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Deliverable information

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Deliverable title	**Development of targeted indicators and their uncertainties for demonstrators and Forecasts**
Description	This deliverable reports on the achievements of the EuroSea project in developing targeted indicators co-designed with demonstrators (WPs 5–7) and forecasts (WP4). For this, the indicators implemented are expressed in term of Essential Ocean/Climate Variables (EOVs/ECVs) together with their requirements. The co-development undertaken address ocean indicators for all range of scales: from the large, basin scale to the regional and local scales. Such approach as well as the proposed solution to focus, at regional/local scales, on EEZs, represent one of the innovative results of EuroSea that will help to rationalize risks assessments and guide environmental management approaches in European Seas.
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Lead beneficiary	ENS
Lead authors	S. Speich
Contributors	A. Pascual, H. Dayan, B. Barcélo, M. Balmaseda, C. Cusack, T. Dabrowski, I. Graves, K. Horsburgh, U. Lips, R. McAdam, S. Masina, G. Navarro, J. She, K. von Schuckmann
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Executive summary

Indicators can provide information to guide sustainable management. They are necessary for regular reporting on the state of the ocean, its variability and change. Indicators can also be used to identify knowledge gaps and observing system gaps that limit our capacity to respond to society's needs for ocean information and thus serve as useful guides to prioritize investments in the observing system. They are also key communication tools for the general public, enhancing ocean literacy and the engagement of citizens in the global effort. Indicators can apply both to the state of the marine environment and to considerations of performance against environmental targets and/or limits in a defined geographical area. In order to guide management, indicators should be set within a reference framework and hierarchies of indicators can provide coordinated support.

Through this deliverable, the EuroSea project seeks to improve existing climate and marine indicators via a co-development process with stakeholders involved in different sectors represented by the project's different Working Packages (WP2 "Ocean Observing System Design", WP4 "Data integration, assimilation and forecasting", WP5 "Coastal resilience and operational services demonstrator", WP6 "Ocean Health Demonstrator" and WP7 "Ocean climate indicators demonstrator"). In this, we took into account requirements for important end-users and stakeholders key for different sectors (governments, regulatory bodies, intergovernmental frameworks, fisheries, aquaculture, ocean energy, coastal and port managers, marine research and the public) and interested in assessments at different scales (from that of an entire ocean basin or sea to scales of bays, aquaculture farms, harbours and beaches). This work will provide direct economic benefits and follow-on opportunities in services for countries and industries depending on ocean health and long-term forecasts of weather and climate.

The deliverable presents the process we undertook to co-define scientifically based indicators as well as the requirements in terms of Essential Ocean and Climate Variables (EOVs/ECVs) linked with them for each group of stakeholders included in EuroSea Demonstrators (WP5–7) and Forecast (WP4) working packages. This necessarily also defines the requirements in terms of observations and platforms.

1. Introduction

A major goal in EuroSea is to improve ocean health, security, climate assessments and forecasting, with the aim of aiding marine-based stakeholders to make science-based decisions about their resources and activities.

1.1. Indicators

Ocean indicators are meant to rationalize through quantitative indices the status and health of the marine environment. They consist of maps, time series or trends of key ocean and climate variables. More complex analyses of these variables, such as identifying extreme events, are also indicators. The Copernicus Marine Environment Monitoring Service (CMEMS) and the Copernicus Climate Change Service (C3S) provide dozens of indicators of the European seas and the global ocean. They are derived from a range of historical climate data (e.g., *in situ* data, satellite-derived products) or model analyses (forecasts) and reanalyses. They provide a comprehensive view of the ocean over the past decades or in the near future. Past variability and trends in the marine environment are important to assess natural variability of the system, extreme events, and changes underway whereas accurate prediction of future changes is equally important as it constitutes the substantial base to build adaptation strategies and manage sustainably the marine environment and ocean resources.

However, the current use of ocean indicators is both overwhelming in terms of numbers being used and disparate in terms of the different indicators, systems and terminology employed. The analysis of indicators currently being used highlights different levels of specificity, wide variation in terms of the numbers of indicators, different rationales for indicator selection, different levels of sophistication and, for some parameters, the use of qualitative indicator statements. When trying to compare them across uses and regions, this diversity confuses any underlying assessments, messages and conclusions that may emerge. Indicators in themselves are not sufficient to describe or understand progress against a baseline. To contribute to governance and management efforts as well as requirements and reporting on Climate Adaptation by countries to fulfil the Paris Agreement, indicators should be scientifically based, rationalized, and homogenized across uses and geographical domains. Such indicators should and can be input to regular global and regional status assessments, as well as contributing to risk assessments and ocean management.

This document reports on the set of coordinated indicators reflecting approaches already underway within the stakeholders and user groups of the various sectors associated with EuroSea via the Demonstrators (WPs 5-7) and Forecasts (WP4). In doing so, it provides a framework based on the needs identified across stakeholders and the existing indicators that fulfil multiple reporting requirements. At the same time, it is acknowledged that too many indicators blur any robust assessment and action. We, therefore, focused on an achievable limited set agreed upon with EuroSea stakeholders.

Moreover, we wanted to provide a simple-to-apply framework that allows defining appropriate metrics that can be agreed upon collectively for complex indicators such as Marine Heat Waves and a regionalization approach. This framework can link consistent indicators defined at the large ocean scales to indicators at regional or even local scales, as these are more relevant for various sectors of end users. An illustrative case towards defining a collective approach is proposed in this deliverable.

We conclude that a targeted set of indicators should harmonize effort rather than add to reporting burdens and provide an opportunity to bring together users, the data providers (ocean observing systems and networks) and services.

1.2. Related Essential Ocean and Climate Variables

To meet the need of delivering ocean data to support governance and management, a Framework for Ocean Observing (FOO) emerged from the OceanObs'09 conference (Lindstrom et al., 2012) and has been adopted since by the Global Ocean Observing System (GOOS: Tanhua et al., 2019). This framework proposes the coordination and integration of routine and sustained observations of physical, biogeochemical, and biological essential ocean variables, or EOVs, which are fit for purpose and defined by specific requirements (Lindstrom et al., 2012; Miloslavich et al., 2018). Some of these requirements include international reporting via indicators (e.g., the United Nations Convention on Climate Change (UNFCCC), the UN Sustainable Development Goals (SDGs), the Convention on Biological Diversity (CBD) Aichi Targets) and assessments (e.g., the UN World Ocean Assessment; the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)). A sub-ensemble of EOVs constitutes the ocean Essential Climate Variables (ECVs: Bojinski et al., 2014). EOVs and ECVs are aimed at driving policies to help prepare, adapt, manage, and mitigate the effects of ocean global change and provide the opportunity for developing countries to identify their needs for global participation and support, overall improving the economies and well-being of societies worldwide.

The goal of the work undertaken within EuroSea and reported here is to identify the EOVs/ECVs (as well as their specific requirements and uncertainties) related to the targeted set of ocean indicators we have co-defined together with EuroSea stakeholders.

In this report, we outline the various EOVs/ECVs we have defined as well as their requirements to provide sound guidance to observing networks in assessing present and future needs for observations.

1.3. Aims

The aims of this deliverable are both scientific and stakeholder-orientated, and are to:

- Provide the approach to co-design and rationalize indicators with a large set of stakeholders
- Present the targeted indicators list for a wide range of users
- Introduce to the observing networks and data providers the requirements of the EOVs/ECVs related to the defined set of indicators.

This document reports on the EuroSea indicators together with their requirements. It is the final part of a chain of milestones, scientific papers and deliverables which describe EuroSea's marine indicators development:

- Milestone 6: Definition of EOVs/ECVs in connection with demonstrators and forecasts
- Milestone 10: Requirements of EOVs and platforms for sustaining indicators for WP4-7
- Paper 1: Dayan et al., 2022: Diversity of marine heatwave trends across the Mediterranean Sea over the last decades. In: Copernicus Ocean State Report, issue 6, Journal of Operational Oceanography, 15:sup1, 1-220, doi: 10.1080/1755876X.2022.2095169.
- Paper 2: Dayan, H., R. McAdam, M. Juza, S. Masina and S. Speich, 2023: Marine heat waves in the Mediterranean Sea: an assessment from the surface to the subsurface to meet national needs. Frontiers in Marine Science. In press.
- Deliverable 4.6: Skill assessment of ECV/EOV from seasonal forecast
- Deliverable 6.2: Demonstration of annual/quarterly assessments and description of the production system
- Deliverable 7.4: Skills of user-relevant indicators

2. EuroSea Ocean Indicators

The overall objective of EuroSea is to apply the systems design processes on the European observing to support its evolution towards a fit-for-purpose integrated system. The requirements on which such an observing system should be based are societal benefits. Such requirements should provide a direct link to societal challenges related to the larger Atlantic and Mediterranean basins and the European Blue Growth strategy. The goal of EuroSea is therefore to translate them into strategic recommendations about sustained monitoring of EOVs by deriving them in existing observing networks in support of the relatively large spectrum of ocean information end users associated with the EuroSea demonstrators. This way, EuroSea provides, as a legacy, a process to assess the fitness-of-purpose of the observing system against societal requirements and guidance to improve it.

To achieve this, we have employed a stakeholder engagement strategy to understand what potential users consider as relevant to their activities. In this framework, a large coordination effort has been organized by WP2, partnering with WPs 4, 5, 6 and 7 in the definition of specific or new indicators co-developed with a large set of stakeholders. More precisely, we carried out harmonization of already developed Atlantic, Mediterranean and Baltic Sea indicators and co-designed with stakeholders indicators for climate (WP7), ocean health (WP6), coastal resilience and operational services (WP5), and for verification of forecasts (WP4).

To achieve this, we have organized many technical workshops with all demonstrator and forecast working packages and groups of related stakeholders to learn about their expectations and operational needs in terms of indicators. During these meetings, we have provided explanations of the FOO and EOVs/ECVs concepts. EuroSea stakeholders supported the plans to establish the definition of tailored indicators responding to their requirements. These discussions led to the establishment of an action plan to define a first set of EuroSea indicators. This allowed us to develop and submit to these groups written surveys that provided us with systematic data to define the "EuroSea" set of indicators together with the associated requirements.

However, due to the different maturity of the discussions across the various groups of stakeholders, the indicators have been classified into three groups depending on the status of their definition according to the stakeholders and end-user requirements: Stage 1 (mature indices, already used in some applications, and further refined within EuroSea), Stage 2 (Intermediate stage of maturity, highly relevant for Europe; co-developed within EuroSea) and Stage 3 (additional or more advanced indices co-developed with stakeholders and explored within EuroSea).

In order to provide a legacy for EuroSea we have developed a strategy and best practices to apply for complex indicators to:

1. Assess what are the key metrics that are relevant to stakeholders
2. Examine the relevant EOVs/ECVs
3. Provide a simple process to bridge the definition of indicators at the large ocean scale (i.e., at the scale of an ocean basin or sea) to that of interest of the largest groups of stakeholders which is very often more regional (a limited area within an ocean basin or sea) or even local (a limited zone in a bay where are implanted aquaculture farms, artisanal fisheries, Marine Protected Areas, specific ecosystems, coastal cities, harbours and operational infrastructures, beaches and recreational areas).

