Risk-based assessment of climate change impacts on coastal zones: the case study of the North Adriatic Sea.

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Gallina V., Rianna F., Giove S., Marcomini A.

International Conference Deltas in Times of Climate Change
Rotterdam, 30 September 2010

GLOBAL vs REGIONAL SCALE

- Climate change impacts on coastal zones (e.g. sea level rise inundation, coastal erosion, water quality variations and biodiversity loss) are very dependent on **regional** geographical features, climate and socio-economic **conditions**;
- Impact studies should therefore be performed at the **local or** at most at the **regional level**.

Appropriate **methods are needed** to assess the impacts and risks at the fine scale where impacts happen as a consequence of changed weather conditions.

CMCC project

Development of a GIS based DSS (DESYCO) for climate change impact assessment and management on coastal zones at the REGIONAL SCALE.

Based on downscaled numerical models and on site-specific environmental and socio-economic data.

Useful for the implementation of ICZM strategies.

1

DESYCO
(DEcision support SYstem for COastal climate change impact assessment)

OBJECTIVES:
1) Improve our understanding about the effects of climate change on coastal environments at the regional scale;
2) Apply innovative interdisciplinary approaches and adequate methodologies for a sound assessment and communication of climate change-related-risks;
3) Provide policy planners and decision makers with appropriate information to define adaptation strategies;
4) Provide results for further scientific research and to stimulate the debate of scientific and technical networks.

2

DESYCO: functionalities

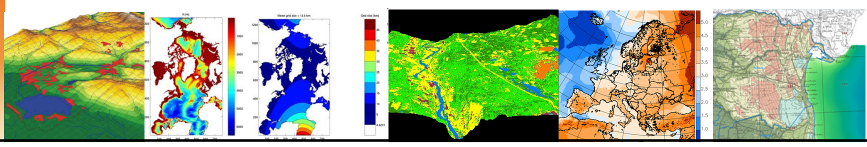
- **Source-Pathway-Receptor-Consequence** risk assessment approach;
- Provide **regional scale scenarios** using the output of **numerical models** simulations, **downscaling** techniques and **time series** analysis;
- **Transfer information about climate change** impacts and risks that is relevant to and usable by different sectors of society (policymakers, industry, cities, etc.);
- Provide a platform for responding to **stakeholders needs and challenges related to Climate Change**;
- Enable various stakeholders, governmental and non-governmental bodies and communities to start the implementation of appropriate **adaptation actions;**
- Use of automated **GIS tools** to **facilitate** the **visualization** and the **identification** of **coastal areas** and **receptors** exposed to the **risk of Climate Change**;
- Help to identify **significant impacts** and **risks** related to **ecological** and **human systems exposed to Climate Change impacts;**
- Provide a base for **coastal zoning** and **land use planning** considering **long-term scenarios** in a **ICZM** perspective**.**

3

DESYCO: structure

The structure of DESYCO comprises 3 major components:

- **A GEODATABASE with bio-physical and socio-economic data for the coastal area of the North Adriatic Sea.**
- **Multi-scale SCENARIOS provided by numerical models simulations or time series analysis.**
- **A Relative Risk Model (RRM) for the application of the Regional Risk Assessment (RRA) methodology.**



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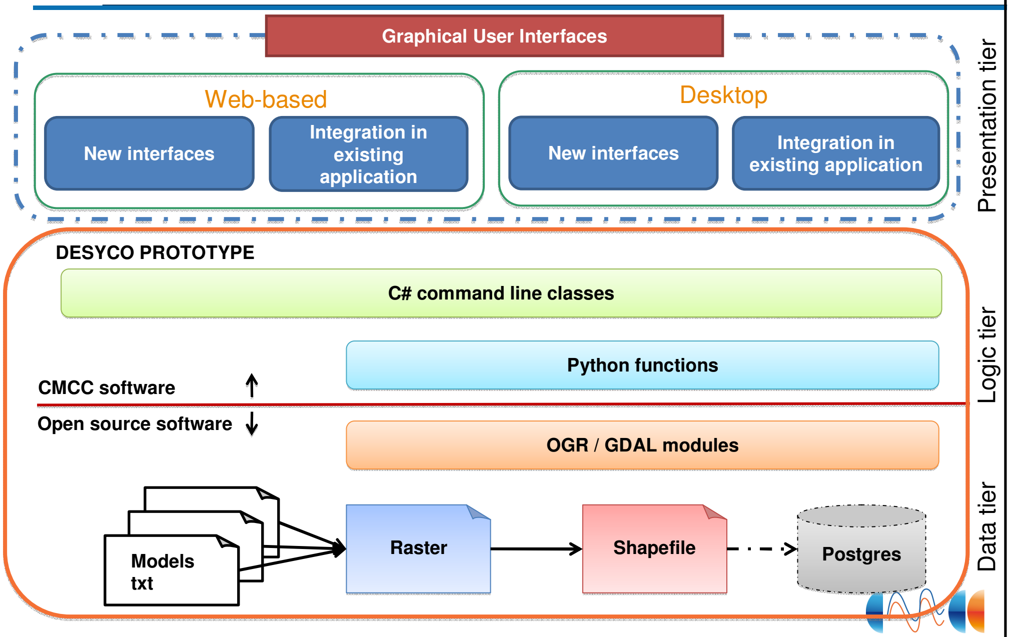
DESYCO Software architecture



