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A strategy for monitoring systemic vulnerability to marine erosion and flooding

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The authors would like to thank all of their colleagues, student trainees and managers who have worked with them on systemic vulnerability over the last fifteen years along the entire French coast. They would also like to thank the funders of the research programs that have enabled progress to be made on this issue: the French National Research Agency (ANR) (Projet-ANR-10-CEPL-0001Cocorisco), Fondation de France and DREAL Bretagne (the regional directorate for environment, planning and housing of Brittany).

1 Although uncertainties remain about the rate and magnitude of sea level rise in relation to climate change, trends are confirmed towards an increase in coastal erosion and flooding hazards. (IPCC, 2018). At the same time, littoralisation, or coastal settlement, continues to intensify on a global scale (Neumann *et al.,* 2015), thereby generating ever more hazard-related stakes. In this context, for the last two decades or so, there have been growing societal concerns about coastal risk and increased demand from public authorities for diagnostic, monitoring and decision-making tools. In France, there has been an upsurge in this demand since the dramatic weather event of storm Xynthia in 2010 in which 47 people lost their lives on the Atlantic coast (Vinet *et al.,* 2012). This dramatic event initiated the development of a national strategy for integrated coastline management (SNGITC) (Medde, 2012) which interacts with and the national strategy for flood risk management (SNGRI) (2014). A government review is currently underway on the feasibility of a "spatial restructuring of coastal areas" for

the sustainable management of urbanised coasts in a context of climate change (CGEDD, 2019).

2 It must be noted that erosion and flooding risk data is still too fragmented to meet this demand. Natural and human and social sciences have still not sufficiently cross-referenced their knowledge and methodologies on these issues to provide synthetic data that is easily understood by decision-makers and citizens, and readily available to inform government decision-making. Inter- and intra-disciplinary dialogue is made difficult by the notion of "vulnerability", a polysemous notion that is often just seen as the social component of risk and therefore unsuitable for synthesising knowledge or supporting decision making. Bearing this in mind, the present article will use the concept of "systemic vulnerability" (Meur-Ferec *et al.,* 2008) as it integrates all the contributing factors (natural, economic, political and social) of the vulnerability of coastal areas.

3 While systemic vulnerability has so far only been used statically as a tool enabling the diagnostic analysis of a region (Hénaff and Philippe (dir.), 2014), the Osirisc[1] research project proposes a dynamic methodology for monitoring its development. Through interdisciplinary and inter-sectorial work between researchers and managers, we have developed a series of indicators for monitoring systemic vulnerability. The dual purpose of this approach is to advance research and to provide a decision-making tool for policy-makers. It is a precursor of an observatory on systemic vulnerability to coastal risks.

1.1. An integrated and broad approach to vulnerability

1.1. Vulnerability, a very common and polysemous term

4 The first thing that became apparent from the literature review was that a consensus on vulnerability is far from being reached. This can be seen from the extensive state of the art on the subject (Delor and Hubert, 2000; Eakin and Luers, 2006; Gallopín, 2006; Gilbert, 2009; Nicholls and Hoozemans, 2005; Turner *et al.,* 2003; Wismer, 2016 to name but a few) and the diversity of conceptual approaches presented and justified by the authors. For example, Thywissen (2006) identifies 36 definitions of vulnerability! Over the past 20 years, this notion of vulnerability has also developed significantly in publications on the impacts of climate change (Adger, 2006; Birkmann and Welle, 2015; Gornitz, 1990; Kasperson, *et al.*, 2005; Magnan, 2009; Klein and Nicholls, 1999; Nguyen *et al.,* 2016; Turner *et al.*, 2003, etc.). Even in the narrow field of coastal zone vulnerability, such differences in the use of the term has prompted the French Ministry of the Environment to commission the bureau of geological and mining research (BRGM) to produce an international literature review on the issue (Romieu and Vinchon, 2009).

5 his polysemous dimension stems from the fact that these definitions developed simultaneously in different disciplinary fields (Thywissen, 2006). "Natural risks" went from a highly hazard-centric approach at the turn of the 1980s-1990s to one that was more oriented towards social dimensions taking into account the structural and functional factors of the communities exposed to hazards (Becerra, 2012; Foucher, 1982; Morel *et al.,* 2006; Léone and Vinet, 2006; Veyret and Reghezza, 2006). Vulnerability is more than just a "negative" notion (Gallopín, 2006; Provitolo, 2012) as it also includes mitigating factors; it refers to a region's hazard preparedness and longer-term

adaptability (Birkmann and Welle, 2015). This is why some authors (Balica *et al.,* 2012; Turner *et al.*, 2003) integrate an organisational component (governance, management methods, etc.) into vulnerability that determines, inter alia, the system's resilience.

6 Finally, vulnerability is region-specific in that it is closely associated with the region's history, land use and population (Barnett *et al.,* 2008; Turner *et al.*, 2003). As such, it cannot be a universal notion, described by a single method based on a single formula (Barnett *et al.,* 2008). Gallopín (2006) highlights that instead of trying to perpetuate the illusion of a one-size-fits-all conceptual approach for all regions and all scales, the key is to adopt local solutions that are scientifically and operationally satisfactory. This ties in with the geographical approach by Cutter *et al.* (2003) through their concept of the "place-based approach" to vulnerability.

