Methods for assessing coastal vulnerability to climate change

Dr. Silvia Torresan
CMCC

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Lecture OUTLINE:

- Overview of climate change impacts in coastal zones;
- Coastal Vulnerability to climate change in Europe;
- Assessment methods:

  - Indicator-based approaches;

  - Index-based methods.

Methods for assessing coastal vulnerability to climate change

ETC CCA Technical Paper 1/2011

Emiliano Ramieri, Andrew Hartley, Andrea Barbanti, Filipe Duarte Santos, Ana Gomes, Mikael Hilden, Pasi Laihonen, Natasha Marinova, Monia Santini

European Environment Agency

European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation

Climate change and coastal zones

COASTAL ZONES are complex systems of strategic importance in different sectors:

- they are **home** to a large percentage of **citizens** worldwide;
- they are a major source of **food** and **raw materials;**
- they are a crucial link for **transport** and **trade;**
- they include valuable **habitats** and **natural resources;**
- they are favoured destination for **leisure time** and **recreational activities.**

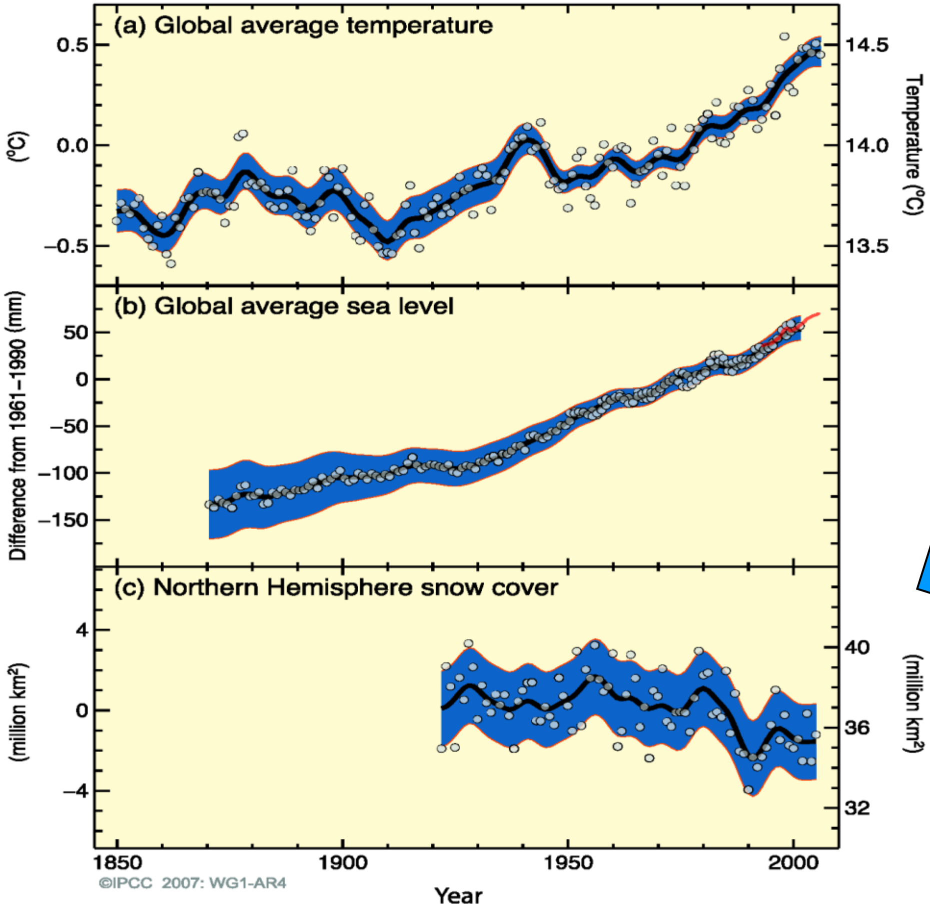
In the last decades **urbanization**, **agriculture**, **industry**, **energy production,** **transportation** and **tourism** posed **increasing pressures** on coastal areas

habitat destruction, **water** and **soil contamination,** coastal **erosion** and **resource depletion**

the depletion of the limited resources of coastal zones and the limited physical space is leading to **increasing conflicts of interests** among different **stakeholders** (e.g. aquaculture and tourism)

importance of ICZM

Coastal systems are projected to be increasingly at risk due to global climate change trough the 21th century and beyond (IPCC, 2007 and 2014).



BIOGEOPHYSICAL IMPACTS:

- Sea-level rise.
- Increasing flood-frequency probabilities.
- Erosion.
- Inundation.
- Rising water tables.
- Saltwater intrusion.
- Negative consequences for biodiversity and ecosystems.
- ….

SOCIO-ECONOMIC IMPACTS:

- Direct loss of economic, cultural and subsistence values through loss of land, infrastructure and coastal habitats.
- Increased flood risk of people, land and infrastructure.
- Damage to coastal protection works and other infrastructure.
- Impacts related to changes in water management, salinity and biological activity.
- Impacts on agriculture and aquaculture…..

Bio-geophysical impacts including relevant interacting climate and non-climate drivers.

Bio-geophysical effect		Other relevant factors: Climate	Other relevant factors: Non-climate
Permanent inundation		Sea level rise	Vertical land movement (uplift and subsidence), land use and land planning
Flooding and storm damage	Surge (open coast)	Wave and storm climate, morphological change, sediment supply	Sediment supply, flood management, morphological change, land claim
	Backwater effect (river)	Run-off	Catchment management and land use
Wetland loss (and change)		CO_2 fertilisation, sediment supply	Sediment supply, migration space, direct destruction
Erosion	Direct effect (open coast)	Sediment supply, wave and storm climate	Sediment supply
	Indirect effect (near inlets)		
Saltwater Intrusion	Surface waters	Run-off	Catchment management and land use
	Groundwater	Rainfall	Land use, aquifer use
Rising water tables/impeded drainage		Rainfall	Land use, aquifer use

(source: modified from Nicholls and Klein, 2005)

Climate change impacts result from the interaction between climate and **non-climate drivers** and have significant regional variations (Nicholls et al., 2008).

A **strategic** approach is needed to ensure that **timely** and **effective adaptation measures** are taken, ensuring **coherency** across **different sectors** and **levels of governance.**

The **challenge for policy-makers** is to **understand climate change impacts** and to **develop** and **implement policies** to ensure an **optimal level** of **adaptation.**

The aims for the **scientific community** are to **improve** the **knowledge** on **climate impact** and **vulnerability** and to **provide methodologies** and **tools** in order to guide the development of appropriate **adaptation measures.**

EC, 2009.

Coastal Vulnerability to climate change in Europe

A significant and increasing share of the EU population lives in coastal areas:

- Approximately 50% of the EU population lives 50 km or less from the coast (ESTAT, 2009).

- 19% of the EU population (86 million people) lives within a 10 km coastal strip (EEA, 2006).

- Approximately 140,000 km^2 of EU land is currently within 1 m of mean sea level.

- growing demands on coastal resources and increasing people's exposure to coastal hazards;

- the assessment of coastal vulnerability to climate change is therefore a key issue at the European level.

Ramieri et al. (2011)

Methodological aspects of coastal vulnerability assessment:

- Coastal vulnerability assessment initially needs the clear definition of **policy** and **decision making objectives** and related questions;
- **Different tools** may be indicated to approach coastal vulnerability assessment at **different spatial** and **temporal scales**, in different regions and for different policy purposes;
- A **multi-hazard approach** is required, evaluating impacts induced by various drivers, such as changes in sea-level, storms, salinity, waves, temperature and sedimentation patterns;
- Vulnerability assessment should consider also the analysis of **current** and **future adaptation strategies** and measures, significantly influencing coastal vulnerability;
- **Data availability** is still a **key issue**: globally available data (e.g. sea level rise projections or digital elevation models) need to be corrected or detailed to address regional specificities.

Ramieri et al. (2011)

Climate change vulnerability and adaptation at the regional and sub-regional level.

Number	European marine regions and sub-regions
1	Baltic Sea
2	North-east Atlantic Ocean: Greater North Sea
3	North-east Atlantic Ocean: Celtic Seas
4	North-east Atlantic Ocean: Bay of Biscay and Iberian Coast
5	North-east Atlantic Ocean: Macaronesian biogeographic region
6	Mediterranean Sea: Western Mediterranean Sea
7	Mediterranean Sea: Adriatic Sea, Ionian Sea and Central Mediterranean Sea
8	Mediterranean: Aegean-Levantine Sea (Eastern Mediterranean)
9	Black Sea

Location of European Marine Regions and sub-regions as defined by the Marine Strategy Framework Directive 2008/56/EC.

Ramieri et al. (2011)

Main climate change hazards and vulnerabilities in different European Marine Regions and sub-regions.

European marine sub-regions	Main hazards and vulnerabilities
Baltic Sea (1)	Storms surges River flooding Salt water intrusion Loss of marine habitats, ecosystems and biodiversity Socio-economic vulnerabilities (fisheries, tourism)
North-east Atlantic Ocean Greater North Sea (2)	Storm surges Coastal flooding Coastal erosion Altered salinity Salt water intrusion Loss of marine habitats, ecosystems and biodiversity Loss of property and infrastructure
North-east Atlantic Ocean Celtic Seas (3)	Coastal flooding Coastal erosion Loss of marine habitats, ecosystems and biodiversity Decrease of salmon production Loss of property and infrastructure
North-east Atlantic Ocean Bay of Biscay and Iberian Coast (4)	Coastal flooding Coastal erosion Loss of marine habitats, ecosystems and biodiversity
North-east Atlantic Ocean: Macaronesian bio-geographic region (5)	Salt water intrusion Loss of marine habitats, ecosystems and biodiversity Socio-economic vulnerabilities (fisheries, aquaculture, tourism, health)

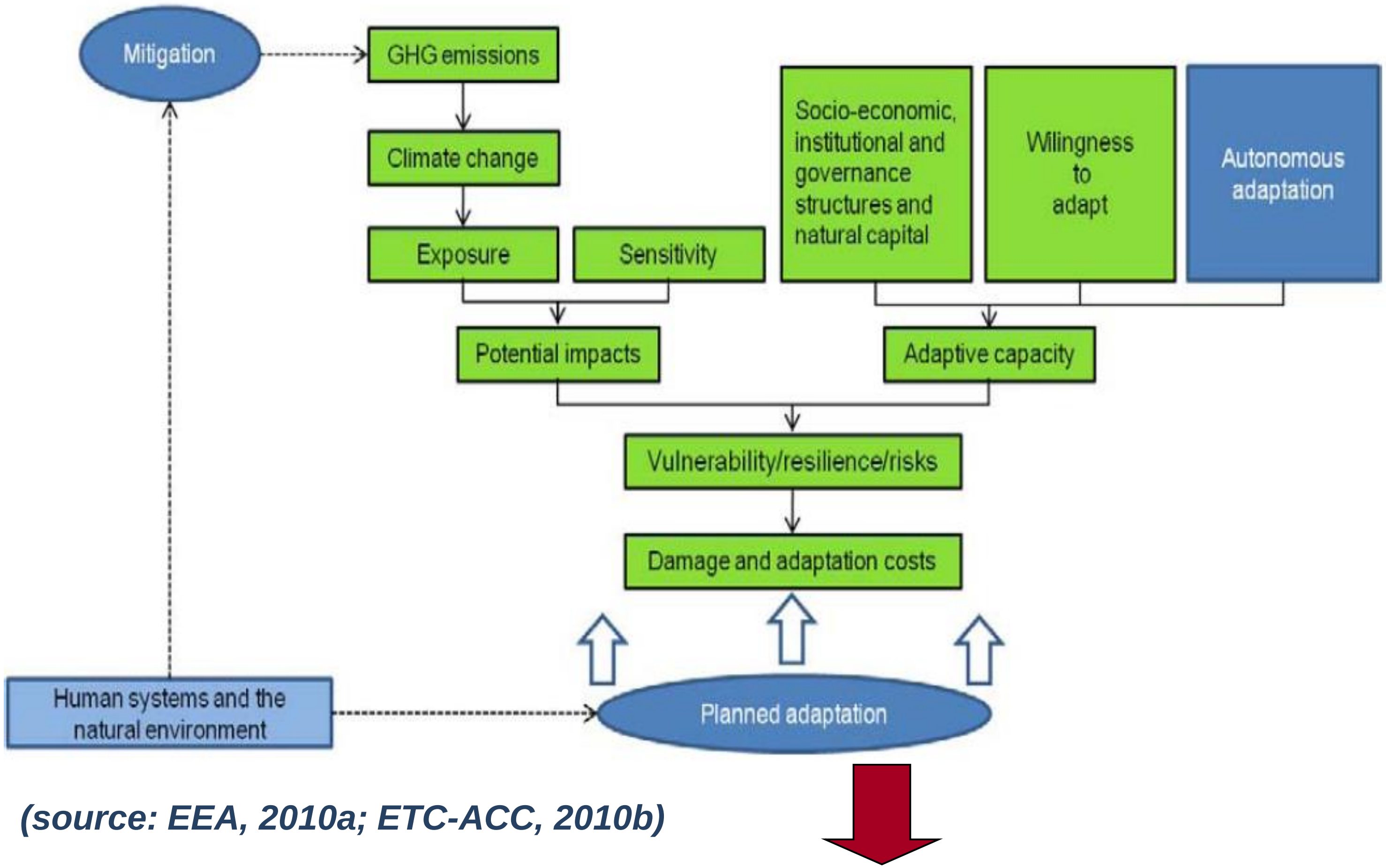
Ramieri et al. (2011)

