Assessment of cumulative human pressures on a coastal area: Integrating information for MPA planning and management

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Abstract

As recently reinforced in the EU Marine Strategy Framework Directive (MSFD), knowledge on the location and intensity of human impacts on marine ecosystems is critical for effective marine management and conservation. Human interaction with ecosystems has to be accounted for in order to effectively implement marine management strategies. In the present study, the main human activities occurring along the mainland Portuguese coast were identified and mapped. The cumulative impact of these activities was calculated in order to assess impacts in different zones, namely in Marine Protected Areas (MPA) and their boundaries. Higher impact values were obtained near the coast, where all the analysed MPAs are located. Furthermore, most MPAs are surrounded by areas with very high impacts, near the largest urban settlements and the most industrialized coastal sections. These results are the first assessment of cumulative human pressures in this study area as a whole (and with this level of resolution) and might be of great usefulness to overcome the current challenges of sustainable management in marine ecosystems. Knowledge provided by this study strengthens the need for a more integrative approach to design and manage MPAs and can be useful to support the requirements of the MSFD. The approach here developed is also a powerful tool to apply in several contexts of sustainable marine management and can be developed in any geographic area.

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1. Introduction

Human activities are having a major impact on ecosystems worldwide (Baillie et al., 2004; Hails, 2008; Halpern et al., 2008; Micheli et al., 2013). While this has long been recognized in terrestrial ecosystems, concerns regarding the need to protect the marine environment only became widely accepted in the 1950’s and 1960’s, when strong declines in catches of various fisheries occurred worldwide (Toropova et al., 2010). Prior to this, the general idea was that marine resources were inexhaustible.

Sea pollutants are usually derived from human settlements, resource use and exploitation, agricultural activities, industrial developments, aquaculture, shipping, touristic uses, among others (Islam and Tanaka, 2004; Williams, 1996). These numerous activities and their pollutants cause severe impacts in marine ecosystems such as decreases in species diversity, population declines, degradation and destruction of natural habitats as well as changes in water chemistry and temperature (Islam and Tanaka, 2004). Even if there are no areas in the ocean unaffected by human impacts (Halpern et al., 2008), it has been shown that open oceans are in good condition when compared to coastal areas (Ban et al., 2010; Halpern et al., 2008; Kelleher, 1999; McIntyre, 1995). Open oceans receive contaminant inputs mainly from the atmosphere and sea transport, while coastal zones around the world are vulnerable to a much larger array of human activities.

The effects of human activities on the oceans have been well documented. However, in most of the cases these studies evaluate the effects of individual activities (e.g. impacts of fisheries (Batista et al., 2009; Jennings and Kaiser, 1998; Swartz et al., 2010) or aquaculture (Forchino et al., 2011; Sarà et al., 2011) in different contexts and lack an holistic perspective. As marine ecosystems are usually under the influence of multiple anthropogenic stressors, the combination and interaction of impacts from various sources over space and time (i.e. cumulative impacts) must to be considered (MacDonald, 2000). Unfortunately, interactions among multiple stressors cannot be easily modelled because they generate net impacts that either exceed (i.e. synergism) or fall below (i.e. antagonism).
antagonism) the addition of individual effects (Folt et al., 1999). Discussions focusing on the type of interactions and how they can be modelled are common, with all types of interactions found among natural systems and synergisms assumed as the most frequent interactions (Crain et al., 2008; Darling and Côté, 2008; Myers, 1995; Sala and Knowlton, 2006). Notwithstanding, there are authors that argue that additive impacts are the most common type of interactions that occur (Cada and Hunsaker, 1990; see also MacDonald, 2000). Apart from these discussions, additive models have been recently used in the field of marine spatial planning and are considered a valuable approach for management and conservation of marine areas (Ban and Alder, 2008; Ban et al., 2010; Coll et al., 2012; Halpern et al., 2009, 2007, 2008; Korpinnen et al., 2012; Selkoe et al., 2009; Stelzenmüller et al., 2010b).

