Studies to support the European Green Deal

Lot 1 Shellfish and algae

Interim Report 2022/05/23

CINEA/EMFF/2020/1.3.1.16/Lot 1

WPM –Task 0: Management

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WPM –Task 0: Management: Overview

This study is commissioned by the European Commission (EC) to support **the European Green Deal**

The specific objective is :

- ⇨ to assess the potential of shellfish and algae to recycle nutrients
- ⇨ to estimate the greenhouse gas emissions generated by their production.

It is a matter of balance between benefits and drawback, using mathematical modelling and optimization.

The general objective is :

- ⇨ to produce digital raster maps of European marine waters
- ⇨ that help plan and analysis of marine aspects of the **Green Deal**

WPM –Task 0: Management: Schedule and Milestone

Today

	M0		M1		M2		M3		M4		M5		M6		M7		M8	
Task 0																		
Task 1																		
Task 2																		
Task 3																		
Task 4																		
Task 5																		
Deliv.	IncR										dIR		IR			dFR		FR
Pres	P1											P2					P3	

IncR : Inception report (validated by CINEA)

P1: Presentation of Inception Report to Steering committee (Done)

dIR : draft Interim Report => **Sent to CINEA on 18/05/2022**

P2: Presentation of Interim Report (draft) to Steering committee => **23/05/2022**

IR : Interim Report => **beginning of June:**

- Submission of Final version of the interim report (including comments following the presentation)
- Submission of interim request for payment (50%)

dFR : draft Final Report + deliverables (T0 + 8 months) => end of July

P3: Presentation of Final Report (draft) to Steering committee => mid of August

FR : Final Report + final version of deliverables (T0 + 9 months) => **end of August !!!**

WPM –Task 0: Management - Achievements

Throughout the project, **monthly meetings** between the partners were held on the last Thursday of each month:

- 27 January
- 24 February
- 31 March
- 28 April

A **meeting with CINEA** was held on 15 February at the request of the consortium to clarify certain points concerning subtasks 2.3 (Nutrient availability model) and 2.6 (impacts on fishing)

WP1 Internal **weekly meetings** were held to review the progress of the developments

WP1 **meetings between partners** ARGANS/BMRS or ARGANS/COFREPECHE were held to clarify various points.

WPM –Task 0: Management - Achievements

WP1 T1 – Development :

- The plateform is operational
- Seaweed model is integrated
- The web interface is under testing / refinement and can launch the models

WP1 T2 – Analysis:

- 2.1 Seaweeds model is operational
- 2.1 Shellfish model is implemented and under testing / refinement and will be intergrated soon on the platform
- 2.2 Farm model is implemented and under testing / refinement (based on the results of T2.1)
- 2.3 Nutrient availability model is in under testing / refinement . The results simulated on a sub-area will be tested with real data on the whole area
- 2.4 Farm optimisation algorithm is under study
- 2.5 Net CO_2 emission is under testing / refinement and will be intergrated soon
- 2.6 Impacts on fishing : the methodology is finalised

WP2 Production:

- T3 : Preparing digital maps has began and will be integrated soon. Draft of Emodnet maps is available for Seaweed growth
- T4 : writing an article will be initiated soon, based on the results of seaweed growth

WP3 T5 – Uptake :

- Will start in few weeks

WPM –Task 0: Management - Staff movements

Quentin Jutard joined **ARGANS** in early January. He graduated from ENSTA ParisTech and holds an additional Master's degree in Environmental Sciences from the University of Paris-Saclay. He has a strong background in mathematics, computer science and physical sciences. He will be responsible for ensuring the link between the scientific teams and the developers.

Margaud Boyer has recently joined **COFREPECHE**. She replaced Chloé Guillerme in mid April. She graduated from the ENSAIA (National Engeenering School of Agronomy and Food Industry). She specialised in environmental engineering and fisheries science, and in coastal and marine issues.

WPM –Task 0: Management - Deviation

- Some facts that have or will disrupt the planned course of the project:
  - Yéelen (Cofrepeche) is on maternity leave since few months
  - Chloé (Cofrepeche) has leave the project in April

  =>Thus Margaux (Cofrepeche) joins the project and must take over their projects

  - Nikolai (ARGANS-FR) will be is on paternity leave in June

  - Martin (BMRS) will be unavailable at the beginning of September due to family commitments

WPM –Task 0: Management: Next steps

<u>Plan for the coming months:</u>

- Continue monthly/weekly meetings
- Finalise WP1
- Generate maps for WP2 (T3)

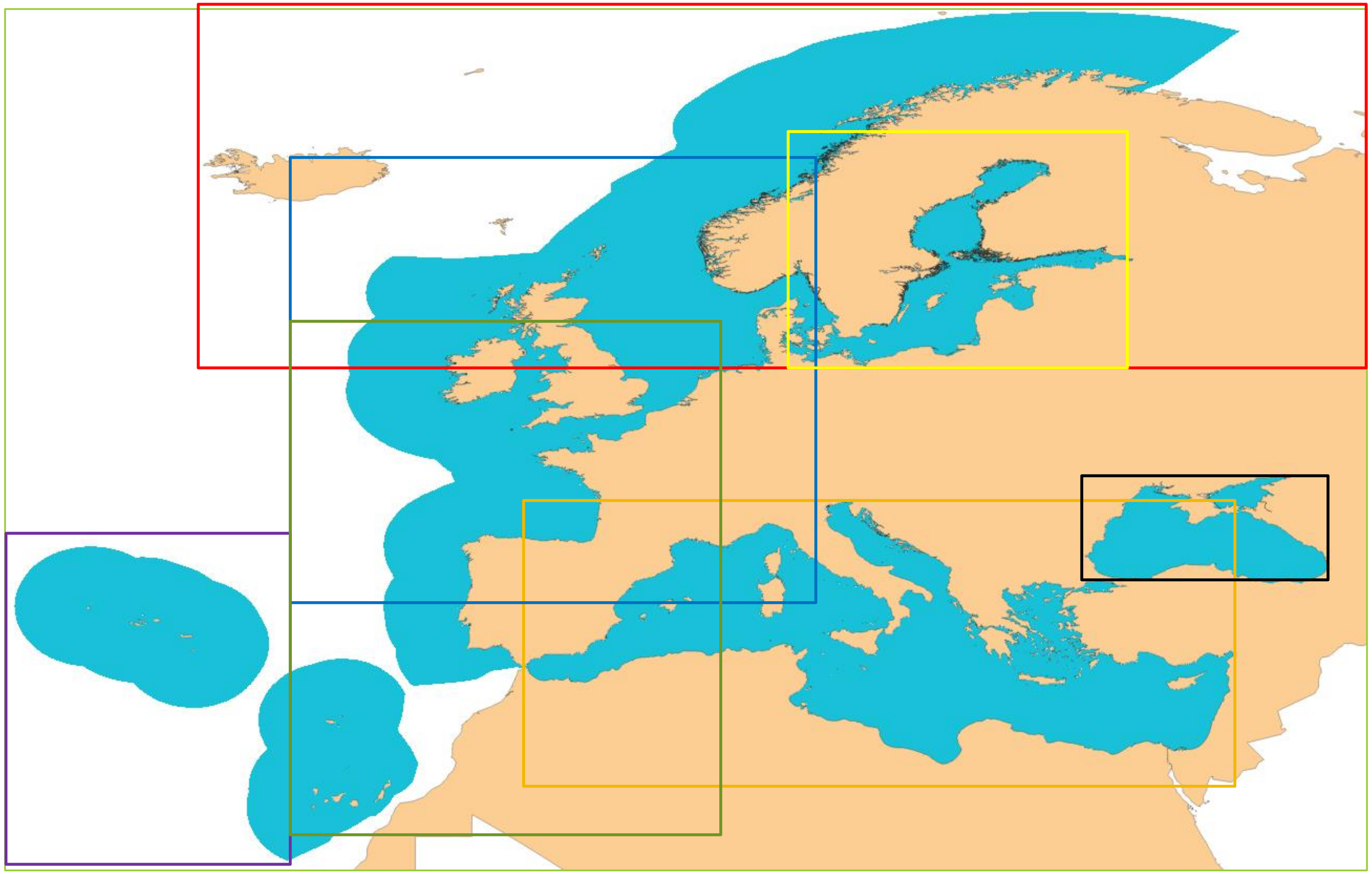
WPM –Task 0: Management – Questions to the European Commission

Copernicus database is divided in 6 areas for European Seas:

- Artic
- Baltic sea
- North West Shelf
- Ireland-Biscay-Iberia
- Mediterranean sea
- Black sea

They do not cover the whole of the exclusive economic zones (EEZ) of EU members states :

- the EEZ of the Azores
- a part of the EEZ of Madeira and the Canaries.