Main climate change hazards and vulnerabilities in different European Marine Regions and sub-regions

European marine sub-regions	Main hazards and vulnerabilities
Mediterranean Sea: Western Mediterranean Sea (6)	Coastal flooding Coastal erosion Altered salinity Salt water intrusion Freshwater scarcity Loss of marine habitats, ecosystems and biodiversity Socio-economic vulnerabilities (fisheries, tourism, health)
Mediterranean Sea: Adriatic Sea, Ionian Sea and Central Mediterranean Sea (7)	Coastal flooding Coastal erosion Salt water intrusion Loss of marine habitats, ecosystems and biodiversity Socio-economic vulnerabilities (heritage, tourism, health)
Mediterranean Sea: Aegean - Levantine Sea (8)	Coastal erosion Coastal flooding Salt water intrusion Introduction of alien species Socio-economic vulnerabilities (agriculture, tourism)
Black Sea (9)	Coastal flooding Coastal erosion Loss of marine habitats, ecosystems and biodiversity Socio-economic vulnerabilities (fisheries)

Ramieri et al. (2011)

Conceptual framework for climate change impacts, vulnerability, disaster risks and adaptation options



(source: EEA, 2010a; ETC-ACC, 2010b)

The **IPCC definitions** of vulnerability to climate change, and its related components (exposure, sensitivity, and adaptive capacity) provide a suitable starting position to explore possibilities for vulnerability assessment but they **are not operational.**

Ramieri et al. (2011)

Methodological aspects of coastal vulnerability assessment:

- The **operational definition** of the vulnerability concept is related to the specific issue and/or context (e.g. the coastal area) addressed by the analysis.

- **Key steps** in the operationalization phase include:

1. Identification of application context: objectives and scenarios.
2. Data availability.
3. Indicator selection.
4. Normalization.
5. Weighting.
6. Aggregation.
7. Uncertainty.

(adapted from Balbi et al., 2012).

Criteria for evaluating methods for coastal vulnerability assessment at the European scale

- **Possibility to address different temporal scenarios.**

  e.g. 2050 and 2100.
- **Relevance for assessing vulnerability related to one or more key climate change impacts.**
- e.g. permanent inundation, change in the frequency and intensity of costal flooding; coastal erosion, saltwater intrusion in rivers and groundwater, impacts on wetlands.
- **Applicability to different typologies of coastal systems**.

  e.g. wetlands, beaches, rocky coasts, and estuaries.
- **Possibility to assess social, economic and ecological risks of climate change in coastal regions.**

  e.g. systems at risk include population, built infrastructure, and economic activities but also natural ecosystems.
- **Consideration of adaptation measures.**

  e.g. already implemented measures as well as scenarios of future adaptation.

Ramieri et al. (2011)

Criteria for evaluating methods for coastal vulnerability assessment at the European scale

- **Possibility to vary assumptions and scenarios.**

  e.g. maps and/or indicators showing how the vulnerability varies in relation to sea level rise scenarios, time horizons, socio-economic dynamic scenarios, adaptation/no adaptation options.

- **Consideration of regional climate change scenarios.**

  e.g. consider regional information about sea level rise, subsidence rates, etc., rather than global or European averages.

- **Assessment of uncertainties.**

  e.g. related to climate change scenarios, current environmental and socioeconomic conditions

- **Availability of underlying data and/or models.**

  e.g. computer models should be publicly available or available at a reasonable cost.

Ramieri et al. (2011)

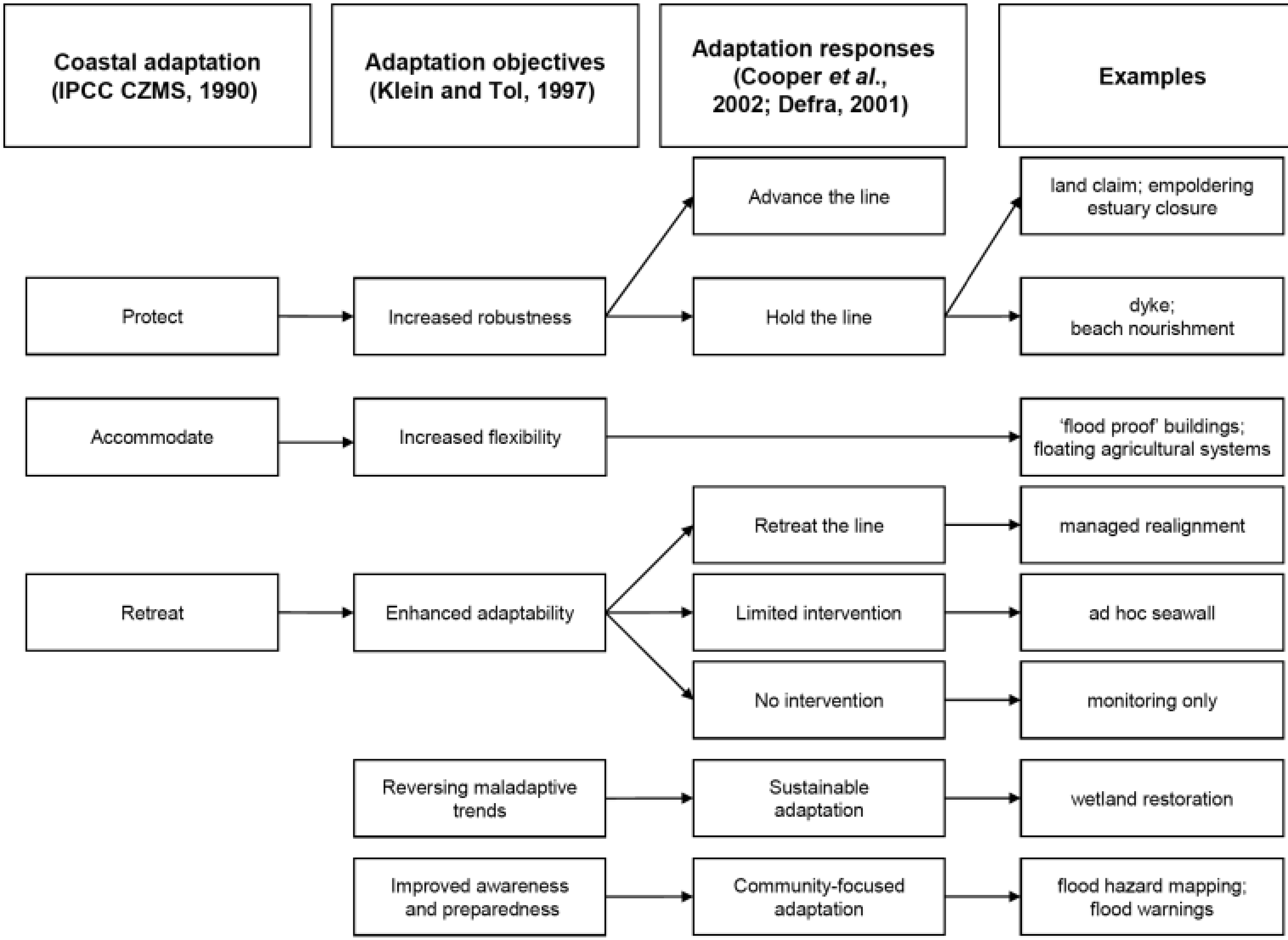
The main purpose of vulnerability assessment is to provide information to guide the process of adaptation.

Coastal adaptation is a complex and iterative process, three basic adaptation strategies are often used:

- **Protect** - to reduce the risk of the event by decreasing the probability of its occurrence;
- **Accommodate** - to increase society's ability to cope with the effects of the event;
- **Retreat** - to reduce the risk of the event by limiting its potential effects.

Ramieri et al. (2011)

Coastal adaptation



Evolution of planned adaptation practices in coastal zones (source: Nicholls et al., 2007).

Ramieri et al. (2011)

Assessment methods:

INCREASING COMPLEXITY

- Indicator-based approaches;
- Index-based methods;
- Software based on GIS applications (e.g. decision support systems, DSSs);
- Methods based on dynamic computer models.

Ramieri et al. (2011)

* Indicator and indices *

An indicator is a **value** that represents a **phenomenon** that cannot be directly measured and may aggregate different types of data.

An Index is a set of aggregated or weighted **parameters or indicators.**

A measurement of a specific variable is the basis for the characterization of an indicator, which in turn can be the basis for the construction of an index.

* Indicator and indices *

Three functions:

- Reduce the **number of parameters** that normally would be required to represent a situation;
- Simplify the **process of results** communication to the users;
- Quantify **abstract concepts** such as ecosystem health or biotic integrity that are not measurable.

In the specific context of climate change:

- Monitoring **climate variations;**
- Characterising **spatial and temporal distributions** of stressors and drivers;
- Identifying **strategic vulnerabilities**.

Indicators and indices

Climate change indicators should consider specific attributes:

Routinely collected: indicators must be based on routinely collected, clearly defined, verifiable and scientifically acceptable data.

Representative at national scale: as far as possible, it should be possible to make valid comparisons between countries using the indicators selected;

Methodologically well founded: the methodology should be clear, well defined and relatively simple. Indicators should be measurable in an accurate and affordable way, and constitute part of a sustainable monitoring system. Data should be collected using standard methods.

Show cause-effect relationship: information on cause-effect relationships should be achievable and quantifiable in order to link pressures, state and response indicators.

EEA, 2012

Indicators and indices

Climate change related indicators should consider specific attributes:

Sensible to changes: indicators should show trends and be able to detect changes in systems in timeframes and on scales that are relevant to the decision makers.

Policy Relevant: indicators should send a clear message and provide information at a level appropriate for policy and management decision-making;

Broadly accepted and intelligible: the power of an indicator depends on its broad acceptance and on its easy communication.

EEA, 2012

Need to identify a broadly accepted definition of indicators and indexes, also considering how they relate to the concepts of vulnerability and risk.

Indicator-based approaches:

- Indicator-based approaches, express the vulnerability of the coast by a set of **independent elements** (i.e. the indicators) that characterize key **coastal issues**.

- These approaches allow the evaluation of **different aspects related to coastal vulnerability** (e.g. coastal drivers, pressures, state, impacts, responses, exposure, sensitivity, risk and damage) within a consistent assessment context.

- These indicators are in some cases combined into a final **summary indicator**.

Eurosion project: http://www.eurosion.org/index.html

13 indicators based on the DPSIR approach (EEA, 1995) to support the assessment of **coastal erosion risk** throughout Europe:

9 sensitivity indicators (referred to pressure and state indicators):

1) Relative sea level rise;
2) Shoreline evolution trend status;
3) Shoreline changes from stability to erosion or accretion;
4) Highest water level;
5) Coastal urbanisation (in the 10 km land strip);
6) Reduction of river sediment supply;
7) Geological coastal type;
8) Elevation;
9) Engineered frontage (including protection structure).