Developing adequate and efficient conservation measures to respond to the high impacts generally affecting marine ecosystems is imperative. In this context, marine protected areas (MPA) are increasingly viewed as an important management tool to reduce, prevent and/or reverse ongoing declines in marine biodiversity (Agardy, 1994; Pauly et al., 2002; Roberts et al., 2005) and have been pointed out as essential tools in several documents and scientific studies (e.g. EU Marine Strategy Framework Directive (MSFD); Code of Conduct for Responsible Fisheries (FAO); Spalding et al. (2008); Wood et al. (2008)). In fact, the MSFD underlines the need for MPA networks that adequately covering the diversity of the constituent Ecosystems (EU, 2008). Despite their rapid expansion in the last decade MPA still represent less than 3% of the total ocean (Abdulla et al., 2013 and references therein). Additionally, fewer than 10% of MPA are achieving their management goals (Wood et al., 2008).

There are a multitude of reasons for these failures but in general we can consider that many are due to inefficient implementation and management processes (Fenberg et al., 2012; Halpern, 2003). Socioeconomic conflicts are a typical problem arising from the customary restrictions on several human activities established within MPA (e.g. fishery closures, prohibition of recreational activities), which may result in illegal behaviours and a consequent MPA inefficiency. In this sense, one of the major challenges affecting MPA success is the overlap between human activities, socioeconomic interests and natural values. The need to protect often derives from the need to minimize human activities in important marine areas in order to avoid irrecoverable ecosystems. Thus, developing and implementing adequate tools for the selection, implementation and management of MPA from the beginning is critical to their success.

Knowledge on pressure sources and impacts on ecosystems is important not only for a better understanding of the ecosystem responses to pressures but also to formulate effective prevention or management measures (Islam and Tanaka, 2004). For example, the MSFD highlights the need to undertake a priori analyses of the pressures and impacts on the marine waters of member states, before the implementation of programmes of measures (see EU (2008) for details).

Given that the already implemented MPAs are clearly insufficient to fulfil conservation targets, namely the requirements of the MSFD, there is a recognised need for more MPAs or the re-dimensioning of existing ones in mainland Portuguese marine waters. In this context, the present study aims to characterise cumulative anthropogenic pressures along the whole extent of the territorial marine waters of Mainland Portugal. This baseline information is of major importance to support an efficient implementation of conservation strategies including the MPA proposals. In addition to its relevance for this particular study area, the developed approach provides a standard framework to support MPA planning and management in other spatial contexts and contributes with relevant information for effective marine management and ecosystem conservation at larger spatial scales.

2. Methods

2.1. Study area

The area considered in this study was the territorial sea of mainland Portugal, i.e. the area comprised between the coast line (942 km long) and twelve nautical miles offshore (Fig. 1). The continental shelf of the west coast is relatively narrow, varying between 5 and 60 km wide, and is wider in the north coast (35–60 km) than in the southwest and south coasts (5–28 km) (Cunha, 2001; Dias, 1987; Pinheiro et al., 1996).

The western coast of Portugal is a high energy shelf environment exposed to NW swell from the North Atlantic, whereas the southern shelf sector has a lower energy regime with dominant SW–S and SE swell (Mil-Homens et al., 2007). Due to upwelling events during the summer, biological productivity along the Portuguese coast is high, particularly in the west coast (e.g. Cunha, 2001; Fiúza et al., 1982; Santos et al., 2011; Wooster et al., 1976).

In terms of sediment composition, deeper areas of the north-western and central sectors and most of its south-western sector are covered by fine and very fine sands. Coarse deposits are found in the inner and middle shelf of the northermost sector and immediately south of the Nazaré and Setúbal canyons. Extensive mud patches are present in the southern shelf due to its lower energy environment, whilst in the remaining coast they are restricted to areas adjacent to major river mouths (Martins et al., 2012).

In mainland Portugal there are six MPAs: Litoral Norte, São Jacinto, Berlengas, Arrábida, Santo André and Sancha (hereafter referred as S. André/Sancha) and Sudoeste Alentejano and Costa Vicentina (hereafter referred as SWACV) (Fig. 1, Table 1).

2.2. Data collection and Human Pressure Index (HPI)

In this study, we used human activities to represent human-derived pressures or stress factors in the marine environment. Due to the complexity and lack of information to precisely classify the impacts of each pressure source in ecosystems, we considered each pressure as having a potentially negative impact on the marine environment.