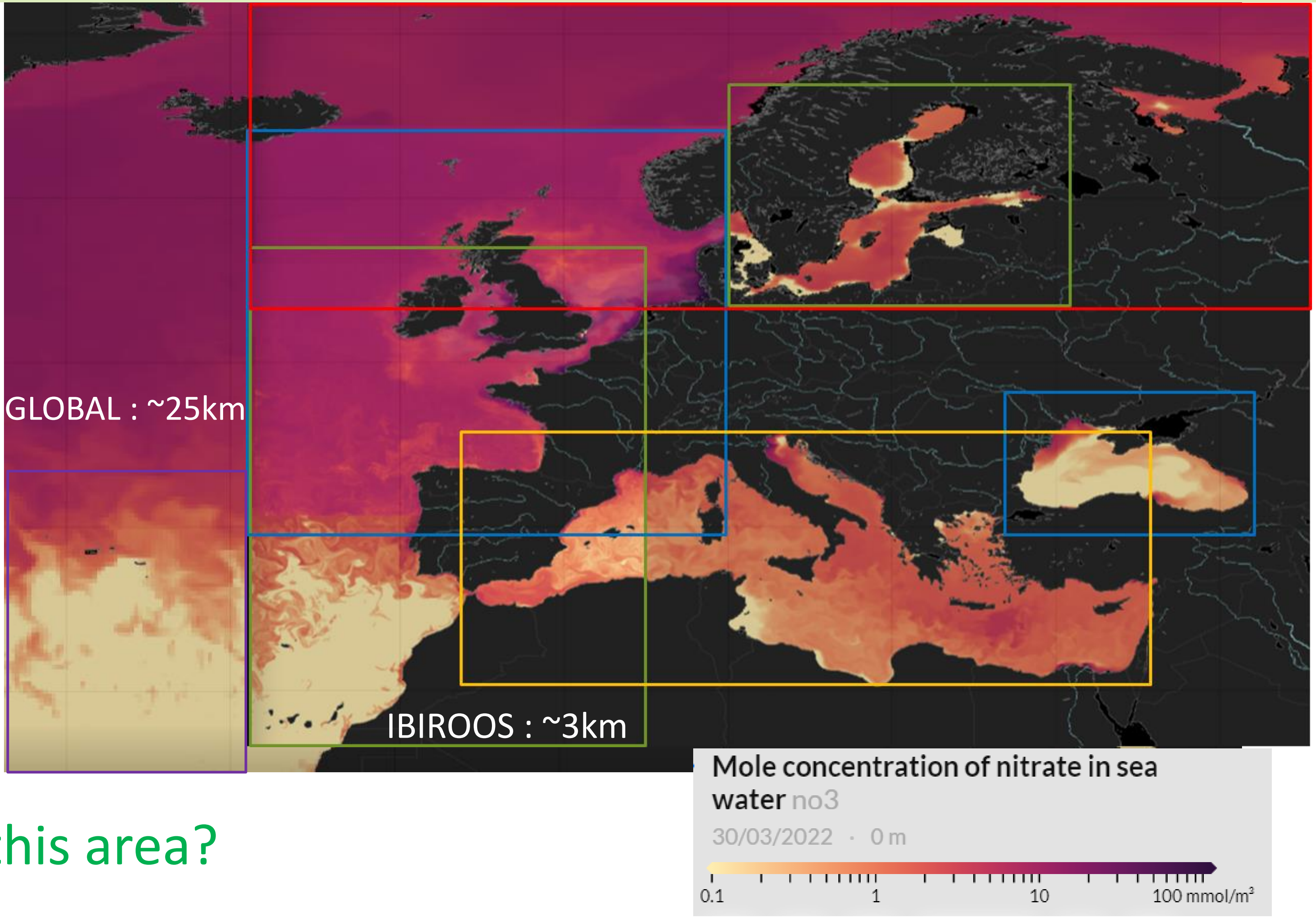


These **areas** are only covered by Copernicus global data with a lower resolution of 8 to 25 km

WPM –Task 0: Management – Questions to the European Commission

We have informed CMEMS of this. There is ongoing action in discussion with Portugal to include Madeira.

The resolution in these areas will give much less fine results than for the rest of the European waters.



Do we still treat this area?

WPM –Task 0: Management – Questions to the European Commission

The project should be finished by the **end of August** during the summer holidays :

*Because of the limited availability of everyone at that time, could the end of the project be **postponed by 6 to 8 weeks** so mid or end of October ?*

Discussion :

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ARGANS

WP 1 – Development – Task1 : Development & test software - Overview

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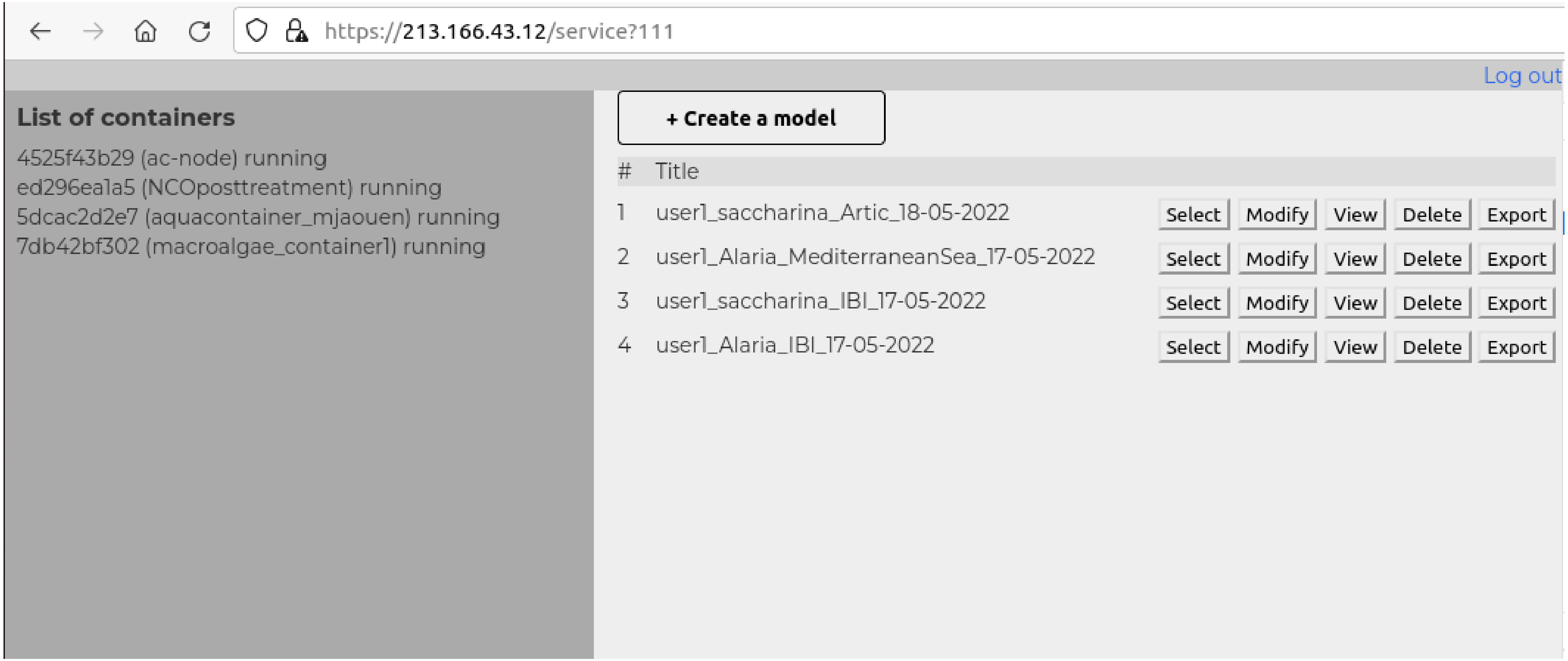
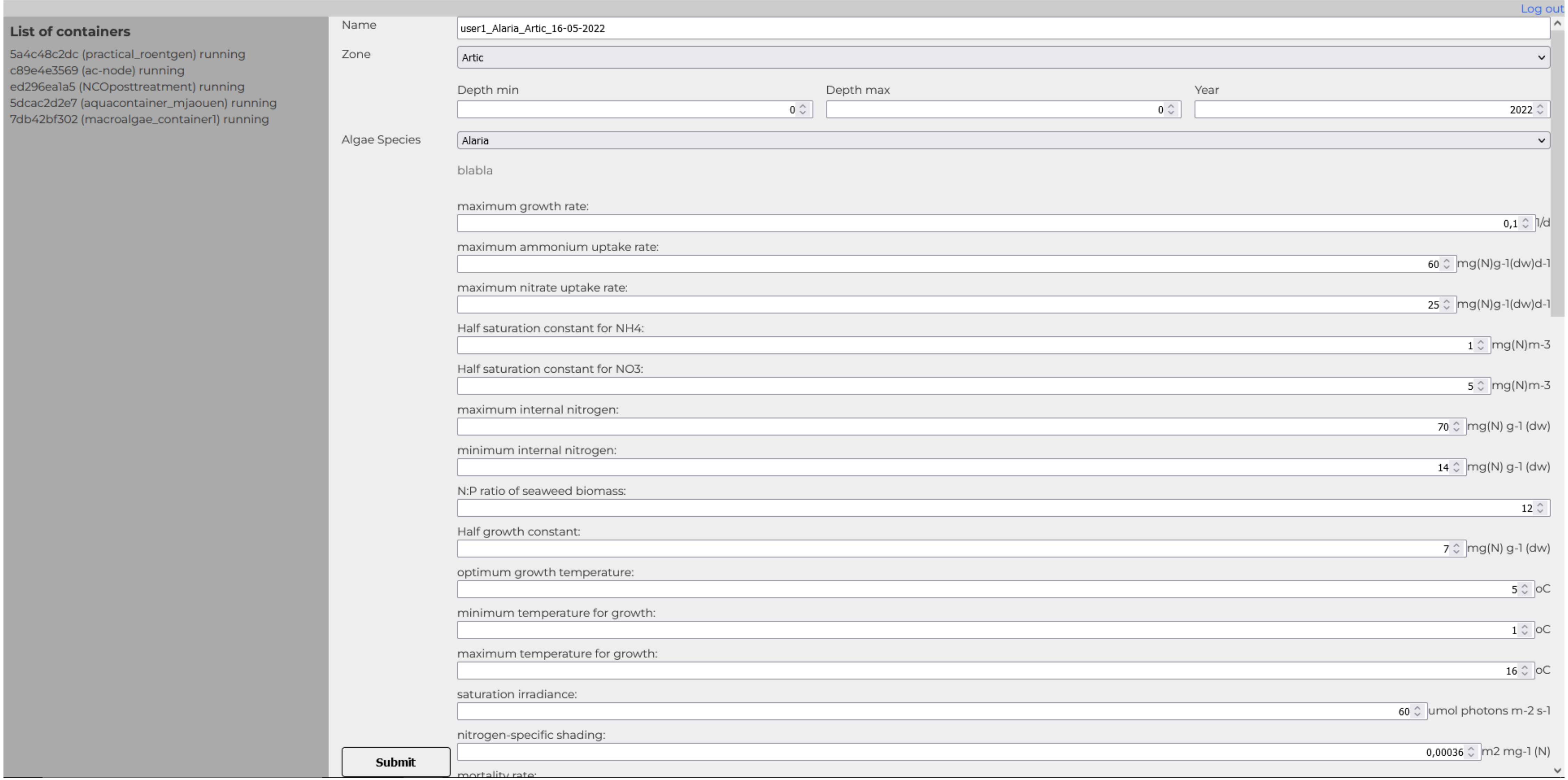
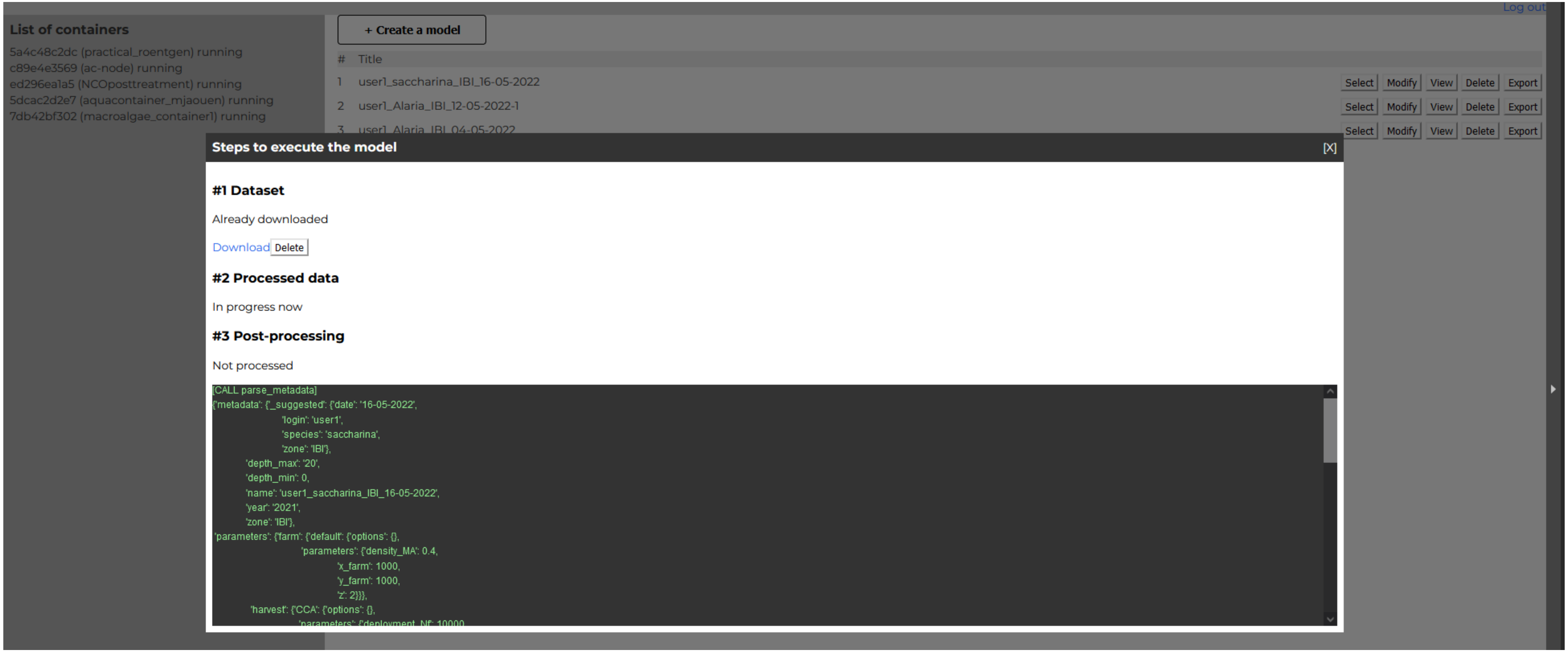


