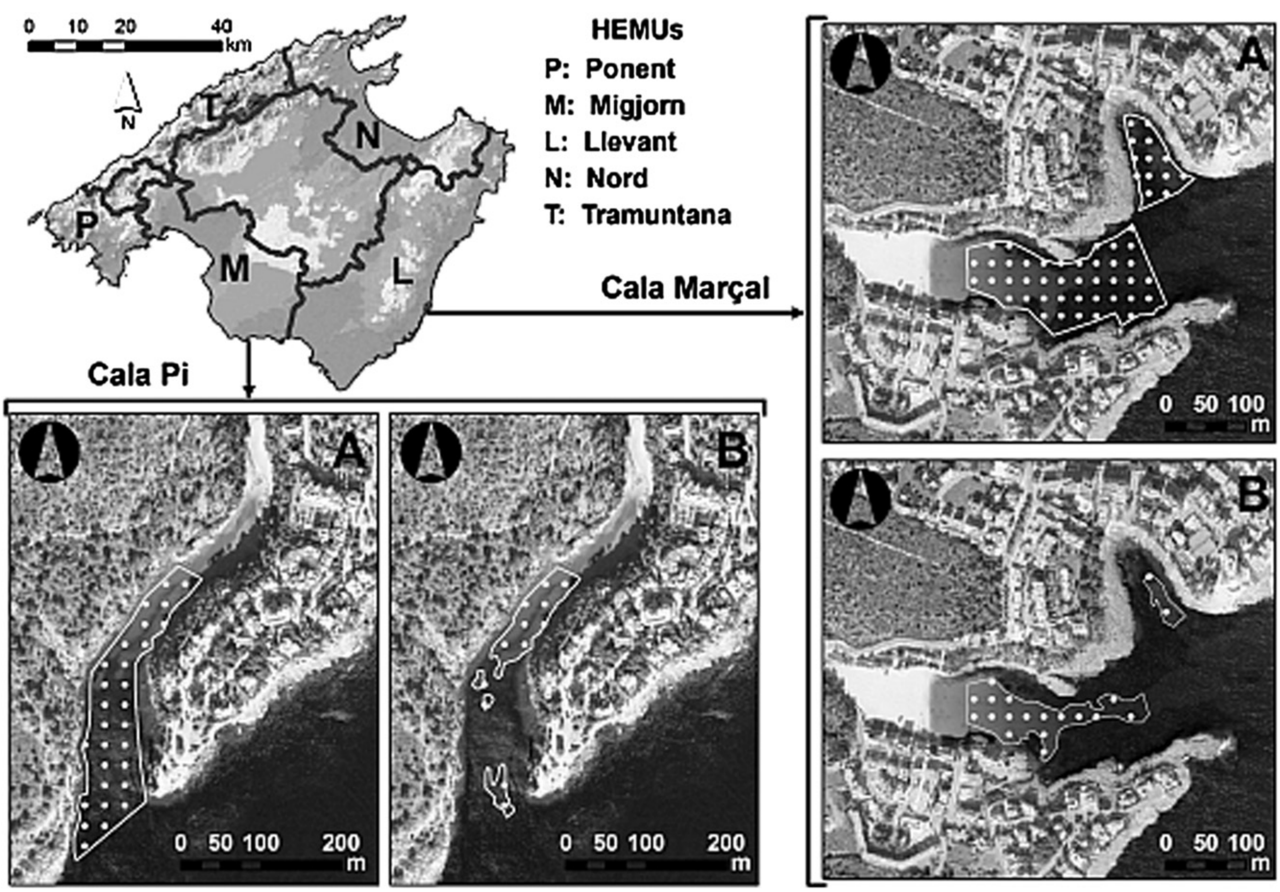

Fig. 3. Example of delimitation of the seabed available for anchoring and implementation of spatial scenarios (mesh developed with GIS) in two areas of study located in the Hemus of Migjorn and Llevant of Mallorca. A) Delimitation of whole seabeds/sensitive seabeds (include seagrass meadows). B) Delimitation of sandy seabeds. Figure shows the mesh corresponding to the anchoring hypothesis for the separation of 50 m.

days where Hs is not reached or surpassed for a determined area. This methodology was used to calculate the number of days not suitable for anchoring (Hs > 0.5 m) in the summer period ranging from June to September (122 days total) in the Balearic Coasts.

