

Cumulative anthropogenic pressure mapping

a case study of the *Alcúdia* Bay - Majorca



Max Siegfried

Raissa Borgmann

Van Hall Larenstein – University of Applied Sciences

Leeuwarden, the Netherlands

October 2013

Front image (left): Aerial view on the *Alcúdia* harbour.

(http://www.salymar.com/sites/default/files/port_d.alcudia.jpg)

Front image (middle): Aerial view on the beach of *Alcúdia*.

(<http://www.bookableholidays.com/images/country/balearics/majorca/alcudia/alcudia-beach.jpg>)

Front image (right): Aerial view on the desalination plant in *Alcúdia*.

(http://www.sadyt.com/es_es/Images/alcudia1-grande_tcm23-3435.jpg)

Front image (big): Aerial view on the *Alcúdia* Bay.

(http://upload.wikimedia.org/wikipedia/commons/c/ce/Badia_d%27Alc%C3%BAdia.jpg)

Cumulative anthropogenic pressure mapping a case study of the *Alcúdia* Bay – Majorca

A tool for the assessment of the European Marine Strategy Framework
Directive - quantifying cumulative anthropogenic pressures on the marine
environment

Written by:

Max Siegfried & Raissa Borgmann

Integrated Coastal Zone Management (ICZM) students

Van Hall Larenstein - University of Applied Sciences (Part of Wageningen University)

Leeuwarden, October 2013

A thesis submitted in fulfilment of the requirements for the degree Bachelor Coastal Zone
Management on behalf of Balearic Islands Coastal Observing and Forecasting System
(SOCIB)

Supervised by:

Peter Hofman & Evelien Jager (Van Hall Larenstein)

Dr. Lluís Gómez-Pujol (SOCIB)



Preface

This thesis is written to fulfil the requirements of the Bachelor degree in Integrated Coastal Zone Management (ICZM) at the Van Hall Larenstein University in Leeuwarden, the Netherlands. Furthermore, a publication of the project and its result is intended and will be realized within the next couple of month.

The initiator of this bachelor thesis is the Balearic Islands Coastal Observing and Forecasting System (SOCIB) which is located on the Balearic Island of Majorca in Spain. The institution provides new technologies, modelling services and oceanographic data (including real time-monitoring and forecasting) in order to support operational oceanography on European, as well as on international scale ([SOCIB, 2013](#)).

We want to express our gratitude to Dr. Joaquín Tintoré, who represents the head of the department and enabled the realisation of the project. He gave us the opportunity to develop our bachelor thesis while using the facilities and the experience of the SOCIB team. Furthermore, we want to convey our deepest gratitude and respect to Dr. Lluís Gómez-Pujol and Mr. David March Morla, for imparting their expertise, knowledge as well as supporting us freely in every aspect of the project.

In addition, we want to thank Mr. Peter Hofmann and Mrs. Evelien Jaeger, who stood alongside us throughout the entire process providing guidance and valuable feedback as supervisors.

Finally, we are indebted to all the scientists and marine experts, who provided their knowledge to underline the reliability of the final outcomes and the project in general. In closing, we express our gratefulness to numerous people we met in the field, who were very helpful providing us with much needed local information to complete our project.

Without the support of all of you, we would not have been able to develop our thesis to the quality it is now. We are deeply grateful for all the inputs you gave to us, helping us to design and report the cumulative pressure model for the *Alcúdia* Bay.

Thank You!

Leeuwarden, October 2013.

Max Siegfried & Raissa Borgmann

Abstract

Coastal and marine ecosystems are subject to threats of many anthropogenic pressures. This report presents a first attempt to adapt a method in order to quantify and spatially visualize the distribution and intensity of cumulative anthropogenic pressures for the *Alcúdia* Bay on Majorca. The applied method takes account of the sensitivity of different ecosystems and their components to a range of different anthropogenic pressures. The quantification of cumulative anthropogenic pressure in the *Alcúdia* Bay was visualized on a high resolution map (with 25m-by-25m cells). The quantification of cumulative pressures is based on data layers of anthropogenic pressures, ecosystems and their components as well as quantification of the vulnerability of ecosystems. For the quantification, 25 distinct pressure layers, 10 ecosystem layers and 250 ecosystem-pressure combination values as judgements of the vulnerability of ecosystems by 11 experts (marine scientists and ecosystem experts of the Balearic Islands) are incorporated. The classification of anthropogenic pressures follows the European Marine Strategy Framework Directive which requires member states to assess the level of human impacts on their marine waters. The resulting cumulative anthropogenic pressure index and its visualisation aim to provide a first approach to fulfil the requirements of the EU directive.

The spatial visualisation of cumulative anthropogenic pressures shows that the highest index were in the south-western area of the bay, close to the touristic centre of *Alcúdia*. The lowest index values were found further eastward and towards the open sea. The result can be regarded as consistent with the population densities along the coastline.

Keywords: *Alcúdia* Bay, human impact assessment, cumulative anthropogenic pressure, visualization of pressure, EU Marine Strategy Framework Directive, vulnerability of ecosystems, ecosystem resistance, ecosystem resilience



Table of content

1	Introduction	6
2	Research description.....	8
2.1	Problem description	8
2.2	Research aim.....	9
2.3	Research question	10
3	Reading guide.....	10
4	Methodology	11
4.1	General framework	11
4.2	Study area	14
5	Cumulative anthropogenic pressure model	17
5.1	Input 1: Distribution and intensity of anthropogenic pressures	17
5.1.1	Methods.....	17
5.1.2	Results	25
5.2	Input 2: Distribution of the selected ecosystems and ecosystem components	26
5.2.1	Methods.....	26
5.2.2	Results	29
5.3	Input 3: Vulnerability matrix.....	31
5.3.1	Description of the vulnerability score.....	31
5.3.2	Methods.....	33
5.3.3	Result	35
5.4	Combination of the three inputs: Calculation of the Cumulative pressure index	40
6	Results.....	42
7	Discussion.....	45
8	Conclusion	49
9	Recommendations.....	50
10	References	53
11	Appendices	57
	Appendix I: Excluded activities and uses.....	57
	Appendix II: Distribution and intensity of anthropogenic pressures	58
	Appendix III: Distribution of the single ecosystem categories.....	83
	Appendix IV: Questionnaire	93



1 Introduction

Our global oceans are of high relevance for ecological, economic, and social reasons (Costanza, 1999). The marine systems are vital to keep the natural climate running and further provide services like coastal protection, resources and livelihoods for mankind. In addition, many economic industries are linked to the marine environment and its resources, such as tourism, energy related sectors, fishery sectors and oil- and offshore industries, which represent the major economic sectors that depend on resources in the sea (Bosch *et al.*, 2010).

Growing human population and an increase in the diversity of human uses and activities in the marine environment, especially concentrated along the coast, put marine resources under increased pressure. Today, global marine ecosystems are subject to many different anthropogenic pressures (e.g. tourism, commercial and recreational fisheries, aquaculture, boat traffic, anchoring, water sport activities, beach zone uses, marine-related industries and coastal development) (Crain *et al.*, 2009). Given the diversity of these anthropogenic pressures and the diversity of natural resources that converge in coastal waters, the resulting potential cumulative impacts on marine ecosystems are an important factor to consider (Kappel *et al.*, 2012). This is very important when thinking about ocean planning as well as conservation management strategies for particular areas (Kappel *et al.*, 2012).

The prevention, reduction and management of independent- and cumulative anthropogenic pressures present a formidable challenge, which gets more important every day (Halpern *et al.*, 2007). The challenge essentially lies in balancing the increase of coastal activities, population growth and securing the health of the marine ecosystems. In order to be able to introduce appropriate management strategies, resource managers first need a better understanding of the relationships between cumulative anthropogenic pressures and the health of the marine ecosystems (Allan *et al.*, 2013).

Additionally, the European Marine Strategy Framework Directive (MSFD), introduced by the European Union, has the ambitious aims to conserve marine biodiversity in European seas more effectively.

The MSFD obligates Member States to develop strategies that measures and assess marine environmental conditions in order to manage potential negative impacts and achieve “good environmental status” of the marine environment by 2020 (MSFD, 2008). For this purpose, it is essential to first identify human activities and uses. Second, to quantify pressures on the marine environment that derive from those activities and uses.

The first method that fully covered a quantitative spatial analysis of anthropogenic pressures on marine ecosystems, and therefore offering a scientific basis for future management plans, had been developed by Halpern *et al.* in 2007. The report “*Evaluating and Ranking the Vulnerability of Global Marine Ecosystems to Anthropogenic Threats*”



(Halpern *et al.*, 2007) describes a model that quantifies cumulative anthropogenic pressures on the ecosystems as well as the benefit it can imply for the evaluation of more effective environmental policies and regulations. In addition, many researchers have been using, or adapting, this model for projects at more regional scales all around the world (Selkoe *et al.* 2008; Selkoe *et al.*, 2009; Ban *et al.*, 2010; HELCOM, 2010; Teck *et al.*, 2010; Grech *et al.*, 2011; Kappel *et al.*, 2012; Korpinen *et al.*, 2012; Allan *et al.*, 2013).

This report presents a project in which the mentioned method is adapted to the local scenario of the *Alcúdia* Bay on the Balearic Island Majorca, Spain. It illustrates a first approach of quantifying and spatially visualizing cumulative anthropogenic pressures that affect present ecosystems in the *Alcúdia* Bay. By spatially visualising these pressures, the resulting cumulative anthropogenic pressure map aims to identify the distribution and intensity of the combined anthropogenic pressures. The initiative for this project came from the Spanish institution of the Balearic Islands Coastal Observing and Forecasting System (SOCIB), which wants to conduct a first approach of cumulative anthropogenic pressure mapping in the *Alcúdia* Bay as a tool for a first assessment of the European MSFD.

The final outcome provides a reliable basis for future development of policies, ocean planning decisions, regulations and management strategies, in order to mitigate the anthropogenic pressures to an acceptable level, and thereby support a sustainable use of the natural environment in the *Alcúdia* Bay.



2 Research description

2.1 Problem description

Considering the numerous human activities and uses taking place in the *Alcúdia* Bay (Section 4.2 and 5.1), the ecosystems are subject to several anthropogenic pressures. Referring to L. Gómez-Pujol ([meeting, 6th of May, 2013](#)), visitors arrive during the whole year, reaching the peak during the summer season. Because of this temporary high concentration, the coastal population in the area rises enormously and as an inevitable consequence associated human activities and uses increase considerably. Therefore, anthropogenic pressures deriving from these human activities and uses put the marine environment under severe stress (i.e. either temporary or permanent disturbance or damage to one or more components of an ecosystem ([Korpinen et al., 2012](#))).

Due to the diversity of anthropogenic pressures, it is crucial to understand potential independent and especially cumulative impacts on the ecosystems ([Kappel et al., 2012](#)).

The significance for understanding these potential independent- and cumulative impacts is further increased by the requirements of the European MSFD. The MSFD requires Member States to assess the level of human impact on their marine waters ([MSFD, 2008](#)), in order to develop an effective basis for future management regulations and policies.

In order to assess the level of anthropogenic pressures and potential impacts on the marine environment, a compilation of comprehensive information (e.g. level and source of different anthropogenic pressures, status of ecosystems, etc.) is a prerequisite.

However, at the moment there is a lack of comprehensive information about the relative vulnerability of marine ecosystems in regard to the associated human uses and activities ([Kappel et al., 2012](#)). Furthermore, another problem is the current lack of datasets concerning the quantification and visualization of cumulative anthropogenic pressures on the environment. Currently, the Balearic government as well as the public are aware about the importance of the issues and the need for more, scientific based and sustainable integrated coastal zone management (ICZM) implementations ([Diedrich et al., 2010](#)). Nevertheless, L. Gómez-Pujol ([meeting, 6th of May, 2013](#)) reported, that no approach to assess and quantify the level of anthropogenic pressures on the marine environment has been conducted until now. This lack of a proper approach leads to a lack of information for decision- makers.

Up until now, available scientific information mostly have focused on threats on specific ecosystems or species rather than ecosystem-pressure interactions ([Kappel et al., 2012](#)). However, taking the importance of the ecosystem context into account is necessary when assessing anthropogenic pressures on ecosystems. Ecosystem-context in this regards means that one pressure can have very different effects on different ecosystems, especially



when considering that each ecosystem responds differently to specific individual and especially cumulative anthropogenic pressures (Halpern *et al.*, 2007).

As a result, no sound understanding of cumulative pressures is present and relevant information is not available for environmental managers and decision-makers, especially not on a regional scale. However, quantification of cumulative anthropogenic pressures on the ecosystems can be regarded as a critical prerequisite for understanding potential impacts on the marine environment (Korpinen *et al.*, 2012). Understanding these impacts should help in order to develop effective future management regulations. For these mentioned reasons, a sustainable management strategy that aims to mitigate the impacts of anthropogenic activities, presents a difficult task for responsible authorities. Therefore, an assessment is needed to quantify relative cumulative pressures, combined with spatial information of the distribution and intensity of these pressures.

2.2 Research aim

The aim of this research is to conduct a cumulative anthropogenic pressure model to the local scenario of the *Alcúdia* Bay. Therefore, the distribution and intensity of relevant cumulative anthropogenic pressures on the ecosystems on site need to be quantified and spatially visualized. The resulting cumulative anthropogenic pressure map is expected to gain insight into the identification and quantification of the distribution and intensity of cumulative anthropogenic pressures.

In order to realize this target a cumulative anthropogenic pressure model that has been previously developed by Halpern *et al.* (2007, 2008) was chosen as guidance.

The approach of Halpern *et al.* (2007, 2008) was developed for spatial visualization of cumulative anthropogenic pressures in coastal sea areas (Korpinen *et al.*, 2012) and can be applied to any ecological setting or list of activities (Halpern *et al.*, 2007, 2008). This approach made the method the most useful technique for the purpose of this project, because it enables to incorporate the local characteristics of the *Alcúdia* Bay.



2.3 Research question

In order to reach the above described aim, a research question was formulated and further subdivided into four sub-questions. The research question displays the general intention of the thesis outcome, while the sub-questions were used to answer the research question. The research aim directly leads to the research question:

How does the intensity and spatial distribution of cumulative anthropogenic pressure, on the ecosystems in the *Alcúdia* Bay, look like?

In order to find an answer to this research question, the underlying sub-questions are formulated. To prevent confusion, the order of the sub-questions was chosen to follow the same order of the variables in the formula (Section 5.4), which finally is used to combine all gathered and assessed information.

1. What is the spatial distribution and intensity of anthropogenic pressures in the *Alcúdia* Bay?
2. What is the distribution of the present ecosystems in the *Alcúdia* Bay?
3. How can the relative intensity of a given anthropogenic pressure on present ecosystems be quantified?
4. How can all relevant information about anthropogenic pressures on the ecosystems be combined, in order to visualize cumulative anthropogenic pressure?

3 Reading guide

The next section (Section 4.1), provides a general schematic overview of the applied method and the process of the project (Fig. 1), followed by a section about the characteristics of the study area (section 4.2). Subsequently, the next three sections (Section 5.1, 5.2 and 5.3) are split up into the different inputs that are required to conduct a cumulative anthropogenic pressure model in the *Alcúdia* Bay. The sequence of these sections reflects the exact order of the formula, which calculates the cumulative anthropogenic pressure index (Section 5.4), by combining the three inputs mentioned above. Furthermore, each input is subdivided into more detailed information about the data collection, the data analyses and the results. In addition, at the beginning of each input a more detailed introduction is provided. Afterwards, a critical discussion of the processes is



provided (Section 7), as well as the conclusion (Section 8) of and some general recommendations (Section 9).

4 Methodology

4.1 General framework

This section describes the framework and methods used to conduct the cumulative anthropogenic pressure model in the *Alcúdia Bay*. The model is based on a general framework developed by Halpern *et al.* (2007, 2008) and provides a useful tool for mapping cumulative anthropogenic impacts on marine ecosystems (Andersen *et al.*, 2013). Considering that the study site is located in the Spanish Kingdom and thus, a part of the European Union, the MSFD was used as guidance as well. This is expected to support the significance and viability of the results, because the necessity for future requirements has been taken into account.

In order to meet the local conditions and the unique list of anthropogenic pressures and ecosystems on site, the method of Halpern *et al.* (2007, 2008) was modified as described in the following sections.

As displayed in the overview (Fig. 1) the method generally includes three inputs which were tackled separately and subsequently combined with help of a formula (Section 5.4).

- The **first input** is the identification of human activities and uses that take place in the area. Furthermore, the information regarding anthropogenic activities were compiled and linked to different types of pressures that can be derived from these activities and uses. Subsequently, all relevant anthropogenic pressures were individually spatially visualized by considering the distribution and intensity of each pressure separately (Halpern *et al.*, 2008).
- The **second input** of the model consisted of the identification of relevant ecosystems and ecosystem components at the site of interest, including their spatial distribution. Subsequently, the gathered information were transformed into individual datasets per ecosystem category as presence/absence layers (Halpern *et al.*, 2008).
- The **third input** is the vulnerability score. Essentially, the vulnerability score is an incorporation of expert judgements to quantify the relative intensity of a specific anthropogenic pressure on a present ecosystem. This input required to survey ecosystem experts and marine scientists (Halpern *et al.*, 2008).



The whole procedure underlines an ecosystem-based management position. Out of this position, the first step to develop a basis for the quantification of anthropogenic pressures on the natural environment, is based on research and mapping of the environment and the anthropogenic pressures which affect its natural condition (Kay & Alder, 2005). In order to realize this, the model of Halpern *et al.* (2007, 2008) ensures the comprehension of variation in sensitivity of each ecosystem to relevant anthropogenic pressures. Namely, that the same anthropogenic pressure can have very different effects depending on the ecosystem in which it occurs (Kappel *et al.*, 2012). In addition to that, by incorporating expert judgments, it is ensured that the vulnerability score is based on a scientific background and thus enforces the reliability of the model (Halpern *et al.*, 2007). The final result of a cumulative anthropogenic pressure map allows outlining the exact position of high pressure areas with regard to the present ecosystems (Halpern *et al.*, 2007).

In order to gather the needed information and realize the model, the use of social sciences (survey via questionnaire) and Geographical Information System (GIS) (as the main analytical tool) was required. In regard to latter, the software ESRI ArcGIS 10.1 was used to analyse and process the collected information and datasets. Thereby, all data layer and model outputs were rasterized on a 25meter-by-25meter grid (i.e. 0,000625 km² area covered per grid cell) in order to ensure their compatibility for the final cumulative model. Thus, the whole study area of 179,53km² in total is divided into 287243 cells, of which each contains distinct values of the calculated cumulative pressure index (Section 4.6) of the study site.

The raster format offers several advantages in comparison to the vector format, namely that, due to the nature of raster maps, it is ideally suited for mathematical modelling and quantitative analyses (Gopi *et al.*, 2008). All data, regardless of original resolution, were mapped, using a projected coordinate system (WGS 1984 UTM Zone 31N).

Identification of pressures:

- Link of anthropogenic activities to pressures they cause
- Selection of an indicator for the pressure(s)
- Elaboration of information about the distribution and intensity for the indicator

Preparation for input 1

Identification of ecosystems:

- Relevant ecosystems at the study site
- Elaboration of information about the spatial distribution

Preparation for input 2

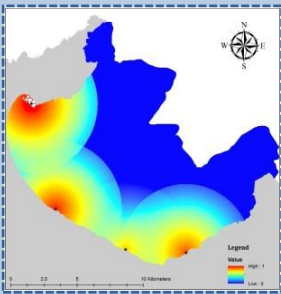
Completion of expert questionnaires:

- Development of a vulnerability score for each individual ecosystem – pressure scenario

Preparation for input 3

Pressure layers

- Log[x+1] – transformation
- Normalization (between 0 – 1)
- Size of the assessment unit: 25meter-by-25meter



Input 1 (P_i)
(Section 5.1)

Vulnerability scores

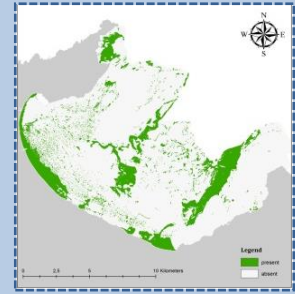
- Calculation based on expert judgments

Pressure category	Pressure type and corresponding activity	Pressure intensity	Pressure frequency	Pressure duration	Pressure proximity	Pressure impact	Pressure vulnerability
1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9
10	10	10	10	10	10	10	10
11	11	11	11	11	11	11	11
12	12	12	12	12	12	12	12
13	13	13	13	13	13	13	13
14	14	14	14	14	14	14	14
15	15	15	15	15	15	15	15
16	16	16	16	16	16	16	16
17	17	17	17	17	17	17	17
18	18	18	18	18	18	18	18
19	19	19	19	19	19	19	19
20	20	20	20	20	20	20	20
21	21	21	21	21	21	21	21
22	22	22	22	22	22	22	22
23	23	23	23	23	23	23	23
24	24	24	24	24	24	24	24
25	25	25	25	25	25	25	25
26	26	26	26	26	26	26	26
27	27	27	27	27	27	27	27
28	28	28	28	28	28	28	28
29	29	29	29	29	29	29	29
30	30	30	30	30	30	30	30
31	31	31	31	31	31	31	31
32	32	32	32	32	32	32	32
33	33	33	33	33	33	33	33
34	34	34	34	34	34	34	34
35	35	35	35	35	35	35	35
36	36	36	36	36	36	36	36
37	37	37	37	37	37	37	37
38	38	38	38	38	38	38	38
39	39	39	39	39	39	39	39
40	40	40	40	40	40	40	40
41	41	41	41	41	41	41	41
42	42	42	42	42	42	42	42
43	43	43	43	43	43	43	43
44	44	44	44	44	44	44	44
45	45	45	45	45	45	45	45
46	46	46	46	46	46	46	46
47	47	47	47	47	47	47	47
48	48	48	48	48	48	48	48
49	49	49	49	49	49	49	49
50	50	50	50	50	50	50	50
51	51	51	51	51	51	51	51
52	52	52	52	52	52	52	52
53	53	53	53	53	53	53	53
54	54	54	54	54	54	54	54
55	55	55	55	55	55	55	55
56	56	56	56	56	56	56	56
57	57	57	57	57	57	57	57
58	58	58	58	58	58	58	58
59	59	59	59	59	59	59	59
60	60	60	60	60	60	60	60
61	61	61	61	61	61	61	61
62	62	62	62	62	62	62	62
63	63	63	63	63	63	63	63
64	64	64	64	64	64	64	64
65	65	65	65	65	65	65	65
66	66	66	66	66	66	66	66
67	67	67	67	67	67	67	67
68	68	68	68	68	68	68	68
69	69	69	69	69	69	69	69
70	70	70	70	70	70	70	70
71	71	71	71	71	71	71	71
72	72	72	72	72	72	72	72
73	73	73	73	73	73	73	73
74	74	74	74	74	74	74	74
75	75	75	75	75	75	75	75
76	76	76	76	76	76	76	76
77	77	77	77	77	77	77	77
78	78	78	78	78	78	78	78
79	79	79	79	79	79	79	79
80	80	80	80	80	80	80	80
81	81	81	81	81	81	81	81
82	82	82	82	82	82	82	82
83	83	83	83	83	83	83	83
84	84	84	84	84	84	84	84
85	85	85	85	85	85	85	85
86	86	86	86	86	86	86	86
87	87	87	87	87	87	87	87
88	88	88	88	88	88	88	88
89	89	89	89	89	89	89	89
90	90	90	90	90	90	90	90
91	91	91	91	91	91	91	91
92	92	92	92	92	92	92	92
93	93	93	93	93	93	93	93
94	94	94	94	94	94	94	94
95	95	95	95	95	95	95	95
96	96	96	96	96	96	96	96
97	97	97	97	97	97	97	97
98	98	98	98	98	98	98	98
99	99	99	99	99	99	99	99
100	100	100	100	100	100	100	100

Input 3 (u_{ij})
(Section 5.3)

Ecosystem layers

- 0/1 (presence/absence)
- Size of the assessment unit: 25meter-by-25meter



Input 2 (E_j)
(Section 5.2)

Calculation of cumulative pressure index (I):

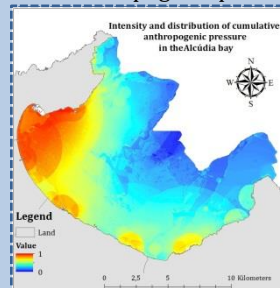
- Multiplication of the three inputs to sum them up within each of the assessment units in the study area

$$I = \sum_{i=1}^n \sum_{j=1}^m P_i \times E_j \times u_{ij}$$

(Section 5.4)

Visualisation of the final product

-> Cumulative anthropogenic pressure map <-



(Section 6)

Figure 1: A schematic overview of the project, including the three inputs of the cumulative pressure model, as well as mandatory preparations, the unit size used in the maps and references to the related sections in this report.



4.2 Study area

The study was conducted in the Spanish bay of *Alcúdia* on Majorca (Fig. 2), which is the most extensive island of the Spanish autonomous community of the Balearic Island. The island composes an area of 3640 km² with a coastline of 722 km in total (Balaguer *et al.*, 2011).

It offers many environmental highlights like scenic beaches or the mountains of the “Sierra de Tramuntana”, which attract numerous national and international visitors every year. Especially during the summer seasons, visitors come to explore the island, to enjoy its natural beauty and to practice recreational activities. Referring to L. Gómez-Pujol (meeting, 6th of May, 2013) tourism already captures most of the regions, but concentrates along the coastlines at places where hotels and similar touristic installations offer the required services.

The study area of the *Alcúdia* Bay in the North-East of the island presents one of these places, and is one of the most popular tourist destinations on Majorca. The bay is located approximately 54km off the capital Palma (position: 39° 51' 12" N, 3° 7' 16" E) (Fig. 2) and stretches along about 43km of coastline, bordered by the municipalities of *Alcúdia*, *Muro*, *Santa Margalida* and *Artà* (Figure 3). *Alcúdia* presents with 19,586 permanent inhabitants the largest municipality, followed by *Santa Margalida* (11,922 inhabitants),

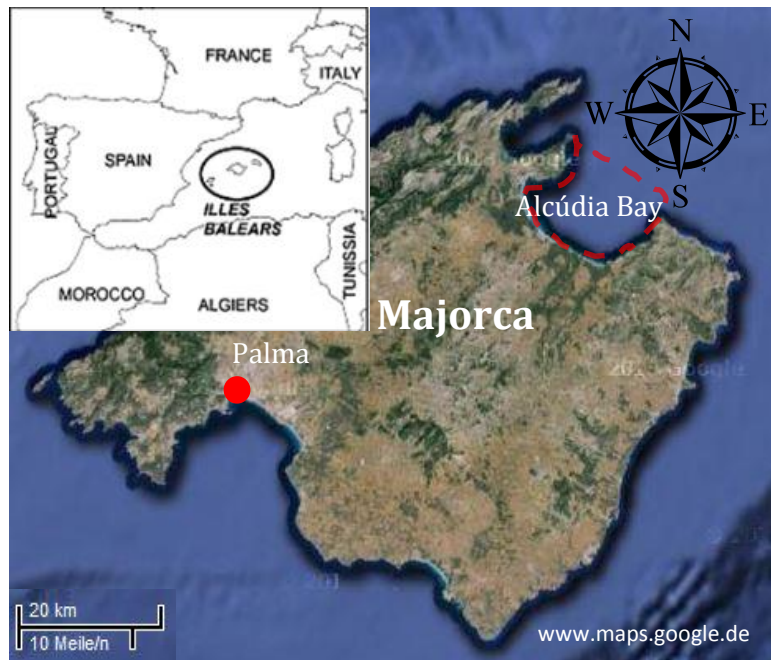


Figure 2: Map of the Balearic Island of Majorca (Spain), showing the location of the capital Palma and the Alcúdia Bay in the north-east of the island

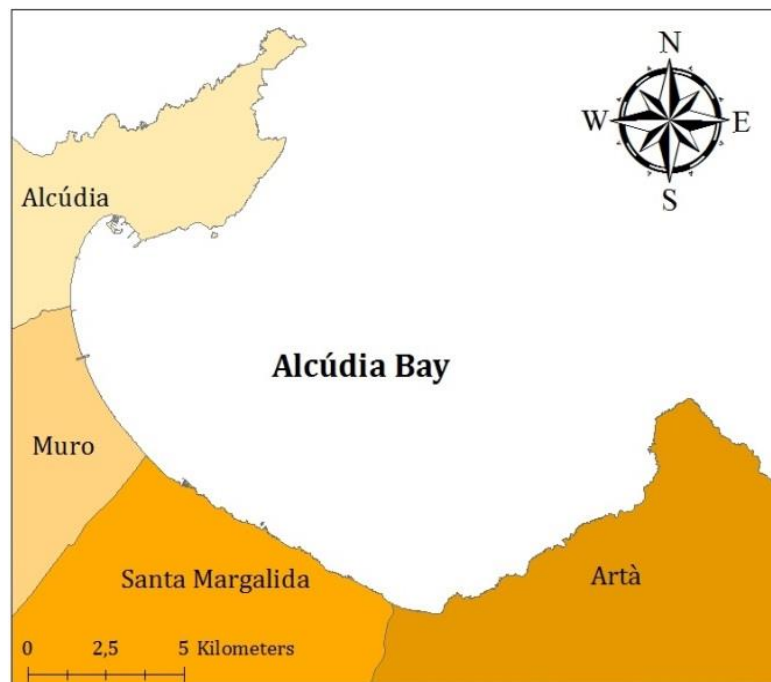


Figure 3: Map, displaying the four municipalities that frame the Alcúdia Bay, including the borders of each municipality



Artà (7629 inhabitants) and Muro (6963 inhabitants) (Instituto Nacional de Estadística, 2012).

The relatively shallow bay which stretches along the four municipalities, presents the study area of the project. It covers roughly 179,52km², while reaching a maximal depth of 40m (Fig. 4). Its shallow shelving littoral zone offer perfect conditions for the establishment of sea grass meadows like *Posidonia oceanica*. *Posidonia oceanica* is an endemic specie to the Mediterranean Sea and dominates the sea floor of the study area. At both sides of the bay, mountains define the landscape, sheltering the bay and causing a relatively steep coastline. In contrast, the wide stretched inner shore gently inclines forming long sandy beaches and the inland behind the urbanized coastline offers fertile plains. These plains are used for agricultural activities (Tamoh *et al.*, 2008).

Most parts of the coast are urbanized and covered by hotels, private (holiday) apartments as well as related infrastructure (Fig. 5). Consequently, the highest concentration of urbanization is present at the north-west side of the bay (close to Alcúdia town), while urbanisation decreases to the east side.

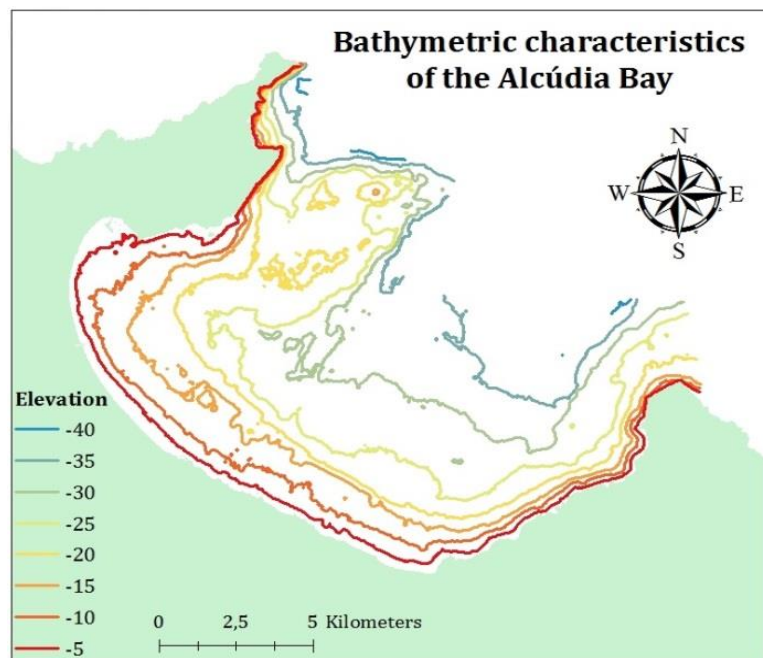


Figure 4: Map visualizing the bathymetric characteristics of the study area



Figure 5: Aerial photograph of the Alcúdia Bay from March 2007, showing areas of urbanization.