4 impact indicators:

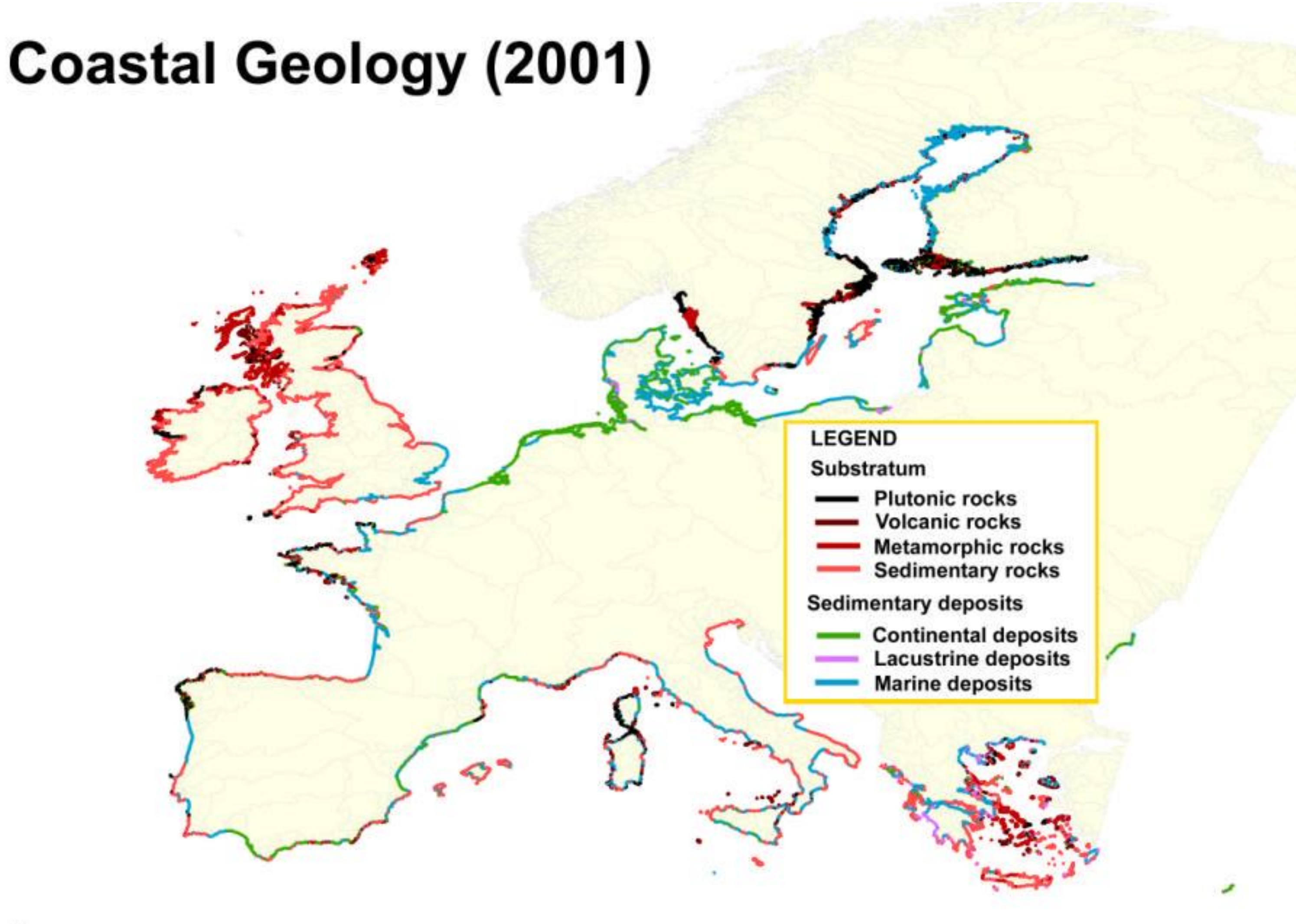
10) Population living within the RICE (Radius of influence of coastal erosion and flooding);
11) Coastal urbanisation (in the 10 km land strip);
12) Urbanised and industrial areas within the RICE;
13) Areas of high ecological value within the RICE.

Eurosion project: http://www.eurosion.org/index.html

Each indicator was evaluated according to a **semi-quantitative score** that represents low, medium and high level of concern about the **expected future risk or impact erosion** (Eurosion, 2004).

The **evaluation** of the identified indicators was supported by the **Eurosion database**, structured in various **spatial data layers** covering the **European scale**.

Eurosion project: http://www.eurosion.org/index.html



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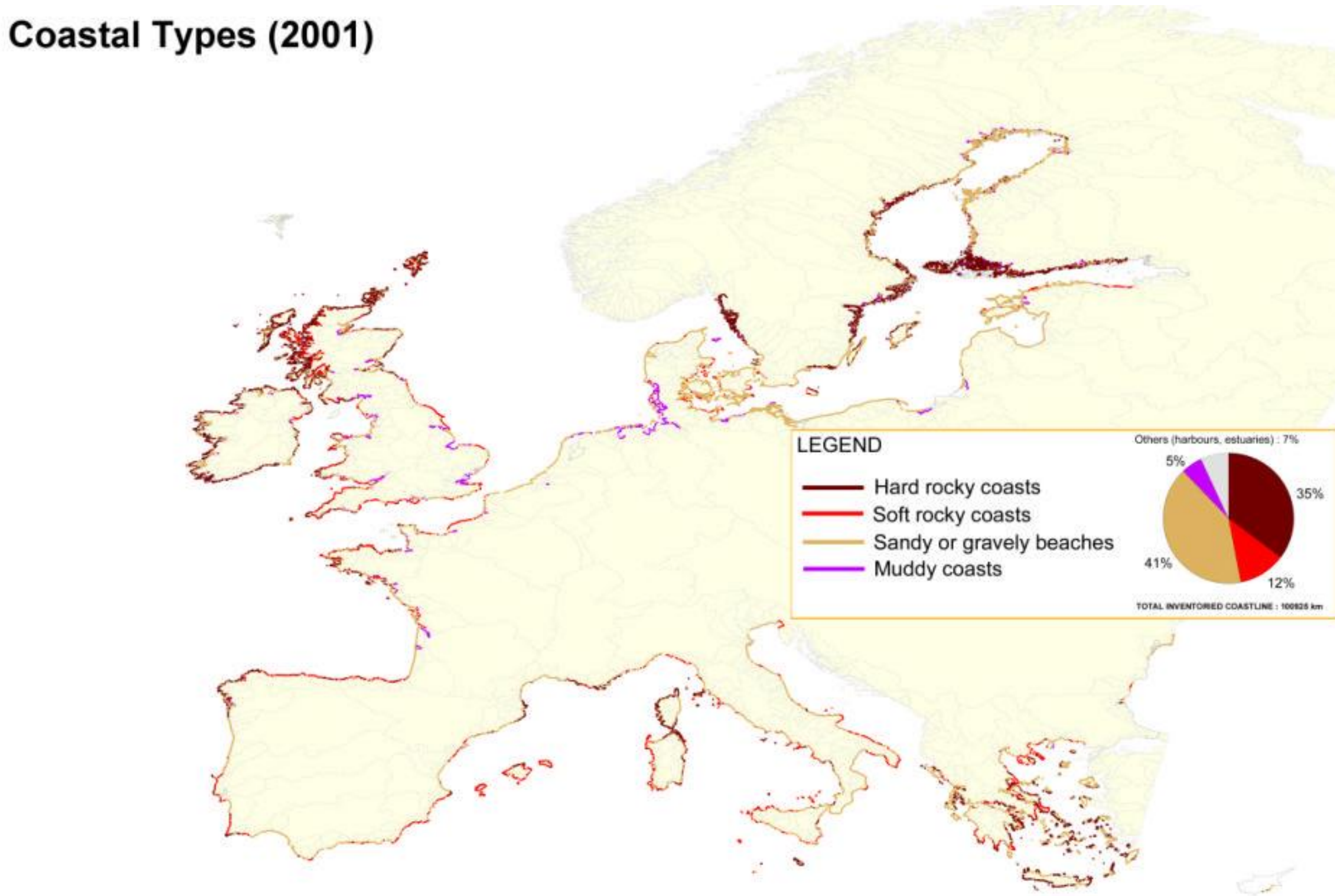

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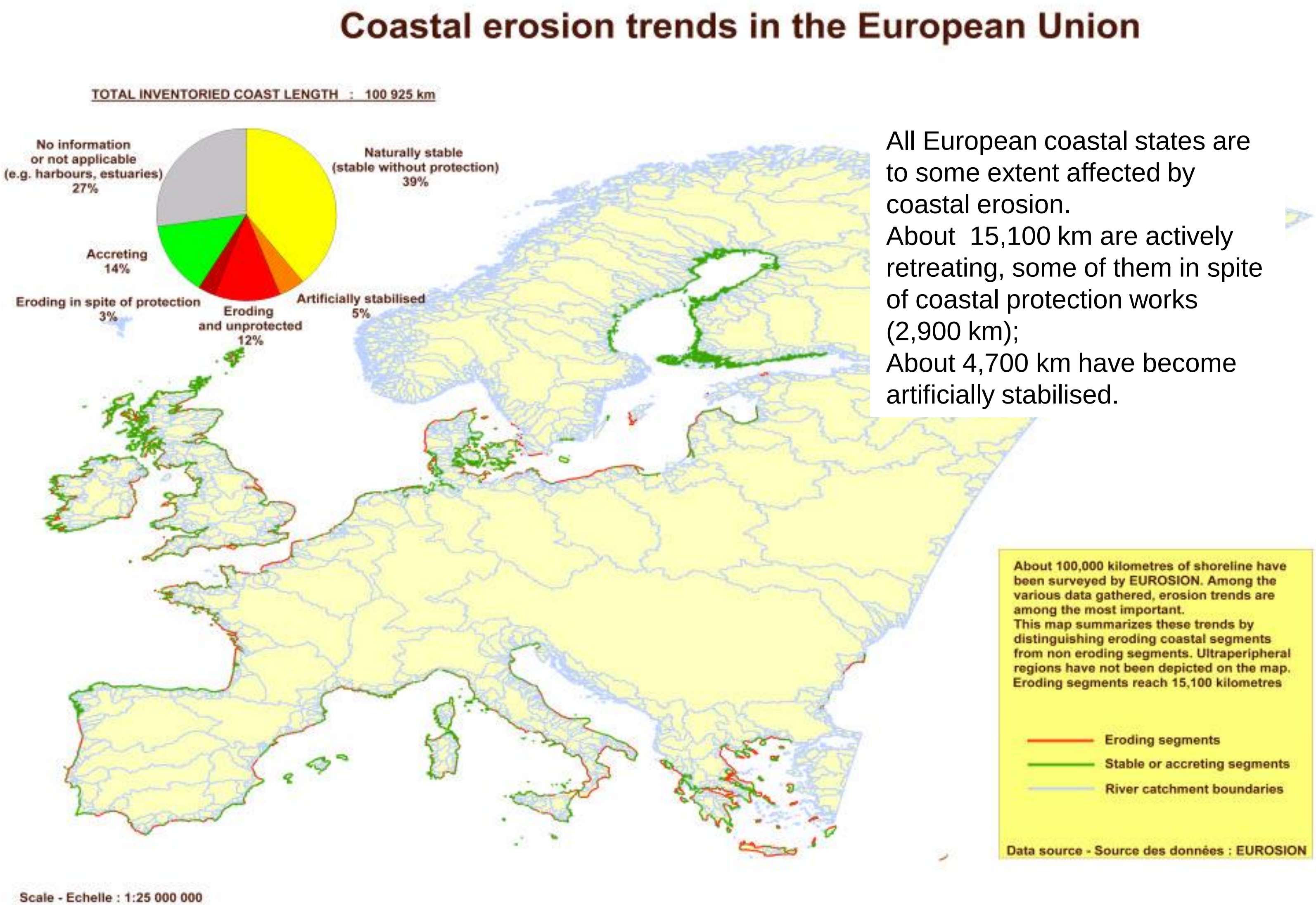
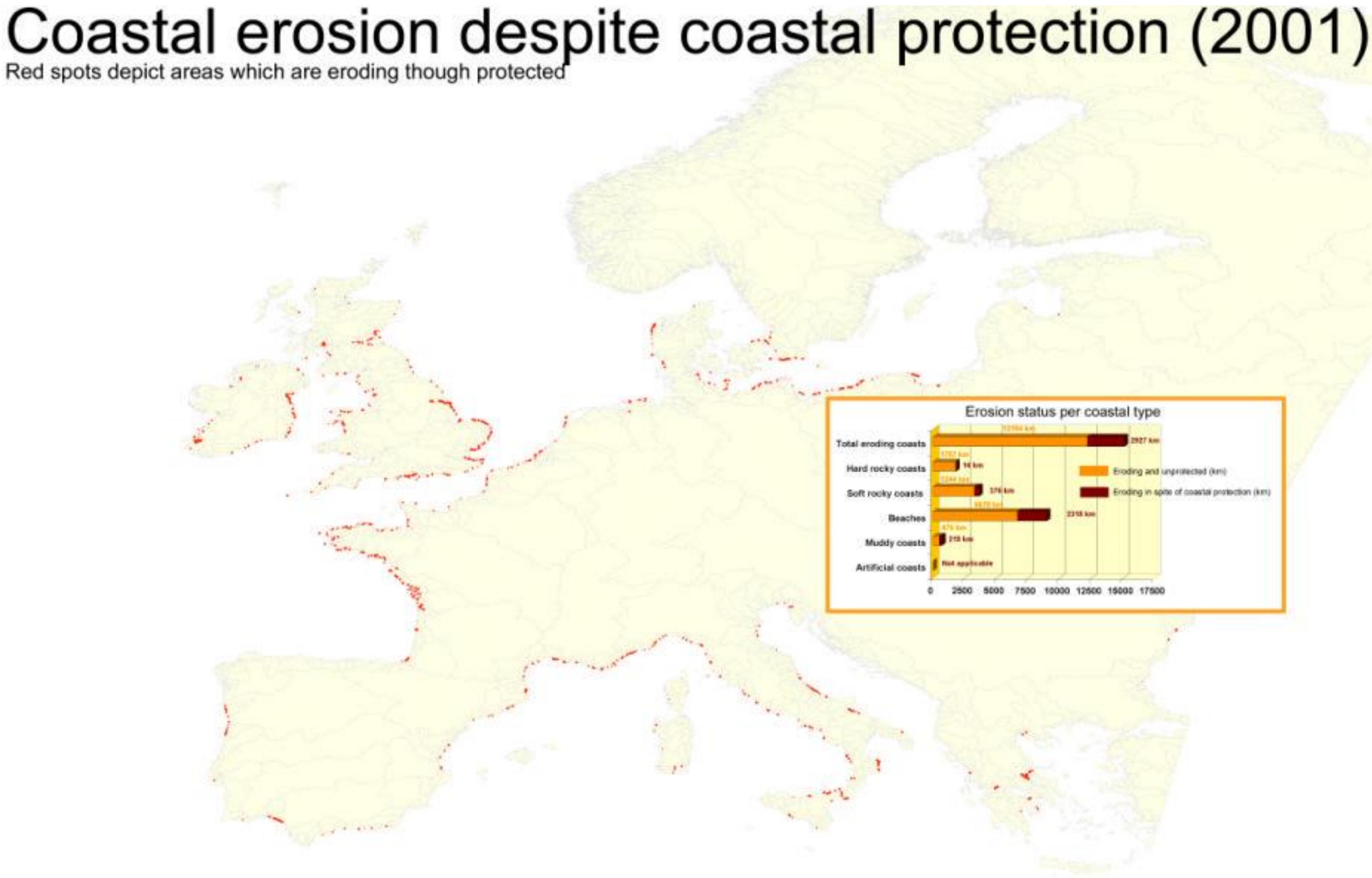


All European coastal states are to some extent affected by coastal erosion.
About 15,100 km are actively retreating, some of them in spite of coastal protection works (2,900 km);
About 4,700 km have become artificially stabilised.

