Supporting **I**mplementation of **M**aritime Spatial Planning in the **Celt**ic Seas

Component: 1.2.4. Establishing case studies on Approaches to MSP implementation – CS#2 Assessment of cumulative impact in the Celtic Sea

Deliverable: D11 – Mapping risk of cumulative effects – Recommendations from the approach tested within French Celtic Sea waters.

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PU	Public	**X**
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About SIMCelt

The SIMCelt Project SIMCelt - Supporting Implementation of Maritime Spatial Planning in the Celtic Seas is a two-year €1.8 million project co-financed by DG MARE and focussed on promoting the development of transnational cooperation to support the implementation of Directive 2014/89/EU in the Celtic Seas. Led by University College Cork, the project consortium comprises both planners and researchers from seven partner institutes representing a mix of governmental authorities and academic institutes from Ireland, France and the UK. This consortium is particularly interested in developing meaningful cooperation between neighbouring Member States to support implementation of spatially coherent plans across transboundary zones of the Celtic Seas, building on previous work and leveraging new opportunities to identify and share best practice on technical, scientific and social aspects of transboundary MSP.

To explore how transboundary working for MSP is being undertaken in the Celtic Seas, SIMCelt project components focus on understanding spatial demands and scenarios, data requirements for MSP and stakeholder engagement. To complement the outputs of these components, four case studies were selected to illustrate how MSP implementation and transboundary working are approached within the Celtic Seas.

This case study seeks to explore tools and methods to assess environmental effects of maritime uses (Cumulative Effects) in the context of MSP. To do so AFB worked along with the Irish Marine Institute to compare approaches undertaken in the French Celtic Sea Waters and in the Irish Sea. Perspectives are also delivered toward a better took into account of the cumulative effects within the MSP processes.

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Warning

This is a warning concerning the interpretation of the results presented in this report. The human activities and pressures considered in this work remain incomplete and only represent a fraction of the diversity of uses, their interactions, pressures and the effect of these pressures on the environment. The choice of human activities and pressures studied in this report must not be considered representative of the processes at work across the study area. These choices are a compromise between advances in methodological developments, effectively usable data and the SIMCelt project schedule. They are designed to illustrate the analysis and working methodology and to enable comparisons and methodological discussions with SIMCelt project partners. Any use of this work for the management of the territory studied would be incomplete and misplaced.

Marine Policy context

Coastlines, seas and maritime spaces are a vital heritage for our society. Developing a suitable long-term strategy for managing this heritage needs to meet a number of emerging issues.
These include: economic issues, such as the development, densification and diversification of human activities associated with use of the coastal and maritime space, and use of living and mineral marine resources; strategic issues, such as a growing number of sectoral approaches and increased competition for space and resources, and, therefore, conflicts resulting from the co-existence of activities and practices; and finally, ecological issues, such as degradation of the state of marine ecosystems due to increased land and marine pressures exerted on physical and chemical processes, biodiversity and marine communities, ecological functions and landscapes.
The fact that these multiple issues are increasingly being taken into account, and the clear challenge of reconciling them, have given rise to ambitious public policies. The EU Integrated Maritime Policy (IMP) is a cross-sector and cross-cutting policy that seeks to support the sustainable development of the maritime economy and improve coordination between different fields of activity. In particular, this more consistent

management of issues in the maritime area has been developed by drawing on the Marine Strategy Framework Directive (2008/56/EC), which is the environmental pillar of the IMP, and using the Framework Directive for Maritime Spatial Planning (2014/89/EU).

Implementation of this strategy is largely reliant on the engagement and collaboration of marine space stakeholders and on the coordination of State services. The quality and relevance of the strategies developed also depend a great deal on our ability to obtain knowledge that can describe, understand and summarise processes. In particular, environmental and socio-economic objectives must be defined on the basis of:

- knowledge of the ecological status of the different ecosystem compartments, and their spatial distribution,
- definition of the sites, species and habitats whose protection is a priority within management measures, for each compartment,
- knowledge of the spatial distribution of the pressures caused by human activities,
- knowledge of the effects that these various pressures may have on the different ecosystem compartments.

In this context of extremely complex natural and anthropogenic processes, issues around using and summarising scientific expertise and data become extremely important.

The French Biodiversity Agency (FBA) supports implementation of environmental public policies by providing the French Ministry for the Ecological and Inclusive Transition with scientific and technical expertise, and in particular through its national technical coordination role for the Marine Strategy Framework Directive (MSFD). It also supports implementation of the Framework Directive for Marine Spatial Planning (MSP), of which the MSFD is the environmental component.

In this framework, the FBA is developing a spatial analysis tool to assess interactions between human activities and ecosystem compartments. The operational objective is to map concomitant pressures, map the risk of exposure to these concomitant pressures, and finally, map the risk of concomitant effects. 2016 and the first half of 2017 were spent on methodological developments, particularly drawing on an inventory (Vanhoutte-Brunier & Quemmerais-Amice, 2017) and consultation with all scientific and institutional partners involved in implementation of the MSFD and MSP directives.

Taking part in the SIMCelt project and cumulative effects case study was a real opportunity, enabling real implementation of the methodological developments in the French part of the Celtic Sea, testing of the different approaches and, most importantly, discussions with project partners. Comparing the methods and approaches developed in the Irish Sea and in the French part of the Celtic Sea is an interesting example of cooperation between EU Member States who share a marine sub-region. Closer ties between institutions and initial comparisons present significant advantages for the development of a shared vocabulary and concepts for establishing consistent management of our maritime heritage.

Introduction

The proposed methodology follows on from analysis of the literature and work to collect scientific expertise from studies carried out in 2016 and 2017 under the Carpediem project. Bibliographical analysis was used to identify the European projects that specifically address the assessment of "cumulative impacts" and to compare the different methodologies used. Work with the scientific coordination teams involved in the 2018 assessment of the MSFD in France laid the foundations for an acceptable and shared assessment method. All of this work is presented in detail in the Carpediem project methodological report (Vanhoutte-Brunier & Quemmerais-Alice, 2017). Their work helped define the title "assessment of the risk of concomitant effects" to specify the type of analysis.
The term **"risk"** comes from recommendations by La Rivière *et al*. (2015) on the assessment of the sensitivity of benthic habitats to determine the "impact risk" (or "vulnerability"). The term "risk" puts the scope of results into perspective, as they are not a quantitative expression of the measurable effects on biological communities. Uncertainties surrounding the results of the assessment are still significant, due to methodological assumptions which simplify real conditions and the way in which habitats and species respond when exposed to a number of pressures. In our case, the term "risk" has no statistical meaning as we are not looking to calculate the probability of an effect occurring. The term **"effects"** is considered preferable to "impacts" as impacts are generally perceived as being negative towards habitats and species. However, a pressure can sometimes generate a positive effect, either directly or indirectly. "Effect" has therefore been more common in recent literature (e.g. Clarke-Murray *et al.*, 2015 *Mapping potential cumulative effects*). The term **"concomitant"** is preferable to "cumulative" as the notion of "cumulation" implies that there are only additional, linear effects when several pressures are exerted on a habitat or species. Many studies underline that there are various types of interactions between effects, including additive effects (AB=A+B), synergistic effects (AB>A+B) and antagonistic effects (AB<A+B).
In this study, the word **"pressure"** refers to a change of status in the space and/or time of the physical, chemical and biological parameters of the environment that influence the ecosystem. Pressures are generated by human activities on land and at sea, and influence the environment either directly or indirectly. Finally, the expression "ecosystem component" can refer to benthic habitats, pelagic habitats, fish and cephalopods, marine mammals, turtles or sea birds, etc.

The publication of a quantitative assessment of the impacts of 17 anthropogenic pressures/activities on 20 marine ecosystems at a global level by Halpern *et al.* (2008) in the *Science* journal led to a wave of regional studies across the world (Selkoe *et al.*, 2009; Ban *et al.*, 2010; Korpinen *et al.*, 2012). These studies highlighted the need to manage human activities as a whole, and not through sectoral approaches. They demonstrate the main trends for the multiple pressures exerted on marine communities and habitats. They also show that it is extremely difficult to produce truly exhaustive maps of anthropogenic pressures and that it is also very complex to realistically conceptualise the relationships between multiple pressures and cumulative impacts. The main challenge in assessing concomitant effects is to establish causal links between human activities, the pressures they generate and their effects on species and habitats. Some publications have summarised the main issues in this exercise, offer an analysis of the limitations of the working assumptions and lack of data, and sometimes recommendations for conducting these assessments (Korpinen & Andersen, 2016; Clarke-Murray *et al.*, 2014; Judd *et al.*, 2015 ; Aish *et al.*, 2016).

In 2015, the working group Ospar ICG-C[1] compared the methods developed under 3 projects carried out in Europe: HARMONY in Denmark, CUMULEO in the Netherlands, and ODEMM in the United Kingdom (Ospar, 2015). The aim was to assess the cumulative effects of all pressures and impacts in the North-Eastern Atlantic by developing a hybrid method based on these projects. Comparison of these three methods gave a general overview of the different assessment strategies. The diagram in Figure 1 shows the main calculation steps and results of each of the three methods analysed.

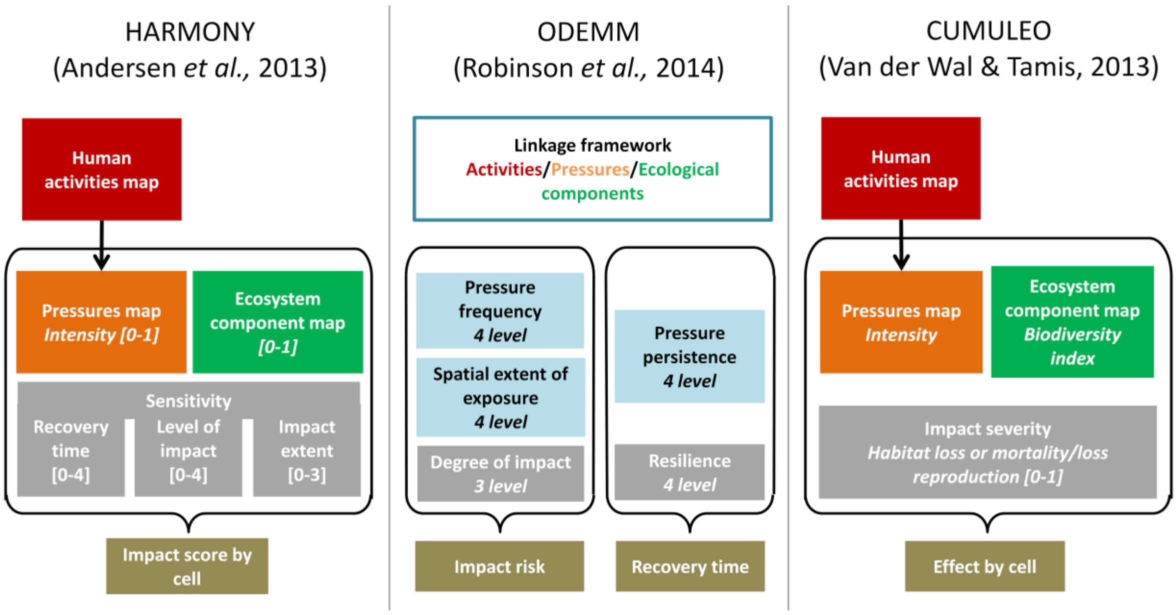

Figure 1: Overview of parameters and calculation step for the projects HARMONY, ODEMM and CUMULEO.

The method used for the HARMONY project (Andersen *et al.*, 2013) carries on from the method developed by Halpern *et al.* (2008). It involves mapping ecosystem components and activities on land and at sea which generate pressures on the marine environment. Consultation with experts helped specify the distances of effect for each pressure, depending on the activity generating the pressure. The experts also assessed three parameters related to the sensitivity of ecosystem components to pressures (resilience, degree of impact and extent of impact). The intensity of the pressure, density of the ecosystem component and sensitivity for each activity - pressure - ecosystem component combination were added together to calculate an impact index for each cell.

The method for the ODEMM project (Robinson *et al.*, 2014; Knights *et al.*, 2015) was first used to assess the impact risks on ecosystems in regional seas, without using spatial analysis of ecosystems, activities and pressures. The impact risk in a regional sea is calculated by considering the frequency of exposure of the habitat or group of species to the pressure and the potential degree of impact of the pressure on the habitat or group of species. The possibility of an ecosystem component recovering was assessed separately depending on the persistence of the pressure and the likely resilience of the ecosystem component once the activity had been stopped. Analysis was based on expert assessment of the

[1] Intersessional Correspondence Group on Cumulative Effect Assessment under the Environmental Impact of Human Activities Committee (EIHA)

pressures generated by each activity (linkage framework). The ODEMM method was later used in a spatialised way (Goodsir *et al.*, 2015).
Like the HARMONY method, the CUMULEO method (Van der Wal & Tamis, 2013) develops a spatialised approach with a fairly limited number of activity sectors (2: fisheries and renewable energies), pressures (5) and ecological receptors (4: marine mammals, birds, fish and benthos). The effects on the species and habitats are considered with regard to the species' mortality and reproduction rates (mobile species) or by the loss of habitats for benthic habitats. The severity of the impact is calculated using a score between 0 and 1.

The main similarities between these three methods are as follows:

- identification of relationships between activities and pressures, and between pressures and ecosystem components;
- assessment of the exposure of ecosystem components to pressures;
- assessment of the sensitivity of ecosystem components to pressures.

The main differences between these three methods are as follows:

- the methods for mapping activities, pressures and ecosystem components, and the use of mapping for assessing exposure;
- the method for taking into account pressures and concomitant effects;
- the calculation of sensitivity.

These comparisons helped lay the foundations for the methodological choices on this project. This methodology aims to produce the following analyses:

- mapping of human activities at sea
- mapping of some pressures generated by these activities and a multi-pressure map
- mapping of the risk of concomitant effects for benthic habitats

The SIMCelt case study was used to test various analysis assumptions and to compare the results for these different assumptions.

1. Material and methods

1.1. Overview

The analysis is based on structuring descriptive data on the marine environment. Descriptive statistical and spatial data on human activities, pressures and ecosystem components are summarised, harmonised and distributed across a marine area grid on a $^{1}/_{60}$ scale (Figure 2). Each cell has a unique code and can be selected and sorted according to various criteria (Figure 2). Data associated with the cells can be used within 3 free open software solutions. Data is integrated into and used within a spatial database management system, PostgreSQL-PostGIS, and administrated using the pgAdmin software suite. Some data preparation operations and maps are produced using the QGIS software, which very easily interfaces with the database. Statistical analysis is carried out using the R software. Figure 3 shows the main steps in the data processing chain.