Reference: J.Rigo, March 2007, Alcúdia Bay (Majorca), http://upload.wikimedia.org/wikipedia/commons/c/ce/Badia_d%27Alc%C3%BAdia.jpg



Besides the historical memorials at the centre of Alcúdia town, the coastal wetlands of the *s'Albufera National Park* are recognized as one of the highlights of the area. The entire wetland area is under natural protection and therefore excluded from coastal development. Attracted by the multifaceted environment and the well-organized infrastructures and services, numerous visitors come to the area throughout the year. However, the highest concentration of visitors occur during the summer season. The periodical growth of population becomes absorbed by the huge amount of hotels and beach resorts, which offer accommodation to the temporal visitors. During the high season, especially the long, sandy beaches become hotspots of recreational activities just like the port facilities of the municipalities, which all offer a combination of restaurants, bars, shopping facilities and recreational docking facilities ([Alcudia Mallorca minicipi ecotouristic, 2013](#)). The largest port in the area is located in the municipality of *Alcúdia* and includes (next to its recreational dockings) a small fishery harbour as well as a commercial port. The commercial port is mainly used for unloading coal, which is used for the production of electricity. Together with terminals for butane and propane gas, this makes the port very important for the local energy companies. In addition to that, the port of *Alcúdia* offers docking facilities for the ferry connections to Menorca, Valencia and Barcelona ([Port Authority of the Balearic Islands, 2013](#)). This accessibility also contributes to the attraction of visitors.

In order to cope with the rising environmental demands caused by the increasing coastal population during the summer season, the area includes several industrial installations. According to L. Gómez-Pujol ([meeting, 13th of May 2013](#)) and local observations, these facilities include two wastewater treatment plants which clean up the sewage of the four municipalities, a desalination plant, which ensures a constant freshwater supply, and a power plant installation, which is running on coal and ensures the availability of electricity in the area.



5 Cumulative anthropogenic pressure model

The cumulative anthropogenic model is a measure to provide a quantification and spatial overview of cumulative anthropogenic pressure on the ecosystems of the *Alcúdia* Bay. The three inputs needed to conduct the model are tackled separately and are shown in the subsequent sections (Section 5.1, 5.2 and 5.3).

5.1 Input 1: Distribution and intensity of anthropogenic pressures

This section provides information about the “*Methods*” (Section 5.1.1) and the “*Results*” (Section 5.1.2) of the first input. The section outlines the performed process to assess the local anthropogenic activities and the related pressures they can cause, as well as their distribution and intensity. The results of the process are 25 digital pressure layers in raster format, which represent the first input of the final cumulative model.

5.1.1 Methods

Data collection

The first input to the cumulative pressure model is based on the identification of the spatial distribution and intensity of anthropogenic pressures (both land- and ocean-based) that affect marine ecosystems. In order to be able to obtain any information about anthropogenic pressures, the first step was to compile information about the source of anthropogenic pressures, namely human uses and activities. The compilation was done by literature review, field work, and own observation as well as interviews to include local knowledge. With that information, a first draft of human activities in the study area was created. This draft compiled all possible scenarios of activities that were present in the area. However, after reviewing the data collected it was decided to not include all of the listed activities in the project. The background for this decision was the limited availability of data sets and information as well as questions around the quality of data or the relevance of an activity to the marine environment. Furthermore, the restricted timeframe of the project did not allow an expanded research and the development of useful data sets.

The result of the process is displayed in table 1, which lists the final compilation of human uses and activities, divided into categories. An extra table, listing the activities that take place on the site, but are not included in the cumulative pressure model, is provided in the appendix (Appendix I, Table A I).



Table 1: Compiled human uses and activities that were included in the project

Groups	Relevant human uses/activities
Aquaculture	Fish farm
Fisheries	Artisanal fishery, recreational fishery
Industry, energy, population and infrastructure	Coastal power plants, Dredging, Artificial coastal structures (including coastal engineering and defence), coastal wastewater treatment plant, urban outfalls, coastal desalination plants, artificial coastal structures
Nutrient enrichment and pollution from land and the atmosphere	Agriculture
Shipping and transport	Harbours, sea traffic, anchoring
Other human activities	Water sport activities, Beach zone activities
Global change	Climate change (sea-level rise, sea temperature rise, ocean acidification)

The framework of the anthropogenic cumulative pressure model requires to link human uses and activities with one or more related pressures. This includes the consideration that many human uses and activities cause multiple pressures, which may spread over different distances and affect different ecosystem components (Andersen *et al.*, 2013; Crain *et al.*, 2009). For example, commercial sea traffic presents a possible source of pollution which has a certain range of influence and therefore affects certain ecosystem components at that location. However, commercial sea traffic also presents a source of underwater noise which may spread over a different distance and therefore affect different ecosystem components. In addition, environmental circumstances, like currents or wind directions may cause an additional effect of the impact and are possibly responsible for an enlargement of the spatial area of the impact. Nevertheless, these factors are not taken into account in this project due to several reasons, discussed later on (Section 7).

In order to meet the requirements of the method, while taking the European MSFD into account, the elaborated anthropogenic activities were linked to the pre-defined pressure categories of the MSFD (Table 2). In this regard, the following definition for anthropogenic pressures was considered: “We define an anthropogenic pressure as a human-derived stress factor causing either temporary or permanent disturbance or damage to or loss of one or several components of an ecosystem” (Korpinen *et al.*, 2012).

The following table (Table 2) displays the pre-defined pressure categories which are considered in the MSFD. Additionally, a second table (Table 3) is provided, outlining information about the anthropogenic uses and activities and the pressures they were linked to.



Table 2: Pressures of the MSFD (MSFD, 2008) with corresponding sub-groups.

Physical loss	- Smothering (e.g. by man-made structures, disposal of dredge spoil)
	- Sealing (e.g. by permanent constructions).
Physical damage	- Changes in siltation (e.g. by outfalls, increased run-off, dredging/disposal of dredge spoil),
	- abrasion (e.g. impact on the seabed of commercial fishing, boating, anchoring),
	- selective extraction (e.g. exploration and exploitation of living and non-living resources on seabed and subsoil).
Other physical disturbance	- Underwater noise (e.g. from shipping, underwater acoustic equipment), marine litter.
Interference with hydrological processes	- Significant changes in thermal regime (e.g. by outfalls from power stations),
	- Significant changes in salinity regime (e.g. by constructions impeding water movements, water abstraction).
Contamination by hazardous substances	- Introduction of synthetic compounds (e.g. priority substances under Directive 2000/60/EC which are relevant for the marine environment such as pesticides, antifoulants, pharmaceuticals, resulting, for example, from losses from diffuse sources, pollution by ships, atmospheric deposition and biologically active substances),
	- Introduction of non-synthetic substances and compounds (e.g. heavy metals, hydrocarbons, resulting, for example, from pollution by ships and oil, gas and mineral exploration and exploitation, atmospheric deposition, riverine inputs),
	- Introduction of radio-nuclides.
Systematic and/or intentional release of substances	- Introduction of other substances, whether solid, liquid or gas, in marine waters, resulting from their systematic and/or intentional release into the marine environment, as permitted in accordance with other Community legislation and/or international conventions.
Nutrient and organic matter enrichment	- Inputs of fertilisers and other nitrogen — and phosphorus-rich substances (e.g. from point and diffuse sources, including agriculture, aquaculture, atmospheric deposition),
	- Inputs of organic matter (e.g. sewers, mariculture, riverine inputs).
Biological disturbance	- Introduction of microbial pathogens,
	- Introduction of non-indigenous species and translocations,
	- Selective extraction of species, including incidental non-target catches (e.g. by commercial and recreational fishing).



Table 3: Human activities and uses categorized into the pressures listed in the MSFD (MSFD, 2008), and additional pressures (*) included in this study. Additionally, relevant information on the associated data layer, the type of indicator and the data source are provided. Note that the pressure group “Systematic and/or intentional release of substances” is listed in the MSFD, but not included in this table and thus this project.

(*not included in the initial MSFD categories)

Pressure types	Data layer (activity)	Indicator	Data source
Physical loss			
Smothering by dumped material	Dredging	Location	National Port authority (Puertos del Estado)
Sealing of seabed	Artificial coastal structures	Length of structures, Location	SOCIB viewer (http://gis.socib.es/sacosta/composer) (field survey and according with the information offered by geomorphological classification of the coast (Environmental Sensitivity of the coast)), (General Directorate of Emergencies (Department of Internal Affairs of the Government of the Balearic Islands), master plan for coastal uses of 1976 (MOP, 1975) and national port authorities for outfall pipes
Physical damage			
Abrasion of seabed	Anchoring	Location of anchoring and mooring buoy sites	Own observation, interviews with local marinas, SOCIB viewer (http://gis.socib.es/sacosta/composer), Aerial photos from the years (2006, 2007 and 2009)
Selective extraction of non-living resources	Dredging	Location	National Port authority
Coastal abrasion *	Beach zone activities	Number of hotels and size (measured by the available beds of each hotel)	Catàleg Hosteleria, Conselleria de Turisme, Govern de les Illes Balears (Hotels Catalogue, Tourism Department, Government of the Balearic Islands), 2013
Other physical disturbance			
Underwater noise	Sea traffic	Intensity of sea traffic in the study area (defined as number of hours per cell in the study area)	Data on the intensity of marine traffic was collected with help of AIS (Automatic Identification System - http://marinetraffic.com/ais/) from the period of January – December 2012,
Interference with hydrological processes			
Changes in thermal regime	Power plant outflow	Location of entry point	Govern de les Illes Balears (Government of the Balearic Islands) (CAIB, 2005)
Changes in salinity regime	Urban outfalls	Location of entry point	IDEIB viewer (http://ideib.caib.es/visualitzador/visor.jsp) (General Directorate of Emergencies (Department of Internal Affairs of the Government of the Balearic Islands).
	Wastewater treatment plant outfall	Location of entry point	IDEIB viewer (http://ideib.caib.es/visualitzador/visor.jsp) (General Directorate of Emergencies (Department of Internal Affairs of the Government of the Balearic Islands)
	Power plant intake	Location of entry point	Govern de les Illes Balears (Government of the Balearic Islands) (CAIB, 2005)
	Desalination plant intake	Location of entry point	We collected the location by conducting an interview with the city council in Alcudia,



Table 3: Human activities and uses categorized into the pressures listed in the MSFD (MSFD, 2008), and additional pressures (*) included in this study. Additionally, relevant information on the associated data layer, the type of indicator and the data source are provided. Note that the pressure group “Systematic and/or intentional release of substances” is listed in the MSFD, but not included in this table and thus this project.

(*not included in the initial MSFD categories)

Contamination by hazardous substances			
Introduction of synthetic compounds	Harbour	Size (represented by the number of moorings), Location	Associated harbour authorities of each municipality
	Wastewater treatment plant outfall	Location of entry point (outfall)	IDEIB viewer (http://ideib.caib.es/visualitzador/visor.jsp) (General Directorate of Emergencies (Department of Internal Affairs of the Government of the Balearic Islands))
	Urban outfalls	Location of entry point	IDEIB viewer (http://ideib.caib.es/visualitzador/visor.jsp) (General Directorate of Emergencies (Department of Internal Affairs of the Government of the Balearic Islands))
Introduction of non-synthetic compounds	Harbour	Size (represented by the number of moorings), Location	IDEIB viewer (http://ideib.caib.es/visualitzador/visor.jsp) (conventional cartography of the coasts of the Balearic Islands and from information of the Regional- and National Agency for port management), field survey and use of guide and port-books of the Balearic Islands (Hutt, 2006) for marinas
Nutrient and organic matter enrichment			
Input of fertilizers and other nitrogen- and phosphorus-rich substances	Agriculture	Location of entry point	Literature review (Donta <i>et al.</i> , 2005)
Inputs of organic matter	Fish farm outfall	Location of entry point	information of the Council of Fisheries of the Government of Balearic Islands (Fisheries Local Administration)
	Wastewater treatment plant outfall	Location of entry point	IDEIB viewer (http://ideib.caib.es/visualitzador/visor.jsp) (General Directorate of Emergencies (Department of Internal Affairs of the Government of the Balearic Islands))
Biological disturbance			
Introduction of microbial pathogens	Wastewater treatment plant outfall	Location of entry point	IDEIB viewer (http://ideib.caib.es/visualitzador/visor.jsp) (General Directorate of Emergencies (Department of Internal Affairs of the Government of the Balearic Islands))
	Urban outfalls	Location of entry point	IDEIB viewer (http://ideib.caib.es/visualitzador/visor.jsp) (General Directorate of Emergencies (Department of Internal Affairs of the Government of the Balearic Islands))
	Fish farm outfall	Location of entry point	information of the Council of Fisheries of the Government of Balearic Islands (Fisheries Local Administration)
Selective extraction of species	Artisanal fishery (trammel nets, morune nets, squid fishing)	Location of nets and squid fishing	Regional fishery expert (via email contact), Literature (Gazo <i>et al.</i> , 2008)
	Recreational fishery (land-based fishing, spear fishing areas and boat-based fishing)	Location of each of the activities	IDEIB viewer (http://ideib.caib.es/visualitzador/visor.jsp), interviews with relevant scientist, field surveys) for land-based fishing, interviews with local people (spear fishing) and observation done by IMEDEA (boat-based recreational fisheries).



Table 3: Human activities and uses categorized into the pressures listed in the MSFD (MSFD, 2008), and additional pressures (*) included in this study. Additionally, relevant information on the associated data layer, the type of indicator and the data source are provided. Note that the pressure group “Systematic and/or intentional release of substances” is listed in the MSFD, but not included in this table and thus this project.

(*not included in the initial MSFD categories)

Changes in wildlife behaviour *	Water sport activities (diving, kayaking, snorkelling and surfing (kite-, wind-, wave))	Location of each of the activities	Own observation, interviews with local tourist operators (Diving points: (Amengual-Gomila & García-Olagorta, 1999), Surfpoints: http://ideib.caib.es/visualitzador/visor.jsp)
Environmental pressures *			
Climate change	Climate change	Distribution of the pressure	Literature review (Philippart et al., 2011)

As shown, human activities were further associated with 16 subcategories of anthropogenic pressures, mainly predefined in the MSFD (Table 3).

In order to map and visualize the elaborated anthropogenic pressures (Table 3), a conceptual framework (Fig. 6) was used. The figure describes the procedure in the case of agriculture and the associated pressure it causes on the marine environment of the *Alcúdia* Bay.

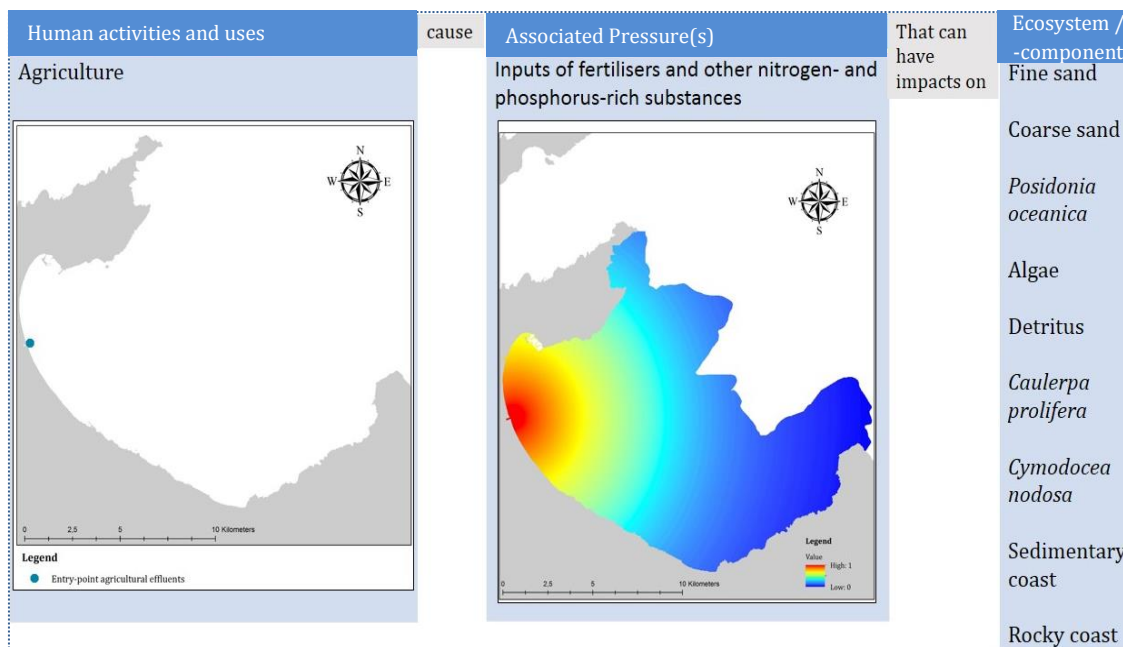


Figure 6: Conceptual framework for mapping anthropogenic pressures, adjusted to the requirements of the MSFD.

As shown, first the assigned indicator was mapped (in this case the entry point of agricultural substances that lead into the marine environment via a creek). In order to link



the activity of agriculture to its related pressure category, now the pre-defined pressures of the MSFD were considered. In the case of this example, the associated pressure of agriculture is related to the MSFD pressure type “input of fertilizers and other nitrogen- and phosphorus-rich substances” (category: *Nutrient input and organic matter enrichment*). To visualize the distribution and intensity of the pressure(s), more information about the distance of the impact and the intensity of the pressure(s) was needed.

These kinds of information present an essential requirement of the method and finally determine the visualization of each pressure. The data collection involved field work, interviews, observation and literature review, but had to be temporary limited, to make sure the process is feasible in the pre-defined timeframe. In the case of the example, literature review was used to gather information about the pressure on the marine environment through the inputs of fertilizers and other nitrogen- and phosphorus-rich substances. According to literature ([Readman et al., 1997](#)), this kind of pressure has an impact up to a distance of 30km before the pressure reaches a negligible level. Based on this information, finally the visualization of the associated pressure of agricultural activities was accomplishable and realized.

The same procedure was performed for each elaborated human activity that takes place in the study area and was selected to be included in the project.

Data analyses

It is important that the model distinguishes between the different pressures that can derive from the same human activity or use. Therefore, the distribution and intensity of each anthropogenic pressure is displayed using different spatial models. In this way, the model distinguishes between each possible combination of anthropogenic pressures they exert on each ecosystem separately.

In general, the different pressure layers were visualized with the help of four different visualization processes (Table 4).



Table 4: Chosen visualization style (left) and the associated method for the data analyses (middle) to visualize the pressure. Additionally, information about how each pressure layer was visually processed.

Visualization style	Method	Pressure layer included
Presence/absence layers, where the pressure layer is binary (i.e. either present (1) or absent (0)).	Presence/absence layer basically were done by creating a new shapefile with either points, lines or polygons that represent the chosen indicator for each pressure layer (e.g. location of the human activity or use). After having drawn the location manually, the shapefile was rasterized at the study area resolution.	Anchoring, moruna nets, squid fishing, trammel nets, spear gun fishing, dredging, land-based recreational fishing and climate change.
Exponential decay functions , which calculates a successive gradient for the pressure intensity from the source with reducing intensity (ranges from 1 at the starting point and decreases towards 0), depending on the distance values.	Exponential decay functions were chosen to indicate the distribution and intensity of anthropogenic pressures which intensity gradually decay with increasing distance to the source. In order to apply an exponential decay function, first a point feature type shapefile was created and the point was drawn at the location of the specific pressure (e.g. the entry point of the wastewater treatment plant outfall, where the effluents enter the marine environment). Subsequently, the shapefile was integrated into the open-source software R, a statistical computing and graphics software using the R programming language (R Development Core Team, 2012). For using an exponential decay model, an input data (the point shapefile) and two distance values were required. One value which indicates at what distance (in meter) the pressure intensity decays to 10% of its initial value, and one value to indicate at what distance the pressure intensity reaches 1% of its initial value and is therefore negligible. Subsequently, the pressure layer was saved as a raster, using the “raster” (Hijmans & van Etten, 2013) package, of the R programming language.	Agriculture, urban outfalls, harbours, desalination plant intake, power plant intake/outflow, fish farm outflow and wastewater treatment plant outflows.
Buffer layer, which creates buffer polygons around the input feature to indicate the same intensity of a pressure for a specified distance around the source (ArcGIS Resources, 2013a).	Buffer layer basically were done by creating a new shapefile with either points, lines or polygons that represent the chosen indicator for each pressure layer (e.g. diving points). After having drawn the location of the dive spots manually, the buffer function was used with a distance (in the case of the diving layer, 500m was chosen). Subsequently, the input feature was rasterized at the study area resolution. Additionally, (in the case of the beach zone activity layer) a buffer was used, which was weighted by the chosen indicator (in this case, the number of hotel beds in a 1km radius. In the case of the artificial coastal structure layer, the length (in meter) of the lines was used for weighting the intensity of the buffer.	Artificial coastal structures, diving, kayaking, snorkelling, surfing and beach zone activities.



Table 4: Chosen visualization style (left) and the associated method for the data analyses (middle) to visualize the pressure. Additionally, information about how each pressure layer was visually processed.

Density model, calculates a magnitude per unit area from point or polyline features using a kernel function (ArcGIS Resources, 2013b).	Density layer were done by creating a new shapefile with either points, lines or polygons to indicate the location of the indicator of a specific pressure. Subsequently, the Kernel Density function was used, in order to visualize the distribution of the pressure which is caused by the associated activity. Thereby, the radius for the density calculation of the location of activity was selected manually (1km). In the end the layers were rasterized to be compatible within the final model.	Boat-based recreational fishing, sea traffic.
---	--	---

Additional information concerning the data analyses of each pressure layer is provided in each pressure layer (Appendix II).

In the final step, in order to meet the model requirements, all pressure variables in a pressure layer needed to be transformed to a uniform numeric scale (Allan *et al.*, 2013). Following Halpern *et al.* (2008) and other projects (e.g. Allan *et al.*, 2013; Andersen *et al.*, 2013) all cells in every pressure layer (except for presence/absence layers) were $\log[x+1]$ transformed in order to avoid an over-dominance of extreme values on the final cumulative anthropogenic pressure map. Also, log-transformation corrects typically skewed frequency distributions of each pressure layer (Allan *et al.*, 2013). Finally, the pressure layers were normalized to the range between 0 (zero or minimum observed value) and 1 (maximum observed value), in order to assess each pressure layer on a comparable scale. The normalization was done using max-min rescaling ($[x_i - x_{\min}]/[x_{\max} - x_{\min}]$) (Allan *et al.*, 2013), using the R software.

5.1.2 Results

The result of the elaboration and analyses of relevant pressures are 25 unique pressure layers (Appendix II), depicting the spatial distribution and intensity of anthropogenic pressures in the *Alcúdia* Bay. The compilation of all pressure layers indicates that some anthropogenic pressures only have local effects (e.g. water sport activities in general, artificial coastal structures). In contrast, other anthropogenic pressures have a greater distribution and intensity (e.g. agricultural effluents, urban outfall effluents, wastewater treatment plant effluents and sea traffic).

The compilation of pressure layers were used to answer to the first sub-question (“What is the spatial distribution and intensity of each anthropogenic pressure in the *Alcúdia* Bay?”) and completes the first input for the cumulative anthropogenic pressure model.



5.2 Input 2: Distribution of the selected ecosystems and ecosystem components

This section provides information about the “*Methods*” (Section 5.2.1) and the “*Results*” (Section 5.2.2) of input two. Additionally, the assessment of the present ecosystems in the study area, including information about their spatial distribution is explained. The results of this process cover 10 ecosystem layers in raster format that represent the second input of the final cumulative model.

5.2.1 Methods

Data collection

The information about the present coastal- and marine ecosystems in the *Alcúdia* Bay were provided by SOCIB and consisted of two single map datasets:

The first dataset was processed by the “Conselleria de medi Ambient de Govern de les Illes Balears” (CAIB) (Local Ministry of the Environment of the Balearic Islands) in 2006, developed on behalf of the European “Life Posidonia” project, which aimed to “guarantee the viability and biological richness of the habitat in Balearic waters” (CAIB, 2013). The provided map contains the marine ecosystems of *Pollença*- and *Alcúdia* Bay and was developed using a side-scan sonar technique and an interpretation of orthophotographs (CAIB, 2013).

The second dataset provided information about the coastal ecosystems and was produced by SOCIB in 2012. This map was based on the Environmental Sensitivity Index Guidelines (ESI) of the NOAA Technical Memorandum (Petersen *et al.*, 2002), which is an internationally recognized standard and includes numeric codes representing different types of coastal composition and ecosystems (Table 5). The map includes the whole coastlines of the Balearic Islands and was developed in order to “respond to the need for standardization in terms of the response to pollution and the location of sensitive resources that may be affected” (SOCIB, 2012).

Data analyses

The provided maps were developed for varying purposes, namely the relocation of *Posidonia oceanica* meadows (CAIB, 2013) (marine ecosystem map – intertidal) and a standardization index of the response to pollution of sensitive resources (SOCIB, 2012) (coastal ecosystem map – subtidal). Also, the original scope of both maps did not match the



scale of the study site. Therefore, the provided information was modified to meet the requirements of the project.

First, the datasets were spatially limited to the study area of the project. Subsequently, a reclassification of the included ecosystem categories was done to eliminate the information that was not relevant for this project. To ensure that the reclassified ecosystem categories still provided the quality to reflect the variation in vulnerability of the ecosystems, ecosystem experts were consulted. Included in the consultation process were SOCIB internal experts as well as a marine scientist and ecosystem expert of IMEDEA, which all are familiar with the study site.

To simplify the datasets, the initial coastal ecosystem dataset of 12 categories, was reclassified into two categories; the rocky coast and the sedimentary coast (Table 5). The same reclassifying procedure was done with the initial marine ecosystem dataset, simplifying 10 ecosystem categories into eight (Table 5). All reclassified mixed- ecosystem types, such as the mix of semi-sciophilous algae, photophilic algae and *Posidonia oceanica* are considered as an independent ecosystem category. Areas where *Posidonia oceanica* occurs collectively with semi-sciophilous- and photophilic algae are not further included in the distribution of the category of *Posidonia oceanica*. Each category is taken as individual ecosystem type in this case.

The reduction of the datasets into 10 ecosystem categories in general was chosen to be adequate enough to reflect the variation in vulnerability of the ecosystems. In accordance with the consulted experts, these ecosystem categories still imply the opportunity to reflect the variation in sensitivity of the present ecosystem types against the different kinds of pressures, and thus correlate to the requirements of the model.

After the adjustment of the datasets to fit the requirements of the project, 10 ecosystem layers were converted to a 25m grid resolution raster. The data of each ecosystem layer was expressed as binary raster, which represents the presence (1) or absence (0) of each ecosystem in every 25m-by25m cell of the study area (Kappel *et al.*, 2012) (Appendix III).

Table 5: Ecosystem categories used in the cumulative anthropogenic pressure model of the Alcúdia Bay, including an outline of the types of ecosystems which were included in each category after the reclassification of the provided dataset. Additionally, the source of the data is provided.

	Ecosystem	Included types	Source
Coastal ecosystems - subtidal	Rocky coast	<ul style="list-style-type: none"> - (1A) Rocky sea-cliffs, - (1C) Rocky sea-cliffs with boulder talus base - (2) Low rocky coast - (3B) Steep slopes rocky sandy shores - (7A) Rocky shores - (7C) Low rocky rubble shores (include rip raps) - (7D) Rocky sea-cliffs with boulder talus base 	<ul style="list-style-type: none"> - SOCIB viewer (http://gis.socib.es/sacosta/composer). based on: NOAA Technical Memorandum (Petersen <i>et al.</i>, 2002)



Table 5: Ecosystem categories used in the cumulative anthropogenic pressure model of the *Alcúdia* Bay, including an outline of the types of ecosystems which were included in each category after the reclassification of the provided dataset. Additionally, the source of the data is provided.

	Sedimentary coast	<ul style="list-style-type: none"> - (3A) Fine to medium sand beaches - (4) Coarse grained beaches - (5) Mixed sand and gravel beaches - (6A) Gravel beaches - (8) Shores close to salt and brackish water marshes 	- SOCIB viewer (http://gis.socib.es/sacosta/composer) , based on: NOAA Technical Memorandum (Petersen <i>et al.</i> , 2002)
Marine ecosystems – intertidal	Fine sand	- Fine sand	Local Ministry of the Environment of the Balearic Islands (CAIB), “LIFE Posidonia” (2006), http://lifeposidonia.caib.es/user/carto/index_en.htm
	Coarse sand	- Coarse sand	Local Ministry of the Environment of the Balearic Islands (CAIB), “LIFE Posidonia” (2006), http://lifeposidonia.caib.es/user/carto/index_en.htm
	<i>Posidonia oceanica</i>	- <i>Posidonia oceanica</i>	Local Ministry of the Environment of the Balearic Islands (CAIB), “LIFE Posidonia” (2006), http://lifeposidonia.caib.es/user/carto/index_en.htm
	Mix of semi-sciophilous and photophilic algae	<ul style="list-style-type: none"> - Semi-sciophilous algae - Photophilic algae 	Local Ministry of the Environment of the Balearic Islands (CAIB), “LIFE Posidonia” (2006), http://lifeposidonia.caib.es/user/carto/index_en.htm
	Mix of semi-sciophilous algae, photophilic algae and <i>Posidonia oceanica</i>	<ul style="list-style-type: none"> - Mix of semi-sciophilous algae and <i>Posidonia oceanica</i> - Mix of photophilic algae and <i>Posidonia oceanica</i> 	Local Ministry of the Environment of the Balearic Islands (CAIB), “LIFE Posidonia” (2006), http://lifeposidonia.caib.es/user/carto/index_en.htm
	Mix of coarse sand and detritus	- Mix of coarse sand and detritus	Local Ministry of the Environment of the Balearic Islands (CAIB), “LIFE Posidonia” (2006), http://lifeposidonia.caib.es/user/carto/index_en.htm
	Mix of <i>Caulerpa prolifera</i> and <i>Cymodocea nodosa</i>	- Mix of <i>Caulerpa prolifera</i> and <i>Cymodocea nodosa</i>	Local Ministry of the Environment of the Balearic Islands (CAIB), “LIFE Posidonia” (2006), http://lifeposidonia.caib.es/user/carto/index_en.htm
	<i>Caulerpa prolifera</i>	<i>Caulerpa prolifera</i>	Local Ministry of the Environment of the Balearic Islands (CAIB), “LIFE Posidonia” (2006), http://lifeposidonia.caib.es/user/carto/index_en.htm



5.2.2 Results

The results of the processed information about the present ecosystems in the *Alcúdia* Bay consist of 10 unique ecosystem raster layers. Each layer displays the distribution of the selected ecosystems per defined ecosystem categories (Table 5) and are provided in detail in Appendix III. The compilation of ecosystem layers completes the second input of the cumulative anthropogenic pressure model.

The general map (Fig. 7) clearly shows that the predominant ecosystem component in the *Alcúdia* Bay is *Posidonia oceanica*, which is an endemic specie to the Mediterranean Sea and presents a key component of its shallow coastal ecosystems. Growing in vertical as well as horizontal direction, the meadows build up reef like structures (Green *et al.*, 2003), which are constantly intermitted by sandy patches of coarse or fine sediments. At some locations, the meadows are partly mixed with species of semi-sciophilous and photophilic algae, which is considered as individual ecosystem category in the data set.

Additionally, the sea grass specie *Cymodosea nodosa*, which only occurs as mixed ecosystem category with the green algae specie *Caulerpa prolifera*, is present in the area. This category is established on a much smaller scale than *Posidonia oceanica*. However, *Caulerpa prolifera*, a type of green algae, also occurs as individual ecosystem category; but occurs exclusively on a small location at the east side of the bay. At deeper locations, further out of the bay, mixtures of detritus and coarse sand are present.