Eurosion project: http://www.eurosion.org/index.html



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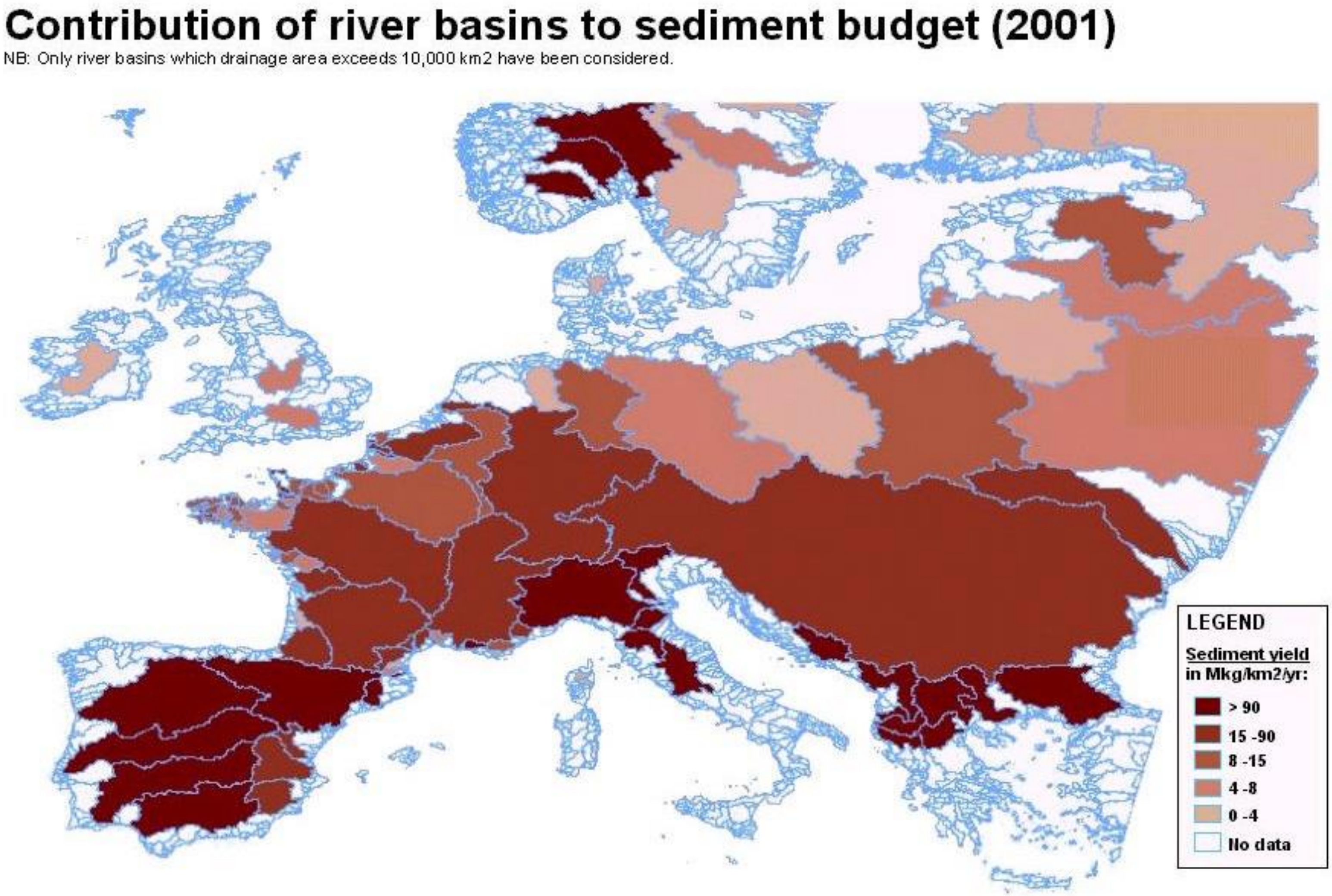

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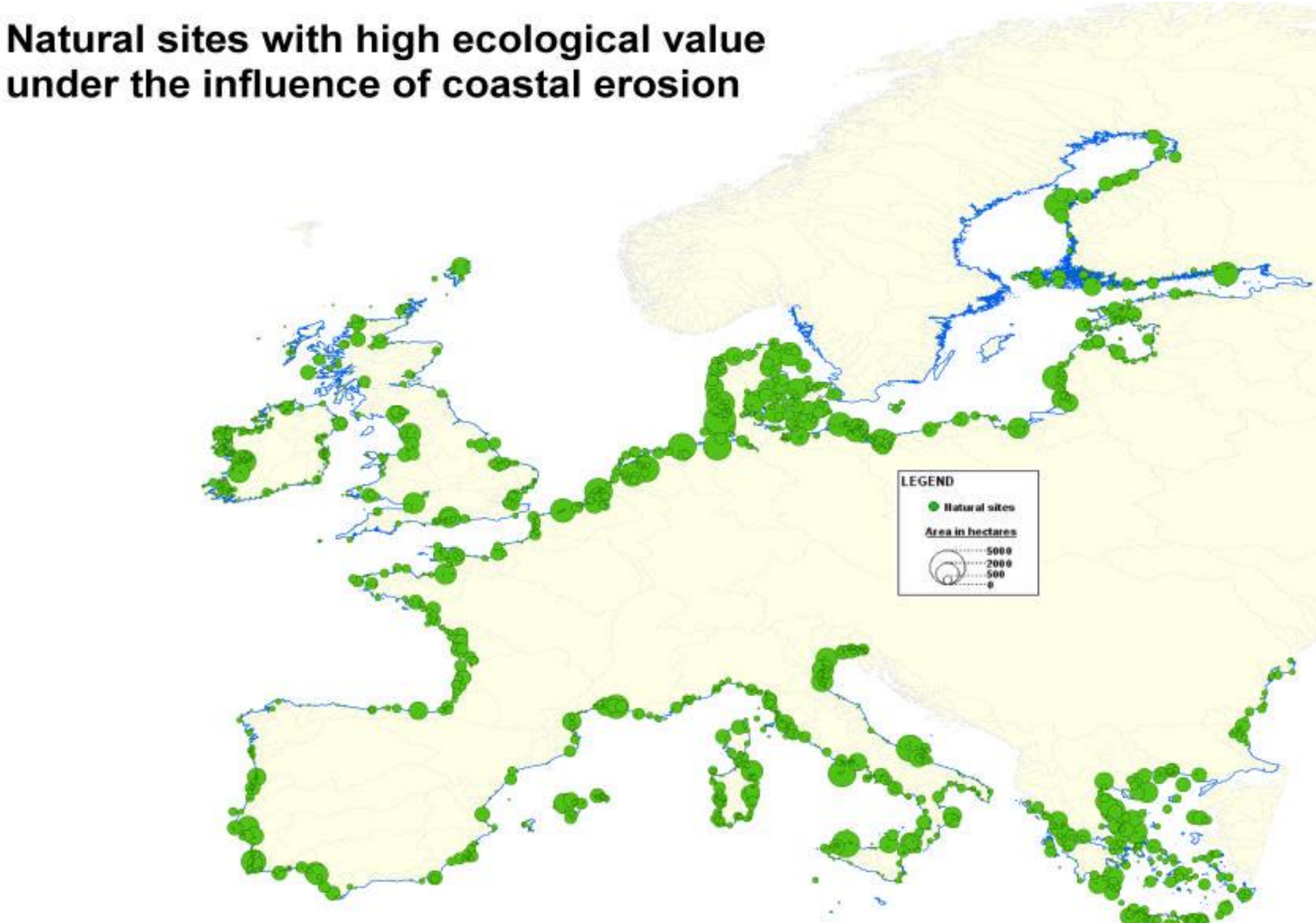


Eurosion project: http://www.eurosion.org/index.html

METHODOLOGY FOR RATING EUROPEAN REGIONS IN TERMS OF COASTAL EROSION AND FLOODING			
Indicator	**0 point**	**1 point**	**2 points**
PRESSURE SCORING			
1) Relative sea level rise (best estimate for the next 100 years)	*< 0 cm (per region)*	*BETWEEN 0 AND 40CM (PER REGION)*	*> 40 CM (PER REGION)*
2) Shoreline evolution trend status	*Less than 20% of the shoreline is eroding (per region)*	*Between 20% and 60% of the shoreline is eroding (per region)*	*More than 60% of the shoreline is eroding (per region)*
3) Shoreline changes from stability to erosion or accretion between the most recent and the previous version of the database	*Less than 10% of the shoreline changes between the 2 versions (CCEr and CEL)*	*Between 10 and 30% of the shoreline have changed between the 2 versions (CCEr and CEL)*	*More than 30% of the shoreline have changed between the 2 versions (CCEr and CEL)*
4) Highest water level	*Less than 1,5 meters*	*Between 1,5 and 3 meters*	*More than 3 meters*
5) Coastal urbanization (in the 10 km land strip)	*Urban areas (in km2) have increased of less than 5% between 1975 and present*	*Urban areas (in km2) have increased of 5 to 10% between 1975 and present*	*Urban areas (in km2) have increased of more than 10% between 1975 and present*
6) Reduction of river sediment supply (ratio)	*Ratio between effective volume of river sediment discharged and theoretical volume (i.e. without dams) is superior to 80%*	*Ratio between 50 and 80%*	*Ratio is less than 50%*
7) Geological coastal type	*> 70% of "likely non erodable" segments[13]*	*"likely non erodable segments" between 40% and 70%*	*< 40% of "likely non erodable segments"*
8) Elevation	*< 5% of the region area lies below 5 meters*	*Between 5 and 10% of the region area lies below 5 meters*	*> 10% of the region area lies below 5 meters*
9) Engineered frontage (including protection structure)	*< 5% of engineered frontage along the regional coastline*	*Between 5% and 35% of engineered frontage along the regional coastline*	*> 35% of engineered frontage along the regional coastline*

Eurosion project: http://www.eurosion.org/index.html

METHODOLOGY FOR RATING EUROPEAN REGIONS IN TERMS OF COASTAL EROSION AND FLOODING			
Indicator	**0 point**	**1 point**	**2 points**