7 The different approaches to vulnerability can be seen as complementary to assessing the concept's complexity and its relation to social-environmental systems (Eakin and Luers, 2006). Bearing this in mind, preference should be given to pragmatic approaches based on the characteristics and problematics of the regions under consideration, by choosing a clear conceptual framework and a common terminology understood by all of the stakeholders concerned.

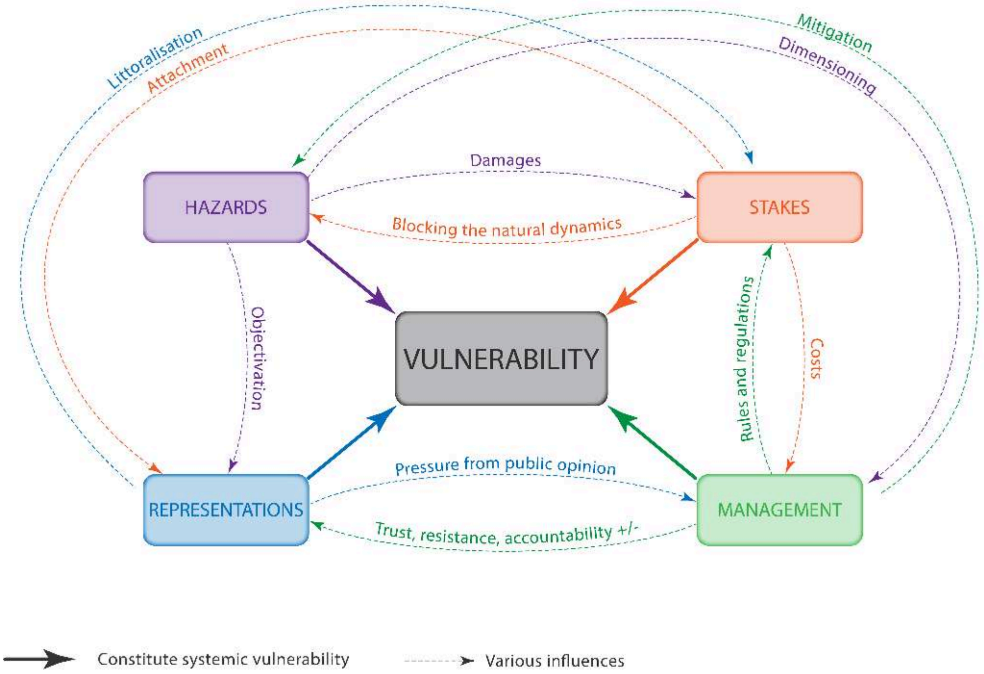
1.2. Systemic, interdisciplinary and inter-sectorial vulnerability

8 Among this proliferation of uses of the concept of vulnerability, we propose a "systemic vulnerability"-based approach towards coastal flooding and erosion risks (Meur-Ferec *et al.,* 2003, 2008; Hénaff and Philippe (dir.), 2014; Nichols *et al.* 2019). It is an approach that draws upon previous studies, in particular those by D'Ercole (1994), who defines the vulnerability of societies through their capacity to respond to potential crises, a capacity which depends on cyclical (hazard) and structural (social, economic, cultural, functional, institutional) factors. One of the features of our approach is that it considers hazards to be an integral part of vulnerability, whereas in general, they are studied separately. This separation of hazards and vulnerabilities, which can be explained by the history of natural, technical and social sciences, is still very much present in research today but has become outdated (Gilbert, 2009; Hellequin *et al.,* 2013). The integration of hazards into vulnerability prevents "a categorical, naïve reading of the hazard-vulnerability pair that pits nature against culture" (D'Ercole and Pigeon, 2000).

9 With this meaning, vulnerability no longer becomes the social parameter of risk, but an outcome of the fragile nature of a region as a whole. Vulnerability as a system is therefore the result of the combination of four interdependent components (fig. 1). Traditionally, *hazards* (1) (here coastal erosion and marine flooding) are more or less natural processes likely to damage or destroy the *stakes* (2) that are exposed to them. The stakes are the people, property and activities in an area exposed to the hazard. These two components enable risk to be defined, but they are not enough to assess vulnerability. Two other components are taken into account. *Management* of risk (3) encompasses protection, prevention and crisis management public policies and their application by the actors involved in governance at the field level. *Representations* (4) reflect the relationship that people living in the region have with risk (risk sensitivity, relationship to place, adaptation preferences, understanding and acceptability of management policies, etc.). This "representations" component has long been neglected

in risk studies, but its importance was dramatically highlighted in France with the Xynthia storm disaster (Hellequin *et al.*, 2013).

Figure 1. Systemic vulnerability modelling approach



Source : Modified from Meur-Ferec *et al.*, 2008

10 This approach can provide a snapshot of systemic vulnerability at any given time (Meur-Ferec *et al.*, 2008). There is no fixed start or finish point for this model; all components are interrelated and considered holistically to examine how they interact and respectively contribute to the formation of systemic vulnerability (fig. 1, solid arrows). First of all, hazards and stakes are essential, constitutive components of risk: without one or the other there would be no risk and therefore little point in assessing management and representations. Similarly, these two components are critical factors influencing the overall assessment of vulnerability: when the hazard is weak and the number of stakes are low, reduced risk sensitivity among populations and management policies that take little account of risk are far less consequential than if the hazards and stakes were high. However, as a general rule, management is consistent with reducing vulnerability (even if improper management can have negative effects). It is much harder to understand the potential impact of people's perceptions of vulnerability as they can cause it to increase or decrease. Finally, the four components are heavily dependent on one another (fig. 1, dotted arrows). For example, management influences stakes by regulating construction in exposed areas, representations of the coastal area as a privileged place to live influence stakes by increasing littoralisation and coastal settlement, and hazards influence management by conditioning the choice and size of coastal protection structures, etc.

