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Triton

Evaluating coastal erosion risks in the Ugento shoreline: A Machine Learning approach supporting multi-scenario analysis

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Project co-funded by European Union, European Regional Development Funds (E.R.D.F.) and by National Funds of Greece and Italy

Outline

1. Motivations and objectives
2. Theoretical background
3. Case study area
4. Data collection and pre-processing
5. BN methodology
6. Results and discussion
7. Conclusion
8. Future developments

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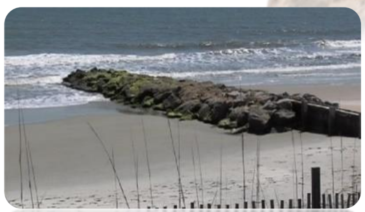
1. Motivations



Measures

Balance between coastal risk management measures and development of integrated approaches.

Consequences

Coastal erosion leading to shoreline movement, water quality deterioration, biodiversity loss and species shift.

Anthropogenic pressures

Coastal economic development and connected land use changes.

Natural pressures

Rising sea-level, changes in dynamics, energy distribution of waters, as well as variations in pattern, frequency and intensity of extreme events.

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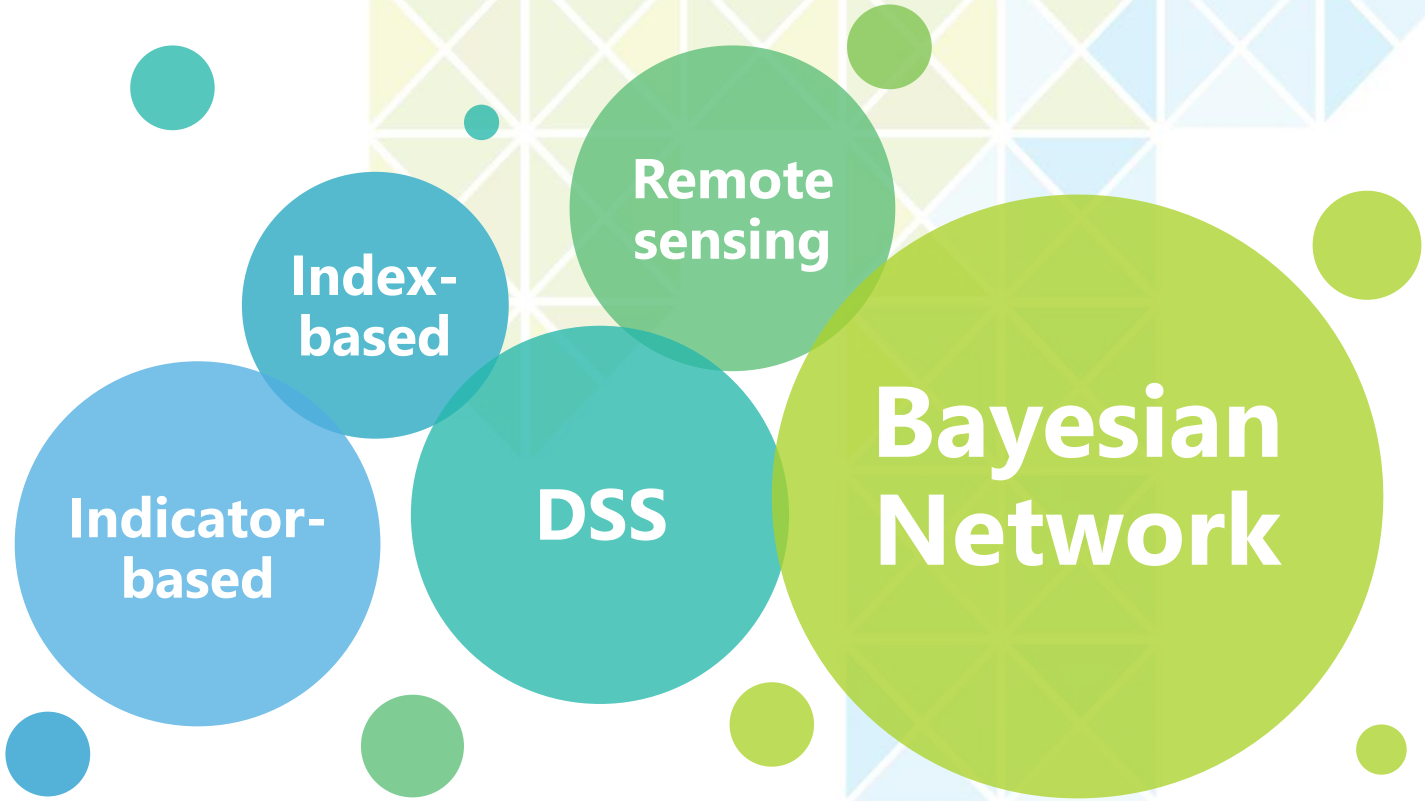
2. Theoretical background



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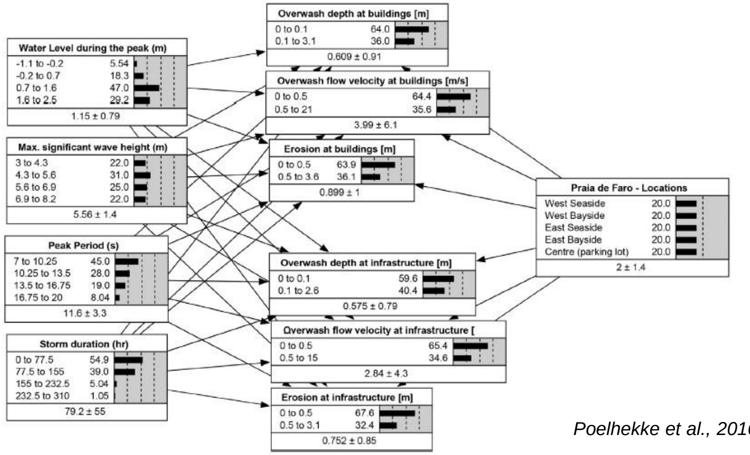
2. Theoretical background

The Bayes' theorem

- **BBNs are probabilistic graphical models** representing the system's components (variables) and their relationships (conditional interdependencies) by combining principles of Graph theory and Probability theory (Pearl, 2011).
- They are **graphically-based to facilitate the rapid conceptualization of the system** to be managed (e.g. marine region) and the evaluation of the dependence/independence between data and their inherent uncertainty evaluated as belief probabilities.
- They allow to **consider multiple stressors and endpoints in the same framework**, supporting modelling and analysis of complex marine environments.
- **They integrate different knowledge domains, expertise and data sources** (e.g. GIS data, MCDA and environmental indicators) into a complex system acting as a **decision support tool** informing coastal risk assessment and management.