5. Results

The results are presented with respect to the four main methodological objectives described in the previous section: a) the resource (seabed) available for recreational boating in Mallorca, b) pressure (demand) for space, c) spatial scenarios: balancing resource availability with pressure and d) wave climate.

5.1. The resource (seabed) available for recreational boating in Mallorca

The total area of the seabed (i.e. areas with and without seagrass) and the area of sandy seabed (i.e. total seabed with no seagrass present) calculated for each HEMU in Mallorca are shown in Table 1. The total seabed available for anchoring around the island is 19.4 km^2, with 9.5 km^2 of sandy seabed. This means that 49% of the seabed suitable for anchoring in Mallorca is sandy, with the remaining 51% being largely constituted of seagrass, a sensitive habitat. Table 1 shows that the HEMU Nord has the greater area of total and sandy and seabed, followed, in order from largest to smallest area, by the HEMUs of Llevant, Migjorn, Ponent and Tramuntana.

5.2. Pressure (demand) for space

Table 1 shows that the HEMU with the largest number of berths is Migjorn with 14 marinas and 5.056 berths (CITTIB, 2009). This is largely due to the presence of the major port of Palma. Following this, in descending order, are the HEMUs of Llevant, Nord, Ponent and Tramuntana. The results of the survey are representative of 29 of the 45 marinas on the island, which comprise 64% of the total berths (9107 of the total berths (CITTIB, 2009) (Table 1)). The average response to the question regarding the percentage of boats leaving their marina to navigate on the busiest day of the high season was 49% with 87% of these vessels remaining in the waters around Mallorca. If those results are extrapolated to include the total number of berths in Mallorca (i.e. all the marinas, 14,270 berths (CITTIB, 2009) all of them occupied by recreational boats), this amounts to an estimated total of 6082 vessels navigating around the island on the busiest day of the high season of summer. Also, it is important to note that there is a high demand for berths (over 6000 requests) and some projects to expand marinas are being developed (FEAPDT, 2008).

5.3. Spatial scenarios: balancing resource availability with pressure

Three spatial scenarios were established based on distances of 25, 50 and 75 m between anchoring points and, using the methods described previously, and the total number of boats that could fit into the anchor zones identified for this study was calculated for each HEMU. Table 1 shows that, for the spatial scenario of 25 m between anchor points, the total available seabed could support 31,043 boats (217% of the total of berths on the island), where the sandy seabed could support 15,266 (107% of the berths). For the spatial scenario of 50 m the total seabed could support 7764 boats (54% of the berths) and the sandy seabed 3844 boats (27% of the berths) (Table 1). Finally, for the spatial scenario of 75 m between anchors, 3443 boats could anchor (24% of berths) on the total seabed and 1679 boats (12% of the berths) on sandy seabeds.

The potential pressure (i.e. number of boats using the space) was estimated using the results of the survey interview implemented with sailing clubs and marinas. The results from the 29 clubs and marinas that participated were extrapolated, resulting in an estimated value of 49% of boats leaving the ports on a busy day in high season (i.e. maximum potential movement on weekends of the high season (June–September)), 87% of which remains in the coastal waters of Mallorca. Thus, from a total 14,270 boats moored in marinas in Mallorca in 2008 (CITTIB, 2009) we estimate that 6992 boats sail regularly (49% of total) and 6082 boats (87% of 6992) regularly sail in the coastal waters of Mallorca. If we apply these results to the relative proportion of berths in each HEMU (Table 1) the estimate maximum transit of boats during the high season in the HEMU of Ponent are 1165 boats, 1013 of them sails in the coastal waters of Mallorca. In the HEMU of Migjorn maximum number of movement of boats are 2482 (weekend in high season) and 2159 of the sails in coastal waters of Mallorca. In the HEMU of Llevant, 1569 boats sails regularly in the high season, 1365 of them do it in coastal waters of Mallorca. In HEMU of Nord maximum number of movements is 1468 and 1303 of them sails around Mallorca. And finally the maximum number of movements in the HEMU of Tramuntana, the HEMU with the lowest number of berths, is 278 boats, 242 of them sails around coasts of Mallorca.

