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1 Introduction

1.1 Purposes and tasks

This is the key document that provides a summary of the activities completed by the project team involved in building the new measures and the prototype tool for integrated coastal resilience and vulnerability assessment.
Several methodologies and tools have been examined because in the last decade a number of tools have been developed to understand, assess, and manage the multiple risks posed by natural hazards to coastal zones but there is still no common agreement on the approach to be adopted for vulnerability assessment.
The web tool developed by the team integrates traditional biophysical measures with the novel social indicators into the spatial dimension provided by remote sensing images. This report explains how the tool brings the new technologies into vulnerability and resilience analysis with innovative numerical models.
A discussion on the strength of the research is provided in order to suggest the next steps to involve and built Public Private Partnerships with the stakeholders' boards.

This reports relates to Task D, E, G (and part of Task C), whose main contents are briefly reported below and in their full extent in the description of works (FORMS T of the proposal):
Task D aimed at developing a well-structured, pre operational approach for vulnerability assessment to flood or storm surge on coastal zones, based on integration of EO derived products, in situ data, modeling and expert knowledge. This provides added value information to decision makers who are involved in defining better-integrated strategies for coastal resilience through the strengthening of the risk prevention and disaster management cycle of the coastal zones. The vulnerability assessment is intended in the most comprehensive sense, and thus including both biophysical and socioeconomic aspects of vulnerability.
Task E framed by the concepts of cooperative science and policy-oriented research to the three main governance stakeholders: government, private sector and the civil society including scientific/academic institutions. The task provides an innovative way of quantifying and assessing physical environmental and social resilience from the risk governance, in response to the growing recognition of the linkages between ecosystem coastal processes and resources at risk due to climate change and natural or anthropogenic hazards and processes of change which may trigger either frequency and magnitude of these hazards or the related vulnerability.
Task G, applies the methodologies, tools and software developed in the previous tasks (i.e. hazard from Task C, D and E), to study cases, in order to test the efficacy – and therefore the pre operational phase – of the adopted approach to assess flood/storm surge vulnerability on coastal areas.

1.2 Document Structure

This document is made up of the following sections:
Section 1 – Purposes and tasks
Section 2 – Glossary related to vulnerability issues and related concepts
Section 3 – Vulnerability assessment framework, indicators and indexes
Section 4 – Case study description
Section 5 – Approach and variables adopted to describe social vulnerability
Section 6 – Testing of a ready to use coastal vulnerability assessment tool (InVEST Coastal Vulnerability module)
Section 7 - A coupled social-ecological approach to coastal vulnerability assessment based on fuzzy logic
Section 8 - Analysis of risk sharing among governmental institutions, private sector (reinsurance industry) and civil society by mean of Public-Private Partnerships (PPP)
Section 9 - Strengths, weaknesses and future opportunities of the research
Technical Annex
Publicity

1.3 Acronyms and Abbreviations

Table 1. Acronyms and abbreviations

Acronym	Meaning
EI	**Exposure Index**
GMES	**Global Monitoring for Environment and Security**
PD	**Po Delta**
PPP	**Public-Private Partnerships**
REA	**Real Elementary Area**
WMS	**Web Mapping Service**
WS	**Wadden Sea**

2 Resilience and Vulnerability: definitions and review

2.1 Definitions

Concepts such as vulnerability, resilience, and adaptive capacity have been studied by different intellectual traditions that have often used the terms in different ways. Even though they emerge as strongly related, the nature of their relationships remains unclear and fertile field to be explored.

In this paragraph is presented a glossary of the most useful concepts in the field of vulnerability assessment according to the several interpretations available by the literature. A great impulse to this theoretical framework is due to the coupled fields of research that involve climate changes and insurances applications, but this set of concepts can be applied to any other type of natural and human induced disturbance, perturbation or stress evaluation need.

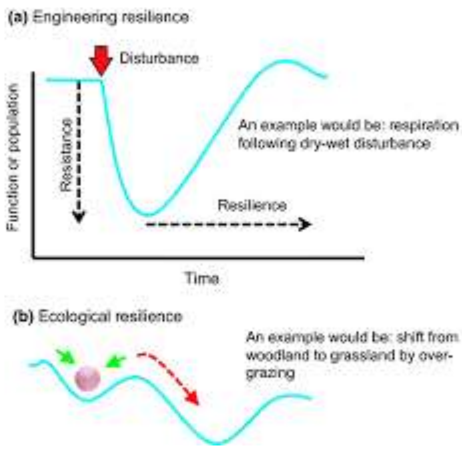
2.1.1 Resistance and resilience

Here, we summarize the recent progress in understanding the resistance and resilience (stability) of coastal systems and discuss the underlying mechanisms of dunes stability together with factors affecting them like storm surge, sea level rise and the sink of the coastal landscapes.

The stability is given by the structure of the biophysical system linked to a range of emerging properties including the social components as vector of the carrying and the adaptive capacities.

We suggest that resistance and resilience are governed by units of natural or manmade structures and that these units exert a role in preventing and reducing the response to disturbance. The dunes, the wetlands, the urban metrics, are then a measure of stability resulting from a combination of biotic and abiotic characteristics and so could provide a quantitative measure of the flood prevention provision.

Figure 1. Resilience



Resilience is a concept originated within ecology, Holling first used the term to describe a "measure of the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling, 1973).
Probably the first to use the concept of resilience in relation to natural hazards and disasters has been Timmerman (1981), according to him resilience is the measure of a system's capacity to absorb and recover from a hazardous event.
In the natural hazards and disaster research domain resilience does not have a common definition. Some authors like Manyena define the resilience using a systems perspective and focusing on the interaction between social and natural systems. In some other cases resilience is described as the opposite of vulnerability
Several definitions of resilience have been provided, Table 2is a selection of them.

Table 2. Definitions of resilience according to reviewed literature

Author	Definition
Timmerman 1981	Resilience is the measure of a system's or part of the system's capacity to absorb and recover from an occurrence of a hazardous event
Wildavsky 1988	Resilience is the capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back
Mileti, 1999	Local resiliency with regard to disasters means that a local is able to withstand an extreme natural event without suffering devastating losses, damage, diminished productivity, or quality of life without a large amount of assistance from outside the community
Adger, 2000	Social resilience is the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, environmental change
Bruneau et al. 2003	Resilience is the ability of social units (e.g. organizations, communities) to mitigate hazards, contain the effects of disasters when they occur and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future disasters
Cardona, 2003	The capacity of a damaged ecosystem or community to absorb negative impacts and recover from these
Rose, 2004	Resilience refers to the inherent and adaptive responses to hazards that enable individuals and communities to avoid some potential losses
UNISDR, 2005	The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures
Paton and Johnston, 2006	Resilience is a measure of how well people and societies can adapt to a changed reality and capitalize on the new possibilities
Cutter et al. 2008	Resilience is the ability of a social system to respond and recover from disasters and includes the inherent conditions that allow the system to absorb impacts and cope with an event, as well as post-event, adaptive processes that facilitate the ability of the social system to reorganize, change, and learn in response to a threat. Resilience has two qualities: inherent (functions well during non-crisis periods) and adaptive (flexibility in response during disasters)
Zhou et al., 2010	Resilience is broadly defined as the capacity to resist and recover from loss

Source: Burton, 2012

The conditions defining resilience change in terms of spatial, social, and temporal scales. A society may be considered resilient to environmental hazards e.g. to short-term phenomena such as severe weather due to mitigation measures that have been adopted but not another at long-term scale such as climate change. The temporal scale will affect the variables and parameters chosen to develop general indicators as well as their availability.

Resilience is evolving from theory into policy and practice and one example is represented by its recent appropriation by bilateral and multilateral donor organizations (HERR, 2011; Bahadur et al., 2010; Harris, 2011).

Social Resilience

When resilience is examined from a social perspective describes the behavior of communities, institutions and economies in their response prior to and after the hazard occurs. For researchers like Witheford (2002) to address community resilience it is necessary to analyse the contextual conditions within the social system.

The research community can be distinguished in those who see resilience from a social perspective as outcome oriented and those who see it as a process. In some cases the outcome oriented approach is critiziced because reinforces the tendency of the reactive approach to disaster planning and management (McEntire et al. 2002). More and more Disaster resilience is defined in terms or continual learning and it is seen like a process.

For instance Adger (2000) defines social resilience as the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change. The system not only has the capacity to return to the state (or multiple states) that existed before the disturbance, but also, through learning and adaptation to advance (Adger et al. 2005; Klein et al.,2003; Folke 2006).

Furthermore social resilience is understood as having three properties comprising aspects of how people respond to disasters: resistance, recovery, and creativity (Kimhi & Shamai, 2004). A community that is highly resilient has the capacity to demonstrate each of these properties (Maguire, 2007).

Also Cutter (2008) gives importance to the learning dimension, in her definition resilience includes the inherent conditions that allow the system to absorb impacts and cope with both an event and the post-event adaptive process that facilitate the ability of the social system to re-organize, change and learn in response to a threat. Learning from the disaster experience can lead to an optimal recovery (Kimhi & Shamai, 2004; Pooley, Cohen, & O'Connor, 2006; Sonn & Fisher, 1998). This is the property of creativity (Kimhi & Shamai, 2004) and is represented by a gain in resilience achieved as part of the recovery process.

Since the communities are the totality of social system interactions within a geographic space such as neighborhood, census tract, city or county, the different sub-populations may have a different level of vulnerability and resilience that could result in recovery disparities (Cutter, 2008).

Communities may contain multiple social groups that may differ in terms of their socio-economic status, their degree of geographic isolation, or vulnerability to psychological trauma. This may mean that different groups within the one society can be more or less resilient to a disaster (Buckle, Marsh, & Smale, 2000b). Social groups, such as the elderly, children, or the economically disadvantaged, may have fewer resources available to cope with disaster.

Focusing on social resilience directly, rather than vulnerability or poverty reduction, is important since disaster resilience activities can 'lead to actions such as enhancing community coping capacity and livelihoods and allowing communities to make appropriate choices within the context of their environments (Manyena, 2006)

A model that focuses on the resilience at the community level and on the social resilience of places is the Disaster Resilience Of Place (DROP) proposed by Cutter et al. (2008). Resilience in this model is considered as both an inherent or antecedent condition and process. Among the characteristics that influence both vulnerability and resilience there are the socio-economic status, the education, insurance.

2.1.2 Hazard, Perturbation, Stress, Shock

Turner et al (2003) has defined hazards as threats to a system, comprised of perturbations and stress (and stressors, the sources of stress).

According to Brooks 2003 three broad categories of hazard may be identified:

- Discrete recurrent hazards, such as storms, droughts and extreme rainfall events;
- Continuous hazards, for example increases in mean temperatures or decreases in mean rainfall occurring over many years or decades (Hulme, 1996; Adger and Brooks, 2003);
- Discrete singular hazards, for example shifts in climatic regimes associated with changes in ocean circulation; (Roberts, 1998; Cullen et al., 2000; Adger and Brooks, 2003).

In certain definitions it is not clear whether the hazard represents a trigger event or the outcome of such an event.

For Jones and Boer (2003) hazard is defined in physical terms. For Stenchion (1997) and UNDHA (1992) hazard is an event that might precipitate a disaster but which does not itself constitute a disaster.

In the cases where vulnerability is included in the definition of risk, it is viewed as distinct from hazard. Risk defined as a function of hazard and of social vulnerability is compatible with risk defined as probability x consequence, and also with risk defined in terms of outcome. The probability of an outcome will depend on the probability of occurrence of a hazard and on the social vulnerability of the exposed system, which will determine the consequence of the hazard.

Turner et al. (2003) explicitly state that the hazards acting on the system arise from influences outside and inside the system.

In some other cases the term hazard is used to refer specifically to physical manifestations such as droughts, floods, storms, episodes of heavy rainfall.

According to IPCC (2014) hazard is defined as "The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources."

Perturbation is a sudden, severe increase in pressure, stress is a continuous or slowly increasing pressure commonly within the range of normal variability.

In some cases perturbation it is seen as coming from outside, but for (Gallopin, 2006) this vision is restrictive. Both societal and ecological systems survive, thanks to a constant exchange of matter, energy, and information with their external environment (Gallopin, 2006).
Depending on the scale of observation, the ecosystems may show characteristics that correspond to a relatively stable, vulnerable equilibrium state: they might change abruptly or gradually due to repetitively, stochastically or continuously acting events. Disturbance, perturbation and stress are the terms referred to these events in ecological studies. Even if disturbance is the older and more general term, in ecology perturbation or disturbance are synonymous of stress and the three terms are applied when, under some (external or internal) stimulus one or several of the system attributes change(s) considerably. Rykiel (1985) overviewed the semantic and conceptual problems of the terms and made a proposal for working definitions of perturbations, stress and disturbance, but these did not become generally accepted (partly, because his concept did not fit into other models, e.g. Grime's well-known CSR theory). As consequence, changes of the environment evoke adaptation responses at various timescales and at different levels of biological organization. Frequency of changes of the environment basically influences the level of response. Continuous and high frequency impacts in example might generate physiological, population-level and community-level adaptation mechanisms.

2.1.3 Exposure

Exposure in most formulations is seen as one of the elements constituting vulnerability, however authors like Bohle (2001), recognizes a qualitative difference between exposure (defined as the external side of vulnerability) and the coping capacity (the internal side).
Adger, 2006; Kasperson et al., 2005 describes it as the degree, duration, and/or extent in which the system is in contact with, or subject to, the perturbation. Fussel and Kline (2006) define exposure as "The nature and degree to which a system is exposed to significant climatic variations.
From Gallopın (2003) perspective, a system (i.e., a city, a human community, an ecosystem) may be very vulnerable to a certain perturbation, but persist without problems insofar as it is not exposed to it.
For the approaches that includes exposure as a component of vulnerability, a system that is not exposed to a perturbation would be defined as non-vulnerable. This shows as the choice of including or not 'exposure' as a component of vulnerability has consequences. If exposure is considered external from vulnerability, vulnerability is a system attribute existing prior to the disturbance and it becomes expressed when the system is exposed to the perturbation.
According to (Burton et al., 1993) exposure is the nature and the degree of environmental changes faced by systems that can be characterized by their amplitude, frequency, duration, areal extent, etc.
The IPCC (2001) report defines exposure as "The nature and degree to which a system is exposed to significant climatic variations." while the IPCC (2014) defines exposure as "The presence of people, livelihoods, species or ecosystems, environmental functions, services, and

resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected."

2.1.4 Sensitivity

The concept of sensitivity varies across authors. Smit and Wandel (2006) talk about exposure sensitivity, highlighting that sensitivity is not separable from exposure. Luers (2005) also combines sensitivity and exposure, and defines sensitivity as the degree to which a system will respond to an external disturbance he also includes in the concept the ability to return to a previous condition after the stress has been removed. Adger (2006) defines it as ‘‘the extent to which a human or natural system can absorb impacts without suffering long-term harm or other significant state change’’.

For Gallopın (2003), sensitivity is the degree to which the system is modified or affected by an internal or external disturbance or set of disturbances.

The IPCC (2001) report defines sensitivity as "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli[1]. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)."

In the Odum traditional definitions, the ecosystem sensitivity is certainly an attribute of the system but it is an emerging attribute that exist and can be measured only in the presence of stress.

2.1.5 Vulnerability

There are more than two dozen definitions of vulnerability (some of them are listed below) and there is general consensus on the fact that vulnerability is determined by a complex range of physical, economic, political and social factors (Manyena, 2006).

Although several vulnerability assessment techniques have been developed, some common elements can be found among them (Cutter et al, 2008):

1) the examination of the vulnerability from a social-ecological perspective

2) the importance of place-based studies

3) the conceptualization of vulnerability as an equity of human rights issue

4) the use of vulnerability assessment to identify hazard zones.

For some research vulnerability originates from underlying social conditions, exposure is considered as given and researchers search for patterns of differential access to resources. There is then a second perspective that sees vulnerability as a function of proximity to the source of risk or hazard (Alexander, 1993). A third perspective considers vulnerability as a function of biophysical risk and social response and how this manifest itself locally (Hewitt and Burton, 1971).

Selected definitions are listed in Table 3 on the base of the presence of a relation with the definition of resilience and in Table 4 where the definitions have not relations with the definitions of resilience (Manyena, 2006).

[1] "by climate variability or change" in the IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Annex II. Glossary. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp

Table 3. Definitions of vulnerability having relation with definitions of resilience

Author	Definition
Timmerman, 1981	Vulnerability is the degree to which a system acts adversely to the occurrence of a hazardous event. The degree and quality of the adverse reaction are conditioned by a system's resilience (a measure of the system's capacity to absorb and recover from the event).
Pijawka and Radwan, 1985	Vulnerability is the threat or interaction between risk and preparedness. It is the degree to which hazardous materials threaten a particular population (risk) and the capacity of the
Dow, 1992	Vulnerability is the differential capacity of groups and individuals to deal with hazards, based on their positions within physical and social worlds.
Watts and Bohle, 1993	Vulnerability is defined in terms of exposure, capacity and potentiality. Accordingly, the prescriptive and normative response to vulnerability is to reduce exposure, enhance coping capacity, strengthen recovery potential and bolster damage control (i.e., minimise destructive consequences) via private and public means.
Green et al., 1994	Vulnerability to flood disruption is a product of dependence (the degree to which an activity requires a particular good as an input to function normally), transferability (the ability of an activity to respond to a disruptive threat by overcoming dependence either by deferring the activity in time, or by relocation, or by using substitutes), and susceptibility (the probability and extent to which the physical presence of flood water will affect inputs or outputs of an activity).
Weichselgartner and Bertens, 2000	By vulnerability, we mean the condition of a given area with respect to hazard, exposure, preparedness, prevention, and response characteristics to cope with specific natural hazards. It is a measure of the capability of this set of elements to withstand events of a certain physical character.

Source: Manyena (2006) adapted from Weichselgartner (2001)

Table 4. Definitions of vulnerability with little or no relation with definitions of resilience

Author	Definition
Gabor and Griffith, 1980	Vulnerability is the threat (to hazardous materials) to which people are exposed (including chemical agents and the ecological situation of the communities and their level of emergency preparedness). Vulnerability is the risk context.
UNDRO, 1982	Vulnerability is the degree of the loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude.
Susman, O'Keefe and Wisner, 1983	Vulnerability is the degree to which different classes of society are differentially at risk.
Mitchell, 1989	Vulnerability is the potential for loss.
Liverman, 1990	The author distinguishes between vulnerability as a biophysical condition and vulnerability as defined by political, social and economic conditions of society. She argues for vulnerability in geographic space (where vulnerable people and places are located) and vulnerability in social space (who in that place is vulnerable).
Downing, 1991	Vulnerability has three connotations: it refers to a consequence (e.g. famine) rather than a cause (e.g. drought); it implies an adverse consequence (e.g., maize yields are sensitive to drought; households are vulnerable to hunger); and it is a relative term that differentiates among socioeconomic groups or regions, rather than an absolute measure or deprivation
Alexander, 1993	Human vulnerability is function of the costs and benefits of inhabiting areas at risk of natural disaster.
Cutter, 1993	Vulnerability is the likelihood that an individual or group will be exposed to and adversely affected by a hazard. It is the interaction of the hazard of place (risk and mitigation) with the social profile of communities.
Dow and Downing, 1995	Vulnerability is the differential susceptibility of circumstances contributing to vulnerability. Biophysical, demographic, economic, social and technological factors such as

Author	Definition
	population ages, economic dependency, racism and age of infrastructure are some factors which have been examined in association with natural hazard.
Gilard and Givone, 1997	Vulnerability represents the sensitivity of land use to the hazard phenomenon
Comfort et al., 1999	Vulnerability are those circumstances that place people at risk while reducing their means of response or denying them available protection

Source: Manyena,2006 adapted from Weichselgartner, 2001

Even in the IPCC report the definition of Vulnerability has changed through the time. In the 2001 Report vulnerability was “The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.”, while in the 2014 Report is defined as “The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. See also Contextual vulnerability[2] and Outcome vulnerability[3].”

Biophysical Vulnerability

For Brooks (2003), biophysical vulnerability is a function of the frequency and severity (or probability of occurrence) of a given type of hazard and has among its determinants social vulnerability. It is the interaction of hazard with social vulnerability that produces an outcome, generally measured in terms of physical or economic damage.

For Sarewitz et al. (2003), the concept of biophysical vulnerability addresses the same issues as the concept of outcome risk. Both [outcome] risk and biophysical vulnerability are functions of hazard and social vulnerability.

The report from the International Strategy for Disaster Reduction of the United Nations illustrates the essential equivalence of [outcome] risk and biophysical vulnerability, in addition “risk factors” are separated into two components: 1. hazard (that determines geographical location, intensity and probability) and “vulnerability/capacities (that determines susceptibilities and capacities).

For Fellmann (2007), biophysical model approaches focus on biophysical processes and are limited in the integration of contextual issues, this means that these model approaches have limited capacity to model adaptation options.

Social Vulnerability

In the 1970s researchers recognized that vulnerability also involves socioeconomic factors that affect community resilience (Juntunen, 2005) and introduced the concept of social vulnerability within the disaster management context.

[2] « Contextual vulnerability (Starting-point vulnerability). A present inability to cope with external pressures or changes, such as changing climate conditions. Contextual vulnerability is a characteristic of social and ecological systems generated by multiple factors and processes (O’Brien et al., 2007). » (IPCC, 2014)

[3] « Outcome vulnerability (End-point vulnerability). Vulnerability as the end point of a sequence of analyses beginning with projections of future emission trends, moving on to the development of climate scenarios, and concluding with biophysical impact studies and the identification of adaptive options. Any residual consequences that remain after adaptation has taken place define the levels of vulnerability (Kelly and Adger, 2000; O’Brien et al., 2007).

In its broadest sense, social vulnerability is one dimension of vulnerability to multiple stressors and shocks, including natural hazards. Social vulnerability refers to the inability of people, organizations, and societies to withstand adverse impacts from multiple stressors to which they are exposed. These impacts are due in part to characteristics inherent in social interactions, institutions, and systems of cultural values.

Factors, such as age, the strength of social networks, and neighborhood characteristics influence vulnerability to hazards, in addition categories of people living in a disaster-stricken area are not affected equally.

As underlined by Juntunen, 2005 population characteristics “are an important indicator of everything from evacuation compliance during an event to successful long-term recovery after one” with the socially vulnerable are “more likely to die in a disaster event and less likely to recover after one”.

Social vulnerability is still a highly arguable concept in the scientific world. The arguments are amongst scientists working in different disciplines, among governing agencies etc.. There are many definitions of social vulnerability and many projects providing a comprehensive literature review on this matter (ENSURE project, 2009, FloodSite, 2005, ECLAC 2011, emBRACE, 2012), nevertheless some components or major factors affecting social vulnerability, according to reviewed literature are agreed among several researchers (Table 5).

These include: lack of access to resources (information, knowledge, and technology); limited access to political power and representation; social capital, including social networks and connections; beliefs and customs; building stock and age; frail and physically limited individuals; and type and density of infrastructure (Cutter, 2001; Tierney, Lindell, and Perry, 2001; Putnam, 2000; Blaikie et al., 1994). Disagreements can be found in the selection of specific variables to represent these broader concepts.

Table 5. Characteristics that influence social vulnerability according to reviewed literature

Concept	Description	Increases (+) or Decreases (-) Social Vulnerability
Socioeconomic status (income, political power, prestige)	The ability to absorb losses and enhance resilience to hazard impacts. Wealth enables communities to absorb and recover from losses more quickly due to insurance, social safety nets, and entitlement programs. Sources: Cutter, Mitchell, and Scott (2000),Burton, Kates, and White (1993), Blaikie et al. (1994), Peacock, Morrow, and Gladwin(1997, 2000), Hewitt (1997), Puente (1999), and Platt (1999).	High status (+/-) Low income or status (+)
Gender	Women can have a more difficult time during recovery than men, often due to sector specific employment, lower wages,and family care responsibilities. Sources: Blaikie et al. (1994), Enarson and Morrow (1998), Enarson and Scanlon (1999), Morrow and Phillips (1999), Fothergill (1996), Peacock, Morrow, and Gladwin (1997, 2000), Hewitt (1997), and Cutter (1996).	Gender (+)
Race and ethnicity	Imposes language and cultural barriers that affect access to post-disaster funding and residential locations in high	Nonwhite (+) Non-Anglo (+)

Concept	Description	Increases (+) or Decreases (-) Social Vulnerability
	hazard areas. Sources: Pulido (2000), Peacock, Morrow, and Gladwin (1997, 2000), Bolin with Stanford (1998), and Bolin (1993).	
Age	Extremes of the age spectrum affect the movement out of harm's way. Parents lose time and money caring for children when daycare facilities are affected; elderly may have mobility constraints or mobility concerns increasing the burden of care and lack of resilience. Sources: Cutter, Mitchell, and Scott (2000), O'Brien and Mileti (1992), Hewitt (1997), and Ngo (2001).	Elderly (+) Children (+)
Commercial and industrial development	The value, quality, and density of commercial and industrial buildings provides an indicator of the state of economic health of a community, and potential losses in the business community, and longer-term issues with recovery after an event.	High density (+) High value (+/-)
Employment loss	The potential loss of employment following a disaster exacerbates the number of unemployed workers in a community, contributing to a slower recovery from the disaster. Source: Mileti (1999).	Employment loss (+)
Rural/urban	Rural residents may be more vulnerable due to lower incomes and more dependent on locally based resource extraction economies (e.g., farming, fishing). High-density areas (urban) complicate evacuation out of harm's way. Source: Cutter, Mitchell, and Scott (2000), Cova and Church (1997), and Mitchell (1999).	Rural (+) Urban (+)

Source: Cutter, Boruff, and Shirley (2001); Heinz Center for Science, Economics, and the Environment (2002).

According to Brooks (2003) although social vulnerability is not a function of hazard severity or probability of occurrence, certain properties of a system will make it more vulnerable to certain types of hazard than to others. The nature of the hazard to which the human system is exposed influences the nature of the social vulnerability. For example, the community's (social) vulnerability is influenced by quality of housing, but this aspect will not be important on its vulnerability to drought. Being vulnerability to a certain extent hazard specific, for Brooks we must ask the questions: "vulnerability of who or what to what?"

Moreover, there is an increasing attention to the relationship between social vulnerability and resilience. Vulnerability and resilience are commonly related concepts in a number of scientific disciplines. It is suggested in the literature that factors, which determine vulnerability, may also contribute to the building of resilience. (ECLAC 2011).

2.1.6 Risk

Beck (1992) described the modern or post-industrial landscapes as a "risk society." The fundamental characteristic of this risk society is its interdependence that makes systems and networks highly complex so much so that they are often vulnerable.

When talking about risk, disaster management research and practice often refer to the following formula: Risk = Hazard * (Vulnerability – Resources) where Risk is the likelihood or expectation of loss; Hazard is a condition posing the threat of harm; Vulnerability is the extent to which persons or things are likely to be affected; and Resources are those assets in place that will diminish the effects of hazards (Dwyer et al. 2004; UCLA Center for Public Health and Disasters, 2006).

For Blaikie et al, 1994 Risk is explicitly defined as a function of the perturbation, stressor, or stress and the vulnerability of the exposed unit.

UNISDR defined it as "The combination of the probability of an event and its negative consequences" (UNISDR, 2009).

In popular usage the emphasis is usually placed on the concept of chance or possibility, such as in "the risk of an accident"; whereas in technical settings the emphasis is on the consequences, in terms of "potential losses" for some particular cause, place and period. In addition not necessarily people share the same perceptions of the significance and underlying causes of different risks.

Usually definitions of risk are probabilistic and relate either to (i) the probability of occurrence of a hazard that acts to trigger a disaster or series of events with an undesirable outcome, or (ii) the probability of a disaster or outcome, combining the probability of the hazard event with a consideration of the likely consequences of the hazard (Smith, 1996; Stenchion, 1997; Downing et al., 2001; Brooks, 2003;Jones and Boer, 2003). This latter definition is compatible with that of Brooks et al. (2006) that views risk as a function of hazard and vulnerability.

As an alternative to the probabilistic approach, the outcome-based measures can be used (particularly where research is concerned with historical data). However the two approaches are complementary ways of approaching risk assessment.

The following table (Table 6) provides an overview of definitions of risks and hazards.

Table 6. Definitions of risks and hazards according to reviewed literature

Author	Risk definition
Smith, 1996	Probability x loss (probability of a specific hazard occurrence). Hazard = potential threat
IPCC, 2001	Function of probability and magnitude of different impacts
Morgan and Henrion, 1990 /Random House, 1966	"Risk involves an 'exposure to a chance injury or loss'"
Adams, 1995	"a compound measure combining the probability and magnitude of an adverse affect"
Crichton, 1999	"Risk" is the probability of a loss, and depends on three elements, hazard, vulnerability and exposure."
Downing et al., 2001	Expected losses (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period Hazard: a threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area.

Source: Definitions of risk and hazard (Brooks, 2003)

Manyena (2006) underlines the importance to estimate risk on a multidisciplinary basis to be aware of both the expected physical damage and of the victims or economic losses, and of social, organisational and institutional aspects.

Models such as the 'access model' suggests that risk is generated as a result of the difficulties that some social groups or families have in accessing certain resources over time.

Risk Management

For UNISDR (2009) is the systematic approach and practice of managing uncertainty to minimize potential harm and loss. It comprises risk assessment and analysis and the implementation of strategies and specific actions to control, reduce and transfer risks. Risk management is a core issue for sectors such as water supply, energy and agriculture whose production is directly affected by extremes of weather and climate.

Coastal risk management cycle (Figure 2) entails several phases. Each phase is briefly described here below taking into account its goal and the tool to achieve it.

Prevention aims at avoiding or minimizing risk, e.g., by specific regulations for new building areas in hazard zones. Hence, the main tool is spatial planning.

Protection aims at minimizing the probability of a harmful event by technical measures (e.g., dikes, sand recharging, groins, etc.).

Preparedness has much to do with hazard awareness. Informed people are (more) willing to take precautionary actions (incl. evacuation), and they accept the high costs and other possible constraints of coastal risk management. The main tool to achieve hazard awareness is risk communication.

Like protection, emergency response manages the "worst case" scenario (i.e., flooding). Flood warning and evacuation are two well-known measures.

Recovery defines all aftercare measures, such as repairing the dike breaches and psychological assistance for those affected.

Finally, the review phase is meant as a "learning phase" which account for new data and research outcomes as well as disasters. It aims at optimizing the next control loop and monitoring programs are an important aspect of it. As a result the next control loop will be made of new or, perhaps more correctly, re-invented prevention and preparedness phases.

Figure 2. Coastal risk management cycle

Source: Hofstede, 2007

2.1.7 Disasters Impact

The total hazard or disaster impact is a cumulative effect (or sum) of the antecedent conditions, event characteristics, and coping responses. The antecedent conditions interact with the hazard event characteristics such as frequency, duration, intensity, magnitude, and rate of onset, which vary depending on the type of hazard and the location of the study area. In addition the effects can be attenuated or amplified depending on the presence or absence of mitigating actions and coping responses in the community, which themselves are a function of antecedent conditions.

The overall local impact can be moderated by the absorptive capacity of the community.

Absorptive capacity (or threshold) is the ability of the community to absorb event impacts using predetermined coping responses. If a community has sufficient coping responses, the impact of the hazard event will be attenuated and the absorptive capacity will not be exceeded, and the degree of recovery will be high.

The community's absorptive capacity will be exceeded if the hazard event is so large to overwhelm local capacity; and second if the event is less catastrophic, but existing coping responses are insufficient to handle the impact. If either occurs the community may exercise its adaptive resilience through improvisation and learning. Improvisation includes actions which may aid in the recovery process. Social learning is defined as ''the diversity of adaptations, and the promotion of strong local social cohesion and mechanisms for collective action'' (Adger et al., 2005).

When impromptu actions are formalized into institutional policy for handling future events social learning occurs; this aspect is particularly important because individual memory is subject to decay over time. Manifestations of social learning include policy making and pre-event preparedness improvements.

The human dimensions of risk reduction has come to the forefront of the international focus, one of the most relevant and recent effort is represented by the adoption of The Hyogo Framework for Action 2005–2015 by the United Nations International Strategy for Disaster Risk Reduction (UNISDR). The Hyogo framework identified the need and ways to build resilient communities by 1. Integrating disaster prevention, mitigation, preparedness and vulnerability reduction perspectives into sustainable development 2. Increasing local capacity for building hazard resilience and incorporating risk reduction into the design and implementation of emergency preparedness, response, recovery, and reconstructions programmes (International strategy for disaster reduction, 2005).

In the literature there has been a shift to disaster-resistant communities (Mileti, 1999) that emphasized the interactive nature of natural and human system, the built environment and the role of human agency in producing hazards and disasters.

In addition two more concepts have been introduced: 1. Resistance which can be understood in terms of the degree of disruption that can be accommodated without the community undergoing long-term change, e.g. to its social structure, (Adger, 2000); 2. Recovery which relates to a community's ability to 'pull through' the disaster (Adger, 2000; Buckle, Marsh,& Smale, 2000a; Kimhi & Shamai, 2004).

The sociologist Mileti in his second assessment revealed an underlying inconsistency between how professionals estimate risk from natural hazards and how people and societies perceive and deal with those same risks. Sometimes science view risk probabilistically and often presume that people and societies will act rationally to mitigate losses and costs in proportion to the risks faced. This is not always the case. In general, human beings, as individuals and groups – even entire societies – dichotomize risks into those that will be acted on and those that will be ignored. Because human risk perception does not follow objective estimates and definitions, human and societal action to mitigate risk can often be inconsistent with estimated scientific probabilities (Slovic 2000; Tweeddale 1996).

When talking about Disasters three more concepts come into play:

Disaster preparedness: is the phase during which it is planned how to respond, this phase includes plans or preparations made in advance of an emergency that help individuals and communities get ready. Human and material resources needed during a specific disaster are identified

Disaster response: once a disaster strikes first responders respond, assess the situation and take action such as to save lives and to prevent further property damage. Ideally, disaster response involves putting already established disaster preparedness plans into motion. Typically, this phase of the disaster life cycle draws the most attention.

Disaster recovery: Disaster recovery happens after the immediate response phase has been completed and actions are focused on the longer term response. During the recovery phase actions to return the affected community to its pre-disaster state are implemented. Lessons learned are collected and shared within the emergency response community. Subsequent efforts may range from physical upgrades to education, training, and public awareness campaigns.

2.1.8 Sustainable mitigation

A comprehensive approach to enhancing society's ability to reduce the costs of disaster is needed. In this framework the concept of "sustainable hazards mitigation" was formalized by the sociologist Mileti in his "Disasters by Design" (1999). According to his vision, Sustainable mitigation is a concept that links the wise management of natural resources with local economic and social resiliency, and views mitigation as an integral part of a much larger set of issues.

Usually the strategies for managing hazards follow a specific planning model:

study the problem, implement a situation-specific solution, and move on to the next problem. This approach views hazards as static and mitigation as an upward, positive, linear trend, while mitigation should emerge as a concept that most citizens deem worthwhile (Mileti, 1999).

Often there is inconsistency between how professionals estimate risk from natural hazards and how people and societies perceive and deal with those same risks.

In parallel researchers have come to recognize that demographic differences play a large role in determining the risks people encounter, whether and how they prepare for disasters, and how they fare when disasters occur (Mileti, 1999).

Often society's most vulnerable groups are the poor, women, and those who are members of other disenfranchised groups. In addition resource management, social organization, and political economies increasingly put some population groups more at risk than others from disaster (Enarson and Morrow 1998).

Sustainability in the context of hazards and disaster studies, means that a locality can tolerate and overcome damage and reduced quality of life inflicted by an extreme event without significant outside assistance (Mileti, 1999). Communities can achieve sustainability by evaluating their environmental resources and the type and extent of possible future losses that they are willing to bear.

In his second assessment of hazards and disasters in the US undertaken in the late 1990s Mileti et al highlighted that when communities consider actions for sustainable hazards mitigation there are six objectives to be aware of :

- Maintain and enhance environmental quality: Human activities to mitigate hazards should not reduce the carrying capacity of ecosystems. Hazard reduction must be coupled to natural resource management and environmental preservation.
- Maintain and enhance people's quality of life: Local communities must define the quality of life they want and select only those mitigation strategies that help them to reach that vision of sustainability.
- Foster local resiliency and responsibility: to take mitigation actions such that a local can withstand an extreme natural event with a tolerable level of losses.
- Recognize vibrant local economies are essential to foster a diversified local economy.
- Ensure inter- and intragenerational equity: Select mitigation activities that reduce hazards across all ethnic, racial, and income groups, and between genders.
- Adopt local consensus building: Selecting mitigation strategies that evolve from full participation among all public and private stakeholders.

