Impatti dei cambiamenti climatici sulle risorse idriche: approcci e strumenti integrati a supporto delle politiche di adattamento

Silvia Torresan, Fondazione Centro Euromediterraneo sui Cambiamenti Climatici

CReIAMO PA

Per un cambiamento sostenibile

UNIONE EUROPEA
Fondo Sociale Europeo
Fondo Europeo di Sviluppo Regionale

Agenzia per la Coesione Territoriale

Presidenza del Consiglio dei Ministri
Dipartimento della Funzione Pubblica

MINISTERO DELL'AMBIENTE E DELLA TUTELA DEL TERRITORIO E DEL MARE

PON GOVERNANCE E CAPACITÀ ISTITUZIONALE 2014-2020

SOGESID

Climate change impacts on water resources

Climate change is likely to affect the quantity, quality and availability of water resources in multiple ways (Jiménez-Cisneros et al., 2014);

Extreme precipitation, storms, and floods:

- Increase urban and agricultural runoff into surface waters;

Extended droughts and dry soil conditions:

- Soils more susceptible to erosion
- Rapid transit of chemicals into groundwaters;

Increase in CO_2 level:

- Water acidification;

Extreme temperatures:

- Thermal Stratification
- Salinity changes

Changes in structure and functioning of aquatic ecosystems

- Shifts in timing and magnitude of phytoplanktonic blooms & consequent effects on higher trophic levels;
- Loss of habitat and biodiversity;
- Harmful algal blooms;
- Hypoxic and anoxic events.
- Reduced ecosystem services (regulation, provisioning, cultural, supporting);

CReIAMO PA

Climate change impacts on water resources

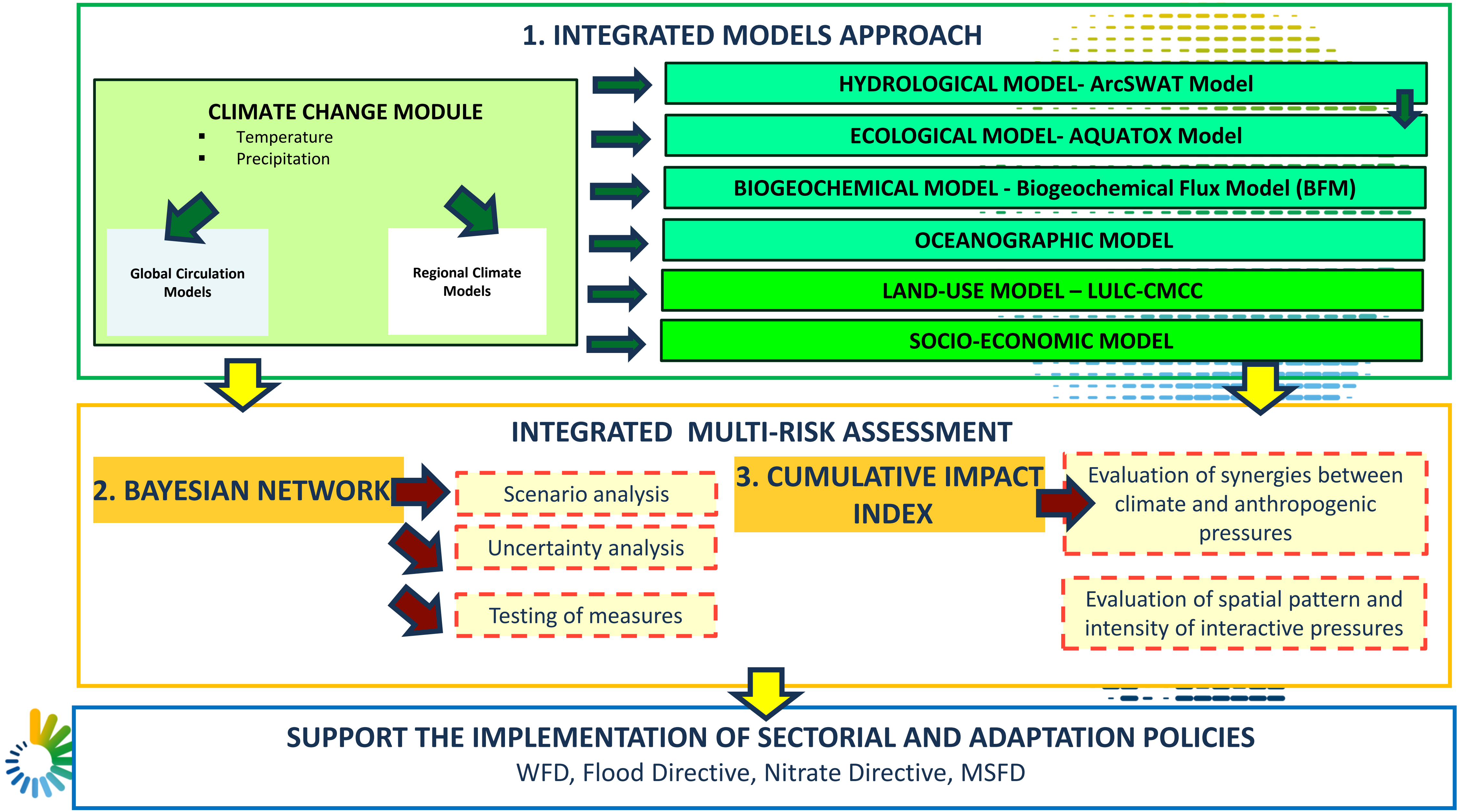
The assessment of climate change impacts on water resources is notoriously difficult due to the **multiplicity of physical processes involved** and the **dynamic nature of socio-ecological systems:**

- **Multiple scale** (temporal and spatial);
- **Multiple agents** or stressors (environmental, social and economic);
- **Complex and non-linear relations and responses**;
- High degree of **uncertainty**.

Predicting the conjoined impact of multiple stressors **is required to support the implementation of well targeted management strategies** exploiting potential synergies between climate change adaptation and sectorial water policies (**e.g. WFD, Flood Directive, Nitrate Directive, MSFD).**

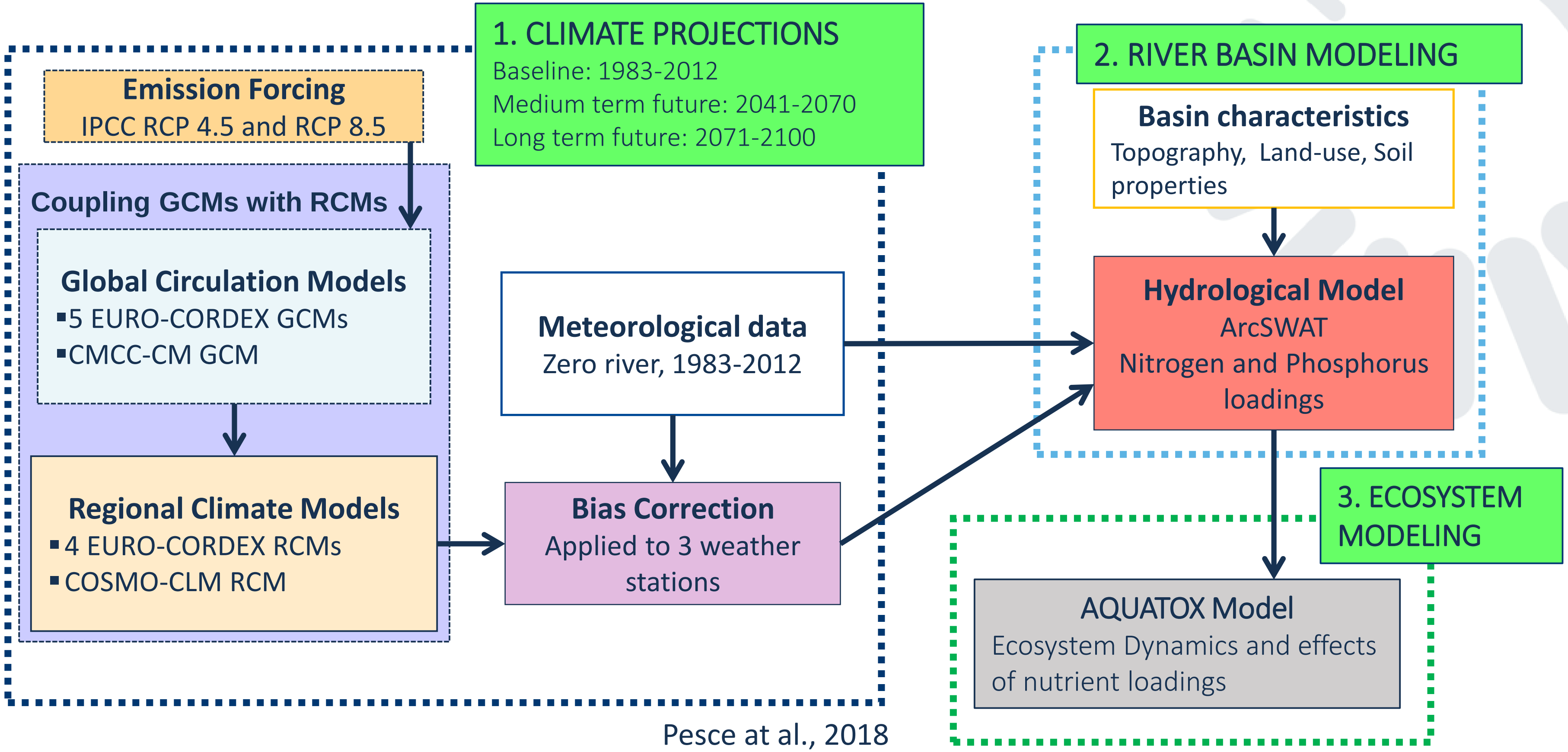
Need of integrated models and approaches

Tools and methods for climate change impact assessment



INTEGRATING CLIMATE-HYDROLOGICAL-ECOLOGICAL MODELS:

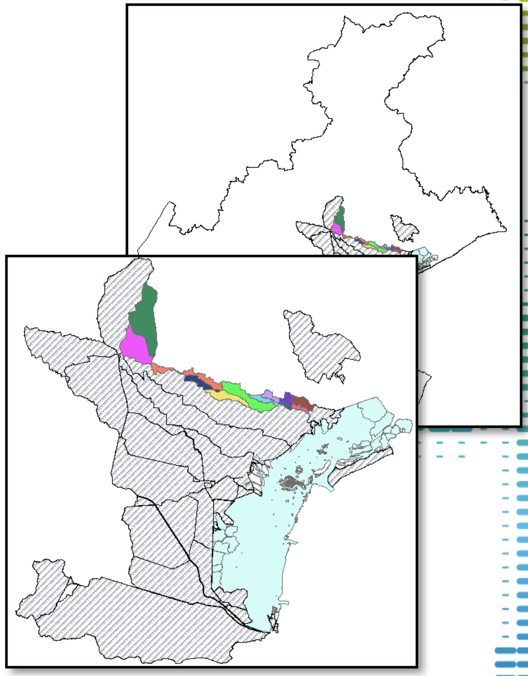
Development & application of an integrated modeling approach to study medium to long-term impacts of climate change on nutrient loadings and the consequent effects on coastal aquatic ecosystems over the 21st century.



