Ref. Ares(2020)7253638 - 01/12/2020

Horizon 2020

H2020 LC-SPACE-04-EO-2019-2020

Copernicus Evolution – Research for harmonised and Transitional-water Observation (CERTO)

Project Number: 870349

Deliverable No: D6.1		Work Package: 6 - Indicators	
Date:	26-NOV-2020	Contract delivery due date	30-NOV-2020
Title:	Analysis of User Requirements for Indicator Development		
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Dissemination level (PU=public, RE=restricted, CO=confidential)			PU
Report Status (DR = Draft, FI = FINAL)			DR

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme grant agreement N° 870349

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List of acronyms

AMA	Mediterranean Aquaculture Association
APA	Portuguese Environment Agency
ARH	Administration of the Tagus Hydrographic Region
BAW	Federal Waterways Engineering and Research Institute
BC	Brockmann Consult
BSH	Federal Maritime and Hydrographic Agency of Germany
C3S	Copernicus Climate Change Service
CDS	Climate Data Store
CHL	Chlorophyll-*a*
CHL P90	Chlorophyll-*a* 90th percentile
CLMS	Copernicus Land Monitoring Service
CMEMS	Copernicus Marine Environment Monitoring Service
CNR	Italian National Research Council
CNR-ISMAR	Italian National Research Council - Marine Science Institute
CODA	Copernicus Online Data Access
CORILA	Consortium for coordination of research activities concerning the Venice Lagoon system
CSI	Coastal State Indicator
DANUBIUS-RI	International Centre for Advanced Studies on River-Sea Systems
DDBRA	Danube Delta Biosphere Reserve Authority
DEM	Digital Elevation Model
DO	Dissolved Oxygen
EO	Earth Observation
EU	European Union
FU	Fisherman’s Union

GEOECOMAR	National Institute for Research and Development of Marine Geology and Geoecology
GIS	Geographic Information System
HR-OC	High Resolution Ocean Colour
ICNF	Institute for Nature Conservation and Forests
IPMA	Portuguese Institute for the Ocean and Atmosphere
JCH	Jurilovca City Hall
KU	Maritime Research Institute of Klaipeda University
LNEC	Portuguese National Civil Engineering Laboratory
LTER	Long-Term Ecological Research Network
LUSI	Land Uses Simplified Index
MBTC	Marine Business Technology Centre
MSFD	Marine Strategy Framework Directive
NERC	National Environment Research Council
OC	Ocean Colour
PMLA	Plymouth Marine Laboratory Applications
REE	Concentration of emergent metals
Rrs	Remote Sensing Reflectance
SESVI	Social-Ecological System Vulnerability Index
SPM	Suspended Particulate Matter
SRTM	Shuttle Radar Topography Mission
SSH	Sea Surface Height
SST	Sea Surface Temperature
TSM	Total Suspended Matter
TUR	Turbidity
Thales	Maritime Autonomy Systems Business
WFD	Water Framework Directive

1 Executive Summary

- This report represents the first deliverable from CERTO WP6, focused on the development of indicators. The general objective of Task 6.1 is to analyse the list of indicators provided by Task 2.1 and identify those indicators with potential to be included in the CERTO prototype, or to be provided as a downstream service.
- This deliverable provides an overview of the context of the work, including a short description of the six case-study regions.
- Copernicus services that can be incorporated in the development of indicators are also described, in particular the Copernicus Marine Environment Monitoring (CMEMS), Climate Change (C3S) and Land Monitoring (CLMS) Services.
- Users considered in each case-study region are also briefly described, including their typology (intermediate vs final users) and sector of activity.
- This deliverable presents a summary of the results obtained in Task 2.1, focused on the assessment of user requirements. For detailed results, refer to D2.1. Results herein are integrated in one single table to provide a comprehensive and easy way to understand what are the most popular or needed products and what are the most frequent requirements in terms of specifications, such as spatial and temporal resolution, production mode (real-time *vs* not real-time), targeted products or level of product processing (L2 to L4, reports or forecasts) and type of service (operational *vs* on demand).
- An integrated analysis and critical perspective is also provided to guide the selection of products and indicators for development in WP6. For example, some products can be improved in terms of their spatial and temporal resolution or production mode. This represents a significant improvement of service and fulfils part of users' needs. Some products/indicators are not suitable for development within CERTO because they still represent challenges in the remote sensing field (e.g. nutrients and dissolved oxygen) or because they are out of scope of the CERTO conceptual approach for water quality indicators (e.g. seafloor and wetlands vegetation, shoreline and bathymetry).
- Finally, selected indicators are presented in Section 6 with a description of the plan for their implementation, which may be subject to changes during the development phase. Additional information, such as the identification of source data needed for implementation and regions where the WP6 output will be applied, are also provided. Moreover, an overview of how each indicator type contributes to fulfil users' needs and to the overall CERTO's objectives is presented.

2 Introduction

The development of indicators is of utmost importance to demonstrate the added value of CERTO's improved products. CERTO WP2 enabled identification of a list of indicators and relevant products for users and stakeholders from industry (e.g. shipping and aquaculture), local authorities (e.g. port authorities) and regulators (e.g. environmental agencies) in charge of reporting on the European Union (EU) Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD). The main objective of WP6 is to develop and evaluate those indicators that are considered the most feasible and the most valuable for the CERTO prototype service. The development of common or harmonised indicators across the water continuum, from lakes to estuaries to coastal waters and offshore water, should ultimately contribute to the harmonisation of the WFD and the MSFD based on common datasets, making it possible to elaborate integrated management strategies. It would likely also be the only set of indicators with a fully harmonised methodology across EU Member States and their transboundary waters.

Some indicators developed in CERTO WP6 could be suitable for future production in one or more upstream Copernicus service, in a similar manner to the Ocean Monitoring Indicators in CMEMS, or Trophic Status in CLMS; others may be implemented in downstream services by value-adding companies: as is the case currently a more likely outcome is a combination of both. The demonstration of proposed indicators will be done in WP8, where they will be tested against 'real life' situations and exposed to service providers and end-users. At this stage, technical limitations and recommendations for implementation will also be identified.