2.1.9 Adaptation (Reactive, Proactive)

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities." The IPCC further distinguishes between different types of adaptation: anticipatory vs. reactive, private vs. public, and autonomous vs. planned

- Anticipatory adaptation takes place before impacts of climate change are observed
- Autonomous adaptation is not a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems.
- Planned adaptation is based on an awareness that conditions have changed or are about to change and is therefore the result of a policy decision.

For Smit et al. (2000) adaptation can be "reactive" or "proactive", it depends on whether an action is in response to observed climate impacts, or in anticipation of future climate change. Historically it has been largely if not entirely reactive, however because of the human-induced climate change for the first time societies face the challenge of adapting to climatic changes forecast but not yet experienced.

In the reactive adaptation action is informed by direct experience. However, uncertainties in the extent, timing, and distribution of impacts make it harder to determine what measures are needed.

Adaptation can also be reactive or proactive in form. In this case the distinction is related to the nature of society's response. A proactive approach aims to reduce exposure to future risks; a purely reactive approach aims only to alleviate impacts once they have occurred. For Burton et al. we can talk of maladaptation when a reactive response, for instance by assisting reconstruction in a flood-prone area, perpetuates exposure to climate risk.
Adaptation can have two dimensions: 1. building adaptive capacity increasing the ability of individuals, groups, or organizations to adapt to changes 2. implementing adaptation decisions for example by transforming that capacity into action. In this vision, adaptation is a continuous stream of actions and decisions. The adaptation options can be classified considering their purpose, mode of implementation, or on the institutional form they take.
Effective adaptation must operate at the intersection of policy areas and requires discrete institutions and policies to assess priorities, resources, and efforts.

Adaptive Capacity

The term Adaptability (or adaptive capacity) was originally defined in biology and means the ability to become adapted (i.e., to be able to live and to reproduce) to a certain range of environmental contingencies.
Dobzhansky (1968) noted that a species may be highly adapted to a constant environment but have little capacity to adapt to others or to changes in its environment.
In general by improving its condition in its environment, a species, population, or individual may also become better adapted.
For Gallopin et al. (1989) "in the human realm adaptability or adaptive capacity can be defined as the capacity of any human system to increase (or at least maintain) the quality of life of its individual members in a given environment or range of environments".
In the generic concept of adaptive capacity of an SES (Socio-Ecological System) two different components can be involved: (1) the capacity of the SES to be able to maintain or even improve its condition in the face of changes and (2) the capacity to improve its condition in relation to its environment(s) (Gallopin, 2006).
For researchers like Adger (2006) and for the IPCC (2001) the system's coping capacity Turner et al. (2003) or capacity of response Gallopin (2003) is called adaptive capacity, while Turner et al. (2003) considers capacity to cope or respond and adaptive capacity as components of the resilience of a system.
Smit and Wandel (2006) noted that some authors apply ''coping ability'' to shorter-term capacity or the ability to just survive, and employ ''adaptive capacity'' for longer-term or more sustainable adjustments.
For Gallopin (2006) capacity of response is an attribute of the system and it exists prior to the perturbation, the system's ability to adjust to a disturbance, moderate potential damage, take advantage of opportunities, and cope with the consequences of a transformation that occurs.
For Brooks et al. (2005) the adaptive capacity of a human system represents the potential of the system to reduce its social vulnerability and thus to minimise the risk associated with a given hazard.
Although many factors determine a system's capacity to adapt to a variety of existing or anticipated hazards, some aspects of adaptive capacity are hazard-specific. The nature of the

adaptive capacity and of appropriate adaptation strategies of a human system will be determined by the nature of the hazards faced and the timescales associated with them.

For Burton (2003) a society's ability to undertake actions such as the establishment of an early warning system for flooding or heat waves, or the introduction of heat- or drought-resistant crop varieties is largely a function of its adaptive capacity

One objective of adaptation policy should be ensuring that specific adaptations are as successful and cost-effective as possible by coupling them with corresponding advances in adaptive capacity.

2.1.10 Understanding community vulnerability and resilience

Many disaster losses are the result of interactions among three major systems: the physical environment (the events themselves); the social and demographic characteristics of the communities that experience them; and the buildings, roads, bridges, and other components of the built environment. This vision has determined a shift in the approach to reducing losses from natural hazards and disasters, the concept of disaster-resistant communities has become central as well as the interactive nature of natural and human systems, the built environment and the role of human agency (Mileti, 1999).

Communities can be seen as the totality of social system interactions within a defined geographic space (neighborhood, city, province). In the defined space there are different sub-populations with different levels of vulnerability and resilience.

Although in many communities hazards may be identified, usually risk reduction and vulnerability are not taken into consideration until the disaster occurs (Cutter, 2008).

When analyzing how communities will be affected by a significant hazard event the concepts of vulnerability and resilience as well as the adaptive capacity come into play.

Vulnerability and resilience are closely inter-related concepts (Adger, 2003; Fiskel, 2003; Gallopin, 2006), but the nature of these dynamic relations is not so obvious.

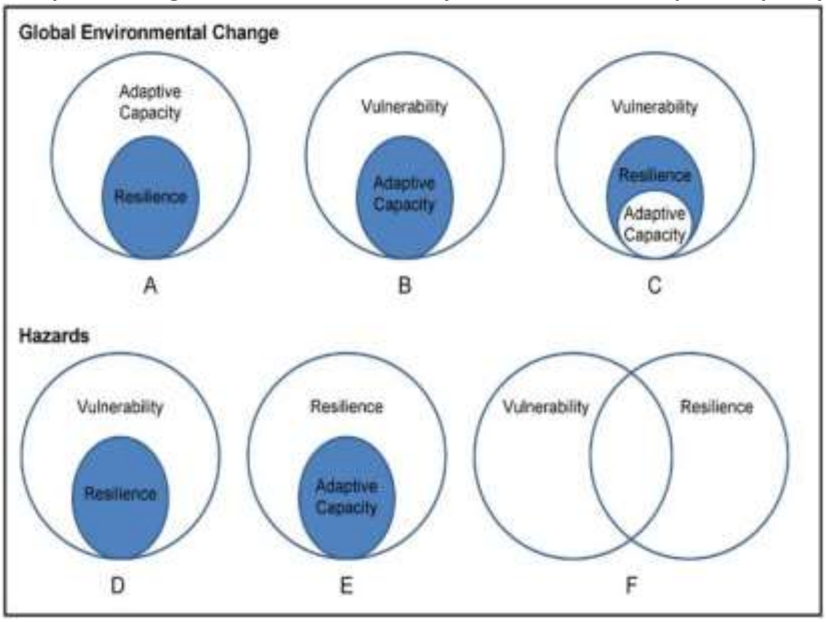
The link between vulnerability and resilience originates from O'Keefe et al. (1976) who introduced the concept of social vulnerability into the disaster discourse by emphasising the human agency as the driver of vulnerability. According to this vision disasters are more a consequence of socio-vulnerability than natural factors.

Questions concerning the relationship between vulnerability, resilience and adaptive capacity have emerged.

For some researchers resilience is an integral part of adaptive capacity (Figure 3A) (Adger, 2006, Folke 2006) while for other adaptive capacity is a main component of vulnerability (Figure 3) (Burton et al., 2000, Manyena 2006, Tierney and Bruneau 2007). In the global change perspective hazards researchers embed adaptive capacity or mitigation within resilience (Figure 3E) (Paton and Johnston, 2006).

The conceptual linkages between vulnerability, resilience and adaptive capacity are illustrated in the figure below.

Figure 3. Conceptual linkages between vulnerability, resilience, and adaptive capacity



Source: Cutter et al. 2008

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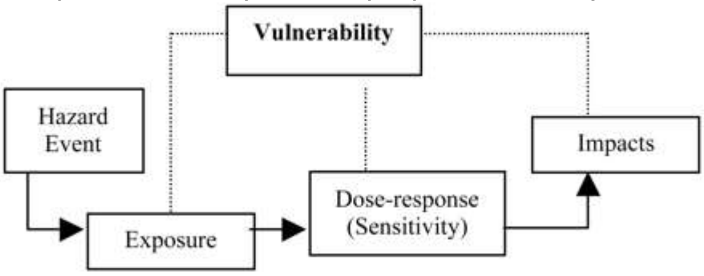
3 Resilience and Vulnerability: methodologies, indicators and indexes

3.1 Vulnerability assessment framework

Most of the vulnerability assessment schemes come firstly from the field of disaster risk reduction and then from the evolution of climate change adaptation framework.
The former field is related to the amount of damages (actual or potential) a particular risk can cause to a system, and thus the assessment is mainly focused on impacts while human system role in mediating them is greatly underestimated or neglected/overlooked.
Two of the principal archetypal reduced-form models of vulnerability are the Risk-Hazard (RH) model (Figure 4) and the Pressure and Release model (PAR).
Initial RH models wanted to understand the impact of a hazard as a function of exposure to the hazardous event and the sensitivity of the entity exposed (Turner et al., 2003). Exposure and sensitivity to perturbations and stressors (Kates, 1985; Burton et al., 1978) have been emphasized in the applications of this model.

Figure 4. RH framework (common to risk application). Chain sequence begins with hazard; concept of vulnerability commonly implicit as noted by dotted lines

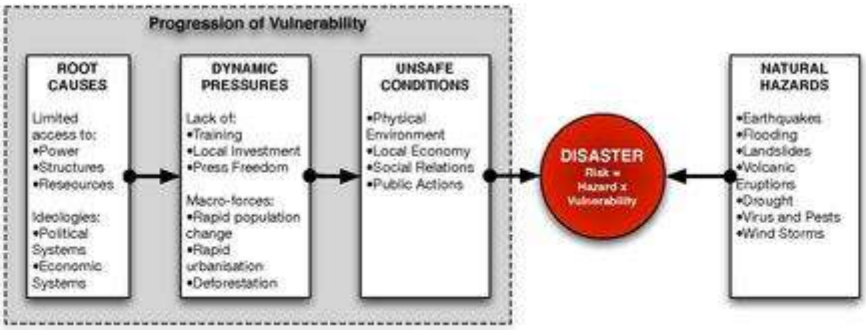


Source: Turner et al., 2003

According to (Martine & Guzman, 2002) the model is inadequate: firs of all because it does not treat the ways in which the systems amplify or attenuate the impacts of the hazard, secondly the model does not address the distinction among exposed subsystems and components that lead to significant variations in the consequences of the hazards, or the role of political economy in shaping differential exposure and consequences (Blaikie et al., 1994, Hewitt, 1997).
For all the above mentioned reasons the PAR model was developed.
The Pressure and Release (PAR) Model (Figure 5) sees the disaster as the intersection between socio-economic pressure and physical exposure. The attention is directed to the conditions that make exposure unsafe, leading to vulnerability and to the causes creating these conditions. The model is used primarily to address social groups facing disaster events and emphasizes distinctions in vulnerability by different exposure units such as social class and ethnicity. According to the model there are three components on the social side: root causes, dynamic pressures and unsafe conditions, and one component on the natural side, the natural hazards itself.

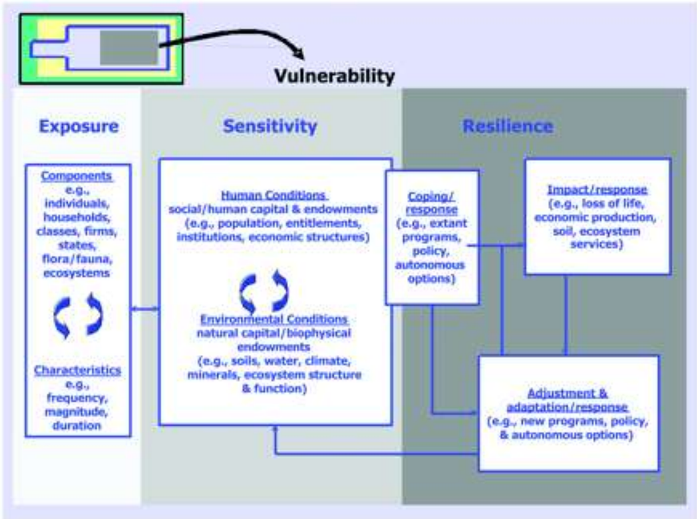
Turner et al. (2003) stressed that even if this model makes explicit reference to vulnerability it is not able to address in a complex manner “the coupled human–environment system in the sense of considering the vulnerability of biophysical subsystems, it provides little detail on the structure of the hazard’s causal sequence”.

Figure 5. Pressure and Release (PAR) model after Blaikie et al. (1994) showing the progression of vulnerability



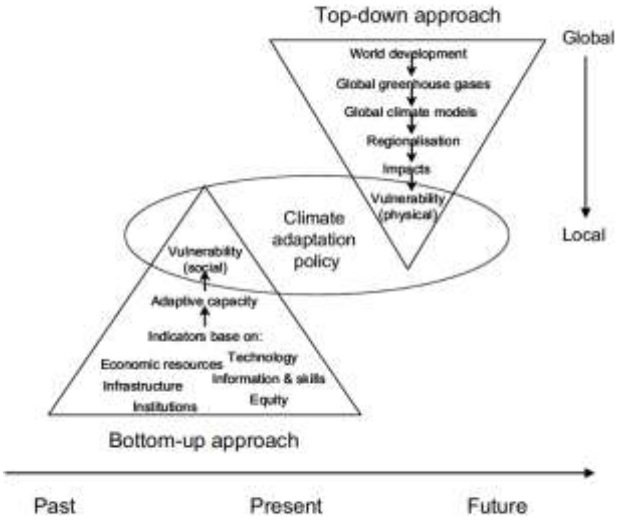
Later climate change adaptation requirements triggered the combination of natural and social science perspectives in order to manage human-nature interactions. As result several vulnerability conceptual framework were developed: e.g. Turner et al., 2003 (Figure 6), Dessai and Hulme, 2004 (Figure 7), O’Brien et al., 2007 (Figure 8), etc..

Figure 6. Details of the exposure, sensitivity, and resilience components of the vulnerability framework.



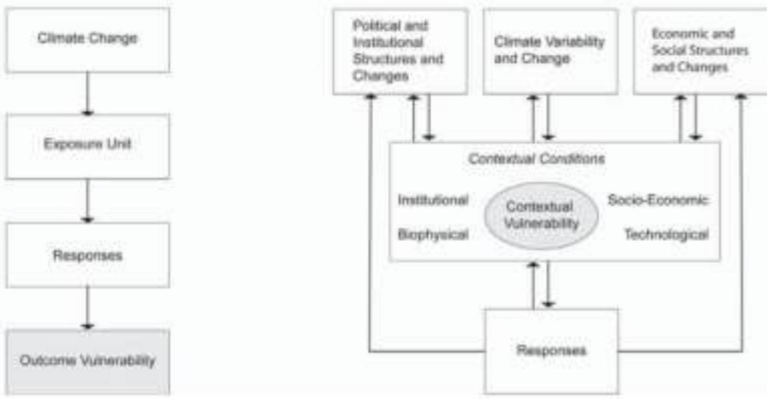
Source: Turner et al., 2003

Figure 7. "Top-down" and "bottom-up" approaches used to inform adaptation to climate change



Source: Dessai and Hulme, 2004

Figure 8. Reproduced from the O'Brien et al (2007) paper: Frameworks depicting two interpretations of vulnerability to climate change, outcome vulnerability (left) and contextual vulnerability (right)



Fussel and Kline (2006) distinguished vulnerability assessments to climate change into four typologies: impact assessment, first- and second-generation vulnerability assessment, and adaptation policy assessment. First and second generation vulnerability assessments - which are the most properly related to vulnerability - can be considered an evolution of an impact assessment taking into account societal relevance of impacts and potential adaptation the first (Figure 9. Conceptual framework for a first-generation vulnerability assessment) and a more deep evaluation of the adaptive capacity of people and feasible adaptation the second (Figure 10. Conceptual framework for a second-generation vulnerability assessment).

Figure 9. Conceptual framework for a first-generation vulnerability assessment

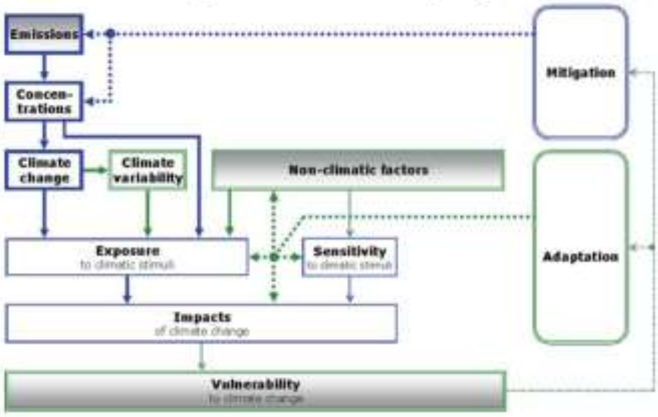
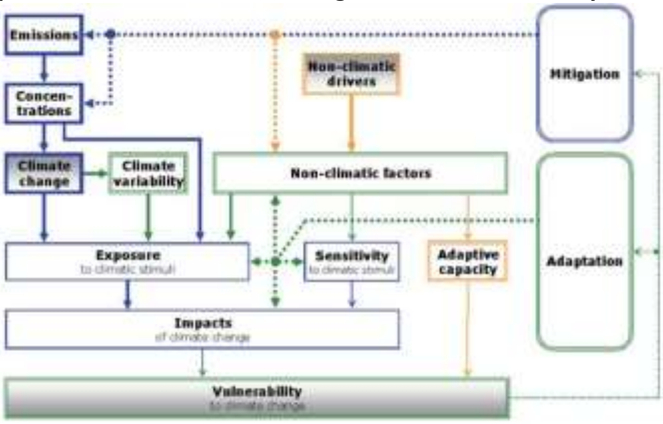


Figure 10. Conceptual framework for a second-generation vulnerability assessment



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3.2 Social Vulnerability approach and indicators

The qualification and quantification of social vulnerability start from identification of indicators. These indicators for the evaluation of social vulnerability are dependent on place, scale and are generally referring to poverty, gender, age, population with special needs, institutional, political capacities.

A number of indices related to vulnerability, sustainability, and quality of life has gained prominence in the literature.

Indices include: the Prevalent Vulnerability Index (PVI) (Cardona,2005); the index of Social Vulnerability to climate change for Africa (SVA) (Vincent,2004); the Predictive Indicator of Vulnerability (PIV) (Adger et al. 2004); the Social Vulnerability Index (SoVI) (Cutter et al. 2003); the Human Development Index (HDI) (UNDP).

The Prevalent Vulnerability Index (PVI) focuses on social, economic, institutional, and infrastructural capacity to recover from natural hazards. The PVI provides a measure of both direct effects (as a result of exposure and susceptibility) and intangible effects (as a result of socioeconomic fragilities) of hazard events. The 24 indicators used comprise a set of demographic, socioeconomic, and environmental national indicators (Cardona et al., 2012). Indicators are aggregated into three sub-indices with varying weights, then summed to generate the final index score.

The index of Social Vulnerability to climate change in Africa (SVA) concentrates on social vulnerability to climate change, particularly water availability. SVA uses 9 indicators as a proxy for social vulnerability going from amount of population in poverty to the presence of household and community telephones. By combining weighted and unweighted averaging for aggregation the SVA arrives to a final index score.

The Predictive Indicator of Vulnerability considers risk (outcome) as a function of both biophysical and social vulnerability. The PIV's aim is to identify driving factors of social vulnerability and adaptive capacity (Adger et al.2004), it aggregates climate-related mortality and then standardizes hazard mortality by population size. 45 social vulnerability variables are reduced to a set of eleven indicators. By averaging the eleven indicators of social vulnerability without imposing weights, the authors arrive to a final PIV score.

The SoVI is a multidimensional, scale dependent, spatially reliant algorithm, for quantifying relative socio-economic and demographic quality of a place. 42 socioeconomic variables (derived from US Census and County Data Books) reduced to 11 statistically independent factors that were aggregated to compute a summary score (the SoVI score) (Cutter et al. 2003).

The Human Development Index (HDI) examines the quality of life considering three dimensions of human development: health, education and income. These dimensions are reflected by four indicators: life expectancy, adult literacy rate, educational enrollment, and GDP per capita. The the HDI's aim is compare the relative levels of development and improvements in well-being among nations.

The development of credible measures represent a challenge for vulnerability research and a key aspect to enable decision makers to assess the possible impacts of disasters, as underlined by the Hyogo Framework for Action.

3.2.1 Italian Upper Adriatic Static Relative Social Vulnerability Index (Static ReSVI)

Introduction

The ECOSTRESS project envisages developing a Self-assessment tool for coastal communities, which could ultimately return values allowing for a 'spatialisation' of such data. This value, returning static 'social relative vulnerability index' (ReSVI) framed in comparative terms within a given geographical area.

In the following paragraphs explain the methodology adopted, namely:

- The criteria deemed relevant for the selection of context-based variables to be included within the tool, in order to measure relative vulnerability of coastal communities;
- The sample of coastal communities selected for the first piloting of the tool;
- The methodology and the criteria used to compute scores of variables and dimensions.

Variables selection

Based on previous research (Burton 2012, p. 37), the selection of variables was based on:

- Literature review: Variables selected among those identified by Burton (2012), Holand et al. (2011) and Borden et al. (2007), Tapsell (2005), ENSURE (2009), Eidsvig et al. (2011) and Cardona (2005).
- Contextualisation. The availability and the quality of data from "national data sources" (Burton 2012, p. 37) was deemed a fundamental aspect in the selection of variables. In fact, the tool is intended as a standardized and easy to use instrument for communities to evaluate their vulnerability/resilience to floods. Data needed to assess the variables for each municipality are statistical data, released by national statistical offices (i.e. in Italy the ISTAT data source) and accessible by any stakeholder.

The variables identified have been clustered into four relevant dimensions (according to literature):

- social
- economic
- infrastructural
- institutional

Table 7. List of variables for the coastal communities self-assessment tool for

Variable	Relevance in literature	Availability of data
SOCIAL DIMENSION		
% of the population that is a minority	*(Burton 2012, p.100)*	ISTAT data source; municipal level
% of the population (25-64) with at least a high school diploma	*(Burton 2012, p.100)*	ISTAT data source; municipal level
% of the population with vehicle access	*(Burton 2012, p.100)*	ISTAT data source; municipal level

Variable	Relevance in literature	Availability of data
% of the population that is elderly (75 years or above)	*(Burton 2012, p.101); (Holand et al. 2011, p. 8)*	ISTAT data source; municipal level
Young dependency ratio	…	ISTAT data source; municipal level
Elderly dependency ratio	…	ISTAT data source; municipal level
% of the population 6 years or younger	*(Holand et al. 2011, p. 8)*	ISTAT data source; municipal level
Incidence of population living in condition of crowding	*(Burton, 2012)*	ISTAT data source; municipal level
Population density	*(Eidsvig et al. 2011); (Cardona 2005)*	ISTAT data source; municipal level
Percentage of elderly living alone	*(Baum et al 2008); (ENSURE 2009); (Tapsell 2005)*	ISTAT data source; municipal level
Per capita expenditure for assistance and social services	*(Burton, 2012)*	ISTAT data source; provincial level
Incidence of families in potential lack of assistance	*(Baum et al 2008)*	ISTAT data source; municipal level
Incidence of centres and settlements	*(Burton 2012, p. 79)*	ISTAT data source; municipal level
N. of beds per 1,000 inhabitants	*(Burton 2012, p. 113)*	ISTAT data source; provincial level
N. of active NGOs per 1,000 inhabitants	*(Burton 2012, p. 113)*	ISTAT data source; municipal level (by crossing the n. of active enterprises with the n. of inhabitants)
ECONOMIC DIMENSION		
Per capita income (average income)	*(Burton 2012, p. 102); (Holand et al. 2011, p. 8); (Baum et al, 2008)*	ISTAT data source; municipal level
Incidence of housing in property	*(Burton 2012, p. 102)*	ISTAT data source; municipal level
% of population that is employed	*(Burton 2012, p. 102)*	ISTAT data source; municipal level
Unemployment rate	*(Holand et al. 2011, p. 8)*	ISTAT data source; municipal level
% female labour force participation	*(Burton 2012, p. 102)*	ISTAT data source; municipal level
Index of households with potential economic difficulty	*(Cardona 2005)*	ISTAT data source; municipal level
Incidence of employed in the agricultural sector	*(Burton 2012, p. 102); (Holand et al. 2011, p. 8)*	ISTAT data source; municipal level
Incidence of employed in the industrial sector	*(Burton 2012, p. 103); (Holand et al. 2011, p. 8)*	ISTAT data source municipal level
Incidence of employed in low-skill service sector	*(Holand et al. 2011, p. 8); (ENSURE 2009); (Tapsell 2005)*	ISTAT data source municipal level
N. of active enterprises per 1,000 inhabitants	*(Burton 2012)*	ISTAT data source municipal level (by crossing the n. of enterprise and the n. of inhabitants)
INFRASTRUCTURAL DIMENSION		
Schools (primary and secondary education) per 10 km2	*(Burton 2012, p. 107)*	ISTAT data source; municipal level (crossing the number of schools per km^2)
Density of building (n. of households per Km2)	*(Burton 2012)*	ISTAT data source; municipal level (the number of households per km^2)
INSTITUTIONAL DIMENSION		
% electorate voting in municipal election	*(Holand et al. 2011, p. 8); (ENSURE 2009); (Tapsell 2005)*	Ministero dell'Interno data source; Municipal data source; municipal level
Municipal spending capacity	*(Holand et al. 2011, p. 8)*	ISTAT data source; municipal level
Funds allocated for major hydrogeological emergencies (2009-2012) - in EUR	*(Eidsvig et al, 2011)*	Legambiente; regional level
Amounts allocated within the Program	*(Eidsvig et al, 2011)*	Legambiente; regional level

Variable	Relevance in literature	Availability of data
Agreements from 2010 - in EUR		

Sample of coastal communities selected

The piloting of the tool was performed on costal municipalities (33 coastal municipalities) on the Italian Upper Adriatic Sea coast.

Table 8. Sample of coastal municipalities selected

Region	Province	Municipality
Emilia-Romagna	Ferrara	Comacchio
		Codigoro
		Goro
	Forlì-Cesena	Cesenatico
		Gatteo
		San Mauro Pascoli
		Savignano sul Rubicone
	Ravenna	Cervia
		Ravenna
	Rimini	Cattolica
		Misano Adriatico
		Riccione
		Rimini
		Bellaria-Igea Marina
Friuli-Venezia Giulia	Trieste	Duino Aurisina
		Muggia
		Trieste
	Gorizia	Grado
		Staranzano
		Monfalcone
	Udine	Lignano Sabbiadoro
		Marano Lagunare
Veneto	Rovigo	Ariano nel Polesine
		Porto Tolle
		Porto Viro
		Rosolina
	Venezia	Caorle
		Chioggia
		Cavallino-Treporti
		Eraclea
		Jesolo
		S. Michele al Tagliamento
		Venezia

Calculation of the static 'relative social vulnerability Index'

For index calculation the following was performed:

1. For each variable selected, data were collected at municipality level from national data sources (ISTAT) for all the coastal communities included in the sample;
2. For each variable, mean value and standard deviation were computed;
3. Deviance from mean value was given a positive or negative sign depending on whether the variable was conceptually held as reducing or increasing vulnerability respectively.

4. **Z-score**: standardized values were computed by calculating for each variable and for each coastal community the Z-score according to the formula:

$$Z = \frac{X - \mu}{\sigma}$$

5. Calculation of the index, as follows:
    a. the score of each of the four dimensions for each municipality was computed as the mean of the Z-scores of the variables defining each dimension;
    b. Sum of the scores of the four dimensions;
    c. Transformation of such scores in an index on a 0 to 1 scale (where 0 is minimum relative vulnerability and 1 is maximum relative vulnerability) , using the formula

$$(x - m_r) * (M_t - m_t) / (M_r - m_r) + m_t$$ [4]

[4] M = max; m= min; t = theoretical; r= real.

Table 9. Relative social vulnerability Index (ReSVI) for selected coastal municipalities

	Ariano nel Polesine	Bellaria-Igea Marina	Caorle	Cattolica	Cavallino-Treporti	Cervia	Cesenatico	Chioggia	Codigoro	Comacchio	Duino-Aurisina	Eraclea	Gatteo	Goro	Grado	Jesolo	Lignano Sabbiadoro	Marano Lagunare	Misano Adriatico	Monfalcone	Muggia	Porto Tolle	Porto Viro	Ravenna	Riccione	Rimini	Rosolina	San Mauro Pascoli	San Michele al Tagliamento	Savignano sul Rubicone	Staranzano	Trieste	Venezia
SOCIAL																																	
% of the population that is a minority	0,79	-1,06	-0,04	-0,76	0,03	-0,65	-0,14	1,14	0,54	0,84	1,14	0,28	-0,88	1,65	0,07	-0,65	-1,20	1,26	-0,18	-2,57	1,30	1,58	1,03	-0,83	-0,41	-0,92	0,91	-0,23	-0,90	-1,57	0,84	-0,18	-0,23
% of the population (25-64) with at least a high school diploma	-0,97	0,58	-0,69	1,16	-0,90	0,75	0,47	-0,98	-0,67	-1,00	1,59	-1,14	-0,32	-2,66	0,62	0,00	0,90	-0,97	0,40	0,76	0,42	-1,33	-0,94	1,01	1,00	1,30	-0,76	-0,34	-0,28	-0,27	1,04	1,16	1,08
vehicles per 1,000 inhabitants	0,80	-0,21	-0,75	0,19	-2,29	0,84	0,53	-2,51	0,90	0,45	0,72	-0,08	0,11	-0,54	-0,51	0,01	1,12	-0,85	0,98	-0,51	0,80	0,30	0,61	0,93	0,50	-0,07	0,88	0,23	0,09	0,41	0,84	-1,16	-2,75
% of the population that is elderly (65 years or above)	-0,84	1,38	-0,06	0,08	0,63	0,08	0,69	0,37	-1,68	-0,18	-1,33	0,69	2,02	-0,24	-1,82	0,77	0,37	-1,22	1,44	-0,61	-1,77	-0,41	0,25	0,02	-0,09	0,34	0,60	1,64	-0,58	1,47	0,05	-1,13	-0,93
Young dependency ratio	1,32	-1,67	-0,35	-0,12	0,24	0,25	-0,59	0,06	1,81	0,91	-0,27	-0,38	-1,70	1,34	1,51	-0,10	0,48	0,84	-1,21	-0,48	0,61	1,54	1,03	-0,42	-0,29	-0,63	0,52	-2,22	0,23	-1,61	-0,72	0,23	-0,14
Elderly dependency ratio	-0,74	1,25	0,05	-0,14	0,76	0,16	0,55	0,58	-1,51	0,18	-1,50	0,89	1,91	0,09	-1,66	0,57	0,45	-1,04	1,27	-1,38	-1,58	0,17	0,45	-0,24	-0,17	0,07	1,00	1,29	-0,39	1,23	0,38	-1,60	-1,36
% of the population 6 years or younger	1,09	-1,77	-0,19	-0,01	-0,20	-0,14	-0,57	0,34	1,71	0,69	0,55	0,16	-2,66	0,81	1,68	-0,08	-0,30	0,87	-1,73	-0,06	0,94	1,06	0,70	-0,42	-0,05	-0,50	-0,07	-1,68	0,63	-1,55	-0,18	0,51	0,41
Incidence of population living in condition of crowding	0,97	-1,94	-0,07	0,39	-0,01	-0,84	-1,45	-1,23	1,95	0,50	-0,08	0,89	-2,07	1,02	0,32	0,80	0,50	0,87	-1,84	-1,60	0,44	0,89	0,98	-0,72	0,07	-0,46	0,41	-0,04	0,62	-0,57	1,12	0,30	-0,12
Population density	0,75	-0,69	0,72	-3,15	0,40	0,31	0,00	0,44	0,73	0,72	0,55	0,64	-0,10	0,66	0,72	0,46	0,22	0,80	0,02	-1,21	-0,57	0,78	0,67	0,48	-2,11	-0,70	0,71	-0,12	0,68	-0,29	0,29	-2,71	-0,10
Percentage of elderly living alone	-0,41	0,13	0,08	-0,53	0,65	-0,61	0,57	0,20	0,09	-0,30	-0,60	1,41	1,61	0,38	-1,60	0,10	-1,59	-1,00	1,07	-1,70	-0,76	0,92	0,96	-0,03	-0,22	0,12	0,13	1,81	0,73	1,58	0,18	-2,25	-1,10
Per capita expenditure for assistance and social services	-1,00	-0,68	-0,13	-0,68	-0,13	0,14	-0,75	-0,13	-0,28	-0,28	2,53	-0,13	-0,75	-0,28	1,03	-0,13	0,59	0,59	-0,68	1,03	2,53	-1,00	-1,00	0,14	-0,68	-0,68	-1,00	-0,75	-0,13	-0,75	1,03	2,53	-0,13
Incidence of families in potential lack of assistance	-1,10	0,75	0,40	-0,87	1,45	-0,04	0,69	1,05	-2,18	1,31	0,20	0,40	1,64	-0,46	-0,24	0,14	1,99	-0,56	0,56	-1,90	-0,84	-0,45	-0,18	-1,01	-1,12	-0,84	0,96	0,94	-0,20	0,56	0,60	-0,79	-0,85
Incidence of centres and settlements	0,89	-1,24	0,76	-2,58	0,15	0,13	-0,12	0,74	0,83	0,81	0,52	0,71	-0,11	0,84	0,94	0,36	-1,78	1,03	-0,04	-1,40	-1,65	0,95	0,79	0,71	-2,12	-0,17	0,49	0,03	0,47	-0,36	0,54	-1,27	0,16