Pesce at al., 2018

CReIAMO PA

CASE STUDY: The Zero river basin and Palude di Cona

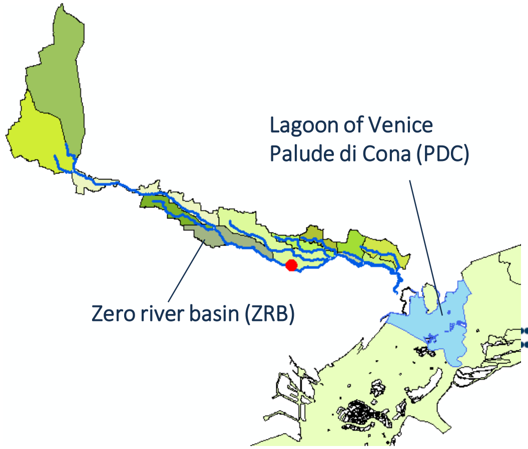


Zero River Basin (ZRB)

- Drainage area: 140 km^2
  - Urban areas: 24%
  - Agricultural areas: 69% (corn, soy, wheat)
  - Green & Pasture areas: 7%
- Jointly with Dese river, it delivers the greatest contribution of freshwater and nutrients into the Lagoon of Venice
- Complex hydrological network: *irrigation channels, emergency flow regulation, complex groundwater recharge system*

Palude di Cona (PDC)

- Surface: 2 km^2
  - Shallow waters (mean depth 0.5 m)
  - Main ecological features: salt-marshes & mudflats
  - Influenced by freshwater input of Zero & Dese rivers (average salinity: 23 PSU)



CReIAMO PA
www.sicab.net

INPUT DATA:

1. Integrated models

Climate projections obtained from an **ENSEMBLE** of global and regional climate models **(CMCC+ EUROCordex)** under different radiative forcings **(RCP4.5-8.5**) were used to describe future climate conditions

- **Precipitation (mm)**
- **Temperature (°C)**

2 Representative Concentration Pathways (RCPs): indicate the radiative forcing (W m^{-2}) by 2100:

RCP 4.5 (4.5 W m^{-2} by 2100) → +1.8 °C (1.1 to 2.6 °C)

RCP 8.5 (8.5 W m^{-2} by 2100) → +3.7 °C (2.6 to 4.8 °C)

GCM	RCM	RCPs	Resolution
CMCC-CM	**COSMO-CLM**	**4.5, 8.5**	**8 km**
ICHEC-EC-EARTH	RACMO22E	4.5, 8.5	12.5 km
IPSL-IPSL-CM5A-MR	RCA4	4.5, 8.5	12.5 km
MOHC-HadGEM2-ES	RCA4	4.5, 8.5	12.5 km
MPI-M-MPI-ESM-LR	RCA4	4.5, 8.5	12.5 km
ICHEC-EC-EARTH	RCA4	4.5, 8.5	12.5 km
ICHEC-EC-EARTH	HIRHAM5	4.5, 8.5	12.5 km
CNRM-CM5	CCLM4-8-17	4.5, 8.5	12.5 km
CNRM-CM5	RCA4	4,5, 8,5	12,5 km
MOHC-HadGEM2-ES	RCA4	4,5, 8,5	12,5 km

Reference Period
1983 - 2012

Medium-term Period
2041 - 2070

Long-term Period
2071-2100

Future projections (30-year monthly mean)

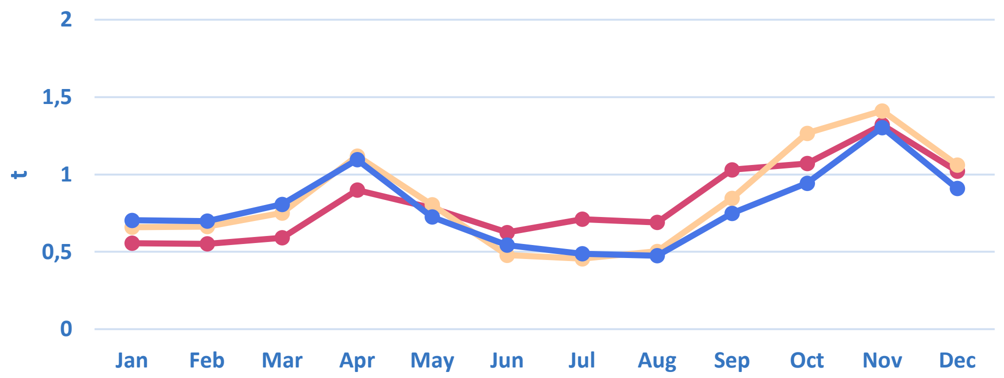
1. Integrated models

Hydrologic modelling: Soil and Water Assessment Tool (SWAT)-Zero river

CMCC-CM (GCM) **/ COSMO-CLM** (RCM)

RCP 4.5

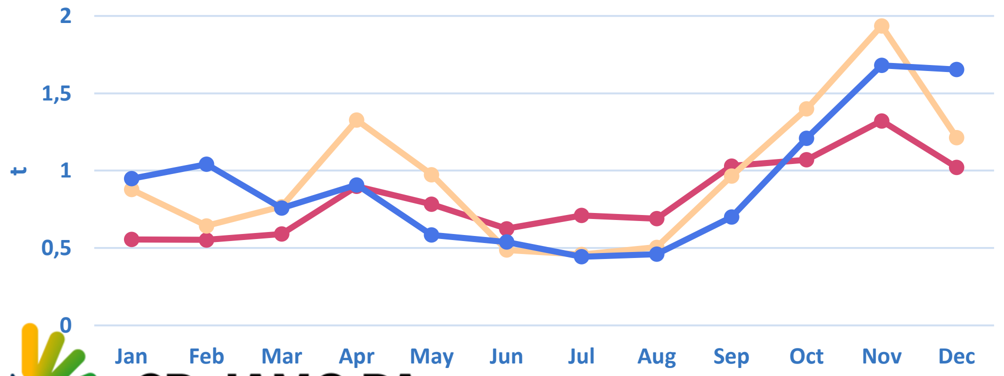
N-NH_4^+ loadings (t/mo.)



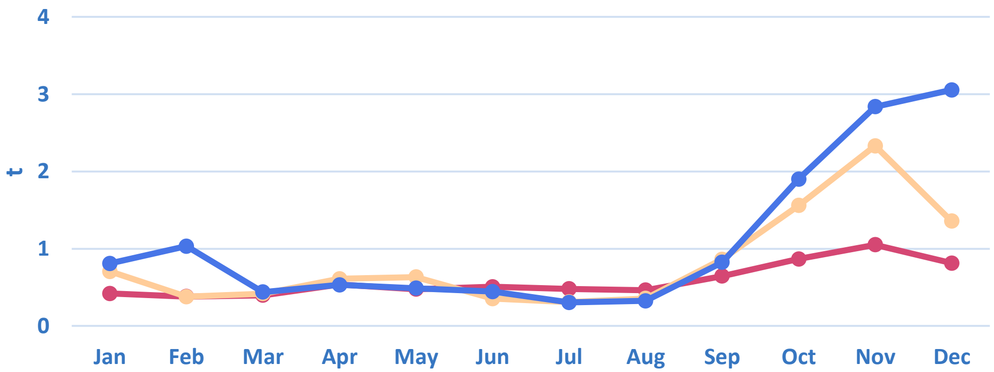
P-PO_4^{3-} loadings (t/mo.)

RCP 8.5

N-NH_4^+ loadings (t/mo.)



P-PO_4^{3-} loadings (t/mo.)