To fulfil the aforementioned objectives, results from WP2 have been evaluated to understand how WP6 can meet the requirements of user communities and stakeholders in six user-case areas (i.e., Danube Delta, Venice Lagoon and North Adriatic Sea, Tagus Estuary, Plymouth Sound, Elbe Estuary and German Bight, and Curonian Lagoon). WP2 started a continuous process of engagement with local communities. Some of these actors are key final users (e.g. the Portuguese Environment Agency - APA) while others are intermediate (e.g. Thales UK Limited), i.e. they will utilise CERTO products to further develop downstream services. As described in D2.1, community requirements were collected through a questionnaire, which was approved by the Ethics committee of the University of Stirling. This process was performed as one-to-one discussions, albeit remotely as necessitated by the COVID-19 pandemic, which were very helpful to understand not only the user's needs in terms of data products but also in terms of integrated indicators. Quality and technical requirements (e.g. spatial and temporal resolutions) were also evaluated. It is important to stress that discussions with end-users will continue throughout the project to support any adjustments and potential improvements of the CERTO's products and indicators.

Some examples of indicators which may be developed include chlorophyll-*a* 90th percentile (CHL P90), phytoplankton bloom intensity and frequency (phenology), and the Land Uses Simplified Index (LUSI). Satellite products that are already available to end-users (i.e., chlorophyll-*a* - CHL and Suspended Particulate Matter - SPM) will be provided with better quality (in terms of uncertainty statistics) and higher resolution. Moreover, a social-ecological systems index will be extended to demonstrate the additional benefit obtained from using different global data sources, including several Copernicus services, as described below.

2.1 Description of Copernicus Services

The development of harmonised indicators across the water bodies continuum “falls between” the remits of the three relevant Copernicus services producing water quality information (Figure 1): the Copernicus Marine, Climate Change and Land Services. Therefore, extensive knowledge of the aforementioned services is key for the development of common indicators to bridge those gaps.

CMEMS provides regular and systematic information about the physical state and dynamics of the oceans and marine ecosystems for the global ocean and the European regional seas and the provision of retrospective data records. CMEMS calculates and provides products describing currents, temperature, wind, salinity, sea level, sea ice, and biogeochemistry. Typical products provided by the service are:

- Maps and data for oceanographic hindcasts and forecasts (real time or long time series);
- Retrospective assessment of the sea state for research and development or operational purposes;
- Simulations of the ocean physical state (for drift calculations, routing, input for scenarios, site survey, etc);
- Boundary conditions for coastal models.

The service provides a single point of access to a catalogue of a large variety of marine data and information. The products use international metrics and are described in quality information documents.

CLMS provides geospatial information on land cover and its changes, land use, vegetation state, water cycle, cryosphere, and Earth surface energy to a broad range of users. The service is based on Earth Observation (EO) data combined with data from other sources. It supports applications in a variety of domains such as spatial and urban planning, forest management, water management, agriculture and food security, nature conservation and restoration, rural development, ecosystem accounting, and mitigation/adaptation to climate change. CLMS consists of the following main components:

- The systematic monitoring of biophysical parameters, which produces mainly a series of bio-geophysical products on the status and evolution of land surface (i.e., Snow and Ice, High Resolution Phenology);
- Land cover and land use mapping, which produces land cover classifications at various level of detail at pan-European and global context (i.e., imperviousness, forests, grassland, water and wetness);
- Thematic hot-spot mapping, which aims to provide tailored and more detailed information on specific areas of interest, known as hot-spots, including coastal zones;
- Imagery and reference data, which provide satellite image mosaics in high and very high resolutions, and reference datasets (i.e., Sentinel-2 image mosaic production at global level).

C3S supports the adaptation and mitigation policies of the European Union by providing information about past, present and future climate change. It delivers free and open access climate data records to monitor major drivers and document emerging patterns, signals and indices that characterize climate variability.

Climate data are provided through the Climate Data Store (CDS), which is designed to enable users to tailor services to more specific public or commercial needs.

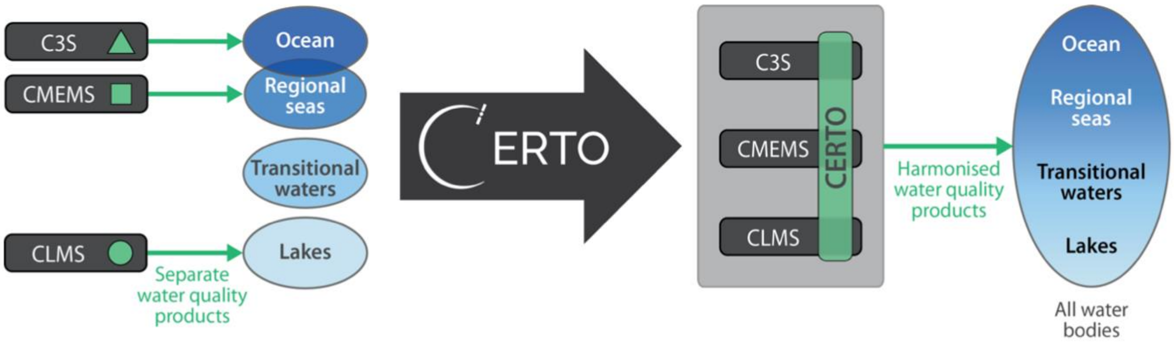

Figure 1. *Role of the CERTO project in the harmonization of water quality products and indicators from the different Copernicus Services.*

3 Description of users

CERTO users are local institutions, privately or publicly funded, working within one of the six case-study regions of the project. These can be national or international institutions, as well as academic or industry-based, but are generally government entities that focus on the monitoring or policy involved within their area and have expressed a necessity for the end products proposed within CERTO. All users were interviewed within the first year of the CERTO project, where their specific needs were discussed as pertaining to the possibilities and end goals of CERTO. An overview of the interview results, obtained within WP2 and discussed in depth in deliverable D2.1 (Sections 3.2 and 4.1), are presented in Table 1 of this deliverable D6.1.