Distribution of the selected ecosystems and ecosystem components in the bay

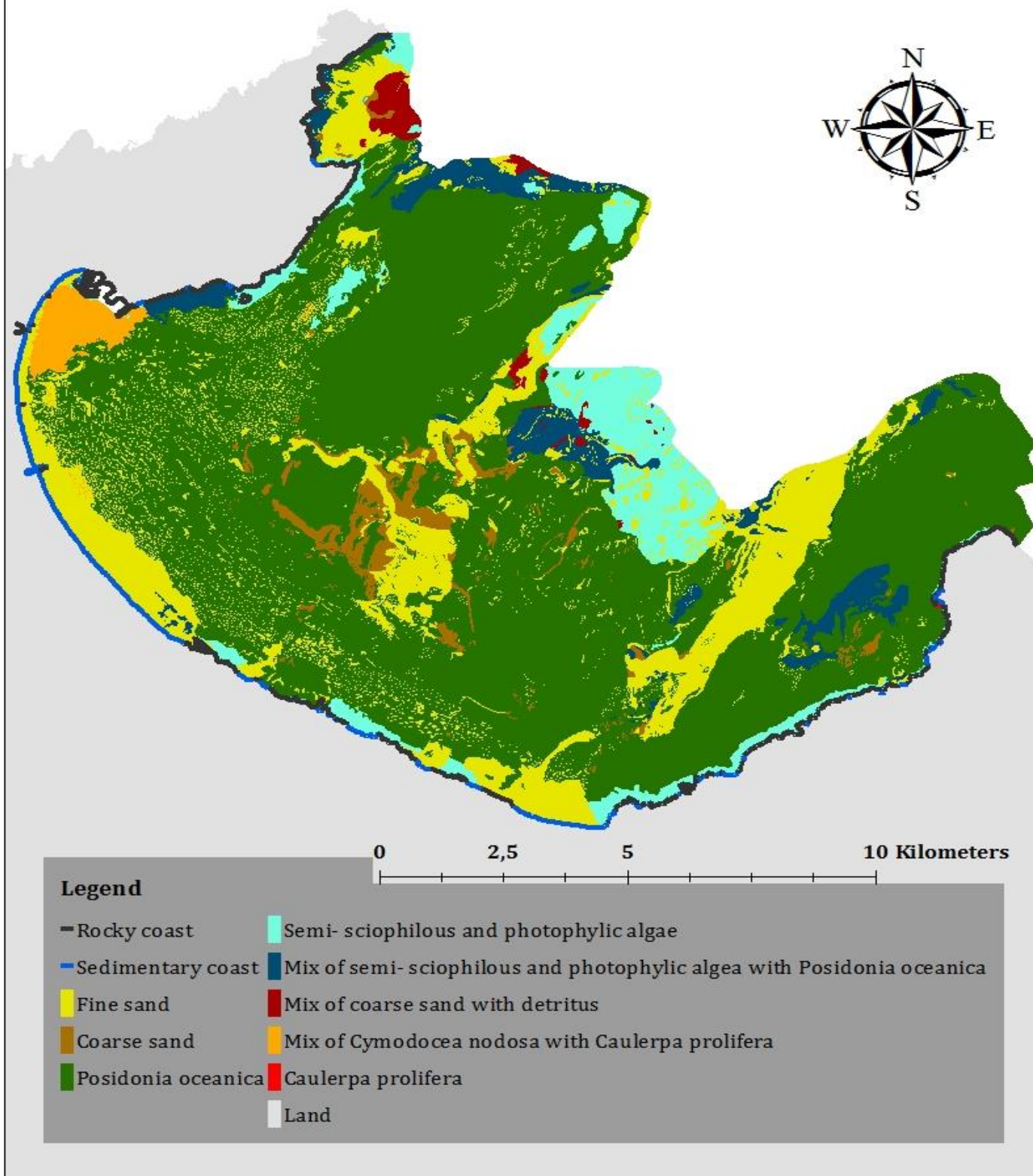


Figure 7: Distribution of selected coastal- and marine ecosystem categories (for detailed maps per ecosystem category see Appendix III)



Regarding the coastal ecosystems in the bay, two categories are considered and displayed individually in the map; the sedimentary- and the rocky coast. In reference to the map, sedimentary coastlines (e.g. sandy beaches) predominantly occur on the long stretched south-western part of the bay, while rocky coastlines dominate the eastern- and north-western part of the bay.

The 10 ecosystem layers (Appendix III) give answer to the second sub-question (“*What is the distribution of the present ecosystems in the Alcúdia Bay?*”) and are used as the second input of the cumulative anthropogenic pressure model.

5.3 Input 3: Vulnerability matrix

Concerning the complexity of this input, first a short description of the vulnerability score is provided (Section 5.3.1). Following, information about the “*Methods*” (Section 5.3.2) and the “*Results*” (Section 5.3.3) of the third and thus the last input of the model are provided. The sections outline the conducted assessment for the development of the vulnerability score. The result of this process is a vulnerability matrix, which contains the vulnerability weight for each relevant ecosystem- pressure scenario.

5.3.1 Description of the vulnerability score

The vulnerability score represents the basis of the vulnerability matrix, which is the third input of the cumulative anthropogenic pressure model. The score is regarded as a weighting coefficient for the relative intensity of a specific anthropogenic pressure on a certain ecosystem and used to reflect the vulnerability of an ecosystem, in reference to the pressure that faces it. Therefore, all possible ecosystem-pressure combinations were taken into account.

Resting upon the method of Halpern *et al.* (2007, 2008) and some modifications of Korpinen *et al.* (2012), the vulnerability score compounds three factors, which are considered to ultimately affect the intensity of an anthropogenic pressure on an ecosystem. The factors include (1) the “extend of the pressure”, (2) the “resistance” of an affected ecosystem and its (3) level of “resilience” after the removal of a pressure (Table 6).

The first vulnerability factor focuses more on the pressure itself, while the other two concentrate on the affected ecosystems and its components Korpinen *et al.* (2012). Furthermore, the factor “certainty” is included in the model. The certainty does not attend to measure any part of an ecosystem-pressure combination. In fact, it can be regarded as a



measure of reliability because it represents the quality of estimation of the three other factors (Halpern *et al.*, 2007). The value of the certainty is individually evaluated by every participant of the survey. It provides the opportunity to the surveyed participants, to express how certain one feels about the given value that evaluates a certain ecosystem pressure scenario.

Each of the factors includes an individual score which ranks from zero to four (Table 6). The vulnerability scores provide the relative intensity of the anthropogenic pressures which face the ecosystems and therefore present another key component of the method. The following table (Table 6) displays the three vulnerability factors and their individual scale. In addition, a short explanation per factor is provided.

Table 6: Vulnerability factors for the assessment of the weighting scores, after Halpern *et al.* (2007, 2008) and Korpinen *et al.* (2012)

Vulnerability factor	Value	Explanation
Extend of the pressure	0 = not available (no impact or positive) 1 = Species (single or multiple) 2 = Single trophic level 3 = > 1 trophic level 4 = Entire community, including habitat structure	The scale of the “extend of the pressure” measures the quantity of trophic levels which are affected by an pressure.
Resistance	0 = not available (No impact or positive) 1 = High 2 = Medium 3 = Low 4 = vulnerable	The scale of the “Resistance” measures the qualitative tendency of an ecosystem to resist against a pressure and persist in its natural conditions.
Resilience	0 = not available (No impact or positive) 1 = < 1 year 2 = 1-10 years 3 = 10-100 years 4 = > 100 years	The score of the “Resilience” measures the temporal scale, which an ecosystem (or its affected aspects) needs to recover from the impact of a pressure, after its removal.
Certainty	0 = None 1 = Low 2 = Medium 3 = High 4 = Very high	The scale of the “Certainty” displays the “reliability” of the judged three factors.



5.3.2 Methods

Data collection

Dealing with 10 ecosystems categories and 25 activities causing 25 varying pressures, results in 250 possible and unique ecosystem-pressure combinations, which needed to be estimated in order to develop the vulnerability matrix. Most of these combinations have not been investigated scientifically and therefore, reviews of scientific literature and empirical data could not provide comprehensive information about all possible ecosystem-pressure combinations specific to a regional location (Kappel *et al.*, 2012).

However, in order to obtain the individual vulnerability scores, the project thus highly depend on the knowledge of ecosystem experts and marine scientist, who are familiar with the ecosystems in the study area.

In order to gather and incorporate their knowledge, the best method represents the performance of a questionnaire to survey the relevant marine scientist and ecosystem experts (Baarda & De Goede, 2006). This seemed to be the best way to elaborate a weighting coefficient for the sensitivity of an ecosystem against the pressure(s). Furthermore, the expert knowledge about the present ecosystems is expected to increase the reliability of the outcomes and thus the final result of the model. Other methods, such as evaluating peer-reviewed literature and empirical data seemed to be too time-consuming or simply not feasible for the extent of the project.

In order to incorporate expert knowledge, relevant marine scientists and ecosystem experts were first defined as academic, autonomic, agency, non-governmental scientists or experts with extensive knowledge about specific ecosystems or specific anthropogenic pressures. Based on this definition, relevant persons were identified in a second step by using the well-established network of SOCIB. The network includes local research facilities like the Mediterranean Institute for Advanced Studies (IMEDEA), the Universitat de les Illes Balears (UIB), the “Govern de les Illes Balears” (CAIB), and Laboratorio de Investigaciones Marinas y Acuicultura (LIMIA). In addition, some SOCIB internal experts were willing to be surveyed.

After having compiled the necessary information about relevant marine scientist and ecosystem experts, a questionnaire was designed (Appendix IV) and conducted in June 2013. Each questionnaire was individually adapted to the ecosystems of expertise of each participant and includes additional information material in order to explain the procedures and to avoid misunderstandings. The questionnaire was chosen to be conducted anonymous, therefore personal information is limited to the age, the status of employment and the familiarity with the study site. To enhance the reliability of the survey, only closed questions were asked. This further helped to get the desired answers with help of a set of good elaborated questions (in this case, pre-defined scores) (Reulink & Lindeman, 2005). In order to restrict the length of the questionnaire, and thus increase the probability of responses, each participant was asked to fill in the weighting scores for a maximum of three



ecosystem categories, referring to the subject area of its expertise. Thereby, the weighting coefficients of the single components of the mixed categories were asked to be estimated individually.

The questionnaire asked each participant to estimate the relative intensity of a pressure for the elaborated ecosystem- pressure combinations, while using the three vulnerability factors and their weighting scores (Appendix IV). Thereby, the lowest value (0) always represents the expression of “not available”, which offered to the respondent the possibility to express their ignorance about an issue or furthermore, that the considered pressure does not have any negative impact on the ecosystem of evaluation. In contrast, the highest value of the scale (4) represents a high level of impact and therefore should be assessed by the person in the case that a pressure causes high impact on an ecosystem.

In general, 15 relevant experts were invited to participate in the survey. A 100% response rate, would have offered a base of at least four estimated vulnerability scores per ecosystem category. This seemed acceptable for the scale of the project and enabled to encompass estimations about the relative intensity of anthropogenic pressure layers on the ecosystems in the *Alcúdia* Bay.

Data analyses

Based on the responses to the survey, the final vulnerability scores per pressure-ecosystem combination needed to be processed in order to develop the vulnerability matrix. The calculation and explanation on how to transform the individual weighting coefficients which were assessed for each vulnerability factor into a single value, is displayed below (Fig. 8).

Following the procedure, displayed in the figure (Fig. 8), the calculation of the vulnerability score was performed by taking the average of all expert responses per ecosystem category:

- First, the final score per person was calculated by summing up the single weighting coefficients of the three vulnerability factors (step 1).
- Then the result of this calculation was multiplied by the value of the certainty (step 2).
- In addition, the value of the certainty was multiplied by the value of three, which represents the quantity of included factors (step 3).
- In the following, the outcome of step two was divided by the result of step three in order to develop the final vulnerability weight per participant.



- To calculate the final vulnerability value for the vulnerability matrix, the vulnerability values of the participants were finally averaged to a single value.

Ecosystem type or component: <i>Posidonia oceanica</i>										
Respond of participant A, B and C --> Assessment of the vulnerability weight per participant --> Final vulnerability coefficient										
Pressure Type	Participant (expert)	factor 1 Extend of impact	factor 2 Resistance	factor 3 Resilience	Certainty (for 3 factors)	Step 1 Sum of factors per participant	Step 2 Sum of factors x certainty	Step 3 Certainty x Number of factors	Result step 2 / Result step 3 = Final score per participant	Relative vulnerability weighting coefficient (for the pressure of "smothering" on the ecosystem of "Posidonia oceanica")
Smothering	A	0	1	0	1	$(0+1+0)=1$	$(1 \times 1)=1$	$(1 \times 3)=3$	$(1/3)=0,333$	$(0,333+4+3,333)/3$ <u>= 2,555</u>
	B	4	4	4	4	$(4+4+4)=12$	$(12 \times 4)=48$	$(4 \times 3)=12$	$(48/12)=4$	
	C	4	3	3	2	$(4+3+3)=10$	$(10 \times 2)=20$	$(2 \times 3)=6$	$(20/6)=3,333$	

Figure 8: Generation process of the vulnerability scores per ecosystem pressure combination, explained on the example of "*Posidonia oceanica*" confronted with the pressure of "smothering".

In the cases of the defined mixed- ecosystem categories, a precaution approach was used to include the weighting coefficients in the final model. This means, that the highest value which was estimated for one of the ecosystem components that are included in the mix category, was used to represent the vulnerability of the whole category. In this way the vulnerability scores are based on the most vulnerable component of the mixed categories and ensure its significance in the final model.

This means in the case of the mixed ecosystem category of *Cymodonocea nodosa* and *Caulerpa prolifera* in combination with the pressure of smothering, that the higher weighting coefficient of 3,6 (evaluated by the experts for the ecosystem component of *Cymodonocea nodosa*) is used in the final model to represent the vulnerability of the mixed ecosystem category. Consequently, this includes, that the lower value of 1,3 (which was evaluated by the experts for the component of *Caulerpa prolifera*) is not included in the cumulative model.

5.3.3 Result

The results of the survey, which provide the basis of the vulnerability matrix, encapsulate 11 completed questionnaires. This corresponds to a participation rate of 73,33%.



The average age of the participants was 45 years, ranging between a maximum age of 62 years and a minimum age of 27 years. The majority of the respondents (five persons) are employed at the University of the Balearic Islands (UIB). Four of the participants are working for an academic agency, including three persons at the “Mediterranean Institute for Advances Studies” (IMEDEA) and one at the “Laboratorio de Investigaciones Marinas y Acuicultura” (LIMIA). The two remaining people are employed at the “Balearic Islands Coastal Observing and Forecasting System” (SOCIB). Beside two participants, who held a Master of Science degree, all other respondents received a PhD degree.

Regarding the experience and familiarity with the study area, the range highly varies from three up to 30 years of expertise at the *Alcúdia* Bay and the Balearic Islands in general. The average value of expertise on the site ranks at 12,4 years.

Considering that each participant was asked to estimate the vulnerability scores for at least two to maximal three ecosystem categories, the responds finally provided 40 estimated vulnerability scores in general, including 640 (40 expert judgments for 16 pressure types) single weighting coefficients of possible ecosystem- pressure scenarios. Thereby, the sample size of evaluated scores per ecosystem- pressure scenario varies because of missing responds (Table 7). Based on this outcome, the 640 estimated values were further processed in order to calculate the final vulnerability score per ecosystem- pressure scenario (Fig. 8).

The result is presented as a matrix including 250 averaged and unique vulnerability weighting coefficients for all potential pressure-ecosystem combinations. In all cases, the related Standard Error (\pm SE) and the mean value of certainty ($C = x$) is provided as well (Table 7). The Standard Errors display the statistical spreading of the individual evaluated weighting coefficients of the participants and thus provide information about the unambiguousness of the averaged values included in the matrix. A low Standard Error displays that the range of the sampled vulnerability weights exhibit only small difference, while a higher Standard Error indicates more variation in a range. Additionally, the table includes information about the mean certainty of the outcomes and the sample size per ecosystem- pressure scenario. This extra information helps to impart knowledge concerning the reliability of the vulnerability values.

Considering, that the vulnerability scores for the mixed ecosystem categories were estimated individually per component of the mix, the expert sample size of these categories is related to the values which are included in the final model after they had been evaluated using the precaution approach (in the matrix displayed using different colours, namely green or blue).

The following table (Table 7) displays the results of the survey (Appendix IV), after the vulnerability weighting coefficients were processed and re-categorized into the ecosystems categories.



Table 7: The scores represent the mean results of the questionnaire. Ecosystem categories are presented as: RC = Rocky coast, SC = Sedimentary coast, FS = Fine sand, CS = Coarse sand, Po = *Posidonia oceanica*, Cp = *Caulerpa prolifera*, Al = mixed semi-sciophilous and photophilic algae, MAP = Mix of semi-sciophilous and photophilic algae (blue) with *Posidonia oceanica* (green), MCsD = Mix of coarse sand (green) with detritus, MCC = Mix of *Cymodocea nodosa* (green) with *Caulerpa prolifera*. Additionally the related Standard Error (\pm SE) and the mean certainty (C = x) vales are provided.

Ecosystem category	RC	SC	FS	CS	Po	Cp	Al	MAP	MCsD	MCCp	Mean score	Summed score per pressure
Expert sample size	4	5	3	4	5	3	2	2+5	4	3		
Pressure type and corresponding activity												
Smothering												
Dredging	3,1 $\pm 0,08$ C=3,3	3,3 $\pm 0,34$ C=2,6	2,9 $\pm 0,29$ C=3,0	2,5 $\pm 0,35$ C=2,5	2,9 $\pm 0,66$ C=2,4	0,9 $\pm 0,89$ C=2,0	1,5 $\pm 1,17$ C=1,5	2,9 $\pm 0,66$ C=2,4	2,5 $\pm 0,35$ C=2,5	3,6 $\pm 0,29$ C=3,0	2,6 $\pm 0,26$ C=2,5	26,1
Sealing												
Artificial coastal structures	3,5 $\pm 0,29$ C=3,5	3,4 $\pm 0,27$ C=2,8	3,3 $\pm 0,19$ C=3,0	2,6 $\pm 0,37$ C=2,8	3,1 $\pm 0,36$ C=2,8	1,7 $\pm 0,84$ C=2,0	2 $\pm 0,67$ C=1,5	3,1 $\pm 0,36$ C=2,8	2,6 $\pm 0,37$ C=2,8	3,6 $\pm 0,29$ C=3,7	2,9 $\pm 0,20$ C=2,8	28,9
Abrasion												
Anchoring	2,6 $\pm 0,63$ C=3,5	2 $\pm 0,28$ C=3,0	2,2 $\pm 0,40$ C=2,0	2 $\pm 0,36$ C=2,0	3,3 $\pm 0,24$ C=2,4	1,7 $\pm 0,84$ C=2,0	2,8 $\pm 0,17$ C=1,5	3,3 $\pm 0,24$ C=2,4	2 $\pm 0,36$ C=2,0	3 $\pm 0,19$ C=3,3	2,5 $\pm 0,19$ C=2,4	24,9
Selective extraction												
Dredging	2,9 $\pm 0,55$ C=3,3	2,1 $\pm 0,36$ C=3,0	2,7 $\pm 0,19$ C=3,0	2,6 $\pm 0,32$ C=2,5	2,5 $\pm 0,68$ C=1,8	1,4 $\pm 0,78$ C=1,0	1,2 $\pm 1,17$ C=1,5	2,5 $\pm 0,68$ C=1,8	2,6 $\pm 0,32$ C=2,5	3 $\pm 0,19$ C=2,0	2,4 $\pm 0,19$ C=2,2	23,5
Coastal abrasion												
Beach zone activities	1,5 $\pm 0,69$ C=3,0	1,9 $\pm 0,08$ C=2,6	1,7 $\pm 0,00$ C=2,7	1,9 $\pm 0,37$ C=2,3	3,1 $\pm 0,40$ C=1,6	1,3 $\pm 0,77$ C=1,0	3 $\pm 0,00$ C=1,5	3,1 $\pm 0,40$ C=1,6	1,9 $\pm 0,37$ C=2,3	2,6 $\pm 0,48$ C=1,3	2,2 $\pm 0,22$ C=2,0	22
Underwater noise												
Sea traffic	1 $\pm 0,58$ C=2,5	1,2 $\pm 0,34$ C=3,2	1 $\pm 0,51$ C=2,7	1,2 $\pm 0,44$ C=2,3	1,1 $\pm 0,51$ C=1,8	0,6 $\pm 0,56$ C=1,7	1,8 $\pm 0,83$ C=1,5	1,8 $\pm 0,83$ C=1,5	1,2 $\pm 0,44$ C=2,3	0,6 $\pm 0,56$ C=1,0	1,2 $\pm 0,13$ C=2,0	11,5
Changes in thermal regime												
Power plant outflow	2,6 $\pm 0,08$ C=2,5	2 $\pm 0,45$ C=2,2	1,7 $\pm 0,77$ C=2,7	1,9 $\pm 0,57$ C=2,3	2,7 $\pm 0,72$ C=2,4	1,3 $\pm 0,77$ C=2,3	1,5 $\pm 1,15$ C=1,5	2,7 $\pm 0,72$ C=2,4	1,9 $\pm 0,57$ C=2,3	1,8 $\pm 0,97$ C=2,0	2,0 $\pm 0,16$ C=2,3	20,1
Changes in salinity regime												
Wastewater treatment plant outfall	2,5 $\pm 0,10$ C=2,5	1,9 $\pm 0,44$ C=2,2	1,6 $\pm 0,78$ C=2,7	1,8 $\pm 0,57$ C=2,3	2,8 $\pm 0,44$ C=2,2	1,3 $\pm 0,77$ C=2,0	2,3 $\pm 0,06$ C=1,5	2,8 $\pm 0,44$ C=2,2	1,8 $\pm 0,57$ C=2,3	1,8 $\pm 0,97$ C=2,0	2,1 $\pm 0,16$ C=2,2	20,6
Urban outfalls	2,5 $\pm 0,10$ C=2,5	1,9 $\pm 0,44$ C=2,2	1,6 $\pm 0,78$ C=2,7	1,8 $\pm 0,57$ C=2,3	2,8 $\pm 0,44$ C=2,2	1,3 $\pm 0,77$ C=2,0	2,3 $\pm 0,06$ C=1,5	2,8 $\pm 0,44$ C=2,2	1,8 $\pm 0,57$ C=2,3	1,8 $\pm 0,97$ C=2,0	2,1 $\pm 0,16$ C=2,2	20,6
Power plant intake	2,5 $\pm 0,10$ C=2,5	1,9 $\pm 0,44$ C=2,2	1,6 $\pm 0,78$ C=2,7	1,8 $\pm 0,57$ C=2,3	2,8 $\pm 0,44$ C=2,2	1,3 $\pm 0,77$ C=2,0	2,3 $\pm 0,06$ C=1,5	2,8 $\pm 0,44$ C=2,2	1,8 $\pm 0,57$ C=2,3	1,8 $\pm 0,97$ C=2,0	2,1 $\pm 0,16$ C=2,2	20,6
Desalination plant intake	2,5 $\pm 0,10$ C=2,5	1,9 $\pm 0,44$ C=2,2	1,6 $\pm 0,78$ C=2,7	1,8 $\pm 0,57$ C=2,3	2,8 $\pm 0,44$ C=2,2	1,3 $\pm 0,77$ C=2,0	2,3 $\pm 0,06$ C=1,5	2,8 $\pm 0,44$ C=2,2	1,8 $\pm 0,57$ C=2,3	1,8 $\pm 0,97$ C=2,0	2,1 $\pm 0,16$ C=2,2	20,6



Table 7: The scores represent the mean results of the questionnaire. Ecosystem categories are presented as: RC = Rocky coast, SC = Sedimentary coast, FS = Fine sand, CS = Coarse sand, Po = *Posidonia oceanica*, Cp = *Caulerpa prolifera*, Al = mixed semi-sciophilous and photophilic algae, MAP = Mix of semi-sciophilous and photophilic algae (blue) with *Posidonia oceanica* (green), MCsD = Mix of coarse sand (green) with detritus, MCC = Mix of *Cymodocea nodosa* (green) with *Caulerpa prolifera*. Additionally the related Standard Error (\pm SE) and the mean certainty (C = x) vales are provided.

Introduction of synthetic compounds												
Harbour	3,3 $\pm 0,08$ C=3,3	2,9 $\pm 0,27$ C=3,2	2,8 $\pm 0,29$ C=2,0	2,5 $\pm 0,42$ C=2,3	2,3 $\pm 0,68$ C=2,5	1,3 $\pm 0,77$ C=2,0	2,5 $\pm 0,17$ C=1,5	2,5 $\pm 0,17$ C=1,5	2,5 $\pm 0,42$ C=2,3	1,8 $\pm 0,97$ C=1,7	2,4 $\pm 0,18$ C=2,2	24,4
Wastewater treatment plant outfall	3,3 $\pm 0,08$ C=3,3	2,9 $\pm 0,27$ C=3,2	2,8 $\pm 0,29$ C=2,0	2,5 $\pm 0,42$ C=2,3	2,3 $\pm 0,68$ C=2,5	1,3 $\pm 0,77$ C=2,0	2,5 $\pm 0,17$ C=1,5	2,5 $\pm 0,17$ C=1,5	2,5 $\pm 0,42$ C=2,3	1,8 $\pm 0,97$ C=1,7	2,4 $\pm 0,18$ C=2,2	24,4
Urban outfalls	3,3 $\pm 0,08$ C=3,3	2,9 $\pm 0,27$ C=3,2	2,8 $\pm 0,29$ C=2,0	2,5 $\pm 0,42$ C=2,3	2,3 $\pm 0,68$ C=2,5	1,3 $\pm 0,77$ C=2,0	2,5 $\pm 0,17$ C=1,5	2,5 $\pm 0,17$ C=1,5	2,5 $\pm 0,42$ C=2,3	1,8 $\pm 0,97$ C=1,7	2,4 $\pm 0,18$ C=2,2	24,4
Introduction of non-synthetic substances and compounds												
Harbour	3,2 $\pm 0,17$ C=3,3	3 $\pm 0,28$ C=3,4	2,8 $\pm 0,29$ C=2,3	2,3 $\pm 0,49$ C=2,0	2,3 $\pm 0,66$ C=2,0	1,3 $\pm 0,77$ C=2,0	2,3 $\pm 0,00$ C=1,5	2,3 $\pm 0,66$ C=2,0	2,3 $\pm 0,49$ C=2,0	1,8 $\pm 0,97$ C=1,7	2,4 $\pm 0,18$ C=2,2	23,6
Inputs of nutrients / Inputs of fertilizers and other nitrogen and phosphorus-rich substances												
Agriculture	3,2 $\pm 0,17$ C=3,3	3,1 $\pm 0,16$ C=3,2	2,9 $\pm 0,22$ C=2,0	2,6 $\pm 0,44$ C=2,5	3,2 $\pm 0,31$ C=2,4	1,8 $\pm 0,11$ C=3,0	2,7 $\pm 0,33$ C=1,5	3,2 $\pm 0,31$ C=2,4	2,6 $\pm 0,44$ C=2,5	2,9 $\pm 0,22$ C=3,0	2,8 $\pm 0,14$ C=2,6	28,2
Inputs of organic matter												
Fish farm outfall	2,4 $\pm 0,44$ C=3,3	2,1 $\pm 0,37$ C=2,4	1,7 $\pm 0,84$ C=1,7	2,1 $\pm 0,60$ C=2,0	3 $\pm 0,40$ C=2,6	1,8 $\pm 0,11$ C=3,0	2,3 $\pm 0,67$ C=1,5	3 $\pm 0,40$ C=2,6	2,1 $\pm 0,60$ C=2,0	2,9 $\pm 0,22$ C=3,0	2,3 $\pm 0,15$ C=2,4	23,4
Wastewater treatment plant outfall	2,4 $\pm 0,44$ C=3,3	2,1 $\pm 0,37$ C=2,4	1,7 $\pm 0,84$ C=1,7	2,1 $\pm 0,60$ C=2,0	3 $\pm 0,40$ C=2,6	1,8 $\pm 0,11$ C=3,0	2,3 $\pm 0,67$ C=1,5	3 $\pm 0,40$ C=2,6	2,1 $\pm 0,60$ C=2,0	2,9 $\pm 0,22$ C=3,0	2,3 $\pm 0,15$ C=2,4	23,4
Introduction of microbial pathogens												
Fish farm outfall	2,6 $\pm 0,16$ C=3,0	2,7 $\pm 0,30$ C=1,6	2,2 $\pm 0,22$ C=1,0	1,8 $\pm 0,35$ C=1,3	1,5 $\pm 0,44$ C=1,5	0,7 $\pm 0,33$ C=1,0	2 $\pm 0,33$ C=1,5	2 $\pm 0,33$ C=1,5	1,8 $\pm 0,35$ C=1,3	0,7 $\pm 0,33$ C=1,0	1,8 $\pm 0,22$ C=1,5	18
Urban outfalls	2,6 $\pm 0,16$ C=3,0	2,7 $\pm 0,30$ C=1,6	2,2 $\pm 0,22$ C=1,0	1,8 $\pm 0,35$ C=1,3	1,5 $\pm 0,44$ C=1,5	0,7 $\pm 0,33$ C=1,0	2 $\pm 0,33$ C=1,5	2 $\pm 0,33$ C=1,5	1,8 $\pm 0,35$ C=1,3	0,7 $\pm 0,33$ C=1,0	1,8 $\pm 0,22$ C=1,5	18
Wastewater treatment plant outfall	2,6 $\pm 0,16$ C=3,0	2,7 $\pm 0,30$ C=1,6	2,2 $\pm 0,22$ C=1,0	1,8 $\pm 0,35$ C=1,3	1,5 $\pm 0,44$ C=1,5	0,7 $\pm 0,33$ C=1,0	2 $\pm 0,33$ C=1,5	2 $\pm 0,33$ C=1,5	1,8 $\pm 0,35$ C=1,3	0,7 $\pm 0,33$ C=1,0	1,8 $\pm 0,22$ C=1,5	18
Selective extraction of species												
Artisanal fishery	2,4 $\pm 0,10$ C=2,5	2,5 $\pm 0,23$ C=2,4	1,9 $\pm 0,29$ C=2,3	1,9 $\pm 0,57$ C=1,8	1,8 $\pm 0,55$ C=2,3	0,9 $\pm 0,48$ C=1,7	2 $\pm 0,67$ C=1,5	2 $\pm 0,67$ C=1,5	1,9 $\pm 0,57$ C=1,8	1,4 $\pm 0,78$ C=1,3	1,9 $\pm 0,14$ C=2,0	18,7
Recreational fishery	2,4 $\pm 0,10$ C=2,5	2,5 $\pm 0,23$ C=2,6	1,9 $\pm 0,29$ C=2,0	1,9 $\pm 0,57$ C=2,0	1,8 $\pm 0,55$ C=2,5	0,9 $\pm 0,48$ C=2,0	2 $\pm 0,67$ C=1,5	2 $\pm 0,67$ C=1,5	1,9 $\pm 0,57$ C=2,0	1,4 $\pm 0,69$ C=1,7	1,8 $\pm 0,13$ C=2,0	18,1
Changes in wildlife behavior												
Water sport activities	1 $\pm 0,58$ C=2,8	2,3 $\pm 0,29$ C=3,0	2,2 $\pm 0,29$ C=2,0	1,8 $\pm 0,22$ C=2,3	1,1 $\pm 0,44$ C=2,8	0,6 $\pm 0,56$ C=2,3	2 $\pm 0,00$ C=1,5	2 $\pm 0,00$ C=1,5	1,8 $\pm 0,22$ C=2,3	0,6 $\pm 0,56$ C=2,3	1,5 $\pm 0,21$ C=2,3	15,4
Environmental pressures												
Climate change	3,3 $\pm 0,19$ C=3,3	3,3 $\pm 0,15$ C=2,8	1,7 $\pm 0,88$ C=2,0	2,8 $\pm 0,48$ C=2,3	3 $\pm 0,50$ C=2,6	1,7 $\pm 0,84$ C=3,0	2,2 $\pm 1,17$ C=1,5	3 $\pm 0,50$ C=2,6	2,8 $\pm 0,48$ C=2,3	3,1 $\pm 0,20$ C=3,0	2,7 $\pm 0,19$ C=2,5	26,9
Mean score	2,6 $\pm 0,13$ C=3,0	2,4 $\pm 0,11$ C=2,3	2,2 $\pm 0,12$ C=2,2	2,1 $\pm 0,08$ C=2,7	2,4 $\pm 0,14$ C=2,3	1,2 $\pm 0,08$ C=2,0	2,2 $\pm 0,08$ C=1,5	2,6 $\pm 0,09$ C=2,2	2,1 $\pm 0,08$ C=2,2	2,0 $\pm 0,19$ C=2,1		
Summed score per ecosystem	65	60,8	54	52,3	60,3	30,9	54,3	64,6	52,3	49,8		



As the matrix displays, the highest vulnerability score (mean 2,9) was estimated for the pressure of sealing, caused by artificial coastline structures (e.g. jetties, breakwater structures, piers). Regarding the relatively low associated Standard Error (SE) of the result ($SE \pm 0,20$) and a certainty of almost 75% ($C=2,8$), the identification of sealing as the highest pressure to the present ecosystems can be regarded as reliable in reference to the processed data.