11 The systemic vulnerability approach therefore involves a multi-criteria analysis. It also enables the systemic vulnerability of a region to be deconstructed and, for example, the components that contribute the most to overall vulnerability to be identified. Depending on the region, these may be major hazards (strong coastline retreat,

exposed low-lying areas, etc.), a high concentration of stakes on the coastal strip (housing, shellfish farming facilities, etc.), little consideration of risk in urban planning documents, and/or residents' lack of interest, etc.

12 Due to the wide range of skills needed to address systemic vulnerability, this approach involves interdisciplinarity as a matter of course, and even a "broad" interdisciplinarity (Jollivet, 1992) that combines natural sciences (physics, geology, geography, etc.) and social sciences (geography, economics, law, psychology, sociology, etc.). Systemic vulnerability helps to break out of the nature-society dichotomy by placing vulnerability within the ecumene. It is accepted that geography, at the interface between natural and social sciences, might play the role of "environmental science" (Berque, 1996).

13 In addition to this conceptual coherence, systemic vulnerability implies a cross-sectorial approach that links academia and industry. This calls for research to be opened up to practitioners and regional authorities, and enables the two-fold objective of research and management to be met. Risk managers (government services, elected representatives, technical services of local authorities, etc.) are both knowledge providers who contribute to the vulnerability components, and users of the systemic analysis results. The aim of this integrated approach is to help inform political decisions to take action on vulnerability by defining, for example, priorities for short and medium-term interventions and choices for the strategic and sustainable management of coastal areas.

14 We have progressively developed this concept of systemic vulnerability in several research projects (Pnec[2] 2002-04, ANR Miseeva[3] 2008-11, ANR Cocorisco[4] 2011-2013), but so far only statically as a tool for regional diagnosis at a specific time. We know, however, that from a temporal perspective, the vulnerability system is mostly dynamic: each component and its constitutive variables has its own trajectory with different temporalities, sequences and impulses (Gallopín, 2006; Magnan, 2018). Temporal monitoring of their developments through regular assessments will therefore improve knowledge about them and better inform management strategies. To achieve this, we have developed, within the framework of the Osirisc[5] project (2016-20) and in close collaboration with managers, an indicator-based method for monitoring the dynamics of the four components of systemic vulnerability.

2. Using an interdisciplinary and inter-sectorial method to build a monitoring tool for systemic vulnerability

15 As a complex notion, vulnerability cannot be measured directly because it is derived from a social construct as well as an objective "reality" (Kienberger *et al.*, 2009; Morrow, 1999). It requires the construction of a set of thematic variables for describing their different components, and then the combination of these variables, particularly in the form of indexes (Barnett *et* al., 2008; Cutter *et al.*, 2000; McLaughlin and Cooper, 2010; Preston *et al.*, 2011). As the variables are produced from different metrics, collected in the field or extracted from different databases, they must be recorded in a common repository so that they can be compared and jointly analysed. The variables then become indicators. The search for relevant and operational indicators for evaluating

and monitoring vulnerability is therefore the first and necessary step towards a systemic approach to sustainable coastal risk management (Barnett *et al.,* 2008; Meur-Ferec *et al.*, 2009).

16 Monitoring mechanisms and indicators addressing hazards are plentiful: the inventory of the various coastline observatories in France carried out by the bureau of geological and mining research (BRGM) (Bulteau *et al.,* 2011) showed that there were 52 coastline monitoring operations, all with very different scopes. The more recent inventory carried out as part of the Osirisc+ project (Cocquempot, *et al.*, in prep) listed 69 coastal "observation institutions" with very diverse functions. This wide range of initiatives even prompted the Ministry of Ecological and Solidarity Transition to support the creation of a National Network of Shoreline[6] Observatories in 2017.

17 However, the same cannot necessarily be said for the development of other systemic vulnerability components that have not attracted the equivalent methods and tools. In this respect, it is conceptually and methodologically challenging to determine the relevant monitoring indicators for *issues*, *management* and even more so for *representations* (which are difficult to gauge).