The main human activities occurring along the Portuguese coast, or having direct impact on it, were identified (Table 2). Due to the lack of appropriate or quantifiable information, recreational fishing, illegal activities, hand harvesting, dumping and offshore ship traffic were not included in this study though their occurrence along the Portuguese coast is recognized. Expected natural pressures (e.g. ocean acidification, increase in sea temperature) were also not included in the analyses.

The areas and locations of human activities were mapped using ArcGIS 10.1 software. Each activity was mapped in an individual vector layer. All layers were combined to calculate the Human Pressure Index (HPI) in order to account for the differences of scale and features in relation with this study area. HPI calculation and overall methodology were adapted from previous work by (Halpern et al., 2008) and have been previously successfully applied by the authors in a smaller area (Henriques et al., 2014):

\[
HPI = \sum_{i=1}^{n} A_i \times w_i
\]

where \(A_i\) is the intensity of the human pressure at location \(i\) and \(w_i\) is the weight attributed to that human activity at the same location.
i. \( n \) is the number of human activities considered (\( n = 18 \)). An HPI value was calculated for each grid parcel (a 500 m grid size was chosen because it represents a good compromise between resolution and information availability) using the module “Environmental Risk Surface (ERS)” of the package “Protected area tools v4” for ArcGIS 10 (Schill and Raber, 2009). Created risk surfaces are therefore raster files with 500 m wide pixels, and each pixel value is the HPI obtained for that location. The range of values obtained represent the relative importance of pressures among grid parcels where the higher HPI value obtained corresponds to the higher pressure level identified in the study area.

For HPI calculation, values of (1) Intensity (relative intensity among spatial distribution), (2) Weight (relative importance of an activity in different locations) and (3) Influence distance (one value per layer, equal for all locations) were assigned to each human activity considered and added to the layer attribute tables. (1) Intensity was calculated based on measurable parameters among different locations. The best data available for the period 2000–2010 was used to fulfil this purpose and a five-level scale was used to assign an intensity class to each location (e.g. Cabral et al. (2007), Wise et al. (2005); (2007), Erzini et al. (2003), Santos et al. (2003) for commercial fisheries; but see Table 2 for details). For some activities (e.g. SCUBA diving), for which an intensity gradient did not make sense, or when appropriate data were not available, an intermediate intensity level was applied to all locations. (2) The Weight parameter reflects the relative importance of an activity in different locations and was obtained by averaging the values for frequency and magnitude attributed to each of the activities. Frequency values were assigned following a scale from 1 to 4 (adapted from Halpern et al. (2007); see also Table 3) and magnitude values were attributed by expert judgement, following a scale from 1 to 5 (see Table 3 for details). Finally, obtained weight values were standardized in a 1–3 scale (1 being the smallest weight). Overall, this parameter reflects the relative “potential for environmental damage” among the various activities. (3) For each activity, an Influence distance was assigned based on the fact that each human activity exerts an influence over the areas adjacent to their main sources of impact. Influence distances were based on a literature review and, in some cases, these ranges were estimated by the authors (based on the compilation of available information, informal expert consultation and personal experience; see Table 2 for further details). A linear decay function was utilized in this parameter in order to simulate the decrease in intensity with increasing distance from the source.

2.3. Data analyses

Average HPI values were calculated for the whole study area, for each Marine Protected Area (MPA) and by habitat type. In this study, due to the limitations of the available data, habitat type was defined as the combination of sediment type (mud, sand and gravel and rock), depth range (<30 m; >30 m) and latitude (North and South of the Carvoeiro cape, due to proven biogeographic differences between these regions — see Fig. 1 and Cunha (2001)). Sediment information was available for 90.1% of the study area. HPI means and standard deviations for each zone (i.e. MPA and habitat types) were calculated (using the zonal statistics tool of spatial analyst extension of ArcGis 10.1 software, ESRI) and compared in order to understand how human activities affect different areas. The relative importance of each individual pressure was also analysed. All geographic data were obtained from official cartography of the Portuguese Hydrographic Institute.

Finally, the 18 individual pressures considered were analysed through a Principal Component Analysis (PCA), using Statistica 11 software. PCA aimed to identify patterns and relationships between
human pressures and the different areas considered (MPA and habitat type).