5.4. Wave climate characterization

Table 2 shows the total number of suitable and non-suitable days between June–September, the high season for boating, based on the model and wave height criteria defined previously (Hs > 0.5 m), separated by HEMUs and the coastal exposure zones within each HEMU (Fig. 2). Coastal exposure zones with the most suitable days for anchoring can be found in coastal exposure zone 1 in Ponent and zone 6 of Llevant, both with 110 suitable days (Fig. 2

Table 1
Maximum number of boats which can anchor in the coast of Mallorca, based on the distance between them (spatial scenarios).

Anchoring zones (HEMUs)		Seabed area (km^2)	Distance between anchors			Number of berths (2008)	Boats sails regularly in coastal waters
			25 m	50 m	75 m		
Ponent	Sandy seabed	1.1	1.759	447	184	2.377	1.013
	Whole seabed	2.9	4.596	1.155	513		
Llevant	Sandy seabed	2.8	4.602	1.176	497	3.203	1.365
	Whole seabed	5.3	8.485	2.118	937		
Nord	Sandy seabed	3.0	4.741	1.189	522	3.057	1.303
	Whole seabed	6.5	10.359	2.592	1.151		
Tramuntana	Sandy seabed	0.6	973	238	112	568	242
	Whole seabed	1.0	1.659	409	184		
Migjorn	Sandy seabed	2.0	3.191	794	364	5.065	2.159
	Whole seabed	3.7	5.944	1.490	658		
Total results	Sandy seabed	9.5	15.266	3.844	1.679	14.270	6.082
	Whole seabed (sensitive seabeds)	19.4	31.043	7.764	3.443		

and Table 2). Coastal zones with fewer suitable days for the anchoring are located in the zone 9 of Nord and zone 2 of Ponent with 92 and 93 days respectively (Fig. 2 and Table 2).

6. Discussion

The use of the coastline in Spain is becoming more intense, with accumulation of a greater number of users and uses (Barragán, 2003, 2004; Yepes and Cardona, 2001). In the case of recreational boating, continuous proliferation of this and additional activities in coastal waters increases the probability of conflicts and accidents (McKnight et al., 2007; Widmer and Underwood, 2004) as well as public statements of protest (Yepes and Cardona, 2001). In this context there is a need to understand and regulate coastal areas from a spatial perspective, in order to increase compatibility among uses and, where necessary, establish limits. Science can provide key contributions in order to establish limits through providing descriptive data and indicators to inform changes in current management or set up prescriptive management measures (Cole, 2003). The historical relationship between marine science and implementation of management policies is challenging and often conflictive, mainly due to the reality that scientific works often do not respond to the needs of the management (Ojeda-Martínez et al., 2009; Stojanovic et al., 2009). The aim of this work is to generate scientific information that responds to the need to spatially manage an important leisure activity in the coastal zone of Mallorca which, to date, is not subject to much regulation.

As mentioned previously, this study was designed to characterize the relationship between the area of available seabed for anchoring (resource) and the number of boats that can anchor in that area (pressure). Pressure (demand for anchoring) was based on (a) the total number of berths (CITTIB, 2009), (b) the use of oblique aerial photographs by SCS of Balearic Government and (c) a survey interview to managers of marinas for determining an approximation of boats that regularly sail. The relationship between pressure and resource was explored using three spatial scenarios of separation distances between anchors (25 m, 50 m and 75 m) (Table 1). Wave climate studies have determined the number of suitable days for anchoring (Hs < 0.5 m) during the summer season (June–September, 122 days) (Table 2). The pressure (i.e. maximum number of boats using the space at any given time) has also been associated with these data. As mentioned previously in the results section, the number of suitable days is an estimate and will vary in location depending upon the prevailing wind conditions on any given day. The relevance of this data is that it highlights an additional limit upon total available anchoring space, which is that not all space will be suitable for use at all times.

In the following subsections we discuss the limitations of the study and consider the implications of the results for the management of anchoring areas and possible limits to use of coastal areas.

Table 2
Number of suitable days for anchoring in the coastal zones (Fig. 2) of each HEMU according with the characterization of wave climate.

