FORCOAST

Earth Observation Services For Wild Fisheries, Oystergrounds Restoration And Bivalve Mariculture Along European Coasts

PROJECT DELIVERABLE REPORT

Deliverable Number: 5.1

Deliverable Title: Report outlining the use cases, challenges and requirements produced

Author(s): D. Pereiro, T. Dabrowski, L. Barbut, A. Caballero, A. Capet, F. Campuzano, M.Maar, J. Murawski, A. Reid, I. Serban

Work Package Number: 5

Work Package Title: Service Operationalization, Demonstration & Validation

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

FORCOAST Project Information	
Project full title	Earth Observation Services For Wild Fisheries, Oystergrounds Restoration And Bivalve Mariculture Along European Coasts
Project acronym	FORCOAST
Grant agreement number	870465
Project coordinator	Ghada El Serafy, Deltares
Project start date and duration	1st November 2019, 36 months
Project website	https://forcoast.eu/

Deliverable Information	
Work package number	5
Work package title	Service Operationalization, Demonstration & Validation
Deliverable number	5.1
Deliverable title	Report outlining the use cases, challenges and requirements produced
Description	This deliverable outlines the use cases, challenges and requirements produced. It will provide a description of each use case in terms of background information, challenges and requirements and how these are addressed by the platform developed in WP3-4
Lead beneficiary	Marine Institute
Lead Author(s)	D. Pereiro - Marine Institute, Ireland T. Dabrowski - Marine Institute, Ireland
Contributor(s)	L. Barbut - Royal Belgian Institute of Natural Sciences A. Caballero - AZTI A. Capet - University of Liège F. Campuzano - Instituto superior Técnico, Universidade de Lisboa, Portugal M. Maar - Aarhus University, Denmark J. Murawski - Danish Meteorological Institute A. Reid - Cuan Beo I. Serban - TERRASIGNA
Revision number	4

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

Revision Date	14/10/2022
Status (Final (F), Draft (D), Revised Draft (RV))	F
Dissemination level (Public (PU), Restricted to other program participants (PP), Restricted to a group specified by the consortium (RE), Confidential for consortium members only (CO))	PU

Document History			
Revision	**Date**	**Modification**	**Author**
0	18/04/2022	1st draft, including contributions for Service Modules	D. Pereiro, T. Dabrowski SM/Pilot Leaders
1	29/04/2022	Review and formatting	L. Rodriguez
2	03/10/2022	Discussion section added	D. Pereiro, T. Dabrowski
3	11/10/2022	Review	L. Meszaros
4	14/10/2022	Review	Ghada El serafy

Approvals				
	Name	**Organisation**	**Date**	**Signature (initials)**
Coordinator	Ghada El Serafy	Deltares	14/10/2022	GES
WP Leaders	Tomasz Dabrowski	Marine Institute	03/10/2022	TD

Reviewer comments and reply		
Date	**Comment**	**Reply**
Sep 2022	A draft of this deliverable has been made available for review. The current text identifies the service modules and how they were designed to meet the user	A critical discussion of the services being offered versus the initial users'

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

	requirements. **What is now needed is a critical review of the platform/services versus what the user requirements were and details of what the longer-term (including beyond the end of the project) requirements are.**	requirements has been added (Section 4).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

Executive Summary

After the identification of the stakeholders' requirements for each of the economic sectors considered (wild fisheries, bivalve mariculture and oysterground restoration), the objective of this report is to describe how these are addressed by the FORCOAST platform. First, a summary of the background information, challenges and requirements associated to each of the economic sectors considered is presented, linking to the corresponding Service Module that addresses each requirement (Section 2). Next, there is a description of the FORCOAST Service catalogue, what information can be derived from each, and how they effectively address the stakeholders' needs (Section 3). Finally, a critical discussion of the services being offered versus the initial users' requirements is presented (Section 4).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

Table of Contents

1 Introduction 1
2 Background information, challenges and requirements 2
2.1 Wild fisheries... 2
2.2 Bivalve mariculture 2
2.3 Oysterground restoration 3
3 How the FORCOAST services address users' needs 4
3.1 SM-F1 Suitable Fishing Areas 4
3.2 SM-F2 Front Detection 4
3.3 SM-A1 Marine Conditions 5
3.4 SM-A2 Land Pollution 9
3.5 SM-A3 Site Prospecion 10
3.6 SM-A4 Spat Capture Assistance 11
3.7 SM-R1 Contaminant Source Retrieval 12
4 Discussion 14
5 Conclusions 18
6 References 19

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

List of Figures

Figure 1. Example of Suitable Fishing Areas SM already integrated in FORCOAST platform. 4
Figure 2. Example of Front Detection SM already integrated in FORCOAST platform. 5
Figure 3. Notification messages shared through Telegram for the Exporsado production area. 6
Figure 4. Marine Conditions service bulletin shared through Telegram for the Limford production area 9
Figure 5. Detailed bulletin, as provided by the routine execution of the Land Pollution service, with explanation of their components. 10
Figure 6. Example of the habitat suitability index from May to September 2010 in the Limfjord. Higher values mean higher suitability...11
Figure 7. Spat Capture Assistance service bulletin including a map showing the different prediction arrival as well as the following information; a) summarized the parametrization used; b) the maps of the different origin location; and c) a table with the likely date of spat arrival. 12
Figure 8. Example map present in the Contaminan Source Retrieval service bulletin showing the dispersion of contaminants in Galway Bay. 13

List of Tables

Table 1. User requirement for the information service of maritime conditions in the Limfjord (Pilot 6) 7

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

1 Introduction

One of the first and most important tasks within the FORCOAST project has been the identification of the stakeholders’ needs and requirements for each of the economic sectors considered (wild fisheries, bivalve mariculture and oysterground restoration) and at each Pilot site, a task accomplished by WP2 that culminated with the delivery of report *D2.1 - Stakeholders Interests and Needs by Sector and Pilot Site*. Determining the end users’ needs was an essential step before the designing, development and operationalization of the different Service Modules that integrate the FORCOAST central platform and that are expected to fulfil the identified stakeholders’ necessities.

Now, the task of WP5 is to ensure that any shortcomings and issues are identified and addressed in the pre-operational platform and to continuously gather feedback during the operational phase for this purpose. The objective of this report is to describe how the platform satisfactorily fulfils the end users’ requirements. Along this process, any flaws are identified.

The document is structured as follows. First, Section 2 provides a summary of the background information, challenges and requirements associated to each of the economic sectors considered, as described in D2.1, but here linking to the corresponding Service Module that addresses each requirement. Next, Section 3 provides a description of the Service Modules that can be accessed through the platform, what information can be derived from each, and how they effectively address the stakeholders’ needs identified at the beginning of the project. Finally, Section 4 provides a critical review of those end users’ needs including those that have not been addressed during the lifetime of the project.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 870465.

2 Background information, challenges and requirements

This section presents the sectorial user requirements as described in D2.1. To avoid repetition, only a summary of the findings in D2.1 is presented. Here, the emphasis is on how the Service Modules address the stakeholders' needs.