N. of active NGO per 1,000 inhabitants	0,39	-0,80	-0,25	-0,46	-0,59	-0,28	-0,60	-0,69	-0,62	-1,08	0,92	-1,69	-1,10	-1,45	1,60	-0,60	1,03	2,61	-1,11	0,96	0,56	-0,23	-0,40	0,54	-0,22	0,49	0,10	-0,74	-0,21	-0,36	1,85	1,25	1,17
N. of hospital beds per 1,000 inhabitants	1,09	0,07	-0,80	0,07	-0,80	0,05	-0,02	-0,80	1,24	1,24	1,24	-0,80	-0,02	1,24	-2,11	-0,80	-0,11	-0,11	0,07	-2,11	1,24	1,09	1,09	0,05	0,07	0,07	1,09	-0,02	-0,80	-0,02	-2,11	1,24	-0,80
ot Dimension	**0,20**	**-0,39**	**-0,09**	**-0,50**	**-0,04**	**0,01**	**-0,05**	**-0,09**	**0,19**	**0,32**	**0,41**	**0,12**	**-0,16**	**0,16**	**0,04**	**0,06**	**0,18**	**0,21**	**-0,07**	**-0,85**	**0,11**	**0,39**	**0,40**	**0,01**	**-0,39**	**-0,17**	**0,40**	**-0,01**	**0,00**	**-0,14**	**0,38**	**-0,26**	**-0,38**
ECONOMIC																																	
Per capita income (average income)	-0,80	-0,51	-0,49	0,14	-0,29	0,43	-0,30	-0,84	-0,04	-0,73	1,90	-0,82	-0,49	-3,10	0,77	0,36	0,95	-0,46	-0,32	0,60	1,28	-1,25	-0,76	1,32	0,05	0,49	-0,76	-0,32	0,12	-0,25	0,75	1,78	1,59
Incidence of housing in property	0,73	-0,38	-0,42	-1,17	0,29	-0,10	-0,63	-0,05	-0,13	-0,39	1,90	0,92	0,06	1,87	1,19	-0,51	-0,61	0,51	-0,73	-0,53	0,55	0,51	-0,29	-0,09	-1,63	-1,64	0,92	-0,04	1,25	-0,95	2,27	-1,33	-1,34
Employment rate	-0,97	0,97	-1,07	-0,19	0,19	0,37	0,85	1,20	-0,38	-0,86	-0,52	-0,23	2,46	0,47	-0,87	0,74	-0,29	-0,74	-1,13	-1,56	-1,35	0,99	-0,73	0,73	-0,22	0,19	0,31	2,18	-0,49	-1,81	-0,23	-0,84	-0,66
Unemployment rate	0,25	-0,03	-2,24	-1,70	-0,20	0,53	-0,36	-0,65	1,26	-0,91	2,02	0,33	-0,56	2,33	0,54	0,88	-1,02	-0,84	-0,30	-0,81	1,23	0,50	-1,26	1,19	-0,46	0,22	-0,88	0,37	-0,07	-0,47	0,41	-0,27	0,94
% female labour force participation	-1,10	0,71	-0,79	0,48	0,16	0,40	0,94	-1,31	-0,14	-0,40	-0,17	-0,97	2,33	-2,29	-0,73	0,26	-0,19	-0,92	1,13	-1,55	-0,54	0,56	-0,79	0,84	0,35	0,58	0,00	1,92	-0,40	1,78	0,27	0,05	-0,43
Index of households with potential economic difficulty	0,22	-0,99	-2,12	-1,32	-0,20	-0,52	-0,45	-0,10	1,15	-0,63	1,08	-0,50	-0,17	1,32	0,66	-0,79	-2,70	1,30	-1,24	0,04	1,27	1,53	-0,04	0,78	-0,75	0,08	-0,20	0,55	-0,19	0,44	0,85	0,88	0,75
Incidence of employed in the agricultural sector	-0,39	0,36	0,07	0,60	0,10	0,36	0,13	-0,17	-0,71	-0,08	0,56	0,40	0,02	-4,47	0,19	0,46	0,59	-1,29	0,59	0,66	0,66	-2,12	0,06	0,31	0,56	0,56	-0,38	0,06	0,32	0,03	0,61	0,70	0,65
Incidence of employed in the industrial sector	1,17	-0,05	-0,30	0,02	-0,84	-0,42	-0,31	-0,46	0,61	-0,05	-0,72	1,57	1,19	-2,60	-1,06	-0,61	-1,40	-0,37	0,14	1,42	0,02	0,21	1,27	0,26	-0,45	-0,65	0,50	1,98	0,35	1,38	0,70	-1,23	-1,27
N. of active enterprises per 1,000 inhabitants	-0,40	0,16	0,13	0,65	-0,99	0,19	0,33	-0,72	-0,74	0,11	-1,06	-0,60	-0,34	4,01	-0,16	0,44	1,66	0,49	0,14	-0,82	-1,15	1,72	-0,27	-0,55	0,43	0,02	0,33	-0,43	0,21	-0,39	-1,20	-0,81	-0,39
Incidence of employed in low-skill service sector	-1,93	0,11	0,25	0,86	-1,15	0,25	-0,04	-1,28	-2,45	-0,89	1,51	-0,58	-1,45	0,63	0,68	0,46	1,52	0,62	0,74	-0,08	1,36	0,17	-0,69	-0,14	0,50	0,49	-0,30	-0,54	-0,53	-1,00	1,68	1,12	0,10
ot Dimension	**-0,32**	**0,04**	**-0,70**	**-0,16**	**-0,29**	**0,15**	**0,01**	**-0,68**	**-0,16**	**-0,48**	**0,65**	**-0,05**	**0,31**	**-0,18**	**0,12**	**0,17**	**-0,15**	**-0,17**	**0,13**	**-0,26**	**0,33**	**0,28**	**-0,35**	**0,46**	**-0,16**	**0,03**	**-0,05**	**0,57**	**0,06**	**0,24**	**0,61**	**0,00**	**-0,01**
INFRASTUCTURAL																																	
Schools (primary and secondary education) per 10 km2	-0,68	0,48	-0,77	2,56	-0,50	-0,37	-0,73	-0,41	-0,74	-0,73	-0,11	-0,61	0,41	-0,62	-0,73	-0,49	-0,14	-0,81	-0,06	1,44	0,79	-0,77	-0,70	-0,56	2,13	0,68	-0,75	-0,01	-0,68	0,33	-0,08	3,06	0,19
N. of households per km2	0,79	-0,55	0,55	-2,56	0,53	0,19	-0,12	0,56	0,78	0,52	0,66	0,63	0,14	0,73	0,60	0,19	-3,14	0,83	-0,04	-0,70	-0,22	0,82	0,74	0,54	-1,68	-0,36	0,58	0,17	0,26	0,15	0,47	-2,16	0,10
ot Dimension	**0,05**	**-0,04**	**-0,11**	**0,00**	**0,01**	**-0,09**	**-0,43**	**0,08**	**0,02**	**-0,11**	**0,28**	**0,01**	**0,27**	**0,06**	**-0,07**	**-0,15**	**-1,64**	**0,01**	**-0,05**	**0,37**	**0,28**	**0,02**	**0,02**	**-0,01**	**0,22**	**0,16**	**-0,09**	**0,08**	**-0,21**	**0,24**	**0,19**	**0,45**	**0,15**
INSTITUTIONAL																																	

% electorate voting in municipal election	0,72	0,86	0,49	0,01	-0,25	0,64	0,71	-1,65	0,45	-1,36	-0,35	0,77	0,34	1,46	0,46	-1,94	-0,04
Municipal spending capacity	-0,32	0,55	0,84	2,88	-0,61	0,41	1,42	0,99	-0,18	0,70	-0,03	0,84	-0,47	0,26	-1,49	-0,18	-0,76
Funds allocated for major hydrogeological emergencies (2009-2012)	1,39	-0,61	1,39	-0,61	1,39	-0,61	-0,61	1,39	-0,61	-0,61	-0,83	1,39	-0,61	-0,61	-0,83	1,39	-0,83
Amounts allocated within the Program Agreements from 2010	-0,60	1,09	-0,60	1,09	-0,60	1,09	1,09	-0,60	1,09	1,09	-1,16	-0,60	1,09	1,09	-1,16	-0,60	-1,16
ot Dimension	**0,30**	**0,47**	**0,53**	**0,84**	**-0,02**	**0,38**	**0,65**	**0,03**	**0,19**	**-0,05**	**-0,59**	**0,60**	**0,09**	**0,55**	**-0,75**	**-0,33**	**-0,70**
TOTAL	**0,23**	**0,08**	**-0,37**	**0,18**	**-0,34**	**0,45**	**0,19**	**-0,66**	**0,24**	**-0,31**	**0,75**	**0,69**	**0,50**	**0,58**	**-0,67**	**-0,26**	**-2,31**
Italian Upper Adriatic Relative Vulnerability Index	0,24	0,28	0,42	0,25	0,41	0,17	0,25	0,51	0,24	0,40	0,08	0,10	0,16	0,13	0,51	0,39	1,00

% electorate voting in municipal election	0,27	0,19	-0,42	-0,63	0,41	1,05	-1,12	0,50	0,61	1,58	0,39	-2,77	0,60	0,46	-1,42	-1,00
Municipal spending capacity	-0,47	0,55	-0,47	-0,03	0,11	-2,36	-0,47	-1,63	-0,03	-1,05	-0,76	-0,90	-0,18	0,70	0,70	1,42
Funds allocated for major hydrogeological emergencies (2009-2012)	-0,83	-0,61	-0,83	-0,83	1,39	1,39	-0,61	-0,61	-0,61	1,39	-0,61	1,39	-0,61	-0,83	-0,83	-0,83
Amounts allocated within the Program Agreements from 2010	-1,16	1,09	-1,16	-1,16	-0,60	-0,60	1,09	1,09	1,09	-0,60	1,09	-0,60	1,09	-1,16	-1,16	-0,60
ot Dimension	**-0,55**	**0,31**	**-0,72**	**-0,66**	**0,33**	**-0,13**	**-0,28**	**-0,16**	**0,26**	**0,33**	**0,03**	**-0,72**	**0,22**	**-0,21**	**-0,68**	**-0,25**
TOTAL	**-0,50**	**0,32**	**-1,47**	**0,06**	**1,03**	**-0,06**	**0,19**	**-0,49**	**0,29**	**0,59**	**0,66**	**-0,88**	**0,56**	**0,98**	**-0,48**	**-0,49**
Italian Upper Adriatic Relative Vulnerability Index	0,46	0,21	0,75	0,29	0,00	0,33	0,25	0,46	0,22	0,13	0,11	0,57	0,14	0,02	0,45	0,46

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4 Case studies

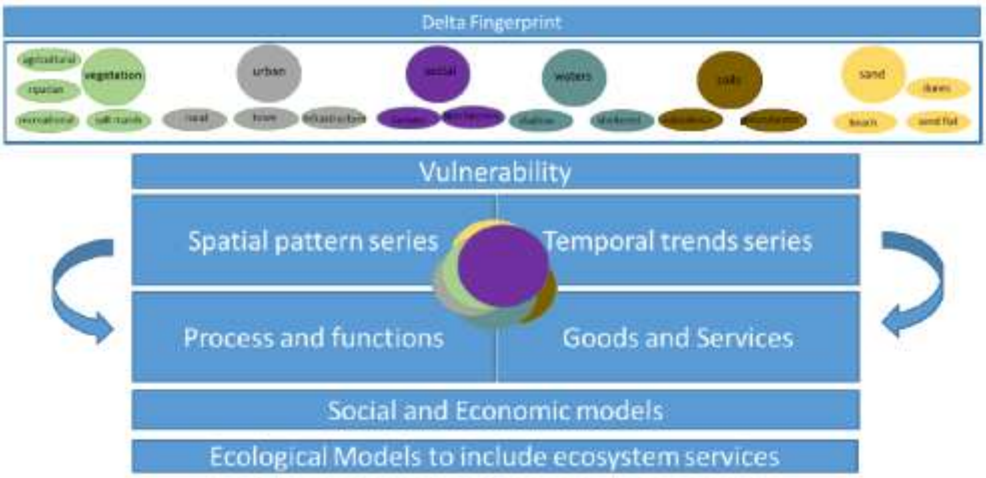
4.1 Deltaic areas

Coastal and especially deltaic areas are highly dynamic coastal systems of great importance from several points of view. These areas have always been highly populated, giving access to great amount of food and raw materials, hosting several ecosystems and related services, and being privileged hotspots for trading at the interface between land and sea (Ericson et al., 2006).

At the same time these areas are among the most exposed to harmful natural and manmade effects: for example habitat destruction, coastal erosion and flooding generate direct consequences endangering and compromising the health status of coastal social and ecological systems, while resources overexploitation produces conflict of use over land and marine environments.
Coastal population of world's deltas is expected to grow further in the next decades increasing socio-economic vulnerability (Nicholls et al., 2007) and leading to the spread of anthropogenic landscapes at the expense of natural ones (Valiela, 2006).

Many of the deltas are low-lying coastal plains that will increasingly experience adverse impacts due to climate change and natural environmental variability such as coastal flooding, and coastal erosion due to relative sea level rise (Wong et al., 2014). Even if common features can be found, each deltaic area has to be seen as a unique complex coexistence of natural and anthropic patterns and drivers and therefore the above mentioned impacts will be spatially non-uniform depending both on drivers magnitude and coastal morphology, and on human systems and values.

Figure 11. Delta fingerprint scheme



4.1.1 The Dutch Waddenzee case study (The Netherlands)

National framework

Water has a strong influence in the Netherlands: at present much of the spatial planning system is implicitly driven by the problems the Dutch encounter with their salt and fresh water systems.

For instance, in the framework of river basin management the Dutch spatial planning system delivered in 2007 a key planning decision (PKB) called "Ruimte voor de Rivier" (Space for the Rivers)[5], which states that sufficient space should be left within the river basin to cope with extreme run-off. The PKB includes measures[6] aimed to increase the discharge and storage of the rivers and, where possible, to provide more space for recreation (e.g. widening of the floodplain, relocation of dikes, etc.). This decision represents a break with the policies in the past, the emphasis has shifted from dike improvements to river basin management.

In addition, the "Derde Kunstnota", "Third Coastal Policy Document", forbids building outside designated areas and allows natural sand movement along the coasts.

The planning process used to focus on the definition of the functions that were permitted in a certain area, but a paradigm shift has taken place: development planning is not more focused on which functions are permitted but rather on which functions are desired in a certain area.

Sea Water scenario: past and future

Since 1900 sea level rise of the North Sea near the Dutch coast has been 19 cm, which is comparable with the global average (Platform Communication on Climate Change, 2006). In addition, the subsidence of the Dutch soil has been 0-4 mm/year, depending on the location in The Netherlands (Ministry of Transport, Public Works and Water Management, Ministry of Agriculture, Nature and Food Quality, and Ministry of Housing, Spatial Planning and the Environment, 2010).

Following the scenarios of the Royal Netherlands Meteorological Institute, there is an 80% chance that the sea level in 2050 will be 15 to 35 cm higher than in 1990. For 2100, with respect to 1990, a sea level rise of the North Sea of 35-85 cm is projected (Platform Communication on Climate Change, 2006). In addition, the subsidence of the Dutch soil will continue up to 4 mm/year, depending on the location in The Netherlands (Platform Communication on Climate Change, 2006).

According to the Royal Netherlands Meteorological Institute, changes in the wind climate in the 21st century will be small with respect to natural variability (Platform Communication on Climate Change, 2006).

Recent regional studies provide evidence for positive projected future trends in significant wave height and extreme waves along the western European coast (Debernard and Røed, 2008). However, considerable variation in projections can arise from the different climate

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[5] https://www.ruimtevoorderivier.nl/meta-navigatie/organisatie

[6] The work in the context of « Ruimte voor de Rivier" is carried out in collaboration with Rijkswaterstaat, the Ministries of Infrastructure and Environment and Economic Affairs, Agriculture and Innovation, various water boards, provinces and municipalities.

models and scenarios used to force wave models, which lowers the confidence in the projections (IPCC, 2012).

Dutch policy on flood protection

For **Dutch policy on flood protection** it is considered unlikely that the storm regime along the Dutch North Sea coast and the associated maximum storm surges will change significantly in the 21st century (Ministry of Housing, Spatial Planning and the Environment, 2009). For the Dutch coast no statistically significant change in the 10,000-year return values of surge heights was projected for the 21st century because projected wind speed changes were not associated with the surge-generating northerlies but rather non-surge generating south-westerlies (Sterl et al., 2009 in IPCC, 2012).

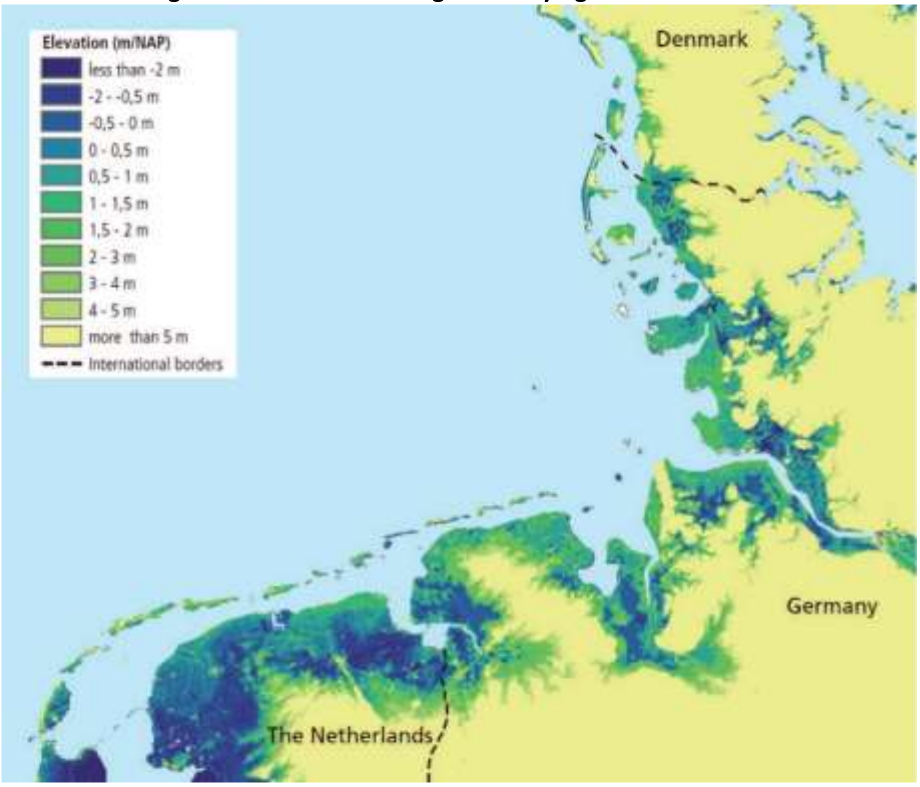
The dunes, dikes, dams and storm surge barriers have to meet safety standards set by law. This law, the 1996 Flood Protection Act, is of relatively recent date but the standards for the coastal zone have already been recommended and accepted since 1960.

The safety standards recommendations for the coastal zone followed the 1953 storm surge which induced flooding and killed over 1800 people in the southwest of the Netherlands. The standards demand for a minimum height and strength of the flood defences surrounding a given area, thus protecting this area from flooding from the sea, the main rivers and large lakes. Such an enclosed area protected by one set of dikes is called a dike ring. The flood prone part of the Netherlands consists of 53 dike rings (and a number of small embankments along the Meuse) (Ten Brinke, et al., 2008).

Actual flood probability

The safety standards indicate a minimum level of safety. A safety standard of 1/10,000 per year means that the coastal flood defence must be high and strong enough to withstand storm surges that have a likelihood of occurrence of 1/10,000 per year. The actual coastal flood probability is even (much) lower. The actual flood probability cannot be quantified exactly because it depends on many factors, such as the strength of dikes and the likelihood of storm surges, that cannot be quantified exactly. According to estimates, actual flood probability of the low-lying (Figure 12), densely populated area in the western part of the country, with the major cities of Amsterdam, Rotterdam and the Hague, may be less than 1/100,000 per year (RIVM, 2004).

Figure 12. Wadden Sea region low-lying areas



Source: Safecoast, 2008

At present about a third of all flood defences (including those of the coast, the rivers and the large lakes) do not comply with the current standards. For about half of these defenses improvements are being implemented; the improvements of the other half of the defenses that failed the assessment still have to be planned (Ministry of Infrastructure and the Environment, and Ministry of Economic Affairs, Agriculture and Innovation, 2012).

Dutch authorities use several scenarios as a basis for their flood protection and contingency planning policies, and for their strategy to adapt to the consequences of climate change.

The Wadden Sea coast scenario results in a flooded area of 4560 km2 but the estimated number of casualties (some 3,000) and potential damage (40 billion Euros) is far less since this part of the Netherlands is less densely populated. The flooding proceeds at a slower rate than the scenario for the south-western and central coastline: 50% of the 4560 km2 gets flooded 12 hours after the breaches, 73% after one day. Again, not the entire flood prone area gets flooded: higher ground and objects stop the flood in parts of the area. In approximately 70% of the flooded area the water depth is less than 2 meters (Ten Brinke et al., 2010).

Safety against flooding from the sea can be ensured with current, available methods, even in the worst case scenario of 1.5 meters sea level rise per century (Ministry of Housing, Spatial Planning and the Environment, 2009).

Coastal protection: law and authorities

In 2008 a new Water Law was adopted, through which most of the laws concerning water management were modernized, co-ordinated and integrated. The Water Law covers surface waters and ground waters and co-ordinates water management and spatial planning.

At the national level, the Ministry of Transport, Public Works and Water Management (Min V&W) and the Ministry of Agriculture, Nature and Food Quality (Min LNV) are responsible respectively for coastal defence and nature conservation in the Wadden Sea. The Ministry of Housing, Spatial Planning and the Environment (Min VROM) drew up the guidelines for local and regional plans in a national directive, the PKB-Waddenzee (Key Planning Decision Decision Wadden Sea; see below).

The protection of the North Sea coast of the islands is the responsibility of the Directorate-General for Public Works and Water Management (RWS) of the Min V&W. Each Province (Figure 13) along the coast have a Provincial Consultative Body for the Coast (POK). Through this body, national, provincial and municipal authorities and regional water boards discuss all issues concerning coastal defence and give recommendations to the Minister of VROM.

Figure 13. The 12 provinces of Netherland

For coastal defence the following points are the most important:

1) The law stipulates that safety standards must be defined for all primary water defences. Based on the advice of the Delta Committee (2008), the National Water Plan states that prevention of flooding is the core of the Dutch water safety management strategy. Spatial planning and innovative techniques may be used to achieve this goal.

In 2008 the new spatial law entered into force. The main provision is that binding planning in land-use plans takes place at the municipal level. Land-use plans specify which functions are allowed and sought in certain areas. These plans are valid for 10 years.

2) The law states that landward retreat of the coastline will be prevented by the State, as far as this is needed for maintaining safety. In practice, this will be done mainly by sand nourishment and, where they exist, maintaining the dikes.
However, new clay extraction requirements for dike restoration projects have appeared in the last fifteen years: namely one of the new requirements is that nature conservation or habitat restoration measures have to be included.

Conservation and Protection

There are three National Parks within the Dutch Wadden Sea region, the Dunes of Texel, the island of Schiermonnikoog and the Lauwersmeer. The system of National Parks protects a wide range of landscapes characteristic of the Netherlands, ranging from dunes, tidal flats and stream valleys to woodland, heath and fens. A National Park must extend to at least 1000 ha.
Important instruments in the Netherlands are the "Water Directive River Basin management plans". These describe the agreements on the qualitative and quantitative goals and on how to implement them, with some species or habitats specifically named. Natura 2000 and the Water Framework Directive are closely linked, with all Natura 2000 sites part of a Water Directive River Basin which often rely heavily on water quality. Coordination between them is therefore essential.

Ecosystem functions

According to Folmer et al. (2010), the Wadden Area, one of the most important wetlands in Europe, performs several functions (or provide several ecosystem services):

- Production services, i.e. products obtained from ecosystems;
- Regulating services, i.e. benefits obtained from the regulation of ecosystem processes;
- Information services, i.e. non-material benefits that people obtain through spiritual enrichment, cognitive development, recreation etc. ;
- Habitat services, necessary for the production of all other ecosystem services.

Breaking down further the previous list, following Whitten and Bennett (2005) classifications, in the Wadden area is possible to distinguish the following functions:

- flood control;
- flora and fauna production;
- sediment accretion and deposition;
- ground water recharge;
- ground water discharge;
- water purification;
- storage of organic matter;
- food-chain support / cycling;
- water transport;
- tourism and recreation; and
- contribution to climatic stability.

Particularly important is the role that salt marshes and intertidal flats (, governed by complex natural mechanism such as sea-level and sediment-supply regimes, play coastal protection, but at the same time coastal flood defense and protection cause the main interference with the natural development of salt marshes.

Upward sea-level movements provide accommodation space within which marshes build upwards. The marshes along the Wadden Sea are mineralogenic, i.e. built up of marsh sediments, i.e. fine-grained material (also referred to as silt), and coarse-grained material (also referred to as sand). They consist of a vegetated platform, typically dissected by extensive networks of blind-ended, branching tidal creeks. The flow-resistant surface vegetation both traps and binds tidally introduced mineral sediment, but also contributes an organic component of indigenous origin to the deposit.

Thus, according to the Wadden Sea Plan (Common Wadden Sea Secretariat, 2010) – which is a Wadden Sea Plan constitutes the common framework among Dutch, German and Danish governments for the protection and sustainable management of the Wadden Sea as an ecological entity - it is important to increase natural dynamics in conjunction with dune areas and tidal flats, to allow adaptation to sea level rise and to achieve favorable conservation status where not interfering with the protection of the islands.

Figure 14. Salt marshes of Spiekeroog

Figure 15. Common glasswort at the border between tidals flats and salt marshes

Source: http://www.waddensea-secretariat.org

Existing spatial plans for the Wadden Sea coastal area

The Dutch Wadden sea area includes 3 provinces (North Holland, Firiesland and Groningen), 4 water boards and 18 municipalities.

The PKB-Waddenzee is an integrated policy document, covering areas covering areas of competence of several ministries. The current PKB Wadden Sea, the third (PKB Derde Nota Waddenzee) runs from 2007 to 2017 and covers an area, which includes the proper Wadden Sea and uninhabited parts of the islands and is bounded by the dikes on the mainland side (Figure 16). The main aim for this area is the sustainable protection and development of the Wadden Sea as a wildlife area and conservation of its unique open landscape.

Figure 16. Boundaries of Key Planning Decision PKB and municipalities

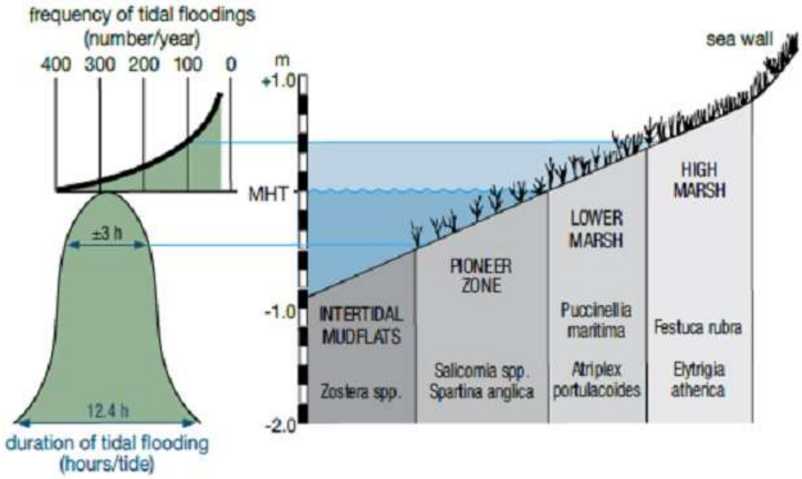
Source: Derde Nota Waddenzee

The PKB itself does not specifically address coastal protection or the possible impacts of sea level rise. These themes are covered in the management and development plan, setting out the main points of the implementation of the PKB

The three Wadden Sea provinces, Noord-Holland, Fryslân and Groningen, have also drawn up a joint policy plan for the Wadden Sea (1994). This Plan, which remains in force, contains a section on coastal defence, referring to the national policy plan for coastal protection. This national plan aims at dynamically maintaining the sandy coastline as it was in 1990. The framework for the implementation of the PKB is set out in the Management and Development Plan (B&O Plan). One of the four main implementation objectives of the B&O Plan is to increase the resilience of the Wadden Sea area against possible impacts of climate change. Improving and restoring natural processes and interactions within the Wadden Sea, its salt marshes, islands and the mainland will achieve this.

Strengthening and re-inforcing of dunes by sand suppletion and repairs to dikes have been or will be encouraged through spatial plans and the dynamics of dunes and salt marshes will be augmented (Figure 17). The role of bio-engineers (mussel beds, sea grass beds) for coastal protection will be further investigated. Increasing the storage volume and providing sufficient sluice and pump capacity will tackle anticipated problems with fresh water storage on the mainland. Furthermore, measures will be taken to prevent salinization of agricultural areas behind the dikes or to anticipate this process by growing salt-tolerant crops. Further refinement of the above broad objectives is planned for the period 2009 to 2014.

Figure 17. Salt marshes scheme in relation to inundation duration and frequency



Source: Coldewey & Erchinger 1992

Involved authorities and offices

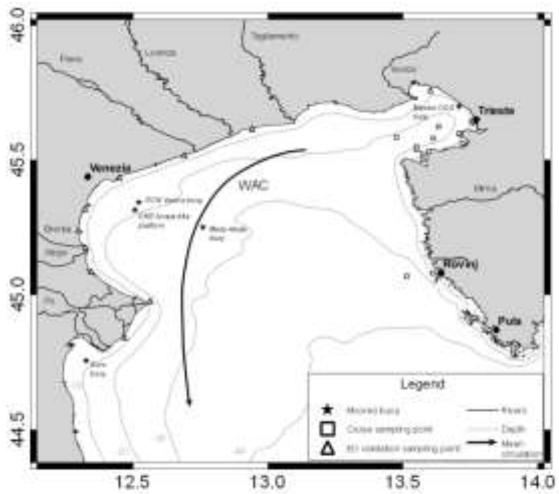
- Ministry of Transport, Public Works and Water Management (Min V&W), responsible for coastal defense
- Ministry of Agriculture, Nature and Food Quality (Min LNV) responsible for nature conservation
- Provinces and local authorities

4.1.2 The Northern Adriatic – Po Delta case study (Italy)

The Adriatic Sea is a shallow (depth < 100 m with a gentle slope about 0.02°) semi-enclosed shelf sea located between western and eastern parts of the Mediterranean Sea, it is about 800 Km long and 150 Km wide.

One of the major features is a coastal current along the western side of the basin, the Western Adriatic Coastal Current (WAC), driven by wind and thermohaline forcing (Figure 18).

Figure 18. Study area for Mediterranean site: the northern Adriatic Sea. In the map the WAC is the Western Adriatic Coastal Current driven by wind and thermohaline forcing



Annual cycle of rivers is characterized by two low-discharge periods, in winter and summer, alternated by two high-discharge peaks, the first one during early spring due to melting snow, glacial ice and frontal rainfall and a second one during late autumn related to rainfall. Po River constitutes the main freshwater discharge in northern Adriatic Sea, collecting the runoff of a large drainage basin (71057 Km2) that has a resident population of 16 million inhabitants (Cozzi and Giani, 2011). Riverine freshwater inputs affects the productivity of certain areas, especially in the proximity of Po delta (Cataudella & Spagnolo, 2011) where the largest rate of oxygen consumption due to biochemical processes is recorded (Artegiani et al., 1997b). Po River discharge has been estimated to be approximately 50% of total external contribution of nutrients to the northern Adriatic Sea (Degobbis and Gilmartin, 1990), inducing intense phytoplankton development in winter and autumn.

One of the main feature/landform of this area in terms of geomorphological, economic and cultural value is the Po Delta (Figure 19) , which underwent many changes of shape (Simeoni & Corbau, 2008) and use through the time, but still represents one of the areas considered among the most productive and rich in biodiversity and includes territorial and ecological features that make it unique.

The system of the Po Delta is an alluvial fan that prograded from Pianura Padana into the Adriatic Sea. The Po Delta covers an area of about 400 km2 and extends seaward for about 25 km. It is characterized by very young coastal and alluvial deposits, and it is also subject to subsidence. Many dune systems and barrier islands delimit lagoon areas along its coastline. Taking into account its natural variability and complexity, it can be considered as one of the most important European natural areas. Climate conditions have favoured agricultural development and aquaculture that has deeply conditioned it. In the past decades the natural rates of subsidence were enhanced by human activities (groundwater and methane extraction, sediment supplies, drainage and intensive farming practices).

Currently the Po Delta is almost completely below the sea level, except for embankments, sandbars and dunes. Water management is under the control of the Reclamation Consortium of Po Delta and Adige that manages a huge hydraulic drainage system of with water pumps that can lift a billion cubic meters of water a year by entering it in drains channel.

The Po Delta belongs to two Italian regions: Veneto and Emilia Romagna. In 1995 part of the territory was included in the UNESCO World Heritage list: because of its history of cultural and economic value and its capacity of preserving important vestiges of its glorious past that influence the natural landscape in an exceptional manner it is an example of an outstanding planned cultural landscape able of retaining its original feature to a remarkable extent.

The actual landform of the Delta Po is the results of the river sedimentation processes but also of the manmade actions that over the centuries have regulated the waters and reclaimed the land.

Figure 19. Po Delta area

Conservation and Protection

The Delta Po area comprehends two protected areas: the Regional Park of the Po Delta in Emilia-Romagna region (that includes the smallest and southern part of the of the delta) and Veneto Regional Park of the Po Delta.

An interregional Po Delta Park should have benne constituted jointly by 1993, in accordance with the National Law on Protected Areas (Law no. 394 of 1991, Art. 35). Since no agreement has been reached between the parties, two separate regional parks were set up.

Despite being one of the protected areas more populated and economically developed of the country, the Po Delta presents an incredible biodiversity (especially birds) and preserves the Italian greatest extension of protected wetlands, both are ecological values not easy to be estimated.

The Regional parks cover an area of great complexity, which is at the same time an inland, a river and a coastal environment. But there is no doubt that the water is the natural element that most characterize it and determined its evolution in time and space.

The unstable relationship between water and land, their increasingly precarious balance, which in the Po Delta has resulted in a so changeable landscape in which forests, pine forests and flooded forests alternate with inland freshwater or salty wetlands.

The salt wetlands, are due to coastal flooding in low laying areas or to anthropic landscape change for fishing and salt production, while the freshwater were not touched by land reclamation activities because of their capability to be used as retention basins. Beneath wetlands, other distinctive landscape features of the Po Delta are: dunes, levees, floodplains (*golene*), fishing valleys (*valli da pesca*), lagoons, and spits.

The presence of the Regional Parks, their activities and management strategies have been able to move many human activities towards a more sustainable regime, helping sometimes also in mitigating conflicts between social and economic actors.

Economic, cultural and recreational activities

The land reclamation undertaken in historical times, but implemented, in particular, between the end of the nineteenth century and the 70s, allowed the cultivation of tens of thousands of fertile land hectares previously occupied by marshland.

The large areas of wet meadows and valleys used for fishing therefore were replaced, with agricultural areas drained in most cases by water pumps.

Agriculture is, today, the main productive activity conducted in areas surrounding wetlands and strongly affecting their state of conservation, negatively affecting their quality (eutrophication from fertilizers and manure; pollution from pesticides) and water quantity (water for irrigation). The dominant crops are wheat, corn, sorghum, sugar beet, alfalfa, sunflower, soybean, while where the land is more peaty rice cultivation spread. There are also areas with specialized vegetable crops, poplar groves, other tree crops, and small plots of vineyards and orchards.

Recently some poorly productive agricultural areas have been flooded or reforested under the framework of incentives offered by the EU policies for the withdraw of land from production.

Human activities linked to aquaculture and to professional fishing in the Parks wetlands of the Park are allowed and favoured not only because they are very important the economy and represent a source of employment but also because they have a strong historical and traditional value.

Both lagoons and "*sacche*" are environments for mussels and clams farming, while aquaculture is conducted more in the "fishing valleys" (*valli da pesca*), namely manmade salty environment where the influx of fresh and salt water is artificially regulated by sluices.

Furthermore the Regional Parks both offer several touristic and sport activities in the Delta environment: by bike, by boat, by canoe, or on foot, it is possible to carry out tours and better discover the protected areas of the Park. In addition they have a strong commitment in environmental education activities for school classes and are involved in many national, crossborder cooperation and European projects.

Risk prevention and planning process

Directive 2007/60/ EC (or Floods Directive) on the assessment and management of risks from floods, introduces the obligation for Member States to adopt a coordinated framework for the assessment and management of flood risks and a flood risk management plan for the safety of exposed people and assets and the mitigation of damages due to floods. The overall aim of the Directive is to reduce the negative consequences for human health, environment, cultural heritage and economic activities associated with floods. The Legislative Decree no. 49/2010, which implements the Directive 2007/60/EC at Italian national level, indeed establishes the preparation of Flood risk management plan (in Italian *Piano di Gestione del rischio alluvioni* - PGRA) within the activities of Basin Planning Authority. In accordance with the Directive the development, updating and revision of PGRA have conducted with the wider involvement of the public and stakeholders, encouraging their active participation.

The PGRA addresses all aspects of flood risk management: prevention, protection, preparedness, including flood forecasting and early warning systems. It is a strategic plan or a policy paper, which - at the district level - defines the concrete objectives that are to be achieved over a period of time, and the measures make all the general and sectoral planning tools, including the emergency planning that belongs to the Civil Protection system, to converge towards the common objectives of the safety of the population and its land.

The planning process, to be repeated cyclically every 6 years, that ends up with the PGRA, is divided into two phases involving:

- a preliminary assessment of flood risk;
- the preparation of hazard and flood risk maps: Hazard maps show the extent of potential flooding caused by rivers (natural and artificial), sea and lakes, with regard to three scenarios (flooding rare, infrequent and frequent).

The other planning tools which the PGRA has to interact and cope with are the Plan of the hydrogeological layout (*Piano Stralcio per l'assetto Idrogeologico* - PAI), the Management Plan for the river basin district of the Po River (*Piano di Gestione del distretto idrografico del fiume Po* – PDGPO) prepared according to the Water Framework Directive (2000/60/CE) and the Emergency Plan of the Civil Protection.

In view of the fact that in recent years the programmatic and strategic component of the PAI have been losing effectiveness with regard to actions from short to medium term, the PGRA review and adapt these components and provide additional knowledge to their common framework.

The Basin Authority of Po River prepared the PGRA related to Po Delta Area in 2014.