WP 1 – Development – Task1 : Development & test software - Overview



WP 1 – Development – Task1 : Development & test software - Overview



Achievements

- Storing model data in a database.

  About 10-20 min of download time per EU sub-area per year if the data is not already stored.

- Automation of the code for importing and reading data in a non-interactive mode on the server, then compute the macroalgae model.

  About 2-3h of computation time per EU sub-area per year spread across 10 cores.

- The user is able to download tiff files of a number of interest variables:
  - Dry weight (per volume, per length of line, per unit area)
  - Full weight(per volume, per length of line, per unit area)
  - Kcal per unit area
  - Protein weight per unit area
  - Biomass CO2 per volume
  - CO2 emission per unit area

Deviation

- The executed data import code may not return results for some user-provided dataset properties. The code should be debugged or include explanations for the user in the documentation.
- We still have problems connecting via ssh. This happens from time to time and is caused by the network configuration.
- The execution of code in a virtual machine is not visible to users, users cannot receive an exception that may occur during code execution.

WP 1 – Development – Task1 : Development & test software - Next steps

Plan for the coming months:

- Resolve user experience issues
- Provide a solution for overlaying Tiff files on a map
- Open the VM to Cofrepeche for testing

WP1 – Development – Task1 : Development & test software

By the end of the project:

- Include the shellfish model in the same interface
- Implement the possibility to do simulations following scenarios b and c
- Make the interface more visually appealing

WP1 – Development – Task1 – Questions to the European Commission

- Should the NetCDF file(s) delivered to emodNET contain all variables at once or should they be separated into distinct files?

Thank you for your attention

WP1 – Analysis

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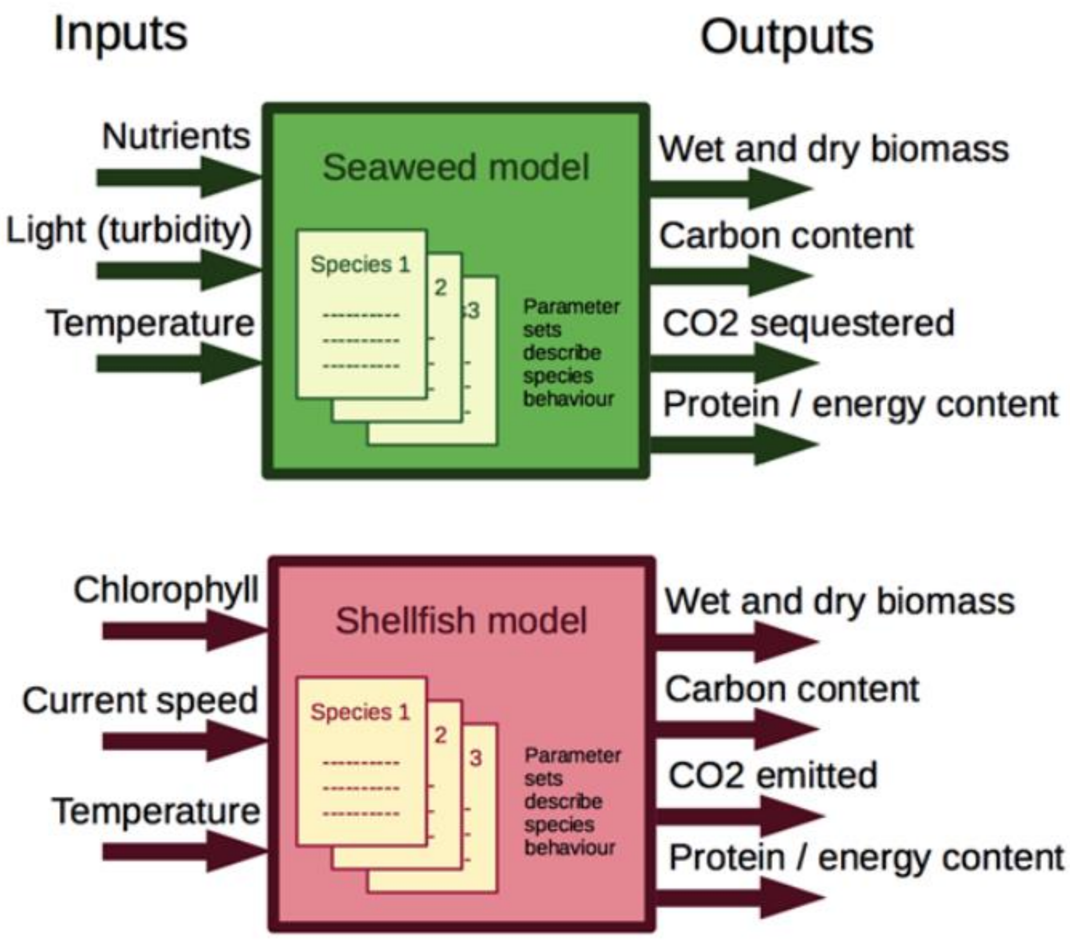
WP1 – Analysis – Task 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling - Overview

Modelling approach

- Box modelling approach to biomass growth
- Adapt published + validated multispecies models for seaweed (Hadley et al., 2015) and shellfish (Hawkins et al., 2013)
- Develop parameter sets for species not already covered by the models
- Key characteristic: Flow-through modelling of nutrient / food availability (i.e. partially or fully replenished per timestep)



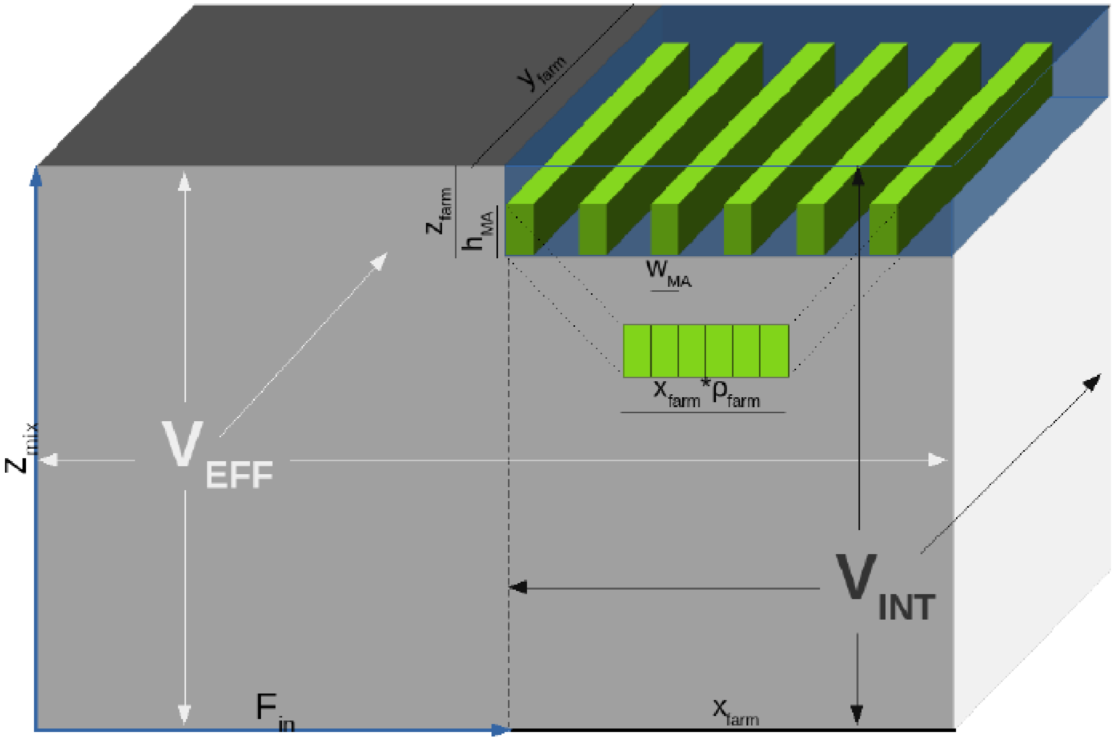
Hadley, S., Wild-Allen, K., Johnson, C., & Macleod, C. (2015). Modeling macroalgae growth and nutrient dynamics for integrated multi-trophic aquaculture. *Journal of Applied Phycology*, *27*(2), 901–916. https://doi.org/10.1007/s10811-014-0370-y

