**AQUASPACE**

**Ecosystem Approach to making Space for Aquaculture**

**EU Horizon 2020 project grant no. 633476**

# *Deliverable 2.5*

# *Online Environmental Feasibility Application*

# *And*

# *Milestone MS15 Release of on-line Environmental Feasibility Application*

| | |
|---|---|
| Lead Beneficiary | LLE |
| Deliverable authors | F.J. Boogert, A.M. Cubillo, J.P. Nunes, J.G. Ferreira, R.A. Corner |
| Deliverable version | 2.0 |

| | |
|---|---|
| Type of deliverable | Website, patent filling etc. |
| Dissemination level | PU |
| Delivery date in DoW | Month 15 |
| Actual delivery date | V1: January 2017; V2: August 2018 |

| | |
|---|---|
| Reviewed by | V1 & v2: R. Gomes Ferreira; V2: P. Tett |

The research leading to these results has been undertaken as part of the AquaSpace project (Ecosystem Approach to making Space for Aquaculture, http://aquaspace-h2020.eu) and has received funding from the European Union's Horizon 2020 Framework Programme for Research and Innovation under grant agreement n° 633476.

Change log

| Version | Date | Author | Reason for change |
|---|---|---|---|
| 0.1 | 20/01/2017 | A.M. Cubillo | Initial draft |
| 0.2 | 21/01/2017 | F.J. Boogert, J.P. Nunes | Delivered report on environment aspects |
| 0.3 | 25/01/2017 | A.M. Cubillo | Add references for Species database and provide examples of how the data can be leveraged |
| 0.4 | 30/01/2017 | J.G. Ferreira | Final draft |
| 1.1 | 12/08/2018 | J.G. Ferreira, J. Lencart e Silva | Revised deliverable |
| 2.0 | 29/08/2018 | P. Tett | Minor edits |

Review log

| Version | Date | Reviewer | Comments |
|---|---|---|---|
| 1.0 | 31/01/2017 | R. Gomes Ferreira | Approved |
| 1.5 | 21/08/2018 | R. Gomes Ferreira | Approved |
| 2.0 | 29/08/2018 | P. Tett (SAMS – co-ordinator) | Approved resubmission |

# Executive Summary

This report describes the web-based application **WATER** (Where can Aquaculture Thrive in Europe), which combines a data base of species properties (**META** - Maritime and Environmental Thresholds for Aquaculture) with an environmental data base, to make maps showing regions suitable for the cultivation of aquatic organisms.

WATER is a complex product that combines big data with online processing to provide information for industry, management, and the public. It is written in SQL (Structured Query Language) used to query a database. The software uses mapping tools, species and parameter thresholds and individual growth models to identify the environmental potential for aquaculture with an emphasis on sites, both in freshwater and the sea, where different cultivated species can be grown.

This report documents META and WATER. This version 2 includes, in Annex III, responses to recommendations by external reviewers of the AquaSpace second Periodic report (and associated deliverables).

# Contents

# Introduction and objectives

The AquaSpace project has the goal of providing increased space for aquaculture, to encourage and allow increased aquaculture production in marine and freshwater systems.

AquaSpace Work Package 2, *Accurately Identify Industry-Wide Issues and Options*, aims to identify issues and options that condition aquaculture development in Europe in general, and in the EU in particular. The consortium felt the need to do this in a quantitative manner, in order for the work to be of direct practical use to industry, managers, and policy-makers, as well as to other AquaSpace work packages.

The main environmental analysis was developed in Task 2.2, described below.

Task 2.2 – Quantitative Assessment of Aquaculture-Environment issues (Lead LLE)

*This task will evaluate how the environment limits cultured species (and infrastructure) selection and spatial deployment due to natural (e.g. bathymetry, current speed, temperature, dissolved oxygen), and anthropogenic factors.*

*This will be executed following a systems approach, starting with the development and population of an online relational database of cultivated species, gear, and mooring types, and identification and definition of ranges for all relevant factors at the European scale. Where possible, we will build on existing applications such as www.aquaculture.scotland.gov.uk. This work will be developed into a web application which will allow anyone to examine the potential Europe-wide development of culture from the environmental standpoint (feasibility). It will focus on the potential feasibility in coastal waters, and will not address the influence of aquaculture on the environment, because the final siting decision is multi-sectorial by nature of the definition of carrying capacity (production, ecological, social, governance).*

Because we aimed to perform a quantitative assessment, several tools needed to be developed for task implementation. These are not necessarily tools *sensu* WP3, the dedicated AquaSpace *Tools* package, but they do reinforce the overall toolbox provided by the project.
The relevant specifications in the DOW were:

- D2.5: “On-line Environmental Feasibility application”
- MS15: “Release of on-line Environmental Feasibility website”

The deliverable is the on-line application. This report is thus, strictly, not a requirement of AquaSpace, except insofar as it documents the achievement of the milestone and deliverable. Its main **objectives** are, however, to describe the steps of the work executed, and their principal outcomes. As such, it focuses mainly on the methodology, but a few examples are provided to help the reader understand the outcomes of the task.

Three components are essential for the quantitative analysis of the influence of the environment on aquaculture (Fig. 1).

The fundamental components are represented in the lower part of the figure:

- A species thresholds database;
- An environmental conditions database.

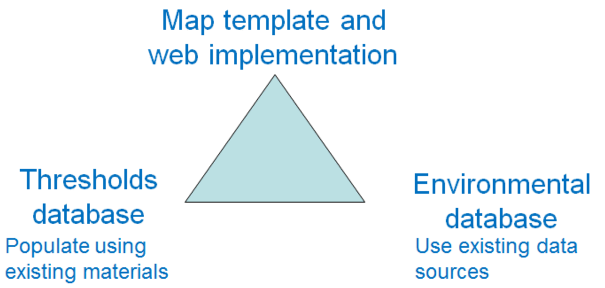


*Fig. 1. General schematic of components of the WATER platform.*

The final element is a web platform that combines both of these, entitled WATER – Where Can Aquaculture Thrive in Europe. The main focus of this report is on the first two components, since these constitute the science base for the quantitative analysis.

# Environmental thresholds for cultivated species

## Data acquisition

Data were collected for the top 45 species produced in the EU from 2010 to 2014 (Table 1).

*Table 1. List of aquaculture species considered, classified by culture group and environment.*

| Common Name | Genus | Species | Culture Group | Environment |
|---|---|---|---|---|
| Atlantic salmon | *Salmo* | *salar* | Finfish | Marine[1] |
| Gilthead sea bream | *Sparus* | *aurata* | Finfish | Marine |
| European seabass | *Dicentrarchus* | *labrax* | Finfish | Marine |
| Turbot | *Psetta* | *maxima* | Finfish | Marine |
| Sea trout | *Salmo* | *trutta m. trutta* | Finfish | Marine |
| Atlantic bluefin tuna | *Thunnus* | *thynnus* | Finfish | Marine |
| Meagre | *Argyrosomus* | *regius* | Finfish | Marine |
| Shi drum | *Umbrina* | *cirrosa* | Finfish | Marine |
| Grey mullet | *Mugil* | *cephalus* | Finfish | Marine |
| Senegalese sole | *Solea* | *senegalensis* | Finfish | Marine |
| Red porgy | *Pagrus* | *pagrus* | Finfish | Marine |
| Atlantic halibut | *Hippoglossus* | *hippoglossus* | Finfish | Marine |
| Common sole | *Solea* | *solea* | Finfish | Marine |
| Rainbow trout | *Oncorhynchus* | *mykiss* | Finfish | Freshwater |
| Common carp | *Cyprinus* | *carpio* | Finfish | Freshwater |
| North African catfish | *Clarias* | *gariepinus* | Finfish | Freshwater |
| Bighead carp | *Hypophthalmichthys* | *nobilis* | Finfish | Freshwater |
| European eel | *Anguilla* | *anguilla* | Finfish | Freshwater |
| Silver carp | *Hypophthalmichthys* | *molitrix* | Finfish | Freshwater |
| Grass carp | *Ctenopharyngodon* | *idella* | Finfish | Freshwater |
| Roach | *Rutilus* | *rutilus* | Finfish | Freshwater |
| European catfish | *Silurus* | *glanis* | Finfish | Freshwater |
| European whitefish | *Coregonus* | *lavaretus* | Finfish | Freshwater |
| Tench | *Tinca* | *tinca* | Finfish | Freshwater |
| Brook trout | *Salvelinus* | *fontinalis* | Finfish | Freshwater |
| Pike perch | *Sander* | *lucioperca* | Finfish | Freshwater |
| Northern pike | *Esox* | *lucius* | Finfish | Freshwater |
| Nile tilapia | *Oreochromis* | *niloticus* | Finfish | Freshwater |
| Arctic char | *Salvelinus* | *alpinus* | Finfish | Freshwater |
| Danube sturgeon | *Acipenser* | *gueldenstaedtii* | Finfish | Freshwater |
| Siberian sturgeon | *Acipenser* | *baerii* | Finfish | Freshwater |
| European perch | *Perca* | *fluviatilis* | Finfish | Freshwater |
| Mediterranean mussel | *Mytilus* | *galloprovincialis* | Bivalve shellfish | Marine |
| Blue mussel | *Mytilus* | *edulis* | Bivalve shellfish | Marine |
| Pacific Oyster | *Crassostrea* | *gigas* | Bivalve shellfish | Marine |
| Manila clam | *Ruditapes* | *philippinarum* | Bivalve shellfish | Marine |
| Good clam | *Ruditapes* | *decussatus* | Bivalve shellfish | Marine |
| European flat oyster | *Ostrea* | *edulis* | Bivalve shellfish | Marine |
| Pullet carpet shell | *Venerupis* | *pullastra* | Bivalve shellfish | Marine |
| Queen scallop | *Aequipecten* | *opercularis* | Bivalve shellfish | Marine |
| Great Atlantic scallop | *Pecten* | *maximus* | Bivalve shellfish | Marine |
| Common cockle | *Cerastoderma* | *edule* | Bivalve shellfish | Marine |
| Winged kelp | *Alaria* | *esculenta* | Macroalgae | Marine |
| Sea belt | *Saccharina* | *Lattisima* | Macroalgae | Marine |
| Sea lettuce | *Ulva* | *Lactuca* | Macroalgae | Marine |

[1] Marine may in some cases also include brackish water (estuaries or lagoons)

The species considered account for 85% and 95% of current EU aquaculture production in tonnage and revenue, respectively (FAO Fishstat Plus database - FIGIS).

Data were organized in multiple spreadsheets, and include 32 species of finfish, 10 species of bivalve shelfish, and 3 seaweed species. We have considered the same common names used by FAO, but in addition have inserted various *local name* fields, in order to build a multilingual database.

For each of these 45 farmed species, we have performed an extended literature review on tolerance and optimal ranges for thirteen environmental parameters (Table 2).

*Table 2. Environmental parameters for defining the aquaculture potential of candidate species on land and open-water sites across the European Exclusive Economic Zone.*

| Parameter name | Unit | Category |
|---|---|---|
| Water temperature | ºC | Physical |
| Salinity | psu | Physical |
| pH | - | Chemical |
| Total Ammonia Nitrogen (TAN) | mg $L^{-1}$ | Chemical |
| Un-ionized ammonia | mg $L^{-1}$ | Chemical |
| Nitrite | mg $L^{-1}$ | Chemical |
| Nitrate | mg $L^{-1}$ | Chemical |
| Cultivation depth | m | Physical |
| Dissolved oxygen | mg $L^{-1}$ | Chemical |
| Current speed | m $s^{-1}$ | Physical |
| Chlorophyll | ug $L^{-1}$ | Biological |
| Suspended solids | mg $L^{-1}$ | Physical |
| Carbon dioxide | mg $L^{-1}$ | Chemical |

The spreadsheet includes other qualitative parameters, such as the countries where species are farmed, the production systems employed, and the seeding methods. We have specified four *Culture Types* (land-based, suspended, off-bottom, and bottom culture) and considered ten different *Culture Structures* or production systems at the on-growing stage (cages, ponds, tanks, raceways, pens, rafts, longlines, stakes, trestles, and bottom). The *Seeding Method* refers to the way the seeds are obtained (hatchery, wild catch, spat collectors, or nursery).

The *Species* data relate the core species names to their scientific names, and to the common names used in different countries (United Kingdom, France, Italy, Spain, Portugal, Norway, USA, and China).

The source(s) of information for each threshold defined are collated by means of a *Reference List* that associates each parameter value to its literature reference(s): author(s), date, study title and publication journal, and provides hyperlink(s), where applicable (see Annex II for the complete listing).

Table 3 shows some examples of optimal and threshold ranges. Every parameter has four categories (threshold low; optimal low; optimal high, and threshold high).

*Table 3. Examples of optimal and threshold ranges for water temperature and salinity.*

| Genus | Species | Water temperature (°C) | | | | Salinity (psu) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Threshold low | Optimal low | Optimal high | Threshold high | Threshold low | Optimal low | Optimal high | Threshold high |
| Salmo | salar | 2 | 10 | 16 | 24 | 0 | 22 | 28 | 35 |
| Sparus | aurata | 6 | 17 | 25 | 32.5 | 5 | 15 | 38 | 44 |
| Dicentrarchus | labrax | 2 | 19 | 25 | 32 | 4 | 13 | 30 | 40 |
| Oncorhynchus | mykiss | 1 | 12 | 18 | 25 | 0 | 0 | 20 | 35 |
| Cyprinus | carpio | 4 | 20 | 25 | 36 | 0 | 0 | 2.5 | 12 |
| Mytilus | galloprovincialis | 5 | 14 | 20 | 30 | 8 | 25 | 30 | 39 |
| Mytilus | edulis | 2 | 8 | 18 | 27 | 4 | 22 | 30 | 40 |
| Venerupis | philippinarum | 0 | 20 | 22 | 40 | 14 | 20 | 30 | 38 |

## WATER species database

Although a spreadsheet format is useful for raw data collection, it does not constitute a database in the true sense, but is rather a collection of unrelated flat-file tables. In order to leverage the power of the data collected, and to make it available to the type of mapping framework illustrated in Fig. 1, the different data entities need to be structured as a relational (or some other type of) database.

The second stage of this work was therefore to design a framework for the organisation of the species database (Fig. 2).

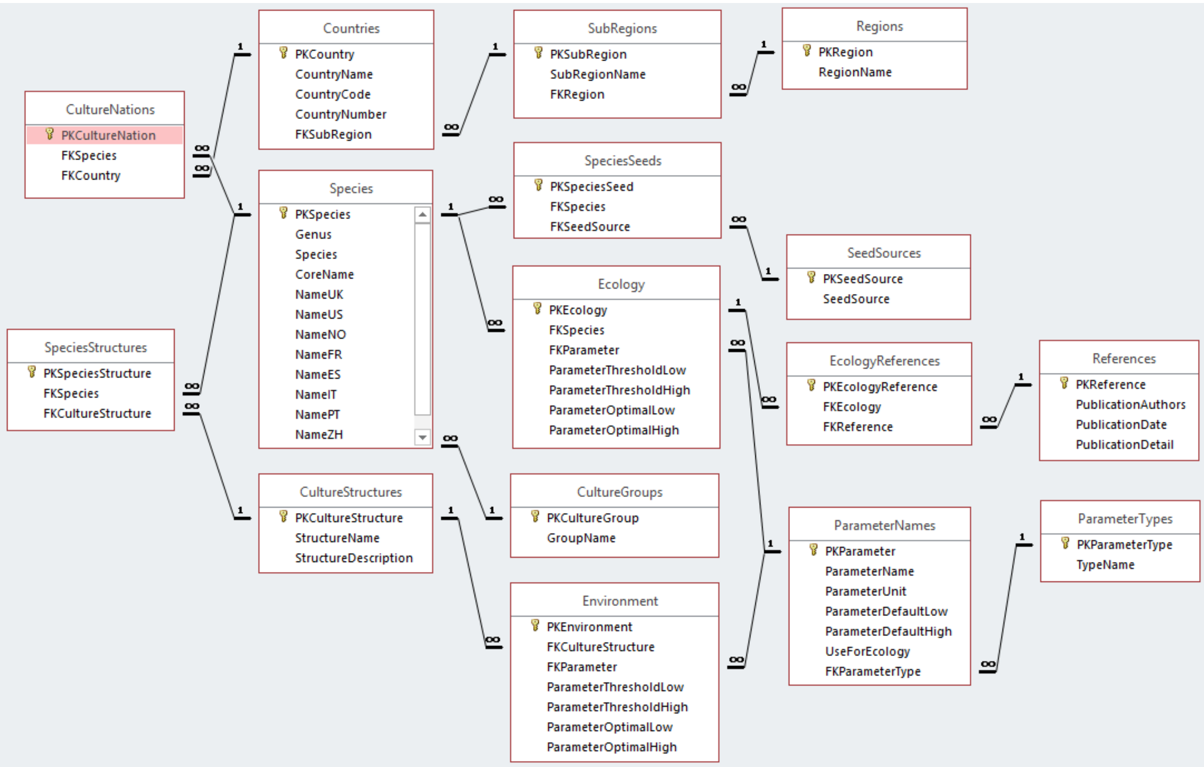


*Fig. 2. Framework for the species relational database.*

The framework shown in Fig. 2 contains 16 tables, all of which are populated from the core spreadsheet. The database was designed using MS-Access, but it can subsequently be easily imported and used in any Structured Query Language (SQL) platform, such as MySQL, MS-SQL, or ORACLE.