2.1. A common methodological framework

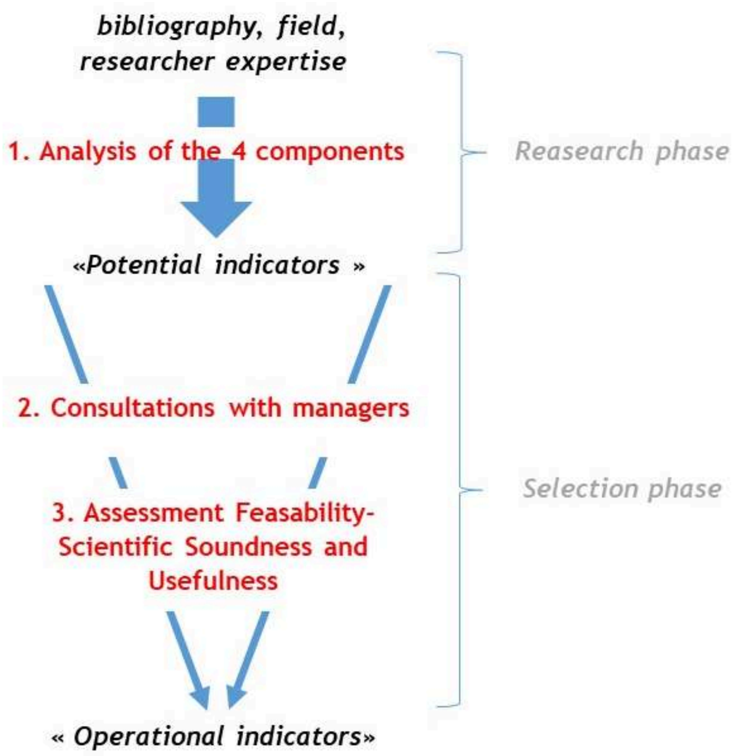
18 A methodological framework common to all the components and disciplines involved in the research was selected. The study was carried out on the basis of bibliographies related to methodological approaches in various disciplines, fieldwork, and close collaboration with the Osirisc project monitoring committee made up of coastal risk managers (government services and local authorities).

19 The first step was to select quantitative and/or qualitative variables that would serve as indicators and that were representative of the different components. Without minimising the interrelationships between the components highlighted in Figure 1, we decided to develop indicators that were independent of one another. As a result, the second phase involved exploring the different combination of indicators to generate the relevant indexes. Thus, for example, stakes were considered separately from hazards and it is only through their combination that a risk index is obtained. This choice was also linked to the study's dynamic dimension: a population currently unaffected by a hazard is not at risk, but the way in which these hazards or stakes evolve may pose a risk in the future. Therefore, care must be taken not to compromise the future scientific and operational uses of the proposed observatory. Furthermore, and contrary to sectoral approaches, such as the exposure of residential buildings and their residents to coastal erosion or flooding (Juigner *et al.,* 2017; Créach *et al.*, 2015), we aim to integrate all of the dimensions of coastal vulnerability. As such, one of the difficulties encountered was reducing the number of variables to obtain a sturdy tool while still making sure it remained operational for the managers who would be expected to input information about certain variables.

20 The study was divided into several phases (fig. 2): an initial inventory (1), by component, was carried out based on a literature review of the indicators and drawing on the expertise of the researchers involved. In this phase, nearly 90 "potential indicators" were obtained for the management component alone, which brought to light the danger of creating a tool that was scientifically sound but operationally unusable. There was an initial selection (2), along with the occasional addition, that

relied on consultation with managers'. Then, researchers (3) made choices based on the criteria of both scientific soundness and operational usefulness, taking into account the exhaustiveness, accuracy, and accessibility, etc. of the data.

Figure 2. The different steps of the methodology of constructing indicators



Source : modified from Quillet *et al.*, 2019

21 The end result of 62 "operational indicators" was obtained from a process of conceptual and methodological discussions, both between researchers from different disciplines and through expertise sharing between researchers and managers (Kienberger *et al.*, 2009; Papathoma-Köhle *et al.*, 2016). These indicators are the result of concessions made between the complexity of the vulnerability system and the time required for the repeated collection and processing of very different types of data from very different sources. They also reflect the compromise made between this complexity on the one hand, and the clarity, usefulness, accessibility and social acceptability of the information generated on the other.

22 Once the indicators had been selected, calibration was used to transform the heterogeneous raw data (that which had been measured, collected in the field or gathered in a database) into hierarchical data. To successfully homogenise quantitative and qualitative data expressed in different units (distances, surface areas, numbers, proportions, opinions, etc.), the data were classified according to a five-point rating scale and where possible, according to the impact of the indicator on overall vulnerability. Depending on the nature of the raw data, these scales can be defined by statistical, arithmetic or empirical methods. Where variables are quantitative and have a normal distribution, the use of quantiles is recommended. Calculated from all of the data in the study area, quantiles make it possible to preserve the distribution of the source data and to highlight extreme values. When the amount of data is limited,

statistical discretization methods are of little relevance, for example, the number of listed buildings or protected historical and architectural monuments (for stakes). Data observation (natural thresholds) thus makes it possible to empirically establish the class boundaries. Finally, when the variables are qualitative (as is often the case for the management component, for example), ratings from 1 to 5 are defined by researchers together with practitioners.

23 Finally, two dimensions are essential for the operationalisation of all monitoring indicators: space and time. The spatial scale at which the indicators are reported may vary according to component, but the dimension of the elementary entity adopted to present the indicators (granularity) must be defined. An elementary grid of 200 x 200 metres is used for the hazards and stakes components. As this grid is not very suitable for management and representations, the data are aggregated at the *commune* level for these two components. The temporal scale, corresponding to the repeated time step for the measurements and surveys, is specified for each indicator according to its greater or lesser temporal variability.

2.2. Adjustments to the features of each component

24 The variety of components and disciplines involved leads to adjustments in the methodology of constructing indicators according to the components.