Actual flood probability and associated risk

In the Atlas of the PRGA tables, graphic and maps on hazard and flood risk are presented (see from Figure 20 to Figure 25, Source: PGRA, 2014).

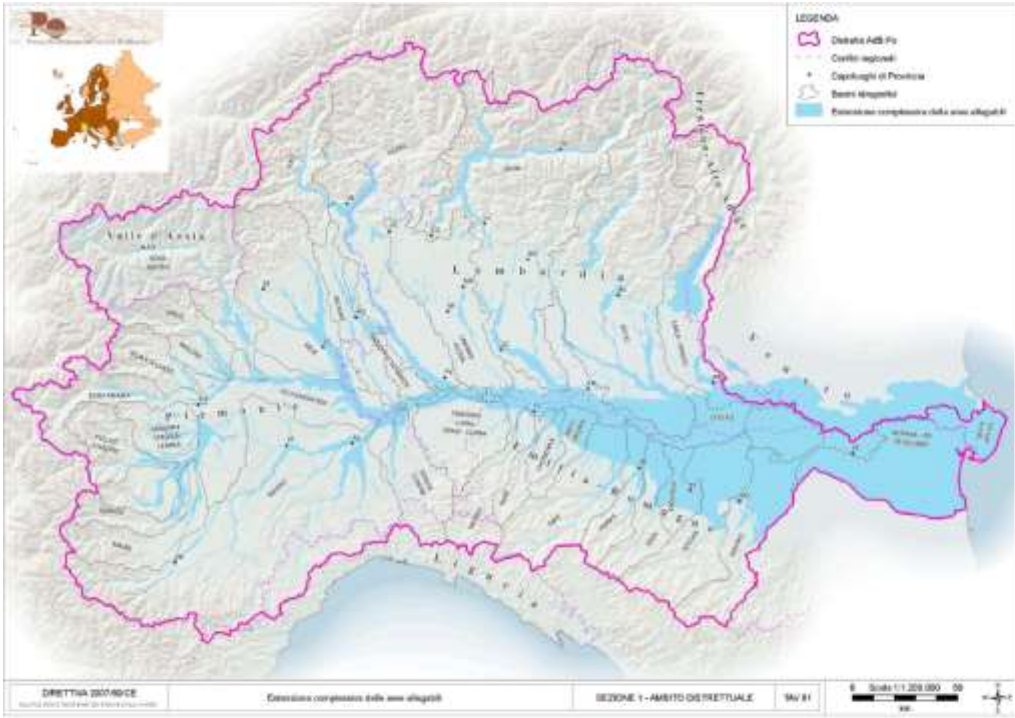
Hazard maps, show the extent of potential flooding caused by rivers (natural and artificial), the sea and lakes, with regard to three scenarios of probability of occurrence of flooding L= Low probability, M= Medium probability M, H= High probability). For each areas are also reported some information on the elements exposed to flood risk (number of inhabitants, type of economic activities, etc.).

Risk maps shows the presence of elements potentially exposed to flooding (population, services, infrastructure, economic activities, etc.) and the corresponding level of risk, divided into four classes: R1 - Moderate risk or no risk, R2 - Medium risk, R3 - High risk, R4 - Very high risk.

The Atlas contains also the most Areas of Significant Risk (ARSs) that, because of the 'intensity of flood events and the elements potentially involved, are those in which the Management Plan Risk of Flood (PGRA) will focus its actions[7].

[7] Source of Figure 20 to Figure 25is ALLEGATO 7 Atlante di distretto of the PGRA, 2014

Figure 20. Overall extent of floodable areas Po River Basin (PGRA, 2014). Floodable area in the Po Delta is about 450 km2, namely between 80 and 100% of the total sub basin extent



Source: PGRA, 2014

Figure 21. Floodable areas (Coastal Marine zones) according to three flood probability scenarios: L=Low probability (light blue), M=Medium probability (blue), H=High probability (dark blue)

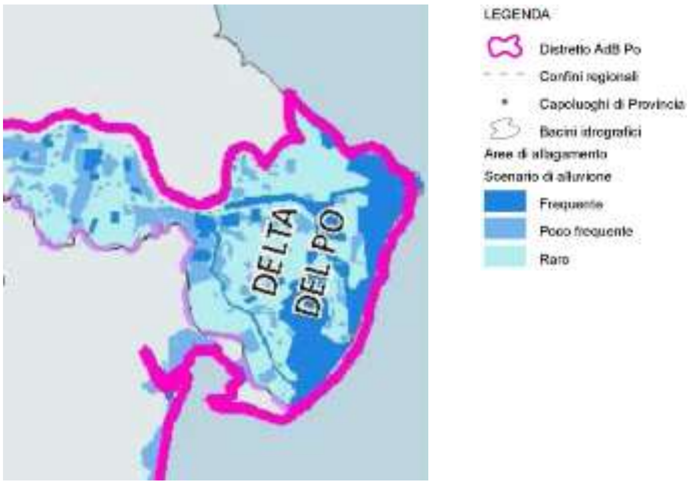


Figure 22. In the Po Delta area flooding event occurs in different environment: coastal marine zones, primary and secondary hydrographic network

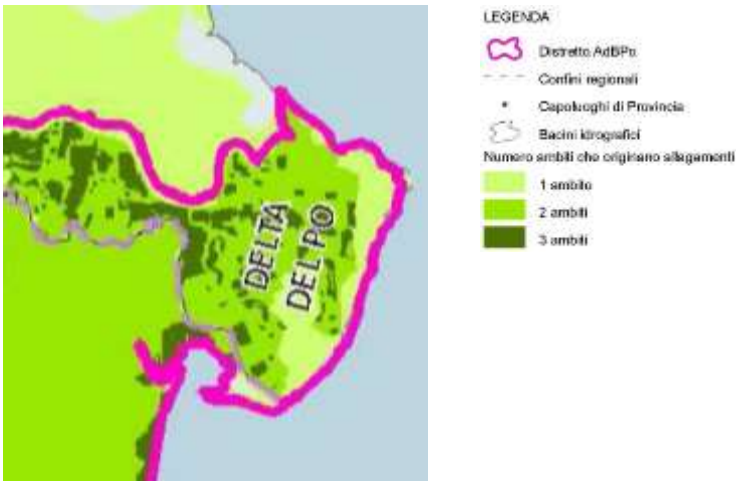


Figure 23. Risk classes for punctual, linear and areal elements (Moderate risk=yellow; Medium risk=orange; High risk=red; Very High risk=purple)

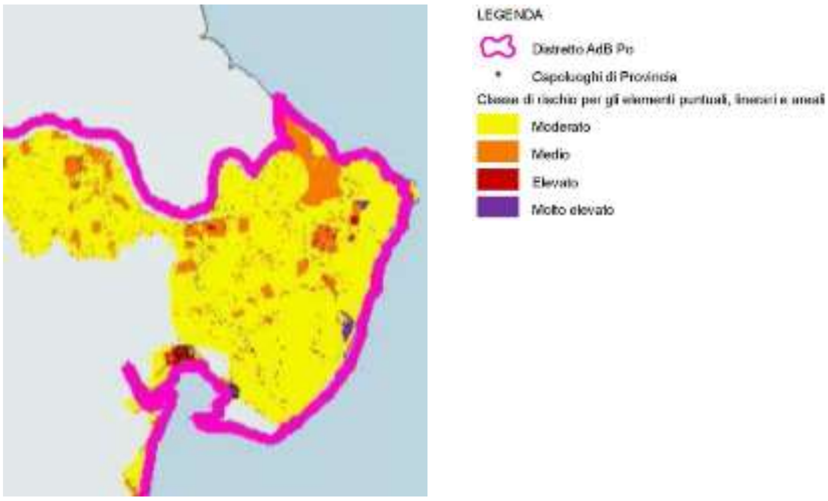


Figure 24. Po Delta area is recognized as a plain Areas of Significant Risk (ARS). ARS are defined as result of analysis that takes into account indexes related to population, residential fabric, economic activities and linear infrastructures

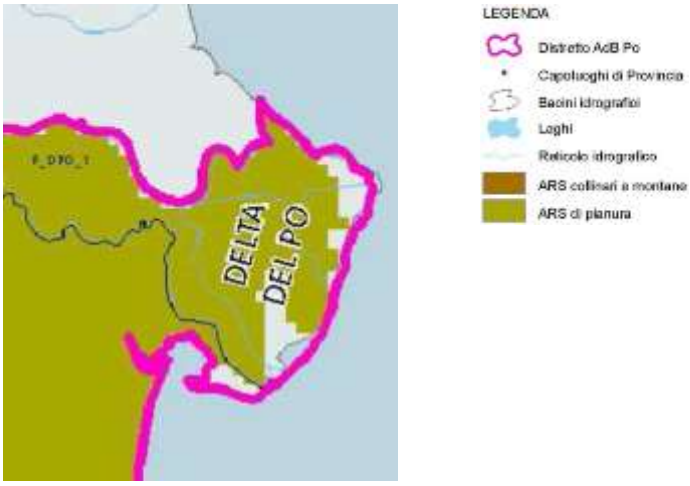
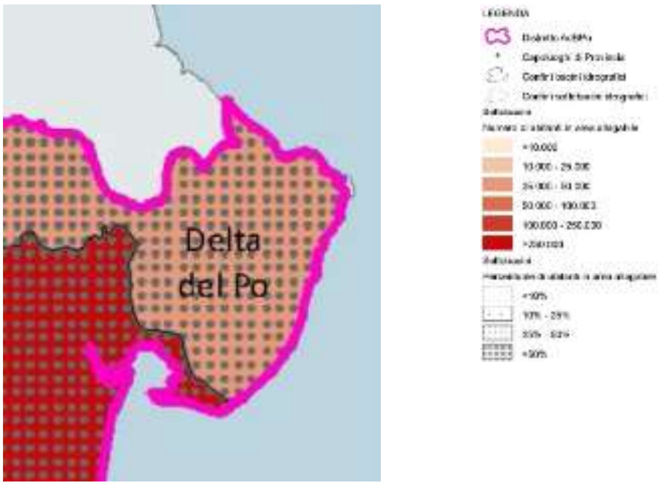


Figure 25. More than 50% of the Po Delta inhabitants are in the floodable area



Involved authorities and offices

Several Institutions and Authorities are involved in risk prevention and management activities related to flooding.

At the state level are involved the President of the Council, the Committee of Ministers of land protection and the Minister for the Environment. Moving towards the local government there are the State-Region conference, the Institute for Environmental Protection and Research (ISPRA), the Basin Authorities, the Regions, the Provinces, the Municipalities, and other Local authorities, consortia and associations.

Emergency activities are strongly related to the Civil Protection system (Law 225/1992 and 100/2012) defining the civil protection activities and identify the tasks and responsibilities of the various levels of government, from the state to the local authorities. The activities include:

prediction, prevention, emergency management and rescue, and overcome of the emergency situation.

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5 An existing Coastal Vulnerability Model

5.1 Integrated Valuation of Ecosystem Services and Tradeoffs - InVEST

Recognizing that ecosystems provide several goods and services which are fundamental to support humans and their societies (e.g. food, water purification, recreation opportunities, coastal protection, etc.), InVEST aims at enabling decision makers to assess quantified tradeoffs associated with alternative ecosystems management choices and to identify areas where investment in natural capital can enhance human development and conservation.

InVEST - Integrated Valuation of Ecosystem Services and Tradeoffs, developed within the Natural Capital project (http://www.naturalcapitalproject.org/InVEST.html) is a free and open-source software suite that includes sixteen distinct modules, running independently, suited to terrestrial, freshwater, and marine ecosystems. Input data are maps, parameters, indices and tables. Its outputs describe natural resources in terms of their biophysical supply, the service they provide humans, or their projected socioeconomic value, thus generating a framework for governments, corporations, development banks, conservation organizations and other decision makers to evaluate the impacts of their decisions on the environment and on human well-being.

The software runs models based on production functions that define how an ecosystem's structure and function affect the flows and values of ecosystem services. The models account for both service supply (e.g. living habitats as buffers for storm waves) and the location and activities of people who benefit from services (e.g. location of people and infrastructure potentially affected by coastal storms).

The modules - spatially- explicit, using maps as information sources and producing maps as outputs - returns results in either biophysical terms (e.g., tons of carbon sequestered) or economic terms (e.g., net present value of that sequestered carbon), or judgment value according to expert knowledge input (e.g. exposure/vulnerability index). The spatial resolution of analyses is flexible, allowing users to address issues at the local, regional or global scales, and the modules can be feed with data and parameters, etc. built by the users.

Promoting an ecosystem based management approach, InVEST favors an iterative process in running the modules, so that the users may generate different scenarios among which choose the suitable management solution/configuration.

The software is designed to meet the needs of a wide range of users from governments and policy makers to non-profits and corporations who are involved in natural resource management. It can be a useful tool to orientate action or to prioritize needs, but its applicability strongly depends on the quality and availability of data.

5.2 InVEST Coastal Vulnerability Model

5.2.1 Description of the Model functioning and outputs

The InVEST Coastal Vulnerability model produces a qualitative index of coastal exposure to erosion and inundation and a distribution of vulnerability. The model can be used to investigate in a coarse manner how some management action or land use change can affect the exposure of human populations to erosion and inundation.

The exposure index (delivered as a .csv table or a raster) is the ranks of the relative exposure of different coastlines segments to inundation caused by storms within the area of interest. It overlays the shoreline and has a spatial resolution defined by the user (according to the spatial resolution of input data). The model computes the physical exposure index maps by combining the ranks of the following seven biological and physical variables at each shoreline segment: Geomorphology and Relief (which describe the geomorphic characteristics of the area), Natural habitats (which represent the natural characteristics of the area), Net sea level change, Wind and Wave Exposure (which represent the forcing associated with storms), and Surge potential. Ranks of each variables (see Table 10) vary from very low exposure (rank=1) to very high exposure (rank=5), based on a mixture of user- and model-defined criteria. This ranking system is based on methods proposed by Gornitz et al. (1990) and Hammar-Klose and Thieler (2001).

Moreover, the model maps an erosion index (delivered as a .csv table or a raster) as a combination of geomorphology, habitat and wave exposure ranks and adding a population data it also assesses the population residing near any segment of coastline (as a c.sv table or a raster).

The vulnerability instead is delivered by the module in the form of a distribution histogram (i.e. not spatialized) in which vulnerability is ranked from very low vulnerability (rank=1) to high very vulnerability (rank=5).

Table 10. List of Bio-Geophysical Variables and Ranking System for Coastal Exposure used by InVEST Coastal Vulnerability model

RANK	Very Low	Low	Moderate	High	Very High
VARIABLE	**1**	**2**	**3**	**4**	**5**
Geomorphology	Rocky; high cliffs; fiord	Medium cliff; indented coast	Low cliff; glacial drift; alluvial plain	Cobble beach; estuary; lagoon; bluff	Barrier beach; sand beach; mud flat; delta
Relief	0 to 20 Percentile	21 to 40 Percentile	Average value or 41 to 60 Percentile	61 to 80 Percentile	81 to 100 Percentile
Natural Habitats	Coral reef; mangrove; coastal forest	High dune; marsh	Low dune	Seagrass, kelp	No habitat
Sea Level Change	Net decrease or 0 to 20 Percentile	< 25th Percentile	±1 or Average value or 41 to 60 Percentile	61 to 80 Percentile	Net rise or 81 to 100 Percentile
Wind Exposure	0 to 20 Percentile	21 to 40 Percentile	Average value or 41 to 60 Percentile	61 to 80 Percentile	81 to 100 Percentile
Wave Exposure	0 to 20 Percentile	21 to 40 Percentile	Average value or 41 to 60	61 to 80 Percentile	81 to 100 Percentile

RANK	Very Low	Low	Moderate	High	Very High
			Percentile		
Surge Potential	0 to 20 Percentile	21 to 40 Percentile	Average value or 41 to 60 Percentile	61 to 80 Percentile	81 to 100 Percentile

5.2.2 The model output

Here below are listed the outputs of InVEST Coastal Vulnerability Model:

- Shore Exposure, which depends on fetch threshold, depth threshold and exposure proportion and is ranked by the software;
- Geomorphology whose rank is based on expert knowledge;
- Relief which is averaged on a radius defined by the user and then is ranked by the software according to Table 10;
- Wave Exposure which depends on bathymetry, wind and wave statistics, and fetch distance and is ranked by the software according to Table 10;
- Surge potential which depends on bathymetry, depth contour, wind and is ranked by the software according to Table 10;
- Sea Level Rise which can be an available information or can be expert knowledge base and then ranked by the software according to Table 10;
- Natural habitats are at first rank on the base of expert knowledge according to Table 10 and then, if different habitats are present simultaneously on the same shore segments, their rank are combined by the software according to the following formula:

$$R_{Hab} = 4.8 - 0.5\sqrt{(1.5 \max_{k=1}^{N}(5 - R_k))^2 + (\sum_{k=1}^{N}(5 - R_k)^2 - \max_{k=1}^{N}(5 - R_k))^2)}$$

- Their value can range from 1.025 to 4 (lower values mean segments less vulnerable)
- Erosion Index depends on: geomorphology, habitat, wave height/period and then ranked by the software according to the following formula;

$$ErI = (R_{Geomorphology} R_{Habitats} R_{WaveExposure})^{1/3}$$

- Coastal Exposure depends on: geomorphology, relief, habitat vulnerability, wave exposure, surge potential, sea level rise and then ranked by the software according to the following formula:

$$EI = \left(\prod_{i=1}^{n} R_i\right)^{1/n}$$

5.2.3 Limits and constraints

Here below are briefly reported limits and constraints of the Coastal Vulnerability Model as stresses by the developer.

Model limits:

- the dynamic interactions of complex coastal processes occurring in a region are overly simplified into the geometric mean of seven variables and exposure categories;
- hydrodynamic or sediment transport processes that could determine different behaviour within an area are not considered (i.e. all the coastline segments show similar behaviour);
- storm surge or wave field are not modelled in nearshore regions;
- the amount and the quality of habitats are not taken into account, habitats are considered only because of their protective distance;
- the role of habitats in reducing coastal hazards is not quantified;
- the model does not take into account any interactions between the different variables;
- the model is designed to be used at a relatively large scale;
- it does not predict the response of a region to specific storms or wave field;
- the model does not value directly any ecosystem service, but ranks sites as having a relatively low, moderate or high risk of erosion and inundation

Data limits:

- in order to make the model applicable to as much as possible of the world regions, storm wind speeds input has to be provided as the average of winds speeds above the 90th percentile value, failing thus to correctly represent the impacts of extreme events. In the same way to estimate the exposure to oceanic waves the model uses waves statistics of the closest wind-wave grid point;
- for some of the input data (e.g. Relief and population) the model requires a user-defined radius within which it computes the average values;
- data has to be provided according to the specific requirement of the developer.

Output limits:

- as the model assesses the relative exposure of different areas within the domain of interest, model outputs are relevant when computed for a relatively large and/or non-uniform coastal region.
- the model produces qualitative outputs that thus cannot be used to quantify the exposure to erosion and inundation of a specific coastal location.

5.2.4 Dataset description

Here below are listed all the data (raster, vector, and .csv format) and parameters that are needed to run the InVEST Coastal vulnerability model. The specific data and parameters used for each of the two case study are described in par. 5.2.5.

Input data: Area of Interest, Land Polygon (the geographic shape of the coastal area of interest), Bathymetry, Relief, Geomorphology, Natural Habitat, Climatic forcing, Sea level rise, Population.

Parameters required: Area computed (to determine if the output data is about all the coast or about sheltered segments only), output Cell size, Depth threshold (depth in meters cutoff to determine if fetch rays project over deep areas), Exposure proportion (minimum proportion of rays that project over exposed and/or deep areas need to classify a shore segment as exposed), Depth contour (used to delineate shallow and deep areas), Urban center threshold (minimum population required to consider the shore segment a population center), Elevation averaging radius (each pixel average elevation will be computed within this radius), Maximum fetch distance, Mean sea level datum, Population radius (radius length used to count the number of people leaving close to the coast), Rays per sectors (number of rays to subsample the fetch distance within each of the 16 sectors), Spread radius (tolerance threshold in meters to make geomorphology and land polygon coastal segments overlap).

5.2.5 Case study data and parameters

Wadden Sea case study

Here below are listed the input data (Table 11), the characteristics related to habitat (Table 13) and the input parameters (
Table 14) for the Wadden Sea case study.

Table 11. Description of data used – Wadden Sea case study

Layer name	Format	Resolution	Coordinate system	Source
Land polygon	vector	/	WGS84	The original data coming from global land mass polygon shapefile provided as default (Wessel and Smith, 1996) by InVEST, was modified according to expert knowledge (i.e. dike in front of Schiermonnikoog island and Ijsselmeer were added to land polygon)
Bathymetry	raster	20m	WGS84 UTM 31N	Provided by project partner (Deltares)
Relief	raster	25m	WGS84 UTM 31N	Actueel hoogtebestand Nederland 25m (AHN 25) from the Dutch National Georegister (NGR) https://www.pdok.nl/en/producten/pdok-downloads/atomfeeds/
Geomorphology	vector	/	WGS84	EUROSION project + Expert Knowledge http://www.eurosion.org/
Natural Habitat	vector	/	WGS84 UTM31N	Dry open areas and Wet open area were extracted from Landuse CBS Bestand Bodemgebruik 2008 (BBG 2008) https://www.pdok.nl/en/producten/pdok-downloads/atomfeeds/ MudFlat areas were obtained from raster AHN 25m taking only pixels between -1m and +1m (the assumption is that the Wadden Sea tidal range is between these values)
Climatic forcing	vector	/	WGS84	Own elaboration on data provided by Deltares
Sea level rise	vector		WGS84 UTM 31N	Derived from an EEA Report containing the Trend in absolute sea level in European Seas based on satellite measurements (1992–2013) http://www.eea.europa.eu/DATA_WS-and-maps/figures/sea-level-changes-in-europe-october-1992-may-1
Population	raster	30 arc-	WGS84	Provided by InVEST from the Global population data from the Global

Layer name	Format	Resolution	Coordinate system	Source
		second (1km) grid cells		Rural-Urban Mapping Project (GRUMP): it contains global estimates of human populations in the year 2000. http://sedac.ciesin.columbia.edu/data/collection/gpw-v3

Among the data required by InVEST Coastal Vulnerability, two of them (geomorphology and natural habitat) have to be ranked.

In order to rank geomorphology as starting point we took the layer generated within the EUROSION EU project (code CEMOV2) that classified all coastline segments with regard to their geomorphology. Then we attributed rank value (Table 12) according to the advice provided by module developers (see Table 10) and to expert knowledge.

Table 12. Geomorphology ranking for Wadden Sea coastline

EUROSION CEMOV2 code	Description	RANK
K	Artificial beaches	**4**
Y	Artificial shoreline or shoreline with longitudinal protection works (walks, dikes, quays, rocky strands) without sandy strands	**2**
E	Developed beaches (> 1 Km long) with strands fine to coarse sand.	**4**
J	Harbour areas	**1**
G	Shoals consisting of muddy and sandy sediments	**3**

Natural Habitats were ranked according to Table 13, also identifying a protective distance for each examined habitat.

Table 13. Ranks and protection distance used for Wadden Sea habitat

Natural Habitat type	ID	Rank	Protection distance (m)
Dry Open areas	1	2	200
Wet Open areas	2	3	200
Mud Flat	3	4	200

Table 14. Parameters used – Wadden Sea case study

General Parameter name	Value
Area computed	Both
Cell size	200
Depth threshold	30 m
Exposure proportion	0.8
Depth contour	20 m
Urban center threshold	1000 m

Advanced Parameter name	Value
Elevation averaging radius	5000 m
Max fetch	12000 m
Mean sea level datum	0 m
Population radius	1000 m
Rays per sector	1
Spread radius	250 m

Po Delta case study

Here below are listed the input data (Table 15), the characteristics related to habitat (Table 17) and the input parameters (Table 18) for the Po Delta case study.

Table 15. Description of data used – Po Delta case study

Layer name	Format	Resolution	Coordinate system	Source
Land polygon	vector	/	WGS84	The original data coming from global land mass polygon shapefile provided as default (Wessel and Smith, 1996) by InVEST, was modified according to expert knowledge (i.e. dike in front of Schiermonnikoog island and Ijsselmeer were added to land polygon)
Bathymetry	raster	~1 km	WGS84 UTM 33N	ISPRA
Relief	raster	~10 m	WGS84 UTM 33N	INGV
Geomorphology	vector	/	WGS84 UTM 33N	EUROSION project + Expert Knowledge http://www.eurosion.org/
Natural Habitat	vector			
Climatic forcing	vector		WGS84	Own elaboration on data provided
Sea level rise	vector	/	WGS84 UTM31N	Derived from an EEA Report containing the Trend in absolute sea level in European Seas based on satellite measurements (1992–2013) http://www.eea.europa.eu/DATA_WS-and-maps/figures/sea-level-changes-in-europe-october-1992-may-1
Population	raster	30 arc-second (1km) grid cells	WGS84	Provided by InVEST from the Global population data from the Global Rural-Urban Mapping Project (GRUMP): it contains global estimates of human populations in the year 2000. http://sedac.ciesin.columbia.edu/data/collection/gpw-v3

As for the Wadden Sea case, in order to rank geomorphology as starting point we took the layer generated within the EUROSION EU project (code CEMOV2), and then we attributed rank value (Table 16) according to the advice provided by module developers (see Table 10) and to expert knowledge.

Table 16. Geomorphology ranking for Po Delta coastline

EUROSION CEMOV2 code	Description	RANK
Y	Artificial shoreline or shoreline with longitudinal protection works	**2**
J	Harbour areas	**1**
F	Coastlines made of soft non-cohesive sediments (barriers, spits, tombolos).	**3**
H	Estuary (virtual line).	**4**
E	Developed beaches (> 1 Km long) with strands fine to coarse sand.	**5**

Table 17. Ranks and protection distance used for Po Delta habitat

Natural Habitat type	ID	Rank	Protection distance (m)
Dry Open areas	1	2	200
Wet Open areas	2	3	200
Mud Flat	3	4	200

Table 18. Parameters used – Po Delta case study

General Parameter name	value
Area computed	Both
Cell size	200
Depth threshold	8 m
Exposure proportion	0.8
Depth contour	25m
Urban center threshold	1000

Advanced Parameter name	Value
Elevation averaging radius	200m
Max fetch	12000
Mean sea level datum	0
Population radius	1000 m
Rays per sector	1
Spread radius	300

5.2.6 EO derived data

Despite of the current model testing took advantage of data already available online or provided by the project partner, among all the required input several of them can be successfully obtained from EO data processing. These products can be generated by the user running the model or be available from local agencies or institute, or could be available through Copernicus core services or Copernicus Downstreaming services.

5.2.7 Results of running the InVEST model

Wadden Sea

Here below are reported and mapped results from the Coastal Vulnerability model run for the Wadden Sea case study.

Figure 26. Wadden Sea area of interest and coastline

Figure 27. Wadden Sea and Habitat (general view)

For the Wadden Sea case study (Figure 26), the model was run at 200 m cell size (taking into account the resolution of the input data), developing two scenario: the first one without the habitat, and the second one adding also three habitat (i.e. Mud Flat, Wet Open Areas and Dry Open Areas as in Figure 27). This approach is pursued in order to evaluate at the same time the functioning of the model as an exposure/vulnerability assessment tool and the protective effect exerted by different habitat on the costal vulnerability of each coastline segment.

Except for the output referred to the natural habitat, all the others are equal if we run the model with or without habitat (Figure 28 shows model output with the InVEST visualization Tool for Coastal Vulnerability module [8]).

As expected the North Sea side of the islands is the most exposed to storm surge and especially the coastline segments looking westward (see Figure 33, Figure 34 general view, and Figure 35, Figure 36 focus on Ameland island).

Results of running InVEST Coastal Vulnerability Model describe very well the pressures coming from the sea (wind, wave, surge potential): Exposure Index highest values are located on island (both north sea side and Wadden Sea side) and on inland coastal segments in front of the Wadden Sea inlets

The overall exposure on case studies does not seem to diminish in a relevant manner because of the presence of the natural habitat. Habitat coastal protection services seem to be very low as the presence of habitat (ex. Dry Open Areas presence on the north side of the islands) determine a decrease of 1 unit of EI rank at most (comparison between Figure 33 and Figure 34), while class number does not change.

Nevertheless it can be noticed the change in the degree of coastline exposure by plotting the frequency of distribution of EI value (namely number of coastal segments for each EI value) as shown in Figure 31 and Figure 32.

Finally, confronting the vulnerability histogram (the model does not provide the vulnerability as a spatialized information, but only as a frequency of distribution) of the two model runs (Figure 37 without habitat and Figure 38 with habitat) clearly in the case with habitat the number of coastal segments with vulnerability rank equal to “4” diminished in favour of an increase of

[8] http://vulpes.sefs.uw.edu/ttapp/cv-dash.php

number of coastal segments with vulnerability rank equal to “3”. At however at the same time coastal segments with vulnerability rank equal to “3”. This situation could maybe be explained by the fact that habitat have a twofold role: on one hand they exert a protective function against storm surge, on the other they can be harmed from it.

Figure 28. Wadden Sea InVEST Coastal Vulnerability output

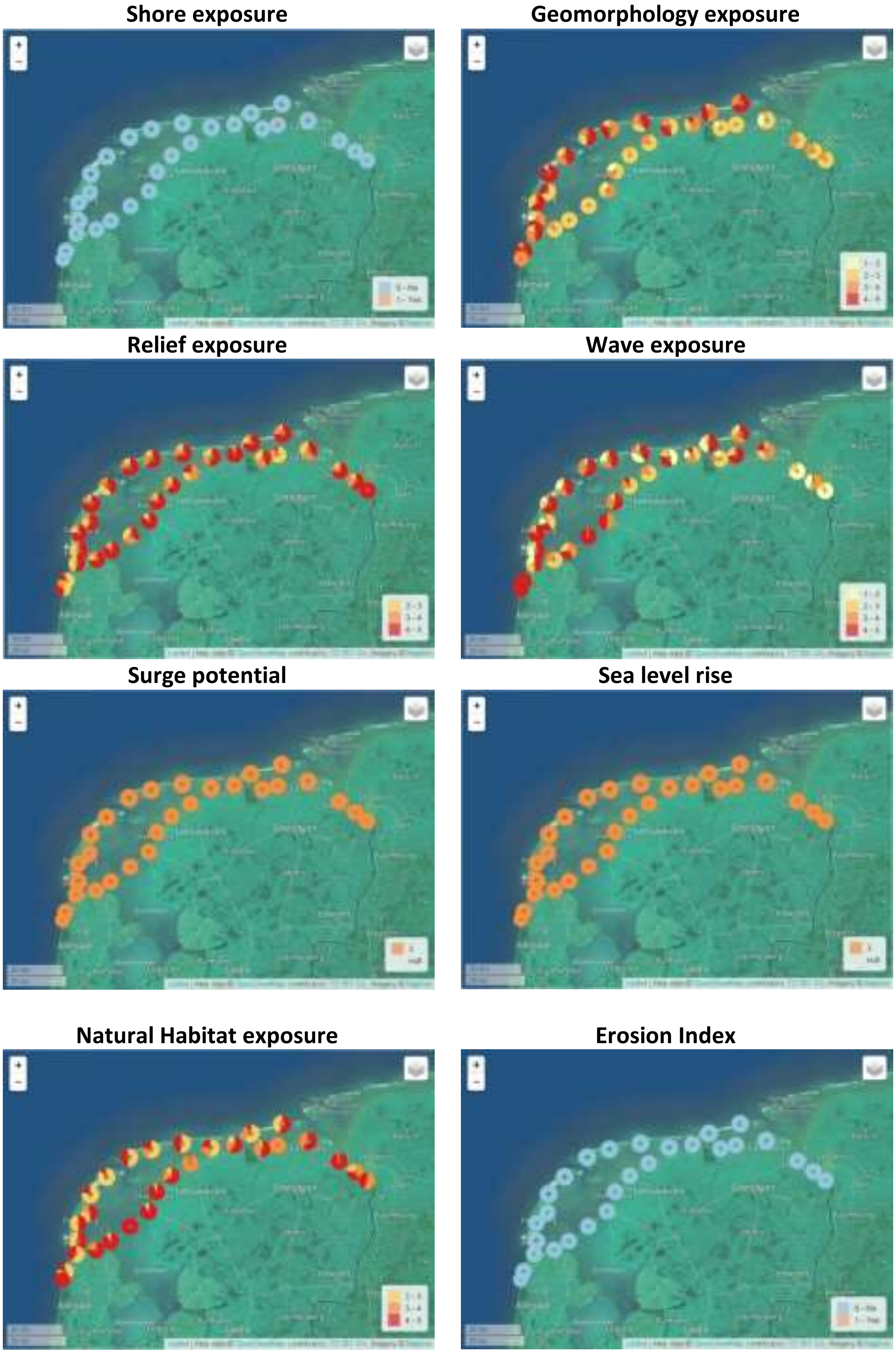


Figure 29. Wadden Sea Coastal Exposure Index in the case without Habitat

Figure 30. Wadden Sea Coastal Exposure Index with Habitat

Figure 31. Wadden Sea distribution of the Coastal Exposure Index in the case without Habitat

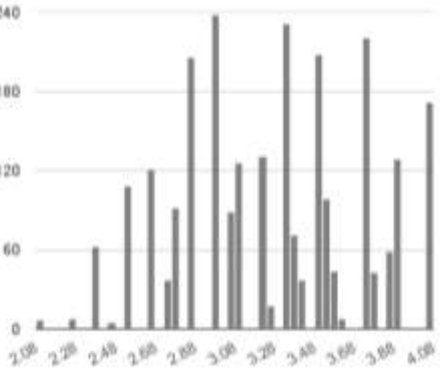


Figure 32. Wadden Sea distribution of the Coastal Exposure Index in the case with Habitat

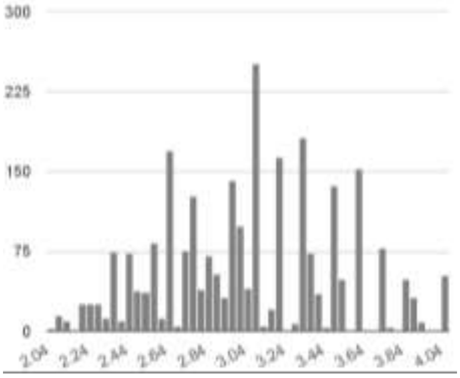


Figure 33. Wadden Sea Coastal Exposure Index without Habitat (vector format)

Figure 34. Wadden Sea Coastal Exposure Index with Habitat (vector format)

Figure 35. Wadden Sea Coastal Exposure Index without Habitat: focus on Ameland island (vector format)

Figure 36. Wadden Sea Coastal Exposure Index with Habitat: focus on Ameland island (vector format)

Figure 37. Wadden Sea Coastal Vulnerability Histogram (case without Habitat)

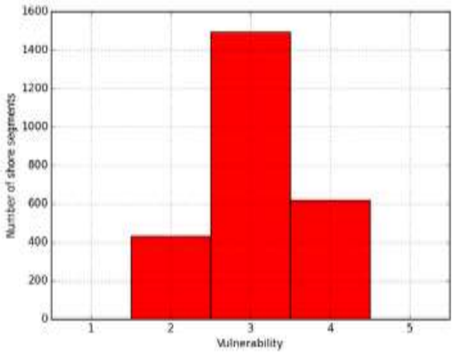
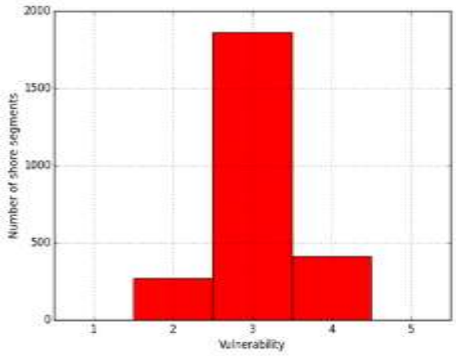


Figure 38. Wadden Sea Coastal Vulnerability Histogram (case with Habitat)



Po Delta

Here below are reported and mapped results from the Coastal Vulnerability model run for the Po Delta case study.