The consolidated list of EuroSea indicators across the wide range of stakeholders and end-user groups represented within WP4-7 are listed in the following subsections. The last section provides the best practices developed for a complex indicator, Marine Heat Waves, to exemplify point 3 above.

2.1. Indicators for verification of forecasts (WP4)

WP4 seeks to define indicators to verify and evaluate the skill of seasonal forecasts. These are large-scale indicators, suitable to monitor and predict variability and changes at monthly temporal resolution. To define these indicators, the following sectorial applications have been identified: seasonal forecasts of atmospheric variables (North Subtropical Atlantic and Tropical Atlantic); climate variability and change: changes in ocean circulation, in ocean heat uptake, sea level changes (North Atlantic Subpolar Gyre, North Atlantic - East and West, Latitudinal bands in Atlantic basin.); coastal sea level change (North Eastern Atlantic); marine health: large scale preconditioning for marine heat waves (Mediterranean, North East Atlantic); marine productivity in the Tropical Atlantic and two Eastern Boundary Upwelling Systems (EBUS): The Canary Upwelling region (C-EBUS, from 11N to 31N and 6W-30W) and the Benguela Current System (BC-EBUS,15◦S-35◦S, from the coast to 5°E). To test the sensitivity of the EBUS indicator, the same indicator will be applied to the other two Eastern Boundary Upwelling Systems: the Humboldt Current System (H-EBUS, 5°S-40°S, from coast to 85°W) and the California Current System (CalC-EBUS, 22°N-45°N, from coast to 135°W).

The indicators identified by WP4 were mostly at a mature stage and the related EOVs as well as the data sources that are listed for each of them.

Mature Indicators (Stage 1)

- **Sea level in the Atlantic (different regions), Pacific and Indian Ocean**
  - EOVs: Sea surface height (from the European Space Agency Climate Change Initiative – ESA-CCI, delivered by Copernicus Climate Change Service -C3S) spanning on period 1993-present at monthly resolution.
- **Sea Surface Temperature (SST, differences across the regions) as indicator of changes in ocean circulation in the Atlantic (different regions), Pacific and Indian Ocean**
  - EOVs: Sea surface temperature (from Copernicus Marine & Environmental Monitoring Service (CMEMS)) spanning on period 1993-present at monthly resolution.
- **Ocean Heat Content (from Copernicus Marine – Production Provision and Analysis of Reanalysis Products for the Global Ocean – CMEMS GLORAN) for heat absorption in the Atlantic (different regions), Pacific and Indian Ocean**
  - EOVs: Sea surface temperature and Subsurface temperature spanning on period 1993-present at monthly resolution.

Indicators co-developed within EuroSea (Stage 2)

- **Sea level in the Mediterranean Sea**
  - EOVs: Sea surface height (from ESA-CCI, delivered by C3S) spanning on period 1993-present at monthly resolution.
- **SST (differences across the regions) as indicator of changes in ocean circulation in the Mediterranean Sea**
  - EOVs: Sea surface temperature (from CMEMS) spanning on period 1993-present at monthly resolution.
- **Ocean Heat Content (from CMEMS GLORAN) for heat absorption in the Mediterranean Sea**
  - EOVs: Sea surface temperature and Subsurface temperature spanning on period 1993-present at monthly resolution.
- **Marine Heat Waves:**
  - EOVs : Sea surface temperature from ESA-CCI delivered by C3S and spanning on period 1993-present at monthly resolution.

New indicators proposed within EuroSea (Stage 3)

- **Upwelling intensity for marine productivity in Atlantic EBUS**
  - EOVs: Sea surface temperature, sea surface salinity, subsurface temperature, and subsurface salinity.
- **Upwelling intensity for marine productivity in Pacific EBUS**
  - EOVs: Sea surface temperature, sea surface salinity, subsurface temperature, and subsurface salinity.

The whole set of these forecast indicators has been tested in terms of skill in two operational seasonal forecasting systems contributing to the Copernicus Climate Change Service (C3S). Forecasts, of up to 2 seasons ahead, of indicators over the period 1993-2016 are compared to satellite-derived records from the C3S and a global ocean reanalysis ensemble product from the Copernicus Marine & Environmental Monitoring Service (CMEMS). The results of these tests, which show the reliability of these forecasting systems, have been described in the EuroSea deliverables D4.6 and D7.4.

2.2. Indicators for Coastal resilience and operational services (WP5)

Estimations of changes in coastal sea level are of extreme relevance for societal impacts. WP5 focuses on sea level indicators as it threatens coastal areas. WP5 identified three main EOVs which are essential to estimate sea level change at a regional scale: sea surface height, subsurface temperature, and subsurface salinity.

Mature Indicators (Stage 1)

- **Sea level**
  - EOVs: Sea surface height (SSH), Subsurface temperature and salinity

SSH estimations at a global to a local scale have a major interest for policymakers, the Intergovernmental Panel on Climate Change (IPCC) and United Nation (UN) bodies, the scientific community, regional and local coastal managers, and the general public.

In terms of temporal sampling requirements, for climate monitoring, data are usually analysed in terms of annual means. For short-term hazards (e.g., tsunamis, storm surges) the The Global Sea Level Observing System (GLOSS) recommendation is a data availability at a frequency of 6 minutes although 1 minute would be ideal.

SSH data are available from satellite altimetry measurements since the end of 1993. Satellite data have a global coverage but a relatively low spatio-temporal resolution (current optimal interpolation gives products at typically 1/4 or 1/8 degree (latitude, longitude) spatial resolution at daily temporal scale). Tide gauges are *in situ* sea level observations. The tide-gauge network comprises piers and moorings deployed along the global coasts. However, their distribution is sparse, and they provide only local data albeit the time series for a few of them is very long for example for Amsterdam (annual data from 1700) and the current sampling frequency is very high (order of minutes). Real-time tide gauge data is essential for hazard monitoring (tsunamis and storm surges).

Subsurface temperature and subsurface salinity measured at a global scale is important for sea level communities, IPCC, and UN bodies in order to estimate the steric component of sea-level variations. Both variables are derived from *in situ* observations from various platforms (Argo floats, Expendable Bathythermographs – XBTs – profiles, Global Ocean Ship-Based Hydrographic Investigations Program – GO-SHIP – sections). These data are then interpolated or reanalysed globally to resolutions between 1/4 and 1 degree of latitude and longitude. The relevant vertical resolution is between 700 and 2000 m and very few below 2000m. For sea level studies, analyses are usually performed on annually averaged values and a majority of compiled datasets are 1970-present day.

New Indicators (Stage 3)

The new indicators developed within EuroSea assess the local coastal risk associated with different phenomena. These indicators are expressed in terms of values (sea level increase, waves height, wind and ocean currents intensity etc) but also, for sake of simplicity for end users who are not experts, as levels of risk and warning (three levels- green, orange and red).

- **Sea level risk nowcast indicator**
  - EOVs: Sea surface height (SSH), Subsurface temperature and salinity

This indicator will determine the level of risk in real-time. Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine in real time the risk of inundation, and water column depth, useful for navigation inside the port.

- **Wind risk nowcast indicator**
  - EOVs: Surface wind

This indicator will determine the level of risk in real-time. Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine in real-time the risk associated to wind for several uses, such as crane operation, vessel drift and others.

- **Sea state risk nowcast indicator**
  - EOVs: Surface waves

This indicator will determine the level of risk in real-time. Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine in real-time the risk associated to waves for several uses, such as overtopping, beach safety, etc.

- **Ocean currents risk nowcast indicator**
  - EOVs: Surface velocity; Subsurface velocity

This indicator will determine the level of risk in real-time. Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine in real-time the risk of high currents for Navigation and other purposes.

- **Sea level risk forecast indicator**
  - EOVs: Sea surface height (SSH), Subsurface temperature and salinity

This indicator will determine the level of risk in the coming hours and days. Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine for the following days the risk of inundation, and water column depth, useful for navigation inside the port.

- **Wind risk forecast indicator**
  - EOVs: Surface wind

This indicator will determine the level of risk in the coming hours and days. Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine for the following days the risk associated to wind for several uses, such as crane operation, vessel drift and others.

- **Sea state risk forecast indicator**
  - EOVs: Surface waves

This indicator will determine the level of risk in the coming hours and days. Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine for the following days the risk associated to waves for several uses, such as overtopping, beach safety, etc.

- **Ocean currents risk forecast indicator**
  - EOVs: Surface velocity; Subsurface velocity

This indicator will determine the level of risk in the coming hours and days. Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine for the following days the risk of high currents for Navigation and other purposes

2.3. Indicators for ocean health (WP6)

WP6's objective is to develop a shared understanding of water management among end-users in Aquaculture, Fisheries, Tourism, Environmental Agencies and Scientists by working together to co-create products that help to identify and foresee "Extreme Marine Events" threatening marine ecosystems, resources, and related businesses, and supporting adaptive management decisions.

Examples of such "Extreme Marine Events" are low pH or oxygen levels, rough sea state and marine heat waves.

On this basis, several indicators and associated EOVs emerged. EOV's parameters are listed below depending on the related indicator.

Mature Indicators (Stage 1)

These indicators were mature in concept, but not yet applied to "real cases". Within EuroSea and in partnership with different stakeholders associated in the very early stage of the project to WP5, these indicators have been tested in real testbeds for different cases representing different groups of stakeholders: Sea food development agencies such as Bord Iascaigh Mhara (BIM), Ireland; Aquaculture sector with representants such as Mowi Ireland; Marine Protected Areas (MPA) managers such as National Parks & Wildlife Service (NPWS) Ireland; Water Framework Directives (WFD) managers, Environmental Protection Agency (EPA) Ireland. The related geographical domain was ranging from the whole Baltic Sea area to smaller coastal domains of 2° x 2° down to localized points on the shelf corresponding to an aquaculture farm or a Marine Protected Area.

- **Sea Surface Temperature (SST) as a proxy of Marine Heat Waves**
  - EOVs: Sea surface temperature

SST estimations has a major interest for:

1. Aquaculture (Seafood Development). The related geographical domain was about 2° longitude x 2° latitude. Depths: 25 to 50 m on the shelf of interest to the aquaculture industry and shelf waters up to 200 m of interest to regulators. Model covers shelf waters up to the shelf edge at 200 m. Note that a small geographic area in the model domain covers water depths of >1,000 m. Horizontal and vertical resolution needs to be about 1 Km and 30 sigma levels, respectively. Time resolution of interests is daily and at least 30 years are available; forecast (3-day).
2. Aquaculture (Seafood Development) at specific sites. The related geographical domain was one location. Depths: about 30m. Horizontal and vertical resolution need to be about 10 m (close to the fish cages in a body of water that represents water flowing toward the farm) and from surface to bottom waters, respectively. Time resolution of interests is at least hourly and real-time; forecast (2-3-days).
3. The "Baltic Sea Area". Horizontal and vertical resolution need to be about 2-3 Km and at sea surface, respectively. Time resolution of interests is from daily to weekly and based on past reconstructions and future predictions for decades.

- **Sea level**
  - EOVs: Sea surface height

Sea level have a major interest for:

1. Baltic Marine Environment Protection Commission (HELCOM), Baltic Earth, national environmental authorities (Baltic Sea countries). The related geographical domain is Baltic Sea Area (the Baltic Sea and

the entrance to the Baltic Sea bounded by the parallel of the Skaw in the Skagerrak at 57° 44.43'N). Horizontal and vertical resolution need to be about 10 km and at sea surface, respectively. Time resolution of interests is from weekly to monthly and based on past reconstructions and future predictions for decades.