CERTO users can be divided as belonging to one or more of the targeted sectors shown in Figure 2. These sectors were identified in the project lead-up and are described in more detail in D2.1 (Section 3.2). Overall, CERTO users are distributed throughout all environmental matrices, whether concentrating more on inland-transitional or marine-transitional waters, highlighting the importance of the transitional waters themselves.

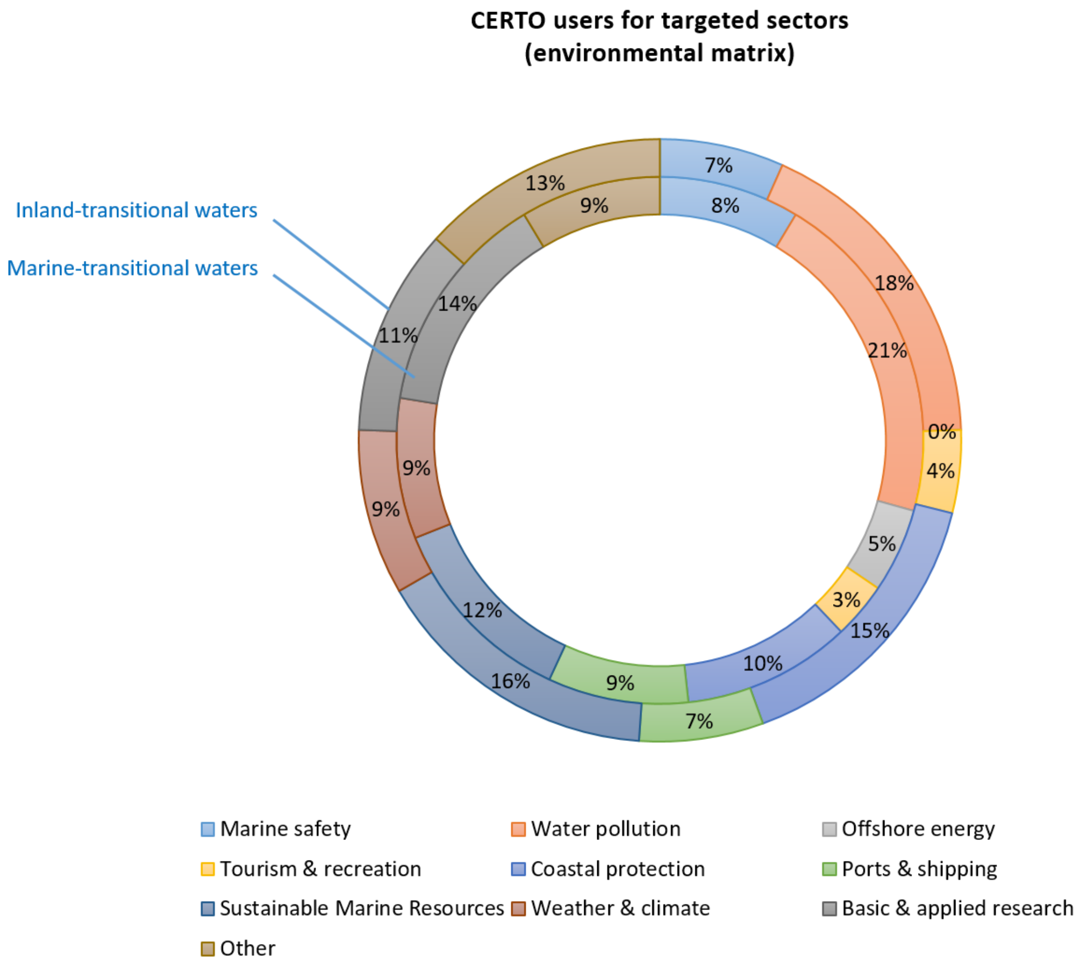

Figure 2. *Percentage of identified users by the different sectors, considering the two main environmental matrices that are explored in CERTO (From CERTO Deliverable 2.1-Figure 3).*

CERTO users can also be classified as being either *Final* or *Intermediate* users. *Final* users are those end-users that will benefit directly from CERTO products, since they obtain data directly from the Copernicus services. Taking the Tagus region as an example, users such as APA, Administration of the Tagus Hydrographic Region (ARH), and Portuguese Institute for Nature Conservation and Forests (ICNF) are *Final* users, since they will receive and apply CERTO data directly to their own interests. *Intermediate* users are those who will exploit CERTO outputs to provide additional downstream services developed from the products. In the example of the Tagus region, the National Civil Engineering Laboratory (LNEC) and the Portuguese Institute for the Ocean and Atmosphere (IPMA) are considered as *Intermediate* users, since they receive CERTO data and can subsequently provide new products from that data, whether in the form of research results, publications, or reports on their own behalf. In general, a specific user can be a *Final* user for a certain targeted sector and, on the other hand, an *intermediate* user for other sectors. Table 1 provides a list of all of the CERTO users currently existing as project stakeholders within each case-study region, along with the user Type and the specific Sectors of each.

Table 1. *List of the interviewed CERTO users organised by case-study region, with the user type (Intermediate/Final) and the specific sector(s) where each user performs analysis and requires data.*

case-study region	user Name	Type	Sectors: Maritime Safety	Water Pollution	Offshore Energy	Tourism & Rec.	Coastal Protection	Ports & Shipping	Sustainable Res.	Weather & Climate	Research
1. Danube Delta	Jurilovca City Hall	Final	X	X		X	X	X	X	X	
	Danube Delta Biosphere Reserve Authority (DDBRA)	Final		X		X	X		X	X	X
2. Venice Lagoon and North Adriatic Sea	Mediterranean Aquaculture Association (AMA)	Final	X	X			X		X		
	THETIS	Intermediate	X	X			X		X	X	X
	International Centre for Advanced Studies on River-Sea Systems (DANIBUS-RI)	Final					X			X	X
	Italian National Research Council (ISMAR-CNR)	Final		X					X	X	X
	Consortium for coordination of research activities concerning the Venice Lagoon system (CORILA)	Intermediate	X			X	X		X		
3. Tagus Estuary	Portuguese Environment Agency (APA)	Final		X							

