MODULE 4 – METHODOLOGIES AND RECOMMENDATIONS FOR ADAPTIVE MANAGEMENT IN THE BLACK SEA

BRIDGE-BS

Presenter

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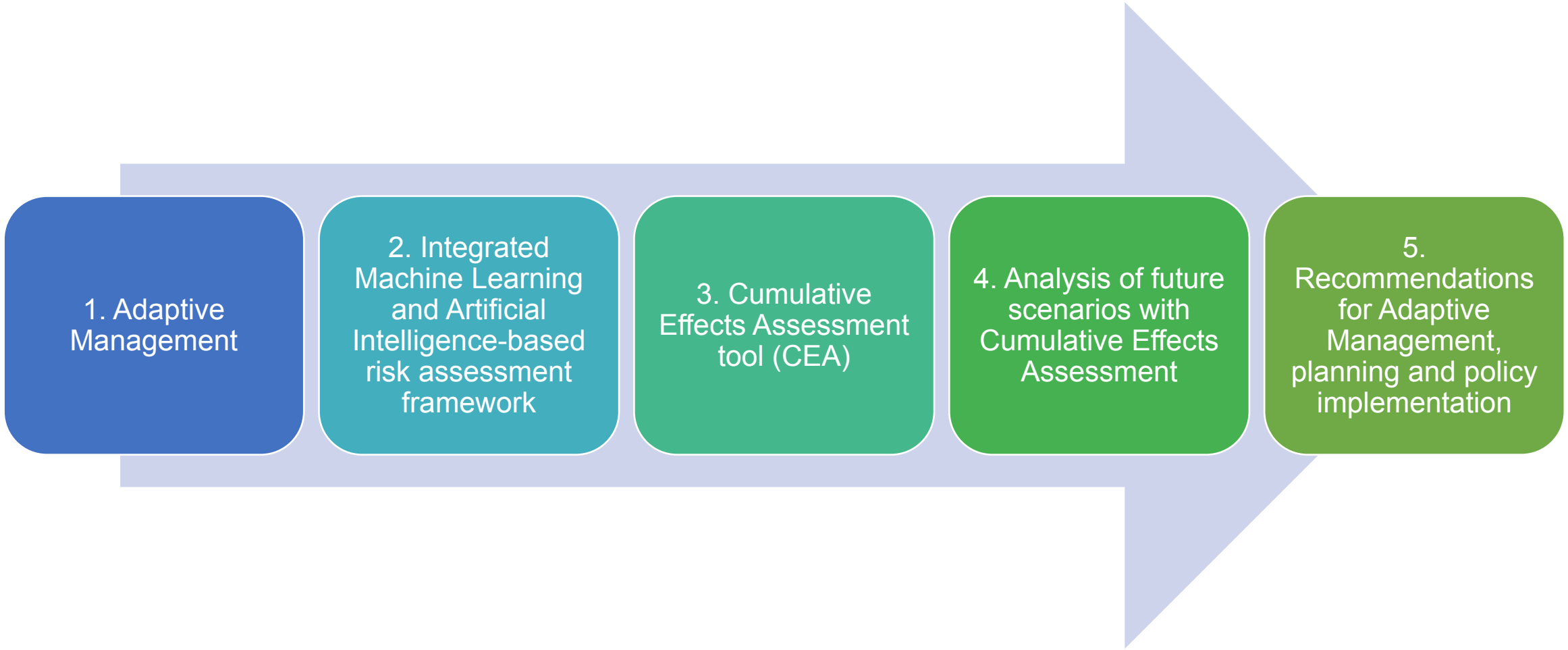
This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No:101000240.

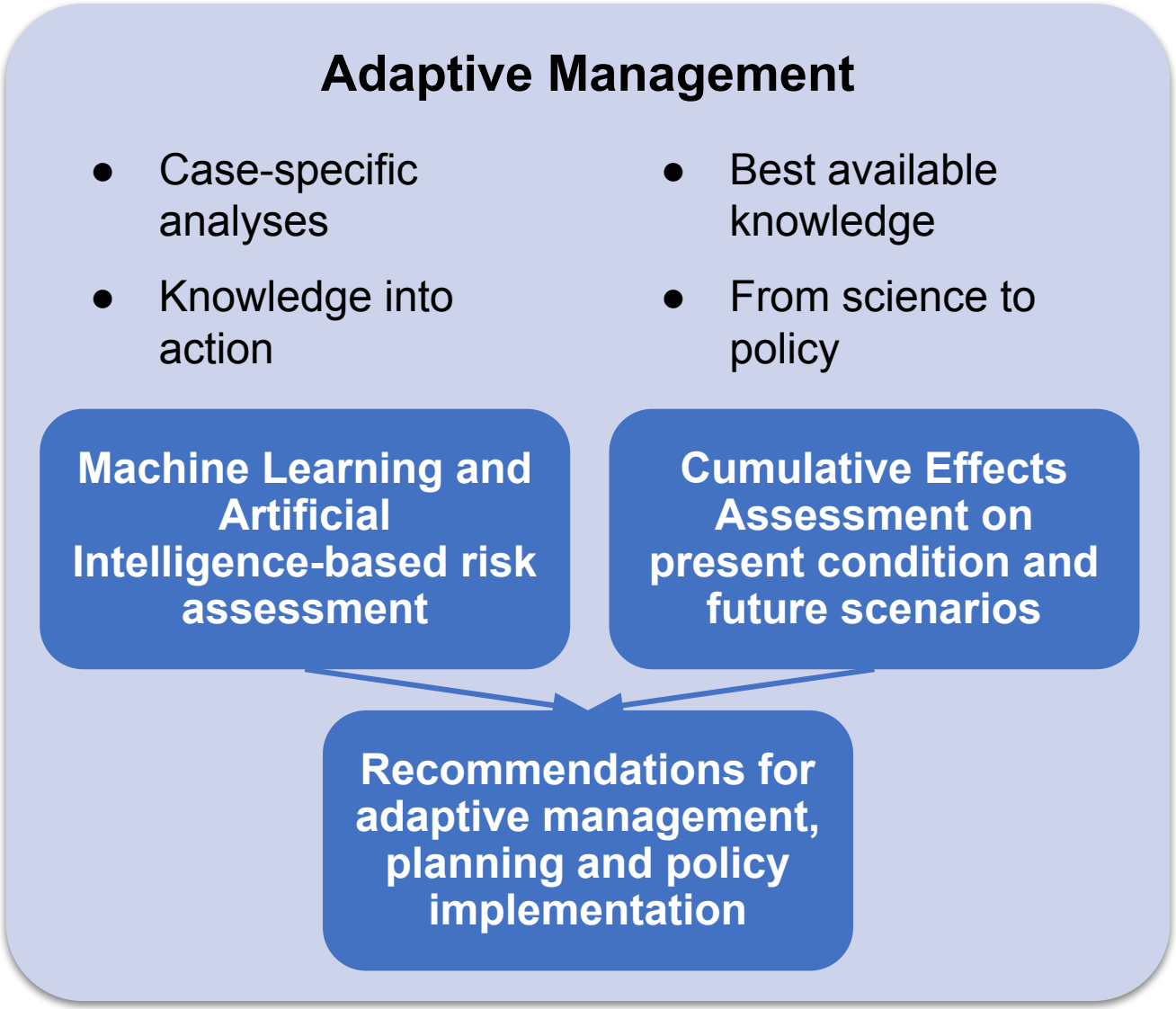
Methodologies and recommendations for adaptive management in the Black Sea

Outline of Module 4



Introduction

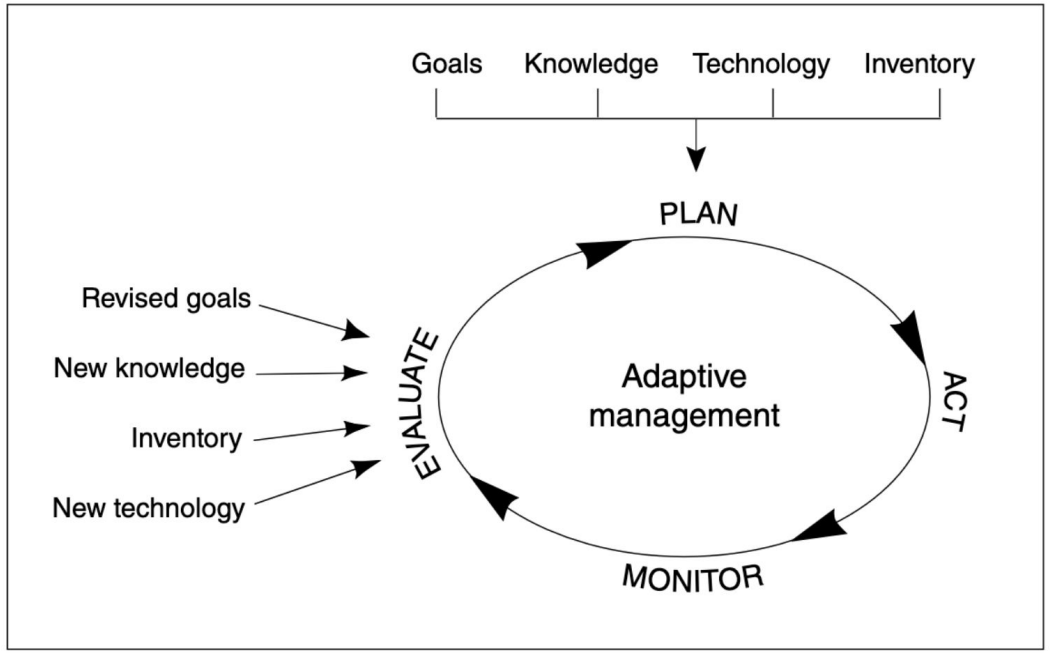
- **Context:** Black Sea (basin-wide and 3 Pilot Sites)
- **Challenge**: sustainable management of complex and dynamic coastal and marine systems
- **Strategy**: perform multi-stressor analysis of risks and impacts to develop adaptive management strategies and policy recommendations



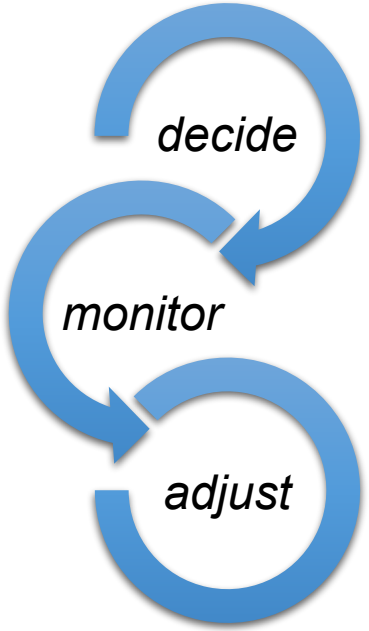
1. ADAPTIVE MANAGEMENT

What is Adaptive Management?
General definition

Adaptive Management is a continuous and systematic process where one learns from experience and adjusts actions accordingly.