HEMU	Coastal exposure zone (Fig. 2)	Suitable days ($n = 122$)	Non-suitable days (Hs > 0.5 m)
Ponent	1	110	12
	2	93	29
	3	99	23
Migjorn	4	99	23
Llevant	5	104	18
	6	110	12
	7	106	16
Nord	8	98	24
	9	92	31
Tramuntana	10	101	21

6.1. Limitations

Boundary delimitation of anchoring areas has presented some inevitable limitations due to the lack of bathymetries between 0 and 5 m depth (Muirhead and Cracknell, 1986; Pillai and Antonion, 2000). The absence of bathymetric data means that the landward boundary of anchoring areas has been estimated based on the presence of boats in the photographs of the SCS of the Balearic Government (over 4000 oblique aerial photographs taken during summers of 2006 and 2007). These oblique aerial photographs were also used for the identification of anchoring areas along the coast of Mallorca, but their validity as a tool for the measurement of the actual number of boats in each area is limited because the photographs were taken between 8:00 and 13:00 and do not reflect the maximum number of boats at rush hours (we have noticed rush hour in anchoring areas starts approximately at 14:00). Given the limited validity of these photographs, pressure (anchored boats) has been linked directly with the total number of berths in Mallorca (Table 1) and the results of the survey interview. More objective measures taken from aerial photographs had they been more consistent and complete would have been more viable estimates of demand. The methods we used represent a necessary adaptation to the information that was available.

It is important to note that available anchoring areas have been identified for this study without taking into account the distances bounded by legislation because the aerial photographs indicate that existing regulations for anchoring are not enforced. As mentioned previously, with respect to the legal framework concerning anchoring on the coasts of Mallorca and Spain, Law 22/1988 of coasts (national law) and Decree 72/1994 (autonomic law) prevents anchoring less than 200 m from beaches and less than 50 m from other type of coasts and inside coves with outer capes separated less than 200 m. Observations made for several anchoring areas show that the distance to the coastline is not respected and users only obey it in those places where bathing areas are bounded by buoys. With respect to coves, there are numerous examples in the HEMU of Llevant (coastal exposure zone number 6 (Fig. 2) where the outer capes are separated by less than 200 m. Fig. 3 shows two examples of well-known anchoring areas where the outer capes are separated less than the minimum distance required by the Decree 72/1994 (200 m).

6.2. Reconciling the resource with the pressure: management implications

The spatial scenarios established for this study may be proportionately related to the degree of saturation: high (boats distributed every 25 m) middle (boats distributed every 50 m) and low saturation (boats separated every 75 m). There are some international examples of regulation of space and anchoring distance through recommendations of minimum distances between anchored boats. This is the case of the "*Mooring Buoy Planet Guide*" generated by *AWARE Foundation* and the *PADI International Resort Association* (2009) which proposes a minimum distance of 40 m. There is also the recommendation of the *U.S. National Park Service* (visit www.nps.gov for more information) which proposes a minimum distance of 30 m. Some of the *Marine Special Areas of Conservation* (SAC) of the *Natura 2000 Network* in the Balearic Islands have installed mooring or anchoring buoys (4 areas in Mallorca, 2 in Menorca, and 3 in Eivissa-Formentera) to prevent damage to the *Posidonia oceanica* meadows. Anchoring buoy systems are designed to support different sized boats (i.e. varied length and weight). The distribution of the existing anchoring buoys in SACs in Mallorca are not based on established spatial criteria and vary from 15 m to 100 m to accommodate different sizes of boat (distances established using ArcGIS 9.1). The oblique aerial photographs of SCS of Balearic Government show that in areas where anchoring is not regulated, boats may anchor less than 15 m apart. On Google Earth (popular and accessible tool) boats can be observed anchoring less than 10 m apart along the coast of Mallorca. Taking this variability into account (i.e. the reality and the observed behaviour), we consider that the anchoring scenarios we used for this analysis to be an appropriate coverage of the existing reality. The results of this study can be used to explore the amount of potential pressure on the seabed in relation to the spatial scenarios. These results estimate that 6082 boats sail in the coastal waters of Mallorca on a busy day in the high season. In 2008 in Mallorca there are 14,270 berths (CITTIB, 2009), all of them occupied by recreational boats. There is also a high demand for berths (over 6000 requests) and some projects for expand marinas are being developed (FEAPDT, 2008).