	Administration of the Tagus Hydrographic Region (ARH)	Final									
	Portuguese National Civil Engineering Laboratory (LNEC)	Intermediate									
	Institute for Nature Conservation and Forests - Tagus Estuary Reserve (ICNF)	Final									
	Portuguese Institute for the Ocean and Atmosphere (IPMA)	Intermediate									
	Fishermen’s Union (FU)	Final									
4. Plymouth Sound	Marine Business Technology Centre (MBTC)	Intermediate									
	Maritime Autonomy Systems Business Lead (Thales)	Intermediate									
5. Elbe Estuary and German Bight	Federal Maritime and Hydrographic Agency of Germany (BSH)	Intermediate									
	Federal Waterways Engineering and Research Institute (BAW)	Intermediate									
6. Curonian Lagoon	Marine Research Institute, Klaipeda University (KU)	Final									

Depending on their focus, sector, and the type of service they provide, end-users may require different types of products or indicators. A general display of user requirements is displayed in Table 2. Users are institutions that can receive the required products as individual datasets or as indicators incorporating a multitude of datasets. The most valuable indicators that have been identified by users are discussed in Section 4.

4 List of indicators identified by users

Users from the six case-study regions were interviewed within WP2, through a questionnaire which served as the basis of one-to-one discussions. In general terms, user requirements yielded several similarities (e.g. parameters of interest, spatial and temporal resolution, *etc.*) (Table 2). Differences in user requirements were mainly influenced by: i) their different roles and responsibilities in aquatic systems; ii) the existence (or not) of long-term *in-situ* monitoring data; and iii) different staff technical competencies and skills, in terms of data processing and use. The general description of user requirements for each case-study region is provided below.

4.1 Razelm-Sinoe Lagoon System (Danube Delta - Black Sea)

Two main end-users were identified in the Razelm-Sinoe Lagoon System: the **Jurilovca local administration (City Hall)** and the **Danube Delta Biosphere Reserve Authority (DDBRA). Jurilovca City Hall (JCH)** is the local administration for one of the villages bordering the lagoon and an important tourism and fishing hub in the area. They require simple and integrated information (e.g. maps, reports) to make informed decisions. **DDBRA** is the main authority in charge of monitoring water quality in the Danube Delta and for managing important activities, such as tourism, navigation, fish stocks and reed harvesting. They receive scientific information from local entities and gather their own data, when possible. Nevertheless, for some situations the information is incomplete in time and space or not in an easy format to analyse. Overall, their specific tools for monitoring the lagoon may be limited. Thus, it has been difficult to take decisions and implement measures. They identified a set of parameters as the most important: chlorophyll-*a*, total suspended matter (TSM), turbidity (TUR), sea surface temperature (SST) and salinity, nutrients and other types of pollution (plastic and hydrocarbons), and vegetation cover/shoreline. They require high-level, L4 integrated data, in a near-real time, high spatial resolution, operational system. They are familiar with Geographic Information Systems (GIS)-like interfaces, Excel files and tools, statistical analysis tools, data integration and interpretation, forecast systems.

4.2 Venice Lagoon (Northern Adriatic Sea)

The Venice Lagoon is a complex system where various biogeochemical, eco-geomorphological and anthropogenic processes occur. In this context, several end-users interviewed in WP2 (e.g. **CORILA, THETIS, AMA, DANUBIUS-RI**) raised concerns about the need of a gap analysis and for the harmonisation of datasets, which makes CERTO relevant and timely. They identified CHL, TSM, SST and salinity for the coastal environment as the most relevant parameters for their studies and assessments. Through the Long-Term Ecological Research Network (LTER) - Venice site (LTER-Italy; www.lteritalia.it), ecological observations are carried out by **CNR-ISMAR.** They are particularly interested in the synergies with satellite data to assess long-term trends in algal biomass and its implications on nutrients and dissolved oxygen. All users require high-spatial resolution daily data. Most users do not need near-real time data.

4.3 Tagus estuary (Atlantic Ocean)

The Tagus estuary includes a major natural reserve, however, there is a significant lack of data on physical, chemical and biological structure of the water. Most end-users have limited capacity to obtain their own data and are eager to receive data from Copernicus. Almost all end-users (**APA, ARH, ICNF, IPMA, LNEC** and **Fishermen's Union - FU**) reported similar needs. They identified CHL, salinity, temperature, TSM and dissolved oxygen as the most important parameters, and access to data in a dedicated platform would be useful. However, integrated water quality indicators would be preferable, that could be useful for licensing purposes, as well as to address the main environmental legislation, such as the WFD. Additionally, intertidal delimitation and bathymetry data would also be of interest. Some users, such as **IPMA** and **LNEC**, are interested in low-level processed data (e.g. L2), but others would prefer user-friendly CSV, Microsoft Excel or GIS formats. Most users require high spatial resolution data, from daily to monthly at a high level of processing (L4). However, they do not need near-real time data.

4.4 Plymouth Sound (English Channel)

The approach taken in the Plymouth Sound differs from the other test sites given that users are private entities (**Marine Business Technology Centre-MBTC** and **Thales UK Ltd**) that provide services to final end-users. The information requirements represent what these entities consider could be of benefit for end-users. **MBTC** supports small and medium-sized enterprises through research, testing, proving, and production. The main focus is on marine autonomy, clean propulsion, advanced manufacturing materials, environmental monitoring and modelling, and cybersecurity. They are particularly interested in CHL, TSM and remote sensing reflectances (Rrs). **Thales UK Ltd** is the Maritime Autonomy Systems Business lead and are interested in digital data to drive underwater vehicles. For this, they are mainly interested in turbidity and other indicators of water quality. They are also interested in the detection of phytoplankton blooms and areas with sudden changes in optical properties (e.g. fronts). They would be interested in hourly to daily high spatial resolution products (i.e. 10-20m), in near real time.