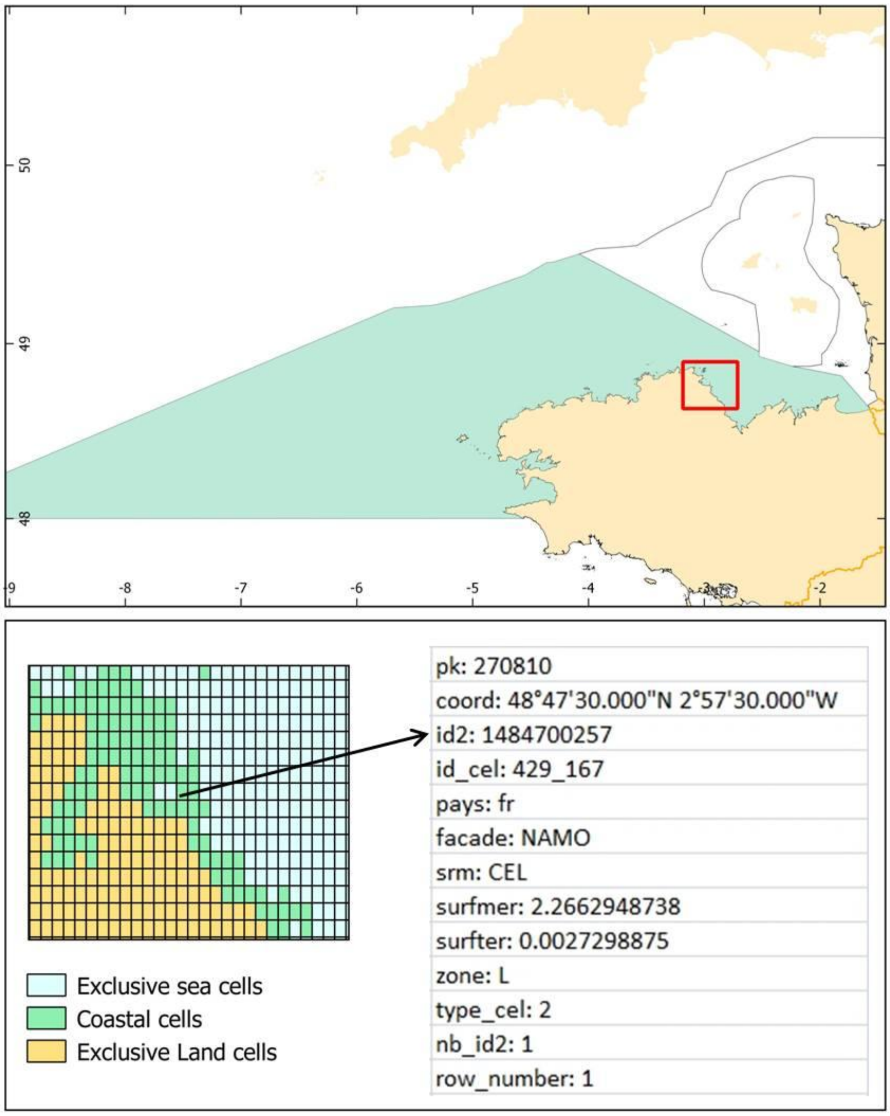

Figure 2: SIMCelt study area in French waters, overview of the 1’ x 1’ grid layer and cell metadata example (id2: unique cell ID, pays: country, façade: French administrative area, srm: MSFD sub region, surfmer: sea surface in km² by cell, surfter: land surface in km² by cell, zone: Sea, Coastal or Land – the cell is crossed by the coastline)

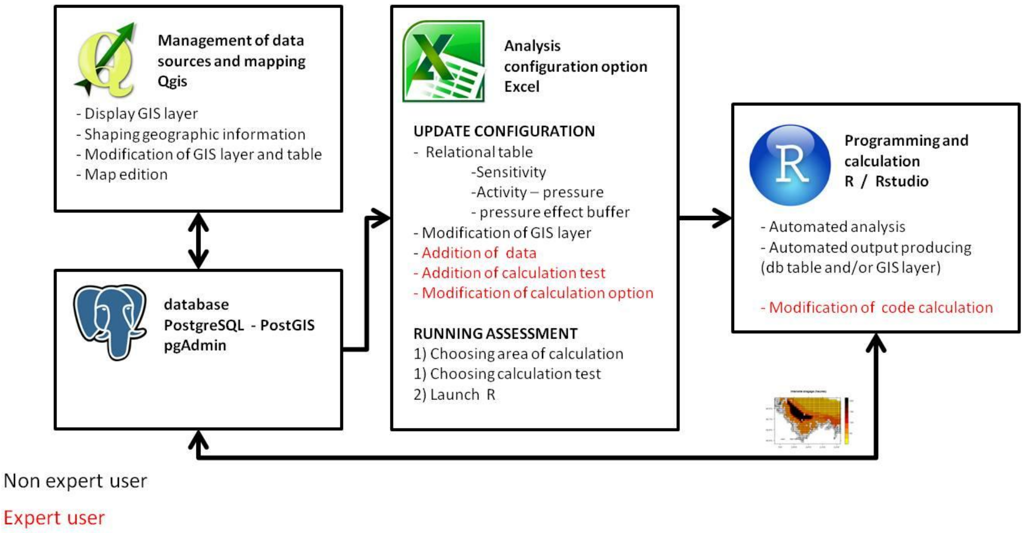

Figure 3: Software and processing chain

The main steps of data analysis are shown in Figure 4. At each step of mapping analysis, intermediate results are produced (multi-activity maps, multi-pressure maps, risk of exposure map), which provide a summary of the data required for interpreting the final result of assessment of the concomitant effects for benthic habitats ($REF\_P_{1\text{-}njd}E_1$).

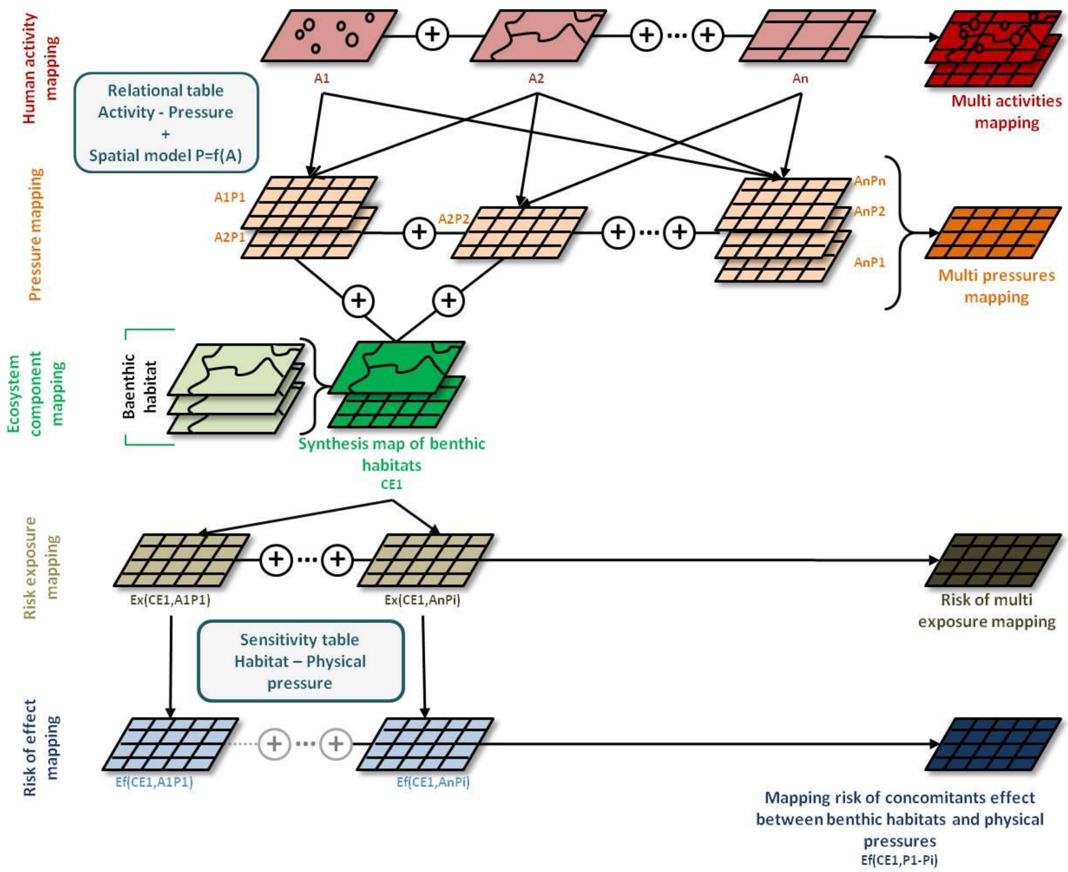

Figure 4: Overview of the 5 steps of analysis, A: activity, P: pressure, E: Ecosystem component (benthic habitat).

1.2. Human activities data and mapping

Descriptive data of human activities is collected from the administrative bodies responsible for monitoring and managing the different uses. The data is prepared in order to describe the presence or absence of activities in each cell, along with their intensity in different units (number of ships, quantity, time, etc.). For the study under the SIMCelt project, an attempt was made to record and collect descriptive data on the main activities exerting direct physical pressures on benthic habitats. The list of activities considered in the study is presented in Table 2.

Table 1: List of human activities

Human sector of activity	Intensity parameters	Unit per cell	Period of available data	Human use included	Code
Aggregate dredging	Interannual average quantity of dredged material	tonne / year	2011-2014	calcareous sand and siliceous sand and gravel	A_54_P_1
Submarine cables	Sum of linear cables	linear km	continuous	submarine cable	A_51_P_3
Navigational dredging	Interannual average quantity of dredged material	tonne / year	2011-2015	Navigational dredging operation	A_45_P_1
Immersion of dredged material	Interannual average quantity of dumped material	tonne / year	2005-2013	Immersion of dredging material	A_46_P_1
Aquaculture	estimation of maximum quantity of livestock farming	tonne	unknown	Oyster and mussel on net	A_31_P_1
			unknown	Intertidal mussel pole culture « bouchot »	A_32_P_1
			unknown	Intertidal oyster bag culture	A_33_P_1
			unknown	mollusc culture on floor	A_35_P_1
Benthic trawls	Interannual average fishing effort	hours / year	2013-2016	Benthic trawls	A_1_P_1
Bottom nets	Interannual average fishing effort	hours / year	2013-2016	Bottom nets	A_9_P_1
Bottom longlines	Interannual average fishing effort	hours / year	2013-2016	Bottom longlines	A_16_P_1
Scoubidou	Interannual average fishing effort	hours / year	2013-2016	Scoubidou device for kelp harvesting	A_26_P_1
Dredge	Interannual average fishing effort	hours / year	2013-2016	*L. hyperborea* dredge	A_25_P_1
			2013-2016	Mollusc dredges	A_5_P_1

A multi-activity map gives a qualitative and quantitative overview of the use of marine and coastal areas, which is useful for marine planning. In particular, it must produce relatively homogeneous areas with similar types and intensities of human activities. The definition and analysis of these areas will show sectors with potentially strong interaction between the activities and between the activities and the marine environment. Areas with fewer constraints between activities and with the environment may also be located. Three complementary methods are proposed for mapping human activities.

a) **Calculation of the index of multi-activity presence (IMA1), corresponding to the cumulative number of activities present in each cell over a defined period.** The period may be defined to take into account the diversity of sets of data. The activities with several years of available data may be taken into account using an inter-annual average. Activities with just one year of available data may only be taken into account with this annual data, until more information is available.

b) **Calculation of the index of multi-activity intensity (IMA2), corresponding to the cumulative intensities of each activity in each cell**. For this approach, the intensity data for each activity is normalised between 0 and 1 [0-1] using a log transformation. This operation is used to work with source data in very diverse units. For approaches a) and b), the index of multi-activity (IMA) is calculated as follows:

$$IMA = \sum_{i=1}^{ni} A_i$$

where: A_i presence/absence of the activity [0/1] or intensity of the activity which has been log transformed and normalised [0-1]

ni number of activity sectors

c) **Calculation of the index of multi-activity intensity (IMA3), corresponding to the partitioning of the cells according to the intensity of human activities at sea**: the aim of this analysis is to classify and define sectors characterised by similar types of activities and intensities. In this approach, the activity intensity values (whether or not equal to 0) are quantitative variables that describe the cells, so that they can be grouped into several homogeneous groups. The aim is to group cells into a small number of homogeneous categories. This analysis may be conducted using non-hierarchical clustering methods, where cells are partitioned into a few homogeneous groups with no hierarchical relationship between them, or by hierarchical methods where cells are grouped by pairs and then ranked. In the first case, each cluster is compiled to maximise similarities within the group and maximise differences outside the group. Various data partitioning methods exist, such as the k-means method. Carrying out a Principal Component Analysis before the partitioning analysis removes non-explained variables from the clusters and helps better define the most suitable category number for the analysis.

Descriptive data on human activities can then be used to map the pressures. Mapping marine activities does not represent all activities that generate pressures, as many of them are located on land, especially agricultural and industrial activities which generate significant pressures on marine habitats and ecological functions. Some pressures, especially chemical and biological pressures, can be mapped without representing land or coastal activities.

1.3. Pressures data and mapping

In the first cumulative impact studies, the dividing line between activities and pressures was not clear, and, often, the activity considered to be the main contributor to the pressure was mapped as a pressure proxy (Ban *et al.*, 2010) by applying a circular zone of influence or a more advanced spatial model to the activity. The possibility of considering several activities that contribute to generating a pressure was developed later (Andersen *et al.*, 2013). Intensity is the combined magnitude, frequency and duration of a pressure (La Rivière *et al.*, 2015). For the purposes of analysis, it is assumed that the intensity of the activity (see Table 1) can be used to estimate the intensity of the pressure. Furthermore, in a spatial approach, the area over which the activity or pressure is exerted must also be taken into account.

1.3.1. Mapping activity – pressure combination

Under the SIMCelt project, only physical pressures generated by some human activities at sea are taken into account under the study. Other pressures, particularly biological and chemical pressures generated by land activities, such as farming, industry and coastal urbanisation, are very important and significantly contribute to the effects on marine habitats and communities. However, given the advances in methodological developments made in 2016 and 2017, and the SIMCelt project schedule, they were not taken into account in this study. This section therefore only discusses the mapping of physical pressures generated by a selection of human activities at sea, with the aim of illustrating the proposed approach and its possibilities. Mapping the physical pressures generated by human activities at sea requires the use of descriptive information concerning:

- the relationship between the activity and the pressure(s) generated (a);
- the location and intensity of activities (b);
- the zone of influence of the pressures generated (c);
- the persistency of the pressure over time (d).

a) Estimation of the relationships between activities and pressures

For the purposes of the project, a theoretical relationship matrix between the activities and pressures has been developed in order to establish a theoretical link between the activities and pressures. Table 2 shows an extract of the matrix developed exclusively for the activities and pressures studied under the SIMCelt project. It uses the same activity and pressure types as the MSFD and the activity-pressure relationships previously defined by other projects, in particular the “sensitivity” project led by UMS 2006 PatriNat (La Rivière *et al.*, 2015) and the technical and economic guidelines drawn up by the French Biodiversity Agency (Maison, 2009; Le Fur, 2010; Ragot, 2010, Guégan, 2014). The matrix was produced in two stages. Firstly, during a workshop in December 2016 with the scientific and administrative teams involved in the 2018 assessment of the MSFD. Secondly, during an internal FBA workshop, which completed and presented arguments for the relationships in the matrix. A confidence index for each relationship describes the level of expertise involved in establishing the relationship between the activity and pressure. Interpreting the confidence index will help update the matrix by identifying the relationships with insufficient expertise. The matrix lists all human activities that contribute to each pressure. Using this list, the descriptive data on activities needed to map each pressure can be identified.

Table 2: Extract of the relational matrix between activities and pressures, only for activities listed in table 1 and physical pressures (0: activity doesn't generate the pressure, 1: activity generates the pressure, NA: not assessed, (1): very low confidence index, (2): low, (3): medium, (4): high, (5): IC very high, (NA): not assessed

Human activity \ Pressure	Physical loss	Physical change	Removal of substratum (extraction)	Abrasion/disturbance of the substrate	Penetration and/or disturbance of the substrate below the surface of the seabed	Smothering and siltation rate changes (Light)	Smothering and siltation rate changes (Heavy)	Water flow (tidal current) changes, including sediment transport considerations	Changes in suspended solids (water clarity)	Temperature change (decrease or increase)	Salinity change (decrease or increase)
Benthic trawls	0(5)	0(5)	0(5)	1(5)	1(5)	1(5)	0(5)	0(5)	1(5)	0(2)	0(2)
Dredge	0(5)	0(5)	1(5)	1(5)	1(5)	0(5)	0(5)	0(5)	0(5)	0(2)	0(2)
Bottom nets	0(5)	0(5)	0(5)	1(5)	0(5)	0(5)	0(5)	0(5)	1(5)	0(2)	0(2)
Bottom longlines	0(5)	0(5)	0(5)	1(5)	0(5)	0(5)	0(5)	0(5)	0(5)	0(2)	0(2)
L. hyperborea dredge	0(5)	0(5)	1(5)	1(5)	1(5)	0(5)	0(5)	0(5)	1(5)	0(2)	0(2)
Scoubidou	0(5)	0(5)	1(5)	1(5)	1(5)	0(5)	0(5)	0(5)	1(5)	0(2)	0(2)
Oyster and mussel on net	0(2)	0(2)	0(4)	0(2)	0(2)	1(2)	0(2)	1(3)	1(3)	0(1)	0(1)
Intertidal mussel pole culture « bouchot »	0(2)	0(2)	0(4)	0(2)	0(2)	1(3)	1(3)	1(2)	1(4)	0(1)	0(1)
Intertidal oyster bag culture	0(2)	1(2)	0(1)	1(2)	1(2)	1(2)	1(2)	1(2)	1(4)	0(1)	0(1)
Mollusc culture on floor	0(2)	0(2)	0(4)	1(2)	1(2)	1(2)	0(2)	0(2)	1(4)	0(1)	0(1)
Kelp culture on net	0(2)	0(2)	0(4)	0(2)	0(2)	0(2)	0(2)	0(2)	1(4)	0(1)	0(1)
Navigational dredging	0(NA)	1(NA)	1(NA)	1(NA)	1(NA)	1(NA)	0(NA)	NA (NA)	1(NA)	0(NA)	0(NA)
Immersion of dredged material	0(NA)	1(NA)	0(NA)	0(NA)	1(NA)	1(NA)	1(NA)	1(NA)	1(NA)	0(NA)	0(NA)
Submarine cables	0(NA)	1(NA)	0(NA)	1(NA)	1(NA)	1(NA)	0(NA)	0(NA)	0(NA)	1(NA)	0(NA)
Aggregate dredging	0(NA)	1(NA)	1(NA)	1(NA)	1(NA)	1(3)	0(NA)	1(NA)	1(NA)	0(NA)	0(NA)
Coastline artificialization	1(NA)	1(NA)	0(3)	1(3)	1(3)	1(3)	0(3)	1(3)	1(3)	1(NA)	1(NA)

b) Mapping the location and intensity of pressures

Very diverse data is available for mapping the location and intensity of the physical pressures generated by human activities at sea. In particular, this may be satellite monitoring data, exploitation concession zoning data or statistical data. This data comes from a number of sources and various government bodies and departments involved in sectoral management of activities and/or territorial management. Table 3 presents the different data sources used.