In the third stage of the work, a bespoke software application (Fig. 3) was developed in Visual C++ to automate the loading of all data from the spreadsheet format into the SQL database. This application is part of the toolset required for the web-based application WATER (Where can Aquaculture Thrive in Europe). It bears the same name, but is alternatively called META (Maritime and Environmental Thresholds for Aquaculture) in the AquaSpace ToolBox.

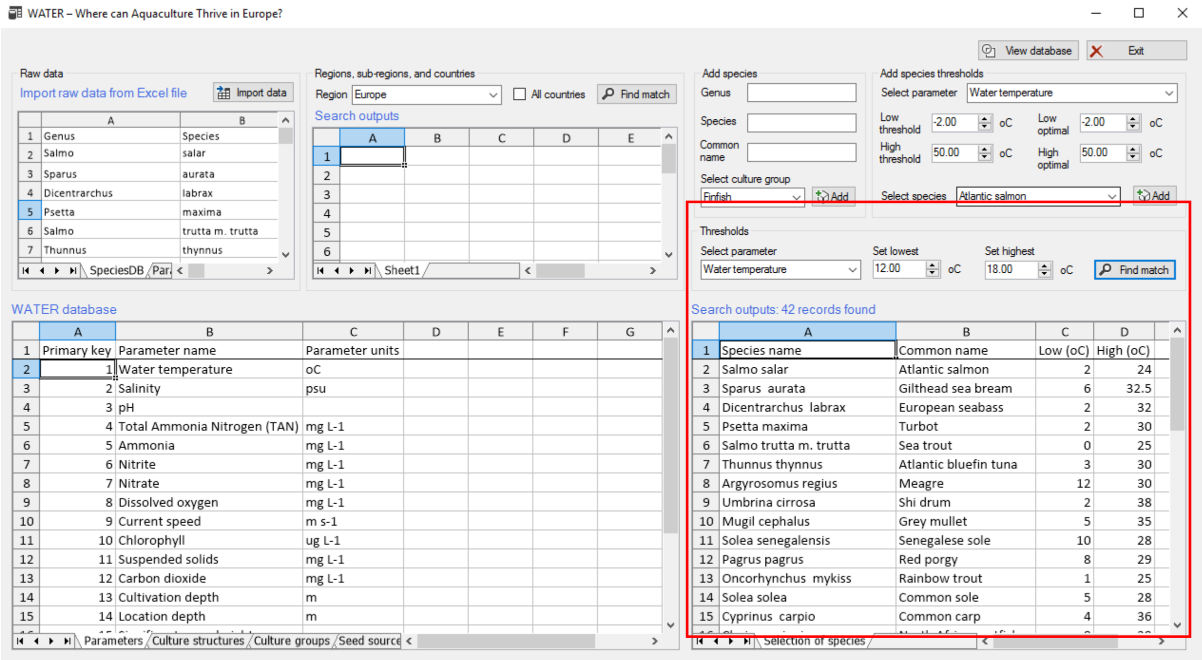


*Fig. 3. The WATER species import application, which can also be used for species selection (see red rectangle).*

This software can also be used to search for the suitable species that can be cultivated in a particular area based on their tolerance range for the environmental parameters, e.g. temperature.

Fig. 3 shows an example table of the species that would perform well in the average temperature range of Galician Rias (12-18ºC). The WATER (species) application has found that 42 out of the 45 species considered could be potentially cultivated in Galician waters, if we only take temperature into account. All marine species of the database would survive in Galicia, but this does not mean that aquaculture would be commercially viable. For that, this temperature range would need to fall within the optimal growth range for each species.

# Environmental database: Ocean and freshwater data

The aim of WATER is to provide Europe-wide mapping of a combination of environmental and economic possibilities for aquaculture siting. WATER deals with a database of 40 gigabytes for marine waters (full European EEZ) at a scale of squares of one nautical mile, and 54,000 spatial records for freshwater (all the major European lakes and reservoirs).

## Design

The database created is based and expanded upon work by the FAO (Kapetsky, Aguilar-Manjarrez, & Jenness, 2013). The spatial data used for classification in this paper is separated into two categories, physical and Environmental parameters as shown in Table 4.

*Table 4: data sources used by FAO* (Kapetsky et al., 2013)

| Physical parameters | |
|---|---|
| Currents | Ocean surface currents that are wind- or tidally driven. Suitability assessment and site selection for offshore mariculture needs long-term historical information on the speed and variability of currents because currents disperse aquaculture wastes and possibly lessen the prevalence of certain ectoparasite infections; however, currents that are too strong can impact the safety of the installation and the cost of marine transport and access and servicing of the facilities, as well as the cultured organisms themselves (e.g. energy expended on swimming rather than growth) |
| Wind | Average wind speed. Suitability assessment and site selection for offshore mariculture may benefit from long-term information on the exposure of an area to strong winds and storms given the impact on wave heights and currents. There is also a direct wind effect on service boat operations apart from wave height. Monitoring for warnings and forecasts regarding the expected track and severity of storms may also be useful. |
| Wave height | Technically defined as the difference in elevation between the crest of an ocean wave and the neighbouring trough; significant wave height (SWH) is a commonly used measure and is the average height of the one-third largest waves. Suitability assessment and site selection for marine aquaculture needs long-term information on SWH because of its importance for cost-effective and robust engineering of the marine aquaculture structures. |
| Environmental parameters | |
| Sea surface temperature (SST) | Sea surface temperature is physically determined by the incidence of solar radiation, ocean circulation and the depth of the mixed layer, which is affected by upwelling, surface winds and bathymetry. Offshore mariculture requires data and information on sea temperatures because fish and shellfish growth rates (and survival) are affected by average temperature and temperature variability. SST is the temperature of the water close to the surface, or the ocean "skin", and SST data are most likely applicable for suitability assessment and monitoring, the latter because models of ocean productivity need temperature data. |
| Primary production | Production of organic compounds from carbon dioxide through the process of photosynthesis, primarily by microscopic algae. Net primary production accounts for losses due to processes such as cellular respiration. Primary production is mostly determined by the availability of light and mineral nutrients, the latter being affected by stratification and mixing of the water column. Offshore mariculture requires data and information on the primary production of an area because shellfish are filter-feeders that rely on sufficient concentration of food particles such as phytoplankton for their growth. Chlorophyll-a concentration products that remote sensing can support are suitability assessment, zoning and site selection, and monitoring. Fish farmers may be interested in historical data and monitoring extremes of primary production, which may be harmful to fish health through oxygen depletion or production of toxic compounds. |
| Turbidity | Indicator of seawater transparency. Turbidity can be affected by local and regional currents and waves, coastal erosion, bottom type, phytoplankton concentration and river plumes. Offshore mariculture requires data and information on turbidity of an area because high concentrations of inorganic suspended matter can negatively affect fish and shellfish growth and health. The primary interest would be historical data. |
| Salinity | Content of dissolved salts, and variations can result from rainfall, evaporation, river discharge and ice formation. Offshore mariculture needs to understand the variable levels of salinity because feeding, growth and survival of shellfish can be affected by low salinity. Freshwater river plume distribution is an important site section issue and the interest is in historical data. |
| Dissolved oxygen | Concentration of oxygen that is dissolved in a given medium. Marine aquaculture needs to understand the typical levels of DO and the presence of "dead zones" (i.e. hypoxic areas in the world's oceans) because hypoxia may have detrimental effects on fish physiology (feed intake, growth), well-being, and survival. |

Going from global scale to a regional scale, in this case Europe, and the use of several different species means that several data sources needed to be changed and added. The spatial data used in water can be separated into three sections: ocean data, lake data and environmental data.

*Table 5: Ocean data sources*

| Type | Source | Description | Units |
|---|---|---|---|
| Bathymetry | www.gebco.net | Bathymetry (water depth) | m |
| Chlorophyll | http://marine.copernicus.eu/ | A hind cast model was used for the years 1998 to 2014 | mg $m^{-3}$ |
| Currents | http://marine.copernicus.eu/ | A hind cast model was used for the years 1993 to 2014 | m $s^{-1}$ |
| Dissolved Oxygen | http://marine.copernicus.eu/ | A hind cast model was used for the years 1998 to 2014 | mmol $m^{-3}$ |
| SST | http://marine.copernicus.eu/ | A hind cast model was used for the years 1993 to 2014 | ºC |
| Significant wave height | https://wwz.ifremer.fr/ | A hind cast was used for the years 2007, 2008, 2009, 2012, 2013, 2014, 2015, and April 2016 | m |

As seen in Table 5, 3 different sources have been used for ocean data. These sources provide over 15 years of data that need to be adapted for use in the classification. Table 6 shows 15 parameters from 2 sources, though it has to be noted that, as there are over 50000 lakes in Europe, it is impossible to get a complete set of data for any of these parameters. In Table 7, environmental vector data sources are given. These provide location-based information that will allow for querying and spatial analysis. The Corine landcover map of 2012 was used for extracting the location and shape of all lakes in Europe that are larger than 25 hectares.

*Table 6: Lake data sources*

| Data | Units | Source |
|---|---|---|
| General[2] | | Water Framework Directive (http://www.eea.europa.eu) |
| Alkalinity | mmol $L^{-1}$ | Water Framework Directive (http://www.eea.europa.eu) |
| Chlorophyll | mg $m^{-3}$ | Water Framework Directive (http://www.eea.europa.eu) |
| Dissolved oxygen | mg $L^{-1}$ | Water Framework Directive (http://www.eea.europa.eu) |
| Oxygen saturation | % | Water Framework Directive (http://www.eea.europa.eu) |
| Lake surface temperature[3] | ºC | MODIS MYD11C3 |
| Organic nitrogen | mg $L^{-1}$ | Water Framework Directive (http://www.eea.europa.eu) |
| pH | | Water Framework Directive (http://www.eea.europa.eu) |
| Secchi depth | M | Water Framework Directive (http://www.eea.europa.eu) |
| Total ammonium | mg $L^{-1}$ | Water Framework Directive (http://www.eea.europa.eu) |
| Total nitrogen | mg $L^{-1}$ | Water Framework Directive (http://www.eea.europa.eu) |
| Total organic carbon | % | Water Framework Directive (http://www.eea.europa.eu) |
| Total oxidised nitrogen | mg $L^{-1}$ | Water Framework Directive (http://www.eea.europa.eu) |
| Total phosphorus | mg $L^{-1}$ | Water Framework Directive (http://www.eea.europa.eu) |
| Pressures | | Water Framework Directive (http://www.eea.europa.eu) |

All parameters needed for this database are freely available, except for the lake surface temperature, which has been calculated from land surface temperature satellite imagery from the MODIS land surface temperature data product (The Land Processes Distributed Active Archive Center, 2016).

[2] General information about sampling stations and lakes, such as location, depth, and area.

[3] Temperatures calculated from MODIS land surface temperature data.

*Table 7: Environmental data sources*

| Name | Source | Description |
|---|---|---|
| Corine landcover 2012 | Land.copernicus.eu | The Corine landcover vector map was obtained from Copernicus land monitoring services land.copernicus.eu. It has a mapping unit of 25ha and is in the process validation. |
| Economic exclusive zones | www.marineregions.org | published on February 2th 2014. The EEZ map is a list of georeferenced place names and areas based on information from VLIMAR Gazetteer and MARBOUND. |
| Protected zones | www.protectedplanet.net | Published in May 2016, the protected planet website is a source for protected areas around the world. |
| World port index | msi.nga.mil | The maritime safety information website provides the port index to aid maritime navigation. |

## Data formats

For the data, two formats where chosen, NetCDF (Network common data form) for raster data and SHP (shape) for vector data.

The NetCDF file format offers several advantages over the more traditional Geotiff format. The main advantage is that it is a self-describing file ("Unidata," n.d.). Several conventions can be used to describe the data and this allows easy sharing without metadata getting lost. Another advantage is that large datasets can be queried faster in comparison to Geotiff files because there is a smaller number of files to deal with. However, the main reason to use NetCDF is for its ability to handle multidimensional data. Multidimensional data handling is preferred so that datasets of one or several parameters could be included in one file containing information for several months.

For the parameters that contain temporal variation, long-term "normal" maps where created. This was done by calculating for each parameter a mean and standard deviation for each month from all years of available data, resulting in a total of 24 maps per parameter which are then integrated into a single NetCDF file.

The ESRI SHP format for vector files was chosen because the attribute tables used to describe the data also allow multidimensional data and is a common data format with may.

## Preparation

In order to create a database that allows for easy use and integration of all these different parameters all data needed to be prepared; several scripts where created and utilised to address the very large amount of data to be processed. The preparation of data was achieved by utilizing the tools provided by UNIDATA and GRASS (See Annex I).

For the creation of the lake surface maps, the MODIS Terra Land Surface Temperature and Emissivity version 4 dataset and data from the water framework directive where used. The MODIS dataset provides an average land surface temperature for each month from 2002 to 2016. Several method have been described to estimate lake surface temperature from land surface temperature or other satellite sources (Chavula, Brezonik, Thenkabail, Johnson, & Bauer, 2009; Liu et al., 2014; Piccolroaz, Toffolon, & Majone, 2013; Reinart & Reinhold, 2008). Most methods are based on extensive knowledge of the waterbody in question and the papers indicate that there is a fairly linear correlation between land and lake surface temperature. A small investigation was done comparing the MODIS dataset with available data from the water framework directive on lake surface temperature. A comparison between 98 measurements from the WFD database (including only annual averages created from at least 6 samples taken throughout the year) with processed land surface temperature maps from MODIS shows a linear correlation with an $R^2$ of 0.73 as seen in Fig. 4.

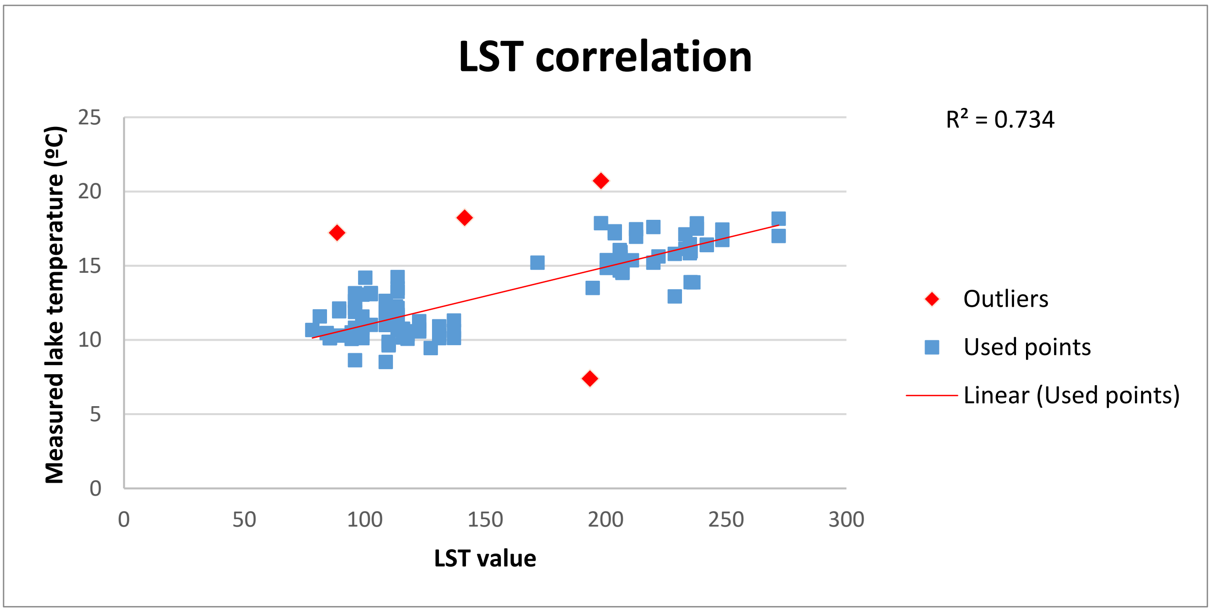


*Fig. 4. Land surface temperature to water surface temperature correlation*

From this analysis Eq. 1 was derived, where LST is Lake Surface Temperature and $T_{land}$ is the raw MODIS land surface temperature.

$$\text{LST} = 0.8142 * (0.02T_{land} - 273.15) + 2.9963 \qquad \text{(Eq. 1)}$$

Using this equation, the monthly surface temperature for 50722 lakes was calculated from MODIS land surface temperature products from 2002 to 2016.

