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 a 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
Task0									
Task1									
Task2									
Task3									
Task4									
Task5									
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 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 CO2 emission 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 ç Task 0: Management - Deviation

ü Some facts that have or will disrupt the planned course of the project:

- Á Yéelen (Cofrepeche) is on maternity leave since few months
- Á Chloé (Cofrepeche) has leave the project in April

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

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

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

WPM ςTask 0: Management: Next steps

Plan for the coming months:

- ωContinue monthly/weekly meetings
- ωFinalise WP1
- ωGenerate maps for WP2 (T3)

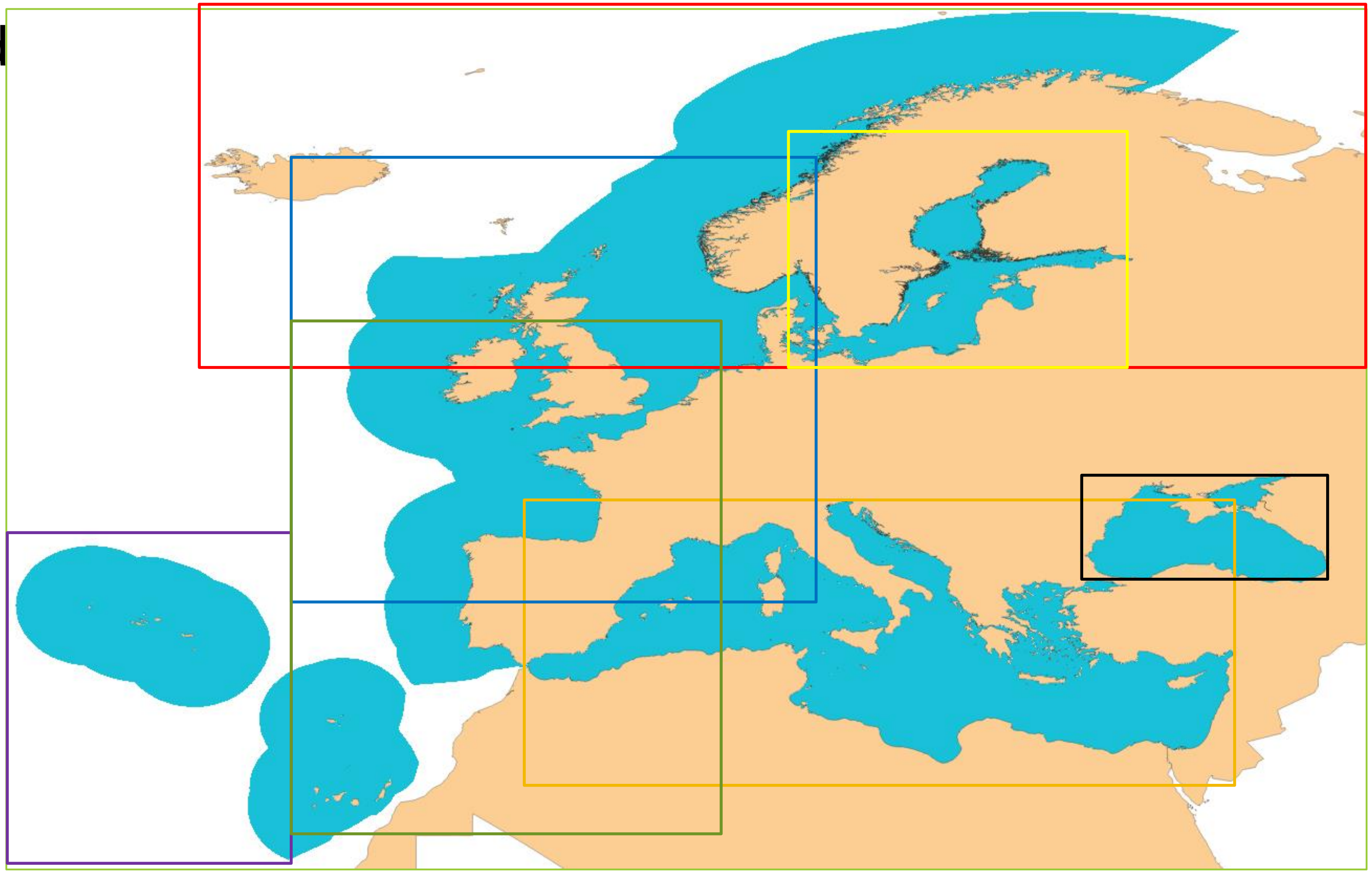
WPM – Task 0: Management – Questions to the European Commission

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

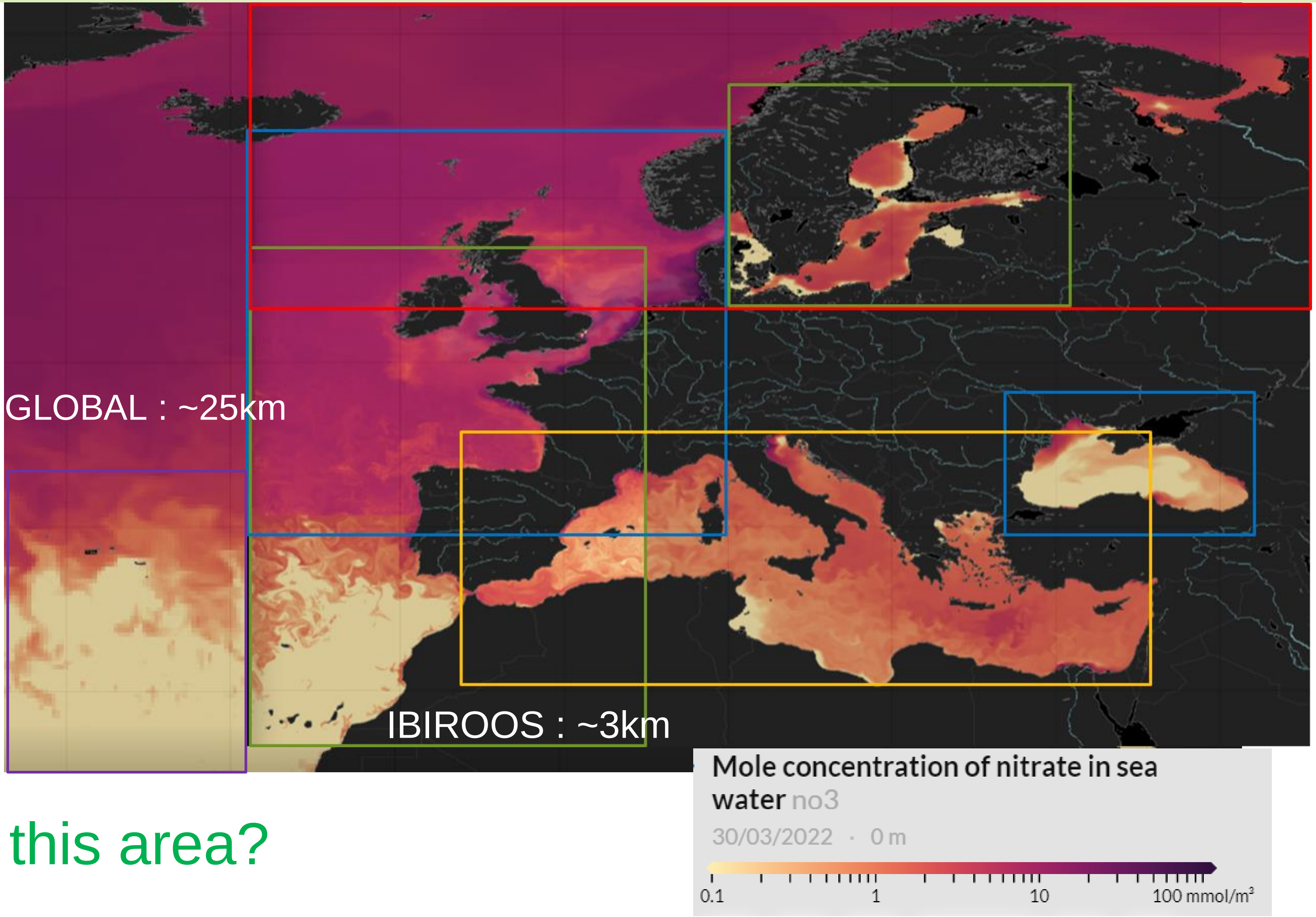


These areas are only covered by Copernicus global data with a lower resolution of 8 to 25 km