Poelhekke et al., 2016

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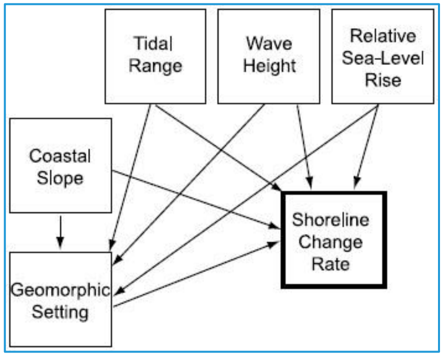
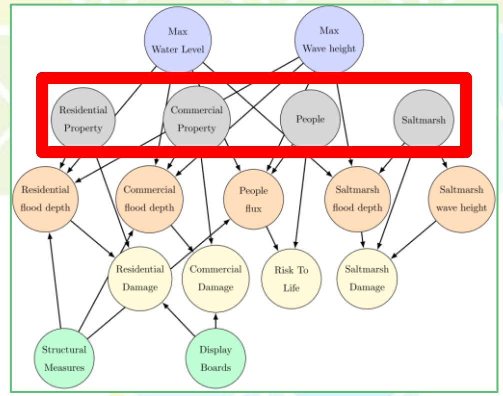
2. Theoretical background



Integration of location and baseline scenario analysis

Poelhekke et al., 2016

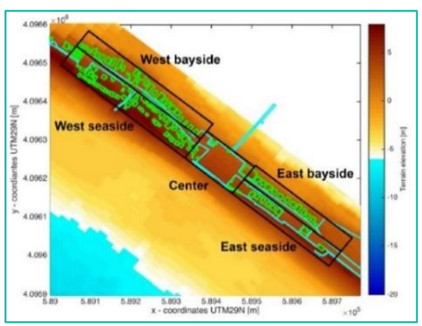


Implementation of potential management measures

Plomaritis et al., 2017

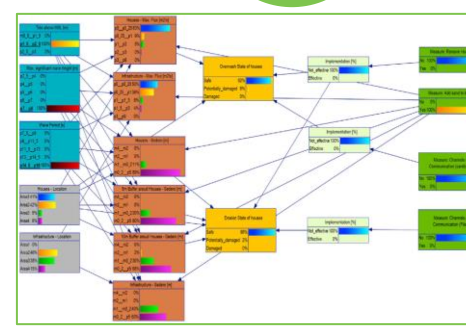
Gutierrez et al., 2011

BN application to coastal erosion and mapping outcomes



Jäger et al., 2017

Integration of environmental and human receptors



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3. Case study area

Apulia region

- 970 km of coastline (mostly flat, sandy beaches)
- 13.8% characterized by marine protected areas, national and regional parks

Regional Coastal Plan

- Shoreline analysis (2005-2017 timeframe)
- Identification of 7 Physiographic Units
- Analysis performed within a 10 m buffer zone

Municipality of Ugento

- 13 km of coastline
- one of the mostly affected shorelines in the Apulia region (about 1.5 km of eroded coast)

> ✓ Selected as best practice for coastal erosion management within the **TRITON** project
> ✓ Integration of nature-based solutions (NBS) to address coastal erosion risk

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4. Data collection and pre-processing

Data collection

Data type	Spatial domain	Year	Spatial resolution	Time-frame Reference period	Data Format	Reference/Link
Basemap data						
Administrative Boundaries	World	2015	/	/	Shapefile	http://gadm.org
Coastline	Europe	2015	/	/	Shapefile	https://www.eea.europa.eu/data-and-maps/data/eea-coastline-for-analysis-1
Oceanographic forcing						
Sea surface height above geoid	Europe	2018	0.0625*0.0625	1987-2018	NetCDF	http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=MEDSEA_REANALYSIS_PHYS_006_004
Eastward sea water velocity	Europe	2018	0.0625*0.0625	1987-2018	NetCDF	http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=MEDSEA_REANALYSIS_PHYS_006_004
Northward sea water velocity	Europe	2018	0.0625*0.0625	1987-2018	NetCDF	http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=MEDSEA_REANALYSIS_PHYS_006_004
Wave direction from	Europe	2019	0.042*0.042	2006-2019	NetCDF	http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=MEDSEA_HINDCAST_WAV_006_012
Significant wave height	Europe	2019	0.042*0.042	2006-2019	NetCDF	http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=MEDSEA_HINDCAST_WAV_006_012
Sea surface wave mean period	Europe	2019	0.042*0.042	2006-2019	NetCDF	http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=MEDSEA_HINDCAST_WAV_006_012
Wind wave direction	Europe	2019	0.042*0.042	2006-2019	NetCDF	http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=MEDSEA_HINDCAST_WAV_006_012
Significant wind wave height	Europe	2019	0.042*0.042	2006-2019	NetCDF	http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=MEDSEA_HINDCAST_WAV_006_012
Sea surface wind wave mean period	Europe	2019	0.042*0.042	2006-2019	NetCDF	http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=MEDSEA_HINDCAST_WAV_006_012
Environmental data						
Suspended Matter	Europe	2017	4km	1997-2019	NetCDF	http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=OCEANCOLOUR_GLO_OPTICS_L4_REP_OBSERVATIONS_009_081
Diffuse attenuation	Europe	2017	4km	1997-2019	NetCDF	http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=OCEANCOLOUR_GLO_OPTICS_L4_REP_OBSERVATIONS_009_081
Nature-based solution	Ugento	2018	User-defined	2009-2018	Shapefile	(Comune di Ugento, 2014; Regione Puglia, 2018)
Socio-economic data						
Infrastructures	Ugento	2018	User-defined	2009-2018	Shapefile	(Regione Puglia, 2018)