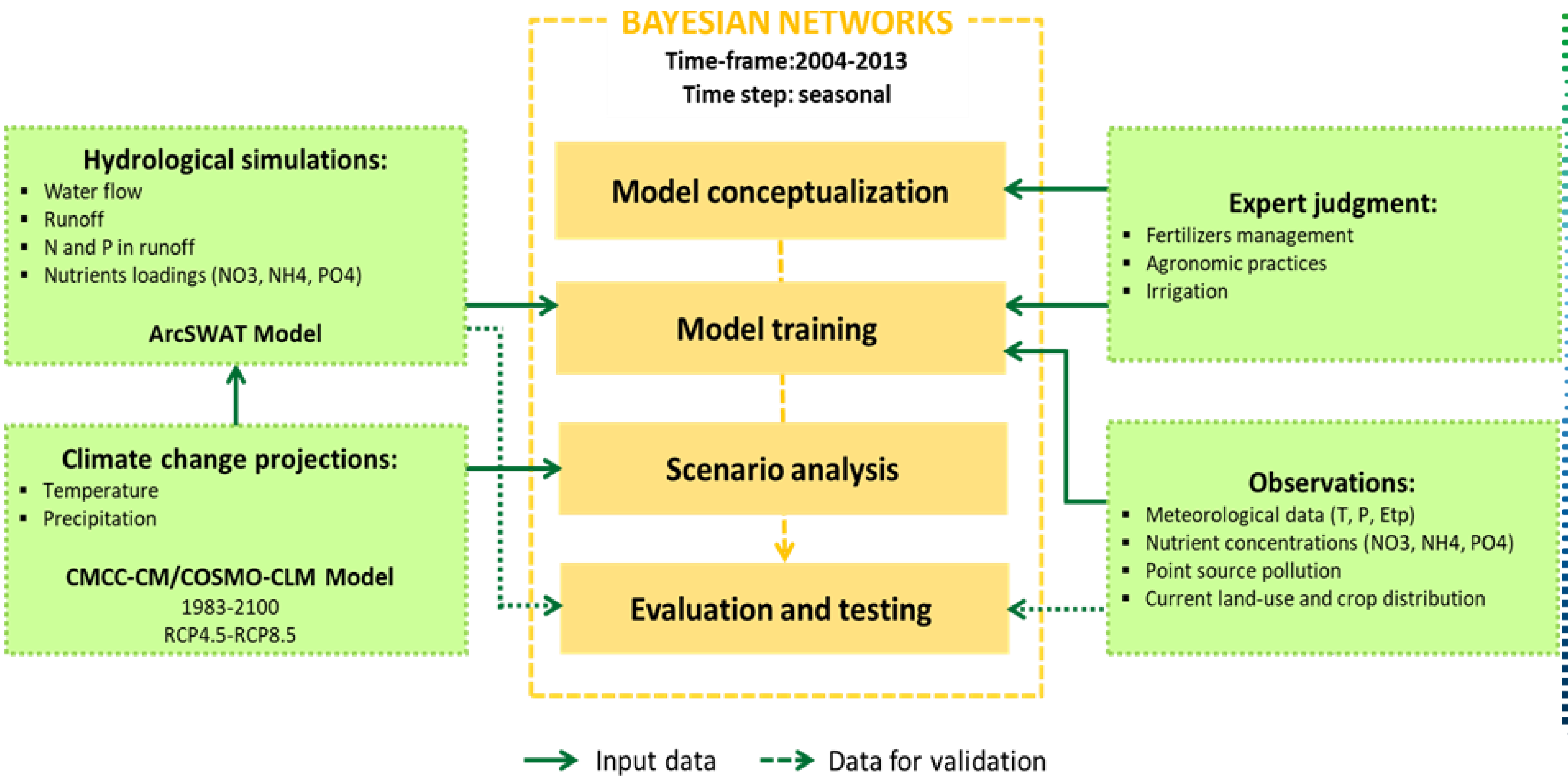
1983 - 2012　2041 - 2070　2071 - 2100

CReIAMO PA

2. Integrated multi-risk assessment-Bayesian Networks

PROBABILISTIC APPROACH BASED ON BAYESIAN NETWORKS (BNs):

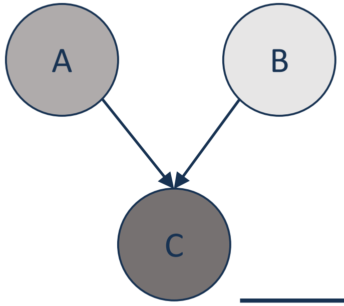
integrating model simulations results with those regarding land use and diffuse and point pollution sources → produce alternative risk scenarios to communicate the probability of changes in nutrients delivered over future scenarios.

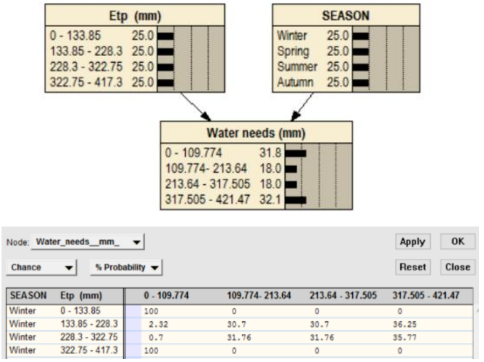


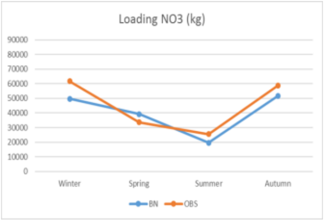
CReIAMO PA

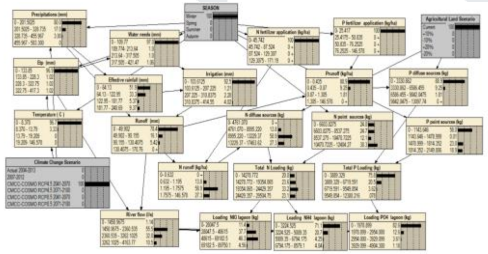
2. Integrated multi-risk assessment-Bayesian Networks

BAYESIAN NETWORKS DEVELOPMENT STEPS (Kragt, 2009):









a.
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.

b.
PARAMETRIZATION:
Define **states** for all variables and calculate the associated **prior probability** resulting from data distribution as well relationships between nodes described by the **conditional probability** distributions.

c.
EVALUATION:
Evaluate the **predictive performance** of the BN by means of **sensitivity analysis** and **data-based validation**.

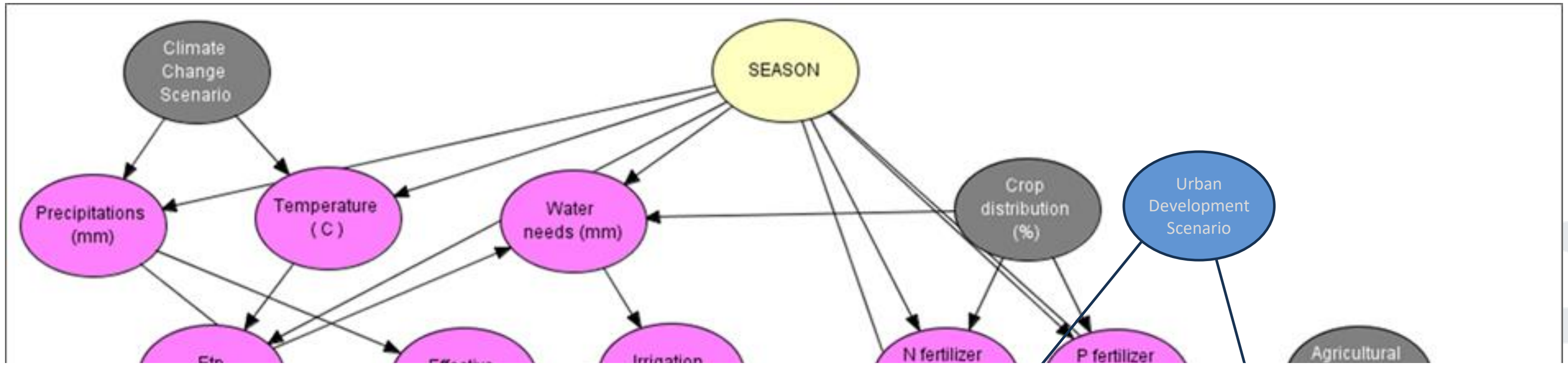
d.
SCENARIO ANALYSIS:
By inferring behavior of the variables at stake against different conditions defined by setting specific state/s of a node/s (**evidence**) and then propagating information between nodes based on the Bayes theorem, thus resulting in **the posterior probability**.

CReIAMO PA

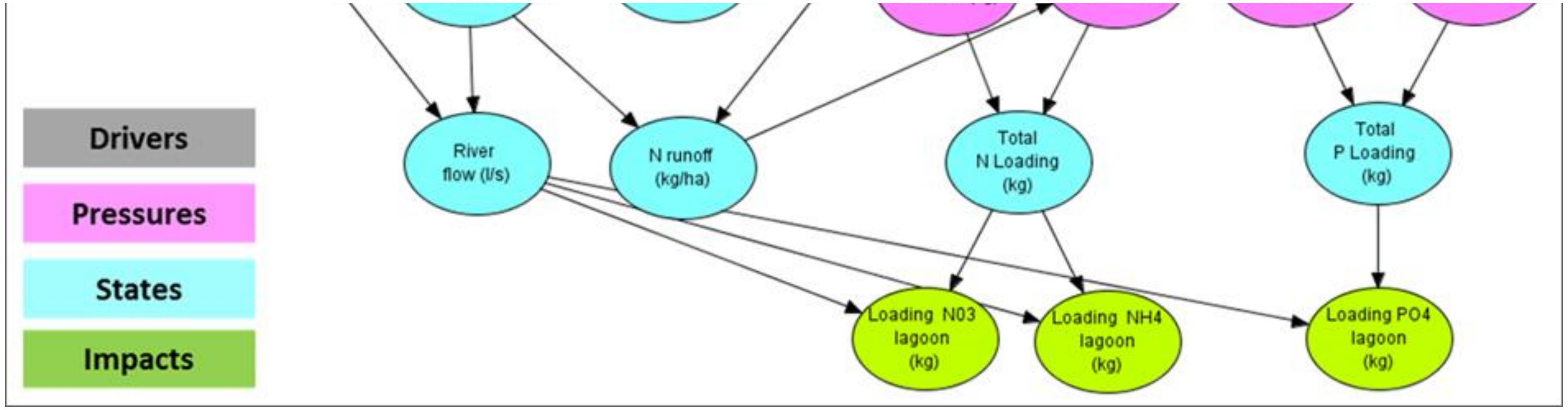
HUGIN Expert, version 8 (Bromley et al., 2005; Madsen et al., 2005), https://www.hugin.com/

2. Integrated multi-risk assessment-Bayesian Networks

a. CONCEPTUAL MODEL: development of the conceptual framework of the systems based on DPSIR framework.



- Definition of **final objectives (i.e. assessment endpoints)** of the model;
- **Identification** of relevant **system variables (i.e. nodes) by means DPSIR Framework** and representation of their **causal-relationships (i.e. arcs).**