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 :

WP1 ςDevelopmentςTask1 : Development & test software

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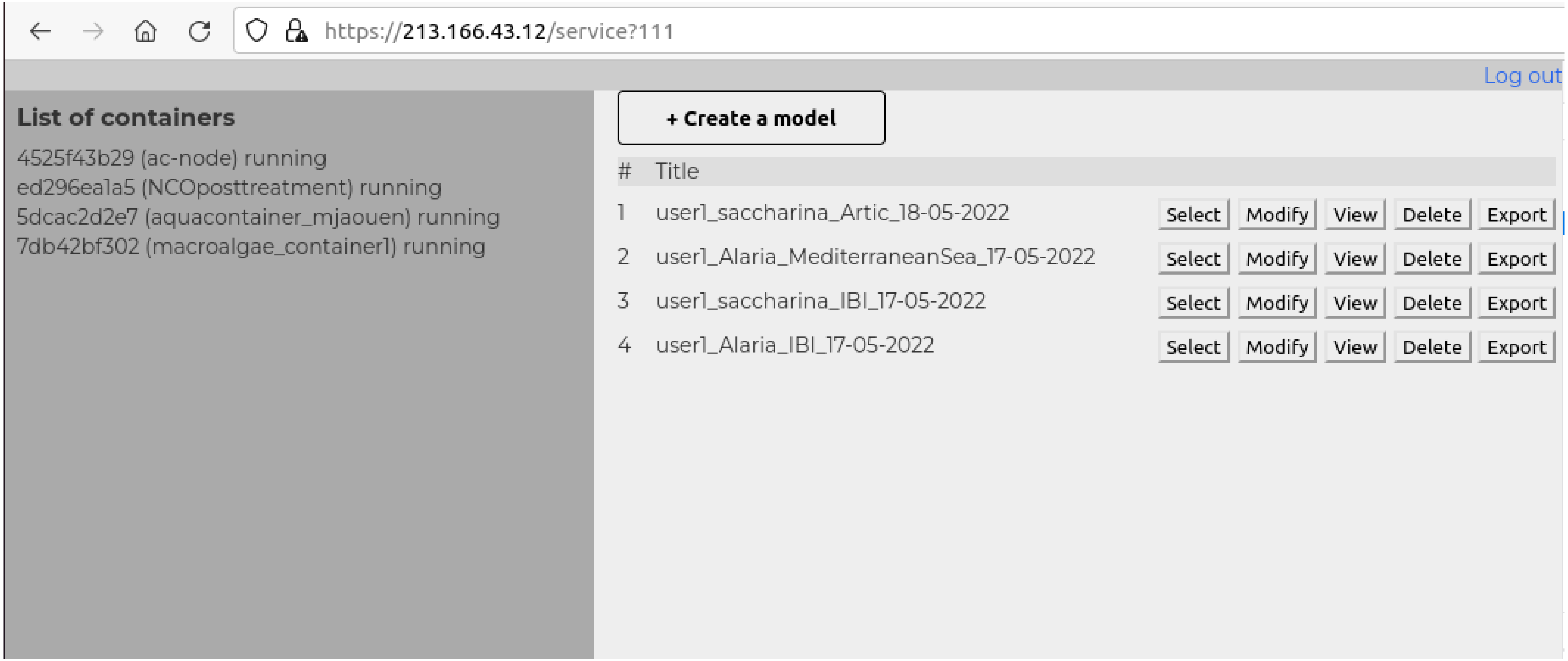
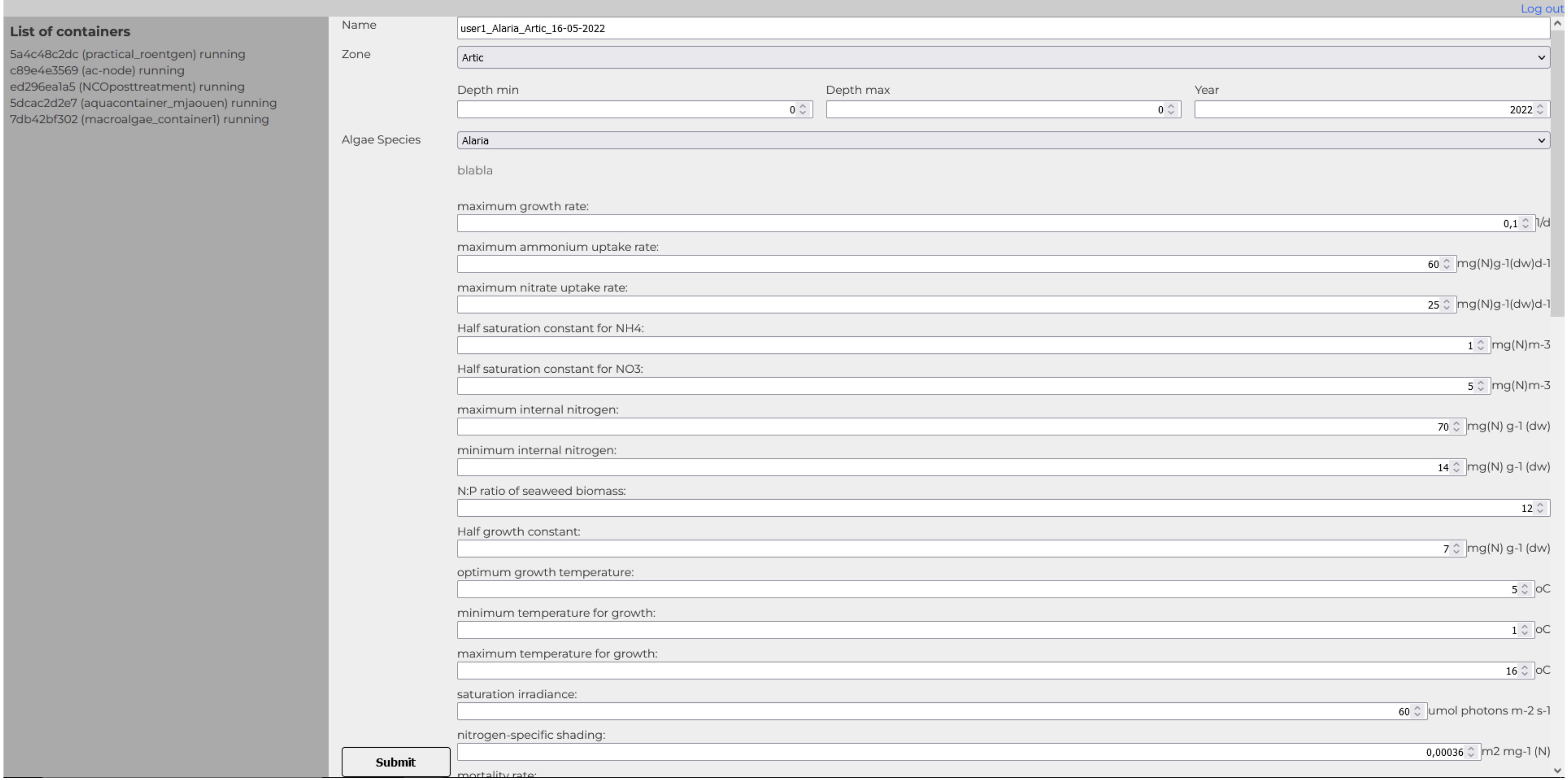
ARGANS