2.1 Wild fisheries

The needs of the wild fisheries sector are:

a. To determine the distribution of suitable habitat for small pelagic fisheries. FORCOAST has developed two services that aim to fulfil this requirement as this is the identified main requirement: **SM-F1 Suitable Fishing Areas** and **SM-F2 Front Detection**. A detailed description of how these services will help in the identification of productive fishing grounds is provided in Sections 3.1 and 3.2, respectively.

b. Also, to be informed about the ocean conditions for planning operational activities. FORCOAST is providing **SM-A1 Marine Conditions** to address this need. The characteristics of this new service can be consulted in Section 3.3 below.

2.2 Bivalve mariculture

The needs of the bivalve mariculture sector are:

a. Similarly as in the wild fisheries sector, to be provided with short time scale meteorological information for operational planning. In particular, accurate and high-resolution metocean conditions of sea level, temperature, ocean circulation, winds and solar radiation are needed, being sea level the priority. Again, this is achieved in FORCOAST through the **SM-A1 Marine conditions** (Section 3.3).

b. Development of an alert system to help planning of mitigation and recovery actions in case of harmful events. Different types of harmful events for the aquaculture sector have been identified, including storms, exceedance of critical biogeochemical thresholds (e.g. hypoxia or eutrophication) or water pollution (e.g. oil spills or fecal contamination). Information and forecasts of such harmful events are provided in FORCOAST through **SM-A1 Marine Conditions** (Section 3.3), **SM-A2 Land Pollution** (Section 3.4) and **SM-R1 Contaminant Source Retrieval** (Section 3.7). In addition, the platform provides a viewer of the oceanic conditions at the different pilot sites, derived from both remote sensing and coastal hydrodynamic and biogeochemical models, with varying data availability across pilots.

c. Development of an operational plan at mid-term temporal scales, based on the long-term (i.e. climatological) conditions relevant for the healthy growth and reproduction of the aquaculture livestock, including temperature, salinity, food availability, chlorophyll concentration, hypoxia, and nutrients concentration. This climatology information can be used to determine habitat suitability through habitat modelling or through Dynamic Energy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

Budget (DEB) models. This specific requirement is fulfilled in FORCOAST through **SM-A3 Site Prospection** (Section 3.5).

d. Forecasting of the arrival of the oyster spat, maximizing spat collection and reducing production costs associated to the purchasing of oyster seeds and inefficient capture rate. This is achieved in FORCOAST through **SM-A4 Spat Capture Assistance** (Section 3.6).

2.3 Oysterground restoration

The needs of the oysterground restoration sector are:

a. To assess the disease status of native oyster by tracing virus and bacteria. This is achieved in FORCOAST through **SM-R1 Retrieve Sources of Contamination** (Section 3.7) to investigate the origin of pollution whenever fecal or other types of contamination is detected in the farms.

b. To provide environmental data and short-term forecasts for parameters that may affect oyster mortality and growth. This is achieved through a regional hydrodynamic model predicting the temperature and salinity and delivering 3-day forecasts. The data viewer in the FORCOAST platform makes these forecasts accessible to the end users as long as this forecast data is available.

c. To determine the distribution of suitable habitat for native oysters through habitat modelling using synoptic maps of salinity, temperature, chlorophyll a (chl-a) concentration and hypoxia. FORCOAST **SM-A3 Site Prospection** (Section 3.5) provides an assessment of habitat suitability based on long-term conditions of these ocean parameters.

d. Finally, other rekated requirements highlighted in deliverable D2.1 for the oysterground restoration sector include the prediction of oyster spat arrival timing. **SM-A4 SM-A4 Spat Capture Assistance** (Section 3.6) can be used.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

3 How the FORCOAST services address users' needs

3.1 SM-F1 Suitable Fishing Areas

The presence of areas with high concentrations of fish resources in Bulgarian and Romanian coastal waters (Pilot where the SM has been initially developed) is highly influenced by seasonal variations. In addition, spatial distribution of zones with high fish resources could represent an issue – large distances between fishing areas and collecting centers. Initial requirements to be addressed by the FORCOAST SM-F1 Suitable Fishing Areas service are to facilitate user`s access to tailored geospatial information that can assist them to identify the most susceptible areas for finding fish stocks. The aim of the Fishing Suitability Index developed within this service module is to address these specific stakeholder needs by offering information regarding the localization of optimal conditions for fishing activities in the area of interest. The index has values ranging from 0.1 (less suitable) and 1.0 (best condition).

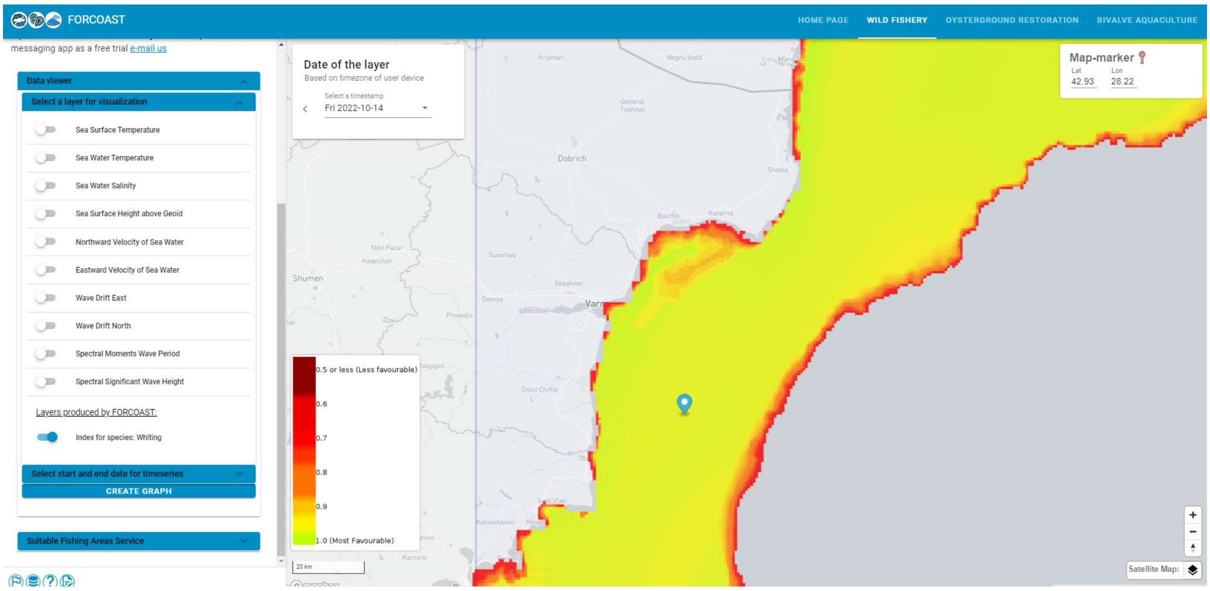


Figure 1. Example of Suitable Fishing Areas SM already integrated in FORCOAST platform.

3.2 SM-F2 Front Detection

The aim of SM-F2 Front Detection is to provide information about the location and extension of the main temperature fronts and chlorophyll-a fronts within the sea surface.