4.5 Elbe Estuary - German Bight (North Sea)

The principal information requirements in the Elbe estuary and the German Bight are on water quality and sediment fluxes. The **Federal Maritime and Hydrographic Agency of Germany (BSH)** and the **Federal Waterways Engineering and Research Institute (BAW)** were the main end-users interviewed for WP2. They reported the need to receive spatial information on water quality products, such as TUR or TSM. This would also be useful to monitor dredging activities. In this case, they already have access to some *in-situ* data, collected during dedicated campaigns and fixed monitoring stations, but they are interested in improving data quality and spatial coverage. There is also the interest in using remote sensing data, for normal activities as well as for reporting for the MSFD, but users need assurance regarding the quality of the data provided. The parameters required for the Elbe river case study are CHL, TUR and TSM. Depending on usage, daily averaged products are the basis. Near-real time is not mandatory, but would be welcome. The spatial resolution required is 300m for the more open parts of the estuary (and going into the German Bight). For the Elbe itself, the higher the resolution, the better, i.e. 20-60m would be the best.

4.6 Curonian Lagoon (Baltic Sea)

The Curonian Lagoon is a hypereutrophic environment often dominated by cyanobacterial blooms in the summer, due to a combination of favourable nutrient stoichiometry (N and Si limitation), elevated water temperature, low wind speed, and low grazing pressure. *In-situ* data are available, mainly provided by the Marine Research Department of the Lithuanian Ministry of Environment. The end-user interviewed for WP2 was the **Marine Research Institute of Klaipeda University (KU)**. They consider that more information is needed to develop better tools for environmental evaluation and management, as well as to promote nature conservation. KU considers CHL, TSM, salinity, Rrs and SST as the most relevant parameters. They would be interested in receiving daily to weekly products at near-real time. High spatial resolution would be important but a higher resolution of 300m would be reasonable.

Table 2 – *Details of specific requirements needed for CERTO's case studies (Danube Delta, Venice Lagoon, Tagus estuary, Plymouth Sound, Elbe estuary and Curonian Lagoon).*

		Danube Delta		Venice Lagoon					Tagus estuary						Plymouth Sound		Elbe estuary		Cur Lag	Total (out of 18)
		JCH	DD BRA	AMA	THETIS	DANUBIUS -RI	CNR-ISMAR	CORILA	ARH	APA	LNEC	ICNF	FU	IPMA	MBTC	Thales	BAW	BSH	KU	
Environmental matrix	Marine			■	■		■	■	■	■	■	■	■	■	■	■	■	■		14
	Transitional	■	■	■	■	■	■	■			■			■		■			■	11
	Inland	■	■			■					■						■		■	6
General name of the Targeted product	CHL	■	■	■	■	■	■	■		■	■	■	■		■	■		■	■	15
	TSM	■	■	■	■	■	■	■		■	■	■			■		■		■	13
	Water TUR	■	■							■			■			■	■		■	7
	Rrs				■	■									■	■			■	5
	SST	■	■	■		■				■	■	■	■						■	9
	Salinity			■		■				■	■	■	■							6
	DO		■				■			■	■	■								5

	Nutrients																			**3**
	Shoreline																			**6**
	pH																			**1**
	REE																			**1**
	SSH																			**1**
	Microplastic																			**2**
	Bathymetry																			**2**
Type of service/ frequency	**Operational**																			**15**
	On demand																			**15**
Processing level of targeted product	**L2**																			**3**
	L3																			**11**
	L4																			**9**
	Static map																			**4**
	Report																			**5**

	Forecast																			**2**
Production mode	**Real-time**																			**7**
	Not real-time																			**12**
Temporal resolution	**Hourly**																			**2**
	Daily																			**12**
	Weekly																			**3**
	Monthly																			**4**
	Any																			**2**
Spatial resolution (m)	**10-50**																			**10**
	50-100																			**7**
	100-500																			**2**

5 Analysis of user requirements

The majority of CERTO users require data fulfilling the **Marine** (14 users) and **Transitional** (11 users) environmental matrices, with fewer users (6) additionally seeking Inland water data (Table 2). This puts the emphasis of CERTO targeted products on transitional-to-open waters, with the possibility of specifically aimed products concentrating on inland, river and freshwater sources.

Within this focus, the majority of users require data on the biological structure, composition, and overall quality of water. These include parameters such as **CHL, TSM** and basic physico-chemical water properties that may have an effect on the biogeochemical dynamics of the water body, such as **salinity** and **SST**. **CHL** and **TSM**, in particular, were identified by more than 10 users as relevant information/data for their activities. This was confirmed by users from all case studies, i.e. Danube Delta, Venice Lagoon, Tagus estuary, Plymouth Sound, Elbe estuary and Curonian Lagoon. Compositional properties, such as **SST, TUR, salinity** and **Dissolved Oxygen (DO)** of the water column were also considered valuable products by nine, seven, six and five users, respectively. An **SST** product was considered important by users from all case studies, except Plymouth Sound and Elbe estuary. **Water turbidity** was considered important in all case studies, except Venice Lagoon. **Salinity** was only considered relevant by users from North Adriatic Sea (i.e. Venice Lagoon and Po River Delta coastal area) and Tagus estuary. **DO** was considered important by users from Danube Delta, Venice Lagoon and Tagus estuary.

It is important to note that these results are also likely to reflect the on-going monitoring programmes in place at the different case-study regions, as well as on their current ability to access data. For example, SST is a standard product that is useful for understanding local dynamics. Nevertheless, it was not identified by users in Plymouth Sound and Elbe estuary. These are sites where *in-situ* continuous monitoring systems are implemented and additional data are also available. Users from Venice Lagoon did not identify water turbidity as one of the most important needs because they have access to it already. However, DANUBIUS-RI in the Northern Adriatic Sea indicated that real-time data on TSM and TUR would be key for modelling approaches of storm surges. All in all, it seems that all users are interested in these standard products (e.g. CHL, TSM, SST, TUR). In most cases, however, they are expecting **improved products**, in terms of higher spatial and temporal resolutions and harmonised for the water continuum, as well as **integrated information**, in the form of trend analysis, anomalies, percentiles, *etc*. This seems crucial for helping users in their local responsibilities, such as decision-making, licensing and EU Directives reporting.

