Project	AtlantOS – 633211
Deliverable number	D8.13
Deliverable title	Report AtlantOS fitness for offshore aquaculture siting
Description	European policy intends to expand the space available to aquaculture by cultivating sites that are offshore. This presents challenges in terms of building structures, e.g., fish cages that withstand the effects of offshore weather conditions along the Atlantic coast. In order to establish possible future sites for offshore aquaculture production AtlantOS T8.5 gathered relevant wave, current velocity and water column structure measurements from the coasts of Ireland, Norway and Spain and used these data to validate site assessment models of the potential new offshore aquaculture sites. This deliverable report assesses the fitness for purpose of the generic aquaculture decision support tool developed.
Work Package number	WP 8
Work Package title	Societal benefits from observing/information systems
Lead beneficiary	NIVA
Lead authors	Trine Dale, Caroline Cusack, Manuel Ruiz Villareal
Contributors	Tomasz Dabrowski, Kieran Lyons, Ramona Carr
Submission date	13th March 2019
Due date	31st December 2018
Comments	Deliverable report was delayed due to issues of working schedules related with the deadline coinciding with the end of the year.

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Last updated: 09 April 2019

Stakeholder engagement relating to this task*

WHO are your most important stakeholders?	☒ Private company SME ☒ National governmental body ☒ International organization ☐ NGO ☐ others Please give the name(s) of the stakeholder(s):
WHERE is/are the company(ies) or organization(s) from?	☒ Your own country ☒Another country in the EU ☐ Another country outside the EU Please name the country(ies): Norway, Ireland & Spain
Is this deliverable a success story? If yes, why? **If not, why?**	☒ Yes, because this task helped us to create a proof of concept for an Aquaculture Site selection decision support tool that is expected to evolve and assist future marine spatial planning efforts. ☐ No, because …..
Will this deliverable be used? **If yes, who will use it?** **If not, why will it not be used?**	☒ Yes, by mapping specialists in Ireland for Marine Spatial Planning with the development of an online platform planned in coming year. ☐ No, because …..

NOTE: This information is being collected for the following purposes:

1. To make a list of all companies/organizations with which AtlantOS partners have had contact. This is important to demonstrate the extent of industry and public-sector collaboration in the obs community. Please note that we will only publish one aggregated list of companies and not mention specific partnerships.
2. To better report success stories from the AtlantOS community on how observing delivers concrete value to society.

*For ideas about relations with stakeholders you are invited to consult D10.5 Best Practices in Stakeholder Engagement, Data Dissemination and Exploitation.

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Glossary; Definitions, Acronyms and Abbreviations

Name	Meaning
Characteristics	Environmental Ocean Variable of the upstream data used in the products
EMODnet	European Marine Observation and Data network (DG Mare) with discipline-based themes, an EU programme to support the further development of an Integrated Maritime Policy (Reg. EU 1255/2011)
EOVs	Essential Ocean Variables are the fundamental physical, biogeochemical, and biological measurements required to understand ocean phenomena well enough to provide applications that support Societal Benefits.
Fitness for Purpose	Rationale for creating a dataset "fitness for purpose" of the datasets used to help create (and validate) the product. Fitness for purpose is evaluated by the producer.
Fitness for Use	Rationale for selecting a dataset "fitness for use" (e.g. end-user satisfaction) of the science-based products for the benefit of civil society. Fitness for use is evaluated by the user.
GIS	Geographic information systems
Input dataset	This is the collection of existing data used as the input to produce the end- Use-Case products and services. Data can be raw or processed to make it interoperable with other data. The data can be derived from international data networks and programmes (e.g., Copernicus programme), and from other national and international open access databases.
Product	Solution to an end-user problem
SST	Sea Surface Temperature
TRL	Technology Readiness Level
Quality elements	Properties of the data used as an input to produce the products (i.e. upstream data) such as spatial resolution, temporal resolution, temporal coverage, etc.
Use-Case	The AtlantOS Task i.e. pilot action / feasibility study
Use-Case / Pilot Action	Synonymous of AtlantOS Task
Use-Case product	Targeted product build from "input data sets" that are related to "characteristics"

Executive summary

The AtlantOS WP8 targeted products address five GEO/GEOSS societal benefit areas related to climate, disasters, ecosystems, health and water. AtlantOS WP8 seeks to demonstrate the value and societal benefit of the existing observing system in the Atlantic through eight pilot actions. This report provides a description of the input data sets used in the Use-Case Pilot Action on the "Offshore Aquaculture Siting", part of AtlantOS Work Package 8 "Societal Benefits from observing/information systems" of H2020 AtlantOS project. A data adequacy summary, highlighting important gaps in the observing system, based on "expert opinion" is provided for the Offshore Aquaculture suitability maps. The report focuses on the ability of the targeted product to 'sufficiently satisfy a requirement or meet a need' of the end-users. We have created a proof of concept Aquaculture Site selection tool in three European areas that is a good basis for development and we score the quality of our products in the different areas from "sufficient" to "very good"". We have identified as a challenging issue in some areas that not all datasets required are open and free. Not all relevant datasets (wave and current atlas) at adequate spatial and temporal resolution for aquaculture siting exist in all Atlantic European areas.