Table 3: List of human activities data and sources (location and intensity data).

Human sector of activity	Data used for localisation	Source of localisation data	Data used for intensity	Source of intensity data
Aggregate dredging	official mining concession perimeter	Ifremer Géoscience Marine	Annual quantity of dredged material	Each coastal DREAL
Submarine cables	location of cable route	Shom and submarine cable operators	Sum of linear cables	Shom and submarine cable operators
Navigational dredging	representative point of each dredging area	Cerema	Annual quantity of dredged material	Cerema
Immersion of dredged material	representative point of each immersion area	Cerema	Annual quantity of dumped material	Cerema
Aquaculture	official aquaculture concession perimeter	DDTM, Cerema	description of maximum authorised quantity of livestock farming by surface unit and by aquaculture sector	Each coastal DDTM
Benthic trawls	Aggregated annual fishing effort by 1' x 1' cell from VMS survey	DPMA	Aggregated annual fishing effort by 1' x 1' cell from VMS survey	DPMA
Bottom nets	Aggregated annual fishing effort by 1' x 1' cell from VMS survey	DPMA	Aggregated annual fishing effort by 1' x 1' cell from VMS survey	DPMA
Bottom longlines	Aggregated annual fishing effort by 1' x 1' cell from VMS survey	DPMA	Aggregated annual fishing effort by 1' x 1' cell from VMS survey	DPMA
Scoubidou	Aggregated annual fishing effort by 1' x 1' cell from VMS survey	DPMA	Aggregated annual fishing effort by 1' x 1' cell from VMS survey	DPMA
Dredge	Aggregated annual fishing effort by 1' x 1' cell from VMS survey	DPMA	Aggregated annual fishing effort by 1' x 1' cell from VMS survey	DPMA

c) Mapping the zone of influence of pressures

The zone of influence of pressures is the distance from the source beyond which the pressure exerted by the activity is zero. The maximum distance of effect for a pressure generated by an activity is unique to each activity-pressure pairing. Andersen *et al*. (2013) compiled a table of maximum distances of effects for each activity-pressure pairing, completed in consultation with scientific experts.

These theoretical assessments do not take into account local hydrodynamic effects which can mitigate, accentuate and set the direction of the zone of influence of pressures in the water column and on the sea floor. Theoretical estimations by scientific experts of the zone of influence for each activity-pressure pairing could not be not carried out under this study. The estimations produced by Andersen *et al.* (2013) could be used but would need to be adapted to take into account French legislation governing activities at sea, whose technical rules influence the implementation of apparatus and *in situ* techniques, consequently influencing the spread and intensity of pressures (e.g. sifting of aggregates during material extraction operations). This work could be carried out at a later date, under the Carpediem project.
Consequently, for the SIMCelt project, no spatial model was used to estimate the zone of influence of pressures for each activity type. The intensity of activities is integrated into the 1' x 1' grid. For this methodological activity, it is considered that pressures only have a local influence.

d) Consideration of the persistency of pressures

Maps of pressures need to take into account the persistency of the pressure once the activity has stopped. Each pressure needs to be mapped for a reference period, taking into account activities prior to this period if they have generated pressures that persist over time. The ODEMM North-East Atlantic project provides quantitative calculations on the persistency of pressures after an activity has been stopped. Taking into account persistency requires a theoretical matrix to define the persistency of pressures for each type of activity, along with sufficiently precise descriptive data on human activities in order to assess their frequency and existence over a fairly long period of time. These two criteria represent an important step up in terms of quality, but are not available in the study area. The persistency of the pressure over time was therefore not taken into account in the study.

In conclusion, the calculation of each activity-pressure pairing P_jA_i (pressure j generated by activity i) can be expressed as an equation. To compare the distributions of pressures, avoid over-representation of extreme values and correct any frequency distribution bias (Andersen *et al.*, 2013), the pressure intensities are log transformed (log[X+1]) and normalised (N function), with regard to the maximum pressure intensity value in the area (all cells 1 to nz). All mapping of P_jA_i therefore has an intensity of between 0 and 1. These considerations result in the intensity of pressure *j* generated by activity *i* in a cell *z* being calculated as follows:

$$P_jA_i = \mathrm{N}\left[Log\left[A_i \times \gamma_{P_jA_i} \times f(Dist\_P_jA_i)\ + 1\right]\right]_{z=1,nz}$$

Where: A_i — intensity of activity *i*

$f(Dist\_P_jA_i)$ — the spatial model for mapping pressure *j* from activity *i*. In this study, its value is 1, as no spatial model was developed or used

$\gamma_{P_jA_i}$ — the presence or absence of pressure *j* generated by activity *i*

N — normalisation between 0 and 1 of the value obtained in the cell

A confidence index could be established for each estimation of P_jA_i by combining the confidence index of the activity-pressure relationship matrix between A_i and P_j ($\gamma_{P_jA_i}$) and a confidence index for estimating the zone of influence of the pressure ($Dist\_P_jA_i$).

1.3.2. Mapping a single pressure index (SPI)

In most cases, pressures are generated by several activities on land or at sea. Pressure P_j can therefore be estimated by calculating the sum of the activity - pressure pairings P_jA_i. The methodological challenge of this calculation step is to assess the respective contribution $c_{i,j}$ of each activity - pressure pairing P_jA_i to pressure P_j. For example, the compaction caused by a fish trap is not of the same intensity as compaction caused by wind turbine construction work, regardless of the duration of the activity. To resolve this methodological issue, a frame of reference needs to be developed to compare the intensity of the pressure generated by one-off events caused by anthropogenic practices on a unit of area. Until additional work is able to be carried out by experts to compensate for this lack of knowledge, this project uses the assumption that activities make an identical contribution to the pressure for standard events ($c_{i,j}$ =1). The equation to calculate the single pressure index can therefore be written as follows:

$$P_j = \sum_{i=1}^{ni} P_jA_i \times c_{i,j}$$

Where: P_j intensity of pressure *j*

P_jA_i intensity of pressure *j* generated by activity *i* normalised between 0 and 1

$c_{i,j}$ relative contribution of activity *i* to pressure *j*

1.3.3. Mapping a concomitant pressures index (CPI)

The concomitant pressures index is calculated using the sum of pressures P_j. The concomitant pressures index (CPI) is calculated as follows:

$$CPI = \sum_{j=1}^{nj} P_j$$

where: P_j intensity of pressure j

nj number of pressures

1.4. Benthic habitats data and mapping

1.4.1. Synthesis benthic habitats map based on multi-source and multi-scale data

Descriptive data on benthic habitats needs to be able to identify and rank the risk of concomitant effects for each zone and habitat type. The following data is required:

- a relatively stable and standard categorisation of benthic habitat types;
- spatial information for measuring habitat areas with a sufficient classification resolution;
- information for estimating the sensitivity of habitats to different pressures.

Considering the project's European context and the need to develop comparable approaches between partner countries, the EU Eunis habitat types were chosen to describe the benthic habitats. These types are commonly used and regularly updated. There are a number of mapping products which can be used directly with this classification or which can be transferred from national to European classification.

In accordance with benthological experts consulted in 2016 and 2017 and with the scientific team responsible for assessing benthic habitats for MSFD Descriptor 1 in France, it was decided that the risk of concomitant effects only needed to be estimated for habitats mapped at least to Eunis level 4. Habitats mapped at lower Eunis levels (1, 2 and 3), which consequently do not include information on biological communities, were not included in analysis.
These two choices guided work to produce a level of geographical information which could be used for mapping the risk of concomitant effects. Work on mapping benthic habitats at European level, using the Eunis, EMODnet/EUSeaMap[2] habitat types (Populus *et al*., 2017), was used as the basis for mapping.
However, despite the quality and usefulness of the EMODnet EUSeaMap, it must be supplemented by another data source to cover non-mapped areas, especially areas close to the coastline and areas with insufficient resolution for classifying the habitat types. A multi-source synthesis map was therefore produced by identifying all available mapping products available and retaining only the most relevant data. Given the allocated time for this exercise, the geographical information to be included was chosen using a very simple methodology, as illustrated in the decision tree in Figure 5.

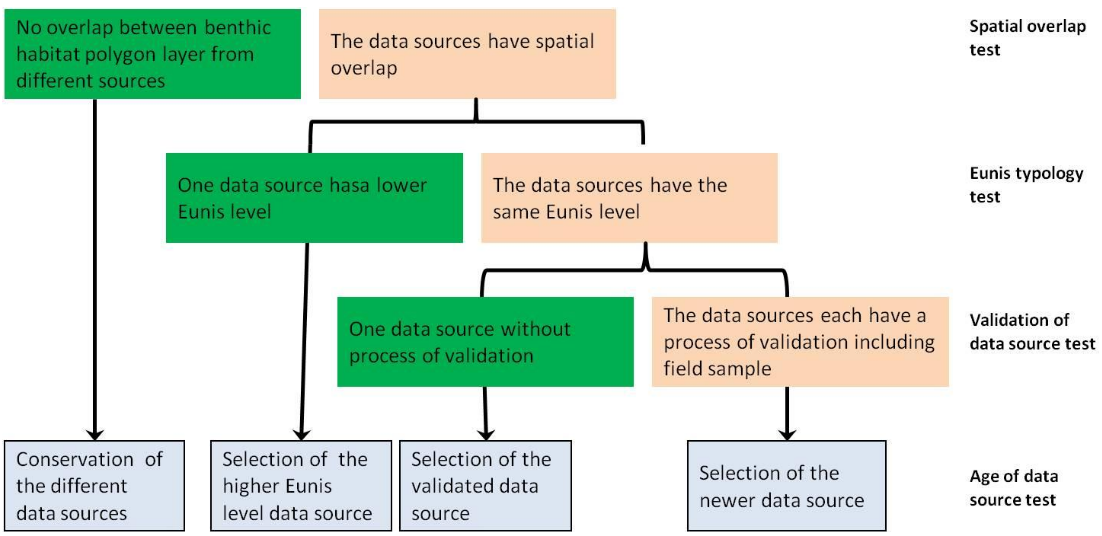

Figure 5: decision tree for management of multiple data sources for benthic habitats

The synthesis map (Figure 6) is accompanied by the calculation of a confidence level for each spatial entity (*IndConf_E1*). This confidence level is established depending on the path taken in the decision tree to select the habitat and on the validation of the original map. Once this synthesis map has been produced, the habitats selected are integrated into the 1’ x 1’ resolution grid. Each cell can include a list of the different types of habitats present (Figure 7), how many of them are present, their Eunis levels, the surface area of each habitat in absolute terms and as a percentage of the total cell area.

Integration of the EMODnet/EUSeaMap map and incorporation of additional local data took place in the first half of 2017, i.e. prior to publication of the new Eunis habitat types and the latest version of the EMODnet/EUSeaMap map. This work is very long and meticulous as there are a number of data sources for the area studied, especially very close to the coast, and it is often difficult to compare the different data sources. The data collected in the study area was produced by 12 data-producing bodies or groups of bodies.

[2] EMODnet: http://www.emodnet.eu/seabed-habitats

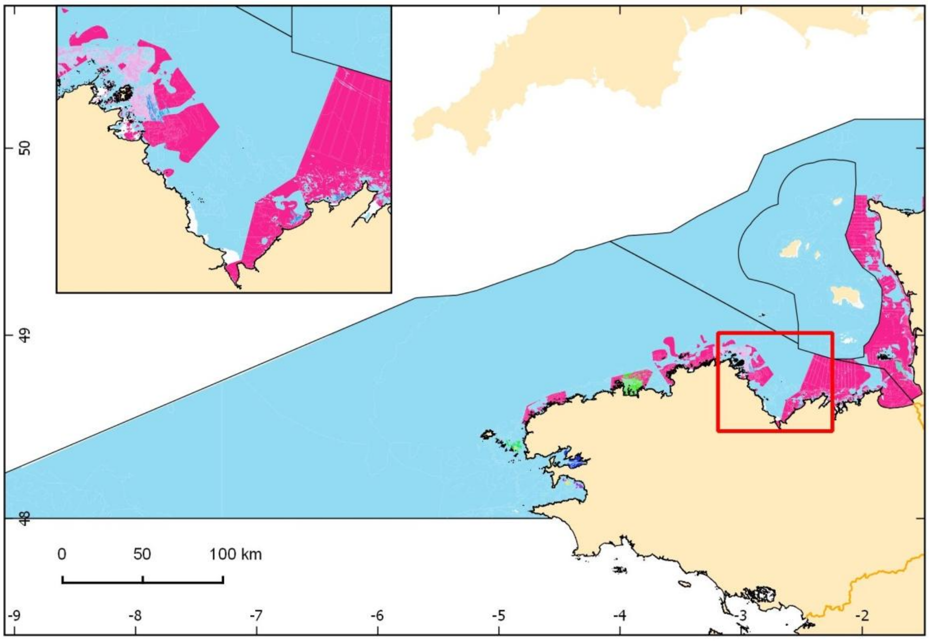

Figure 6: Map of the different benthic habitat data sources (major data sources example: light blue: EMODnet/EUSeamap, deep pink: Cartham project map for Natura 2000 sites)

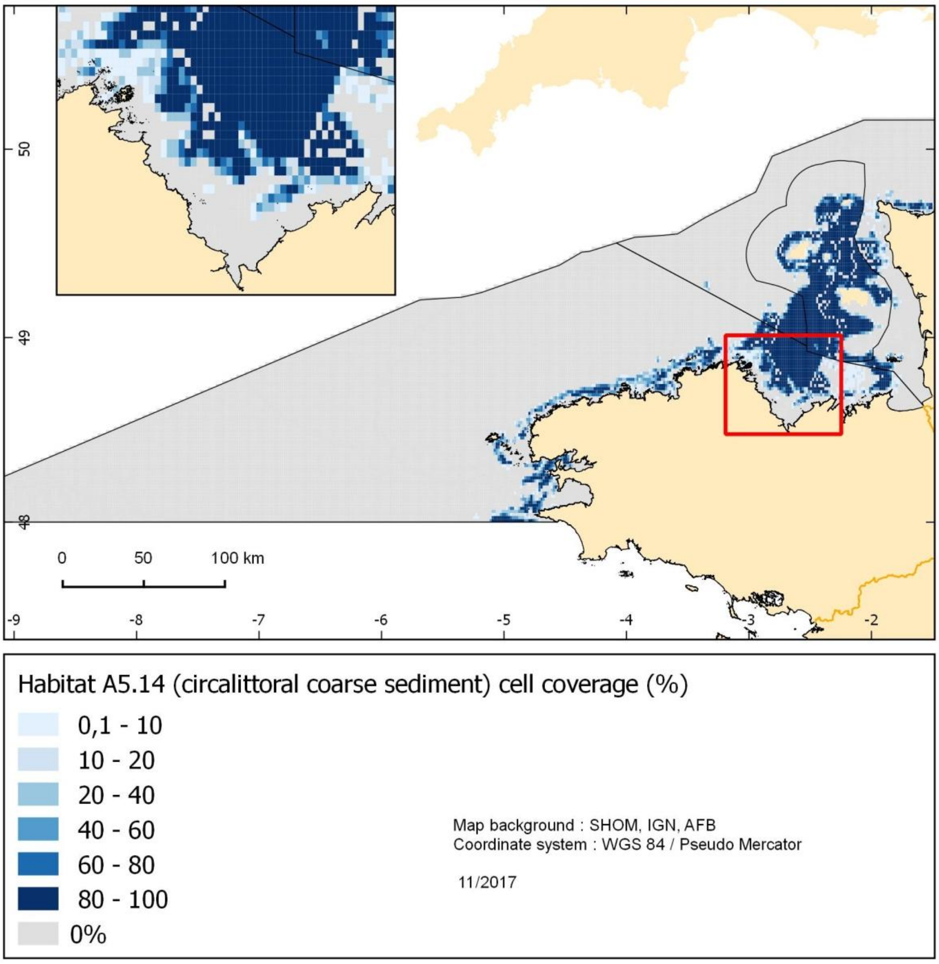

Figure 7: Example of benthic habitat information: distribution and cell covered by habitats A5.14 (Eunis level 4) Circalittoral coarse sediment)

1.4.2. Benthic habitats' sensitivity to pressure: sensitivity matrix

Assessing the risk of effect requires information on the sensitivity of habitats to the pressures to which they are exposed. Along with the assessment of the exposure of ecosystem components to pressures, the sensitivity matrix is used to estimate a risk of effect of pressures on the ecosystem components. The projects and methods studied include criteria under a variety of names which are included in the sensitivity assessment. Table 4 lists the terms and sensitivity assessment parameters for the various studies.