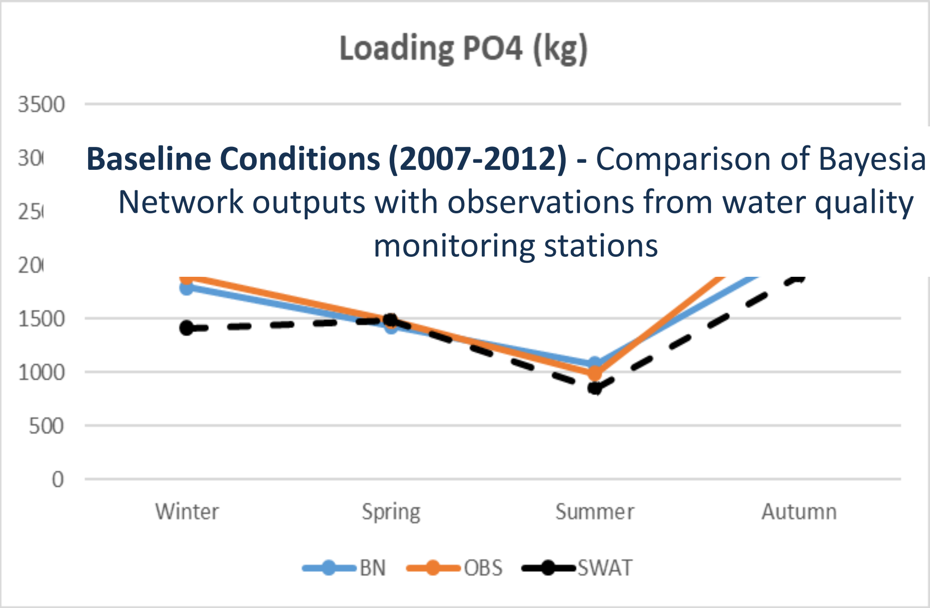


CReIAMO PA

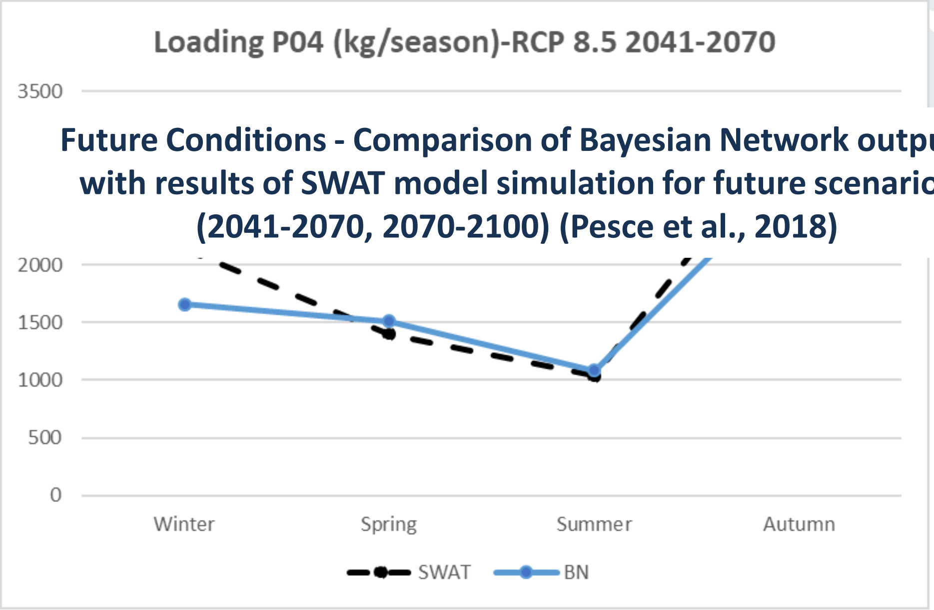
Dataset used for the network training in the case study

2. Integrated multi-risk assessment-Bayesian Networks

c. MODEL EVALUATION: Data Evaluation of the predictive accuracy of the model through the comparison of Bayesian Network outputs with an independent data set.



Baseline Conditions (2007-2012) - Comparison of Bayesian Network outputs with observations from water quality monitoring stations



Future Conditions - Comparison of Bayesian Network outputs with results of SWAT model simulation for future scenarios (2041-2070, 2070-2100) (Pesce et al., 2018)

Expected Value of the probability distributions of **observed data (a) and simulated data (SWAT) (b) and of Bayesian Network outputs (blue)**

2. Integrated multi-risk assessment-Bayesian Networks

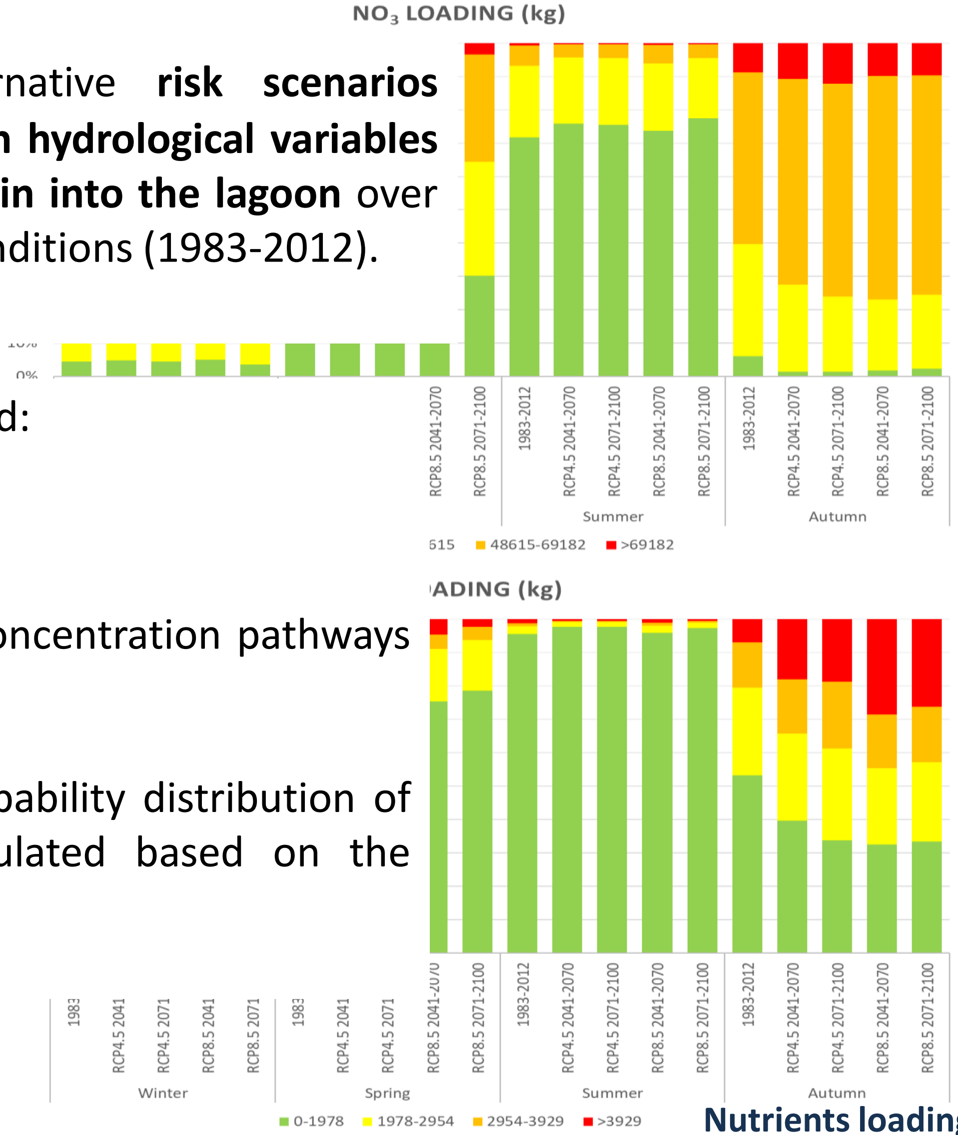
d. SCENARIO ANALYSIS: Alternative **risk scenarios** showing the **probability of changes in hydrological variables and nutrients delivered from the basin into the lagoon** over future scenarios respect to current conditions (1983-2012).

Five 30-year scenarios were developed:

- control period (1983-2012),
- a mid-term (2041-2070)
- long-term (2071-2100)

under two different representative concentration pathways (i.e. RCP4.5-RCP8.5).

BN alternatively forced with the probability distribution of temperature and precipitation calculated based on the respective **model simulations.**

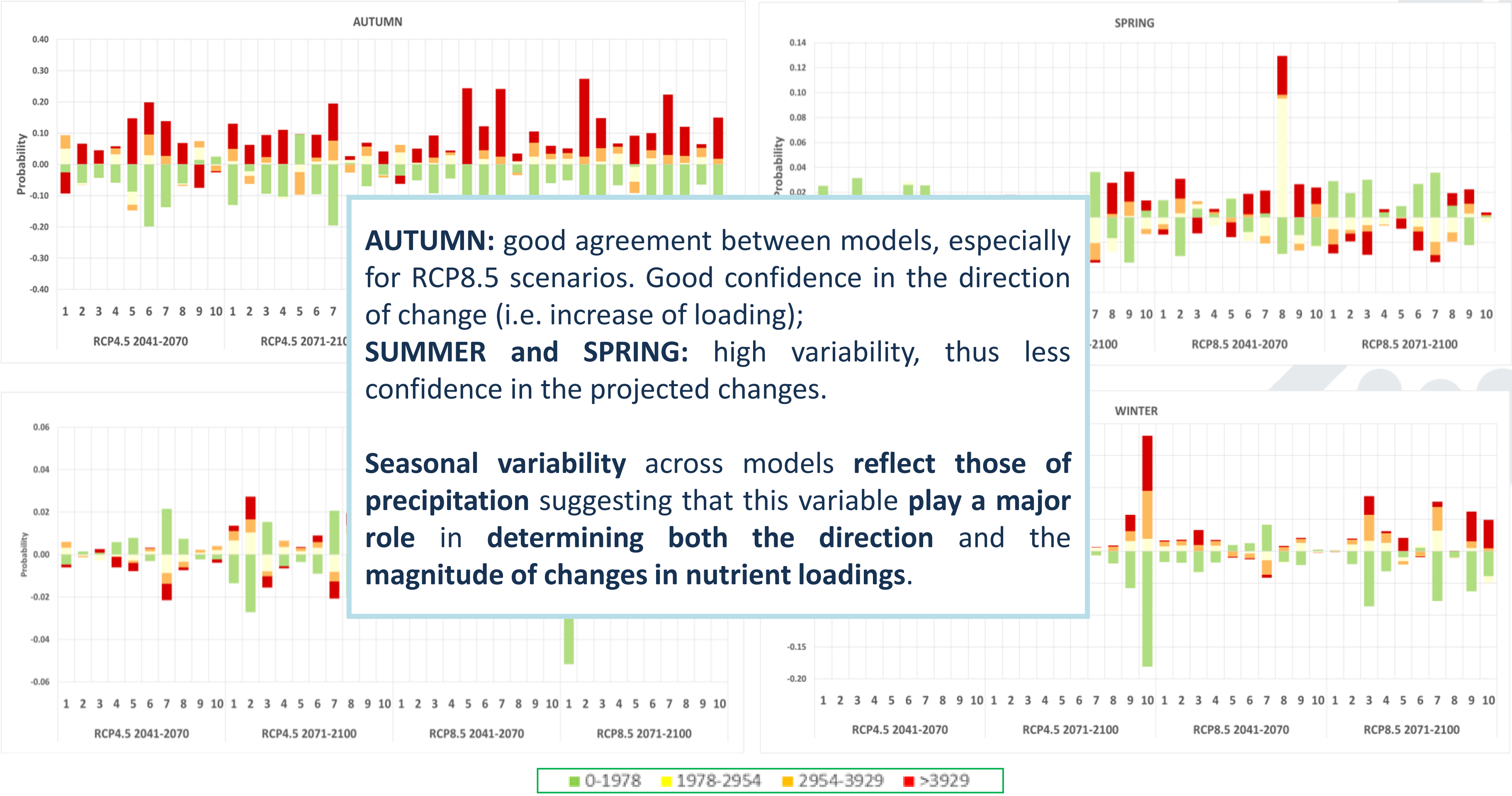


Nutrients loading under different climate change scenarios (CMCC-CM/COSMO-CLM Model)

CReIAMO PA

2. Integrated multi-risk assessment-Bayesian Networks

d. SCENARIO ANALYSIS: Analysis of the variability and uncertainty of the results across GCM-RCM combinations



AUTUMN: good agreement between models, especially for RCP8.5 scenarios. Good confidence in the direction of change (i.e. increase of loading);
SUMMER and SPRING: high variability, thus less confidence in the projected changes.