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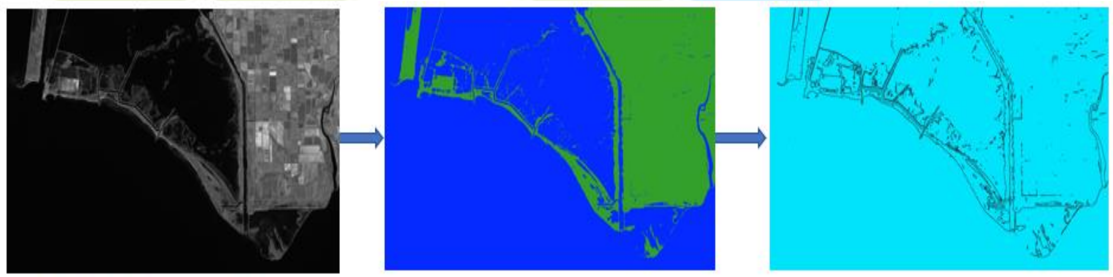
4. Data collection and pre-processing

Data pre-processing

Shoreline evolution

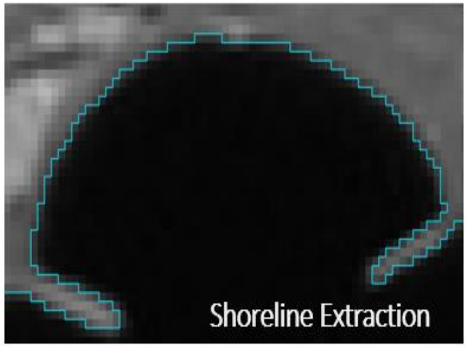
Satellite images
RapidEye
Spatial resolution 5m

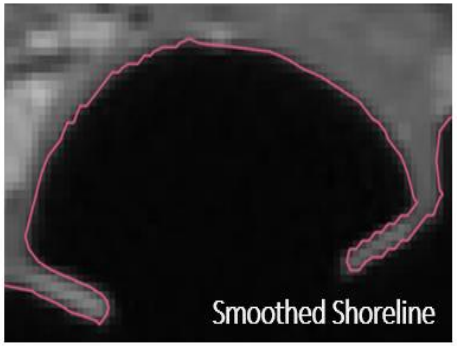


Satellite Image – Near Infrared Band

Classified Image (Land - Sea)

Raster to Vector





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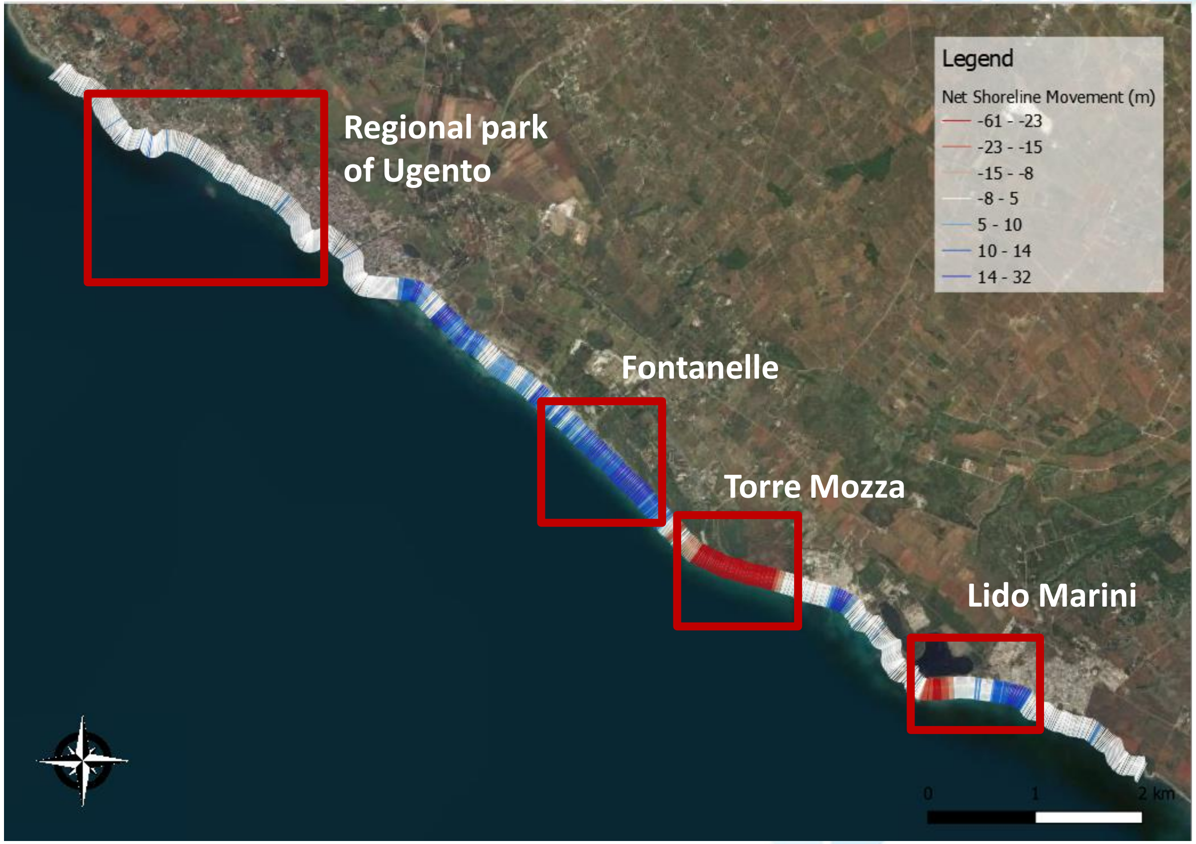
4. Data collection and pre-processing