Some entities have also requested products related to **nutrient** concentrations, **Rrs**, **pH** values, **Sea Surface Height (SSH)**, and **microplastic** concentration. Rrs data seems to be very important for CERTO's intermediate users, who will benefit from the improved dataset to further develop products for local end-users. The other products (nutrients, pH, SSH and microplastic) are only requested sporadically and do not form the basis of what users are generally seeking.

However, an important aspect that needs to be included in this analysis is the **feasibility in developing these products**, identified as needs by users. This is particularly relevant for some products, such as **DO** and nutrient data products. Currently, the development of such products is still a major challenge for the remote sensing field. Additionally, in the last couple of years, efforts have been placed in the development of microplastic data products. However, these products are still in an early phase of development and will not be considered for CERTO at this stage.

Several users have expressed an additional interest in obtaining geomorphological data in the form of **shoreline** composition, shoreline delimitation, and bathymetry measurements, which are lacking in under-sampled regions such as the Tagus Estuary. While important to certain regions, geomorphology and bathymetry are not directly related to the initial goals of CERTO, since they are not traditionally regarded as datasets for water quality.

Datasets should be provided to users as either **high-level processed data** (at least **L3**, preferably **L4)**, or in the form of static maps or reports available to users with little or no additional processing required by the users themselves. Reports can be in the form of publications or reports addressing EU Directives, such as the WFD and the MSFD. Some research-oriented institutions (LNEC, IPMA and KU) have additionally requested the availability of lower-level processing data (**L2**) for the purposes of forecasting, research, or modelling. **Temporal and spatial resolutions** are generally requested to be on the **finer scales**, especially for spatial resolution, where datasets are desired in the **10-100 meter** range.

User requirements are split evenly in terms of the need for **real-time data**. In general, users belonging to the Danube Delta, Venice Lagoon, and Tagus Estuary do not require real-time data. Users in the Elbe Estuary, Curonian Lagoon, and Plymouth Sound are seeking real-time data, where possible. This is also the case of specific users in the Venice Lagoon and Danube Delta. Finally, users interviewed across all regions are seeking both Operational and/or On-Demand service of the products, wherever each is possible depending on the product, region, and context of the dataset requested.

Discussion with end-users is ongoing and will continue throughout the project. It is worth noting that some requirements expressed by end-users represent a demand for *improved* quality of data to which users already have access. THIs is a fundamental outcome of the CERTO project. Data can also be reprocessed and reanalysed to produce mean values or trends. For example, this could include common indicators such as the chlorophyll-*a* 90^{th} percentile or other similar existing products that could be refined in accordance to the users' needs. Of special interest for discussion will be the production of **more integrated *indicators for water quality***, including various parameters (e.g. SPM, TUR) into specific indicators, harmonised across the six CERTO study areas for potential application over all water matrices.

The CERTO project also proposed the development of more **complex indicators**, such as the **Social-Ecological System Vulnerability Index (SESVI)**. SESVI aims to integrate data from different sources and services (e.g. CMEMS, CLMS) to evaluate the vulnerability of a water body to a specific pressure or change. This is a relatively novel approach and was not considered in the questionnaires applied to users, as they are not aware of it yet. However, the CERTO research team is planning to develop and showcase the product in the six case-study regions as a complementary high-level indicator for local managers as explained below in section 6. SESVI will be a clear example of the added value created by integrating different Copernicus Services.

Indicators and their development are discussed at greater length in section 6 of this report, including the planning and management indicators for industry and local authorities (Section 6.1), indicators to support EU policy (section 6.2), and SESVI (Section 6.3).

6 Development of Indicators

6.1 Planning and management indicators for industry and local authorities

6.1.1 Description of indicators to be developed

Type of indicator

The indicators envisaged in Task 6.2 will focus on the influence of sediments and will be based mainly on standard CERTO-improved EO products of TSM and/or TUR, which can already be considered as primary indicators (Falcini et al., 2012; Brando et al., 2015; Braga et al., 2020). From the user requirements, already having an idea of the concentration of sediments in their area of interest is highly relevant for CERTO users. Several indicators will be developed, assessed, and selected during this Task:

- Temporal indicators such as TSM/TUR maximum, plume duration (e.g. during high river discharge events) will be used to characterise water bodies;
- Spatial indicators such as a Coastal State Indicator (CSI), based on statistics from combined chlorophyll and TSM/TUR information. By using the backscattering parameter, we also plan to develop an indicator to assess sediment input based on particle size analysis (Pitarch et al., 2019).

Region for application

This (these) indicator(s) should be applicable to all river-delta-sea continuum thanks to local tuning of the primary indicators (TSM, TUR) during processing by using the optical water type classification to be implemented in the CERTO Processing System. This (these) indicator(s) may be more applicable to intertidal areas with varying sediment loads through seasons.

Satellite data used for the production of the indicator

TSM and TUR products are the basis for this task. They can either be provided by the CERTO Processing System, as implemented in Copernicus services (e.g. through the High Resolution Ocean Colour - HR-OC) or by downstream service providers such as BC or PML Applications. The decision to take one or the other data source will depend on the use case, as spatial and temporal resolution may come into play; this means that we may need to go to a downstream provider if what is offered via Copernicus services does not fit user requirements. For example, the CMEMS 1km resolution data may not be of much help/use here as: i) the estuarine/coastal areas are often flagged out in these products; ii) there is only SPM available; and iii) only for the Atlantic Region (i.e. not for the Mediterranean and Black Sea regions).

***In-situ* data needed**

For Task 6.2, *in-situ* data is needed for the calibration/validation of the TSM/TUR products to make sure the indicators we will develop are not only correct on their formulation, but also provide relevant information to the users. These data will be obtained through CERTO WP3.