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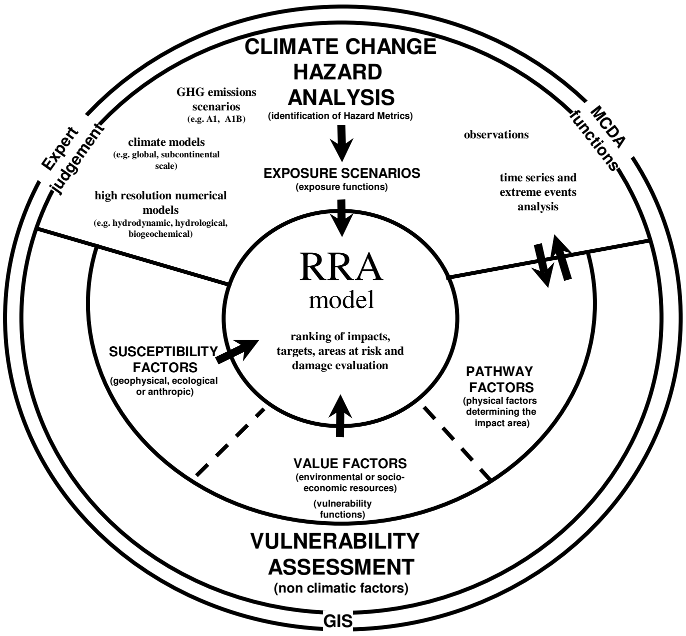
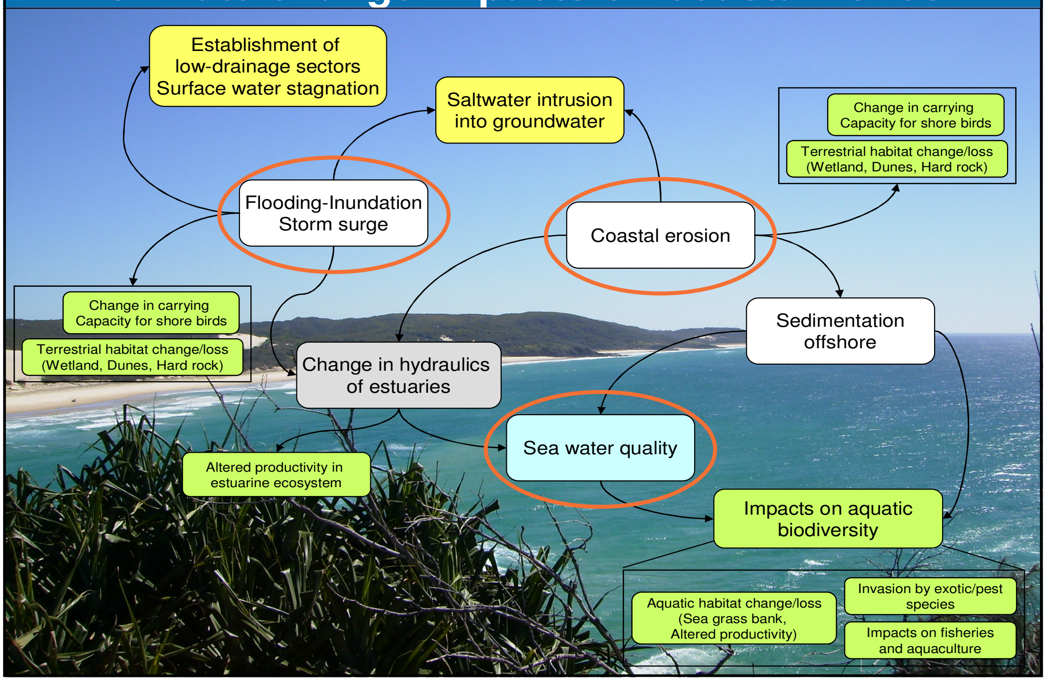
Regional Risk Assessment (RRA) conceptual framework



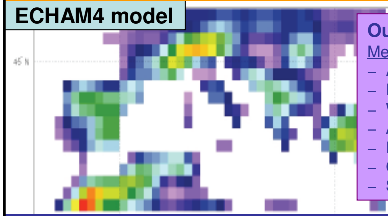
Climate change impacts on coastal zones



EXPOSURE SCENARIOS

Global climate simulations

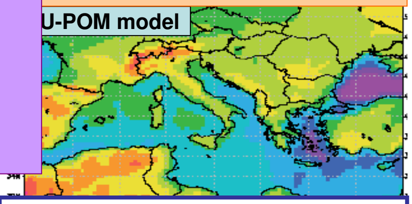
ECHAM4 model



World scale: 1,125°- 2°

Mediterranean climate simulations

U-POM model

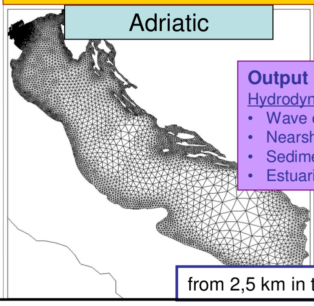


Med scale: 0,2° - 0,25°

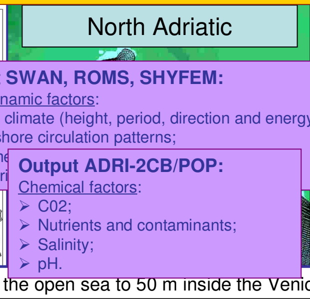
Output EBU-POM:
Meteoclimatic factors:
- Air/sea temperature;
- Rainfall;
- Winds;
- Atmospheric pressure;
- Relative humidity;
- Cloudiness;
- Salinity.