Seasonal variability across models **reflect those of precipitation** suggesting that this variable **play a major role** in **determining both the direction** and the **magnitude of changes in nutrient loadings**.

CReI

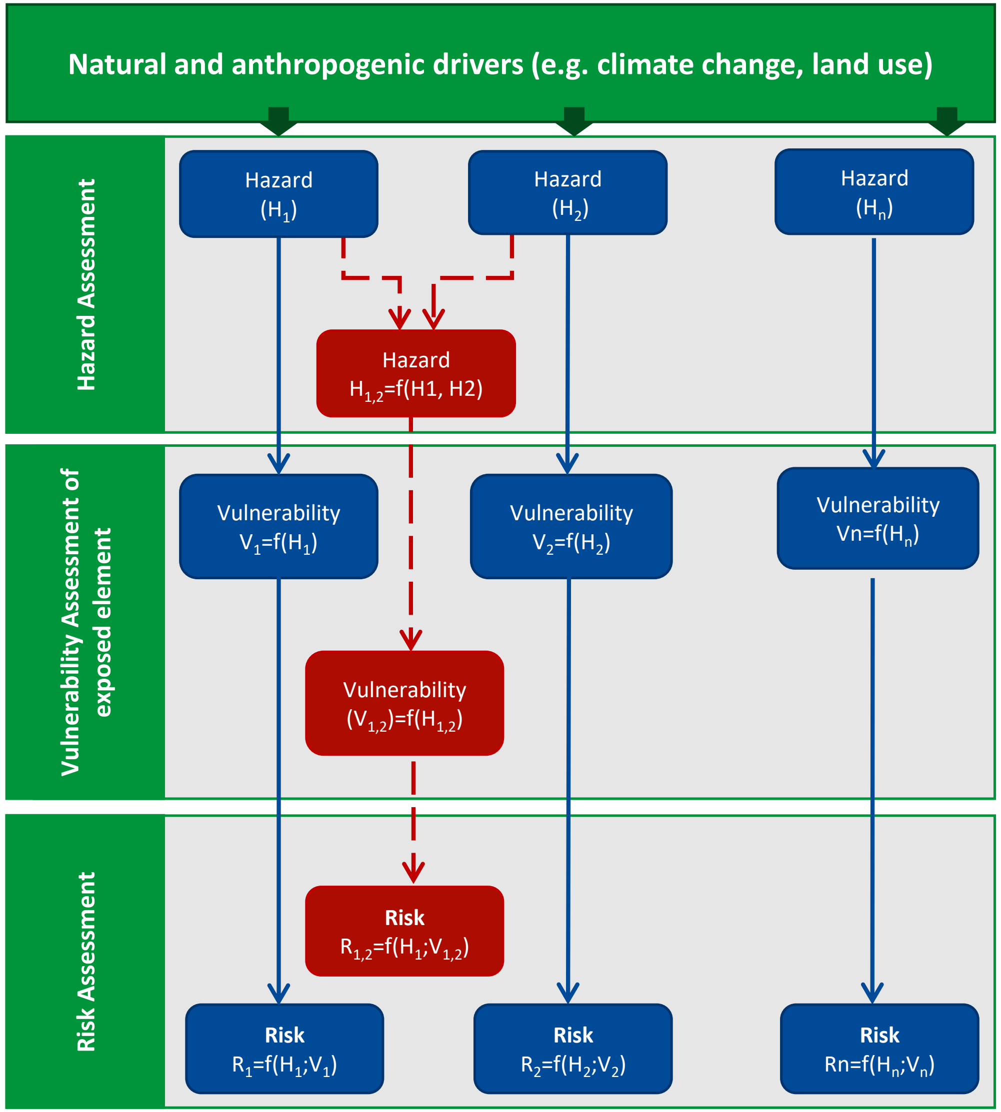
Variations in the probability of each PO4(3-) loading classes respect to the baseline (i.e. 1983-2012) under different scenarios and GCM-RCM combinations

3. Integrated multi-risk assessment

MULTI-RISK ASSESSMENT

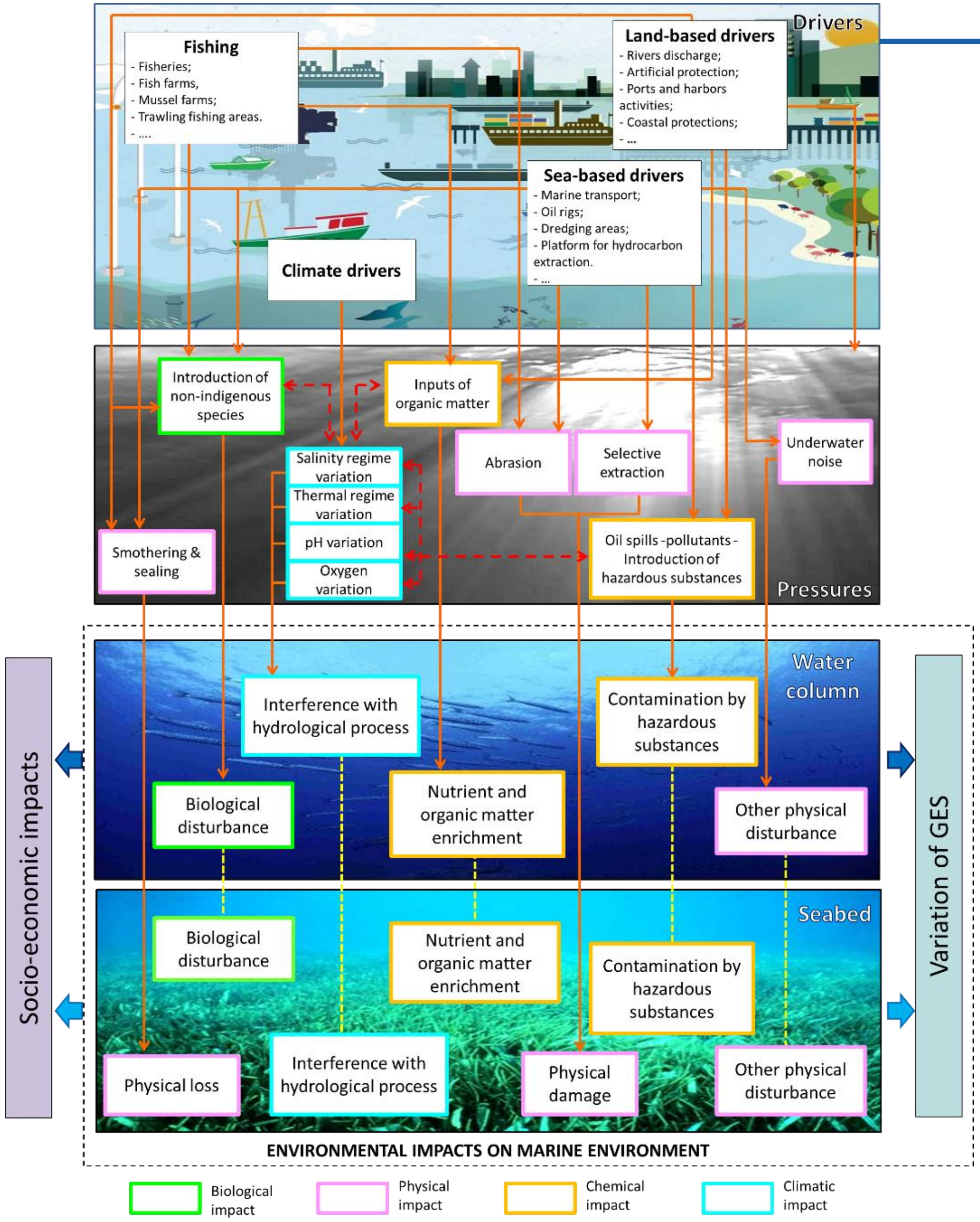
considering multiple hazards and risk (threatening the same exposed elements) and their spatial and temporal relationships:

- Provide a **semi-quantitative evaluation** of **hazards interactions (i.e. synergies antagonisms);**
- Estimate **cumulative impacts** induced by climatic and no-climatic stressors **(es. temperature variation, chemical pollution)**
- Combine **spatial-temporal information** related to **multi-hazards** and **multi-vulnerability** in order to identify key risks **across sectors and regions;**
- Support **ranking and prioritization of risks** affecting the same target.
- Support the simultaneous consideration of **multiple climate change scenarios** and the **prioritization** of available **adaptation and management options.**