The most vulnerable ecosystem identified in this scenario, represents the rocky shore. This is indicated by the highest vulnerability score per ecosystem category (mean 2,6) and the related Standard Error ($SE \pm 0,13$). The reliability of this impression is further supported by a certainty of 75% ($C=3,0$). Furthermore, the product of the summed vulnerability weights per pressure (28,9) and per ecosystem (65) emphasizes these findings in both cases.

In relation to the predominantly high certainty of the elaborated vulnerability weights in general, the matrix can be accepted as illustrative estimation of the ecosystem vulnerability and thus completes the third input of the database for the cumulative anthropogenic pressure model. Also, the vulnerability matrix gives answer to the third sub-question (*“How can the relative intensity of a given anthropogenic pressure on present ecosystems be quantified?”*).



5.4 Combination of the three inputs: Calculation of the Cumulative pressure index

This section provides information about the cumulative pressure index. The cumulative pressure index is calculated with help of the formula, which finally combines the results of the three inputs. The outcome of the index calculation presents the sum of the multiplication of the inputs and is calculated for every assessment unit (cell size = 25m-by-25m) of the study area.

The following section aims to give a better understanding of how all three inputs (distribution of selected ecosystems and ecosystem components, distribution and intensity of anthropogenic pressures and the averaged vulnerability score) have been combined into the final product –the cumulative anthropogenic pressure map.

The formula, used to calculate the cumulative pressure index (I) for each cell (assessment unit) of the study area is as followed:

$$I = \sum_{i=1}^n \sum_{j=1}^m P_i \times E_j \times u_{ij}$$

In reference to (Halpern *et al.*, 2007, 2008), each variable represents one of the inputs and is defined as followed:

- P_i:** (P_i) in the formula displays the $\log[x+1]$ transformed and normalized value (scaled between 0 and 1) of an anthropogenic pressure in one assessment unit (i) in the study area.
- E_j:** (E_j) displays the presence or absence (scaled either 0 or 1, respectively) of an ecosystem (j).
- U_{i,j}:** ($U_{i,j}$) is the averaged vulnerability score (representing the averaged weight coefficient of the relative intensity) for an anthropogenic pressure (i) in an ecosystem (j) (which ranges from a minimum of 0 to a maximum of 4, depending on the estimated weighting coefficient of a pressure layer on a specific ecosystem category).



In the final cumulative map, the values of the cumulative pressure index (I) are demonstrated on base of a colour range. Each value is calculated per cell of the study area with a resolution of 25m-by25m (0,000625km² grid cells). Thereby, each pressure layer is multiplied with each ecosystem layer and the related, averaged vulnerability score. Therefore, the formula directly takes all 250 possible pressure-ecosystem combinations in one assessment unit into account, given the sum of $n= 25$ anthropogenic pressures and the sum of $m= 10$ ecosystems. The sum of all possible combinations represents the cumulative anthropogenic pressure of human activities on all ecosystems that are present in a specific cell.

It was recognized, that most places are affected by multiple anthropogenic pressures and that often the effect of these pressures is multiplicative rather than simply additive. However, taking the most conservative course, we will assume that the anthropogenic pressures are additive, because the nature and magnitude of this synergism is unknown for most ecosystems (Halpern *et al.*, 2007).

The pressure of any ecosystem-pressure combination therefore is zero, if an anthropogenic pressure (P_i) or ecosystem (E_j) is absent. Furthermore, it is important to keep in mind that the weight score does not take the distribution of the pressure into account (whether in one cell or the general geographical distribution of the pressure). The intensity and distribution of a specific pressure is exclusively determined by the pressure datasets.

In the end, the cumulative anthropogenic pressure map was also $\log[x+1]$ transformed and normalized. The normalization of the data was done to simplify the map, in order to provide the reader with a more comprehensive scale (0 to 1), rather than using a scale which ranges from 0 to the highest value included in the data set. With the successful application of the cumulative anthropogenic pressure model, the fourth sub-question of the project can be answered (*"How can all relevant information about anthropogenic pressures on the ecosystems be combined, in order to visualize cumulative anthropogenic pressure?"*)



6 Results

The final result of the project is the visualization of the intensity and distribution of the cumulative anthropogenic pressure index (Fig. 9) on the ecosystems of the *Alcúdia* Bay.

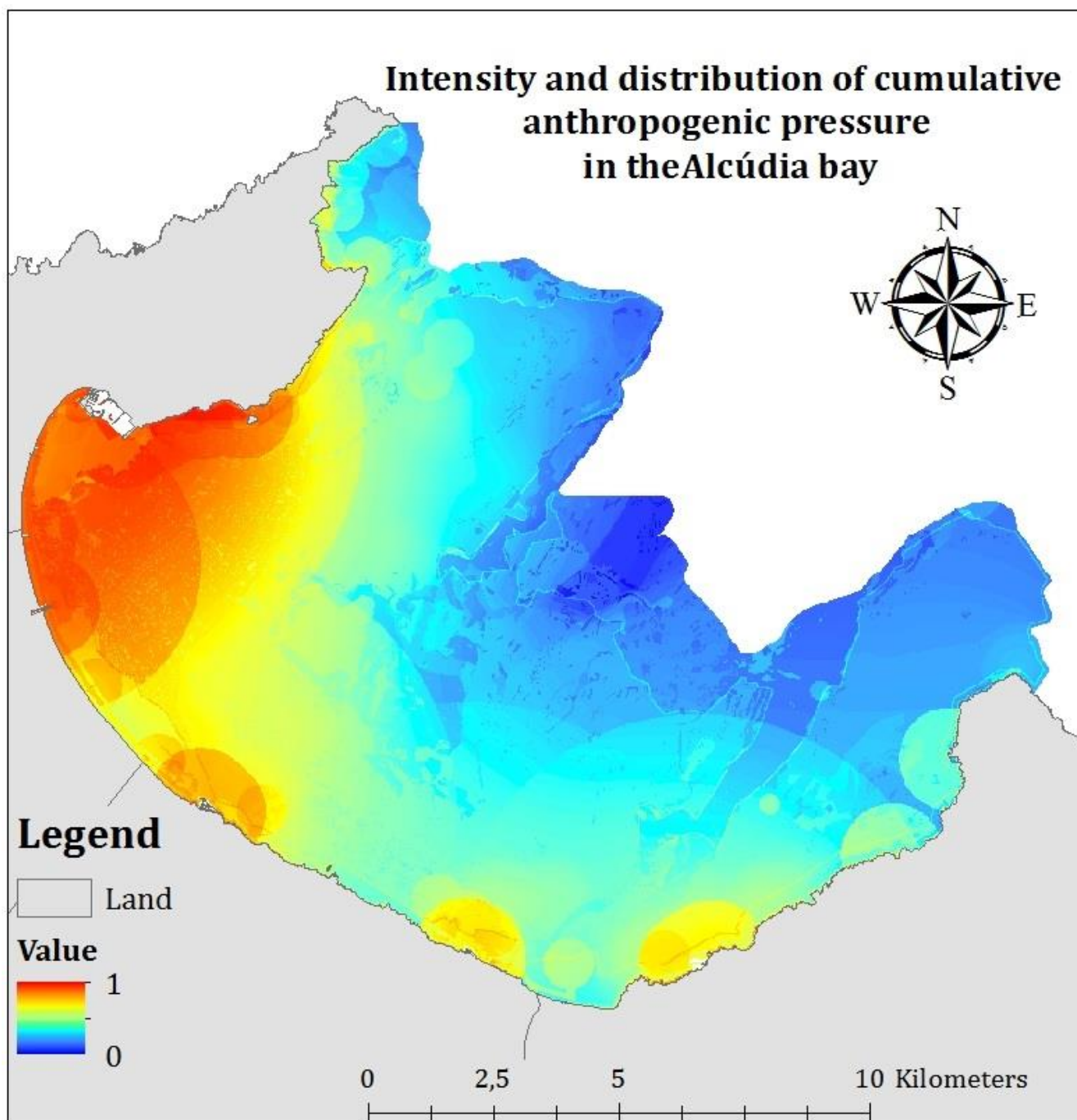


Figure 9: Final cumulative anthropogenic pressure map of the *Alcúdia* Bay, displaying the spatial distribution and intensity of cumulative anthropogenic pressure on the ecosystem categories that were assessed for the *Alcúdia* Bay.



The map is based on the results of the calculated cumulative pressure index and provides a spatial overview of cumulative anthropogenic pressure in the *Alcúdia* Bay. The visualization is based on a stretched equalization of the associated histogram (Fig.10), using ArcGIS 10.1. This approach was chosen, in order to equally stretch out the initial values (grey) of the dataset. Consequently, the revised histogram spreads all values more equally, therefore expands their visual intensity, but arranges a more uniform distribution that improves the visualization of the data in the final map.

Furthermore, in order to avoid jagged transitions between the values of the histogram, the applied stretched histogram equalization was smoothed in a subsequent step. As result, irregularities in the initial dataset were smoothed out for smoother transitions in the visual model ([ArcGIS Resources, 2013c](#)).

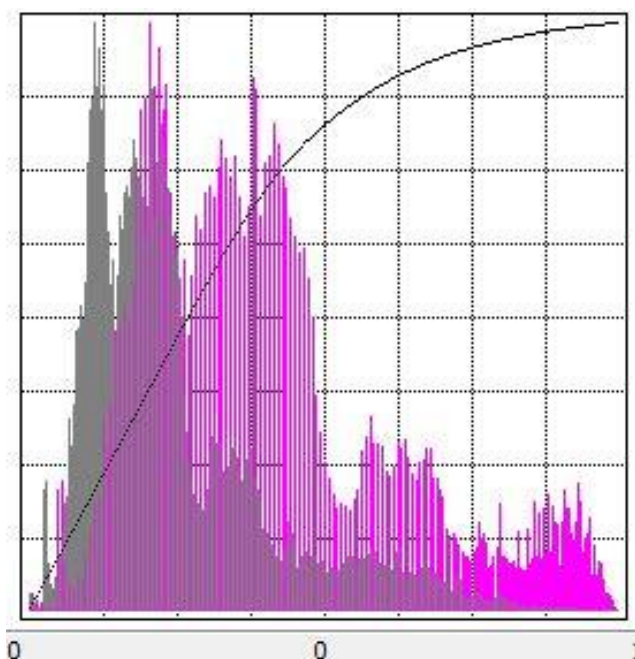


Figure 10: Image histogram of the final cumulative anthropogenic pressure map; displaying the original spreading of the values (grey) and their spreading after the application of the stretched histogram equalization and the smothering (purple).

In reference to the cumulative anthropogenic pressure index, the map visualizes high index values with red colours, while low values are visualized in blue colours. Consequently, red areas display high intensity of cumulative anthropogenic pressure on the present ecosystems, indicating that many human activities occur at these locations. The highest intensity concentrates along the coastline and at more urbanised areas. Especially the north-eastern part of the bay, along the coast of the municipality of *Alcúdia*, a high pressure index is apparent. A plausible explanation for this pattern is to consider the high popularity of tourism at this location, including the highest concentration of hotels and urbanisation as well as the presence of the major industries (the commercial port).

In contrast, blue colours, indicating less pressurized areas are mostly concentrated further out of the bay, towards the open sea and away from urbanized areas. Also, the decrease in cumulative anthropogenic pressure slightly to the east is a visible tendency of the map. At these locations the intensity of anthropogenic activities decrease and generally less cumulative pressure accumulates.

Furthermore, the result indicates that the potential cumulative anthropogenic pressure are very likely based on the maximum number of overlapping effects from activities ([Ban et al., 2010](#)), rather than the variation in vulnerability of the different ecosystem categories.

The cumulative anthropogenic pressure map clearly visualizes that almost the entire study area is being affected by cumulative pressure in some regard. Also, it currently provides the most advanced, scientific-based dataset regarding cumulative anthropogenic pressure



density for the region. Therefore, it can be a useful base for future developments of integrated management plans that aim to mitigate the level of anthropogenic pressure on the marine environment (Ban *et al.*, 2010).

In order to evaluate the final map statistically, a Pearson correlation test was applied. The projects cumulative anthropogenic pressure index values of each cell were tested with results of the final map from Halpern *et al.* (2008). The test aimed to determine the Pearson correlation coefficient, which expresses how well both results relate with each other. The test showed a coefficient of 0,960 , which is a high positive correlation and underlines the high correlation between the two datasets.

The final map completes the research and answers the main question of the project (*“How does the intensity and spatial distribution of cumulative anthropogenic pressure, on the ecosystems in the Alcúdia Bay, look like?”*).



7 Discussion

The conducted study provides a regional quantitative estimate of anthropogenic pressures and cumulative anthropogenic pressure on the ecosystems of the *Alcúdia* Bay. The study presents a first approach to conduct a cumulative anthropogenic pressure model to the study area and the following sections point out encountered data gaps and limitations of the study.

Data availability and gaps

The most extensive work during the development of the cumulative pressure index for the *Alcúdia* Bay consisted of the data collection and analyses of human activities and uses in the area as well as the elaboration of associated anthropogenic pressures. Most of the datasets about human activities, uses and anthropogenic pressures were collected by external sources (e.g. governmental agencies, other research facilities and own observation/interviews with local people and authorities), which was not only very time-consuming, but in some cases datasets were also very difficult to obtain. The reason for the difficulty was mainly based on the fact that the data collection for this project incorporates datasets of four municipalities, each handling the availability of relevant datasets differently. Therefore, all municipalities needed to be interviewed separately, in order to obtain the relevant information and datasets.

Many of the obtained datasets mostly contained only basic information about the location or distribution of a certain anthropogenic pressure and available data and information provided by the municipalities mainly concentrate on the shore and inland. Therefore, much information regarding marine activities were usually not included in datasets. Apart from that, more detailed information about each pressure they can cause was missing for almost all the gathered datasets. For example, the location of the entry point of agricultural activities into the study area was obtained quite easily, however more detailed information, such as the concentration of nutrients in the water or the amount of water flushing into the study area was not achievable in such a short time period. Based on the lack of groundtruthing data, it also has to be noted, that the model is not able to reflect the harmfulness of the evaluated cumulative anthropogenic pressure distribution and intensity. Thus, the cumulative anthropogenic pressure map displays that red to yellow coloured areas are under higher pressure intensity than greenish and bluish once, but cannot provide information how heavy the pressure actually is ([Kappel et al., 2012](#)).

In the case of the selection of indicators for each anthropogenic pressure, it has to be noted that the location of the pressure mostly had to be chosen to indicate the associated pressures. Ideally, indicators such as concentrations of the associated pressures (e.g. concentrations of agricultural nutrient input rather than the location of the entry point of agricultural activities) would significantly improve the quality of each pressure layer and additionally represent a more local character to the datasets. Unfortunately, given the time restrictions and the extent of the project, it was simply not feasible to conduct the mentioned improvements to the project.



Furthermore, some major human activities and uses could not be incorporated into the cumulative anthropogenic pressure map due to non-availability- or data gaps of relevant information and datasets (Appendix I, Table AI). Most of these uses and activities could add local pressures to the study area and under certain circumstances change patterns of the anthropogenic cumulative pressure map.

In contrast, the data collection and analyses of the distribution of ecosystem components for the *Alcúdia* Bay was eased a lot due to the availability of existing datasets about the study area. However, it has to be noted that the reliability of the distribution of the ecosystem components should be regarded with caution, due to the fact that the cartography was primarily conducted to map the extensions of *Posidonia oceanica* meadows rather than mapping the seabed and the distribution of all ecosystem components in the *Alcúdia* Bay. Additionally, the number of check dives was not traceable; nevertheless the existing datasets provide the best available information about the study area when taking the time constraints of the project into account.

One issue of importance also presented the availability of background information on relevant governmental regulations. At a number of occasions, only Spanish or Catalan documents were available. This slowed down the data collection process for several relevant aspects of the project.

In summary, though a lot of datasets about anthropogenic pressures and human uses and activities has been obtained in a relative short time, most of the datasets presented in this thesis could be improved quite significantly, given access to better source data, resources and especially more time.

Limitations

The basic method applied in this report is adapted from previous peer-reviewed projects (Halpern *et al.*, 2007, 2008 and Korpinen *et al.*, 2012), dealing with cumulative anthropogenic pressure mapping. The initiative for applying this method was introduced by Halpern *et al.* (2007), and was adapted by several other scientists for projects in other coastal areas. However, the method has also shortcomings and gaps that have to be mentioned: **(1)** pressures are treated as additive, **(2)** visualisation of anthropogenic pressure layer, **(3)** single vulnerability factors are treated with equal importance.

First, the method treats anthropogenic pressures as additive due to scientific gaps regarding the effects of multiple pressures on ecosystems (Halpern *et al.*, 2008). This is a conservative approach that was chosen to indicate cumulative pressures in the coastal- and marine environment. However, in reality two pressures combined occurring at the same place and time can have larger effects than just the sum of the two pressures (Ban *et al.*, 2010). Moreover, under circumstances combined pressures can even have less effect than the sum of single pressures. Due to this uncertainty of scientific information regarding pressure interactions, the method assumes pressures to be additive, based on conducted anthropogenic pressure models in the past (Halpern *et al.*, 2008, Ban & Alder, 2008, Selkoe *et al.*, 2009). Thus, while the report is able to present areas of particular concern due to their relative higher cumulative pressure index, a better understanding of cumulative



effects on the environment is a crucial step for future analyses. Understanding interactions between different anthropogenic pressures and their potential effects can improve the quality of the cumulative anthropogenic pressure map regarding accuracy. For these reasons, a conservative approach was chosen and multiple anthropogenic pressures are treated as additive.

Secondly, all anthropogenic pressure layer included in this study are visualized without taking environmental variations such as tides, wave movements and wind directions into account. According to that, linear decay of pressures from their origin was assumed in several pressure layer, due to the fact that not enough is known about the effects of varying distance decays for varying environmental factors to apply specific functions for each type of pressure ([Ban *et al.*, 2010](#)). These environmental variations can potentially change the pattern of the resulting cumulative anthropogenic pressure map. Including these variables would certainly enhance the quality of the final product, however it would also greatly increase the effort needed per pressure layer of the study. Given the fixed time frame for this project, this would not only have inevitably resulted in a decrease in number of pressure layers that could be included, but would have been simply not possible.

Thirdly, all three vulnerability factors of the questionnaire were weighted equally when calculated into the final vulnerability score. However, it may be the case that marine scientists and ecosystem experts regard one factor, such as the extent of the pressure, as more important than the other two factors. If one factor would be regarded as more important than other factors, the calculation for quantifying the relative vulnerability of ecosystems to anthropogenic pressures would possibly change significantly to the chosen approach. A previous study ([Stelzenmueller *et al.*, 2010](#)) outlined different scenarios for the incorporation of the weighting factors for the quantification of anthropogenic impacts. The different scenarios were developed by ranking the importance of one factor higher than the other ones, meaning that the end score is more determined by the most important factor, rather than by all factors equally. So generally speaking, it can be said that these different scenarios could be used to describe a different ranking of importance for the factors that ultimately determine the relative vulnerability of an ecosystem to each anthropogenic pressures.

However, this would mean that another additional survey had to be prepared and conducted beforehand to ask the participants for their opinion on a ranking of the different vulnerability factors. Given the number of respondents ($n=11$), the extent to develop and conduct an additional survey in advance to the actual survey would have been very time consuming. Given the full schedules of the surveyed marine scientists and ecosystems experts, as well as the time constraints as project coordinators, the approach for a different weighting scenario was simply not feasible in the time limitations of the projects, even though the concept should be taken into account as further improvement for the future.

Another limitation, affecting the calculation of the final vulnerability scores, was the fact that time constraints determined the extent of the questionnaire. A first draft allowed the participants to judge each vulnerability factor with a certainty value, rather than only each



pressure. However, after a trial run with this configuration of the questionnaire, it was obvious that the questionnaire required shortening. The participants of the trial run needed more than one hour to complete the questionnaire; therefore it was decided to abandon the idea to give the participants the chance to judge the certainty value per vulnerability factor, instead only asking for an estimation per pressure. The top priority was to get as many responds as possible and asking for an estimation per pressure ensured, that most of the participants were willing to take part in the survey and incorporate their knowledge to the project.

Due to the fact that mixed categories of ecosystems were present as one ecosystem layer, the calculation for the final vulnerability scores for these ecosystems required special attention. In the beginning, the idea was to average the outcomes of the ecosystem components that form an ecosystem category. After a great deal of thought, it was decided to use a precautionary approach for the mixed categories, in order to present the higher of the two values per category (Section 4.5.3). Because of many uncertainties that come with complex issues like this, the precautionary principle was applied in this case. In terms of choosing a conservative approach for the model, this harmonizes with the approach that cumulative anthropogenic pressures were treated as additive.



8 Conclusion

The process of applying the cumulative anthropogenic pressure model has been instructive in several aspects. Even though the report presents only a first approach of the cumulative anthropogenic pressure model, the results can provide information and datasets for a wide range of purposes.

The overall aim of the project was the quantification and spatial visualization of the distribution and intensity of relevant cumulative anthropogenic pressures on the ecosystems and can be regarded as accomplished. The result of the thesis provides high resolution spatial analysis of anthropogenic pressures (Allan *et al.*, 2013) on the coastal- and marine ecosystems at the regional scale of the *Alcúdia* Bay. Because of the diversity of anthropogenic pressures and ecosystems that converge in the area, the visualization of the resulting cumulative anthropogenic pressures can provide a helpful tool for several planning and management strategies.

The high resolution spatial analyses can be regarded as a scientific basis for decision-makers, ocean planners for future management plans and regulations. This scientific basis is crucial for future management strategies that tackle the prevention, reduction and management cumulative anthropogenic pressures in order to balance the increase in coastal activities, population growth and securing the health of the ecosystems and the related services. Furthermore, the report presents a first approach to provide resource managers with a better understanding of the relationships between cumulative anthropogenic pressures and the health of the marine ecosystems (Allan *et al.*, 2013).

In this regard, the cumulative anthropogenic pressure model gets also relevant regarding social- and economic aspects, because of the dependency on a qualitative and productive environment and its services. The identification and visualisation of high pressure areas helps to develop effective conservation strategies that are based on the sensitivity of the marine ecosystem and its health. This does not only support the preservation of an attractive environmental scenery for residents and visitors; it also provides the opportunity to lead to conservation strategies of important environmental services.

However, a clear understanding about data gaps and the limitations of the project also reveals the need for further improvements. The project results clearly reveal the need for more fundamental and scientific information regarding ocean management and coastal- and marine spatial planning at the study area. Furthermore, limitations and knowledge gaps (e.g. cumulative pressures and their impacts on ecosystems, ecosystem vulnerability) were revealed by this project and demonstrated the need for additional research in order to satisfy the requirements of the MSFD until 2020. Addressing the mentioned limitations could start initiating new research agendas for the area and further provides help for ocean management in the *Alcúdia* Bay.



Nevertheless, the project can be regarded as a first approach to fulfil the requirements of the MSFD. In addition to that, the cumulative anthropogenic pressure map identified areas and ecosystems that are highly affected by multiple anthropogenic pressures. This can present a useful spatial information for conservation efforts in the area and identifying areas of particular interest for studies, monitoring and a better focus on management attention in general. Therefore, this project presents a significant input and basis for potential future management plans and regulations to conserve and improve environmental health and natural services in the area.

9 Recommendations

This section aims to provide recommendations concerning the outcomes of the thesis and the potential for future development. The focus is set on general gaps that were identified during the procedure, rather than extensive literature study and detailed research, evaluation and analyses of potential management strategies.

The following short paragraphs deal with potential points of improvement and shall be regarded as a superficial suggestion within the frame of the thesis.

Cooperation

The first recommendation concerns the cooperation between the regional- and the four local responsible administrations of the *Alcúdia* Bay. During the fieldtrips and meetings with local governments a complete lack of cooperation and exchange of knowledge was discovered. Currently, each municipality operates by itself under guidance of the regional government of the Balearic Islands (Fig. 11). Regarding the complexity of environmental problems in general and in this case the future requirements and challenges that will be

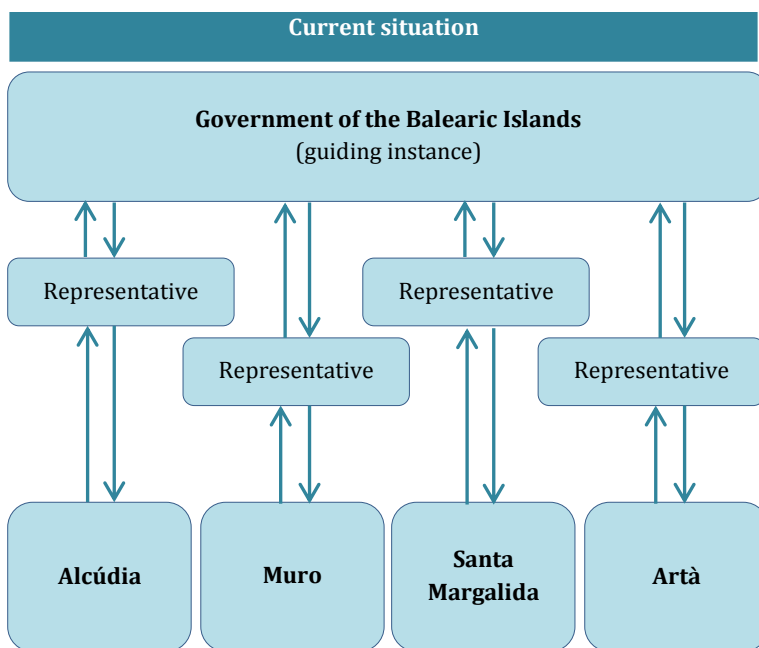


Figure 11: the current situation of communication and collaboration between the municipalities of *Alcúdia*, *Muro*, *Santa Margalida* and *Artà*.



implicated by the MSFD, cooperation between the municipalities could be helpful in order to fulfil the requests. In this way, local knowledge would be equally accessible for responsible parties and could be further improved comprehensively.

Furthermore, an improved cooperation structure could support the development of a more holistic view on the area and associated environmental factors.

For these reasons, the development of close collaboration structures between the four municipalities *Alcúdia*, *Muro*,

Santa Margalida and *Artà* should be improved and further linked to the Balearic Government in terms of representatives of each municipality (Fig. 12).

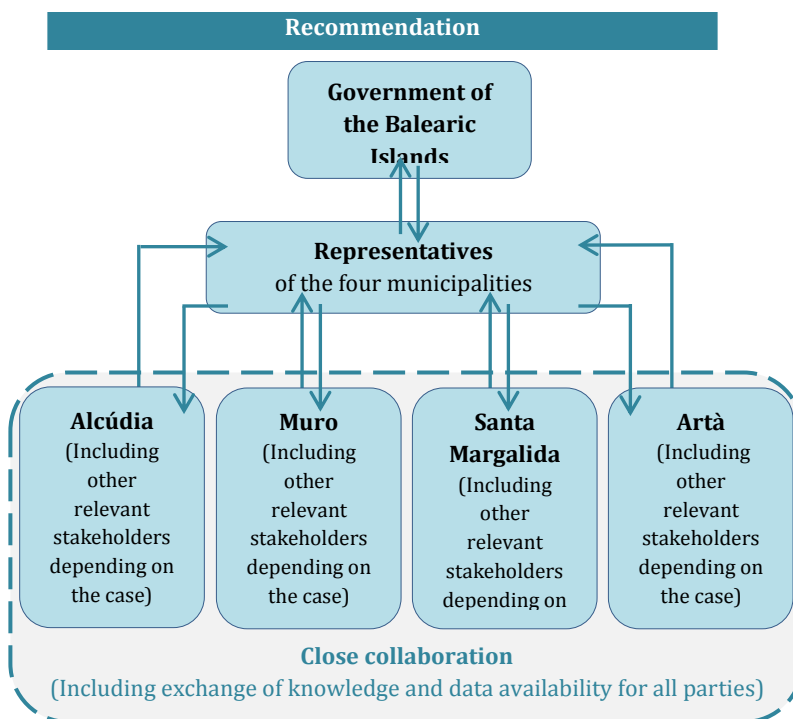


Figure 12: recommended flow of communication and collaboration between the municipalities of *Alcúdia*, *Muro*, *Santa Margalida* and *Artà*.

In addition, the establishment of a collaborative forum for planning environmental strategies and future directives for all municipalities could improve a common future vision.

This can help to counteract variation in quality of environmental conservation strategies at the study site and thus support an equal level of environmental quality on a regional scale.

Upgrade data

The second recommendation concerns the identification of data gaps during this project. The project outlines several lacks of knowledge and data availability (Section 7), which need to be tackled in order to develop adequate regulations for effective environmental conservation on site. This issue also includes continuous scientific research programs, to create a base for new available data, as well as updates and data maintenance. The applied cumulative anthropogenic pressure model provides the opportunity to easily add and/or update relevant data if they become available (Halpern *et al.*, 2008). This attribute enhances the signification of the model enormously and should be used when new data become available in order to keep it up-to-date and constantly improve it.



General orientation

In general, it is recommended to use the provided cumulative anthropogenic pressure model and information as a foundation for further improvement of scientific knowledge. The results of the model offer the opportunity for developing plans and effective strategies for the regulation and mitigation of human pressure on the marine environment. All processes should be based on an ecosystem-based approach, while taking the requirements of the MSFD into account.