Graphical representation of Adaptive Management as a continuous and systematic process. Source: USDA and USDI 1994:E-14.0

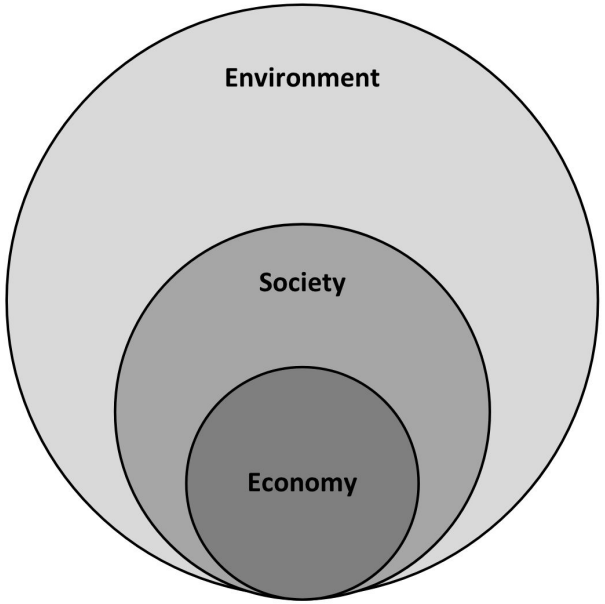


learn by doing

From Stankey, George & Clark, Roger & Bormann, Bernard. (2005).

What is Adaptive Management?
Key features

The 10 tenets for sustainable environmental management.



The three core dimensions of sustainability are in a hierarchical relationship.

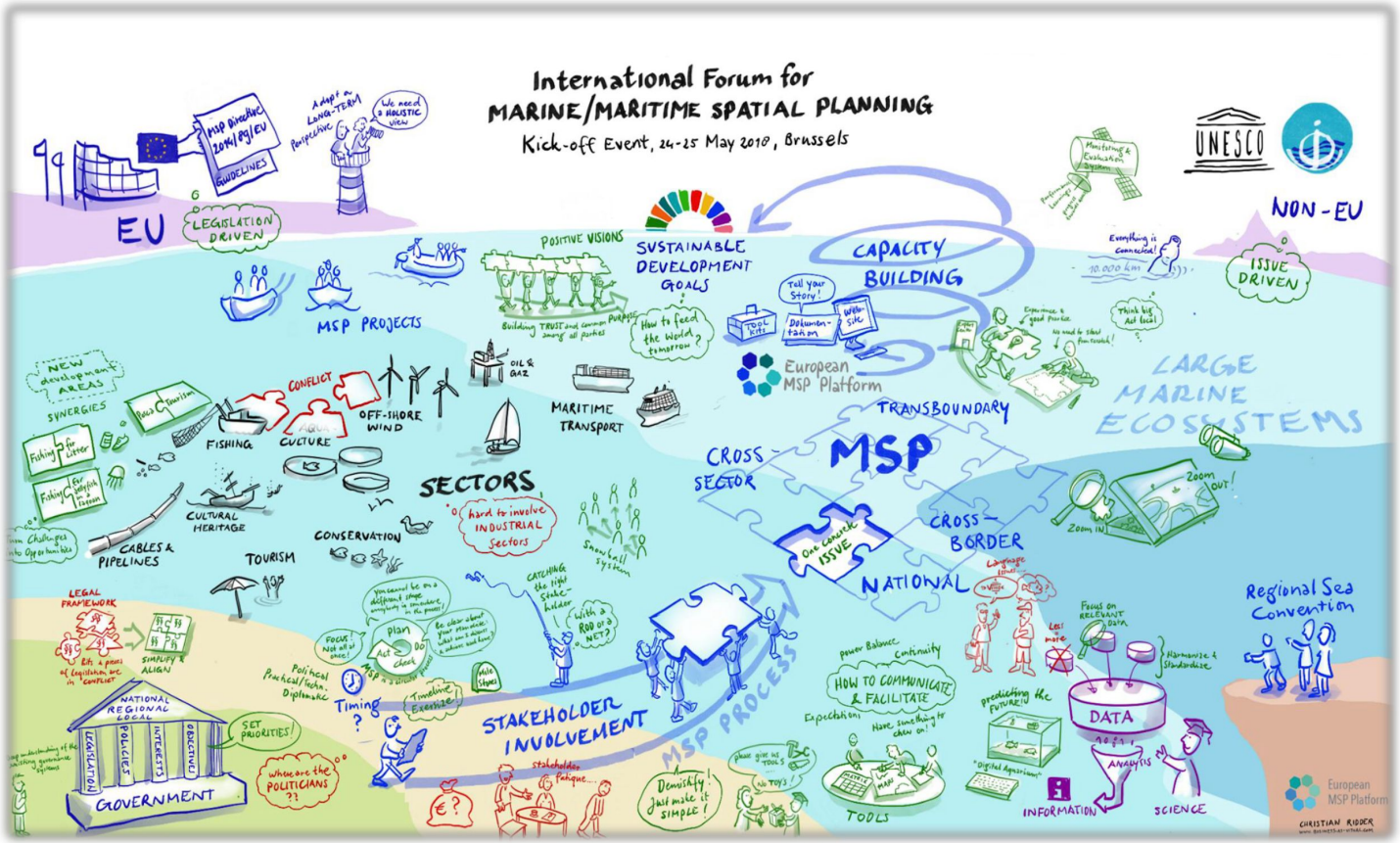
1. Socially desirable/tolerable
2. Ecologically sustainable
3. Economically viable
4. Technologically feasible
5. Legally permissible
6. Administratively achievable
7. Politically expedient
8. Culturally inclusive
9. Ethically defensible (morally correct)
10. Effectively communicable

From Barnard, S., & Elliott, M. (2015).

How to operationalize adaptive management in a maritime context?

Introducing Maritime Spatial Planning (MSP)

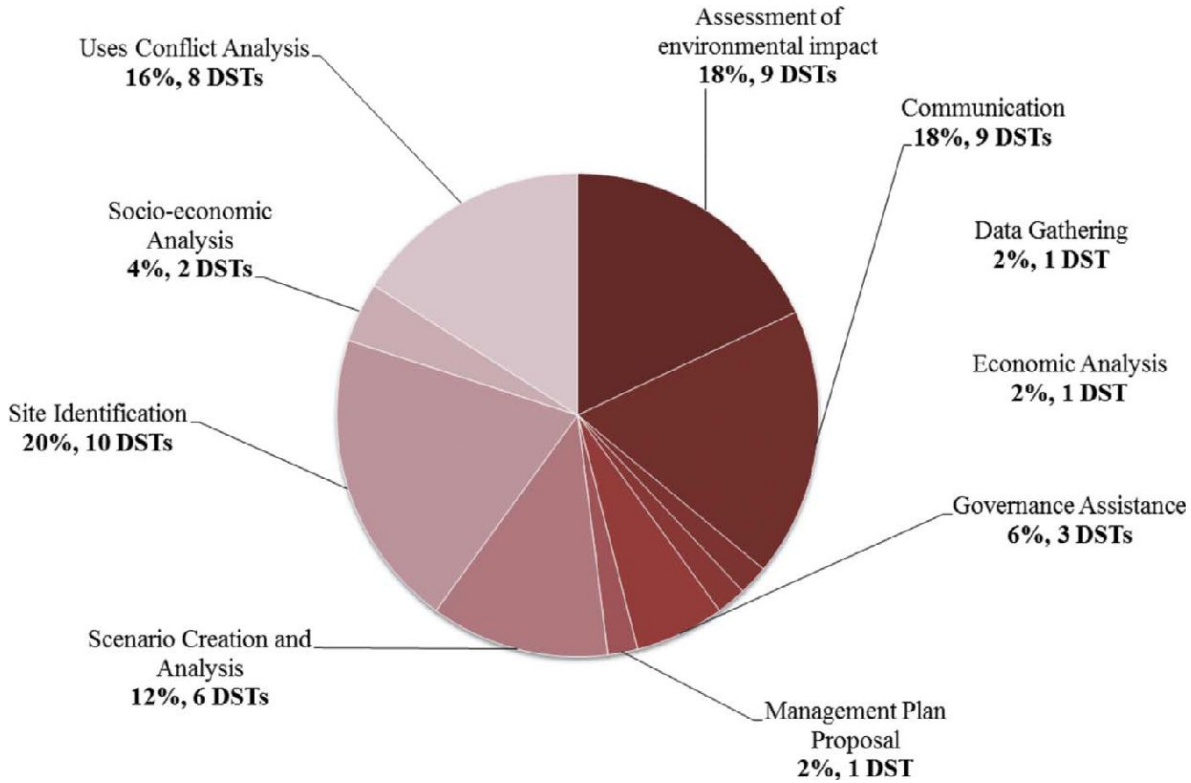
Maritime Spatial Planning (MSP) is a practical way to create and establish a more **rational organization of the use of marine space** and the **interactions between its uses**, to **balance demands for development** with the need to **protect marine ecosystems**, and to achieve **social and economic objectives** in an open and planned way.