Adapted from Marzocchi et al., 2012

3. Integrated multi-risk assessment

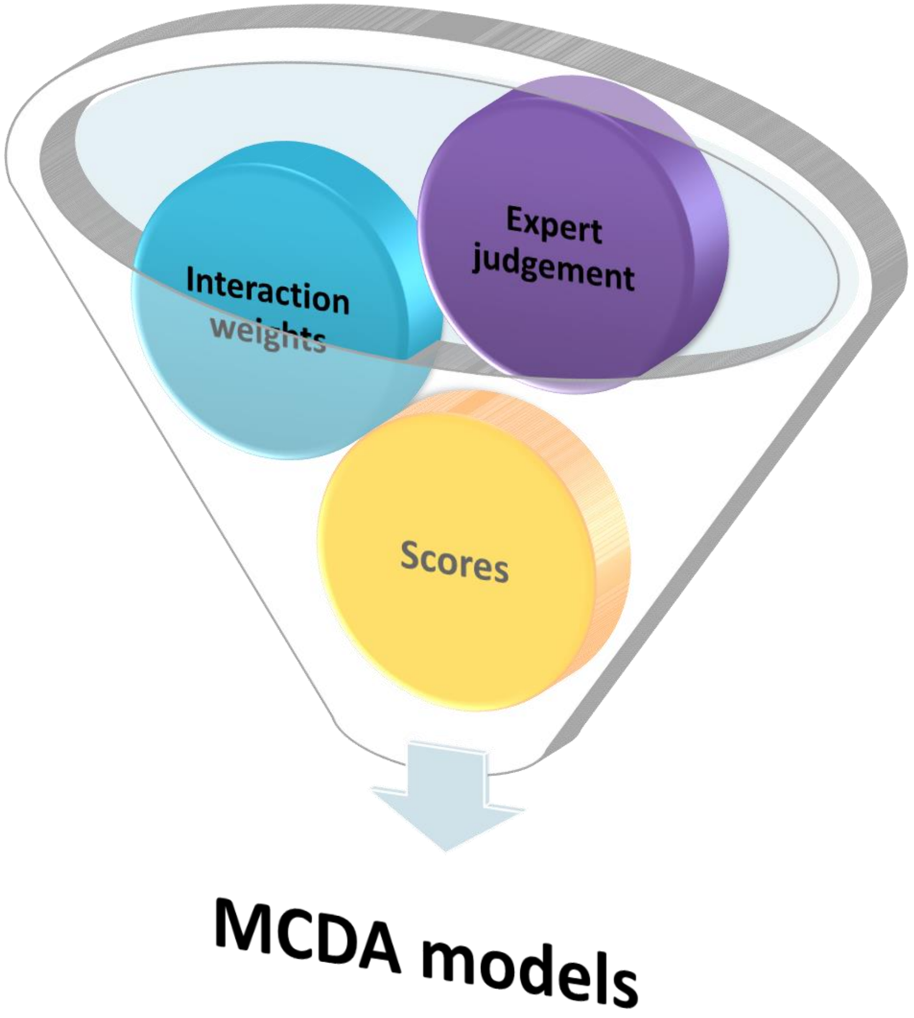


Adriatic sea: the multi-risk conceptual framework

Highlights **pathways of interaction** between **climate and land/sea based drivers**, their related **pressures** potentially affecting sensitive **receptors** (e.g. seagrasses, MPAs), leading to **socio-economic impacts as well as environmental ones with the variation of GES.**

3. Integrated multi-risk assessment

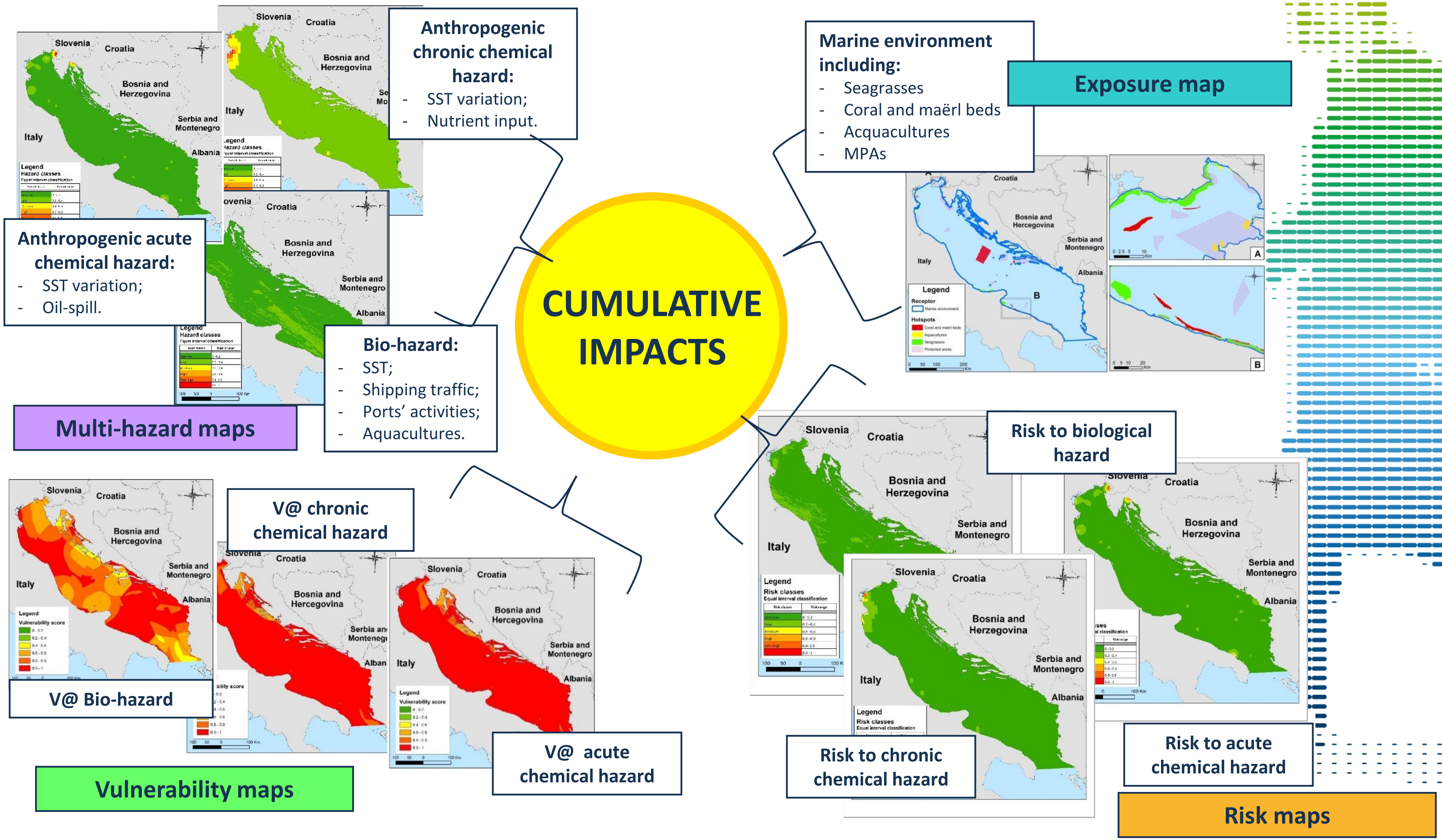
Adriatic sea: data integration by means of MCDA



Multi-risk approach **integrating heterogeneous information through MCDA models** for the evaluation of cumulative impacts

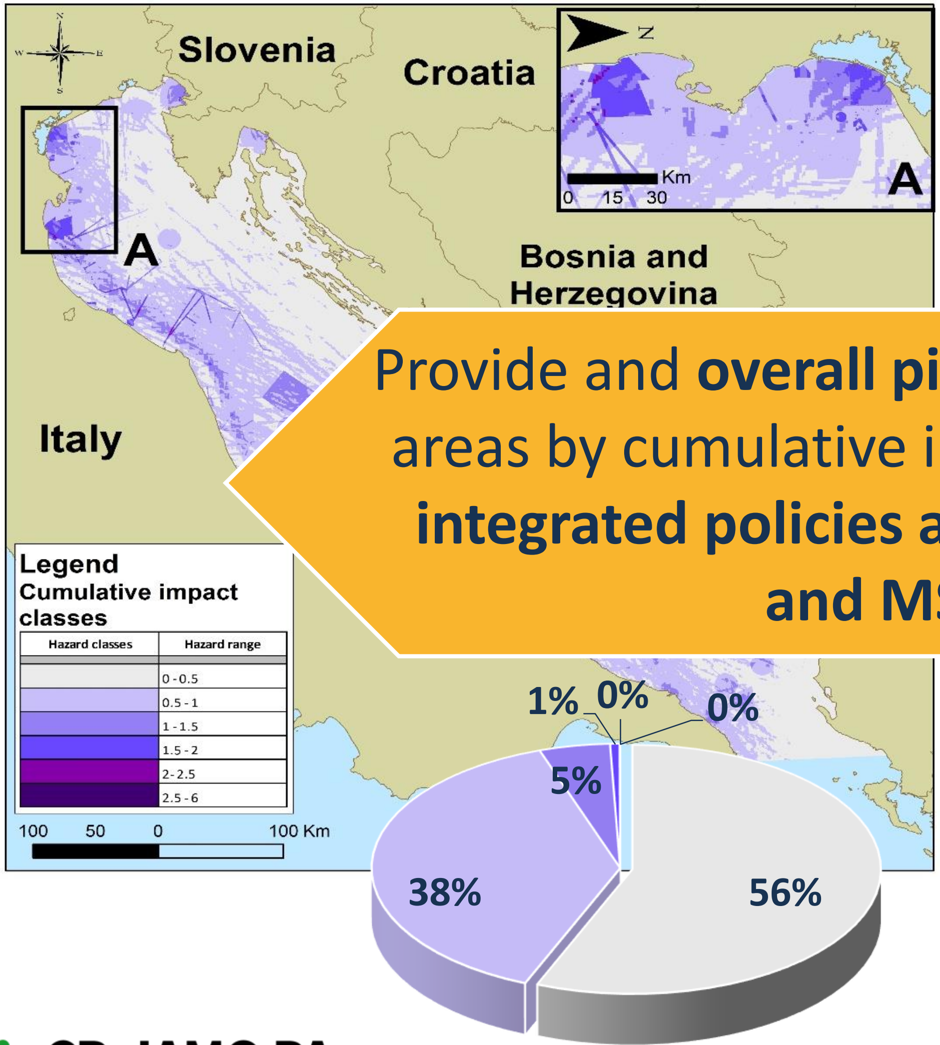
- **Experts judgment** to evaluate hazards' interaction through the assignment of specific interaction weights and scores
- **MCDA integration** functions to shape more complex synergic and antagonistic behaviors between hazards in complex environmental systems