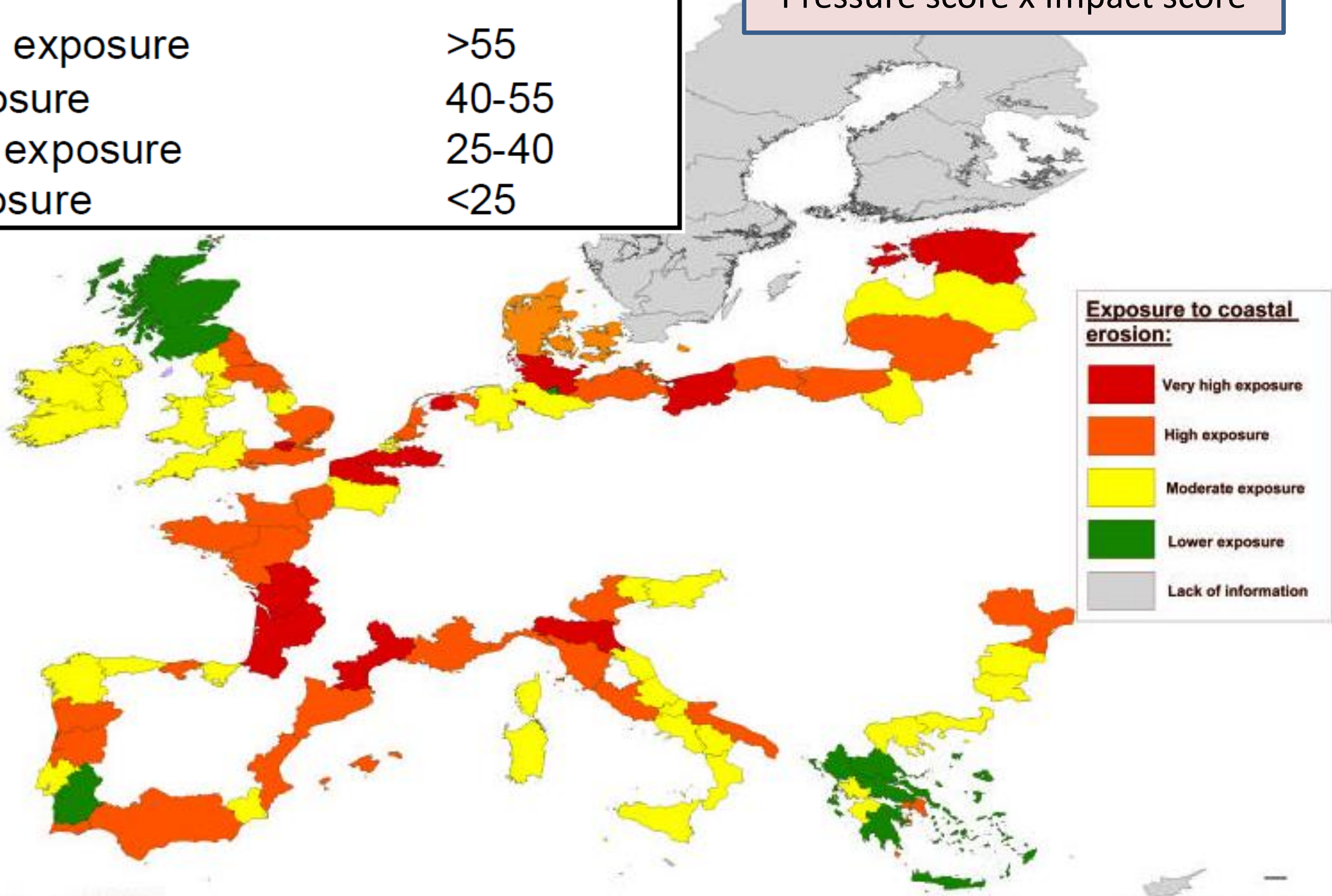
IMPACT SCORING

10) Population living within the RICE[14]	*< 50,000 inhabitants per region*	*Between 50,000 and 200,000 inhabitants per region*	*> 200,000 inhabitants per region*
11) Coastal urbanization (in the 10 km land strip)	*Urban areas (in km2) have increased of less than 5% between 1975 and present*	*Urban areas (in km2) have increased of 5 to 10% between 1975 and present*	*Urban areas (in km2) have increased of more than 10% between 1975 and present*
12) Urban and industrial living within the RICE	*< 10% of the land cover within the RICE is occupied by urban and industrial areas (per region)*	*Between 10% and 40% of the land cover within the RICE is occupied by urban and industrial areas (per region)*	*> 40% of the land cover within the RICE is occupied by urban and industrial areas (per region)*
13) Areas of high ecological value within the RICE*	*< 5 % of areas of high ecological value within the RICE per region*	*Between 5% and 30% of areas of high ecological value within the RICE per region*	*> 30% of areas of high ecological value within the RICE per region*

Exposure of European regions to coastal erosion

Classes	*Exposure*
Very high exposure	>55
High exposure	40-55
Moderate exposure	25-40
Low exposure	<25

Exposure =
Pressure score x Impact score



Data source - Sources des donnees : EUROSION

Scale - Echelle : 1:20 000 000

Eurosion project: http://www.eurosion.org/index.html

Class 1 – Very high exposure: Regions of class 1 should deserve **immediate attention** from the European Commission, the Member State and the Regional Authority concerned. **Coastal sediment management plans (CSMP)** covering class 1 regions should be established before end of **2006** and their achievements **monitored** and evaluated on a **yearly basis**. Due to their significance at the European level, elaboration of coastal sediment management plans for class 1 regions should receive **financial and technical support** from **European** and **national authorities**;

Class 2 – High exposure: Regions of class 2 deserve **attention** from the European Commission, the Member State and the Regional Authority concerned. Coastal sediment management plans covering class 2 regions should be established before end of 2008 and their achievements monitored and evaluated on a **3-year basis**. Due to their significance at the national level, elaboration of shore and sediment management plans for class 2 regions should receive **financial and technical support** from **national authorities**;

Class 3 – Moderate exposure: Regions of class 3 should deserve **attention** from the Member State and the Regional Authority concerned. Coastal sediment management plans covering class 3 regions should be established before end of **2008** and their achievements monitored and evaluated on a **5-year basis**;

Class 4 – Low exposure: Regions of class 4 do **not deserve short term attention** from the European Commission nor the Member State with respect to coastal erosion. shore and sediment management plans covering class 3 regions should however be established before end of **2010** and their achievements be monitored and evaluated on a **10-year basis**;

Deduce Interreg project
http://www.deduce.eu/

DEDUCE [Sustainable Development of European Coastal Zones]

- Deduce defines a core set of **27 indicators** to monitor the **sustainable development** of the coastal zone at different scales (European, national, regional and local).

- The 27 indicators are specifically oriented to monitor the progress towards the achievement of **seven key goals**.

- The Deduce indicator set does **not specifically assess coastal vulnerability** and adaptation to climate change but it represents a useful tool to contextualize these issues within the wider ICZM framework.

- The Deduce project also defined a core set of **progress indicators** to measure the progress of the implementation of ICZM.

Deduce sustainable development indicators (source: Deduce Consortium, 2007).

Goals	Indicators
1. To control further development of the undeveloped coast as appropriate	1) Demand for property on the coast
	2) Area of built-up land
	3) Rate of development of previously undeveloped land
	4) Demand for road travel on the coast
	5) Pressure for coastal and marine recreation
	6) Land taken up by intensive agriculture
2. To protect, enhance and celebrate natural and cultural diversity	7) Amount of semi-natural habitat
	8) Area of land and sea protected by statutory designations
	9) Effective management of designated sites
	10) Change in significance coastal and marine habitats and species
3. To promote and support a dynamic and sustainable coastal economy	11) Loss of cultural distinctiveness
	12) Patterns of sectoral employment
	13) Volume of port traffic
	14) Intensity of tourism
	15) Sustainable tourism
4. To ensure that beaches are clean and that coastal waters are unpolluted	16) Quality of bathing water
	17) Amount of coastal, estuarine and marine litter
	18) Concentration of nutrients in coastal waters
	19) Amount of oil pollution
5. To reduce social exclusion and promote social cohesion in coastal communities	20) Degree of social cohesion
	21) Relative household prosperity
	22) Second and holiday homes
6. To use natural resources wisely	23) Fish stocks and fish landings
	24) Water consumption
7. To recognise the threat to coastal zones posed by climate change and to ensure appropriate and ecologically responsible coastal protection	25) Sea level rise and extreme weather conditions
	26) Coastal erosion and accretion
	27) Natural, human and economic assets at risk

Deduce Interreg project: http://www.deduce.eu/

Vulnerability to climate change is addressed in the following three indicators:

- **Sea level rise and extreme weather conditions** including three measures: number of “stormy days”, rise in sea level relative to land, length of protected and defended coastline;

- **Coastal erosion and accretion** including three measures: length of dynamic coastline, area and volume of sand nourishment, number of people living within an “at risk” zone;

- **Natural, human and economic assets at risk** including two measures: area of protected sites within an “at risk” zone; value of economic within an “at risk” zone.

Index-based methods:

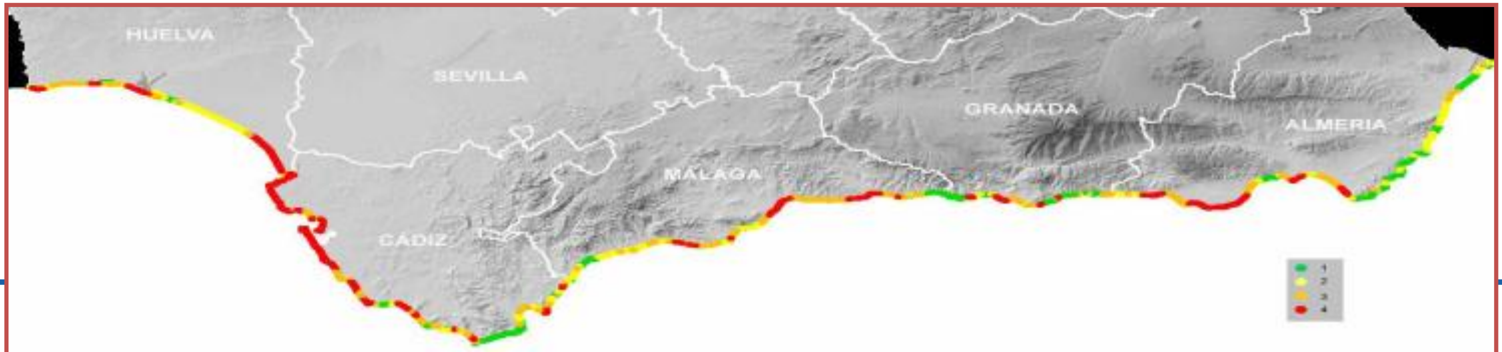
- Express coastal vulnerability by a **one-dimensional**, and generally **unitless**, risk/vulnerability **index**.
- This index is calculated through the **quantitative** or **semi-quantitative** evaluation and **combination** of **different variables**.
- The ranking of variables is a somewhat **subjective exercise**, and the criteria by which they are ranked must be **clearly defined**.
- A vulnerability index **aims to simplify** a number of **complex** and **interacting** parameters, represented by diverse data types, to a form that is **more readily understood** and therefore has **greater utility** as a **management tool**.

Coastal Vulnerability Index – CVI

The CVI is one of the **most commonly used** and **simple** methods to **assess coastal vulnerability** to **sea level rise**, in particular due to **erosion** and/or **inundation** (Gornitz et al., 1991).

The CVI provides a **simple numerical basis** for **ranking sections** of **coastline** in terms of their **potential for change** that can be used by **managers** to **identify** regions where **risks** may be **relatively high**.

The CVI **results** can be displayed on **maps** to highlight **regions** where the factors that contribute to shoreline changes may have the greatest potential to contribute to **changes** to **shoreline retreat** (Gutierrez et al., 2009).



Coastal Vulnerability Index – CVI

The **first** methodological step deals with the **identification** of **key variables** representing **significant driving processes** influencing the coastal vulnerability and the coastal evolution in general.

The **number** and **typology** of **key variables** can be slightly modified according to specific needs; in general CVI formulation includes 6 or 7 variables.

The **second** step deals with the **quantification** of **key variables:** generally based on semi-quantitative scores according to a 1-5 scale (1 low contribution to coastal vulnerability of a specific key variable, 5 high contribution).

CVI (USGS, 2004)

Table 1: Ranges for Vulnerability Ranking of Variables on the Pacific Coast.

Variables	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
GEOMORPHOLOGY	Rocky cliffed coasts, Fjords	Medium cliffs, Indented	Low cliffs, Glacial drift, Alluvial	Cobble Beaches, Estuary	Barrier beaches, Sand beaches, Salt marsh, Mud flats, ...rove, ...s
SHORELINE EROSION/ACCRETION (m/yr)	> 2.0				
COASTAL SLOPE (%)	> 14.7	10.9 – 14.65	7.75 – 10.85	4.6 –7.7	< 4.55
RELATIVE SEA-LEVEL CHANGE (mm/yr)	< 1.8				
MEAN WAVE HEIGHT (m)	< 1.1				
MEAN TIDE RANGE (m)	> 6.0	4.0 - 6.0	2.0 - 4.0	1.0 - 2.0	< 1.0

GEOLOGIC VARIABLES: they account for a shoreline's relative resistance to erosion and its susceptibility to flooding,

PHYSICAL PROCESS VARIABLES: contribute to the inundation hazards of a particular section of coastline over time scales from hours to centuries.

Key variables and scores used in the USGS CVI for the Pacific Coast.

