FORCOAST

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

Project Deliverable Report

Deliverable Number: 3.10

Deliverable Title: Technical Specifications for Tailored Products

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Comment	Response
As was stated in D3.1 (2020), the project is facing difficulties with the lack of validation data in the chosen deployment sites. In this D3.10 deliverable, information about these difficulties was not updated in a precise manner.	As stated upon discussion of the recovery plan, validation aspects are overviewed within WP5, of which deliverables have been planned at a later stage. D3.10 was conceived as a description of the technical specifications required to overview the implementation of a service module at the central platform level. This update now describes technical specifications that have been clarified by achieving the central platform uptake of the SM. Yet, validation aspects are pending. We provide in Section 1, the various WP5 deliverable that will be devoted to these issues (ie. respectively, model validation, performance indicators and service validation)
The actual status of the services per site is insufficiently clarified. For instance, p36, the table of deployments lists "mockups" as "deployments", as well as indications such as "pilot setup" and "pilot op setup", and colour codes which are not precisely defined. For an illustration of this, a deployment that is either "ongoing" or "initiated" can reflect very different realities. The deployment data, dated as of June 2021, was not updated and presented for the review meeting in Dec 2021, and any progress is difficult to assess from the deliverables only.	We included a section (2.3) describing the **typology of Service Modules development status**, and used the same format in every table and text in the document.
Beyond the performance evaluation, the transferability of the services is also lacking details, with only one service tested, and colour codes that are confusing with regards to the planned results. For instance, the deep green "leading service" in table p10 is not defined. The accompanying text only lists 4 categories, yet the table uses 6 colour codes: "Table 2.2.2 details the cases where such transfer is feasible, tested, irrelevant, or if it	We included a section (2.4) describing the **typology of Service Modules transferability (ie. deployment) status**, and use the same format in every table and text in the document. In addition we clarified the notion of "feasibility" used in this document, ie. *"Note that the last three typologies only refer to technical feasibility in terms of data requirements, and are indicated here as indicative of potential expansion of the*

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would demand an extension of data provision by pilot models" [4 categories]. In addition, these categories are not properly defined. For instance, "feasible" does not indicate the degree of technical difficulties, delays, cost, to achieve the expected results.	*Forcoast service portfolio beyond the project's lifetime. We do not consider here market feasibility, which would encompass estimates of deployment cost and expected revenue estimates. Such matters are treated in the frame of WP6."*
Overall this document does not reflect with sufficient clarity the achievable specifications for each service/site within the scope of this project, and beyond the project as a commercially operable/replicable service.	Upon initial submission of this deliverable, the FORCOAST central platform development had not been initiated. Substantial developments have been achieved since then, with all service modules being now operational through the platform for at least one pilot site (and most often two). In addition, the vast majority of service modules have now completed the design of "bulletins", i.e. short graphical notification framework conveying the key information for subscribed users. We believe the update descriptions provided below specifically for each SM now reflects the achieved specifications with sufficient clarity. We explicitly clarified any development items as either "Done", "Scheduled" (providing due date), or "Not scheduled within the project lifetime".

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Executive Summary

This deliverable 3.10 describes the portfolio of services that will be deployed through the FORCOAST project for the sectors of Fisheries (2 services), Bivalve Aquaculture (4 services) and Oysterground restoration (2 services, one of which is adapted from the Bivalve Aquaculture sector).

First, this document presents the architecture of the FORCOAST systems of services and defines the notion of Service Modules, based on the foundation established in deliverable D3.9. Service Modules are generic, model independent algorithms and routines that use input data from local hydrodynamic and/or water quality models and translate these into specific information products which are offered to end-users as a service. This architecture was adopted to ensure evolution, transferability and modularity of services being first developed at individual pilot level, and then made available to a wider user community (i.e. other pilot areas) by their uptake on a central, cloud-based, FORCOAST platform.

Second, a short overview of the Service Module portfolio is provided, detailing the requirements of transferability for different services across the pilot sites

Third, each Service Module is described in terms of functionality and data requirements. Compared to previous deliverables, D3.10 puts an emphasis on the technical specifications of each Service Module, and details elements of their integration in the central platform framework. As such, the deliverable is complemented with an appendix table, providing technical information on data requirements (incl. format, resolutions, etc…), post-processing code units (incl. dedicated code repository and triggers for execution), and user-specific definitions (incl. means for acquisition and format).

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1 Introduction

D3.10 - "Technical Specifications for tailored products" - first describes the general framework of the system of service that has been designed for FORCOAST, in particular it defines the concept of Service Modules. Then, it lists all technical specifications for each of the Service Modules developed within FORCOAST. These technical specifications include operational and information requirements and can be split into different levels, which are based on the decisions that were to be taken within deliverable D.3.9 - "Operational Workflow to set up specific Service Modules" and that drive the prospection, implementation, operation, and interaction with customers.

The operational and information requirements should answer the following:

- What data/information is required by the service? Where can the service be deployed?
- What functions/capabilities does the system perform? What computations are achieved on the basis of marine information in order to convey the required service? How can the service be used by customers? When is it updated/triggered to perform its intended function and for how long?

A great deal of these questions are already answered in the Operational Workflow D3.9 but are more elaborated in this deliverable and complemented with technical details, that have been clarified while working out the operational uptake of the service modules within the cloud-based central FORCOAST platform.

Finally, we should note that, according to FORCOAST's work plan and the Improvement Plan as submitted in March 2022, all aspects of validation of the services are considered within WP5 and therefore not detailed in the present deliverable. In particular:

- D5.4 (due within June 2022) details the validation of the pilot models, i.e. specify the accuracy of met-ocean data provision by the models from which the services are derived. Process-oriented validation protocols as reported in D5.4 will specifically target those aspects of marine dynamics that are most relevant for the service developed at this pilot, e.g. currents for lagrangian-based services, nutrients and oxygen for biogeochemistry-based services, etc.
- D5.5 (due within August 2022) reports on system performance through key performance indicators, and specifies the adequacy of the service provided in regards to user's operational requirements.
- D5.7 (due within September 2022) reports on the validation of the services (Service Modules) as detailed in the present deliverable, from the perspective of usability and value they provide to the users.

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2 Service Modules : Overview

2.1 General Concept

The notion of **Services Modules** (SM) introduced in D3.9, constitute the central innovation of FORCOAST service infrastructure. The main idea is to separate the steps of data production and data processing. Marine information, be it from model simulations, remote sensing, or other sources, is made available around Europe through institutional platforms (CMEMS, EUMETSAT, ...), on the basis of data sharing protocols that make them operationally available for downstream services. The FORCOAST Pilot models complete this information by providing local downscaling, i.e. increasing the spatial resolution to reach spatial scales and phenomena that are relevant to end-users, most often by exploiting CMEMS and external products for boundary conditions, atmospheric and terrestrial forcings.

The system of services designed within FORCOAST dissociates the service production from this data provision, while pursuing three overarching principles: evolution, transferability and modularity.

Each service module consists of a set of post-processing operations, that applies on local marine information and provides user-specific outputs, in a way that is parameterized by user inputs. This set of processing scripts (see Appendix 2) are embedded in docker containers[1] and executed on a central cloud platform. Required input (marine information) is accessed via THREDDS servers or similar, while user specific information (e.g. farm locations, local biogeochemical thresholds, etc..) are defined by users upon subscription to the services, through the platform front-end interface.

Service **evolution** is ensured as the services automatically benefit from enhancement operated at the level of Pilot models. In addition, extension of the service can be implemented after the project's lifetime by accessing new high-resolution operational models implemented around Europe (as inventoried for instance in Capet et al. 2020).

Service **transferability** is ensured by the development guidelines (D3.9). SMs are first developed by Pilot teams at a local level, and therefore benefit from a close user-developer interaction environment. Yet, SMs data requirements are defined in terms of CF convention standard variable names (see Appendix 1), and designed in a way to manage data acquisition from different sources. As such, from the list of state variable requirements and the list of data provision by the different Pilot models (cf. D3.8), the technical feasibility of transferring SMs from one pilot site to another can be assessed. This allows future exploiters (i.e. post-FORCOAST project) to consider, on the basis of market arguments (cost, expected benefits), whether or not to enlarge the Service portfolio to reach users across a wider geographical scope, and to expand the community for further evolution of the SM portfolio (cf. D3.9). Within the FORCOAST project, service transferability is demonstrated by implementing each SM for at least 2 pilot areas, selected based on market arguments.

Service **modularity** lies in that SMs are designed with user specific parameters centralised in namelists files (see Appendix 3), that can be updated through the front-end interface. This ensures that each generic SM can provide information that is directly relevant to specific users and be integrated as a routine tool for its own operations.

[1] https://www.docker.com/ Implementation by WP4.

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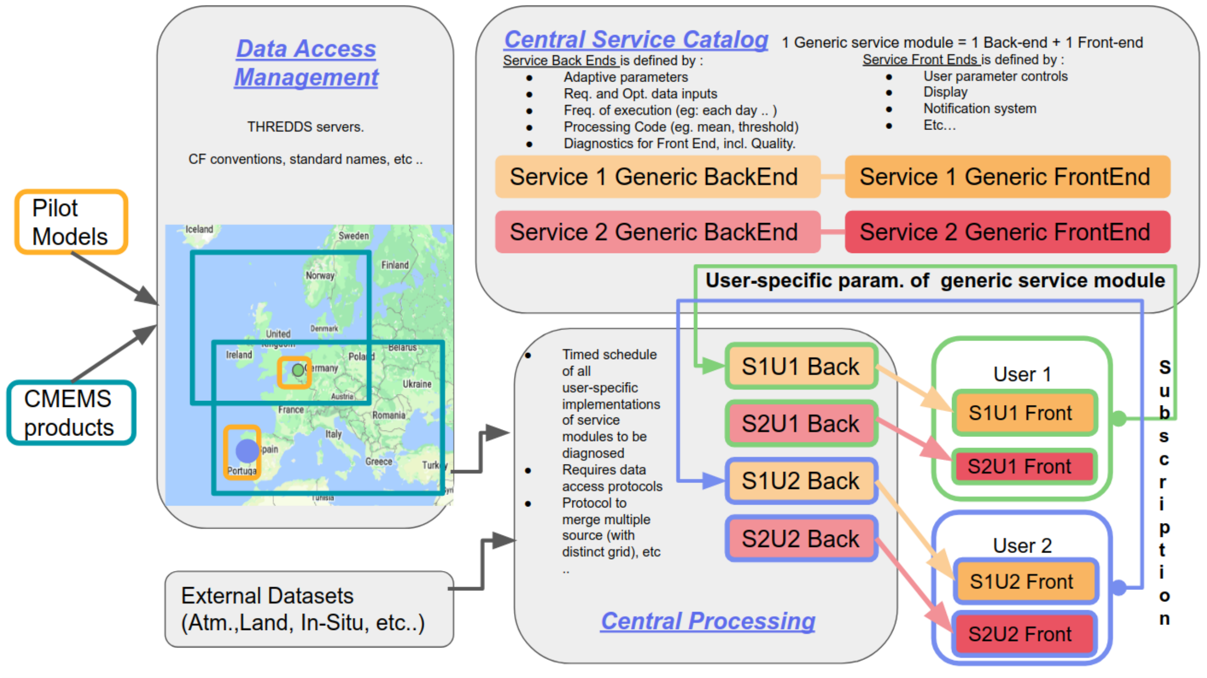

Figure 2.1.1 *- Service Module: General Framework*

2.2 Portfolio Overview

The final list of service modules is the results of pilot initial intentions, interaction with users (cf. WP2 deliverables), as well as technical constraints and feasibility considerations (cf. WP4 deliverables). It gathers two services targeting the Fishery sector, 5 services for the aquaculture sector, and 2 services for the oyster ground restoration sector. In addition, one of the Aquaculture services (SM-A3), can be readily adapted to meet the requirements of the FORCOAST Oyster Ground restoration sector.

Table 2.2.1 provides a rapid overview of the service portfolio, while each SMs is described in more detail in the following sections.