3. Integrated multi-risk assessment-Cumulative Impact Index

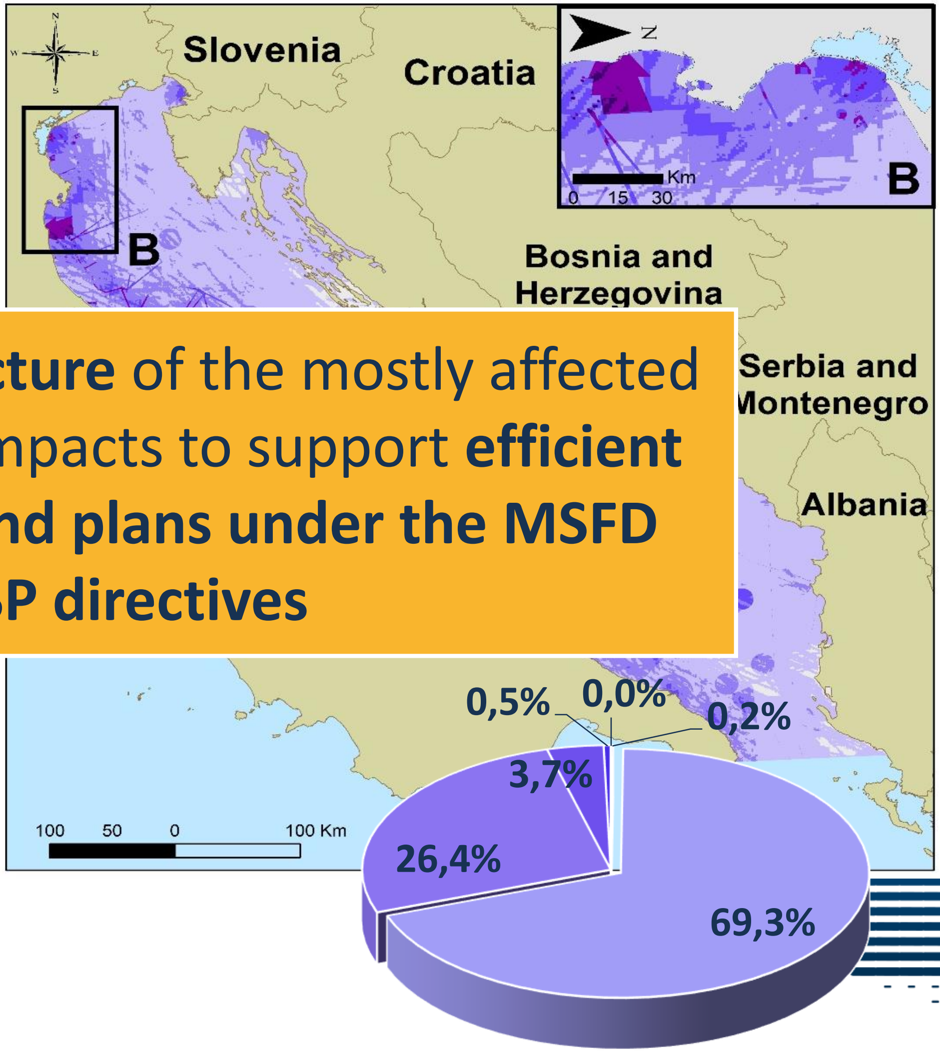


3. Integrated multi-risk assessment-Cumulative Impact Index

Baseline scenario 2000-2015



Future scenario 2035-2050

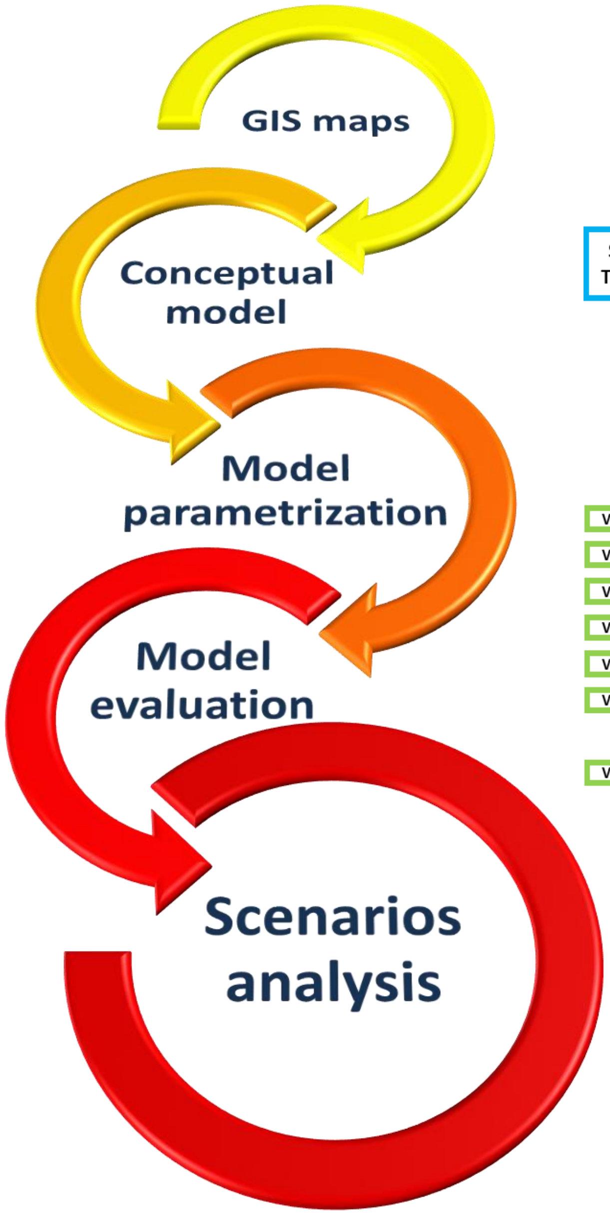


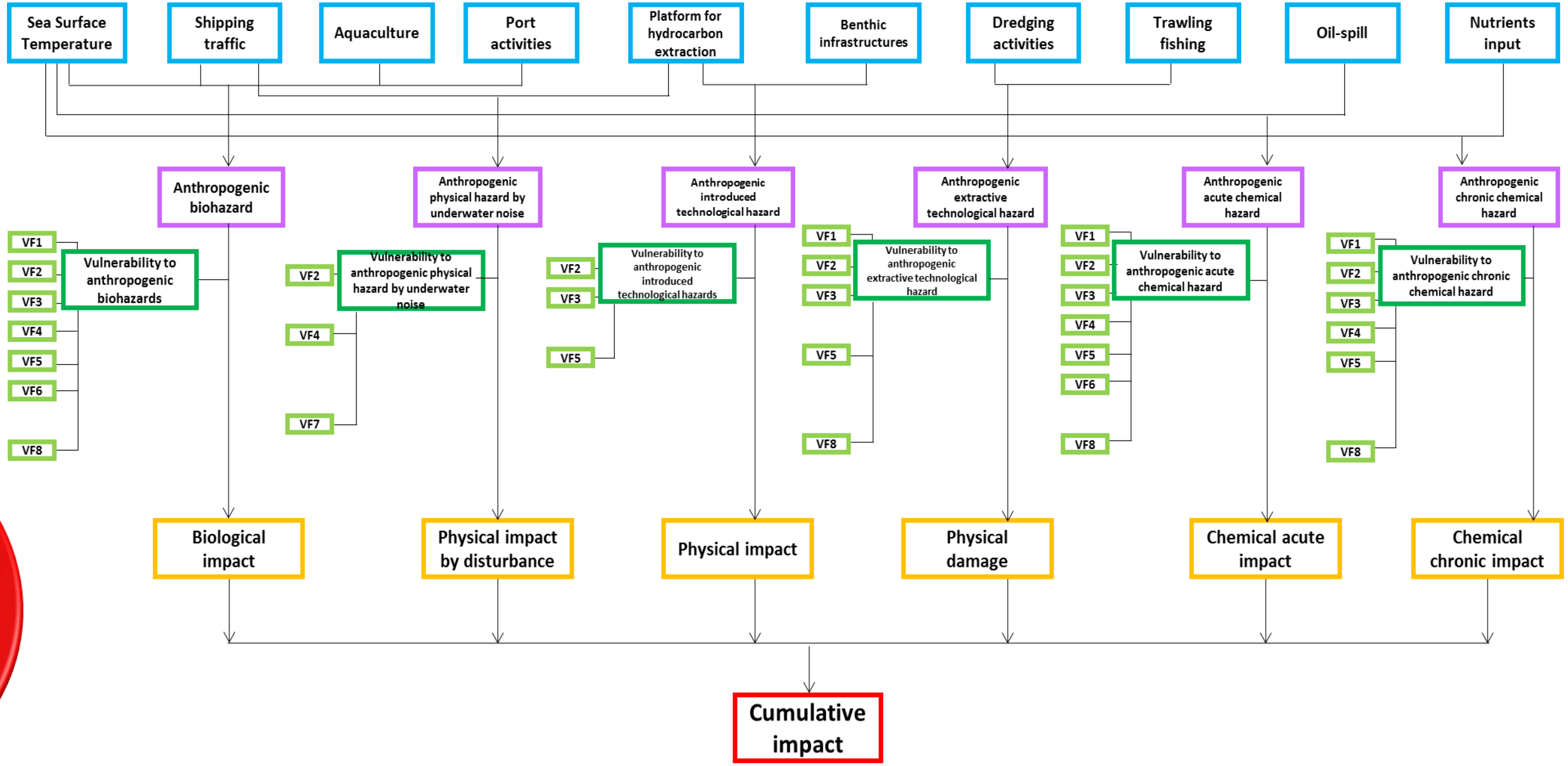
Provide and **overall picture** of the mostly affected areas by cumulative impacts to support **efficient integrated policies and plans under the MSFD and MSP directives**