2. Local authorities. The related geographical domain is coastal areas in Baltic Sea. Horizontal and vertical resolution need to be about 1 km and at sea surface, respectively. Time resolution of interests is hourly with forecasts renewed every 12 hours for the next 48 hours.

- **Mixing layer depth (MLD)**
  - EOVs: Sea surface temperature, sea surface salinity, subsurface temperature, and subsurface salinity.

These EOVs have a major interest for Baltic Marine Environment Protection Commission (HELCOM), Baltic Earth, national environmental authorities (Baltic Sea countries). The related geographical domain tested was the whole Baltic Sea Area. Horizontal and vertical resolution need to be about 2-3 km and from 2-3 m sea surface to 80 m, respectively. Time resolution of interests is daily and based on time span covering decades.

- **Nutrients**
  - EOVs: Subsurface nutrients

Nutrients estimations have a major interest for the Baltic Marine Environment Protection Commission (HELCOM), national environmental authorities (Baltic Sea countries)". The related geographical domain tested was the whole Baltic Sea Area Horizontal and vertical resolution need to be about 2-3 Km and from sea surface to seabed with a resolution of 5-10 m, respectively. Time resolution of interests is from weekly to monthly and based on past reconstructions and future predictions for decades.

- **Oxygen**
  - EOVs: Subsurface dissolved oxygen

This indicator has a major interest:

1. At local scale for aquaculture (Seafood Development. Depths: about 30m. Horizontal and vertical resolution need to be about 10 m (close to the fish cages in a body of water that represents water flowing toward the farm) and from surface to bottom waters, respectively. Time resolution of interests is at least hourly and real-time; forecast (2-3-days).
2. In Baltic Sea Area. Horizontal and vertical resolution need to be about 2-3 Km and from sea surface to seabed with a resolution of 5 m, respectively. Time resolution of interests is weekly and based on past reconstructions and future predictions for decades.

Indicators co-developed within EuroSea (Stage 2)

- **More developed Marine Heat waves indexes based on subsurface temperature and ocean heat content**
  - EOVs: Sea surface temperature, subsurface temperature

This indicator is of major interest for:

1. Aquaculture (Seafood Development). The related geographical domain is a region of about 2° x 2° SE of Ireland. Depths: 25 to 50 m on the shelf of interest to aquaculture industry and shelf waters up to 200 m of interest to regulators. Model covers shelf waters up to shelf edge at 200 m. Note that a small geographic area in the model domain covers water depths of >1,000 m. Horizontal and vertical

resolution need to be about 1 Km and 30 sigma levels, respectively. Time resolution of interests is daily and at least 30 years are available; forecast (3-day).

2. Aquaculture (Seafood Development) for local Aquaculture farms. The related geographical domain was a single location on the shelf. Depths: about 30m. Horizontal and vertical resolution need to be about 10 m (close to the fish cages in a body of water that represents water flowing toward the farm) and from surface to bottom waters, respectively. Time resolution of interests is at least hourly and real-time; forecast (2-3-days).

- **Sea state**
  - EOVs: Sea State

  This EOV gives access to sub variables such as significant wave height, wave period, wave direction, maximum wave height, swell, directional spectrum and whitecap fraction.

  This indicator is of major interest for:

  1. Aquaculture development areas within coastal region at daily time resolution; 48 hours forecasts.
  2. Aquaculture industry, [safety at sea]. The related geographical domain is a region of about 2° x 2° SE of Ireland. Depths: shelf waters up to shelf edge at 200 m Note: a small geographic area in the model domain covers water depths of >1,000 m) & at the fish farm site Latitude: approx. 51.733° N; Longitude: approx. 10.212° W; Depths: ~ 30 m. Horizontal and vertical resolution need to be about 1 Km and 30 sigma levels, respectively. Time resolution of interests is daily in real-time and forecast (3 to 7 days).
  3. General public, shipping companies, local authorities, port authorities in Baltic seas and coastal areas. Horizontal and vertical resolution need to be about 1 Km and at sea surface, respectively. Time resolution of interests is hourly; forecasts renewed every 12 hours for the next 48 hours.
  4. Baltic Marine Environment Protection Commission (HELCOM), Baltic Earth national environmental authorities (Baltic Sea Countries). The related geographical domain is horizontal and vertical resolution need to be about 2-3 km and at sea surface, respectively. Time resolution of interests is daily based on past reconstructions and future predictions for decades.

- **Ocean health**
  - EOVs: Oxygen, Nutrients, sea surface temperature, subsurface temperature, turbidity, and pH are needed to assess ocean health.

This indicator is of major interest for Aquaculture developments. The related geographical domain are: Spanish Med coastal region; NE Atlantic; NE Atlantic; Spanish Med coastal region; Spanish Med coastal region / NE Atlantic. Time resolution is daily; 48 hours forecasts.

New indicators proposed within EuroSea (Stage 3)

- **Upwelling intensity**
  - EOVs: Sea surface temperature, sea surface salinity, subsurface temperature, and subsurface salinity.

  This indicator is of major interest for:

  1. Baltic Marine Environment Protection Commission (HELCOM), Baltic Earth, national environmental authorities (Baltic Sea countries). The related geographical domain is Baltic Sea Area (the Baltic Sea and the entrance to the Baltic Sea bounded by the parallel of the Skaw in the Skagerrak at 57° 44.43'N). Horizontal and vertical resolution need to be about 2-3 km and from 2-3 m sea surface to

80 m, respectively. Time resolution of interests is from daily to weekly and based on time span covering decades and focusing on interannual variability in summer (mostly).
2. Local authorities. The related geographical domain is coastal areas in Baltic Sea. Horizontal and vertical resolution need to be about 1 km and at sea surface, respectively. Time resolution of interests is hourly with forecasts renewed every 12 hours for the next 48 hours.

- **Ocean surface current**
  - EOVs: Surface current direction and velocity is needed to compute ocean subsurface current and transport.

  This indicator has a major interest for:
  1. Aquaculture (Seafood Development), BIM, Ireland; Aquaculture sector, MOWI, Ireland; MPA managers, NPWS, Ireland; WFD managers, EPA, Ireland [marine heat waves]. The related geographical domain is a region of about 2° x 2° SE of Ireland. Depths: 25 to 50 m on the shelf of interest to aquaculture industry and shelf waters up to 200 m of interest to regulators. Model covers shelf waters up to shelf edge at 200 m. Note that a small geographic area in the model domain covers water depths of >1,000 m. Horizontal and vertical resolution need to be about 1 Km and 30 sigma levels, respectively. Time resolution of interests is daily; forecast (3-day).
  2. Local authorities and coast guards. The related geographical domain is coastal areas in Baltic sea. Horizontal and vertical resolution need to be about 1 km and at sea surface, respectively. Time resolution of interests is hourly with forecasts renewed every 12 hours for the next 48 hours.

- **Ocean subsurface current**
  - EOVs: Current subsurface direction and velocity is needed to compute ocean subsurface current and transport.

  This indicator has a major interest for:
  1. Aquaculture (Seafood Development), BIM, Ireland; Aquaculture sector, MOWI, Ireland; MPA managers, NPWS, Ireland; WFD managers, EPA, Ireland. The related geographical domain is a region of about 2° x 2° SE of Ireland. Depths: 25 to 50 m on the shelf of interest to aquaculture industry and shelf waters up to 200 m of interest to regulators. Model covers shelf waters up to shelf edge at 200 m. Note that a small geographic area in the model domain covers water depths of >1,000 m. Horizontal and vertical resolution need to be about 1 Km and 30 sigma levels, respectively. Time resolution of interests is daily and at least 30 years are available; forecast (3-day).
  2. Baltic Marine Environment Protection Commission (HELCOM), Baltic Earth, national environmental authorities (Baltic Sea countries). The related geographical domain is Baltic Sea Area. Horizontal and vertical resolution need to be about 2-3 km and from 2-3 m sea surface to 80 m, respectively. Time resolution of interests is daily and based past reconstructions and future predictions for decades; higher resolution (daily) in the case of ongoing inflow events.

2.4. Indicators for climate (WP7)

WP7 is the working package dedicated to designing innovative ways to assess the role of the oceans and seas in the Earth's climate through new ocean climate indicators developed within EuroSea and verified based on performance. This WP is meant to generate observable and user-relevant ocean climate and forecasting indicators with reliable uncertainty for the Atlantic Ocean and the Mediterranean Sea. The aim is to demonstrate the end-to-end connection from climate and seasonal forecast products to a wide variety of stakeholders.

Mature Indicators (Stage 1)

A large set of WP7 indicators overlaps with WP4 indicators for the Atlantic Ocean and the Mediterranean Sea. Indeed, as per the construction of the EuroSea project, WP7 implement EU Copernicus products (CMEMS, C3S) into indicators to provide a novel decision-making tool for policy and other stakeholders whereas WP2 elaborates the best observing strategies for EOVs/ECVs, and the data assimilation and forecasting systems in WP4 deliver a 4-dimensional view on EOVs/ECVs over past, present, and future.

Hence, WP7 accompanies WP4 in the development of indicators and provides the test bed for these from observations in general, including Copernicus products. It also investigates new observational resources from the observing networks and new possible climate indicators.

In the following, we only mention those indicators that are not listed under the previous WP4 section (Section 2.1.2) as they are co-developed with WP7.

In the following, we list the extra (with regards to WP4) potential indicators (they are under discussion or development), for which we have the general definition in terms of associated EOVs, but not yet a precise idea of their geographical definition.

Indicators co-developed within EuroSea (Stage 2)

- **Sea level: exploration at regional scale**
  - EOVs: Sea surface height (from ESA-CCI, delivered by C3S) spanning on period 1993-present at monthly resolution.
- **Ocean Heat Content (from Argo and CMEMS GLORAN) for heat absorption: exploration of regional indicators**
  - EOVs: Sea surface temperature and Subsurface temperature spanning on period 1993-present at monthly resolution.
- **Marine Heat Waves: exploration of metrics and regionalization**
  - EOVs: Sea surface temperature from ESA-CCI delivered by C3S and spanning on period 1993-present at monthly resolution.

New indicators proposed within EuroSea (Stage 3)

- **Net primary productivity**
  - EOVs: Chlorophyll-a from Colour satellite images and regional verification from BGC Argo (North Atlantic and Tropical Atlantic Ocean).