Frontal areas are those where there is a sharp gradient in certain properties of seawater, such as temperature or chlorophyll-a concentration. These areas are characterized by a higher-than-normal biological activity, and therefore can be used as an indicator of the presence of certain commercial fish species, helping the user identify potential fishing grounds.

Sea fronts can be identified using both remote sensing and model imagery. As the fishing sector needs easy to understand and highly processed data to make fast decisions in combination with the user knowledge and experience. This service module has been designed with both qualities in mind, which allows identifying the areas of interest at a glance, with the subsequent reduction in the time spent at sea and fueling usage.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

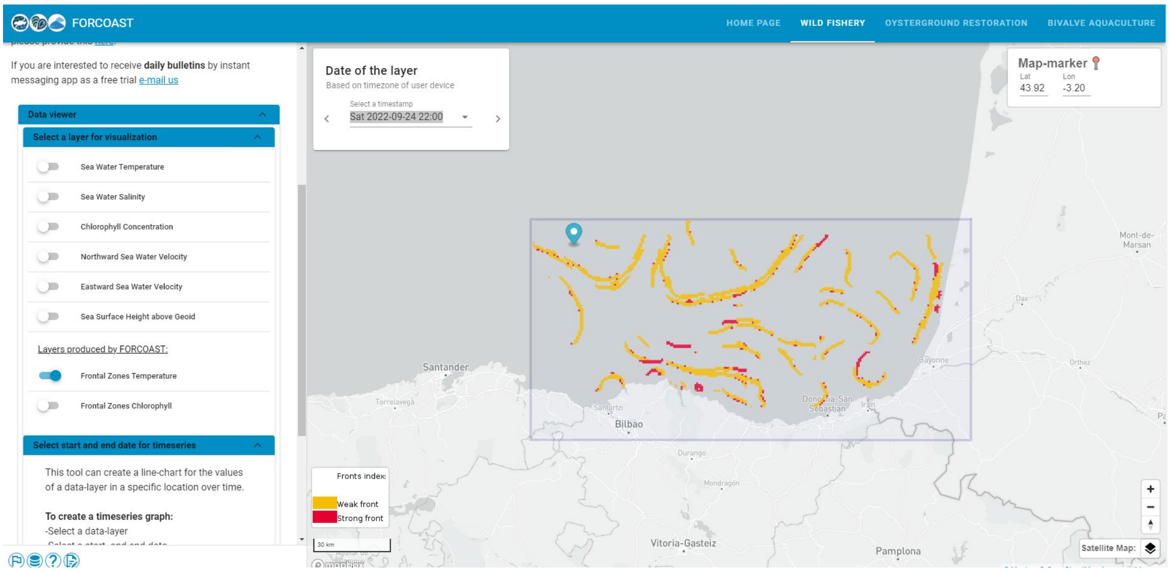


Figure 2. Example of Front Detection SM already integrated in FORCOAST platform.

The user can select different layers for visualization: Chlorophyll, Sea Surface Temperature (both used as input of the processing of their respective sea fronts), or Frontal Zones Temperature (product of the service).

3.3 SM-A1 Marine Conditions

The proliferation of means to extract and utilise environmental data (observed and modelled) enables their potential use to optimise their use in the target users daily outdoor activities. In other words, many ocean-related businesses can further improve their efficiency, reduce costs, and maximise profits should they start using data science tools. At the same time, the users' contribution to the development of data interface/delivery systems is paramount to tailor data services to their specific needs.

During the FORCOAST project, a novel service, named Ytide when used independently of the platform (see deliverable D4.1/4.3/4.3 for the federated FORCOAST ecosystem), aims to provide easy access to tailored information for the aquaculture sector through existing mobile messaging applications. It has been co-designed by IST and the Exporsado project partners and with the support of +ATLANTIC CoLAB to meet the requirements of professional bivalve producers in intertidal areas and to reduce their operational environmental constraints, considering that:

- Producers need to reach the production areas in time, following local tides,
- Bivalve producers can only work during low tide conditions,
- Production sites are frequently located distant from tidal gauges,
- Local meteorology, hydrology and hydrography influencing water levels are commonly disregarded,
- location-specific information is needed with a few days in advance for planning.

The current version of Ytide provides access to various environmental parameters that are key for the oyster production activity: daylight period, high and low tide heights and times, and optimum operation time window. Other environmental limiting factors, such as wind and rain, are also included (Figure 3).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

The main innovation of the Ytide service is that the information is formatted and distributed automatically through existing messaging smartphone apps, Telegram in this case. The main advantages include:

● Ease of access: faster and easier to access a smartphone app than a website to consult information on the go,

● Interaction with coworkers: sharing information and interacting is quick and easy, and

● Productivity: enables better performance, time optimisation and more efficient work

To configure a new service, provided that the necessary data input is available for their area of interest, the end-user must provide geographic coordinates of the aquaculture production areas, optimal water height for their activities, thresholds of environmental limiting factors and a list of contacts that will receive the information. After that, the end-users simply need to install the Telegram application to start receiving the information.

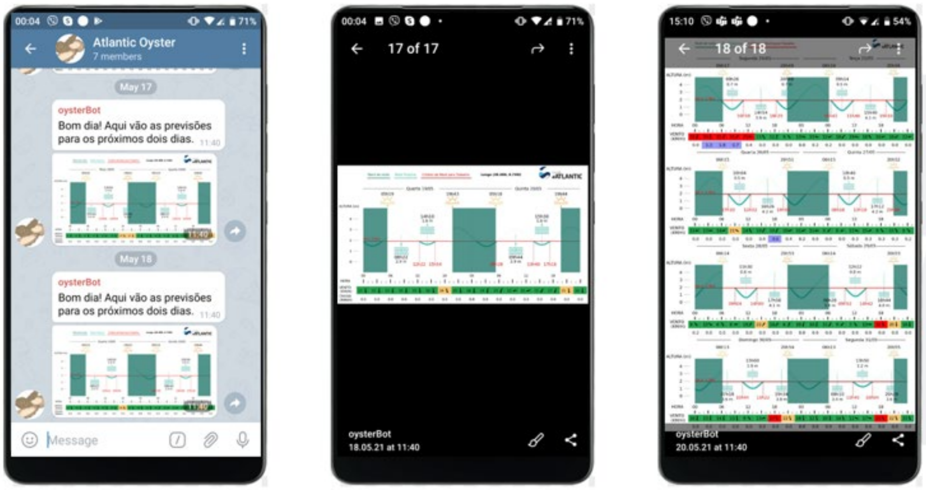


Figure 3. Notification messages shared through Telegram for the Exporsado production area.

Based on the identified needs of local oyster producers, the Sado estuary aquaculture community is being used as a pilot application for this Service Module. The service is being executed automatically in two formats:

● Daily service: information for the two following days with the best operational forecast, and
● Weekly service: every Thursday, with information on the conditions for the next week.