0 - 0.5 | 0.5 - 1 | 1 - 1.5 | 1.5 - 2 | 2 - 2.5 | 2.5 - 6

CReIAMO PA

3. Integrated multi-risk assessment-Bayesian Networks

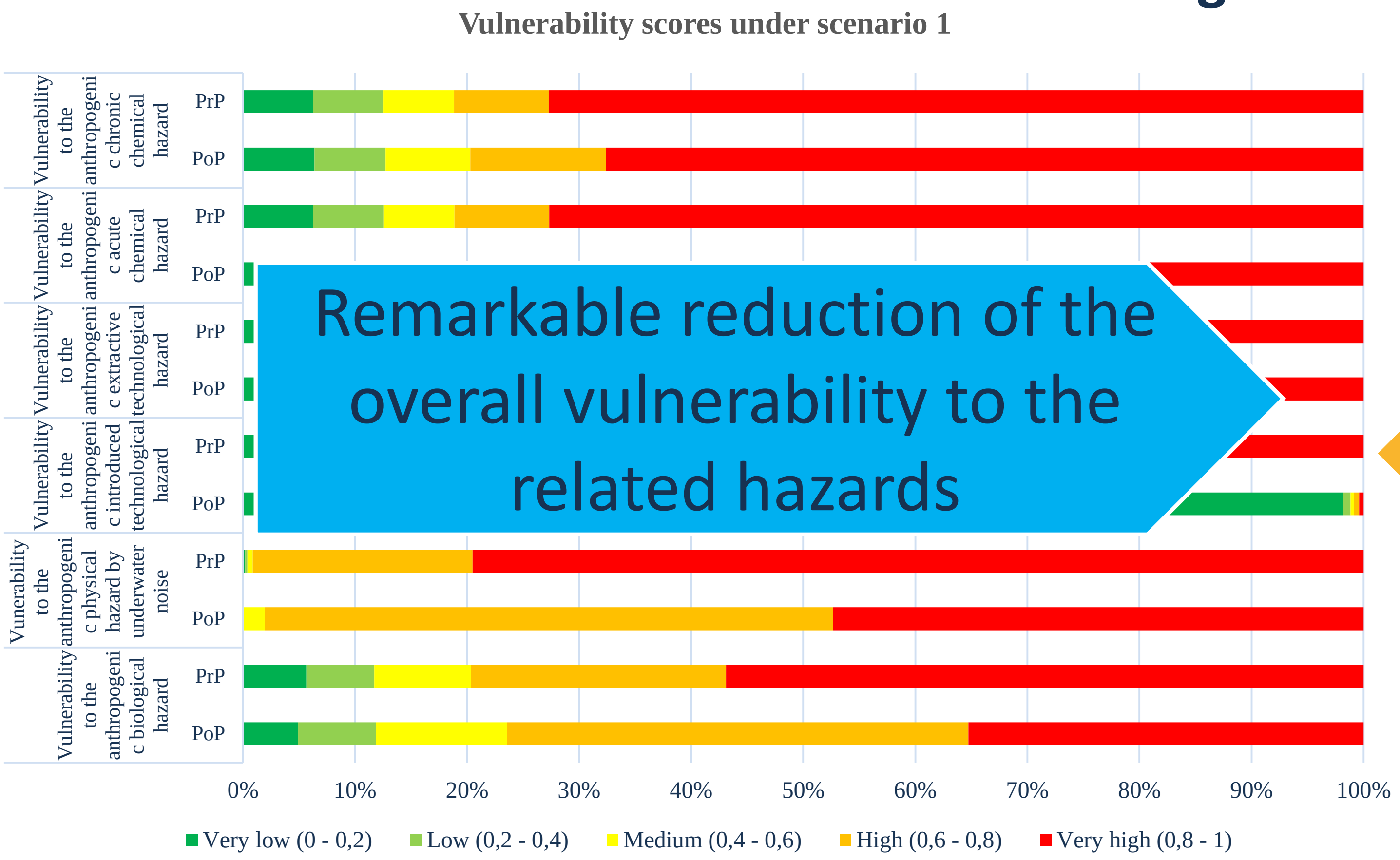




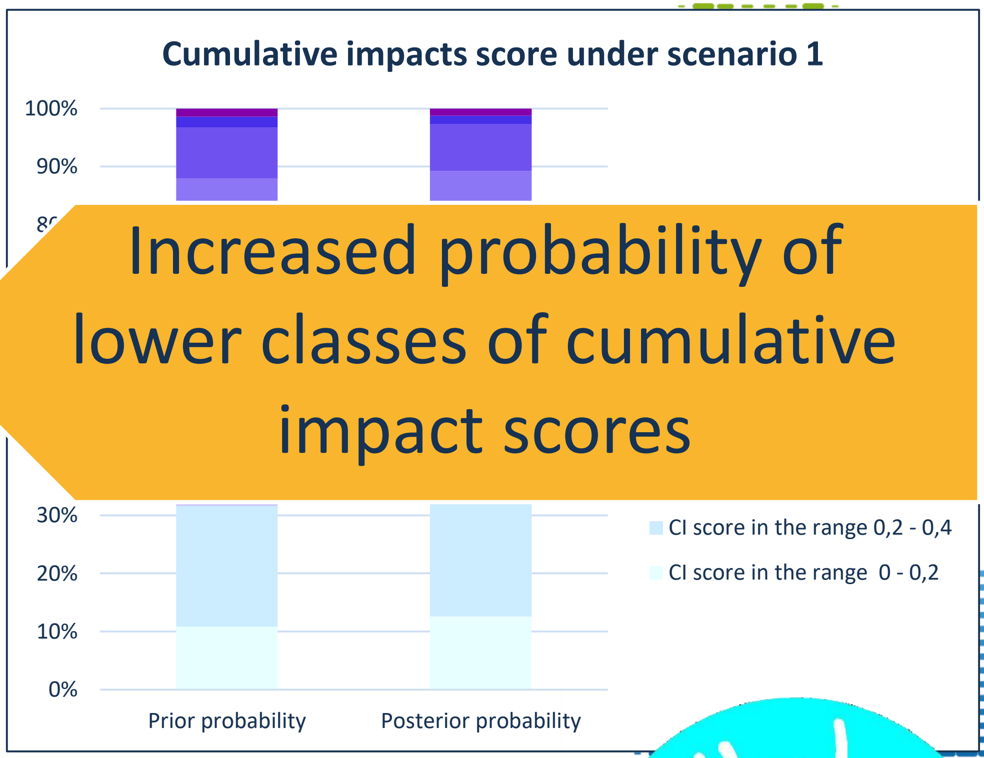
Trained on the baseline scenario 2000- 2015

CReIAMO PA

3. Integrated multi-risk assessment-Bayesian Networks



Remarkable reduction of the overall vulnerability to the related hazards



Increased probability of lower classes of cumulative impact scores

SCENARIO 1:

establishment of new MPAs to reinforce ecological connectivity

CReIAMO PA

Conclusions

Different kind of **risk assessment tools** each characterized by its **strengths and weaknesses**.

A combination of approaches is required to deal with the **complexity of risks** posed by climate change.

Need to converge toward **integrated decision support tools** able to support:

- The integration of **different domains and perspective** (environmental, social and economic sciences)
- The consideration **of uncertainty** about climate change and policy/management scenarios
- The combination of **quantitative and qualitative approaches** and information
- The **communication and translation of knowledge** between the science and practitioners interfaces.

Relevant Publications:

- HV Pham, S Torresan, A Critto, A Marcomini. Alteration of freshwater ecosystem services under global change–A review focusing on the Po River basin (Italy) and the Red River basin (Vietnam). Science of The Total Environment 652, 1347-1365.
- Mysiak, Jaroslav; Torresan, Silvia; Bosello, Francesco; Mistry, Malcolm; Amadio, Mattia; Marzi, Sepehr; Furlan, Elisa; Sperotto, Anna *Climate risk index for Italy* in PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON SERIES A: MATHEMATICAL PHYSICAL AND ENGINEERING SCIENCES, vol. 376, pp. 20170305;
- Furlan, Elisa; Torresan, Silvia; Critto, Andrea; Marcomini, Antonio *Spatially explicit risk approach for multi-hazard assessment and management in marine environment: The case study of the Adriatic Sea* in SCIENCE OF THE TOTAL ENVIRONMENT, vol. 618, pp. 1008-1023 (ISSN 0048-9697);
- Pesce, M.; Critto, A.; Torresan, S.; Giubilato, E.; Santini, Michele; Zirino, Albert; Ouyang, W.; Marcomini, A. *Modelling climate change impacts on nutrients and primary production in coastal waters* in SCIENCE OF THE TOTAL ENVIRONMENT, vol. 628-629, pp. 919-937 (ISSN 0048-9697);
- Sperotto, Anna; Molina, Josè-Luis; Torresan, Silvia; Critto, Andrea; Marcomini, Antonio Reviewing Bayesian Networks potentials for climate change impacts assessment and management: a multi-risk perspective in JOURNAL OF ENVIRONMENTAL MANAGEMENT, vol. 202, pp. 320–331;
- Furlan, E.; Torresan, S.; Ronco, P.; Critto, A.; Breil, M.; Kontogianni, A.; Garmendia, M.; Pascual, M.; Sauzade, D.; Skourtos, M.; Marcomini, A. *Tools and methods to support adaptive policy making in marine areas: Review and implementation of the Adaptive Marine Policy Toolbox* in OCEAN & COASTAL MANAGEMENT, vol. 151, pp. 25-35 (ISSN 0964-5691);
- Rizzi, J.; Torresan, S.; Critto, A.; Zabeo, A.; Brigolin, D.; Carniel, S.; Pastres, R.; Marcomini, A. Climate change impacts on marine water quality: The case study of the Northern Adriatic sea in MARINE POLLUTION BULLETIN, vol. 102, pp. 271-282 (ISSN 0025-326X);
- Torresan, Silvia; Critto, Andrea; Rizzi, Jonathan; Zabeo, Alex; Furlan, Elisa; Marcomini, Antonio DESYCO: A decision support system for the regional risk assessment of climate change impacts in coastal zones in OCEAN & COASTAL MANAGEMENT, vol. 120, pp. 49-63 (ISSN 0964-5691);

The Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici (Fondazione CMCC) **is a non-profit research institution**. CMCC's mission is to **investigate and model our climate system and its interactions with society** to provide reliable, rigorous, and timely scientific results, which will in turn **stimulate sustainable growth, protect the environment, and develop science driven adaptation and mitigation policies** in a changing climate.

Offices

Partners

- Università del Salento
- Università degli Studi della Tuscia
- uniss – Università degli Studi di Sassari
- Istituto Nazionale di Geofisica e Vulcanologia
- Politecnico Milano 1863
- Università Ca' Foscari Venezia
- Resources for the Future
- CIRA – Centro Italiano Ricerche Aerospaziali

Scientific Research

ASC
Advanced Scientific Computing

CSP
Climate Simulation and Prediction

ECIP
Economic Analysis of Climate Impacts and Policy

IAFES
Impacts on Agriculture, Forest and Ecosystem Services

ODA
Ocean Modelling and Data Assimillation

OPA
Ocean Predictions and Applications

RAAS
Risk Assessment and Adaptation Strategies

REMHI
Regional Models and Hydrogeological Impacts

SEME
Sustainable Earth Modelling Economics

The Supercomputing Center

High-performance computing to understand the climate of the future

1,200 TeraFlops,

1,000 Terabytes

4,000 Terabytes
(Tape Library)

Risk Assessment and Adaptation Strategies Division (RAAS)

https://www.cmcc.it/it/divisions/raas

cmcc
Centro Euro-Mediterraneo sui Cambiamenti Climatici

Università Ca'Foscari Venezia

CMCC@Ca'Foscari

Impact assessment at regional scale

- **Integrated approaches and tools** (e.g. risk and vulnerability assessment, multi criteria decision analysis, spatial indicators, Regional Risk Assessment, ecological risk models)

Economic analysis of risk and disaster risk reduction

- **Effects** of extreme climate and meteorological events as well as **policy instruments** set to reduce societal vulnerability and increase resilience

Participative processes and decision making

- **Decision analysis approaches** for the assessment of stakeholders' needs for climate change management;
- Implementation of **GIS-based Decision Support Systems (DSSs)** for the spatial analysis of the potential consequences associated to climate change.

Thanks for your attention!

Silvia Torresan

silvia.torresan@cmcc.it

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