2.5. An approach for complex indicators and for bridging relevant scales: The case for Marine Heat Waves

Marine Heat Waves (MHWs) occur when ocean temperatures are much warmer than normal for an extended period of time (Hobday et al., 2016; 2018; Holbrook et al., 2020). In our application, we used the MHWs detection algorithm from Hobday et al. (2016), freely available online[1]. MHWs are usually defined with SST which is an accessible EOV/ECV from satellite data. The approach from Hobday et al. (2016) defines a MHW as being an SST value that exceeds a threshold value for at least five consecutive days. The threshold value they use is the daily 90th percentile of the local SST distribution over a long-term reference period. Two successive MHWs with a break of two days or less are considered a single continuous event. Finally, the daily

[1] https://github.com/ecjoliver/marineHeatWaves

climatological mean and threshold are smoothed using a 30-day moving window as recommended by Hobday et al. (2016), to extract useful climatologies from inherently variable data. Hobday et al. (2016) define a hierarchy of various metrics to describe the characteristics of a MHW event. Working together as the large group of EuroSea stakeholders, we defined the best subset of metrics with societal relevance. These are the frequency (number of discrete events), the duration (consecutive period of time that the temperature exceeds the threshold), the total number of days (annual total days during which the temperature exceeds the threshold, which results from a combination of frequency and duration), the maximum intensity - highest temperature anomaly value relative to the mean climatology - and the cumulative intensity - integral of intensity over the duration of the event, which results from a combination of duration and intensity - (see Hobday et al., 2016 for more details on the calculation of each of these metrics). These turned out to be the most suited MHWs set of metrics according to the whole group of stakeholders we interviewed.

The requirements in terms of indicators across the various EuroSea stakeholders and end-user groups resulted to be different, even for the same indicator such as "Sea Level" or "Sea Surface Temperature". Indeed, some stakeholders are interested in the definition of such indicators at the scale of an ocean basin or marginal sea delivered monthly, whereas many end users were interested in a more regional if not local assessment of these same indicators and delivered at a daily frequency. Also, some end users have slightly different "definitions" or "expectations" for the same indicator (for example in terms of upper ocean temperature marine farmers or fisheries are more interested in the temperature at 20 m of depth instead of the Sea Surface Temperature). To start responding to such end-user needs, within WP2.1 we developed a new approach encompassing WPs 4-7 requirements in terms of Marine Heat Waves. Indicators of MHWs are not yet homogeneous or standardized across the scientific community. Moreover, as they are defined by different metrics (such as MHWs intensity, number, duration etc), they are relatively complex. Also, the same name of indicator is used for basin-scale events as well as more regional and local declinations but there are no direct connections, at present, in the definition of the two.

Defining the "appropriate" downscaling from large to local scales for MHWs

Initially, we explored the diversity of surface MHW trends in sub-regions of the Mediterranean Sea (Dayan et al., 2022). To help provide context for future ecological and economic impact studies, we chose to split the Mediterranean Sea into four sub-regions characterized by their distribution of chlorophyll concentrations. We focused on MHW frequency, duration, maximum intensity, and category (a measure of "exceptionality"). It was not within the scope of this study to comment on how extreme events have affected productivity. Instead, we highlighted that the ecologically diverse regions in the Mediterranean Sea are each experiencing a different evolution of MHW characteristics.

However, dealing with this "geobiological" complexity at the scale of a large basin such as the Mediterranean or any other is extremely challenging. Indeed, a large variety of end-users are involved, such as marine ecosystems managers, fisheries, Marine Protected Areas (MPAs) and aquaculture farms. Taking this highly complex challenge into account and to help provide context for future ecological and economic impact studies, we reached the conclusion that there was a need to go beyond the limit set by the complexity of a biological approach by exploring a national-scale approach. Rather than responding individually to many end-users, we proposed to focus on Exclusive Economic Zones (EEZs) – where special rights are held by a sovereign country - as an initial stakeholder-oriented approach.

Our choice to split and classify MHWs by using EEZs is motivated by the need for smaller-scale subdivisions (Juza et al., 2021, 2022). In particular, the EEZ classification has been used to respond to societal needs although it is not based on specific ocean processes or ecosystem requirements. The EEZ partitioning (the boundaries of which may be modified in the future depending on the agreement and delegation of the different countries), is a pragmatic way of regionalizing relevant marine information for decision support in the very particular and sensitive social, economic, and cultural contexts. By doing so, this manuscript aims at bridging the gap between scientific metrics of physical oceanic extreme events and MHW indicators relevant to different groups of end users. Indeed, whereas often MHWs are defined at the scale of an ocean basin or sea from sea surface temperature derived by satellites observations, end users (fisheries, Marine Protected Areas, aquaculture farming) are interested in more regional, if not local, expressions of MHWs between the surface and the depths of interest.

Within each type, there may be a need for location-specific and species-specific monitoring and indicators. We cannot tackle each of them simultaneously and instead must first choose demonstrator examples. As an initial approach, this study focused on EEZ areas. Rather than responding individually to many end-users, taking a national-scale approach can first provide an overview of local conditions. Then, one can “zoom in” on specific stakeholders, armed with the knowledge of characteristics and trends for the national waters in which they find themselves. Moreover, an EEZ-scale approach creates a more direct narrative to capture attention at a national authority or governmental scale.

As highlighted in Dayan et al. (2022; 2023: Figure 1) and Juza et al. (2022), the high spatial variability of ocean response to global warming and extreme events in the Mediterranean makes it necessary to further subdivide the largest EEZs for scientific relevance in relation to this variability. The regionalization of MHWs at the EEZ level provides a tool for countries to build MHW alert thresholds and risk assessments, not only for the EEZ but also at smaller regional or local levels, as all EEZ MHW metrics consist of gridded maps at the resolution of the original dataset or modelled field. Furthermore, the strengthening of the observing systems required to improve the accuracy of MHW detection and risk assessments in national waters will be encouraged by the need of countries to develop national adaptation strategies. An exciting possibility is to provide an interactive tool so that a wider range of users and stakeholders can choose individually the area of interest for a specific indicator. This could include splitting geographical regions into a range of ‘eco-regions’ and ‘sub-ecoregions’.

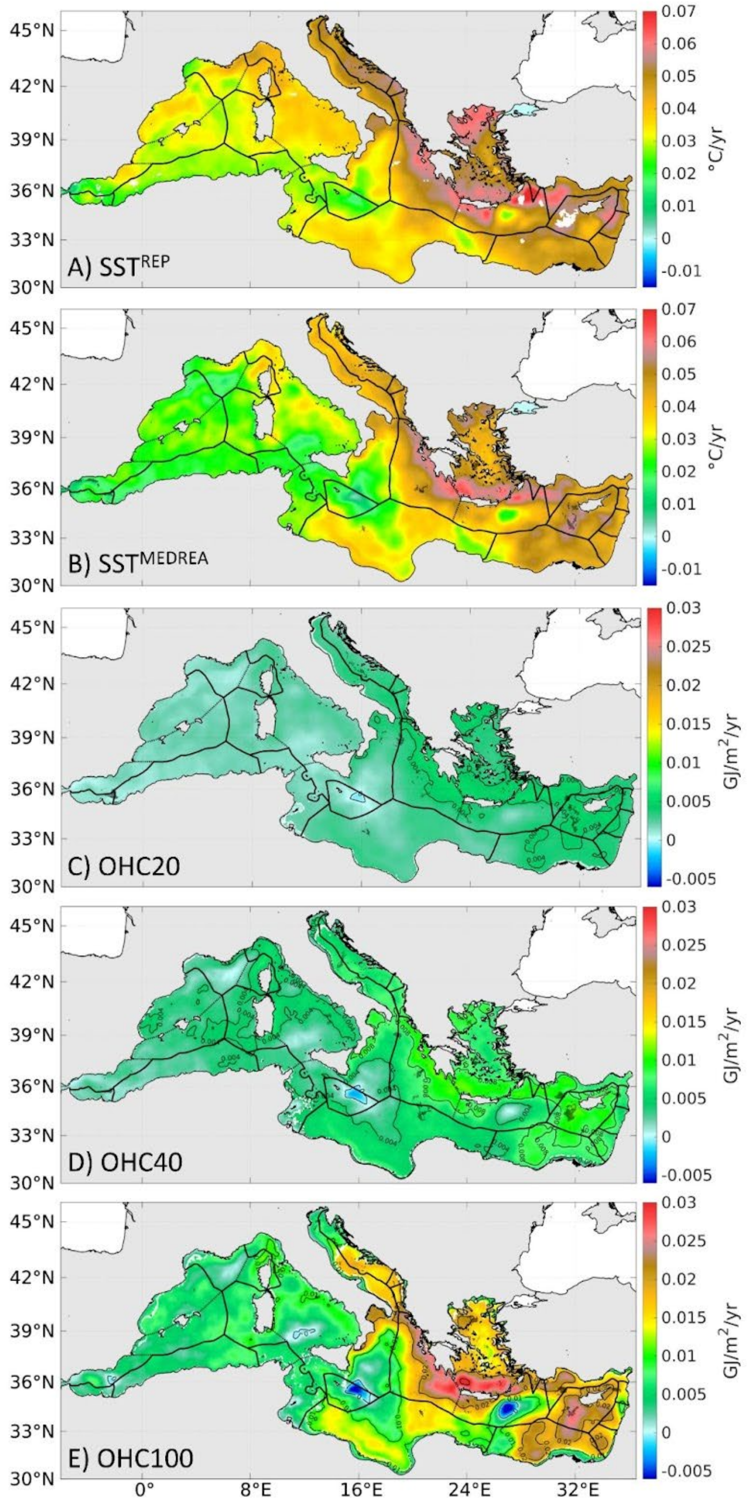

Figure 1. Linear trends over the period 1987-2019 of SST (in ºC/year) from REP (A) and MEDREA (B), and of OHC within the layers [0-20 m] (C), [0-40 m] (D) and [0-100 m] (E) from MEDREA (in GJ/m2/year). No significant values at the 95% confidence level based on a Mann-Kendall trend test are dashed. Adapted from Dayan et al., 2023.

Co-definition of a better suited MHWs indicator: Including a rationalized depth expression of MHWs

MHWs are commonly defined via the Sea Surface Temperature (SST) EOV/ECV whereas end users need Subsurface Temperature EOV/ECV and this at various depths that can range from 10 m to 200 or even 600 m depending on the user (aquaculture farmers, fisheries, climate assessments, seasonal predictions). Indeed, MHWs are phenomena not exclusively limited to the first few metres of the water column (Simon et al., 2022). The work undertaken in this framework is to reconcile MHWs metrics and scales by operating some choices in terms of index definition and requirements. Among various metrics, we have also investigated how to include the subsurface expression of these phenomena and derive a well-documented and easy-to-generalise indicator for MHWs to be used in CMEMS or by national/local operational agencies after the completion of the EuroSea project (Dayan et al., 2023, accepted in Frontiers of Marine Science).

To provide a more suited MHWs indicator, we included not only the surface expression of these exyreme events, but we took into account also their subsurface expression. Indeed, ecological species may be more impacted by subsurface MHWs than surface (Simon et al., 2022). To co-develop the best metrics to include in the surface-only classical metrics for MHWs indicators described in the previous section, we combined satellite observations and a regional reanalysis in the Mediterranean, both at daily and high spatial resolutions, over their common period (1987-2019). Our study showed that instead of looking at the subsurface temperature variations at every depth, it was more meaningful to use Ocean heat Content (OHC) computed over the upper 20, 40 and 100 m layers (Dayan et al., 2023, accepted in Frontiers of Marine Science). The metrics obtained from OHC can be combined with SST-based surface indicators to provide a more complete assessment of the MHWs impacts on ecological species which live below the surface. The chosen layers for the OHC indicators correspond to ocean layers in which there is a deep chlorophyll maximum - an indication of high biological activity, since chlorophyll is at the base of the ocean food web - (Siokou-Frangou et al., 2010; Lavigne et al., 2015), and thus strong economic interests such as in fisheries and aquaculture (Sacchi, 2011). In particular, these layers host some of the top pelagic predators, such as bluefin tuna whose larvae are vertically distributed down to 20-30 m (e.g., Alvarez-Berastegui et al., 2018). The latter take advantage of these depths close to the surface to live in during the first month and breed, as the surface layers provide the best environmental conditions for their survival. For each EEZ, surface and subsurface MHWs characteristics (frequency, duration, total days, maximum intensity, and cumulative intensity) have been analysed to showcase the diversity and importance of both expression, surface and subsurface, of MHWs and the OHC metrics to take the subsurface metrics (Dayan et al., 2023; Figures 2 and 3).