CVI (Abuodha and Woodroffe, 2006)

	Very Low	Low	Moderate	High	Very high
Variable	**1**	**2**	**3**	**4**	**5**
Dune height (m)	> 30.1	20.1 - 30.0	10.1 - 20.0	5.1 - 10.0	0 - 5.0
Barrier types	Transg				lainland beach
Beach types	Dissipa… Longshore bar trough (LBT)	Rhythmic bar beach (RBB)	Transverse bar rip (TBR)	Low tide terrace (LTT)	Reflective (R)
Relative sea-level change (mm/yr)	≤ -1.1 Land rising	-1.0 - 0.99	1.0 - 2.0 Eustatic rise	2.1 - 4.0	≥ 4.1 Land sinking
Shoreline erosion accretion (m/yr)	≥ +2.1 Accretion	1.0 – 2.0 Stable	-1.0 - +1.0 Erosion	-1.1 - -2.0 Erosion	≤ -2.1 Erosion
Mean tidal range (m)	≤ 0.99 Microtidal	1.0 – 1.9 Microtidal	2.0 – 4.0 Mesotidal	4.1 – 6.0 Mesotidal	≥ 6.1 Macrotidal
Mean wave height (m)	0 – 2.9	3.0 – 4.9	5.0 – 5.9	6.0 – 6.9	≥ 7.0

The first three variables replaced the geomorphology and coastal slope, variables identified by USGS (2004).

Key variables and scores used in a CVI for the Australian beach case.

Coastal Sensitivity Index (CSI) (Shleupner, 2005)

Sensitivity to Inundation and Erosion	*1*	*2*	*3*
	Low	**Intermediate**	**High**
1. **Morphology and Elevations**			
a. Relative elevation	High (>20 m, mountainous inland area)	Intermediate (>10 to ≤ 20 m, hilly inland area)	Low (0 to 10m, flat land, lake, wetlands)
b. Coastal morphology	steep coast protected through rubble	active cliffs	sand beaches
	lifted steep coast (>100m)	low steep coast	muddy bays
	lifted rocky shore	stone beach, rocky shore	
		mangroves	
c. $a^2 + b^2 / 2$	1 to 3	4 to 6	7 to 9
2. Erodibility (based on geology)	**Low**	**Intermediate**	**High**
	volcano cones	lime	alluvium
	lava flows	unconsolidated volcanic breccia	deeply weathered volcanites
		heat tuff	pumice
			tuff
3. Exposition to wind regime	leeward	other coast	windward
4. Natural protection	sheltered by bay/island/reef	partly sheltered	open coastal area
5. Sedimentation	**High**	**Intermediate**	**Low**
	shelf area with sedimentation	shelf without sedimentation	shelf without sedimentation

Key variables and scores used in the CSI in Martinique.

Coastal Vulnerability Index – CVI

The **third** step deals with the **integration** of the **key variables** in a **single index** (i.e. the final CVI) using different formulas:

Product mean: $CVI_1 = \frac{(x_1 * x_2 * x_3 * x_4 * \ldots x_n)}{n}$,

Modified product mean: $CVI_2 = \frac{[x_1 * x_2 * \frac{1}{2}(x_3 + x_4) * x_5 * \frac{1}{2}(x_6 + x_7)]}{n - 2}$,

Average sum of squares: $CVI_3 = \frac{(x_1^2 + x_2^2 + x_3^2 + x_4^2 + \ldots x_n^2)}{n}$,

Modified product mean (2): $CVI_4 = \frac{(x_1 * x_2 * x_3 * x_4 * \ldots x_n)}{5^{(n-4)}}$,

Square root of product mean: $CVI_5 = [CVI_1]^{1/2}$, and

Sum of products: $CVI_6 = 4x_1 + 4x_2 + 2(x_3 + x_4) + 4x_5 + 2(x_6 + x_7)$.

Where: n = variables present
x_1=mean elevation
x_2=local subsidence trend
x_3=geology
x_4=geomorphology
x_5=mean shoreline displacement
x_6=maximum wave height
x_7=mean tidal range.

Coastal Vulnerability Index – CVI

The CVI formulation based on the square root of product mean (CVI_5) has been widely used in applications at the local, regional and supra-regional level (Thieler and Hammar-Klose, 1999; Thieler et al., 2002).

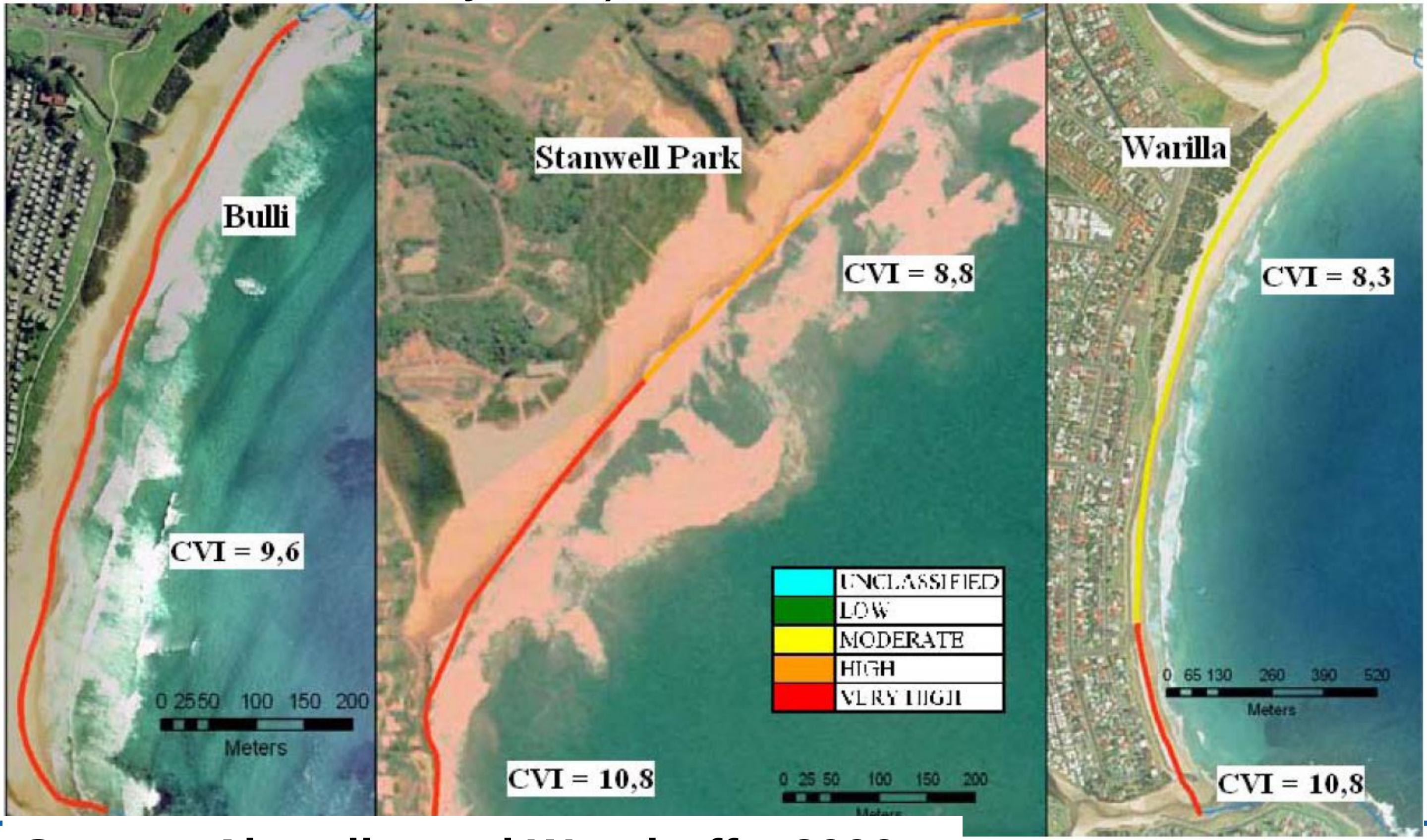
United States Geological Survey (USGS) uses 6 variables combined through the following equation:

$$CVI = \sqrt[2]{\frac{a \cdot b \cdot c \cdot d \cdot e \cdot f}{6}}$$

a = geomorphology;
b = shoreline change rates;
c = coastal slope;
d = relative sea level rate;
e = mean significant wave height;
f = mean tidal range.

Coastal Vulnerability Index – CVI

In the **fourth** step CVI values are **classified** in n different groups (e.g. 3, 4 or 5) using n-1 percentiles as limits (e.g. 25%, 50%, 75%).
This classification enables the **evaluation** of the **relative coastal vulnerability** of the different studied coastal parcels (such as sub-areas included in a wider coastal system).



Source: Abuodha and Woodroffe, 2006.

CVI for sea level rise impacts (Özyurt, 2007)

Aim: to assess impacts induced by sea level rise.

The index is determined through the **integration** of **5 sub-indices**, each one **corresponding** to a **specific sea level rise related impact:**

- coastal erosion;
- flooding due to storm surges;
- permanent inundation;
- salt water intrusion to groundwater resources;
- salt water intrusion to rivers/estuaries).

Each **sub-index** is determined by the **semi-quantitative** assessment of both **physical** and **human** influence parameters.

Özyurt (2007) and Özyurt et al. (2008))

CVI for sea level rise impacts (Özyurt, 2007)

Physical parameters

- Rate of SLR;
- Geomorphology;
- Coastal slope;
- Significant wave height;
- Sediment budget;
- Tidal range;
- Proximity to coast;
- Type of aquifer;
- Hydraulic conductivity;
- Depth to groundwater level above sea;
- River discharge;
- Water depth at downstream.

CVI for sea level rise impacts (Özyurt, 2007)

Parameters of human influence

- Reduction of sediment supply;
- River flow regulation;
- Engineered frontage;
- Groundwater consumption;
- Land use pattern;
- Natural protection degradation;
- Coastal protection structures.

CVI for sea level rise impacts (Özyurt, 2007)

	Range					
		Very low	Low	Moderate	High	Very high
Physical Parameters		**1**	**2**	**3**	**4**	**5**
Rate of SLR	mm/yr	<1	1-2	2-5	5-7	7-9 and over
Geomorphology		Rocky cliff coasts, fiords	Medium cliffs, indented coasts	Low cliffs, glacial drift, alluvial plains	Cobble beaches, estuary, lagoon	Barrier beach, sand beach, salt marsh, mudflats, deltas, mangrove, coral reefs
Coastal slope		>1/10	1/10-1/20	1/20-1/30	1/30-1/50	1/50-1/100
Significant wave high	m	<0.5	0.5-3.0	3.0-6.0	6.0-8.0	>8.0
Sediment budget		More than 50% of the shoreline is in accretion	Between 10-30% of the shoreline is in accretion	Less than 10% of the shoreline is in erosion or in accretion	Between 10-30% of the shoreline is in erosion	More than 50% of the shoreline is in erosion

Physical parameters and corresponding ranges (source: Özyurt, 2007).

CVI for sea level rise impacts (Özyurt, 2007)

	Range					
		Very low	**Low**	**Moderate**	**High**	**Very high**
Physical Parameters		**1**	**2**	**3**	**4**	**5**
Tidal range	m	>6.0	4.0-6.0	2.0-4.0	0.5-2.0	<0.5
Proximity to coast	m	>1000	700-1000	400-700	100-400	<100
Type of aquifer		Leaky confined		Confined		Unconfined
Hydraulic conductivity	m/day	0-12	12-28	28-41	41-81	>81
Depth to groundwater level above sea	m	>2.00	1.25-2.00	0.75-1.25	0.00-0.75	<0,00
River discharge	m^3/s	>500	250-500	150-250	50-150	0-50
Water depth at downstream	m	≤1	2	3	4-5	>5

Physical parameters and corresponding ranges (source: Özyurt, 2007).

CVI for sea level rise impacts (Özyurt, 2007)

	Range				
	Very low	Low	Moderate	High	Very high
Human Parameters	**1**	**2**	**3**	**4**	**5**
Reduction of sediment supply	>80%	60-80%	40-60%	20-40%	<20%
River flow regulation	Not affected		Moderate affected		Strongly affected
Engineered frontage	<5%	5-20%	20-30%	30-50%	>50%
Groundwater consumption	>20%	20-30%	30-40%	40-40%	>50%
Land use pattern	Protected area	Unclaimed	Settlement	Industrial	Agricultural
Natural protection degradation	>80%	60-80%	40-60%	20-40%	<20%
Coastal protection structures	>50%	30-50%	20-30%	5-20%	<5%

Parameters of human influence and the corresponding ranges (source: Özyurt, 2007)

Parameters used to calculate the sub-indeces of each impact of sea level rise (source: Özyurt, 2007)

Impacts of Sea Level Rise	Physical Parameters	Human Influence Parameters
Coastal Erosion	1. **Rate of Sea Level Rise** 2. Geomorphology 3. Coastal Slope 4. Significant Wave Height 5. Sediment Budget 6. Tidal Range	1. Reduction of Sediment Supply 2. River Flow Regulation 3. Engineered Frontage 4. Natural Protection Degradation 5. Coastal Protection Structures
Flooding due to Storm Surges	1. **Rate of Sea Level Rise** 2. Coastal Slope 3. Significant Wave Height 4. Tidal Range	1. Engineered Frontage 2. Natural Protection Degradation 3. Coastal Protection Structures
Inundation	1. **Rate of Sea Level Rise** 2. Coastal Slope 3. Tidal Range	1. Natural Protection Degradation 2. Coastal Protection Structures
Salt Water Intrusion to Groundwater Resources	1. **Rate of Sea Level Rise** 2. Proximity to Coast 3. Type of Aquifer 4. Hydraulic Conductivity 5. Depth to Groundwater Level Above Sea	1. Groundwater consumption 2. Land Use Pattern
Salt Water Intrusion to Rivers/Estuaries	1. **Rate of Sea Level Rise** 2. Tidal Range 3. Water Depth at Downstream 4. Discharge	1. River Flow Regulation 2. Engineered Frontage 3. Land Use Pattern

CVI for sea level rise impacts (Özyurt, 2007)

$$CVI_{impact} = \frac{(0,5 \times \sum_{1}^{n} PP_n) + (0,5 \times \sum_{1}^{m} HP_m)}{CVI_{least\ vulnerable}}$$

PP = Physical Parameters;
HP = Human Influence Parameters;
n and **m** = the number of physical and human influence parameters, respectively, considered for a particular impact;
$CVI_{least\ vulnerable}$ = the value of the sub-index for the least vulnerable theoretical case, meaning all parameters equal to 1.