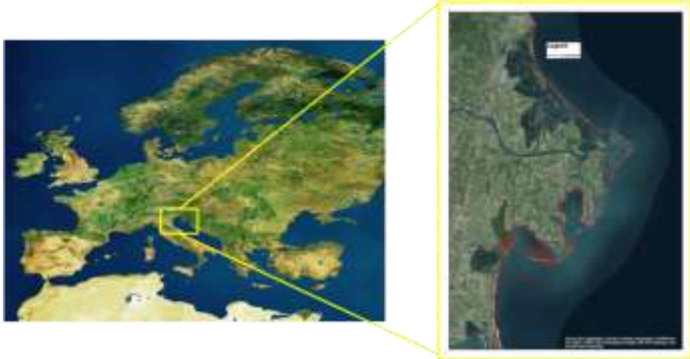


Figure 39. Po Delta area of interest and coastline

Figure 40. Po Delta and Habitat (general view)

As for the previous case study Po Delta case study (

Figure 39), the model was run at 200 m cell size (taking into account the resolution of the input data), developing two scenario: the first one without the habitat, and the second one adding also two habitat (i.e. lagoon and salt marshes, and dune, as in Figure 40). This approach is pursued in order to evaluate at the same time the functioning of the model as a exposure/vulnerability assessment tool and the protective effect exerted by different habitat on the costal vulnerability of each coastline segment.

Except for the output referred to the natural habitat, all the others are equal if we run the model with or without habitat (Figure 41 shows model output with the InVEST visualization Tool for Coastal Vulnerability module[9]).

As a general statement we can affirm that north and south side of the prominence show a different behavior with regard to both marine forcing (wave exposure, surge potential) and land characteristics (geomorphology, relief, natural habitat).

- Results of running InVEST Coastal Vulnerability Model describe very well the pressures coming from the sea (wind, wave, surge potential). In PD case results show clearly a higher exposure of the south side of the prominence in agreement with the surge potential distribution on north and south side of delta.
- The overall exposure on case studies does not seem to diminish in because of the presence of the natural habitat (few exception can be seen in Figure 46 and Figure 47). Habitat coastal protection services seem to be very low as the presence of habitat (dunes and salt marshes along the coastline) determine a decrease of 1 unit of EI rank at most and make EI classes increase of one class. This can be observed comparing Figure 46 and Figure 47 which show Po Delta Coastal Exposure Index without and with Habitat in vector format.
- Nevertheless it can be noticed the change in the degree of coastline exposure by plotting the frequency of distribution of EI value (namely number of coastal segments for each EI value) as shown in Figure 44 and Figure 45.
- Finally, confronting the vulnerability histogram (the model does not provide the vulnerability as a spatialized information, but only as a frequency of distribution) of the two model runs (Figure 44 without habitat and Figure 45 with habitat) it appears that in the case with habitat not only the number of coastal segments with vulnerability rank equal to "4" does not diminish but increases as well as that of rank equal to "3", at the expenses of coastal segments with rank equal to "2".
- This situation could maybe be explained by the fact that habitat possibility to be harmed is greater than the protective function they exert.

[9] http://vulpes.sefs.uw.edu/ttapp/cv-dash.php

Figure 41. Po Delta InVEST Coastal Vulnerability model output

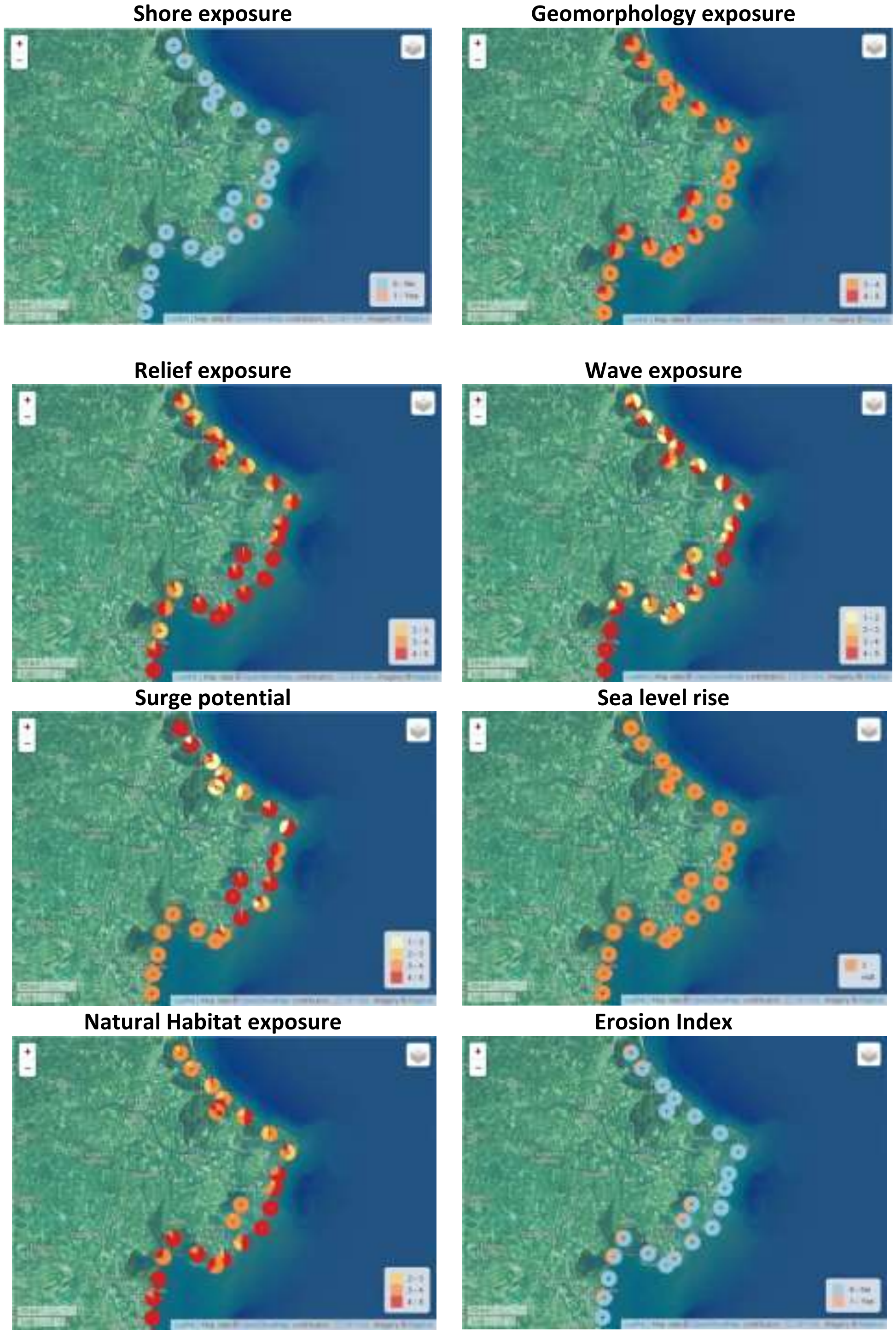


Figure 42. Po Delta Coastal Exposure Index in the case without Habitat as shown

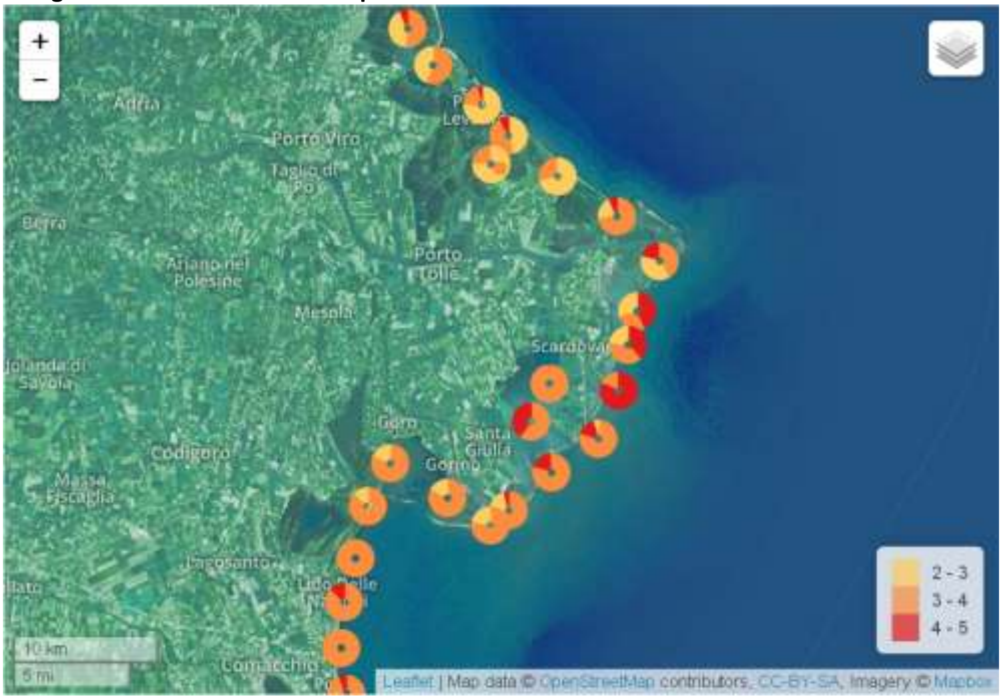


Figure 43. Po Delta Coastal Exposure Index in the case with Habitat

Figure 44. Po Delta distribution of the Coastal Exposure Index in the case without Habitat

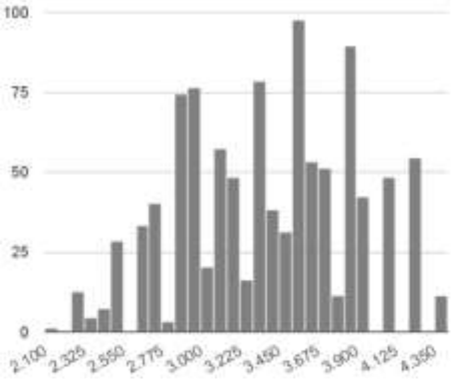


Figure 45. Po Delta distribution of the Coastal Exposure Index in the case with Habitat

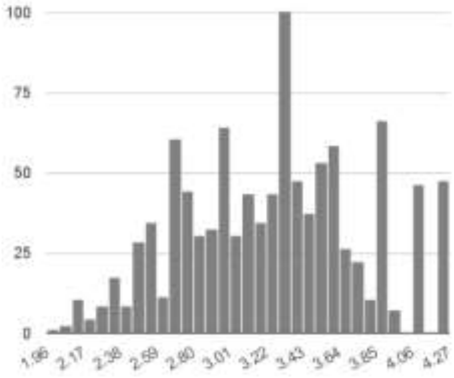


Figure 46. Po Delta Coastal Exposure Index without Habitat (vector format) Background image from

Figure 47. Po Delta Coastal Exposure Index with Habitat (vector format). Background image from

Figure 48. Po Delta Coastal Vulnerability Histogram (case without Habitat)

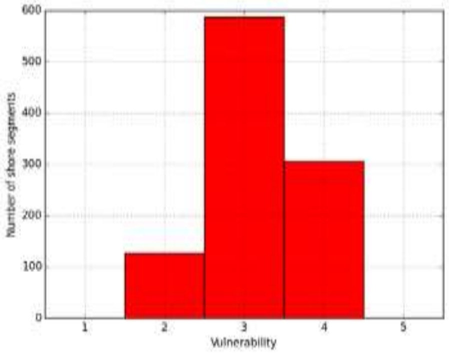
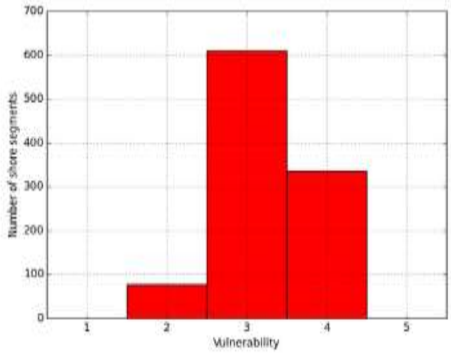


Figure 49. Po Delta Coastal Vulnerability Histogram (case with Habitat)



5.2.8 InVEST Coastal Vulnerability model: discussion of model and results

Here low are listed some observation on InVEST Coastal Vulnerability results and on the functioning of the tool for the assessment of vulnerability:

- the model does not provide properly a vulnerability assessment but more an exposure one; moreover the user manual is not very clear about exposure and vulnerability definitions adopted by the developers (and sensitivity is not even mentioned);
- the model is ready to use and includes a storm surge and wave field model otherwise very difficult to be managed by a no-expert user; natural habitat protective action is easy to manipulate to design different scenarios but it doesn't consider the site-specific characteristics (e.g. Subsidence);
- the model offers a coarse understanding of how modifications of the biological and physical environment (i.e. direct and indirect removal of natural habitats for coastal development) can affect their exposure to storm-induced erosion and flooding (inundation);
- there seems to be some interdependence between some variables: like relief, natural habitats and geomorphology, but their relation a/o correlation is not considered;
- the ranking does not enable to maintain the natural gradient that characterizes transitional environments; moreover is mostly expert based and very subjective;
- parameters to be taken into account are decided a priori and cannot be changed according to the characteristics of the site (site specific);
- All results are extent related as well as ranking values: comparison of results between EI of different areas, even within the same region, is senseless if the areas do not present the same class type for each considered biophysical value. Thus results cannot be used to prioritize intervention if not within the same area
- health status and height of the habitat which are fundamental in contrasting storm surge are not considered
- the protective distance value (expert knowledge based) exerted by each habitat is a key parameter.

- not all the output are spatialized: the vulnerability one is only in the form of a plot of frequency distribution which is not very useful to reach the aim of providing to decision makers (politician, planner, those involved in environmental management) added value information.
- The possibility to generate several scenario of the same are by changing habitat type, extent, distribution, protective distance make easy to understand, even in a very simplified manner, the existence of protection ecosystem services delivered.

6 Coupled social-environmental tool

6.1 Overall aim

As the aim of the project is to search for better-integrated strategies through the strengthening of the risk prevention and disaster management cycle of the coastal zones, it is necessary to take into account all the different dimensions that give rise to coastal systems, namely the biophysical (natural and human shaped), the social (social, economic and cultural), and the institutional and management ones.

Unlike the strictly physical approach to vulnerability adopted within the context of for example seismic or hydrogeological vulnerability, climate change research brought attention to a more comprehensive approach to place-societies vulnerability assessment.

This way of proceeding is due to the acknowledgment that current and future conditions – and thus change – result from the combination of geomorphological structure, environmental resources (e.g. presence and localization of ecosystems, quality and quantity of ecosystems services delivered, etc.), natural processes (e.g. subsidence), and, at the same time, past and present man made decision like policies and planning concerning, for example, land use or exploitation of available resources, environmental management strategies, etc. etc…

If on one hand human decision can directly or indirectly affect the biophysical context, on the other it is affected and constrained itself by both biophysical and socio economic drivers. Therefore in approaching the evolution of coastal systems and related societies, as well as in assessing their vulnerability state, the need for a more integrated long-term approach is strongly required (EEA, 2006).

In developing the vulnerability assessment method the goals we set are:

- developing a method for mapping (and thus in a spatially based manner) vulnerability to storm surge able to integrate relevant environmental data with related socio-economic data to the extent current available information allows; and replicable as much as possible at different scales;
- stressing the role of ecosystems in storm/flood protection (i.e. mapping ecosystem services);
- providing public and private stakeholders, involved in policies, planning and management activities etc., valuable information to support their decisions;
- developing suggestions to reduce the vulnerability of coastal systems by applying resilience principles focusing on the role of ecosystems services.

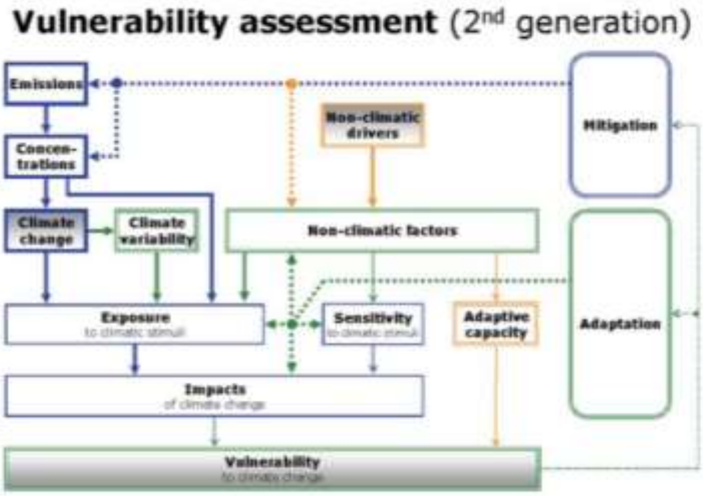
The focus on ecosystems services has a multiple reasons:

- coastal areas include a great variety of ecosystems which provide to coastal societies a range of services (such as flood and erosion protection, food provision, recreational service), and goods (such as raw materials, etc.);
- this great variety of ecosystems in coastal areas can be considered critical for the existence of coastal societies (e.g. not to be harmed by sea water) and for their sustenance and economy (e.g. fisheries or aquaculture);

- partial failure in term of effectiveness and efficiency of hard engineered structures for coastal protection has shift attention to green soft adaptation measures as showed by the diffusion of the Ecosystem Based Adaptation (EBA) (Temmerman et al., 2013).

According to such premises, our approach to vulnerability, and as a consequence to its assessment, includes both biophysical and socioeconomic aspects of vulnerability.
Starting from the definition of vulnerability of the Fifth Assessment Report of IPCC[10], the chosen approach within this project makes reference to vulnerability assessment scheme proposed by Füssel and Klein (2006) (see Figure 50) and then examined in depth within the ESPON Climate project (2011) (Figure 51). This scheme is related to climate change but the assumption is that it can be applied to every environmental stress/perturbation such as storm surge and related flooding event.

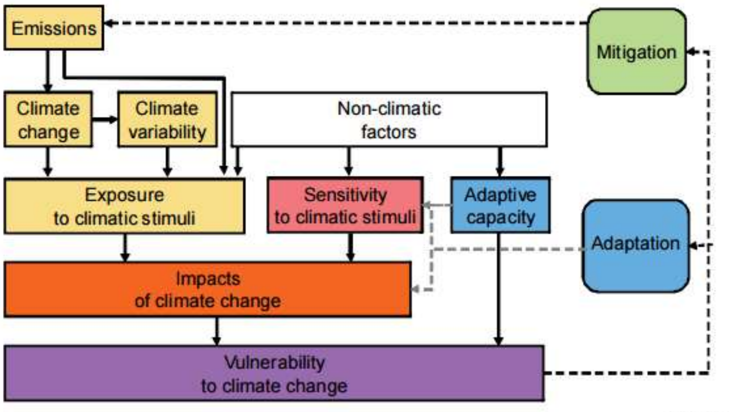
Figure 50. Second generation vulnerability assessment scheme: components influencing/determining vulnerability



Source: Fussel and Klein, 2006

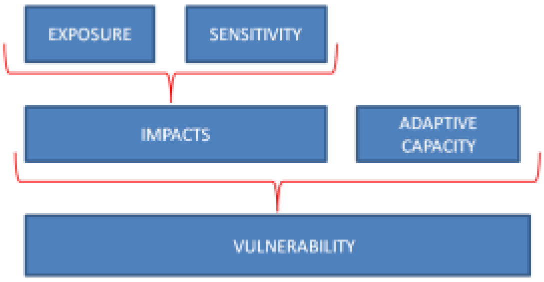
[10] Vulnerability is « The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. See also Contextual vulnerability and Outcome vulnerability.”

Figure 51. ESPON Climate change research framework (adapted from Fussel and Klein, 2006)



The above mentioned scheme was simplified to be used within this project (Figure 52).

Figure 52. Simplified Vulnerability assessment framework adopted within the ECOSTRESS project



Furthermore in order to answer the questions of who is vulnerable and to what and thus describe a vulnerable situation, four dimensions are fundamental (Füssel 2007[11]):

- the system of analysis;
- the valued attributes of concern;
- the external hazard;
- a temporal reference .

On the base of such scheme the approach we adopted includes four key components for assessing storm surge/flood vulnerability of coastal areas, which are: exposure, sensitivity, potential impact and adaptive capacity.

6.1.1 Adopted vulnerability assessment components definitions

Exposure

Two are the most diffused interpretation of exposure available in the literature: the first one refers to it as the presence of people, ecosystems, services, and in general assets that could be adversely affected by a certain – climatic – perturbation (IPCC, 2014); the second one that refers to it as the nature, the degree, the duration, and/or the extent to which the system is in

11

contact with, or subject to, the perturbation (Adger, 2006; Kasperson et al., 2005; Fussel and Kline, 2006) or as the degree of environmental changes faced by systems that can be characterized by their amplitude, frequency, duration, areal extent (Burton et al., 1993).

The definition we adopted is more close to the latter interpretation as we considered exposure as an *a priori* condition related only to the characteristics of the perturbation to which a system is exposed, including all the factors determining the extent to which the system is in contact with. It is the only component of the assessment directly related to the hazard event parameters. Since the nature of the hazard we are dealing with (i.e. storm surge/flood) has a strong spatial dependence in affecting coastal zones, we consider also physical conditions such as geomorphology, elevation, subsidence, etc., as contextual conditions determining real coastal exposure.

Sensitivity definition

The sensitivity concept is quite agreed within the climate change community. It is worth to stress that sensitivity is to be intended as indissolubly related to the examined hazard and place and thus to exposure condition. We refer to it as the degree to which a system is modified or affected, directly or indirectly, either adversely or beneficially, by an internal or external disturbance (hazard stimuli) or set of disturbances (Fussel and Kline, 2006; Gallopın, 2003; IPCC, 2001 and 2014). Sensitivity of a system is made of the characteristics of the system which are somehow sensitive to a perturbation.

Sensitivity is the component that bring together:

- a physical dimension: natural capital (habitats), manmade artefacts (settlements, roads, etc.);
- an environmental dimension: to be intended as the degree to which ecosystems state and functions (existence functioning and ecosystem services) can be affected;
- a social and cultural dimension: related to human populations characteristics and needs (safety, health, access to place, etc.), and shared values ascribed to specific assets, resources, and functions;
- an economic dimension: which includes different economic sectors and activities that can be diversely affected by the same hazard (e.g. tourism, agriculture, etc.);
- a cultural dimension: related to values attributed by a society to the component of its territory.

We do not include, for example, slopes and soils susceptibility to erosion as sensitivity, because we consider sensitivity as related to human values and interests: nature itself does not care about perturbation such as storm surge. From a natural perspective perturbation is part of nature.

Impacts definition

Impacts are defined as the consequences of climate change or other perturbations or stresses on natural and human systems, which strongly depend on the overlap and combination of exposure and sensitivity.

Impacts can be direct (e.g. erosion) or indirect (e.g. loss of income due to interruption of economic activities) and according to the degree of implementation of adaptation measures can be further divided into (Fussel, 2007):

- potential impacts: assuming no adaptation measure are implemented;
- expected impacts: assuming only autonomous adaptation is implemented;
- residual impacts: assuming both autonomous adaptation and feasible planned adaptation are implemented;
- unavoidable impacts: impacts that despite a perfect adaptation still remain.

Impacts assessment entail as many dimensions as sensitivity does.

Adaptive capacity definition

The adaptive capacity of a system is both the availability of a set of tools, resources, skills to implement adaptation measures and the ability to modify its characteristics, functioning and behavior (i.e. reorganize itself) in order to expand its ability to cope with current, expected or unexpected perturbations (Brooks, 2003; Brooks e Adger, 2005) and not experience a decline in its functioning and wellbeing.

In ecological system the adaptive capacity depends on its health status, genetic and biologic diversity and on the heterogeneity of the environmental context in which is located (Carpenter et al. 2001, Peterson et al. 1998).

Adaptive capacity of social systems depends on space and functioning organization, social and economic development, its material and immaterial resources (i.e. social capital, financial capital, natural capital, technical capital, etc.), government and governance structure, presence of institutions that collect and store knowledge and experiences, and able to regulate stakeholders interests (Berkes et al., 2002) and to effectively implement measures and policies.

Some authors, like Gallopin (2006), consider the adaptive capacity as an attribute of the system which exists prior to the perturbation, but it has to be stressed that it is not a static capacity and some of its characteristics are hazard-specific and locally determined.

According to Brooks (2003) community adaptive capacity does not translate automatically and immediately into adaptation (it needs will, tools, and time), and therefore it is only a premises for a real adaptation.

6.2 Vulnerability assessment method: a Fuzzy logic approach

6.2.1 Fuzzy logic

Exposure and vulnerability assessments of a coastal areas deal with several physical (environmental and anthropic) and socio-economic elements that vary in space and time. Fuzzy logic (Zadeh 1965, Zimmerman 1996), applied to complex and imprecise problems enables to handle the non-linearity, which is common in multi-criteria framework, and the vagueness which is common in environmental issues, and has the ability to model complex behaviors as a collection of simple ‘‘if–then’’ rules based on expert knowledge.

Dealing with uncertainty and vagueness of complex systems, poses many problems, but assessing vulnerability of complex systems such as those of coastal societies, poses many more because we are facing a characteristic – vulnerability - that cannot be exactly shaped and measured. As stated by Phillis and Andriantiatsaholiniaina (2001) referring to the sustainability of a system – but the statement can be usefully applied to vulnerability – "*the border between sustainability, and unsustainability is not sharp but rather fuzzy. This means that it is not possible to determine exact reference values for sustainability, and a scientific evaluation of uncertainty must always be considered in the procedure of sustainability assessment. For this reason, the use of natural language and linguistic values based on the fuzzy logic methodology (Munda et al., 1994) seems more suitable to assess sustainability*". In this view fuzzy approach is a set of concepts and method for dealing with systems by mean of modes of reasoning that we recognize as approximate rather than exact (Demicco and Klir, 2004).

Leaving aside uncertainty of measurements, in assessing the vulnerability of a system we have to cope with vagueness related to:

- complex systems behaviour and model used to represent them (i.e. their functioning);
- way of understanding or distinguishing vulnerable and not vulnerable state of a system (no exact values to describe each state are available);
- actual contribution of each system component in determining the overall system vulnerability;
- natural language used to describe component or system characteristics influencing system vulnerability and borderline cases (Regan et al., 2002), which are not directly referable to definite values and which can be extremely subjective (i.e. based on interest, experience or knowledge).[12]

To manage this kind of evaluation researchers often enlist the design of expert systems, but as stated by Zadeh (1983), they are not free from uncertainty "*because much of the information in the knowledge base of a typical expert system is imprecise, incomplete or not totally reliable*".

6.2.2 How does it work

According to what said above Fuzzy logic is a very convenient method for representing some form of uncertainty due to not precise human language descriptions which are more frequently qualitative than quantitative.

As to describe or order a phenomena, we usually characterize them into classes, the assumption to draw upon fuzzy logic is the acknowledgement that human language cannot be used to define classes/attributes of a variable in a strictly manner, and that imprecision in assigning classes can affect the analysis of a set of variables and therefore decision making.

In fuzzy logic each variable (e.g. Temperature in Figure 53) is "fuzzified", i.e. it becomes a fuzzy set, choosing:

- the appropriate membership function (examples of membership function are shown in Figure 54) according to the user judgment (e.g. trapezoidal), having in mind the problem to be solved and the context it refers to;

[12] "fuzzy-set method is well suited to dealing with uncertainties when little information is known imprecise knowledge associated with human-language descriptions »

- the fuzzy intervals extent (i.e. range of values belonging to each statement (i.e. linguistic value such as “cold”, “warm”, “hot”).

Performing this operation, each value of the original variable belongs to the fuzzy set to some degree (membership degree), and a statement referred to a certain value/element of a given variable/fuzzy set can be either true or false and also can be neither true nor false[13].

Membership values are indicated by a value in the range 0 -1 with 0 for absolute falsity and 1 for absolute truth.

Figure 53 contains a fuzzy set for temperature. According to Klir (2004) definition:

- Temperature is the “linguistic variable”;
- Cold, warm and hot are the “linguistic values”;
- the range of x values of each trapezoids constitutes the “fuzzy interval”;
- x-axis represent base variable values;
- y-axis represent membership degree (μ);
- the rules through which assign to each linguistic value its meaning in terms of an appropriate fuzzy interval on the base of the variable range values, are called “semantic rules”.

Borderline cases, in which uncertainties associated with linguistic variables take place, are represented, for example, in Figure 53 as membership degrees smaller than 1 (partial membership) corresponding to variable values at the intersection between trapezoids (i.e. between cold and warm, or warm and hot). This is the way fuzzy logic describes the inaccuracies of class boundaries.

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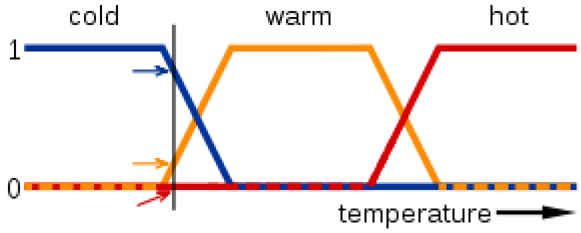
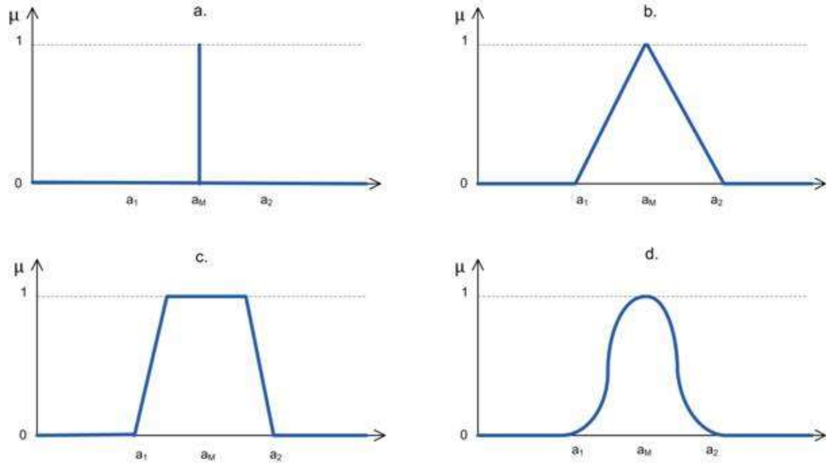
Figure 53. Temperature fuzzy set



[13] In conventional set theory, crisp set are used. Each element of a crisp set is either a member of the set (full membership) or not (non membership).

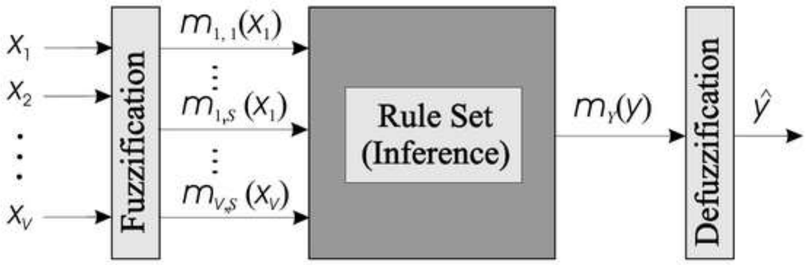
Figure 54. Example of membership functions: a) Singleton; b) Triangular fuzzy number; c) Trapezoidal fuzzy number; d) Bell-shaped, piecewise quadratic fuzzy number



According to Guillaume (2001) Fuzzy inference systems (FIS) are one of the most famous applications of fuzzy logic and fuzzy sets theory.

A fuzzy inference system (FIS) is a system that interprets the values in the input vector (features in the case of fuzzy classification) and, based on some set of rules, assigns values to the output vector (classes in the case of fuzzy classification). Among the more common FIS there are the so called Mamdani FIS and the Sugeno FIS.

Figure 55. Mamdani Fuzzy model



Within ECOSTRESS project we did not use Fuzzy inference systems (FIS), but applied fuzzy logic to overlay rasters. The adopted approach is fully explained in the next paragraph.

Fuzzy logic vs provability: fuzzy sets are often incorrectly assumed to indicate some form of probability: it is important to realize that membership grades are not probabilities.

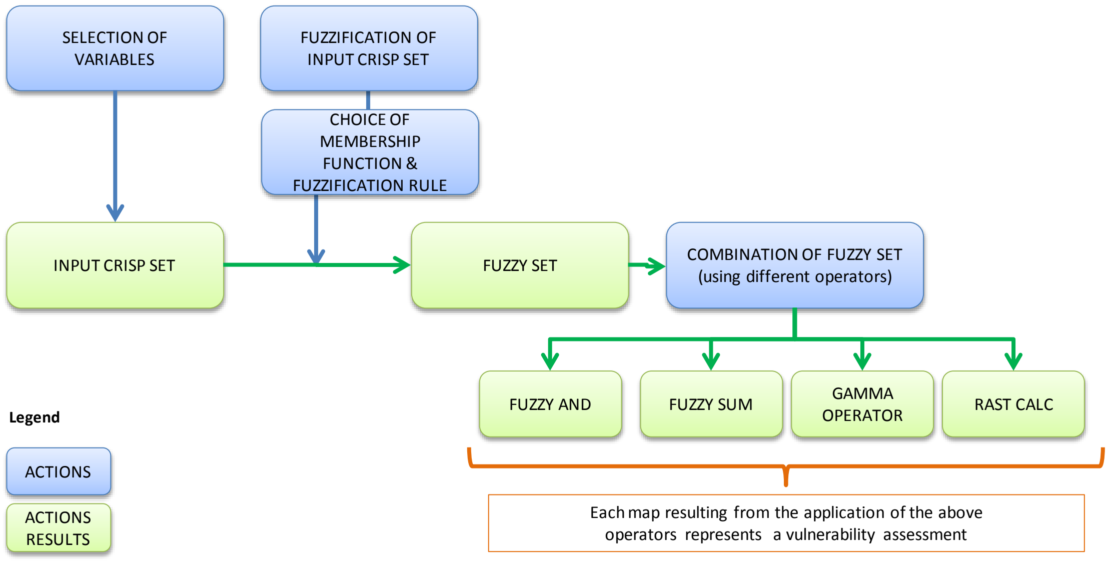
6.2.3 Data and processing

Fuzzy logic approach to vulnerability assessment was applied only on the Delta Po case study. We proceeded as follows (Figure 56):

1. selection of variables relevant to vulnerability of coastal areas;
2. fuzzification of variables by choosing membership function to obtain fuzzy sets;
3. combination of selected fuzzy sets using several operators for raster overlay.

All the actions were implemented through the Spatial Analyst Tool in ArcMap® 10.0 (Fuzzy Membership Tool and Fuzzy Overlay Tool).

Figure 56. Workflow of Fuzzy analysis



1.Selection of variables relevant to vulnerability of coastal areas

Variables to be used in the fuzzy logic approach were selected according to the literature review of vulnerability indicators and approaches and to the understanding of InVEST Coastal vulnerability module, taking into account the data currently available from EO, in situ measurements and modeling.

Here below the list of selected variables and related characteristics is provided, while all processing applied to each variables is briefly described in Table 20.

- Significant wave height 90: 90th percentile or greater of significant wave height values observed (format: raster, unit of measurement: meters)
- Geomorphology: coastline segments ranked according to their vulnerability on the base of their morpho-sedimentological type derived from EUROSION project (format: vector, attribute: rank from 1 to 514)
- Erosion Evolutionary trend: coastline segments ranked according to their vulnerability on the base of their erosion evolutionary trend derived from EUROSION project (format: vector, rank from 1 to 5 according to Table 19)

Table 19. Ranking of Erosion Evolutionary trend data

EUROSION CEEVV2 code	Description	RANK
50	Erosion confirmed (available data), localised on parts of the segment.	1
51	Erosion confirmed (available data), generalised	2

[14] See Table 16

EUROSION CEEVV2 code	Description	RANK
	to almost the whole segment.	
2	Stable: Evolution almost not perceptible at human scale	3
70	Aggradation confirmed (available data), localised on parts of the segment.	4
71	Aggradation confirmed (available data), generalised to almost the whole segment.	5

- Digital Elevation model (DEM): terrain elevation (format: raster, unit of measurement: meters)
- Subsidence: result of kriging of mean vertical velocity values displacement (format: raster, unit of measurement: mm/yr)
- Dune: cover type classified as dune (format: vector, attribute: existing=1; not existing=0)
- Population: number of inhabitants (format: raster, unit of measurement: inhabitants)
- Land use/land cover: coverage type ranked according to their vulnerability (format: vector, attribute: rank from 1 to 5)
- Static ReSVI: static 'social relative vulnerability index' (format: vector, attribute: rank from 0 to 1)

These variables feed the vulnerability assessment scheme described in Figure 52 as follows (last column of Table 20):

- HAZARD: Significant wave height 90
- EXPOSURE: Geomorphology, Erosion Evolutionary trend, Digital Elevation model, Subsidence, Dune
- SENSITIVITY: Population, Land use/land cover, static ReSVI

No adaptive capacity was taken into account within the project thus the resulting vulnerability has to be considered as the worst vulnerability condition (i.e. no adaptive capacity available).