The EuroSea codesign approach to the MHWs indicator highlights the need to strengthen surface and subsurface monitoring systems in national waters, and to strongly encourage the development of better national adaptation strategies in order to address the impacts of MHW. Our downscaling approach to EEZs scale will be useful to (local and national) decision makers and stakeholders who may depend on decisions made at the national or even transnational level.

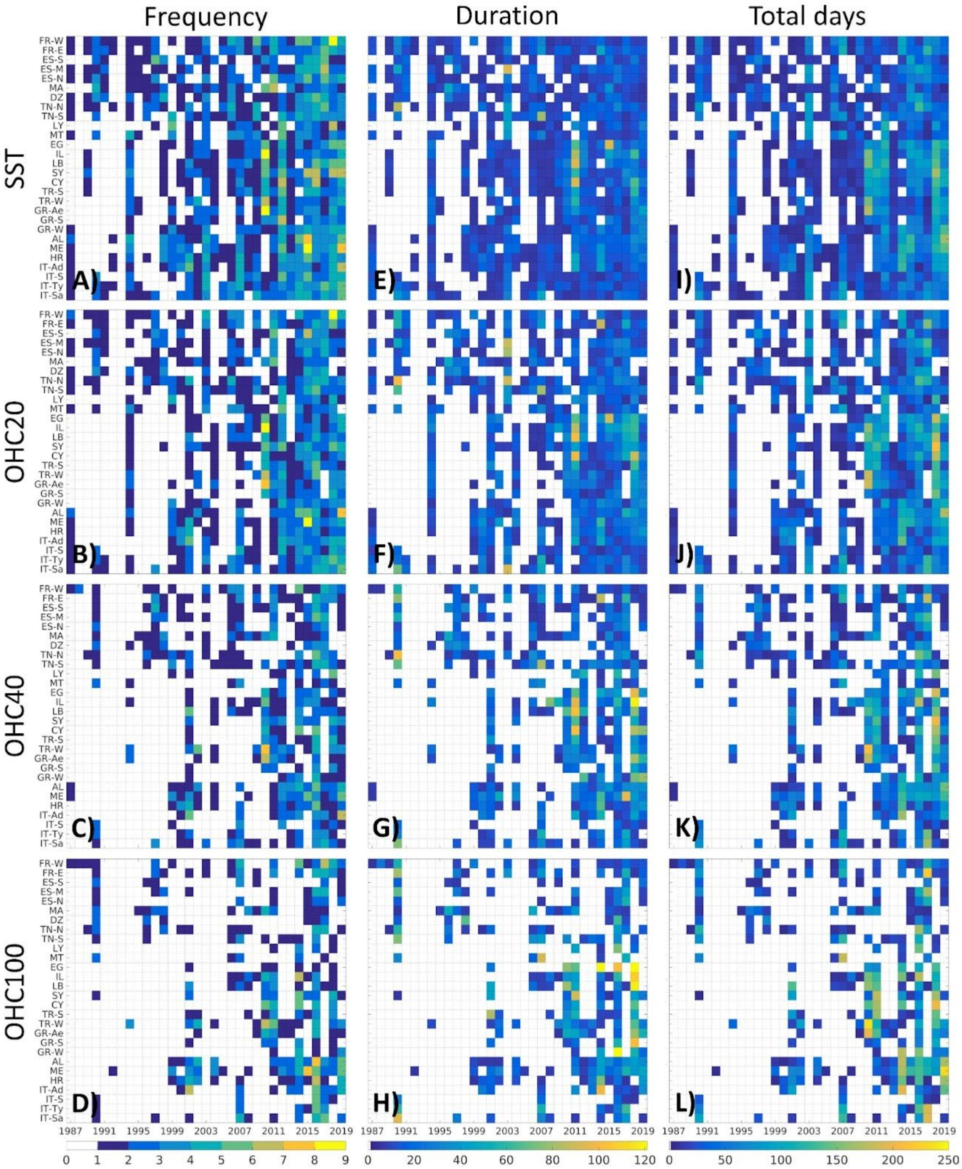

Figure 2. Annual means of MHW frequency (A, B, C, D), duration (in days; E, F, G, H) and total days (in days; I, J, K L) over the period 1987–2019 in the different EEZs, computed from MEDREA SST (A, E, I), OHC within [0-20 m] (B, F, J), OHC within [0-40 m] (C, G, K) and OHC within [0-100 m] (D, H, L). Adapted from Dayan et al., 2023.

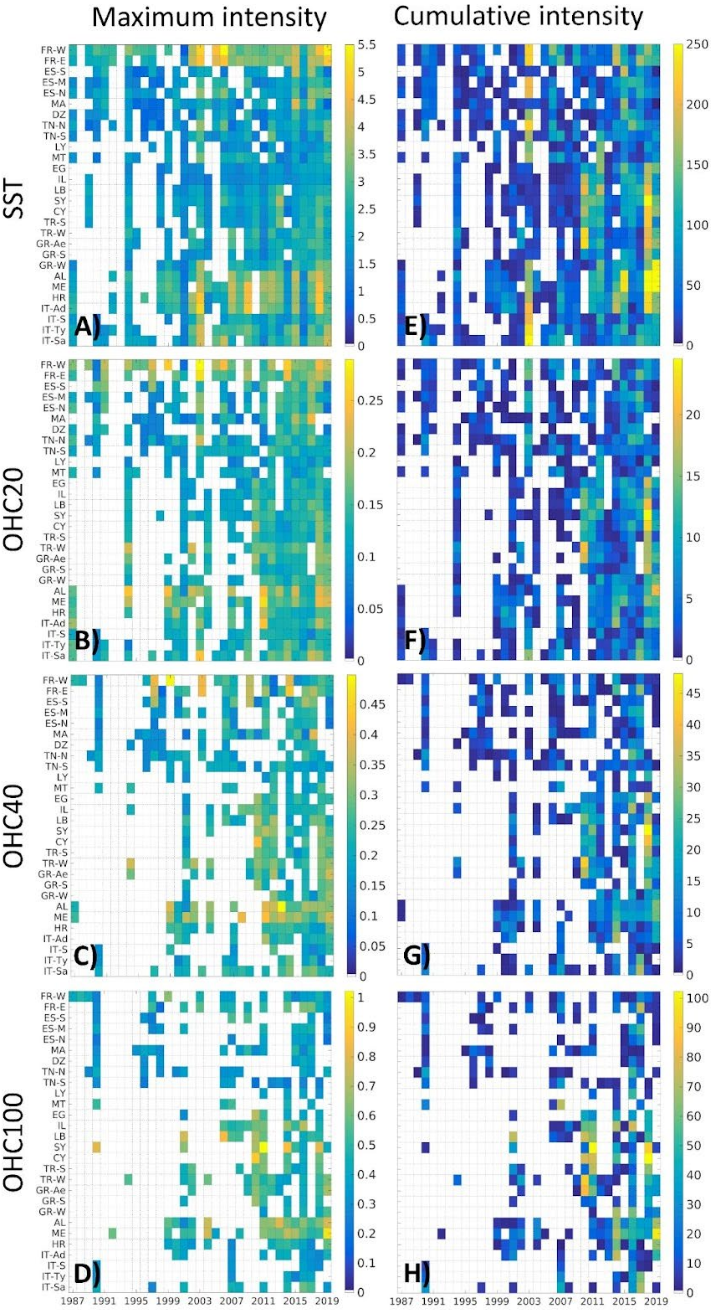

Figure 3. Annual means of MHW maximum (A, B, C, D) and cumulative (E, F, G, H) intensities (in ºC for A, E and in GJ/m2 for B, C, D, F, G, H) over the period 1987–2019 in the different EEZs, computed from MEDREA SST (A, E), OHC within [0-20 m] (B, F, J), OHC within [0-40 m] (C, G) and OHC within [0-100 m] (D, H). Adapted from Dayan et al., 2023.

3. EuroSea Essential Ocean/Climate Variables and their requirements

The set of “indicators” co-designed with EuroSea stakeholders represent key quantitative measures of the status of the system in line with one or more societal requirements (such as climate change monitoring, ecosystem health, coastal management, etc.) apt to provide a quantitative but simple and readily understood way of tracking important changes. In this report, we present the list of the EOVs/ECVs and sub-variables we defined within EuroSea, at the present stage of the project, in link with the various stakeholder's requirements identified in the project WPs. For these EOVs/ECVs we also provide the geographical domain of interest, their spatial and temporal resolution and the frequency and time span of interest. This information will be used in the coming months to design and define the EuroSea indicators.

The list of EOVs/ECVs can be found in the annexes as tables that list all the EOVs/ECVs for each indicator defined within each WP.

4. About observing platform requirements

Discussions have started within WPs 4–7 to assess the capabilities in terms of indicators evaluation, EOVs/ECVs requirements and the current observing system.

All indicators seem to be useful and their skill is relatively accurate for the various uses and stakeholders/end-user groups. Whereas seasonal forecasts have shown not completely satisfactory skill in some indicators (Mixing Layer Depth and Upwelling indices for example), this might be due to both, modelling limitations but also the relatively limited availability of subsurface data in very dynamic regions, such as (for example) the boundary current systems. There, the Argo floats cover only a limited part of the boundary current systems (offshore of the isobath 1500 m) and even in that part, they are not in a dense enough coverage for a such highly energetic region. If completely funded the OneArgo program will improve the latter point, but not the coverage onshore of the 1500 m isobath. To improve the coverage there, Argo floats should be seeded in a much larger number and their parking depth should be decreased to 100 m instead of 1000 m. Alternatively, other platforms (either autonomous as ocean gliders or Saildrones or equivalent surface autonomous vehicles with conductivity, temperature, and depth – CTD – capabilities, or fixed stations) should be implemented to improve the availability of data to be assimilated in models.

A question that remains unresolved from the discussions we have had within WPs, is how to measure the impact of observations and how to improve the observing system for a given indicator. Indeed, many WPs indicators are built against numerical modelling information that evolve in parallel to the evolution of the observing components. Indeed, modelling capabilities seem to improve when their spatial resolution is increased. Clearly, numerical simulations at high resolution improve the quality of reanalyses for example, in the Mediterranean Sea compared to the global product (see Dayan et al., Ocean Status Report 2020, in press) and in the Baltic Sea (Liu et al. 2019).