1. General scope of the Use Case

Today, nearly all global aquaculture is carried out inshore. For example, in the Mediterranean where 80 % of fish cages and pens were located within 1 km from the coast (Trujillo *et al.* 2012). Even though offshore aquaculture has been a topic of interest for decades (e.g., Wilcox 1982, Ryan 2004, Benetti & Welch 2010, Simpson 2011) commercial offshore aquaculture practice is still in its infancy.

There are drivers both at local and global levels that incentivise aquaculture to move to the unprotected waters of the open sea. At the local level, competing claims on available space and resources exist. This is compounded by regulatory restrictions, water quality issues and negative public perception of aquaculture operations related to environmental and aesthetic impact concerns. At the global level, there is a need to maintain food security as the human population size increases, and there is the conviction that the potential of the world's oceans for food supply is vastly underutilised (Kapetsky *et al.* 2013).

Site selection is indeed a key factor in any aquaculture operation and maybe even more important for offshore aquaculture, since the risk of offshore operations are higher. Proper site selection is a prerequisite for the economic sustainability of the operation, for animal welfare and for product quality. Furthermore, proper site selection can help to avoid and/or solve competing demands for access and use of areas, and prevent potential negative environmental impacts of the operations.

A comprehensive site selection analysis was outside the scope of this Use Case. In this AtlantOS Use Case we aimed to make a "proof of concept" to show how AtlantOS data can be used to develop suitability maps of potential areas for offshore aquaculture with emphasis on water depth, wave height, current velocity, temperature and chlorophyll *a*. In addition, some spatial restrictions such as protected areas and habitats, fisheries areas, and maritime activities (e.g., Ship Routes, Oil & Gas installations) were included. A geographical information system (GIS) approach was the chosen analytical tool. For a more detailed description of the Use case, please confer AtlantOS D.8.2. (Dale *et al.* 2017).

2. User needs and user requirements identification

The overall user needs are maps that shows areas/sites that are suitable for offshore aquaculture of salmon and mussels. A suitable area/site for offshore aquaculture for a given species must fulfil criteria related to the various aspects of the farming operations such as animal welfare, equipment restrictions, logistics, environmental impact and legal restrictions. Therefore, the identification of user requirements was broken down to the identification of requirements of the different aspects of farming as exemplified in

Table 1.

Some requirements might be overlapping between potential users, and others may not. For some users physical suitability criteria for a given species (e.g., temperature or chl *a* concentrations) or a given type of farm (e.g., current velocity or wave height) is most important. For other users the identification of suitable areas/sites also needs to address, e.g., legal and logistic issues. We have aimed to identify user requirements for the physical suitability criteria since these are the ones that rely on ocean observations data. However legal issues such as area restrictions are also included in some products since compliance to laws and regulations are fundamental suitability criteria. The user requirements are identified from literature, from national aquaculture legislation, from surveys carried out in already finalized and ongoing EU projects, and from industry "rule of thumb" derived from direct communication with aquaculture producers and equipment manufacturers.

Table 1 Examples of suitability criteria for offshore aquaculture sites with corresponding threshold ranges. * Threshold taken from Kapetsky *et al. (2013)*. ** Industry "rule of thumb", * META - Maritime and Environmental Thresholds for Aquaculture (https://longline.co.uk/meta/list).**

Criteria	Threshold
Suitable areas are areas not used by other sectors, and areas not restricted for further development due to environmental legislation	
For example: • Fishing areas • Spawning Grounds • Feeding/Nursery Grounds • Legal restrictions (e.g., Natura 2000, Cultural Heritage areas), Marine Protected Areas, nature conservation, marine environment protection • Other aquaculture sites • Wind parks/offshore wind farms & Oil/Gas installations • Ship-routes / ports / harbours • Security Zones around Shipping Routes (coastal waterways) • Sea Cables	Variable, depends on use type and local legislation
Suitable areas are areas with favourable grow-out conditions for target species (in this case Atlantic salmon and Blue mussel)	
For example: • Environmental characteristics, such as, temperature, salinity, pH etc., • Food availability (e.g., Chl *a* concentrations) • Current speed • Wave climate	Temperature (°C): • Atlantic salmon 1.5 – 16 °C* (2.0 – 20 °C***) • Blue mussel 2.5 – 19 °C* (2.0 – 27 °C***) Salinity (PSU): • Atlantic salmon 0.0 – 35*** • Blue mussel 4 – 40*** pH: • Atlantic salmon 5.0 – 9.0*** • Blue mussel 6.7 – 9.0*** Carbon dioxide (mg/L): • Atlantic salmon 7 – 20*** Ammonia (mg/L): • Atlantic salmon 0.00 – 0.28*** • Blue mussel 0.00 – 7.00*** Nitrite (mg/L): • Atlantic salmon 0.00 – 0.60*** • Blue mussel 0.00 – n/a*** Nitrate (mg/L): • Atlantic salmon 0 – 300*** • Blue mussel 0.00 – 1.17*** Dissolved Oxygen (mg/L): • Atlantic salmon 5.0 – 13.0*** • Blue mussel 1.0 – 12.5*** Suspended solids (mg/L): • Atlantic salmon n/a – 75*** • Blue mussel 1 – 1000*** Cultivation depth (m): • Atlantic salmon 0 – 210*** • Blue mussel 0 – 10*** Food availability (mg/m^3): • Blue mussel Chl *a* > 0.5 (0.5 104.0***) Current speed (cm/s): • Atlantic salmon fish cages 10 – 100* • shellfish longlines 10 – 100* (0.0 – 60 for blue mussels***) Significant wave height (m); Hs • Atlantic salmon < 4.5**