WP1 ‒ Development ‒ Task1 : Development & test software Overview

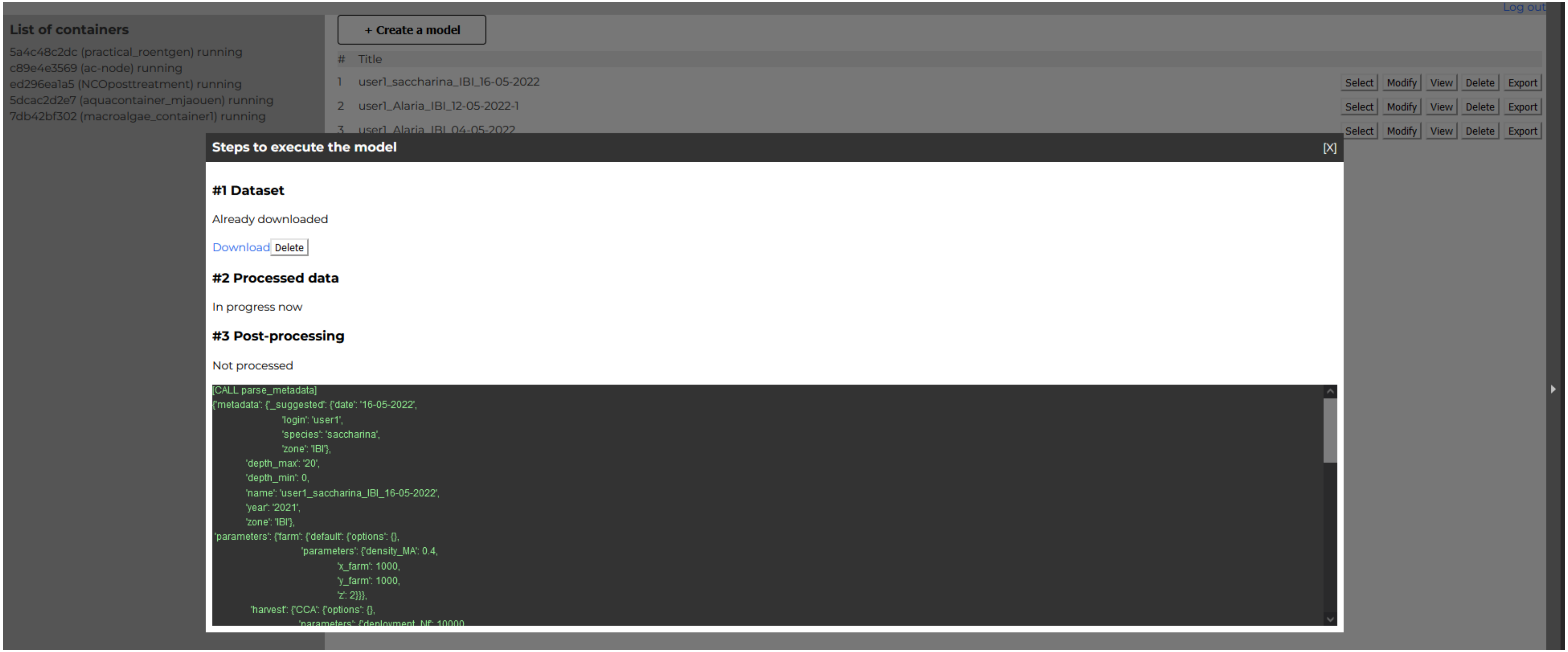
WP1 ςDevelopmentςTask1 : Development & test software Overview



WP1 – Development – Task1 : Development & test software – Overview



WP1 ςDevelopmentςTask1 : Development & test software Overview



WP1 ςDevelopmentςTask1 : Development & test software Achievements

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.

WP1 ς Development ς Task1 : Development & test software Next steps

Plan for the coming months:

- ωResolve user experience issues
- ωProvide a solution for overlaying Tiff files on a map
- ωOpen the VM to Cofrepeche for testing

WP1 ςDevelopmentςTask1 Development & test software

By the end of the project:

- ωInclude the shellfish model in the same interface
- ωImplement the possibility to do simulations following scenarios b and c
- ωMake the interface more visually appealing

WP1 ςDevelopmentςTask1ςQuestions to the European Commission

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

Discussion :

Thank you for your attention

WP1 ςAnalysis

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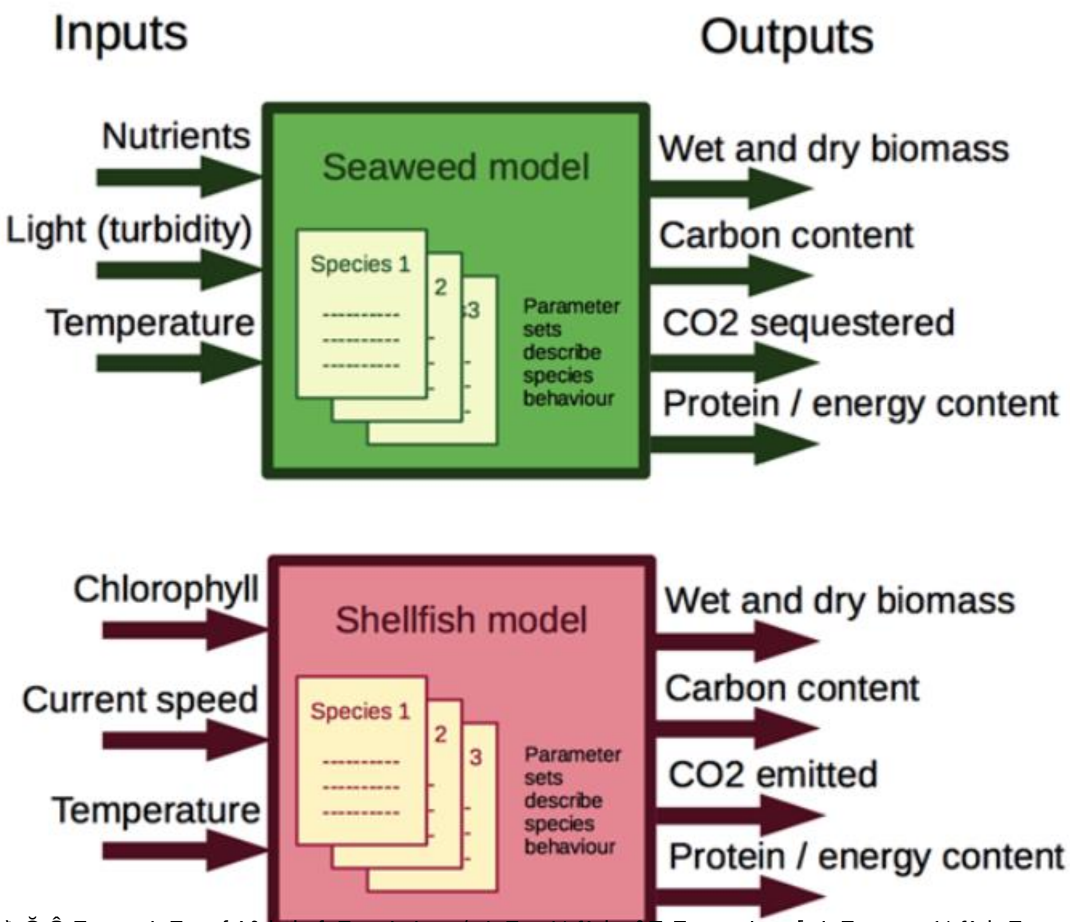
WP1 – Analysis – Task 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling – Overview

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

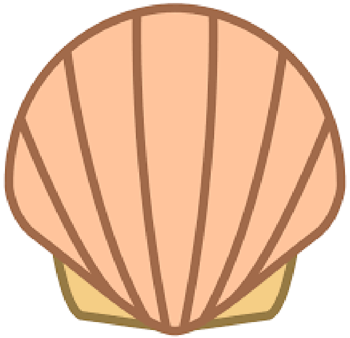
Hawkins, A. J. S., Pascoe, P. L., Parry, H., Brinsley, M., Black, K. D., McGonigle, C., Moore, H., Newell, C. Shellsim: A Generic Model of Growth and Environmental Effects Validated Across Contrasting Habitats in Bivalve Shellfish. *Https://Doi.Org/10.2983/035.032.0201*, *32*(2), 237–253. https://doi.org/10.2983/035.032.0201