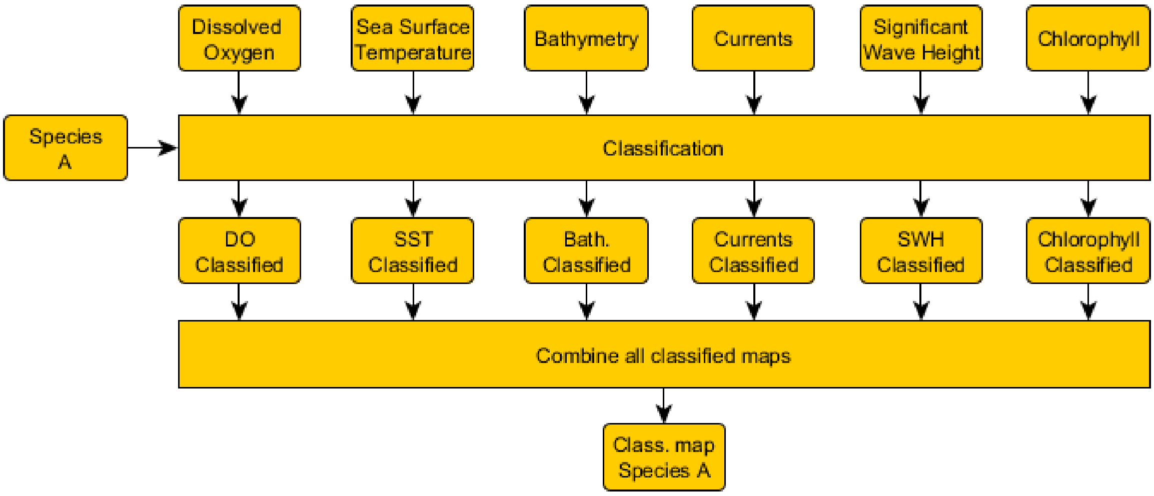


*Fig. 5. Classification flowchart.*

The long-term normals for all parameters are calculated using NCO and CDL packages (Unidata, n.d.), GDAL and GRASS in a Linux environment. In short, all existing data for a certain period (e.g. from 1998 to 2014 for chlorophyll concentration) is aggregated by month (irrespective of year), and then the average and standard deviation are calculated as can be seen in ANNEX 1.

With both the Species database and the spatial database complete areal classifications can be created. This is shown in Fig. 5.

The intermediate results from this process are shown in Fig. 6 and Fig. 7 with a potential final result shown in Fig. 8.

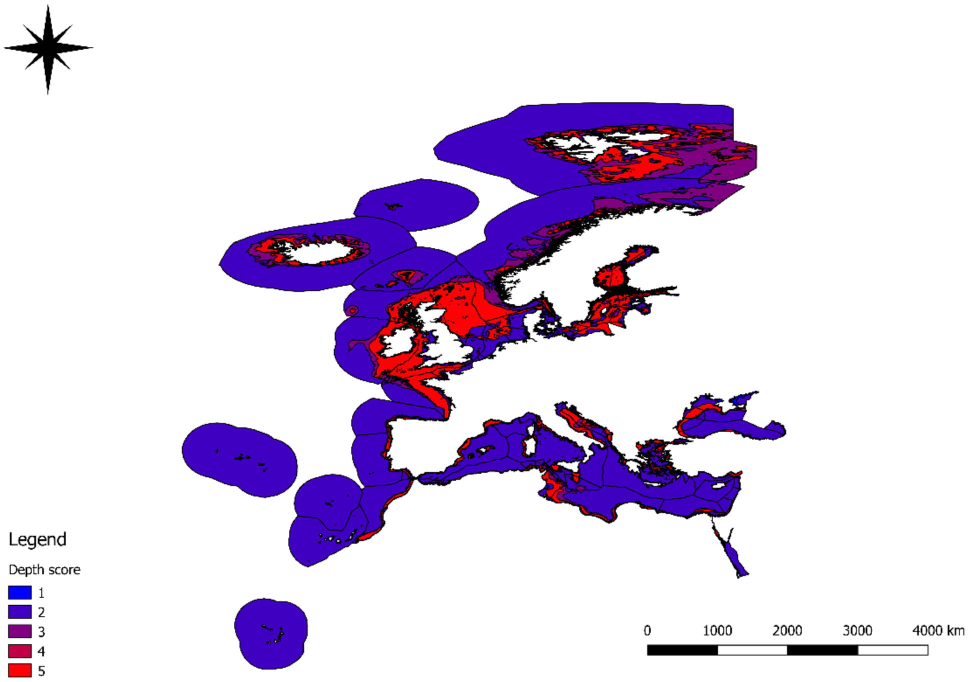


*Fig. 6. Classified depth map.*

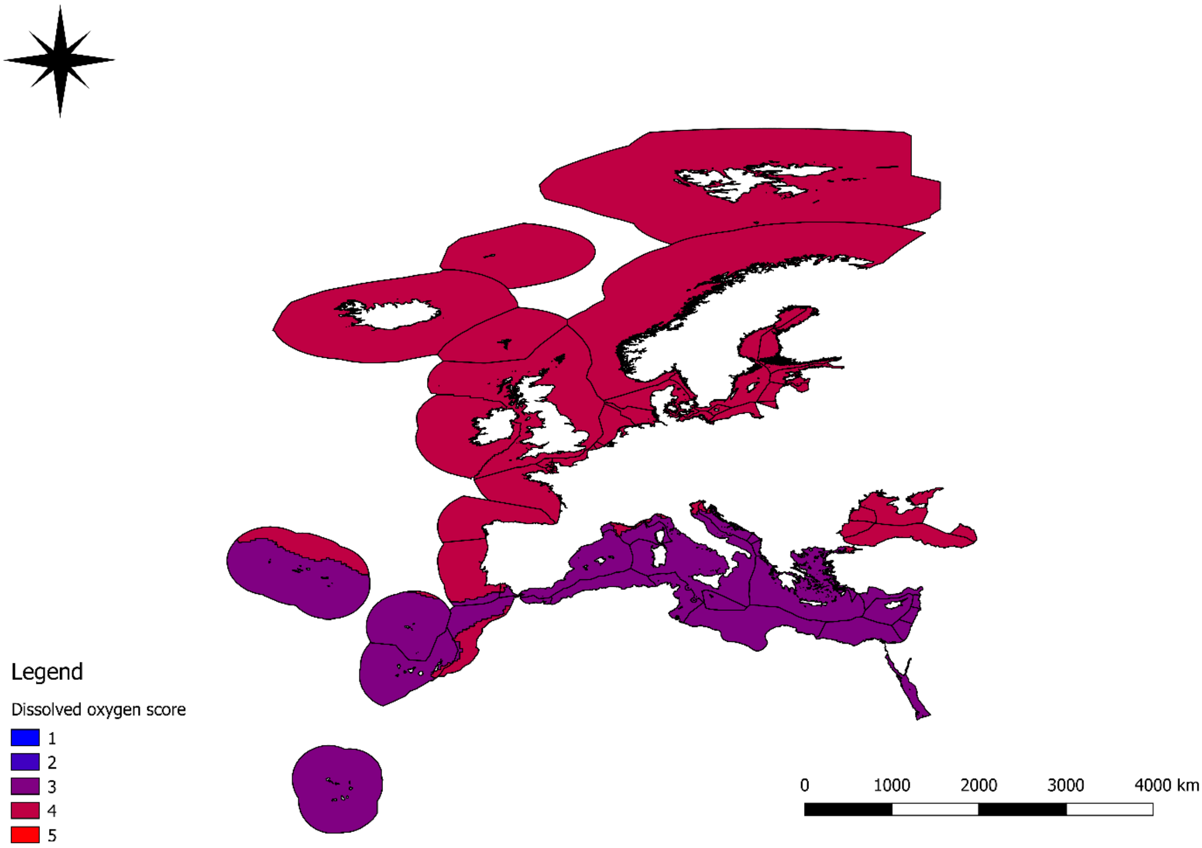


*Fig. 7. Classified dissolved oxygen map.*

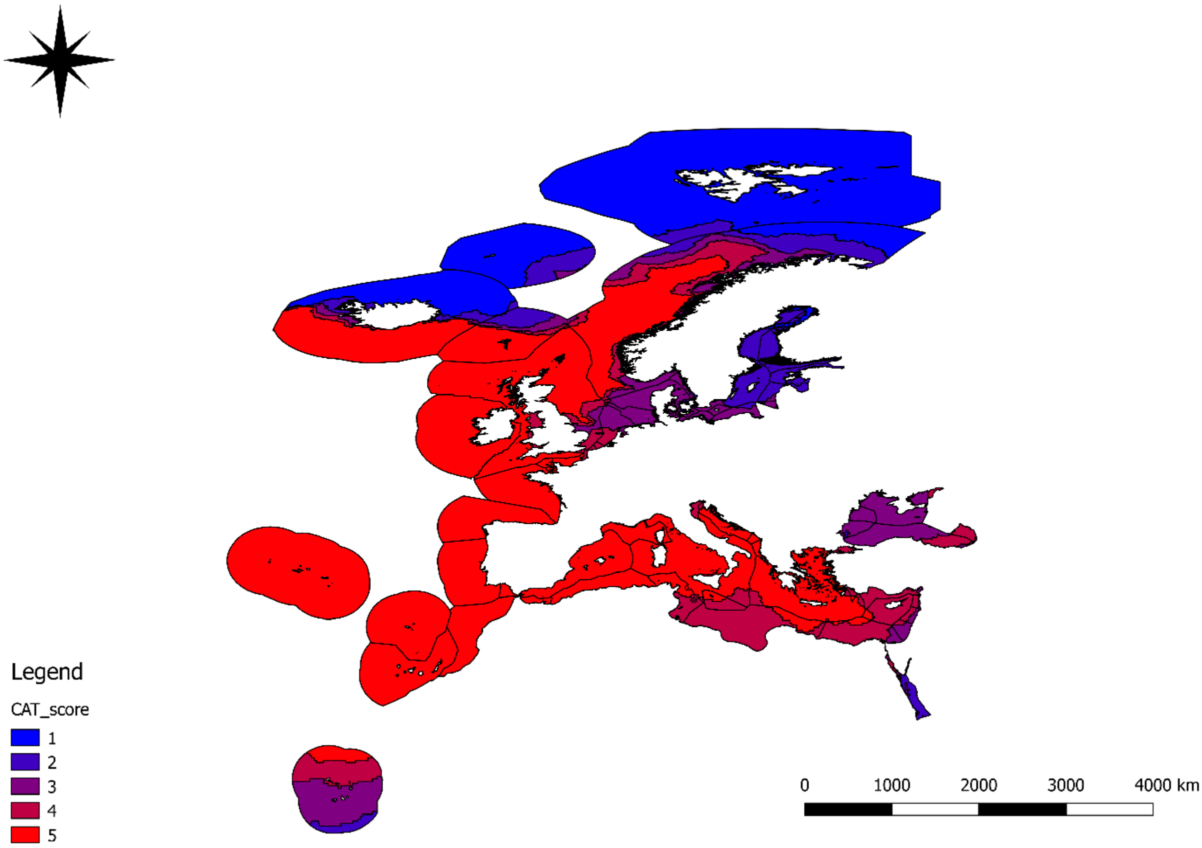


*Fig. 8. Final classified map for sample species.*

## Data volume

Table 8 and Table 9 summarize the volume of environmental data collected for the WATER application in marine and freshwater respectively.

*Table 8: Volume of data collected for the entire European Exclusive Economic Zone.*

| Parameter | Units | Resolution | File size | Source |
|---|---|---|---|---|
| Depth | m | 1km | 911 MB | GEBCO |
| Chlorophyll a | mg $m^{-3}$ | 1km | 5636 MB | Copernicus MEMS |
| Dissolved oxygen | mmol $m^{-3}$ | 1km | 5636 MB | Copernicus MEMS |
| Significant wave height | m | 1km | 5636 MB | IFREMER |
| Current speed | m $s^{-1}$ | 1km | 5636 MB | IFREMER |
| Sea surface temperature | ºC | 1km | 5636 MB | Copernicus MEMS |
| Turbidity | m | - | ± 5636 MB | Copernicus MEMS |
| Total nitrogen | mg $m^{-3}$ | - | ± 5636 MB | Copernicus MEMS |

The species database contains 586 records for different farmed organisms, although not all records contain all fields (i.e. threshold low; optimal low; optimal high, and threshold high). These are limitations imposed by the existing experimental data, and provide valuable guidelines for research, particularly in the context of climate change.

*Table 9: Volume of data collected for freshwater systems.*

| Parameter | Units | Nº lakes | Source |
|---|---|---|---|
| Mean lake depth | m | 257 | WFD |
| Chlorophyll | mg $L^{-1}$ | 739 | WFD |
| Dissolved oxygen | mg $L^{-1}$ | 100 | WFD |
| Lake surface temperature | ºC calculated by using Modis land surface temperature images | 50722 | MODIS LST |
| Secchi depth | m | 67 | WFD |
| Total nitrogen | mg $L^{-1}$ | 51 | WFD |
| Total ammonium | mg $L^{-1}$ | 20 | WFD |
| Total organic carbon | mg $L^{-1}$ | 43 | WFD |
| Total oxidized nitrogen | mg $L^{-1}$ | 1825 | WFD |
| Total phosphorus | mg $L^{-1}$ | 60 | WFD |
| pH | - | 27 | WFD |

A detailed representation of lake data can only be viewed in a zoomed image on the Geographic Information System, or in the WATER application, due to the small size of the water bodies in relation to the overall land masses of different European countries.

Nevertheless, Fig. 9 provides a snapshot for dissolved inorganic nitrogen (DIN), marked in red for freshwater systems throughout Europe. The image provides a sense of scale, particularly in countries such as Finland, and illustrates the value of the freshwater dataset.

As for marine systems, the data e.g. for lake surface temperature, where almost 60,000 datapoints exist, can be tested against species thresholds, and this is of great value in determining the potential for aquaculture expansion in inland waters. Furthermore, this dataset can be exploited to account for a changing climate, by using Eq. 1 in combination with relevant IPCC scenarios.

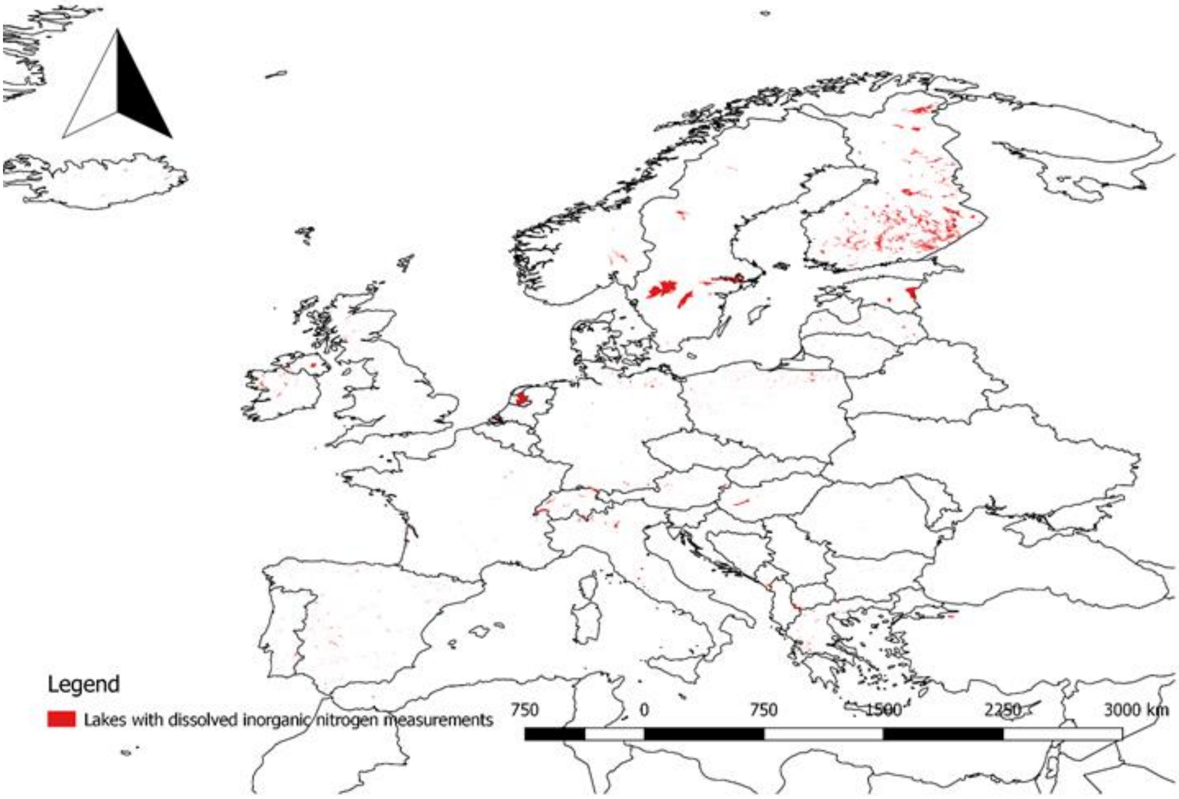


*Fig. 9. Illustration of the freshwater datapoints (water bodies) stored in the Environment component of WATER.*

These enviromental datasets are of great value *per se*, and the maps shown above for depth and dissolved oxygen have already been used to generate suitability maps for different species, and were applied in the development of the Aquaculture Investor Index (AquaSpace Deliverable 2.5).