From Ehler & Douvere, (2009)

How to operationalize adaptive management in a maritime context?
Introducing Decision Support Tools (DSTs)

- DSTs are **software-based instruments** designed to support an evidence-based **decision-making** process (such as MSP or Adaptive Management) in a **systematic, objective and transparent way**.
- Users of DSTs span from **policy- or decision-makers,** to **scientists, industry, practitioners**, and even **NGOs.**



Purpose of use for Decision Support Tools (DST) (percentage within Marine Spatial Planning process). From Pınarbaşı et al., (2017)

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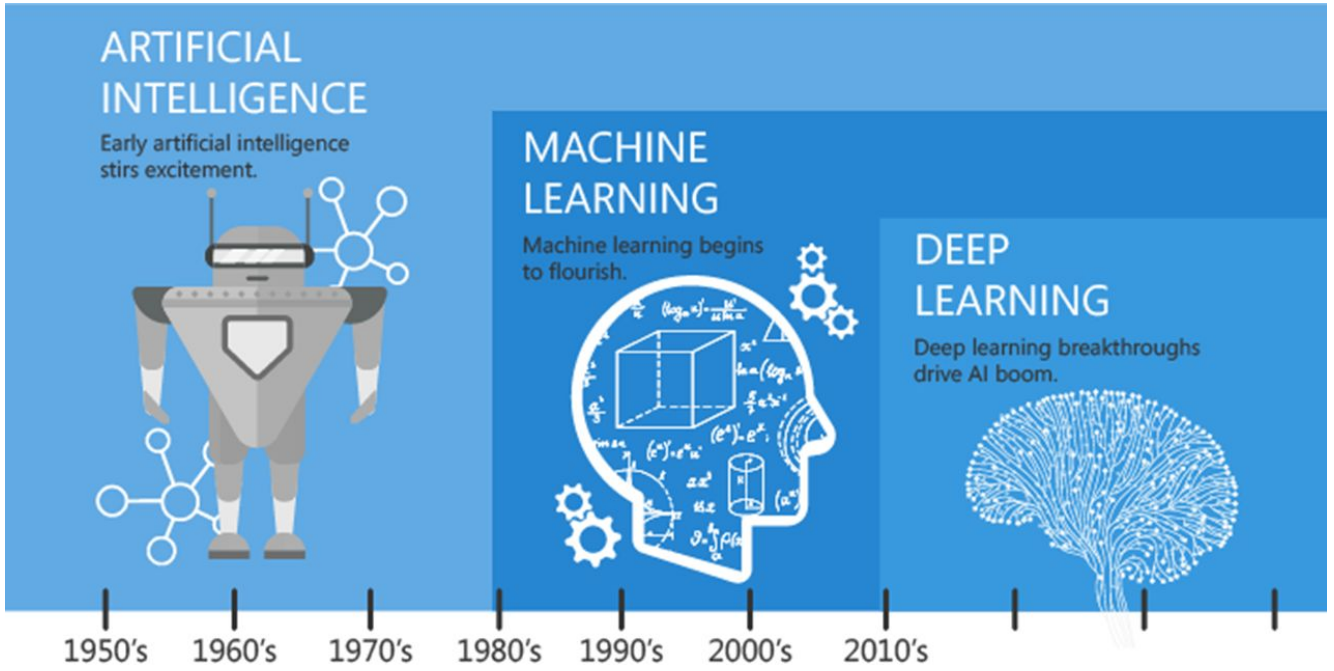
2.Integrated Machine Learning and Artificial Intelligence-based risk assessment framework

What is Machine Learning/AI?

Artificial Intelligence (AI): Can be considered as a broad field of computer science solving complex problems, using human-like decision making processes..
Example: Chess-playing program, rule-based expert systems

Machine Learning (ML): Data-driven methods that find patterns and trends from large, diverse datasets.
Example: An email spam filter trained on labeled emails, using chosen attributes like sender, words, and links.

Deep Learning (DL): A specialized branch of ML especially powerful for big data analytics with neural networks developed to learn patterns directly from raw data, such as images, audio, or text.
Example: Your photo app that auto-recognizes faces and groups pictures by person, learning directly from the pixels, without hand-written rules like “find eyes and nose.”



What can AI/ML do?

Deep learning has become a powerful tool for understanding and predicting complex Earth system and ocean processes by learning directly from vast, multi-source environmental data.

Analyze satellite and sensor data: Automatically detect and classify patterns such as ocean currents, algal blooms, oil spills, and cloud formations from raw imagery or remote-sensing data.

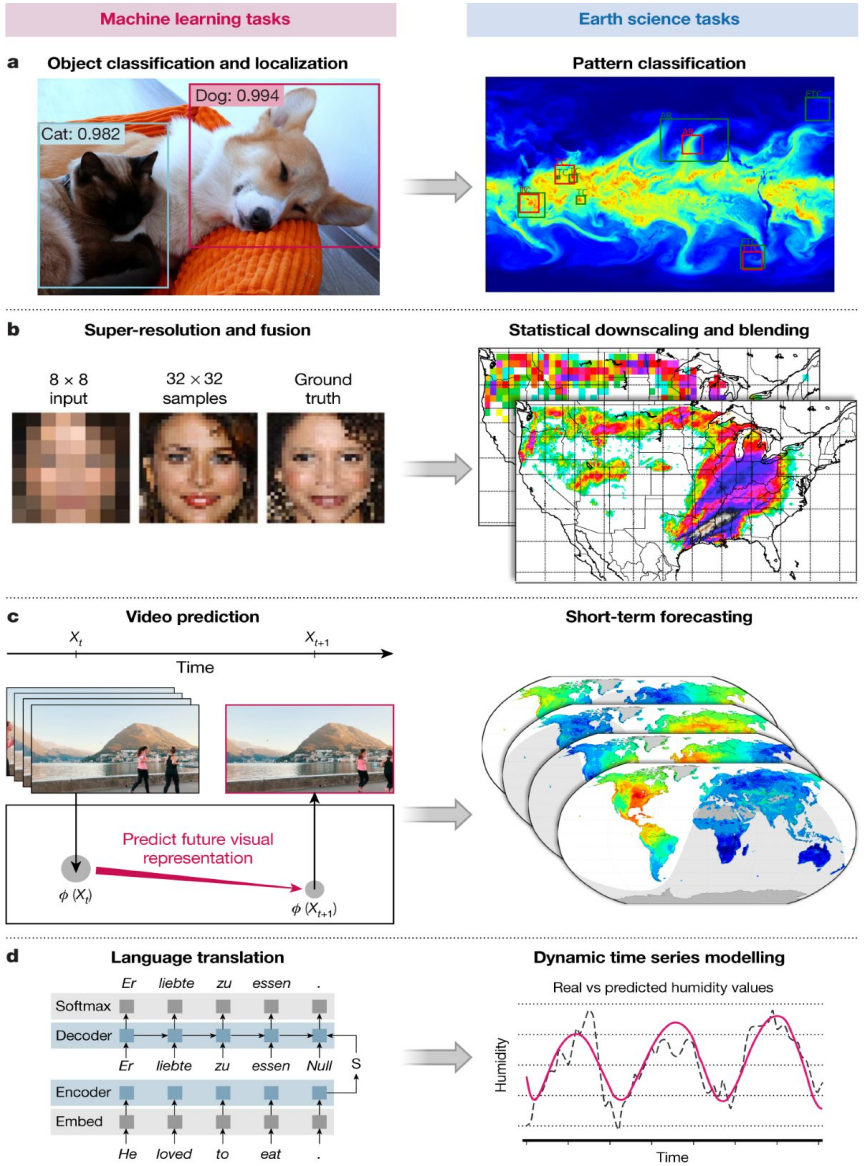
Improve ocean and climate forecasting: Enhance numerical models by learning nonlinear relationships between variables, leading to more accurate short- and long-term predictions (e.g., emulating ocean and earth system dynamics).

Monitor environmental change: Automatically track sea-level rise, glacier retreat, coral bleaching, and deforestation using time-series and image-based deep learning models.

Model biogeochemical and physical processes: Learn complex interactions between atmosphere, ocean, and land components, supporting better understanding of carbon cycles and ecosystem dynamics.

Support autonomous ocean exploration: Enable underwater robots and drones to interpret sonar, visual, and acoustic signals in real time for mapping seafloor habitats or detecting marine life (e.g. advanced control systems, and on-board data processing).

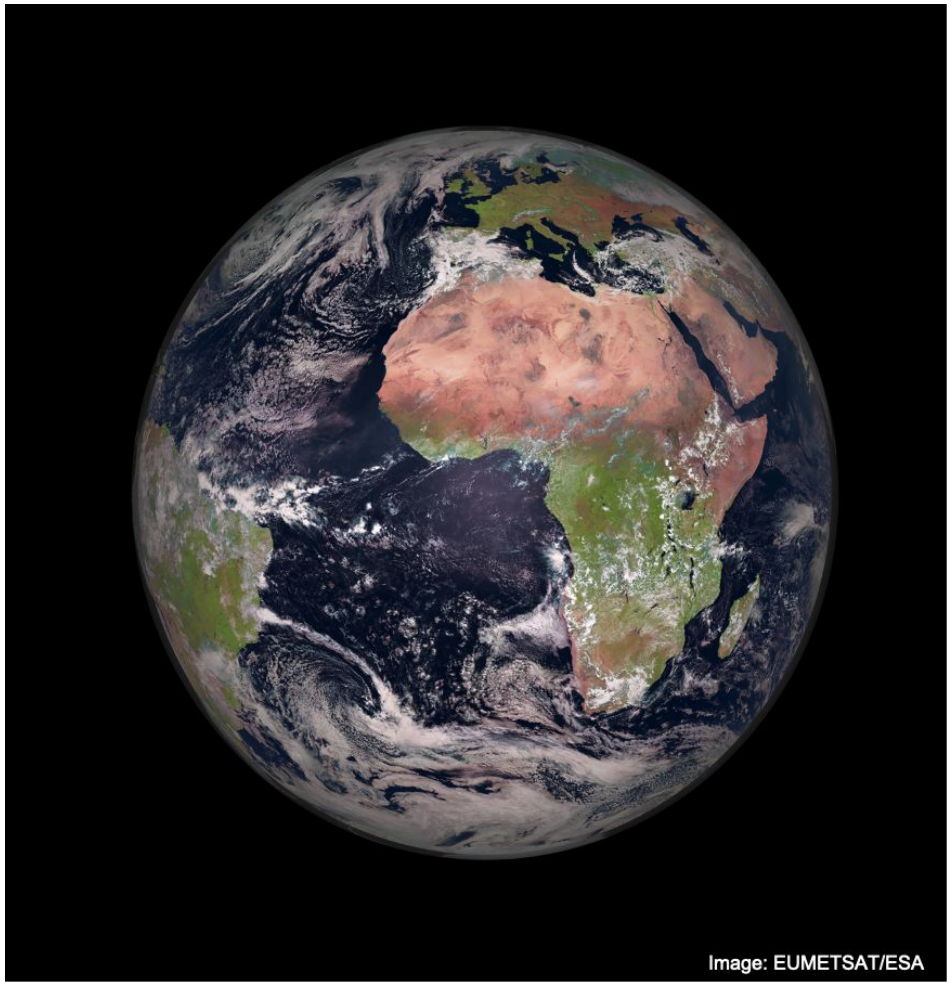
Fuse heterogeneous data sources: Combine satellite imagery, in-situ observations, and model outputs to produce high-resolution and more reliable environmental datasets.



Reichstein et al 2019 https://doi.org/10.1038/s41586-019-0912-1

Emulators of Earth System Model

- Process-based numerical simulations are powerful but computationally intensive
- In such scenarios, emulators provide efficient supplement
- Neural networks may be used to learn, approximate, and predict trends and dynamics in spatio-temporal data, such as simulation data
- Once trained, emulators can **effectively model complex system behaviors** and **predict changes over time** based on various types of inputs
- Analyses of these networks may highlight **key ecosystem drivers** and **indicators** to support **early warning systems** of for **ecosystem changes** or **extreme events**
- They may also help identify **ecological regime shifts** over time, providing insights into transitions in **ecosystem states** and **their drivers**.