Applying the results of the survey interview to the values obtained from establishment of spatial scenarios in each HEMU (Table 1) it may seem there are enough sandy seabeds for anchoring. Sensitive seabeds are not considered in this calculation since, in the absence of buoys, they can't be considered suitable for anchoring from an environmental perspective. According with the estimates obtained from the survey, in the HEMU of Ponent there are 1013 boats regularly sail on a busy day in the high season (maximum estimated pressure), which implies that these boats could be distributed in sandy areas with a separation between anchor points of about 25 m (Table 1). In the HEMU of Llevant, the maximum estimated pressure is 1365 which, given the available space, would allow a separation of between 25 m and 50 m between anchor points (Table 1). The same calculations for the HEMU Nord (maximum estimated pressure is 1303 boats) correspond to a separation of between 25 m and 50 m, and in Tramuntana (maximum estimated pressure is 242 boats) between 25 m and 50 m (closer to 50 m) between anchor points (Table 1). Finally, in the HEMU of Migjorn estimates indicate that 2159 boats of its marinas sail regularly, and could anchor on sandy beds with a separation slightly larger than 25 m (Table 1). Is important to note that HEMU of Migjorn contains 35% of the total of berths of the island. This HEMU, together with part of the HEMU of Ponent contains the Bay of Palma and is shared by 3 municipalities (from W to E: Calvià, Palma and Llucmajor). The population of coastal urban nucleus of the Bay of Palma is 386,148. The area is the most important hub of recreational boating of Mallorca and Illes Balears with 10 port infrastructures hosting 16 sailing clubs and marinas (non commercial ports) (Fig. 2) which contain 5.580 berths (39% of total of Mallorca) (CITTIB, 2009). These characteristics mean that the Bay of Palma has a higher probability of saturation of anchoring zones.

Measures designed to protect the marine environment from negative impacts of anchors are generally directed towards the installation of mooring buoys and the promotion of environmental awareness and educational programs for recreational boaters (Francour et al., 1999; Milazzo et al., 2004; Montefalcone et al., 2006; Lloret et al., 2008). In the Balearic Islands there are 10 marine SACs of the Natura 2000 Network where there are ecological mooring buoys. Beyond the scope of Mallorca and the Balearic Islands, the presence of mooring buoys in the western Mediterranean is common in the region of Liguria (NW Italy) in areas characterized by presence of seagrass (Montefalcone et al., 2006) and in small coves included into Integral Reserves the MPA of Cap de Creus (Girona, Spain) (Lloret et al., 2008). Educational programs are often considered to be the most appropriate measure (Francour et al., 1999; Milazzo et al., 2004; Montefalcone et al., 2006; Lloret et al., 2008) since the installation of mooring buoys limits users and therefore considered to be too restricting (Milazzo et al., 2004). Although some authors propose a combination of both measures; environmental education programs for users of light or small boats and the installation of buoys only to minimize the impact of large boats which use big anchors.

The results of this study indicate that there is enough sandy seabed to accommodate the maximum estimated number of boats that navigate in the high season, if they anchor between 25 and 50 m apart (Table 1). This distance corresponds with the low end of the recommended distances cited earlier. However, these estimates do not take into account the fact that personal preferences and weather conditions (see Table 2) as well as actual distance from port will influence boaters to move among these coastal areas and pressure will not be evenly distributed. Areas closer to major ports and with more favourable weather conditions may be subject to more pressure than others. These factors mean that an accurate calculation of pressure is subject to many more variables that those available in this study. However, the results do give a valid first indication of a level of pressure on sandy areas that is approaching saturation (i.e. corresponding mostly with the most saturated spatial scenario), particularly if additional factors (wave climate etc.) are taken into consideration. The study also highlights a lack of implementation of the law, suggesting that management measures should be implemented. On an island such as Mallorca, which is a mature tourism destination with an intense use of the coastal areas, this study should contribute to the consideration of the need to develop environmental education plans to recreational boaters about the negative impacts of anchoring on seagrass meadows. A common awareness about anchoring on sandy seabeds could avoid the installation of anchoring or mooring buoys which could be expensive to implement.