Hawkins, A. J. S., Pascoe, P. L., Parry, H., Brinsley, M., Black, K. D., McGonigle, C., Moore, H., Newell, C. R., O'Boyle, N., Ocarroll, T., O'Loan, B., Service, M., Smaal, A. C., Zhang, X. L., & Zhu, M. Y. (2013). Shellsim: A Generic Model of Growth and Environmental Effects Validated Across Contrasting Habitats in Bivalve Shellfish. *Https://Doi.Org/10.2983/035.032.0201*, *32*(2), 237–253. https://doi.org/10.2983/035.032.0201

WP1 – Analysis – Task 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling - Progress

Summary of achievements to date:

- *Seaweed model developed*
  - *Behaviour characterised*
  - *Parameterised for 3 species*
  - *Run on analysis system for wide domain (NWES)*
  - *Results compared at key test site – Bantry Bay*
- *Shellfish model developed*
  - *Behaviour characterised*
  - *Parameterised for 2 species (3rd to follow)*
  - *Results compared at key test site – Bantry Bay*
- *Post processing models give key parameters of interest: protein, energy, biomass yield*
- *Simple CO2 emissions model for seaweed farms implemented.*

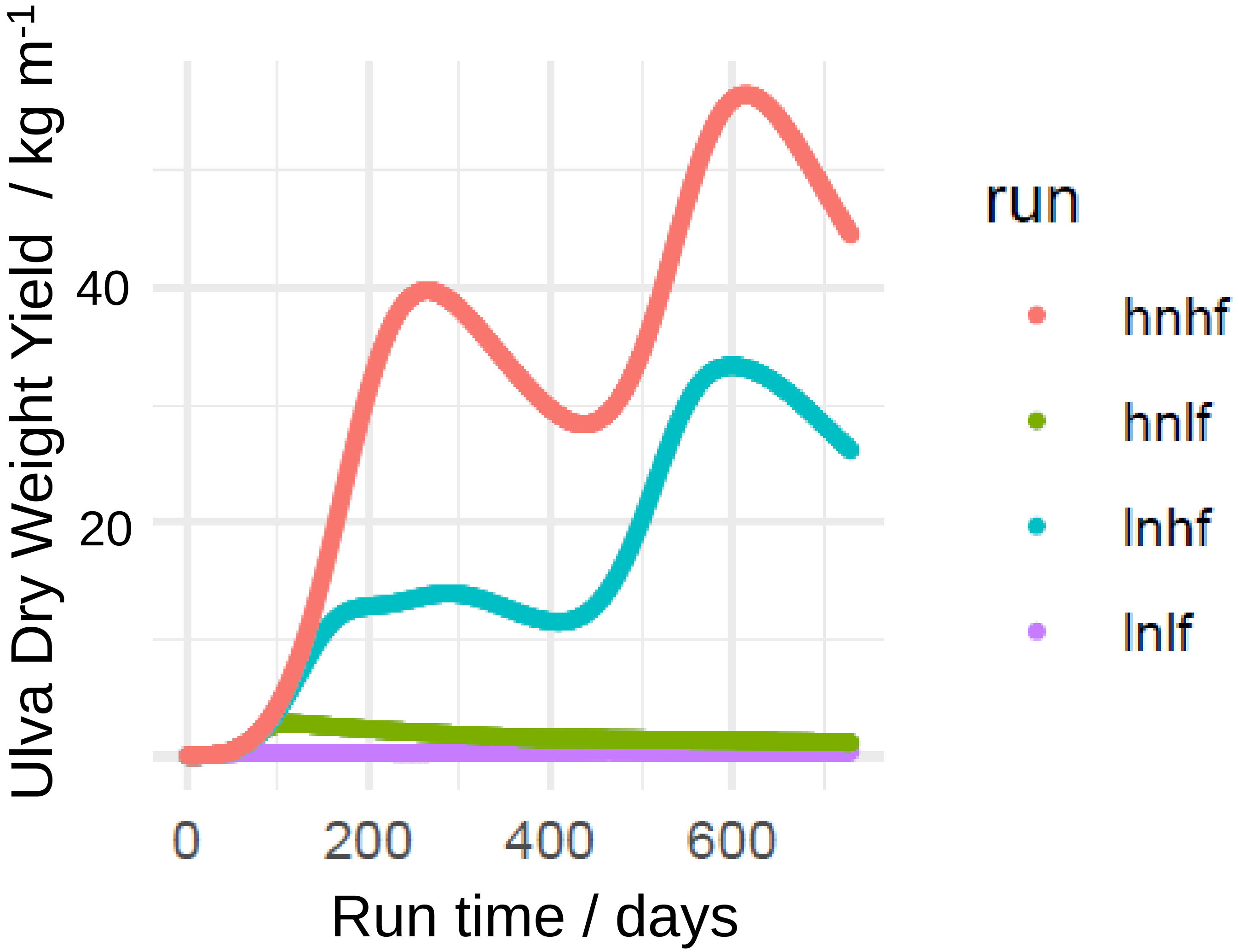


Above: seaweed model schematic demonstrating that farm interacts with wider body of water, the volume of which is determined by flow rate and mixing depth

WP1 – Analysis – Task 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling - Results

Seaweed model behaviour

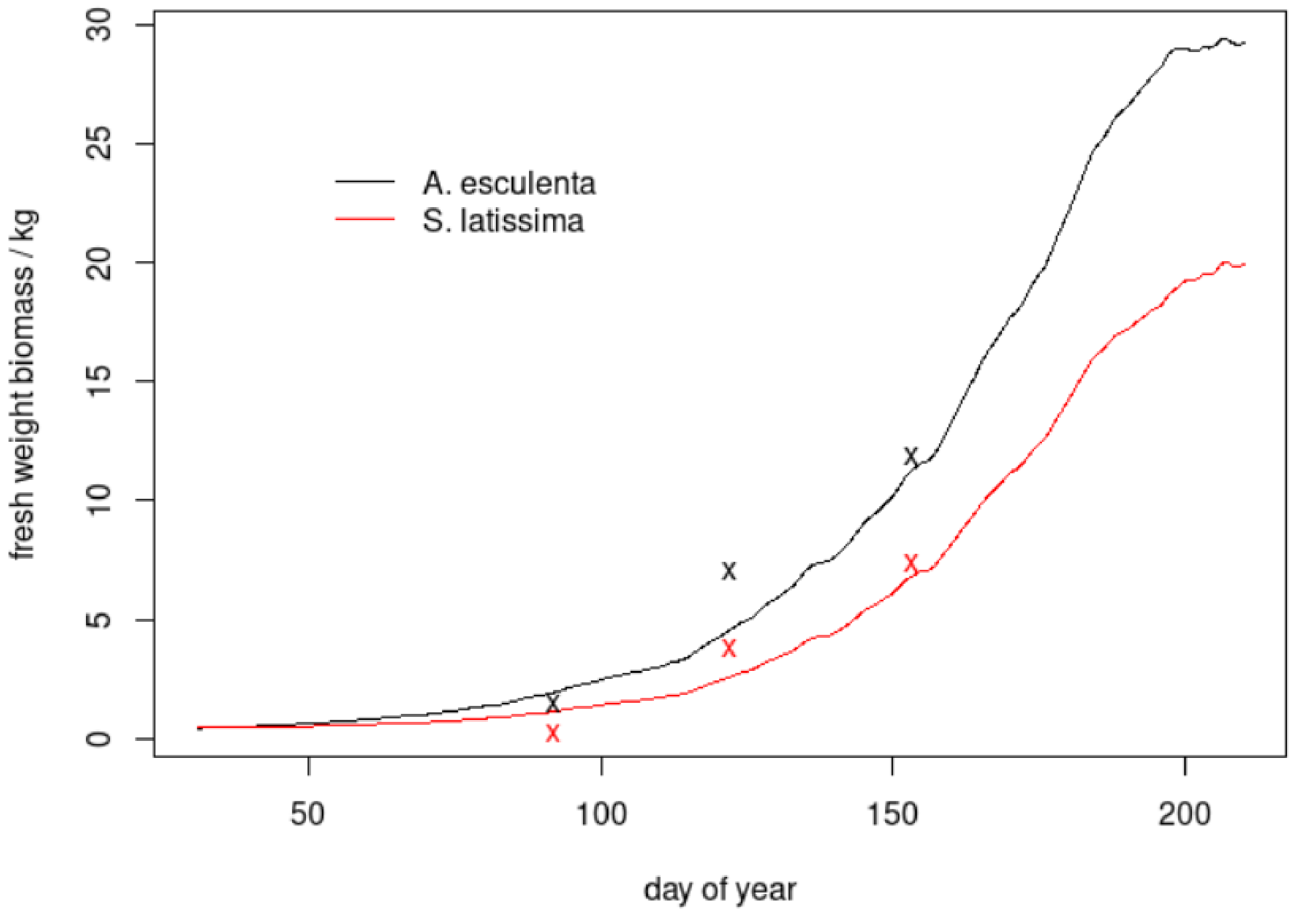
- Reference runs compare high / low nutrient and high / low flow conditions
- Flow rate (i.e. resupply of nutrients) is key for maintaining growth
- Absolute nutrient concentration at which growth is viable depends on species-specific nutrient affinity parameters



WP1 – Analysis – Task 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling - Results

Bantry Bay results

- ***Model uses literature-derived parameters for S. latissima and A. esculenta, with tunable model parameter set to optimal values.***
- ***Driven by CMEMS environmental data for Bantry Bay grid square for 2020***
- ***IDREEM data for species grown at Bantry Bay site in 2015***
- ***Generally good agreement in relative performance of Alaria vs Saccharina***



WP1 – Analysis – Task 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling - Results