Why Use DL-based emulators for Risk Assessment?

DL methods can be used to build emulators of process-based models by training specialised networks.

By integrating diverse data sources and simulating nonlinear dynamics in the ocean environment, DL methods can be used to :

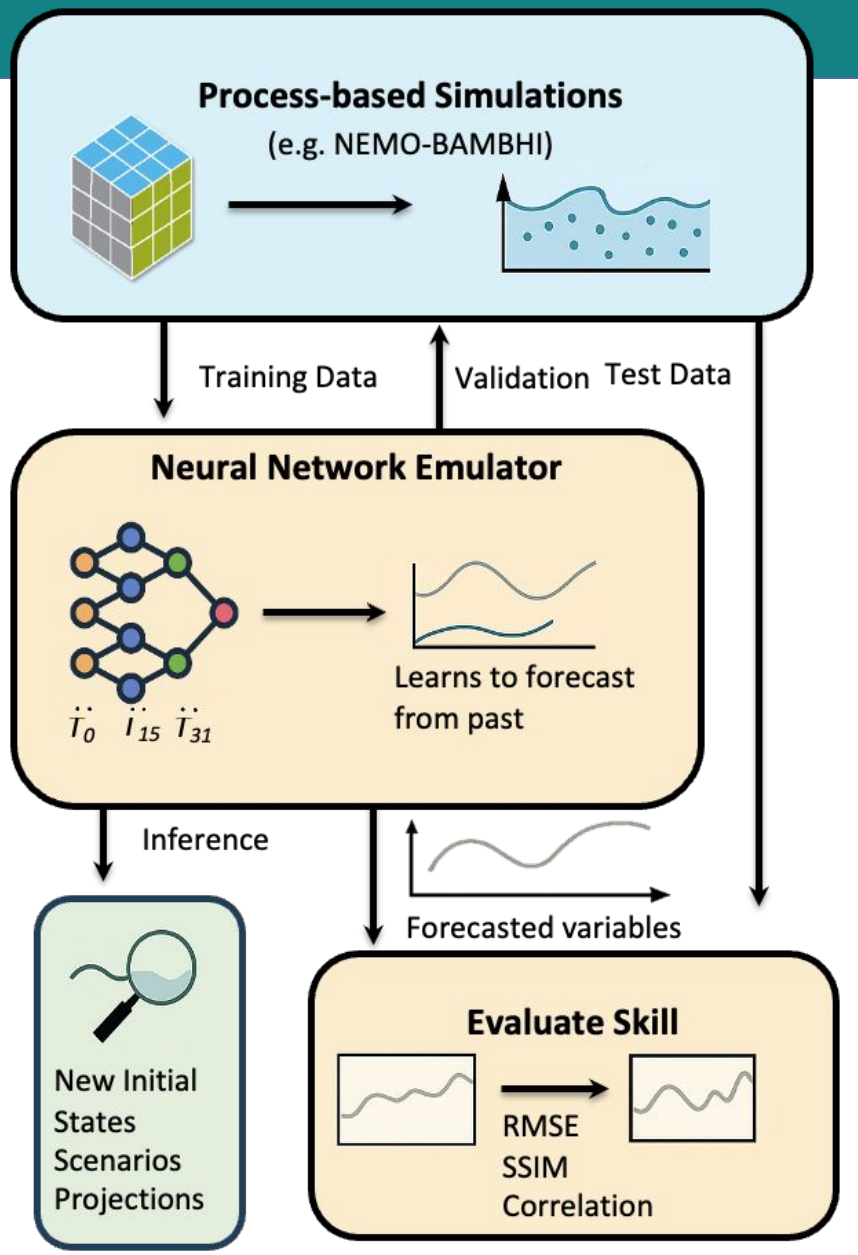
Understand drivers and vulnerabilities - analyse drivers of change in ecosystem dynamics across scales

Enhances early warning systems – detects and predicts hazards like storms, algal blooms, and flooding.

Automates pattern recognition – identifies critical features (e.g., pollution plumes, anomalies) from raw data.

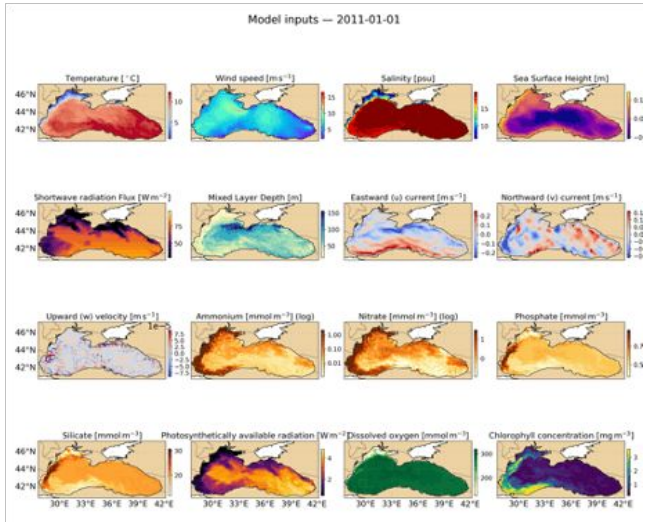
Improves prediction accuracy & resolution – refines risk maps and supports data-driven decision-making.

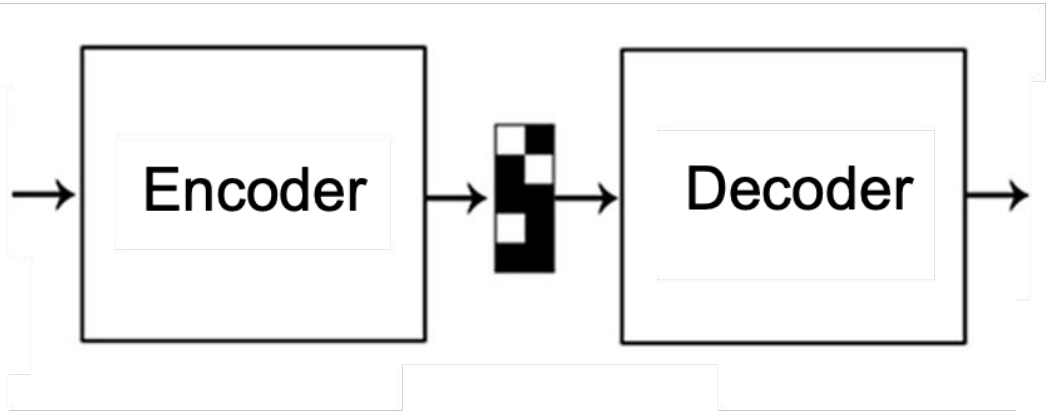
Supports resilience & planning – provides actionable insights for coastal management and policy

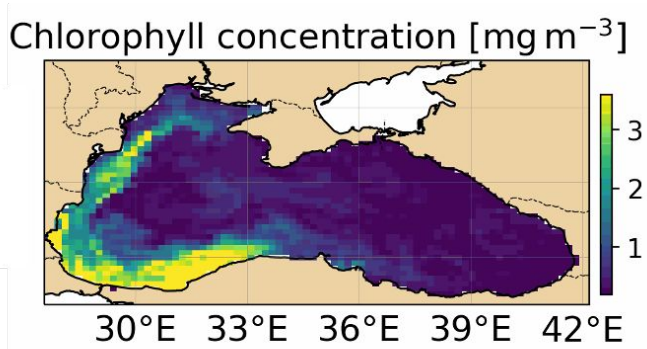


Machine Learning/AI in Environmental and Ocean Sciences

EMULATING BLACK SEA DYNAMICS





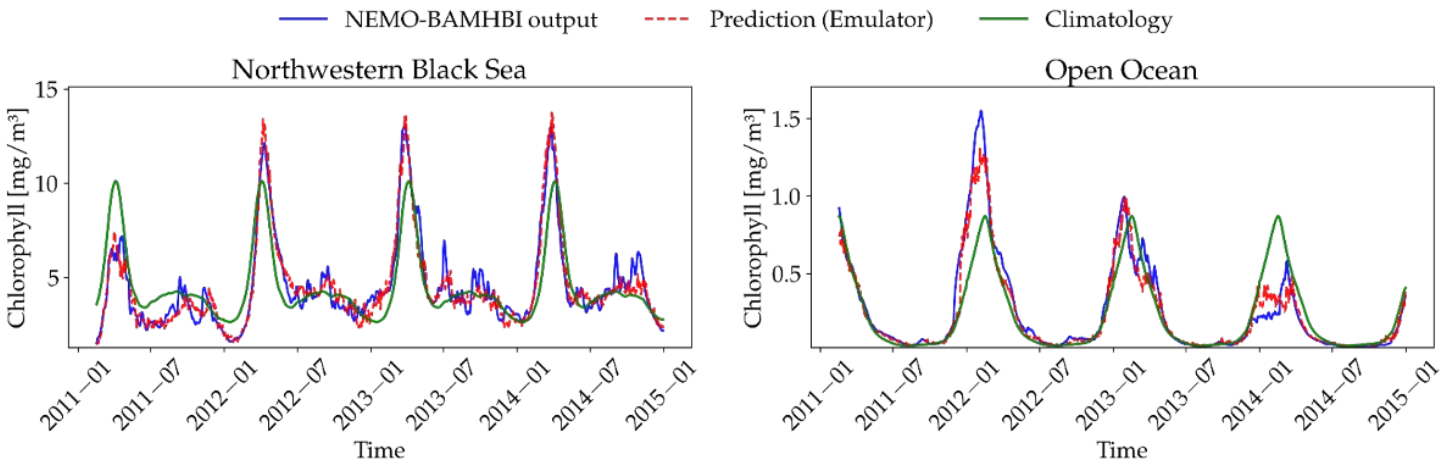


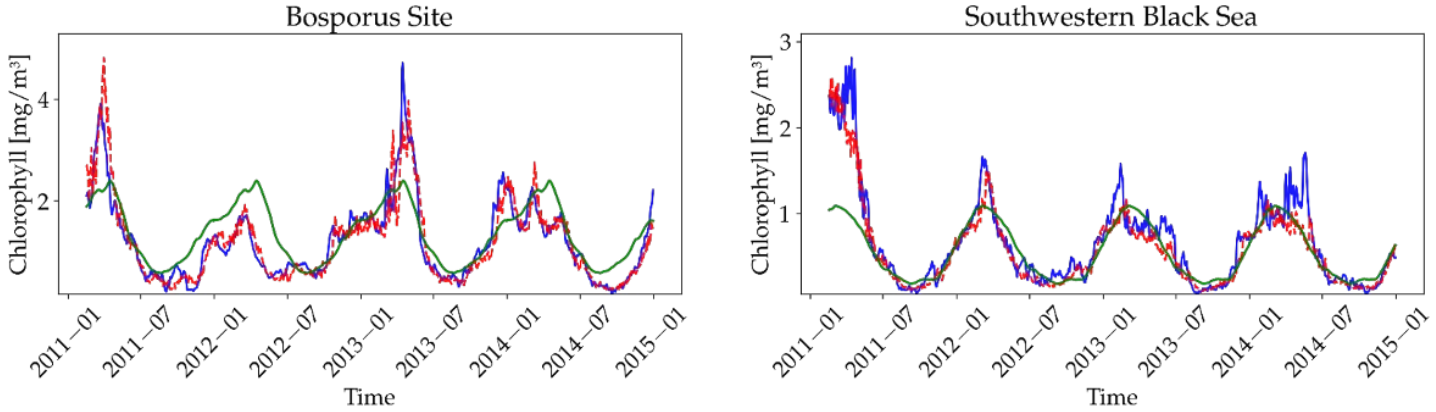
Inputs are a sequence of images from different variables changing then in time and space

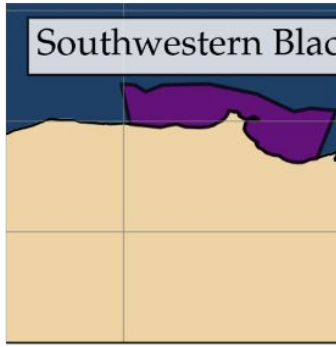
The Neural Network is based or an encoder decoder architecture often used for sequential data processing and generation.