Data pre-processing

Shoreline evolution

DSAS tool



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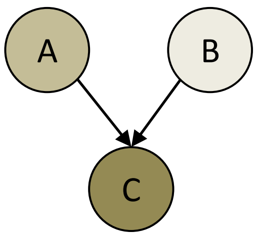
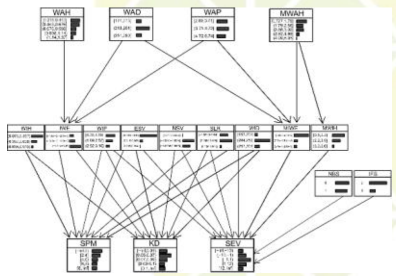
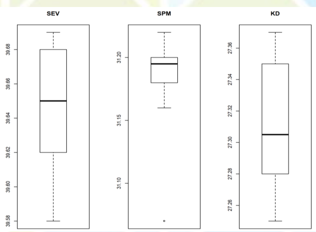
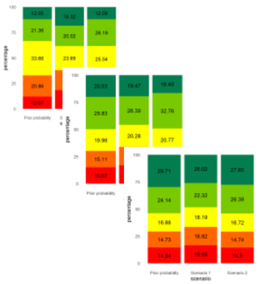
5. BN methodology

Methodological steps for BN implementation









CONCEPTUAL MODEL:
Define the structure of the network and identify its main variables and relationships represented by using a conceptual/ influence **'nodes and arrow'** diagram, and by applying different learning processes to automatically extract the network structure

MODEL PARAMETRIZATION:
Define **states** for all variables (interval, boolean, labelled) and calculate the associated **prior probability** resulting from data distribution as well relationships between nodes described by the **conditional probability** distributions.

CALIBRATION and VALIDATION:

Evaluate the performance/ prediction accuracy of the BN model through two different types of validation methods:
- the data-based validation;
- the qualitative evaluation.

SCENARIOS ANALYSIS:
By inferring behavior of the variables at stake against different conditions defined by setting specific state/s of a node/s (**evidence**) and then propagating information between nodes based on the Bayes theorem, thus resulting in **the posterior probability.**

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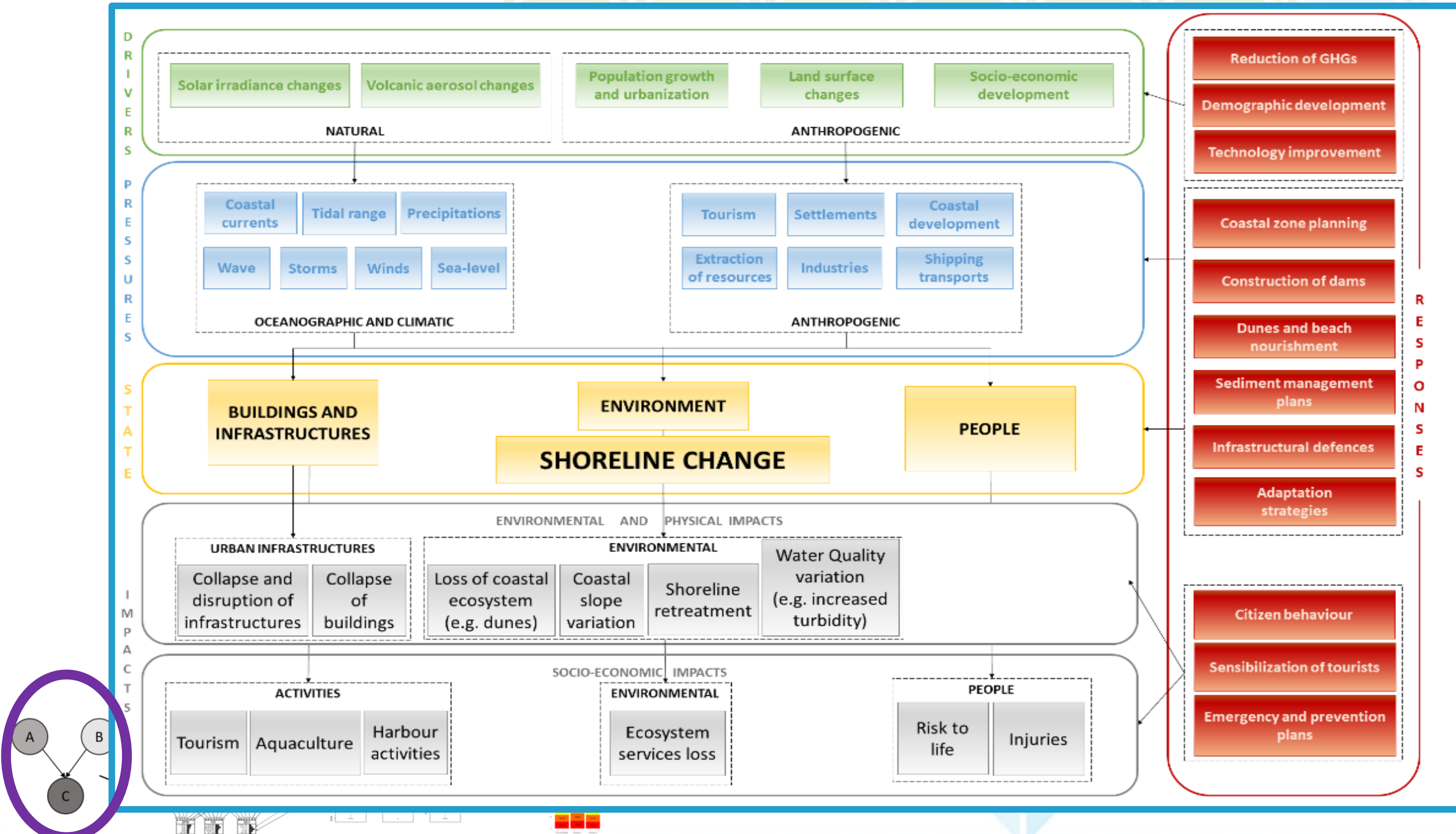
5. BN methodology