High resolution models:

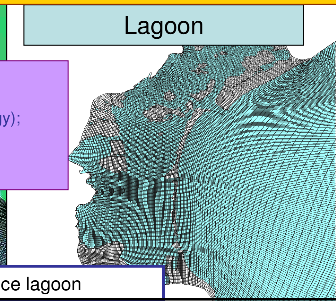
Adriatic



North Adriatic



Lagoon



Output SWAN, ROMS, SHYFEM:
Hydrodynamic factors:
- Wave climate (height, period, direction and energy);
- Nearshore circulation patterns;
- Sedime
- Estuari

Output ADRI-2CB/POP:
Chemical factors:
- C02;
- Nutrients and contaminants;
- Salinity;
- pH.

from 2,5 km in the open sea to 50 m inside the Venice lagoon

VULNERABILITY ASSESSMENT

Based on the considered IMPACT, the RVA require the identification of VULNERABILITY FACTORS for each analyzed RECEPTOR.

RECEPTORS

- Beaches and Dunes
- Estuaries and Deltas
- Wetlands
- Hydrological systems
- Terrestrial and Marine Biological systems
- Protected areas
- Fisheries and aquaculture
- Urban areas
- Agricultural areas

IMPACTS

- Hydrodynamic impacts
- Impacts on soil and groundwater
- Impacts on water
- Impacts on biodiversity

VULNERABILITY MATRIX

RECEPTORS / IMPACTS	BEACHES	RIVER MOUTHS	WETLANDS	HYDROLOGICAL SYSTEMS
HYDRODYNAMIC IMPACTS				
SLR Inundation	- Elevation	- Elevation	- Elevation	- Elevation
	- Protection level	- Protection level	- Protection level	- Water body configuration
		- Urban typology	- Extension of wetlands	- Protection level
		- Agricultural typology		
Storm surge flooding	- Elevation	- Elevation	- Elevation	- Elevation
	- Distance from coastline	- Distance from coastline	- Distance from coastline	- Distance from coastline
	- Artificial protections	- Artificial protections	- Artificial protections	- Water body configuration
	- Vegetation cover	- Vegetation cover	- Vegetation cover	- Protection level
	- Coastal slope	- Coastal slope	- E[illegible]sion of wetlands	
	- Geomorphology	- Geomorphology	- Protecti[illegible]	
	- Dunes	- Protection level		
	- Protection level	- Urban typology		
		- Agricultural typology		

VULNERABILITY FACTORS

Vulnerability factors and available dataset

VULNERABILITY FACTORS

Pathway factors:
- Elevation
- Distance from coastline

Susceptibility factors:
- Artificial protections
- Vegetation cover
- Coastal slope
- Geomorphology
- Dunes
- Wetland extension
- Water body configuration
- Sediment budget
- Mouth typology (estuary, delta)
- Seagrasses

Value factors:
- Protection level
- Urban typology (commercial buildings)
- Agricultural typology
- Fish farms
- Mariculture and musselculture
- Tegnue
- Fishing prohibited areas

DATASET:
Contour lines 1:5000
Digital Elevation Model (DEM)
Coastline

DATASET:
Corine Land Cover 2000
Coastline variations
Bathymetric points
Geomorphological maps
Relevant areas of environmental interest (ARIA)
River and Channels maps
Site of community importance (SCI) and Special Protection Areas (SPA)

DATASET:
Protected areas maps
Fish farming data
Corine Land Cover 2000

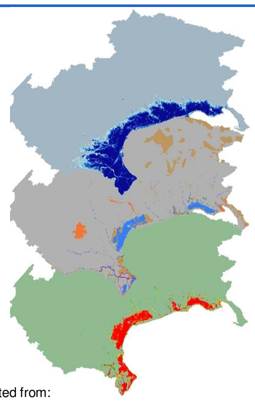
RRA output

Vulnerability maps	HAZARD METRICS, PATHWAY FACTORS	Exposure maps	Risk maps	Damage maps
	SUSCEPTIBILITY FACTORS →	Susceptibility maps		
	VALUE FACTORS →	Value maps		

Exposure map

Susceptibility map

Risk map



decision support tools useful to guide the impact/risk management phase.

Adapted from:
http://www.adrc.or.jp/publications/Venten/HP/herath4.jpg

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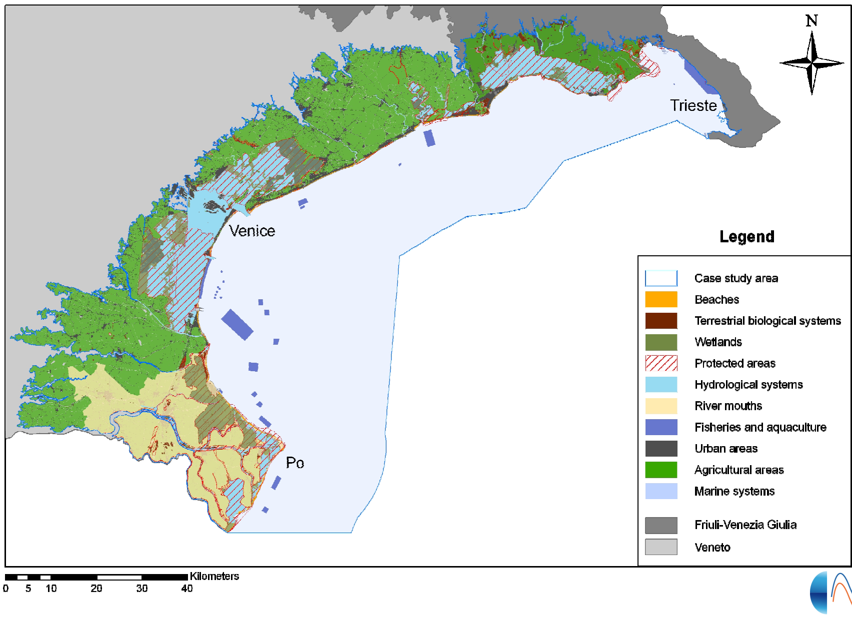
DESYCO CASE STUDY AREA: coast of the North Adriatic Sea