User requirements for the Norwegian case study area

This use case aims to provide a "proof of concept" on how to identify areas/sites suitable for the offshore production of Atlantic salmon. The Norwegian legislation that regulate aquaculture apply to the entire exclusive economic zone (EEZ) including potential areas for offshore aquaculture. This means that requirements set by Norwegian legislation that pertains to i) the biological needs of farmed animals and their welfare, ii) the compliance to marine spatial plans, iii) protected areas iv) distance to other aquaculture facilities, oil & gas installations and shipping routes are important requirements both for planning authorities, management, and aquaculture industry. We also applied user requirements given in literature, and industry "rule of thumb"

Initial user requirements specification for the Norwegian Use Case are suitability maps that shows potential areas for offshore Atlantic salmon aquaculture including:

- Administrative and legal restrictions (Oil & Gas fields, Offshore Windfarms, Other Aquaculture Sites Security Zones around Shipping Routes, Spawning Grounds, Feeding/Nursery Grounds, Fishing Areas, Marine Protected Areas)
- Water depth
- Temperature
- Currents
- Wave height

User requirements for the Irish case study area

The initial end-user requirements for the Irish Use Case were very restrictive and focused mainly on sea state suitability for aquaculture operations. Activities in AtlantOS Task 8.5 were used as a "proof of concept" exercise to provide suitability maps of potential areas for offshore Atlantic salmon aquaculture using hydrodynamic models. Several limiting variables (bathymetry, wind, wave and currents, exposure) were selected and used to develop the end-user product (i.e. shapefiles for use in GIS mapping; see Deliverable 8.2 for details).

The target dataset delineates Atlantic marine waters around Ireland that meet all the criteria below:

- water depth ≥ 15 m,
- maximum tidal velocity of < 1 m/s,
- maximum significant wave height, *max_Hs*, < 4 m
- Ninetieth percentile value of a significant wave height (*Hs*), *Hs_P90* < 2 m

Since environmental monitoring and the regulation aspects of marine spatial planning (2014 EU Marine Spatial Planning Directive) are important, several administrative and legal restrictions layers were investigated to provide more detailed information on the competition for space in identified suitable areas.

Administrative layers included:

- Aquaculture Sites,
- Sea Cables,
- Security Zones around Shipping Routes (coastal waterways),
- IAA Danger Area & Traffic Separation Scheme (UKHO),
- Offshore Wind Farms,
- Oil & Gas Installations,
- Spawning Grounds,
- Feeding/Nursery Grounds,
- Fishing Areas

User requirements for the Spanish case study area

Initial user requirements specification for the Spanish Use Case are suitability maps that shows potential areas for offshore mussel farms including:

- Administrative and legal restrictions (Marine Protected Areas: Atlantic Islands national park, Nature 2000 Sites of Community Importance, Fisheries reserve (Galician autonomous government protection), Location of mussel rafts, Fishing grounds) and harbour areas
- Water depth: Depth below 15 meters (option a) or below 50 m (option b)
- Wave height constraints from a long run of a wave model at high spatial resolution inside the Galician rias.
    - Maximum significant wave height, max Hs, < 4 m. Obtained from the extreme values with a return period of 10 years
    - Ninetieth percentile value of significant wave height (Hs), Hs_P90 < 2 m

3. Targeted Users

Table 2. Targeted users for the Use Case Products.