Table 4: Evaluation of parameters related to the sensitivity index in the methods HARMONY, ODEMM and MarLIN/MarESA.

Methods	Sensitivity parameters		
HARMONY	**Extent of the impact** none -> community score [0-4]	**level of impact** none -> lethal score [0-3]	**Recovery time** none -> > 10 year score [0-4]
ODEMM		**Degree of impact** low -> severe semi quantitative scale, 3 level	**Resilience** none -> strong semi quantitative scale, 4 level
MarLIN/MarESA		**Resistance** none -> high semi quantitative scale, 4 level	**Resilience** none -> very high semi quantitative scale, 5 level

As no suitable assessments on the sensitivity of benthic habitats in France were available for the SIMCelt study area, the MarLIN-MarESA[3] matrix (Tillin *et al.,* 2010; Tillin & Tyler-Walters, 2014) was selected for carrying out the initial technical tests. For the SIMCelt project, a sensitivity index between pressure j and habitat k was developed, expressed as, $\mu_{j,k}$. This index was used to estimate the theoretical level of interaction for each benthic habitat - pressure pairing. The index was calculated using the assessments carried out under MarLIN-MarESA. Associating the sensitivity index with the effectively mapped benthic habitats requires significant preparatory work.

The MarLIN-MarESA sensitivity matrix was developed for benthic habitats in the British Isles. Habitats mapped within the SIMCelt study area in France may therefore have no direct equivalence in the matrix. Furthermore, the Eunis level of the benthic habitats mapped is often lower than the Eunis level of the habitats whose sensitivity is assessed. The Eunis habitat types are ranked by level, meaning that a sensitivity score can be attributed to the Eunis level 4 habitats mapped which are not listed in the sensitivity matrix, providing that there are "sub-"habitats at a higher Eunis level in the matrix. For these cases, the rules for determining sensitivity scores are presented in the Table 5. Attribution of a sensitivity score is only possible for habitats mapped at least at level 4 of the Eunis typology, in accordance with the choices made previously.

[3] The Marine Life Information Network – marine Evidence based Sensitivity Assessment http://www.marlin.ac.uk/species/sensitivity_rationale

Table 5: Criteria for assigning sensitivity scores

Criteria for assigning sensitivity scores
For habitats mapped at Eunis levels 3 or lower with no equivalence in the MarLIN-MarESA matrix: no sensitivity score is assigned (sensitivity score = null value)
For habitats mapped at Eunis levels 4 or higher (5,6...) with no exact equivalence in the MarLIN-MarESA matrix and for which one or more upper "child" Eunis codes are listed in the MarLIN-MarESA matrix with sensitivity scores undefined (= null value) : no sensitivity score is assigned (sensitivity score = null value)
For habitats mapped at Eunis level 4 with no exact equivalence in the MarLIN-MarESA matrix, but for which at least one upper "child" Eunis codes is listed in the MarLIN-MarESA matrix without undefined sensitivity score: assignment of a sensitivity score with precautionary or median value option
For habitats mapped at Eunis level 4 with no exact equivalence in the MarLIN-MarESA matrix, but for which all the upper "child" Eunis codes are listed in the MarLIN-MarESA matrix without undefined sensitivity score: assignment of a sensitivity score with precautionary or median value option
For habitats mapped at Eunis levels 4 or higher (5, 6...) with an exact equivalence in the MarLIN-MarESA matrix: assignment of the MarLIN-MarESA sensitivity score

As recommended in La Rivière *et al.* (2015), the precautionary principle lead to select the most sensitive habitat's sensitivity score, as presented in the Figure 8.

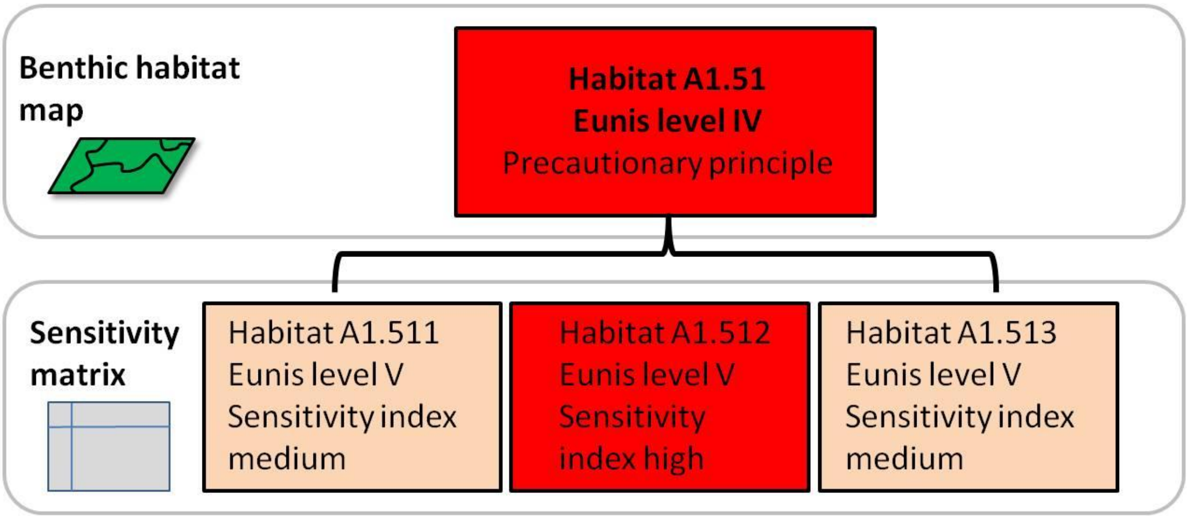

Figure 8: Aggregation of sensitivity scores, precautionary principle. (Colours indicate different levels of sensitivity).

In order to perform digital calculations on the risks of effects, the semi-quantitative sensitivity scores, established using resistance and resilience scores, are converted into quantitative scores (Table 5).

Table 6: Semi-quantitative MarLIN-MarESA matrix sensitivity scores and correspondence with the quantitative scores used for the analyses (in red).

Sensitivity index $\mu_{j,k}$		Resilience				
		None >25 years	**Low 10-25 years**	**Medium 2-10 years**	**High 1-2 years**	**Very High < 1 year**
Resistance	**None**	Very high **(1.0)**	High **(0.75)**	High **(0.75)**	Medium **(0.50)**	Low **(0.25)**
	Low	High **(0.75)**	High **(0.75)**	Medium **(0.50)**	Medium **(0.50)**	Low **(0.25)**
	Medium	High **(0.75)**	Medium **(0.50)**	Medium **(0.50)**	Low **(0.25)**	Low **(0.25)**
	High	Medium **(0.50)**	Medium **(0.50)**	Low **(0.25)**	Low **(0.25)**	Very Low **(0.0)**

One expected outcome of the aggregation of sensitivity scores and benthic habitat mapping is the creation of benthic habitat sensitivity maps for each pressure. This intermediate step in calculating the risk of concomitant effects is in itself useful for activities management. The method for assigning the confidence index is presented in Table 6.

1.5. Mapping risk of concomitant effects

1.5.1. Calculation of the risk of effect for each pressure – habitat combination

The first step in calculating the risk of concomitant effects involves assessing the risk of effect for each pressure on an ecosystem component. Figure 6 presents the different calculation steps, considering activity A1 which generates pressure P1 on ecosystem component C1.

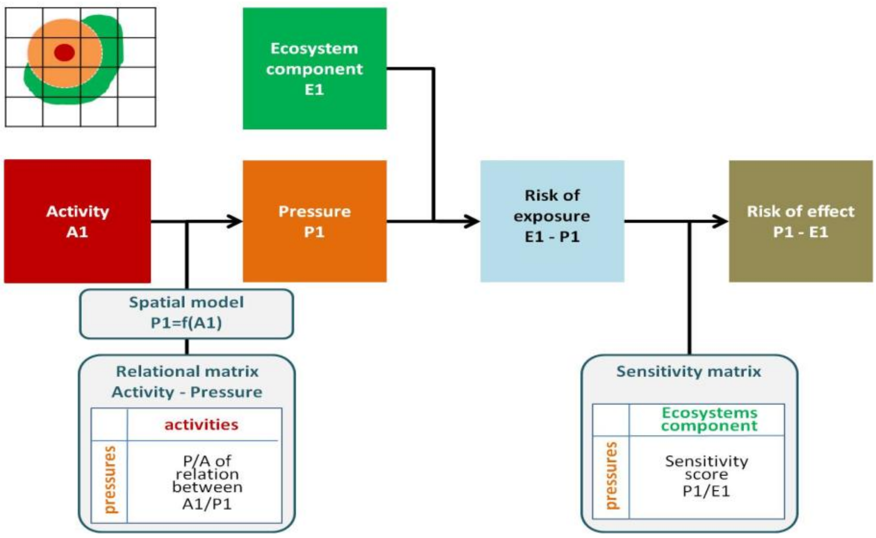

Figure 9: Simplified diagram of the assessment of the risk of effect of a pressure P1 generated by an activity A1 on the benthic habitat C1.

This calculation first requires assessment of the risk of exposure, corresponding to the overlap in space and time between the pressure and habitat. For each habitat *k*, the risk of exposure to a pressure *j* ($REX\_P_jE_k$) is calculated as follows:

$$REX\_P_jE_k = P_j \times E_k$$

where: P_j normalised intensity of pressure *j* [0-1]
E_k normalised surface area of habitat *k* [0-1]

This risk of effect for pressure *j* on habitat *k* ($REF\_P_jE_k$) is calculated by multiplying the risk of exposure by the sensitivity, considering that the intensity of pressure *j* calculated in the risk of exposure takes into account all activities generating this pressure:

$$REF\_P_jE_k = REX\_P_jE_k \times \mu_{j,k}$$

where: $REX\_P_jE_k$ exposure of habitat *k* to pressure *j*
$\mu_{j,k}$ sensitivity index between habitat *k* and pressure *j*

1.5.2. Calculation of the Index of Concomitant Effects (ICE)

The method for calculating the risk of concomitant effects (*REFC*) assumes the additivity of effects as follows:

$$REFC = \sum_{j=1}^{nj} \sum_{k=1}^{nk} REF\_P_jE_k$$

where: $REF\_P_jE_k$ the risk of effect of pressure *j* on habitat *k*

1.6. Assessment of the quality and variability of the results

The methodology use a number of data sets of variable quality and is based on approximations and theoretical working assumptions. These drawbacks are an integral part of this type of analysis and should not be avoided, especially if we wish to better identify the data whose quality is a problem and / or the working assumptions that must be redefined. Also, it is proposed to evaluate the influence of these methodological constraints on the quality and variability of the results. The evaluation of the quality and variability of the results will provide the necessary elements to estimate the confidence that can be placed in the results and will guide the work needed to advance the overall quality of the analysis and will support requirements for data acquisition and/or additional scientific expertise. This chapter presents the first methodological guidelines for assessing the quality and variability of the results, but the following methodological proposal have not been finalized and implemented before the final conference of the SIMCelt project at the end of November 2017 and before the publication of this report.

1.6.1. Assessment of the quality of the results

The confidence that can be placed in the intermediate and final results of the analysis is largely conditioned by the quality of the different data used. It is proposed to develop a data quality index (DQI) for each of the datasets used. Each of the indexes will provide explanations and guidance for identifying needs for additional data acquisition and / or scientific expertise. These data quality index will make it possible to calculate a results quality index (RQI) which will evaluate the final quality of the result. It is proposed to evaluate the DQI of the different data according to a 5 level evaluation grid as follow:

DQI = 0: data is undefined (value is null due to absence of data and/or assessment);
DQI = 1: data value is not null and quality is mediocre;
DQI = 2: data value is not null and quality is low;
DQI = 3: data value is not null and quality is medium;
DQI = 4: data value is not null and quality is high;

We propose measuring the data quality index for the following data:

- Theoretical relationships between activities and pressures as recorded in the activity-pressure matrix. The data quality index assesses the level of scientific expertise to support each relationship.

- Sensitivity scores between habitats and pressures. The data quality index assesses the precision of equivalence between the habitat types listed in the sensitivity matrix and the habitats effectively mapped, and the confidence index assessed by the experts who produced the sensitivity matrix.

- Benthic habitats mapping. The data quality index assesses the data sources, the method used for habitats validation and the age of the data.

- Activities and pressures mapping. The data quality index assesses the quality of the data sources used, the period of time covered by the data sets and their age.

The joint interpretation of the DQIs and the RQIs will ultimately make it possible to judge the overall confidence that can be accorded to the various analyzes and intermediate and final results. On the basis of these different quality index, the calculation method of the Result Quality Index remains to be developed and adapted to each intermediate analysis:

- mapping of human activities: Calculation of the RQI for IMA1, IMA2 and IMA3
- mapping of single and multi pressures: Calculation of the RQI for single pressure - single activity mapping $P_j A_i$, for for single pressure mapping P_j and for the Concomitant Pressures Index (CPI)
- mapping of the risk of concomitant effect: Calculation of the RQI for the risk of exposure between an ecosystem component *k* and pressure *j* ($REX\_P_jE_k$), the risk of effect between a habitat *k* and pressure *j* ($REF\_P_jE_k$) and for the risk of concomitant effects.

1.6.2. Assessment of the variability of the results

Finally, we propose comparing the results of analysis in the light of the different methodological options. These comparisons will help better estimate the variability of results depending on the methodological options, thereby better estimating the trends and interpretations that can reasonably be inferred on the basis of these results. For each of the six work steps identified in Table 7 it is proposed to test the influence of two different calculation options. Option 1 corresponds to the method implemented by default in this report and option 2 corresponds to a different approach.

Test 1: rule for assigning sensitivity scores to the benthic habitats mapped. When there is no exact equivalence between the benthic habitat typology mapped and the benthic habitat typology listed in the sensitivity matrix, option 1 uses the precautionary principle to assign a sensitivity score, according to the rules described in the table 5. The second option proposed is to calculate the median sensitivity score.

Test 2: rule for mapping activities. Option 1 is based on the use of a precise classification of human activities and practices as presented in the table 2. This resolution is used for multi-activity mapping and for calculating the risk of concomitant effects. As expected, many studies have shown that the variability of the final result is a function of the resolution for classifying the human activities studied (e.g. Ban *et al.*, 2010, for the commercial fisheries sector). Option 2 uses an approved less precise activity classification.

Test 3: rule for mapping pressures using data on activities at sea. Option 1 considers that the pressure is exerted where the activity is exerted, without identifying a potential area of effect for pressures caused by these activities. The step for integrating descriptive data on human activities into a relatively detailed grid (1' x 1') already indirectly produces an area of influence for pressures associated with activities. However, it is impossible to know whether this grid under- or overestimates the potential area of effect for pressures. Option 2 goes further but is much more complex to implement and involves identifying area of pressure effect for each activity-pressure combination. These areas of pressure effect can be defined on the basis of grey and scientific literature and scientific expertise.

Test 4: rule for mapping the concomitant Pressures Index (CPI). In the absence of a frame of reference on the relative contributions of activities to a single pressure, the contributions are considered to be identical ($c_{i,j}$=1).
Option 1 calculates the Concomitant Pressures Index as the sum of the pressures (P_j) without prior normalisation. This option gives greater weight to pressures resulting from many activities (P_jA_i). In option 2, pressures resulting from multiple activities (P_j) are considered to have equivalent weight for calculating the Concomitant Pressures index. in this option, each pressures (P_j) is normalised between 0 and 1, thereby erasing the influence of the number of activities considered.

Test 5: rule for assessing the Concomitant Effects Index (CEI): In option 1, the CEI is calculated using the sum of the risks of effects of pressures on ecosystem components ($REF\_P_jE_k$). Option 2 draws on the spatialised ODEMM method (GoodSir *et al.*, 2015) which identifies the cells where more than two "severe" pressures are exerted (level of impact = "severe and acute"). This method can be adapted for Carpediem by counting the Activity - Pressure - Habitat trios in each cell with a sensitivity score of $\mu_{i,j} \geq 0.75$ and identifying the cells where the sum of these scores is 2 or higher. This approach does not take into account the area of the habitat exposed to the pressure.