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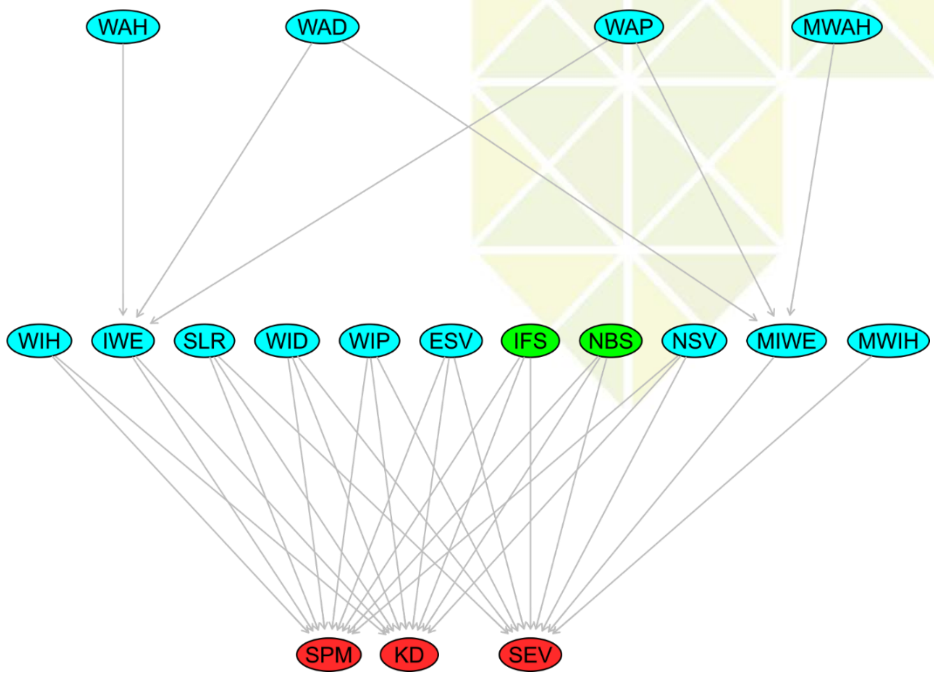
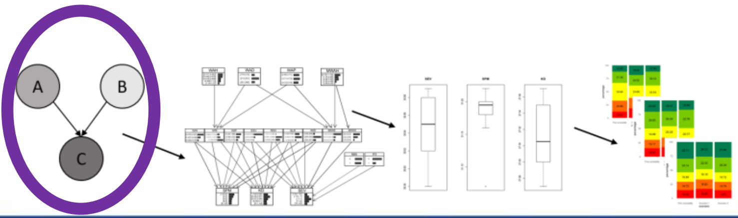
5. BN methodology – *BN design*



Oceanographic drivers
Management measures
Assessment endpoints

Acronym	Unit	Variable
KD	$[m^{-1}]$	Diffuse attenuation
ESV	$[m\ s^{-1}]$	Eastward sea water velocity
IWE	$[J\ m^{-1}\ s^{-1}]$	Incident wave energy at the breaker zone
IFS	[0 or 1]	Infrastructures
MWAH	[m]	Max significant wave height
MWIH	[m]	Max significant wind wave height
MIWE	$[J\ m^{-1}\ s^{-1}]$	Max incident wave energy at the breaker zone
NBS	[0 or 1]	Nature-based solutions
NSV	$[m\ s^{-1}]$	Northward sea water velocity
SLR	[m]	Sea-level rise
WAP	[s]	Sea surface wave mean period
WIP	[s]	Sea surface wind wave mean period
SEV	[m/year]	Shoreline evolution
WAH	[m]	Significant wave height
WIH	[m]	Significant wind wave height
SPM	$[g\ m^{-3}]$	Suspended matter
WAD	[degree]	Wave direction from
WID	[degree]	Wind wave direction from



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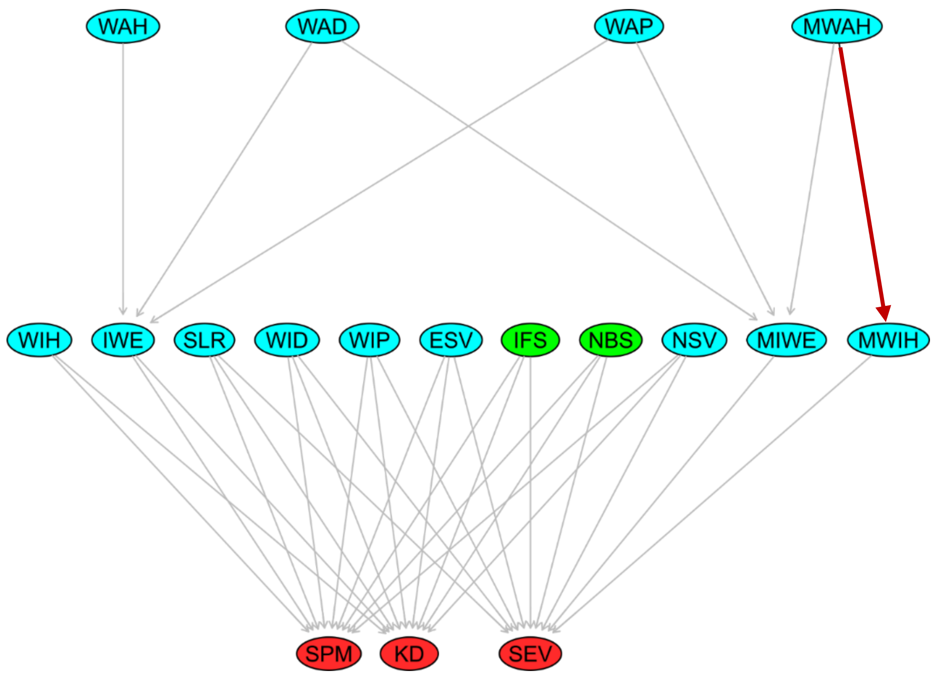
5. BN methodology – *BN model learning*