2.2.1. Hazards

25 The construction of hazard indicators draws from the national and international literature, which is relatively extensive for this component (for example, Gornitz, 1991; Abuodha and Woodroffe, 2010; Hegde and Reju, 2007; Martínez-Grana *et al.,* 2016; Cerema, 2017). Eroded distances established in segments of 200 linear metres serve as the national reference values for the erosion hazard (including the National Coastal Erosion Indicator produced by the Centre for studies and expertise on risks, environment, mobility and urban and country planning – Cerema). The flooding hazard is based on water levels in low-lying zones and the 100-year flood return period established by the naval hydrographic and oceanographic service Shom, and the maritime and river technical research centre Cetmef (2012) is used. These data averaged over several decades (erosion), or observed or modelled (flooding), make it possible to define the magnitude of each hazard and to produce the five severity classes for each of them. As for granularity, erosion measurements are taken from reference points, along transects or from portions of coastline showing morpho-sedimentary and/or hydro-sedimentary homogeneity. In the field, measurements are taken according to the protocols set up in the numerous coastal observatories, by topography, the acquisition of geolocalised ground photographs, or by smartphone applications such as Rivages and Crisi (Cerema). The flooding hazard is measured when it occurs. Specifically, the water level in the flood extended area is measured according to procedures adapted from existing protocols (Cerema, 2017). These data points are then assigned to a 200-metre grid. This grid has the advantage of being independent from the administrative division, which is key to the naturalistic data of this component.

26 Calibration from 1 to 5 is based on the principle that the greater the severity of the hazard (eroded distance, flooding level), the closer the value of the indicators is to 5.

Logically, and all other things being equal, more hazards mean increased risk and therefore increased vulnerability.

2.2.2. Stakes

27 In France, data on the stakes are increasingly abundant and accessible through geographical reference information (France's large-scale reference database (*Référentiel à grande échelle* – RGE) by the National Institute of Geographic and Forest Information (IGN), the Public Finances Directorate General (DGFIP) cadastral database, gridded data from the Institute of Statistics and Economic Studies (Insee), etc.). This makes it possible to reduce field work, which is generally very time consuming, and to access descriptors that are hard to see or not visible on the ground (living space, materials, etc.). However, field work is still indispensable for describing certain attributes that are not included in these databases (roof openings, elevations, "safe havens" etc.) and must therefore be collected on site, which may require lengthy survey work. Partnerships with local authorities and government services are therefore valuable, especially as the authorities produce these data for operational purposes, which tends to improve their quality and updating, and their regional legitimacy makes individual data collection acceptable to the residents concerned.

28 Geographic information repositories make it possible to produce most of the indicators at a fine granularity level, which is relevant for our indicators, while still making them reproducible at the regional or national level. However, while it is desirable to describe the stakes as accurately as possible, it is also essential to guarantee the confidentiality of individual data (housing status: main or secondary, occupant characteristics, etc.) and access to this data is regulated by the French data collection watchdog CNIL. For this reason, Insee now disseminates census data through its 200-metre granularity gridded data. In addition, some data have a strategic value that may make disseminating them sensitive. For example, a representation aggregated to the 200-metre grid makes it possible to provide information on these indicators while preserving the confidentiality of the detailed data. As this 200-metre grid is also the basic grid used for hazards, these two components can be easily cross-referenced to determine risk.

29 In terms of calibration, the more stakes there are, the closer the score will be to 5. As with hazards, an increase in stakes leads, all other things being equal, to an increase in risk and therefore vulnerability.

2.2.3. Management

30 The management indicators are partly based on data that is available on the internet (risk prevention plan, i.e. *plan de prévention de risque* – PPR), action plan for flood prevention (*plan d'action pour la prévention d'inondations* – Papi), etc.), and partly on the field surveys by government services and local authorities.

31 One of the special characteristics of this component is that it directly affects the work of managers who, more so than for the other components, are both data generators and end users. Therefore, the indicators can only be constructed in close collaboration with these managers. Sorting and calibrating indicators is done in full cooperation but does not always lead to a consensus as each party may have different opinions about an indicator's importance or meaning (Quillet *et al.,* 2019). Not all managers are in the

same position and differences often arise between government services and local/ regional authorities. When managers disagree, some decisions are made by the researchers in their capacity as experts. For example, we believe that levying a tax for the management of aquatic environments and flood prevention (*gestion des milieux aquatiques et prévention des inondations* – Gemapi) is a step towards greater accountability for local actors and thus a means of reducing vulnerability, whereas for some local authorities it is more a sign of government disengagement and a means of increasing regional inequalities.

32 In the management component, particular attention must be given to ensuring that managers do not feel that they are being assessed by the researchers. This is not a judgement on the quality of their work, but rather a comparison of the region's progress with other regions and above all an analysis of its development over time. This highly management-oriented trajectory can be influenced by political or financial levers. For this component, more so than for the others, knowledge is clearly shared between researchers and practitioners, between public policy theories and the realities of their applications in the field.

33 The calibration of management indicators is the opposite to that of hazards and stakes, based on the principle that management tends to reduce vulnerability. Thus, the more the management is considered to be "advanced", the closer the score is to 5, and the more vulnerability tends to be reduced.