ID	Title	Lead Pilot	Service provided	Time Scale	Source
F1	**Suitable Fishing Areas**	Bulgaria	Dynamic maps for commercial fisheries habitats	Medium - Present	Model / RS
F2	**Fronts Detection**	Spain	Dynamic maps of frontal zones	Short - Present/Forecast	Model / RS
A1	**Marine Conditions**	Portugal-Denmark	Met-ocean conditions on site	Short - Forecast	Model
A2	**Land Pollution**	Romania	Influence of harmful influence on-site	Short - Forecast	Model
A3	**Site Prospection**	Denmark	Scope-for-growth maps for oysters	Long - Analysis	Model / RS

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A4	**Spat Captures Assistance**	Belgium	Provides date of larvae arrival to help on-site collection	Long - Forecast	Model
R1	**Contaminants Source Retrieval**	Ireland	Backward retrieval of pollution sources	Short - Forecast	Model

Table 2.2.1 *- Overview of FORCOAST's service portfolio. RS stands for remote sensing.*

2.3 SM Development Status typology

The development status of FORCOAST's Service module is declined with the following typology, referring to the different development and deployment stages established in the operational workflow. The statuses includes:

- ***Mock-up*** : A graphical sketch of the SM's functionality and graphical information provided to users is set-up, in accordance with user requests.
- ***Implementation at pilot level*** : The SM's computation scripts, ie. the code ensuring the processing from marine information towards the relevant metric/indicator/maps that are relevant to the user, are working, debugged and implemented at the Pilot's level.
- ***Operational implementation at pilot level*** : An operational chain relating operational pilot model forecast and the SM execution is established at the pilot level. Note that, should the SM be directly established in its operational form at the FORCOAST central platform level, this development stage can be bypassed.
- ***Test at another pilot :*** The service module has been tested at another pilot site than the one for which it has been developed initially. This may be achieved with or without implementation through FORCOAST's central platform.
- ***Source code on Github :*** The code source for the SM's computation scripts is uploaded on a Github repository (or similar). Access to this repository is provided to the central platform managers to enable the central implementation of the SM.
- ***Source code on Zenodo :*** The GitHub repository for the SM's computation scripts is archived on a Zenodo repository. This enables formal versioning, and referencing of the code.
- ***Implementation on the central platform:*** The SM is implemented and running on the central platform.
- ***Bulletin provision:*** A user-specific bulletin provision system is built upon execution of the CP version of the SM, that can be automatically provided to users upon manual or scheduled execution of the SM.

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2.4 Technical transferability requirements

Each Service module has first developed locally at pilot level (see operational workflow D3.9). Then, on the basis of the Service Module data requirement, and pilot data provision, the service module may potentially be "transferred", ie. deployed at other pilot sites to benefit further users. To demonstrate and test this principle, with the exception of F1, A3 and A4 each SM is implemented for at least 2 pilot areas within the FORCOAST project. The cross table 2.2.2 (SM vs Pilots) details the transferability cases using the following typology :

- **Irrelevant:** The SM is irrelevant to the pilot location.
- **Platform operational:** The SM is operational, through the platform for this pilot.
- **Under development:** The SM has been tested for this pilot location and is foreseen to be operational through the platform before the end of the project.
- **Technically feasible:** The pilot provides the required data to support the transfer of this SM.
- **Feasible for reduced functionality**: The pilot data provision could only support a part of the SM functionality.
- **Require additional data:** Data provision at the pilot is not sufficient to enable the SM transfer.

Note that the last three typologies only refer to technical feasibility in terms of data requirements, and are indicated here as indicative of potential expansion of the Forcoast service portfolio beyond the project's lifetime. We do not consider here market feasibility, which would encompass estimates of deployment cost and expected revenue estimates. Such matters are treated in the frame of WP6.

Also, note that within the FORCOAST project lifetime, all SM / pilot combinations marked green (either light green or dark green) in Table 2.2.2 will be implemented. All SM / pilot combinations marked yellow and orange are feasible to implement, given the transferability as demonstrated for the SM / pilot combinations marked green. However, the SM / pilot combinations marked yellow or orange will not be implemented during the FORCOAST project lifetime.

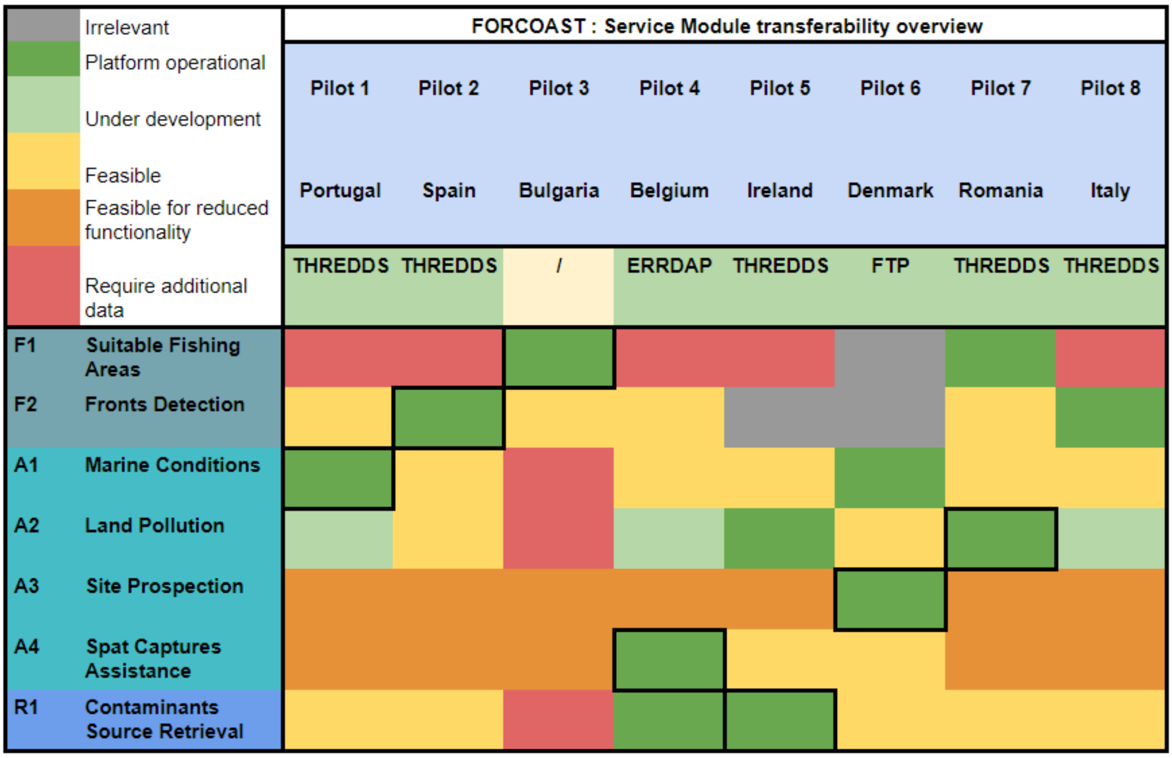

Table 2.2.2 *- Transferability of FORCOAST's service modules. Bold Cells indicates the SM development teams. Details on the colour code statements are given in the text (Sect. 2.4).*

2.5 Content of the specific descriptions

2.5.1 General description

A short section restating the context and objectives of the service module.

2.5.2 Input requirements

Data requirements for each of the specific Service Modules must be seen at different levels:

- ***User data***:
    - End-user specific data is based on better knowledge and foresight of some aspects of the marine environment and specific subsets of activities that are relevant for the development of the Service Module, *e.g.* coordinates of the farm site, conditions for specific operations, location of sources of pollution, water treatment effluents of overflows, etc.
    - User specific thresholds of certain physico-chemical variables in order to run models on certain events, *e.g.* timing for harvesting, respawning, site selection, species selection for farms, etc.
    - Information requirements to support the decisions that are expressed in terms of marine state variables and detailed on aspects such as spatial coverage, time frame (i.e. forecast length), and accuracy/resolution at which the information is needed to properly enhance the chance of taking correct operation/management decisions.

- ***Local expertise:***
  - Specific biological data *e.g.* spawning period of shellfish, feeding behaviour of fish species, natural habitat preferences of target species, growth parameters for microalgae and shellfish, etc.
  - Specific data from services: what is the bathymetry in the area, what are the current regimes, water level, obstacles (*e.g.* dike, sandbanks, tidal flats), river discharge data, GIF maps, EuskOOS, etc.
  - Local evidence to identify physico-chemical thresholds (*e.g.* value of salinity, turbidity, etc.) triggering biological processes that are directly relevant in terms of operational management of the targeted sectors, *e.g.* spawning of shellfish, larval duration of shellfish, (toxic) algal blooms, mortality due to extreme heat, sea surface temperature & chlorophyll concentration gradient for fronts detection, for optimal working times, etc., including scheduling. Some of these data can be taken as default values.
- ***Pilot model data:*** Data made available from existing local models developed in the frame of FORCOAST (cf. D3.7, D3.8) , *e.g.* wind speed and direction, air temperature, wave activity and direction, storms, sunlight period, etc.
- ***Substitute model data:*** Met-Ocean information distributed at European scale, generally at a coarser resolution, from services such as CMEMS, ECMWF.
- ***Remote sensing data:*** What EO data, either directly or indirectly (post-processing involving thresholds, time-integrated quantity, etc.) are needed for the Service Module (e.g. sea surface temperature and salinity, currents, mixed layer depth, sea surface height, chlorophyll a concentration, primary production, euphotic zone depth)?

2.5.2 Code sources

Code source for the execution of service modules are shared through code-sharing platforms (eg. **Github**). The developers share the repositories with WP4 members, to allow updating the service module executable scripts in accordance with requirements stemming from their uptake on the central platform. Note that the use of Github platform allows for publication of referenced releases, through the EC service **Zenodo**. References are given below for each service module when available.

When implemented satisfactorily at pilot level, access to the code repository is to be handled towards WP4 for containerization, via an uptake in a docker repository.

Note that, during development, we are adopting an open-source, closed community policy for some of the FORCOAST repositories. Provided links may thus not be accessible without authorised Github credentials. To get access, please share your GitHub credentials with info@forcoast.eu.

2.5.3 Graphical display

Executable scripts should result in outputs that can be displayed through the user dashboard, or transferred to the user via platform facilities (e.g. smartphone notifications, bulletins). This can consist of a NetCDF file, rendered by NC-WMS viewers, static figures, or any other forms to be handled to display facility or information transfer protocols (e.g. notification messages).

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3 Service Modules: specific description

3.1 SM-F1 : Suitable Fishing Areas

3.1.1 General description

The service is developed as a decision support tool for the fisheries engaged stakeholders in the north-western Black Sea. It will provide access to valuable information, such as upwelling events and areas favorability for some species, in order to help fishermen to maximise the economic efficiency of their activities. The service directly addresses multiple categories of stakeholders, from individual fishermen, to mid-size and industrial fishing companies in Bulgaria and Romania.

The main objective of this service module is to offer stakeholders valuable information to identify the most favourable conditions for fishing. In order to achieve it, the following information will be provided:

- Fishing Suitability Index – optimal conditions for specific species
- Upwelling information – upwelling events are known to generate the most fertile marine ecosystems.
- Information on waves coming from nested wave model for the Northern Black Sea

3.1.2 User-Specific information

There are no specific information requirements from the user to be provided. The user should access the module and choose the time and the geographical location and the layers of information he is interested in.

3.1.3 Marine information requirements

The service needs information on the Sea Surface Temperature and Chlorophyll, measured from satellites, as well as Sea Surface Salinity. Model data for the current velocity and direction within the 100 m depth layer is necessary to complete the upwelling identification. In addition the nested wave model for the NW part of the Black Sea requires information from the Copernicus Wave model for the whole sea. Meteorological information for the air temperature, humidity, wind and pressure is also used.

3.1.4 Scientific Rationale and Methods

The idea behind the SM is to identify the favourable conditions for fishing by showing information on:

- Fishing suitability index – main point
- waves - there should be weak to moderate waves;
- areas with rapid decrease in the SST
- areas with offshore Ekman transport
- meteorological conditions, in future it is intended to show information for extreme events (like heavy rain, intense wind, cold weather)

Fishing Suitability Index is implemented to reflect the optimal conditions for specific species. It is similar to the already developed Habitat suitability Index (HSI) for whiting (Merlangius merlangus euxinus) within the SkyFISH project (http://skyfish.terrasigna.com/). Optimal conditions were identified based on literature references and National Institute for Marine Research and Development "Grigore Antipa" (NIMRD) experts. Fishing Suitability Index is determined from the temperature, salinity and depth (with values ranging from 0.1 – less suitable to 1 – best conditions). Survey and fishery data was used to tune the parameters .

The upwelling events are identified by a strong decrease in a day-to-day tendency of the SST, as well as offshore integral Ekman transport calculated from the 3D field of the velocity in the area of interest. The input data are taken from satellite and model products available through Copernicus Marine Service.

The information on waves is coming from a developed for this purpose a nested downscaled wave model in the NW part of the Black Sea. The existing wave models do not provide sufficient spatial resolution, thus represent the significant wave height and period in more detail. NWS wave model is downscaled in the Copernicus configuration (CMEMS data at the open boundary).

3.1.5 Execution/scheduling

The computation of the Fish Index is presently updated on a daily basis, taking input from a 9-day forecast into account to calculate the Index.