In addition to the Sado estuary, SM-A1 is also applied to the Limfjord area, where operational ocean data services for the assessment of maritime conditions are needed for planning of farming activities 6 days ahead, and the operating of a warning service for critical conditions will help to devise mitigation actions. The forecasting service focuses on physical ocean parameters: currents, winds, temperatures and sea ice information, which are provided by the operational Limfjord model (HBM) and DMI's operational weather model (HARMONIE). Users find the information useful for (1.) the assessment of growth conditions at the aquafarming sites, for (2.) the identification of critical conditions, i.e., too high ocean temperatures, that could affect oxygen conditions and (3.) for the identifying critical sea level, icing, currents and wind conditions that could threaten the installations. Biogeochemical information is currently not provided by the operational Limfjord model that is used

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

for generating maritime conditions (Table 1, 5-11). Information about bacteria (E. coli) and parasites (Marteilia and Bonamia) are not commonly provided by ecosystem components of ocean models.

The identification of user needs is based on an investigation carried out by the SMA Oyster Boat, a FORCOAST partner in the Limfjord oyster restoration pilot (Pilot 6), the top five primary producers and wholesale dealers in Denmark. The following forecast parameters of marine conditions have been identified (Table 1).

Table 1. User requirement for the information service of maritime conditions in the Limfjord (Pilot 6)

	Forecast Parameter	Type	Data Structure	Service
1	Water temperature profiles	Physical ocean condition	Vertical Profile	Provided
2	Advance icing information	Physical ocean condition	Surface	Provided
3	Sea level and storm surge warning	Physical ocean condition	Surface	Provided
4	Currents	Physical ocean conditions	Surface	Provided
5	Oxygen profiles	Biogeochemical ocean conditions	Vertical Profile	Not provided
6	Hypoxia, release of Hydrogen Sulfide (H2S)	Biogeochemical ocean conditions	Vertical Profile	Not Provided
7	Algae, shellfish nutrition	Biogeochemical ocean conditions	Oyster farm depth	Not Provided
8	Venomous algae leading to shell closure and non-feeding	Biogeochemical ocean conditions	Oyster farm depth	Not Provided
9	*E. coli* bacteria in the water	Biogeochemical ocean conditions	Oyster farm depth	Not Provided
10	*Marteilia* and *Bonamia*, parasites	Biogeochemical ocean conditions	Oyster farm depth	Not Provided

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

11	Spatfall of blue mussels and oysters	Biogeochemical ocean conditions	Oyster farm depth	Not Provided

The user requirements have been addressed by improving the model configuration for better sea level and storm surge forecasts, by upgrading the HBM radiation scheme of the thermodynamic module in shallow waters and by providing sea ice information for the Limfjord, which was not part of the product portfolio at the beginning of the project. A complete description of the upgraded Limfjord model is available in Murawski *et al.* (2021).

The model performance concerning sea level and currents was improved by tuning of the model bathymetry and configuration, especially in the narrow straits. Long-term and scenario studies have been carried out to assess the model performance in reproducing average conditions and extreme conditions during storms.

The quality of the water temperature forecast at aquafarming sites was improved by implementing a shallow water radiation scheme, to reduce the cool temperature bias in very shallow water. The updated model includes the effect of solar radiation being reflected by the seabed, which turned out to be essential for accurate temperature forecasts in shallow waters. Earlier model versions neglected this fraction of the solar energy, which is now used to heat the ocean. The upgrade has reduced the cool bias of the model and increased the diurnal variability of the temperature forecast, which used to be too low.

Sea ice forecasts are provided by the HBM ice module, an integral component of the Limfjord forecasting model. There have not been resources for ice-model development in the project. However, the sea ice module is likely to benefit from the upgrade of the thermodynamic model. HBM ice-thermodynamic module is treating the formation, advance and retreat of ice, the drift of ice and the formation and degradation of coastal fast ice. It has been tuned for the Baltic Sea, which is seasonally ice covered in the north.

The SM-A1 Marine Conditions service is currently being produced, customized and tested for the Limfjord area. Some examples are can be seen in Figure 4. The implementation of the other explained parameters in the area, in a similar manner as water level, is subject to the viability and demand of such information service as products of this service.

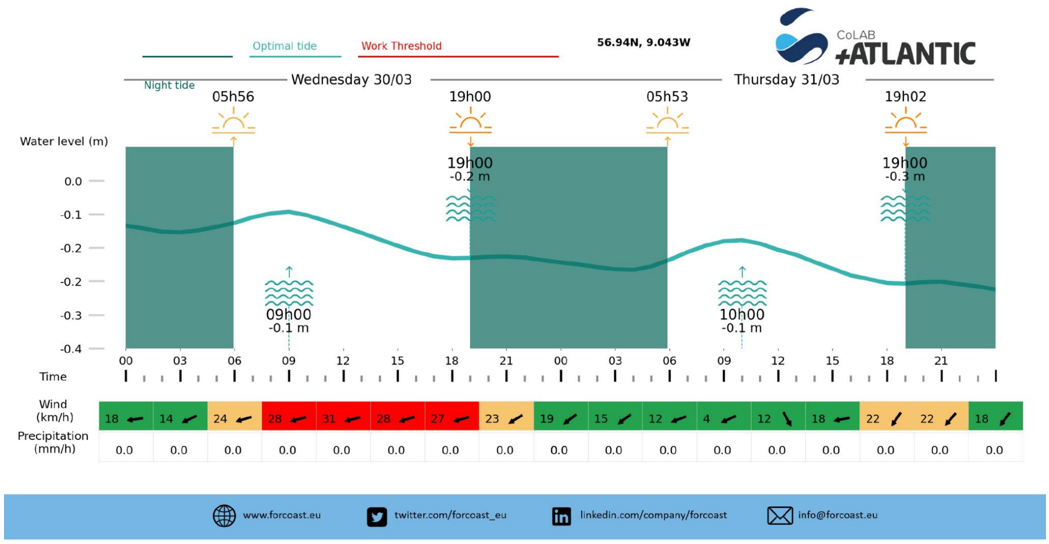


Figure 4. Marine Conditions service bulletin shared through Telegram for the Limford production area

3.4 SM-A2 Land Pollution

Nearshore farming infrastructures are exposed to land discharges, which in some cases carry harmful substances (e.g. E. coli, pollutants). High-resolution circulation forecasts can be used to assess the likelihood of a farm being affected by material released from potentially harmful sources. This service aims to support quality control, by providing a measure of the probability for farming sites to be affected by harmful land discharge.

User-specific parameters consist of farming site locations, and potential release sources:

Farming sites are defined as polygons of geolocated points. These are defined upon subscription to the service. Users may choose to enter different areas or to characterize a large domain including all operated farms.

Sources of release are currently defined as the location of a potentially harmful source(s). If no further characterization can be provided, a constant discharge rate of passive material is considered (see Methods given in D3.10).

Thresholds are considered to raise alarms and defined in terms of: time elapsed since release, fraction of the release. Those are set upon subscription, and summarized as a "risk scale", attributing factors of risk to different classes of travel time from source to farming areas. .