3. Results

Mapping human activities along the study area (Fig. 1) revealed that, although there are differences in intensity and number of overlapping activities, there is no single area free of human pressure. The maximum HPI value, i.e. the maximum level of pressure obtained, was 73 though the average for the entire study area was much lower (9.18).

HPI achieved much higher values in areas near the coast (usually shallower than 30 m), as shown in Fig. 2. In general, northern areas had higher HPI values, deeper areas had similar HPI in average and there were no relevant differences among sediment types. In shallower areas, the average HPI was slightly lower on rocky substrates, followed by sand and gravel. Higher HPI values were found for shallower muddy areas, mainly to the north of Carvoeiro cape. Average HPI calculated inside MPA was higher than the one obtained for the whole study area or to areas deeper than 30 m. Nevertheless, it is clear that most MPA are surrounded by areas with very high HPI, as shown in Fig. 1, namely areas near the largest urban and industrial settlements (Porto, Aveiro, Figueira da Foz, Lisboa, Setúbal and Sines).

An analysis of the contribution of individual activities to the global (cumulative) HPI values showed that fisheries accounted for 74% of the global HPI (32% for bottom trawl, 25% for multigear fisheries and 17% for seine fisheries) and pressures from transitional waters contributed to 18% of the global HPI. Among the remaining considered activities, industrial loads and sewage discards were the most important (8% of the global HPI).

The assessment of human pressures in the different MPA (Fig. 3) showed that higher HPI values were obtained for São Jacinto (mean HPI = 23) and Arrábida (mean HPI = 20), followed by S. André/Sancho (mean HPI = 11), Litoral Norte (mean HPI = 11) and SWAVC (mean HPI = 6) (see Fig. 1 for locations). Berlangas (mean HPI = 1) obtained the lowest HPI value among MPA. The values obtained for MPA follow the tendencies observed in areas shallower than 30 m, where HPI was higher near larger urban and/or industrial areas.

The relative importance of individual pressures affecting MPA are shown in Fig. 4. Activities with major importance for the final HPI within MPA are similar to the ones affecting the study area as a whole, although with differences in their relative importance. Within MPA, the contribution of fisheries did not exceed 50% of the HPI, and these were mostly multi-gear fisheries (albeit purse seine also occurred). The remaining contribution came mainly through inputs from transitional waters. In Litoral Norte, transitional waters represented 55% of the global HPI in this MPA. Sewage loads also had an important contribution to the HPI of most MPA, while industrial discards were relevant in the southern MPA. In Berlangas the HPI was very low and the contribution of tourism activities the most representative pressure source, with a relative importance of 55% to the its HPI. Fisheries and sewage also had a role in the obtained HPI value for the Berlangas MPA.

The PCA complemented and supported observed patterns in HPI, with 53.42% of the total variance explained by the first two principal components (Fig. 5a and b). This analysis showed that shallower zones (<30 m deep) were clearly separated from the deeper areas. Most of the MPA were clustered together in between these two groups with the exception of Arrábida (A). The cumulative effects of diving, beach activities, sewage and pipelines seem to influence Arrábida in a particular way, which differentiated it from the other zones (Fig. 5a and b). Local fishing and coast line artificiality were also important in this MPA. Trawl fishing has an important role in the observed HPI in areas deeper than 30 m. The PCA diagram also showed that most of the human pressures considered seems to be of particular importance in shallower zones.

4. Discussion

Recognizing the magnitude of impacts acting upon the oceans has led to a general increase in awareness towards the need to protect marine ecosystems and ensure the sustainable use of resources (e.g. CBD, 1999; EU, 2008; Halpern et al., 2008; OSPAR, 2010-3). Although this problem has been scarcely addressed in most countries, several efforts to implement appropriate legislation are being made (e.g. EU, 2008; EU, 2013). However, to accomplish the aims of these documents there is a crucial need to obtain more and/or better information, namely on human impacts spatial distribution and their effects on marine ecosystems (Benn et al., 2010; Henriques et al., 2013). The better the knowledge base and the quality and representativeness of data available to scientists and managers, the more effective marine management will be (Pais et al., 2012). There is a growing need to base marine management on a wide range of factors and also consider their potential interactions (e.g. spatial distribution of human activities, ecosystems overlapped by those activities, ecosystem resilience, predictable influence of natural pressures, socioeconomic issues, species life cycles and connectivity data) (Ban et al., 2010; Christie et al., 2003; Kelleher, 1999; Pomeroy et al., 2005; Reis-Santos et al., 2013; Stelzenmüller et al., 2008; Tanner et al., 2013). In this sense, the present results provide new basal information on spatial distribution of human activities in the study area and their overlap with the