The following points present a possible sketch of a guideline on how to deal further with the provided information:

- Implementation of a platform for close collaboration and communication between relevant parties
- Development of regulations with the provided results and information
- Implementation of scientific research program(s)
 - to fill the identified gaps
 - to acquire new relevant datasets as input for the model
 - constant updates and maintenance of datasets
 - to improve the scientific knowledge about cumulative anthropogenic impacts
 - to develop adequate management and / or policy strategies that meet the characteristics of the area (including natural as well as user)
- Ensure data access of existing and new data



10 References

Books and Papers

- Agencia Estatal Boletín Oficial del Estado, (2005a). 12513, RESOLUCIÓN de 23 de junio de 2005, de la Secretaría General para la Prevención de la Contaminación y el Cambio Climático, por la que se formula declaración de impacto ambiental sobre la evaluación del proyecto Construcción de la instalación desaladora de agua marina de la bahía de Alcudia, promovido por la Dirección General del Agua, BOE (Boletín Oficial del Estado núm 172., pp. 25987, from the 20th of July 2005
- Agencia Estatal Boletín Oficial del Estado, (2005b). 12.513/05. Resolución de la Dirección del Agua por la que se anuncia información pública del proyecto de construcción de la instalación desaladora de agua marina de la Bahía de Alcúdia y de su estudio de impacto ambiental, BOE núm. 78, pp. 2758, from the 1st of April 2005
- Allan, J.D., McIntyre, P.B., Smith, S. D., Halpern, B.S., Boyer, G.L., Buchsbaum, A., & Steinman, A.D. (2013). Joint analysis of stressors and ecosystem services to enhance restoration effectiveness. *Proceedings of the National Academy of Sciences*, 110(1), 372-377. doi:10.1073/pnas.1213841110
- Amengual-Gomila, B.; García-Olagorta, G. (1999). *Aeroguía del Litoral de Mallorca*. Editorial Planeta.
- Andersen, J.H. & Stock, A. (eds.), Mannerla, M., Heinänen, S. & M. Vinther, M. 2013. Human uses, pressures and impacts in the eastern North Sea. *Aarhus University, DCE – Danish Centre for Environment and Energy*. 136 pp. *Technical Report from DCE – Danish Centre for Environment and Energy No. 18*. <http://www.dmu.dk/Pub/TR18.pdf>
- Baarda, D.B., De Goede, M.P.M. (2006). *Basisboek methoden en technieken*. Wolters-Noordhoff bv., Groningen/Houten, The Netherlands.
- Balaguer, P., Diedrich, A., Sardá, R., Fuster, M., Cañellas, B., & Tintoré, J. (2011). Spatial analysis of recreational boating as a first key step for marine spatial planning in mallorca (balearic islands, spain). *Ocean and Coastal Management*, 54(3), 241-249. Retrieved from www.scopus.com
- Ban, N., & Alder, J. (2008). How wild is the ocean? Assessing the intensity of anthropogenic marine activities in British Columbia, Canada. *Aquatic Conservation: marine and freshwater ecosystems*, 18(1), 55-85.
- Ban, N. C., Alidina, H. M., & Ardrón, J. A. (2010). Cumulative impact mapping: Advances, relevance and limitations to marine management and conservation, using Canada's Pacific waters as a case study. *Marine Policy*, 34(5), 876-886.
- Bosch, T., Colijn, F., Ebinghaus, R., Körtzinger, A., Latif, M., Matthiessen, B., Meizner, F., Oschlies, A., Petersen, S., Proeß, A., Quaas, M. ... & Weinberger, F., *World Ocean Review*, 2010, Hamburg, Mare Verlag
- CAIB, (2005). 16819, Decret 96/2005, de 23 de Septiembre, d'aprovació definitiva de la revisió del Pla Director Sectorial Energètic de les Illes Balears, BOIB (Butlletí Oficial de les Illes Balears) núm. 143, pp. 18, from the 27th of September 2005
- CAIB, (2012). 18880, Acuerdo del Pleno de la Comisión de Medio Ambiente de las Illes Balears del Proyecto de Adecuación del Vertedero de Biniatrina (CT de Alcúdia) de Gas y Electricidad Generación, SAU, BOIB núm. 152, pp. 2083-2088, from the 18th October 2012
- Costanza, R. (1999). The ecological, economic, and social importance of the oceans. *Ecological Economics*, 31(2), 199-213. Center for Environmental Science and Biology Department, University of Maryland Institute for Ecological Economics
- Crain, C. M., Halpern, B. S., Beck, M. W., & Kappel, C. V. (2009). Understanding and managing human threats to the coastal marine environment. *Annals of the New York Academy of Sciences*, 1162(1), 39-62.
- Diedrich, A., Tintoré, J., & Navinés, F. (2010). Balancing science and society through establishing indicators for integrated coastal zone management in the Balearic Islands. *Marine Policy*, 34(4), 772-781.



- Donta, A., Lange, M. A., & Herrmann, A. (2005). Water on Mediterranean Islands: current conditions and prospects for sustainable management. *Centre for Environment Research (CER), University of Muenster (Germany)*, 5, 516.
- Erbe, C., MacGillivray, A., & Williams, R. (2012). Mapping cumulative noise from shipping to inform marine spatial planning. *The Journal of the Acoustical Society of America*, 132(5), EL423-EL428.
- Gazo, M., Gonzalvo, J., & Aguilar, A. (2008). Pingers as deterrents of bottlenose dolphins interacting with trammel nets. *Fisheries Research*, 92(1), 70-75.
- Gopi, S., Sathikumar, R., & Madhu, N. (2008). *Advanced Surveying: Total Station, GIS and Remote Sensing*. Dorling Kindersley.
- Grech, A., Coles, R., & Marsh, H. (2011). A broad-scale assessment of the risk to coastal seagrasses from cumulative threats. *Marine Policy*, 35(5), 560-567.
- Green, E. E. P., & Short, F. T. (Eds.). (2003). *World atlas of seagrasses*. University of California Press Berkeley, USA.
- Halpern, B. S., Selkoe, K. A., Micheli, F., & Kappel, C. V. (2007). Evaluating and ranking the vulnerability of global marine ecosystems to anthropogenic threats. *Conservation Biology*, Vol.21 (5), 1301-1315.
- Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, C., & Watson, R. (2008). A global map of human impact on marine ecosystems. *Science*, 319(5865), 948-952.
- Hatch, L., Clark, C., Merrick, R., Van Parijs, S., Ponirakis, D., Schwehr, K., & Wiley, D. (2008). Characterizing the relative contributions of large vessels to total ocean noise fields: a case study using the Gerry E. Studds Stellwagen Bank National Marine Sanctuary. *Environmental management*, 42(5), 735-752.
- HELCOM. (2010). Towards a tool for quantifying anthropogenic pressures and potential impacts on the Baltic Sea marine environment: a background document on the method, data and testing of the Baltic Sea Pressure and Impact Indices. *Balt. Sea Environ. Proc.*, 125, 1-72.
- Hutt, G. (2006) Islas Baleares. Ibiza, Formentera, Mallorca, Cabrera y Menorca. Guías Náuticas IMRAY. *Royal Cruising Club Pilotage Foundation*. Ed. Tutor. 271 pp.
- Kappel, C. V., Halpern, B. S., & Napoli, N. (2012). Mapping Cumulative Impacts of Human Activities on Marine Ecosystems. *Sea Plan, Boston, Massachusetts*.
- Kay, R. & Alder, J. (2005). *Coastal Planning and Management* (2nd edition). London and New York: Taylor & Francis
- Korpinen, S., Meski, L., Andersen, J. H., & Laamanen, M. (2012). Human pressures and their potential impact on the Baltic Sea ecosystem. *Ecological Indicators*, 15(1), 105-114.
- MOP (Ministerio de Obras Públicas), (1975). Plan Indicativo de Usos del Dominio Público Litoral. Dirección General de Puertos y Señales Marítimas. Subdirección General de Costas y Señales Marítimas. Jefatura de Costas y Puertos de Baleares.
- MSFD, 2008. Directive 2008/56/EC of the European Parliament and the Council of 17 June 2008 Establishing a Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Framework Directive). *Official Journal of the European Union*, L 164, 25/6/2008, 19-40 pp. Accessed online 25.04.2013 from: http://ec.europa.eu/environment/water/marine/index_en.htm.,
- Petersen, J., Michel, J., Zengel, S., White, M., Lord, C., & Plank, C. (2002). Environmental Sensitivity Index Guidelines. Version 3.0. *NOAA Technical Memorandum NOS OR&R*, 11, 1-192.
- Philippart, C. J., Anadón, R., Danovaro, R., Dippner, J. W., Drinkwater, K. F., Hawkins, S. J., ... & Reid, P. C. (2011). Impacts of climate change on European marine ecosystems: Observations, expectations and indicators. *Journal of Experimental Marine Biology and Ecology*, 400(1), 52-69.



Readman, J. W., Albanis, T. A., Barcelo, D., Galassi, S., Tronczynski, J., & Gabrielides, G. P. (1997). Fungicide contamination of Mediterranean estuarine waters: Results from a MED POL pilot survey. *Marine pollution bulletin*, 34(4), 259-263.

Reulink, N. en Lindeman, L. (2005). *Kwalitatief onderzoek: participerende observatie, interviews, documentanalyse*. Radboud University Nijmegen. The Netherlands.

Selkoe, K. A., Halpern, B. S., & Toonen, R. J. (2008). Evaluating anthropogenic threats to the Northwestern Hawaiian Islands. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 18(7), 1149-1165.

Selkoe, K.A., Halpern, B.S., Ebert, C.M., Franklin, E.C., Selig, E.R., Casey, K.S., Bruno, J. & Toonen, R.J. (2009): A map of human impacts to a “pristine” coral reef ecosystem, the Papahānaumokuākea Marine National Monument. - *Coral Reefs* 28(3): 635-650.

Tamoh, K., Von Igel, W., Soler, M., & Candela, L. (2008). Analysis of water use patterns and conflicts in the Sa Pobla Plain and Alcudia Bay (Majorca, Spain). *Options Méditerranéennes, Series A*, 83, 131-141.

Teck, S.J., Halpern, B.S., Kappel, C.V., Micheli, F., Selkoe, K.A., Crain, C.M., Martone, R., Shearer, C., Arvai, J., Fischhoff, B., Murray, G., Neslo, R. & Cooke, R. (2010). Using expert judgment to estimate marine ecosystem vulnerability in the California Current. *Ecological Applications*, 20(5), 1402-1416.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Reidy Liermann, C., Davies, P.M., (2010). Global threats to human water security and river biodiversity. *Nature* 467 (7315), 555–561.

Web pages

Alcudia Mallorca minicipi ecotouristic. (2013). Accessed on 10.03.2013 from:

[http://web.archive.org/web/20090106071114/http://www.alcudiamallorca.com/de/de_visita/alcudias-strande-\(majorca\).html](http://web.archive.org/web/20090106071114/http://www.alcudiamallorca.com/de/de_visita/alcudias-strande-(majorca).html)

ArcGIS Resources, 2013a: ArcGIS Resources. (2013). Buffer (Analysis). ArcGIS Resource Center. Accessed on 01.07.2013 from: <http://resources.arcgis.com/en/help/main/10.1/index.html#//000800000019000000>

ArcGIS Resources, 2013b: ArcGIS Resources. (2013). Kernel density (Spatial Analyst). ArcGIS Resource Center. Accessed on 06.07.2013 from: <http://resources.arcgis.com/en/help/main/10.1/index.html#//009z0000000s000000>

ArcGIS Resources, 2013c: ArcGIS Resources. (2013). Working with the histogram when displaying raster data. ArcGIS Resource Center. Accessed on 01.10.2013 from: <http://resources.arcgis.com/en/help/main/10.1/index.html#//009t00000083000000>

Conselleria de medi Ambient de Govern de les Illes Balears (CAIB), (Local Ministry of the Environment of the Balearic Islands). (2006). “LIFE Posidonia”. Accessed on 01.07.2013 from: http://lifeposidonia.caib.es/user/carto/index_en.htm

Hijmans, R. J., & Van Etten, J. (2013). Geographic analysis and modeling with raster data. R Package Version 2.1-41. Accessed on 10.07.2013 from: <http://cran.r-project.org/web/packages/raster/raster.pdf>
Instituto Nacional de Estadística, January 2012, Accessed on 03.03.2013 from: <http://www.ines.es>

MarineTraffic.com, Live ship maps - AIS - vessel traffic and position, developed and hosted by the Department of Product & Systems Design Engineering - University of the Aegean, Accessed on 02.07.2013 from: <http://marinetraffic.com/ais/>

Port Authority of the Balearic Islands, Accessed on 12.03.2013 from:



<http://www.portsdebalears.com/141.php3?puerto=1&idioma=eng>

R Development Core Team. R: A Language and Environment for Statistical Computing—R Foundation for Statistical Computing. 2012. Accessed on 02 July 2013 from:

<http://www.R-project.org/>

SOCIB, SOCIB website, accessed on 01.02.2013 from SOCIB:

http://www.socib.es/?seccion=textes&id_textotextes=director



11 Appendices

Appendix I: Excluded activities and uses

Table AI: Major human activities and uses that were not included in the project

Potentially important pressures	Reason to not include pressures in the project
Sea-Surface-Temperature (SST) anomalies	No indicator, no compatible datasets available
Oil slicks and spills	No indicator, no datasets available
Ocean-based pollution	Insufficient scientific information and datasets for the area
Marine litter	Insufficient scientific information and datasets for the area
Introduction of non-indigenous species	Insufficient scientific information and datasets for the area, no compatible dataset available
Sediment extraction	Not conducted in the study area, therefore irrelevant
Erosion	Insufficient scientific information and datasets for the area, no compatible dataset available
Beach nourishment	Last conducted in 2002 and therefore neither relevant nor sufficient datasets available
Hypoxia risk	Insufficient scientific information and datasets for the area, no compatible dataset available
Light pollution	Insufficient scientific information and datasets for the area, no compatible dataset available



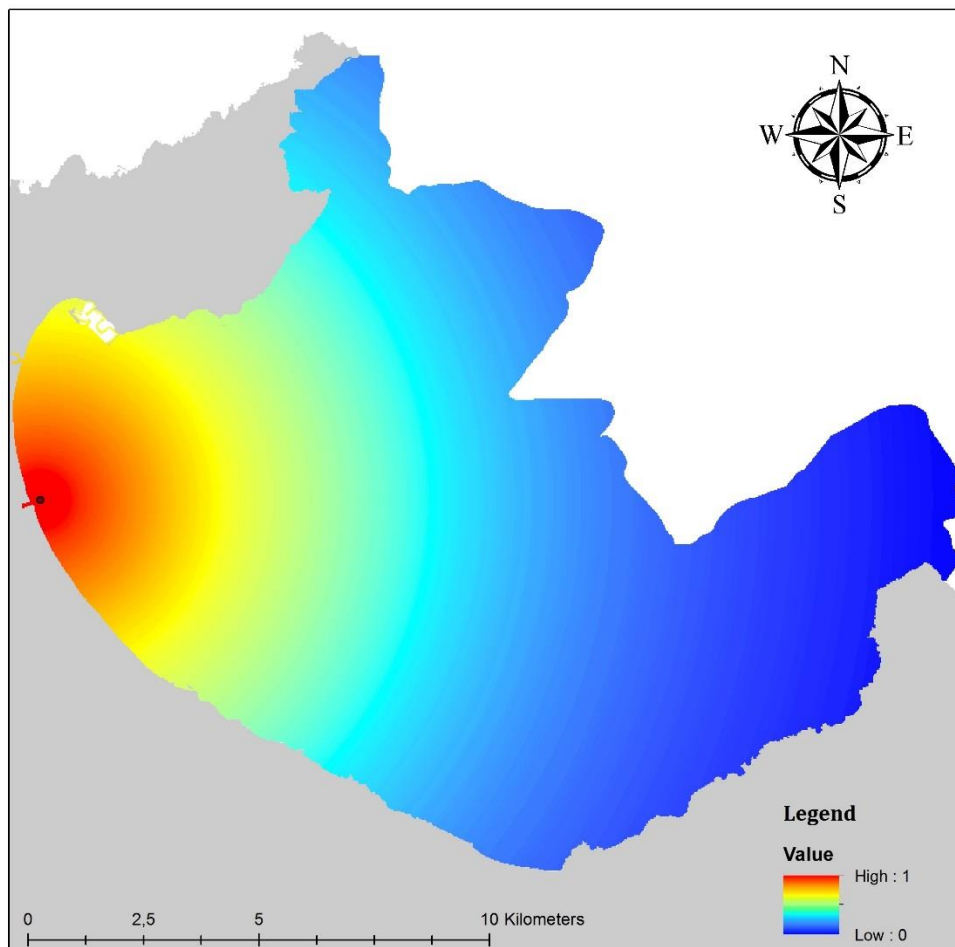
Appendix II: Distribution and intensity of anthropogenic pressures

Artificial coastal structures	
<p>The layer includes the major artificial structures in the <i>Alcúdia</i> Bay and represents the distribution and intensity of the associated pressure of sealing.</p> <p>Included are defence structures, boat ramps, piers, outfall pipes and harbours</p>	
Data source: SOCIB viewer (http://gis.socib.es/sacosta/composer).	
Layer type: Buffer	
<p>Visualisation process:</p> <p>Artificial coastal structures were visualized as lines. The length of each structure (in meter) was used to weight the intensity of the pressure. We assumed the pressure intensity is local and applied a 1km buffer around the structures, containing the length value (the sum of the length of all structures within the buffer respectively, if more than 1 structure was present within the buffer). Subsequently, buffers were rasterized, $\log[x+1]$ transformed and normalized between 0 and 1.</p>	
Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)	
Resolution: 25 meter cell size	
Time period covered: Year 2012	
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)	
Additional information: The lines to indicate the artificial coastal structures are not included in the final layer. The lines rather should be regarded as a visualisation help.	



Agriculture

The layer represents the distribution and intensity of inputs of fertilizers and other nitrogen- and phosphorus rich substances, due to agricultural activities.



Data source: Google maps

Layer type: Exponential decay function

Visualisation process:

The entry point is represented as a point. We used a decay function to indicate the distribution and intensity of the pressure. According to previous reviews about spatial distribution of pressures (Ban *et al.*, 2010), we assumed that the influence of agricultural inputs of nutrients decay to 10% within 10km and dissipates to 1% within 30km (Readman *et al.*, 1997). The review relates to the impact of pesticides used in agriculture, but due to data gaps we applied the same function for inputs of fertilizers, other nitrogen- and phosphorus rich substances. Subsequently, the layer was rasterized, $\log[x+1]$ transformed and normalized between 0 and 1.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: Year 2013

Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

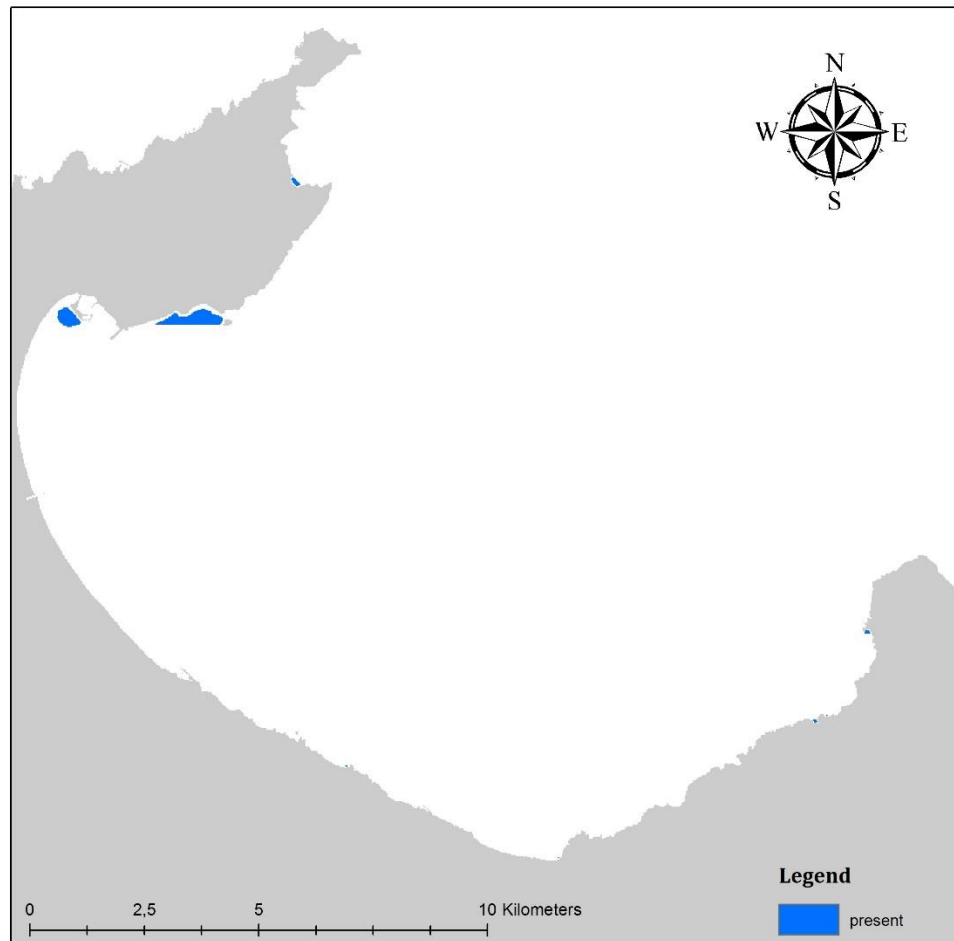
Additional information: The point in the image simply represents the entry point of the pressure and is not included in the final pressure layer.



Anchoring

The layer represents the distribution of observed anchoring locations for recreational boating in the *Alcúdia* Bay.

The related pressure to the locations of anchoring is abrasion.



Data source: SOCIB viewer (<http://gis.socib.es/sacosta/composer>); aerial photos from the years 2006 – 2008; own observation and local knowledge

Layer type: presence/absence

Visualisation process:

Anchoring locations were drawn as spatial polygons which were subsequently rasterized and $\log[x+1]$ transformed.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: Year 2013

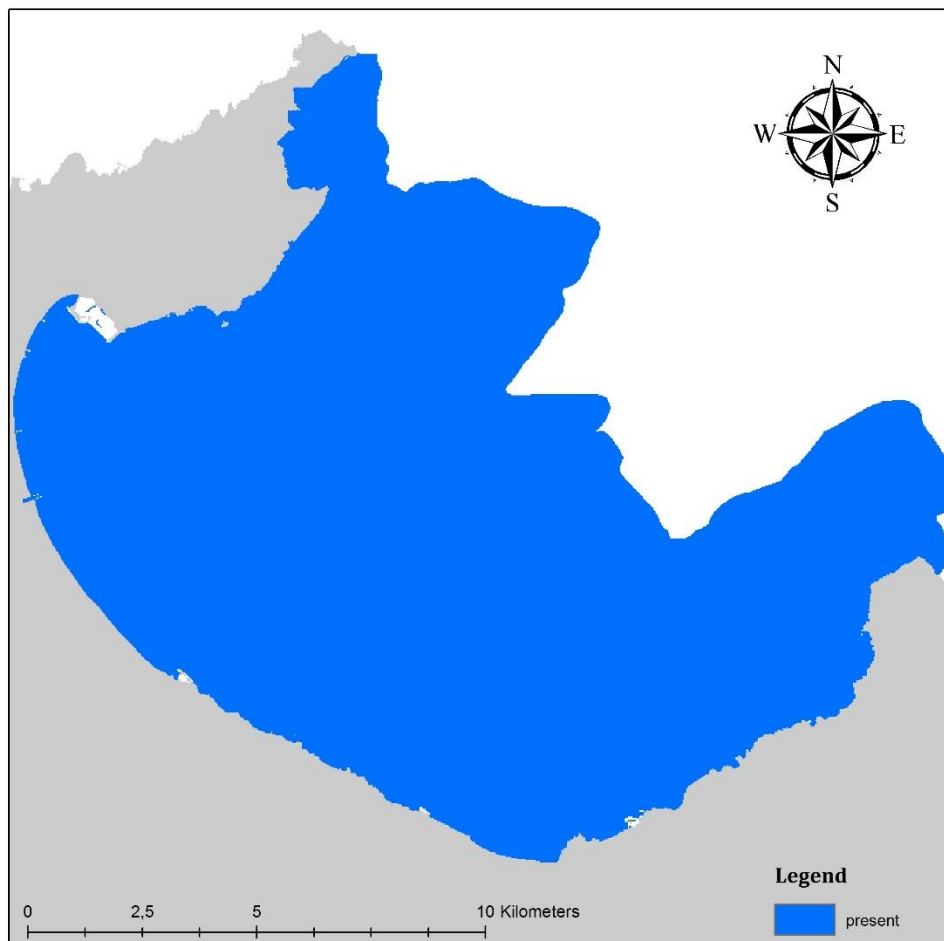
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Climate change

The layer indicates the distribution and intensity of Climate change in the *Alcúdia* Bay. We considered climate change as a combination of different pressures (i.e. sea-level rise, sea-temperature rise and ocean acidification), however it is considered as one pressure category.



Data source: Based on general literature study (Philippart et al., 2011)

Layer type: presence/absence

Visualisation process:

We assumed that the associated pressures of climate change (sea-level rise, sea-temperature rise and ocean acidification) affect the whole bay (hence, all ecosystems). Therefore, we created a spatial polygon that covers the whole area and assigned the same value for the polygon. Subsequently, the polygon was rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: none

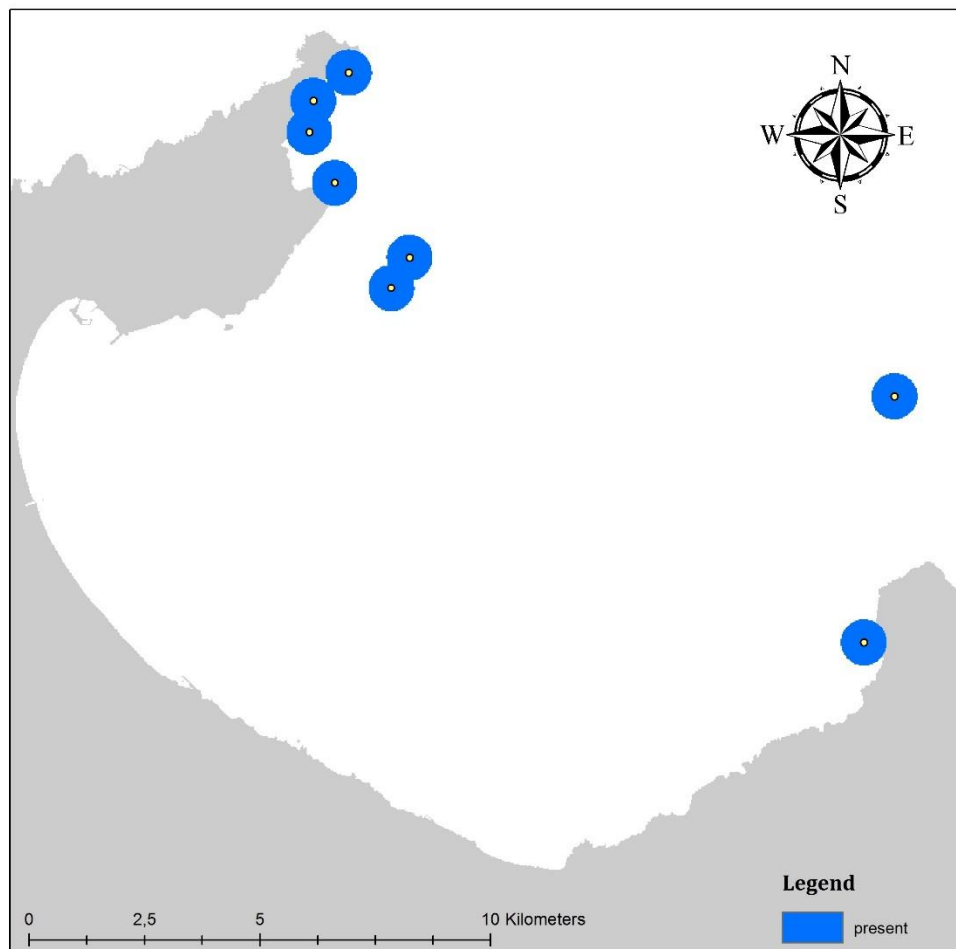
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Scuba diving (watersport activities)

The layer represent the distribution and intensity of the associated pressure of changes in wildlife behaviour, caused by Scuba diving in the Alcúdia Bay.



Data source: service provided by different dive-operators on site, obtained by interviews IDEIB dataset (based on: Amengual-Gomila & García-Olagorta, 1999)

Layer type: Buffer

Visualisation process:

We drew points to indicate locations of dive sites and digitalized a total of 8 scuba diving spots in the bay. We assumed a very local effect of the associated pressures of the activitiy and applied a 500-m buffer to all diving locations (Ban *et al.*, 2010).

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2012, 2013

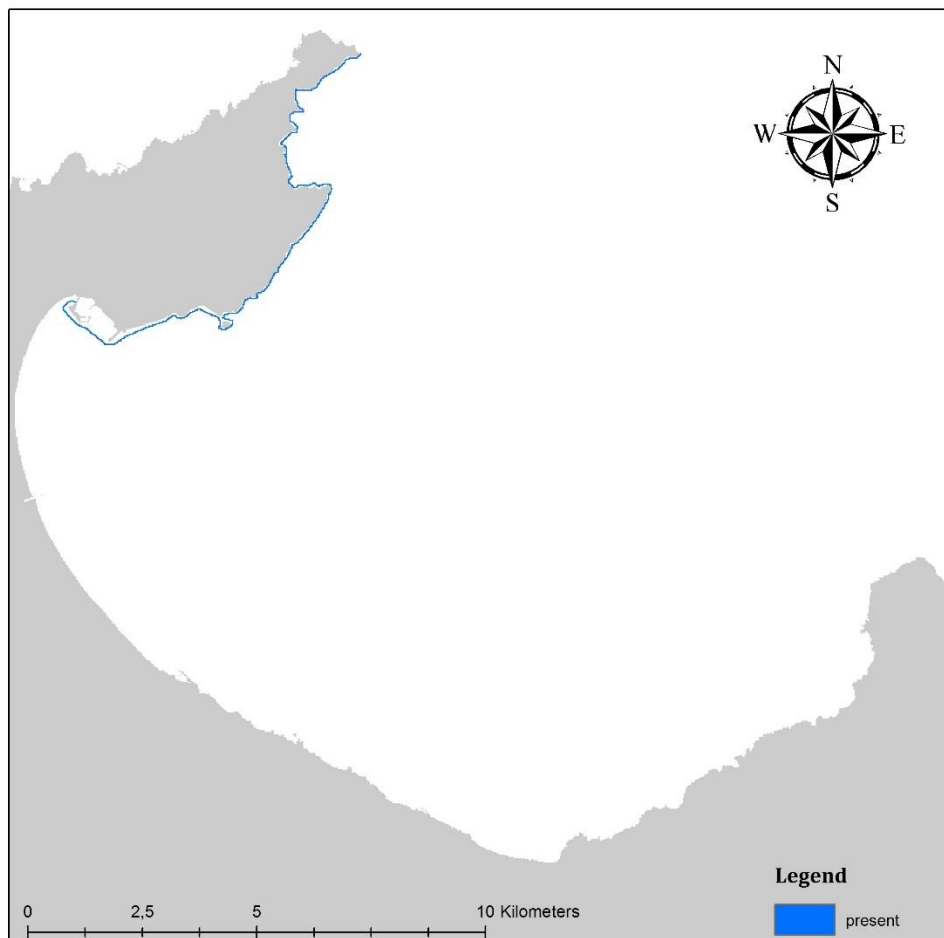
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: The points in the image are only displayed to get a better idea of the dive locations. Note that the final layer just contains the rasterized buffer.



Kayaking (watersport activities)

The layer represents the known kayaking tour route in the *Alcúdia* Bay. The associated pressure is the changes in wildlife behaviour.



Data source: service provided by different rental- and tour operators on site, obtained by interviews; own observation

Layer type: Buffer

Visualisation process:

The route of kayaking tours was mapped as lines. Lines further received a buffer of 500m to each direction, indicating the distribution of the influence of the associated pressures. Subsequently, lines were rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2013

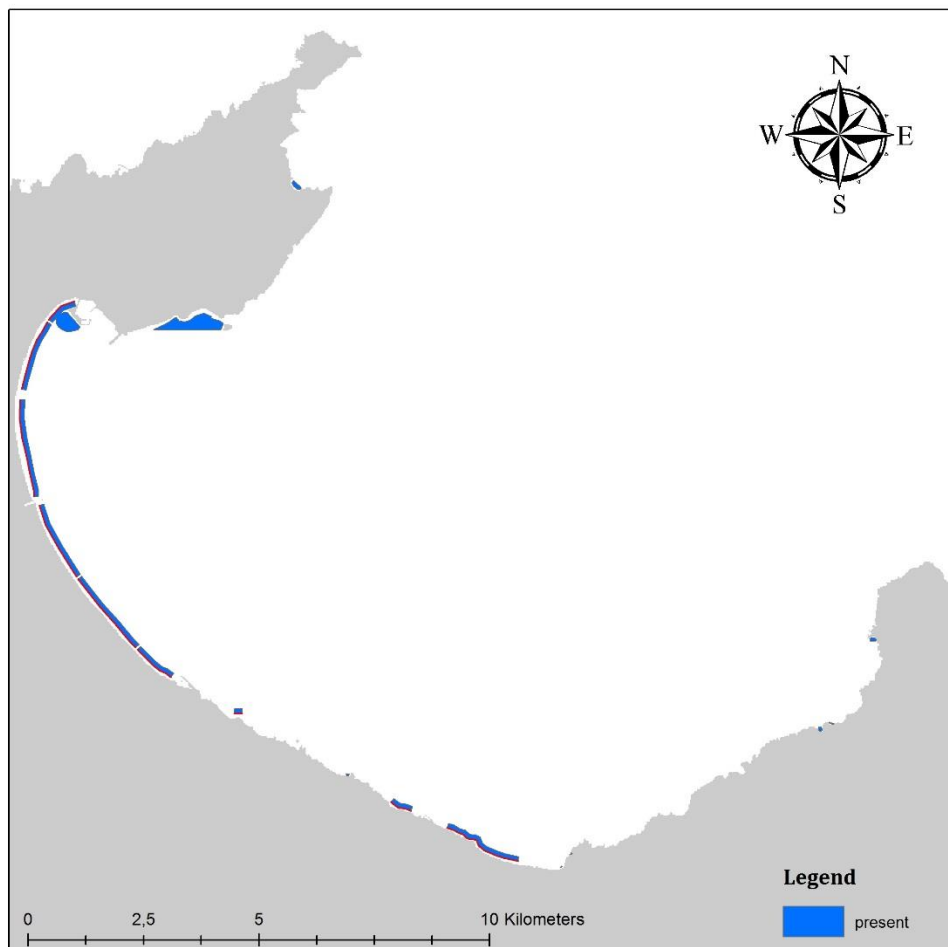
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Snorkelling (watersport activities)

The layer represents the distribution of snorkelling locations in the *Alcúdia* Bay. The associated pressure type is the changes in wildlife behaviour.