The **feedback to users** is updated daily, and consists of bulletins with the information specific to the service, as exemplified in Figure 5 below.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

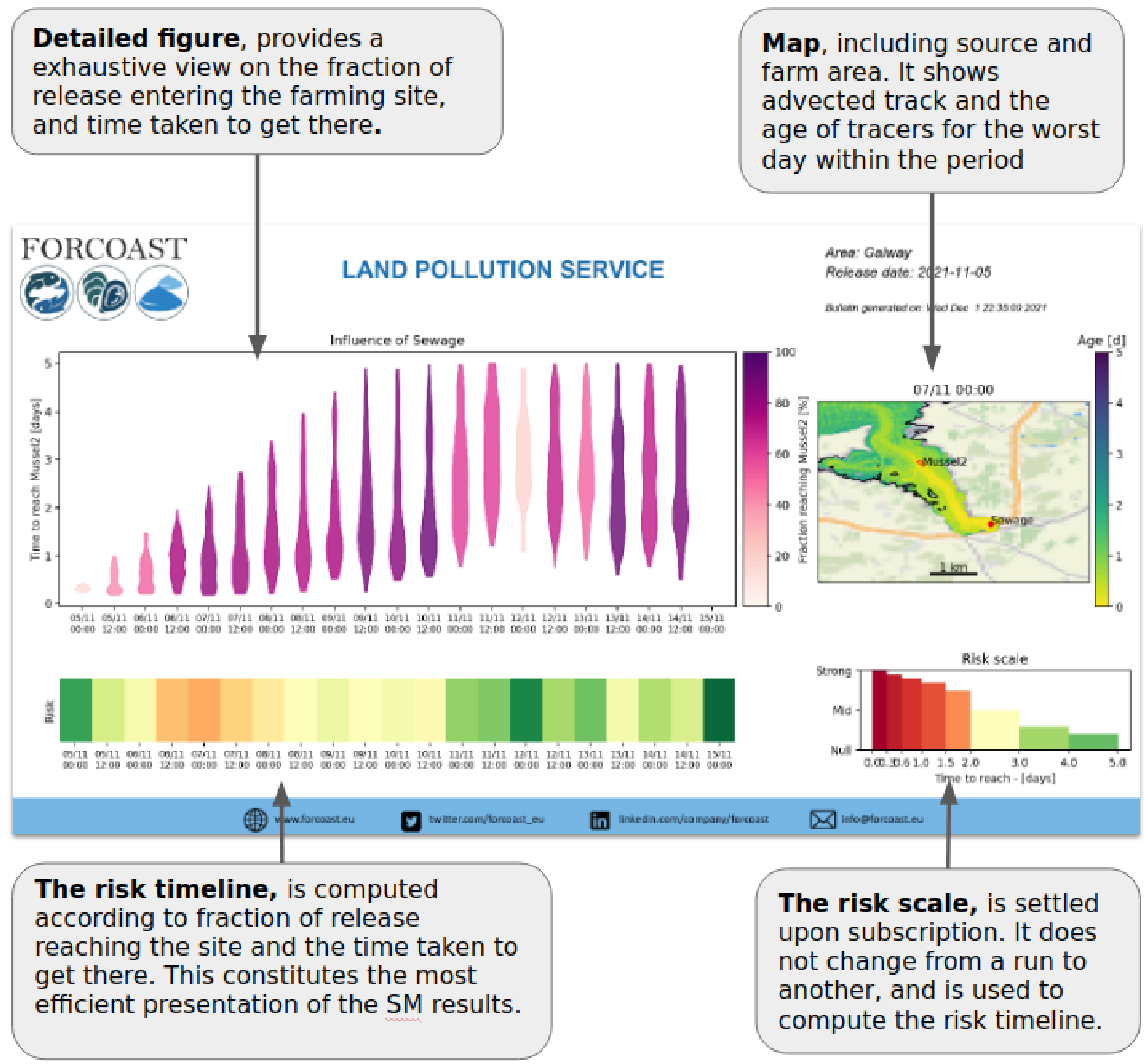


Figure 5. Detailed bulletin, as provided by the routine execution of the Land Pollution service, with explanation of their components.

3.5 SM-A3 Site Prospecion

The purpose of the service module is to identify areas with highest growth potential and lowest mortality for flat oysters, Ostrea edulis, and thereby increase harvest and restoration potential. The oyster farmers tend to face challenges with high spat mortality and variable growth depending on environmental conditions. The module can be extended to include other commercial benthic species when viable and with prospect demand, e.g. blue mussels, by altering the algorithm that weights the different values arriving to the final suitability map.

The service module contains maps of monthly means and variability (Standard deviations) of selected environmental variables. The considered variables are temperature, salinity, Chl-a, hypoxia, and resuspension of particulate organic matter (POM) causing risk of burial. These variables were identified by end-users as the most important factors for oyster growth and survival. The environmental variables are obtained mostly from ecological model data, but some (e.g. temperature, POM, Chl-a) can also be provided by remote sensing data. The data is used to create a spatial habitat suitability index (HSI) of flat oysters showing the most optimal locations for bottom aquaculture and restoration. The HSI is informed by user-specific provided knowledge of the considered species (e.g.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

salinity tolerance), DEB modeling, and the literature. The obtained HSI is based on the integration of the scoring indices (0 to 1) for each environmental variable for the chosen period by the user (Figure 6). A value of 1 is the best suitable location and value of 0 means not suited.

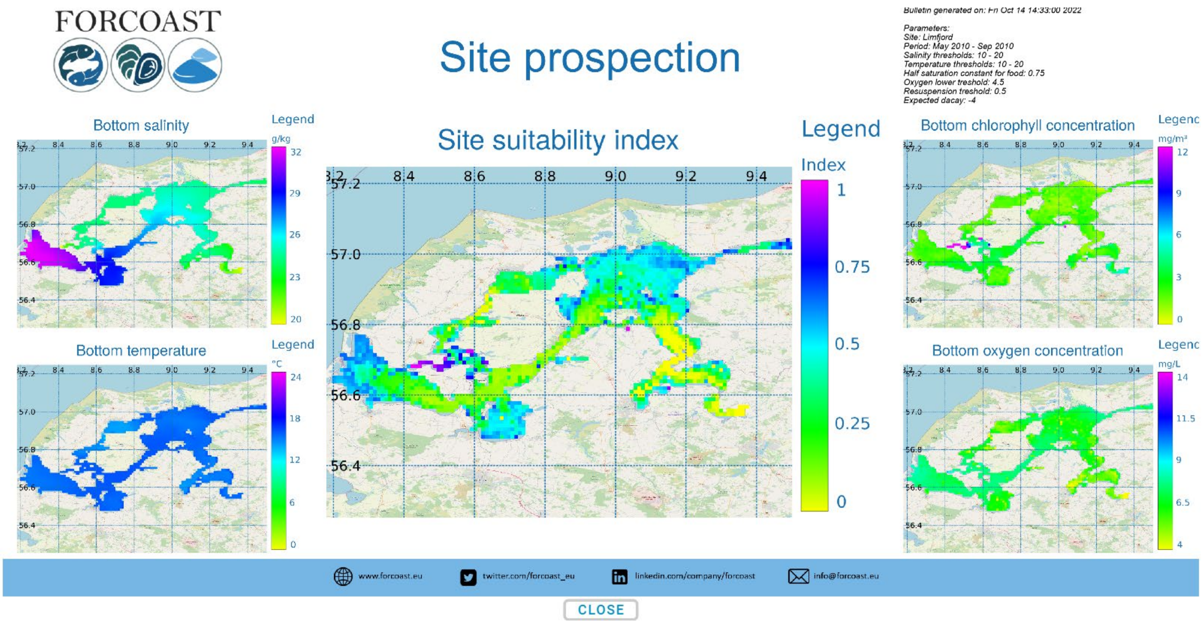


Figure 6. Example of the habitat suitability index from May to September 2010 in the Limfjord. Higher values mean higher suitability.