Test 6: rule for assessing concomitant effects: independent and combined pressures. The method for assessing the sensitivity score refers to a single pressure event that is exerted once on the habitat. This method was not designed for estimating the risks of concomitant effects. In option 1, whatever the frequency of activities and the number of activities exerting this pressure on the habitat, the resistance of the benthic habitat is considered identical and is that of a habitat with good conservation status. Option 2, inspired by Goodsir *et al.* (2015), involves downgrading the resistance score (e.g. by -0.25) for habitats facing pressure (P_j) generated by at least two activities in the same cell. With this option the response of the analysis to the intensity of pressure is therefore not completely linear.

Given the SIMCelt project schedule and the data formatting operations required for all tests, these different methodological proposals had not been developed and implemented before the end of 2017.

Table 7: Methodological options to test the variability of the analysis results

Test	Assessment step	Parameter or method	Option 1 implemented by default	Option 2
1	**Assignment of a sensitivity score to each habitat mapped**	Aggregation of habitat-pressure sensitivity scores	Use of the highest score (precautionary principle)	Use of median score
2	**Mapping of activities**	Resolution of classification of human activities	Level of description of activities = 3	Level of description of activities = 2
3	**Mapping of pressures using data on activities at sea**	Consideration of a potential area of effect for pressures	No potential area of effect identified (pressure is exerted where the activity is carried out)	An area of influence is identified for each activity-pressure combination
4	**Mapping of multi-activity pressures**	Calculation of P_j from P_jA_1 to P_jA_{ni}	No normalisation of P_j in order to retain the influence of the number of activities exerting the pressure	Normalisation of the sum of the intensities of pressured caused by the various activities P_jA_i
5	**Assessment of concomitant effects: calculation of the *REFC***	Effects integration method	Sum of the risks of effects of pressures on ecosystem components ($REF\_P_jE_k$)	Counting of “severe” pressures for each cell
6	**Assessment of concomitant effects:**	Use of the resistance score	Pressures considered independently: no impact on the resistance score	Pressures considered together: decrementation of the resistance score

2. Results

2.1. Human activities map

Three complementary versions of the index of multi-activity (IMA) are presented to illustrate the options for mapping human activities.

IMA1: Index of multi-activity 1

Mapping the sum of the presences and absences of an activity in each cell (IMA1) is the easiest and quickest option. This is presented in Figure 10. This map only provides information on the number of activities present at least once in each cell. This approach could be improved by differentiating between categories of activity such as mobile surface activities (transport, fishing, extraction) and on-ground facilities (shellfish aquaculture, artificialisation, cables, etc.). No information on the intensity of activities is included in the calculation. This approach is very easy to understand and very easy to implement.

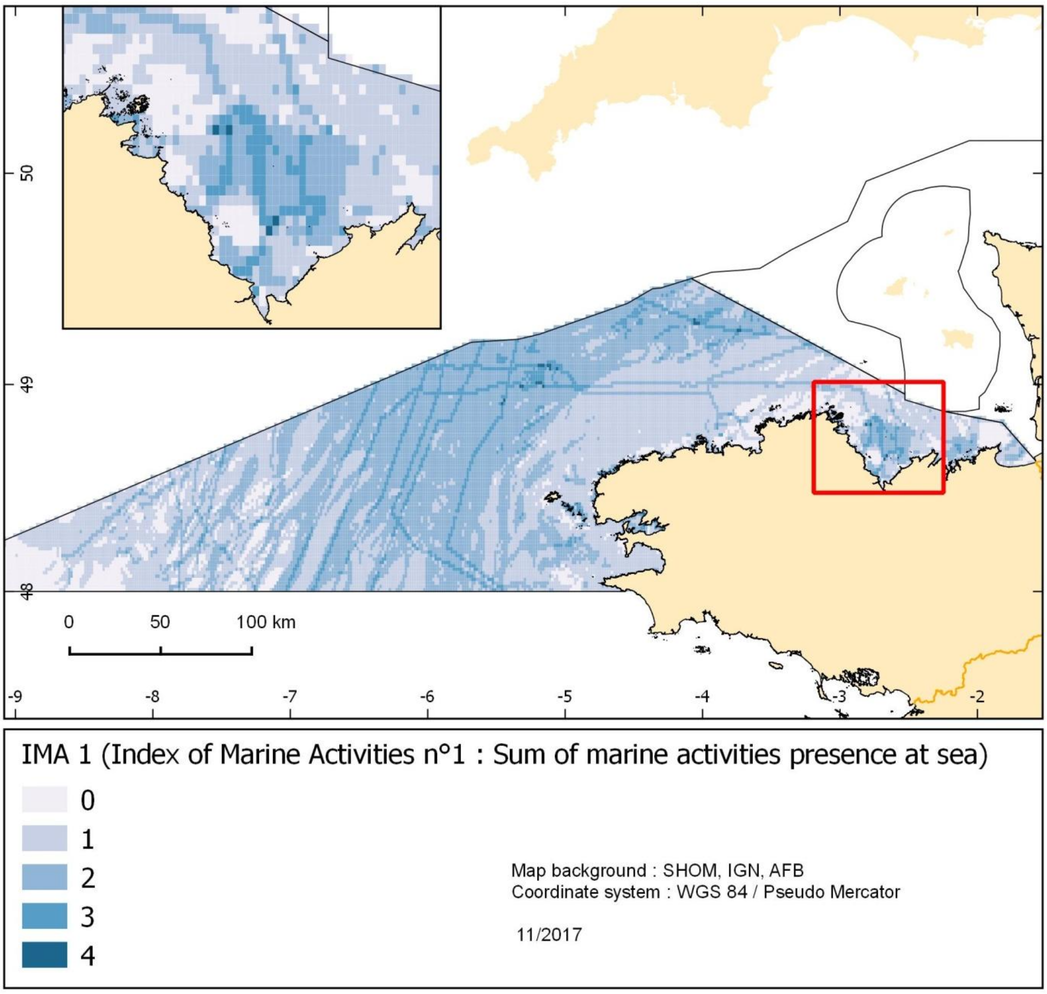

Figure 10: Map of IMA 1: Index of Multi-Activity (sum of the activities present at sea)

With the human activities actually studied in this analysis example, only a tiny proportion of the area, approximately 6% of cells, contain 3 or 4 activities. Most cells (over 80%) are used for 1 or 2 activities. Finally, around 12% of cells are not used for any of the activities considered.

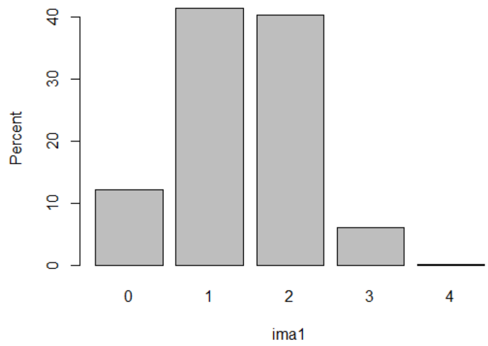

Figure 11: Distribution of cells, in percentage, for each IMA1 class (number of activities by cell)

IMA2: Index of multi-activity 2

The second proposal for an index to describe human activities involves adding together the log transformed and normalised intensity of the activities present in each cell. The IMA2 index shows both the number and intensity of activities. A single very intensive activity can produce a high IMA2 value, and vice versa. This analysis differentiates between areas with a high intensity of activity and areas with the presence of activities with lower intensities. Figure 12 shows the map of this analysis.

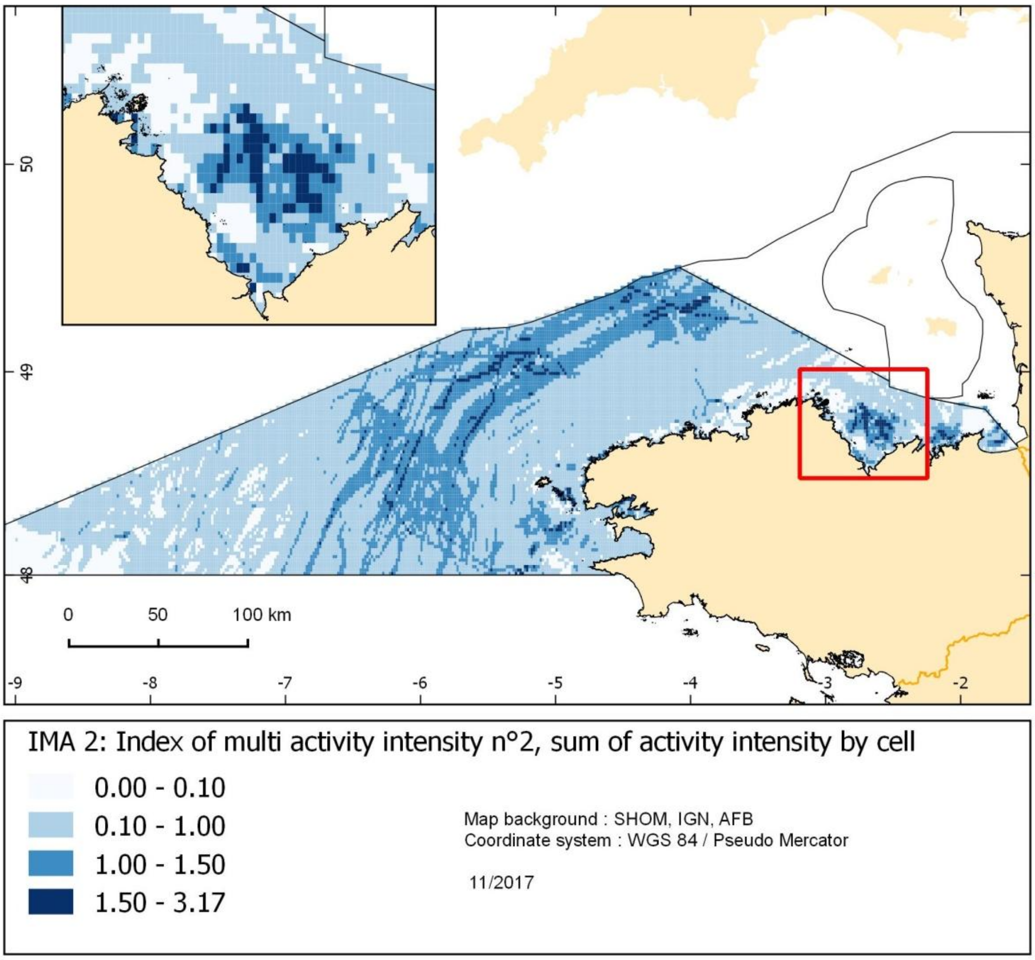

Figure 12: Map of IMA 2: Index of Multi-activity (sum of the log normalised activity intensity at sea)

However, the context of analysis (data studied and probably the study area) show no clear difference between IMA1 and IMA2. As shown in Figure 13, there is a very clear relationship between the number of activities present and the overall intensity of activities. The areas with the greatest diversity of activities also have the highest overall intensity.

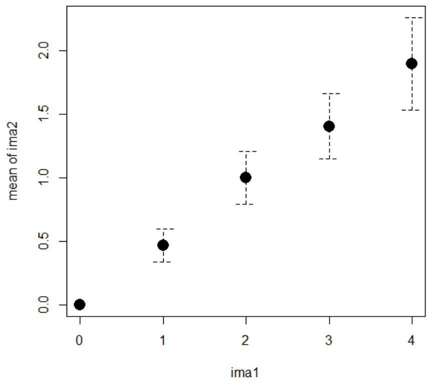

Figure 13: Average value of IMA2 (and standard deviation) for each IMA1 (IMA1=0: 0 activity, IMA1=4: 4 activities)

IMA3: Index of multi-activity 3

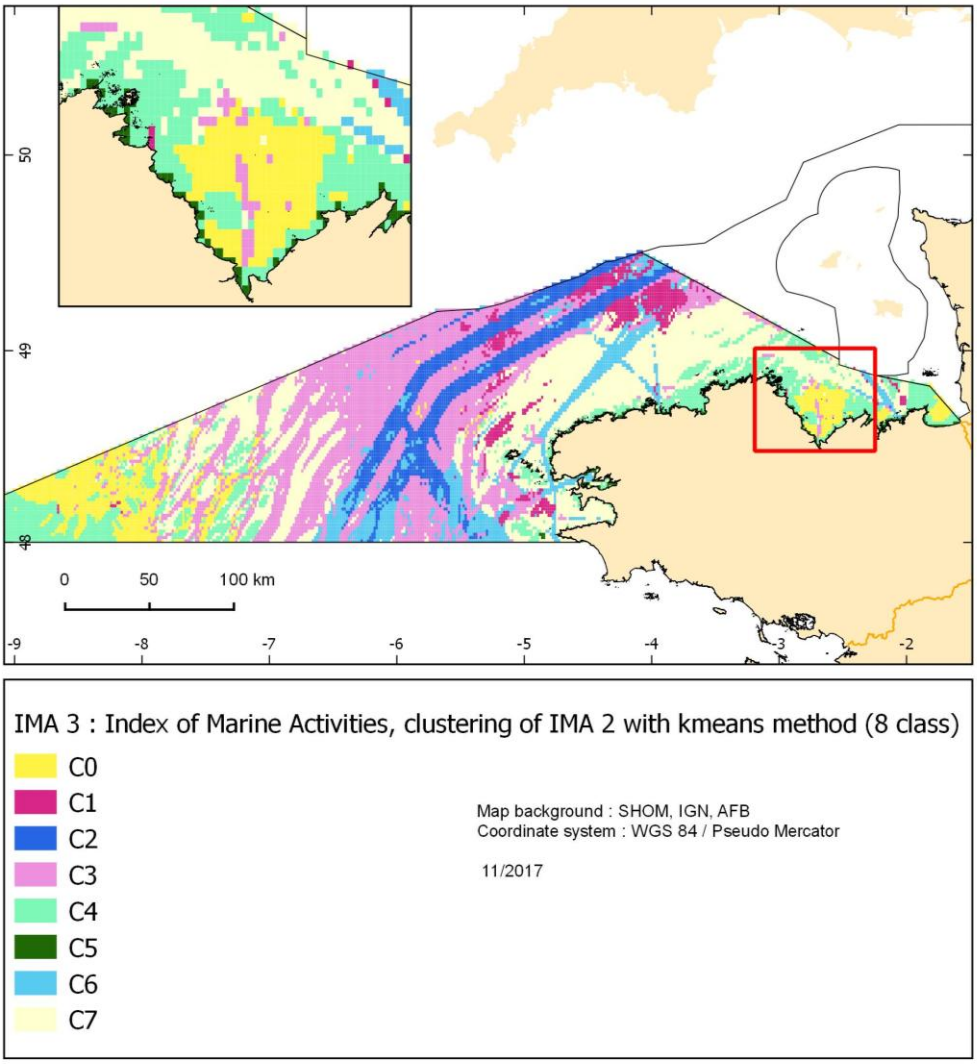

Figure 14: Map of IMA 3: Index of multi-activity (k-means clustering of IMA 2 in 8 class)

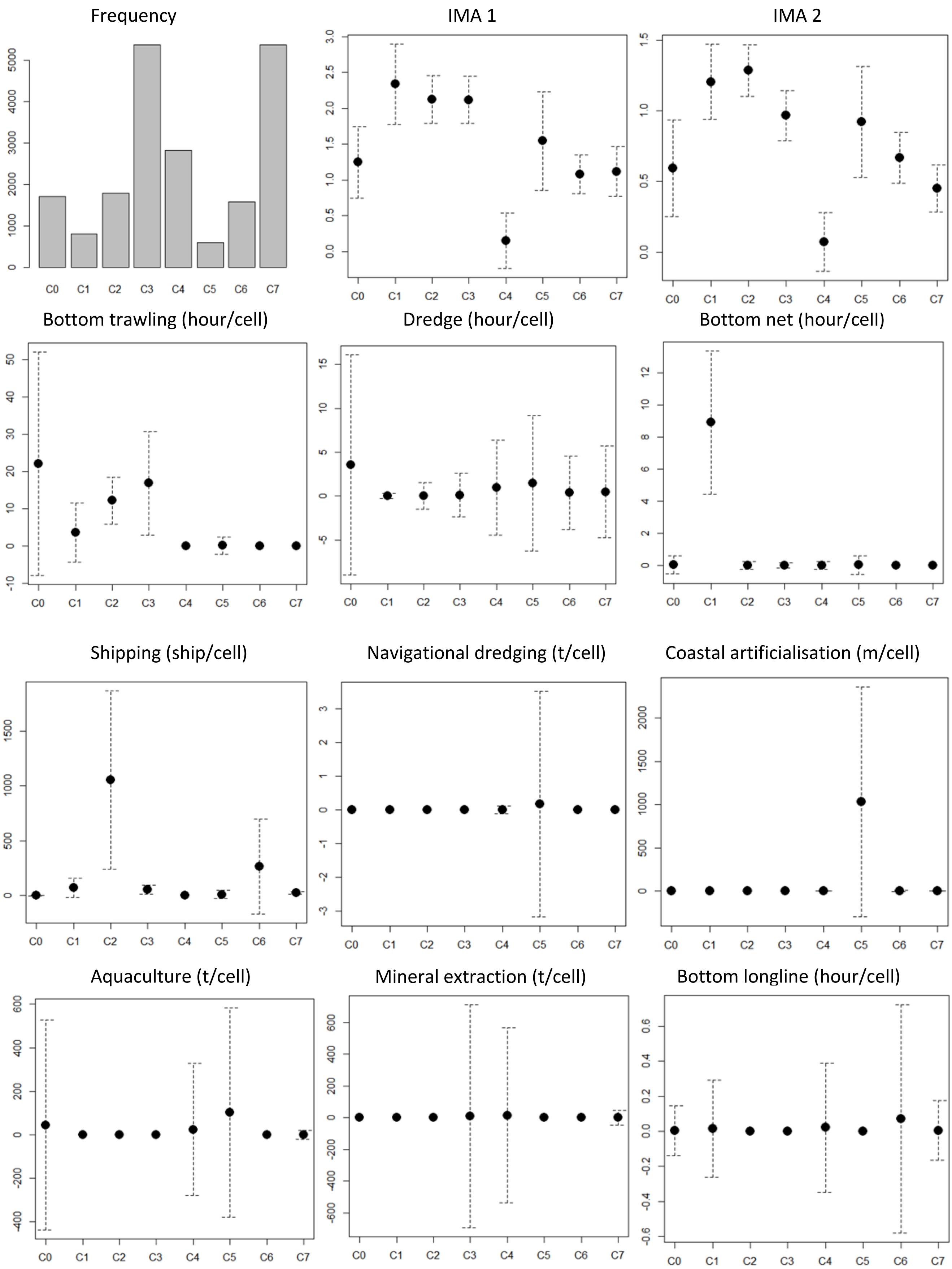

Figure 15: Class frequency and average intensity (standard deviation) for some activities

The final analysis proposed to describe human activities involves clustering cells together according to the similarity and intensity of their activities. The analysis carried out for this report does not apply to all human activities that exist in the area, making it impossible to draw realistic conclusions about the distribution of uses at sea. The following interpretations are designed to illustrate potential discussion of Figures 12 and 13.