Fine-tuning of the method can include **weighting** of individual parameters and of groups of parameters (physical PP and human influence HP groups).

In the above formula no weight definition is considered; meaning that parameters contribute equally to the definition of the sub-indices.

CVI for sea level rise impacts (Özyurt, 2007)

CVI index values vary between 1 and 5, and can be integrated in an **overall final index CVI (SLR),** according to the following formula:

$$\text{CVI(SLR)} = \frac{\sum_{i=1}^{5} \text{Total Impact}_i}{\sum_{i=1}^{5} \text{Least Vulnerable Case}_i}$$

The formula may integrate **all the five sub-indexes** or only **a subset** of the five considered impacts, those playing a more relevant role in the vulnerability of the studied coastal system.

CVI for sea level rise impacts (Özyurt, 2007)

Matrix for Goksu Delta (source: Özyurt 2007)

Impact	Physical Parameters							Human Influence Parameters							Total impact	Least Vulnerable Theoretical Case	CVI Impact
	Parameter	1	2	3	4	5	**Total**	**Parameter**	1	2	3	4	5	**Total**			
Coastal Erosion	P1.1 Rate of Sea Level Rise		1				2	H1.1 Reduction of Sediment Supply			1			3			
	P1.2 Geomorphology					1	5	H1.2 River Flow Regulation			1			3			
	P1.3 Coastal Slope					1	5	H1.3 Engineered Frontage		1				2			
	P1.4 H⅓				1		4	H1.4 Natural Protection Degradation					1	5			
	P1.5 Sediment Budget				1		4	H1.5 Coastal Protection Structures					1	5			
	P1.6 Tidal Range					1	5										
	TOTAL	0	1	0	2	3	**25**	**TOTAL**	0	1	2	0	2	**18**	21,5	5,5	**3,90909**
Flooding due to Storm Surge	P2.1 Rate of Sea Level Rise		1				2	H2.1 Engineered Frontage		1				2			
	P2.2 Coastal Slope					1	5	H2.2 Natural Protection Degradation					1	5			
	P2.3 H⅓				1		4	H2.3 Coastal Protection Structures					1	5			
	P2.4 Tidal Range					1	5										
	TOTAL	0	1	0	1	2	**16**	**TOTAL**	0	1	0	0	2	**12**	14	3,5	**4**
Inundation	P3.1 Rate of Sea Level Rise		1				2	H3.1 Natural Protection Degradation					1	5			
	P3.2 Coastal Slope					1	5	H3.2 Coastal Protection Structures					1	5			
	P3.3 Tidal Range					1	5										
	TOTAL	0	1	0	0	2	**12**	**TOTAL**	0	0	0	0	2	**10**	11	2,5	**4,4**

CVI for sea level rise impacts (Özyurt, 2007)

The CVI (SLR) matrix illustrates the contribution of each specific parameter and sub-index to the overall coastal vulnerability.

Impact	Physical Parameters						Human Influence Parameters						Total impact	Least Vulnerable Theoretical Case	CVI Impact
	Parameter	**1**	**2**	**3**	**4**	**5**	**Total**	**Parameter**	**1**	**2**	**3**	**4**	**5**	**Total**			
Salt Water Intrusion to Groundwater Resources	P4.1 Rate of Sea Level Rise		1				2	H4.1 Groundwater Consumption				1		4			
	P4.2 Proximity to Coast				1		4	H4.2 Land Use Pattern					1	5			
	P4.3 Type of Aquifer			1			3										
	P4.4 Hydraulic Conductivity	1					1										
	P4.5 Depth to Groundwater Level Above Sea		1				2										
	TOTAL	1	2	1	1	0	**12**	**TOTAL**	0	0	0	1	1	**9**	10,5	3,5	**3**
Salt Water Intrusion to River/Estuary	P5.1 Rate of Sea Level Rise		1				2	H5.1 River Flow Regulation			1			3			
	P5.2 Tidal Range					1	5	H5.2 Engineered Frontage		1				2			
	P5.3 Water Depth at Downstream		1				2	H5.3 Land Use Pattern					1	5			
	P5.4 Discharge				1		4										
	TOTAL	0	2	0	1	1	**13**	**TOTAL**	0	1	1	0	1	**10**	11,5	3,5	**3,28571**

Composite Vulnerability Index (Szlafsztein and Sterr, 2007)

It combines a number of **separate variables** that reflect **natural** and **socio-economic characteristics** that contribute to **coastal vulnerability** due to natural hazards;

Selected **indicators** can **differ** in **number**, **typology** and **scales** of evaluation according to the study area.

Data for each variable are placed into **classes**, assigning a rank between 1 and 5 according to their relative vulnerability (i.e. very low, low, moderate, high and very high).

Each indicator is then **weighted** according to its importance in determining the vulnerability of coastal areas to natural hazards.

Indicators are then **aggregated** according to an appropriate set of **weights**.

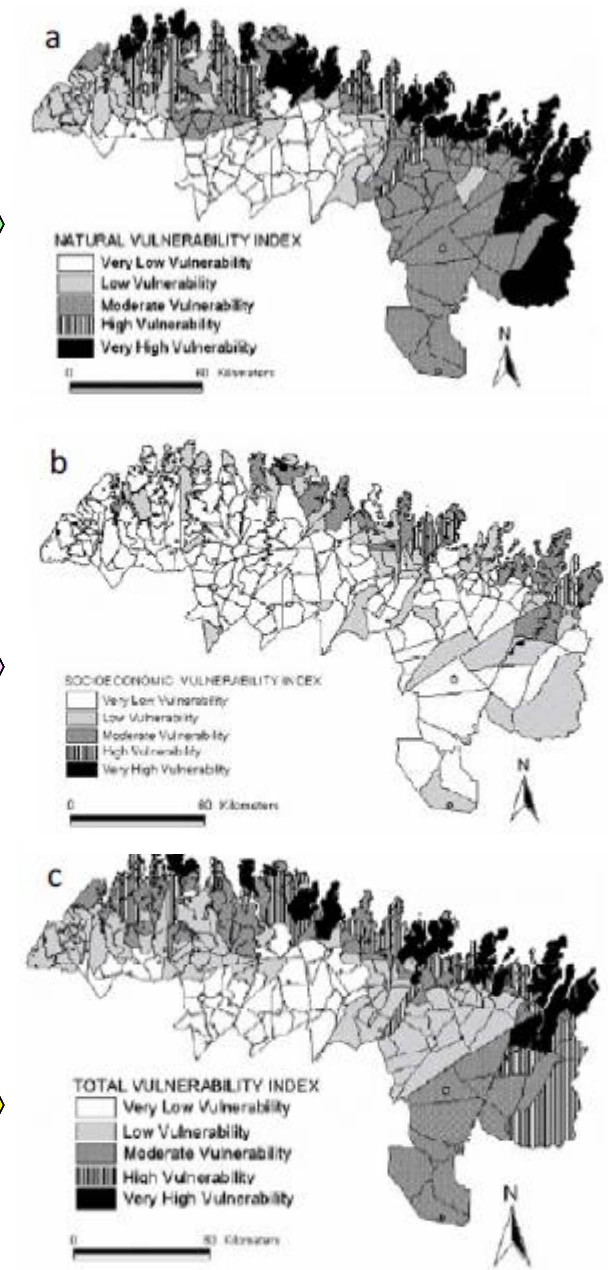
Composite Vulnerability Index

Application to a coastal area in Brazil.

Natural parameters:
- coastline length and sinuosity;
- continentality in terms of coastline density into municipal areas;
- coastal feature (estuarine, beach etc.);
- coastal protection measures;
- fluvial drainage;
-flooding areas.

Socio-economic parameters:
- total population and total population affected by floods (both divided into age classes);
- density of population;
- non-local population (i.e. born elsewhere but living in considered areas);
- poverty;
- municipal wealth.

Separated **GIS-layers** are overlaid and the variable scores combined into natural and socio-economic vulnerability indices, which when combined represent the **total vulnerability index.**



Multi-scale coastal vulnerability index (McLaughlin and Cooper (2010)

Basic assumptions:

- Indices incorporating a diversity of indicators have been used extensively to provide **spatial analyses** of the degree of **vulnerability**.
- Such indices are typically applied at global and national scales, and they involve **varying degrees** of **simplification** and **aggregation** of information.
- The **degree of simplification** that is desirable depends on the **management scale**, and higher resolution is required at the local compared to the global scale.

Importance of **spatial scale** in developing indices of vulnerability:

while a **common** index **architecture** can be applied, the **selection of variables** must take account of the scale at which the hazard is to be assessed.

Multi-scale coastal vulnerability index (McLaughlin and Cooper (2010).

The index integrates three sub-indices:

- a **coastal characteristic sub-index**, describing the resilience and coastal susceptibility to erosion;
- a **coastal forcing sub-index**, characterizing the forcing variables contributing to wave-induced erosion;
- a **socio-economic sub-index**, describing targets potentially at risk.

The computation of each sub-index is determined on the basis of various **variables**, whose specific **identification** (number and typology) **depends** on the considered **application scale** (i.e. national, regional or local).

The identified variables are **ranked** according to a **1-5 scale** in order to express their contribution to the coastal system vulnerability; with 5 being the highest value and 1 the lowest.

Sub-index	Variable	1	2	3	4	5
CC	**Shoreline type**	High cliff (>40 m)	Medium cliff (20-40 m)	Low cliff (10-20 m)	Shingle ridge/bar	Sand beach/dune
	Rivers	Absent				Present
	Solid geology	Plutonic, high–me… metamor…				Fine unconsolidated sediment, volcanic ash
	Drift Geology	Bedrock,				Alluvium, blown sand, peat, glacial sands and gravels, glacial outwash sands, recent marine
	Elevation	>30				<5
	Orientation	Not relevant, e.g. sea loughs		Easterly		Northerly
	Inland buffer	500-1000				0-500 m inland
CF	**Significant wave height (m)**	0-0.74 N 0-0.24 E				>2.98 N > 0.96 E
	Tidal range (m)	>5				<1
	Difference in modal and storm waves (m)	<0.10 N <0.10 S	0.10-1.70 N 0.10-0.25 S	1.70-3.30 N 0.25-0.40 S	3.30-4.90 N 0.40-0.55 S	>4.9 N >0.55 S
	Frequency of onshore storms (%)	0-2.8	2.8-5.6	5.6-8.4	8.4-11.2	>11.2
SE	**Settlement**	No settlement	Village	Small town	Large town	City
	Cultural heritage	Absent				Present

At the national scale geology was deemed as essential variable to distinguish areas of potential vulnerability to erosion: there is a wide variation in the types of solid and drift geology.

Were considered important at the National and borough council scale but not included in the local scale index (little local variations)

National scale application in Northern Ireland (McLaughlin and Cooper, 2010).
Resolution: 500 x 500 mq.

At the **borough council** scale it was possible to use a more relevant **landform variable** integrating both the solid and drift geology.

Landform are classified according to their **slope**, **volume** and **lithology**.

	Variable	1	2	3	4	5
Characteristics	Landform				boulder ridges	udflat ltmarsh ach – no dunes
	Elevation (m)	>30	20 to <30	10 to <20	5 to <10	<5
	Rivers	Absent	Stream	Small river	Medium river	Large river
	Inland buffer (m from the MHWM)	300 to >1000		50 to <300		0 to <50
Forcing	Tidal range (m)	>5	3.5 to <5	2 to <3.5	1 to <2	<1
	Storm probability (based on coastal orientation)	North easterly	Northerly Easterly	North westerly South easterly	Southerly South westerly	Westerly
	Morpho-dynamic state (Dean's parameter)	Rocky coasts and gravel beaches	<1.5 or >5.5	<1.5 to <5.5	>1.5 to >5.5	<1.5 to >5.5
Socio-economic	Cultural heritage	Absent				Present
	Landuse	Water bodies Marsh/bog and moor Sparsely vegetated areas Bare rocks	Natural grasslands Coastal areas	Forest	Agriculture	Urban and industrial Infrastructure
	Population	0 to <5	5 to <20	20 to <50	50 to <100	100 to >200
	Roads	Absent	Minor roads (<4 m)	Minor roads (>4 m)	B-class roads	A-class roads
	Railways	Absent				Present
	Conservation designation	Absent		European International		National

Regional scale (McLaughlin and Cooper, 2010).
Resolution: 25 x 25 mq.