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Climate change issues

Relative sea level rise causes an increase of **high tide events** that flood the city of Venice which is a very important international monument.

Relative sea level rise in the last 100 years: 1,2- 2, 5 mm/year
(Antonioli et al., 2007)

30 high tide events ≥ 110 cm from 2000 to 2009.
(Municipality of Venice, 2008)

Erosion has been active both on the coastal sea floor and on the beach since the beginning of the 20th century and especially after 1960 (Bondesan et al. 1995).

ca. 14 % of Northern Adriatic coasts are eroding.
(Augelli et al., 2007)

Coastal areas located below sea level and affected by natural or man-induced **subsidence** are very frequent.

Po Plain subsidence: 1-2 mm/year. (Carminati and Martinelli, 2002)
Venice subsidence: 1,3 mm/year. (Carbognin et al., 2009)
Trieste subsidence**:** 0,25 mm/year. (Furlani et al., 2010)

Changes in **wetland** extent, position and type can be expected as accelerated sea-level rise increases forcing on wetland system (McFadden et al., 2007).

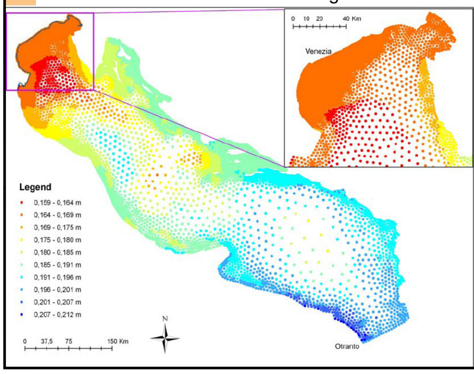
2,242 km^2 Ramsar areas.

Sea Level Rise inundation impact: data sources

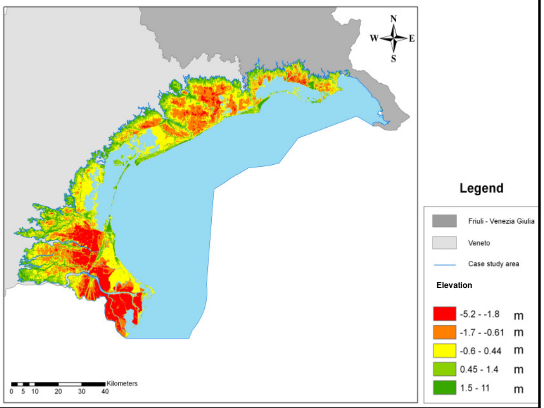
The **risk function** for the sea level rise inundation impact aggregates **data** provided by regional **hydrodynamic models** forced with climate change scenarios and **topographical data** coming from Digital Elevation Models in order to calculate coastal areas and targets at risk from inundation.

North Adriatic data sources:

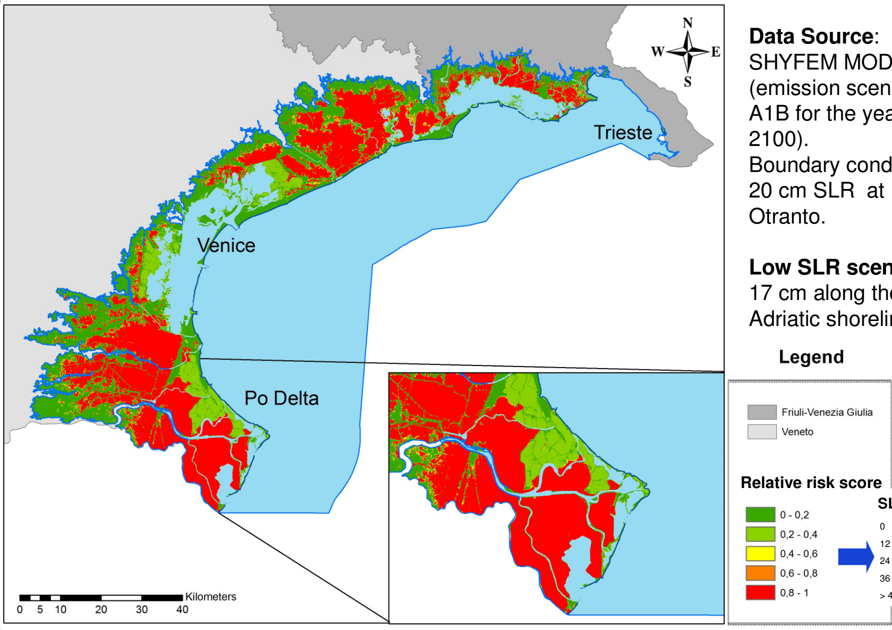
SHYFEM hydrodynamic model.
The resolution varies from 2,5 km in the open sea to 50 m inside the Venice lagoon.