- Category C0 represents approximately 9% of cells. It is characterised by the dominant presence of bottom trawling and dredge activities and the near absence of other activities.

- Category C1 represents approximately 4% of cells. It is characterised by dominant intensity of the bottom net activity. Various activities are present, in particular other fishing activities, but with lower intensities than for the bottom net.

- Category C2 represents approximately 9% of cells. It is characterised by the high intensity of shipping.

- Category C3 represents approximately 27% of cells. It is characterised by bottom trawling. Various activities are present, in particular other fishing activities, but with lower intensity levels.

- Category C4 represents approximately 14% of cells. It is characterised by low IMA1 and IMA2 values, corresponding to areas with little or no human activity, and with low intensities where activities are present. No activity really dominates this category. Activities include mineral extraction, aquaculture, bottom longline and dredging.

- Category C5 represents approximately 3% of cells. It is mainly characterised by very coastal activities such as shore and coastal artificialisation and aquaculture.

- Category C6 represents approximately 8% of cells. It is characterised by the presence and intensity of the secondary shipping traffic. Other activities are present, particularly bottom longline.

- Category C7 represents approximately 27% of cells. It is characterised by the presence of activities and medium intensities. Dredging and bottom longline are the most dominant activities.

2.2. Pressures and multi pressures index map

12 physical pressures from the human activities studied have been mapped

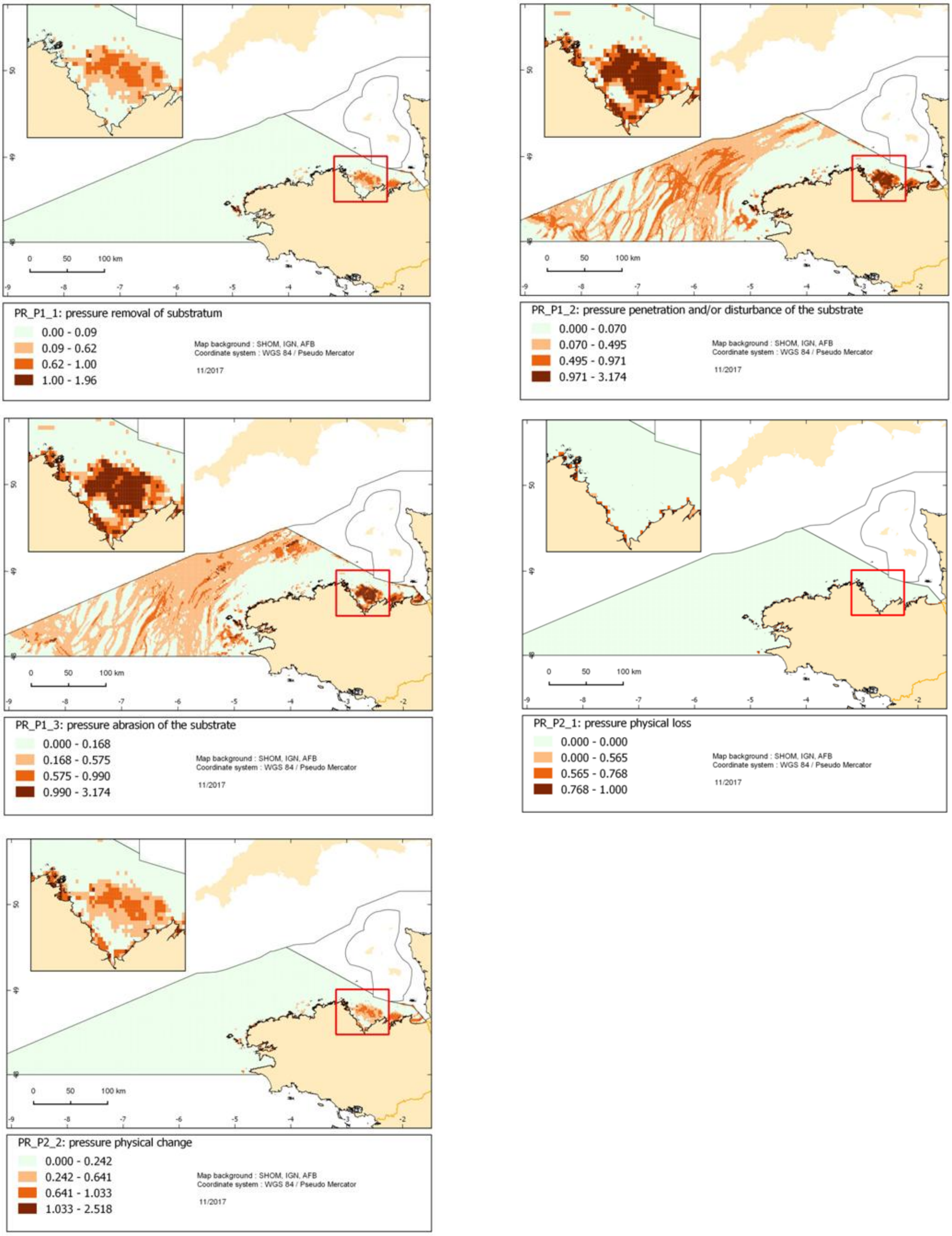

Figure 16: Physical pressures intensity map, part 1

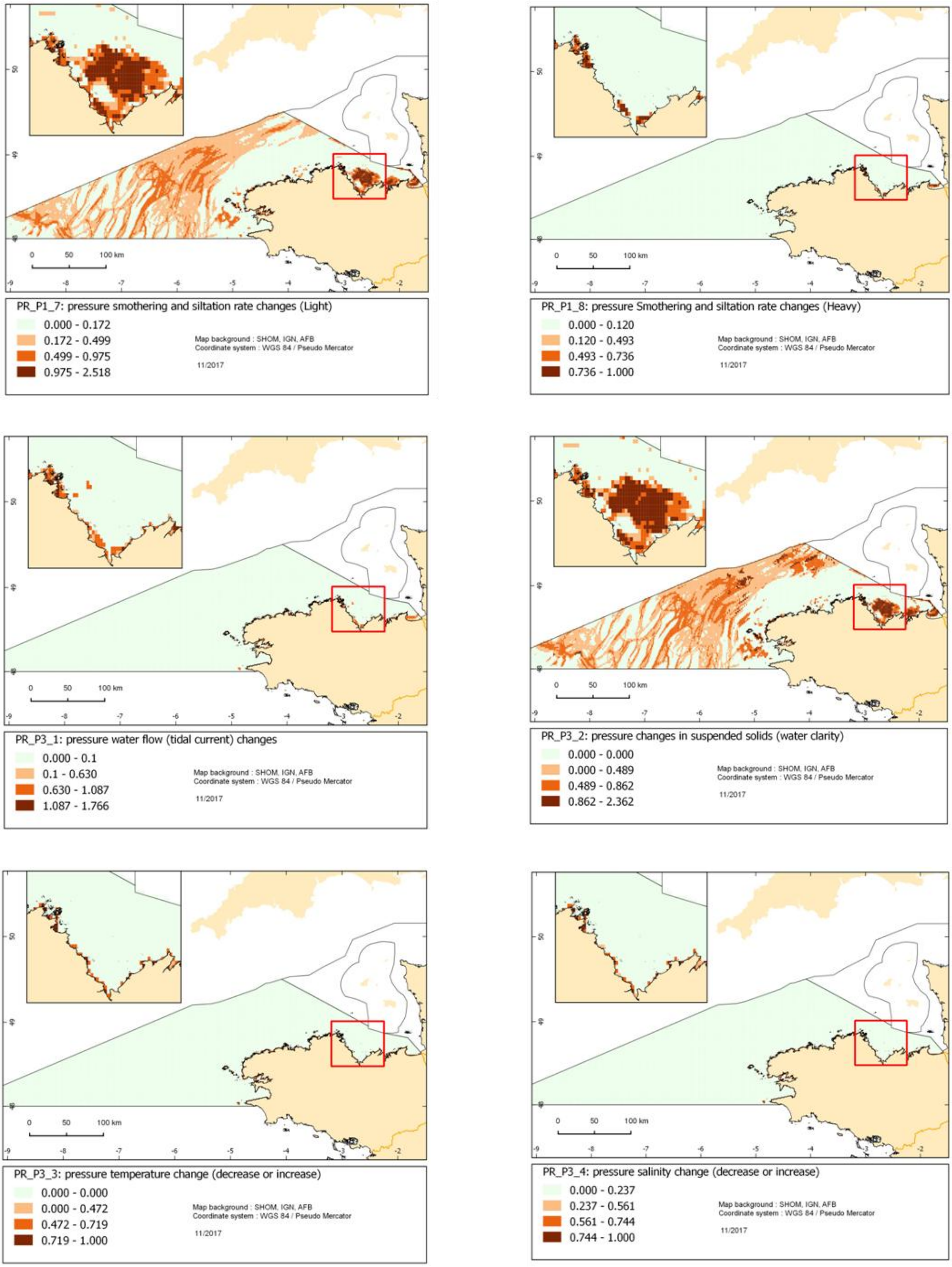

Figure 17: Physical pressures intensity map, part 2

Considering the human activities taken into account in the analysis, the pressures mapped are mainly exerted in the offshore fishing sectors and very coastal and shore sectors which are very diverse in terms of activities and facilities. The sum of all intensities of all these pressures is used to produce the Risk of Concomitant Pressure Index (IRPC), as presented in Figure 18. In this example, the shore areas and centre of Saint-Brieuc Bay are shown to present a number of issues for the management of physical pressures, given the intensity of the IRPC seemingly exerted here.

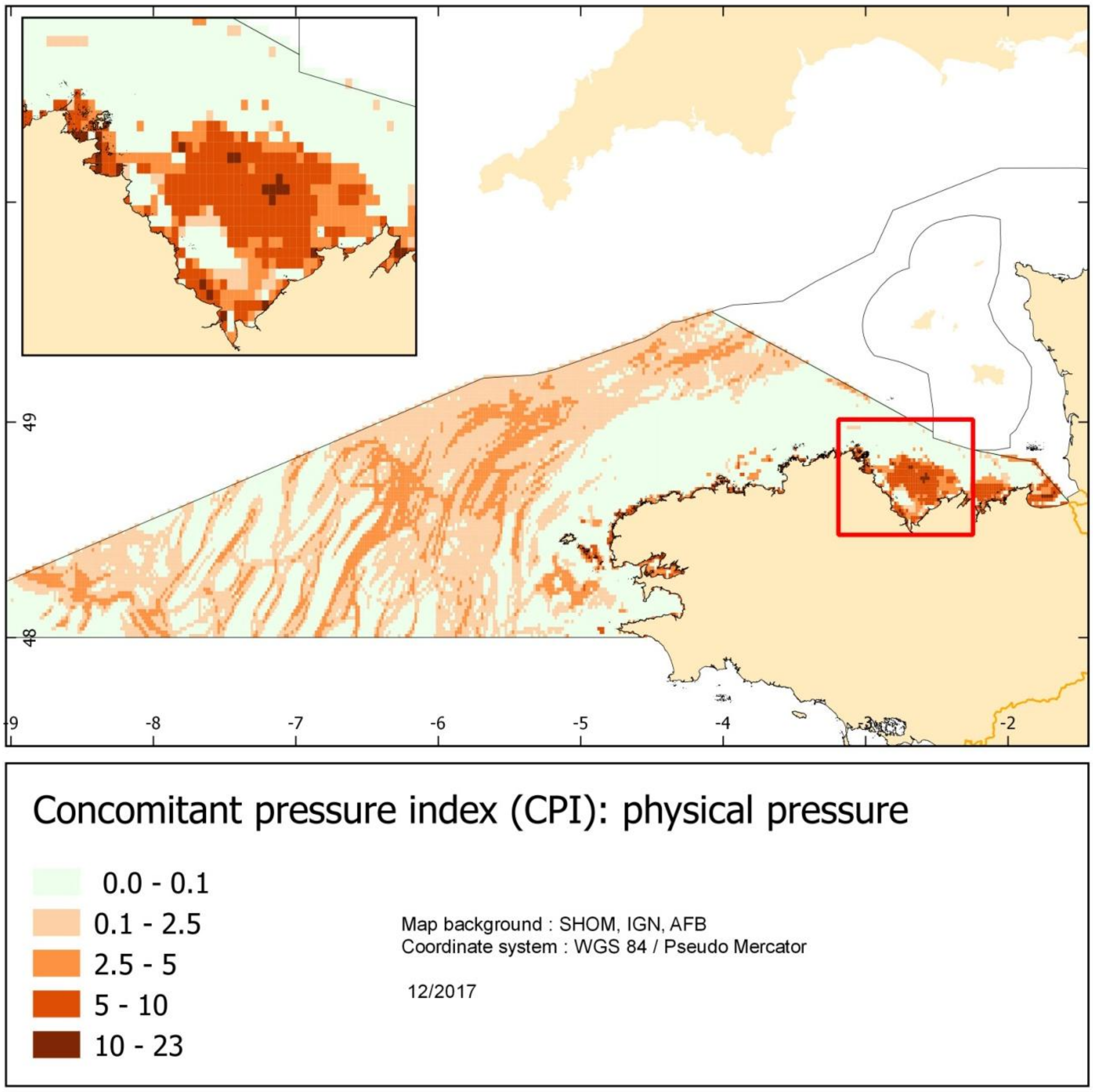

Figure 18: Concomitant Pressure Index map

A second approach based on a k-means clustering analysis to identify sectors with relatively homogeneous pressures and intensities. The pressures and intensities are grouped into 6 categories, described in Figures 19, 20 and 21:

- Category C0 represents approximately 30% of cells. It is characterised by an average CPI. Almost all pressures are present but with very low or almost zero intensities.
- Category C1 represents approximately 47% of cells. It is characterised by an CPI of around zero and the almost total absence of pressures.
- Categories C2 and C3 represent less than 5% of cells (C2: approx. 3%; C3: approx. 2%) and are characterised by a strong CPI. All pressures are present in these two categories,

with high intensities. The two categories differ through an inverse representation of dominant pressures: pressures mainly exerted in shore areas for C2 and pressures exerted further offshore, especially in Saint-Brieuc Bay or coastal areas, for C3.

- Category C4 represents approximately 3% of cells. It is characterised by a low CPI. There are only two significant pressures, both of medium intensity. It is primarily found offshore and appears characteristic of the sectors dominated by the bottom net activity, with the presence of other activities with a low intensity (Figure 14, category C1).
- Category C5 represents approximately 15% of cells. It is characterised by an average CPI. Many pressures are present but at medium or low intensity. These areas are primarily offshore and are characterised by bottom trawling and other fishing activities, but at a lower intensity level.