Moreover, most of Observing System Simulation Experiments (OSSEs) undertaken in EuroSea (but also within the OceanPredict community) did look more in general to classical global observing improvement but did not focus on regional ones or even provide an analysis of the impact of the “classical” OSSEs on the EuroSea indicators. It would be interesting therefore to learn if other assessments (Observing System Experiment – OSE – for example or any other quantitative assessment) have been undertaken in the EuroSea region (and not necessarily within the EuroSea project) to evaluate what are the critical EOVs requirements to be observed to improve the EuroSea indicators, and this at all scales (from the large “classical” scale to regional and local scales).

There is an important effort within EuroSea to link with the OceanPredict community. EuroSea has already organized an OcenPredict workshop dedicated to EuroSea. A second one will be organized in early 2023. These efforts will provide an important legacy to develop pathways and guidelines on how to approach such assessments. The outcomes will be very relevant to the UN Ocean Decade Program “Ocean Observing Co-Design” sponsored by the Global Ocean Observing System (GOOS).

5. Conclusions

We developed a co-design approach to defining a set of consolidated EuroSea indicators for all stakeholders groups represented by EuroSea demonstrators ("Coastal resilience and operational services demonstrator", "Ocean Health Demonstrator" and "Ocean climate indicators demonstrator") and verification for operational forecast services ("Data integration, assimilation and forecasting"). In this, we took into account requirements for important end-users and stakeholders key for different sectors (governments, regulatory bodies, intergovernmental frameworks, fisheries, aquaculture, ocean energy, coastal and port managers, marine research and the public) and interested in assessments at different scales (from that of an entire basin to scales of harbours and beaches).

Some of the selected indicators and related requirements are associated directly with observed EOVs/ECVs, but most of them are related to analyses, reanalyses or forecast products. Hence, the definition of requirements in terms of observed EOVs/ECVs is less straightforward. We have organised additional meetings with the OceanPredict community that started during the OceanPredict-EuroSea 2022 Workshop as well as with WPs 4-7 to better assess the observing system capabilities in delivering indicators defined via numerical analyses, reanalyses, and forecasts. Indeed, improvement in the skill of these indicators is not entirely linked with the distribution of observations but also with new developments in modelling and data assimilation. Pathways in how to assess more quantitatively the impact of observations on these indicators should be developed via OSEs and OSSEs. Whereas such exercise goes well beyond the various OSSEs assessments funded in EuroSea, WP4 (Balmaseda et al. 2022) showed sizeable impacts of the Atlantic observing system elements on the skill of Seasonal Forecasts for the Atlantic basin but also at the world scale. Moreover, during the recent Climate Observation Conference organized by the Global Climate Observing System programme in Darmstadt, Germany (17-19 October 2022), some contributions showed the impact of observing elements other than Argo floats on WP7 topics (as, for example, the Ocean Heat Content estimates: Cheng et al., 2022).

In terms of the legacy of EuroSea, we have undertaken additional actions. Within the UN Decade of Ocean Sciences and the GOOS Ocean Observing Co-Design programme we have included some of the EuroSea case studies as specific topics the programme will be addressing in the first 3 years of its execution (Marine Heat Waves, Marine ecosystems, the Ocean carbon) and this across the different EuroSea stakeholders and end users (including seasonal forecasts, climate indicators and ocean health). This programme focuses on the co-design to provide a fit-for-purpose observing system. A strong partnership between Ocean Observing Co-Design and the SynBios UN Decade of Ocean Science project of the ForSea programme has been developed with the aim to undertake appropriate OSSEs. Started within EuroSea, the development of indicators has resulted in a strong partnership across GOOS panels (and beyond) to co-develop science-based indicators responding to different societal requirements (from climate change assessments as well as indicators focusing on mitigation and adaptation to assessments of marine life). This will help to bridge the evolving societal needs with the observing system needed to tackle them.

We acknowledge that the requirements in terms of the assessed EOVs/ECVs which are related to EuroSea indicators to observing system networks are not completely satisfying scientifically, as this would have required the implementation of OSEs and many more OSSEs than those designed and undertaken within EuroSea. In particular, this would have required the development of dedicated regional OSEs and OSSEs relevant to the different EuroSea indicators. This approach, which has been started within EuroSea in task 2.3, has been suggested for implementation within the Ocean Observing Co-Design UN Ocean Decade programme in collaboration with SynBios as a legacy of EuroSea.

This work will provide direct economic benefits and follow-on opportunities in services for countries and industries depending on the status of the ocean and forecasts of ocean state, weather and climate.

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ANNEX I: WP4 Indicators and EOV requirements

*Table I.1. List of products for **WP4 – Seasonal Forecasts***

INDICATOR	Extended description
Sea surface temperature	Sea surface temperature is a key indicator for assessing marine ecosystems health, tourism quality offer, estimates of air-sea interactions, key ingredient of seasonal and extremes forecasts as well as in coastal, sea farming and fisheries management.
Sea level	Sea level estimations have a major interest for impact and mitigation on all coastal infrastructures and navigation security; seasonal forecasts of extremes.
Surface currents	Sea Surface scurrents estimations have a major interest for impact and mitigation on all coastal infrastructures and navigation security; seasonal forecasts of extremes.
Ocean heat content	Ocean heat content is a key indicator for assessing marine ecosystems health, tourism quality offer, estimates of air-sea interactions, key ingredient of seasonal and extremes forecasts as well as in coastal, sea farming and fisheries management.
Mixing layer depth	Mixing layer depth is an important indicator for marine ecosystems health, estimates of air-sea interactions, key ingredient of seasonal and extremes forecasts as well as in coastal, sea farming and fisheries management.
Upwelling intensity	Upwelling intensity is key for marine ecosystems health, and in coastal, sea farming and fisheries management.
Marine heat waves	Marine heat waves strongly impacts marine ecosystems health including sea farming and fisheries management.

*Table I.2. Requirements associated to **Sea Surface Temperature***

WP 4	Extended description	Comments
Name of INDICATOR	**Sea Surface Temperature**	This indicator will determine level of risk on real time
Horizontal extent	Different regions of the Atlantic, Pacific and Indian oceans (large scale) and Mediterranean Sea.	
Vertical extent	NA	
Horizontal resolution	¼°	
Vertical spatial resolution	NA	
Temporal extent	Seasonal forecasts	
Temporal resolution	Monthly averages	
Usability	Seasonal forecasts useful for assessing marine ecosystems health, tourism quality offer, estimates of air-sea interactions, sea farming and fisheries management	
Input observational or model/reanalyses sources	CMEMS	
Algorithm/model used	Anomalies analysis.	
If applicable, written resources that describes the INDICATOR		

*Table I.3. Requirements associated to **Sea Level***

WP 4	Extended description	Comments
Name of INDICATOR	**Sea Level**	This indicator will determine level of risk on real time
Horizontal extent	Different regions of the Atlantic, Pacific, and Indian oceans (large scale) and Mediterranean Sea.	
Vertical extent	NA	
Horizontal resolution	¼°	
Vertical spatial resolution	NA	
Temporal extent	Seasonal forecasts	
Temporal resolution	Monthly averages	
Usability	Seasonal forecasts useful for for impact and mitigation on all coastal infrastructures, and navigation security	
Input observational or model/reanalyses sources	ESA-CCI	
Algorithm/model used	Anomalies analysis.	
If applicable, written resources that describes the INDICATOR		

*Table I.4. Requirements associated to **Surface Currents***

WP 4	Extended description	Comments
Name of INDICATOR	**Surface currents**	This indicator will determine level of risk on real time
Horizontal extent	Different regions of the Atlantic, Pacific and Indian oceans (large scale) and Mediterranean Sea.	
Vertical extent	NA	
Horizontal resolution	¼°	
Vertical spatial resolution	NA	
Temporal extent	Seasonal forecasts	
Temporal resolution	Monthly averages	
Usability	Seasonal forecasts useful for impact and mitigation on all coastal infrastructures, and navigation security	
Input observational or model/reanalyses sources	CMEMS	
Algorithm/model used	Anomalies analysis.	
If applicable, written resources that describes the INDICATOR		

*Table I.5. Requirements associated to **Ocean Heat Content***

WP 4	Extended description	Comments
Name of INDICATOR	**Ocean Heat Content**	This indicator will determine level of risk on real time
Horizontal extent	Different regions of the Atlantic, Pacific and Indian oceans (large scale) and Mediterranean Sea.	
Vertical extent	NA	
Horizontal resolution	¼°	
Vertical spatial resolution	NA	
Temporal extent	Seasonal forecasts	
Temporal resolution	Monthly averages	
Usability	Seasonal forecasts useful for impact and mitigation on all coastal infrastructures, and navigation security	
Input observational or model/reanalyses sources	CMEMS GLORAN	
Algorithm/model used	Anomalies analysis.	
If applicable, written resources that describes the INDICATOR		

*Table I.6. Requirements associated to **Marine Heat Waves***

WP 4	Extended description	Comments
Name of INDICATOR	**Marine Heat Waves**	This indicator will determine level of risk on real time
Horizontal extent	Different regions of the Atlantic, Pacific and Indian oceans (large scale) and Mediterranean Sea.	
Vertical extent	NA	
Horizontal resolution	¼°	
Vertical spatial resolution	NA	
Temporal extent	Seasonal forecasts	
Temporal resolution	Monthly averages	
Usability	Seasonal forecasts useful for impact and mitigation on marine ecosystems, fisheries, marine farming and tourisms.	
Input observational or model/reanalyses sources	CMEMS	
Algorithm/model used	Anomalies analysis.	
If applicable, written resources that describes the INDICATOR		

*Table I.7. Requirements associated to Eastern Boundary Systems **Upwelling Intensity***

WP 4	Extended description	Comments
Name of INDICATOR	**Upwelling Intensity**	This indicator will determine level of risk on real time
Horizontal extent	The eastern boundary upwelling systems of the Atlantic and Pacific	
Vertical extent	NA	
Horizontal resolution	¼°	
Vertical spatial resolution	NA	
Temporal extent	Seasonal forecasts	
Temporal resolution	Monthly averages	
Usability	Seasonal forecasts useful for impact and mitigation on marine ecosystems, fisheries, marine farming and tourisms.	
Input observational or model/reanalyses sources	CMEMS	
Algorithm/model used	Anomalies analysis.	
If applicable, written resources that describes the INDICATOR		

ANNEX II: WP5 Indicators and EOV requirements

Table II.1. List of products for WP5

INDICATOR	Extended description
Sea level risk nowcast indicator	This indicator will determine level of risk on real time (three levels- green, orange and red). Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine in real time the risk of inundation, and water column depth, useful for navigation inside the port.
Wind risk nowcast indicator	This indicator will determine level of risk on real time (three levels- green, orange and red). Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine in real time the risk associated to wind for several uses, such as crane operation, vessel drift and others
Sea state risk nowcast indicator	This indicator will determine level of risk on real time (three levels- green, orange and red). Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine in real time the risk associated to waves for several uses, such overtopping, beach safety, etc.
Circulation risk nowcast indicator	This indicator will determine level of risk on real time (three levels- green, orange and red). Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine in real time the risk of high currents for Navigation and other purposes
Sea level risk forecast indicator	This indicator will determine level of risk on real time (three levels- green, orange and red). Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine for the following days the risk of inundation, and water column depth, useful for navigation inside the port
Wind risk forecast indicator	This indicator will determine level of risk on real time (three levels- green, orange and red). Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine for the following days the risk associated to wind for several uses, such as crane operation, vessel drift and others
Sea state risk forecast indicator	This indicator will determine level of risk on real time (three levels- green, orange and red). Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine for the following days the risk associated to waves for several uses, such overtopping, beach safety, etc.
Circulation risk forecast indicator	This indicator will determine level of risk on real time (three levels- green, orange and red). Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user. Determine for the following days the risk of high currents for Navigation and other purposes