Oceanographic drivers
Management measures
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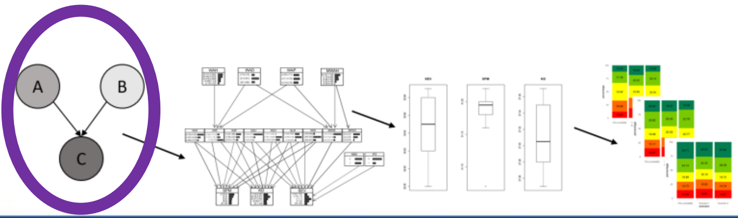

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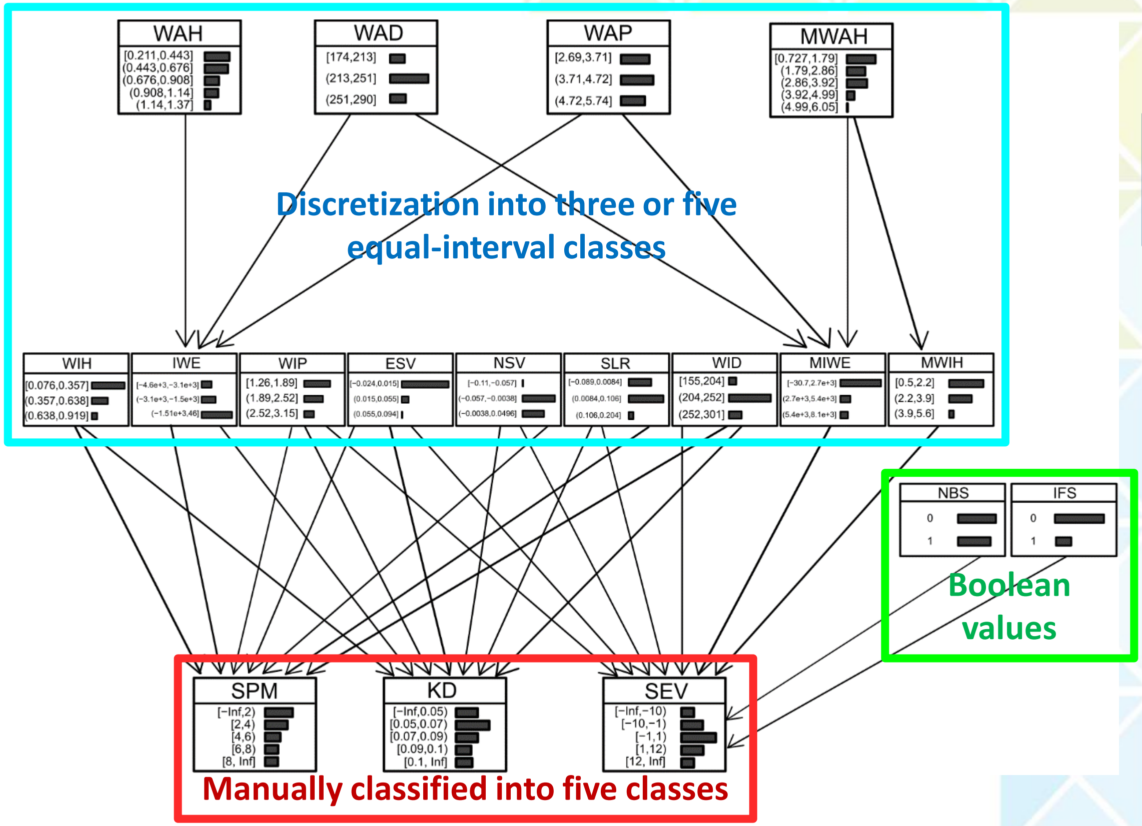
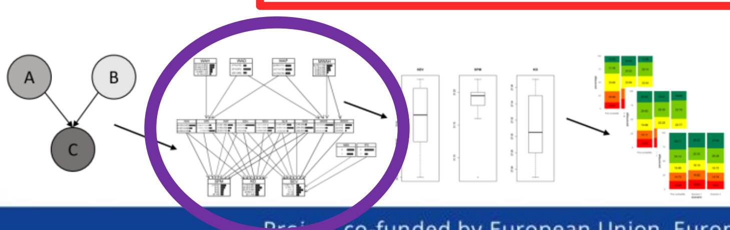
5. BN methodology – *BN parametrization*