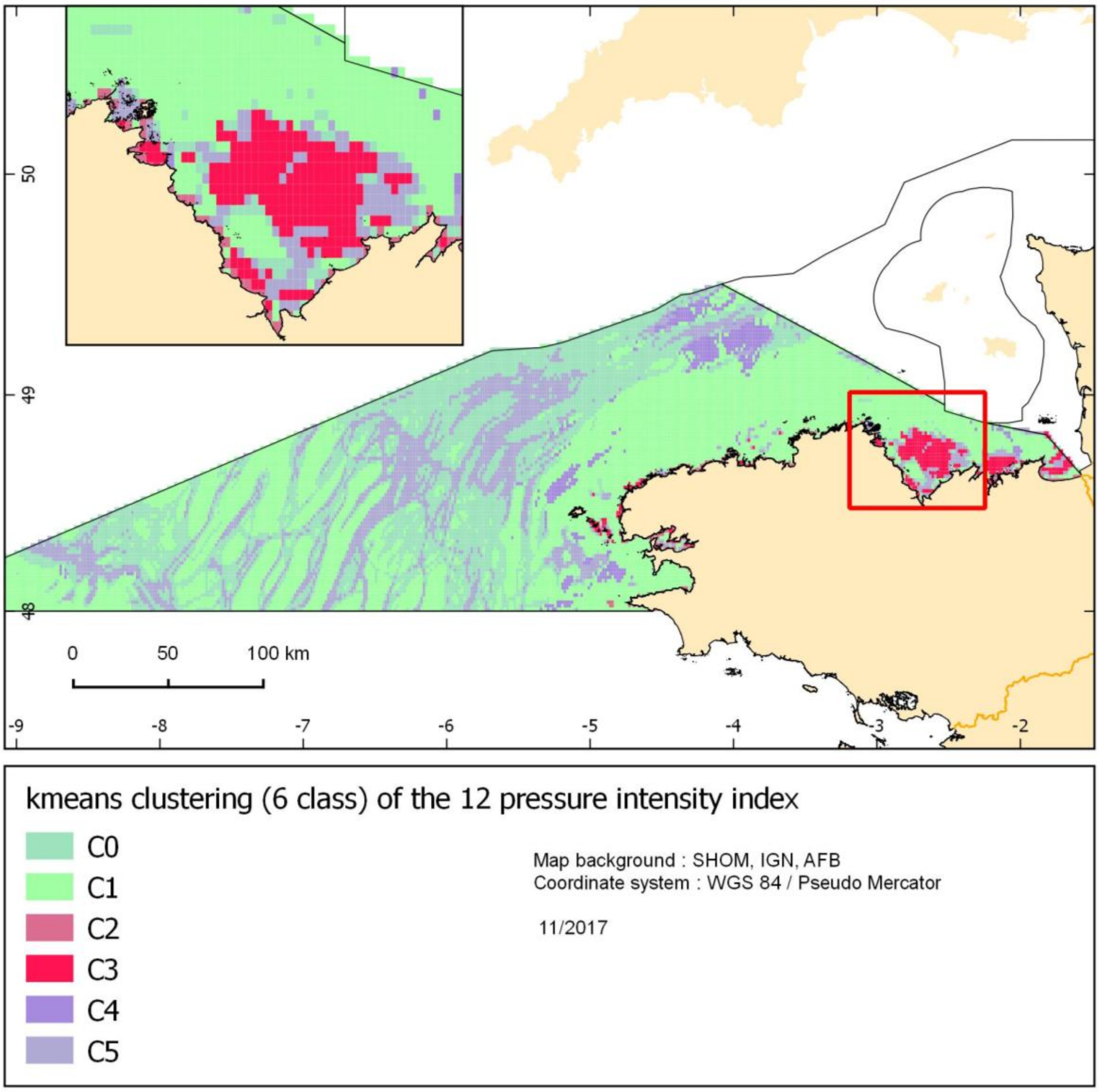

Figure 19: k-means clustering of the 12 pressure intensity index

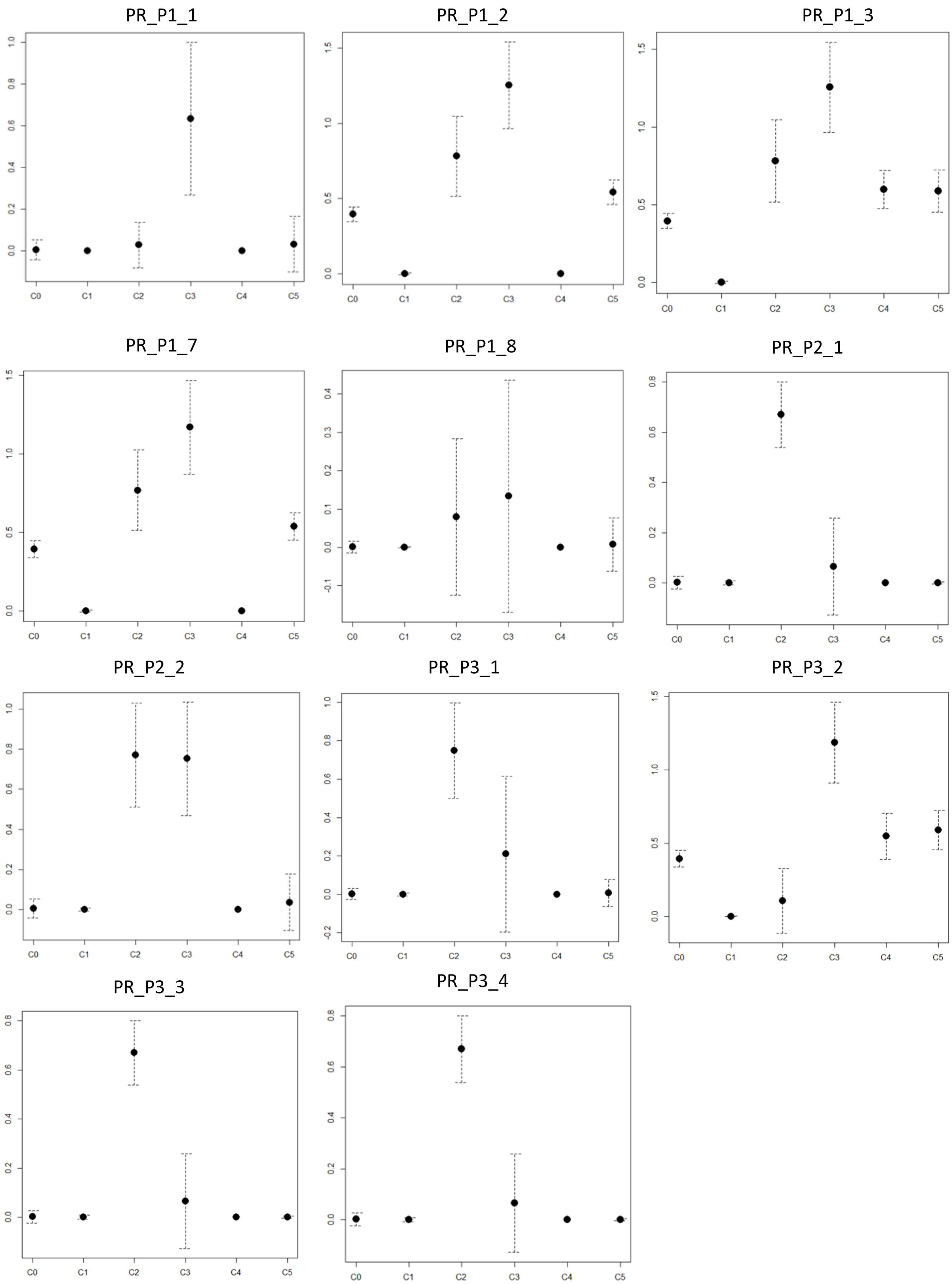

Figure 20: Average pressure intensity (standard deviation) for each pressure class

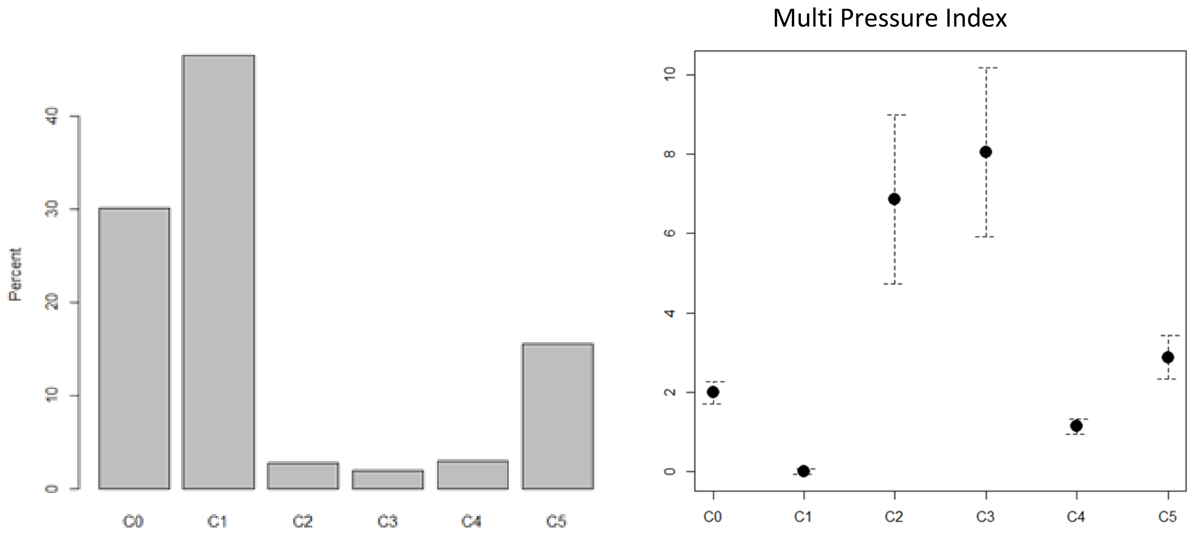

Figure 21: Class frequency and average Multi Pressure Index value (standard deviation) for each pressure class

2.3. Risk of concomitant effects map

The risk of concomitant effects was assessed for the benthic habitats mapped at least at Eunis level 4. Cells where the benthic habitats are mapped at lower levels were excluded from analysis. Only habitats whose sensitivity has been assessed for the pressures studied were analysed. Figure 22 shows the percentage of non-assessed benthic habitats in each cell. Most of the study area has not been assessed. A huge area off the Brittany coast to the north is home to habitat A5.15 (deep circalittoral coarse sediment, EMODnet-EUSeaMap) whose sensitivity has not been assessed for the pressures considered. This area represents approximately 85% of the number of cells in the study area. Analysis only actually considered 11% of the study area cells, most of which are located along the coastline.

Areas close to the coast also have areas that are not mapped with sufficient Eunis levels (approx. 9% of cells) or with a sometimes significant proportion of habitats with no available sensitivity assessment. This exercise used the Marlin-Maresa sensitivity matrix developed for the British Isles. It is therefore to be expected that some habitats present in the study area were not assessed under the Marlin-Maresa matrix as they are simply not present in British waters. Fortunately, the Saint-Brieuc Bay is covered by habitats with both a sufficient Eunis level and available sensitivity assessment.

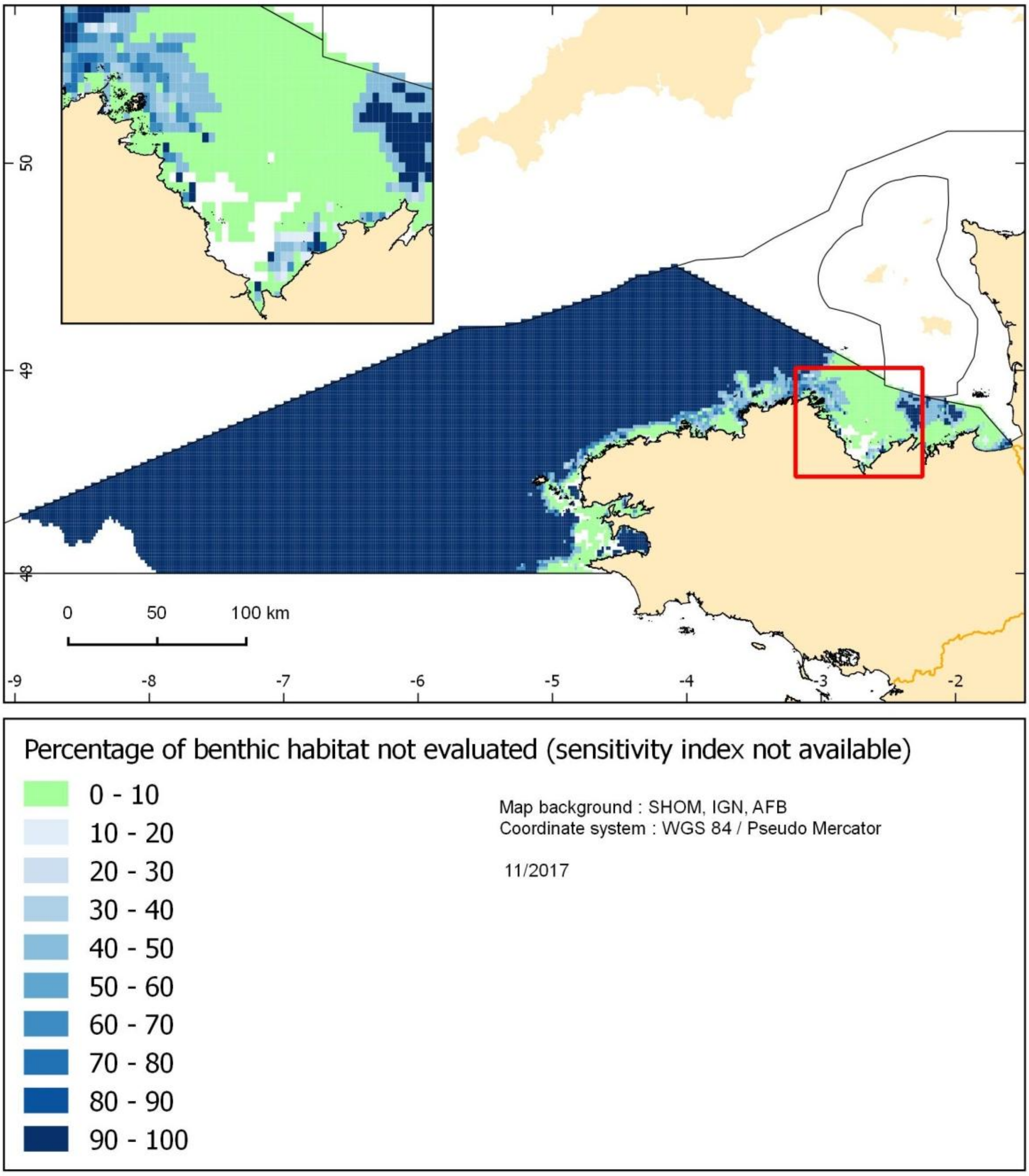

Figure 22: Percentage of benthic habitat not evaluated (sensitivity index not available). White cells inside the study area are not evaluated (benthic habitats mapped at Eunis level 2 or 3).

Figure 23 shows a map of the risk of concomitant effects for benthic habitats and the physical pressures considered in the analysis. Given that most of the area was not included in calculating the risk of concomitant effects, especially offshore areas, it is impossible to give statistics on the risk of concomitant effects index with regard to human activity areas (IMA3, sorted into 8 categories, Figure 14) and multi-pressure index areas (sorted into 6 categories, Figure 19). It is merely possible to observe that the IMA3 C0 category and the multi-pressure index C3 category are generally in the area with the highest risk of concomitant effects index.

The confidence indexes (Part 1.6) could not be calculated and calculation methods and working assumptions could not be compared (Part 1.7) before this report was published, which significantly limits assessment of the robustness and usefulness of the results presented.

