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REPORT STRATEGI LAKSELUS 2017- 19

FHF «3D hydrodynamic and lice forecast model »

Photo Tom Haga

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Abstract:

A collaborative project for the implementation of a user-friendly tool for alerting producers about high concentrations of infectious larvae in Rogaland, in order to prevent infection and plan and implement the right measures at the right time. Partners in the project included: Norwegian Computing Center, Veterinary Institute, Proactima, Blue Planet and the fish farming companies in Rogaland.

Proactima and partner DHI developed a front end for the 3D hydrodynamic – infectious larvae prediction model and provided access to a user group from the various producers in Rogaland. The user group was provided with training and support and met to discuss the use and potential for the model.

Output from the model was provided to NR and VI for analysis and use in their own models

Key word	Hydrodynamic, model lice, copepodid, Ryfylke, Rogaland, salmon farming
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1 Summary

The Final report for «Enhetlig proaktiv lakselus strategi Rogaland» (FHF project 901414) provides the overall background and objectives to the project. This document reports on the development and testing of a live portal to provide access to users and is supplementary to the overall project report. This report focusses on the elements relating to the hydrodynamic/lice model for Rogaland. The background of the Rogaland hydrodynamic model is provided in Appendix A. There is also a description of the ABM model contained in Appendix B .

As part of this project (901414) a "live" version of the model was established, with output updated twice daily providing predicted hydrodynamic and infectious lice data for the whole of Rogaland included within the Rogaland Hydrodynamic model. The output from the model was presented via user friendly interface and a user group trained and engaged in using and evaluating the model.

Output data from the model has also been provided to NR and VI for use in their models and further analysis.

Proactima and DHI would like to thank FHF for providing the opportunity to work on this project together with our colleagues at NR and VI. We would also like to thank Blue Planet for managing and coordinating the overall project. The efforts and enthusiasm of the user group is also acknowledged and appreciated. Finally, the cooperation of the Rogaland producers and Steinsvik and Fishtalk in providing site data and the support was fundamental to the work undertaken.

2 Sammendrag

Sluttrapporten for «Enhetlig proaktiv lakselusstrategi Rogaland» (FHF-prosjekt 901414) gir prosjektets overordnede bakgrunn og mål. Dette dokumentet rapporterer om utvikling og testing av en live portal for å gi tilgang til brukere, og kommer i tillegg til den samlede prosjektrapporten. Denne rapporten fokuserer på elementene knyttet til hydrodynamisk modell / lusemodellen for Rogaland. Bakgrunnen for den hydrodynamiske modellen til Rogaland er gitt i vedlegg A. Det er også en beskrivelse av ABM-modellen i vedlegg B.

Som en del av dette prosjektet (901414) ble det opprettet en "live" versjon av modellen, med utdata oppdatert to ganger daglig, som forutsa hydrodynamiske og smittsomme lusedata for hele Rogaland, inkludert i Rogaland Hydrodynamic-modellen. Utdata fra modellen ble presentert via et brukervennlig grensesnitt, og en brukergruppe var trent i å bruke og evaluere modellen.

Utdata fra modellen har også blitt gitt til NR og VI for bruk i modellene og videre analyse.

Proactima og DHI vil takke FHF for at de ga muligheten til å jobbe med dette prosjektet sammen med kollegene i NR og VI. Vi vil også takke Blue Planet for å styre og koordinere det totale prosjektet. Brukergruppens innsats og entusiasme blir også anerkjent og verdsatt. Til slutt var samarbeidet med rogalandprodusentene, Steinsvik og Fishtalk om å gi stedsdata. Deres støtte var grunnleggende for arbeidet som ble utført.

3 Introduction

3.1 Background

3.1.1 The Salmon Lice Challenge

Salmon lice are a national problem for the Norwegian salmon industry, and challenge and cost all parties significantly, both in terms of fish welfare, economy and impact on wild salmon especially migrating smolt. Today there is a great need to prevent, limit and control salmon lice infection in the fjords. Several infection models have been developed. However there is a need for a user-friendly dynamic "lice model" for everyday use.

An "online salmon lice infection model" will help fish farming operators to prevent and plan measures to prevent salmon larvae from attaching to salmon and developing to become fertile adult lice over time – see lice life-cycle illustration in Figure 1. Better knowledge of salmon lice population, dispersion and spread of eggs and larvae in the sea will provide a better basis for making joint decisions for the future.