# Suitability maps

In order to enable AquaSpace WP3 *Tools* to incorporate site suitability data for species, a subset of 14 key species (Table 10) were selected, and tested against environmental data.

*Table 10. List of 14 aquaculture species considered, representing the main finfish and shellfish.*

| Common Name | Latin name | Sea Surface temperature | Dissolved oxygen | Current speed | Chlorophyll a concentration | Depth |
|---|---|---|---|---|---|---|
| Atlantic salmon | *Salmo salar* | X | X | | | X |
| Gilthead sea bream | *Sparus aurata* | X | X | X | | X |
| European seabass | *Dicentrarchus labrax* | X | X | X | | X |
| Meagre | *Argyrosomus regius* | X | X | | | X |
| Rainbow trout | *Oncorhynchus mykiss* | X | X | | | X |
| Mediterranean mussel | *Mytilus galloprovincialis* | X | X | | X | X |
| Blue mussel | *Mytilus edulis* | X | X | | X | X |
| Pacific Oyster | *Crassostrea gigas* | X | | | | X |
| Manila clam | *Ruditapes philippinarum* | X | | | | X |
| Good clam | *Ruditapes decussatus* | X | | X | | X |
| European flat oyster | *Ostrea edulis* | X | | | | X |
| Queen scallop | *Aequipecten opercularis* | X | | X | | X |
| Great Atlantic scallop | *Pecten maximus* | X | | X | | X |
| Common cockle | *Cerastoderma edule* | X | | X | | X |

Fig. 11 shows the climatology for January for sea surface temperature created in GRASS, which was then used the create a binary map per species to indicate suitability. The classification is based on the tresholds described in the Environmental thresholds for cultivated species chapter and was sequentially constructed based on threshold checks on environmental climatology data described in Table 5 giving the value 1 or positive if in the climatology the condition is met for all months, with the exception of depth which has no temporal variance. Some examples can be seen in Fig. 12 and Fig. 13 in ANNEX 1 for Atlantic salmon. In Fig. 13 it is possible to see that all conditions are favorable in the United Kingdom for sea surface temperature, dissolved oxygen concentration, and depth thus giving it a score of 1 or positive, unfavorable conditions are displayed as 0 or negative. This analysis has produced 14 Europe-scale maps and 714 local economic exclusive zone (EEZ) scale maps in GeoTiff format, available for the AquaSpace partnership.

# Web application

WATER can be used to examine the feasibility and suitability of cultivating a particular species in a selected area within the European Exclusive Economic Zone. Triage is based on species-specific tolerance ranges and a pre-defined set of conditions for cultivation, such as culture depth, production system or type of culture – land, suspended, off-bottom and bottom, e.g. an area may have environmental conditions to grow salmon, but not physical conditions to moor cages.

*Table 11. GIS decision-support system examples.*

| Example | Website |
|---|---|
| Connecticut shellfisheries mapping atlas | http://seagrant.uconn.edu/whatwedo/aquaculture/shellmap.php |
| Scottish Executive aquaculture areas | http://aquaculture.scotland.gov.uk/ |
| DEFRA shellfish areas | http://www.magic.gov.uk/magicmap.aspx |
| IPMA HAB maps | http://www.ipma.pt/en/pescas/bivalves/prev.toxinas/ |
| NASA SST anomaly | http://data.giss.nasa.gov/gistemp/maps/ |
| EU maritime atlas | http://ec.europa.eu/maritimeaffairs/atlas/index_en.htm |

The general architecture is represented in Fig. 10, which illustrates the connection between the two databases: *Main Database* is the environmental repository, held in NetCDF, and it interacts with the *Species Database*. "*GeoServer is an open source server for sharing geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standards*."

Substantial discussions were held within Longline Environment Ltd., and with other AquaSpace partners with expertise in this area, to determine what would be the best way to implement the web application.

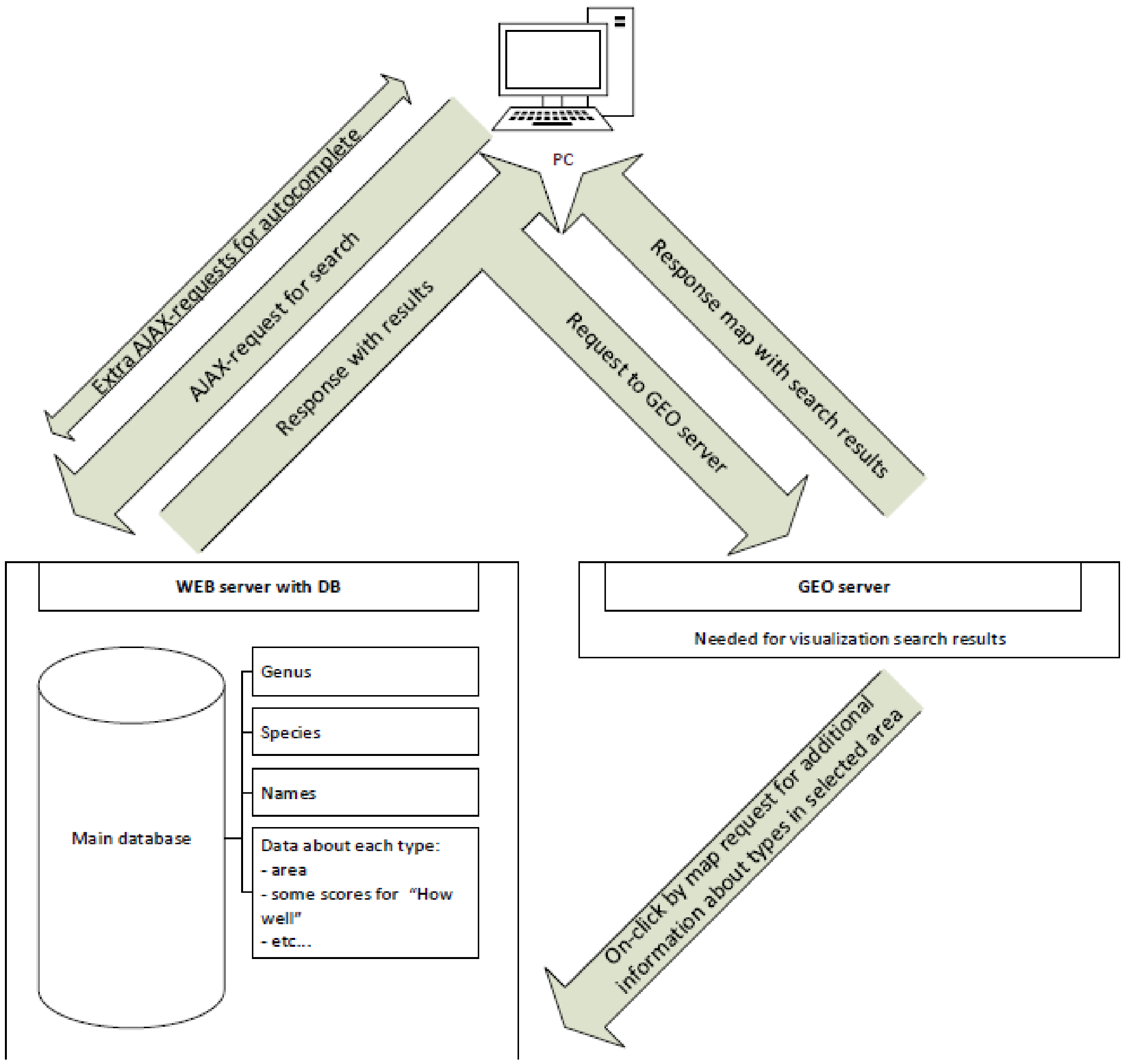


*Fig. 10. Software architecture of the WATER web application.*

There was a consensus that we would not want to produce another GIS application, with a similar approach to e.g. Google Earth, which provides a capacity to overlay multiple layers (see examples in Table 11). The alternative was to develop a 'question-based' system, which would query the databases and produce mapped results in response to specific questions such as:

- *Where can I grow salmon in Europe?*
- *How well will this (these) species grow here?*
- *What can I grow in this area?*
- *How well will these species grow in this area*
- *Aquaculture near me*
- *EEZ-specific outputs*
- *Climate change driven questions*

The system is implemented on a dedicated server, which can be queried through any web browser, and provides a response based on the question asked and the data retrieved by crossing the species requirements with the environmental conditions.

The core outputs are georeferenced maps, but synthesis data are also produced, aggregating total areas, percentage of EEZ, and other statistics. Shapefiles of outputs are available as an input to the cost-benefit analysis tool in AquaSpace Work Package 3 (Tools), which will then impose other limitations which extend beyond the way in which the environment limits aquaculture, and deal with co-use and impacts.

WATER was designed to support the analysis of available areas for farming, and will be maintained and extended as part of the AquaSpace legacy programme, to include other kinds of models, such as dynamic growth and environmental effects simulations.

# References

*In addition, Annex II provides references for all species data used in META.*

Chavula, G., Brezonik, P., Thenkabail, P., Johnson, T., & Bauer, M. (2009). Estimating the surface temperature of Lake Malawi using AVHRR and MODIS satellite imagery. *Physics and Chemistry of the Earth*, *34*(13–16), 749–754. http://doi.org/10.1016/j.pce.2009.08.001

FAO Fisheries Global Information System (FAO Fishstat Plus database version 2.3)

http://www.fao.org/fishery/statistics/global-aquaculture-production/query/en

Kapetsky, J. M., Aguilar-Manjarrez, J., & Jenness, J. (2013). A global assessment of offshore mariculture potential from a spatial perspective. Rome.

Liu, G., Ou, W., Zhang, Y., Wu, T., Zhu, G., Shi, K., … Qin, B. (2014). Validating and Mapping Surface Water Temperatures in Lake Taihu: Results From MODIS Land Surface Temperature Products. *IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING*, *8*(3). http://doi.org/10.1109/JSTARS.2014.2386333

Piccolroaz, S., Toffolon, M., & Majone, B. (2013). A simple lumped model to convert air temperature into surface water temperature in lakes. *Hydrol. Earth Syst. Sci*, *17*. http://doi.org/10.5194/hess-17-3323-2013

Reinart, A., & Reinhold, M. (2008). Mapping surface temperature in large lakes with MODIS data. *Remote Sensing of Environment*, *112*(2), 603–611. http://doi.org/10.1016/j.rse.2007.05.015

The Land Processes Distributed Active Archive Center. (2016). MODIS. The Land Processes Distributed Active Archive Center. http://doi.org/10.5067/MODIS/MYD11C3

Unidata. (n.d.). http://doi.org/10.5065/D6H70CW6

# ANNEX I

Annex I provides a detailed example of how the processing was done using open-source tools. Though only one parameter is described most steps followed are identical for others.