34 *Commune*-level granularity was selected for the scale of the management indicators. It is the smallest link in the application of public policies, even if inter-municipality is now becoming the preferred scale for the application of many coastal risk management tools.

2.2.4. Representations

35 The representation component undoubtedly poses the most conceptual and methodological challenges. How can we achieve an "observatory of representations"? Numerous measures are necessary for the construction and especially the interpretation of indicators.

36 The first feature of this component is that the data are not pre-existing (no national databases, no dedicated website) and as such must be created by repeated surveys among people concerned by the municipalities studied. A pre-test was carried out for three months in spring 2018 in *communes* in the Gulf of Morbihan. Several means of communication were used to encourage people living or working in these *communes* to answer an online questionnaire. Information was published on town hall and tourist office websites, Facebook pages, etc., and associations and schools were contacted and provided with the link. Information posters were put up in the town hall, media centre, and on scrolling billboards in the town. A parallel face-to-face questionnaire was carried out in one *commune*. Conducting a survey is difficult because, despite numerous requests, the number of respondents is often low for self-administered questionnaires (for example, 79 responses were obtained from eight *communes* during the pre-test carried out in 2018). People must often be recruited to directly conduct these surveys, which consequently requires considerable working time and costs.

37 The second feature is that the data provide answers to survey questions on place attachment, trust in actors, on being more or less concerned or even worried about

coastal risks, development preferences, etc. Most of these indicators are not directly associated with vulnerability. For example, a strong place attachment can both heighten vulnerability as it may mean that individuals will not relocate even if they are in an at risk situation, and also reduce vulnerability because the person may be very "concerned" (Brunet, 2008) and therefore have greater mobilisation and adaptation capabilities. Performing a 5-point calibration is therefore difficult because these indicators are, for the most part, indirectly associated with vulnerability, and only make sense when interpreted together. In other words, this component aims to provide qualitative information on vulnerability. It provides a snapshot of a person's representation of their living place, which is important knowledge at the managerial level and useful for gaining an understanding of how this representation evolves, which is of paramount importance to researchers studying social dynamics.

38 This makes representations complex to analyse as they are the results of a range of individual and collective factors (social, cultural, environmental, etc.) (Hellequin *et al.*, 2013; Michel-Guillou and Meur-Ferec, 2017).

3. Results: the monitoring indicators in the four components

39 Our results yielded 62 indicators divided into four components. They are presented in Table 1.

Table 1. Osirisc indicators

Component	Theme	Description
Hazards	Erosion	Eroded distance per year per 100 linear metres Eroded area per year per 100 linear metres Eroded volume per year per 100 linear metres
	Migration	Speed of dune migration
	Flooding	Water level Coastal areas exposed to seawater and run-off
Stakes	Human	Number of inhabitants Number of residential buildings Percentage of people < l0 years or > 65 years Percentage of low income households Percentage of second homes Residential building footprint
	Economic	Tourism accommodation capacity Number of jobs Average property value (per m2) Diversity of activities Ground surface area of buildings for economic purposes

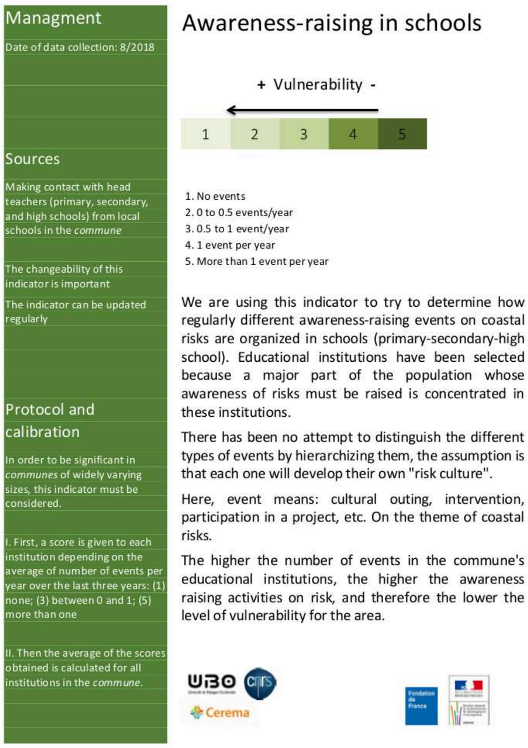
	Structural	Hosting capacity of institutions that are open to the public Location of at-risk industrial establishments Road density Percentage of the coastal area with coastal defence structures Location of residential buildings without a "safe haven" Presence of an emergency facility Distance from an emergency facility Number of listed buildings or protected historical and architectural monuments Presence of a port
	Buffer zones	Areas taken up by agriculture Number of environmental zones[1]
Management	Land use planning	Constraints for constructability in hazardous areas Status of the risk prevention plan (*plan de prévention de risque* – PPR) (coastal or marine flooding)
	Local strategy	Local approach (Papi[2], SLGRI[2], SLGITC[3], other) Relocation covered in local strategy Papi implementation Stakeholders involved in the local strategy Investment in people for coastal risks Integration of actors from outside the region Levying of the GEMAPI tax in place Condition of the coastal defence structures
	Crisis management	Integration of the SDIS[4] in the PCS[5] Update of the commune safeguarding plans (PCS[5]) Means of alert
	Awareness raising	Flood and coastline retreat markers Coastal risk associations Awareness raising in schools Methods of disseminating the background document on the major risks for the *commune* (DICRIM) Pedagogical analysis of the DICRIM
	Knowledge	Scientific publications on coastal risks
Representations	Sense of place	Place attachment Sea-related activities
	Risk awareness	Personal experience of risk Indirect experience of risk Active information (voluntary search for information) Place of coastal risks in local issues Awareness and level of concern about risk Knowledge of management programs Individual practices put in place