*Table II.2. Requirements associated to **Sea level risk nowcast indicator***

WP 5	Extended description	Comments
Name of INDICATOR	**Sea level risk nowcast indicator**	This indicator will determine level of risk on real time (three levels- green, orange and red)
Horizontal extent	Indicator only for the area covered by an OSPAC deployment	
Vertical extent	NA	
Horizontal resolution	One single point per OSPAC deployment	One tide gauge is sufficient to monitor low frequency sea level oscillations, but a good monitoring of higher frequency oscillations, such as infragravitatory waves, would require more stations
Vertical spatial resolution	NA	
Temporal extent	Real time	
Temporal resolution	2 Hz	
Usability	Determine in real time the risk of inundation, and water column depth, useful for navigation inside the port	
Input observational or model/reanalyses sources	EUROSEA tide gauges	
Algorithm/model used	Threshold analysis.	Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user
If applicable, written resources that describes the INDICATOR		

*Table II.3. Requirements associated to **Wind risk nowcast indicator***

WP 5	Extended description	Comments
Name of INDICATOR	**Wind risk nowcast indicator**	This indicator will determine level of risk on real time (three levels- green, orange and red)
Horizontal extent	Indicator only for the area covered by an OSPAC deployment	
Vertical extent	NA	
Horizontal resolution	Several points per OSPAC deployment	Wind variability is high. A minimum of three stations is desirable, being 10 a good target
Vertical resolution	NA	
Temporal extent	Real time	
Temporal resolution	10 min	
Usability	Determine in real time the risk associated to wind for several uses, such as crane operation, vessel drift and others	
Input observational or model/reanalyses sources	Pre-existing Meteo stations in the areas where OSPAC is being deployed	In the future a tool like OSPAC should be accompanied by the deployment of instrumentation
Algorithm/model used	Threshold analysis.	Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user
If applicable, written resources that describes the INDICATOR		

Table II.4. Requirements associated to ***Sea state risk nowcast indicator***

WP 5	Extended description	Comments
Name of INDICATOR	**Sea state risk nowcast indicator**	This indicator will determine level of risk on real time (three levels- green, orange and red)
Horizontal extent	Indicator only for the area covered by an OSPAC deployment	
Vertical extent	NA	
Horizontal resolution	Several points per OSPAC deployment	Waves inside the port should be recorded by high temporal resolution tide gauges. Outside, a minimum of two buoys is required (one in deep water, another at shallow water)
Vertical resolution	NA	
Temporal extent	Real time	
Temporal resolution	1 hour	
Usability	Determine in real time the risk associated to waves for several uses, such overtopping, beach safety, etc.	
Input observational or model/reanalyses sources	Pre-existing buoys in the areas where OSPAC is being deployed	In the future OSPAC should be accompanied by the deployment of additional instrumentation. In the case of waves, a certain level of redundancy is important. A configuration with three buoys (one deep water and 2 coastal – one for the city and one for the port) would be optimal.
Algorithm/model used	Threshold analysis.	Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user
If applicable, written resources that describes the INDICATOR		

*Table II.5. Requirements associated to **Circulation risk nowcast indicator***

WP 5	Extended description	Comments
Name of INDICATOR	**Circulation risk nowcast indicator**	This indicator will determine level of risk on real time (three levels- green, orange and red)
Horizontal extent	Indicator only for the area covered by an OSPAC deployment	
Vertical extent	NA	
Horizontal resolution	One single point per OSPAC deployment	Current meter required at areas of special risk (for example at Port Mouth
Vertical resolution	1 meter	ADCP data
Temporal extent	Real time	
Temporal resolution	10 min	
Usability	Determine in real time the risk of high currents for Navigation and other purposes	
Input observational or model/reanalyses sources	Pre-existing current meters	In the future a tool like OSPAC should be accompanied by the deployment of instrumentation
Algorithm/model used	Threshold analysis.	Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user
If applicable, written resources that describes the INDICATOR		

*Table II.6. Requirements associated to **Sea level risk forecast indicator***

WP 5	Extended description	Comments
Name of INDICATOR	**Sea level risk forecast indicator**	This indicator will determine level of risk for the next days (three levels- green, orange and red) based on numerical models
Horizontal extent	One single point per OSPAC deployment	
Vertical extent	NA	
Horizontal resolution	One single point per OSPAC deployment	At OSPAC we are dealing with low frequency sea level oscillation forecast. High frequency oscillations is beyond the scope of Eurosea, but interesting for the future.
Vertical resolution	NA	
Temporal extent	Several days ahead	
Temporal resolution	hourly	
Usability	Determine for the following days the risk of inundation, and water column depth, useful for navigation inside the port	
Input observational or model/reanalyses sources	CMEMS and Eurosea High resolution models	High resolution nested in CMEMS
Algorithm/model used	Threshold analysis.	Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user
If applicable, written resources that describes the INDICATOR		

Table II.7. Requirements associated to ***Wind risk forecast indicator***

WP 5	Extended description	Comments
Name of INDICATOR	**Wind risk forecast indicator**	This indicator will determine level of risk for the next days (three levels- green, orange and red) based on numerical models
Horizontal extent	Indicator only for the area covered by an OSPAC deployment	
Vertical extent	NA	
Horizontal resolution	Spatial resolution of 1 km	Wind variability is high. Much higher resolution of wind fields is desirable
Vertical resolution	NA	
Temporal extent	Several days ahead	
Temporal resolution	10 min	
Usability	Determine for the next days the risk associated to wind for several uses, such as crane operation, vessel drift and others	
Input observational or model/reanalyses sources	Pre-existing Meteo forecasts in the areas where OSPAC is being deployed	In the future a tool like OSPAC should be accompanied by higher resolution (10 meters) downscaled wind models.
Algorithm/model used	Threshold analysis.	Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user
If applicable, written resources that describes the INDICATOR (		

Table II.8. Requirements associated to ***Sea state risk forecast indicator***

WP 5	Extended description	Comments
Name of INDICATOR	**Sea state risk forecast indicator**	This indicator will determine level of risk on real time (three levels- green, orange and red)
Horizontal extent	Indicator only for the area covered by an OSPAC deployment	
Vertical extent	NA	
Horizontal resolution	10 meters	High resolution wave modeling required
Vertical resolution	NA	
Temporal extent	Several days ahead	
Temporal resolution	1 hour min	
Usability	Determine for the next days the risk associated to waves for several uses, such overtopping, beach safety, etc.	
Input observational or model/reanalyses sources	CMEMS and Eurosea high resolution wave models	High resolution nested in CMEMS
Algorithm/model used	Threshold analysis.	Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user
If applicable, written resources that describes the INDICATOR		

*Table II.9. Requirements associated to **Circulation risk forecast indicator***

WP 5	Extended description	Comments
Name of INDICATOR	**Circulation risk forecast indicator**	This indicator will determine level of risk on real time (three levels- green, orange and red)
Horizontal extent	Indicator only for the area covered by an OSPAC deployment	
Vertical extent	NA	
Horizontal resolution	High resolution EuroSea numerical models	These models will be used for additional purposes, such as oil spill modeling
Vertical resolution	1 meter at surface, variable towards the bottom	
Temporal extent	Several days ahead	
Temporal resolution	10 min	
Usability	Determine in real time the risk of high currents for Navigation and other purposes	
Input observational or model/reanalyses sources	CMEMS and Eurosea high resolution circulation models	High resolution nested in CMEMS
Algorithm/model used	Threshold analysis.	Threshold values could vary depending on the part of the city/port studied. These thresholds should be arranged by the final user
If applicable, written resources that describes the INDICATOR		

ANNEX III: WP6 Indicators and EOV requirements

Table III.1. List of products for WP6

INDICATOR	Extended description
Dissolved inorganic nitrogen (DIN)	Winter concentrations of dissolved inorganic nitrogen (DIN) in the surface layer
Dissolved inorganic phosphorus (DIP)	Winter concentrations of dissolved inorganic phosphorus (DIP) in the surface layer
Chlorophyll-a (Chl-a)	Summer concentrations of chlorophyll-a (Chl-a) in the surface layer
Oxygen debt	Oxygen debt in the deep layer
Baltic Sea extremes	Extremes in sea level, surface waves, ice, etc.
Sea surface temperature (SST)	SST yearly, seasonal and monthly averages and variability, including heat waves, upwelling intensity, etc.
Stratification	Upper mixed layer (UML) characteristics (depth), deep layer salinity (salt water inflows) and vertical stratification
Near-bottom hypoxia and anoxia	The area and volume of hypoxic and anoxic waters in the Baltic Sea

*Table III.2. Requirements associated with **Dissolved inorganic nitrogen (DIN)***

WP6	Extended description	Comments
Name of INDICATOR	**Dissolved inorganic nitrogen (DIN)**	
Horizontal extent	Baltic Sea area	
Vertical extent	Surface to bottom	
Horizontal resolution	1 nm, assessment results derived for the HELCOM sub-basins	
Vertical resolution	20 m	
Temporal extent	1993-2019	During the project will be extended to Present
Temporal resolution	Yearly, average winter values (December-February)	
Usability	HELCOM eutrophication assessments	
Input observational or model sources	BALTICSEA_REANALYSIS_BIO_003_012	
Input observational or model sources	BALTICSEA_ANALYSISFORECAST_BGC_003_007	
Input observational or model sources	HELCOM monitoring data	
Algorithm/model used	BAL MFC PDAF-NEMO-ERGOM model complex DMI interim reanalysis by assimilating more near real time HELCOM and operational data HELCOM core indicator "Dissolved inorganic phosphorus (DIP)"	
Written resources that describe the indicators		

Table III.3. Requirements associated with ***Dissolved inorganic phosphorus (DIP)***

WP6	Extended description	Comments
Name of INDICATOR	**Dissolved inorganic phosphorus (DIP)**	
Horizontal spatial extent	Baltic Sea area	
Vertical extent	Surface to bottom	
Horizontal resolution	1 nm, assessment results derived for the HELCOM sub-basins	
Vertical resolution	20 m	
Temporal extent	1993-2019	During the project will be extended to Present
Temporal resolution	Yearly, average winter values (December-February)	
Usability	HELCOM eutrophication assessments	
Input observational or model sources	BALTICSEA_REANALYSIS_BIO_003_012	
Input observational or model sources	BALTICSEA_ANALYSISFORECAST_BGC_003_007	
Input observational or model sources	HELCOM monitoring data	
Algorithm/model used	BAL MFC PDAF-NEMO-ERGOM model complex DMI interim reanalysis by assimilating more near real time HELCOM and operational data HELCOM core indicator "Dissolved inorganic nitrogen (DIN)"	
Written resources that describe the indicators		

Table III.4. Requirements associated with ***Summer concentrations of chlorophyll-a (Chl-a) in the surface layer***