3.1.6 Service provided

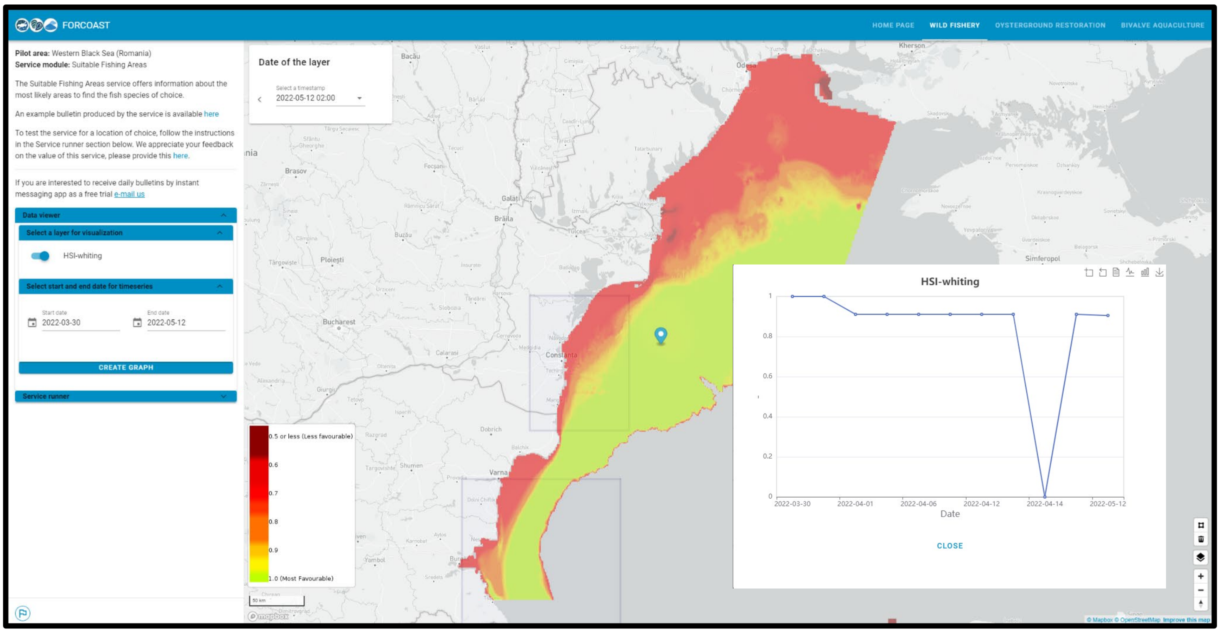

Figure 3.1.1 *: Snapshot of the service module "Fish Index" in the Black Sea*

The web interface, developed in accordance with user requirements (Figure 3.1.1) allows them to:

- Interact with service module products in an elegant and efficient manner.
- Included tools and functionalities, such as date selection, time series plot ('graph') and background information with each service.

3.1.7 Code source

The fish suitability index is developed using batch scripting, GDAL Library and Python programming language. The upwelling event identification is done through Fortran code programming. The nested

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model is written in Fortran. The code is available in the following private GitHub repository: https://github.com/FORCOAST/Test-FORCOAST-SM-F1

3.1.8 Status Check-list

SM Mock-up is defined	Done
SM implemented at Pilot level	Done
SM operational at Pilot level	Done
SM tested at another pilot	Will not be carried out during FORCOAST project
SM source code on Github (or similar)	Done
SM code repository on Zenodo	Not initiated yet, foreseen for September 2022
Implementation on central platform	Done
Bulletin provision	Ongoing, to be completed by June 2022

***Table 3.1.1** : Development status for SM-F1*

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3.2 SM-F2 : Fronts Detection

3.2.1 General description

Ocean fronts are narrow areas in the sea surface where a sharp gradient between two water masses with different hydrodynamic properties occur. Across frontal areas there is a strong gradient in a short horizontal distance in the physical and biochemical properties of the sea water. There are different types of fronts depending on their location, persistence, and size. Frontal areas play an important role in the ecosystems and in different human activities, such as fisheries since there is usually a higher concentration of commercial fisheries along fronts. In this service module we will focus on the following fronts: shelf, shelf-break, coastal-upwelling and estuarine fronts; as well as, on frontal areas in the deep ocean. Ocean-front information together with other ocean information is useful in fisheries to search suitable habitat for small pelagic and avoid other species. This information would reduce the costs associated with days at sea (person-work, fuel, fungible...); thus, optimising the resources in sea operations.

The fronts algorithm is able to distinguish between strong and weak fronts. In the previous example, the green lines correspond to strong fronts, whereas the white lines represent weak fronts. The following figure shows an example of how the Fronts Detection service might appear through the FORCOAST platform. This image shows both sea surface temperature fronts (in red) and chlorophyll fronts (in green).

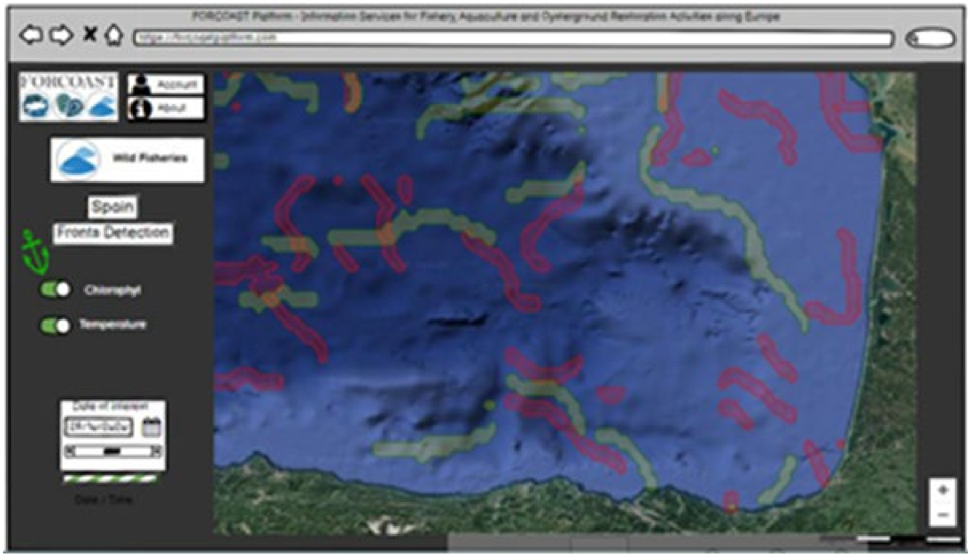

***Figure 3.2.1** - Mock-up proposed for SM-F2: Fronts Detection*

Since the model running in the pilot provides only physical variables, the fronts detection service module has been applied only to sea surface temperature maps.

In short, the Fronts Detection service module is addressed to the fisheries sector by providing it with another source of information about the ocean conditions to reduce the time at sea and the distance travelled, with the final purpose of contributing to a more efficient activity.

3.2.2 User-Specific information

There is not any information that the user must provide. The user only has to activate/deactivate the fronts detection service module from the dashboard.

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3.2.3 Marine information requirements

The fronts detection algorithm is applied usually to sea surface temperature and sea surface chlorophyll concentration maps (remote sensing or model data), but it could be applied to other variables (e.g., salinity). The code is designed for its application to netCDF files and to regular arrays with a resolution of 0.04°. Regarding the temporal requirements there is no limit, but usually in the case of remote sensing data, it is applied to daily maps.

3.2.4 Scientific Rationale and Methods

An ocean front is defined as a zone where abrupt changes (horizontal gradients) take place in some property of water masses (e.g., temperature, phytoplankton concentration, altimetry) (Rivas & Pisoni 2010). They are border areas between waters of different density, recognizable by strong temperature and/or salinity gradients (Sund et al. 1981). Typically, these regions separate large areas with different vertical structures (stratification) and/or bodies of water of different hydrographic characteristics. Fronts can be classified depending on their size (Sund et al. 1981, Belkin & O'Reilly 2009): frontal systems, mesoscale fronts, small-scale fronts, etc; and also, by the process from which they originate (Belkin and Cornillon, 2007): estuarine fronts, shelf break fronts, tidal mixing fronts, coastal upwelling fronts, western boundary current fronts, etc. Fronts are of biological importance since they are areas with interesting characteristics in terms of biological richness. In various studies, such as the one carried out by Worm et al. (2005), greater diversity in areas with thermal fronts was found. The chlorophyll fronts represent the primary production of the area, which in turn supports the production of zooplankton and higher levels of the trophic chain. These horizontal chlorophyll gradients have been used as a proxy for food availability (Druon et al. 2015). Finally, oceanic fronts have been used to shape the large marine ecosystems that are an essential part of the world's oceans (Belkin and Cornillon, 2007).

The fronts detection algorithm is based on the method developed by Cayula and Cornillon (1992), which operates at the picture, window, and local level. Instead of detecting the absolute strength of the front it computes the strength of the edge as a function of the surrounding oceanic area. The algorithm is written for its application to images of around 4 km resolution.

3.2.5 Execution/scheduling

The computation of the fronts is presently updated on a daily basis providing 4 days of forecast data.

3.2.6 Service provided

This service module provides on an hourly basis an update of the frontal areas detected in the sea surface maps from the model. These outputs could be consulted directly from the FORCOAST platform. An example of this type of output is provided in the following figure.

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

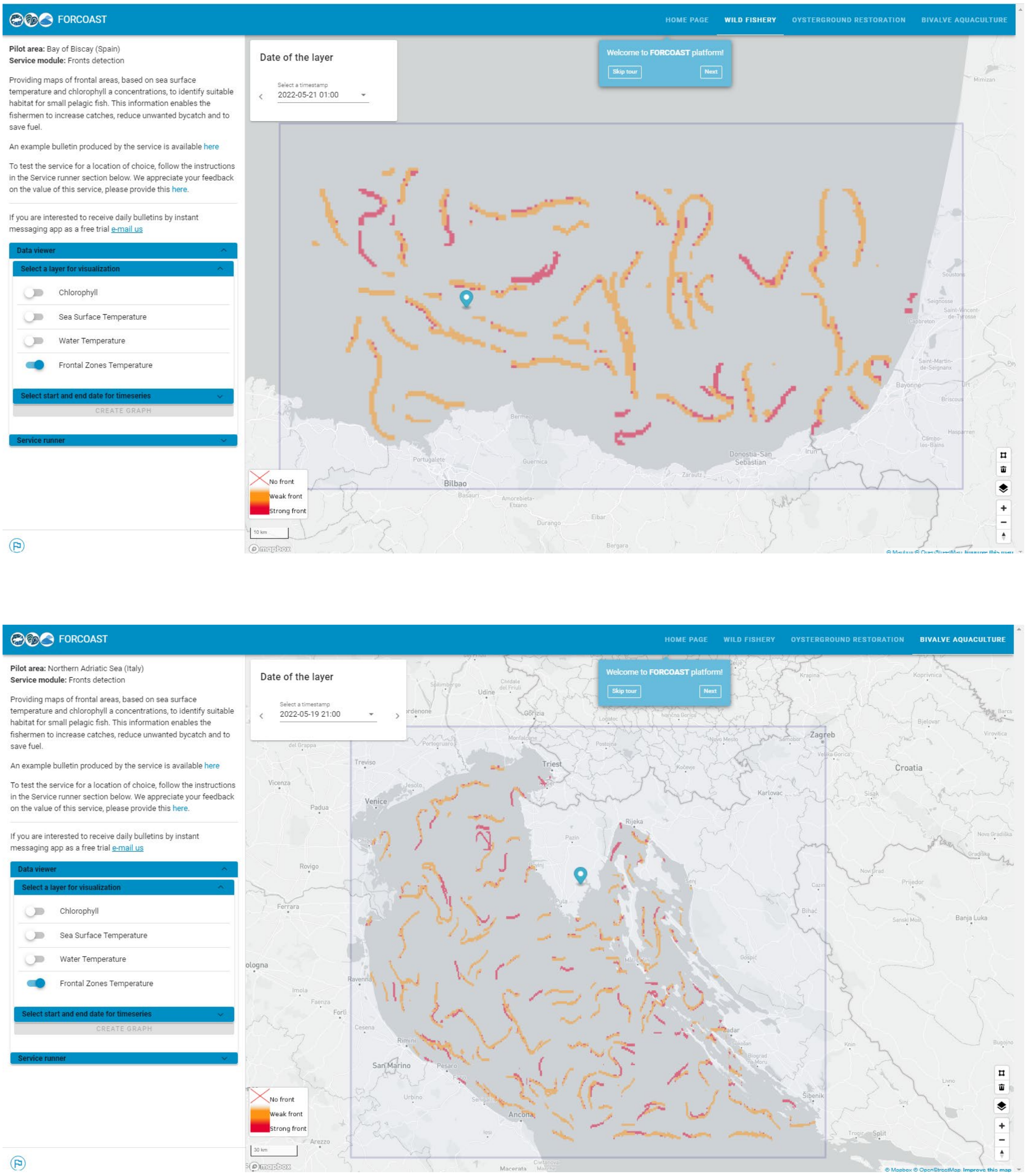

Figure 3.2.2 - *(Top) Snapshot of the service module "Fronts Detection" in the Bay of Biscay (Spain) and (bottom) in the Northern Adriatic Sea (Italy).*

The feedback to users consists also of a bulletin, sent to the users where a sequence of the last frontal maps are provided through the Telegram API.