Target User Name	URL of User	User needs (from previous work or literature)
Primary end-user group Norway:		
Private sector • Aquaculture companies • Aquaculture industry Association (Sjømat Norge) • The Norwegian Fishermen's Association • Insurance companies (can be several)	http://sjomatnorge.no www.fiskarlaget.no	• Licence application support • Support for hearing statements regarding the industry's interests • Risk assessment
Regulatory and control authorities • Norwegian Food Safety Authority • Fisheries Directorate • Ministry of trade, industry and fisheries • Norwegian environment agency • The Norwegian Ministry of Climate and Environment	www.mattilsynet.no www.fiskeridir.no www.regjeringen.no www.miljodirektoratet.no www.regjeringen.no	• Aquaculture licence decision support
Primary end-user group Ireland:		
Private sector • Aquaculture companies • Higher Education	www.ifa.ie/sectors/aquaculture	• Licence application support • Educational purposes
Regulatory and control authorities: • Government Department and Agencies • Policy makers – marine spatial planners	www.housing.gov.ie/planning/maritime-spatial-planning/maritime-spatial-planning-directive/maritime-spatial-planning	• Aquaculture licence decision support "Marine Spatial Planning Directive 2014/89/EU Establishing a Framework for Marine Spatial Planning was transposed into Irish legislation in 2016. The Directive ensures balanced development and aims to reduce conflicts between sectors, encourage investment, increase cross-border cooperation and protect the environment. Robust spatial data and evidence are required to support the implementation of marine planning"
Primary end-user group Spain:		
Regulatory authorities Spain: • In Galicia, coastal waters where mussel rafts are installed are regulated by Conselleria do Mar from Xunta de Galicia.	https://mar.xunta.gal	• Regulation in Galicia: https://mar.xunta.gal/gl/institucional/normativa/cultivos-marinos/acuicultura-na-zona-maritima

4. Use-case product Technology Readiness Level

The Technology Readiness Level (TRL) of the Offshore aquaculture siting maps was assessed by the scientists in each region (Norway, Ireland and Spain) using the TRL guidelines in Table 3 below. The Norwegian product was given a TRL of 5, while the Irish and Spanish were given a TRL of 4.

Table 3. Technology Readiness Levels (TRL) to define different research and innovation steps going from basic research to the commercialisation of a product.

TRL	Definition
TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	Component and/or subsystem validation in laboratory environment
TRL 5	Component/subsystem/system validation in relevant environment
TRL 6	Demonstration in relevant environment
TRL 7	Prototyping demonstration in an operational environment
TRL 8	Actual system completed and qualified through test and demonstration
TRL 9	Actual system proven through successful operations

5. Use-case products description

AtlantOS Deliverable 8.2. (Dale et al. 2017) describes the scope of the use case in detail, the characteristics/Essential Ocean variable (EOVs) and the data sources used in the Targeted products. A brief summary describing the scope is given in paragraph 1. The targeted products from Task 8.5. are shape files (maps) showing areas that are suitable for offshore aquaculture according to the set of suitability criteria used (Table 4).

Table 4. Brief description of the targeted products.

Nb	Name of Targeted product component	Short description	Format
#1	AtlantOS Case 8.5 product 1	A suitability map for offshore aquaculture in Norway with respect to production conditions and environmental conditions.	Shape file
#2	AtlantOS Case 8.5 product 2	A suitability map for offshore aquaculture in Norway with respect to production conditions, environmental conditions and legal/administrative constrains.	Shape file
#3	AtlantOS Case 8.5 product 3	Environmental suitability map of potential areas for offshore Atlantic salmon aquaculture in Irish waters using hydrodynamic models	Shape file
#4	AtlantOS Case 8.5 product 4	A suitability map for offshore mussel aquaculture in Galicia (NW Spain) with respect to environmental conditions. Additional layers with legal/administrative constraints can be overlaid.	Shape file

6. Use-case product specification

Metadata information of the targeted products is given in the table below (Table 5). The metadata table summarise the quality elements / data properties of the data products (i.e. upstream data) such as spatial resolution, temporal resolution, temporal coverage, etc.

Table 5. Targeted product specification.

Targeted Product #1 specification	
Product component name	**AtlantOS Case 8.5 product 1**
Product component description	**A suitability map for offshore aquaculture in Norway with respect to production conditions and environmental conditions.**
Geographic description	**NE Atlantic areas of Norway**
Horizontal extent	*Give latitude, longitude of sea area bounding box* **The area is a polygon defined by the following coordinates:** **64° 25.696N 10° 29.922E, 64°49.928N 8°58.319E, 67°25.924N 13°24.180E, 67°18.935N 10°29.922 E**
Horizontal resolution	*Give lat. long resolution (fraction of lat, long) of products if in a grid, station locations if stations, etc.* **800 m**
Vertical extent	*Approximate range of depth where the product is significant (surface if the product is only surface, surface-to-bottom if the product is defined in the whole water column, etc.)* **Surface**
Vertical resolution	*Give number of depth or layers where the product is defined if possible* **Surface**
Temporal extent	*Give an estimate of the time period where the product is defined to be relevant* **Winter months (Sept-March) 2016/2017. (Simulation period of numerical modelled data on waves & current)**
Temporal resolution	*Give the time resolution (hourly, daily, weekly, monthly, annual, etc.) of the product* **See "Temporal extent"**
Spatial representation	*Give a description of the specific graphical representation of the results* **Maps showing areas that are suitable for offshore aquaculture of Atlantic Salmon (*Salmo salar*) with respect to production conditions and environmental conditions. Suitable areas are shown in colour.**