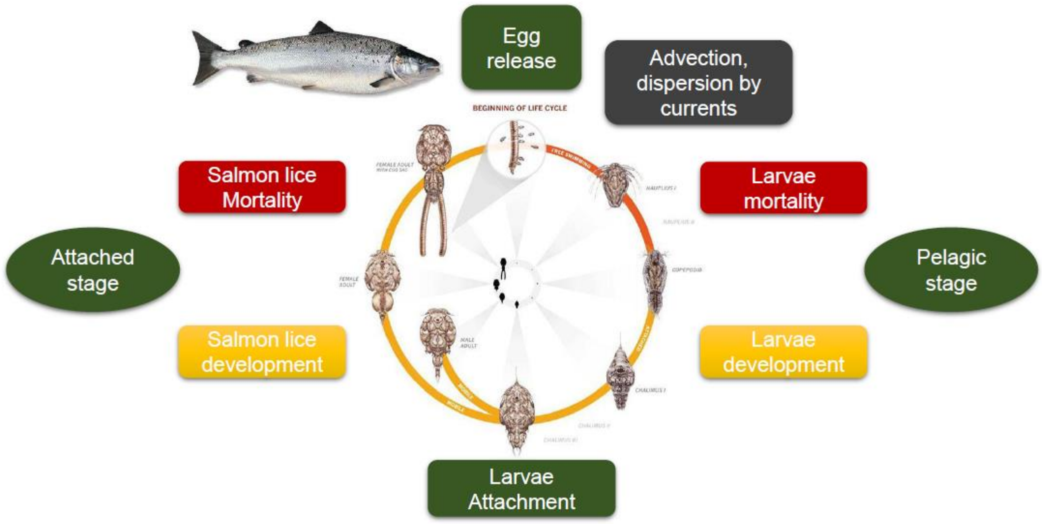

Figure 1 Salmon lice life cycle illustration

The project is a follow-up FHF project on the evaluation of the zone division in Rogaland (2017) and a further development project based on the population models of VI and NR (2014-16).

Goal: Develop a tool to prevent salmon lice infection, through a "live" salmon lice infection model

3.1.2 Rogaland Water forecast model

The hydrodynamic model for Rogaland (Rogaland Water Forecast), developed based on MIKE 3 Flow Model FM (Flexible Mesh) simulates the variation in time and space of parameters such as:

- Water level;
- Current direction and velocities;
- Salinity; and
- Water temperature.

This provides the basis for the **A**gent **B**ased sea lice **M**odelling (ABM) Sea lice forecast model. A general description of the MIKE 3 HD model can be found in references **Error! Reference source not found.** and **Error! Reference source not found.**.

This document reports on the development and testing of a live portal to provide access to users and is supplementary to the overall project report. The Final report for «Enhetlig proaktiv lakselus strategi Rogaland» (FHF project 901414) provides the overall background and objectives to the project. This report focusses on the elements relating to the hydrodynamic/lice model for Rogaland. The background of the Rogaland hydrodynamic model is provided in Appendix A, which was previously part of a validation process where the output from the model for 2013 and 2014, was compared with historical data gathered by Rogaland Helsenettverk via Blue Planet. There is also a description of the ABM model contained in Appendix B .

The 3D hydrodynamic flow model covers an area of approximately 10.000 km^2, from Karmøy in the north to Klepp kommune in the south. To the east, the model includes all inner fjords and to the west it extends approximately 50 km out into the open ocean. The water depth in the area (>700m) is integrated in the 3D model with high resolution bathymetrical maps. The model extends to the full depth of the fjords, but in lower detail for depths over 50m. It is necessary to have a relatively large model area in order to allow for external factors impacting the more localised areas. The model also includes all concessions (operational or non-operational) in Rogaland as these are all potentially important as contributors and/or receptors.

The current model was previously compared versus historical data for 2013 and 2014 as a process of validation. The results from this project in 2016/17 showed good correlation across a range of parameters. These included a strong correlation between model prediction for spread of infectious larvae to production sites and subsequent increase in adult female lice several weeks later (water temperature dependent maturity rate). The infectious larvae pressure model delivers 5-day forecasts of infectious larvae, salinity, temperature and current (speed and direction).