Environmental forcings to the macroalgae model

forcing	description	units
PAR	photosythetically active radiation	μmol m^{-2}s^{-1}
SST	sea surface temperature	°C
NH_{4_ext}	ambient NH4 concentration	mg m^{-3}
NO_{3_ext}	ambient NO3 concentration	mg m^{-3}
PO_{4ext}	ambient PO4 concentration	μM
K_d	light attenuation coefficient in water	m^{-1}
F_{in}	water current flow rate	m d^{-1}
z_{mix}	vertical mixing length term	m
D_{ext}	detrital concentration	mg m^{-3} (N)
theta	solar angle	°

Environmental forcings to the shellfish model

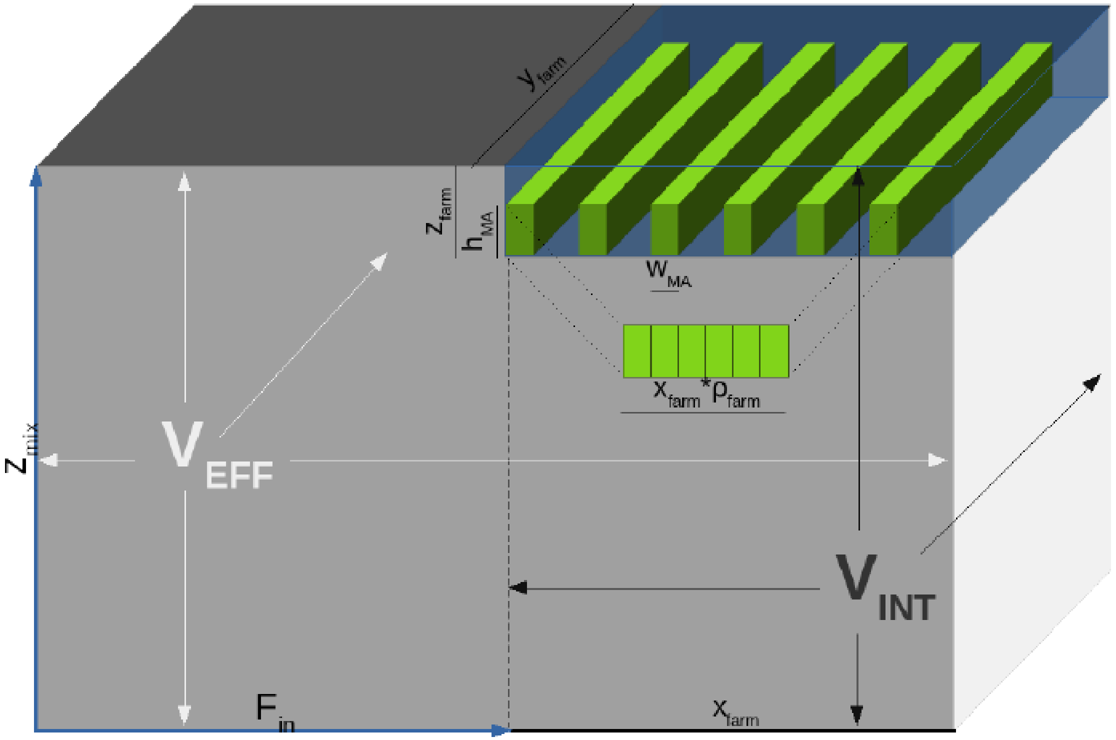
forcing	description	units
SST	sea surface temperature	°C
CHLA	chlorlophyll concentration	μg/l
PhytoC	Phytoplankton carbon concentraion (optional)	μg/l
POC	Particulate organic carbon (optional)	μg/l
F_{in}	Water current flow rate	m d^{-1}
z_{mix}	vertical mixing length term	m



WP1 ςAnalysisςTask 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.*

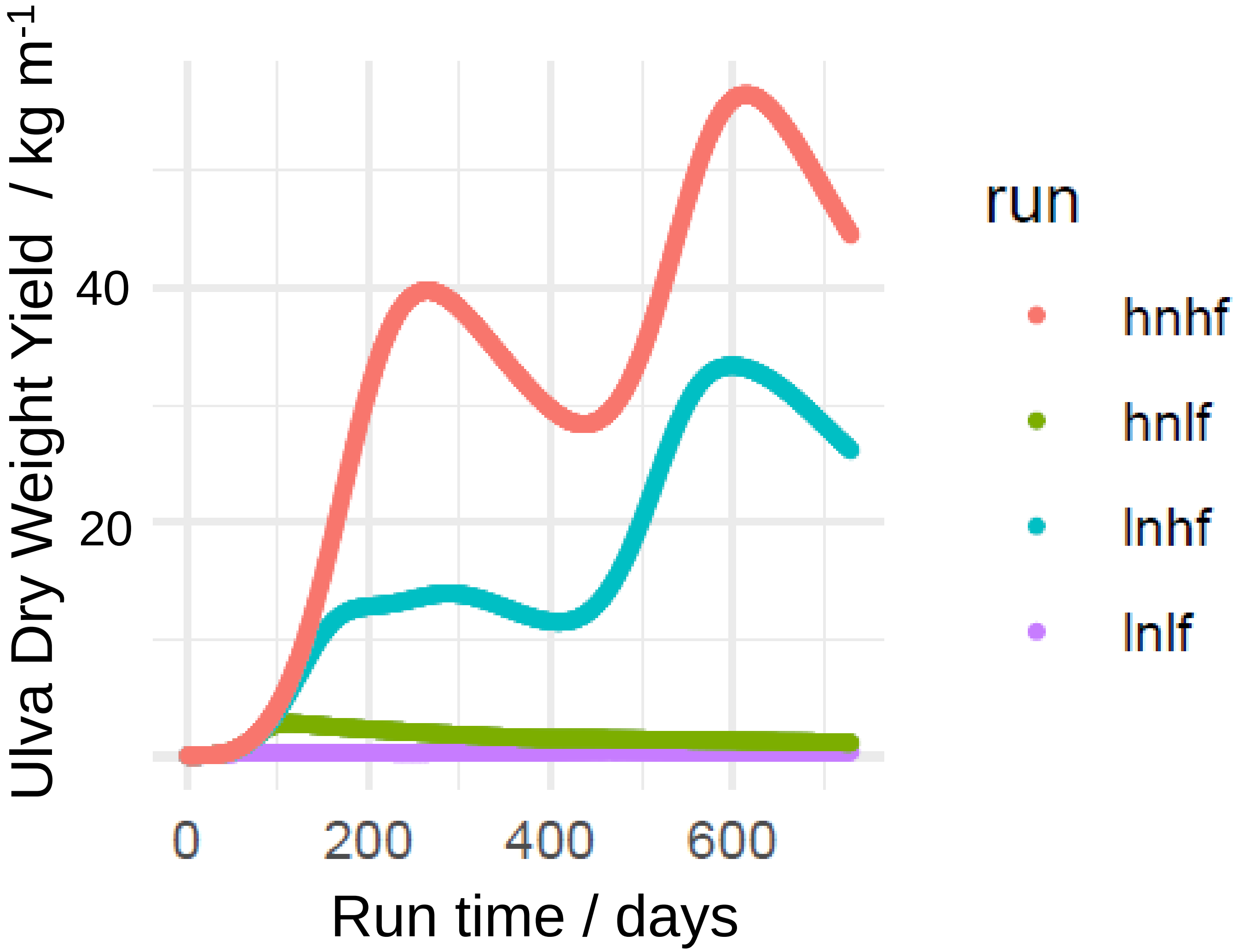


Above: seaweed model schematic demonstrating that farm interacts with wider body of water, the volume of which is determined by flow rate and mixing depth