Data source: own observation; local knowledge

Layer type: Buffer

Visualisation process:

Snorkeling sites were mapped from the shoreline with a line. Rocky and sedimentary coast were included, but shores with difficult access and industrial infrastructure was excluded. A 100m buffer was assigned to indicate the influence of the associated pressure, deriving from this activity. Furthermore, the locations of anchoring points for recreational boating were included. Subsequently, the buffer were rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2013

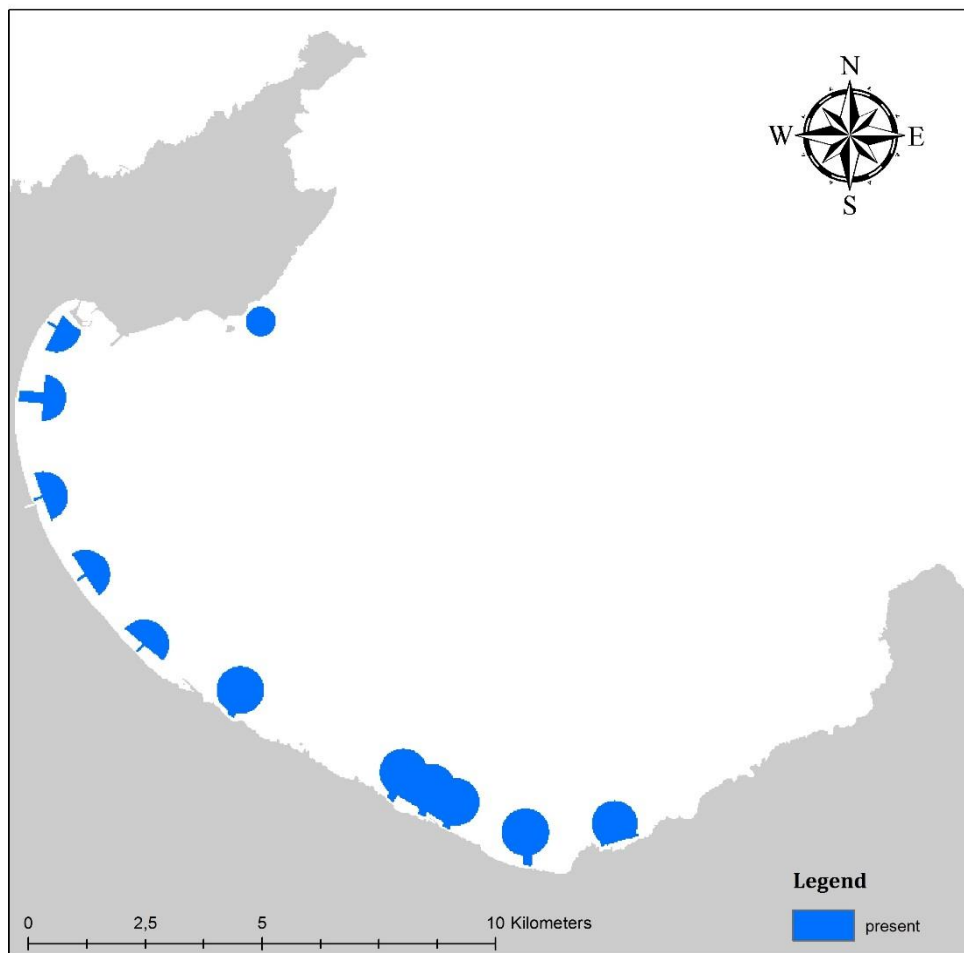
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Surfing (watersport activities)

The layer represents the distribution and intensity of surfing spots in the *Alcúdia* Bay. Surfing in this case includes wind-, wave-, and kitesurfing. The associated pressure type is the changes in wildlife behaviour.



Data source: Partly SOCIB viewer (<http://gis.socib.es/sacosta/composer>); on-site interviews with surf schools and operators; own observation

Layer type: Buffer

Visualisation process:

Entry points at the surf schools were modeled as 50m wide and 200m long corridors. After that, the area spreads as half-circles 500m seawards. Subsequently, buffer were rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2012, 2013

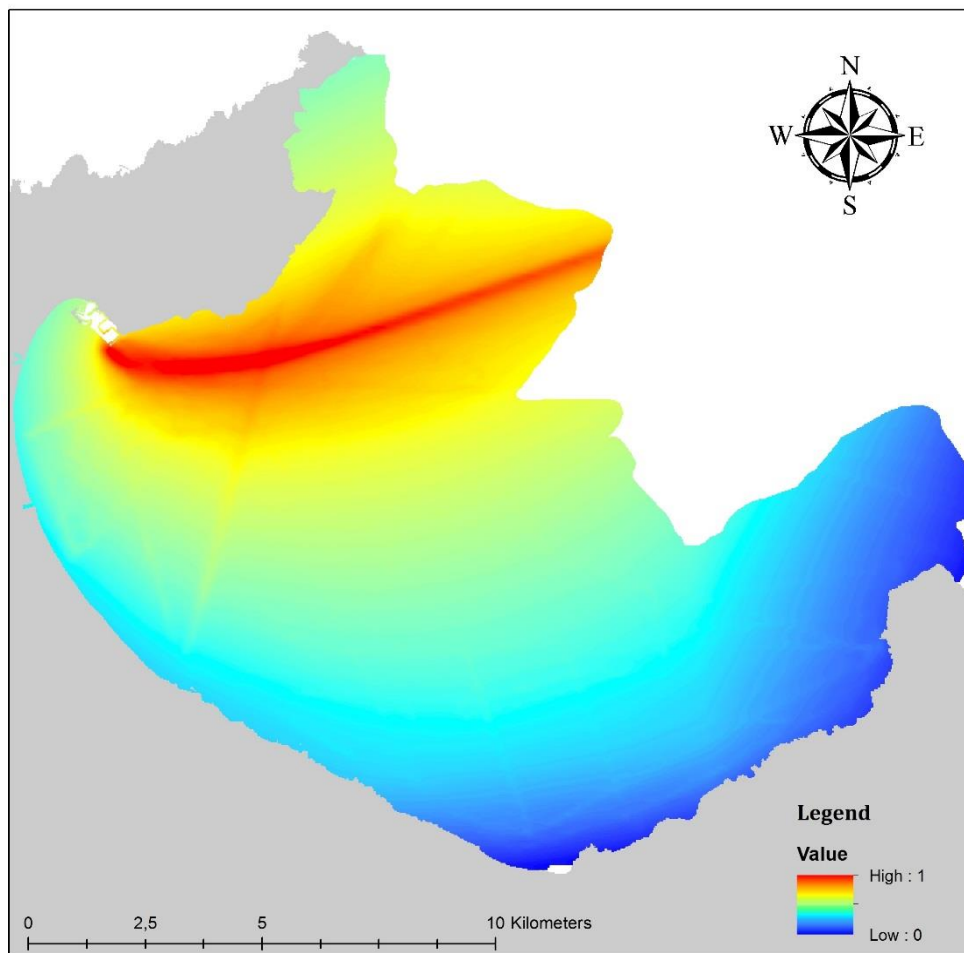
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Sea traffic

The layer represents the distribution and intensity of sea traffic in the *Alcúdia* Bay. The indicator used was the overall number of hours per cell during one year per boat type. The layer includes both recreational and commercial boat tracks. The associated pressure of sea traffic is underwater noise.



Data source: AIS (Automatic Identification System - <http://marinetraffic.com/ais/>)

Layer type: intensity, based on AIS

Visualisation process:

We first calculated the overall number of hours per cell during one year per boat type. Then, we used source levels per boat type from the literature (Hatch *et al.*, 2008) and used a spherical transmission loss function to estimate the cumulative noise on each cell (Erbe *et al.*, 2012). Subsequently, the layer was rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: January 2012 to December 2012

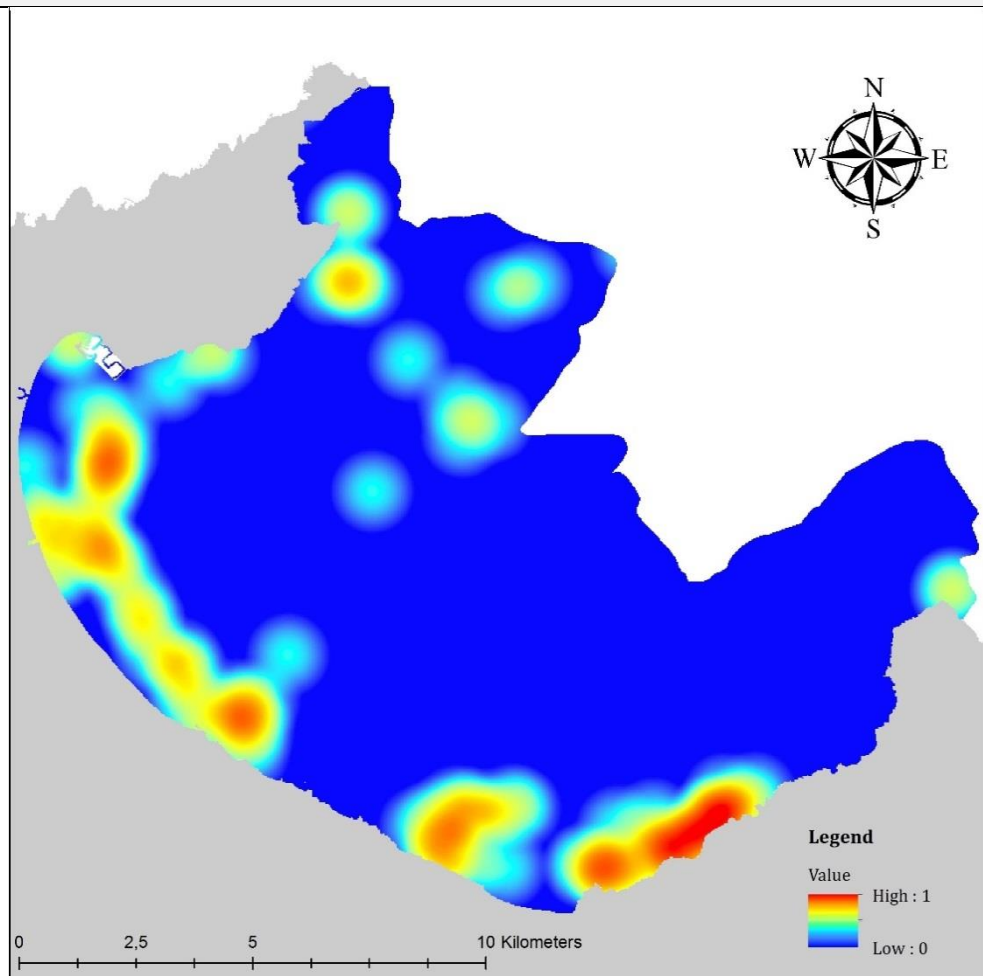
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Boat-based fishing (recreational fishery)

The layer represents the distribution and intensity of boat-based recreational fishing in the *Alcúdia* Bay. The indicator of the pressure was the density of recreational fishing boats. The associated pressure is the selective extraction of species.



Data source: IMEDEA

Layer type: Kernel density

Visualisation process:

Locations of recreational fishing (boat-based) were visualized as points. Based on the location of the points, the kernel density function was used with a search radius of 1km to visualize the density boat-based fishing points. Subsequently, the layer was rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2002

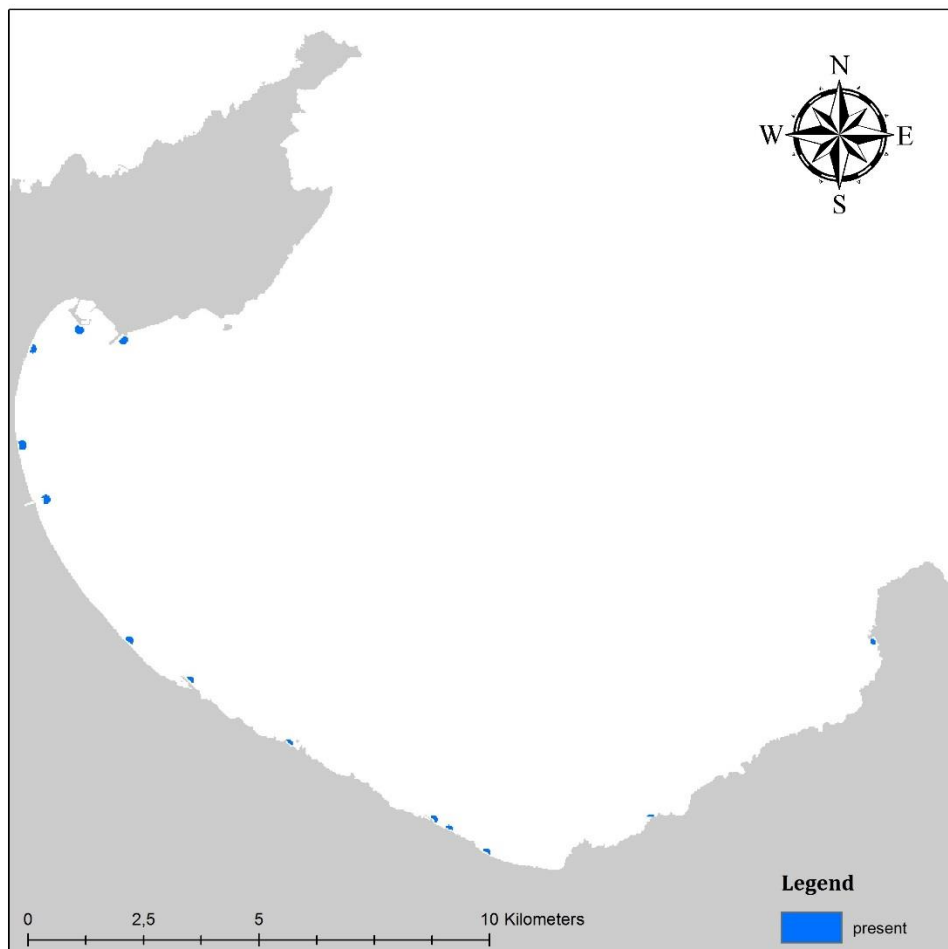
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Land-based fishing (recreational fishery)

The layer represents the distribution of land-based recreational fishing in the Alcúdia Bay. Land-based fishing locations are focused on specific areas on the coastline and in harbour areas. The associated pressure is the selective extraction of species.



Data source: SOCIB viewer (<http://gis.socib.es/sacosta/composer>), own observation, Local knowledge

Layer type: presence/absence

Visualisation process: Fishing from the shoreline was represented with spatial polygons and further rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2012, 2013

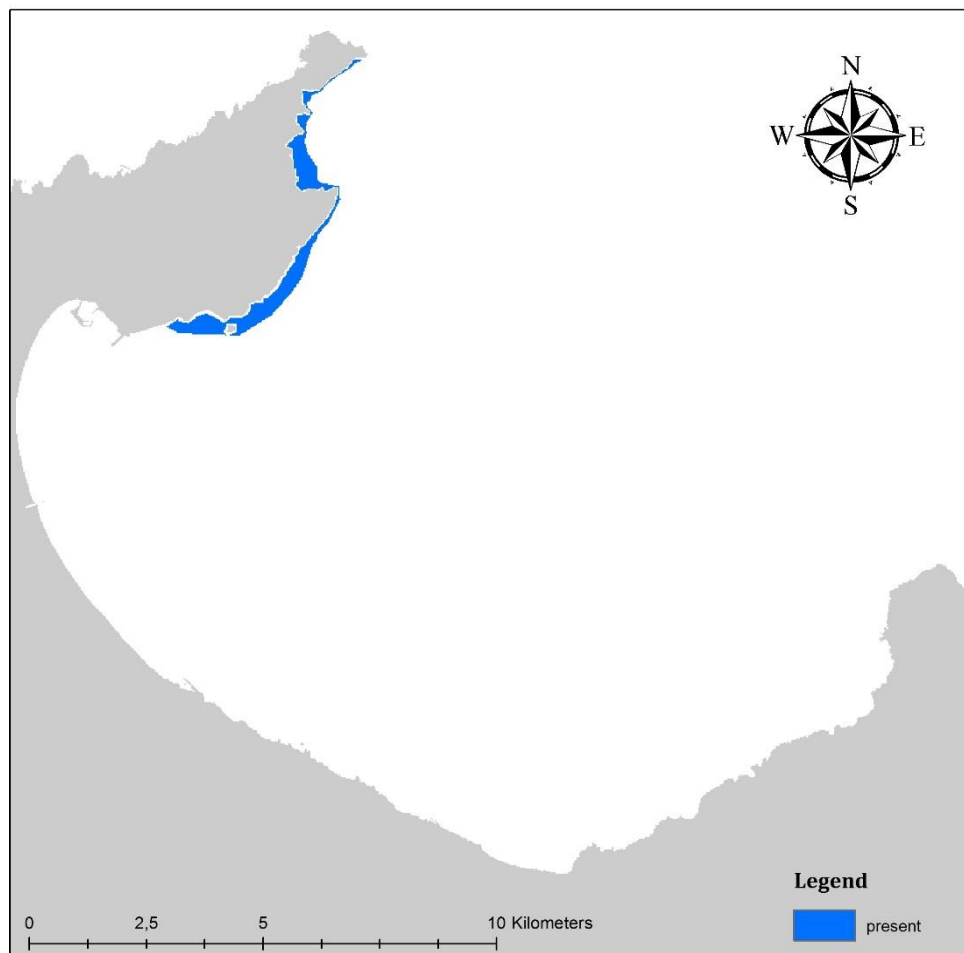
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Spear gun fishing (recreational fishery)

The layer represents the distribution of spear gun fishing in the *Alcúdia* Bay. Spear gun fishing is a favoured activity among Majorcan people. The associated pressure is the selective extraction of species.



Data source: Local knowledge, obtained by interviews

Layer type: presence/absence

Visualisation process:

Spear-fishing is represented by spatial polygons near the shoreline up to 20m depth (located using an existing bathymetric dataset). Subsequently, the layer was rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2013

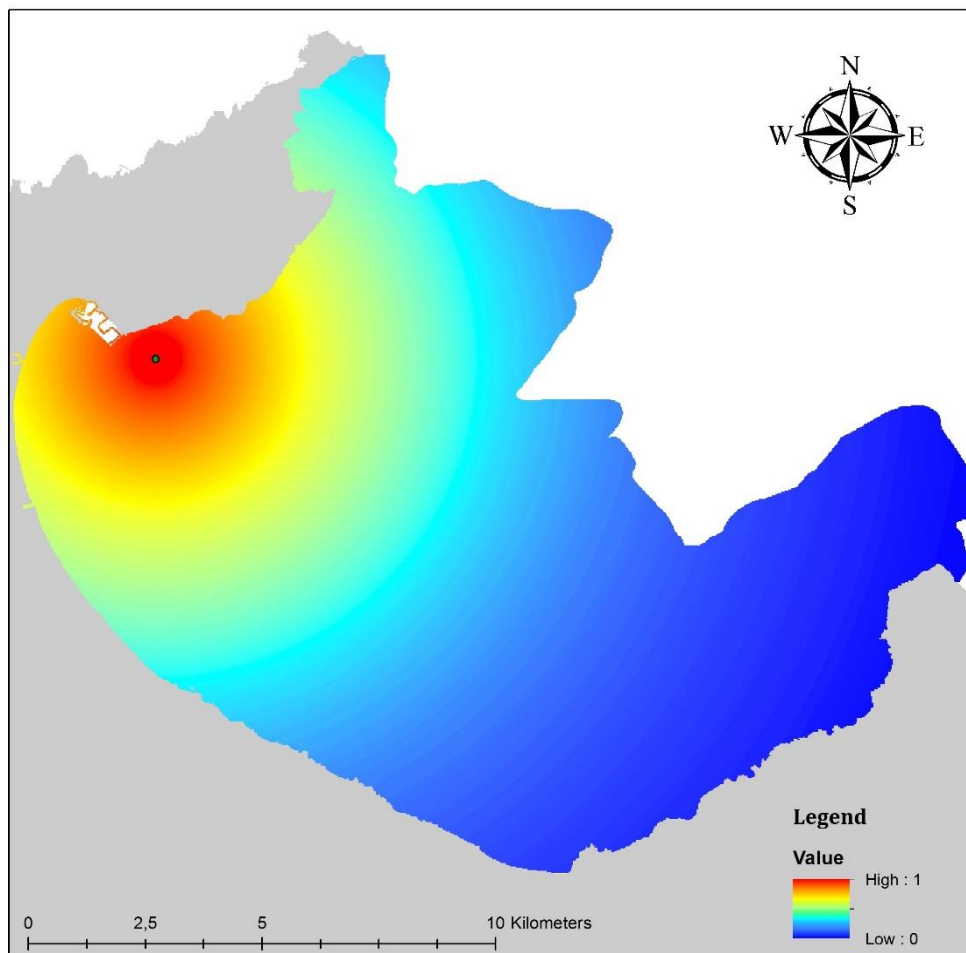
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Coastal wastewater treatment plant outfall

The layer represents the distribution and intensity of the wastewater treatment plant outfall in the *Alcúdia* Bay. This layer represents the distribution and intensity for the associated pressures of organic matter input and microbial pathogen input. The input occurs via the outfall of the wastewater treatment, leading into the marine environment.



Data source: IDEIB viewer (<http://ideib.caib.es/visualitzador/visor.jsp>), based on the General Directorate of Emergencies (Department of Internal Affairs of the Government of the Balearic Islands)

Layer type: exponential decay function

Visualisation process:

We created a point at the end of the wastewater treatment plant outfall and used a decay function to model the spatial distribution and intensity for organ matter- and microbial pathogen input. Based on previous review about spatial extend of pressures (Ban *et al.*, 2010), we defined that the contribution of organic matter input of the wastewater treatment plant for the associated pressures dissipates to 10% within 10km and to 1% within 24km. Subsequently, the layer was rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2012

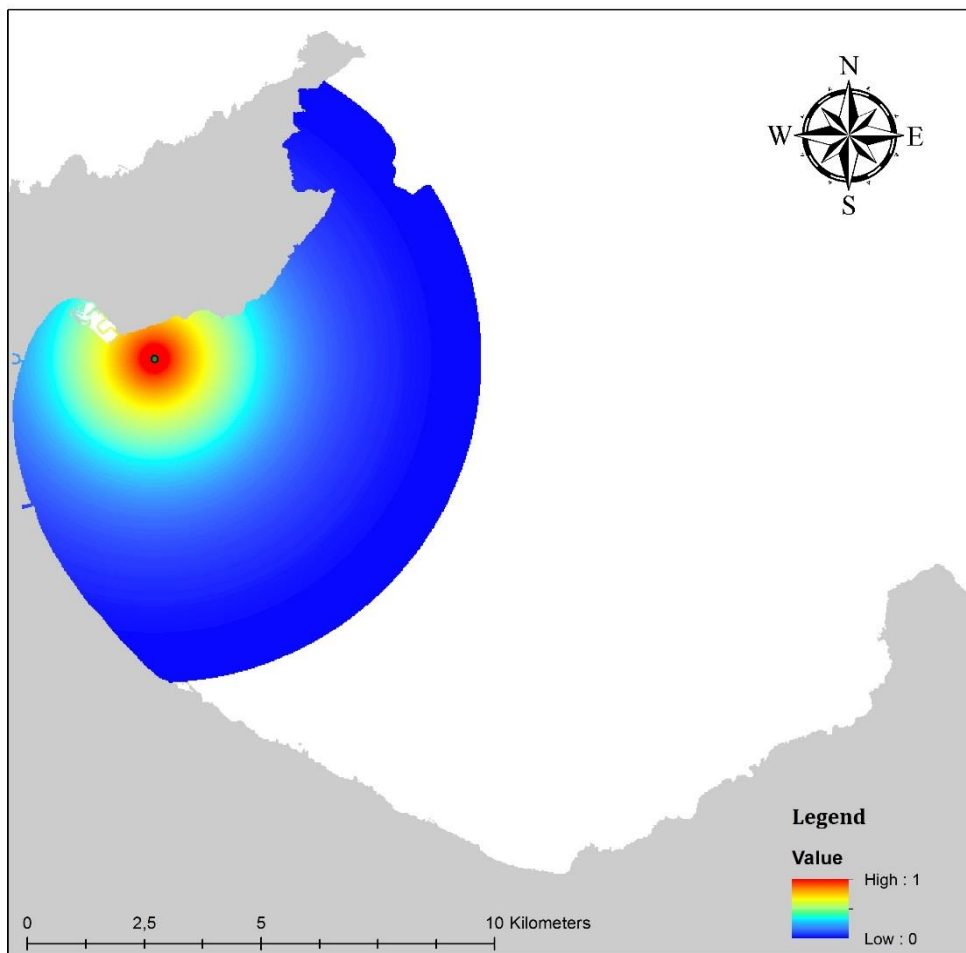
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: The point in the image simply represents the entry point of the pressure and is not included in the final pressure layer.



Coastal wastewater treatment plant outfall

The layer represents the distribution and intensity of the associated pressures of the wastewater treatment plant outfall in the *Alcúdia* Bay. This layer represents the distribution and intensity for the associated pressures of changes in salinity regime (due to freshwater input) and introduction of synthetic compounds (e.g. pharmaceuticals). The input occurs via the outfall of the wastewater treatment, leading into the marine environment.



Data source: IDEIB viewer (<http://ideib.caib.es/visualitzador/visor.jsp>), based on the General Directorate of Emergencies (Department of Internal Affairs of the Government of the Balearic Islands)

Layer type: exponential decay function

Visualisation process:

We created a point at the end of the wastewater treatment plant outtake and used a decay function to model the spatial distribution and intensity of the associated pressures. Following the same criteria as Allan *et al.* (2013), we defined that the contribution of freshwater input of the wastewater treatment plant into the marine environment dissipates to 10% within 3,5km and to 1% at 7km. Subsequently, the layer was rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2012

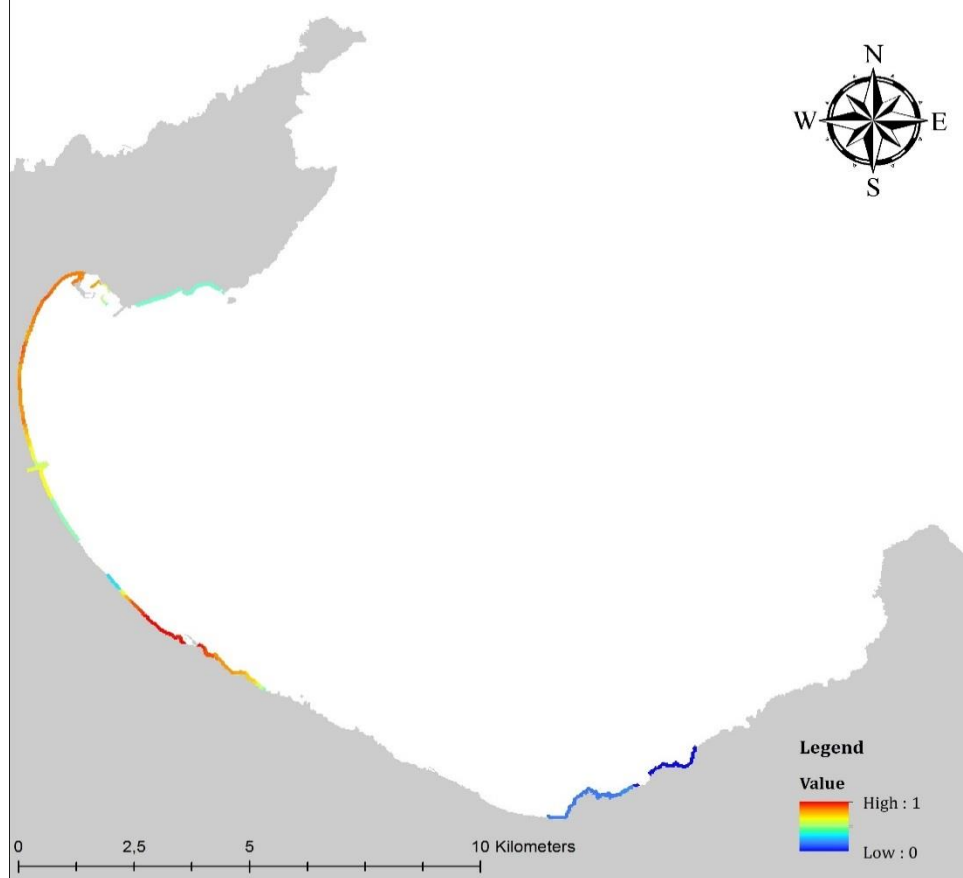
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: The point in the image simply represents the entry point of the pressure and is not included in the final pressure layer.



Beach zone activities

The layer represents the distribution and intensity of Beach zone activities in the *Alcúdia* Bay. The number of hotels in a 1km radius was used as an indicator, to represent this pressure and further projected onto the shoreline cells (plus 50 meter seawards). The associated pressure for beach zone activities is coastal abrasion.