A number of variables could be used in all three index scales, with the level of detail increasing with the resolution of the study area.

TABLE 3 Local vulnerability ranking

	Variable	1	2	3	4	5
Coastal characterisitcs	Landform	High resistance cliff Seawall	Low resistance cliff	Multiple sand dune ridges	Single sand dune ridges Gravel and boulder ridges	Mudflat Saltmarsh Beach – no dunes
	Elevation (m)					
	Rivers					t
	Inland buffer (m from MHWM)					50
Coastal forcing	Storm probability (based on coastal orientation)	North easterly	Northerly Easterly	North westerly South easterly	Southerly South westerly	Westerly
	Morphodynamic state (Dean's parameter)	Inland areas and rocky cliffs	Dissipative or Reflective	Intermediate	Reflective Intermediate Dissipative	Dissipative Reflective
Socio-economic	Cultural heritage	Absent				Present
	Landuse	Rocky cliffs	Scrub	Beach Sand dunes Forest	Agricultural land Tee boxes	Urban Residential Carparks
	Population					
	Roads					

At the National scale only major rivers were identified; at the local scale the influence of smaller rivers becomes of increasing importance.

Increasing detail for population and roads from the national to the local scale:

1. from the identification of cities settlements/villages to the census of number of people (houses);
2. from main national roads to minor roads and footpaths.

(McLaughlin a
Resolution: 1 x 1mg.

Multi-scale coastal vulnerability index

- Sub-indices are calculated by the **sum** of the values of the relative **variables**;
- the results were then **normalized** by working the results out as a **percentage** of the **maximum** and **minimum scores;**
- the obtained number is then standardized to the **range 0-100**.

Coastal Characterization (CC) sub-index = {[(sum of CC var.) – 7]/28} x 100

Coastal Forcing (CF) sub-index = {[(sum of CF var.) – 4]/16}·x 100

Socio-Economic (SE) sub-index = {[(sum of SE var.) – 6]/24}·x 100

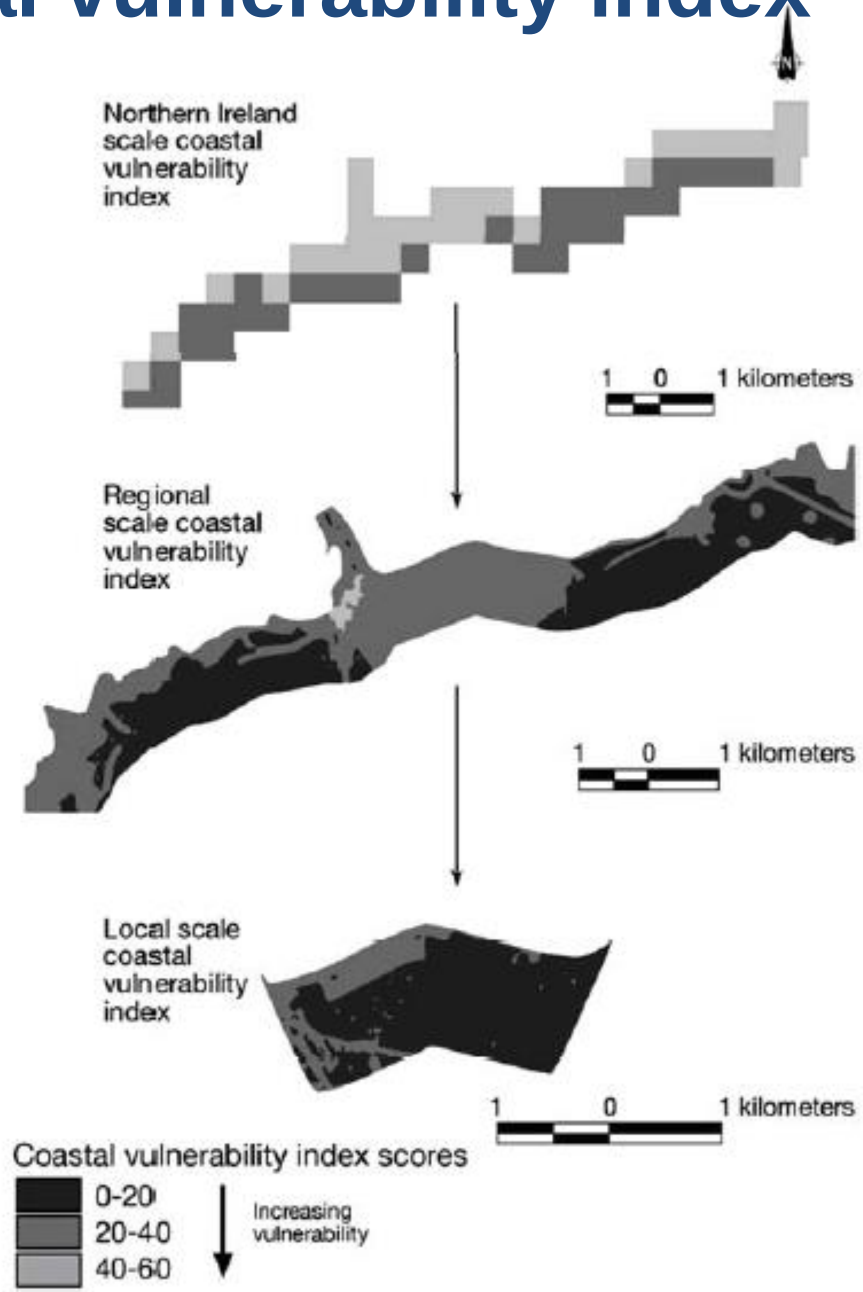
The final CVI index is computed through the **average** of the three sub-index values, as shown in the formula below:

CVI = (CC sub-index + CF sub-index + SE sub-index) / 3

Multi-scale coastal vulnerability index

CVI values can be visualized as a colour-coded **vulnerability maps**.

The CVI index is easy to calculate and can be applied to various spatial scales, thus supporting multiscale analysis important for costal planning and management.



Multi-scale coastal vulnerability index

There is no 'one size fits all' index of coastal vulnerability that can be applied at all scales:

Global-scale : enable international approaches to be coordinated and global policies to be debated;

National scale : allow the definition of national level policy and the prioritization of resources;

Local scale : is commonly implemented to define the practical response to coastal hazards.

Conclusions

- Indicators and index-based approaches are generally **simple to implement**.

- Their **application** at the scale of Europe and Regional Seas essentially **depends on data availability** that could be a limiting factor in the practical application.

- **Adjustments** of the methodology should be needed in order to address relevant characteristics **in different regions** and/or to make best use of available data.

- Indicators or index-based approaches are useful tools for a scoping or **"first look" assessment** - thus supporting identification of **priority vulnerable coastal areas and systems**.

Conclusions

- They are not useful for a more detailed quantitative assessment of costal vulnerability and the related identification of adaptation measures.

- Due to their simplified approaches, indicators and indices can be also very useful for communication purposes.

- Index-based approaches are not immediately transparent since the final computed indices do not allow the user to understand the assumptions and evaluation that led to its calculation.

- A clear explanation of the adopted methodology is therefore essential to support the proper use of these methods.

Thanks for your attention!

Silvia Torresan
torresan@unive.it

For more information:
Environmental Risk Assessment Unit, Ca' Foscari University, Venice: http://venus.unive.it/eraunit/

Euro-Mediterranean Center on Climate Change (CMCC), RAAS - Risk assessment and adaptation strategies, Venice: www.cmcc.it/it/divisions/raas

cmcc
Centro Euro-Mediterraneo sui Cambiamenti Climatici

Proactive adaptation

Aims to reduce a system's vulnerability by minimizing risk and/or enhancing the system's resilience.

5 objectives of proactive adaptation for coastal zones (Nicholls and Klein; 2005) :

- increasing **robustness** of **infrastructural designs** and long-term investments;
- increasing **flexibility** of vulnerable managed systems;
- enhancing **adaptability** of vulnerable natural systems;
- **reversing maladaptive** trends;
- improving **societal awareness** and **preparedness**.

Overview table of main indicators and index-based characteristics

Method	Spatial scale	Spatial resolution	Temporal scale	Main driver of changes	Main climate change impacts	Coastal systems	Assessment targets	Adaptation measures	Main data input	Output
Eurosion	European scale	Indicators and indexes were calculated at the regional level, i.e. NUTS 1 or NUTS 2 depending on the country	Depending on time scale and resolution of input data	Sensitivity indicators, e.g. sea level rise, shoreline evolution, sediment budget, etc.	Coastal vulnerability to erosion	Coastal zone in general	Targets represented by the impact indictors, i.e. population, urban and industrial areas and areas of high ecological value	Partially addressed by the indicator "engineered frontage", also including protection structure	Eurosion database: terrestrial boundaries, maritime boundaries, shoreline, bathymetry, elevation, geomorphology and geology, erosion trends and coastal deference works, hydrograph, infrastructure, wave and wind climate, tidal regime, sea level rise, land cover, areas of high ecological values	Sensitivity score Impact score Finale score, i.e. exposure to coastal erosion
CVI Index	Applied at the local, regional, supra-regional scale. Theoretically it can be applied to any spatial scale; it depends on data availability	Depending on the considered spatial level and data availability	Depending on time scale and resolution of input data	Sea level rise	Coastal vulnerability to sea level rise, in particular due to erosion and/or inundation	Coastal zone in general	Physical system	Not addressed by the index	Data input depends on key variables used to calculate the CVI index. Most common ones include: geomorphology, geology, elevation, coastal slope, shoreline change rates, significant wave height, relative sea level change, tidal range	CVI tables and maps; CVI is classified in groups using percentage limits
CVI (SLR)	Applied at the local scale. It appears to be suitable for the regional scale as well. Actually spatial scale of application depends on data availability	Depending on the considered spatial level and data availability	Depending on time scale and resolution of input data	Sea level rise	Coastal erosion, flooding due to storm surges, permanent inundation, salt water intrusion to groundwater resources and salt water intrusion to rivers/estuaries	Applied to a delta area by Özyurt (2007) and Özyurt *et al.* (2008). Theoretically it can be applied to the coastal zone in general	Physical system; some component of the socio-economic (i.e. land use) and ecological systems (i.e. natural protection degradation) are considered	Considered in terms of evaluation of coastal protection structures	12 physical (e.g. geomorphology, sediment budget and water depth at downstream) and 7 human influence (e.g. reduction of sediment supply and land use pattern) parameters	5 CVI sub-indices, each one related to a specific sea level rise impact. These are integrated in a final CVI (SRL) index.
Composite Vulnerability Index	Applied at the regional scale in Brazil (State of Para). Spatial scale of application depends on data availability	Depending on the considered spatial level and data availability In the application to the State of Para, spatial resolution was the census collection area (343 in total)	Depending on time scale and resolution of input data	Natural and socio-economic parameters used to derive the index	The index assesses coastal vulnerability in general, i.e. not specifically referring to climate change vulnerability. It also considers coastal flooding that can be strongly influenced by climate changes drivers.	Coastal zone in general	Physical and socio-economic targets	Considered in terms of evaluation of coastal protection measures	Natural parameters: coastline length and sinuosity, continentality in terms of coastline density into municipal areas, coastal features (estuarine, beach etc.), coastal protection measures, fluvial drainage, flooding areas. Socioeconomic parameters: population and population affected by floods, density of population, non-local population (i.e. born elsewhere but living in considered areas), poverty, municipal wealth	Three different indices: natural, socio-economic and total vulnerability index. Indexes can be represented in maps
Multi-scale CVI	Applied from the local to the national scale. Actually spatial scale of application depends on data availability	National scale: 500 X 500 m² grid cells Regional scale: 25 X 25 m² grid cells Local scale: 1 X 1 m² grid cells Spatial resolution depends also on data availability	Depending on time scale and resolution of input data	Forcing variables contributing to wave-induced erosion, i.e.: significant wave height, tidal range, storm and modal wave height, storm frequency	Coastal erosion	Different typologies of coast (e.g. cliff, sandy beaches)	Mainly socio-economic targets	Not addressed by the index	Key variables are defined according to the specific application (location and scale). Variables refer to: (i) resilience and coastal susceptibility to erosion, (ii) forcing variables contributing to wave-induced erosion, (iii) socio-economic target potentially at risk	Three sub-indices: (i) coastal characteristic sub-index, (ii) coastal forcing sub-index, (iii) socio-economic sub-index. Final CVI index. Indices can be represented in maps