Digital Elevation Model (DEM) 25 m.



Risk map for the Low Sea Level Rise scenario (17 cm)



Data Source:
SHYFEM MODEL (emission scenario A1B for the year 2100).
Boundary condition: 20 cm SLR at Otranto.

Low SLR scenario:
17 cm along the North Adriatic shoreline.

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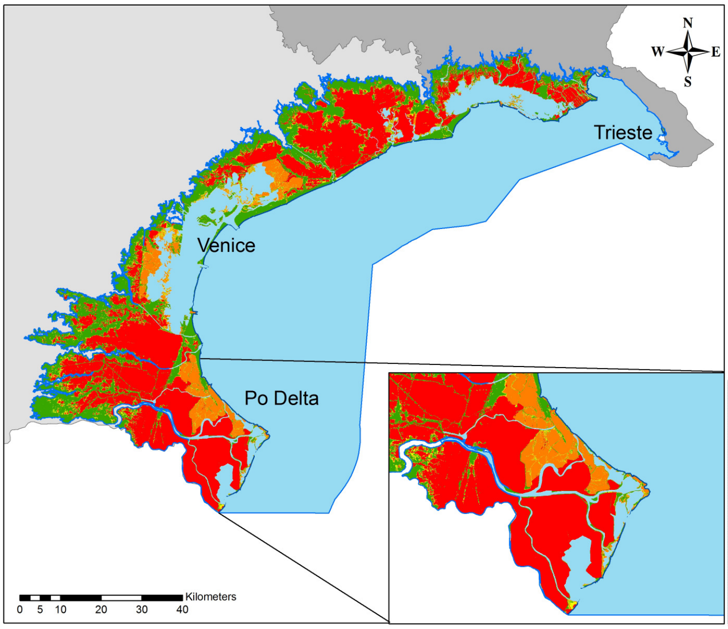
Risk map for the High Sea Level Rise scenario (42 cm)



Data Source:
SHYFEM MODEL (emission scenario A1B for the year 2100). Boundary condition: 20 cm SLR at Otranto.

High SLR scenario:
42 cm along the North Adriatic shoreline.

Legend

Friuli-Venezia Giulia
Veneto

Relative risk score

0 - 0,2
0,2 - 0,4
0,4 - 0,6
0,6 - 0,8
0,8 - 1

SLR (cm)

0 – 12
12 – 24
24 – 36
36 – 48
> 48

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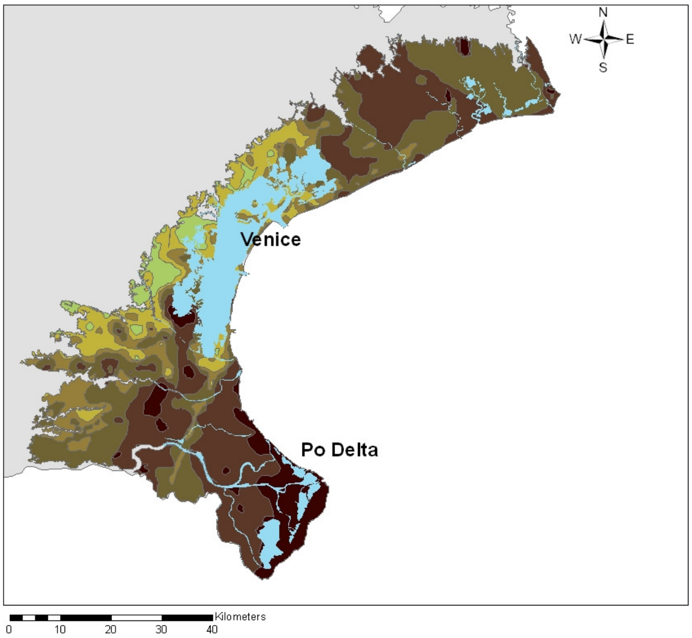
Relative Sea Level Rise inundation impact (including subsidence)



Veneto data source:
Subsidence map
(Carbognin et al., 2009)

Legend

Subsidence mm/y

0 < sub < 3
-1 < sub < 0
-2 < sub < -1
-3 < sub < -2
-5 < sub < -3
-10 < sub < -5