WP1 ςAnalysisςTask 2.1,2.2,2.5 : Seaweed and Shellfish Farm ModelResults

Seaweed model behaviour

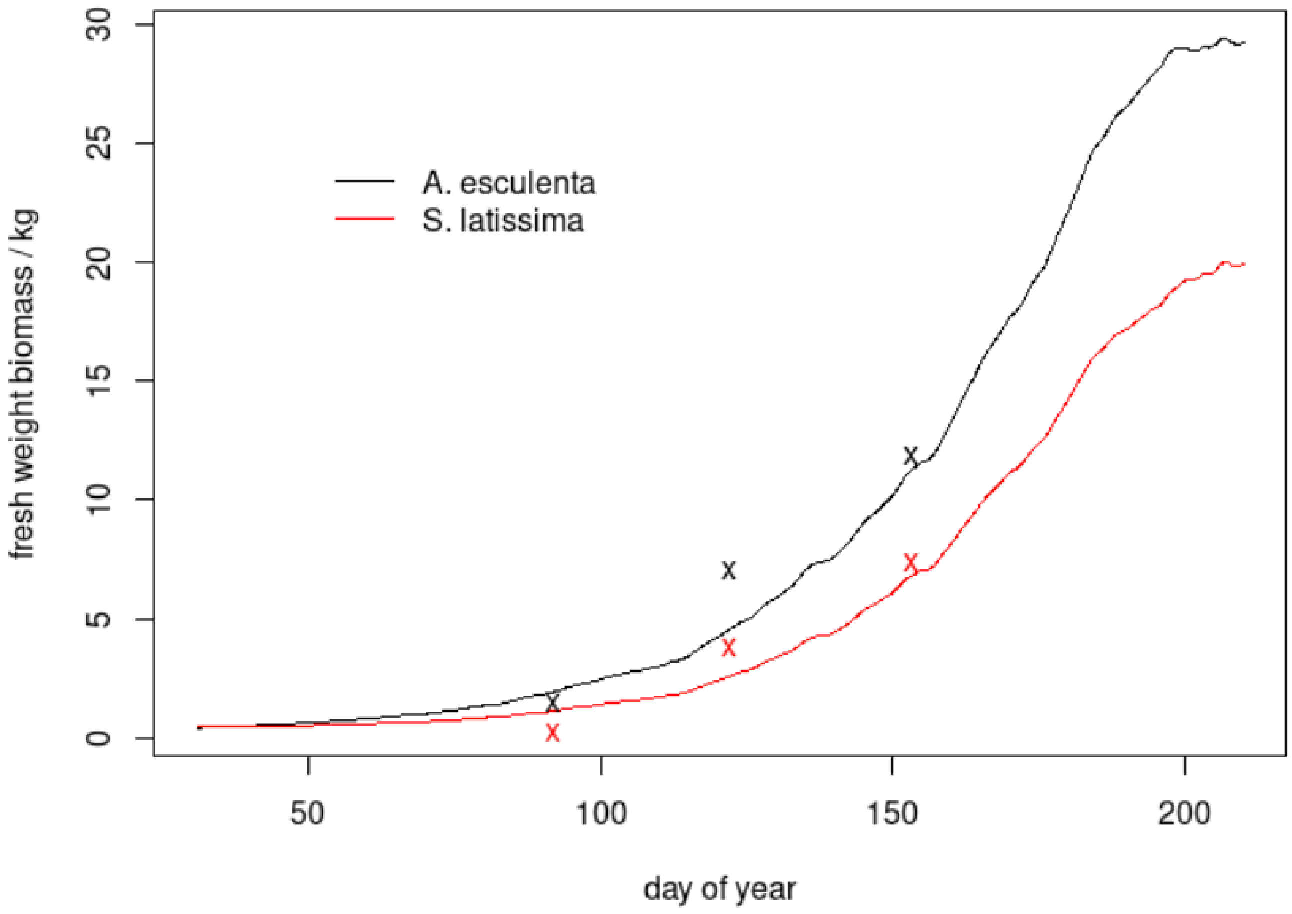
- Reference runs compare high / low nutrient and high / low flow conditions
- Flow rate (i.e. resupply of nutrients) is key fomaintaining growth
- Absolute nutrient concentration at which growth is viable depends on speciesspecific nutrient affinity parameters



WP1 ςAnalysisςTask 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling Results

Bantry Bay results

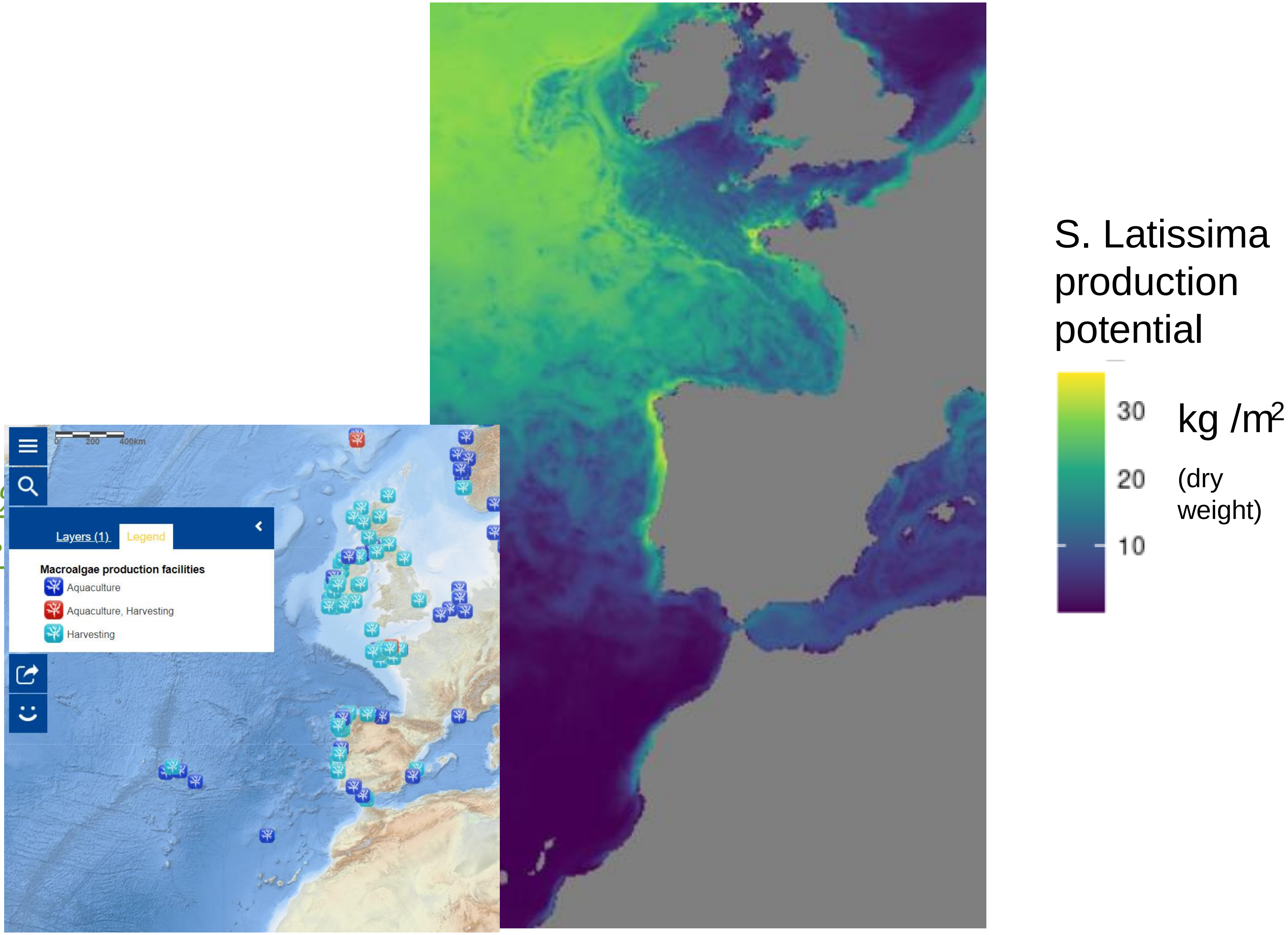
- ***Model uses literature-derived parameters for S. latissima and A. esculenta, with tunable model parameter set to optimal values.***
- ***Driven by CMEMS environmental data for Bantry Bay grid square for 2020***
- ***IDREEM data for species grown at Bantry Bay site in 2015***
- ***Generally good agreement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