IBI region run for S.Latissima

Note high productivity areas largely coincide with areas of high aquaculture activity (inset – source *https://ec.europa.eu/jrc/en/science-update/algae-biomass-production-bioeconomy#:~:text=In%20contrast%20to%*
0the%20global,based%20in%2015%20Me
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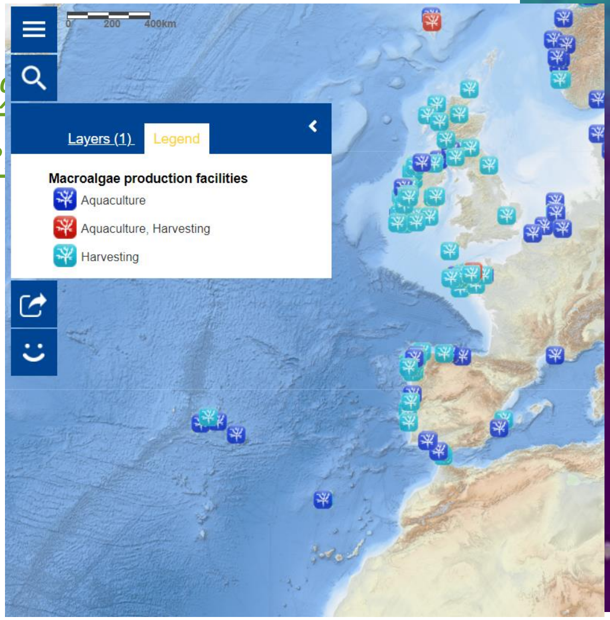
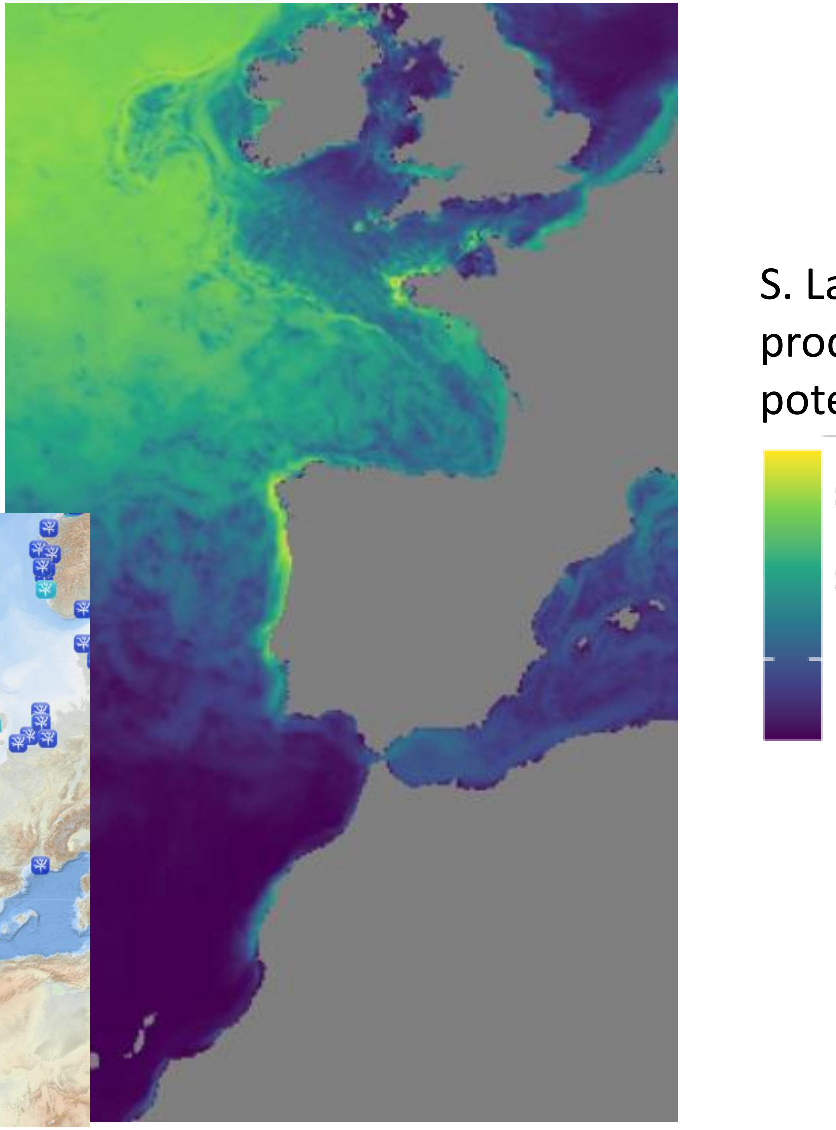




S. Latissima production potential

kg /m^2

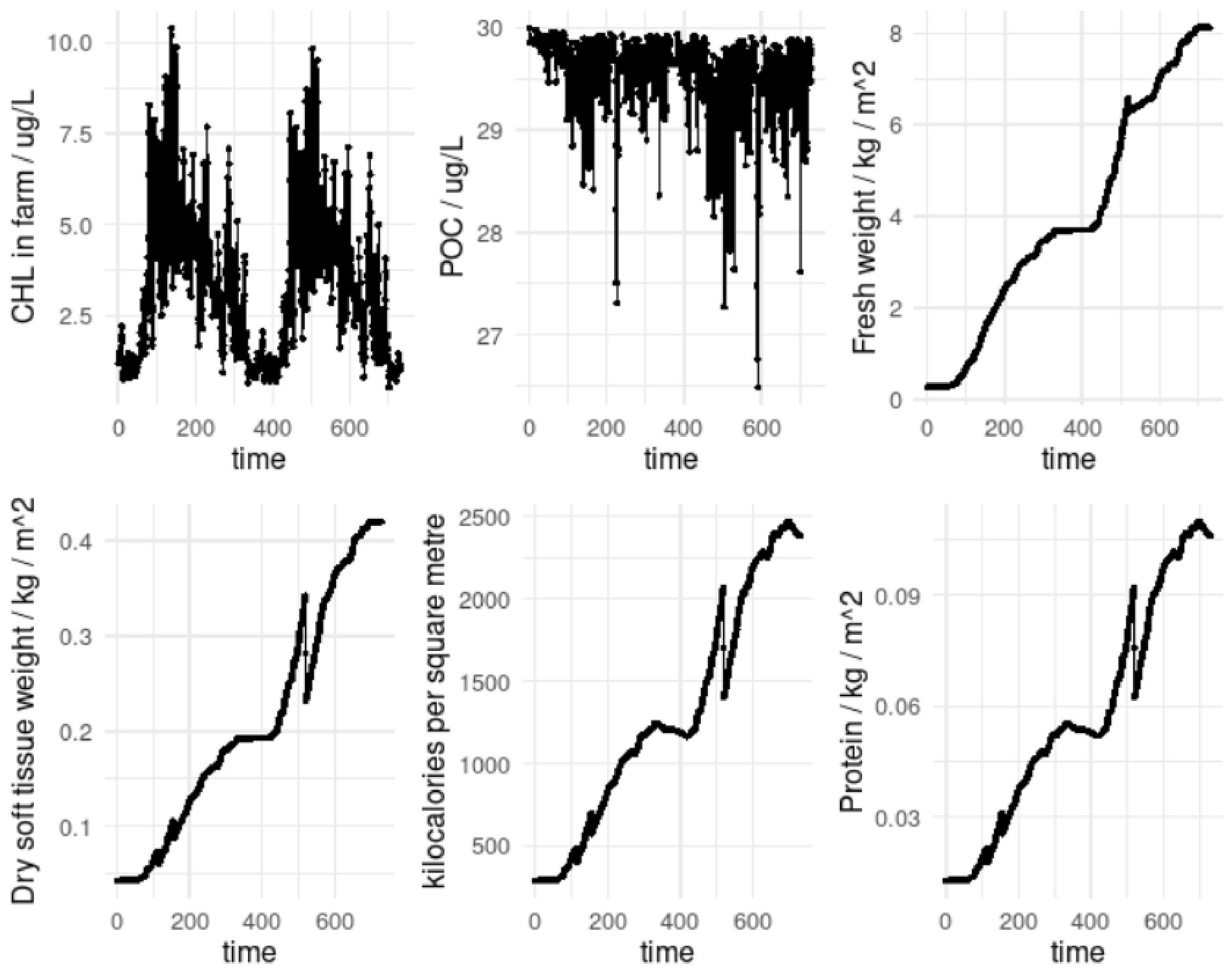
(dry weight)

WP1 – Analysis – Task 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling - Results

Shellfish model Bantry bay – M Edulis run

Model captures spawning and general patterns of growth well.

Productivity is low in the model at Bantry Bay by about a factor of 2 compared to observational data from 2015 (model run with 2020 data).



WP1 – Analysis – Task 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling - Deviations

- We have had to implement more complex models than originally envisaged in order to meaningfully characterise the behaviour of different species.

- With the complexity also comes a lack of robustness. E.g. representing within species plasticity in temperature response for instance.

- There will be substantial uncertainty associated with biomass yields and species-specific response across the model domain.

- As well as extended development times, the models take longer to run and are more difficult to meaningfully validate across the whole domain.

- Our validation strategy will therefore focus on a few key sites with on-the-ground data availability for multiple species e.g. Bantry Bay

WP1 – Analysis – Task 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling – Next Steps

Plan for the coming months:

- Whole domain runs for shellfish and seaweed models, all species (i.e. scenario 1)
- Finalise nutrient interactions solution
- Scenario runs (see questions re: scenarios)

WP1 – Analysis – Task 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling – Questions

How to address scenarios:

Scenario a) is conceptually simple – quantify potential production for each species in each grid square assuming no interaction (anticipated use – selecting potential sites / regions for aquaculture)

Scenario b) appears to be requesting the same as a) but modelling nutrient interactions. This is not computationally tractable or, we argue, worthwhile - we can't put aquaculture everywhere!

We propose combining b) [and c] with the fishing impact scenarios of 1,2 and 5m tonnes production distributed realistically across EU waters.

Q. - 1,2 and 5 million tonnes of each species or of a combination of species?

The call for tenders requests:

(1) Lot 1 Shellfish and algae

The contractor shall analyse production potential in kg (dry and wet), kg protein, kcal, kg CO_2 and kg CO_2 equivalent emissions in terms of production for each species in the areas listed under section 1.4.2., all expressed per unit area per year.

And further

The analysis should only take into account physical, chemical and biological factors – not distance from markets or legal restrictions – protected areas, military areas, shipping lanes etc. The aim is not to consider the issue of the water quality requirements from the point of view of EU Food legislation.

Three scenarios should be developed:

(a) assuming current availability of nutrients in each area;
(b) maximising production taking into account the carrying capacity of the sea. In other words assuming that nutrients taken up in one area cannot be taken up elsewhere;
(c) the same as (b) but assuming no production within one nautical mile of the coast.

The impact on fishing should be analysed

(a) assuming 1, 2 and 5 million tonnes (wet weight) of algae and shellfish production in the EU27;
(b) realistic distribution of cultivation in waters of EU27 Member States.

Discussion :

WP-1 – Task 2 – Subtask 2.3: Nutrient uptake model

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Numerical Modelling of Nutrients Uptake Dynamics.