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Table 1: Marine Protected Areas (MPA) of the study area. Classification status, designation and management plan publication dates, total protected area (km²) and main goals. Dates between parentheses correspond to alterations in MPA limits.

<table>
<thead>
<tr>
<th>MPA</th>
<th>International designation</th>
<th>IUCN Category</th>
<th>Designation</th>
<th>Management plan publication</th>
<th>Total area (km²)</th>
<th>Main goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Litoral Norte</td>
<td>Nature Park</td>
<td>V</td>
<td>2005</td>
<td>2008</td>
<td>76.5</td>
<td>Protect marine biodiversity</td>
</tr>
<tr>
<td>São Jacinto</td>
<td>Nature Reserve</td>
<td>IV</td>
<td>2004</td>
<td>2005</td>
<td>2.5</td>
<td>Sustainable exploitation of marine resources</td>
</tr>
<tr>
<td>Berlangas</td>
<td>Nature Reserve</td>
<td>IV</td>
<td>1981</td>
<td>2008</td>
<td>95.6</td>
<td>Protect marine biodiversity</td>
</tr>
<tr>
<td>Arrábida</td>
<td>World Biosphere Reserve</td>
<td>Nature Park</td>
<td>V</td>
<td>1998</td>
<td>52.9</td>
<td>Promote sustainable nature tourism and fishing with traditional selective fishing gears</td>
</tr>
<tr>
<td>Sudoeste Alentejano and Costa Vicentina</td>
<td>Nature Park</td>
<td>V</td>
<td>1995</td>
<td>2011</td>
<td>289.9</td>
<td>Protect marine biodiversity and improve ecological status of exploited species</td>
</tr>
<tr>
<td>Threat category</td>
<td>Threat sub-category</td>
<td>Metrics used for intensity categorization</td>
<td>Range of influence (m)</td>
<td>Frequency impact magnitude</td>
<td>Weight</td>
<td>Data sources</td>
</tr>
<tr>
<td>----------------------------------------</td>
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<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Offshore</td>
<td>Aquaculture</td>
<td>Fish and shellfish aquaculture, Aquaculture companies</td>
<td>Annual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Commercial Fisheries</td>
<td>Hauls per zone, Landings (kg/km²/year)</td>
<td>500</td>
<td>3</td>
<td>4</td>
<td>VMS data legislation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-multi-towing -trawling</td>
<td></td>
<td></td>
<td></td>
<td>Legislation interviews</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-habitat-creative — purse seines</td>
<td>100</td>
<td>3</td>
<td>2</td>
<td>Legislation interviews</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-gear (lines, nets, traps), Local vessels (Total length &lt; 9 m)</td>
<td>100</td>
<td>3</td>
<td>3</td>
<td>Legislation interviews</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-gear (lines, nets, traps), Coastal vessels (Total length &gt; 9 m)</td>
<td>100</td>
<td>3</td>
<td>3</td>
<td>Legislation interviews</td>
</tr>
<tr>
<td></td>
<td>Subtidal artificial reefs</td>
<td>Presence/Absence</td>
<td>1000</td>
<td>4</td>
<td>2</td>
<td>Nautical cartography</td>
</tr>
<tr>
<td>Dredging activities</td>
<td>Dredging deposition</td>
<td>Amount of dredged materials deposited (m³) from 2000 to 2010</td>
<td>1500</td>
<td>3</td>
<td>3</td>
<td>Reports from national ports authorities (IPTM; port administration)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of entrances and exits per year per port – 2005-2006 average</td>
<td>1000</td>
<td>4</td>
<td>2</td>
<td>National Cartography</td>
</tr>
<tr>
<td></td>
<td>Recreational activities</td>
<td>SCUBA diving</td>
<td>100</td>
<td>3</td>
<td>1</td>
<td>Interviews to diving enterprises; National ports authorities (DGRM, 2010)</td>
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<tr>
<td></td>
<td>Recreational motor boating</td>
<td>Number of anchor places in the adjacent marinas</td>
<td>1000</td>
<td>3</td>
<td>1</td>
<td>National ports authorities (DGRM, 2010)</td>
</tr>
<tr>
<td></td>
<td>Marinas</td>
<td>Number of anchor places</td>
<td>1000</td>
<td>4</td>
<td>2</td>
<td>Nautical cartography</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marine management plans</td>
<td></td>
<td></td>
<td></td>
<td>Estimated by authors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Population, N and P concentrations in the watershed (averaged intensity level) – 2007-2009</td>
<td>30000</td>
<td>4</td>
<td>3</td>
<td>National water management authorities (INAG); National Cartography</td>
</tr>
<tr>
<td></td>
<td>Small estuaries and coastal lagoons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Estimated by authors</td>
</tr>
<tr>
<td></td>
<td>Direct human impact/Population</td>
<td>Presence/Absence</td>
<td>750</td>
<td>4</td>
<td>1</td>
<td>Nautical Cartography</td>
</tr>
<tr>
<td></td>
<td>Beaches (leisure activities, e.g. swimming, kayaking, kitesurf)</td>
<td>Beach typologies (classification from coastal management plans) – 1998-2007</td>
<td>500</td>
<td>3</td>
<td>1</td>
<td>Coastal management plans</td>
</tr>
<tr>
<td></td>
<td>Coastal line artificialization (peers, docks, harbours and other constructions)</td>
<td>Pressure/Absence</td>
<td>1000</td>
<td>4</td>
<td>1</td>
<td>National water management authorities (INAG); National Cartography</td>
</tr>
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<td></td>
<td>Sewage (urban nature)</td>
<td>Annual sewage discards to the sea (m³/year)</td>
<td>5000</td>
<td>4</td>
<td>3</td>
<td>National water management authorities (INAG); National Cartography</td>
</tr>
<tr>
<td></td>
<td>Industrial infrastructures (I) and thermal plants (TP)</td>
<td>Annual discards to the sea (m³/year)</td>
<td>7500</td>
<td>4</td>
<td>1-2 TP</td>
<td>National water management authorities (INAG); National Cartography</td>
</tr>
</tbody>
</table>