The output is the forecasted dynamics of Chlorophuyll-a in the Black Sea

Machine Learning/AI in Environmental and Ocean Sciences





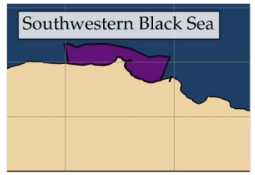


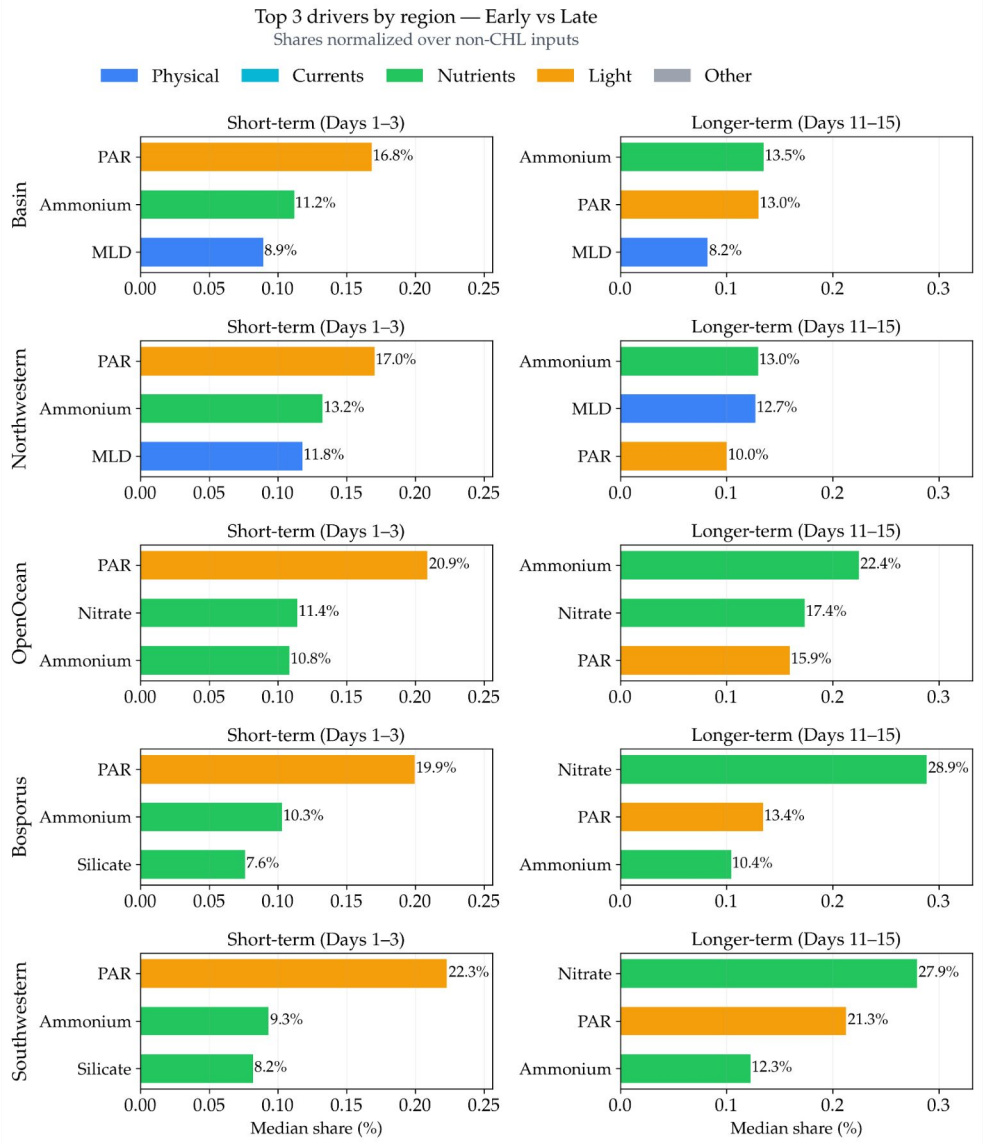
Results can be then analised over time and at different locations by comparing prediction from the network to the source process-based modeling and its climatology used as baseline for comparison

Machine Learning/AI in Environmental and Ocean Sciences

Drivers can then be analysed at different geographical locations using perturbation analyses on the trained neural network

The same can be done over different time periods and including response to different climate scenarios





Machine Learning/AI in Environmental and Ocean Sciences

In conclusion:

- ➔ Emulators are essential tools for addressing societal needs using the best scientific knowledge
- ➔ Easy to integrate in European Digital Twin of the Ocean (EDITO) : Black Sea case as well as for other regions
- ➔ Successful for testing what-if scenarios and deliver short term forecasts

3. Cumulative Effects Assessment tool (CEA)

3.1 What do we mean by “cumulative” impacts / effects?

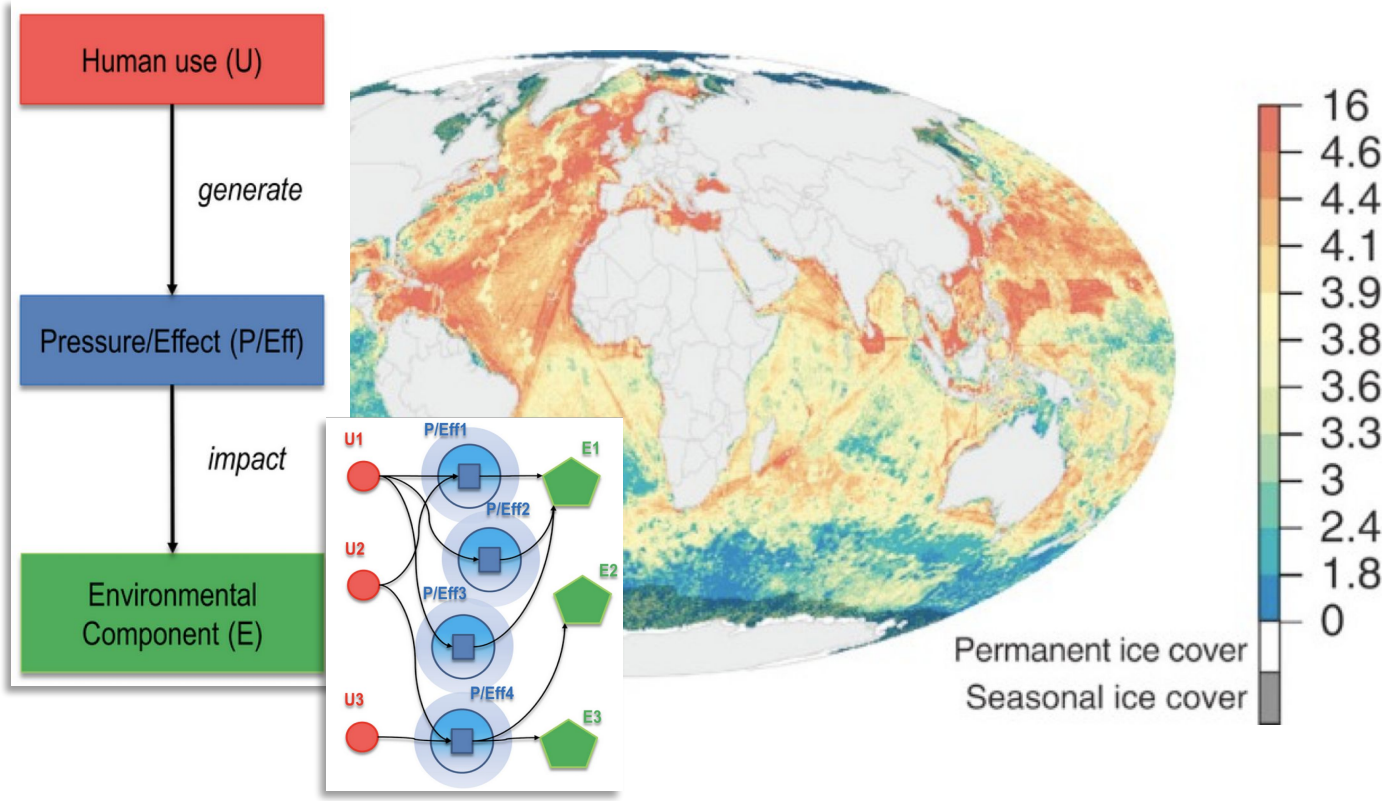
- The marine environment hosts a variety of human activities, which may become sources of negative impacts on marine species and habitats.
- These impacts may be small or insignificant when taken individually, or at a fixed time, or at a particular location…
- … But may have global repercussions when combined.

Cumulative impacts are those that result from the **successive, incremental, and/or combined effects** of an action, project, or activity when added to other existing, planned, and/or reasonably anticipated future ones.

From Cardinale, P. Introduction to Cumulative Impact Assessment and Management

3.2 How can cumulative impacts be evaluated?
Introducing Cumulative Effects Assessment (CEA)

- *Human activities* (U) generate *pressures* (P) which impact a series of *environmental components* (E). This is known as the **impact chain**.
- By combining **quantitative** and **spatial data** on these three variables (U, P and E), we can obtain **maps of cumulative impacts**.
- This type of analysis is known as a **Cumulative Effects Assessment (CEA),** first published by Halpern et al. (2008).