Uncertainty was taken into account by considering subsidence and erosion evolutionary trend, as these two variables - affected by a certain degree of uncertainty - describe dynamic territorial status that combined with the hazard characteristics can enhance or diminish its exposure and thus vulnerability. Furthermore, different measure (or forecasting) of subsidence and erosion trend can generate different vulnerability state or scenarios.

2.Fuzzification of variables by choosing membership function to obtain fuzzy sets

In order to fuzzify the original data set (crisp set) into fuzzy membership values (fuzzy set) in the interval (0–1) among the fuzzification functions available through ArcMap® 10.0 Fuzzy Membership tool, i.e. Gaussian, Small, Large, Near, Mean-Standard Deviation-Large and Mean-Standard Deviation-Small, and Linear, we choose to apply to each input variables (x) the latter.

Linear membership function (LMF) calculates membership on the linear transformation of the input raster, assigning a membership value of 0 at the minimum and a membership value of 1 at the maximum. If the minimum value is less than the maximum, the linear function will have a positive slope. If the minimum value is greater than the maximum, the linear function will have a negative slope.

Fuzzification of each variable was performed applying the parameters listed below adopting the following rule: maximum value (i.e. membership value of 1) corresponds to condition of maximum contribution to vulnerability status and minimum value (i.e. membership value of 0) corresponds to condition of minimum contribution to vulnerability status. Adopting this approach in fuzzifying the variables enables us to avoid to explicitly define inference rules (IF x IS A THEN y IS B) - that in the case of a great amount of input variables can be a very complex problem – but to use fuzzy set with fuzzy logic operators or simple raster overlay (e.g. sum) making the implicit assumption that higher membership degree determine higher vulnerability.

Before performing fuzzification each data underwent some processing in order to get all raster data at 100m cell size and co-registered. Fuzzification parameters for each variable are shown below as min(x) and max (x).

- Significant wave height 90: min(x) = 0 m; max(x) = 1,05504 m
- Geomorphology: min(x) = 1 m; max(x) = 5
- Erosion Evolutionary trend: min(x) = 5 m; max(x) = 1
- Digital Elevation model (DEM): min(x) = 19,787 m; max(x) = 5,101 m
- Subsidence: min(x) = 10,907 mm/yr; max(x) = 3,122 mm/yr
- Dune: min(x) = 1; max(x) = 0
- Population: min(x) = 0 inh; max(x) = 986 inh
- Land use/land cover: min(x) = 1; max(x) = 5
- Static ReSVI: min(x) = 0, max(x) = 0,51

Each fuzzy set can be displayed as maps of degree of membership (μ).

3.Combination of selected fuzzy sets using several operators for raster overlay.

In order to spatially assess study area vulnerability due to the influence of chosen parameters, after fuzzification, Fuzzy set were combined using the following fuzzy operators:

- Fuzzy AND (μ_{AND}): used to obtain in output a map characterized by the degree of membership among the lowest of the different input maps, where μ_A is the degree of membership of the map A in a particular lease.

$$\mu_{AND} = MIN(\mu_A, \mu_B, \mu_C, \dots\dots)$$

- Fuzzy SUM (μ_{SUM}): operator which returns output in a degree of membership always greater than or equal to the greater of those combined.

$$\mu_{SUM} = 1 - \prod_{i=1}^{n} 1 - (\mu_i)$$

- GAMMA Operator (μ_{GAMMA}):

$$\mu_{GAMMA} \ (Fuzzy\ a\lg ebraic\ sum)^{\gamma} * (Fuzzy\ a\lg ebraic\ product)^{1-\gamma}$$

where Fuzzy PRODUCT $\mu_{PRODUCT} = \prod_{i=1}^{n} \mu_i$

where γ is a parameter between 0 and 1.

γ = 1 gives the same results of Fuzzy SUM while γ = 0 gives the same results of Fuzzy PRODUCT

In addition to the above mentioned operators fuzzy set were combined also by using a simple Raster Calculator Sum, i.e. sum of fuzzy set.

$$\mu_{RAST\ CALC\ SUM} = \sum_{i=1}^{n} \mu_i$$

All data were reprojected into WGS84 UTM33N

All data were rasterized to snap to the geomorphology layer at 100 m cell size

Table 20. Selected variables for vulnerability assessment on Po Delta applying Fuzzy logic approach

Data	Source	Format	Processing	Fuzzification parameters	Component of Vulnerability assessment
Significant wave height 90	wind from ECMWF, wave from Univ. Of Cantabria model	raster (1km resolution)	*Obtained from a point shapefile at the coastline: each point containing Significant Wave Height 90th percentile (SWH90) for a period of 5 years *Rasterized at 100m cell size according to field "SWH90" *Fuzzified: linear function (0=not vulnerable; highest value=vulnerable)	min(x) = 0 m max(x) = 1,05504 m	EXPOSURE (HAZARD)
Geomorphology	EUROSION Project (CEMOV2)	vector	*Original layer already ranked for running InVEST Coastal Vulnerability model (1=not vulnerable, 5=vulnerable) *Buffering: 300m *Rasterized at 100m cell size according to field "Rank" *Fuzzified : linear function (1=not vulnerable; 5=vulnerable)	min(x) = 1 max(x) = 5	EXPOSURE
Erosion Evolutionary trend	EUROSION Project (CEEV2)	vector	*Layer ranked as follows: 1=erosion confirmed and generalized; 5=aggradation confirmed and generalized *Buffering: 300m *Rasterized at 100m cell size according to field "Rank" *Fuzzified : linear function (5=not vulnerable, 1=vulnerable)	min(x) = 5 max(x) = 1	EXPOSURE
Digital Elevation model (DEM)	INGV	raster (10m resolution)	*Positivization: in order to transform all values into positive ones a constant value raster (value=10) was added to the original layer * Resampling from 10m cell size to 10m cell size *Fuzzified: linear function (highest value =not vulnerable; lowest value=vulnerable)	min(x) = 19,787 m max(x) = 5,101 m	EXPOSURE
Subsidence	SBAS su ASAR EO data	raster (100m resolution)	*Kriging on layer value corresponding to vertical velocity *Positivization: in order to transform all values into positive ones a constant value raster (value=10) was added to the original layer *Fuzzified: linear function (highest value =not vulnerable; lowest value=vulnerable)	min(x) = 10,907 mm/yr max(x) = 3,122 mm/yr	EXPOSURE
Dune	Corine Land Cover 2006 (level 3)	vector	*Extract Level 3 class corresponding to beach, dune, sand * Rasterized at 100m cell size (beach, dune, sand=1; other=0)	min(x) = 1 max(x) = 0	EXPOSURE
Population	InVEST (Landscan 2010)	raster	*Original layer clip on Area of Interest * Rasterized at 100m cell size *Fuzzified: linear function (0=not vulnerable; highest value=vulnerable)	min(x) = 0 max(x) = 986	SENSITIVITY
Land use/land cover	Corine Land Cover	vector	*A new field "Rank" was added to the original file. Each level 1 class was ranked as follows:	min(x) = 1	SENSITIVITY

Data	Source	Format	Processing	Fuzzification parameters	Component of Vulnerability assessment
	2006 (level 1)		urban=5, agricolture=4, forest=3, wet areas=2, riverine and marine waters=5 * Rasterized at 100m cell size according to field "Rank" * Fuzzied: linear function (1=not vulnerable; 5=vulnerable)	max(x) = 5	
Static ReSVI	statistical data, released by national statistical offices	Excel table	* Static ReSVI values were associated to a vector coastline *Buffering: 300m * Rasterized at 100m cell size according to field "ReSVI" * Fuzzied: linear function (0=not vulnerable; 1=vulnerable)	min(x) = 0 max(x) = 0,51	SENSITIVITY

6.2.4 Results of Fuzzy logic vulnerability assessment

Fuzzy operators and Raster Calculator of fuzzy set were used in the Po Delta to test two vulnerability case: without and with habitat in order to evaluate habitat role in delivering coastal protection ecosystem service.

Case without habitat

Tests without habitat were performed using different operators, namely Fuzzy AND, Fuzzy GAMMA, Fuzzy SUM and a simple Raster Calculator SUM. Results of these test are showed in Figure 57.

Observing maps related to Fuzzy AND and Fuzzy GAMMA operator[15] maximum values of membership degree are very low and much lower than 1 (0,16 and 0,24 respectively) that, according to the rule on the basis of which we fuzzified the data set[16], should correspond to maximum condition of vulnerability (i.e. combination of the various parameters values that give raise to the occurrence of the condition of maximum vulnerability). For this reason the results of these operators were not further taken into account in discussing the value of vulnerability assessment method based on fuzzy logic.

Application of Fuzzy SUM operator, which returns a degree of membership always greater than or equal to the greater of those combined, produced a result in which almost all the coastline show a very high membership degree (values are between 0,9 and 1). As this operator tends to smooth values around the highest, it makes all the coastal vulnerability substantially homogeneous (High exposure).

By applying Raster Calculator SUM we performed the sum of all fuzzy set of selected variables (except dune data). Its result describes a more differentiated vulnerability behavior of coastal segments, that seems closer to reality.

Considering all the results of chosen operators a higher vulnerability degree is distributed along the south coast of Delta prominence.

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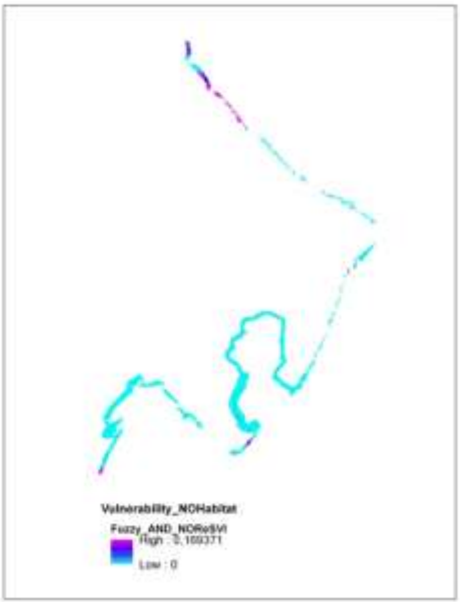
[15] With regard to GAMMA operator several test were performed using different γ value. In Figure 57 is presented result of GAMMA operator with γ=0.7

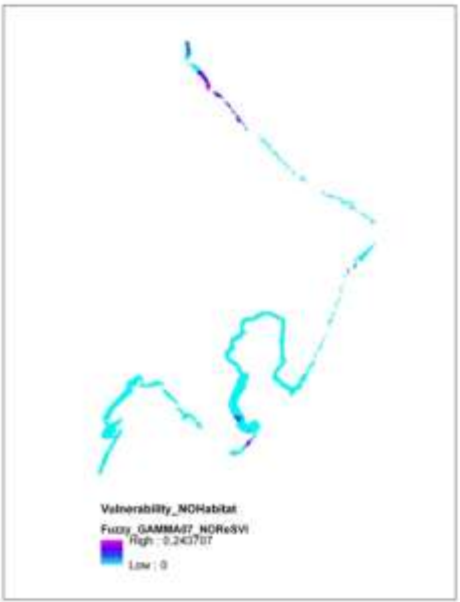
[16] See paragraph 6.2.3 (2. Fuzzification of variables by choosing membership function to obtain fuzzy sets): Maximum value (i.e. membership value of 1) corresponds to condition of maximum contribution to vulnerability status and minimum value (i.e. membership value of 0) corresponds to condition of minimum contribution to vulnerability status

Figure 57. Fuzzy logic vulnerability assessment results: case without Habitat

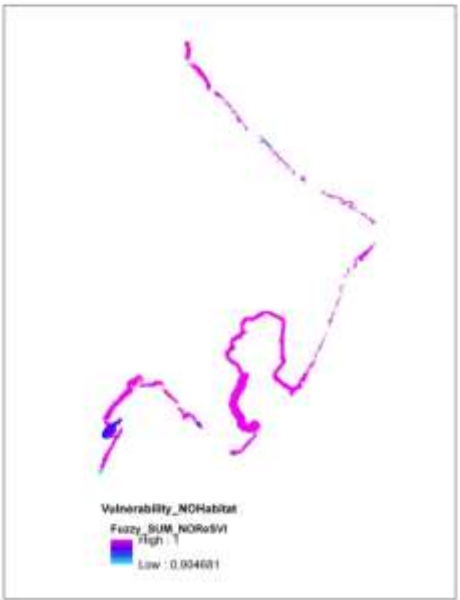
Fuzzy AND



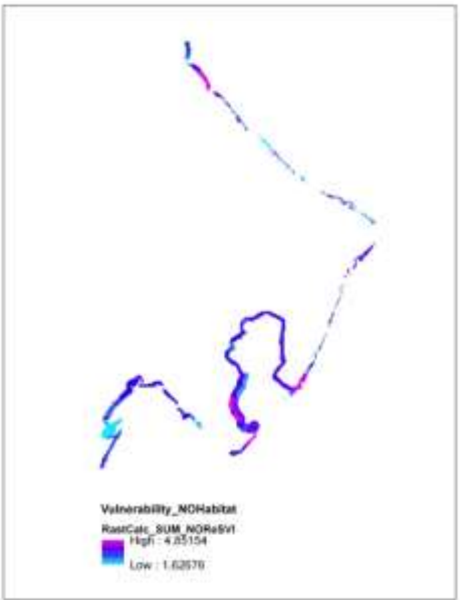
Fuzzy GAMMA



Fuzzy SUM

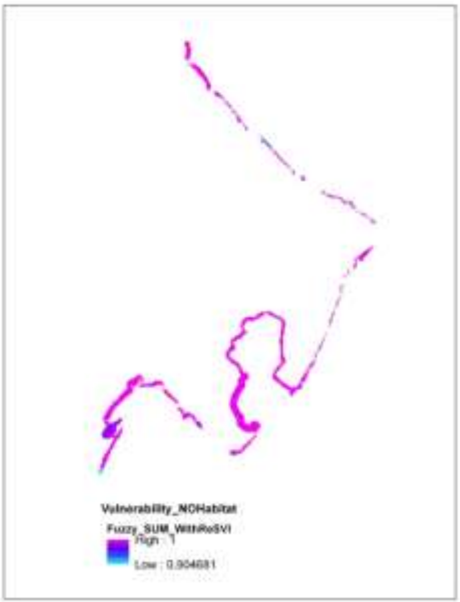


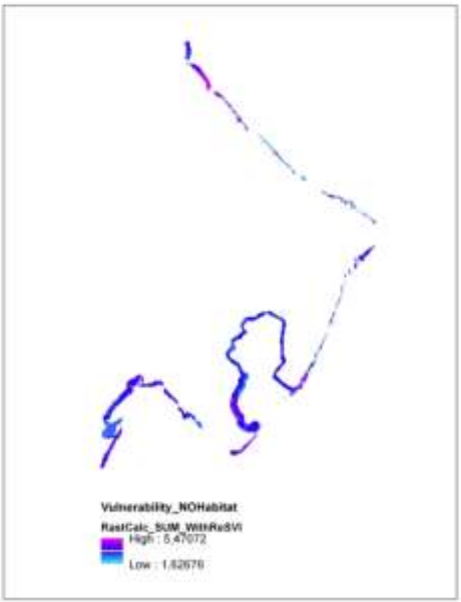
Raster Calculator SUM



Coastal Vulnerability values are calculated through Fuzzy AND, Fuzzy GAMMA, Fuzzy SUM operators and Raster Calculator SUM, considering all INPUT variables (Table 20) except Dune, and Static ReSVI

Fuzzy SUM **Raster Calculator SUM**





Coastal Vulnerability values are calculated through Fuzzy SUM operator and Raster Calculator SUM, considering all INPUT variables (Table 20) except Dune

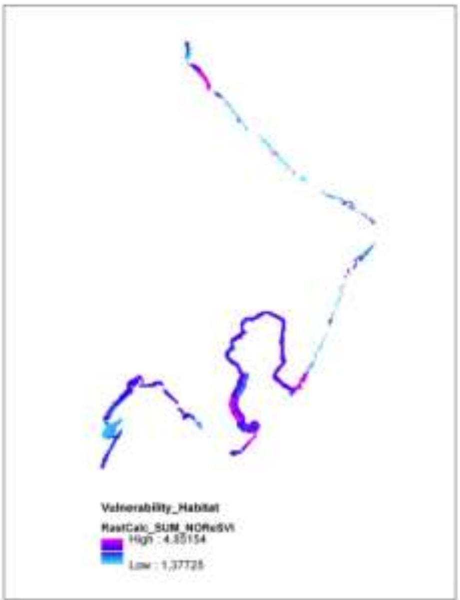
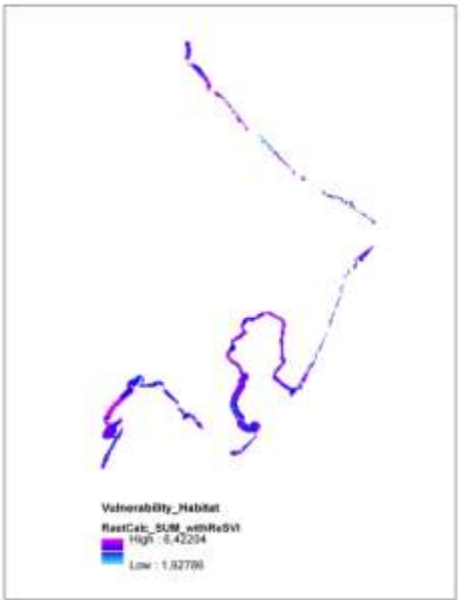
Case with habitat

As the result of Raster Calculator SUM without habitat was considered the most reliable among all the tests, it was the only one considered to perform the test with the habitat. Result is showed in Figure 58.

Raster Calculator SUM in the case with Habitat was performed adding to the sum of all the other fuzzy set, the dune fuzzy set (characterized by 0 membership degree where the dune is present and by 1 where the dune is absent).

Effect of habitat presence in reducing vulnerability degree is visible especially on the delta prominence. Different behavior between north and south side of the prominence is still clear, even because habitat further reduced the vulnerability of the north one.

Figure 58. Fuzzy logic vulnerability assessment results: case with Habitat Dune Habitat

Raster Calculator SUM	Raster Calculator SUM
	
Coastal Vulnerability value is calculated through Raster Calculator SUM, considering all INPUT variables (Table 20) except Static ReSVI	**Coastal Vulnerability value is calculated through Raster Calculator SUM, considering all INPUT variables (Table 20)**

6.2.5 Comparing InVEST Coastal Vulnerability module and Fuzzy logic vulnerability assessment

In order to compare results of the two selected approach, i.e. InVEST and Fuzzy, we took into account only fuzzy results considered reliable (i.e. Fuzzy SUM and Raster Calculator SUM). A summary of the used variables used for InVEST Coastal vulnerability module and Fuzzy logic vulnerability approach is showed in Table 21.

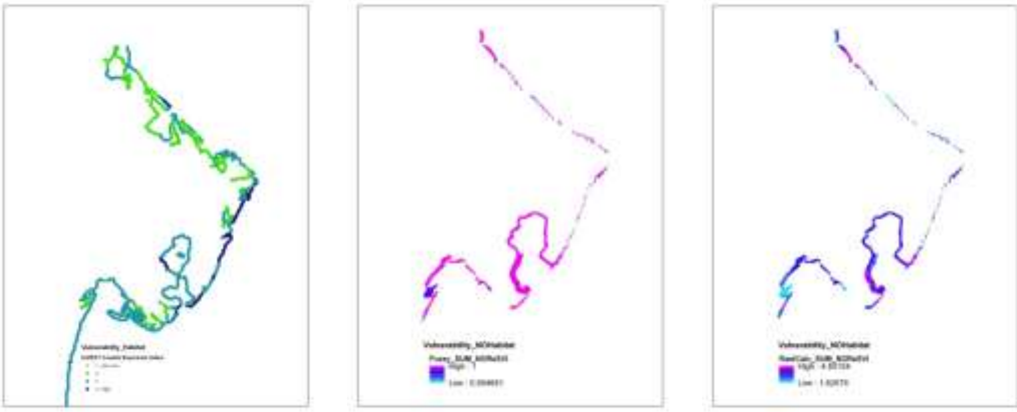
Table 21. Summary table of variables used for InVEST Coastal vulnerability module and Fuzzy logic vulnerability assessment

VARIABLES FOR ASSESMENT		InVEST model		Fuzzy Logic Approach		
				Fuzzy 'SUM'	Raster Calc 'SUM'	Raster Calc 'SUM'
		no habitat	habitat	no habitat	habitat	no habitat
		A	B	C	D	E
Physical forcing	Waves (Height - Direction - Intensity	X	X	X	X	X
Physical settings	Digital Terrain Model	X	X	X	X	X
	Geomorphology	X	X	X	X	X
	Erosion			X	X	
	Subsidence			X	X	
	Sea Level Rise	X	X			
Social component	Population	X	X	X	X	X
	Corine Land Cover 2007			X	X	X
Habitat	Dune presence		X		X	
	Lagoons/Saltmarshes presence		X			

Case without habitat

Figure 59. InVEST Coastal Vulnerability model and Fuzzy approach results: case without habitat

InVEST model **Fuzzy SUM** **Raster Calculator SUM**

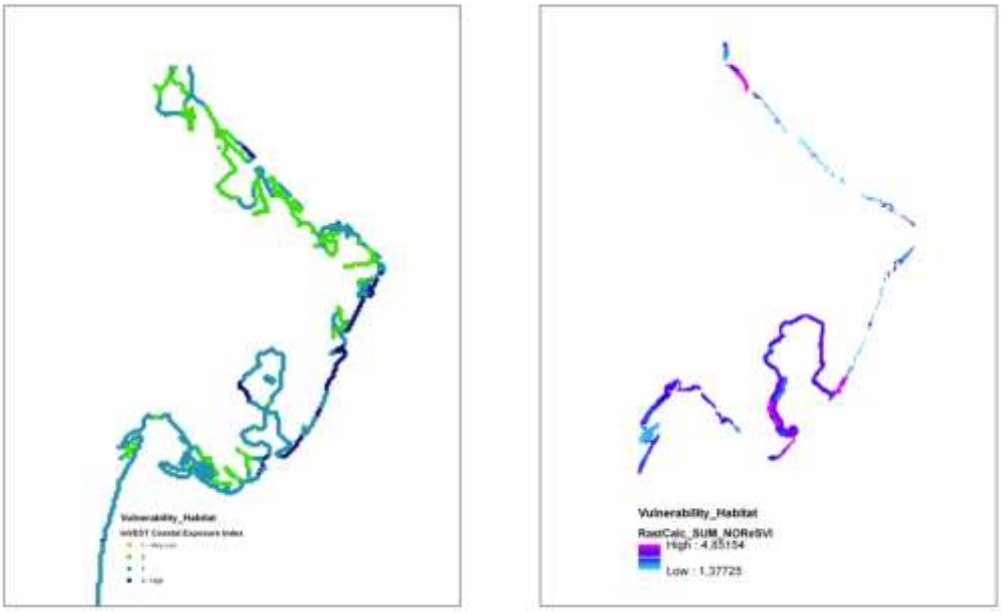


NO Habitat: Higher vulnerability distributed along the south coast of Delta prominence Fuzzy SUM returning a degree of membership always greater than or equal to the greater of those combined, tend to smooth values around the highest thus making all the coastal vulnerability substantially homogeneous (High exposure); Raster Calc SUM describe a more differentiated behavior thus closer to reality; InVEST output shows a medium vulnerability degree but does not provide information on its distribution, on the base of knowledge of the case study it can be assumed that there is a correspondence between vulnerability and exposure

Case with habitat

Figure 60. InVEST Coastal Vulnerability mode and Fuzzy approach results: case with habitat

InVEST model **Raster Calculator SUm**



Habitat: Habitat presence generates a reduction in vulnerability degree (especially western area of the prominence). In the InVEST model the protective distance allows to generate a protection gradient depending on the distance of the habitat from the coastline while in the Raster Calc SUM (sum of fuzzy sets) the habitat protection service is only based on their presence (or absence).

6.2.6 Discussion

InVEST model is ready to use; "fair" qualitative description on coastal exposure; includes a storm surge and wave field model otherwise very difficult to be managed by a no-expert user; natural habitat protective action is easy to manipulate to design different scenarios but it doesn't consider the site-specific characteristics (e.g. Subsidence). On the other side Fuzzy Approach allows the inclusion of multiple variables but they should be rasterizable and varying continuously in space (habitat generally don't respond to this assumption).

InVEST is not a properly a vulnerability assessment but more an exposure one; the ranking does not enable to maintain natural gradient characterizing transitional environments; ranking expert based and very subjective; comparison between EI of different areas is senseless because the EI is area extent dependant while the Fuzzy Approach is a-priori site specific.

Fuzzy logic limitation

However, fuzzy logic has at least has two limitations:

- strong reliance on subjective inputs;
- it can fail to capture the ranges of values in complex data sets and the correlations among the parameters.

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7 Analysis of risk sharing among governmental institutions, private sector (reinsurance industry) and civil society by mean of Public-Private Partnerships (PPP)

7.1 Regulementary tools in support to coastal communities vulnerability assessment

The European Flood directive[17] appears as an innovative text in the perspective of flood risk prevention. It fully integrates coastal marine submersion. It imposes studying hazard impact on four socio-economic “receptors”: human health, environment, cultural heritage and economy. It has the advantage of leading Union Member States to work on vulnerability and resilience for risk assessment and prevention practices.

Today, this directive has been transposed into the legal framework of many European countries (http://ec.europa.eu/environment/water/flood_risk/timetable.htm). All Union Members have completed the preliminary risk assessment, but none have yet published hazards and risk maps, as requested for March 2014. Producing this information directly impacts national practices and sometimes leads to an in-depth review of these practices. An introducing element of the ECOSTRESS project is therefore to compare available frameworks in the participating countries (France, Italy, Netherlands) an in the countries bordering the Wadden Sea test area (Denmark, Germany). This paper describes the French Case as in mid 2015.

7.1.1 The French case

In France, flood risk prevention regulations are contained in the Environmental Code[18] which encompasses the laws and decrees dealing with the matter. The origins of this corpus can be dated back to the 1858[19] law, adopted after the catastrophic general floods having occurred in 1856. Its general principle was to evaluate the territories exposure to flood risk, while maintaining the capacity of the river discharge.

This legal framework, dedicated to inundation has slowly evolved up to the last quarter of the 20th century. It’s only in 1982 (risk prevention plans) and 1995 (insurance) that the law redefined and structured the risk prevention policy as it is today, extending the scope to other natural hazards, the coastal areas hazards being the poor parent of the system.

The principles of the policy are:

a) The **geographic scale** for defining the components of risk and issuing prevention plans is the town territory;

[17] Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26 November 2007 http://ec.europa.eu/environment/water/flood_risk/index.htm

[18] Links to the major texts have to be found on : http://jurisprudence.prim.net/textesFondateurs2011.html

[19] Law, dated 28 May 1858, related to works aimed at protecting towns against inundation.

b) The **state administration**, namely the Prefet of the department has the responsibility of defining the risk. It identifies the town territories at risk and informs the concerned local authorities. Afterwards, it prescribes the preparation of the risk prevention plan (PPR) on the territories at risk and, after concertation with the local stakeholders, it endorses the plan.

c) The **local authority**, namely the Mayor, has to implement the risk prevention policy on its territory, as it is responsible for urban planning and for citizen security. This means: introducing PPR prescriptions into the local urban development plan [20], defining the town safeguard plan [21] in case of catastrophic event and, amongst others maintaining dykes and levees when present (protection against flood and sea).

d) The **citizen** has the right to access information on the risks, and the authorities have the obligation to make this information available, especially where a PPR has been approved.

The risk prevention plans (PPR) are the core of the risk prevention policy. Established at the town territory scale, they are urban and land planning documents crossing hazard maps with assets maps to define zones where constraints are prescribed (stop building, building with conditions, no constraints). They address the material assets (housing and industry) and do not highlight human safety impact. They do not integrate vulnerability assessment and therefore cannot be considered as risk evaluation tools.

Initially build around the river flooding risk, this policy has progressively aggregated other natural risks (seismicity, landslides, etc.) but no specific attention was given to coastal areas and to the risk of marine submersion. Therefore, when the Xynthia storm occurred in February 2010, only a very few coastal territories were covered by a prevention plan.

As a support to the policy described here, a **risk transfer system**, based on solidarity between insured stakeholders has been established. It is called the Natural Catastrophes system (Cat Nat), relying on a tax on all housing insurance contracts. It is detailed in another work package of the project.

In 2015, the legal framework described above has been largely reviewed in accounting the transposition of the flood directive, and the consequences of two major disasters having happened in France in 2010: the Xynthia storm in February, and the Var flash floods, in May.

The European Flood directive appears as an innovative text in the perspective of flood risk prevention. It fully integrates coastal marine submersion. It imposes studying hazard impact on four socio-economic “receptors”: human health, environment, cultural heritage and economy. It has the advantage of leading to work on vulnerability and resilience for risk assessment and prevention practices.

To give a perspective to the directive implementation, France has adopted a National Strategy for Flood Risk Management (SNGRI – Stratégie nationale de gestion du risque d’inondations) on 15 July 2014, along the following general principles:

20 In French : Plan local d'Urbanisme (PLU)

21 In French : Plan communal de sauvegarde (PCS)

a) Increase security of communities exposed to flood and marine submersion risk;

b) Stabilize and reduce the cost of damages due to inundations;

c) Reduce the delay for the return to the normal after a disaster.

This strategy still includes the solidarity principle. It insists on the necessary subsidiarity and synergy between the levels of authorities for an efficient governance of the policy, which is aimed at a sustainable land planning. It insists also on the development of information knowledge for disaster risk reduction, and promotes an approach enabling the citizen to live in facing inundations.

The Xynthia Storm (February 2010) and the Var flash floods (2010), have led to take entirely account of the problematic of the coastal flooding, and a more coherent approach of risk component evaluation. Amongst others :

- An update of the guide for the elaboration of Coastal risk prevention plans (PPRL), accounting the impact of climate change;
- The Rapid submersion plan (PSR), including the development of the existing multi-hazards early warning system (the Vigilance system) to include marine submersion and flash floods;
- The procedure for the Action programmes for floods prevention (PAPI), including marine submersion. These action programmes call for the study of risk at a larger scale than the town territory, namely the river basins, a submersible area or an economic perimeter. For the first time they call for some insight on vulnerability through a request for cost-benefit analysis, that require access to socio economic data.
- A National observatory for natural risks (Observatoire national des risques naturels – ONRN) has been created ion support to the strategy. It is a public private partnership aimed at gathering and providing information on the territories vulnerability and for the evaluation of the risk prevention policy. It shall answer to the requirements of the cost benefit analysis and of the risk mapping deriving from the European directive (www.onrn.fr) .

The responsibility of the local authorities with respect to the risk prevention has been précised by the law reorganising the local governance structures (MAPTAM)22. It reaffirms the responsibility described in the c) above. These local authorities have the responsibility of the implementation of the water management policy, which includes inundation prevention and specifically the maintenance of dykes and levees. The novelty is that these community can unite to implement a policy at a larger scale that the classical town territory.

After four years of implementation, these actions are under reviews, and some conclusions may be derived to be inserted in the National strategy implementation plan, which is also supported by the creation on the national observatory for natural risks (ONRN) – to be developed.

[22] Law Nr 2014-58 dated 27 January 2014 on the modernisation of territorial public action.

Summarizing: Taking opportunity of the floods directive and of the 2010 disasters, France has reviewed her tools in keeping the four principles described above, and introducing new approaches at larger scales than the town territory. They are now operative on the coastal areas where the governance structures can be used to study and, later, implement some results of the ECOSTRESS project.

8 Strengths, weaknesses and future opportunities of the research: an evaluation of the proposed fuzzy based coastal vulnerability assessment method

8.1 Strengths

The proposed method for assessing coastal vulnerability stems from other assessment methodologies taking advantages, wherever possible, of their experiences and achievements (Coastal vulnerability index formula, model based software, dataset of considered variables, spatial and temporal application scales, remote sensing etc.) and maks a step forward in accordance with the goals set within the ECOSTRESS project.
Point of strength are:

- the use of a simplified Vulnerability assessment framework (Figure 52) well known within the vulnerability research community (especially the climate change one) and easy to communicate with decision makers;
- the effort to integrate within the same analysis all dimensions involved in shaping coastal systems (biophysical and social-economic-cultural aspects of vulnerability): in a word a more comprehensive approach to place-societies vulnerability assessment;
- the effort to integrate within the same analysis external (exposure) and internal (sensitivity and adaptive capacity) factors determining coastal vulnerability;
- variables taken into account are not decided *a priori* and can be changed according to the characteristics of the site, i.e. variables are site specific and can be selected according to users' interest and data availability;
- data used within the assessment can be derived from multiple sources (in situ, EO, modeling);
- fuzzy approach not based on the definition of an inference systems allows the emergence of vulnerability conditions due to combination of factors not foreseen *a priori* by the user[23];
- selecting appropriate membership functions enables to handle the non-linearity of variables in a multi-criteria framework;
- the replicability at different scales and in different contexts;
- the possibility to generate several scenarios of the same area by changing habitat type, extent, distribution, makes easy to understand, even in a very simplified manner, the existence of protection ecosystem services delivered;
- result is a spatialized information as required to inform management and planning policies for implementing proactive adaptation and strengthening risk prevention and disaster management cycle of the coastal zones;

[23] Zadeh (1983), referring to expert systems, stated that they are not free from uncertainty "*because much of the information in the knowledge base of a typical expert system is imprecise, incomplete or not totally reliable*".

- result is a very "easy to read" map showing coastal segments according to their degree of vulnerability. Though the result is area dependant (i.e. comparison among different areas are senseless if the areas are not analyzed within the same fuzzification process), avoiding to explicitly define inference rules, that can be a very complex problem in the case of a great amount of input variables, allows to have a clear information on highest vulnerable segments in order to select priority areas.

8.2 Weaknesses

The developed assessment method is not a final version but rather a first attempt to contribute to mapping and assessing coastal ecosystems protection service through coastal vulnerability evaluation. Therefore, rather than highlighting the weaknesses of the method here we propose/list the issues on which it is worth to put more effort to produce a further development and improvement:

- in stressing the role of ecosystems in storm/flood protection (i.e. mapping ecosystem services), a higher characterization of ecosystems features relevant for coastal protection is required (e.g. protective distance value, vegetation cover of dunes, wetland extent, etc.);
- it would be worth to assess coastal ecosystems services by associating them a biophysical value, a flux value or an ecological value: this would facilitate the communication with the user community and within the user community;
- is there a minimum set of essential vulnerability variables (EVV) to define the coastal vulnerability? (e.g. in order to make the assessment result recognizable from several communities?)
- as ranking value approach does not enable to maintain the natural gradient that characterizes transitional environments and is mostly expert based and very subjective, it is necessary to find other kind of indicators a/o indexes to characterize variable attributes;
- with regard to the fact that the method does not use models either ecological or biophysical: a deeper understanding is needed in order to find out strengths and weaknesses of this choice. Which kind of benefits derives from avoiding the use of models? (This topic is especially relevant with regard to marine hazard directional component)
- Examining in depth the interdependence between variables: like relief, subsidence, erosion, trends, geomorphology, etc.. How can we consider these interdependences? Using weights?
- a deeper understanding of how modifications of the biological and physical characteristics of ecosystems (i.e. removal of natural habitats or change in their characteristics, etc.) can affect exposure to erosion and flooding: in the proposed assessment habitats are present or absent, there is no other way to characterize them and thus a change involving their quality or quantity;

- at the moment the coastal vulnerability is expressed as a value between 0 and 1 (Fuzzy SUM operator) or as a value between 1 and 6 (Raster Calculator SUM operator)[24] . It would be worth evaluating the advantages of expressing the coastal vulnerability a/o the protective ecosystem service delivered by mean of a biophysical, ecological or flows oriented metrics;

A completely missing issue within the proposed assessment is the monetary valuation that is fundamental for the decision maker to decide where, how and on which ecosystems or coastal subsystems intervene.

Estimation of monetary values can be performed for example on the base of a per-unit market, social, avoided, or replacement cost.