WP1 ςAnalysisςTask 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%20the%20global,based%20in%2015%20Member%20States.* *)*

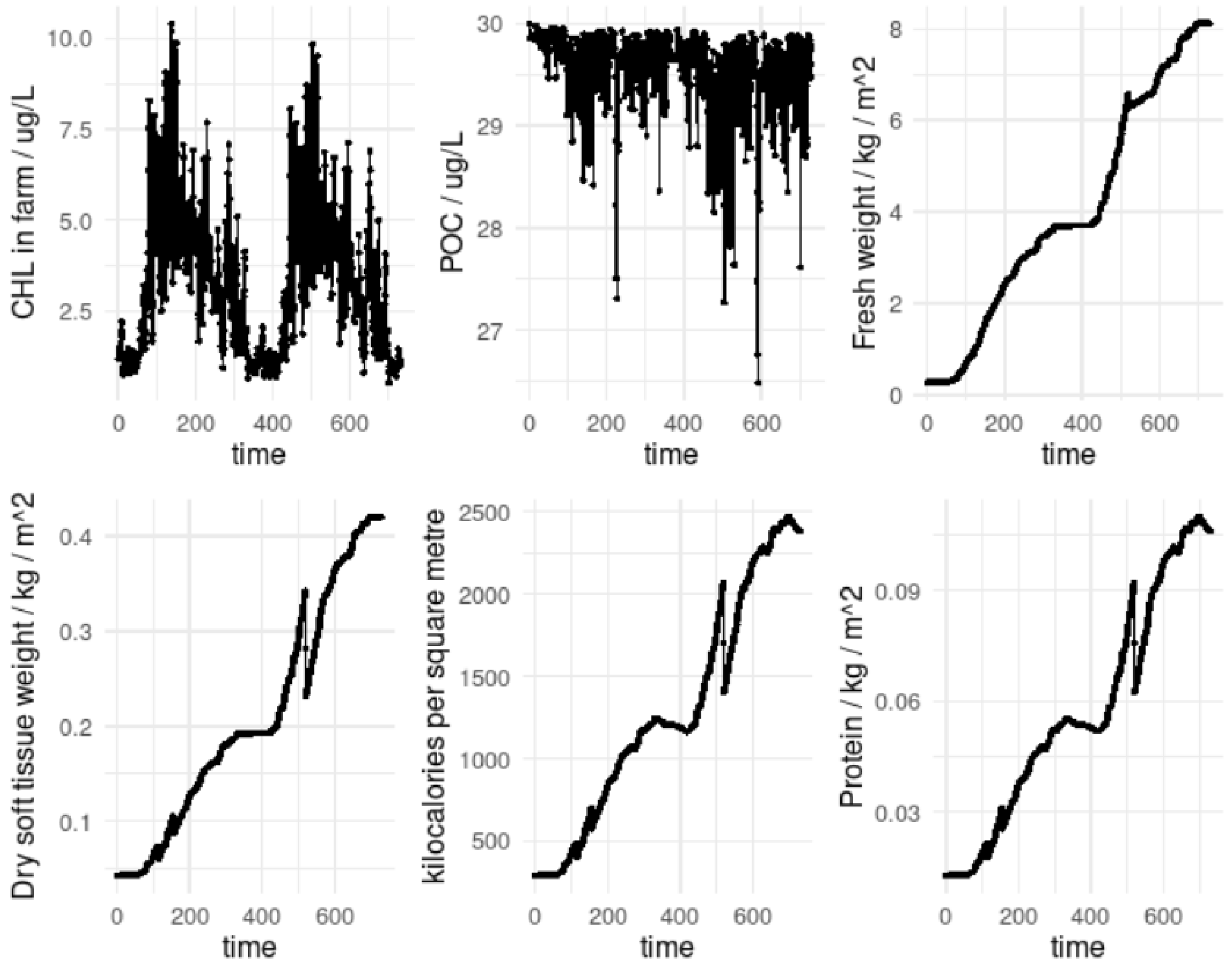


WP1 ςAnalysisςTask 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling Results

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 - Limitations

- 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 ς Analysis ς Task 2.1,2.2,2.5 : Seaweed and Shellfish Farm Modelling ς Next Steps

Plan for the coming months:

- ω Whole domain runs for shellfish and seaweed models, all species (i.e. scenario 1)
- ω Finalise nutrient interactions solution
- ω 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?

Scenarios 1, 2, 5 and 10 million tonnes of fresh weight per species will have to be carried out

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

Numerical Modelling of Nutrients Uptake Dynamics.

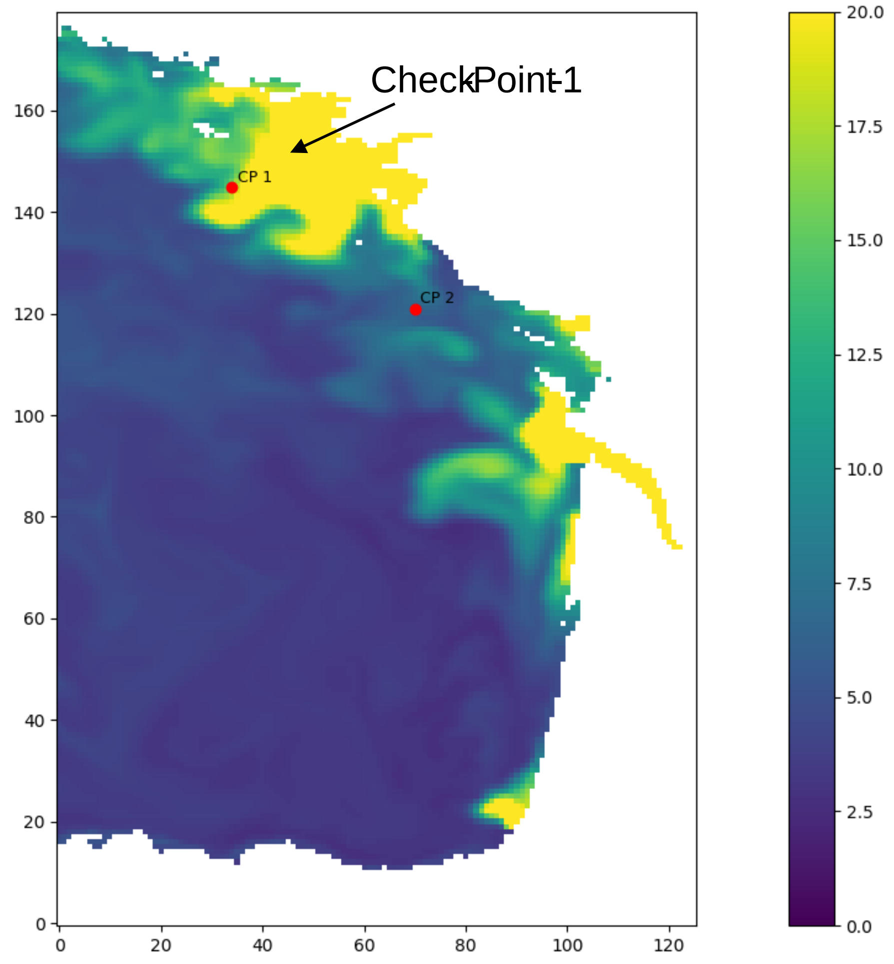
An application in the Bay of Biscay

- 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

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

Nutrient uptake simulation

During our tests we take $\epsilon = \mathrm{pct} \cdot \mathrm{C}'$ as uptake function

With:
-> C' the concentration of nutrient after introduction of algae 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

Warning: do not think that we uptake *pct* % of the nutrient present in the environnement.