WP6	Extended description	Comments
Name of INDICATOR	**Summer concentrations of chlorophyll-a (Chl-a) in the surface layer**	
Horizontal extent	Baltic Sea area	
Vertical extent	Surface to bottom	
Horizontal resolution	1 nm, assessment results derived for the HELCOM sub-basins	
Vertical resolution	NA	
Temporal extent	1993-2019	During the project will be extended to Present
Temporal resolution	Yearly, average summer values (June-September)	
Usability	HELCOM eutrophication assessments	
Input observational or model sources	BALTICSEA_REANALYSIS_BIO_003_012	
Input observational or model sources	BALTICSEA_ANALYSISFORECAST_BGC_003_007	
Input observational or model sources	OCEANCOLOUR_BAL_CHL_L3_NRT_ OBSERVATIONS_009_049	
Input observational or model sources	HELCOM monitoring data	
Algorithm/model used	BAL MFC PDAF-NEMO-ERGOM model complex DMI interim reanalysis by assimilating more near real time HELCOM and operational data HELCOM core indicator "Chlorophyll-a (Chla-a)"	
Written resources that describe the indicators		

Table III.5. Requirements associated with ***Oxygen debt in the deep layer***

WP6	Extended description	Comments
Name of INDICATOR	**Oxygen debt in the deep layer**	
Horizontal extent	Baltic Sea area	
Vertical extent	Deep layers only	
Horizontal resolution	1 nm, assessment results derived for the HELCOM sub-basins	Only deep basins with halocline
Vertical resolution	Deep basin, below the halocline	Only deep basins with halocline
Temporal extent	1993-2019	During the project will be extended to Present
Temporal resolution	Yearly average values	
Usability	HELCOM eutrophication assessments	
Input observational or model sources	BALTICSEA_REANALYSIS_BIO_003_012	
Input observational or model sources	BALTICSEA_ANALYSISFORECAST_BGC_003_007	
Input observational or model sources	HELCOM monitoring data	
Algorithm/model used	BAL MFC PDAF-NEMO-ERGOM model complex DMI interim reanalysis by assimilating more near real time HELCOM and operational data HELCOM core indicator “Oxygen debt”	
Written resources that describe the indicators		

*Table III.6. Requirements associated with **Baltic Sea extremes***

WP6	Extended description	Comments
Name of INDICATOR	**Baltic Sea extremes**	
Horizontal extent	Baltic Sea area	
Vertical extent	Surface to bottom	
Horizontal resolution	2 km (reanalysis 4 km)	
Vertical resolution	1 m surface, variable with depth	
Temporal extent	1993 to Present	
Temporal resolution	Daily (extremes monthly, seasonally, yearly); quarterly update of reports (web products)	
Usability	HELCOM environmental factsheets on abnormal events Potentially HELCOM driver indicators for status assessments	
Input observational or model sources	BALTICSEA_REANALYSIS_PHY_003_011	
Input observational or model sources	BALTICSEA_ANALYSISFORECAST_PHY_003_006	
Input observational or model sources	BALTICSEA_ANALYSISFORECAST_WAV_003_010	
Input observational or model sources	BALTICSEA_REANALYSIS_WAV_003_015	
Input observational or model sources	INSITU_BAL_NRT_OBSERVATIONS_013_032	
Input observational or model sources	SEAICE_BAL_SEAICE_L4_NRT_ OBSERVATIONS_011_004	
Algorithm/model used	BAL MFC PDAF-NEMO-ERGOM model complex DMI interim reanalysis by assimilating more near real time HELCOM and operational data Algorithms developed within Task 6.3	
Written resources that describe the indicators		

*Table III.7. Requirements associated with **Sea surface temperature (SST)***

WP6	Extended description	Comments
Name of INDICATOR	**Sea surface temperature (SST)**	
Horizontal extent	Baltic Sea area	
Vertical extent	NA	
Horizontal resolution	2 km	
Horizontal resolution	NA	
Temporal extent	1993 to Present	
Temporal resolution	Daily data; quarterly update of reports (web products)	
Usability	HELCOM environmental factsheets on hydrography	
Input observational or model sources	BALTICSEA_REANALYSIS_PHY_003_011	
Input observational or model sources	BALTICSEA_ANALYSISFORECAST_PHY_003_006	
Input observational or model sources	SST_BAL_SST_L4_NRT_OBSERVATIONS _010_007_B	
Input observational or model sources	SST_BAL_SST_L4_REP_OBSERVATIONS_010_016	
Input observational or model sources	INSITU_BAL_NRT_OBSERVATIONS_013_032	
Algorithm/model used	BAL MFC PDAF-NEMO-ERGOM model complex DMI interim reanalysis by assimilating more near real time HELCOM and operational data Algorithms developed within Task 6.3	
Written resources that describe the indicators		

*Table III.8. Requirements associated with **Stratification***

WP6	Extended description	Comments
Name of INDICATOR	**Stratification**	
Horizontal extent	Baltic Sea area	
Vertical extent	Surface to bottom	
Horizontal resolution	2 km	
Vertical resolution	1 m at the surface, variable with depth	
Temporal extent	1993 to Present	
Temporal resolution	Daily, quarterly update of reports (web products)	
Usability	HELCOM environmental factsheets on hydrography Potentially HELCOM driver indicators for status assessments	
Input observational or model sources	BALTICSEA_REANALYSIS_PHY_003_011	
Input observational or model sources	BALTICSEA_ANALYSISFORECAST_PHY _003_006	
Input observational or model sources	INSITU_BAL_NRT_OBSERVATIONS _013_032	CTD profiles from HELCOM monitoring cruises will be incorporated
Algorithm/model used	BAL MFC PDAF-NEMO-ERGOM model complex DMI interim reanalysis by assimilating more near real time HELCOM and operational data Algorithms developed within Task 6.3	
Written resources that describe the indicators		

*Table III.9. Requirements associated with **Near-bottom hypoxia and anoxia***

WP6	Extended description	Comments
Name of product	**Near-bottom hypoxia and anoxia**	
Spatial extent	Baltic Sea area	
Vertical extent	Bottom layer	
Horizontal resolution	2 km	
Vertical resolution	Near bottom only	
Temporal extent	1993 to Present	
Temporal resolution	Daily data; quarterly update of reports (web products)	
Usability	HELCOM environmental factsheets on hydrography Potentially HELCOM driver indicators for status assessments	
Input observational or model sources	BALTICSEA_REANALYSIS_PHY_003_011	
Input observational or model sources	BALTICSEA_ANALYSISFORECAST_PHY _003_006	
Input observational or model sources	BALTICSEA_REANALYSIS_BIO_003_012	
Input observational or model sources	BALTICSEA_ANALYSISFORECAST_BGC_003_007	
Input observational or model sources	INSITU_BAL_NRT_OBSERVATIONS _013_032	CTD profiles from HELCOM monitoring cruises will be incorporated
Input observational or model sources	HELCOM monitoring data	
Algorithm/model used	BAL MFC PDAF-NEMO-ERGOM model complex DMI interim reanalysis by assimilating more near real time HELCOM and operational data Algorithms developed within Task 6.3	
Logical consistency		
Thematic accuracy		

ANNEX IV: WP7 Indicators and EOV requirements

Table IV.1. List of products for WP7 – Ocean Climate Indicators

INDICATOR	Extended description
Sea level	Sea level estimations have a major interest for impact and mitigation on all coastal infrastructures and navigation security; seasonal forecasts of extremes.
Ocean heat content	Ocean heat content is a key indicator for assessing marine ecosystems health, tourism quality offer, estimates of air-sea interactions, key ingredient of seasonal and extremes forecasts as well as in coastal, sea farming and fisheries management.
Marine heat waves	Marine heat waves strongly impacts marine ecosystems health including sea farming and fisheries management.
Net primary productivity	Upwelling intensity is key for marine ecosystems health, and in coastal, sea farming and fisheries management.

Table IV.2. Requirements associated to ***Sea Level***

WP 7	Extended description	Comments
Name of INDICATOR	**Sea Level**	This indicator will determine level of risk on real time
Horizontal extent	Different regions of the Atlantic ocean and Mediterranean sea.	
Vertical extent	NA	
Horizontal resolution	¼° in the Atlantic, 1/8° in the Med	
Vertical spatial resolution	NA	
Temporal extent	From 1993 – to present	
Temporal resolution	Daily, monthly	
Usability	Climate index and NRT information useful for climate adaptation	
Input observational or model/reanalyses sources	ESA-CCI	
Algorithm/model used	Anomalies analysis.	
If applicable, written resources that describes the INDICATOR		

Table IV.3. Requirements associated to ***Surface Currents***

WP 7	Extended description	Comments
Name of INDICATOR	**Surface currents**	This indicator will determine level of risk on real time
Horizontal extent	Different regions of the Atlantic ocean and Mediterranean sea.	
Vertical extent	NA	
Horizontal resolution	¼° in the Atlantic and 1/8° for the Med	
Vertical spatial resolution	NA	
Temporal extent	1993 – to present	
Temporal resolution	Dauly and monthly averages	
Usability	Climate index and NRT information useful for climate adaptation	
Input observational or model/reanalyses sources	CMEMS	
Algorithm/model used	Anomalies analysis.	
If applicable, written resources that describes the INDICATOR		

Table IV.4. Requirements associated to ***Ocean Heat Content***

WP 7	Extended description	Comments
Name of INDICATOR	**Ocean Heat Content**	This indicator will determine level of risk on real time
Horizontal extent	Different regions of the Atlantic ocean and Mediterranean Sea.	
Vertical extent	NA	
Horizontal resolution	¼° in the Atlantic, 1/8° in the Med	
Vertical spatial resolution	NA	
Temporal extent	1993 – to present	
Temporal resolution	Daily, monthly	
Usability	Climate index and NRT information useful for climate adaptation	
Input observational or model/reanalyses sources	CMEMS GLORAN	
Algorithm/model used	Anomalies analysis.	
If applicable, written resources that describes the INDICATOR		

Table IV.5. Requirements associated to ***Marine Heat Waves***

WP 7	Extended description	Comments
Name of INDICATOR	**Marine Heat Waves**	This indicator will determine level of risk on real time
Horizontal extent	Different regions of the Atlantic, ocean and Mediterranean Sea.	
Vertical extent	NA	
Horizontal resolution	¼° in the Atlantic, 1/8° in the Med	
Vertical spatial resolution	NA	
Temporal extent	1993 – to present	
Temporal resolution	Daily, monthly	
Usability	Climate index and NRT information useful for climate adaptation	
Input observational or model/reanalyses sources	CMEMS	
Algorithm/model used	Anomalies analysis.	
If applicable, written resources that describes the INDICATOR		

Table IV.6. Requirements associated to Eastern Boundary Systems ***Net Primary Productivity***

WP 7	Extended description	Comments
Name of INDICATOR	**Net Primary Productivity**	This indicator will determine level of risk on real time
Horizontal extent	Different regions of the Atlantic and Mediterranean Sea	
Vertical extent	NA	
Horizontal resolution	¼° in the Atlantic, 1/8° in the Med	
Vertical spatial resolution	NA	
Temporal extent	1993 – to present	
Temporal resolution	Daily, weekly, monthly	
Usability	Climate index and NRT information useful for climate adaptation	
Input observational or model/reanalyses sources	CMEMS satellite colour maps and BGC Argo floats	
Algorithm/model used	Anomalies analysis.	
If applicable, written resources that describes the INDICATOR		