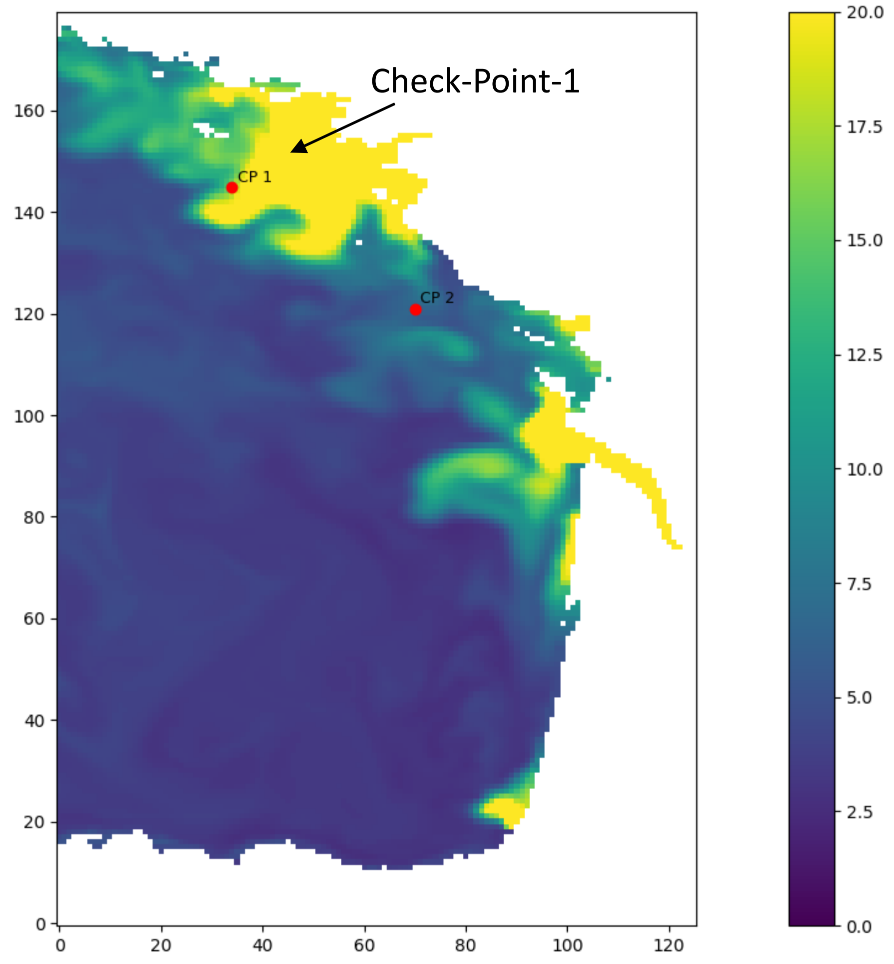
An application in the Bay of Biscay

. *C* is the CMEMS Iberian/Biscay/Ireland regional solution (daily files).
. C' is the concentration of nutrient after introduction of algae farms.
. ε (the nutrient uptake) causes a variation *c* of the local concentration.

The 2D eq. of the advection of this deficit *c=(C-C')* may be written:

$$\frac{\partial c}{\partial t} + \frac{\partial (uc)}{\partial x} + \frac{\partial (vc)}{\partial y} = \epsilon$$

To remain consistent with the CMEMS calculation procedures, this equation of the nutrient deficit caused by algae production is then solved in a well mixed upper layer using the numerical scheme applied in the CMEMS/IBI/BGC model (Quickest).



Extension of the Biscay area. CMEMS Nitrate concentration. 16/01/2021

Nutrient uptake simulation

Each time step we introduce $\epsilon = \mathrm{pct} \cdot \mathrm{C}'$

With:
-> C' the concentration of nutrient after introduction of seaweed farms.
-> pct a percentage $(0 \leq \mathrm{pct} \leq 1)$

Thus at each time step we uptake a percentage of C' value at this time step

If we neglect C variations, and the spatial terms, we have for each day:

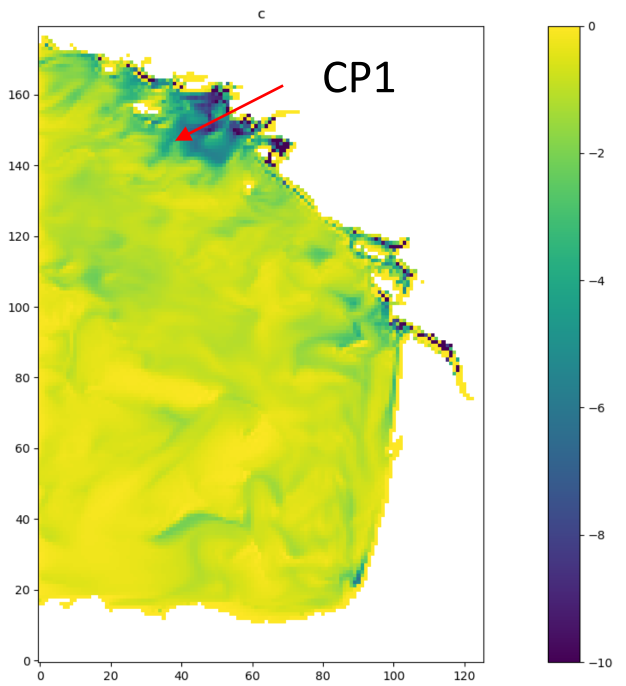
$$C'_{\{day+1\}} = C'_{\{day\}} \cdot e^{-pct}$$

WP-1 – Task 2 – Subtask 2.3: Nutrient uptake model - Achievements

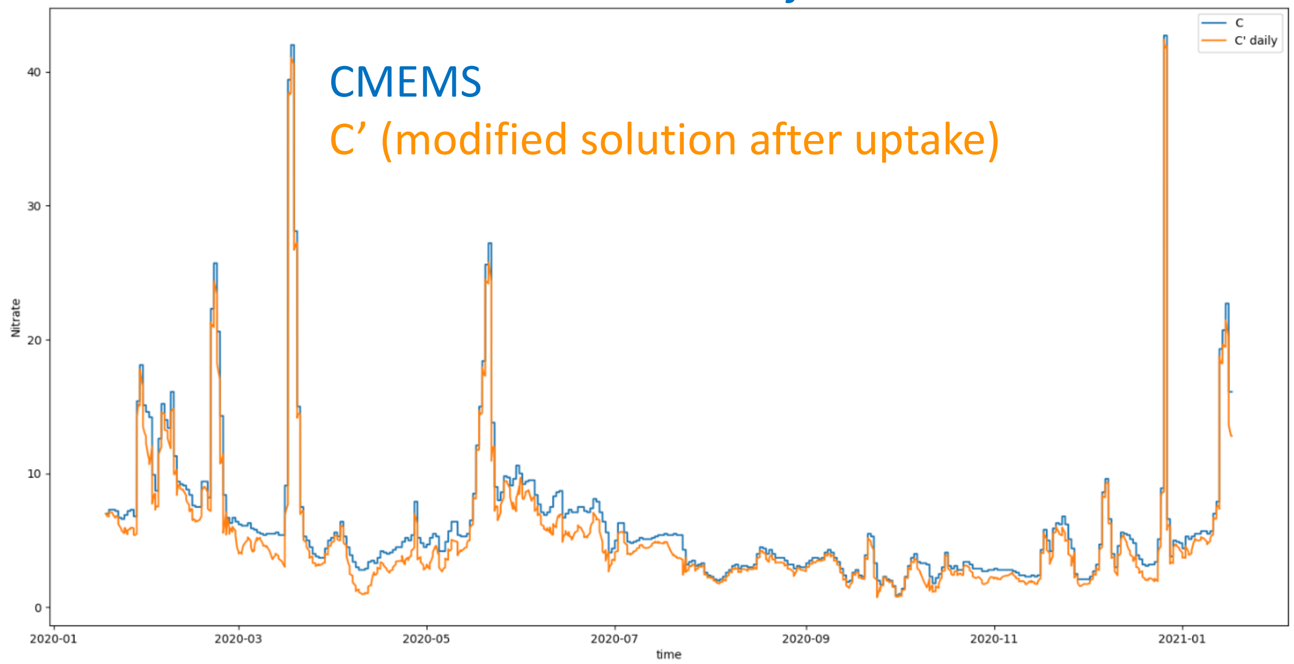
Simulation of 10 % nutrient uptake each day

- Daily current velocity and nutrient files.
- One year simulation (year 2020).
- **t_0= 18/01/2020**
- Δt=300 s
- Computation time ≃ 160 sec./month

t0+365



C' solution. Nitrates – surface. CP1



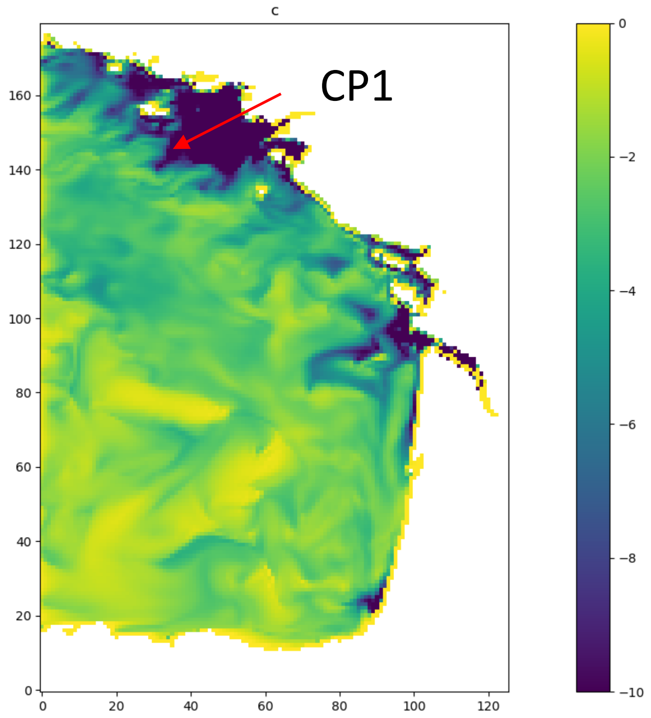
➡ Stable model for a year of simulation, we do not notice any significant variation of the nutrients, thanks to the circulation that renews the nutrient field