## Maps

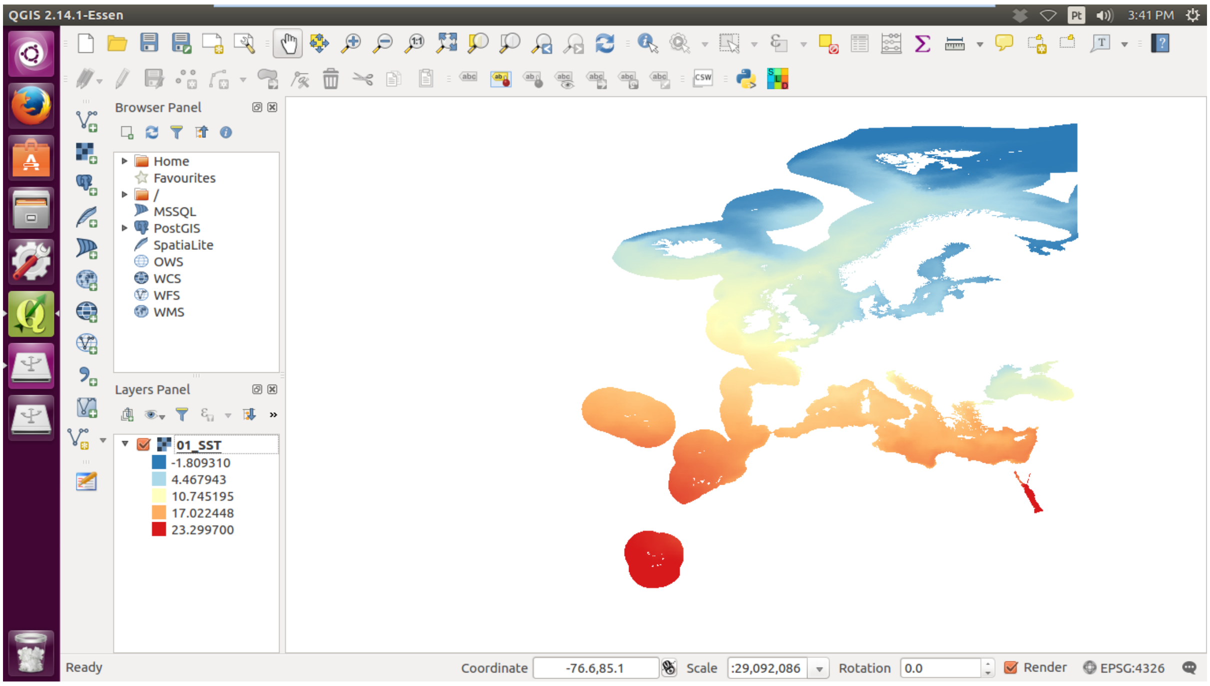


*Fig. 11. Sea surface temperature climatology for january*

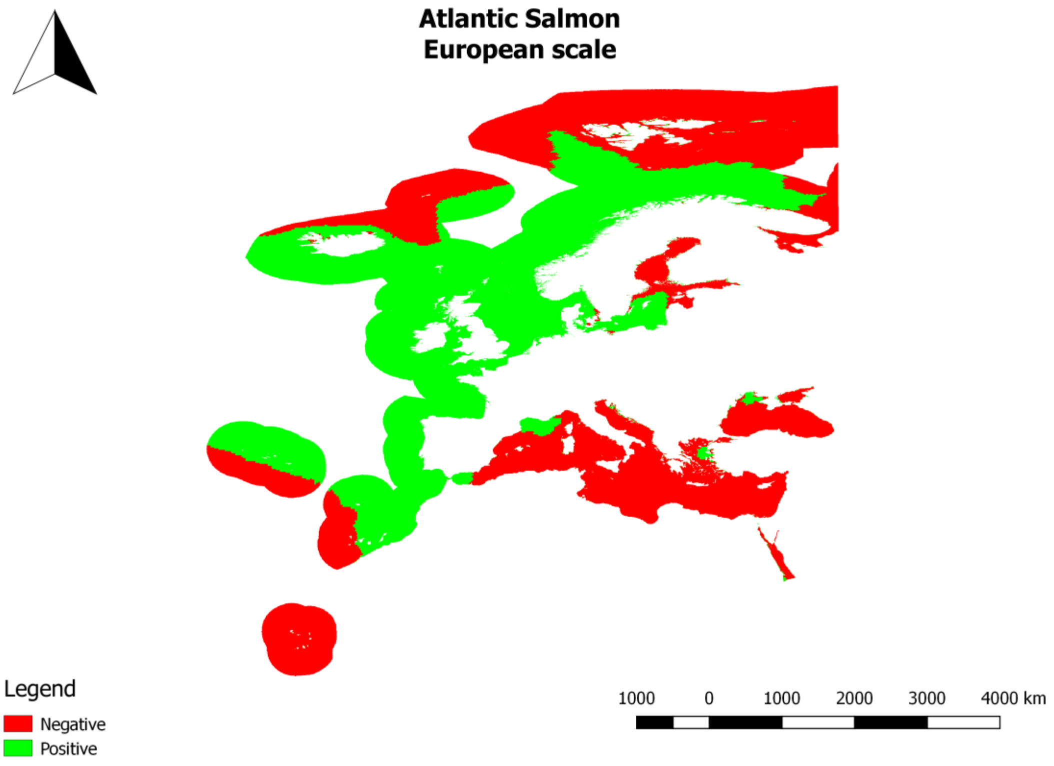


*Fig. 12. Atlantic salmon European scale*

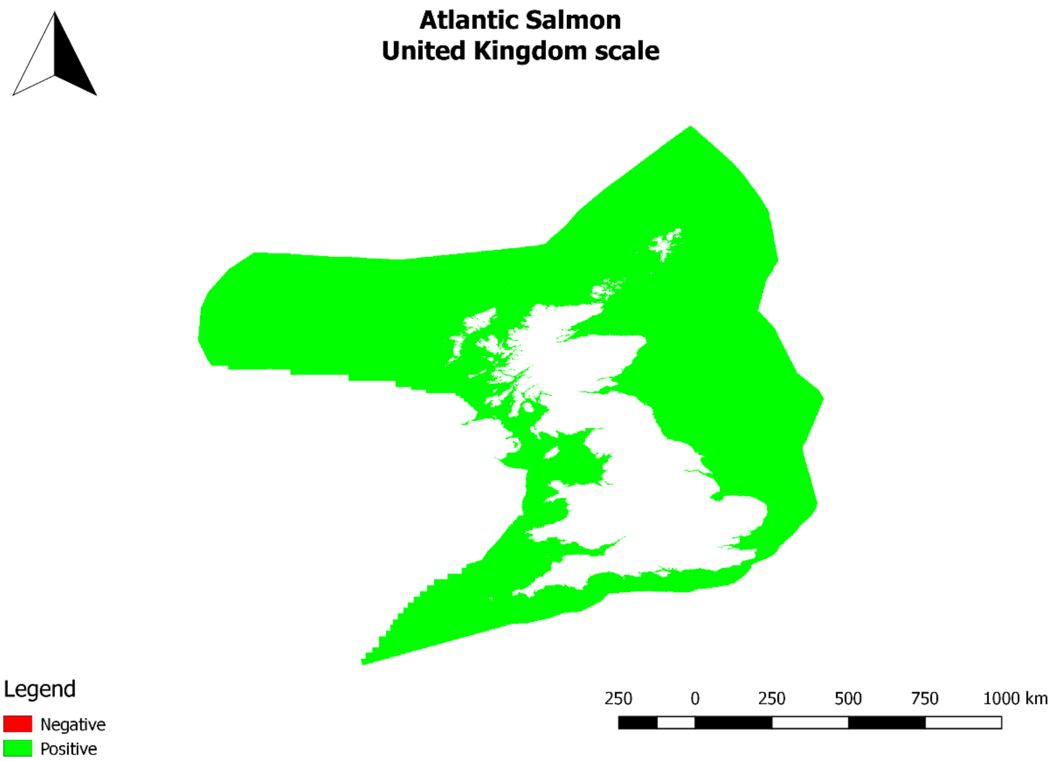


*Fig. 13. Atlantic salmon United Kingdom scale*

## Execute bash

This file steers the whole process of preparation and calls upon several tools (NCO, CDL, GDAL and GRASS) to execute the preparation.

```
!/bin/bash
#This batch is for preparing the Chlorophyll files for use in grass.

#########Parameters########
#script location
loc_s=/example_scripts_location/
#grass mapset location
loc_m=/Grass_mapset_location/
#input location
loc_i=/example_data_location/CHL
#temporary file location
loc_t=/Temporary_output_location/CHL

#GRASS mapset to be used
mapset=PERMANENT

###netcdf variables
var1=CHL_M
var2=CHL_STDDEV
##script names##
S1=setup_mapset.sh
S2=CHL.sh
S3=import.sh
S4=calc_stats.sh
########Export_Variables########
# here these variables are temporarily made global so they can be used in other scripts called upon by
     this script.
```

```
export loc_s
export loc_i
export loc_t

###create folders###
#Here temprorary folders are created in case they do not excist yet.
mkdir -p $loc_t/v1
mkdir -p $loc_t/v2
mkdir -p $loc_t/v3
mkdir -p $loc_t/v4
mkdir -p $loc_t/v5
mkdir -p $loc_t/v6
mkdir -p $loc_t/v7
mkdir -p $loc_t/v8
mkdir -p $loc_t/v9
mkdir -p $loc_t/v10

###########prepare mapset and delete files in the mapset###########

	#run GRASS with script
	echo "run SETUP_MAPSET.SH"
	chmod u+x $loc_s$S1
	export GRASS_BATCH_JOB=$loc_s$S1
	grass70 $loc_m$mapset

###########run batch chlorophyll preperation and import###########

for file in $loc_i/*.nc
do
	echo "run CHL.sh"
	export file
	#run GRASS with script
	chmod u+x $loc_s$S2
	export GRASS_BATCH_JOB=$loc_s$S2
	grass $loc_m$mapset
done

for file in $loc_t/v2/*
do
	echo "run import.sh"
	export file
	#run GRASS with script
	chmod u+x $loc_s$S3
	export GRASS_BATCH_JOB=$loc_s$S3
	grass $loc_m$mapset
done


###########calculate stats###########
	#run GRASS with script
	chmod u+x $loc_s$S4
	export GRASS_BATCH_JOB=$loc_s$S4
	grass70 $loc_m$mapset

###Remove files from mapset and reset environment
	#run GRASS with script
	echo "run SETUP_MAPSET.SH"
	chmod u+x $loc_s$S1
	export GRASS_BATCH_JOB=$loc_s$S1
	grass70 $loc_m$mapset


###########Clip to boundary###########
for file in $loc_t/v3/*
do
	echo "clip" $(basename $file) "to boundary raster extent"
	gdalwarp -cutline /media/fjboogert/Disk1/Aquaspace/Disk1/Temp/boundary.shp -crop_to_cutline $file
	$loc_t/v4/$(basename $file)
done

###########Create NetCDF files###########
for file in $loc_t/v4/*
do
```

```
	echo "transform " $(basename $file) "to *.nc"
	gdal_translate -of netCDF -co "FORMAT=NC4" $file $loc_t/v5/$(basename $file .tiff).nc
done

###########Add time dimension and variable names###########
for file in $loc_t/v5/*.nc
do
	echo "add time dimension and variable names to" $(basename $file .nc)
t=`expr substr $(basename $file) 1 2`
Y=2000
x="$(echo $t | sed 's/^0//')"
f=00
d=$(($x*30))

	if echo $(basename $file) | grep -q "_M";
	then
	echo "using mean"
	ncrename -v Band1,CHL_M $loc_t/v5/$(basename $file)
	echo "renamed Band1"

	ncap2 -Oh -s "tin=$d;" -S mean.nco $loc_t/v5/$(basename $file)  $loc_t/v6/$(basename $file)
	ncatted -O -a long_name,CHL_M,o,c,chlorophyll_concentration_in_sea_water_mean
	$loc_t/v7/$(basename $file) #CHange to new values!
	cdo settime,$d $loc_t/v6/$(basename $file) $loc_t/v7/$(basename $file)

	else
	echo "using stddev"
	ncrename -v Band1,CHL_STDDEV $loc_t/v5/$(basename $file)
	echo "renamed Band1"

	ncap2 -Oh -s "tin=$d;" -S stddev.nco $loc_t/v5/$(basename $file)  $loc_t/v6/$(basename $file)
	ncatted -O -a long_name,CHL_STDDEV,o,c,chlorophyll_concentration_in_sea_water__stddev
	$loc_t/v6/$(basename $file)
	cdo settime,$d $loc_t/v6/$(basename $file) $loc_t/v7/$(basename $file)

	fi

	ncks -O --mk_rec time $loc_t/v7/$(basename $file) $loc_t/v8/$(basename $file)
done

###########Combine to last NetCDF file###########
echo "Create final NetCDF files"
cdo mergetime $loc_t/v8/*_M.nc $loc_t/v9/mean.nc
cdo mergetime $loc_t/v8/*_Stddev.nc $loc_t/v9/Stddev.nc
ncks -A $loc_t/v8/mean.nc $loc_t/v9/Stddev.nc
mv $loc_t/v9/Stddev.nc $loc_t/v10/CHL.nc
```

## Setup map set

This script clears all previous data that is loaded in the GRASS map set, this is done to avoid clutter and conflicting filenames or region settings.

```
#!/bin/bash
#####empty mapset######
echo "emptying mapset"
#This removes all maps with all names and types from the mapset.
g.remove -f type=all pattern="*"

#####set environment parameters to mapset######
echo "setting projection"
g.proj -c epsg=4326

############set mask###############
#This imports the mask to be used, in this case it is the exclusive economic zones raster file
	for europe.
r.in.gdal -o --overwrite --quiet input=/source/EEZ.tif output=region
echo "Setting mask and region"
r.mask raster=region
g.region rast=region
```

## CHL

Because most data used is projected in the ORCA grid used by the Copernicus marine service this needs to be adapted to a more commonly used coordinate system. In this case it will be the universal Mercator WGS84 projection or EPSG 4326.

```
!/bin/bash
######File######
#Create output filename for source filename.
F1=$(basename "$file")
Year=`expr substr $F1 22 4`
Month=`expr substr $F1 26 2`
U="_"
name="$Year$U$Month"
temp=temp
T2=t2

######remove dimensions#########
#This part utilises the ncks command to only extract the sea surface, coordinates and chlorophyll data.
ncks -O -v CHL,nav_lon,nav_lat -d deptht,0.50576 $file $loc_t$name.nc
echo "Finished extraction of data"
#####create vrts######
# This command creates vrt files.
gdal_translate -of VRT NETCDF:"$loc_t$name.nc":nav_lon $loc_t/v1/lon.vrt
gdal_translate -of VRT NETCDF:"$loc_t$name.nc":nav_lat $loc_t/v1/lat.vrt
gdal_translate -of VRT NETCDF:"$loc_t$name.nc":CHL $loc_t/v1/name.vrt
echo "Created vrt files"

######edit vrt########
# edit name.vrt
sed -i.bak -e '2,47d' $loc_t/v1/name.vrt
sed -i.bak -e '7d' $loc_t/v1/name.vrt
sed -i.bak -e '13,32d' $loc_t/v1/name.vrt

#edit lat.vrt
sed -i.bak -e '2,33d' $loc_t/v1/lat.vrt
sed -i.bak -e '3,12d' $loc_t/v1/lat.vrt
sed -i.bak '1 a <SRS>GEOGCS["WGS 84",DATUM["WGS_1984",SPHEROID["WGS 84",6378137,298.257223563,AUTHORITY["EPSG","7030"]],TOWGS84[0,0,0,0,0,0,0],AUTHORITY["EPSG","6326"]],PRIMEM["Greenwich",0,AUTHORITY["EPSG","8901"]],UNIT["degree",0.0174532925199433,AUTHORITY["EPSG","9108"]],AUTHORITY["EPSG","4326"]]</SRS>' $loc_t/v1/lat.vrt
sed -i.bak -e '3d' $loc_t/v1/lat.vrt
sed -i.bak '1 a <VRTRasterBand dataType="Float32" band="1">' $loc_t/v1/lat.vrt

# edit lon.vrt
sed -i.bak -e '2,33d' $loc_t/v1/lon.vrt
sed -i.bak -e '3,12d' $loc_t/v1/lon.vrt
sed -i.bak '1 a <SRS>GEOGCS["WGS 84",DATUM["WGS_1984",SPHEROID["WGS 84",6378137,298.257223563,AUTHORITY["EPSG","7030"]],TOWGS84[0,0,0,0,0,0,0],AUTHORITY["EPSG","6326"]],PRIMEM["Greenwich",0,AUTHORITY["EPSG","8901"]],UNIT["degree",0.0174532925199433,AUTHORITY["EPSG","9108"]],AUTHORITY["EPSG","4326"]]</SRS>' $loc_t/v1/lon.vrt
sed -i.bak -e '3d' $loc_t/v1/lon.vrt
sed -i.bak '1 a <VRTRasterBand dataType="Float32" band="1">' $loc_t/v1/lon.vrt
echo "Edited vrt files"

########gdalwarp#########
#The edited vrt the files are now used to create a tiff that is projected in EPSG 4326. With a resolution of 0.0090437173 degrees (-tr)
gdalwarp -srcnodata 9969209968386869000000000000000000000.000000 -dstnodata 9969209968386869000000000000000000000.000000 -geoloc -t_srs epsg:4326 $loc_t/v1/name.vrt $loc_t/v2/$name.tiff
echo "Finished creating reprojected tiff"

####delete files########
rm -f $loc_t/v1/name.vrt
rm -f $loc_t/v1/name.vrt.bak
rm -f $loc_t/v1/lon.vrt
rm -f $loc_t/v1/lat.vrt
rm -f $loc_t/v1/lon.vrt.bak
rm -f $loc_t/v1/lat.vrt.bak
```

## Import

This step imports all created tiff files into grass for further processing.

```
!/bin/bash
r.in.gdal -o --overwrite --quiet -l input=$file output=$(basename $file .tiff)
```

## Calculate statistics

Here 24 maps are created describing the mean and standard deviation of each month.

```
!/bin/bash
echo "calculate statistics"
# here a set is created for all rasters that have a name corresponding to a month and an average and
      standard deviation map are created.

r.series input="`g.list type=raster pattern='*_01' sep=,`" output=01_M,01_Stddev method=average,stddev
r.series input="`g.list type=raster pattern='*_02' sep=,`" output=02_M,02_Stddev method=average,stddev
r.series input="`g.list type=raster pattern='*_03' sep=,`" output=03_M,03_Stddev method=average,stddev
r.series input="`g.list type=raster pattern='*_04' sep=,`" output=04_M,04_Stddev method=average,stddev
r.series input="`g.list type=raster pattern='*_05' sep=,`" output=05_M,05_Stddev method=average,stddev
r.series input="`g.list type=raster pattern='*_06' sep=,`" output=06_M,06_Stddev method=average,stddev
r.series input="`g.list type=raster pattern='*_07' sep=,`" output=07_M,07_Stddev method=average,stddev
r.series input="`g.list type=raster pattern='*_08' sep=,`" output=08_M,08_Stddev method=average,stddev
r.series input="`g.list type=raster pattern='*_09' sep=,`" output=09_M,09_Stddev method=average,stddev
r.series input="`g.list type=raster pattern='*_10' sep=,`" output=10_M,10_Stddev method=average,stddev
r.series input="`g.list type=raster pattern='*_11' sep=,`" output=11_M,11_Stddev method=average,stddev
r.series input="`g.list type=raster pattern='*_12' sep=,`" output=12_M,12_Stddev method=average,stddev

echo "Finished calculating statistics"

###resample
# Here all empty areas are filled based on the pixels with values closest to them. This happes because
      the edges of the mask used do not correspond a 100% with the maps used.

r.fillnulls input=01_M output=01_M2 method=bilinear
r.fillnulls input=02_M output=02_M2 method=bilinear
r.fillnulls input=03_M output=03_M2 method=bilinear
r.fillnulls input=04_M output=04_M2 method=bilinear
r.fillnulls input=05_M output=05_M2 method=bilinear
r.fillnulls input=06_M output=06_M2 method=bilinear
r.fillnulls input=07_M output=07_M2 method=bilinear
r.fillnulls input=08_M output=08_M2 method=bilinear
r.fillnulls input=09_M output=09_M2 method=bilinear
r.fillnulls input=10_M output=10_M2 method=bilinear
r.fillnulls input=11_M output=11_M2 method=bilinear
r.fillnulls input=12_M output=12_M2 method=bilinear

r.fillnulls input=01_Stddev output=01_Stddev2 method=bilinear
r.fillnulls input=02_Stddev output=02_Stddev2 method=bilinear
r.fillnulls input=03_Stddev output=03_Stddev2 method=bilinear
r.fillnulls input=04_Stddev output=04_Stddev2 method=bilinear
r.fillnulls input=05_Stddev output=05_Stddev2 method=bilinear
r.fillnulls input=06_Stddev output=06_Stddev2 method=bilinear
r.fillnulls input=07_Stddev output=07_Stddev2 method=bilinear
r.fillnulls input=08_Stddev output=08_Stddev2 method=bilinear
r.fillnulls input=09_Stddev output=09_Stddev2 method=bilinear
r.fillnulls input=10_Stddev output=10_Stddev2 method=bilinear
r.fillnulls input=11_Stddev output=11_Stddev2 method=bilinear
r.fillnulls input=12_Stddev output=12_Stddev2 method=bilinear

######Export intermediate files#####
echo "export statistics"
#Here the mean and stdev are exported in float 32 tiff raster format to the v3 Folder.
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=01_M2
      output=$loc_t/v3/'01_M.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=02_M2
      output=$loc_t/v3/'02_M.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=03_M2
      output=$loc_t/v3/'03_M.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=04_M2
      output=$loc_t/v3/'04_M.tiff'
```

```
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=05_M2
      output=$loc_t/v3/'05_M.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=06_M2
      output=$loc_t/v3/'06_M.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=07_M2
      output=$loc_t/v3/'07_M.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=08_M2
      output=$loc_t/v3/'08_M.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=09_M2
      output=$loc_t/v3/'09_M.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=10_M2
      output=$loc_t/v3/'10_M.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=11_M2
      output=$loc_t/v3/'11_M.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=12_M2
      output=$loc_t/v3/'12_M.tiff'

####stddev
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=01_Stddev2
      output=$loc_t/v3/'01_Stddev.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=02_Stddev2
      output=$loc_t/v3/'02_Stddev.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=03_Stddev2
      output=$loc_t/v3/'03_Stddev.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=04_Stddev2
      output=$loc_t/v3/'04_Stddev.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=05_Stddev2
      output=$loc_t/v3/'05_Stddev.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=06_Stddev2
      output=$loc_t/v3/'06_Stddev.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=07_Stddev2
      output=$loc_t/v3/'07_Stddev.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=08_Stddev2
      output=$loc_t/v3/'08_Stddev.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=09_Stddev2
      output=$loc_t/v3/'09_Stddev.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=10_Stddev2
      output=$loc_t/v3/'10_Stddev.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=11_Stddev2
      output=$loc_t/v3/'11_Stddev.tiff'
r.out.gdal --overwrite --quiet -c type=Float32 -f format=GTiff input=12_Stddev2
      output=$loc_t/v3/'12_Stddev.tiff'
echo "finished exporting statistics"
```

# ANNEX II

## References for species thresholds


Albentosa M., Beiras R., Pérez-Camacho A. 1994. Determination of optimal thermal conditions for growth of clam (*Venerupis pullastra*) seed. Aquaculture 126: 315-328

Alcaraz G., Espina S. 1997. Scope for growth of juvenile grass carp *Ctenopharyngodon idella* exposed to nitrite. Comparative Biochemistry and Physiology, 116C: 85-88

Alderson, R. 1979. The effect of ammonia on the growth of juvenile Dover sole, *Solea solea* (L.) and turbot, *Scophthalmus maximus* (L.). Aquaculture 17: 291–309

Allen M.A., Hassler T.J. 1986. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest): Chinook Salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.49). U.S. Army Corps of Engineers, TR EL-82-4. 26 pp.