Note: Results from CEA are used to support decision-making within Maritime Spatial Planning. CEA is a DST!

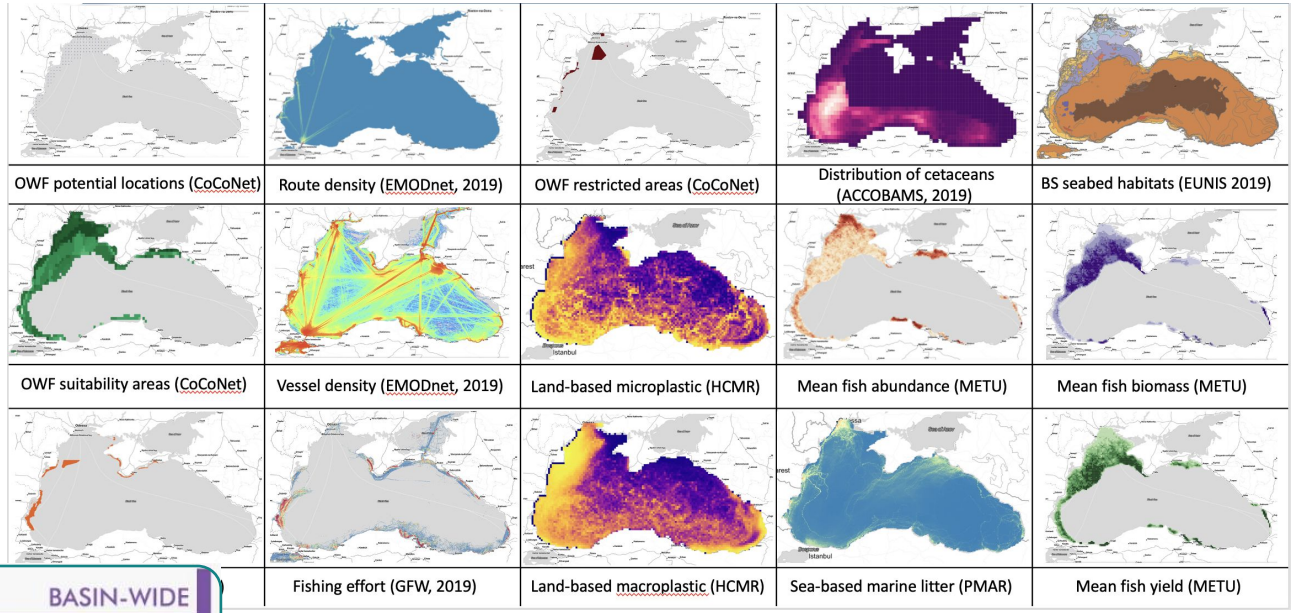
Figures adapted from Menegon, et al. (2018) and Halpern, et al. (2008)

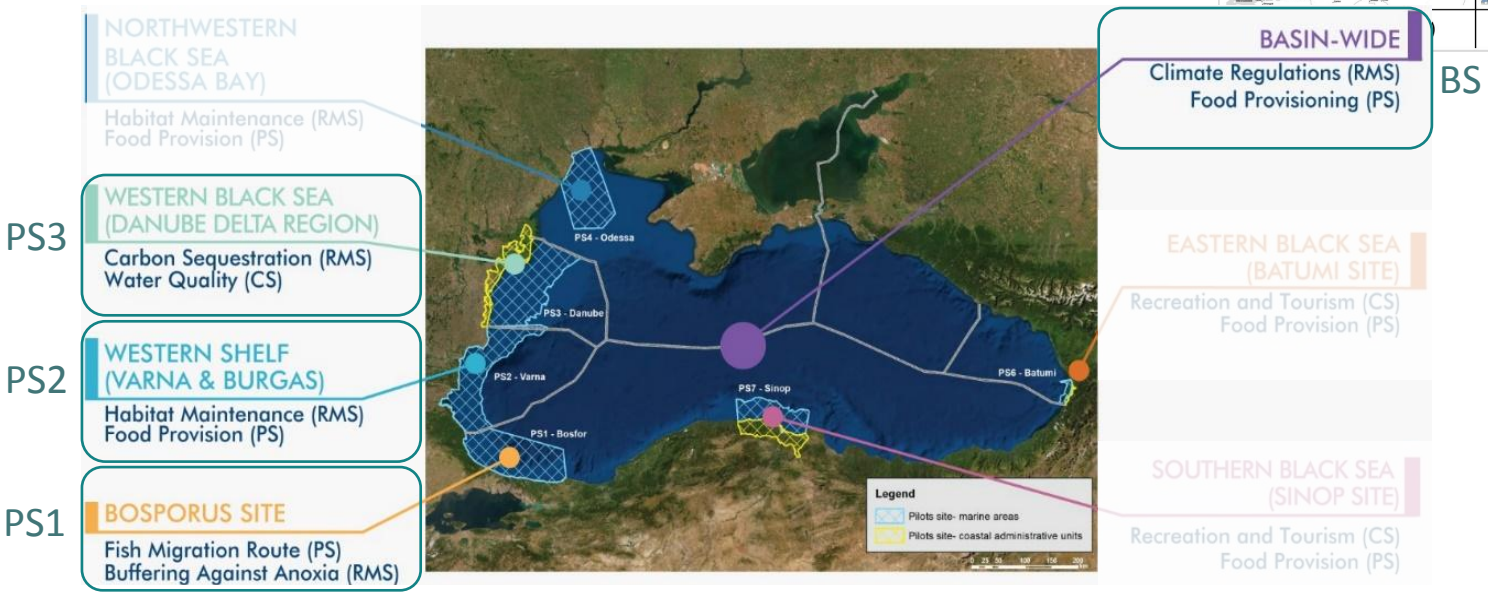
3.3 Risk-based Cumulative Effects Assessment in the Black Sea

Goals and set-up of the analysis

AIM

- To identify hotspots of cumulative impacts on target environmental components and core Ecosystem Services in the Black Sea.
- To support the development of adaptive management strategies in present and future scenarios.





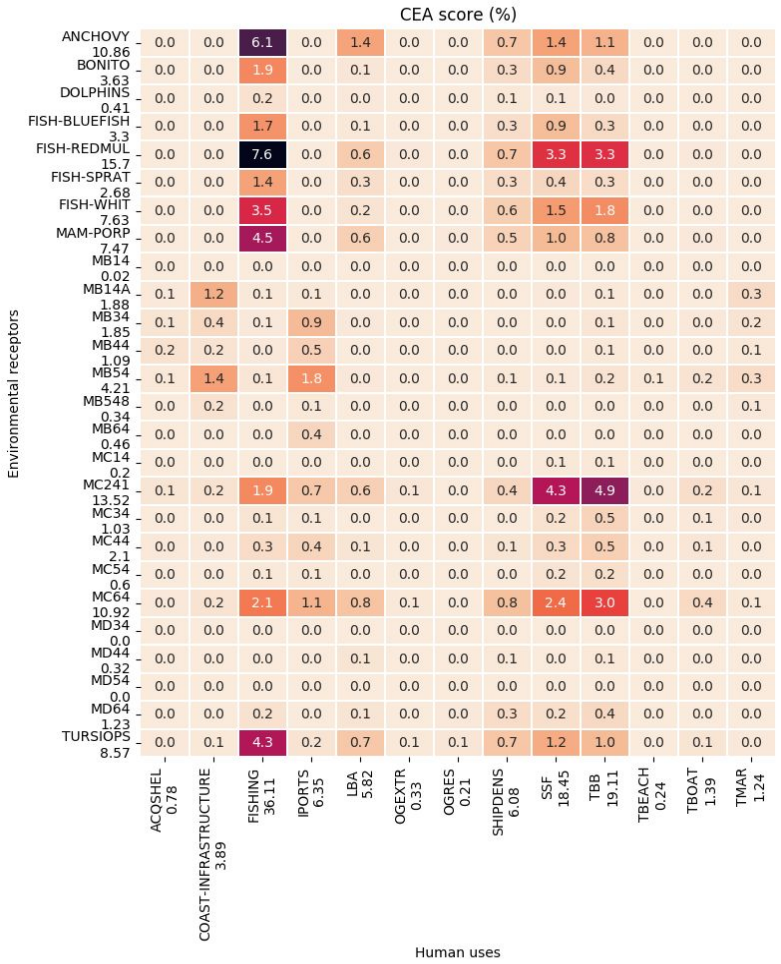
BS

- 4 case studies (3 Pilot Sites, 1 basin-wide)
- Over 110 layers (including human activities, anthropogenic pressures and environmental components)
- 3 teams of local experts involved (one per Pilot Site)

3.4 Cumulative Effects Assessment in the Black Sea

Some results from the CEA analysis: Pilot Site 2 (Varna & Burgas)

Fig. 1. Contribution to total CEA score from each U-E (human use - environmental component) combination.



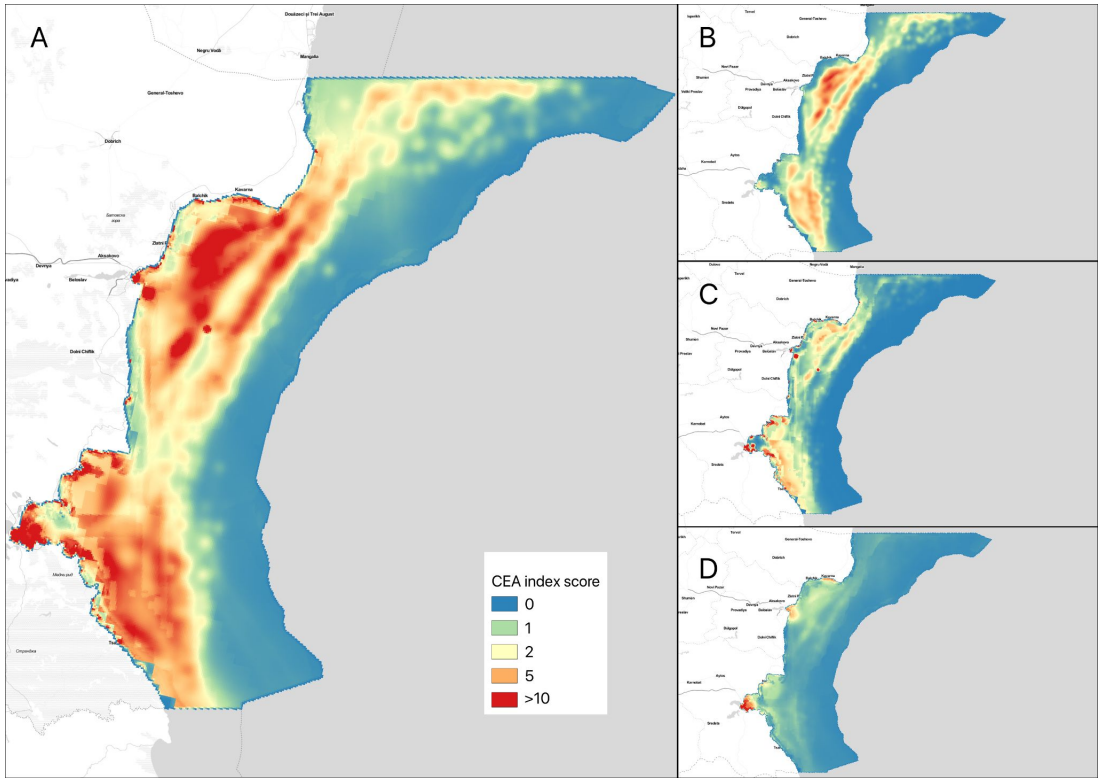


Fig. 2. Geospatial distribution of CEA index score (A). Smaller panels represents the contribution to the total CEA index from biological (B), physical (C), substances, litter and energy pressures (D).