Table 2: List of threat categories and sub-categories used to calculate the Human Pressure Index (HPI). Metrics, influence distance (m), impact frequency (1–4, where 1 is the lowest frequency), magnitude (1–5, where 1 is the lowest magnitude) and weight (1–3, where 1 is the lowest) for each sub-category are indicated and data sources are presented.
Table 3
Classification scales and criteria for frequency (1–4, where 1 is the lowest frequency) and magnitude (1–5, where 1 is the lowest expected impact magnitude) to human activity threat sub-categories.

<table>
<thead>
<tr>
<th>Parameters Level Description</th>
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<tr>
<td>Rare</td>
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<td>Occasional</td>
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<td>Persistent</td>
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</table>

established MPA; the integration of the potential effects of the overlapped human activities via the HPI calculation; and the assessment of cumulative pressures affecting each habitat (including inside and around MPA). The obtained results can also be integrated with accurate habitats data as well as species distributions (not assessed in this study) and thus directly contributing to marine management, namely MPA planning and management. This integration can be performed, for example, through site selection software such as Marxan (Ball and Possingham, 2000) allowing managers to define conservation scenarios that take into consideration the consequences of human exclusion from a given area, and choose those for which the balance between overall negative impacts to economic activities (e.g. commercial fisheries, recreational activities) and overall conservation benefits of their exclusion from a given area is best. This way, the level of compliance with protection areas is expected to be higher and contributing to their higher efficiency. In addition, the identification of areas where levels of impacts are higher than those deemed reasonable to maintain ecosystems integrity (namely in implemented MPA) allows a faster implementation or enhancement of conservation measures. Thus, present results are a valuable contribution to the ongoing processes on marine management and MPA implementation in Portugal (e.g. EU, 2008 National Strategy for the Portuguese Marine Environment). The main outputs (pressure maps) from the present approach are quickly understood by managers and decision-makers, their relevance increased by integrating ecological data, and can easily be recalculated if more data is available. Furthermore, the developed tool can easily be adapted to new geographic or marine management contexts.