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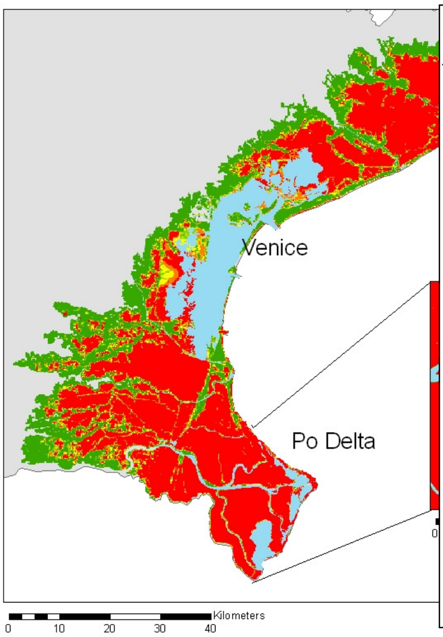
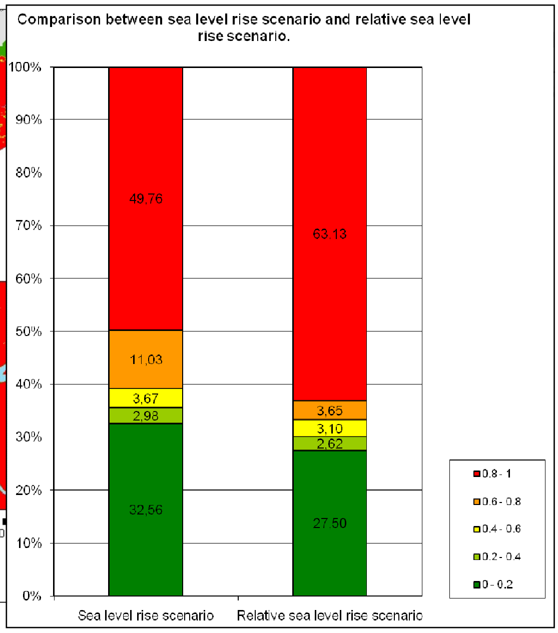
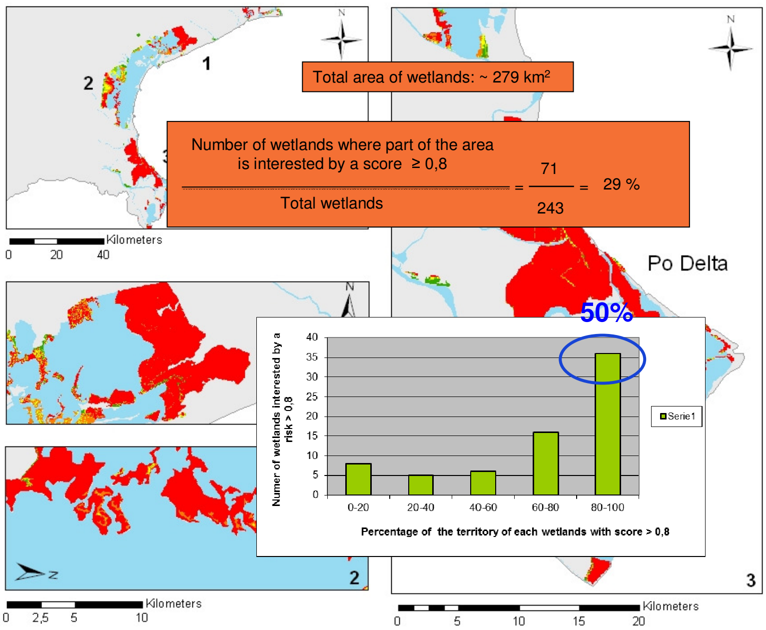
Risk map for the High Relative Sea Level Rise scenario (42 cm) (including subsidence)

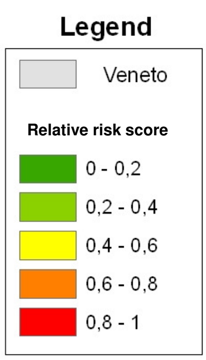




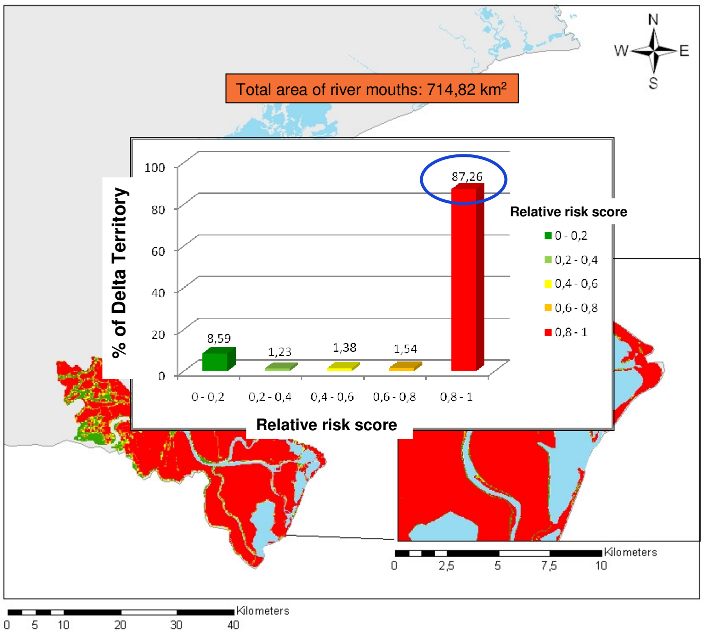
Risk map of wetlands to High RSLR scenario (including subsidence)



Data Source:
SHYFEM MODEL (emission scenario A1B for the year 2100).
Boundary condition: 20 cm SLR at Otranto.
High SLR scenario:
42 cm along the North Adriatic shoreline.
Subsidence map: Carbognin et al., 2009.



Risk map of the Po river Delta to High RSLR scenario (including subsidence)



Data Source:
SHYFEM MODEL (emission scenario A1B for the year 2100).
Boundary condition: 20 cm SLR at Otranto.
High SLR scenario:
42 cm along the North Adriatic shoreline.
Subsidence map: Carbognin et al., 2009.