Almada-Villela P.C. 1984. The effects of reduced salinity on the shell growth of small *Mytilus edulis* L. Journal of the Marine Biological Association of the UK., 64: 171-182

Anderson K.B., Sparks, R.L., Paparo A.A. 1978. Rapid assessment of water quality, using the fingernail clam *Musculium transversum*. WRC Res. Rep. No. 133, Water Resources Center, University of Illinois, Urbana, IL: 115 pages.

Anguis V., Cañavate J.P. 2005. Spawning of captive Senegal sole (*Solea senegalensis*) under a naturally fluctuating temperature regime. Aquaculture 243: 133– 145

Anon 1970. Manual on the biotechnology of the propagation and rearing of phytophagous fish. Moscow, Fishery Ministry of the USSR, All-Union Scientific Research Institute of Pond Fishery, 49 p. (Transl. from Russian by R.M. Rowland 1971).

Aquafarmer, 2004. The farming of Arctic charr. Technical Institute of Iceland, the Holar University College and The Aquaculture Development Centre of Ireland. November 2007 – January 2008.

Arillo, A., Margiocco, C., Melodia, F., Mensi, P., Schenone, G. 1981. Ammonia toxicity mechanism in fish: studies on rainbow trout (*Salmo gairdneri* Rich.). Ecotoxicology and environmental safety 5, 316-328

Arjona F.J., Vargas-Chacoff L., Ruiz-Jarabo I., Martín del Río M.P., Mancera J.M. 2007. Osmoregulatory response of Senegalese sole (*Solea senegalensis*) to changes in environmental salinity. Comp. Biochem. Physiol. A. Mol. Integr. Physiol. 148(2): 413-21

Arnesen A.M., Jorgensen E.H., Jobling M. 1993. Feed intake, growth and osmoregulation in arctic charr, *Salvelinus alpinus* (L.) transferred from freshwater to saltwater at 8 degrees C during summer and winter. Fish Physiology and Biochemistry 12(4): 281-292

Artigaud S., Lacroix C., Richard J., Flye-Sainte-Marie J., Bargelloni L., Pichereau V. 2015. Proteomic responses to hypoxia at different temperatures in the great scallop (*Pecten maximus*). PeerJ3:e871; DOI10.7717/peerj.871

Arzul G. 2004. Aquaculture, Environment and Marine Phytoplankton: Proceedings of a Symposium Held in Brest, 21-23 May 2001. Editions Quae. 248 pages. ISBN: 978-2-84433-072-7

Atwood H.L., Fontenot Q.C., Tomasso J.R., Isely J. J. 2000. Toxicity of Nitrite to Nile Tilapia: Effect of Fish Size and Environmental Chloride. North American Journal of Aquaculture, 63(1): 49-51

Baird R.H. 1966. Factors affecting growth and condition of mussels (*Mytilus edulis*). Fish Investment Series II, London. Ministry of Agriculture Fisheries and food, 25: 1-33

Balarin J.D., Haller R.D. 1982. The intensive culture of tilapia in tanks, raceways, and cages. In: Muir, J.F., Roberts, R.J. (Eds.), Recent Advances in Aquaculture. Westview Press, Boulder, CO, pp. 265–356

Bamber R.N. 1990. The effects of acidic seawater on three species of lamellibranch mollusc. Journal of Experimental Marine Biology and Ecology, 143: 181–191

Barrento S., Lupatsch I., Keay A., Christophersen G. 2013. Metabolic rate of blue mussels (*Mytilus edulis*) under varying post-harvest holding conditions. Aquat. Living Resour., 26: 241–247

Barton B.A. 1996. General biology of salmonids. In Principles of Salmonid Aquaculture (Pennell, W. & Barton, B.A., eds), pp.29-95. Amsterdam. Elsevier.

Bayne B.L., Widdows J., Thompson R.J. 1976. Physiological integrations. In Marine mussels: their ecology and physiology (ed. B.L. Bayne), pp. 261-299. Cambridge: Cambridge University Press.

Bechmann R.K., Taban I.C., Westerlund S., Godal B.F., Arnberg M., Vingen S., Ingvarsdottir A., Baussant T. 2011. Effects of Ocean Acidification on Early Life Stages of Shrimp (*Pandalus borealis*) and Mussel (*Mytilus edulis*). Journal of Toxicology and Environmental Health Part A 74(7-9): 424-38

Becker S., Wiencke C., Bischof K. 2009. Photosynthesis at low temperatures: a case study on the antarctic rhodophyte *Palmaria decipiens* (Reinsch) Ricker. Phycologia 48(4): 7-7

Bein R., Ribi G. 1994. Effects on larval density and salinity on the development of perch larvae (*Perca fluviatilis* L.). Aquat. Sci. 56: 97–105

Belkovskiy N.M., Lega Yu. V., Chernitskiy A. G. 1991. Disruption of water-salt metabolism in rainbow trout, *Salmo gairdneri*, in seawater at low temperatures. J.Ichth. 31: 134-141

Berge J.A., Bjerkeng B., Pettersen O., Schaanning M.T., Øxnevad S. 2006. Effects of increased sea water concentrationsof CO2 on growth of the bivalve *Mytilus edulis* L. Chemosphere 62: 681–687

Bergström P., Lindegarth M. 2016. Developing practical tools for assessing uncertainty of Swedish WFD indicators: A library of variance components and its use for estimating uncertainty of current biological indicators. WATERS Report no. 2016:2. Havsmiljöinstitutet, Sweden.

Bidgood B.F. 1980. Tolerance of rainbow trout to direct changes in water temperature Fish. Res. Rep. Fish Wildl. Div. No. 15: 11p.

Birtwell I.K. 1999. The effects of sediment on fish and their habitat. Department of Fisheries and Oceans Canada, Canadian Stock Assessment Secretariat Research Document 99/139, ISSN 1480-4883, Ottawa, Canada, pp 34.

Björnsson B. 1993. Optimal temperature of immatire halibut (*Hippoglossus hippo*glossus L.): Effects of size. ICES C.M.

Björnsson B., Tryggvadóttir S.V. 1996. Effect of size on optimal temperature for growth and growth efficiency of immature Atlantic halibut (*Hippoglossus hippoglossus* L.). Aquaculture 142: 33–42

Boeuf G., Payan P. 2001. How should salinity influence fish growth? Comparative Biochemistry and Physiology Part C 130, 411-423

Boeuf G., Boujard D., Person-Le Ruyet J. 1999. Control of the somatic growth in turbot. Journal of Fish Biology 55:128 – 147

Bowering W.R. 1986. The distribution, age and growth and sexual maturity of Atlantic halibut (*Hippoglossus hippoglossus*) in the Newfoundland and Labrador area of the northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci. 1432: 1-34

Boyce D.G., Tittensor D.P., Worm B. 2008. Effects of temperature on global patterns of tuna and billfish richness. Marine Ecology Progress Series Vol. 355: 367-276

Brannon E.L. 1991. Trout culture. In Stickney, R.R. (ed), Culture of Salmonid Fishes. CRC Press, Inc. Boca Raton. pp 21 - 56.

Breber P. 1996. Can we use indicator species to define the quality of a lagoon? Page 147-150 in EUCC-Management of Coastal Lagoons in Albania. Proceedings of International seminar held in Texas, May 29-June 7, 1994.

Bregnballe J. 2015. A Guide to Recirculation Aquaculture: An introduction to the new environmentally friendly and highly productive closed fish farming systems. Food and Agriculture Organization of the United Nations and EUROFISH International Organisation

Brett J.R., Groves D.D. 1979. Physiological energetics. In Fish physiology. Edited by W.S. Hoar, D.J. Randall and J.R. Brett. Academic Press, New York, Vol. VIII., pp. 280-352.

Brill R.W., Lutcavage M.E., Metzger G., Bushnell P.G., Arendt M., Lucy J., Watson C., Foley D. 2002. Horizontal and vertical movements of juvenile bluefin tuna (*Thunnus thynnus*), in relation to oceanographic conditions of the western North Atlantic, determined with ultrasonic telemetry. Fishery Bulletin- National Oceanic and Atmospheric Administration 100(2):155-167.

Calabrese A., Davis H.C. 1966. The pH tolerance of embryos and larvae of *Mercenaria mercenaria* and *Crassostrea virginica*. Biological Bulletin 131: 427436

Cardenas S. 2012. Biología y acuicultura de corvinas en el mundo. Revista AquaTIC, num. 37, pp. 1-13

Carregosa V., Figueira E., Gil A.M., Pereira S., Pinto J., Soares A.M.V.M., Freitas R. 2014. Tolerance of *Venerupis philippinarum* to salinity: Osmotic and metabolic aspects. Comparative Biochemistry and Physiology, Part A 171: 36–43

Chervinski J. 1984. Salinity tolerance of young catfish, *Clarias lazera* (Burchell). J. Fish. Biol., 25: 147–149

Cheung S., Shin P. 2005. Size effects of suspended particles on gill damage in green-lipped mussel. Marine Pollution Bulletin, 51: 801–810

Chiba K., Oshima Y. 1957. Effect of suspended particles on the pumping and feeding of marine bivalves especially the Japanese little neck clam (English summary). Bull. Jap. Soc. Sci. Fish. 23: 348-354

Christiansen E.F., Mitchell J.M., Harms C.A., Stoskopf M.K. 2014. Sedation of red porgy (*Pagrus pagrus*) and black sea bass (*Centropristis striata*) using ketamine, dexmedetomidine and midazolam delivered via intramuscular injection. Journal of Zoo and Aquarium Research 2(3)

Clay D. 1977. Preliminary observations on salinity tolerance of *Clarias lazera* from Israel. Bamidgeh, 29(3): 102–109

Çolakoğlu S., Palaz M. 2014. Some population parameters of *Ruditapes philippinarum* (Bivalvia, Veneridae) on the southern coast of the Marmara Sea, Turkey. Helgol Mar Res 68: 539–548

Colle D.E. et al. 1978. Utilization of selective removal of grass carp (*Ctenopharyngodon ideila*) from an 80-hectare Florida lake to obtain a population estimate. Trans.Am.Fish.Soc., 107(5): 724-729

Collins M.T., Gratzek J.B., Shotts E.B. Jr., Dawe D.L., Campbell L.M., Senn D.R. 1975. Nitrification in an aquatic recirculating system. Journal of Fisheries Research Board, Canada 32: 2025-2031

Colt J., Orwitz K., Bouck G. 1991. Water quality considerations and criteria for high-density fish culture with supplemental oxygen. Fisheries Bioengineering Symposium: American Fisheries Society Symposium 10, 372-385

Colt J., Orwicz K. 1991. Modeling production capacity of aquatic systems under freshwater conditions. Aquacultural Engineering 10: 1-29

Colt J., Tchobanoglous G. 1976. Evaluation of the short-term toxicity of nitrogenous compounds to channel catfish *Ictalurus punctatus*. Aquaculture 8: 209-224

Compton T.J., Rijkenberg M.J.A., Drent J., Piersma T. 2007. Thermal tolerance ranges and climate variability: A comparison between bivalves from differing climates. Journal of Experimental Marine Biology and Ecology 352: 200 – 21

Conides A.J., Parpoura A.R., Fotis G. 1997. Study on the effects of salinity on the fry of the euryhaline species gilthead sea bream *Sparus aurata* L. 1758. J. Trop. Aquacult. 12, 297–303

Copp G.H., Britton J.R., Cucherousset J., García-Berthou E., Kirk R., Peeler E., Stakenas S. 2009. Voracious invader or benign feline? A review of the environmental biology of European Catfish *Silurus glanis* in its native and introduced ranges. Fish and Fisheries 10(3): 252-282

Crisp T. 2008. Trout & Salmon: Ecology, Conservation and Rehabilitation. Fishing News Books, Blackwell Science Ltd, Oxford, 2000

Dahl J. 1961. Age and growth of Danish and Swedish brackish water pikes. Ferskvandsfiskeribladet 59: 34–38. (in Danish).

Dalla Via J., Van den Thillart G., Cattani O., de Zwaan A. 1994. Influence of long-term hypoxia exposure on the energy metabolism of *Solea solea*. II. Intermediary metabolism in blood, liver and muscle. Mar. Ecol. Prog. Ser. 111: 17-27

Danecker E. 1964. Die Jauchevergiftung von Fishen-eine Ammoniakvergiftung. Osterreichs Fischerei 3/4: 55-68

Davis H.C., Calabrese A. 1969. Survival and Growth of Larvae of the European Oyster (*Ostrea edulis* L.) at Different Temperatures. Biological Bulletin, Vol. 136(2): 193-199

Deedler C. L. 1970. Synopsis of biological data on the eel *Anguilla anguilla* (Linnaeus) 1758. FAO Fisheries Synopsis No. 80. FAO, Rome

Denzer H. W. 1968. Studies on the physiology of young tilapia. FAO Fisheries Report 44: 357–366

Devauchelle N., Alexandre J.C., Le-Corre N., Letty Y. 1987. Spawning of sole (*Solea solea*) in captivity. Aquaculture 66: 125-147

Elliott, J.M. & Elliott, J.A. 2010. Temperature requirements of Atlantic salmon Salmo salar, brown trout *Salmo trutta* and Arctic charr *Salvelinus alpinus*: predicting the impacts of climate change. Journal of Fish Biology 77, 1793-1817

El-Shafai S.A., El-Gohary F.A., Nasr F.A., van der Steen N.P., Gijzen H.J. 2004. Chronic ammonia toxicity to duckweed-fed tilapia (*Oreochromis niloticus*). Aquaculture 232: 117-127

Elston R., Clam F.L. 2008. Water Quality Handout. Florida Clam Industry Workshop, Tuesday, March 10, 2015, FAU HBOI. Revised and updated by Susan Laramore from Ralph Elston, FL Clam Industry Workshop, Cedar Key, FL Sept. 2008

Epifanio C. E., R. F. Srna. 1975. Toxicity of ammonia, nitrite ion, nitrate ion, and orthophosphate to *Mercenaria mercenaria* and *Crassostrea virginica*. Marine Biology 33: 241-246

Erga S. R. 1989. Ecological studies on the phytoplankton of Boknafjorden, western Norway. 1. The effects of water exhange processes and environmental factors on temporal and vertical variability of biomass. Sarsia, 74 (3): 161-76

Fay C.W., Neves R.J., Pardue G.B. 1983. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid- Atlantic) - bay scallop. U.S. Fish and Wildlife Service, Division of Biological Services, FWS/OBS-82/11.12. U.S. Army Corps of Engineers, TR EL-82-4. 17 pp.