WP-1 – Task 2 – Subtask 2.3: Nutrient uptake model - Achievements

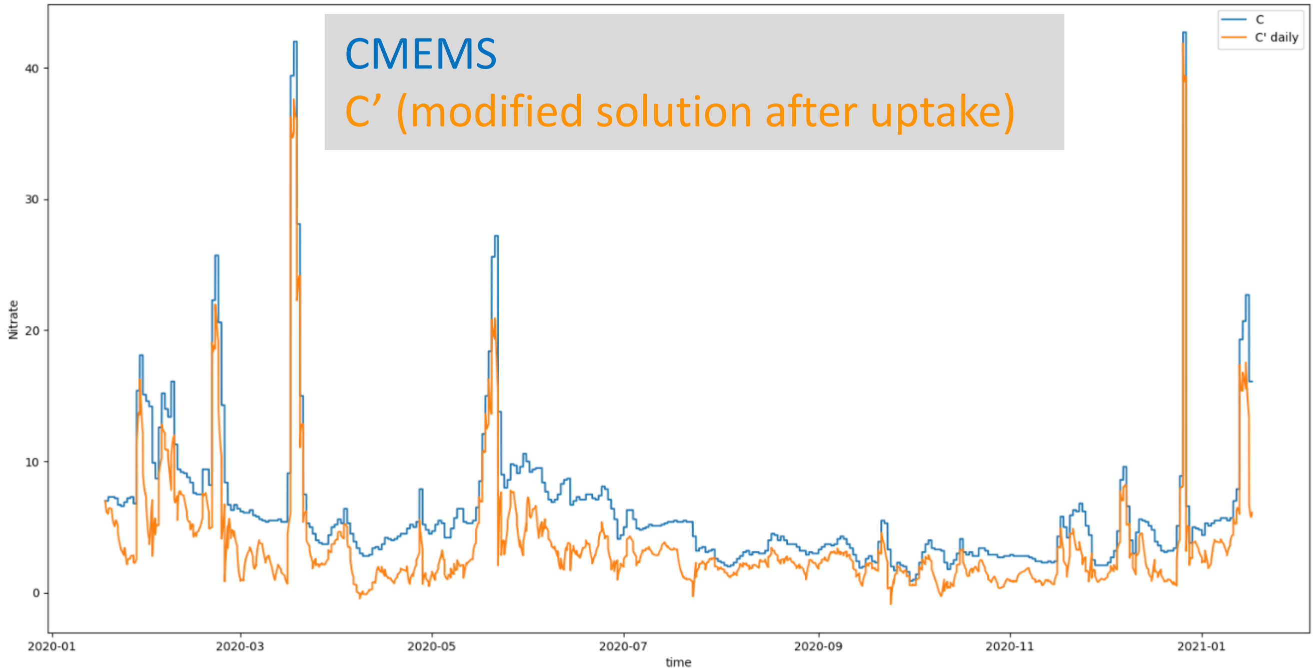
Simulation of 50 % nutrient uptake each day

- Daily current velocity and nutrient files.
- One year simulation (year 2020).
- **t_0= 18/01/2020**
- Δt=300 s
- Computation time ≃ 160 sec./month

t0+365



C' solution. Nitrates – surface. CP-1



⇨ Even though we have a high uptake, we don't consume all the nutrients

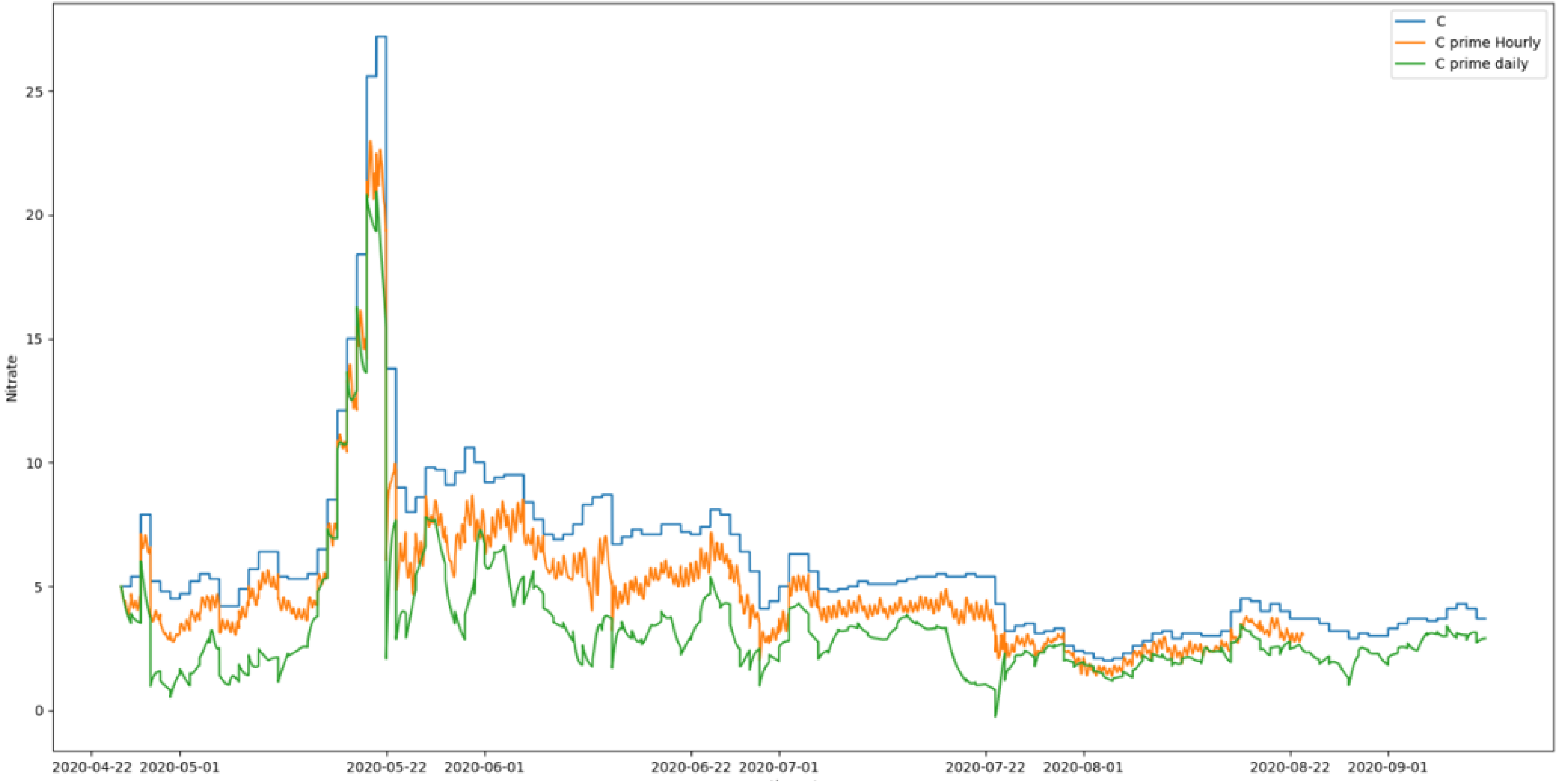
WP-1 – Task 2 – Subtask 2.3: Nutrient uptake model - Achievements

Influence of the temporal resolution of the dynamic

-> **hourly velocity fields seems to be better estimate of the local nutrient deficit.**

C' solutions.
Nitrates.
Surface.
CP-1

➡ The two cases remain consistent with each other



WP-1 – Task 2 – Subtask 2.3: Nutrient uptake model - Next steps

Plan for the coming months:

- integration of the Algae model, considering the parameterizations and forcings (PAR, Temperature, Nutrients …)
- development on another region of interest (an enclosed or semi-closed sea: Baltic, Mediterranean, Black Sea)
- Extend to whole European seas (depending on available computating capacity)

WP-1 – Task 2 – Subtask 2.3: Nutrient uptake model – Stochastic alternative

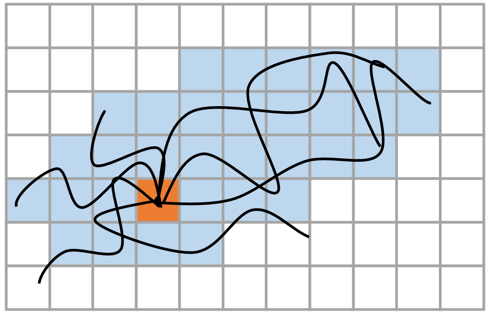
An alternative plan:

In case the full advection model can't be achieved because of computational limitations, we can fall back on a **stochastic alternative** in two steps:

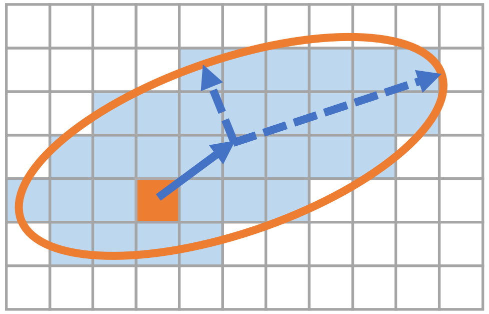
1. Compute statistically a matrix A where $A_{i,j}$ represents the amount of flow exiting farm i that impacts farm j.
2. Use this matrix to provide impact coefficients and **couple multiple farm simulations without a physical model**.

Two possible approaches for step 1:

- **Launch a large number of Lagrangian floats**, then weigh the downstream farms according to the time floats spend there and their time of arrival.



- Compute the **statistical average and standard deviation of the currents** exiting a farm, we can then define an ellipse of influence and weigh the farms according to their distance to the origin.



Theoretical formulation of step 2 (simplified):

The following term needs to be added to all the farm equations:
(It comes down to a vector-matrix multiplication)

$$\frac{dX_j}{dt} \mathrel{+}= \sum_i A_{i,j} \frac{F_{in_i}}{x_{farm_i}} (X_i - X_{ext_i}) \frac{V_{int_i}}{V_{int_j}}$$

Discussion :

WP1 – Development – Task 2.6 : Impact on fishing

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Objectives of subtask 2.6

Identify the impacts of seaweed and shellfish aquaculture development on fishing activities and therefore its potential impact on fish stock in EU waters.

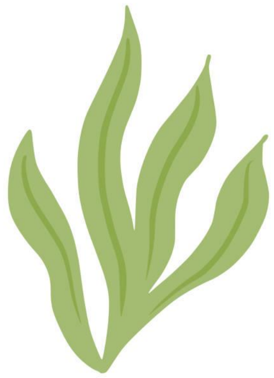
Two parts

- Impact of seaweed and shellfish aquaculture on fisheries
- Link between nutrients and fisheries

***Achievements* -** Impacts of seaweed and shellfish aquaculture on fisheries

What has been done

- Broad bibliographic review using general key words but also more specific key words using species and regions (scientific papers and grey literature) + Impact specific search
- Reading through all the papers to find information on aquaculture impact on fishing activities
- Approx. 40 papers related to seaweed aquaculture impacts
- Approx. 85 papers related to shellfish aquaculture impacts



Achievements - Impacts of seaweed and shellfish aquaculture on fisheries

Main results

- The literature was scarce, and the information was diffuse and non-convergent
- No direct impact on fishing or fish stock could be found except for loss of fishing ground. Only indirect impacts and most of the time non-convergent depending on the aquaculture type but also on the environmental characteristics.
- Only convergence in the literature is : negative impact of aquaculture increases with farm size
- Two recap tables which can be seen here : https://drive.google.com/file/d/1ssdLv8a1aTYFxRrw8Qsl8_NesPn3_3U0/view?usp=sharing

Only sure impact: Loss of fishing ground
Couple fishing effort with farm location – Global Fishing Watch data