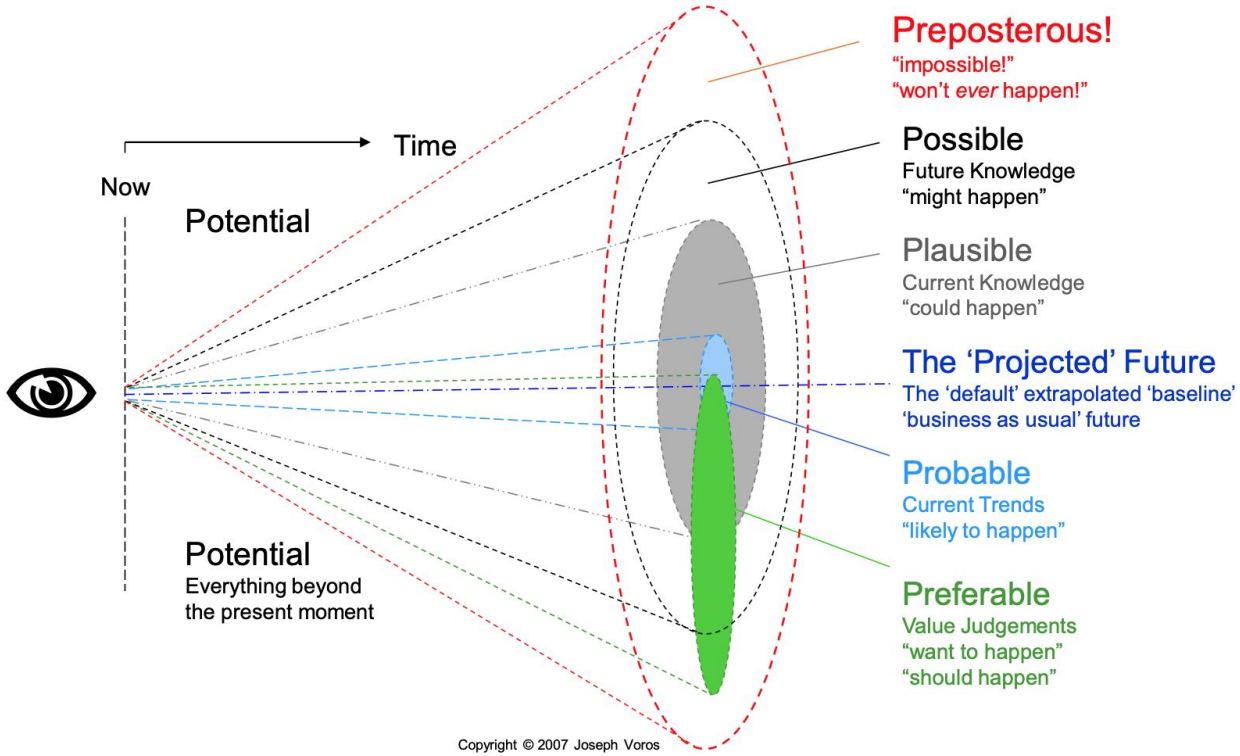
Results of the Cumulative Effects Assessment (CEA) include, but are not limited to:

- Contribution from each U-E combination to the total CEA score (Fig. 1)
- CEA index score per spatial grid cell in each Pilot Area (Fig. 2)

4. Analysis of future scenarios with Cumulative Effects Assessment (CEA)

4.1 Why look at future scenarios in adaptive management and Maritime Spatial Planning?

- **Future scenarios** are imagined or projected versions of the future.
- **MSP is a future-oriented activity**: its purpose is to help us imagine a desirable future and support **short-term proactive decision-making towards long-term objectives**.
- The impending effects of **climate change** require preparation. By exploring and **analysing future scenarios** we can **develop solutions** through innovation and adaption.



The "**futures cone**" depicts different types of future scenarios based on how likely they are to happen.

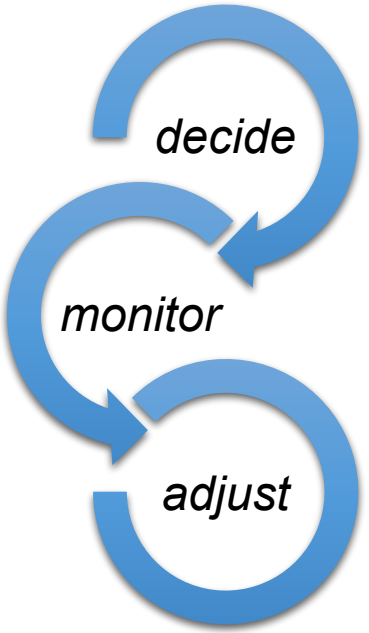
From Mc Cawley et al. (2015)

4.2 Analysis of future scenarios with Cumulative Effects Assessment (CEA)

Advantages and expected outcomes

- Cumulative Effects Assessment can be carried out on the **present** condition, as well as on **future** scenarios (as long as the relevant data is available).
- Integrating CEA with scenario analysis allows decision-makers to **prioritize management measures** based on risk intensity, spatial extent, and relevance to policy objectives.
- Comparing CEA of present and future scenarios allows for the investigation of the **spatial and temporal variations of risk**.
- Assessing cumulative impacts in future scenarios also highlights the implications of different management measures, whether positive or negative, **thus supporting adaptive management**.