	Evaluation of institution and collective practices	Opinion about prevention and evacuation measures Opinion about reinforcement of existing coastal defences/relocation of buildings Trust in institutions

1 We consider here that the stake of natural heritage does not increase vulnerability, but rather provides an opportunity for adaptation: the more natural areas that are "free" for mobility, the less vulnerable they are.
2 SLGRI: Local strategy for flood risk management
3 SLGITC: Local strategy for integrated coastline management
4 SDIS: Departmental fire and rescue service
5 PCS: Commune safeguarding plans

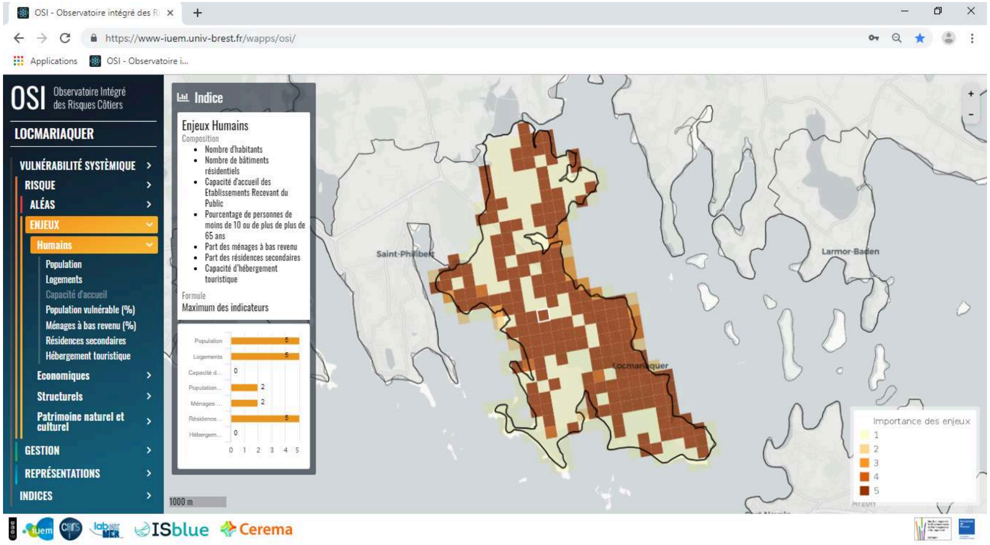
40 Each indicator is accompanied by a metadata and protocol sheet specifying its function, data sources and their quality, if any, and the protocol for filling it in, and performing the calibration in five categories and the update time step (fig. 3).

Figure 3. Example of a metadata and protocol sheet, Osirisc indicators



41 The spatiotemporal data used for the indicators are archived, processed, mapped and disseminated via a web-GIS interface called "Osi", which is currently being finalised (Marcel *et al.*, 2018). This database is shared by scientists and managers. It is an interface offering an interactive graphical and cartographic dashboard enabling the indicators that make up vulnerability to be visualised so that their determining factors can be understood and their development monitored. This has been implemented for five *communes* in the Gulf of Morbihan (fig. 4).

Figure 4. Screenshot of the OSI WEB-GIS interface



4. Discussion on the proposed tool

42 The shift from the concept of systemic vulnerability to the application of indicators highlights a number of important points.

43 First, it is important to bear in mind that reducing the complexity of reality to a limited number of indicators leads to a *loss of information* (Gallopín, 1997). Indicators display a trend but are neither a substitute for knowledge of the field, or for an in-depth analysis of the data that constituted them and the method that created them. They need to be *deconstructed* so that this “raw data” can be accessed and a “black box” effect avoided (Balica *et al.*, 2012; Turner *et al.*, 2003).

44 Second, the fact that monitoring indicators must be regularly *updated* restricts data acquisition methods and justifies, where possible, a preference for indicators from existing and accessible databases (Grasland and Hamez, 2005; Le Berre *et al.*, 2011). Otherwise, precise and relatively “light” survey or measurement protocols should be put in place.

45 Another essential element is that compiling the indicators depends on the *time* available to researchers and managers, which makes the tool dependent on dedicated workforce resources and a permanent structure, such as an observatory, to host it (Le Berre *et al.*, 2011).

46 Moreover, the significance given to the results and their *reception* by the actors concerned are determining factors (Levrel *et al.*, 2010; Nardo *et al.*, 2005). It is therefore essential to define common conceptual and methodological approaches that are understood and accepted by the actors concerned.

47 Finally, all of these indicators can be used as they are, but they can also be aggregated to build indexes (Barnett *et al.*, 2008; Eakins and Luers, 2006; Nardo *et al.*, 2005). Four index categories are still under construction in the Osirisc project: *thematic indexes* integrate a set of indicators derived from the same component and describing the same theme (a flooding index or a human stakes index, for example). The aggregation of thematic indexes of the same component makes it possible to produce *component*

indexes (hazards, stakes, management or representations). Combining these indexes can give rise to an *overall index* describing systemic vulnerability. Finally, *transversal indexes* bring together indicators relating to a particular aspect and derived from different components (e.g. human vulnerability, vulnerability of buildings, or risk only, etc.).