Data source:

Catàleg Hosteleria, Conselleria de Turisme, Govern de les Illes Balears (Hotels Catalogue, Tourism Department, Government of the Balearic Islands)

Layer type: Buffer

Visualisation process:

The spatial location of the hotels was transferred to ArcGIS and represented as points. Additionally the number of hotel beds was included in the attribute table. A buffer of 1km was created around all points, containing the number of hotel beds. Buffer that overlapped were summed together, based on the number of hotel beds. Subsequently, buffers were projected on to the shoreline of the bay and a buffer of 50m was chosen to represent the distribution and intensity of the pressure. Finally, the values were $\log[x+1]$ transformed, normalized and rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2013

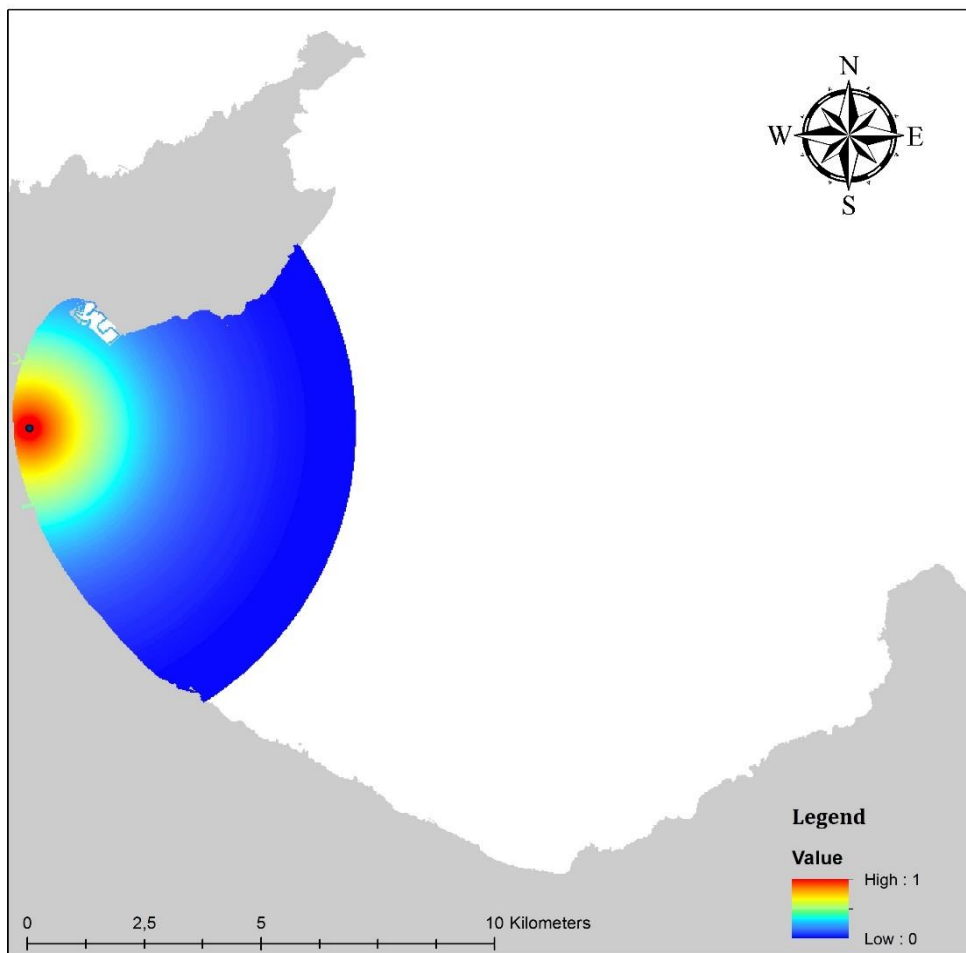
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Power plant intake

The layer represents the distribution and intensity of the associated pressure of changes in salinity regime, caused by the Murterar power plant in the *Alcúdia* Bay. The location of the intake pipe was used as an indicator, to represent this pressure. The intake pipe extracts seawater of the bay for cooling processes.



Data source: Govern des Illes Balears (Government of the Balearic Islands)

Layer type: exponential decay function

Visualisation process:

The location of the point where the intake pipe ended (and hence seawater was abstracted) was mapped as a point. Following the same criteria than Allan *et al.* (2013) we used a decay function to represent the influence of the water abstraction, and assumed that their influence decayed to 10% within 3,5 km and to 1% at 7km. Subsequently, the layer was rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2012

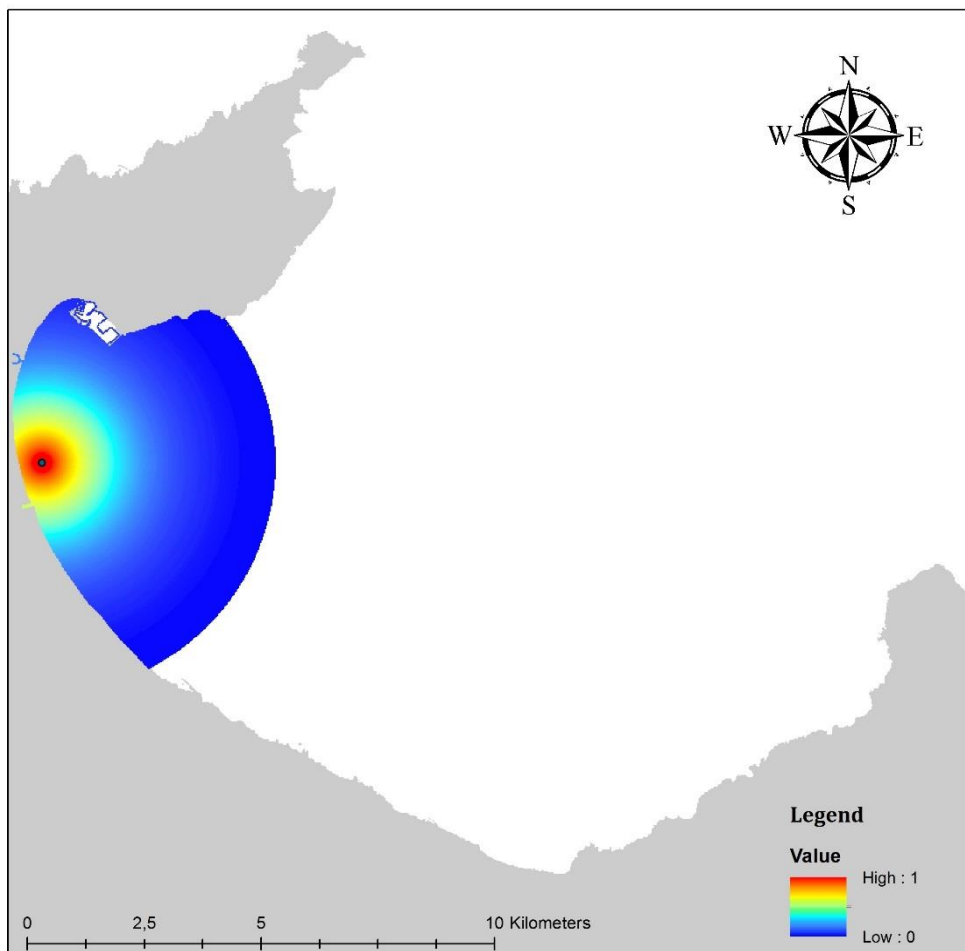
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: The Murterar power plant abstracted 660.000m³ of seawater in 2012 (CAIB, 2012). The point in the image simply represents the end of the intake pipe of the power plant and is not included in the final pressure layer.



Power plant outflow

The layer represents the distribution and intensity of the associated pressure of changes in thermal regime, caused by the Murterar power plant in the *Alcúdia* Bay. The location of the outtake pipe was used as an indicator, to represent this pressure. The outfall flushes warm water of the power plant, which is used for cooling processes, into the marine environment. The influence of the introduction of significant warmer water can cause negative impacts on the marine environment.



Data source: Govern de les Illes Balears (Government of the Balearic Islands)

Layer type: exponential decay function

Visualisation process:

In order to map the intensity and distribution of the changes in thermal regime by the power plant, the location of the outfall was chosen. Following the same criteria than Halpern *et al.* (2009) we used a decay function to represent the influence of the pressure. We defined that the contribution of warm water outflow of the power plant dissipates to 10% within 2,5km and to 1% within 5km. Subsequently, the layer was rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2012

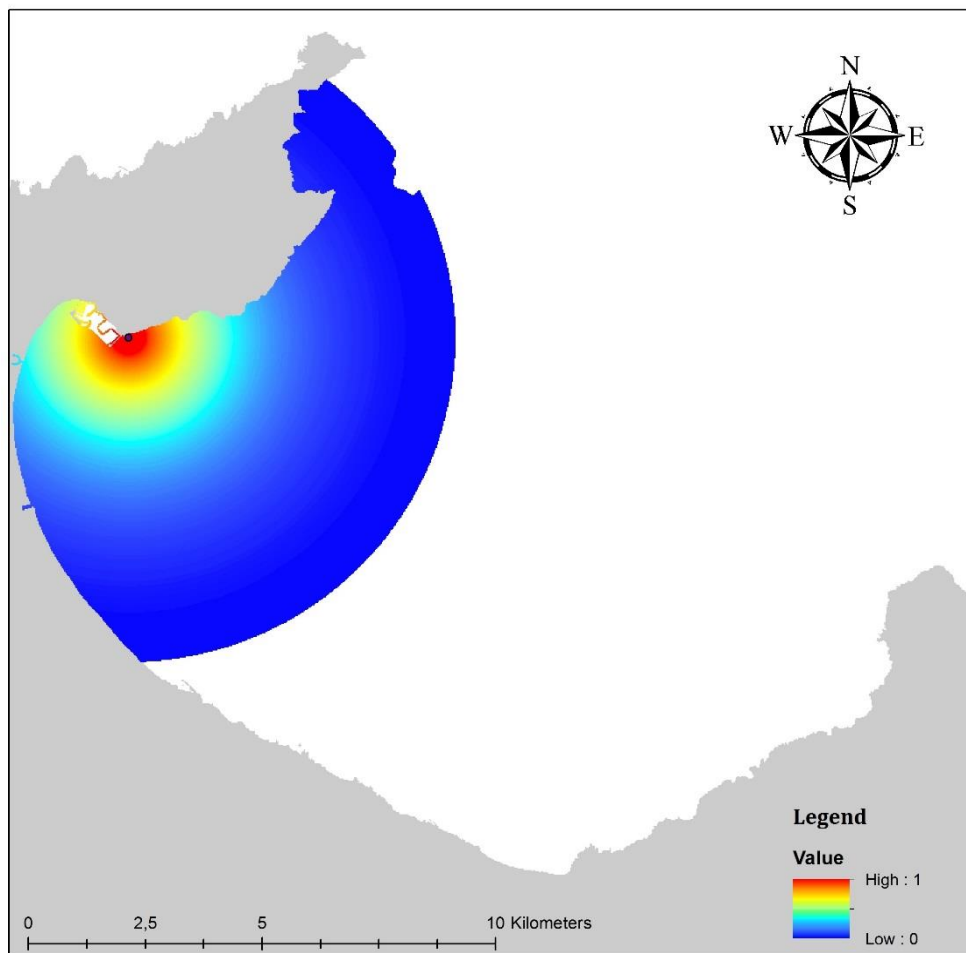
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: The Murterar station has an annually discharge of 550Hm³ (CAIB, 2012), leading into the marine environment. The point in the image simply represents the end of the outtake pipe of the power plant and is not included in the final pressure layer.



Desalination plant intake

The layer represents the distribution and intensity of the associated pressure of changes in the salinity regime, caused by the desalination plant in the *Alcúdia* Bay. The location of the intake pipe was used as an indicator, to represent this pressure. The intake extracts saltwater from the sea, which is used for desalination processes.



Data source: City council in the municipality of *Alcúdia*, obtained by an interview

Layer type: exponential decay function

Visualisation process:

The location of the point where the intake pipe ended (and hence seawater was abstracted) was mapped as a point. Following the same criteria than Allan *et al.* (2013) we used a decay function to represent the influence of the water abstraction, and assumed that their influence decayed to 10% within 3,5km and to 1% at 7km. Subsequently, the layer was rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2005

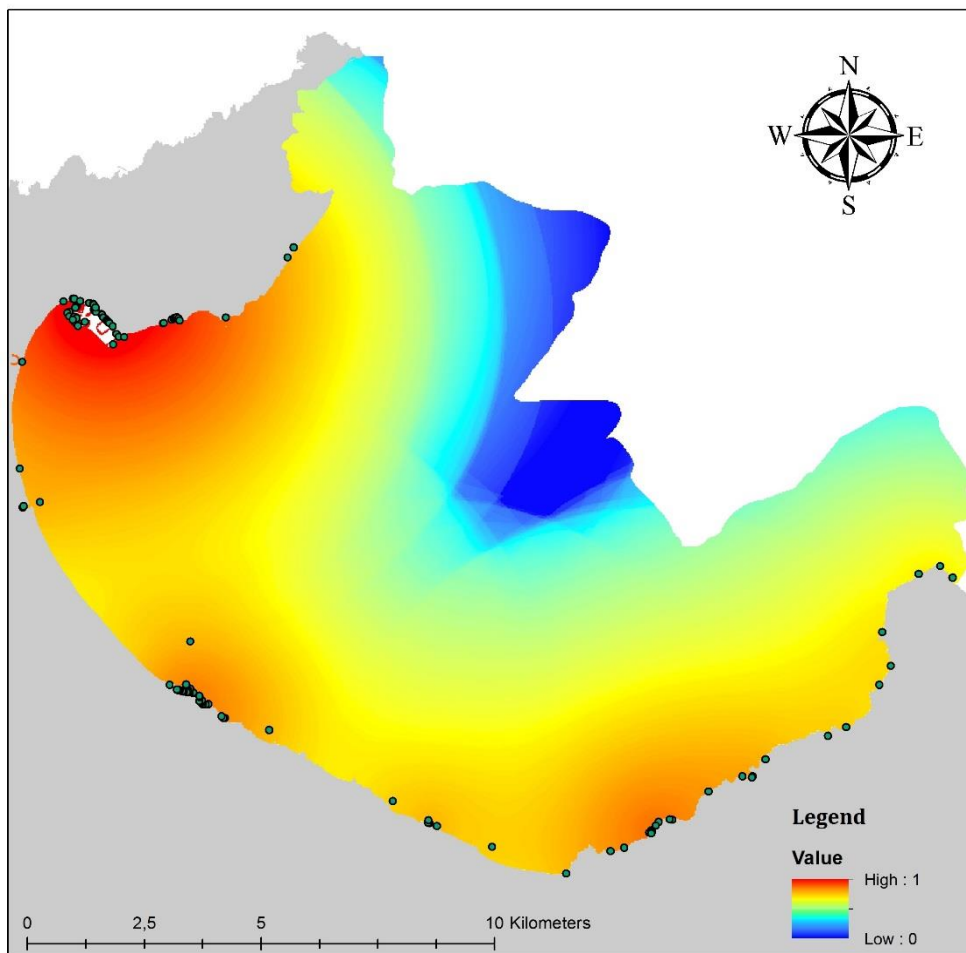
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: The desalination plant has a daily outflow of 85.600m^3 (Agencia Estatal Boletín Oficial del Estado, 2005a) and an intake volume of 31.111 to 46.667m^3 85.600m^3 per day outflow (Agencia Estatal Boletín Oficial del Estado, 2005b), intake: 31.111 to 46.667 m^3 per day. The outfall pipe is located at 5,5m depth and flushes brackish water into the marine environment ($0,0192\text{m}^3/\text{sec}$) (Agencia Estatal Boletín Oficial del Estado, 2005a). The point in the image simply represents the end of the intake pipe of the desalination plant and is not included in the final pressure layer.



Urban outfalls

The layer represents the distribution and intensity of associated pressures of urban outfalls leading into the *Alcúdia* Bay. The location of the outfalls was used as an indicator, to represent these pressure. The outfalls are a potential source of changes in salinity regime (due to freshwater input). In addition to that, urban outfalls potentially represent a source of synthetic compounds, which can include oil and grease compounds, and input of microbial pathogens.



Data source: IDEIB viewer (<http://ideib.caib.es/visualitzador/visor.jsp>), based on the General Directorate of Emergencies (Department of Internal Affairs of the Government of the Balearic Islands)

Layer type: exponential decay function

Visualisation process:

We created a point at the end of each urban outfall pipes that lead into the bay and used a decay function to represent the distribution and intensity of associated pressures into the marine environment. Following the same criteria as Allan et al. (2013), we assumed that the distribution and intensity decayed to 10% within 3,5km and to 1% at 7km. Subsequently, the layer was rasterized

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2012

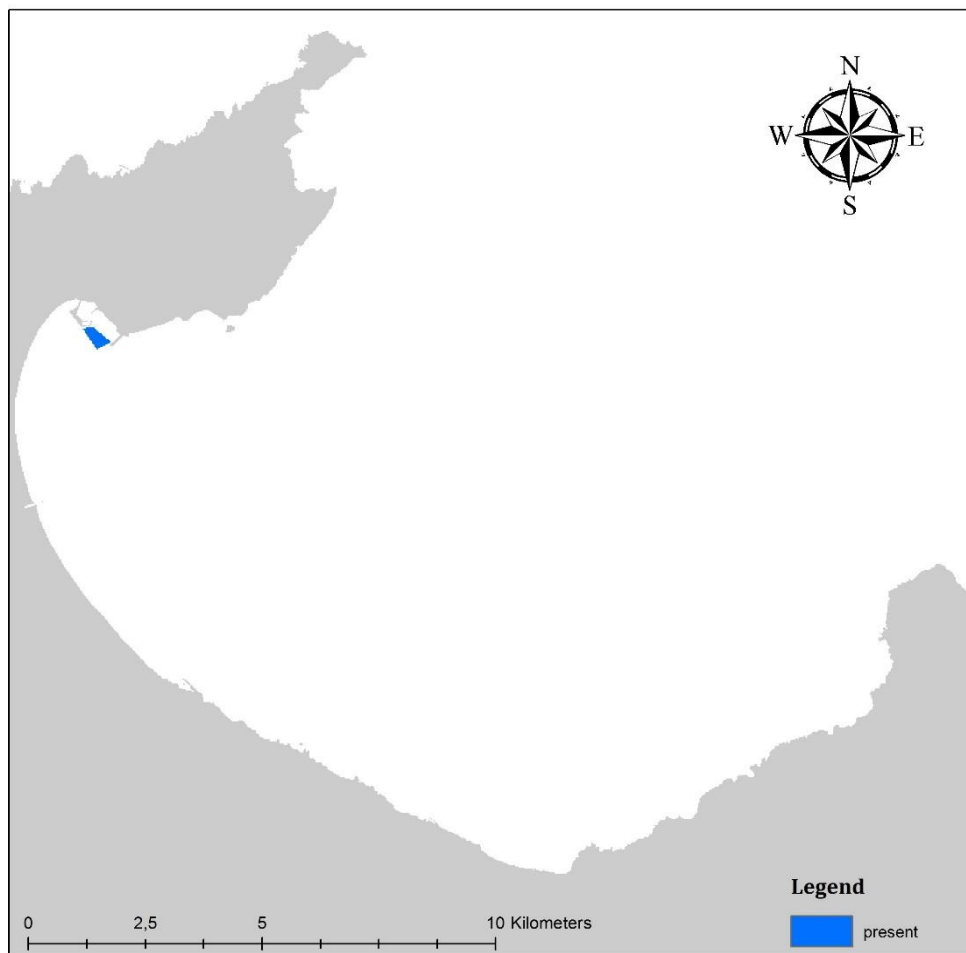
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: The points in the image simply represents the locations of urban outfalls and are not included in the final pressure layer.



Dredging

The layer represents the distribution of relevant dredging location in the *Alcúdia* Bay. Dredging is a potential source of smothering and selective extraction of non-living resources.



Data source: Puertos del Estado (national port authority)

Layer type: presence/absence

Visualisation process:

Spatial polygons were used to indicate the location of the dredging site and subsequently rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2013

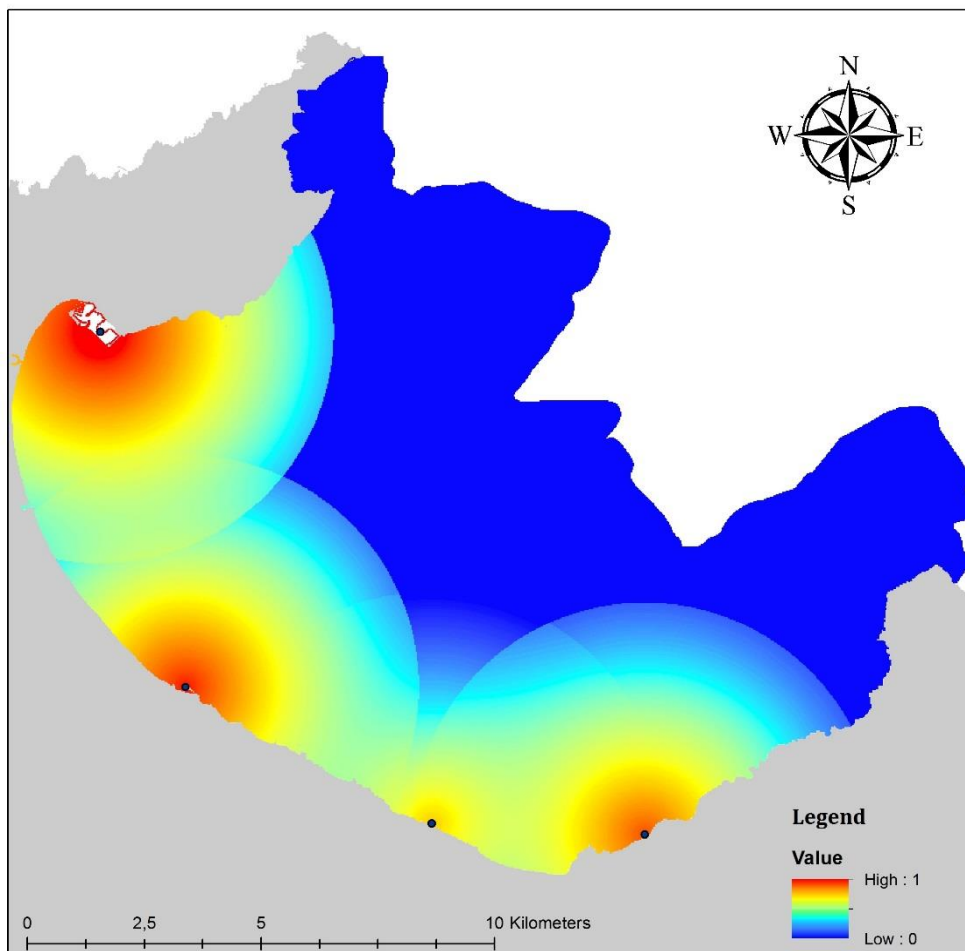
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Harbours

The layer represents the distribution and intensity of associated pressures of harbours in the *Alcúdia* Bay. Harbours present a source of the introduction of synthetic (e.g. antifoulants) and non-synthetic compounds (e.g. heavy metals, hydrocarbons). Harbour discharges may contain hazardous substances and can represent a source of oil pollution, tributyltin (TBT) and other substances (Korpinen et al., 2012).



Data source: Interviews with relevant harbour authorities; SOCIB viewer (<http://gis.socib.es/sacosta/composer>); IDEIB viewer (<http://ideib.caib.es/visualitzador/visor.jsp>), based on conventional cartography of the coasts of the Balearic Islands and from information of the Regional- and National Agency for port management), field survey and use of guide and port-books of the Balearic Islands (Hutt, 2006) for marinas.

Layer type: exponential decay function

Visualisation process: Harbours were weighted by their number of moorings to represent the size of each harbour. We combined the amount of moorings of the commercial, recreational and fishery harbour of Alcúdia into a single point and created 3 additional points for the other 3 recreational harbours that are present in the bay. We used an exponential decay function to model their spatial influence. We assumed the influence to dissipate to 10% within 2.5 km and to 1% within 5 km (Allan et al., 2013). Subsequently, the layer was rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2013

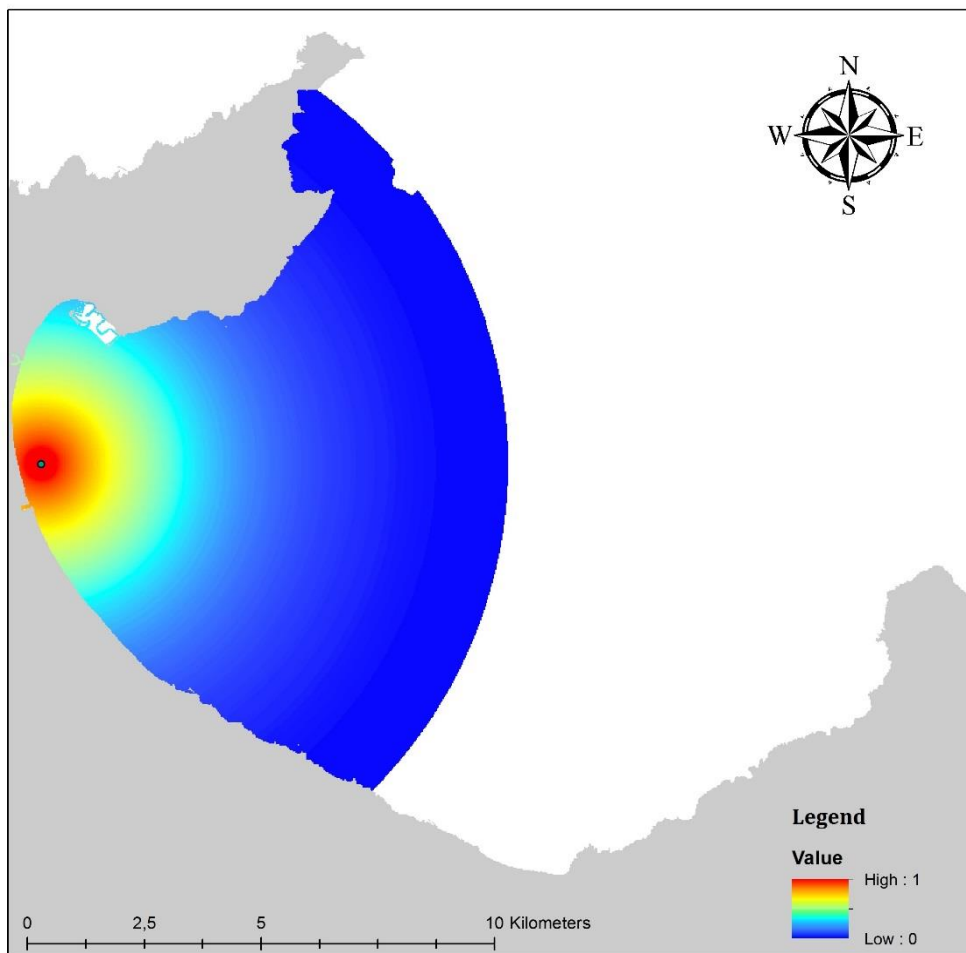
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: The points in the image simply represent each harbour and are not included in the final pressure layer.



Fish farm outfall

The layer represents the distribution and intensity of associated pressures of the land-based fish farm in the *Alcúdia* Bay. Fish farms are potential sources for the introduction of organic matter and microbial pathogens.



Data source: Council of Fisheries of the Government of Balearic Islands (Fisheries Local Administration).

Layer type: exponential decay function

Visualisation process:

We mapped the end point of the outfall as a point. According to Allan et al. (2013) the influence of organic matter decayed to 10% at 5km and to 1% at 10km, however the project considered water-based installations. Due to data gaps, we used the same decay function values, even though the influence in our case derived from a land-based fish farm installation. Subsequently, the layer was rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2013

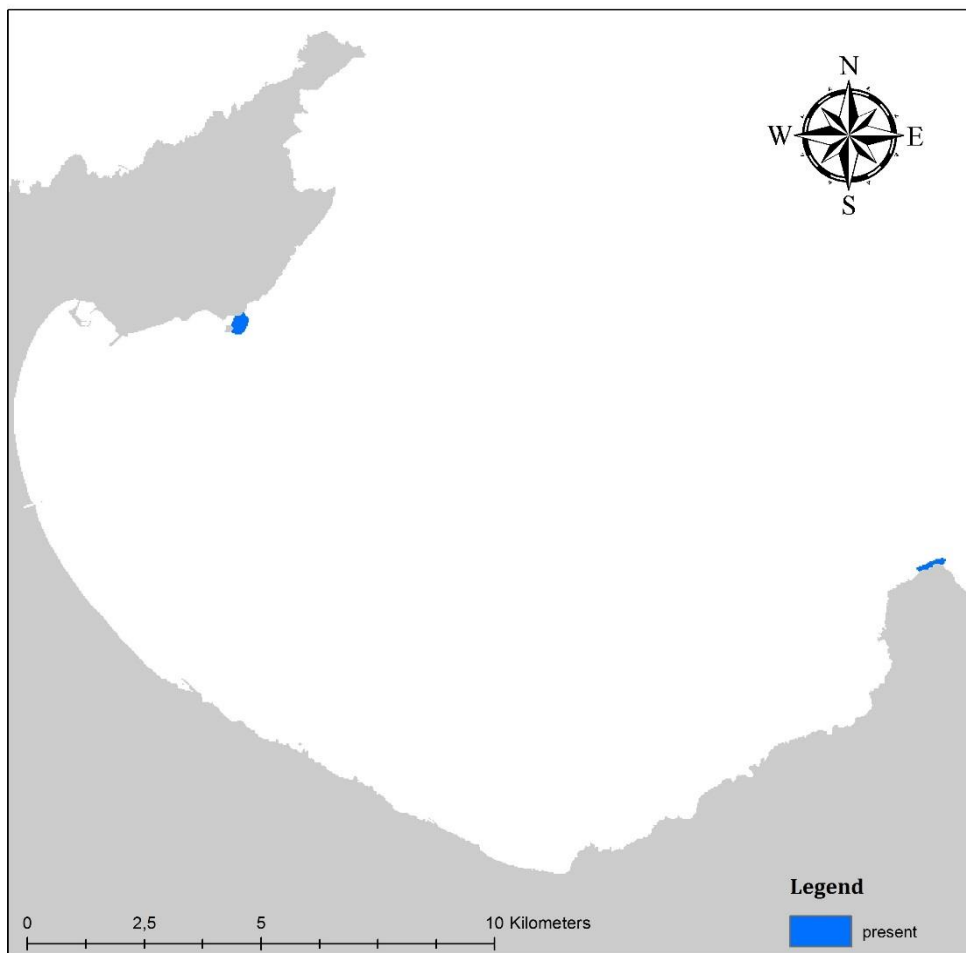
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: The point in the image simply represents the end of the outfall pipe leading into the marine environment and is not included in the final pressure layer.