Targeted Product #2 specification	
Product component name	**AtlantOS Case 8.5 product 2**
Product component description	**A suitability map for offshore aquaculture in Norway with respect to production conditions, environmental conditions and legal/administrative constrains.**
Geographic description	*Use name of sea area or conventional name by users* **NE Atlantic areas of Norway**
Horizontal extent	*Give latitude, longitude of sea area bounding box* **The area is a polygon defined by the following coordinates:** **64° 25.696N 10° 29.922E, 64°49.928N 8°58.319E, 67°25.924N 13°24.180E, 67°18.935N 10°29.922 E**
Horizontal resolution	*Give lat. long resolution (fraction of lat, long) of products if in a grid, station locations if stations, etc.* **800 m**
Vertical extent	*Approximate range of depth where the product is significant (surface if the product is only surface, surface-to-bottom if the product is defined in the whole water column, etc.)* **Surface**
Vertical resolution	*Give number of depth or layers where the product is defined if possible* **Surface**

Temporal extent	*Give an estimate of the time period where the product is defined to be relevant* **Winter months (Sept-March) 2016/2017. (Simulation period of numerical modelled data on waves & current)**
Temporal resolution	*Give the time resolution (hourly, daily, weekly, monthly, annual, etc.) of the product* **See "Temporal extent"**
Spatial representation	*Give a description of the specific graphical representation of the results* **Maps showing areas that are suitable for offshore aquaculture of Atlantic Salmon (*Salmo salar*) with respect to production conditions and environmental conditions. Suitable areas are shown in colour.**

Targeted Product #3 specification	
Product component name	**AtlantOS Case 8.5 product 3**
Product component description	**A suitability map for offshore aquaculture in Irish waters with respect to environmental conditions.**
Geographic description	**NE Atlantic areas off Ireland**
Horizontal extent	*Give latitude, longitude of sea area bounding box* **12.0 to 7.5° W; 50.0 to 56.5° N**
Horizontal resolution	**0.004 degrees**
Vertical extent	*Approximate range of depth where the product is significant (surface if the product is only surface, surface-to-bottom if the product is defined in the whole water column, etc.)* **Surface**
Vertical resolution	*Give number of depth or layers where the product is defined if possible* **Surface**
Temporal extent	*Give an estimate of the time period where the product is defined to be relevant* **13 months of simulated numerical modelled data in the year 2010**
Temporal resolution	*Give the time resolution (hourly, daily, weekly, monthly, annual, etc.) of the product* **13 months**
Spatial representation	*Give a description of the specific graphical representation of the results* **Maps showing sea state suitability areas for offshore aquaculture of Atlantic Salmon (*Salmo salar*) with respect to environmental conditions. Suitable areas are presented as shape files.**

Targeted Product #4 specification	
Product component name	**AtlantOS Case 8.5 product 4**
Product component description	**A suitability map for offshore aquaculture in Galicia (NW Spain) with respect to environmental conditions.**
Geographic description	**NE Atlantic areas off Galicia**
Horizontal extent	*Give latitude, longitude of sea area bounding box* **10.3 to 6° W; 41.7 to 44° N**
Horizontal resolution	**Wave atlas resolution and depth determine horizontal resolution. Depth product resolution is 30 arc seconds (~1.5 km). Wave atlas has high spatial resolution reaching 75 m inside the Galician Rias and even higher in shallow areas.**
Vertical extent	*Approximate range of depth where the product is significant (surface if the product is only surface, surface-to-bottom if the product is defined in the whole water column, etc.)* **Surface**
Vertical resolution	*Give number of depth or layers where the product is defined if possible* **Surface**
Temporal extent	*Give an estimate of the time period where the product is defined to be relevant* **Product is based on a wave atlas computed from results of a model hindcast of the period 1958-1999**
Temporal resolution	*Give the time resolution (hourly, daily, weekly, monthly, annual, etc.) of the product* **Wave climate constraints are based on extreme values with a return period of 10 years**

Spatial representation	*Give a description of the specific graphical representation of the results* **Maps showing sea state suitability areas with respect to environmental conditions. Suitable areas are presented as shape files. Additional layers with legal/administrative constraints have been compiled and can be overlaid.**

7. Upstream Data and Targeted Data Products Fitness

A conceptual model of AtlantOS T8.5 Use Case "offshore aquaculture siting" is presented in Figure 1 below. The figure shows a high-level view of how the targeted products are built using EOVs (essential ocean variables), that are sourced from data integrators (RS, modelling and *in-situ* information) and merged by applying a GIS methodology to identify areas suitable for offshore aquaculture site selection.