Development phase

The development has not started yet.

6.1.2 How is this indicator fulfilling the needs identified by users?

Providing turbidity products to CERTO users is fulfilling many of the user requirements. Some users (e.g. BSH) are already familiar with this indicator, others (e.g. APA) less so and adding the new indicator to the portfolio will enhance the users' capabilities for monitoring and environmental assessment. Specifically, for the industry and local authorities, offering more added value indicator(s) with trend analysis or coastal eutrophication/sediment distribution can help port authorities plan activities (harbour expansions/modifications…) and assess the impact of those activities. Monitoring agencies will benefit from the indicator(s) to monitor environmental changes in dynamic areas.

6.1.3 How is this indicator contributing to the overall objectives of CERTO?

The indicator(s) will be applicable to the water continuum, provided satellite resolution is high enough. In smaller rivers/estuaries, resolution might be too low to provide good information apart from river mouths. For the CERTO case studies, a resolution down to 60m should be sufficient for most.

The indicator(s) should/will also provide indications on water quality, as sediment loads can influence eutrophication.

6.2 Indicators to support EU policy

6.2.1 Description of indicators to be developed

Type of indicator

EU policy will be supported through the development of harmonised CERTO indicators foreseen in Task 6.3. From the analysis of user requirements, it was clear that most users have to perform ecological assessments for WFD and MSFD reporting. For this, it is crucial to provide products that allow evaluating the specific metrics of the Directives, such as the chlorophyll-*a* 90th percentile, used as an indicator of the highest biomass values produced during the most important phytoplankton blooms. Other important metrics are related to the frequency and intensity of phytoplankton blooms. Thus, two sets of common indicators will be refined for six user-case areas:

- Chlorophyll-*a* 90th percentile, calculated using continuous remote sensing datasets over the growing season (Brito *et al*., 2012; Devlin *et al*., 2007; Revilla *et al*., 2009, 2010);
- Phytoplankton bloom intensity and frequency (phenology). The annual bloom will be defined as the period of the highest peak above the mean value of the region for the whole climatological year (Sá *et al.*, 2014). Phenologically-important phases of the phytoplankton growth (Platt and Sathyendranath, 2008; Racault *et al*., 2012) will be calculated: (1) the time of bloom initiation and end, (2) the bloom duration, (3) the bloom maximum and day of occurrence, and (4) the day of maximum growth and value.

In addition, the implementation of the Land Uses Simplified Index (LUSI), which uses information on the anthropogenic land uses that influence coastal waters (agricultural, industrial and urban land uses and riverine effects) and on coastline morphology, will be considered and evaluated. This may be relevant to provide support for the implementation of the phytoplankton metrics identified above.

Region for application

The above-described indicators should be used consistently across the water continuum, from lakes to estuaries to coastal waters, including transitional waters. Therefore, a fully harmonised methodology across EU Member States and their transboundary waters should be developed.

Satellite data used for the production of the indicator

Improved CHL products will be a standard output from by the CERTO Processing System. From these data, higher-level indicators, CHL P90 and phytoplankton phenology, will be computed from the Copernicus Sentinel missions Sentinel-2 and/or Sentinel-3. While Sentinel-3 already has standard chlorophyll-*a* products, the same is not applicable to Sentinel-2. Given that most users have requested high spatial resolution products, it may be necessary to implement novel algorithms to derive CHL from Sentinel-2 in the CERTO Processing System. In addition, the suitability of CHL products (e.g. CHL algorithm retrieval) might depend on the water body concerned, i.e. on its optical properties. Adjustments may be required. Lastly, if implemented, the LUSI index will require data from other Copernicus Services, such as land cover data from the CLMS.

***In-situ* data needed**

In-situ data inputs are not directly required for the development of EU policy indicators, since they will rely on EO-derived products (e.g., chlorophyll-*a* concentration). Nevertheless, *in-situ* data are needed for the calibration/validation of the developed indicators to make sure they represent natural conditions and dynamics and are useful for users. These will be obtained in CERTO WP3 for each case study area.

Development phase

The development has not started yet.

6.2.2 How is this indicator fulfilling the needs identified by users?

Based on the user requirements identified in WP2, the majority of users are seeking high-level processed data on overall quality of marine and transitional waters. In this context, CHL was the most popular data product for all users included in the interviews. Improved versions of the Ocean Colour CHL products from the final CERTO Processing System will already be fulfilling important needs of most users, especially if we provide aggregate data, in the form of trends, anomalies and P90, one of the indicators selected. Phytoplankton phenology analysis will also be crucial for the assessment of ecosystem health and for reporting to the WFD and MSFD, contributing to user compliance with EU Directives.

6.2.3 How is this indicator contributing to the overall objectives of CERTO?

Once developed, the EU policy indicators should be implemented in the CERTO prototype service, providing users, stakeholders from industry and local authorities with common water quality indicators harmonised across the water continuum. The operationalisation of these products is of utmost importance to demonstrate the added value of CERTO's improved products.

6.3 Complex Indicators: Social-Ecological System Vulnerability Index (SESVI)

6.3.1 Description of indicators to be developed

Type of indicator

In Task 6.4 a highly complex index (SESVI) will be developed for lagoon systems and estuaries. SESVI provides an indication on how vulnerable a water body system is to pressure/change, based on its socioeconomic and environmental characteristics, and as a result, it combines a wide variety of datasets and information about the system. SESVI will be developed as a framework concept and, as such, vulnerability can be defined on a case-by-case basis to suit user needs with SESVI tailored to a specific site, or defined universally with SESVI applied globally (SESVI-global) for comparison across multiple sites. As a snapshot in time, SESVI provides a vulnerability score for individual or multiple water bodies across the world, helping policy managers and decision-makers quickly identify vulnerability hotspots in their region. By incorporating time-series data (depending on data availability), SESVI includes a direction and magnitude of change that further informs the degree of vulnerability. However, the significance of the magnitude of change must be interpreted carefully and in-depth knowledge of the water body system in question is pertinent before policy decisions can be made.