Oceanographic drivers
Management measures
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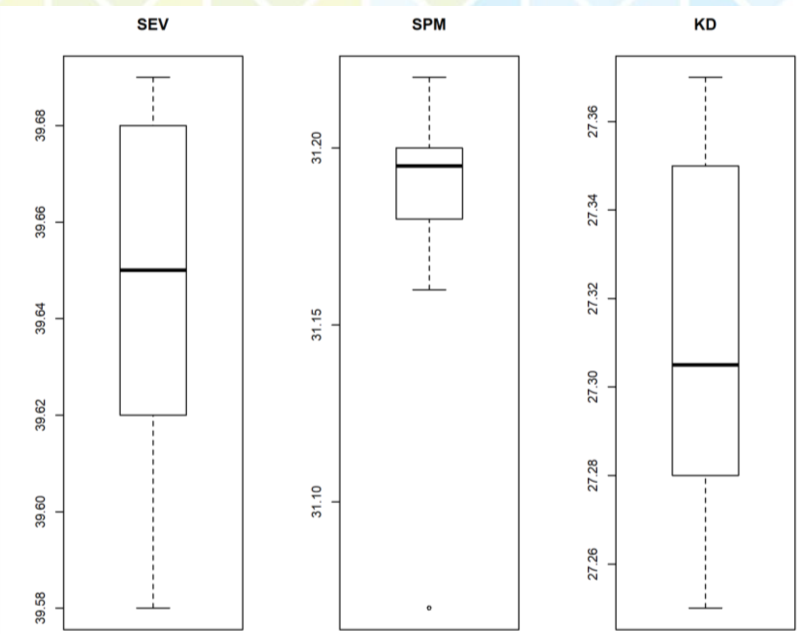
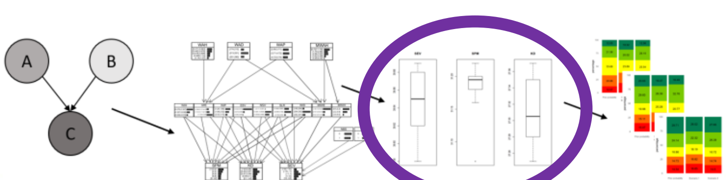
5. BN methodology – *Calibration and validation*

<u>Model validation</u>
- ✓ *k-fold cross-validation (k-cv)*
- ✓ *mean classification error vs. 10-folds*



39.6% | 31.2% | 27.3%

Mean prediction error



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5. BN methodology – *Scenario analysis*

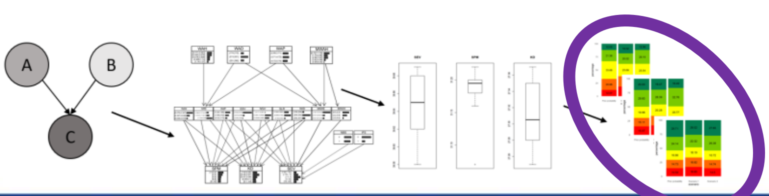
DIAGNOSTIC INFERENCE

A rapid changing world

Extreme events with higher significant wave height, as a consequence of climate change, can strongly impact the shoreline evolution in the Ugento case study?

Green is the new black

What are the required management measures to reduce coastal erosion risks along the Ugento shoreline?



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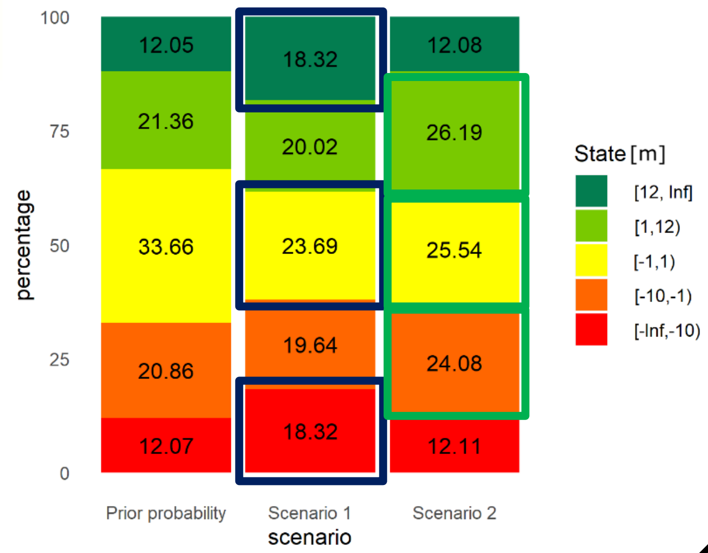
6. Results and discussion

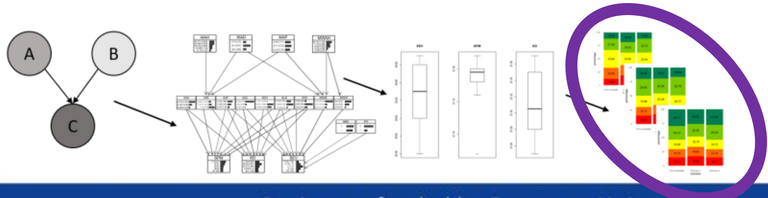
Scenario 2: *Green is the new black*

100% probability of implementing NBSs along the shoreline

Moderate accretion	4.8% increase
Stable	8% reduction
Moderate erosion	3.2% increase



SHORELINE EVOLUTION



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6. Results and discussion

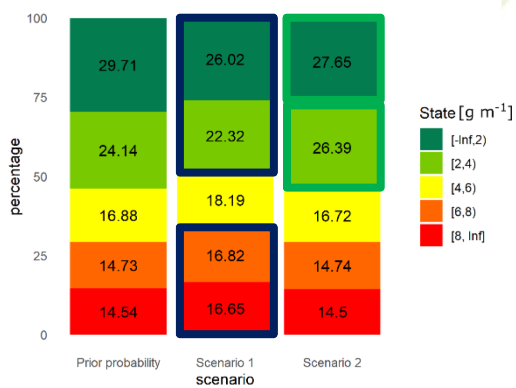
Scenario 2: *Green is the new black*

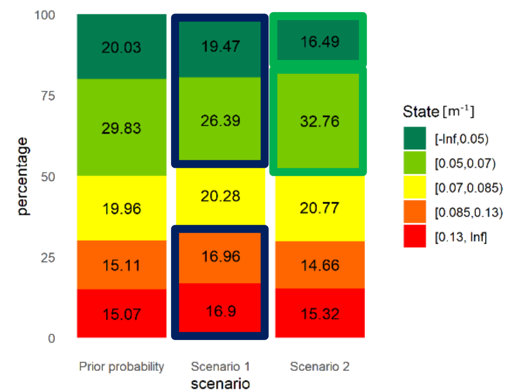
100% probability of locating NBS along the shoreline