Conclusion

48 The creation of monitoring indicators for systemic vulnerability that are simple yet representative, conceptually rigorous and useful to managers, is a complex objective that many researchers have addressed (Balica *et al.,* 2012; Barnett *et al.*, 2008; Birkmann and Welle, 2015). We wanted to contribute to this common goal by formalising interdisciplinary reflections based on a continuous dialogue between field and theoretical thinking and between researchers and managers.

49 It seems that progress is being made on the issue of vulnerability. Firstly, due to the polysemous nature of the term, the definition of vulnerability should be *clarified* for each study (vulnerability: of what and to what). Secondly, it is important to remember that vulnerability is mostly geographic and socially “situated” (place-based vulnerability – Cutter *et al.,* 2000). In other words, when studying it, it is important to consider its regional *context*, its historical roots (Noël, 2014) and the population types facing these problems. This is all the more applicable since management and representation components are a prominent feature in our approach and can differ greatly from one society to another (Douglas and Wildavski, 1984), from one political and administrative organisation to another (differences in public policies, modes of governance of coastal risks, etc.) and from one country to another (differences in coastal risk management, etc.). Finally, and we believe this contribution to be fundamental, the *systemic* vulnerability that we propose means that the artificial dualism pitting nature against society can be avoided. Our choice to *include hazards* in the definition of systemic vulnerability, which is still relatively new, prevents these components from being considered in isolation from the social-environmental system that are closely intertwined and in constant interaction in the field.

50 As for indicators, it seems appropriate to emphasise that, whatever they are and whatever efforts are made to develop them, they can never replace detailed *field* studies, risk management actors, or residents. Secondly, and despite the necessary reservations and caution when working on indicators, the method outlined in this article has the advantage of offering a scientifically robust tool for monitoring systemic vulnerability; it provides elements of knowledge for *researchers* and is also *operational*, providing insightful analysis and informing the actions of *managers*. Co-construction had a positive influence on the method’s assimilation by the actors of the regions involved. Thus, starting from five *communes* in the Gulf of Morbihan involved in the research program (Locmariaquer, Saint-Philibert, Crac’h, Auray, Pluneret), several *communautés de communes* (CCs) in Brittany have now appropriated the method and provided us with the indicators for their regions (CC Pays Bigouden-Sud, and CC Lesneven Côtes des Légendes).

51 Ultimately, co-constructing indicators with the managers, cataloguing them in a database, aggregating them or not into indexes, representing them spatially and disseminating them, is something we can do as researchers. But for this work to be fully operational, for the regular and long-term monitoring of the development of

systemic vulnerability, it must be integrated into a permanent observatory that is supported by local authorities and the government. In this respect, academics can only emphasise the importance of such an observatory and continue to mobilise the actors concerned.

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NOTES

1. Project Osirisc towards an integrated observatory of coastal risks of erosion and sea-flooding (2016-2020) and Project Osirisc+ (2017-2020) co-financed by Fondation de France and DREAL de Bretagne.

2. PNEC: The French Coastal Environment Research Programme.

3. MISEEVA: Marine Inundation hazard exposure modelling and Social, Economic and Environmental Vulnerability Assessment in regard to global changes.

4. Cocorisco: Knowledge, Understanding and Management of Coastal Risks.

5. Osirisc: towards an integrated observatory of coastal risks of erosion and sea-flooding.

6. http://observatoires-littoral.developpement-durable.gouv.fr/.

ABSTRACTS

Littoralisation, or the concentration of people and activities in coastal areas, associated with the intrinsic mobility of coasts and with the context of climate change, tends to increase the vulnerability of coastal areas. This article presents a new interdisciplinary approach towards the concept of vulnerability that makes it possible to move beyond the nature/society dichotomy, and an inter-sectorial researcher-manager method for the development of a series of monitoring indicators for the four components of systemic vulnerability: hazards, stakes, management and representations. These indicators are precursors of an integrated observatory that will act as a source of data for research and inform public policy for coastal areas.

Le phénomène de littoralisation du peuplement et des activités, associé à la mobilité intrinsèque des côtes et au contexte de changement climatique, tend à accroître la vulnérabilité des territoires côtiers. Cet article propose, d’une part, une approche interdisciplinaire renouvelée du concept de vulnérabilité permettant de dépasser la dichotomie nature/société. D’autre part, il présente une méthode intersectorielle chercheurs-gestionnaires de construction d’une série d’indicateurs de suivi des quatre composantes de la vulnérabilité systémique (aléa, enjeux, gestion et représentations). Ces indicateurs préfigurent un observatoire intégré, à la fois source de données pour la recherche, et au service des politiques publiques pour les territoires côtiers.

INDEX

Keywords: coastal risks, erosion, flooding, vulnerability, interdisciplinarity, inter-sectoriality, indicators, adaptation, observatory
Mots-clés: risques côtiers, érosion, submersion, vulnérabilité, interdisciplinarité, intersectorialité, indicateurs, adaptation, observatoire

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