8.3 Opportunities

The developed tool/method for assessing Costal vulnerability to marine hazard within the project represents a valuable mean to answer to several topical issues and to pave the way for novel approaches to vulnerability reduction strategies. This is in the sector of risk communication and awareness, risk reduction, resilience strategies definition, proactive adaptation, risk sharing, risk financing and transfer, etc..

As concerns legal duties, the vulnerability assessment tool could indirectly contribute responding to Flood Directive demands to Member States i.e. assessing coastlines flooding risk, mapping assets and humans at risk, and improving understanding on measures to reduce storm/flood risk especially from an ecosystem services point of view.

Its replicability at several scales (from supranational to local), its ability to develop a comprehensible framework for both public (public administration, civil protection agency, etc.) and private stakeholders (builders, developers, insurance, reinsurance and financial markets players, etc.) could help the development of a collaborative risk governance framework for coastal risk, foster public information and participation in the coastal flood risk management process, and eventually - wherever public and private stakeholders should find a common interests in managing costal systems and assets – the formation of Public-Private Partnerships (PPP) for coping with coastal risk. In these cases, risk would not be in charge only of the public but also of the private.

Moreover, the assessment would deepen the understanding and opportunities related to the exploitation of ecosystems based adaptation (EbA) approach to improve coastal resilience.

Adaptation measures to cope with risks embrace not only structural, functioning, organizational, ecological measures but also financial ones.

[24] See paragraph 6.2.4

Hazard, in accordance to exposure, sensitivity, and adaptive capacity of a certain areas can generate widespread impacts, producing not only physical harm and damage to populations and assets, but also directly or indirectly threaten economic activities. The resulting effects are financial costs aggravating economic and social impacts during the hazard event or the recovery phase. Achieving financial resilience is thus a critical component of effective disaster risk management that can be pursued for example by developing *ex ante* pro-active financial management tools (i.e. risk financing and risk transfer tools and compensation arrangements)[25] as measures complementary to the physical risk reduction ones. Risk financing and risk transfer strategies interact with physical risk reduction: an effective use of the financial instruments asks not only for the assessment of risk but also for its reduction.

These tools beneath providing the required protection by reducing the financial vulnerability, allow to exercise flexibility to keep on modulating the risks across space and time – and as a consequence the needed protection – to better manage them or by transferring risks to those better able to absorb them.

A comprehensive and integrated approach to risk assessment (including all coastal systems dimensions as well as all risk components), as the first attempt here proposed that however does not include the costs of damages to exposed assets, is thus of paramount relevance in designing adequate financial risk strategies and acting in a proactive manner.

[25] Usually these tools are developed by private sector or government

9 ANNEX

9.1 FLOOD DAMAGE MODEL

9.1.1 Introduction

Methodologies to estimate economic flood damages are increasingly important for flood risk assessment and management. Flood damage evaluation is nowadays a crucial component of any strategy of flood risk mitigation and management (Messner and Meyer, 2006; Messner et al., 2007; Merz et al., 2010). In particular, models and methodologies to estimate economic damages are key for evaluating and comparing flood mitigation measures and for defining flood risk management plans (Bouwer et al., 2013; Schröter et al, 2014).

In the context of a risk model, referring to the Figure 61, it is possible to understand the complexity of the framework. There are however three important issues to stress:

- The reliability of a risk model depends on the reliability of each component (equally!)
- The vulnerability assessment is often affected by a high degree of uncertainty (or high errors)
- Most of the existing damage models are empirical

Given this framework, in the ECOSTRESS project we developed a probabilistic methodology to derive synthetic damage curves for residential buildings. The method is based on an explicit component-by-component analysis of physical damages to buildings, which takes into account available knowledge on damage mechanisms. The model is transparent and can be applied in different contexts. Implemented functions and values are clearly explained so that they can be totally or partly modified according to the physical context in which the model is applied. On the other hand, the methodology allows for different levels of detail in the analysis, hence the damage model can be adapted to the actual knowledge of relevant hazard and vulnerability variables. As such, the methodology is suitable for a variety of applications:

- characterization and derivation of damage curves for residential building types (ex-ante vulnerability analysis);
- post-event damage estimation (ex-post vulnerability analysis);
- analysis of uncertainty sources in damage estimation.

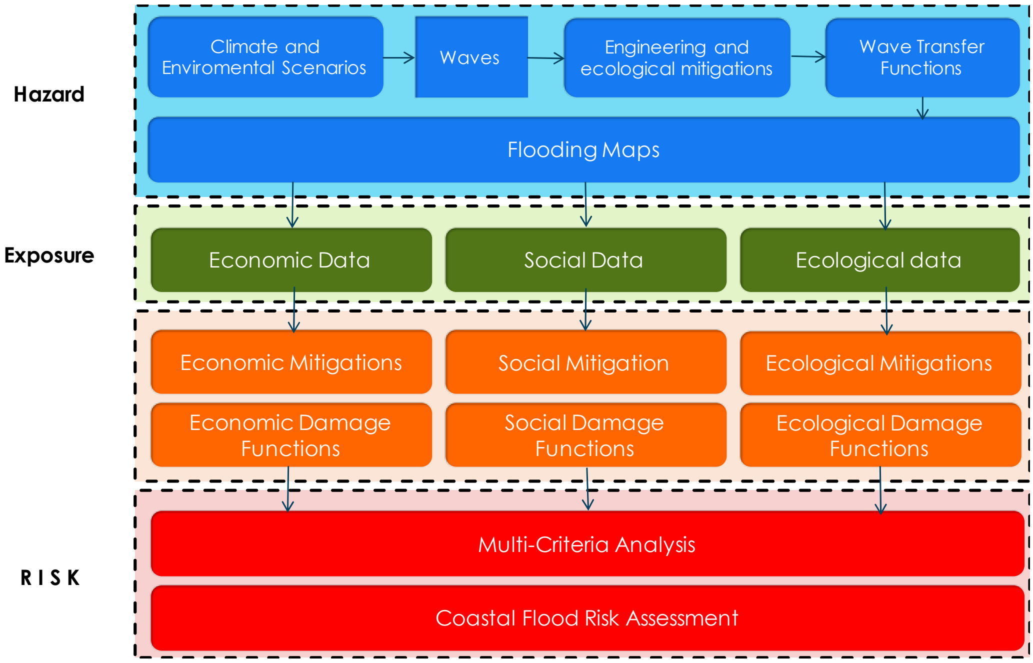

Figure 61 – Conceptual scheme of a coastal flood risk model

9.1.2 Status of the art

Available damage models can be classified in two main classes: empirical and synthetic models (Smith, 1994; Merz et al., 2010). Empirical models use damage datasets collected from past flood events to link vulnerability and hazard variables to damage (data-driven approaches). Synthetic models adopt a more conceptual approach, and use hypotheses and assumptions on damage mechanisms (what-if analysis) to derive damage functions (expert-based approach).

Despite their growing importance, there are still relevant issues in the application of flood damage models (Handmer, 2003; Meyer et al., 2013). First, the relative scarcity of observed damage datasets is a relevant obstacle in developing and improving existing models. Models based on data-driven approaches are especially prone to this issue, as they require specific calibration to be applied in different contexts (Merz et al., 2010; Bubeck and Kreibich, 2011). Synthetic models, adopting conceptual, expert-based assumptions of hazard-damage relationships, are less dependent on datasets for model derivation, though they still require additional data for calibration and validation (Smith, 1994; Merz et al., 2010).

Second, even where reliable and comprehensive datasets are available, it is generally not possible to extrapolate adequate damage functions, due to the well-known complexity of damage mechanisms (Andrè et al., 2013; Scorzini and Frank, 2015). Damage computation methods based on probabilistic approaches might offer a solution to this issue (Schröter et al, 2014), yet this research topic is still relatively unanswered in literature.

Third, the evaluation of flood mitigation measures requires methodologies to estimate economic damages at both the micro (e.g. building-scale strategies for vulnerability reduction) and the meso scale (e.g. spatial planning strategies) (Schröter et al., 2014).

When micro-scale strategies are considered, empirical models are less suitable because the model structure generally considers few explicative variables. For buildings these typically include the water depth, the building structure and the number of floors (Messner and Meyer, 2006; Schröter et al., 2014); as a consequence, it is not possible to evaluate the effect of the full range of mitigation strategies available like the use of permeable materials, the moving of vulnerable components, etc. Synthetic models can overcome this limitation, as their level of complexity can be designed to adapt to the required detail. Still, these models are often affected by a lack of transparency. In many cases, the rationale behind model development (e.g. assumptions, mechanisms considered, built-in parameters) is not clearly presented, and relevant variables to be used are not explained, which limits applicability and transferability, as well as possible improvements (Scorzini and Frank, 2015).

To summarize the main limitations of existing models are:

- Need for a specific calibration
- Difficult to develop due to scarcity of data
- Limits to implement mitigation strategies

Table 22 - Review of existing damage models.

Study	Hazard parameters	Vulnerability parameters	Estimated damage	Monetary evaluation	Validation	Sensitivity analysis	Weaknesses	Strengths
IKIWAD (Neubert et al. 2014)	water depth	12-14 typical buildings according to: * building material * construction technology * design issues * period of construction	* building fabric and functions * building inventory * drying	* building price books * expert interviews	yes	no	use of statistical data for characteristic building inventory	embedded into a GIS tool
Gersonius et al. 2008	* water depth * velocity	5 typical buildings according to: * construction type * ground floor area	* partial collapse * damage to building fabric and functions due to immersion with flood water * clean-up and disinfection	* past experience * expert interviews	no	no	not validated	
Velasco et al. 2015	water depth	1 typical building	* building fabric and functions * building inventory * clean-up * water pumping	Past experience	Yes + "calibration" with past event	no	only one building type is considered	embedded into a GIS tool
FloodProbe (Walliman et al. 2013)	* water depth * velocity * debris content * contaminant content * Flood duration	Possibility of defining the specific features of the affected building	* building fabric and functions * clean-up * drying	* databases used by quantity surveyors * building price books	Yes	yes, only for hazard parameters	huge amount of input variables (no default values)	* In-depth analysis of vulnerability * adjustment factor for regional differences * valid for non-residential building * possibility of analyzing damage items by items
Oliveri e Santoro 2000	water depth	2 typical buildings according to: * number of storey * finishing level	* building fabric and functions * building inventory * dismantling damage components	Building price books	No	no	* only two building types are considered * not validated	
Multi Coloured Manual (Penning-Rowsell et al. 2005)	* water depth * duration	140 Typical buildings according to: * construction type * period of construction * social class of occupants	* building fabric and functions * building inventory * external areas (gardens,fences,sheds) * clean-up	Not specified	No	no		* In- depth analysis of vulnerability * possibility of analyzing damage items by items

Given those limitations within the ECOSTRESS project we decided to developed a probabilistic expert-based model.

Why expert-based?

- To exploit the knowledge from loss adjustment studies and detailed damage data
- Detailed component-by-component analysis
- Adaptable to the level of information available
- Distinction between the physical and economical damage

Why probabilistic?

- Need for an uncertainty estimation, since the data are affected by uncertainty and the model parameters are uncertain
- The uncertainty estimation is fundamental for decision making

9.1.3 The developed model

The developed model adopts a synthetic approach consisting in the simulated, step-by-step inundation of residential buildings and in the evaluation of the corresponding damage, based on building and hazard features. Such a methodology can be also referred to as a what-if analysis.

Damages are first modelled component by component using physically based mathematical functions, and then converted into monetary terms, using full replacement costs derived from reference price lists.

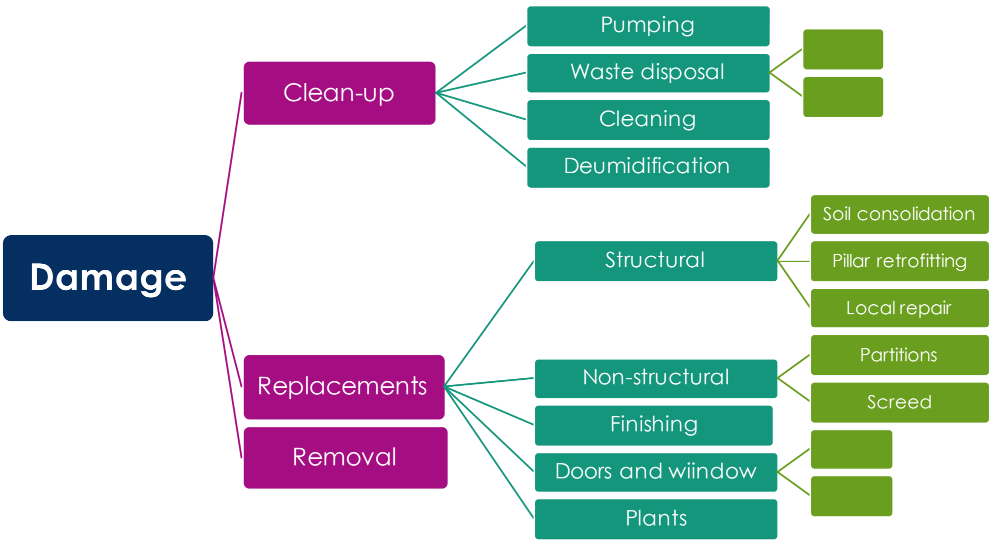

Figure 62 –Tree-chart of the damage components of the model

In detail, the overall damage (*D*) to each single building is decomposed in different damage components (C_i), as follows:

$$D = \sum_{i=1}^{n} C_i = \sum_{i=1}^{n}\sum_{j=1}^{m_i} C_{ij} \qquad (1)$$

where C_i includes clean-up and removal costs, structural damage, non-structural damage, damage to finishing elements, damage to windows and doors, and damage to building systems, and *n* is the total number of components used to define the damage. Each component C_i is subdivided into m_i different subcomponents C_{ij}, specifically referring to the reparation of the damaged elements or to their removal and replacement.

For each subcomponent, a mathematical function describing the damage mechanism and associated cost is formulated, considering expert-based knowledge as well as available technical and scientific documentation. The general formulation can be described as follows:

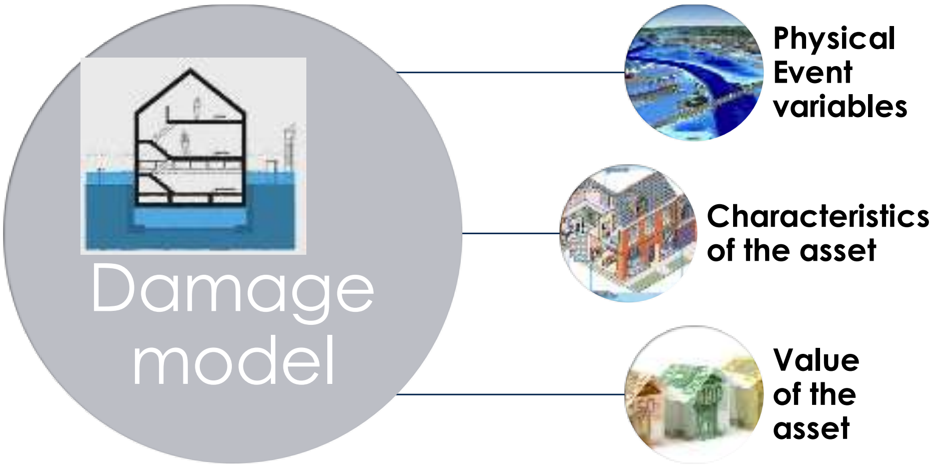

Figure 63 – Conceptual scheme of the model

$$C_{ij} = f(\text{Event features, Building characteristics, Unit prices}) \quad (2)$$

where:

- *Event features* include all the physical variables describing the flood event at the building location, e.g. maximum external and internal water depth, flood duration, water quality (presence of contaminants) and sediment load.

The physical event variables used by the model are:

- external water depth (he)
- flow velocity (v) at building location
- flood event duration (d)
- water quality (q)
- sediment load (s)

that are usually the result from a 1D-2D coastal flood model

- *Building characteristics* include all the variables describing features and geometry of the building. Building features affect damage estimation either by modifying the functions describing damage mechanisms (e.g. system distribution, building structure) or by affecting the unit prices of the building components by a certain factor (e.g. building type, finishing level). On the other hand, the geometrical properties of the building (e.g. footprint area, number of floors) are used in the estimation of the extension of damage to each of the building components.

Unit prices refer to the cost of replacement or reparation of the building components per unit of measure (e.g. doors removal cost per square meter, pavement replacement cost per square meter). For the present study, unit prices are derived from Italian price lists for the year 2013.

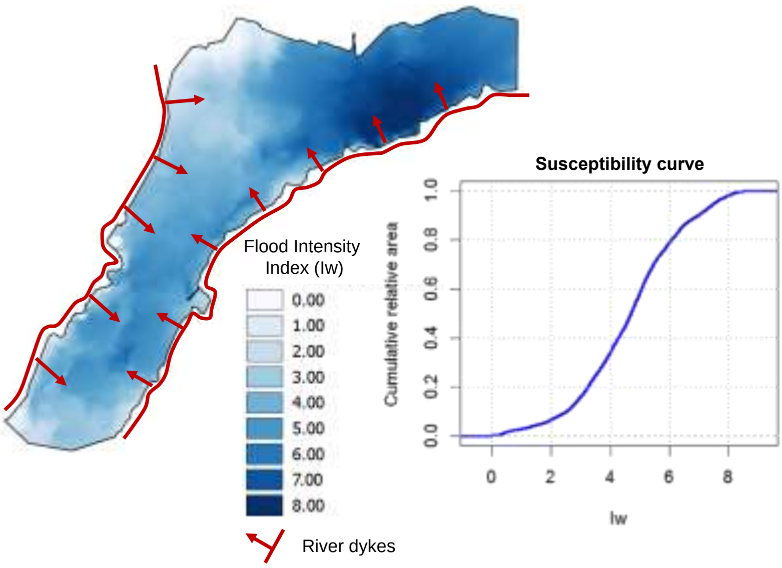

Figure 64 – Example of a model used for the hazard assessment

To complete the model methodology, the absolute damage figures computed can be converted into relative value by dividing them by the replacement value of the building. This value is given as a function of the building type and structure, based on existing literature and official studies (Cresme-Cineas-Ania, 2014).

9.1.4 Model results

The approach followed by the model was derived from a detailed analysis of the present state of art of synthetic flood damage modelling for the residential sector. The table reports, for the main models found in the literature: considered hazard and vulnerability parameters, the estimated types of damage, the approach for the monetary evaluation of damage, whether or not models have been validated and whether or not a sensitivity analysis has been performed. Starting from this analysis, the main strengths of existing models have been identified and incorporated in the model.

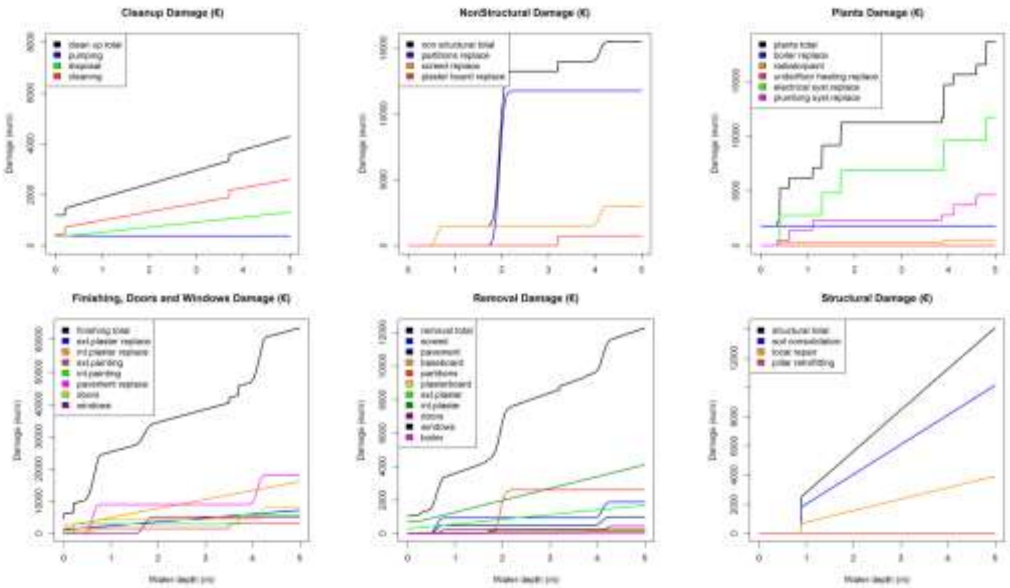

Figure 65 - Model results in terms of 1D damage functions

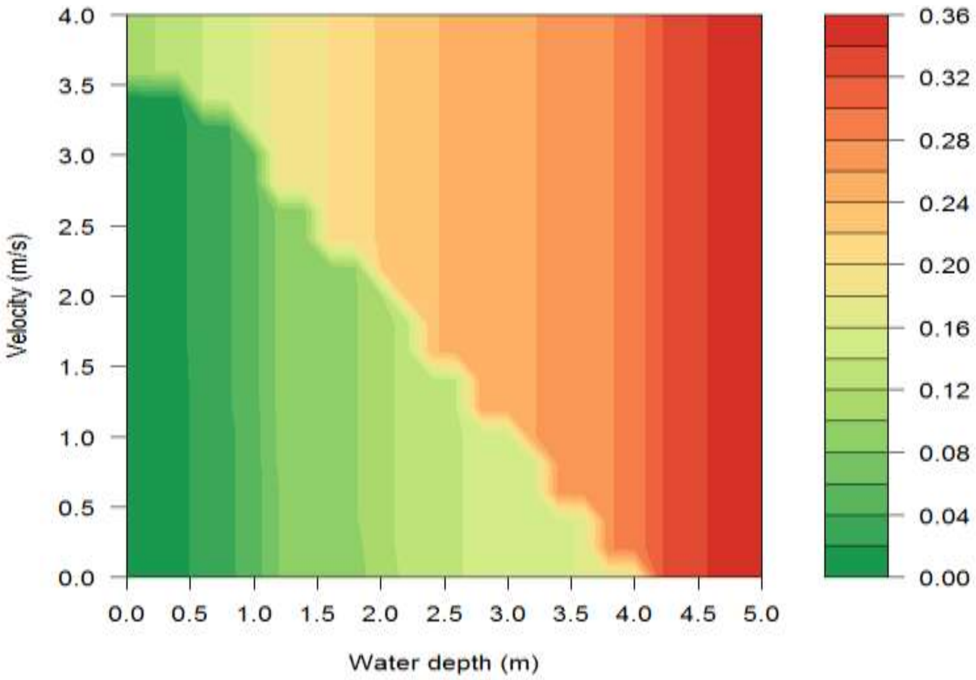

Figure 66 - Results of the model in terms of 2D damage function

In the previous figured the main findings of the model are reported both in terms of the traditional damage functions and in terms of more complex analyses.

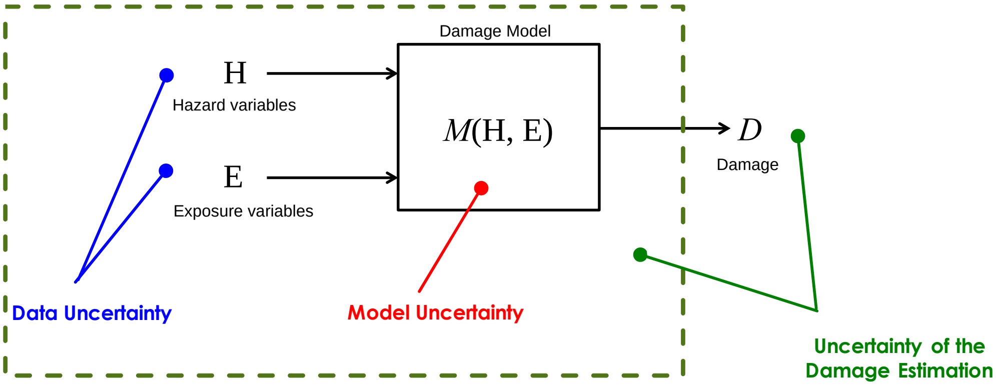

Figure 67- Conceptual scheme of the uncertainty analysis

Another important feature of the model regards the treatment of uncertainty embodied in the model structure. The contribution of hazard components of risk to total damage uncertainty has been highlighted in several research works, considering the uncertainty related to damage models (Merz and Thieken, 2009; Merz et al., 2010, de Moel and Aerts, 2011, Thieken et al., 2014), or comparing the results of various damage models or curves (Apel et al., 2008; Jongman et al., 2012; De Moel and Aerts, 2011; Schröter et al., 2014). Relatively few works performed a comprehensive sensitivity analysis of damage estimations to different sources of uncertainty, or presented methods to explicitly account for it in applications. Egorova et al. (2008) assessed uncertainties in the value of elements at risk and developed a methodology to incorporate uncertainties in depth–damage curves. De Moel and Aerts (2011) evaluated the influence of several factors on damage estimates, and they concluded that the uncertainty coming from the determination of values of elements at risk and the choice of a damage model is much more influent than other sources like land use data and inundation maps. Schröter et al. (2014) applied eight flood damage models with different levels of complexity to predict relative building damage in residential sector for five historic flood events in Germany. The authors observed that the use of additional explanatory variables besides the water depth improved models' predictive capability especially in applications to different regions and different flood events. In addition, models based on probabilistic structure (e.g. Bayesian networks) resulted more reliable than deterministic models.

The results of the uncertainty analyses are reported in the following figures where the boxplots represent the uncertainty both in terms of water depth and in terms of the other hazard variables.

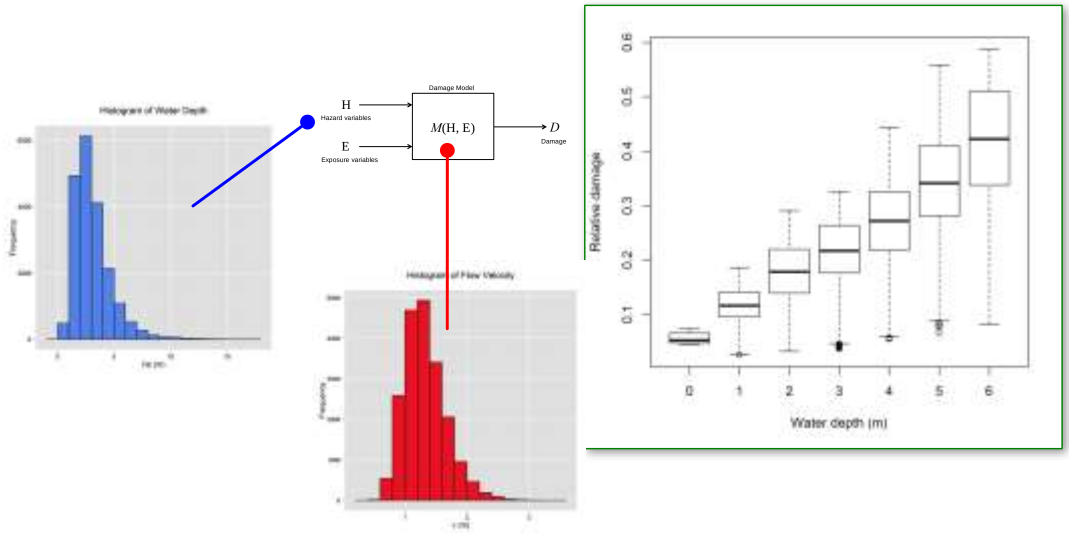

Figure 68 - Montecarlo framework for the uncertainty analysis

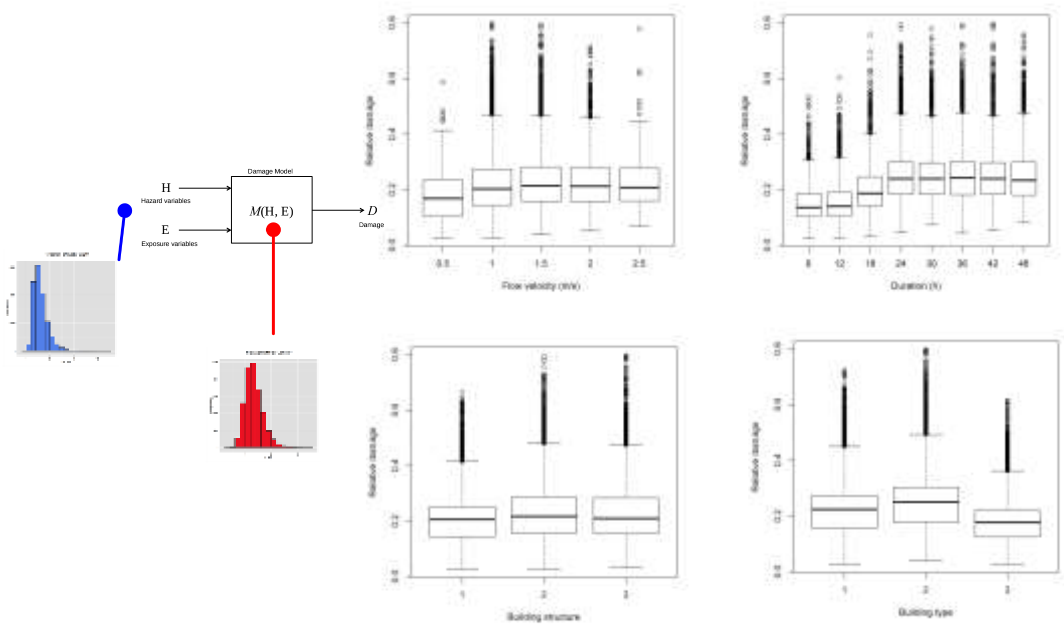

Figure 69 – Uncertainty analyses in terms of the hazard variables

9.1.5 Potential uses of the model

The potential uses of the model are many in the context of risk modelling and risk assessment. To summarize some of them:

- What-if-analysis: evaluation of different hazard scenarios
- Cost-benefit analysis: decision support systems
- Risk assessment: as a fundamental component of risk modelling
- Depth-damage curve: standard damage curves
- Uncertainty analysis: effects of the uncertainty on the decision process

- Sensitivity analysis: evaluation of the interdependencies of the different model components

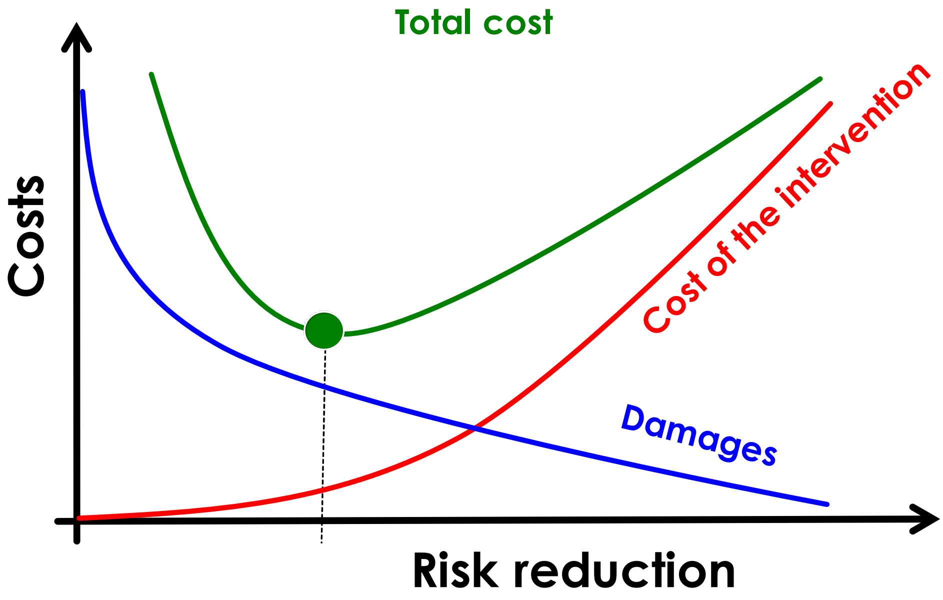

Figure 70 - Cost-benefit analysis in the risk assessment context

As far as hazard and vulnerability are concerned the model allows considering all the hazard parameters which were found as significant in the literature, namely water depth, velocity, sediment and contaminant loads, and flood duration (Kelman and Spence, 2004; Thieken et al., 2005; Kreibich et al., 2009; Merz et al., 2010). Moreover, the vulnerability features of any specific building can be defined by means of a set of parameters (such as building size, type, structure, finishing level, maintenance level, etc.), allowing for an in-depth analysis of vulnerability. This overcomes the problem of the representativeness of the entire building stock by means of a set of predefined building types, presently characterizing the majority of models. On the other hand, some of the information required by the model may not always be available. For this reason, default values are included for all model parameters, based on the most observed common values.

- In summary the advantages of the models are:
- State-of-the-art model
- Flexibility
- Price lists can be updated and modified
- Damage functions can be updated and modified
- Parameters can be fixed or variables according to the level of information
- Exposure values can be updated
- Computational efficiency

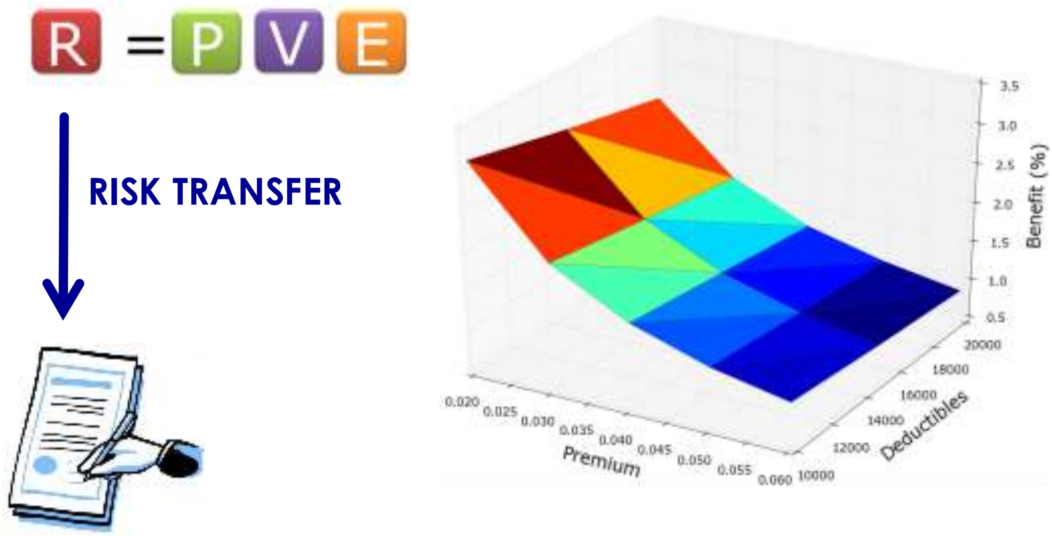

Figure 71 - Example of a risk analysis aiming at risk transfer as a reduction measure

We believe that the damage model developed brought an important contribution to the ECOSTRESS project since it is a ready-to-use tool to perform analyses aiming at the flood risk assessment and reduction. Also the model has been integrated within the EcoStress framework and particularly with the hazard and vulnerability component. Nonetheless future development of the model are also planed in order to include also other important components such as:

- Contents Damages
- Business Interruption Damages
- Fiscal Impacts
- Mitigation measures

9.1.6 References

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9.2 CROWDSOURCING TOOL DEVELOPMENT AND TESTING

The diffusion of smartphones and tablets with built-in GPS receivers and cameras led to what can be called “a dense network of observers”, whose exploitation through a suitable software toolset can add great value to risk mapping.

The main idea was to build an architecture flexible enough to be adapted according to the scope and needs of the collection. The approach is not meant to replace spaceborne remote sensing, but to integrate it with a complementary source of information coming from the ground. The following reports have been prepared on the subject:

- D.B.1: Deployment of WebGIS system with dummy test data (i.e. non case study): among the other sources of information considered in the ECOSTRESS project, crowd-sourced data has been included as a possible way to complement remotely sensed and in-situ data in the extraction of risk-relevant information. The focus is placed on Ambient Geographic Information (AGI) under the form of georeferenced pictures taken and shared by informal contributors to public sharing sites. The first phase of the project involved a review and some analysis of different social networks available nowadays, especially in terms of their suitability for the project purposes. These are: Panoramio, Flickr, Picasa Web Album, Twitter, Facebook, Instagram, Locr, and Smugmug. The analysis focused on availability, and accessibility, of data uploaded by the users. A short description for each of them is reported in the next section. During the second phase of the project, focus was shifted towards the analysis of other projects aimed at collecting information from the crowd.
- D.B.5: Deployment of pilot for tool for crowd sourcing: the aim was to develop a framework for the collection of data from distributed “sensors”, thus implementing a crowdsourcing data collection. The diffusion of smartphones and tablets with built-in GPS receivers and cameras led to what can be called “a dense network of observers”, whose exploitation through a suitable software toolset can add great value to risk mapping.