3.6 SM-A4 Spat Capture Assistance

The capture of spat requires the installation of collectors. Those collectors have to be installed before the arrival of organisms; it is then useful to have a prediction of the arrival date. It is necessary to put the spat collectors in the water not too early to avoid heavy biofouling, with subsequent low settlement of spat.

For many organisms, spawning events are related to environmental conditions (such as temperature, chlorophyll concentration, waves, etc.) and an efficient tool should be able to predict spawning events and to estimate the most likely arrival date of organisms.

The aim of the SM-A4 Spat Capture Assistance is to determine the period where spats of specific species are likely to arrive in the collecting location(s). That implies to have information on potential areas where spat could arrive from, on cue(s) conditioning the release of larvae as well as an estimation of the time lag between the larvae release and the arrival of spat in the farm. This information is given by local expertise or based on scientific literature by the interested user.

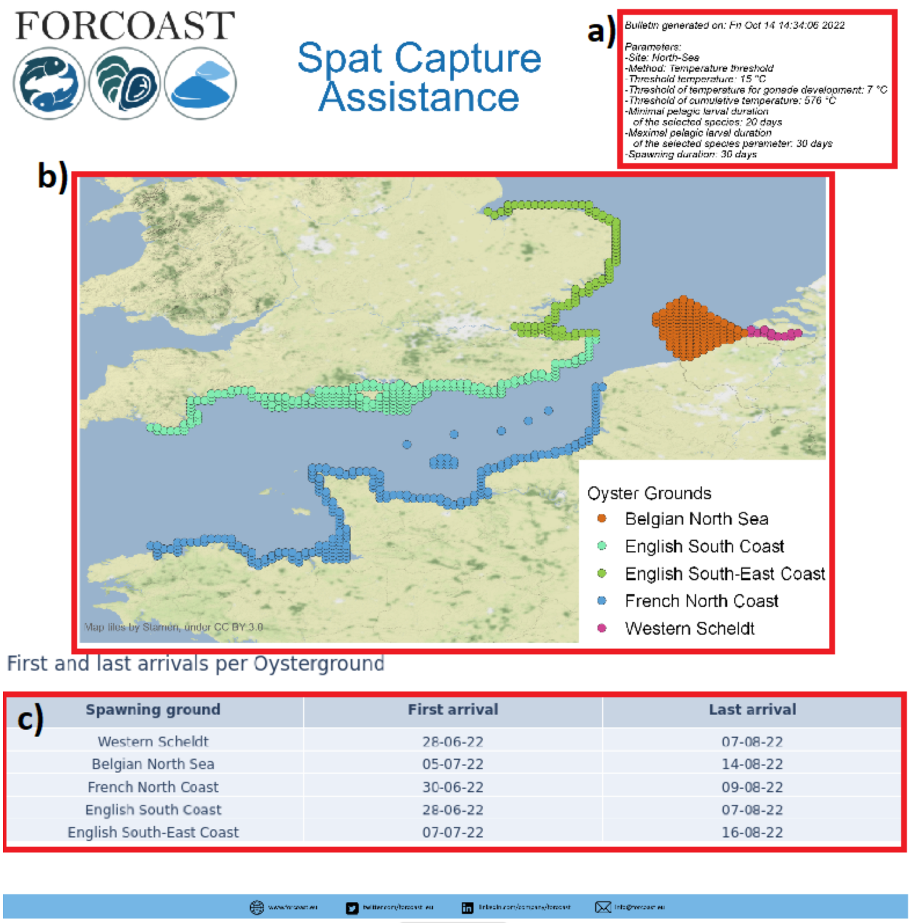
The user can select any origin location on the map within the boundaries defined by each pilot and define species of interest by setting the parameters (cue of spawning and duration of pelagic larval duration). In absence of site-specific information, default species-specific values based on literature are selected. After the request has been processed, the user is provided with a table showing the likely arrival period of spat from a selected origin location.

Improvement of prediction needs a local parameterization to optimize the service. Lagrangian simulations can be used to assess the likely origin of spat. The most challenging aspect to improve the service is data collection (which is taking place again after the pandemic situation in the Belgian Pilot)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

to assess model performance and improve the parameterizations used. Spat arrivals have to be counted on a regular basis on a long period to assess service module performance.

This service has been applied in the Belgian waters to determine spat arrival of oyster and mussels. In parallel with the module, spat are collected weekly to establish performance of prediction. In the case of the Belgian pilot, parameterization based on temperature threshold was chosen, with a temperature threshold of 9°C for mussels and 15°C for oysters for spawning events. Results of the Spat Capture Assistance service are presented in Figure 7 below. Currently, only 1 year of data is available to assess the quality of the predictions. An additional year (2022) will be used to assess model performance and improve the parameterizations if required.



Spawning ground	First arrival	Last arrival
Western Scheldt	28-06-22	07-08-22
Belgian North Sea	05-07-22	14-08-22
French North Coast	30-06-22	09-08-22
English South Coast	28-06-22	07-08-22
English South-East Coast	07-07-22	16-08-22

Figure 7. Spat Capture Assistance service bulletin including a map showing the different prediction arrival as well as the following information; a) summarized the parametrization used; b) the maps of the different origin location; and c) a table with the likely date of spat arrival.

3.7 SM-R1 Contaminant Source Retrieval

Fecal contamination causes massive economic loss in the aquaculture and oysterground restoration sectors. This service module addresses the need to assess the disease status of native oyster by tracing virus and bacteria. The objective of this service module is to track seawater contaminants, assumed to behave as perfect passive tracers. The particle-tracking model used is OpenDrift (Dagestad et al., 2018). Both forward and backward particle tracking are available to the end user. Backward tracking allows the user to investigate the origin of the contamination affecting their farm, whereas forward tracking can be used when the source of contamination is known. The focus is given in the backwards tracking part due to the user identified needs of identifying sources of contaminants, causing diseases.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

The user can select any location on the map within the boundaries defined by each pilot. After the request has been processed, the user is provided with maps showing: (a) the location of the contaminants (see e.g. Figure 8 below), (b) probability density maps based on the concentration of contaminants, (c) an estimation of the local exposure time (Du et al., 2020), which measures the residence time of contaminants within an area.