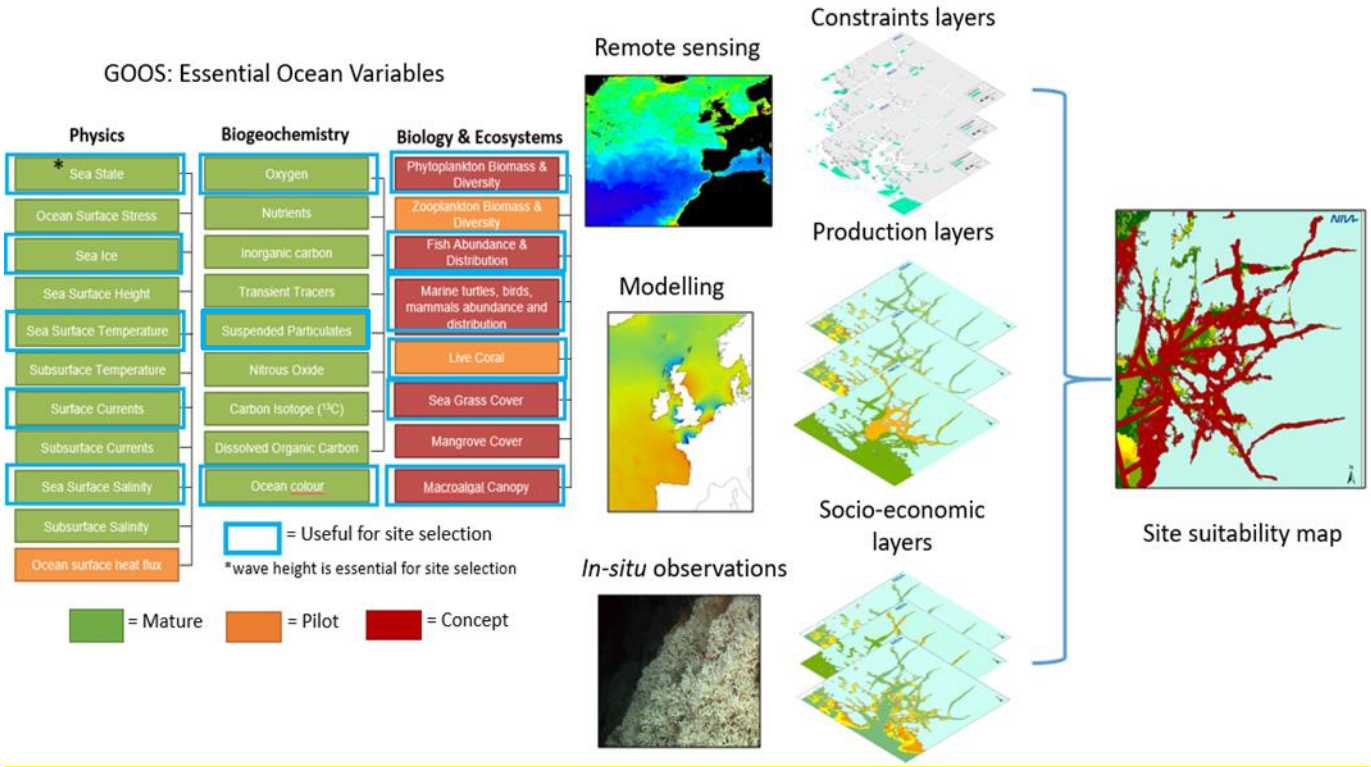

Figure 1. Conceptual model of the aquaculture offshore site selection GIS approach. The left side of the figure presents the GOOS Essential Ocean Variables (EOVs) and indicates their potential use in the development of aquaculture siting tools.

7.1. Criteria for expert evaluation of Use Case product quality and gaps in the input data sets

The objective is to provide an expert evaluation of the "fitness for purpose" of the input data sets to create the product and the "fitness for use" of the Targeted Product (Source: EMODNet checkpoint). The methodology helps us to evaluate the quality of existing data in terms of their accessibility, availability, multiple-use, efficiency, reliability, time consistency, space consistency, as well as the planning of technological advancements, new accessibility, new assembly protocols and observational priorities. To do the evaluation, the Task 8.5 team were asked to provide the following information:

1. Assign an overall product quality score with respect to scope (fitness for purpose) and explain why, according to the scale in Table 6 below.
2. Identify the most important characteristic needed for the Targeted Product quality (if all characteristics are important please say so)
3. Identify the quality element(s) of the most important characteristic(s) that affects the Targeted Product quality.
4. Identify the limitations on the quality of the Targeted product due to the input data set used.
5. Explain which characteristics "fails the most" to meet the scope of the Targeted Product.
6. Provide an expert judgement of the most important gaps in the input data sets for the Targeted Product.