Although the previous global approach by Halpern et al. (2008) included this study area, the present study provides the quantification of the extent and intensity of human activities at a finer scale. This higher resolution can better contribute to overcome current challenges of sustainable management in marine ecosystems (Coll et al., 2012), particularly in respect to MPA implementation, which usually requires the analyses at smaller scales. For example, information on the relative importance of adjacent areas to small scale fisheries are of major importance since the location of a no-take area can vary by only a few kilometres while greatly minimizing the economic impacts on fisheries.

Approaches like the one presented here have many advantages but also some constraints that have to be taken into account when interpreting the results. One of the main issues is the fact that the method only considers additive effects, though synergistic and antagonistic processes are known to sometimes occur. Furthermore, the method does not take into account historical impacts on marine ecosystems, as well as the ecosystems’ health prior to the present state. Additionally, due to the lack of available data or their low resolution, some potential impact sources (namely, recreational fishing, illegal activities, hand harvesting, dumping and offshore ship traffic) were not included in this model, and data on habitats had a low level of detail. Among the excluded activities, recreational fishing, hand harvesting and illegal activities related to fisheries should mostly impact areas where artisanal fisheries were more intense since these areas are expected to be more productive and more easily accessible (e.g. due to favourable sea conditions). Therefore, accounting for those activities would probably increase the HPI of shallower areas for which higher HPI were already obtained in the present assessment. Dumping and offshore ship traffic are harder to predict without data since these activities can occur along the study area with irregular patterns, and the intensity of impacts is highly dependent on the type of substances dumped or spilt. However, it is expected that these activities achieve higher magnitude in offshore areas, due to increased traffic control and more efficient enforcement near shore.

In addition, it is important to stress that the results obtained for the HPI are relative to the study area, which means that the highest HPI value obtained can still be under a lower level of impact when compared to other geographical areas. Despite these constrains, the presented approach is a powerful tool to estimate cumulative human impacts in a given area. The method is appropriate to assess the relative importance of human uses among different zones within a study area as the accuracy and spatial resolution of the data used for calculating the HPI is the same.

As a result of the low level of spatial resolution data for habitat characterization, habitat sensitivity was left out of the index calculation (as firstly defined by Halpern et al. (2008). However, the weight factor (see Section 2 for details) represents a classification according to frequency and magnitude of potential impacts which is an adequate approach to consider when the quality of data available is poor.

The results obtained in the present assessment showed that near shore areas were under higher cumulative impact scores when compared to offshore zones. Generally, near shore zones are under increased direct pressures (e.g. fisheries, shipping activities) and also several indirect land-based activities (e.g. urban sewage, agriculture-related nutrient input). This general conclusion was observed in many studies (e.g. Ban et al., 2010; Halpern et al., 2008; Stelzenmüller et al., 2010a). Although areas farther from shore have lower scores in general, pressures in offshore areas have high destructive potential (e.g. high impact fisheries, intensive maritime traffic, spilling of hazardous substances) which, in combination...
with the poor data available, can be of great concern for governments and scientists (IUCN, 2004; Korpinen et al., 2012) since HPI values would be higher than the estimated. The unknown magnitude of illegal activities can also represent a risk that is scarcely assessed (e.g. Ainsworth and Pitcher, 2005). Furthermore, some of these offshore areas can encompass valuable and sensible ecosystems that may be suffering irreversible impacts (Korpinen et al., 2012). In the present study, the deepest areas were mainly affected by bottom trawl fisheries which uses highly destructive gear and generally implies long recovery periods, when recovery is even achievable (Hiddink et al., 2006; Lambert et al., 2011).