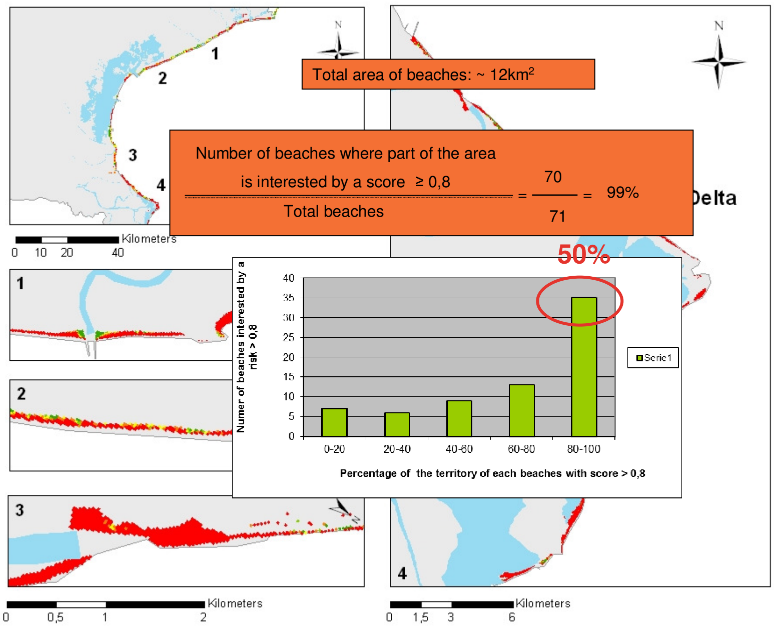
Legend

Veneto

Relative risk score

- 0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1

Risk map of beaches to High RSLR scenario (including subsidence)



Data Source:
SHYFEM MODEL (emission scenario A1B for the year 2100).
Boundary condition: 20 cm SLR at Otranto.
High SLR scenario:
42 cm along the North Adriatic shoreline.
Subsidence map: Carbognin et al., 2009.

Legend

Veneto

Relative risk score

- 0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1

DESYCO: participative approach

It is broadly recognised that a **DSS** can be successful if there is an **involvement** of the **potential end users** during the **development** of the tool (Van Kowen et al. 2007; Matthies, 2005; Uran and Janssen, 2002).

1. Stakeholder analysis: to identify the potential DSS end users.

Public institution	Number	Name
Region	2 (+2)	Friuli-Venezia Giulia Region: -Environment protection area -Town an country planning area Veneto Region: -Environment protection area -Town an country planning area
Province	5	-Trieste -Gorizia -Udine -Venezia -Rovigo
Municipality	18	Muggia, Trieste, Duino-Aurisina, Monfalcone, Staranzano, Grado, Marano Lagunare, Lignano Sabbiadoro, San Michele al Tagliamento, Caorle, Eraclea, Jesolo, Cavallino Treporti,Venezia, Chioggia, Rosolina, Porto Viro, Porto Tolle.
Port Authority	4	-Trieste -Monfalcone -Venice -Chioggia
Civil Engineering office	2	-Trieste -Venice
Regional Environment Protection Agency (ARPA)	2	Arpa FVG: -Upper Adriatic observatory Arpa Veneto: -Upper Adriatic observatory
River Basin Authority	1	Upper Adriatic River Basin Authority
Water Authority	1	Venice Water Authority

2. Administrator and analysis of the questionnaire.

Main fields investigated:

- climate change impacts on coastal zone;
- ICZM strategy and implementation;
- DSS functionalities.

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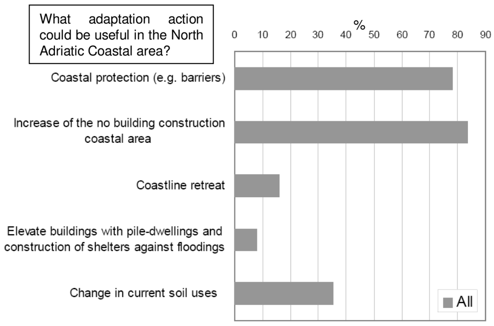
Result presentation

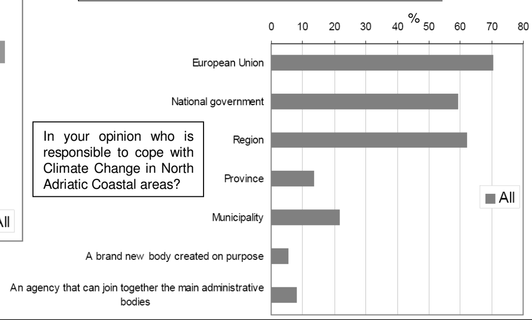
- 37 institution contacted, all of them replied to the questionnaire;
- 19 questions both open and close format.

Ranking of coastal zone receptors on the base of the respondents perceptions on receptors vulnerability.	
1	Beaches and dunes
2	Deltas and estuaries
3	Protected coastal areas
4	Hydrological systems
5	Wetlands
6	Marine biological systems (flora and fauna and respective habitats)
7	Terrestrial biological systems
8	Coastal tourism facilities
9	Coastal agricultural zone
10	Fisheries areas
11	Coastal residential zone
12	Ports
13	Coastal industrial areas
14	High coasts

What adaptation action could be useful in the North Adriatic Coastal area?



In your opinion who is responsible to cope with Climate Change in North Adriatic Coastal areas?



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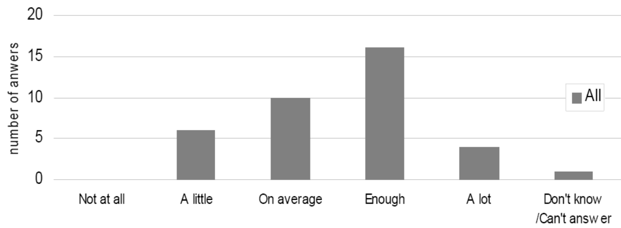
Result presentation

Do you think a DSS supplying climate change impacts information on coastal zones at Regional level (Veneto and Friuli coasts) could be useful for the Institution you are working for?