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

3.2.7 Code source

The fronts detection code is written in Python and available at the following private repository: https://github.com/dminst/ForCoast-SM-F2.

3.2.8 Status Check-list

SM Mock-up is defined	Done
SM implemented at Pilot level	Done
SM operational at Pilot level	Done
SM tested at another pilot	Done
SM source code on Github (or similar)	Done
SM code repository on Zenodo	Not initiated yet, foreseen for September 2022
First implementation on central platform	Done
Bulletin	Ongoing, to be completed by June 2022

Table 3.2.1 *- Development status for SM-F2*

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

3.3 SM-A1: Marine Conditions

3.3.1 General description

This service provides hourly forecasts of marine environment conditions, including sea level, water temperature, salinity and currents in the service area, with detailed presentation on the targeted locations and parameter intervals.

Objectives:

- 5-7 day forecast service for monitoring
- Alerts: short term meteo-ocean alerts
- Historical conditions

The proposed service functions have been discussed with Oyster Boat, with positive feedback. User defined information, e.g., locations, criterion for warning and variables selection are important. It would be useful to present observations in the past week, if available, together with forecasts.Historical data (hindcast and statistics) are also interesting. Quality information is also important.

As SM-A1 - Operational scheduler was merged with SM-A5 – Marine conditions at farming site, Exporsado (portuguese pilot) has also participated in the definition of the requirements of this service, through IST/MARETEC, namely regarding the variables to be measured, its admissible limits, form of access and expectations in general.

3.3.2 User-Specific information

The main information that needs to be provided by the end-user is the coordinates of the aquaculture production areas (Latitude & Longitude) and, if tides is the main limitation, the optimum water level height for working. Thresholds of environmental limiting factors would be needed to edit the colour bar of the variables that would go in the information table. Finally, the end-user needs to provide one or more mobile phone numbers that will receive the information. The end-user needs to install the telegram application in order to access the information.

3.3.3 Marine information requirements

Currently, the essential variables required by the end-user have been related to the daylight time and the water levels including the time for the begin and end of the tide optimal conditions. Other limiting factors have been the wind and rain conditions.

3.3.4 Scientific Rationale and Methods

Two modelling strategies are being implemented for the FORCOAST project (referring to Pilot 1 Portugal, cf D3.8): running the models operationally in 2D and 3D versions. The 2D version of the model will allow an extended forecast of the tides, including the meteorological and river effect while 3D models will better resolve the baroclinic results. This approach has been put into place since CMEMS forecasts are limited to 10 days while to provide the service the aquaculture demands we need a 14 days forecast that includes the atmospheric effect and a year forecast for long-term planning.

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

3.3.5 Execution/scheduling

In Portuguese pilot, the service is executed automatically with two periodicities:

- Daily: It provides information for the two following days
- Weekly: It provides every Thursday, information about the conditions for the next week starting on monday.

3.3.6 Service provided

The service is distributed using the Telegram app and delivered automatically. In the Portuguese case we are always delivering at 11h40 since it's the time when we receive an update with the best meteorological forecast for the next couple of days. The service is delivered daily correcting the weekly forecast and the graphic design includes a table with values and colours indicating some limiting factors.

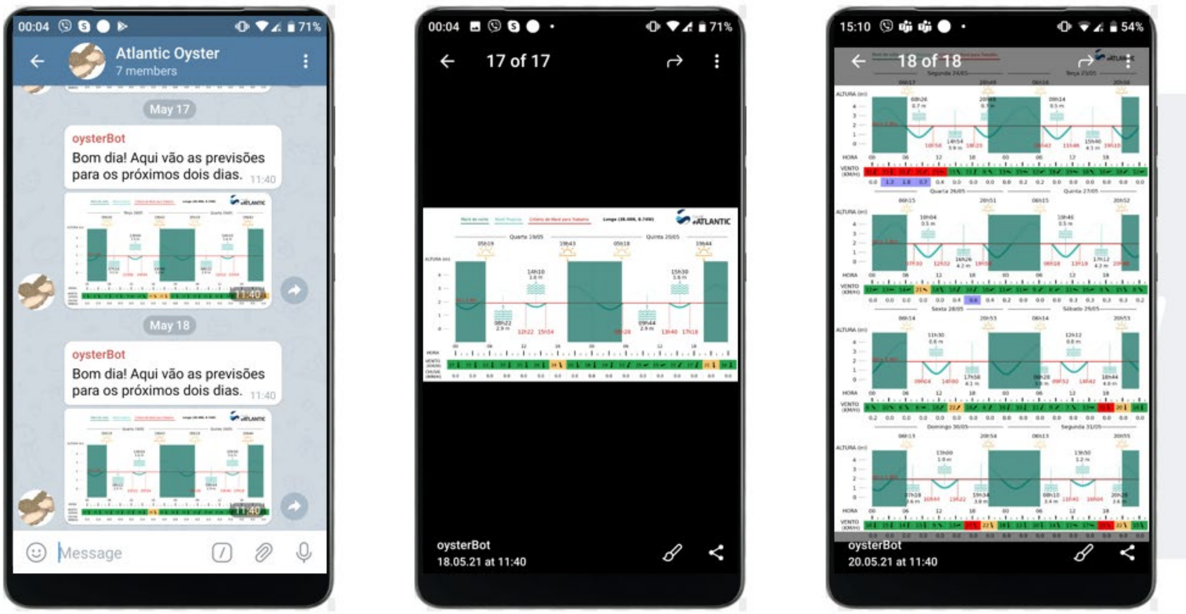

Figure 3.3.1 *- Notifications bulletins shared through Telegram for SM-A1*

3.3.7 Code source

The fronts detection code is written in Python and available at the following private repository: https://github.com/FORCOAST/FORCOAST_SM_A1.

3.3.8 Status Check-list

SM Mock-up is defined	Done
SM implemented at Pilot level	Done
SM operational at Pilot level	Done

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

SM tested at another pilot	Done
SM source code on Github (or similar)	Done
SM code repository on Zenodo	Not initiated yet, foreseen for September 2022
First implementation on central platform	Done
Bulletin	Done

Table 3.3.1 *- Development status for SM-A1*

3.4 SM-A2: Land Pollution

3.4.1 General description

Nearshore farming infrastructures are exposed to land discharges, which in some cases carry harmful substances (eg. 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 the planning of quality control measures, by providing a measure of the probability for farming sites to be affected by harmful land discharge.

3.4.2 User specific information

A user-tailored implementation of this service requires the assignment 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 multiple polygons or to characterise a large domain including all operated farms. A facility to ease this user entry is currently under development, considering options such as import of .kml coordinates, or click-and-point facility based on underlying GoogleEarth images.

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).

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 can be modified from the dashboard.

3.4.3 Marine information requirements

The SM requires, at a minimum, the **grid information** (longitude, latitude, and potentially depth) provided as a separate file or included in the velocity files, and **2D horizontal currents** to advect the pollutants from its source of release (indicated by the user, see above). In this simple case, the pollutants are supposed to be released at the depth at which the currents are provided (usually the surface), and stay at that depth for the entire simulation.

The SM can also be provided with **vertical currents**, in which case pollutants will also be advected vertically. In that case, the release depth can also be specified.

Further optional inputs are:

- 1 or multiple sets of files for other grids, e.g. when multiple nested grids are available
- wave data : **2D Stokes drift** (in case of 2D simulations) completed by **significant wave height** and **peak period** (in case of 3D simulations) ; which will include the effect of Stokes drift on the pollutant trajectories.
- **horizontal diffusion coefficients** (both meridional and zonal), the simulation will then emulate horizontal diffusion by releasing multiple particles at the source and apply random walk processes to each of them.
- **3D fields of vertical diffusion coefficients**, usually computed by the hydrodynamic model's turbulence module, will allow to also emulate vertical diffusion of the pollutants

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- a “beaching” flag indicating what should happen if waves, diffusion or rounding errors push the pollutant onshore, among the following options: do nothing, “freeze" pollutants at their beaching location, or push them back into the sea.

3.4.4 Scientific Rationale and Methods

Lagrangian Particles Tracking:

The Lagrangian tracking software is Ocean Parcels 2.0 (https://oceanparcels.org, Delandmeter and van Sebille 2019) with some modifications.

The implementation readily reads eulerian currents from the NEMO, ROMS, MOHID and MITgcm models, including (in the 3D case) z (horizontal) or *s* (terrain-following) vertical coordinates with or without free surface elevation. It is expected to be further expanded to other hydrodynamic models.

The computation of pollutant tracks is using the input data at the frequency provided by the Pilot site, e.g. hourly or daily. It is recommended that eulerian currents be provided at hourly frequency, whereas other inputs (e.g. vertical diffusion) may be provided with lower frequencies. The frequency can be different for the different input fields. The lagrangian simulation uses a default time step of 10 minutes.

By default, without using diffusion, 1 pollutant particle is released every 10 minutes. When diffusion is used, the default number of particles at the source is 5 every 10 minutes. These settings can be adapted for each Pilot site considering the trade-off between intrinsic variability and computing time. In general, all settings are customisable for the different pilot sites and furthermore for different users in a single pilot site (e.g. farm locations).

Simulations are executed daily on the central platform (supposing daily updates of eulerian currents at the Pilot site) ; but can also be executed “on demand”.

Characterising the **release of potentially harmful substances** constitutes a real challenge for SM-A2. It appears from the user survey (D2.2) that localising potentially problematic sources is considered as feasible. Yet it seems more difficult to characterise temporal variations in the discharge and the nature of released material, although such information and consideration by SM-A2 appears to be important. The nature or discharge rate of harmful material are typically local issues, with potential data providers being known only at a local scale. It thus does not appear feasible to attempt automatizing the identification of release points, nature and discharge rate at this stage, although this aspect is retained as a point of attention. Given the difficulty for users to characterise this essential information, a default version of SM-A2 is developed that provides the best user-feedback while requiring minimal inputs. Only source location is considered, while assuming a constant discharge rate. The risk is evaluated from a combination of age since release, and fraction of release reaching the farm. The first operational release of SM-A2 is based on this approach. Yet, the possibility to embed substance-specific reaction models (forced by marine conditions along drifting tracks) is taken into consideration, together with the possibility to support users in characterising local information for this second level version of SM-A2. Localisation of the source may benefit from the same facility as for the farm polygons.

Diagnostics:

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On the basis of the particle tracks (computed from present-10 days to present+best forecast time), the number of particles crossing the farm is computed for diagnostics time steps of 2 hours. For each diagnostic time step, the mean age of those particles is computed. The Age and Fraction thresholds set by the user are then used to infer the diagnostics timesteps for which both conditions are met (ie. a substantial fraction of the release reaches the farm in a short time interval) and a list of the alarm time steps is issued, that will be used to prepare the user output.

3.4.5 Execution/scheduling

The computation of forecast for particle tracks as well as diagnostics are updated on a daily basis, or according to the update of forecast marine information. Note that an hindcast of marine information should be maintained for 10 days before present.

3.4.6 Service provided

The **feedback to users** is provided daily on the basis of updated forecasts. It consists of a synthesis bulletin, whose elements are summarised in Fig. 3.4.1. Note that an animated version of the bulletin (that can't be displayed here) is used, and provided through the Telegram API.