SESVI aims to be holistic, looking at both the social and ecological systems, taking into account the inherent characteristics of the system and the external forces that can affect its ecological functions (and, by extent, its ecosystem services functions). Thus, it reveals the most relevant pressure factors in each water body. Suitable socioeconomic, terrestrial landscape, ecological and geomorphological variables from existing local and global datasets shall be compiled to (i) identify and assess risk of pressure in a system and (ii) assess the system's sensitivity to external pressure and change. First, a scoring system on the risk of pressures in the lagoon catchment area will be developed and adjusted with weights to account for the magnitude of any observed long-term change. Second, different datasets will be used to score lagoon systems based on their inherent sensitivity to external pressure. SESVI is then defined as the combination of the weighted pressure risk and the inherent lagoon sensitivity scores at any point of time.

Region for application

SESVI works on any water body for which the catchment or basin can be delineated and data successfully extracted. It is limited by the amount of information available in each system and the uncertainty level of that information. It can be tailored to specific water body *types*, and further fine-tuned for individual water bodies, depending on the level of complexity (or detail) one is seeking. For CERTO, the framework for developing SESVI-global will be described and applied to the six case studies. Potential fine-tuning in each study site will depend on site-specific data availability.

Satellite data used for the production of the indicator

Task 6.4 will use both satellite data and modelled outputs. The satellite data include, but are not limited to, Copernicus Land Monitoring Service products and NASA Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data. The spatiotemporal resolution of these datasets varies from tens of meters to a few km, and from monthly to yearly to 'static' products (e.g. DEM data).

***In-situ* data needed**

SESVI-global is a high-level product and does not require *in-situ* data as direct input. However, SESVI-global is based on existing EO data products and modelling outputs and, as such, *in-situ* data are considered an inherent part of the validation and calibration process of those products/outputs, the accuracy of which SESVI heavily relies on. Local, site-specific versions of SESVI could benefit from *in-situ* data in those cases where the spatial resolution of global product inputs is too coarse or when additional detail/variables are required. The latter shall be defined during the development phase of Task 6.4 and upon consultation with experts (i.e., CERTO partners: FC-ID, National Institute for Research and Development of Marine Geology and Geoecology - GEOECOMAR, PML and the Italian National Research Council - CNR, and local stakeholders) in the coming months.

Development phase

SESVI is based on previous research conducted under the UK National Environment Research Council (NERC) GloboLakes project (2012-2019) and builds on a similar index developed for lake systems (Politi *et al.*, in prep). A long list of input datasets already exists which will be further enhanced by more recent versions or new datasets. Data compilation and extraction of all time-series and 'static' datasets at catchment or river basin level will follow. Statistics will then help identify the most relevant variables in lagoons and estuaries and shall also be verified by interactions with experts and local stakeholders. Then, SESVI-global will be developed for lagoons and estuaries, tested for robustness and applied to the six case studies

6.3.2 How is this indicator fulfilling the needs identified by users?

At first sight, it may appear that SESVI is not relevant to the user requirements as it is a complex indicator, different to other "lower level" indicators, and its concept had already been conceived at proposal stage. However, it became apparent during the user interviews and was summarised in D2.1 ‘Content and user requirements for the CERTO prototype’, that there is a strong need for indicators that better describe aquatic systems and their potential changes across time, and indicators that are tailored for specific stakeholder groups, e.g. aquaculture. As mentioned above, SESVI is conceived as a framework that can be adapted to different water body sites or types, and the definition of ‘vulnerability’ and its magnitude can be tuned to suit user needs and the overarching research question. For example, there can be a SESVI-eutrophication that compiles different data sources from the water body itself and its catchment to score systems based on their sensitivity to eutrophication (*cf*. Politi *et al*., in prep). In that sense, SESVI is a framework that aims to better describe aquatic systems and the factors that affect their ecological functions. As it uses time-series data, SESVI can also reveal potential changes across time. However, the nature of SESVI suggests it will be implemented as a service by a downstream provider, many of which are SMEs, based on upstream Copernicus products.

6.3.3 How is this indicator contributing to the overall objectives of CERTO?

SESVI is an exemplar of how different Copernicus Services and products can be integrated into the production of a complex indicator suitable for a downstream service. Existing partners in CERTO (e.g. BC) can benefit from this indicator by incorporating it in their existing Water Services portfolio. It also aligns well with other “lower-level” indicators planned for development in CERTO to satisfy user needs and contributes to the suite of CERTO outputs that are tailored to case studies but is also applicable elsewhere in the world.

7 Conclusions

Among the principal goals of the project, CERTO aims to provide improved water quality products that work across the water continuum, from fresh to marine waters, covering important transitional regions. In this effort, CERTO has the goal to **address the reported requirements of interested stakeholders in the six case-study regions** where the project is focused. As such, CERTO has started a continuous engagement with these users, through interviews and exchanges seeking to find out the needs, uses, and possibilities for improvement of transitional water data at these sites, as reported in deliverable D2.1.

Following this, an initial analysis of the reported results has been detailed and evaluated in the effort to meet the requirements. The reported user requirements point to a need for indicators **mainly in the transitional-to-marine water regions**, with some interest in freshwater. Users are mainly concerned with the basic structure and composition of water, looking to **improve existing products in terms of spatial and temporal availability**. The relevant data products identified the most by users were CHL, SPM, TUR and SST. Special consideration has been given to the potential for the development of more **aggregated indicators of water quality** that help users in decision making and reporting to the EU Directives, such as the WFD and MSFD. Users also raised interest in the development of **integrated indicators that incorporate a variety of water properties** (e.g. SPM, TUR) into a single product for water quality. This can involve the production of new indicators altogether, as well as the improvement of commonly used indicators that are already in existence.

Discussions between CERTO and all stakeholders, as well as the Advisory Board, are ongoing and will continue as the project advances. With the aim to fulfil the most pressing gaps in data at the CERTO case-study regions, and in the effort to provide cohesive products that can be used more generally, we will continue discussions with users, as we work with them throughout the project.

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