The tool developed in this work could assist with the *Department of Environmental Quality and Coastal affairs* (*Council of Environment of the Government of Balearic Islands*) and the *Directorate of Coasts of the Balearic Islands* (*Ministry of Environment, Government of Spain*) with the preparation of planning and programmes that require a Strategic Environmental Assessment (BOIB, 2006) and to achieve a better quality of marine and coastal tourism (recreational boating). Quality nautical and coastal tourism (recreational boating) can contribute to sustainable development of coastal areas since it is a lucrative sector that, if properly managed and regulated, can have minimal impacts on the cultural and natural environment (Hall, 2001; Sardá, 2009). An evaluation of the potential economic implications of this work is outside of the scope of this study. However, it is likely that an economic cost-benefit evaluation would reveal substantial long term benefits of regulating recreational boating and achieving sustainability of this activity and that the potential costs of failing to regulate would be significant.

7. Conclusions

This work represents a preliminary step towards understanding the relationship between the availability of space for anchoring and the pressure exerted upon that space, taking into account environmental considerations (i.e. impacts on benthic habitats). The study makes use of best available data and the simple methods could be applied to any coastal area where spatial information is needed to manage recreational boating. The analysis was carried out using a number of scientific tools including GIS, surveys, and wave climate prediction.

The results indicate an elevated amount of pressure from recreational boating on available anchoring space and suggest that current regulations to protect benthic environments and regulate anchoring in general are not implemented. In this context, the study suggests that necessary management measures should be put in place to enforce current legislation and educate boaters about best practices. Complementary studies, such as those related to boat transit, should also be carried out to deepen our understanding of the dynamic, complex activity of recreational boating around the island so that it may be appropriately managed.

Acknowledgments

This work has been carried out within the framework of *LIM-Costa Mallorca Project* funded by *HYPERLINK "gs1:" \o "gs1:"Cámara de Comercio, Indústria y Navegación de Mallorca*. Also, we would like to acknowledge the support provided by D. José María Aguiló, Director of the *Coordination Center of the Plan of Water Quality of Bathing Department of Environment of Council of Environment of the Government of the Balearic Islands*.

References

Ashton, P.G., Chubb, M., 1972. A preliminary study for evaluating the capacity of waters for recreational boating. Water Resources Bulletin 8, 571–577.

Backhurst, M.K., Cole, R.G., 2000. Biological impacts of boating at Kawau Island, north-eastern New Zealand. Journal of Environmental Management 60, 239–251.

Balaguer, P., Sardá, R., Ruíz, M., Diedrich, A., Vizoso, G., Tintoré, J., 2008. A proposal for boundary delimitation for integrated coastal zone management initiatives. Ocean and Coastal Management 51, 806–814.

Barragán, J.M., 2003. Coastal zone management in Spain (1975–2000). Journal of Coastal Research 19 (2), 314–325.

Barragán, J.M., 2004. Las áreas litorales en España. Del análisis geográfico a la gestión integrada. Ed. Ariel.

Bishop, M.J., 2008. Displacement of epifauna from seagrass blades by boat wake. Journal of Experimental Marine Biology and Ecology 354, 111–118.

BOE, 1988. Ley 22/1988 de 29 de Julio (Jefatura del Estado) de Costas. Boletín Oficial del Estado 181, 23386–23401.

BOIB, 2006. Ley 11/2006 de 14 de Septiembre, de evaluaciones de inpacto ambiental y evaluaciones ambientales estratégicas en las Illes Balears. Boletín Oficial de les Illes Balears 133, 38–56.

Brenner, J., Jiménez, J.A., Sardá, R., 2006. Definition of homogeneous environmental management units for the Catalàn Coast. Environmental Management 38, 993–1005.

Cañellas, B., Orfila, A., Méndez, F.J., Menéndez, M., Gómez-Pujol, Ll., Tintoré, J., 2007. Application of a POT model to estimate the extreme significant wave height levels around the Balearic sea (Western Mediterranean). Journal of Coastal Research 50, 329–333.

Castillo, E., Hadi, A., 1997. Finding the generalised Pareto distribution to data. Journal of the American Statistical Association 92, 1609–1620.

Ceccherelli, G., Campo, D., Milazzo, M., 2007. Short-term response of the slow growing seagrass P. oceanica to simulated anchor impact. Marine Environmental Research 63, 341–349.

CITTIB., 2009. In: Centro de Promoción de la Investigación y las Tecnologías Turísticas (Ed.), Tourism in the Balearic Islands, Yearbook 2008. Consellería de Turismo, Govern de les Illes Balears.