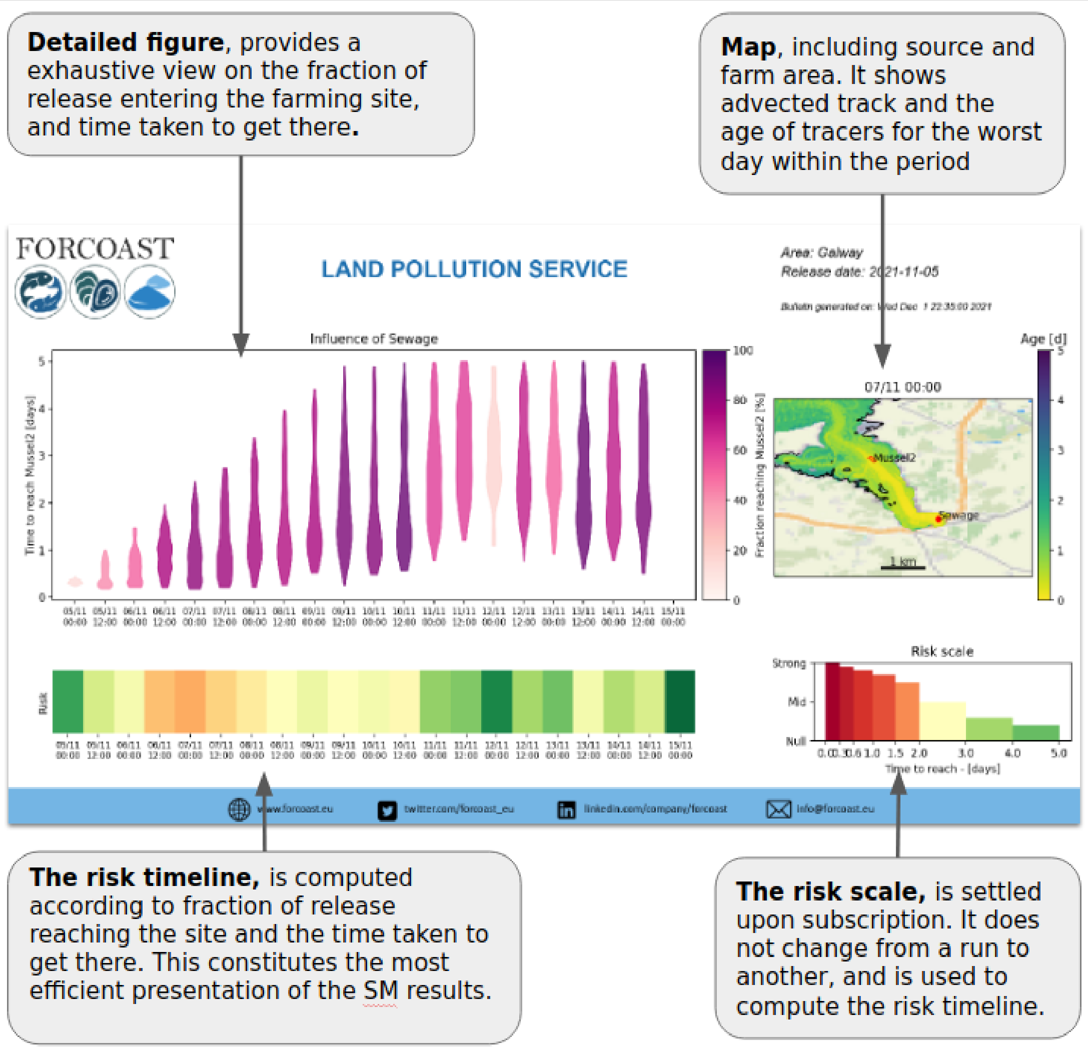

Figure 3.4.1 - Explanation of the bulletin provided to users by the Service Module "Land Pollution".

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3.4.6 Code source

The Processing and post-processing code combined for SM-A2 are written in Python and available on the (currently private) repository : https://github.com/acapet/ForCoast-SM-A2

3.4.7 Status Check-list

SM Mock-up is defined	Done
SM implemented at Pilot level	Done
SM operational at Pilot level	Done
SM tested at another pilot	Done
SM source code on Github (or similar)	Done
SM code repository on Zenodo	Not initiated yet, foreseen for September 2022
First implementation on central platform	Done
Bulletin	Done - Animated GIF bulletin also available.

Table 3.4.1 *- Development status for SM-A2*

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

3.5 SM-A3 : Site Prospection

3.5.1 General description

The purpose of the service module is to identify areas with highest growth potential and lowest mortality for flat oysters and thereby increase harvest and restoration potential. The users tend to face challenges with high spat mortality and variable year-to-year growth depending on environmental conditions.

The service module will show maps of monthly means and variability of selected environmental variables important for oyster growth (temperature, phytoplankton (chl a) concentration, detritus, hypoxia) as these were the variables identified by potential users as being the most suitable to show potential oyster growth at selected sites. This information can be used in the planning of new sites for aquaculture.

3.5.2 User-Specific information

The user has to provide some information about the environmental thresholds of the considered species.

Temperature tolerance: Oyster growth is mainly occurring from May to September with higher temperatures. The user has to define the temperature thresholds for optimal, medium, low and no growth based on the known physiology of the species. Default settings can be applied.

Salinity tolerance: Many species are sensitive to changes in salinity that can affect growth rates and mortality. The user has to define the salinity thresholds for optimal, medium, low and no growth based on the known physiology of the species. Default settings can be applied.

Food levels: High food concentration is important for optimal growth, too low food levels can impose starvation and death. The user can set the half-saturation coefficient of the food response based on the known physiology of the species. Default settings can be applied.

Particulate organic matter (POM): POM consists of Chl a (phytoplankton biomass) and suspended particulate matter. POM can both be a food source to shellfish, whereas high concentrations can hamper filtration and growth. The user can set the half-saturation coefficient of the POM response based on the known physiology of the species. Default settings can be applied.

Oxygen levels: Hypoxia occurs when the bottom oxygen drops to very low values (<4 mg/L). Species have different sensitivity to hypoxia and the oxygen threshold can be defined by the user. Default settings can be applied.

Bottom stress: Turbulent kinetic energy, or bottom stress, is important for the mixing of water and transport of food to the bottom for shellfish. However, high mixing also causes resuspension of POM that can decrease turbidity, hamper filtration and bury the shellfish in sediment material. The user can define a threshold for bottom stress. Default settings can be applied.

3.5.3 Marine information requirements

Environmental bottom variables are needed to define the best locations for oyster growth on the seafloor. This includes bottom temperature, salinity, food concentrations, POM concentrations,

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oxygen concentrations and bottom stress. The data is mainly provided by 3D ecological models as hind-cast data, but e.g. POM and Chl data can be obtained from remote sensing data depending on water column depth. The data will be provided as monthly means for different years with varying climatic and environmental conditions. The variability across years can be used to estimate the robustness of an area to climatic changes. The frequency of hypoxia is e.g. important to consider, hence if there is a high or low risk for hypoxia events. The data can be provided on structured or unstructured grids with geographical location of each grid cell.

3.5.4 Scientific Rationale and Methods

Growth responses of flat oyster to environmental conditions (temperature, salinity, food, POM) has been implemented into a Dynamic Energy Budget model based on field and lab measurements with collaborators outside the FORCOAST project. These physiological responses are used to convert the user defined thresholds into scoring indices from 0 to 1 (Fx in equation below). The geometric mean (GM) is used to combine the different scores into the overall suitability score for the area according to von Thenen et al. (2020):

$$GM = (F_{temp} \times F_{salt} \times F_{chl} \times F_{POM} \times F_{oxy} \times F_{stress})\text{^}(1/n)$$

where ‘n’ is the number of scoring indices ‘Fx’. A value of 0-0.25 means unsuitable, 0.25-0.50 means less suitable, 0.5-0.75 means medium suitable and 0.75-1 means suitable (Table 3.5.1). The geometric mean has the advantage that, if an area is not suitable with regard to one parameter, the area remains unsuitable regardless of the values of the other parameters (Longdill et al. 2008, von Thenen et al 2020). Geometric mean is the calculation of mean or average of a series of values of product which takes into account the effect of compounding and it is used for determining the performance of investment, whereas arithmetic mean is the calculation of mean by sum of total of values divided by number of values.

Table 3.5.1. The overall suitability scores applied from von Thenen et al. 2020.

The overall suitability scores.

Combined PSSF values	Classification
0–0.25	Unsuitable
> 0.25–0.5	Less suitable
> 0.5–0.75	Medium suitable
> 0.75–1	Suitable

3.5.5 Execution/scheduling

The maps can be updated yearly with the conditions including the latest year. The user can change the species setting. Data layers and algorithms can be improved over time.

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3.5.6 Service provided

The user defines the specific settings for each species based on the environmental preferences and tolerances. The scoring indices for each variable and the GM is calculated by the SM. The user can choose to see the different resultant maps either as monthly means of environmental variables or the scoring indices for selected months and years. The Geometric Mean shows the overall most suitable sites. The variability across years can be used to assess the robustness of local areas to climatic changes.

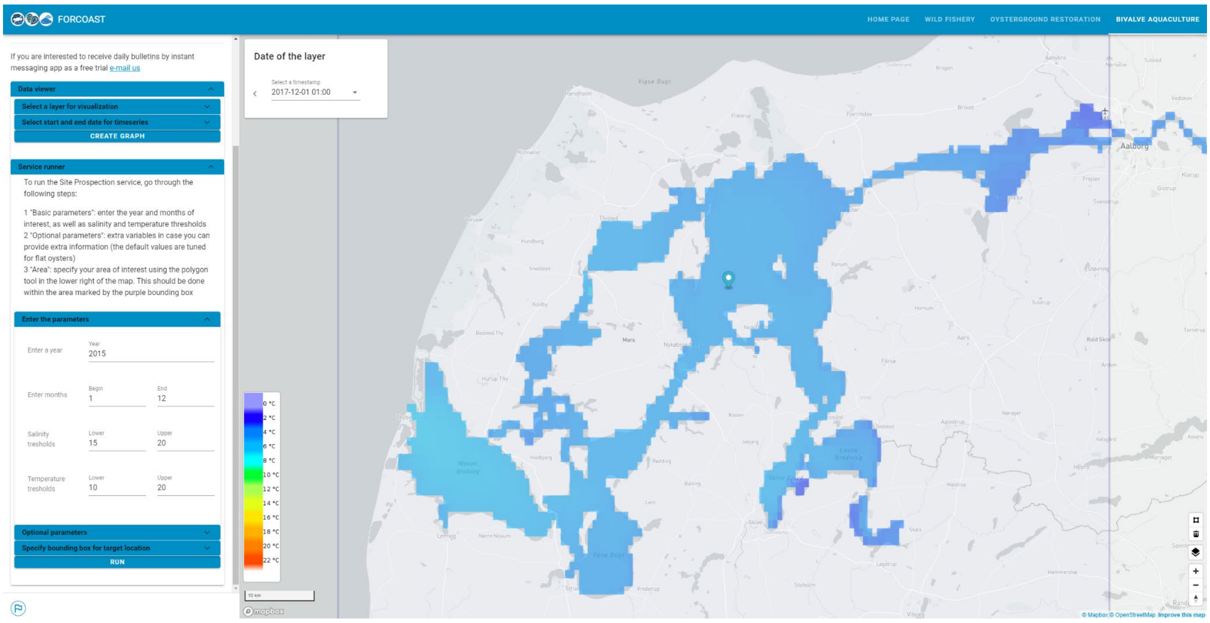

Figure 3.5.1 *- Snapshot of the Service Module "Site Prospection" through the Forcoast platform.*

3.5.7 Code source

The Processing and post-processing code combined for SM-A3 are written in R and Python and available on the (currently private) repository : https://github.com/FORCOAST/Test-FORCOAST-SM-A3

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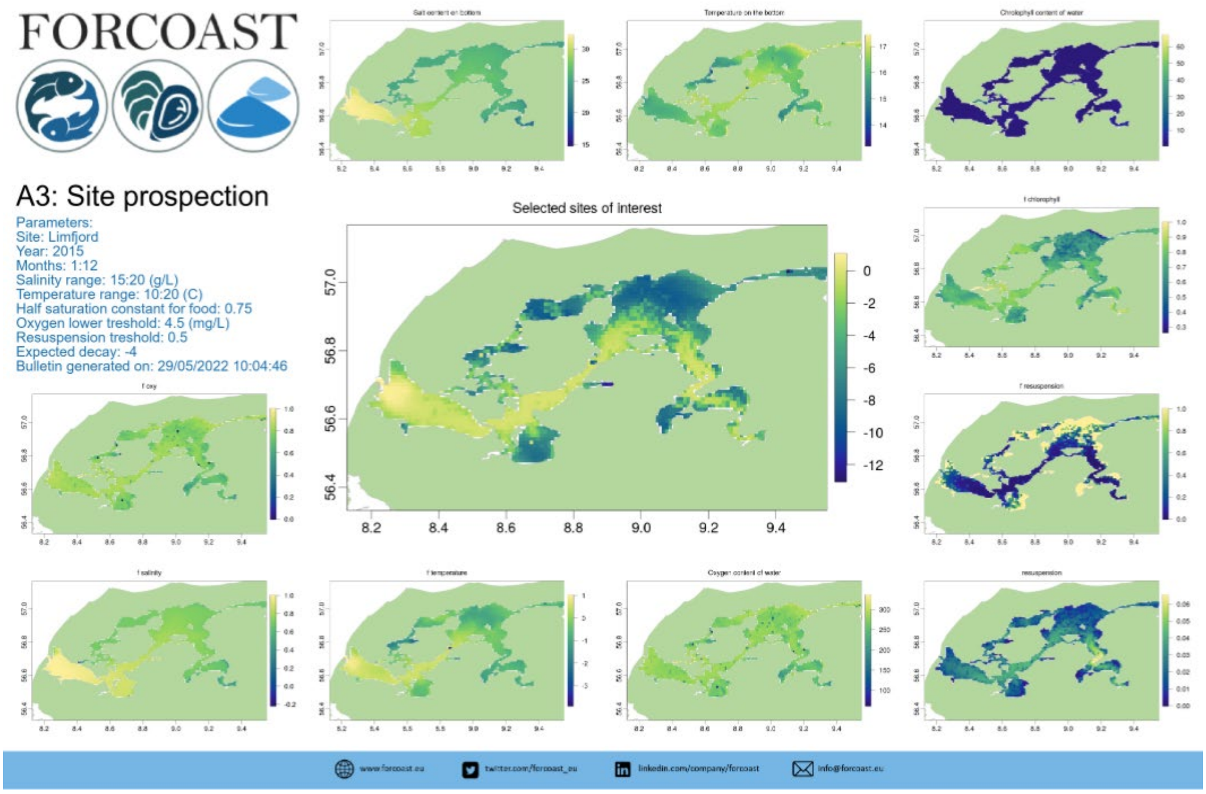

Figure 3.5.2 - *Bulletin provided by the Service Module "Site Prospection".*

3.5.8 Status Check-list

SM Mock-up is defined	Done
SM implemented at Pilot level	Done
SM operational at Pilot level	Done
SM tested at another pilot	Will not be carried out during FORCOAST project
SM source code on Github (or similar)	Done
SM code repository on Zenodo	Not initiated yet, foreseen for September 2022
First implementation on central platform	Done
Bulletin	Done

Table 3.5.1 *: Development status for SM-A3*

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

3.6 SM-A4: Spat Capture Assistance

3.6.1 General description

The capture of spat requires the installation of collectors. Those collectors have to be installed before the arrival of organisms.