This Service Module has been applied to the Galway Bay and is under testing in the Belgian Pilot area. In the Irish Pilot area, being the one with the highest focus on oysterground restoration, the native oyster population has suffered substantial decline owing to a number of factors including fishery management, disease introduction and significant environmental pressures owing to increased land use and land drainage management. The increased land use and land drainage has placed substantial pollution pressures on fresh water inputs into Galway Bay, which has resulted in significant environmental challenges for native oyster populations. These environmental challenges include, among others, substantial drops in salinity and temperature owing to large fresh water discharges and marine water pollution originating from land based pollutants. The backtracking feature allows the user to select an area of the bay and determine the likely point of origin for particles accumulating in this area.

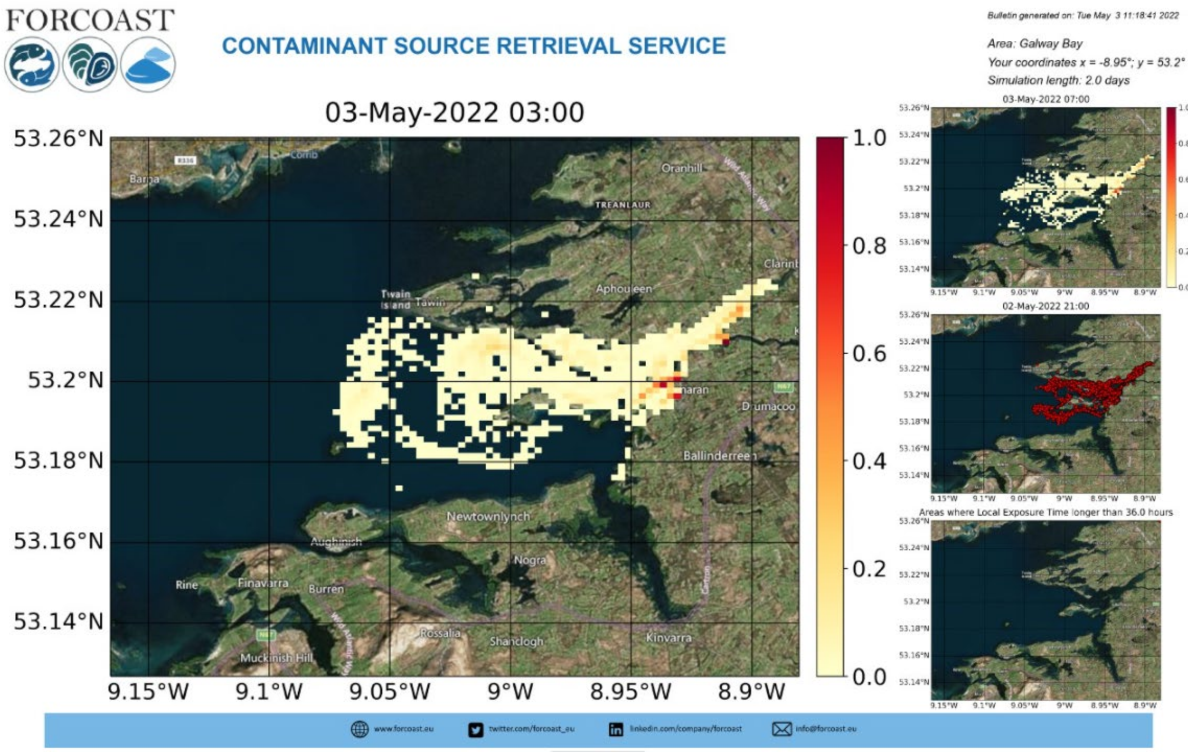


Figure 8. Example map present in the Contaminan Source Retrieval service bulletin showing the dispersion of contaminants in Galway Bay.

4 Discussion

Section 2 above has linked the identified sectorial requirements (WP2) to the FORCOAST services that address end users' needs. However, there are still some (longer-term) requirements (or wish-list) that have not been implemented yet. The following is a critical discussion of the services being offered versus the initial users' requirements that has been added and whatcan possibly be undertaken after the project lifetime. The latterdo not hamper the market uptake of those services according to the users' opinion.

1. **Wild fisheries.** First, an important requirement was *to determine the distribution of suitable* habitat for small pelagic fisheries. It was stated that "in the framework of FORCOAST, to integrate this high priority information as proxys for the fishing suitability in the area of interest will be a priority, by means of a single platform, easy to use and hourly or daily updated with three days forecast." With the design (WP3) and implementation (WP4) of the two fisheries-related Service Modules (**SM-F1 Fish Suitability** and **SM-F2 Front Detection**) these requirements are covered in FORCOAST: the former service providing a fishing suitability index based on environmental conditions, while the latter forecasting the locations of oceanic fronts, where it is known that food abundance is higher and fish populations tend to aggregate.

   Second, to *inform about the ocean conditions*. This is covered with **SM-A1 Marine Conditions**, which is complemented with the data viewer providing environmental conditions from the different coastal models.

   In conclusion, <u>no gaps can be identified with regards to the general sectorial requirements</u>. When looking at the specific users' requirements per pilot, the following can be observed:

   PILOT 2.
   (a) *Provide multi-year hindcast (forecast) products of T, S, currents, mixing*. The current EusKOOS system provides not multi-year hindcast but 96-hour forecasts. For the purpose of predicting the location of fronts and deliver this information to the local fisheries sector, forecasts are of much greater importance tha hindcasts. Therefore, archiving of a multi-year hindcast can be seen as non-priority task in this regard, with 96-hour forecasts being the most relevant information for the stakeholders. The EusKOOS system provides conditions on temperature, salinity and currents, while mixing can be easily derived from the vertical structure of the water column (temperature and salinity).
   (b) *Introduce river flows in the regional models*. Indeed, "*the ROMS simulation includes the last daily averaged freshwater discharges (real-time data) from the following rivers: Adour, Barbadun, Nervion, Butron, Oka, Lea, Artibai, Deba, Urola, Oria, Urumea, Oiartzun and Bidasoa"* (D3.8).
   (c) *Develop indicators of mesoscale processes and location of fronts*. This is achieved with **SM-F2 Front Detection.**

   PILOT 3.
   (a) *Downscaling of the existing CMEMS BS-MFC-WAV products to 1 km resolution*. This has been achieved with the implementation of a Western Black Sea downscaled high-resolution (1 km) model (see D3.8, D5.4).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

(b) *Providing additional downscaled parameters related to the extreme statistics and coastal upwelling.* Information of significant wave height is provided by the Black Sea wave model, which is important to define proper marine conditions for sea-going activities for the fisheries sector. The **SM-F1 Suitable Fishing Areas** identifies the favourable conditions for fishing by showing information on areas with rapid decrease in SST, among other indicators (D3.10). A rapid decrease in SST is related to coastal upwelling.

2. **Bivalve mariculture.** The connection between the general sectorial requirements described in D2.1 and the services developed under FORCOAST have been highlighted in Section 2 of this document. Here, the specific users' requirements per pilot in D2.1 are discussed:

PILOT 1.