Cole, D.N., 2003. Carrying Capacity and Visitor Management: Facts, Values, and the Role of Science. Papers presented at special session of George Wright Society Biennial Conference: Protecting our diverse heritage: The role of Parks, Protected Areas and Cultural sites, San Diego, C.A. http://leopold.wilderness.net/research/recreation/GWSpapers.htm (accessed 11/2009).

Dalton, T., Thompson, D.J., 2010. Mapping human dimensions in marine spatial planning and management: an example from Narragansett Bay, Rhode Island. Marine Policy 34 (2), 309–319.

Davenport, J., Davenport, J.L., 2006. The impact of tourism and personal leisure transport on coastal environments: a review. Estuarine and Shelf Science 67, 280–292.

Douvere, F., 2008. The importance of marine spatial planning in advancing ecosystem-based sea use management. Marine Policy 32, 762–771.

Duarte, C.M., 2002. The future of seagrass meadows. Environmental Conservation 29, 192–206.

Ehler, C., 2008. Benefits, lessons learned, and future challenges of marine spatial planning. Marine Policy 32, 840–843.

FEAPDT, 2008. Federación Española de Asociaciones de Puertos Deportivos y Turísticos. Informe Anual de los Puertos Depotivos en España.

Francour, P., Ganteaume, A., Poulain, M., 1999. Effects on boat anchoring in *Posidonia oceanica* seagrass beds in Port-Cross National Park (north-western Mediterranean Sea). Aquatic Conservation: Marine and Freshwater Ecosystems 9, 391–400.

Hall, C.H., 2001. Trends in ocean and coastal tourism: the end of the last frontier? Ocean and Coastal Management 44, 601–618.

Hemminga, M.A., Duarte, C.M., 2000. Seagrass Ecology. Cambridge University Press, London.

Infantes, E., Terrados, J., Orfila, A., Cañellas, B., Álvarez-Ellacuria, A., 2009. Wave energy and the upper depth limit distribution of *Posidonia oceanica*. Botanica Marina 52 (5), 419–427.

Klein, J., Velarque, M., 2008. The Caulerpa racemosa invasión: a critical review. Marine Pollution Bulletin 56, 205–255.

Leon, M.L., Warnken, J., 2008. Copper and seawage inputs from recreational vessels at popular anchor sites in a semi-enclosed Bay (Qld, Australia): estimates of potential annual loads. Marine Pollution Bulletin 57, 838–845.

Lloret, J., Zaragoza, N., Caballero, D., Riera, V., 2008. Impacts of recreational boating on the marine environment of Cap de Creus (Mediterranean Sea). Ocean and Coastal Management 51, 749–754.

Marbà, N., Duarte, C.M., Holmer, M., Martínez, R., Basterretxea, G., Orfila, A., Jordi, A., Tintoré, J., 2002. Effectiveness of protection of seagrass (*Posidonia oceanica*) populations in Cabrera national Park (Spain). Environmental Conservation 29, 509–518.

Marbà, N., Duarte, C.M., Díaz-Almela, E., Terrados, J., Álvarez, E., Martínez, R., Santiago, R., Gacia, E., Grau, A.M., 2005. Direct evidence of imbalanced seagrass (*Posidonia oceanica*), shoot population dynamics in the Spanish Mediterranean. Estuaries 28 (1), 53–62.

Mas, J., Franco, I., Barcala, E., 1993. Primera aproximación a la cartografía de las praderas de Posidonia oceanica de las costas mediterráneas españolas. Factores de alteración y regresión. Legislación. In: Publicaciones especiales del Instituto Español de Oceanografía, vol. 11 111–119.

McKnight, J.A., Becker, W.W., Pettit, A.J., McKnight, A.S., 2007. Human error in recreational boating. Accident Analysis and Prevention 39, 398–405.

Milazzo, M., Badalamenti, F., Ceccherelli, G., Chemello, R., 2004. Boat anchoring on *Posidonia oceanica* beds in a marine protected area (Italy, western Mediterranean): effect of anchor types in different anchoring stages. Journal of Experimental Marine Biology and Ecology 229 (1), 51–62.

Montefalcone, M., Lasagna, R., Bianchi, C.N., Morri, C., 2006. Anchoring damage on *Posidonia oceanica* meadow cover: a case study in Prelo Cove (Ligurian Sea, NW Mediterranean). Chemistry and Ecology 22, 207–217.