Spat capture is the most efficient when biofouling is not extensive, it is necessary to put the spat collectors in the water not too early to avoid heavy biofouling, with subsequent low settlement of spat. It is the reason why a prediction of the time window where spats are likely to arrive is needed.

For many organisms, spawning events are related to environmental conditions (such as temperature, chlorophyll concentration, waves....) and an efficient tool should be able to predict spawning events and to estimate the most likely arrival date of organisms. The module is based on an alarm system in different source locations identified and returns the likely period where spat will arrive.

The aim of the SM-A4 module is to determine the period where spat of specific species is likely to arrive in the collecting location(s). That implies to have information on potential areas where spat could arrive, 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 if it not the case, an optional service can be provide before utilisation of the service base on scientific literature screening and Lagrangian dispersal model.

The output will provide the potential date of arrival (beginning and end) from each of the source locations. In addition to the arrival period from each source location, the whole period of potential arrival is also estimated by combining all source locations. A table summarises the likely arrival period for the species selected and the source location(s) associated to this arrival.

3.6.2 User-Specific information

If the user had good knowledge on the target species, users can provide a range of pelagic larval duration, duration of spawning period, condition of spawning event, area where spat are likely to come from. If this information is not known, a development step upon new subscription is needed to help users to estimate those parameters.

Specific details and format could be found in the appendix.

3.6.3 Marine information requirements

A daily temperature of the source area we are likely to provide spat to the capture site is required. This information can be completed by optional variables such as chlorophyll concentration during last month, and sea water velocity to improve prediction of the module and for the preparation step.

3.6.4 Scientific Rationale and Methods

The service is organised in three steps. The first one is optional and only needed upon new subscription of services. A second step is an alarm to detect spawning events in source location. A third step informs the user of the likely period of spat arrival.

- Development step upon new subscription: If biological information needed is not known by a user, a scientific expertise can be provided. This step consists of a screening of the literature

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to identify key parameters for the species and in running a larval dispersal model to estimate area likely to provide larvae in the selected site. The aim is

1) to determine pelagic larval duration of the species and spawning period.
2) Identification of the distribution of the target species (from natural population or breeding population)
3) Running a lagrangian model coupling physical and biological information to simulate larval dispersal from the population identified in (2)). This step determines which populations are likely to provide spat in the site where the module is applied. This subset of populations is called “source location”. Description of such models could be found as an example in Lacroix et al. (2013). An important aspect in larval dispersal is interannual variability, the lagrangian model needs to run on a long time period (10 years, the duration of an NAO cycle is a good approximation in North Atlantic) to catch this variability and improve identification of “source location”. If it is not possible, it is also possible to determine a potential range by considering the area close to the collecting(s) location.
4) Once the source location is identified. The module will monitor the different sources location to detect spawning events and determine when spat are likely to arrive from those areas in a selected site.

- Alarm detection of spawning events. Based on the criteria defined by the user, the module will detect spawning events in the different sources area identified by the users (or by development step). The threshold can be a single value or based on a time series. As an example, oyster spawning is based on the cumulative temperature upper than 7C (a threshold for gonad development of oysters) since the first of January, when this sum is upper a value (576 in this case) model considered a spawning event. In the case of mussels in the Belgian coastal zone, the threshold of spawning is when sea surface temperature reaches 10C in considered source location.
- Prediction of spat arrivals. Once the spawning alarm is detected in a source location, the program builds an interval where spats are likely to arrive. Lower bound of the interval is the sum of alarm’s date and minimum pelagic larval duration; upper bound is the sum of alarm’s date, maximum pelagic larval duration and duration of spawning period.

3.6.5 Execution/scheduling

The module is executed each day to allow users to have an overview of the coming weeks at the site. Services will stop after the end of spawning season.

3.6.6 Service provided

The services will return a table with the likely period of spat arrival at the collect site from the different source area.

The end users will receive weekly a table summarizing the likely period to collect the selected species at a specific location, to be distributed according to the central notification system (WP4).

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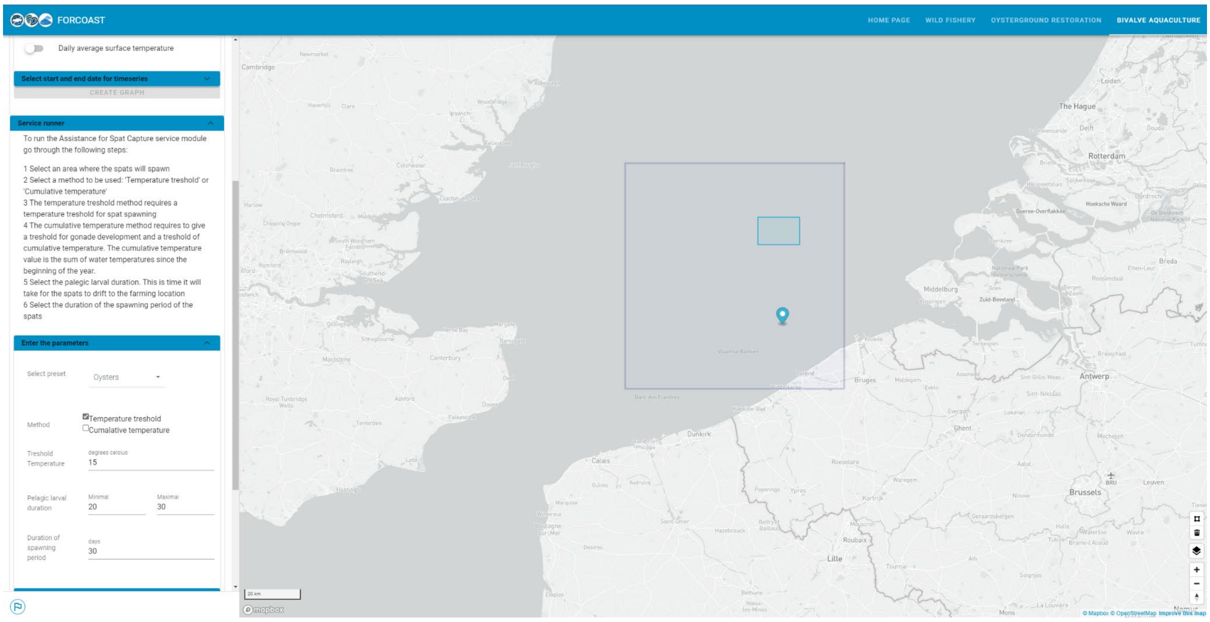
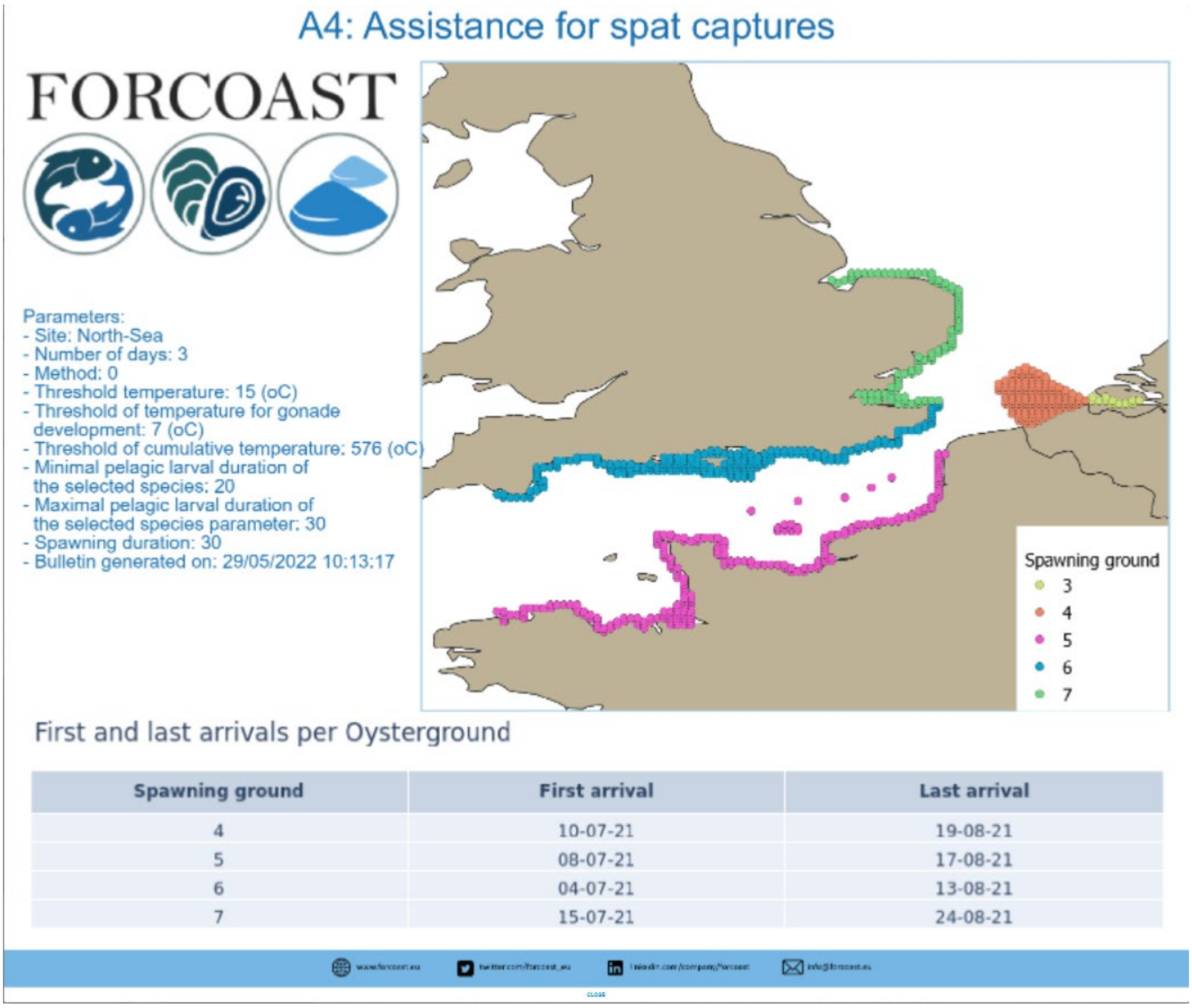


Figure 3.6.1 *- Mockup of the Spat Capture Assistance Service Module*



Spawning ground	First arrival	Last arrival
4	10-07-21	19-08-21
5	08-07-21	17-08-21
6	04-07-21	13-08-21
7	15-07-21	24-08-21

Figure 3.6.2 *- Bulletin of the Spat Capture Assistance Service Module*

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

3.6.7 Code source

The module is write in Python and will be available on https://github.com/naturalsciences (currently set as a private repository).