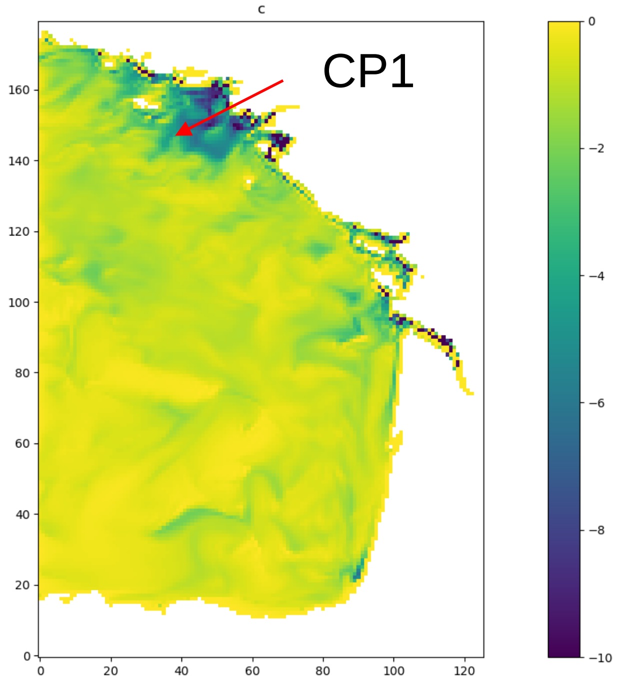
For further explanation, please refer to the annex at the end of the document

WP1 – Task 2 – Subtask 2.3: Nutrient uptake model - Achievements

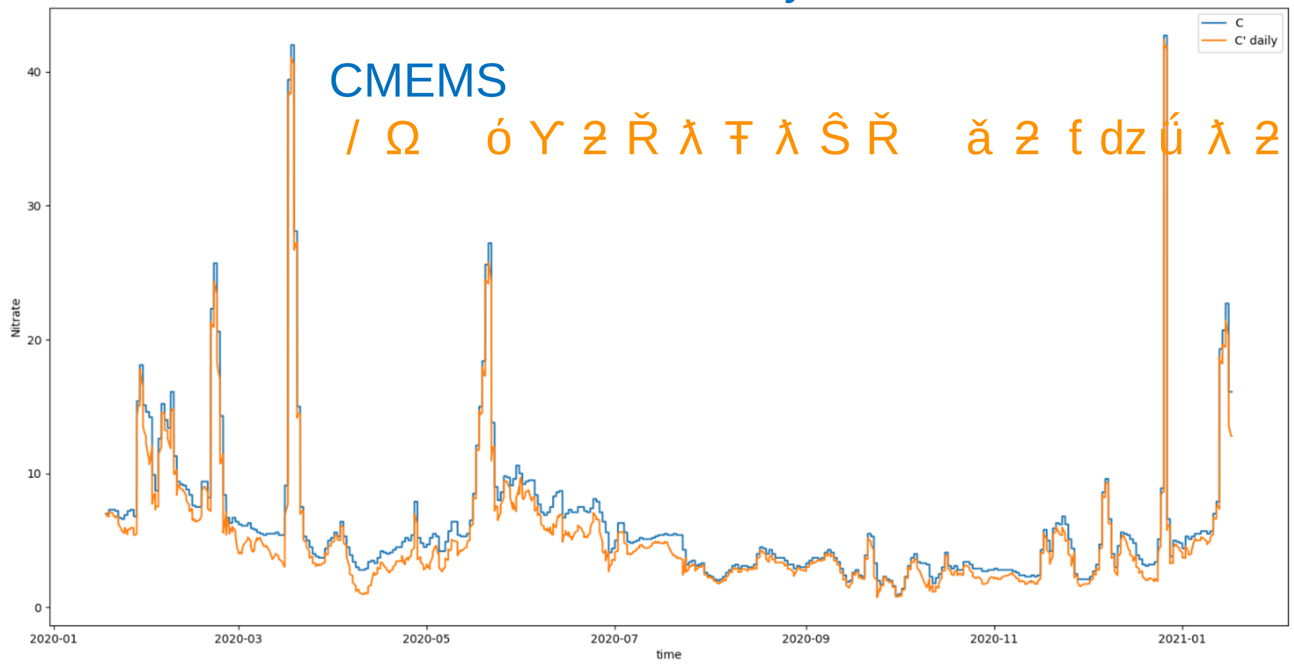
Simulation of 10 % nutrient uptake each day

- 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



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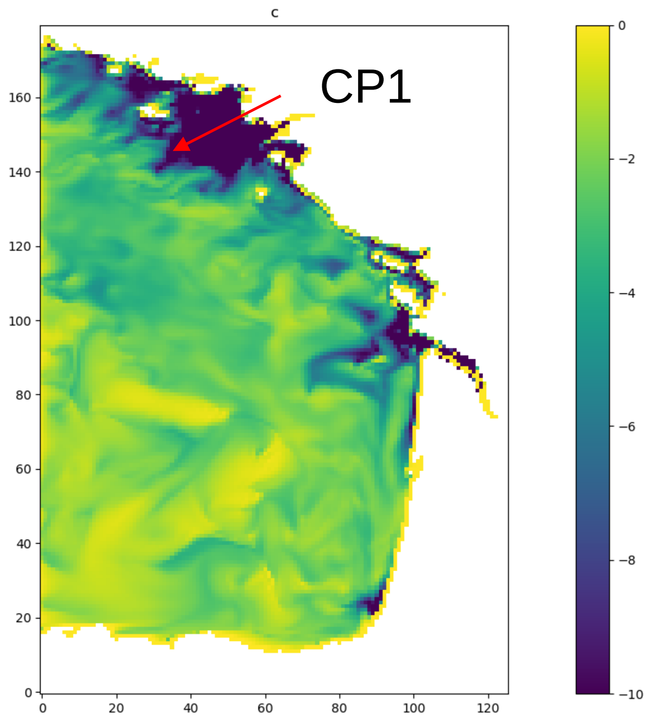
➡ Stable model for a year of simulation, we do not notice any significant variation of the nutrients, thanks to the circula
that renews the nutrient field

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

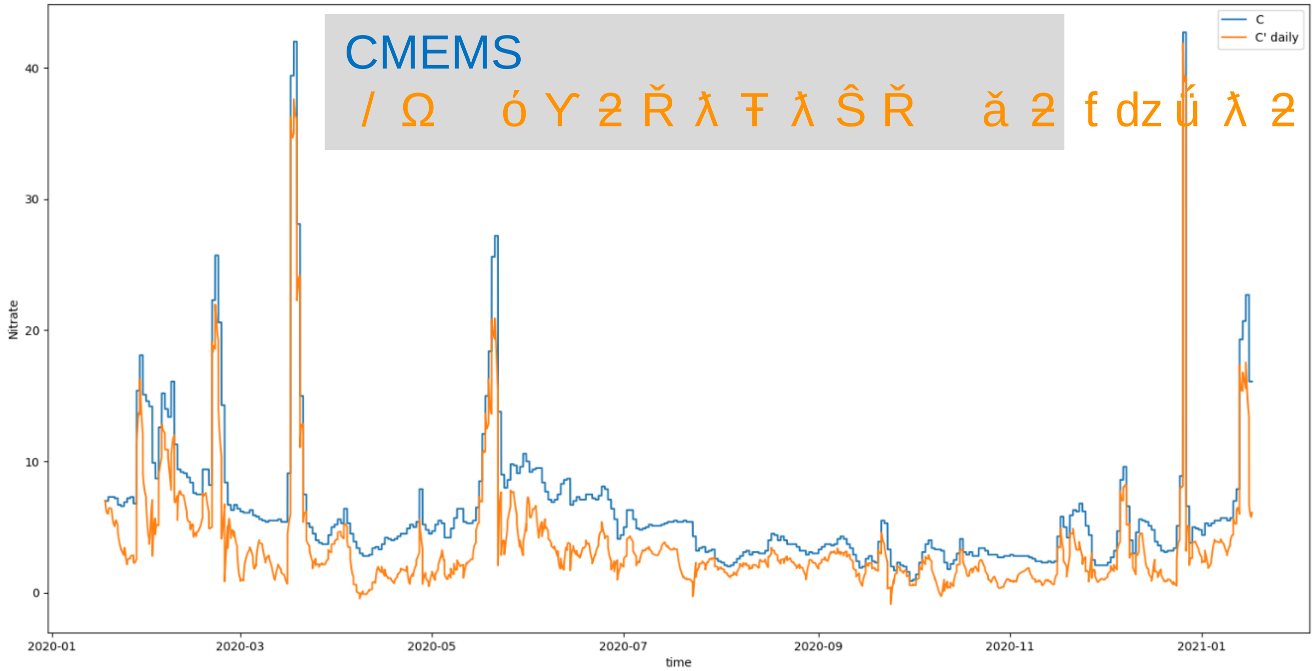
Simulation of 50 % nutrient uptake each day

- 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



CMEMS

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WP-1 ςTask 2ςSubtask 2.3: Nutrient uptake model - Achievements

The exceptionally short time step (300s) of the model, based on those used in CMEMS, seems incongruous for growth processes normally measured in days or weeks:

It is only a numerical problem. Decreasing the time step (e.g., 1 day) leads to an instability of the model which diverges in time.