The main idea was to build architecture flexible enough to be adapted according to the scope and needs of the collection. The approach is not meant to replace spaceborne remote sensing, but to integrate it with a complementary source of information coming from the ground.

- D.B.6: One public (cyber) event to generate users using tool from D.B.5: the report is specifically concerned with the "Cyberevent" organized to test mobile tools developed for data collection using crowdsourcing.

9.3 Making decisions under uncertainties

The project is examining the feasibility and the cost-benefit of risk prevention measures related to the use of wetlands, coastal marine systems and dry lands to naturally mitigate flood. Earth observation data are combined with field studies and statistics in geographic information systems. Uncertainties are being quantified in thematic maps and sensitivity analyses for coastal zones in the test cases of the Wadden Sea and Northern Adriatic adjoining coast. Training to implement algorithm for risk analysis have been achieved for policy makers that enables them to make decisions under uncertainties.

This section presents the methodology developed and applied for the Wadden Sea and how the uncertainties resulted in probability maps for exceeding a certain threshold that is relevant to the good ecological status. This is done through the use of models, earth observation, and with the help of concepts of ensemble forecasting and validation.

The water quality and complex ecological status of the North Sea is represented using the Generic Ecological model (Delft3D-GEM). The hydrodynamics transport is calculated using Delft3D-FLOW, which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing. Moreover, the hydrodynamic simulation used data from ECMWF (European Centre for Medium-Range Weather Forecasts) and Dutch Met Office –KNMI (Koninklijk Nederlands Meteorologisch Instituut). The biochemical (GEM) model simulates the nutrient cycles of carbon, nitrogen, phosphorus, silicon and dissolved oxygen. The state variables included in the model are: nitrate (NO3, representing the sum of nitrite and nitrate), ammonium (NH4), phosphate (PO4) and dissolved silicate (SiO4). Four functional phytoplankton groups are simulated: diatoms, flagellates, dinoflagellates and Phaeocystis.

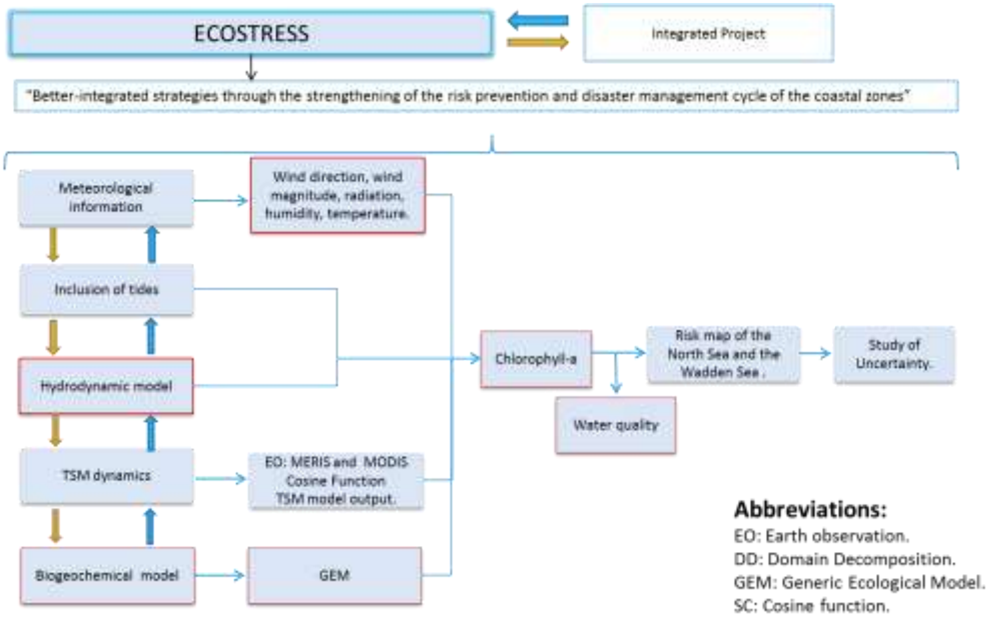

Figure 72 Sketch of the ecological model merge with Satellite information

Satellite information (TSM) MERIS or MODIS is used as a forcing in the model as shown in the figure above. As an output the advective and dispersive transport of substances, biogeochemical processes and loads as well as resulting concentrations for each time step are obtained. On the other hand, the boundary conditions for temperature, salinity and nutrient were derived from measurements (OSPAR Commission, 2013). Numerical weather prediction models face the problem of having various sources of uncertainties in the initial condition inherent. The errors source starts already within the observational data, among other potential errors: possible are reporting errors, bias in frequency measurement, conversion errors. Another source of errors are inherent in the weather forecast models such as the insufficient spatial or time resolution, truncation errors occurring by solving the dynamical equations, coding errors, approximation errors, parameterization.

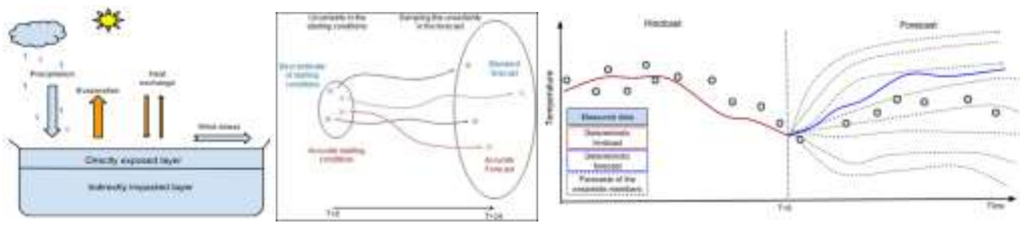

Figure 73 Numerical weather Forecast and possible uncertainty in ensemble forecasting

The figures illustrate the concept of how numerical weather forecast are run, assuming it is possible to know the whole state of the atmospheric system and a perfect forecast model is given, then it would be possible to forecast weather depicted as red line. The blue line depicts an example of running a single forecast, however, it is likely that it does not match with the red line. Hence, multi forecasts are run, shown as black lines with slightly different initial conditions, cover a bigger area and hence are more likely to include with its forecasts the actual future weather condition. The high resolution limited area model HIRLAM 11 v7.2 provided by the Royal Netherlands

Meteorological Institute KNMI and the meteorological WEPROG ensemble forecasts provide the meteorological forcing to the hydrodynamic and water quality model such as air temperature, wind speed and direction, specific air humidity, cloud coverage and pressure. The model output is being validated against measurements available in the area. A comparison of the sea surface temperature profiles for different stations of the ensemble forecasts with the deterministic forecasts and the insitu measurements. From the validation, the variation of temperature for the ensemble forecasts is relatively small i.e. around three tenths of a degree. Here, the range of the ensemble predictions are much smaller than the inaccuracies which is already included in the deterministic model with respect to the insitu measurements. Even though, the ensemble forecast covers the uncertainties of the atmospheric forcing, the impact on the temperature and salinity is very small.

High biomass algal bloom events occur each year in the North Sea, causing nuisance (smelly foam on beaches) and potentially dangerous situations when there are toxic species or when the biomass decays rapidly and sinks to the bottom to form pools of hypoxic matter. These pools can resurface and form dead zones where massive marine life mortality occurs. This type of blooms influences the turn-over of fisheries and aqua-cultural operations in many ways, sometimes with large economic losses. On the other hand, it may be profitable in the future to monitor high biomass blooms because they could be harvested as biofuel or as fertilizer (since the world stock of phosphates is decreasing rapidly). The climax of the spring bloom is dependent on the light availability which varies depending on solar radiation, the depth and the TSM concentration. The spring bloom is often limited by the available amount of phosphorous or silicate, while summer bloom is the nitrogen the limited parameter. However in order to evaluate the impact on different hydrodynamic conditions in the water quality model, 8 different scenarios defined. It is clear from the exercise that the timing of the bloom is very sensitive to the hydrodynamic conditions.

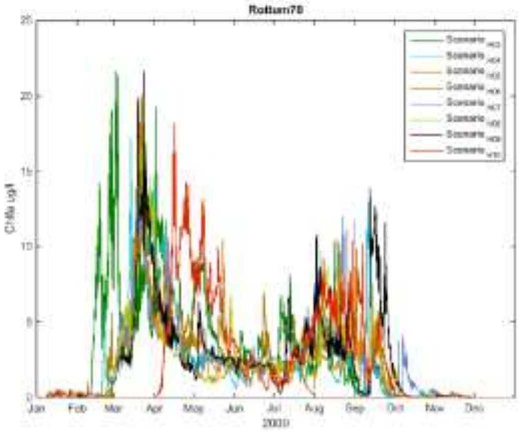

Figure 74 Effect of different hydrodynamics on the ecological ensemble state

The probability of exceeding certain threshold value (7ml/l as an example in the figures) can be visualized including the upper bound of 95 percentile and the lower bound of 5 percentile.

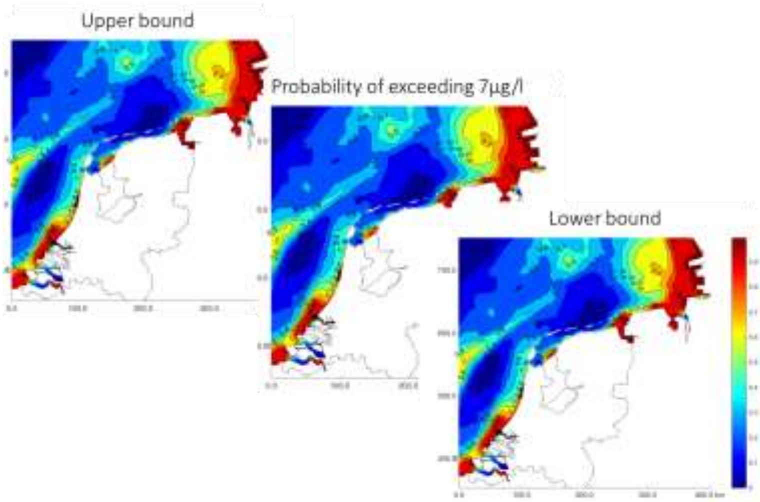

Figure 75 Probability of exceeding the threshold of 7mg/l include the 95 & 5 percentile

Also for the quantification of uncertainty, two set of parameter were taken into account and Monte Carlo simulation procedure was used for finding distributions of output variable values based on distributions and associated errors:

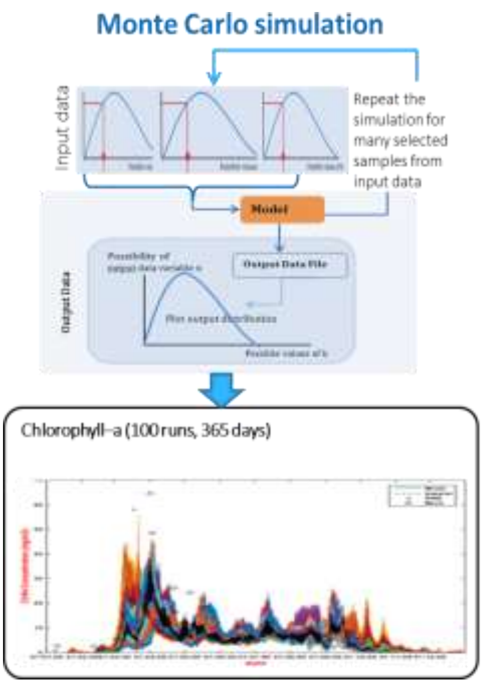

Figure 76 Monte Carlo Simulation setup

The parameters that are expected to be uncertain are parameters that affect the Chlorophyll-a concentration such as Specific Extinction of Inorganic Suspended Matter (i.e. the absorbance of light per unit path length and per unit of mass concentration and the xaximum Growth Rate of Diatoms algae. Other parameters that affect the nutrients concentration are de-nitrification rate or the burial rate of detritus in the bed layers.

Due to sources of errors in different sources in the chain, the bloom of high chlorophyll-a and the evolution of uncertainty in time are presented per month, March and April (trimming of the bloom) presented the higher uncertainty specially in the Dutch coast.

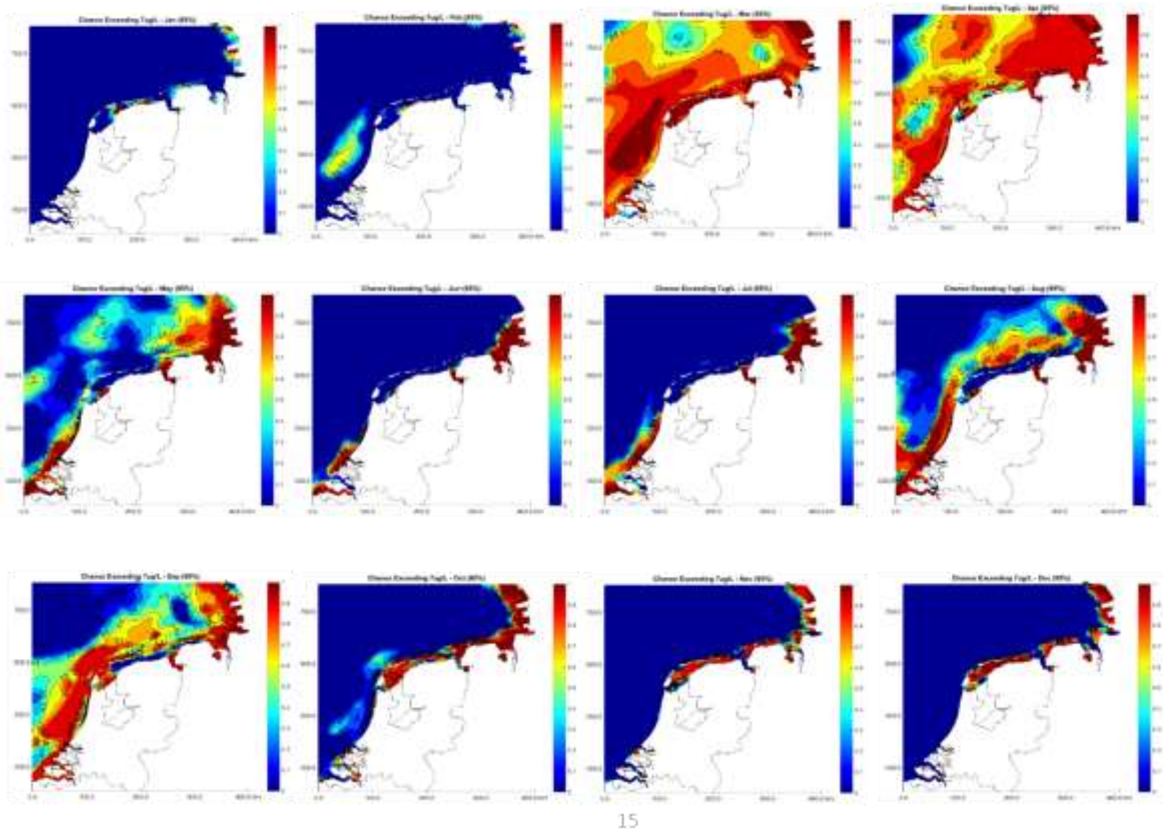

Figure 77 Time dependent probability of exceeding of 7mg/l (95 percentile) starting from January (upper right corner) to Dec (lower left corner)

As observed it is the months of the bloom that is having the highest probability, while along the coast there are also high probability of exceeding a certain threshold (7mg/l) as well.

Wadden Sea in the light of climate change

- Challenges and adaptations to what climate change brings: what kind of sedimentary effects will influence the Wadden Sea developments in different scenarios of waves, wind, sea-level rise, runoff? Will the intertidal flats keep up or not?
- Not keeping up by sedimentation to SLR of the Wadden Sea is deemed important but not yet urgent as a question. Main interest and focus is on ebb-tidal delta's of which the decrease in volume is deemed both threatening to the barrier islands (in terms of shelter and sand deliverance) and the backbarrier tidal flats (in terms of shelter and sand availability).

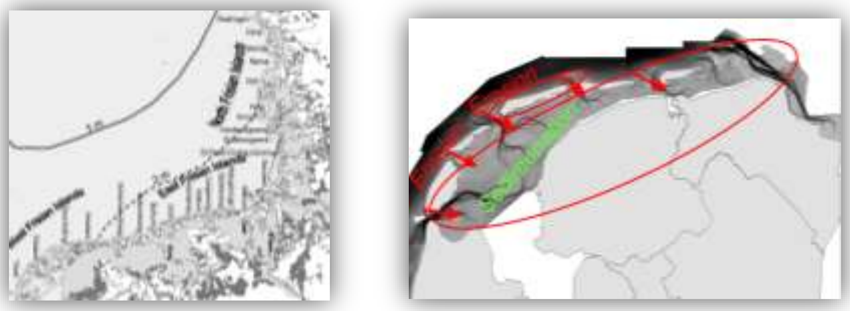

Figure 78 Effect of climate change on the erosion & sedimentation patterns in the wadden Sea

- Not keeping up by sedimentation to SLR of the Wadden Sea is deemed important but not yet urgent as a question. Main interest and focus is on ebb-tidal delta's of which the decrease in volume is deemed both threatening to the barrier islands (in terms of shelter and sand deliverance) and the backbarrier tidal flats (in terms of shelter and sand availability).
- Inter-comparison will deliver more realistic models. It is remarked that there is a clear tension between what policy makers and managers think what is needed and scientific interests
- Modeling and geological research indicates that the breakpoint is 30 to 80 cm/century depending on the size of the basin.

Expected impact would then include the following as shown in the figure.

- Channel shift and (morphological) dredging
- Channels as sediment source due to increasing tidal amplitude
- Channel-shoal interactions
- Channels as a pathway for waves (ebb-tidal delta retreat)

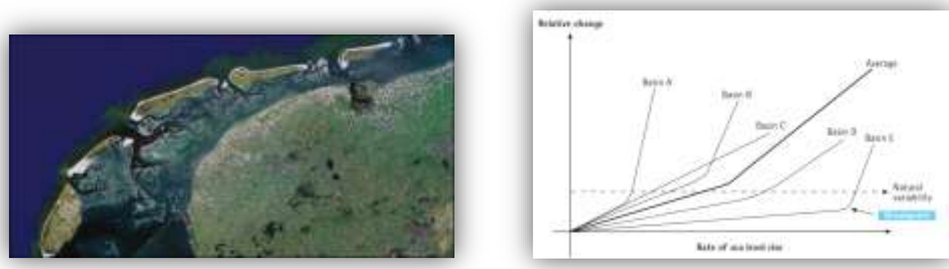

Figure 79 Expected response to accelerated sea level rise

9.4 Web based territorial management system

In the last reporting period activities have been finalized regarding the development of the WebGIS platform of the project ECOSTRESS. The whole structure can be divided into two main sides:

client side
server side

The first one is composed by different javascript framework: Ext-JS, OpenLayers and GeoExt these components allow the access to the functionalities of the WebGIS, simply using a web browser. The client side has been developed in a Java environment, Tomcat server is necessary in order to host the application and the server for the maps management (GeoServer). All the numerical data is stored in a PostgreSQL database with the support of PostGIS extension, for the management of geographical functionalities. Since all the platform is web-based, is possible to access to the WebGIS, simply opening a browser (Mozilla Firefox browser is preferred in order to avoid any compatibility problem) and typing the address: http://egeos-test.eucentre.it/ecostress/web/home as a common website.

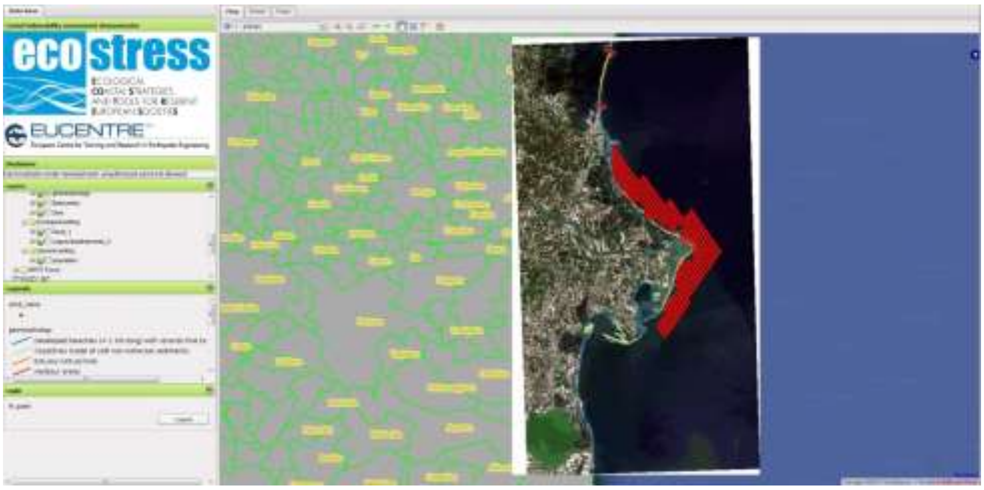

Figure 80. WebGIS platform of the project ECOSTRESS

Once logged in, the user is able to load and visualize several raster maps or vector shapefiles, simply selecting them in the Layers panel on the left side.

Figure 81. Layers panel on the left side

There are two tabs named “Invest” and “Fuzzy” that allows the user to select functions and related parameters, in order to obtain new output maps.

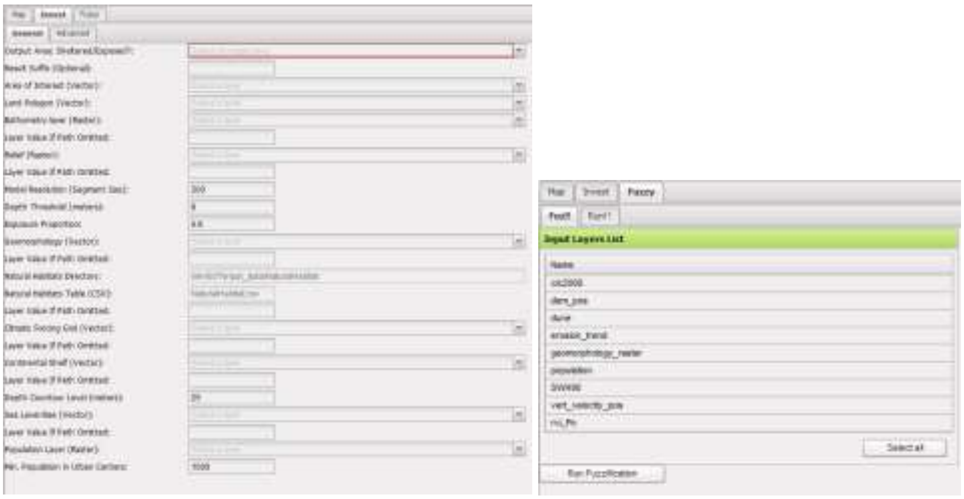

Figure 82. "Invest" and "Fuzzy" panels

In order to access to the WebGIS, is necessary a PC with internet connection and a web Browser, preferable Mozilla Firefox. The WebGIS consists of a viewer that the general public and prevention/awareness official can handle without any GIS training: **http://egeos-test.eucentre.it/ecostress/web/home**

user name: guest

psw: guest

9.5 Guidelines for Financial Management Policies

The **financial management of flood risks** requires a holistic approach that considers the potential contributions of prevention, preparedness and financial protection. This requires careful consideration of the relative efficiency and effectiveness of public investments in structural and non-structural flood mitigation, early warning and emergency preparedness and support for financial protection against both private and public flood losses.

ECOSTRESS (Task E) presents these **guidelines** towards an improved collaborative risk governance framework for coastal flooding risk in Europe. This framework shall comprise governmental actors al supranational (i.e., EU), national, and local levels, but also private sector participants, including the private insurance, reinsurance and financial markets players.

Focusing on legal and policy approaches to the financial management of coastal flooding risk in Europe, ECOSTRESS explored alternative forms of collaborative efforts involving public and private sector participants. A number of countries have established innovative approaches to addressing these challenges by investing in flood risk mitigation at the community and household level, improving the quality and availability of flood risk maps, and enhancing public awareness of the risk of flooding and the need for financial protection. To complement these direct investments, many countries are also examining ways in which communities and households can be encouraged to protect themselves against flood risk, including by ensuring that public sector risk reduction investments and insurance and financial assistance arrangements do not discourage private initiative.

As emphasized by the G20/OECD Methodological Framework for Disaster Risk Assessment and Risk Financing (2012), a **comprehensive and integrated approach is required for financial strategies**, following an assessment of the availability, adequacy and efficiency of different types of financial tools available to the population and within the economy, as well as of their relative costs and benefits, in comparison with possible further risk reduction to complement or substitute for these tools.

Private insurance is one of the main risk financing tools for businesses and households to strengthen their financial resilience against disasters, complementing investments in risk reduction. Risk transfer instruments such as insurance allow for the shifting of a portion of disaster risks to others, in exchange for a price, and for the spreading of such risks.

The financial sector and, in particular, the insurance sector can be called upon to play important roles in this field, depending on the stage of development of these markets, the robustness of their infrastructures, the level of capitalization, solvency and soundness of insurance undertakings, as well as the financial depth of the economy.

At present **not only traditional insurance and reinsurance contracts** can be considered as part of risk financing solutions for coastal flooding risk in Europe, but also **parametric insurance** and **innovative financial products developed in the capital markets**, which may be accessed by large corporations, insurers, and governments.

The availability and cost of these instruments is influenced by **uncertainties characterizing the risk assessment process**: supplying reliable and consistent data on hazards, exposures and vulnerabilities, or at least facilitating their collection, recording, storage and dissemination can greatly enhance the capacity of markets.

The size of potential losses from a flood event, **the ability to establish a diverse pool of insured risks** as well as the level of uncertainty in estimating potential losses, particularly in the context of a changing climate, constitute relevant impediments to the insurability of flood risk in many countries.

Several states in Europe continue to rely on a **purely *ex post* approach** to the funding of flood losses. This approach entails **several limitations**: in many cases it proves to be cost ineffective and untargeted; delivery of compensation is often too slow and, if the hazard risk exposures are significant, the fiscal burden may be unsustainable for the public authorities in the long run.

Moreover, *ex post* allocation of public funds to meet critical needs may divert resources from other projects, and critical decisions have to be made under political pressure, not to mention the likelihood of inequalities in treatment and possible social discontent.

The key challenge is to take a **long-term view and promote the adoption of appropriate protective measures** before flooding occurs, in partnership with the private sector and all relevant stakeholders. In this perspective, risk financing and risk transfer tools, such as insurance, reinsurance and catastrophe-linked securities, can play a fundamental role in reducing the negative economic impacts of coastal flooding.

Fiscal rules may also be reoriented towards the above mentioned policy goals. Taxes, in fact, are the major tool by which the governments direct and influence the reallocation of resources necessary to achieve a nation's economic and social objectives.

Following the **assessment of financial vulnerabilities and possible financing gaps**, targeted policies and measures can be established to support the development and sustainability of private sector solutions for flood risk financing and to promote widespread access to such markets.

These measures may include:

a) Strengthening the legislative and regulatory framework for the financial sector (especially the insurance sector) or amending this framework to facilitate and encourage the development of specific instruments or the coverage of specific risks (e.g., enacting special regulatory regimes for parametric products or cat-linked securities, introducing tax incentives for private insurance coverage);
b) Establishing a financial scheme by industry, government or both, including by means of **Public-Private Partnerships (PPP)**.

Institutional arrangements - or the frameworks, systems, organisations, instruments, rules, and processes established to promote the financial management of coastal flooding risk - may be necessary to support private-sector development of products designed to provide needed financial tools for identified vulnerable populations or sectors of the economy. Institutional arrangements may also facilitate the coordination between public and private sector efforts in various fields, such as data collection, risk modelling and assessment, risk reduction and risk awareness. **PPP** also allow for risk sharing among governmental institutions, private sector (reinsurance industry) and civil society. These arrangements may be complemented by special subsidies or tax incentives.

A crucial element of effective compensation schemes is that such schemes provide **fair, timely and efficient disbursement of funds for flood relief**, recovery and reconstruction. Not only must financial resources for emergency response and reconstruction efforts be available, they must also be deployed in a well-timed and targeted manner.

Clear and streamlined legal and administrative procedures, including *ex ante* specific procedures for the disbursement of public and/or international donors' funds in the aftermath of an event, are key for ensuring a fair and efficient distribution of funds and promoting transparency and accountability at the public sector level.

In conclusion, the following policy objectives shall be considered in the development of financial management strategies aimed at coping with coastal flooding risk:

- Ensuring that *financial vulnerabilities within the economy are addressed* through *adequate and efficient compensation mechanisms*, whether public or private
- Ensuring *proper fiscal management* of flood risks by anticipating potential budgetary impacts and planning ahead to ensure adequate financial capacity and rapid release of funds
- Establishing *clear rules regarding post-event financial compensation* to enable rapid compensation, demonstrating solidarity and ensuring sound incentives
- Ensuring the *soundness and resilience of the financial sector* with respect to flood risk, including through proper regulation, business continuity planning, and stress testing
- Ensuring the *optimal allocation of resources for flood risk management*, including assessment of the cost-effectiveness of major public investments in structural and non-structural flood mitigation measures, including ecosystem-based approaches

Legal, fiscal and institutional approaches in this field should seek to ensure the adequacy of financial resources to meet the costs of disaster events, with the overall goal of strengthening financial resilience within the population and economy.

10 Publicity

Working group at pilot site

The working group meeting has been split in 2 parts. A first meeting was organized in Paris (France) by AFPCN ("French Stakeholders Workshop", 06.11.2015, http://ecostress.eu/pilot-areas/french-stakeholders-workshop/), gathering stakeholders (public local and national authorities; researchers; risk managers) to present their own experience with Copernicus technology and management of coastal flooding and to give feedback on ECOSTRESS tools.

The French stakeholders' workshop "Coastal inundation, realty but not fatality: the challenges of innovating adaptation" has been held in Paris on November 6th 2015 in order to present ECOSTRESS results tested on the Wadden seas within a larger workshop gathering French stakeholders around the problematic of coastal zone governance.

The workshop was aimed at publicizing the interest of multi-criteria analysis for decision making. Together with comparison of project this proved useful for local authorities having to make strategic choices, primarily at the scale of the town and the territory around, including the objective of building back better.
The program was the following:

- 9h30-10h30 : Objectifs de la journée et introduction à ECOSTRESS et COPERNICUS
- 09h30-09h40: objectifs de la journée, François GERARD, AFPCN.
- 09h40-10h00: objectifs et principaux résultats du projet ECOSTRESS, Chiara CASAROTTI, EUCENTRE.
- 10h00-10h20: Utilisation des informations du volet océanique de COPERNICUS dans les études en zone côtière, Sylvain CAILLEAU, Mercator-Océan.
- 10h30-12h30: Les défis de la zone côtière, le cas français
- 10h30-10h50: Point de vue d'un Maire d'une ville côtière sur la vulnérabilité et la prévention (TBC).
- 10h50-11h30: Le cas de deux zones côtières : Baie de Bourgneuf (Atlantique) et Baie de Somme (Manche), Jean MAGNE, Communauté de communes Océan Marais de Mont et Gaëlle SCHAUNER, Syndicat mixte Baie de Somme Grand Littoral Picard.
- 11h30-11h45: Le cadre réglementaire français, incluant les partenariats publics privés, Boris LECLERC, DGPR/Ministère de l'Ecologie.

- 11h45-12h00: Gouvernance et gestion de la vulnérabilité en Europe, Alberto MONTI, IUSS Pavie, EUCENTRE.
- 14h00-16h00 : Ce qu'ECOSTRESS peut apporter aux études de vulnérabilité des zones côtières.
- 14h00-14h20: L'outil d'auto-évaluation de la vulnérabilité sociale, Daniele DEL BIANCO, ISIG.
- 14h20-14h40: L'outil d'évaluation des dommages, Mario MARTINA, IUSS Pavie, EUCENTRE.
- 14h40-15h00: L'outil d'évaluation de la vulnérabilité par approche écosystémique, Emiliana VALENTINI, EUCENTRE.
- 15h00-15h20: L'outil intégré d'évaluation de la vulnérabilité disponible sur internet, Ghada EL SERAFY, DELTARES.
- 15h40-16h40: Table ronde et débat – Quel avenir pour les outils intégrés d'étude de la vulnérabilité des zones côtières? Quel rôle pour les partenariats publics privés? Avec la participation, entre autres, de l'équipe du projet Ecostress, d'Arnaud GUEGUEN, GIP Littoral Aquitain, de Roland NUSSBAUM, Mission Risques Naturels, et de Carlos OLIVEROS, BRGM.
- 16h40-17h00: Conclusion

Attendees included stakeholdersactive in coastal areas prevention policies and project: local decision makers like mayors or local State administration representatives, representatives of the technical services supporting the decision makers, experts in the use of data and information useful for developing decision support tools.
In particular, attending Institutions were: CGAAER, AFPCN, Association pour la Défense des Digues, BRGM, CCR, CEPRI, CGEDD / Ministère de l'Ecologie, Communauté d'agglomération havraise, Communauté de communes Océan Marais de Monts, Deltares, DGALN / Ministère de l'Ecologie, DGPR / Ministère de l'Ecologie, DGSCGC / Ministère de l'Intérieur, e-relation Territoriale, EIVP Paris, EUCENTRE, GIP Littoral, Aquitain, ISIG, IUSS Pavie, EUCENTRE, LittOcean, Mercator Océan, Ministère de la recherche, MRN, Syndicat mixte Baie de Somme Grand Littoral Picard, Université Paris Diderot.

A second working group meeting was organized by ISIG in Gorizia (Italy) during the final event (11.12.2015, http://ecostress.eu/pilot-areas/ecostress-adriatic-workshop/), gathering all stakeholders involved in the pilot case study of northern Adriatic, thus targeting more specifically local administrators and civil protection operators. The experience of ECOSTRESS as well as of the French stakeholders' workshop were presented to the public (local and regional authorities, Civil Protection operators, etc.)

The Final Conference of the ECOSTRESS Project was held in Gorizia (IT) on the 11th of December 2015. The event gathered all project partners as well as 60 local (i.e. Friuli Venezia Gilua Region, Italy), national (Italy) and international stakeholders (Slovenia, Croatia), involved in natural risk prevention (e.g. Local Authorities and Civil Protection representatives, volunteers associations, etc.). The event was structured as follows:

SESSION 1: Tools for risk evaluation and mitigation – European experiences

- Towards a measurement of the protective role of ecosystem services - EUCENTRE
- The Damage Tool as a Decision Support System - EUCENTRE
- Legal frameworks for risk mitigation - AFPCN
- PPPs: a new governance approach - AFPCN
- Self-assessment tool: measuring vulnerability as means of capacity building - ISIG
- MAppERS project experience in CSOs involvement in risk mitigation - CNR IRPI

SESSION 2: Local stakeholders' experiences Risk management: a cross border perspective

- The involvement of Youth Volunteering in Gorizia - Municipality of Gorizia
- Managing risk in a touristic area - Municipality of Lignano Sabbiadoro
- Protected areas management and flood risk mitigation - Municipality of Staranzano
- A Civil Protection Experience - Regional Friuli Venezia Giulia Civil Protection
- The role of volunteers in risk mitigation - Italian Civil Protection

SESSION 3: Roundtable discussion, facilitated by ISIG and summarising all relevant insights from the previous sessions. Participants intervened with feedbacks on project tools, relevance of research in their field of work/competence, potentials for future developments of the project idea and results.

The event represented a great opportunity for end-users feedback on the project outputs, as well as for establishing new contacts for further development and exploitation of the project results. The most relevant contacts were established with the MAppERS EU PROJECT Consortium (wwww.mappers.eu) and the Italian and Regional Civil Protection services.

The project results and final event have been promoted to the large audience by means of:

- The project official communication channels and instruments (i.e. website, socials);
- The partners' official communication channels and instruments (i.e. websites and socials);
- The press releases published in the local newspaper (Il Piccolo, 13.12.2015)

All materials and videos (as well as audio-recording in English) are available on project's website: http://ecostress.eu/pilot-areas/ecostress-adriatic-workshop/

D.H.5 – Training material and video tutorials online

Training materials produced in Task D were made available online on ECOSTRESS website ‘Media & Tools’ Section.

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