‘Very low’ classes 2% and 4% increase

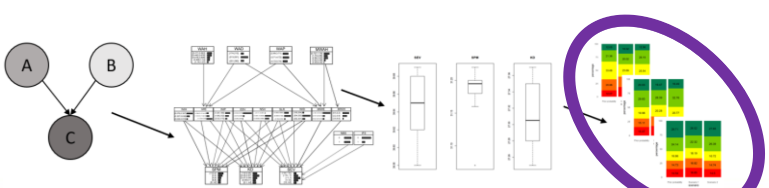
‘Low’ classes 2% and 3% reduction

SUSPENDED MATTER





DIFFUSE ATTENUATION



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7. Conclusions

Strengths and weaknesses

REPLICABLE AND EASY-TO-USE TOOL
taking into account the complexity and uncertainty of the coastal system

BROADER CONCEPT OF COASTAL EROSION RISK
- nexus between oceanographic boundary conditions, management measures and assessment endpoints

DECISION SUPPORT SYSTEM
to drive ICZM and adaptation planning

FLEXIBLE TOOL
- for interdisciplinary studies
- possibility to update the model

COMMUNICATION
- graphically-based conceptualization

INPUT DATA
- coarse spatial resolution
- Integration of other variables influencing water quality variation (e.g. precipitation, river run-offs)

MODEL DESIGN
- limitations in modelling complex synergies and temporal changes occurring in coastal ecosystems

PARAMETRIZATION
- poor representation of spatio-temporal dynamic of environmental processes

OUTPUTS
- gap between GIS and BN integration / mutual dialog

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8. Future development

DYNAMIC PATTERN
of the coastal environment

COMPLEX and ADVANCED Machine Learning
- (e.g. Artificial Neural Networks - ANN)

ICZM PERSPECTIVE
- useful tool for water resources assessment and management

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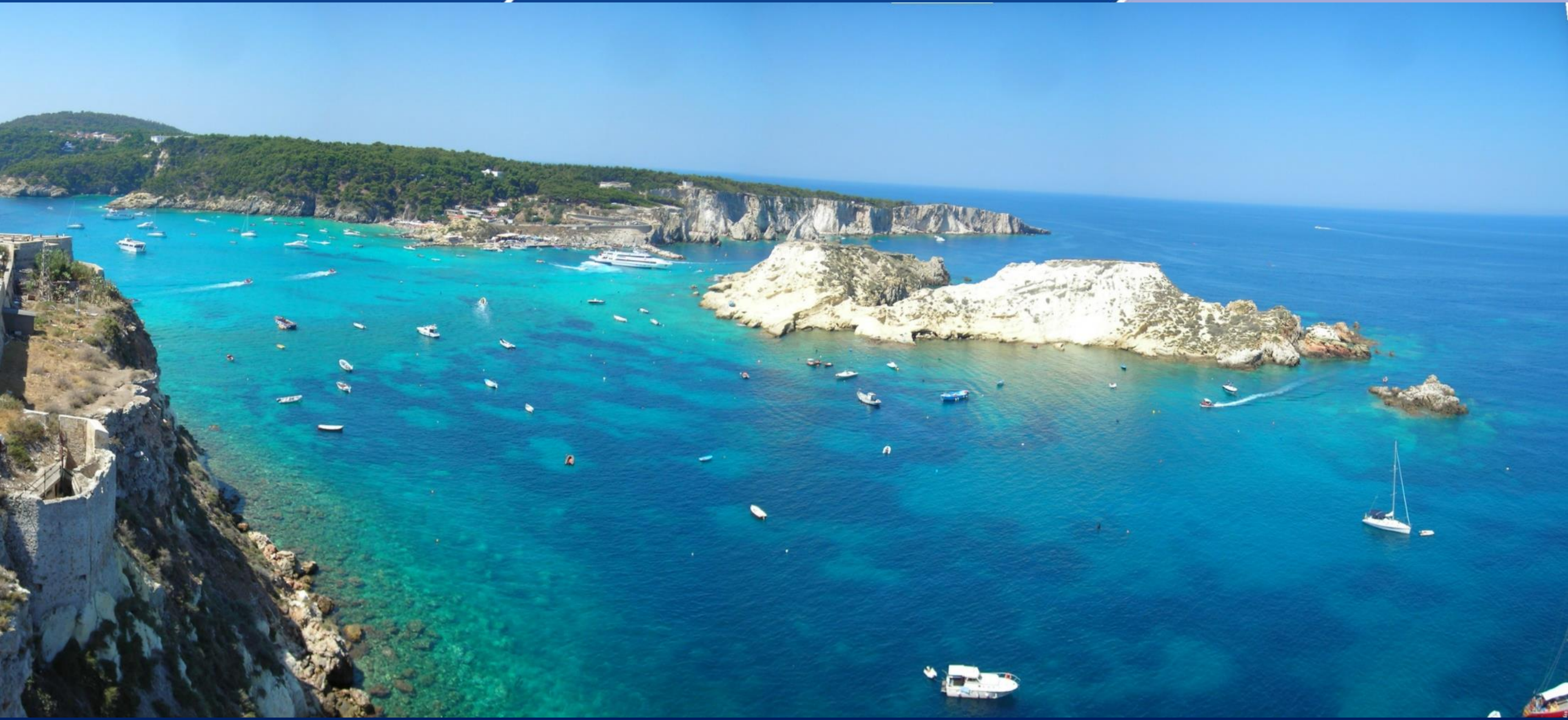

Thanks for your attention!

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For more information:

Euro-Mediterranean Center on Climate Change (CMCC), Risk Assessment and Adaptation Strategies Division, Venice:
https://www.cmcc.it/research-organization/research-divisions/risk-assessment-and-adaptation-strategies