Ferguson R.G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Board Can., 15: 607-624

Filgueira R., Fernández-Reiriz M.J., Labarta U. 2009. Clearance rate of the mussel *Mytilus galloprovincialis*. I. Response to extreme chlorophyll ranges. Ciencias Marinas, 35(4): 405–417

Filgueira R., Fernández-Reiriz M.J., Labarta U. 2010. Clearance rate of the mussel *Mytilus galloprovincialis*. II. Response to uncorrelated seston variables (quantity, quality, and chlorophyll content). Ciencias Marinas, 36(1): 15–28

Finstad B., Staurnes M., Reite O.B. 1988. Effect of low temperature on sea-water tolerance in rainbow trout, *Salmo gairdneri*. Aquaculture 72(3–4): 319–328

Fivelstad S., Haavik H., Lovik G., Olsen A.B. 1998. Sublethal effects and safe levels of carbon dioxide for Atlantic salmon postsmolts (*Salmo salar* L.). Aquaculture, 160: 305–316

Fonds M. 1976. The influence of temperature and salinity on growth of young sole *Solea solea* L. 10th Eur. Sym p. Mar. Biol. 1: 109-125

Freitas V., Campos J., Fonds M., Van der Veer H.W. 2006. Potential impact of temperature change on epibethic predator-bivalve prey interactions in temperate estuaries. Journal of Thermal Biology 32(6): 328-340

Gazeau F., Gattuso J.P., Dawber C., Pronker A.E., Peene F., Peene J., Heip C.H.R., Middelburg J.J. 2010. Effect of ocean acidification on the early life stages of the blue mussel *Mytilus edulis*. Biogeosciences, 7: 2051–2060

Gazeau F., Parker L.M., Comeau S., Gattuso J.P., O'Connor W.A., Martin S., Portner H.O., Ross P.M. 2013. Impacts of ocean acidification on marine shelled molluscs. Marine Biology 160(8)

Gordon D.M., Sand-Jensen K. 1990. Effects of O2, pH and DIC on photosynthetic net-$O_2$ evolution by marine macroalgae. Marine Biology 106: 445-451

Gulyas P., Fleit E. 1990. Evaluation of ammonia toxicity on *Daphnia magna* and some fish species. Aquacultura Hungarica (Szarvas) 6: 171-183

Hamackova J., Vachta R., Adamek Z., Rykavf, J. Marek J., Cernicky J., Kouril J., Stibranyiova I., Kotrch J., Pokorny J., Navrátil S. 1992. New procedures in rearing of early fish stages including introductions of new species. Final Report RIFCH Vodnany, 38 p. (in Czech)

Hampson M.A. 1967. Uptake of radioactivity by aquatic plants and location in the cells. Journal of Experimental Botany 18: 17-33

Harader R.R.J., Allen G.H. 1983. Ammonia toxicity to chinook salmon parr: reduction in saline water. Trans. Am. Fish. Soc. 112, 834-837

Hart J.S. 1952. Geographic variations of some physiological and morphological characters in certain freshwater fish. Publ. Ont. Fish. Res. Lab. 72: 0-7

Haug T., Kjørsvik E., Solemdal P. 1984. Vertical distribution of Atlantic halibut (*Hippoglossus hippoglossus*) eggs. Can. J. Fish. Aquat. Sci. 41: 798-804

Hogendoorn H., Koops W. J. 1983. Growth and production of the African catlish, *Clarias lazera* (C. & V.). 1. Effects of stocking density, pond size and mixed culture with tilapia (*Sarotherodon niloticus* L.) under extensive field conditions. Aquaculture 34: 253-263

Hokanson K.E.F. 1977. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. Journal of the Fisheries Research Board of Canada, 34(10): 1524-1550

Horvath L. 1978. Relation between ovulation and water temperature by farmed cyprinids. Aquacultura Hungarica 1: 58-65

Imsland A.K., Foss A., Conceição L.E.C., Dinis M.T., Delbare D., Schram E., Kamstra A., Rema P., White P. 2003. A review of the culture potential of *Solea solea* and *S. senegalensis*. Reviews in Fish Biology and Fisheries 13: 379–407

Imsland A.K., Jonassen T.M. 2001. Regulation of growth in turbot (*Scophthalmus maximus* Rafinesque) and atlantic halibut (*Hippoglossus hippoglossus* L.): aspects of environment genotype interactions. Rev. Fish Biol. Fish. 11: 71-90

Imsland A.K., Foss A., Nævdal G., Stefansson S.O. 2001. Selection or adaptation: Differences in growth performance of juvenile turbot (*Scophthalmus maximus* Rafinesque) from two close-by localities off Norway. Sarsia North Atlantic Marine Science 86(1): 43-51

Imsland A.K., Sunde, L.M., Folkvord A., Stefansson S.O. 2005. The interaction of temperature and fish size on growth of juvenile turbot. Journal of Fish Biology 49(5): 926 – 940

Inskip P.D. 1982. Habitat suitability index models: northern pike. U.S. Dept. Int., Fish. Wildl. Serv., FWS/OBS-82/10.17. 40 pp.

Irvin D.N. 1973. The growth and survival of Dover sole, *Solea solea*, and some observations on the growth of the plaice *Pleuronectes platessa*, considered at various temperatures. PhD thesis, University of Liverpool, 186 pp.

Jacobsen L ., Skov C ., Koed A ., Berg S. 2007. Short-term salinity tolerance of northern pike, *Esox lucius*, fry, related to temperature and size. Fisheries Management and Ecology, 14: 303–308

Jobling M. 1994. Fish Bioenergetics. Fish & Fisheries Series 13. Springer Netherlands. 309 pp.

Jobling M., Arnesen A-M., Befey T., Carter C., Hardy R., LeFrancois N., Keefe R., Koskela J. & Lamarre S. 2010. The Salmonids (Family: Salmonidae). In: Finfish Aquaculture Diversification (ed. by N. LeFrancoid, M. Jobling, C. Carter & P. Blier), pp. 234–288. CAB International, Wallingford, Oxfordshire, UK.

Johnston G. 2002. Arctic charr aquaculture. Fishing News Books, Oxford

Jorgensen C.B. 1996. Bivalve filter feeding revisited. Marine Ecology Progress Series, 142: 287–302

Kamstra A., Span J.A., Van Veerd, J.H. 1996. The acute toxicity and sublethal effects of nitrite on growth and feed utilization of European eel, *Anguila anguilla* (L.). Aquaculture Research, 27: 903-911

Kandjengo L. 2002. The Molecular systematics of Ulva Linnaeus and Enteromorpha Link (Ulvales, Chlorophyta) form the South Western Cape, South Africa. Masters Thesis. University of Cape Town. South Africa. pp. 80

Kang H.Y., Lee Y.J., Choi K.S., Park H.J., Yun S.G., Kang C.K. 2016. Combined Effects of Temperature and Seston Concentration on the Physiological Energetics of the Manila Clam *Ruditapes philippinarum*. PLoS One. 11(3): e0152427

Karsten U. 2007. Salinity tolerance of Arctic kelps from Spitsbergen. Volume 55(4): 257–262

Kautsky N. 1982. Growth and size structure in a Baltic *Mytilus edulis* population. Marine Biology, 68: 117-133

Kilambi R., Zdinak A. 1981. The effects of acclimation on the salinity tolerance of grass carp *Ctenopharyngodon idella*. J. Fish. Biol. 16: 171-175

Kır M., Topuz M., Sunar M.C., Topuz H. 2015. Acute toxicity of ammonia in Meagre (*Argyrosomus regius* Asso, 1801) at different temperatures. Aquaculture Research, 47(11): 3593-3598

Klontz W., Stewart B.C., Eib D.W., 1985. On the etiology and pathophysiology of environmental gill disease in juvenile salmonoids. In: Ellis A.E. (Ed.), Fish and Shellfish Pathology. Academic Press, London, pp. 199–210.

Knoph M.B. 1992. Acute toxicity of ammonia to Atlantic salmon (*Salmo salar*) parr. Comparative Biochemistry and Physiology Part C Comparative Pharmacology and Toxicology 101(2): 275-82

Korringa P. 1952. Recent advances in oyster biology. Q. Rev. Biol. 27: 266-339

Kraeuter J.N., Castagna M. 2001. Biology of the hard clam. Elsevier Science. 772 pp.

Küçük S. 2012. Acute toxicity of ammonia to blue tilapia, *Oreochromis aureus* in saline water. African Journal of Biotechnology, 13(14): 1550-1553

Lang T., Peters G., Hoffmann R., Meyer E. 1987. Experimental investigations on the toxicity of ammonia: effects on ventilation frequency, growth, epidermal mucous cells, and gill structure of rainbow trout *Salmo gairdneri*. Diseases of Aquatic Organisms, 3: 159-165.

Lappalainen J., Dörner H., Wysujack K. 2003. Reproduction biology of pikeperch (*Sander lucioperca* (L.)) - a review. Ecol. Freshwat. Fish. 12: 95-106

Larmoyeaux J.D., Piper R.G. 1973. Effects of water reuse on rainbow trout hatcheries. Prog. Fish. Cult. 35: 2-8

Le Cren E.D. 1958. Observations on the growth perch (*Perca fluviatilis* L.) over twenty-two years with special reference to the effects of temperature and changes in population density. Journal of Animal Ecology, 27(2): 287-334

Lei J., Payne B.S., Wang S.Y. 1996. Filtration dynamics of the Zebra Mussel, *Dreissena polymorpha*. Canadian Journal of Fisheries and Aquatic Sciences, 53: 29–37

Lin B.S., Wu T.M., Huang B.Z. 1983. The effects of temperature and salinity on the growth and development of the spats of the clam *R. philippinarum*. J. Fish. China, 7: 15-23

Linløkken A. N., Bergman E., Greenberg L. 2009. Effect of temperature and roach *Rutilus rutilus* group size on swimming speed and prey capture rate of perch *Perca fluviatilis* and *R. rutilus*. Journal of Fish Biology 76: 900–912

Lobban C. S., Harrison P. J. 1997. Seaweed ecology and physiology. Cambridge University Press, Cambridge

Locke, A. 2008. Tabulated observations of the pH tolerance of marine and estuarine biota. Can. Manuscr. Rep. Fish. Aquat. Sci. 2857: 28+iv pp.

Loosanoff V.L., Tommers F.D. 1948. Effect of suspended silt and other substances on the rate of feeding of oysters. Science 107: 69-70

Lucas J.S., Southgate P.C. 2012. Aquaculture: Farming Aquatic Animals and Plants. Wiley-Blackwell. 648 pp.

Lutz P.L. 1972. Ionic and body compartment responses to increasing salinity in the perch *Perca fluviatilis*. Comp. Biochem. Physiol. 42A: 711–717

MacConnell E. 1989. Effects of water reuse on lake trout. Prog Fish-Cult 51(1): 33-7

Mackin J.G. 1956. Canal Dredging and Silting in Louisianna Bays. Publ. Inst. Mar. Sci. Texas 7: 262-314

Mahon R. 1997. Demersal fish assemblages from the Scotian Shelf and Bay of Fundy, based on trawl survey data (1970-1993). Can. Manuscr. Rep. Fish. Aquat. Sci. 2426. 38 pp.

Mantri V.A. 2010. Differential response of varying salinity and temperature on zoospore induction, regeneration and daily growth rate in *Ulva fasciata* (Chlorophyta, Ulvales). Journal of Applied Phycology 23: 243 – 250

Margenau T.L., Rasmussen P.W., Kampa J.M. 1998. Factors affecting growth of northern pike in small northern Wisconsin lakes. N. Am. Jour. Fish. Man. 18: 625-639

MarLIN, 2008. http://www.marlin.ac.uk/species/adult_distrib_Cerastodermaedule.htm

McCosker J.E. 1989. Freshwater eels (Anguillidae) in California: Current conditions and future scenarios. CA Fish Game 75: 4-10

McCracken F.D. 1958. On the biology and fishery of the Canadian Atlantic halibut, *Hippoglossus hippoglossus* L. Fish. Res. Board Can. 15: 1269-1311

McGurk M.D., Landry F., Tang A., Hanks C.C. 2006. Acute and chronic toxicity of nitrate to early life stages of lake trout (*Salvelinus namaycush*) and lake whitefish (*Coregonus clupeaformis*). Environ. Toxicol. Chem. 25(8): 2187-96

Mélard C., Baras E., Kestemont P. 1995. Preliminary results of European perch (*Perca fluviatilis*) intensive rearing trials: effect of temperature and size grading on growth. Bull. Fr. Pêch. Pisc. 336: 19-27

Miller D.C., Hansen D.J. 1989. Ambient Water Quality Criteria for Ammonia (Saltwater). U.S. Environmental Protection Agency Office of Research and Development Environmental Research Laboratory Narragansett, Rhode Island

Mirea C., Cristea V., Grecu, R.I., Dediu L., Adina S. 2013. Results Regarding Growth Performance of Nile tilapia (*Oreochromis niloticus*, Linnaeus, 1758) fed with an Additive Feed, Vitamin C, in a Recirculating Aquaculture System. Animal Science and Biotechnologies, 46 (2): 238-243

Mires D. 1995. The tilapias. In: Production of Aquatic Animals. (Eds C. E. Nash and A. J. Novotny.) pp. 133–152. Elsevier. New York

Molleda M.I. 2007. Water quality in recirculating aquaculture systems for Arctic charr (*Salvelinus alpinus* L.) culture. The United Nations University. pp 54

Molony B. 2001. Environmental requirements and tolerances of Rainbow trout (*Oncorhynchus mykiss*) and Brown trout (*Salmo trutta*) with special reference to Western Australia: A review. Fisheries Rerearch Report No. 130.

Morrison J., Piper R. 1988. Effect of reused water on atlantic salmon. The Prog. Fish-Cult. 50(2): 110-112

Munda I.M., Lüning K. 1977. Growth performance of *Alaria esculenta* off Helgoland. Helgolander Wiss. Meeresunters 29: 311

Muus B.J., Dahlstrøm P. 1989. Havfisk og Fiskeri i Nordvesteuropa. GEC Gads Forlag, København, 244 pp. (in Danish)

Negonovskaya I.T, Rudenko G.P. 1974. Oxygen threshold and characteristics of respiratory metabolism in young hervivorous fish grass carp *Ctenopharyngodon idella* and bighead Aristichtye. J. Ichthyol. 14(6): 965-970

Neill W.H., Bryan J.D. 1991. Responses of fish to temperature and oxygen, and response integration through metabolic scope. In Aquaculture and water quality. Edited by D.E. Brune and J.R. Tomasso. World Aquaculture Society, Baton Rouge, LA, pp. 30-57

Nico L.G., Fuller P.L., Schofield P.J., Neilson M.E., Benson A.J., Li J. 2017. *Ctenopharyngodon idella*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL.

Overton J.L., Bayley M., Paulsen H., Wang T. 2008. Salinity tolerance of cultured Eurasian perch, *Perca fluviatilis* L.: Effects on growth and on survival as a function of temperature. Aquaculture 277: 282–286

Overton J.L., Paulsen H. First feeding of Perch (*Perca fluviatilis*) larvae. DFU-rapport 150-05

Parra-Olea G., Yufera M. 1999. Tolerance response to ammonia nitrite exposure in larvae of two marine fish species (gilthead seabream *Sparus aurata* L. Senegal sole Kaup). Aquaculture Research 30(11-12): 857-863

Paul J.D. 1980. Salinity–temperature relationships in the Queen scallop *Chlamys opercularis*. Mar. Biol. 56: 295–300

Pavlidis M., Mylonas C. (Editors). 2011. Sparidae: Biology and aquaculture of gilthead sea bream and other species. Wiley-Blackwell. 408 pp.

Pedersen C. L. 1987. Energy budgets for juvenile rainbow trout at various oxygen concentrations. Aquaculture 62: 289-298

Person-Le Ruyet J., Chartois H., Quemener L. 1995. Comparative acute ammonia toxicity in marine fish and plasma ammonia response. Aquaculture 136: 181–194

Person-Le Ruyet J., Galland R., Le Roux A., Chartois H. 1997. Chronic ammonia toxicity in juvenile turbot (*Scophthalmus maximus*). Aquaculture 154: 155–171

Peterson M.S., Rakocinski C.F., Comyns B.H., Fulling G.L. 1999. Influence of temperature and salinity on laboratory growth of juvenile *Mugil* sp. and implications to variable field growth. Fisheries Ecology Program. Department of coastal sciences, Institute of marine sciences, The University of Southern Mississippi, Ocean Springs, MS, p. 75

Pichavant K., Person-Le-Ruyet J., Le Bayon N., Sévère A., Le Roux A., Quéméner L., Maxime V., Nonnotte G., Boeuf G. 2000. Effects of hypoxia on growth and metabolism of juvenile turbot. Aquaculture, 188(1-2): 103-114

Pillay T.V.R., Kutty M.N. 2005. Aquaculture: Principles and Practices. Blackwell Publishing Ltd, Oxford, UK. 630 pp.

Poxton M.G., Allouse S.B. 1982. Water quality criteria for marine fisheries. Aquacultural Engineering, 1: 153–191.

Raleigh R.F. 1982. Habitat suitability index models: Brook Trout. U.S. Dept. Int., Fish Wildl. Serv., 42 pp.

Ravagnan G. 1992. Vallicoltura integrata. Edizione edagricole, Bologna, 502 pp.

Riba Lopez I., Kalman J., Vale C., Blasco J. 2010. Influence of sediment acidification on the bioaccumulation of metals in *Ruditapes philippinarum*. Environ. Sci. Pollut. Res. 17: 1519-1528

Robinson W.E., Wehling W.E., Morse M.P. 1984. The effect of suspended clay on feeding and digestive efficiency of the surf clam, *Spisula solidissima* (Dillwyn). Journal of Experimental Marine Biology and Ecology, 14: 1–12

Roseboom D.P., Richey D.L. 1977. Acute toxicity of residual chlorine and ammonia to some native Illinois fishes. Department of Registration and Education - Report of Investigation 85. Illinois State Water Survey, Urbana, Illinois, USA.