WP1 – Development – Task 2.6 : Impact on fishing - Achievements

***Achievements* -** Link between nutrients and fisheries

What has been done

- Additional bibliographic review : 10 additional papers

Main results

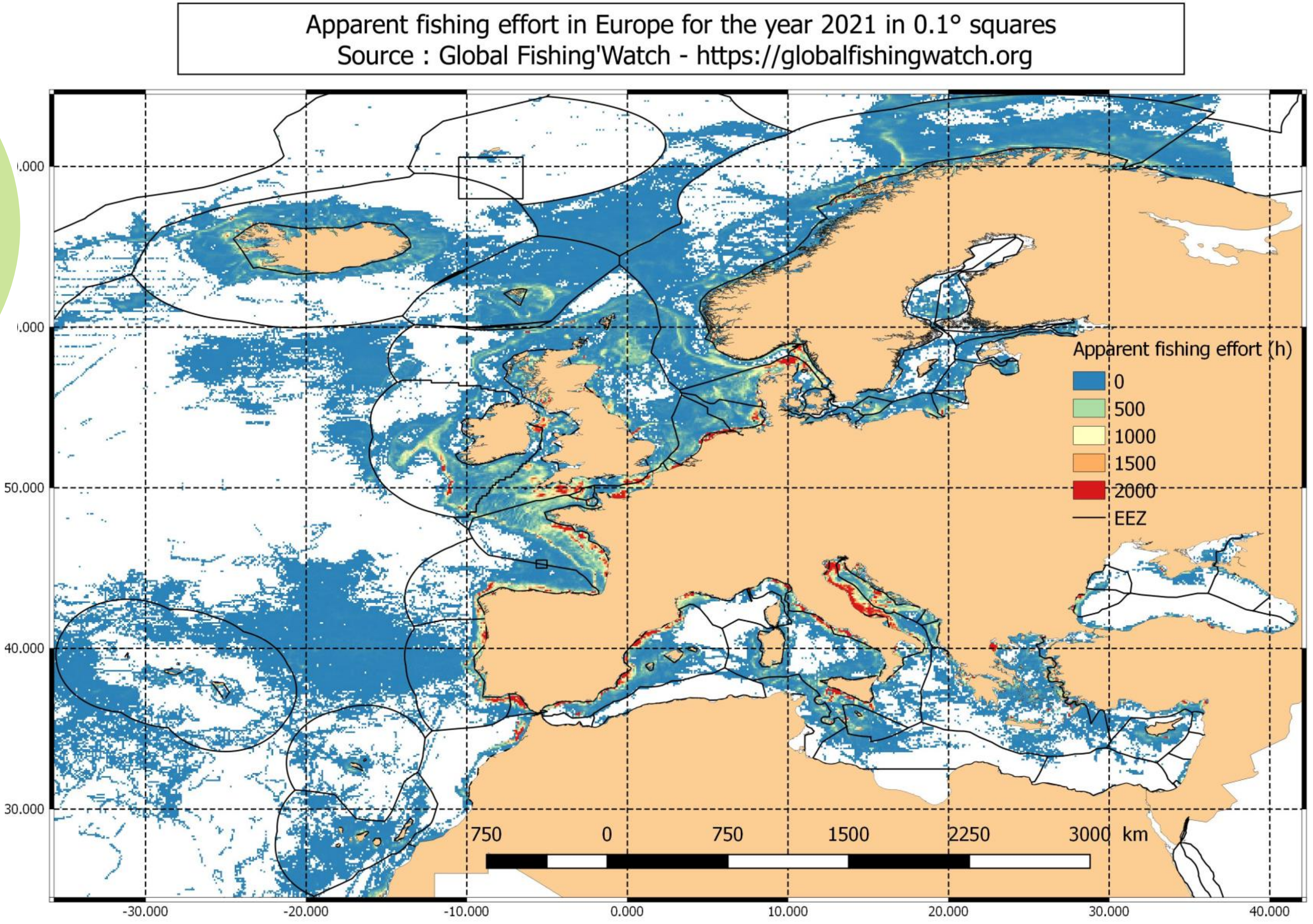
- Few papers found and two particularly interesting taking place in Baltic and Black Sea (semi-enclosed seas)
- Nutrients **enrichment** can **affect both the growth** and **the reproduction** of exploited species (Viet Thanh, 2013, Knowler, Barbier and Strand, 2002) but it highly depends on the species and habitat (Viet Thanh, 2013).
- Difficult to know if **decrease** in nutrient concentration will have **a positive or a negative** impact on exploited species.

Compare a "before aquaculture" **nutrient budget** of each basin/UE scale and compare it with nutrient budget after each scenarios (CCTP)

WP1 – Development – Task 2.6 : Impact on fishing - Overview

Apparent fishing effort in Europe in 2021

Coastal areas will compete with aquaculture



WP1 – Development – Task 2.6 : Impact on fishing - Deviation

Deviation

Problems encountered

Lack of information/literature regarding direct impact of aquaculture development on fisheries

Proposed solution

Additional research on links between nutrients and fisheries

WP1 – Development – Task 2.6 : Impact on fishing - Next steps

Plan for the coming months:

- Couple **fishing effort** with farm location – Global Fishing Watch data to illustrate the loss of fishing ground
- Compare a “before aquaculture” **nutrient budget** of each basin/UE scale and compare it with nutrient budget after each scenarios: 1, 2 and 5 million tones (wet weight) + realistic distribution of the EU27

Discussion :

WP2 – Production – Task 3 : Preparing digital maps

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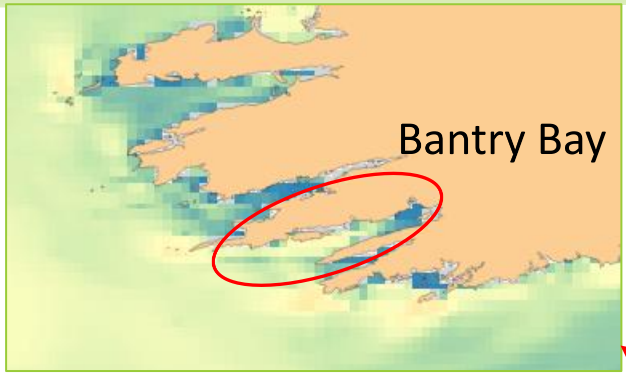
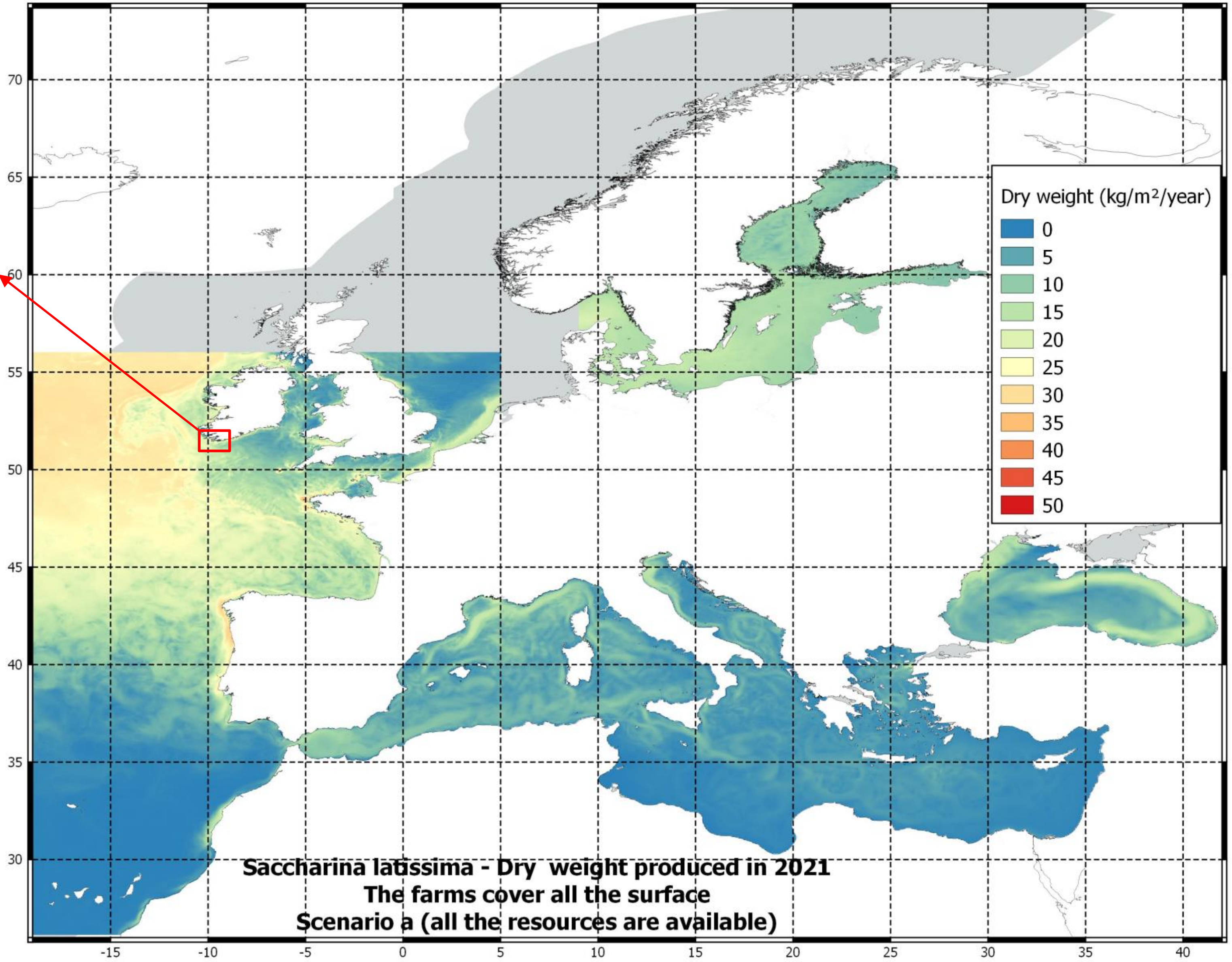
WP2 – Production – Task 3 : Preparing digital maps –Achievments



A draft map of algae production in Europe for the year 2021 has been produced.

A complete map that can be integrated into Emodnet will be produced for the final version of the interim report.

The map presented here shows the simulated production of *Saccharina latissima* in dry weight for the year 2021 and a zoon in Bantry Bay.



WP2 – Production – Task 3 : Preparing digital maps –Next steps

Plan for the coming months:

- Produce maps of the different parameters required for the 3 algae species and the 3 shellfish species
- Produce NetCDF files compatible with Emodnet standards (INSPIRE) and CMEMS standards,

Discussion :

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WP3 – Uptake – Task 5 : Review of the documents and software

Achievements

- Review of the ATBD for the seaweed model

Plan for the coming months:

- Review of the next ATBD for shellfish model
- Write a user manual for the online platform
- Transition and handover about 1,5 month before the end of the project

Technical support will be ensured during 3 months after the end of the projects

Discussion :

General discussion :