Table 6. Scale used to determine "Fitness for purpose and use" quality score of the Targeted Product (i.e. the HAB bulletin)

Score	Result	"Fitness for purpose and use" of the Targeted Product
1	Excellent	completely meets the scope of the Targeted Product
2	VERY GOOD	meets > 70 % of Targeted Product scope
3	GOOD	meets < 50 % of the Targeted Product scope
4	SUFFICIENT	does not really meet the scope but it is a starting point
5	INADEQUATE	does not really fulfil the scope and is not usable

AtlantOS Case 8.5 product #1

1. The overall product quality score with respect to scope (fitness for purpose).

   The product quality score is **very good (2).** The GIS analysis was quite simple. Only Boolean (or Binary) suitability was used, where the data or area is either suitable (1) or unsuitable (0). To exemplify we can look at the suitability criteria significant wave height (*Hs*). We used an industry "rule of thumb" as the suitability threshold where *Hs* maximum of < 4.5 m was considered unsuitable. When one observation exceeded the threshold criterion during the analysed time period the area was deemed unsuitable. For *Hs* and other criteria used the suitability is unlikely to be binary, but rather dependent upon the length of the time exceedance of the threshold is acceptable. Hence, there is scope for refinement of the criteria in dialogue with end-users. Important characteristics such as wave height and current velocity were only available for a limited time period (less than one year), therefore there are no measures of the temporal variability.

2. The most important characteristic needed for the Targeted Product quality.

   Weighting of the suitability criteria was not considered in this case. Therefore, all input characteristics/variables contribute equally to the product quality. Future efforts should consider this option in consultation with end-users.

3. The quality element(s) of the most important characteristic(s) that affects the Targeted Product quality.

   The temporal and spatial resolution of characteristics/variables (temperature, current velocity, wave height, bathymetry) used was good and contributed positively to the product quality.

4. The limitations on the quality of the Targeted product due to the input data set used.

   The product quality is limited by the temporal coverage of some characteristics (see point 1).

5. Which characteristics "fails the most" to meet the scope of the Targeted Product.

   All the characteristics considered contribute to the analysis and meet the scope of the product.

6. Expert judgement of the most important gaps in the input data sets for the Targeted Product. Other characteristics could be important for aquaculture siting. Figure 1 summarises the characteristics/variables used in the AtlantOS Task 8.5. and presents other potential variables that could be included in future efforts should new ocean observing datasets become available. Examples include datasets related to live corals, phytoplankton biomass and biodiversity.

AtlantOS Case 8.5 product #2

1. The overall product quality score with respect to scope (fitness for purpose).

   The product quality score is **good (3)** to **very good (2).** Targeted product #2 builds on #1, therefore the assessment under 1) above is valid also for Targeted Product #2. Targeted Product #2 covers most constraints on area related to legal and administrative restrictions as well as restrictions related to conflict with other sectors.
2. The most important characteristic needed for the Targeted Product quality.

   Weighting of the suitability criteria was not considered in this case. Therefore, all input characteristics contribute equally to the product quality. Future efforts should consider this option in consultation with end-users.
3. The quality element(s) of the most important characteristic(s) that affects the Targeted Product quality.

   The assessment under 3) above is also valid for Targeted product #2. All the constraint layers are based on data issued by public authorities, and their accuracy and completeness have high positive impact on the product quality.
4. The limitations on the quality of the Targeted product due to the input data set used.

   See assessment point 4) above.
5. Which characteristics "fails the most" to meet the scope of the Targeted Product

   See assessment point 5) above.
6. Expert judgement of the most important gaps in the input data sets for the Targeted Product.

   See assessment point 6) above.

AtlantOS Case 8.5 product #3

The AtlantOS aquaculture site selection product #3 was derived from a physical model; validated by the *In-situ* ocean data. Several variables (bathymetry, wind, wave and currents, exposure) were used to develop the product. The resulting shapefiles are a research and development demonstration product only and as such are used as a "proof of concept" and not suitable for Marine Spatial Planning or other similar purposes.

1. The overall product quality score with respect to scope (fitness for purpose)

   The product quality score is **Sufficient (4).** The GIS analysis was very basic with very strict criteria. Only Boolean (or Binary) suitability was used, where the data or area is either suitable (1) or unsuitable (0). To exemplify we can look at the suitability criteria significant wave height (*Hs*). We used an industry "rule of thumb" as the suitability threshold where a *Hs* maximum of < 4.5 m was

considered unsuitable. When one observation exceeded the threshold criterion during the analysed time period, the area was deemed unsuitable. For *Hs* and other criteria used, the suitability is unlikely to be binary, but rather more dependent on a more defined and acceptable exceedance threshold time (to be determined based on the engineering stress limits of cages used). Hence, there is scope for refinement of the criteria in dialogue with end-users. A limited time period (13 months) was used for important characteristics such as wave height.

2. The most important characteristic needed for the Targeted Product quality.

   Weighting of the suitability criteria was not considered in this case. Therefore, all input characteristics/variables contribute equally to the product quality. Future efforts should consider this option in consultation with end-users.

3. The quality element(s) of the most important characteristic(s) that affects the Targeted Product quality.

   The temporal and spatial resolution of characteristics/variables (bathymetry, wind, wave and currents, exposure) used was good and contributed positively to the product quality.

4. The limitations on the quality of the Targeted product due to the input data set used.

   The product quality is limited by the temporal coverage used to create the product (see point 1).