- The survey allowed to gain information that both **confirmed** the **validity** of the **methodology choices** (e.g. the validity of the set of **receptors** investigated by DESYCO; **functionalities** offered by DESYCO);
- The survey supplied some useful **contribution** to the **framework** (e.g. **suggestions** for other **receptors** to be considered in the vulnerability assessment);
- **Knowledge** of public institutions about **ICZM** is really **low**;
- Public institutions ask for **short time** frame **hazard scenarios** while the **DESYCO**, depending on the available information supplied by models, con supply only **long term scenarios**.

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Conclusions

- **DESYCO** and the **RRA approach** are **innovative tools** to study **climate change impacts** on **coastal** zones at the **regional scale** and support the **development** of effective **adaptation strategies** and sustainable **ICZM**, taking into account the **increasing issues** related to **climate change**.
- Regional vulnerability/risk classifications should not attempt to provide **absolute predictions** about the impacts of climate change. Rather, they should be **relative indices** which provide information about the areas within a region likely to be affected more severely than others.
- **DESYCO** can be a useful tool to **investigate** the **impacts** associated to **different climate change scenarios in sensitive areas** (e.g. river deltas, coastal lagoons and estuaries) and to support the **development** of **sustainable policies**, taking into account the **risks** associated to **future climate change projections**.
- **DESYCO** can be used to **prioritize** areas more **vulnerable** to **relative sea level rise** and **coastal erosion** due to climate change and can support the **identification** of more **suitable areas** for the **construction of artificial coastal protections** and for the **nourishment** of **beaches** and **wetlands**.

Risk function for the Sea Level Rise inundation impact

The **risk function** for the sea level rise inundation impact aggregates **data** provided by regional **hydrodynamic models** forced with climate change scenarios and **topographical data** coming from Digital Elevation Models in order to calculate coastal areas and targets at risk from inundation.

$$R_{slr,s} = min\left(max\left(\frac{h_{1(s)} - p_1}{s_1}, 0\right), 1\right)$$

$R_{slr,s}$ = risk score in a scenario *s;*

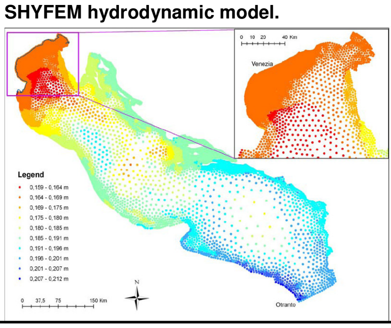
$h_{1(s)}$ = height of sea level rise according to scenario *s;*

p_1 = height of a cell;

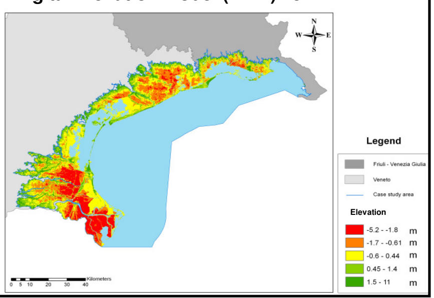
s_1 = threshold representing the amount of water above a cell which generate the maximum impact.

North Adriatic data sources:

SHYFEM hydrodynamic model.



Digital Elevation Model (DEM) 25 m.



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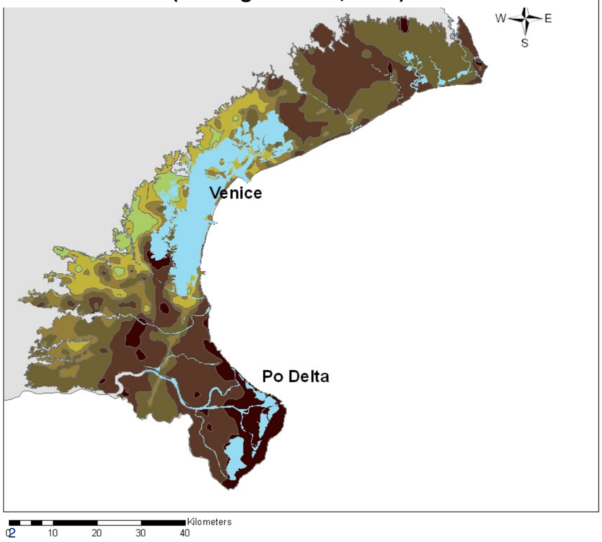
Risk function for the Relative Sea Level Rise inundation impact

Veneto data source: Subsidence map
(Carbognin et al., 2009)



$$R_{rslr,s} = min\left(max\left(\frac{h_{1(s)} - (p_1 + p_2\Delta t)}{s_1}, 0\right), 1\right)$$

$R_{rslr,s}$= risk score in a scenario *s;*

$h_{1(s)}$ = height of sea level rise according to scenario *s*;

p1 = height of a cell;

p2 = uplift/subsidence

Δt = (t_s − t_0), where t_s is the year of the considered scenario *s* and t_0 is the year of the measured subsidence:

s1 = threshold representing the amount of water above a cell which generate the maximum impact.

Legend

Subsidence mm/y

(light green)	0 < sub < 3
(yellow)	-1 < sub < 0
(light brown)	-2 < sub < -1
(olive)	-3 < sub < -2
(brown)	-5 < sub < -3
(dark brown)	-10 < sub < -5