3.6.8 Status Check-list

SM Mock-up is defined	Done
SM implemented at Pilot level	Done
SM operational at Pilot level	Done
SM tested at another pilot	Will not be carried out during FORCOAST project
SM source code on Github (or similar)	Done
SM code repository on Zenodo	Not initiated yet, foreseen for September 2022
First implementation on central platform	Done
Bulletin	Done

Table 3.6.1- *Development status for SM-A4*

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

3.7 SM-R1: Contaminants Source Retrieval

3.7.1 General description

Water pollution poses a serious threat to the health of aquaculture species and human consumers. When the origin of pollution is unknown, farmers are often interested in finding out the source of contamination. The objective of this Service Module is to provide end users with an estimation of the source of contaminants by combining hydrodynamic modelling with backward particle-tracking modelling. This information can be displayed either as the actual paths followed by the pollutants or as a time-varying density distribution map, highlighting the areas with a higher probability to be the source of contamination.

3.7.2 User-Specific information

Under the current exploitation plan, the Service Module will be available in two versions. The first version will operate on demand under user's request. For each request, the user selects the location where contamination has been detected, either entering the coordinates or clicking on a map. Uncertainty can be added by selecting an initial dispersal radius. Finally, it is possible to add a switch, allowing the user to run the simulation either forward or backward in time. Retrieving sources of contaminants would require the user to select the backward mode. However, it is easy to increase the functionalities of this service module by adding a forward tracking option too.

The second version will be accessed through subscription, and will include scheduled runs and access to bulletins.

3.7.3 Marine information requirements

Grid, bathymetry and a binary land/sea mask must be provided. To track pollutants in 2D throughout the model domain, other mandatory inputs are the horizontal currents (u, v). Further optional inputs accepted by the particle tracking model (OpenDrift) are:

- Vertical component of currents (w) to allow pollutants to move along the water column.
- Wave forcing, to include the Stokes drift.
- Vertical diffusivity and/or turbulent parameterizations.

3.7.4 Scientific Rationale and Methods

The particle-tracking model is OpenDrift (Dagestad et al., 2018), an open-source Python-based framework for particle-tracking modelling developed by the Norwegian Meteorological Institute. In particular, the OceanDrift submodule is used, where water pollutants are regarded as perfect passive tracers. Backward particle-tracking model is used, where numerical floats are seeded and tracked to retrieve the areas where there is a higher probability that the contaminants come from. Probability is determined based on the density of numerical floats.

3.7.5 Execution/scheduling

This Service Module is run on demand when the user sends a request. The user, who has detected a contamination event affecting their farm, will enter the starting date and location and a dispersal radius. Then, the particle-tracking model is run. On the other hand, the subscription version offers scheduled runs for the farming area of interest.

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3.7.6 Service provided

The output is a NetCDF file generated by the particle tracking model. Densities of numerical floats are calculated afterwards for each time step and displayed separately on a time-varying heat map. Heat maps are complemented with a colorbar showing the probability associated with each grid cell.

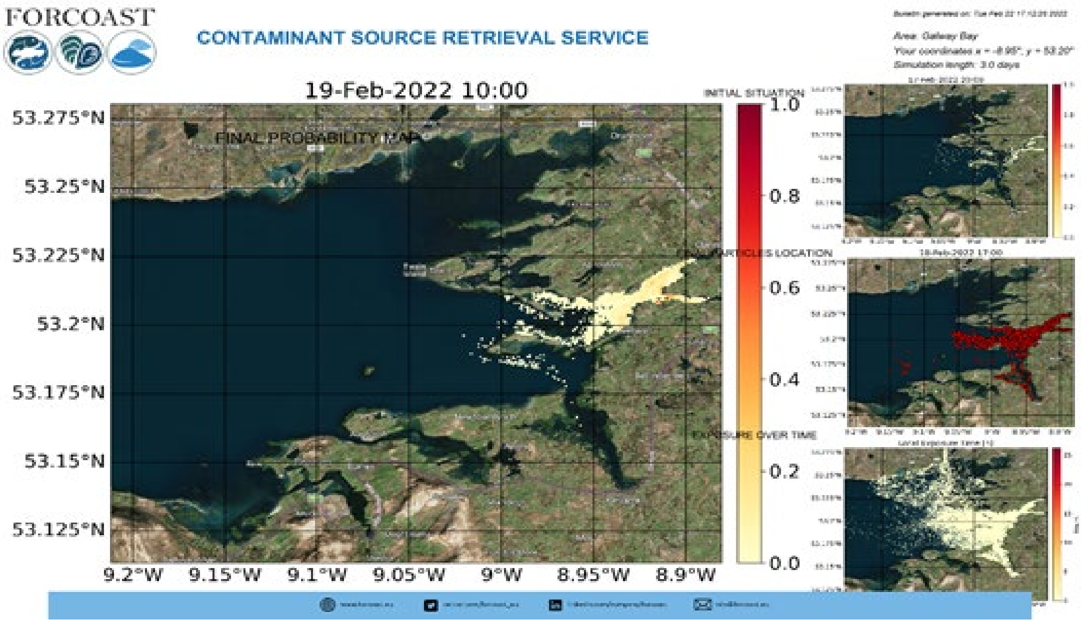

Figure 3.7.1. *- Example bulletin of the SM-R1 "Retrieve Sources of Contaminants".*

3.7.7 Code source

Code is available at https://zenodo.org/badge/latestdoi/416086387

3.7.8 Status Check-list

SM Mock-up is defined	Done
SM implemented at Pilot level	Done
SM operational at Pilot level	Done
SM tested at another pilot	Done
SM source code on Github (or similar)	Done
SM code repository on Zenodo	Done
First implementation on central platform	Done

Table 3.7.1 *: Development status for SM-R1*

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4 Description of supplementary files

In order to pave the way towards an operational cloud-level implementation of this service module portfolio via the central FORCOAST platform, deliverable D3.10 is complemented with an appendix gathering technical specifications. The appendixes consist of 4 specific overview tables.

- **Table 1 - Variable Nomenclature**: provides references and naming convention for state variables. This reference list is common with the Annex to D3.8-Model Inventory, that described the context through which variables are provided operationally by FORCOAST pilot models (ie. file naming conventions, data structure, temporal and spatial extent, etc..).
- **Table 2 - Marine Information Requirements:** lists, for each service modules, the variables of marine informations that are required for archiving the computations underlying the services, and precises the specifications of this requirement (eg. at least 3 days of forecasts, etc..). The columns of this tables are :
  - SM ID,
  - contact persons,
  - type of data (model/remote sensing,
  - variable name (based on Sheet 1),
  - forecast and/or hindcast requirement,
  - the required or optional nature of that variable,
  - preferred timestep, and
  - grid (regular or unstructured).
- **Table 3 - User Information Requirements:** lists the number of user-specific items to be defined for a tailored application of the service module. This concerns for instance, location of a farming site, thresholds for notifications, etc.. Columns for this sheet includes:
  - SM ID,
  - Contacts,
  - Description (eg. farming location),
  - Nature (eg. polygons of coordinates),
  - "defined through" (eg. user-dashboard point-and-click facility),
  - "saved in" (eg. YAML files).
- **Table 4 - Scheduling and Operations:** Defines the different steps of the postprocessing to be executed, such as computing advection tracks, deriving maps of concentrations, preparing netcdf outputs; etc.. The columns of this sheet includes :
  - SM IDs & Contacts,
  - Description (what task)
  - Scheduling : Regular update / Triggered by conditions/ upon subscription
  - Github reference for code repository
  - Status of Docker development
  - Production description for that specific step (eg. maps, text of notifications, trajectories)
  - Production format (e.g., .png files, netcdf file, etc..)
  - Type of user access (eg. smartphone notification, navigation tool, dashboard)

5 Conclusion

The concept of Service Module, and the overarching design for the system of services to be implemented within FORCOAST, match with the objectives of transferability, evolution and modularity. Such principles were adopted to ensure keeping the portfolio of FORCOAST services on-track with ever-increasing user demand and their awareness of numerical tools, as well as the ever-evolving quality and quantity of marine met-ocean data. The offer consolidated for the different sectors is to be considered in regards with the number of pilots dedicated to these sectors, and is considered as meeting the original objectives of the project.

Fisheries benefit from a detailed and complete tool (F1), whose transferability is somehow limited by the important underlying pilot-specific development undertaken by Pilot 3. On the other hand, the fronts detection module (F2) is considered as one of the most easily transferable SM, and is already reaching mature stages of development (ie. first tests ongoing on the central platform).

The Aquaculture sector is the most represented sector amongst the FORCOAST community. As such, the four dedicated service modules cover a wide range of specific operations : daily scheduling (A1), quality control (A2), prospection (A3) and stock management (A4).

The Oyster Ground Restoration sector is only represented in one pilot, but gathers an active and well-organized community. As such, two modules target specific purposes whose finality match the expectancy of the internal en-user community. In addition, it has been recognized that A3 only requires minor adaptations (i.e. to make optional the use of the DEB model specifically developed for Pilot 6) to cover up further needs of the Restoration sector, by providing a tool mapping the frequencies of environmentally induced mortality events.

	F1	F2	A1	A2	A3	A4	R1
	Suitable Fishing Areas	**Fronts Detection**	**Marine Conditions**	**Land Pollution**	**Site Prospection**	**Spat Capture Assistance**	**Contaminants Source Retrieval**
Mock-up							
Pilot Setup							
Pilot op. Setup							
Tested at other Pilot							
Github Repository							
Zenodo Repository							

Platform Setup							
Bulletin							

Table 5 *- Development status summary (at the time of reporting): Green stands for Done, Orange for ongoing/initiated, Red for Not Initiated (NI)/Not Foreseen. More details are given in the SM specific descriptions.*

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

Appendix 1 - Variable Nomenclature

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CF CONVENTIONS
https://cfconventions.org/Data/cf-standard-names/29/build/cf-standard-name-table.html

	CF standard name	Common name	Units	Dimension Longitude	Dimension Latitude	Dimension Depth
Coordinate	longitude					
	latitude					
Hydrodynamics	eastward_sea_water_velocity	Zonal Velocity	m s-1	x	x	x
	northward_sea_water_velocity	Merdional Velocity	m s-1	x	x	x
	upward_sea_water_velocity	Vertical velocity	m s-1	x	x	x
	ocean_vertical_heat_diffusivity	Vertical eddy diffusivity	m2 s-1	x	x	x
	ocean_vertical_diffusivity	Vertical eddy diffusivity	m2 s-1	x	x	x
	sea_water_temperature	Temperature	K	x	x	x
	sea_surface_temperature	Surface temperature	K	x	x	
	sea_water_temperature_at_sea_floor	Bottom temperature	K	x	x	
	sea_water_salinity	Salinity	-	x	x	x
	sea_surface_salinity	Surface salinity	-	x	x	
	sea_water_salinity_at_sea_floor	Bottom Salinity	-	x	x	
	ocean_mixed_layer_thickness_defined_by_mixing_scheme	Mixed Layer Depth	m	x	x	
	water_surface_height_above_reference_datum	Sea Water Level	m	x	x	
	turbulent_generic_length_scale	Turbulent Generic Length Scale	m3 s-2	x	x	x
	turbulent_kinetic_energy	Turbulent Kinetic Energy	m2 s-2	x	x	x
Waves	sea_surface_wave_significant_height	significant wave height	m	x	x	
	sea_surface_wave_mean_period	mean wave period	s	x	x	
	sea_surface_wave_stokes_drift_x_velocity	Stoke Drift Zonal Velocity	m s-1	x	x	
	sea_surface_wave_stokes_drift_y_velocity	Stoke Drift Meridional Velocity	m s-1	x	x	
	sea_surface_wave_mean_period_from_variance_spectral_density_second_frequency_moment		s	x	x	
	sea_surface_wave_period_at_variance_spectral_density_maximum		s	x	x	
Bio	mass_concentration_of_chlorophyll_a_in_sea_water	Chlorophyll	kg m-3	x	x	x
	mass_concentration_of_phytoplankton_expressed_as_chlorophyll_in_sea_water	Chlorophyll	kg m-3	x	x	x
	mole_concentration_of_nitrate_in_sea_water	Nitrate	mol m-3	x	x	x
	mole_concentration_of_phosphate_in_sea_water	Phosphate	mol m-3	x	x	x
	mole_concentration_of_dissolved_molecular_oxygen_in_sea_water	Oxygen	mol m-3	x	x	x
Index	hsi_suitability_index	Species favorability	-	x	x	x
	upwelling_area	Identified upwelling events area	-			
Bathymetry	bathymetry	Depth	m	x	x	x
	sea_floor_depth_below_sea_level	Depth	m	x	x	
	land_binary_mask	Mask		x	x	
Meteorology	x_wind	Wind Velocity X	m s-1	x	x	
	y_wind	Wind Velocity Y	m s-1	x	x	
	air_pressure	atmospheric pressure	Pa	x	x	
	air_temperature	air temperature	K	x	x	
	precipitation_amount	Rain	kg m-2	x	x	
	downwelling_shortwave_flux_in_air	Solar Radiation	W m-2	x	x	