Similar to findings of other authors worldwide, relatively high HPI were obtained for some MPA (Ban et al., 2010; Coll et al., 2012). In the study area, these relatively high values were not entirely surprising since all MPA are extensions of terrestrial protected areas (i.e. generally highly influenced by land-based activities), and most of them are located near estuaries and highly populated urban areas (except Berlengas which is a continental island). In fact, although particular activities such as fishing have less impact within the MPA than in the surrounding areas, other pressures, mostly ones related with land based activities and human settlements, are not regulated within most MPA (Mora and Sale, 2011). Furthermore, a MPA can undergo increasing pressure from some activities, such as scuba diving, leisure boating and tourism. Even though they have lower impacts on ecosystems, it is important to consider carrying capacity issues and establish measures that limit this occupation (Needham et al., 2011) and minimize stakeholder conflicts (Ballantine and Langlois, 2008; Scholz et al., 2004). In the authors’ view, scores obtained within MPA have to be seen with caution since some of the excluded activities (e.g. recreational fisheries, illegal practices), can highly increase the estimated HPI values. In addition, the high HPI values found in surrounding areas should be seen with concern, as they are likely to affect the fulfillment of MPA goals (i.e. high human pressures in surrounding areas can minimize the expected effects of protection).

All studied MPA contain undeniable ecological value however, there was a general lack of research to establish their adequate locations, dimensions and goals. A national strategy to protect ecosystem functions, habitat integrity and the survival of vulnerable or commercially important species (e.g. Botsford et al., 2003; Sala et al., 2002) would have been a much more appropriate approach, rather than an out-dated approach of scattered individual areas and isolated goals. Coherent MPA networks (e.g. including both offshore and coastal areas in order to enclose inter-dependent ecosystems), is needed for a more efficient marine management.
Regarding conservation planning efficiency and MPA establishment, there are some principles that should be generally followed. Primarily, a conservation strategy with clear goals should be defined, along with precise and adequate criteria. This must be followed by the estimation of the resources needed, which have to be adjusted in face of the existing financial constraints and human resources. It is important to keep in mind that the simultaneous consideration and integration of biodiversity conservation targets, the distribution of sources of impact, and the attitudes and perspectives of local stakeholders is imperative for the success of MPA processes (Fraschetti et al., 2009). Although there is a large number of publications focusing on efficient MPA planning (e.g. Botsford et al., 2003; Kelleher, 1999; Sala et al., 2002), recent studies reveal a worrying number of inefficient MPA (Pomeroy et al., 2005; Wood et al., 2008). When the spatial extent and interaction among stressors and their influence on ecosystems is poorly addressed, it is important to adopt a precautionary management approach, in order to ensure an efficient protection of ecosystems and, consequently, the sustainability of key services they provide. Some precautionary approaches are the protection of representative habitats, allocation of larger areas than the apparently needed (e.g. spatial/temporal closures) and improvement on the knowledge regarding spatial distribution, intensity and frequency of human activities.

The present study underlines the importance of implementing efficient approaches to marine management, a task in which MPA are powerful tools. The presented method contributes to the improvement of planning and management of MPAs, since it allows

**Fig. 5.** Principal components analysis (PCA), based on the assessment of human activities in habitats and marine protected areas (MPA). a) Relationship between the intensity of human activities and the first two principal components. b) Habitats and MPA groups obtained in the PCA analysis. LN- Litoral Norte; SJ – São Jacinto; B – Berlengas; A – Arrábida; SAS – Santo André and Sancha; SWACV – Sudoeste Alentejano and Costa Vicentina.
for a high resolution, spatially explicit characterization of human activities affecting marine resources. This approach can and should be extended to other areas and applied to other management contexts, such as the MSFD. In fact, this information is extremely valuable to adequately design programmes of measures targeting the activities responsible for environmental degradation, on the road to the achievement of a “good environmental status” for European marine waters.

Acknowledgements

The authors would like to thank all the Portuguese institutions that contributed for data for this study. The authors would also like to thank Dr. Cristina Catita (Faculdade de Ciências, Universidade de Lisboa) for her assistance with GIS analyses and to Steve Schill for his help with the ERS tool. This study was funded by the Fundação para a Ciência e Tecnologia (FCT) via PTDC/MAR/117084/2010 and host institution was funded with project PEst-OE/MAR/UI0199/2011. A PhD grant attributed to M. I. Batista (SRHR/BD/64395/2009) as well as post-doc grants attributed to S. Henriques (SRHR/BPD/94320/2013) and M. P. Pais (SRHR/BPD/94638/2013) were also funded by FCT and supported by national funds.

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