Adaptive Management

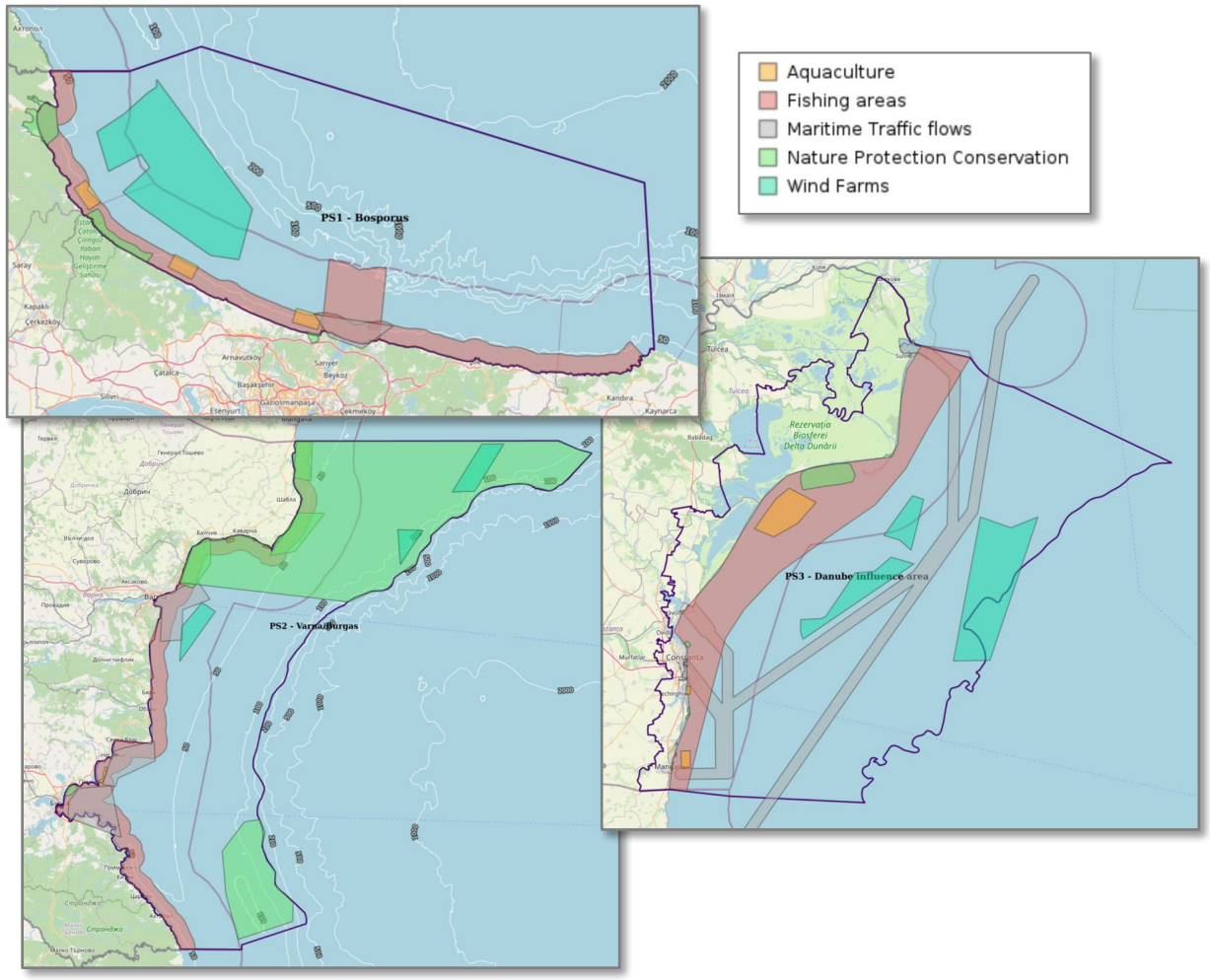


learn by doing

4.3 Analysis of future scenarios with Cumulative Effects Assessment (CEA)

BRIDGE-BS methodology

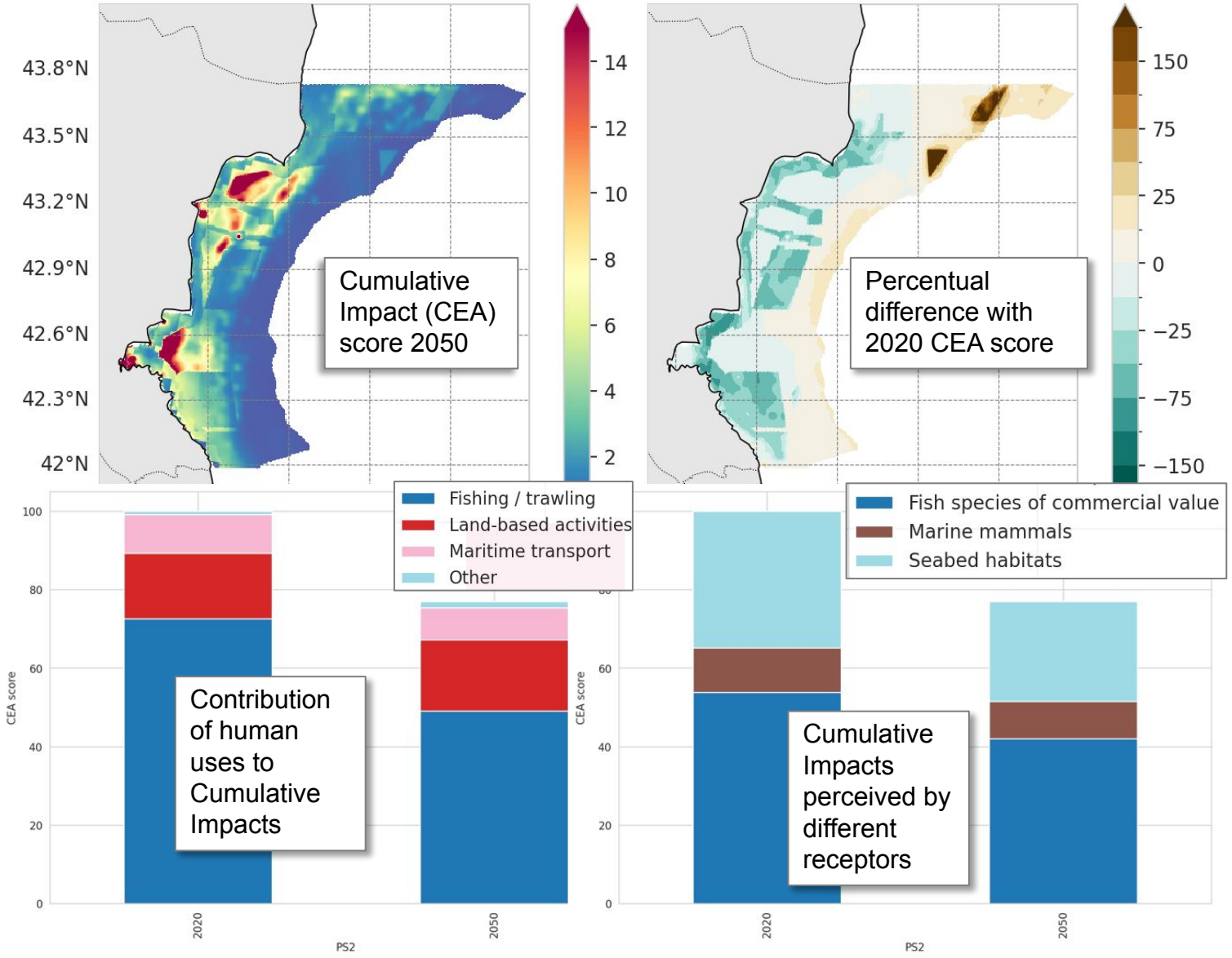
- Future scenarios were developed for each case study area (3 Pilot Sites + basin-wide), referring to the year 2050.
- The 2050 scenarios integrated future projections from state-of-the-art ocean, atmospheric and ecological models in the Black Sea…
- … as well as the visions of local stakeholders for a desired future in their region.
- The CEA methodology was applied to the future scenarios in the same way as it was done for the present condition.



The development of future scenarios for the 3 Pilot Sites involved mapping realistic future developments in maritime sectors, in collaboration with local stakeholders.

4.3 Analysis of future scenarios with Cumulative Effects Assessment (CEA)

Pilot Site 2 (Varna & Burgas) results



- Comparing CEA from the 2050 scenario with the CEA from the present condition (2020) highlights regions where impacts have increased (in brown), or decreased (in blue).
- A decrease in CEA score compared to the present denotes the achievement of a “desired” scenario, as is the case in PS2 here.
- Based on results from these 4 case studies, we conclude that a strong reduction in industrial fishing and maritime transport would significantly reduce cumulative impacts, particularly on commercial fish species.

5.Recommendations for Adaptive Management, planning and policy implementation

5.1. What are recommendations for?

Recommendations are addressed to policy-makers for developing adaptive management strategies to underpin a sustainable Blue Economy in the Black Sea, both at local and regional level

Recommendations contribute to

Policy-making

Planning and environmental goals

Enhanced dialogue

Business opportunities

Recommendations are grouped as

Area-based recommendations

Ecosystem-based recommendations

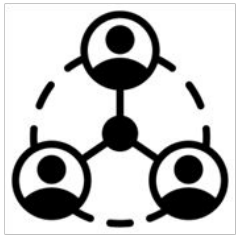
Blue Economy-based recommendations

5.2. Ambition and challenges

Ambition - to have a real impact at the societal and policy levels by changing the current dogma of management practices, which often lack long term vision and coherence.

Challenges

insufficient data / info



stakeholders' reluctance

low confidence in predictions

limited resources and tools

5.3. How to develop the recommendations?




1 2 3 4

BASELINE

Define the current environmental, socio-economic, and policy situation for each Site of Interest and the Black Sea basin as a whole.

ANALYSIS

Identify critical risks and gaps in current management practices. Scientific and stakeholder's inputs feed this phase.

RECOMMENDATIONS

Drafting Recommendations through concrete actions to address the identified risk. Integration of the stakeholders' feedback is very important in this phase.

SYNTHESIS

Integrate all findings into clear diagrams, flowcharts, and visual tools. Support adaptive decision-making with easy-to-use tools for stakeholders and policy makers.

Take-home messages from the 5 sections

- Sustainable **environmental management** is "**adaptive**" when it consists of a continuous and systematic process of: i) monitoring the effects of implemented measures, ii) learning from their outcomes, and iii) adjusting the course of action.

- **Emulators** are essential tools for **addressing societal needs** using the **best scientific knowledge**
- Easy to integrate in European Digital Twin of the Ocean (**EDITO**): Black Sea case as well as for other regions
- Successful for testing **what-if scenarios** and deliver **short-term forecasts**

- Negative impacts caused by human activities at sea may have an amplified effect when combined (**cumulative impacts**).
- A **Cumulative Effects Assessment (CEA) tool** is a Decision Support Tool (DST) which evaluates cumulative impacts spatially, by combining layers of human uses, anthropogenic pressures and environmental receptors.

- The analysis of **future scenarios** is helpful in developing solutions for negative changes caused by **climate change** through innovation or adaptation.
- Within adaptive management, the assessment of **cumulative impacts in future scenarios** can provide information on the **efficiency of management measures** and support the "learning by doing" process.

- The recommendations support managers and planners looking to overcome the inherent uncertainty surrounding climate changes and human activities, their effects, and appropriate responses.

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IT CAN BE USED WHEN A SUBJECT IS EXPLAINED THROUGH LONG TEXTS AND VISUALS

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AN ALTERNATIVE TO EXPLAIN SOMETHING THROUGH TEXTS AND VISUALS

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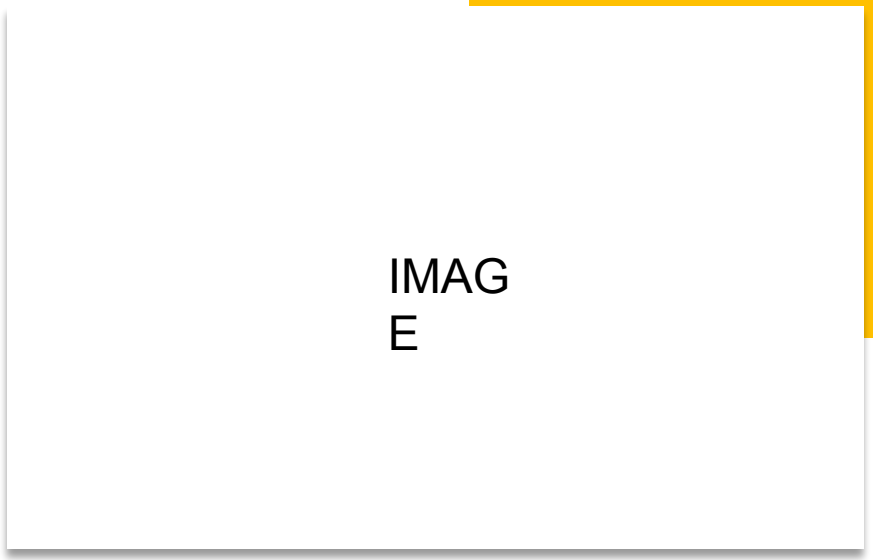

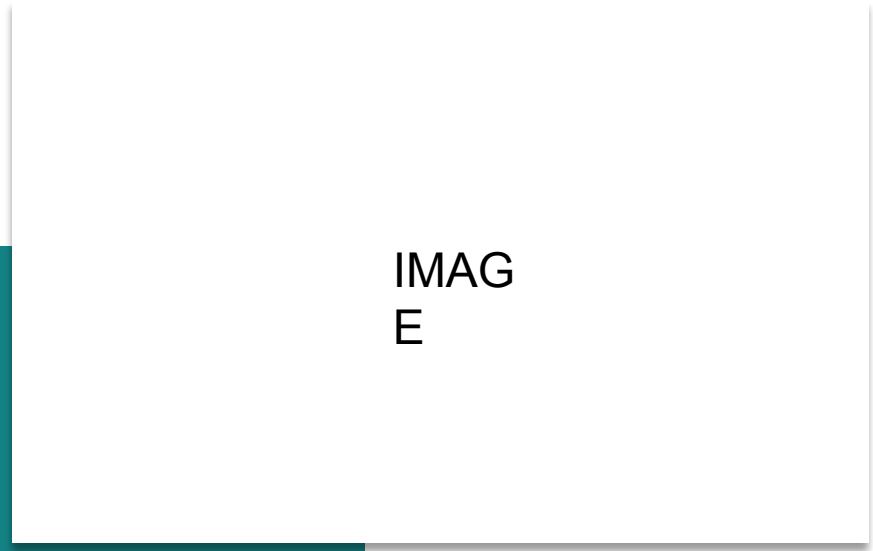

CAN BE USED TO SHOW ONE PARTICULAR IMAGE
NOTE: NEEDS TO BE USED WITH A WHITE FRAME