Appendix 2 - Marine Information Requirements

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

		Data Input requirements						
Service Module	**Service Module Leader(s)**	**Model / Remote sensing**	**Input variable (use nc standard names)**	**Forecast Period**	**Hindcast Period**	**Required / Optional**	**Timestep**	**Grid**
F1 **Suitable Fishing Areas**	**Pilot 3** **Contacts** joanna.staneva@hereon.de elfa@phys.uni-sofia.bg ionut.serban@terrasigna.com	Model	bathymetry					regular
		Model	sea_surface_salinity		3 years	Required	1 d	regular
		Remote Sensing	mass_concentration_of_chlorophyll_a_in_sea_water		3 years	Required	1 d	regular
		Remote Sensing	sea_surface_temperature		3 years	Required	1 d	regular
		Model	sea_surface_wave_mean_period		3 yesrs	Required	1h	regular
		Model			3 years	required	1h	regular
		Model	sea_surface_temperature		3 years	required	1 d	regular
		Model	eastward_sea_water_velocity		3 years	required	1 d	regular
		Model	northward_sea_water_velocity		3 years	required	1 d	regular
F2 **Fronts Detection**	**Pilot 2** **Contacts** acaballero@azti.es; lferrer@azti.es; arubio@azti.es; cromay@marineinstruments.es; dlowe@marineinstruments.es	Remote Sensing	sea_surface_temperature	-	1d		1d	regular
		Remote Sensing	mass_concentration_of_chlorophyll_a_in_sea_water	-	1d		1d	regular
		Model	potential temperature	4d	-	At least one of these three products is required (note that model chl could be considered as well)	1h-4d	regular
A1 **Marine Conditions**	**Pilot 1 / Pilot 6** **Contacts** francisco.campuzano@colabatlantic.com joao.sobrinho@colabatlantic.com js@dmi.dk	Model	water_surface_height_above_reference_datum	14d	7d	Required	10min	timeseries or regular grid
		Model	X_Wind	14d	7d	Required	1h	timeseries or regular grid
		Model	Y_Wind	14d	7d	Required	1h	timeseries or regular grid
		Model/Equation	downwelling_shortwave_flux_in_air	14d	7d	Required	1h	timeseries or regular grid
		Model	precipitation_amount	14d	7d	Required	10min	timeseries or regular grid
A2 **Land Pollution**	**Pilot 7** **Contacts** luc@seamod.ro acapet@uliege.be	Model	eastward_sea_water_velocity	3d	10d	Required	1h-1d	regular
		Model	northward_sea_water_velocity	3d	10d	Required	1h-1d	regular
		Model	upward_sea_water_velocity	3d	10d	Required	1h-1d	regular
		Model	ocean_vertical_heat_diffusivity	3d	10d	Optional	1h-1d	regular
		Model	sea_surface_wave_significant_height	3d	10d	Optional	1h-1d	regular
		Model	sea_surface_wave_mean_period_from_variance_spectral_density_inverse_frequency_moment	3d	10d	Optional	1h-1d	regular
		Model	sea_surface_wave_stokes_drift_x_velocity	3d	10d	Optional	1h-1d	regular
		Model	sea_surface_wave_stokes_drift_y_velocity	3d	10d	Optional	1h-1d	regular
A3 **Site Propsection**	**Pilot 6** **Contacts** mam@bios.au.dk	Model	sea_water_temperature_at_sea_floor	-	9 years	Optional	monthly	unstructured
		Model	sea_water_salinity_at_sea_floor	-	9 years	Optional	monthly	unstructured
		Model	turbulent_kinetic_energy	-	9 years	Optional	monthly	unstructured
		Model	mass_concentration_of_chlorophyll_a_in_sea_water	-	9 years	Optional	monthly	unstructured
		Model	mole_concentration_of_dissolved_molecular_oxygen_in_sea_water	-	9 years	Optional	monthly	unstructured
		Model	mass_concentration_of_detritus_in_sea_water	-	9 years	Optional	monthly	unstructured
A4 **Spat Capture Assistance**	**Pilot 4** **Contacts** leo.barbut@naturalsciences.be glacroix@naturalsciences.be slegrand@naturalsciences.be	Model	sea surface temperature	5d	1 year	Required	1d	regular
		Model	northward_sea_water_velocity	5d	1 year	optional	1h	regular
		Model	eastward_sea_water_velocity	5d	1 year	optional	1h	regular
		Remote Sensing	mass_concentration_of_chlorophyll_a_in_sea_water	-	1 month	optional	1d	regular
R1 **Contaminant Source Retrieval**	**Pilot 5** **Contacts** tomasz.dabrowski@marine.ie diego.pereiro@marine.ie	Model	land_binary_mask	-	-	Required	-	regular
		Model	sea_floor_depth_below_sea_level	-	-	Required	-	regular
		Model	eastward_sea_water_velocity	3 d	10 d	Required	1 h	regular
		Model	northward_sea_water_velocity	3 d	10 d	Required	1 h	regular
		Model	upward_sea_water_velocity	3 d	10 d	Optional	1 h	regular
		Model	ocean_vertical_diffusivity	3 d	10 d	Optional	1 h	regular
		Model	sea_surface_wave_mean_period_from_variance_spectral_density_second_frequency_moment	3 d	10 d	Optional	1 h	regular
		Model	sea_surface_wave_period_at_variance_spectral_density_maximum	3 d	10 d	Optional	1 h	regular
		Model	sea_surface_wave_significant_height	3 d	10 d	Optional	1 h	regular
		Model	sea_surface_wave_stokes_drift_x_velocity	3 d	10 d	Optional	1 h	regular
		Model	sea_surface_wave_stokes_drift_y_velocity	3 d	10 d	Optional	1 h	regular
		Model	turbulent_generic_length_scale	3 d	10 d	Optional	1 h	regular
		Model	turbulent_kinetic_energy	3 d	10 d	Optional	1 h	regular

Appendix 3 - User Information Requirements

Service Module		Service Module Leader (s)	User Specific Inputs (rows do not have to correspond with previous columns)			
			Description	consists of	Defined through	Saved in
F1	Suitable Fishing Areas	Pilot 3 Contacts sorin.constantin@terrasigna.com ionut.serban@terrasigna.com, elfa@phys.uni-sofia.bg, jstaneva@icbm.de	Navigation options.	longitude, latitude	User-dashboard, point and click + editable coordinates	Not saved. Upon navigation.
F2	Fronts Detection	Pilot 2 Contacts acaballero@azti.es; lferrer@azti.es; arubio@azti.es; cromay@marineinstruments.es; dlowe@marineinstruments.es	No specific infomration needed. Only navigation options through the central platfrom navigation tool.			
A1	Marine Conditions	Pilot 1/6 Contacts campuzanofj.maretec@tecnico.ulisboa.pt	Location of the aquaculture production areas	Latitude & Longitude, optimum water level, thresholds of environmental limiting factors, mobile phone number(s)	Email or formulaire or dashboard - not defined yet	to be defined
			Location of the aquaculture production areas	Latitude & Longitude, optimum water level, thresholds of environmental limiting factors, mobile phone number(s)	Email or formulaire or dashboard - not defined yet	to be defined
A2	Land Pollution	Pilot 7 Contacts luc@seamod.ro acapet@uliege.be	Farming polygons	arrays of longitude, lattitude for each farming site + names	User-dashboard , point and click + editable coordinates	YAML file
			Release Sources	coordinates and name for each sources	User-dashboard , point and click + editable coordinates	YAML file
			Risk Scale	Arbitrary risk value ([0-1]) assigned to different class of pollutant's age since release	User-dashboard, sliders	YAML file
A3	Site Prospection	Pilot 6 Contacts mam@bios.au.dk	Scoring indices (0-1) for the considered species, eg. temperature, salinity tolerance, food requirements, inhibition by POM, sensitivity to hypoxia	scoring values between 0 to 1	User-dashboard, text entry	png file
A4	Contaminant Source Retrieval	Pilot 4 Contacts leo.barbut@naturalsciences.be glacroix@naturalsciences.be	Source area (can be provided by devlopement step if needed)	coordinates and names for each sources	text file with coordinates / point and click + editable coordinates	to be defined
			condition of spawning event (can be provided by devlopement step if needed)	thresholds for spawning and type (Temperature or cumulate temperature)	user dash board	to be defined
			pelagic larval duration (can be provided by devlopement step if needed)	2 value of PLD (minimum and maximum) in days	user dash board	to be defined
			duration of spawning period (can be provided by devlopement step if needed)	1 values in days	user dash board	to be defined
R1	Retrieve Sources of Contaminants	Pilot 5 Contacts tomasz.dabrowski@marine.ie diego.pereiro@marine.ie	Site location	longitude, latitude	User-dashboard, point and click + editable coordinates	to be defined
			Date	time	User-dashboard, calendar widget or text entry	to be defined
			Dispersal radius	meter (radius of uncertainty)	User-dashboard, slider or text entry	to be defined

Appendix 4 - Scheduling and Operations

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

Service Module		Service Module Leader (s)	Processing and outputs							
			Description	Scheduling	Scheduling trigger	Code Repository	Docker ?	Production (description)	Production (type of outputs)	Type of user access
F1	**Suitable Fishing Areas**	**Pilot 3** **Contacts** sorin.constantin@terrasigna.com ionut.serban@terrasigna.com, elfa@phys.uni-sofia.bg, jstaneva@icbm.de	Prepare fish index, upwelling data and extreme waves	Demonstration	daily	https://github.com/FORCOAST/Test-FORCOAST-SM-F1	Yes	Maps	netcdf, GeoTIFF	User Dashboard
F2	**Fronts Detection**	**Pilot 2** **Contacts** acaballero@azti.es; lferrer@azti.es; arubio@azti.es; cromay@marineinstruments.es; dlowe@marineinstruments.es	Location of chlorophyll and sst fronts from remote sensing and model data	Regular	Daily	https://github.com/dminst/ForCoast-SM-F2	Yes	Fronts maps	netcdf file	User Dashboard
A1	**Marine Conditions**	**Pilot 1/6** **Contacts** campuzanofj.maretec@tecnico.ulisboa.pt js@dmi.dk	24-72h forecast	Regular	Daily	https://github.com/FORCOAST/FORCOAST_SM_A1.	Yes	Charts/images	Timeseries output with high temporal resolution	existing smartphone app
			Weekly forcast (send thursday and includes from Monday to Sunday next week)	Regular	Weekly	https://github.com/FORCOAST/FORCOAST_SM_A1.	Yes	Charts/images	Timeseries output with high temporal resolution	existing smartphone app
A2	**Land Pollution**	**Pilot 7** **Contacts** luc@seamod.ro acapet@uliege.be	Compute advection	Regular	Daily	https://github.com/acapet/ForCoast-SM-A2	Yes	Lagrangian tracks	Parcels netcdf file	
			Compute risk of exposure	Regular	Daily	https://github.com/acapet/ForCoast-SM-A2	Yes	Alarms	.txt file with dates	
			Send notifications	Regular	Daily	https://github.com/acapet/ForCoast-SM-A2	Yes	Bulletins	.png bulletin	User account notification system
			Prepare animated bulletin	Regular	Daily	https://github.com/acapet/ForCoast-SM-A2	Yes	Animated GIf -> Telegram	.gif bulletin	User account notification system
A3	**Site Prospection**	**Pilot 6** **Contacts** mam@bios.au.dk	Identify optimal locations for shellfish culturing and restoration	Regular	yearly	https://github.com/FORCOAST/Test-FORCOAST-SM-A3	Yes	maps of indicies for shellfish culturing/restoration	png maps and timeseries	User Dashboard
A4	**Spat Capture Assistance**	**Pilot 4** **Contacts** leo.barbut@naturalsciences.be glacroix@naturalsciences.be	development step upon new subscription	Upon Subscription		Lagrangian dispersal model + compilation of scientific litterature. This step depend of the area and species	Yes	Spatial polygone of spawning likely to provide spat	text file	
			Predict mussel settleme	Regular	weekly	https://github.com/naturalsciences	Yes	Short message	.txt file summarizing alarm	User Dashboard / notification system
			Predict oyster settlement	Regular	weekly	https://github.com/naturalsciences	Yes	Short message	.txt file summarizing alarm	User Dashboard / notification system
R1	**Contaminant Source Retrieval**	**Pilot 5** **Contacts** tomasz.dabrowski@marine.ie diego.pereiro@marine.ie	Backward tracking of pollutants from oyster farms	Triggered	Upon user request	https://github.com/irishmarineinstitute/adrift/tree/opendrift	Yes	Lagrangian tracks	.nc	User Dashboard - WMS viewer
			Map, animation	Triggered	Upon user request	https://github.com/irishmarineinstitute/a	Yes	Map	.png	User Dashboard - WMS viewer