(a) *Continuous in-situ observations collected during the lifetime of the project to evaluate the quality of modelling results, including water levels, and remotely observed products.* Continuous *in-situ* observations have been collected thanks to the installation of a monitoring platform. The evaluation of model results, with particular focus on the sea level, has been presented in D5.4 (see e.g. Figures 1.7 to 1.9).

(b) *Forecasts of meteorological, oceanographic and watershed models to generate fit-for-purpose products and services. These products and services will aid in activity planning and increase the understanding of the impact of environmental conditions on oyster growth.* This has been achieved through the development of a set of nested hydrodynamic coastal models, namely the Portuguese Coast Operational Modelling System (PCOMS), the Lisbon Metropolitan Area Operational Model (LisOcean) and Longa Aquaculture Production Area.

(c) *Dynamic Energy Budget (DEB) models will be adapted to the Portuguese oyster and will allow monitoring the performance of this species to environmental changes*. This has been achieved through **SM-A3 Site Prospection**.

(d) *Explain and forecast the green colour observed in the oyster flesh of the Sado estuary.* There is not any FORCOAST service that address this specific problem. In D2.1 it is stated that the green colouration of oyster flesh is harmless for the consumer so, even though the price of the final product can drop up to 70%, this issue has been regarded as a non-priority in FORCOAST. Oyster greening may occur due to the ingestion of *Haslea ostrearia*, a diatom that produces a soluble blue pigment that is fixed in the oyster gills (Gastineau et al., 2012).

(e) *Remote sensing products and numerical modelling results will be compared with continuous in-situ observations and will provide high temporal and spatial information that can aid in decision making to environmental conditions.* This has been presented in D5.4.

PILOT 4.

(a) *Upgrade the river discharge forcing used by its forecast model OPTOS*. (b) *Using MIRO&CO results for estimating primary production and nutrients cycle.* (c) *Further developing the LARVAE&CO model to suit aquaculture needs.* (d) *To develop services to forecast the optimal timing, water quality, risk of a site to be affected by river plumes, etc*.

Most of these requirements refer to model development and implementation, which is described in D3.8. There are no specific FORCOAST services aimed at forecasting water quality and freshwater plume propagation, but tracking of contaminants is possible with **SM-A2 Land Pollution** and the risk of an area of being affected by river plumes can be assessed simply by examining the spatial distribution of long-term average salinity.

PILOT 6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

(a) *Provide multi-year hind-cast products of T, S, currents, mixing from HBM.* (b) *Provide multi-year run for ecological variables from FlexSem-ERGOM.* (c) *Make pre-operational forecasting for physical parameters using HBM*. These three former requirements have been addressed with the implementation and validation of the FlexSem-ERGOM model.
(d) *Design model products and indicators for site selection to oyster farmers.* (e) *Indicators could be temperature, salinity, turbidity, food flux, chl a, oxygen, …* (f) *Identify and map optimal locations for restoration and culturing.* These three latter requirements have been addressed with the development of **SM-A3 Site Prospection**.

PILOT 7.
(a*) A downscaling of the existing CMEMS BS-MFC-BIO forecast to 1 km resolution (northwestern and eventually western Bulgarian shelves).* (b*) Spatial distribution of Danube tributaries and their share in water flow and nutrient loads.* These have been addressed with the development of the numerical models described in D3.8.
(c) *Tailored information products combining model and earth observation*. This latter requirement is too general and FORCOAST has clearly contributed towards this goal with the development of models and services, not just in the Black Sea but in different coastal areas in European waters.

PILOT 8.
(a*) provide statistical analysis and monitoring tool from ocean colour full resolution satellite products (e.g., chlorophyll-a, total suspended matter).* (b) *integrating operational modelling and remote sensing data to develop maps of suitability conditions.* (c) *develop alerting system for hazardous conditions including heat waves and oxygen depleted conditions (i.e., eutrophication).*
In general, these requirements have not been addressed under FORCOAST. There are no services providing alerts for heat waves, oxygen depletion or eutrophication. Remote-sensing products (SST and Chl-*a*) already available can be used for these purposes.

3. **Oysterground restoration** —and **PILOT 5**, since this is the only area where this sector has been considered—. First requirement was *to assess the disease status of native oyster by tracing virus and bacteria from known point insources* […] and *to identify inputs that are detrimental to mariculture*. In this regards, **SM-R1 Contaminant Source Retrieval** provides a useful tool for backtracking sources of contamination using knowledge of water circulation in the bay.

   Second, *to provide environmental data and short-term forecasts for parameters that may affect production.* The hydrodynamic model in Galway Bay provides 3-day temperature and salinity forecasts that can be inspected in the platform. Both temperature and salinity affect feeding and mortality rates in the European flat oyster.

   Third, *to provide data on status (distribution and biomass) of native oyster stocks*. Samplings aiming at assessing the abundance and distribution of *O.* edulis are carried out regularly in Galway Bay.

   Fourth, *to determine the distribution of suitable habitat for native oyster*. This has not been achieved during the project lifetime. Nevertheless, by applying **SM-A3 Site Prospection** to Galway Bay, this objective can be achieved after the end of the project. Long-term (2012-2021) hindcasts of temperature and salinity in the bay have been produced during the project lifetime. Temperature and salinity long-term conditions, together with remote-sensing turbidity and chlorophyll-*a* concentration (as a a proxy for food abundance) can be used to determine a Habitat Suitable Index for oyster growth in the bay.

5 Conclusions

In this report, it has been explained how the services developed within FORCOAST (Section 3) have been designed in order to cover the user needs in the project three target sectors (Section 2), enabling the use of the needed services within the FORCOAST catalog depending on the information gaps each user experiences. A critical discussion of the services being offered versus the initial users' requirements has been presented (Section 4).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

6 References

Dagestad K-F, Röhrs J, Breivik Ø, Ådlandsvik B, 2018. OpenDrift v1.0: a generic framework for trajectory modelling Geosci. Model Dev. 11 1405–20 https://doi.org/10.5194/gmd-11-1405-2018

Du J, Park K, Yu X, Zhang Y.J, Ye F, 2020. Massive pollutants released to Galveston Bay during Hurricane Harvey: Understanding their retention and pathway using Lagrangian numerical simulations. Sci. Total. Environ. 704, 135364. https://doi.org/10.1016/j.scitotenv.2019.135364

Gastineau, R., Hardivillier, Y., Leignel, V., Tekaya, N., Morançais, M., Fleurence, J., Davidovich, N., Jacquette, B., Gaudin, P., Hellio, C., Bourgougnon, N., Mouget, J.-L. (2012). Greening effect on oysters and biological activities of the blue pigments produced by the diatom Haslae karadagensis (Naviculaceae). Aquaculture, vol. 368-369, 61-67. https://doi.org/10.1016/j.aquaculture.2012.09.016

Murawski, J., She, J., Mohn, C., Frishfelds, V., Nielsen, J. W, 2021. Ocean Circulation Model Applications for the Estuary-Coastal-Open Sea Continuum, Frontiers in Marine Science, vol. 8. https://doi.org/10.3389/fmars.2021.657720

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.