Muirhead, K., Cracknell, A.P., 1986. Airbone LIDAR bathymetry. International Journal of Remote Sensing 7 (5), 597–614.

Ojeda-Martínez, C., Jiménez-Casalduero, F., Bayle-Sempere, J.T., Barbera, C., Valle, C., Sanchez-Lizaso, J.L., Forcada-Almarcha, A., Sanchez-Jerez, P., Martín-Sosa, P., Falcón, J.M., Salas, F., Graziano, M., Chemello, R., Stobart, B., Cartagena, P., Pérez-Ruzafa, A., Vandeperre, F., Rochel, E., Planes, S., Brito, A., 2009. A conceptual framework for the integral management of marine protected areas. Ocean and Coastal Management 52, 89–101.

Pillai, S.R., Antonion, A., 2000. A new estimation tecnique for high-resolution bathymetry. Signal Processing 80, 809–818.

Procaccini, G., Buia, M.C., Gambi, M.C., Pérez, M., Pergent, G., Pergent-Martini, C., Romero, J., 2003. The seagrasses of the western Mediterranean. In: Green, E.P., Short, F.T. (Eds.), Word Atlas of Seagrasses. University of California Press, pp. 48–58.

Roig-Munar, F.X., 2003. Análisis de frecuentación del turismo náutico-recreativo del medio marino de la isla de Menorca. Consecuencias ambientales de su falta de regulación. Cuadernos Geográficos 33, 61–73. Universidad de Málaga.

Sánchez-Camacho, M., 2003. Study of the spatio-temporal changes in the distribution of the seagrass Posidonia oceanica in Mallorca (Balearic Islnads, Spain) between 1956 and 2001 by remote sensing and GIS methods. Master Thesis, School of Ocean Sciences, University of Wales-Bangor.

Saphier, A.D., Hoffmann, T.C., 2005. Forecasting models to quantify three anthropogenic stresses on coral reefs from marine recreation: anchor damage, diver contact and copper emission from antifouling paint. Marine Pollution Bulletin 51, 590–598.

Sardá, R., 2009. Espacios protegidos y turismo náutico-recreativo en la ICZM. In: AENOR, Asociación Española de Normalización y Certificación (Ed.), Gestión Integrada de Zonas Costeras, pp. 355–368.

Soares, C.G., 2008. Hindtcast of dynamic processes of the ocean and coastal areas of Europe. Coastal Engineering 55 (11), 825–826.

Stojanovic, T.A., Ball, I., Ballinger, R.C., Lymbery, G., Dodds, W., 2009. The role of research networks for science-policy collaboration in coastal areas. Marine Policy 33, 901–911.

Tseng, Y.P., Kyle, G.T., Shafer, C.S., Greafe, A.R., Bradle, T.A., Schuett, M.A., 2009. Exploring the crowding-satisfaction relationship in recreational boating. Environmental Management 43, 496–507.

Walken, D.I., Lukatellich, R.J., Bastyan, G., McComb, A.J., 1989. Effect of boat moorings on seagrass beds near Perth, Western Australia. Aquatic Botany 36, 69–77.

Warnken, J., Dunn, R.J.K., Teasdale, P.R., 2004. Investigation of recreational boats as a source of copper at anchorage sites using time-integrated diffusive gradients in thin film and sediment measurements. Marine Pollution Bulletin 49, 833–843.

West, E.J., Barnes, P.B., Wright, J.T., Davis, A.R., 2002. Anchors aweigh: fragment generation of invasive Caulerpa taxifolia by boat anchors and its resistance to des iccation. Aquatic Botany 87, 196–202.

Widmer, W.M., Underwood, A.J., 2004. Factors affecting traffic and acnchoring patterns of recreational boats in Sydney Harbour, Australia. Landscape and Urban Planning 66, 173–183.

Williams, S., 2007. Introduced species in seagrass ecosystems: status and concerns. Journal of Experimental Marine Biology and Ecology 350, 89–110.

Yepes, V., Cardona, A., 2001. S.A. La zonificación de la zona marítima de baño y su balizamiento. Equipamientos y Servicios Municipales, vol. 93. Publiteca, Madrid. 28–36.