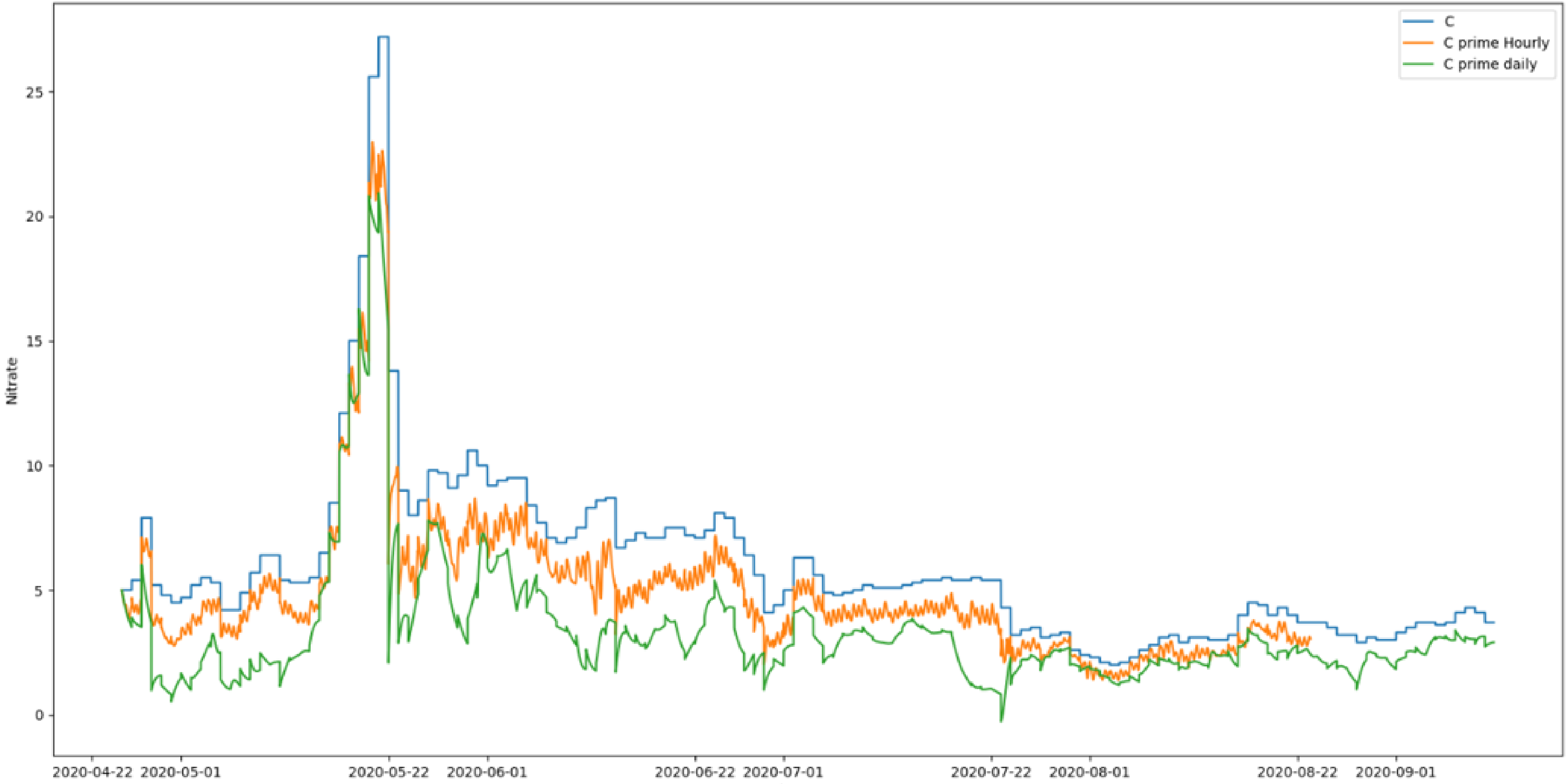
A coarser grid could be useful :

Yes, but the grid used here is already large (~3x3 km), so using a coarser grid would lead to a loss in the quality of spatial resolution of the results

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 ςTask 2ςSubtask 2.3: Nutrient uptake model - Next steps

Plan for the coming months:

ωintegration of the Algae model, considering the parameterizations and forcings
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ωdevelopment on another region of interest (an enclosed or semi-closed sea: Baltic, Mediterranean, Black Sea)

ωExtend to whole European seas (depending on available computating capacity)

WP1 ςTask 2ςSubtask 2.3: Nutrient uptake model ςStochastic alternative

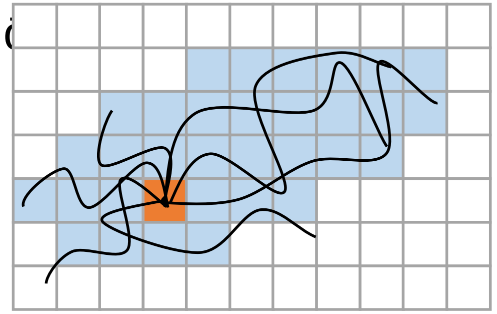
An alternative plan:

Lƴ Ŏŀ ăŜ űĶŜ Ŧdz ƒ ƒ ŀ ŘǾŜ ŎÅŕ achieved because of computational limitations, we can fall back on a stochastic alternative in two steps:

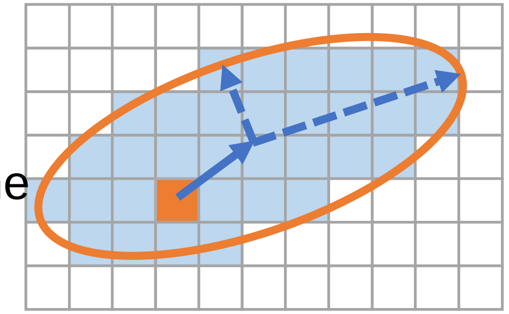
1. Compute statistically a matrix A where $A_{i,j}$ represents the amount of flow exiting farm i that impacts farm j.
2. Use this matrix to provide impact coefficients and couple multiple farm simulations without a physical model.

Two possible approaches for step 1:

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



Å 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)

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

Discussion :

WP1 ςDevelopmentςTask 2.6 : Impact on fishing

WP1 ςDevelopmentςTask 2.6 : Impact on fishing-Overview

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

WP1 ςDevelopmentςTask 2.6 : Impact on fishing- Achievements

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

What has been done

Å Broad bibliographic review using general key words but also more specific key words using species and regions (scientific papers and grey literature) + Impact specific searcl

Å Reading through all the papers to find information on aquaculture impact on fishing activities

Å Approx. 40 papers related to seaweed aquaculture impacts

Å Approx. 85 papers related to shellfish aquaculture impacts

WP1 ςDevelopment ςTask 2.6 : Impact on fishing - Achievements

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 ςGlobal 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 depend 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.

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

Apparent fishing effort in Europe for the year 2021 in 0.1° squares
Source : Global Fishing'Watch - https://globalfishingwatch.org