Russell P.J.C., Petersen G.H. 1973. The use of ecological data in the elucidation of some shallow water European *Cardium* species. Malacologia 14: 223–232

Russo R.C., Thurston R.V. 1977. The acute toxicity of nitrite to fishes. In: Tubb R.A. (Ed.). Recent advances in fish toxicology. Ecological research series. Corvallis, Oregon: US Environmental Protection Agency. p. 118-131 EPA-600/3-77-085

Russo R.C., Thurston R.V., Emerson K. 1981. Acute toxicity of nitrite to rainbow trout (*Salmo gairdneri*): effects of pH, nitrite species, and anion species. Can. J. Fish. Aquat. Sci. 38: 387-393

Sadler K. 1979. Effects of temperature on the growth and survival of the European eel, *Anguilla anguilla* L. J. Fish Biol. 15: 499-507

Sadok S., Uglow R., Haswell S.J. 1995. Fluxes of haemolymph ammonia and free amino acids in *Mytilus edulis* exposed to ammonia. Mar. Ecol. Progr. Ser. 129: 177-187

Säisä M., Salminen M., Koljonen M.-L., Ruuhijärvi J. 2010. Coastal and freshwater pikeperch (*Sander lucioperca*) populations differ genetically in the Baltic Sea basin. Hereditas, 147: 205-214

Sampaio L.A., Wasielesky W.J., Miranda-Filho K.C. 2002. Effect of salinity on acute toxicity of ammonia and nitrite to juvenile *Mugil platanus*. Bulletin of Environmental Contamination and Toxicology, 68: 668-674

Sand-Jensen K. 1988. Photosynthetic responses of *Ulva lactuca* at very low light. Marine Ecology Progress Series 50: 195-201

Sand-Jensen K., Gordon D.M. 1984. Differential ability of marine and freshwater macrophytes to utilize $HCO^{3-}$ and $CO^{2}$. Marine Biology 80: 247-253

Schlumpberger V. 1966. Determination of salt tolerance of pike (*Esox lucius*) by means of Na22. Ref. Zh. Biol. lIll8k (In Russian)

Schofield P.J., Peterson M.S., Lowe M.R., Brown-Peterson N.J., Slack W.T. 2011. Survival, growth and reproduction of non-indigenous Nile tilapia, *Oreochromis niloticus* (Linnaeus 1758). I. Physiological capabilities in various temperatures and salinities. Marine and Freshwater Research, 62: 1–11

Schram E., Bierman S., Teal L.R., Haenen O., van de Vis H., Rijnsdorp A.D. 2013. Thermal Preference of Juvenile Dover Sole (*Solea solea*) in Relation to Thermal Acclimation and Optimal Growth Temperature. PLoS ONE 8(4): e61357

Schram E., Roques J.A.C., Abbink W., Spanings T., De Vries P., Bierman S., Van de Vis H., Flik G. 2010. The impact of elevated water ammonia concentration on physiology, growth and feed intake of African catfish (*Clarias gariepinus*). Aquaculture, 306: 108–115

Schram E., Roques J.A.C., van Kuijk T., Abbink W., van de Heul J., de Vries P., Bierman S., van de Vis H., Flik G. 2014. The impact of elevated water ammonia and nitrate concentrations on physiology, growth and feed intake of pikeperch (*Sander lucioperca*). Aquaculture 420–421: 95–104

Scott K.R., Gillespie D.C. 1972. A compact recirculation unit for the rearing and maintenance of fish. J. Fish. Res. Bd. Can. 29: 1071-1074

Scott W.B., Crossman E.J. 1973. Freshwater Fishes of Canada. Bull. Fish. Res. Board Can. 184. 966 pp.

Sharp G.D. 1978. Behavioural and physiological properties of tunas and their effects on vulnerability to fishing gears. pp. 397-450 In G.D. Sharp and A.E. Dizon (eds), The physiological ecology of tunas, Academic Press, New York: 485 pp.

Sherk J.A.Jr., Cronin L.E. 1970. The effects of suspended and deposited sediments on estuarine organisms. An annotated bibliography of selected references. University of Maryland National Research Institute Ref. 70-19, 61 pp. + addendum

Shireman, J.V. 1975. Predation, spawning and culture of white amur (*Ctenopharyngodon idaho*). Annual report to the Florida Department of Natural Resources. Gainesville, Florida, University of Florida, School of Forest Resources and Conservation, 40 p.

Shireman, J.V., Colle D.E., Rottmann R.W. 1977. Incidence and treatment of columnaris disease in grass carp brood stock. The Prog. Fish-Cult. 38(2): 116-7

Shumway, S.E. 1996. Natural environmental factors. In: V.S. Kennedy, R.I.E. Newell and A.F. Eble, editors. The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant College, University of Maryland, College Park, Maryland. pp. 467-513

Siikavuopio S. I., Knudsen R., Amundsen P.A. 2010. Growth and mortality of Arctic charr and European whitefish reared at low temperature. Hydrobiologia 650: 255–263

Siikavuopio S.I., Knudsen R., Amundsen P.A., Sæther B.S. 2011. Growth performance of European whitefish *Coregonus lavaretus* (L.) under a constant light and temperature regime. Aquaculture Research 43(11): 1592-1598

Skybakmoen S., Siikavuopio S.I., Sæther B.-S. 2009. Coldwater RAS in an Arctic charr farm in Northern Norway. Aquacultural Engineering 41: 114–121

Smith C.E., Piper R.G. 1975. Lesions associated with chronic exposure to ammonia. In: Ribelin W.E., Migah G. (eds.) The pathology of fishes. Univ. Of Wisconsin Press, Madison W.I., p. 497-514

Sobral P. 1995. Ecophysiology of *Ruditapes decussatus*. PhD thesis, Universidade Nova de Lisboa, 197 pp.

Sobral P., Widdows J. 1997. Effects of elevated temperatures on the scope for growth and resistance to air exposure of the clam *Ruditapes decussatus* (L.), from southern Portugal. Scientia Marina 61(1): 163-171

Speece R.E., Nirmalakhandan N., Lee Y. 1988. Design of high purity oxygen absorption and nitrogen stripping for fish culture. Aquacultural Engineering 7: 201-210

Stamnes N. 2014. Comparing Salinity Tolerance of Kelp species local to Burrard Inlet: *Saccharina latissima*, *Costaria costata*, and *Nereocystis luetkeana*.

Stevenson J.P. 1987. Trout farming manual. Fishing News Books Ltd., Oxford. 272 pp.

Stone R.L. 1975. Sublethal effects of experimental turbidity concentrations on selected marine organisms. Report to U.S. Army Corps of Engineers on Contract No. DAC-33-74-C-0101

Strand O., Solberg P.T., Andersen K.K., Magnesen T. 1993. Salinity tolerance of juvenile scallops (*Pecten maximus* L.) at low temperature. Aquaculture 115(1-2): 169–179

Stroganov N.S. 1963. The food selectivity of the amur fishes. In: Problems of the fisheries exploitation of plant-eating fishes in the water bodies of the USSR. Ashkhabad, Akadenii Nauk Turkmenistan SSSR, pp. 181-191

Strohmeier T., Strand Ø., Cranford P., Krogness C. 2007. Feeding behaviour and bioenergetic balance of *Pecten maximus* and *Mytilus edulis* in a low seston environment. Journal of Shellfish Research, 26 (4): 1350-50

Summerfelt S.T., Davidson J.W., Waldrop T.B., Tsukuda S.M., Bebak-Williams J. 2004. A partial-reuse system for coldwater aquaculture. Aquacultural Engineering 31: 157–18

Summerfelt S.T., Vinci B.J., Piedrahita R.H. 2000. Oxygenation and carbon dioxide control in water reuse systems. Aquacult. Eng. 22: 87–108

Summerfelt S.T., Wilton G., Roberts D., Rimmer T., Fonkalsrud K. 2004. Developments in recirculating systems for Arctic char culture in North America. Aquacultural Engineering 30: 31-71

Suresh A.V., Lin C.K. 1992. Tilapia culture in saline waters: a review. Aquaculture 106: 201-226

Szumski D.S., Barton D.A., Putnam H.D., Polta R.C. 1982. Evaluation of EPA un-ionized ammonia toxicity criteria. Journal of the water pollution control federation 54: 281-291

Terjesen B.F., Kolarevic J. 2012. Salmon parr tolerate more ammonia in the water than expected. Nofima. https://nofima.no/en/nyhet/2012/08/salmon-parr-tolerate-more-ammonia-in-the-water-than-expected/

Tesseyre C. 1979. Obtention de loups (*Dicentrarchus labrax*) portions en 20 mois d'élevage intensif avec recyclage de l'eau. In J. E. Halver and K. Tiews (eds.), Finfish Nutrition and Fishfeed Technology, Volume 1. Heenemann, Berlin. 547 pp.

Teugels G. 1986. A systematic revision of the African species of the genus *Clarias* (Pisces: Clariidae). Annales Musee Royal de l'Afrique Centrale, 247: 1-199

Thurston R.V., Phillips G.R., Russo R.C. 1981. Increased toxicity of ammonia to rainbow trout (*Salmo gairdneri*) resulting from reduced concentrations of dissolved oxygen. Can. J. Fish. Aquat. Sci. 38: 983-988

Thurston R.V., Russo R.C., Smith C.E. 1978. Accute toxicity of ammonia and nitrite of cutthroat trout fry. Transactions of the American Fisheries Society 107: 361-368

Timmons M.B., Ebeling J.M., Wheaton F.W., Summerfelt S.T., Vinci B.J. 2002. Recirculating Aquaculture Systems. 2nd Edition. Cayuga Aqua Ventures, Ithaca, NY 14850, USA. 800 p. NRAC Publication No. 01-2

Tinoco A.B., Rodríguez-Rúa A., Calvo A., Cárdenas S. 2009. Effects of salinity on growth and feeding of juvenile meagre, *Argyrosomus regius* (Asso, 1801). Aquaculture Europe 09, 14-17 August. Trodheim, Norway.

tom Dieck I. 1933. Temperature tolerance and survival in darkness of kelp gametophytes (Laminariales, Phaeophyta): ecological and biogeographical implications. Mar. Ecol. Progr. Ser. 100: 253-264

USEPA (United States Environmental Protection Agency). 1984. Ambient water quality criteria for ammonia. National Technical Information Service, Springfield, VA.

USEPA (United States Environmental Protection Agency). 1989. Ambient water quality criteria for ammonia (saltwater). National Technical Information Service, Springfield, VA.

Valero J. 2006. Ostrea edulis: Growth and mortality depending on hydrodynamic parameters and food availability. Master Thesis, University of Göteborg, 48 pp.

van Bussel C.G.J., Schroeder J.P., Wuertz S., Schulz C. 2012. The chronic effect of nitrate on production performance and health status of juvenile turbot (*Psetta maxima*). Aquaculture 326: 163-167

Van den Thillart G., Dalla Via J., Vitali G., Cortesi P. 1994. Influence of long-term hypoxia exposure on the energy metabolism of *Solea solea*. I. Critical O2 levels for aerobic and anaerobic metabolism. Mar. Ecol. Prog. Ser. 104: 109-117

van Dijk P.L.M., Staaks G., Hardewig I. 2002. The effect of fasting and refeeding on temperature preference, activity and growth of roach, *Rutilus rutilus*. Oecologia, 130 (4): 496-504

van Erkom Schurink C., Griffiths C.L. 1993. Factors affecting relative rates of growth in four South African mussel species. Aquaculture 109: 257–273

Velasco L.A., Navarro J.M. 2005. Feeding physiology of two bivalves under laboratory and field conditions in response to variable food concentrations. Marine Ecology Progress Series, 201: 115–124

Verdelhos T., Marques J.C., Anastácio P. 2015. The impact of estuarine salinity changes on the bivalves *Scrobicularia plana* and *Cerastoderma edule*, illustrated by behavioral and mortality responses on a laboratory assay. Ecological Indicators 52: 96–104

Vinagre C., Fonseca V., Cabral H., Costa M.J. 2006. Habitat suitability index models for the juveniles soles, *Solea solea* ans *Solea senegalensis* in the Tagus estuary: defining variables for species management. Fisheries Research 82: 140–149

Wald J. 2010. Evaluatie studie naar mogelijkheden voor grootschalige zeewierteelt in het zuidwestelijke Deltagebied, in het bijzonder de Oosterschelde. Plant Research International, Wageningen UR

Walsh P.J., Foster G.D., Moon T.W. 1983. The effects of temperature on metabolism of the American eel *Anguilla rostrata* (LeSueur): Compensation in the summer and torpor in the winter. Physiol. Zool. 56(4): 532-540

Weatherley A.H. 1963. Thermal stress and interrenal tissue in the perch *Perca fluviatilis* (Linnaeus). Proc. Zool. Soc. Lond. 141: 527-5

Wedemeyer G.A. 1996. Physiology of fish in intensive culture systems. Chapman and Hall, New York, 232 p.

Weithman A.S., Haas M.A. 1984. Effects of dissolved-oxygen depletion on the rainbow trout fishery in Lake Taneycomo, Missouri. Trans. Am. Fish. Soc. 113: 109-124

Wesche T.A. 1974. Evaluation of trout cover in smaller streams. Proc.Western Assoc. Game and Fish Commissioners. 54: 286-294

Westin D.T. 1974. Nitrate and nitrite toxicity to salmonid fishes. Prog. Fish-Cult. 36: 86–89

Widman J.C., Meseck S.L., Sennefelder G., Veilleux D.J. 2007. Toxicity of Un-ionized Ammonia, Nitrite, and Nitrate to Juvenile Bay Scallops, *Argopecten irradians irradians*. Arch. Environ. Contam. Toxicol. 54: 460–465

Wildish D.J., Kristmanson D.D. 1993. Hydrodynamic control of bivalve filter feeders: A conceptual view, p. 299-324. In: R.F. Dame [ed.], Bivalve filter feeders in estuarine and coastal ecosystem processes. Springer-Verlag

Wilson S.G., Block B.A. 2009. Habitat use in Atlantic bluefin tuna *Thunnus thynnus* inferred from diving behaviour. Endang Species Res. Vol. 10: 355–367

Winkler H.M., Klinkhardt M., Buuk B. 1989. Zur Fruchtbarkeit und Reifenentwicklung des Zanders (*Stizostedion lucioperca* (L.)) aus Brackgewässern der südlichen Ostsee. Wiss. Z. Univ. Rostock, N-Reihe, 38: 31-37

Wojda R. 2015. Chów i hodowla karpia. IRS Olsztyn, 457pp.

Woynarovich E. 1968. New systems and new fishes for culture in Europe. FAO Fish. Rep. 44(5): 162-181

Wunder W. 1936. Physiologie der Süsswasserfische Mitteleuropas. Handb. Binnenfisch. Mittelcur. 23: 1-340

Xie K. 1998. Mussel culture. In: Liu Dejing, Cao Jialu et al., Culture technologies on marine mollusks. Beijing, China: China Agricultural Press, 175-198

Yanbo W., Wenju Z., Weifen L., Zirong X. 2006. Acute toxicity of nitrite on tilapia (*Oreochromis niloticus*) at different external chloride concentrations. Fish. Physiol. Biochem. 32: 49–54

# ANNEX III: Deliverable revision notes

The following notes provide an overview of the revision executed to this deliverable, following comments from the AquaSpace project reviewers, received from the European Commission on July 23rd, 2018. The comments received are below, together with an explanation of changes and/or adaptations made to the deliverable to address those comments.

*The very informative web application 'WATER' is not directly accessible from the AquaSpace legacy website but hosted on the LLE website instead. When accessing the tool directly at the relevant link (http://water.longline.co.uk) there is no acknowledgement of EC funding or the AquaSpace project. Moreover, there is very limited technical information on the physical / environmental data considered, and the relevant data sources the App calculations are based on.*

*The 'WATER' tool should be made available on the AquaSpace website, and EC funding as well as project logos should be added to the tool webpage. In addition, technical information should be made available in a user friendly manner, and a link to D2.5 should be provided for interested users.*

1. We have added the AquaSpace and Horizon 2020 logos to the WATER landing page in the about section and on the expandable/collapsible tab on the right-hand side of the website to show the development of the tool was supported by EC funding as part of the AquaSpace project.

2. We have added a link to Deliverable D2.5 (this document), which contains all the technical information required.

3. We have added a download report link to http://longline.co.uk/AAC2017/WATER, an invited talk given at the Aquaculture Association of Canada's 2017 conference, which provides a technical presentation of the WATER application, including algorithms for calculations.

4. We have added a link to the Maritime and Environmental Thresholds for Aquaculture (META) website (http://longline.co.uk/meta).

5. We have ensured that both the AquaSpace and Horizon 2020 logos on the WATER entry page are hot-linked to the main websites for each in the About section.

6. The WATER application has an extremely complex software architecture, which presently requires the simultaneous use of two Amazon cloud servers (AWS) to process and present data. WATER has significant realtime demands of both mass storage and RAM memories. The main AquaSpace website, hosted by SAMS, would not be able to host the application, or maintain it. Neither would it be feasible for LLE staff to access the machines at SAMS for enhancements to the platform. The state-of-the-art approach for distributed computing relies on different platforms that run bespoke software, and use standardized communication protocols to provide information to the user. For these reasons, both the WATER and META websites, which have substantial computational requirements, will be hosted and maintained on LLE servers. The main AquaSpace website has been substantially improved to ensure clear links are provided between it and WATER, to provide a seamless user experience.