5. Which characteristics "fails the most" to meet the scope of the Targeted Product

   All characteristics considered contribute to the analysis and meet the scope of the product.

6. Expert judgement of the most important gaps in the input data sets for the Targeted Product.

   Other characteristics could be important for aquaculture siting. Figure 1 summarises the characteristics/variables used in the AtlantOS Task 8.5. and presents other potential variables that could be included in future efforts should new ocean observing datasets become available. Examples include datasets related to live corals, phytoplankton biomass and biodiversity.

AtlantOS Case 8.5 product #4

1. The product quality score is **Good (3).** The strength of the product comes from the high spatial resolution of the wave atlas. Although the GIS analysis was basic, we were able to give detailed results in the Galician rias and shelf areas of depth below 50 m. The resultant layer together with administrative constraints renders a good product of suitable areas. This is illustrated by the fact that when overlying the location of existing mussel rafts in Galicia, mussel rafts in Galicia are found to be located in the suitable areas obtained in our analysis.

2. The product also benefited from the long period of the wave model hindcast, which allowed us to obtain representative values of significant wave height and peak wave height with a return period of 10 years. With this high-quality input data, the reliability of the suitable areas is high.

3. Administrative layers showing protected areas, harbour and areas with existing mussel rafts have been found. Layers are available in governmental portals and have been overlaid to the suitable layer computed from depth and wave climate constraints. Other potential limitations not considered in this exercise are discussed in the following

4. Other physical layers like currents or temperature could be added to the exercise, although they are not main constraints for mussel aquaculture in Galicia. Maximum tidal currents are not limiting in Galicia, velocities above 1 m/s are only observed in very specific places, like the entrance of Ria de Ferrol or the Miño estuary, which lie in a harbour entrance (Ria de Ferrol) or in a Nature 2000 protected area (Miño estuary). Mussels are adapted to a high temperature range and not suitable temperatures are not met. Galician rias are productive, and availability of nutrients is not limiting in principle for location of mussel rafts. Limitations arising from the carrying capacity of the ecosystem would require specific studies and cannot be performed with the approach we have undertaken. Anyway, as a conclusion, we can say that in the Galician Rias Baixas, the quantity of mussel rafts hinders further aquaculture activities. However, there are a few areas where, according to our criteria, potential aquaculture activities could be explored, although further interaction with stakeholders is required.

5. Other potential conditions that limits aquaculture siting are HABs. However, although historical data on HAB occurrence is available, we have not found any limiting criteria for aquaculture profitability. There are mussel rafts in some locations in Galician rias which are closed on average most of the year and they are still profitable. In fact, high economic losses to the shellfish industry in Galicia have just been reported in years of HAB autumn blooms, since closures last for several months and include the winter (Christmas) harvest season (Rodriguez-Rodriguez et al. 2011). However, this strong HAB autumn blooms causing losses are infrequent, in the last 30 years, the only episodes have been 1989, 1990, 2005 and 2013 (Diaz et. al 2016, Ruiz Villarreal et al. 2016)

In Atlantos deliverable D.10.5. « Best Practices in Stakeholder Engrangement, data Dissemination and Exploitation » stakeholder engagement is described as a circle of 8 steps (« Cicle of engagement »). While most steps (Users identified, prioritised and consulted; products identified by Users, User Requirements

defined, products solutions developed, outreach conducted) are carried out in Task 8.5. we have not carried out any products assessment among users. We therefore have no user feedback to assess the “fitness for use” for these specific products. In our opinion the product is fit for an initial assessment of suitability, because the product identifies areas of conflicting use, and areas that exceed a threshold of important suitability criteria (such as temperature). We therefore believe this type of product is fit for use to support both the initial phase of a licence application as well as for planning purposes. It is less fit for the later step of site selection, both because important suitability criteria are not included and because this process often require detailed knowledge of the operation in question and the weighing different suitability criteria accordingly.

7.2. Recommendations for system improvements

As marine spatial planning methodologies in Europe (2014 EU Marine Spatial Planning Directive) and International “Best Practice” evolve, it is expected that decision support products for aquaculture site selection will mature, building on the work carried out in AtlantOS Task 8.5, to ensure more “fit for use” Targeted Products. We have created a proof of concept Aquaculture Site selection tool in three European areas that is a good basis for development, and we score the quality of our products in the different areas from “sufficient” to “very good””. We have identified as a challenging issue in some areas that not all datasets required are open and free. Not all relevant datasets (wave and current atlas) at adequate spatial and temporal resolution for aquaculture siting exist in all Atlantic European areas. Future work should have a continued integrative approach, as developed in Norway, with datasets from multiple sectors competing for space included in the analyses and the addition of new information on the environmental limits of cultured species (e.g. META - Maritime and Environmental Thresholds for Aquaculture) and new environmental thresholds with advances in aquaculture engineering. Advances can only be achieved with strong end user engagement to ensure developed products are “fit for use”.

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