Moruna nets (artisanal fishery)

The layer represents the distribution and intensity of the associated pressure of selective extraction of species caused by moruna nets in the *Alcúdia* Bay. These nets are used by the artisanal fishery sector and present a pressure to the marine environment



Data source: Email contact with an regional expert

Layer type: presence/absence

Visualisation process:

We drew spatial polygons on the relevant locations. Subsequently, the polygons were rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2013

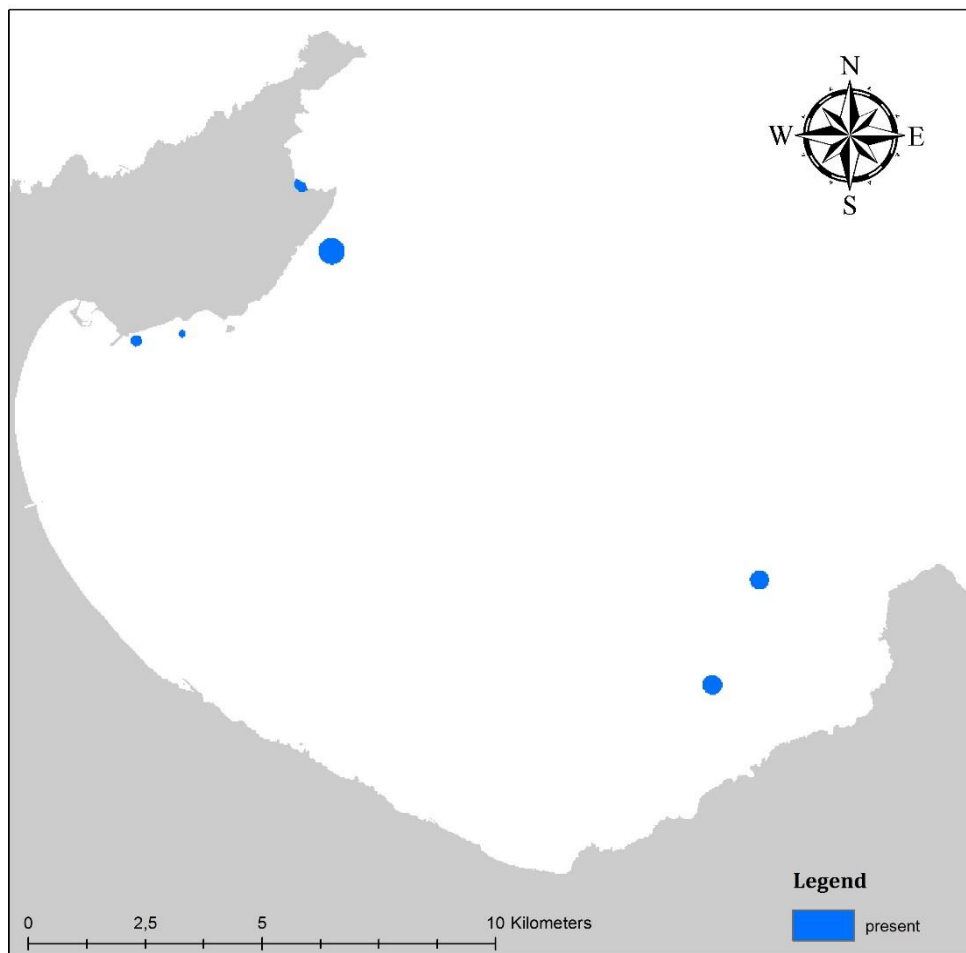
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Trammel nets (artisanal fishery)

The layer represents the distribution and intensity of the associated pressure of selective extraction of species caused by trammel nets in the *Alcúdia* Bay. These nets are used by the artisanal fishery sector and present a pressure to the marine environment



Data source: Email contact with an regional expert; Literature (Gazo et al., 2008)

Layer type: presence/absence

Visualisation process:

We drew spatial polygons on the relevant locations. Subsequently, the polygons were rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

Time period covered: 2013

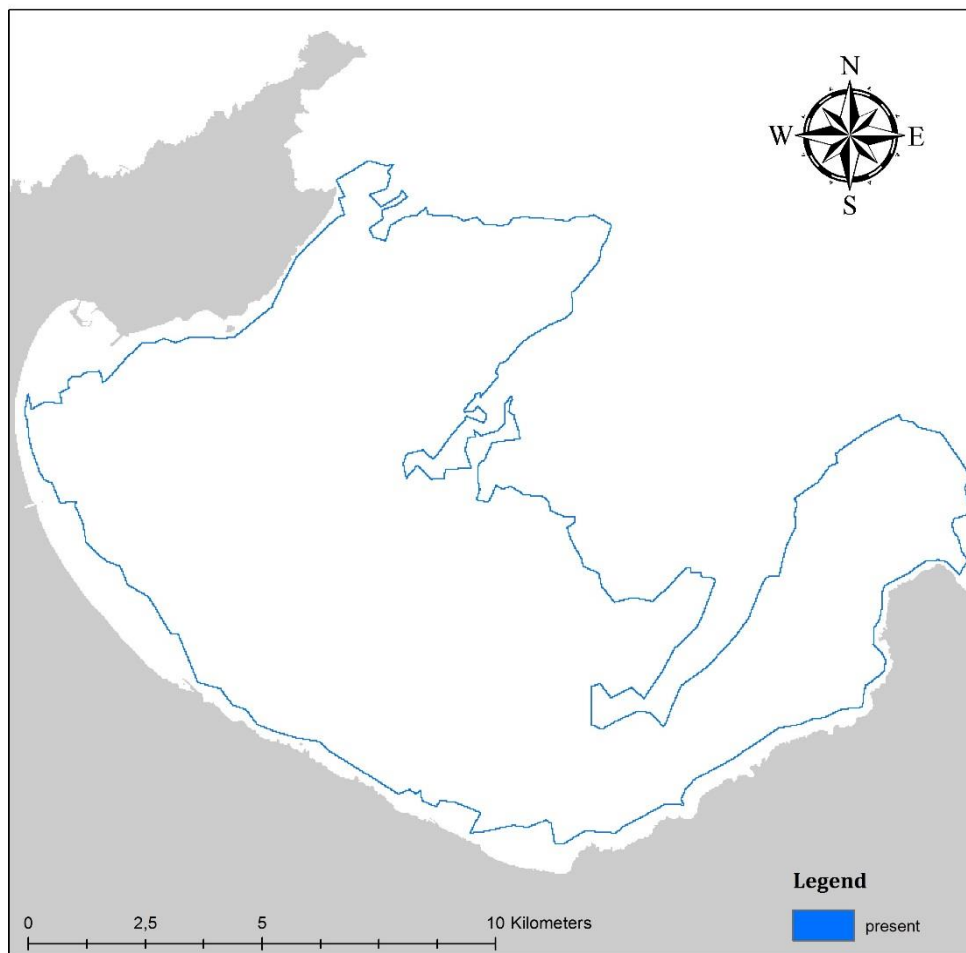
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none



Squid fishing (artisanal fishery)

The layer represents the distribution and intensity of the associated pressure of selective extraction of species caused by squid fishing in the *Alcúdia* Bay. Squid is a targeted species by the artisanal fishery sector and present a pressure to the marine environment



Data source: Email contact with an regional expert; Gazo et al., 2008

Layer type: presence/absence

Visualisation process:

We drew a spatial line around *Posidonia oceanic* meadows. Subsequently, the polygons were rasterized.

Coordinate system: Projected coordinate system (WGS 1984 UTM Zone 31N)

Resolution: 25 meter cell size

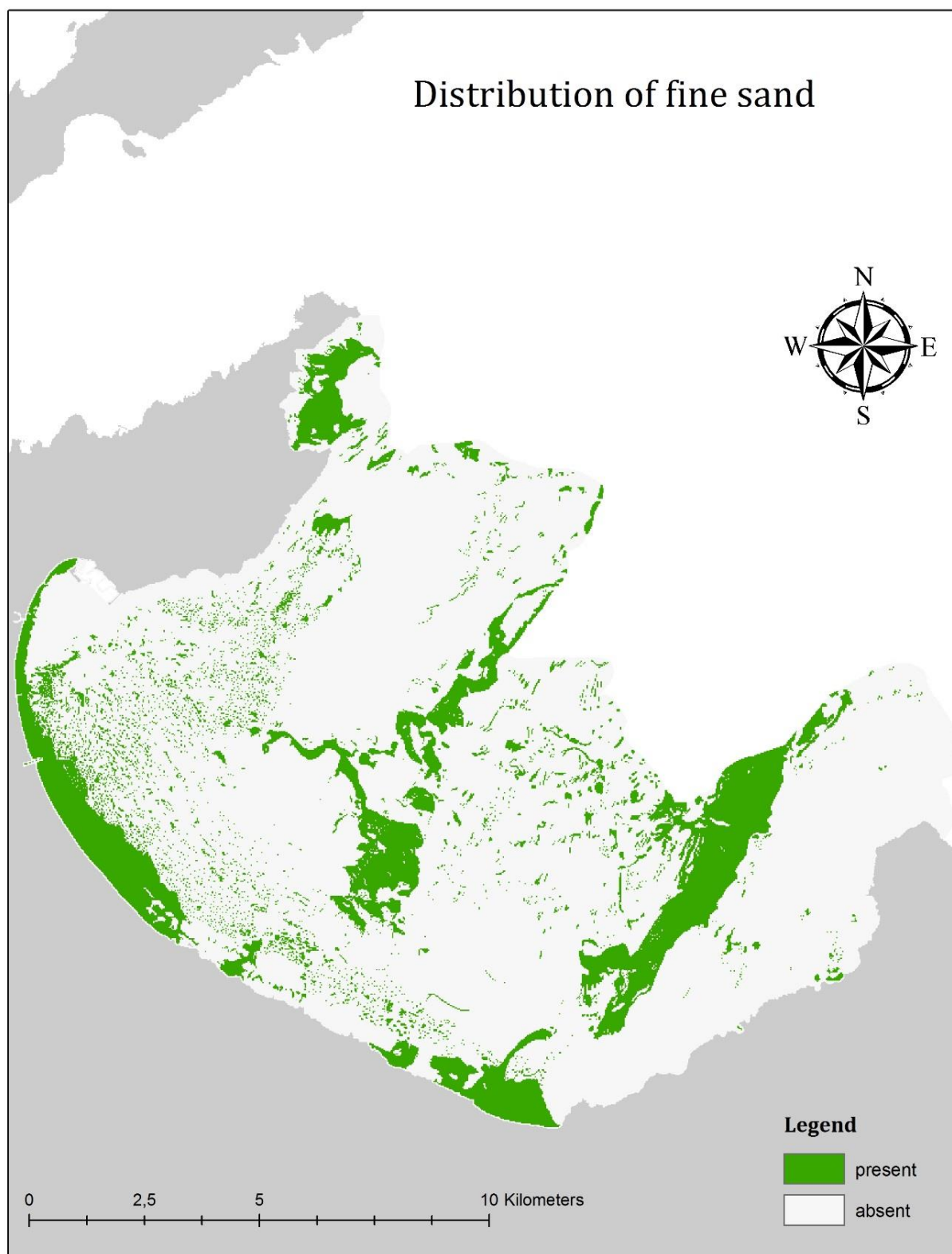
Time period covered: 2013

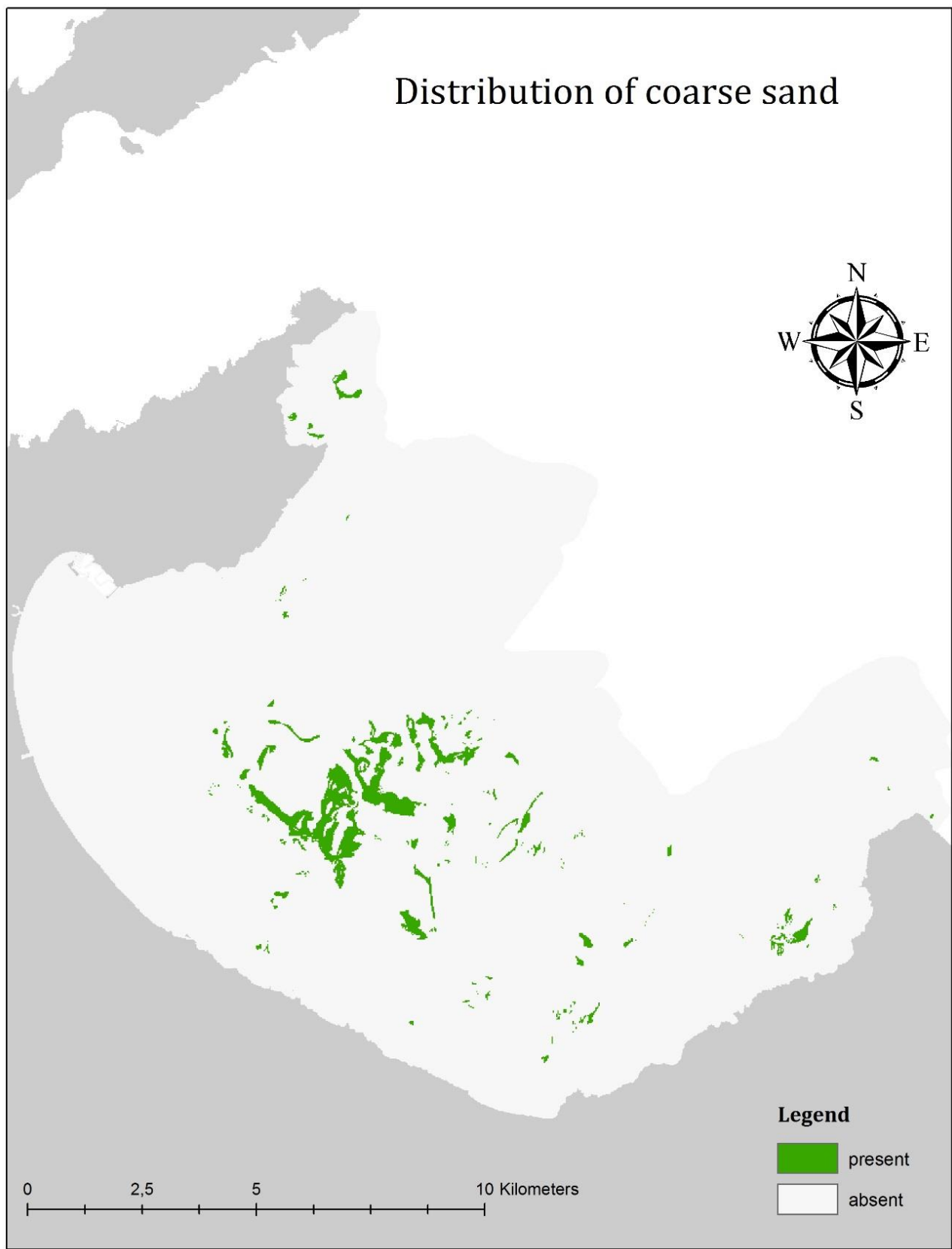
Data available at: The Balearic Islands Coastal Observing and Forecasting System (SOCIB)

Additional information: none

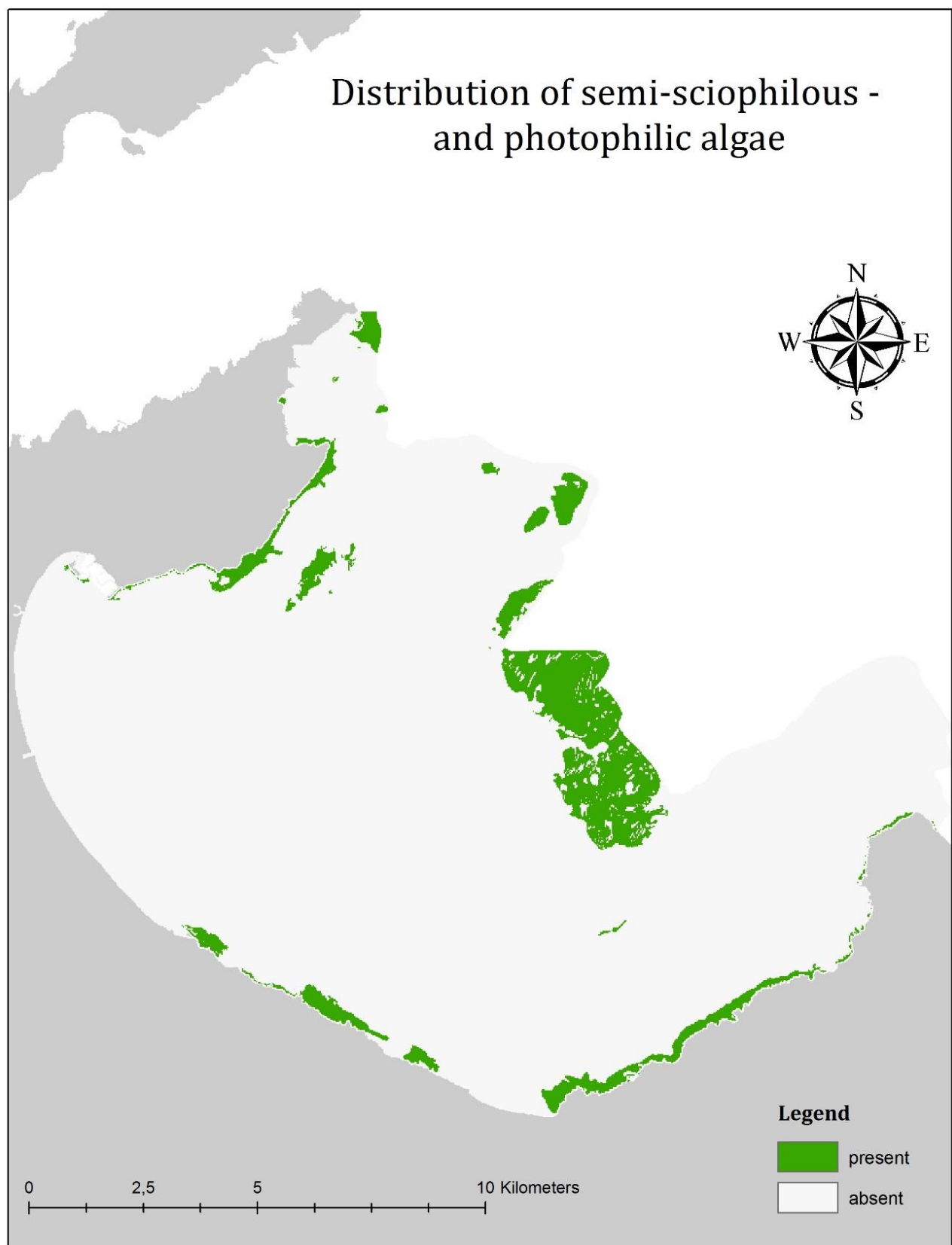


Appendix III: Distribution of the single ecosystem categories

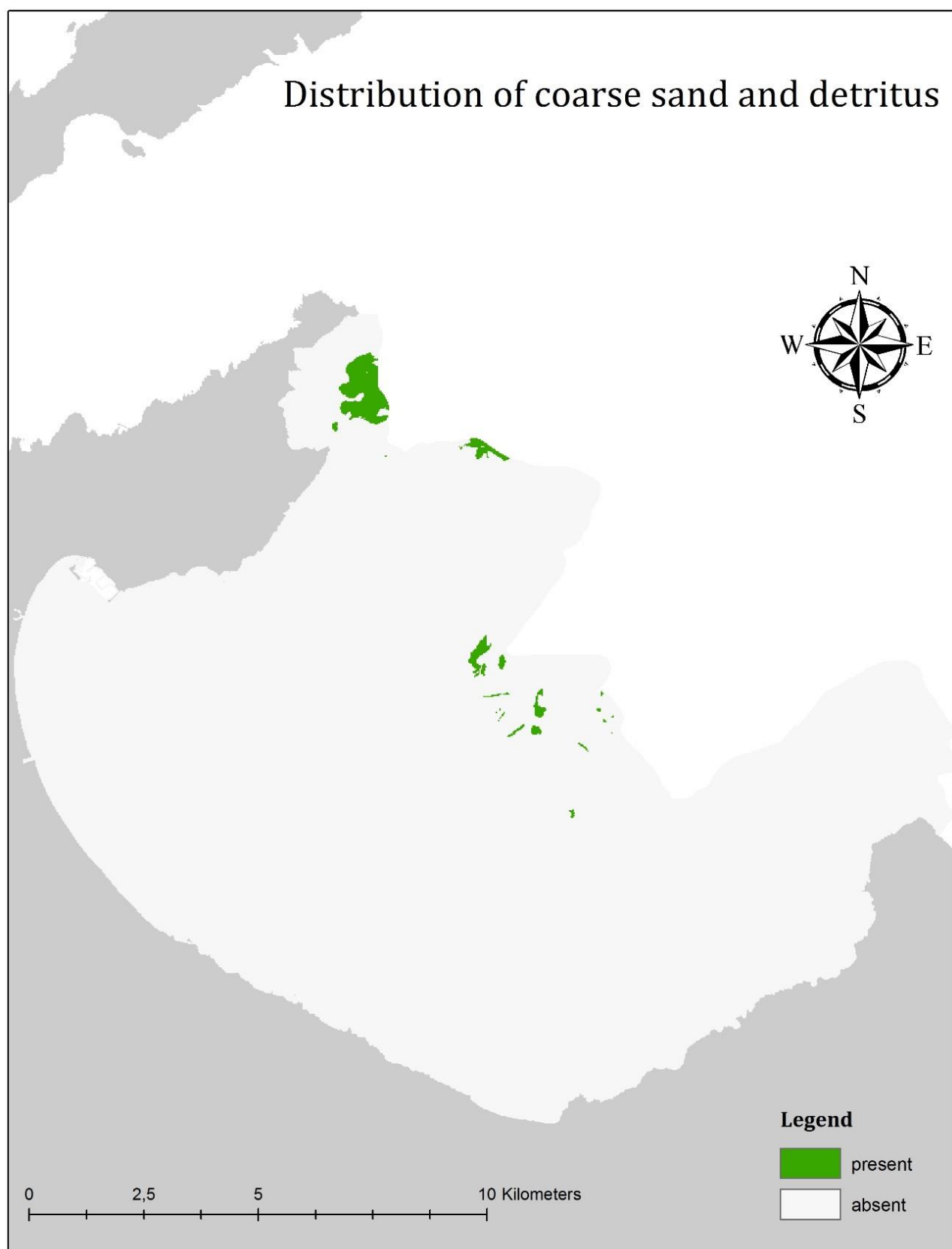






















Appendix IV: Questionnaire

Instructions for contributing information to the Ecosystem vulnerability matrix

This project, “**cumulative pressures on the ecosystems in the Alcúdia bay**” is designed spatially visualize cumulative anthropogenic pressures within the *Alcúdia* bay, on Majorca, Spain. The project is done on behalf of Balearic Islands Coastal Observing and Forecasting System (SOCIB), and being conducted by two ICZM (Integrated Coastal Zone Management) students as part of a bachelor thesis. For the project, we focus on present-day human influences on particular ecosystems and therefore ask you to think about effects as they are manifested today, rather than their projected effects in the future.

The survey includes two parts:

First, we will ask about your background, experience and training;

Second, based upon your expertise, we will ask you to fill in scores for the vulnerability factors and certainty values for each ecosystem-pressure combination.

Concepts and terms will be explained and an **included table** offers extended information about the pressure types which are considered in the project (table at the end of the document: “*Extended explanations for the pressure types*”). However, if you need additional information, please feel free to ask any clarifying question via e-mail.

The judgment you are asked to provide does not include right or wrong ones, but rather asks you to express your personal experience and knowledge about the relative vulnerability. To do so, we will ask you to relate one of the pre-defined values for the different **vulnerability factors** to each of the ecosystem-pressure combinations (see document “Questionnaire”).

The survey should take you about 30-45 minutes to complete. All answers will be used confidentially.

The results of this study will be freely available from SOCIB in an anonymized way. We kindly ask you to return the questionnaire per mail to one of the mail addresses, provided below.

We hope you understand our dependence on your knowledge as a marine scientist or ecosystem expert to develop this dataset and we will be very thankful if you are interested to support our project.

We thank you in advance for your time and assistance.

If you have any further questions or citations for publications, supporting documents, datasets, or websites that you can provide to this project please contact us via max.siegfried@wur.nl (Max Siegfried) or raissa.borgmann@wur.nl (Raissa Borgmann).



Estimating the intensity of anthropogenic pressures to ecosystems

You are asked to weight the relative vulnerability of a particular **ecosystem** to different kinds of anthropogenic **pressures** with help of pre-defined scores. In all cases, please use your best judgment, drawing on published and unpublished empirical data, experiments, reviews, and personal field experience to assess the relative vulnerability of a particular ecosystem.

If a pressure does not seem apply to the ecosystem you are judging, you should still fill out the vulnerability- and certainty score. If you are unable to score a particular factor, (due to data gaps or uncertainty) please choose certainty = 0 (“None”).

Please rate each of the following **vulnerability factors** using the guidelines provided below.

Vulnerability factors

We see vulnerability (in relative terms) as a combination of multiple factors that ultimately affect the intensity of anthropogenic pressure on an ecosystem. In the questionnaire we ask you to judge: 1) the **extent of the pressure** in a given ecosystem, 2) the **resistance** of the ecosystem to disturbance by the particular pressure and 3) its **resilience** or recovery time following such a disturbance. Therefore we have set a quantitative scale for each of these factors. We also include a measure of 4) **certainty** that allows you to quantify your rankings with the level of confidence you have in your responses. The 4 factors, and the individual scale for each factor, are defined and discussed in more detail below.

Vulnerability factors explanation

(1) Extend of the pressure

The *Extend of the pressure* scale measures the quantity of affected trophic levels by an anthropogenic pressure. The score to evaluate this can be composed as shown in the example below.

- Extend of the pressure: 0 = not available (no impact or positive)
1 = Species (single or multiple)
2 = Single trophic level
3 = > 1 trophic level
4 = Entire community, including habitat structure



(2) Resistance

The *Resistance* scale measures the qualitative tendency of an ecosystem to **resist against a pressure** and persist in its natural conditions. The *Resistance* will be measured with the following scale.

Resistance to pressure: 0 = not available (No impact or positive)
1 = High
2 = Medium
3 = Low
4 = vulnerable

(3) Resilience

The *Resilience* score measures the temporal scale, which an ecosystem (or its affected aspects) needs to recover from the anthropogenic pressure, following its removal. Considering that ecosystems and populations are dynamic in nature, it is quite unlikely that they return to the same condition they had previous to the disturbance. Therefore, in this case the time an ecosystem needs to recover is to be seen as the recovery time following the removal of the pressure. The *Resilience* is scored like on the following scale.

Recovery time: 0 = not available (No impact or positive)
1 = < 1 year
2 = 1-10 years
3 = 10-100 years
4 = > 100 years

Certainty

The *Certainty* score does not attend to measure any part of an ecosystem-pressure combination. In fact, it is more related to the quality of the source which is used to evaluate the single values of the five factors described before. That means, *Certainty* displays how “reliable” the judged rankings are, regarding each of the three vulnerability factors. If a person is recognized as an marine scientist/ecosystem expert in the field of interest, including a lot of field work in the associated area, the value of *Certainty* should be high (4 = very high certainty). If an interviewee has less background, the *Certainty* value should be a lower one (e.g. 1 = low). Literature-based results are peer reviewed and indicate high certainty (3 = high), and when being additionally linked with personal experience in the area, the certainty value can be regarded as very high (4).



Therefore, it is important to consider both literature as well as personal experience in order to develop a reliable vulnerability score. The ranking of the *Certainty* is as follows.

Certainty:

- 0 = None
- 1 = Low
- 2 = Medium
- 3 = High
- 4 = Very high

Extended explanations for the pressure types

The following table displays the relevant activities which are associated for each pressure and therefore should be considered while assigning the weights in the questionnaire. Note that the pressure types and categories, except for environmental pressures, are based on the Marine Strategy Framework Directive.

Table A IV: Table of relevant MSFD pressure categories and types and their related activities assessed for the study site.

Category	Pressure Types	Factors and activities involved in the project
<u>Physical loss</u>	Smothering	- dredging sites
	Sealing	- Permanent constructions like artificial coastal structures (including harbours, defence structures, rip raps), land-based structures leading into the marine environment (i.e. Outfalls pipes) and breakwater structures (i.e. jetties)
<u>Physical damage</u>	Abrasion	- Anchoring,
	Selective extraction	- exploration and exploitation of living and non-living resources on seabed and subsoil caused by dredging
	Coastal abrasion	- General beach zone activities
<u>Other physical disturbance</u>	Underwater noise	- Sea traffic (e.g. daily excursions with Catamarans or Glass-bottom boats, Ferries, commercial transport vessels, recreational sea traffic etc.),
<u>Interference with hydrological processes</u>	Significant changes in thermal regime	- Outflow of the power plant cooling installation
	Significant changes in salinity regime	- Water abstraction (includes: intake of saltwater to the power plant, intake of saltwater to the desalination plant)



		- Outfall of wastewater treatment plant and urban outfalls (freshwater input into the marine environment)
<u>Contamination by hazardous substances</u>	Introduction of synthetic compounds (e.g. pesticides, antifoulants, pharmaceuticals)	- Harbours (includes the commercial and recreational harbours), the outfall of the wastewater treatment plant and urban outfalls
	Introduction of non-synthetic substances and compounds (e.g. heavy metals, hydrocarbons)	- Harbours (includes the commercial and recreational harbours),
<u>Nutrient and organic matter enrichment</u>	Inputs of fertilizers and other nitrogen and phosphorus-rich substances	- Agriculture,
	Inputs of organic matter	- Outfall of land based fish farm, outfall of wastewater treatment plant
<u>Biological disturbance</u>	Introduction of microbial pathogens	- Urban outfalls of the streets, wastewater treatment plant outfall and the outfall of the land-based fish farm
	Selective extraction of species due to recreational fishery	- Shore, boat and spear gun recreational fishing
	Selective extraction of species due to artisanal fishery	- practiced with trammel nets, moruna nets and squid fishing
	Disturbance in wildlife behavior	- Water sport activities like wind-, wave- and kite surfing, kayaking, diving, snorkelling
<u>Environmental pressures</u>	Climate change	- please consider sea-level rise, sea-temperature rise and ocean acidification



EXAMPLE - for the evaluation of the vulnerability

The example outlines a possibility, how to mark the values you will assess for the single scores for one ecosystem to one pressure combination (in this case the pressure of **smothering** on *Posidonia oceanica*). Thereby, please use the word document we send to you for filling in the values by using the “text highlight color”

tool function  of the program.

Ecosystem Type: POSIDONIA OCEANICA	Physical	
	Pressure	Smothering
Factors (f) of Vulnerability score	Choose Value for each factor (f)	
Extent of impact 0 = not available (no impact or positive) 1 = Species (single or multiple) 2 = Single trophic level 3 = >1 trophic level 4 = Entire community, including habitat structure	0 1 2 3 4	
Resistance 0 = not available (no impact or positive) 1 = High 2 = Medium 3 = Low 4 = vulnerable	0 1 2 3 4	
Resilience 0 = not available (no impact or positive) 1 = <1 year 2 = 1-10 years 3 = 10-100 years 4 = >100 years	0 1 2 3 4	
Certainty 0 = None 1 = Low 2 = Medium 3 = High 4 = Very high	0 1 2 3 4	



Questionnaire per ecosystem

■ Background, experience and training

Name:

Email address:

Main affiliation:

Other affiliations:

Type of position (please check one of the following):

- | | |
|--|--|
| <input type="checkbox"/> Academic agency | <input type="checkbox"/> Autonomic regional government |
| <input type="checkbox"/> Non-governmental organization | <input type="checkbox"/> Municipality |
| <input type="checkbox"/> University | |

Age:

Highest degree earned:

Year of degree:

Years of expertise in the study site or closest environments (i.e. Alcúdia Bay or Balearic Island in general):

Evaluation of the vulnerability

After you have read the background information and survey instructions (attached on the e-mail), we now ask you to fill in the following scores for a certain ecosystem in regard to all pressure combinations, based on your personal knowledge and experience. While filling in the scores, we advise to use the supplementary table which is extra attached on the email and provides extended explanation for each pressure type.

The ecosystem we want you to consider is already filled in and highlighted in the upper left corner of the table ("Ecosystem Type"). To express your judgement, please use this Word document and mark the values you want to assign (e.g. yellow colour / print, fill in and scan). Thereby, please remember to express also your level of certainty per pressure-ecosystem combination.

(If needed, please check the example, which is also attached on the e-mail, before you start!)



Ecosystem Type:	Pressure	Physical loss		Physical damage			Other physical disturbance	Interference with hydrological processes	
		Smothering	Sealing	abrasion	selective extraction	Coastal abrasion	Underwater noise	Significant changes in thermal regime	Significant changes in salinity regime
Factors (f) of Vulnerability score		Choose Value for each factor (f)	Choose Value for each factor (f)	Choose Value for each factor (f)	Choose Value for each factor (f)	Choose Value for each factor (f)	Choose Value for each factor (f)	Choose Value for each factor (f)	Chose Value for each factor (f)
Extent of impact 0 = not available (no impact or positive) 1 = Species (single or multiple) 2 = Single trophic level 3 = >1 trophic level 4 = Entire community, including habitat structure		0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
Resistance 0 = not available (no impact or positive) 1 = High 2 = Medium 3 = Low 4 = vulnerable		0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
Resilience 0= not available (no impact or positive) 1 = <1 year 2 = 1-10 years 3 = 10-100 years 4 = >100 years		0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
Certainty 0 = None 1 = Low 2 = Medium 3 = High 4 = Very high		0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4



<div>Contamination by hazardous substances</div> <div>Nutrient and organic matter enrichment</div> <div>Biological disturbance</div> <div>Environmental pressures</div>										
	Pressure	Introduction of synthetic compounds	Introduction of non-synthetic substances and compounds	Inputs of fertilizers and other nitrogen and phosphorus-rich substances	Inputs of organic matter	Introduction of microbial pathogens	Selective extraction of species due to recreational fishery	Selective extraction of species due to artisanal fishery	Disturbance in wildlife behavior	Climate change
Factors (f) of Vulnerability score	Choose Value for each factor (f)	Choose Value for each factor (f)	Choose Value for each factor (f)	Choose Value for each factor (f)	Choose Value for each factor (f)	Choose Value for each factor (f)	Choose Value for each factor (f)	Choose Value for each factor (f)	Choose Value for each factor (f)	Chose Value for each factor (f)
Extent of impact	0 = not available (no impact or positive) 1 = Species (single or multiple) 2 = Single trophic level 3 = >1 trophic level 4 = Entire community, including habitat structure	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
Resistance	0 = not available (no impact or positive) 1 = High 2 = Medium 3 = Low	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
Resilience	0= not available (no impact or positive) 1 = <1 year 2 = 1-10 years 3 = 10-100 years 4 = >100 years	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
Certainty	0 = None 1 = Low 2 = Medium 3 = High 4 = Very high	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4