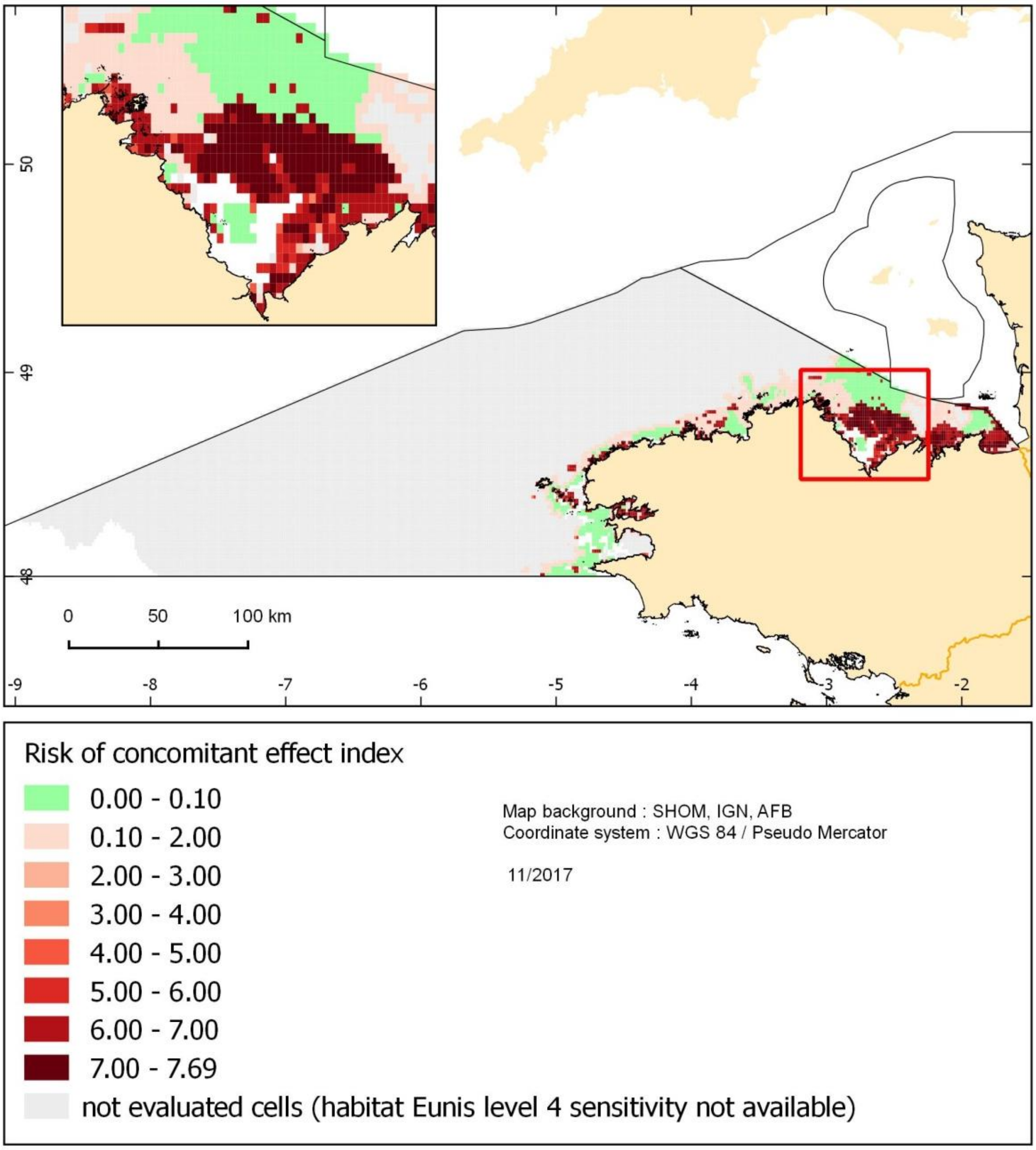

Figure 23: Index of Concomitants Effect (ICE) map

3. Discussion

The results presented in this report primarily seek to illustrate some methodological aspects and give examples of a finished product that could potentially be used in a spatial planning process.

3.1. Introduce risk of concomitant effects into the marine spatial planning process

Under the spatial planning process, mapping the risk of concomitant effects can help inform policymakers on environmental management issues. The approach proposed in this report seeks to develop a replicable process based on an analytical approach. These analyses are used to identify, define and rank the areas where ecological features are already subject to a number of pressures and/or may be subject to additional pressures. The proposed approach is also useful for identifying ecological features and areas which appear to be less subjected to pressures, or certain pressures. Finally, it can identify sectors where knowledge on ecological components, their sensitivity to pressures and/or human activities needs to be produced or made accessible.

The most obvious benefit from such analysis for MSP is to allow decision makers to be informed on the current level of anthropogenic impact in areas arising from MSP process.
Figure 24 shows an overlap between a map of the risk of concomitant effect index and the perimeter of a planned wind farm concession that is to be installed in Saint-Brieuc Bay soon (blue). In this example, the wind farm development will probably create additional pressures on the benthic habitats in very contrasted area regarding existing pressures. According to the data we used in this example, the north of the wind farm area shows a relatively low intensity of bottom fishing activities and associated physical pressures in recent years (2013-2016). Benthic habitats in this area seem to be less exposed to pressures and the risk of concomitants effects seems to be low. In the south of the wind farm area, benthic habitats seems to be more exposed to pressures and the risk of concomitants effects is high, due to a relatively high intensity of bottom fishing activities and associated physical pressures in recent years (2013-2016). Additional pressures associated to the wind farm building and utilisation in these two contrasting areas could probably lead to very different concomitants effects between the north and the south part of the wind farm area. This example, according to the incomplete data we used, could show two different management's issues for this wind farm setting up.
Figure 24 shows perimeters of the marine Natura 2000 network as well (yellow). In the same way as for the windfarm, these MPAs experiments very contrasted situations regarding the risk of concomitant effect within their perimeters. This information could support the management of these MPAs by setting priority areas for uses regulation. Moreover, the risk of concomitant effects index shows that Natura 2000 sites do not appear to be significantly less exposed to pressures than areas over the sites. This assessment could be of importance in the monitoring of these MPAs efficiency. In the context of broader MSP, cumulative effect assessments must be a part of the monitoring process to assess whether or not enforced plans and measures reach environmental requirements.

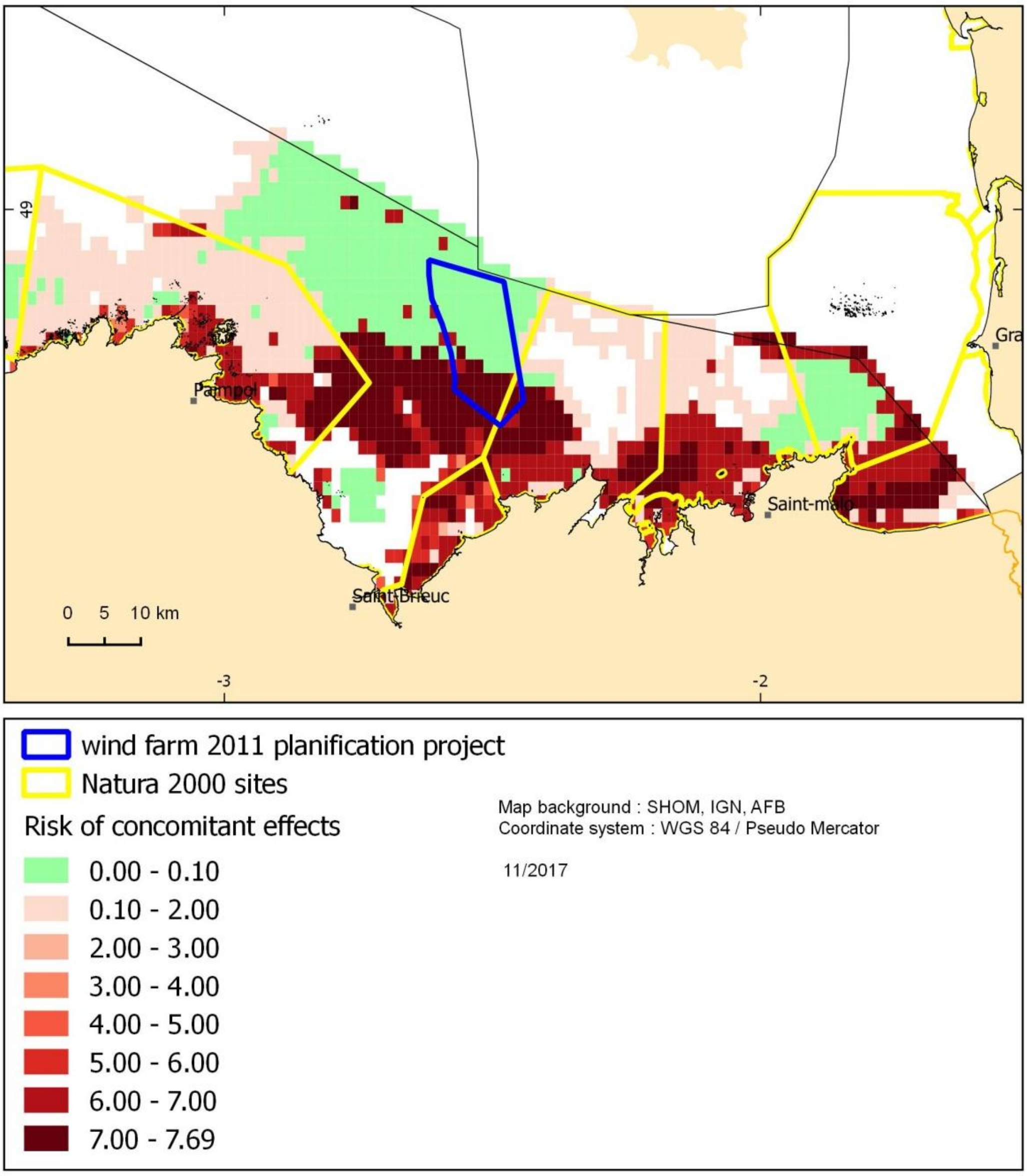

Figure 24: Example of integration of Risk of concomitant effects with Marine Spatial Planning issues (Wind farm project and Natura 2000 sites)

By assessing level of pressures affecting environmental features at their distribution scale (not only within local planning perimeters such as MPAs or areas dedicated to particular activity), statistical analysis of results at a broader scale could also be a way to set priorities for conservation measures.

Figure 25 show statistics calculated at the study area scale (Celtic Sea French waters): average value of the index of concomitant effects and average value of the index of multi activities for benthic habitats within the most exposed areas to the risk of concomitant effects (cells experimenting risk of concomitant effect index of over 4). The benthic habitats considered in this figure are ranked according to their surface within high ICE index cells.

Habitats located on the left of the graphic are largely represented within areas experimenting high level of risk of concomitant effects. These habitats should be considered with attention when planning conservation measures as well as activities that could affect them. Particularly considering that some of these benthic habitats under pressure are considered as very vulnerable and of major conservation issues, like for example maerl beds and phanerogams beds.

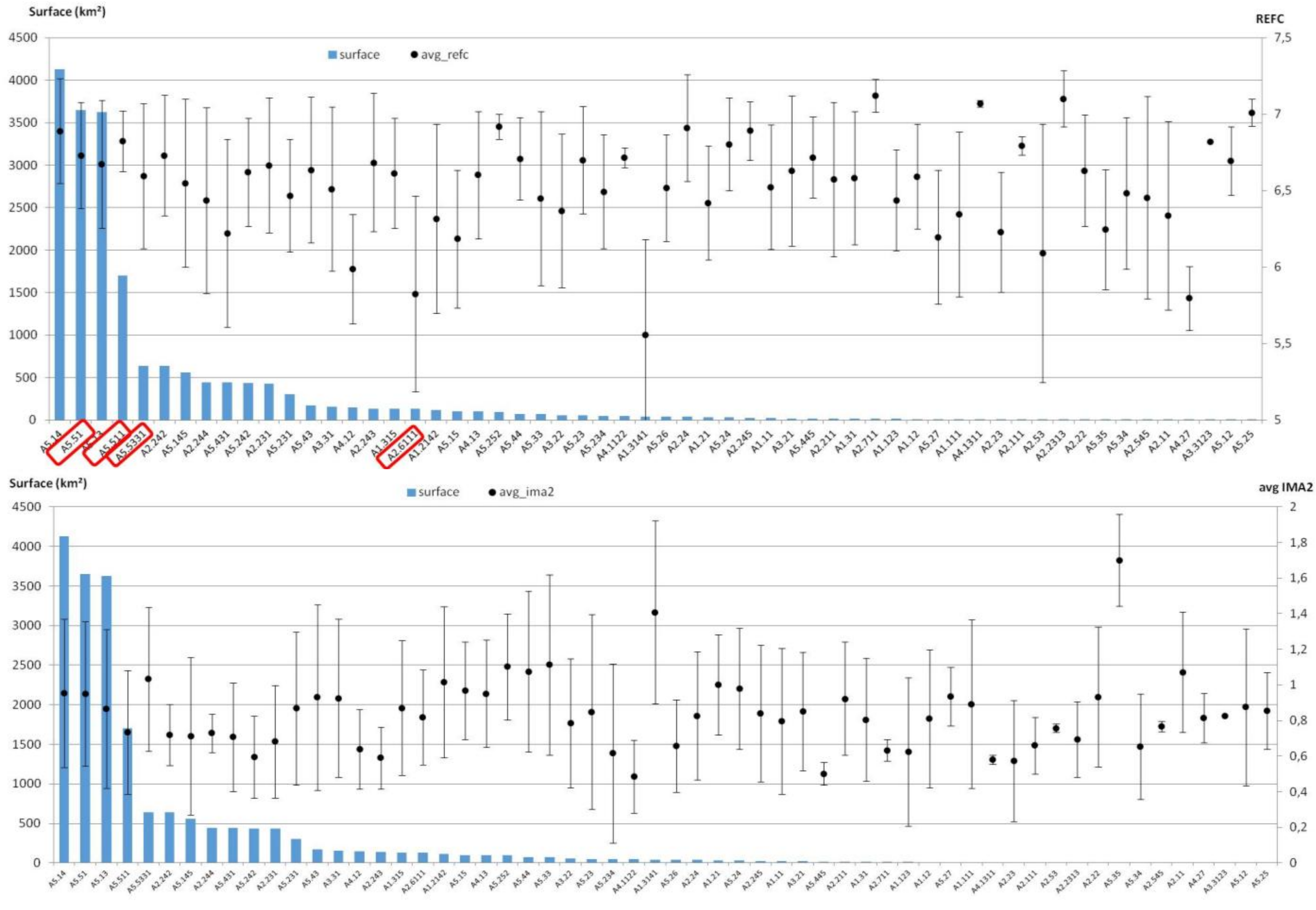

Figure 25: Summary statistics for each of the benthic habitats most exposed to higher value of ICE (located in cells with an Index of Concomitant Effect (ICE) value up to 4. Benthic habitats are listed in x axis, surface of habitats in km² in the left y axis, top: average value and standard deviation of ICE on right y axis, bottom: average value and standard deviation of the IMA2 on right y axis. Red squared habitat codes correspond to maërl beds habitats (A5.51; A5.511) and seagrasses beds (A5.5331; A2.6111).

3.2. Constraints and perspectives

Not all of the methodological aspects of our approach could be developed through this SIMCELT case study, in particular the quality and the variability assessment. A number of methodological difficulties remains and need to be discussed and validated. This concern, for example, the distance of effect from a pressure source and the seasonality. However, with the exception of the seasonal approach that is probably impossible to achieve in the next few years, all these methodological points are not the major constraint associated with this approach.

The biggest constraint with the proposed methodology is the time required to collect and format a broad variety of relatively precise data before conducting analysis. In this context, the chemical and biological pressures originating from rivers and catchment basin were not taken into account in the analysis, while the north coast of Brittany is very concerned by nitrate and phosphate inflows from agricultural activities. The exhaustiveness, the accuracy and the quality of the data is a major challenge in this type of approach. To go further, significant efforts must be made to include chemical and biological pressures from agricultural and industrial activities on land as well as pressures generated in the marine environment beyond national borders.

The implementation of the MSP and MSFD policies poses many challenges in the analysis, cross-checking and synthesis of descriptive data of the marine system. This context should favor the development of multi-purpose tools and cross-cutting approaches. Mapping the risk of concomitant effects is an objective that integrates the entire complexity of the marine system, both human and ecological. As such, this objective can be unifying to advance analytical approaches that truly integrate the human activities planning issues and the challenges of achieving and / or maintaining good ecological status. At the European level, recent studies argue in this sense the need to develop transversal and multi-objective tools to meet these challenges (Depellegrin et al., 2017, Fernandes et al., 2017). These studies and this report argue that the implementation of these marine policies, including the general question of "cumulative effects assessment" need to be addressed in a holistic manner with multi-objective tools.

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Appendix

Pressure code	Pressure
pr_p1_1	Removal of substratum (extraction)
pr_p1_2 & pr_p1_6	Penetration and/or disturbance of the substrate below the surface of the seabed
pr_p1_3	Abrasion/disturbance of the substrate
pr_p1_7	Smothering and siltation rate changes (Light)
pr_p1_8	Smothering and siltation rate changes (Heavy)
pr_p2_1	Physical loss
pr_p2_2	Physical change
pr_p3_1	Water flow (tidal current) changes, including sediment transport considerations
pr_p3_2	Changes in suspended solids (water clarity)
pr_p3_3	Temperature change (decrease or increase)
pr_p3_4	Salinity change (decrease or increase)