As part of this project (901414) a “live” version was established, with output updated twice daily providing predicted hydrodynamic and infectious lice data for the whole of Rogaland included within the Rogaland Hydrodynamic model.

3.2 Purpose

Documenting how one, within a production area, might succeed in keeping persistently low lice levels by combining increased focus on preventive measures and targeted use of treatment, based on tools that provide continuous overview of larvae/lice development, within the entire production area of Rogaland.

3.3 Scope of work

The main tasks and sub tasks included in the joint proposal to FHF where Proactima/DHI have been involved are listed in the following Table 1. In addition a reference is given to the main work package (WP) they relate to and a short comment on how it was addressed. The remainder of this section of the report addresses the main elements of this input.

A timeline is also included as to when the main activities were and the timing of key deliveries.

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Table 1 Work Package elements

No.	Work Package element	Work Package	Status
1	Define the users and what data are needed to access for users, as well as the format of these.	WP1	Completed in WP1 and further followed up in WP5
2	Design proposals for single web interface for information exchange (control panel and visualization of results).	WP1	Completed as part of preparation for launch of portal. Also discussed in WP5
3	Data collection - secure the data sources to be used as input to the live version.	WP1	Completed with Steinsvik and Fishtalk and followed up consistently as quality check under WP1.
4	Quality check of data - go through the data to reveal any errors or uncertainties.	WP1	Completed. Regular QA of incoming data (WP1) and follow up were necessary throughout the period the live model as used on the project.
5	Modification of the model from the latest version	WP1	Completed. Model monitored and adjusted where necessary under WP1
6	Establish a live version (24/7) of the hydrodynamic /lice model, with updates twice a day, thus establishing a warning system for high-level larval concentrations at farm locations.	WP1	Completed and available via portal (WP1)
7	Present the notifications using maps	WP1	Completed – Portal shows results on maps (WP1
8	Run and maintain the hydrodynamic infection pressure model throughout the entire life of the project (end 2018)	WP1	Completed with model available until 1Q 2019 (original scope until Q4 2018) (WP1)
9	Deliver real-time hydrodynamic data eg. current, temperature, salt content for other models	WP1	Completed. Real time hydrodynamic data delivered as required to NR and VI (WP2 and WP3)
10	Support is included for model user who are project participants	WP1	Completed. Support provided for users via phone, email , Facebook and user group meetings (WP1 and WP5)
11	Hydrodynamic model (Proactima/DHI) run with constant lice and egg production as input to produce monthly contact matrices	WP2	Completed. The HD model was run using constant lice and egg production and output generated as input to produce monthly contact matrices (WP2 and WP3)
12	Map based portal presenting prediction for infection pressure development	WP1 & WP3	Completed. Map based portal for HD / lice model part of WP1

No.	Work Package element	Work Package	Status
13	Effect of various scenarios with regard to zone structure to be tested.	WP4	The Hydrodynamic/lice model was used to produce an example of optimal zoning. Further work on this aspect was not proceeded with as this work was not allocated to Proactima/DHI (WP4).
14	Involve interested parties /users in reviewing the user interface and the visualisation of model results	WP5	Completed. Interested parties and users were involved with reviewing the interface and visualisation of results in order to provide feedback (WP5).
15	Involve interested parties/users in workshops or exercises in practical use of the model results.	WP5	Completed. Various user cases discussed within user group meetings based on practical use of results both for current and lice prediction (WP5).
16	Improve the user interface and visualisation for interested parties/users	WP5	Completed. User visualisation improved from first draft and recommendations for further improvement were received from user group meetings (WP1 and WP5).
17	Identify users' needs and potential for further improvement/development	WP5	Completed. As above, user group meetings provided input re potential for improvement/development of HD/Lice model (WP5).
18	Identify and define operational settings for use of the model as a warning and to implement actions. Actions can be either preventive or damage limiting.	WP6	Completed. Settings for medium and high lice concentrations were identified and implemented as settings in the HD/Lice model. Potential actions were discussed with user group (WP1).
19	Identify relevant preventive or damage limiting actions for the involved producers	WP6	Completed. The conclusion here was that easily deployed skirts used for relatively short periods could significantly reduce the exposure to infectious lice. A longer term issue needing attention was the close proximity to land of many locations should be further evaluated (WP5).
20	Written report	WP7	This report supports the overall report

The following Figure 2 is a simple timeline of key milestones and deliveries with regard to Proactima/DHI involvement.

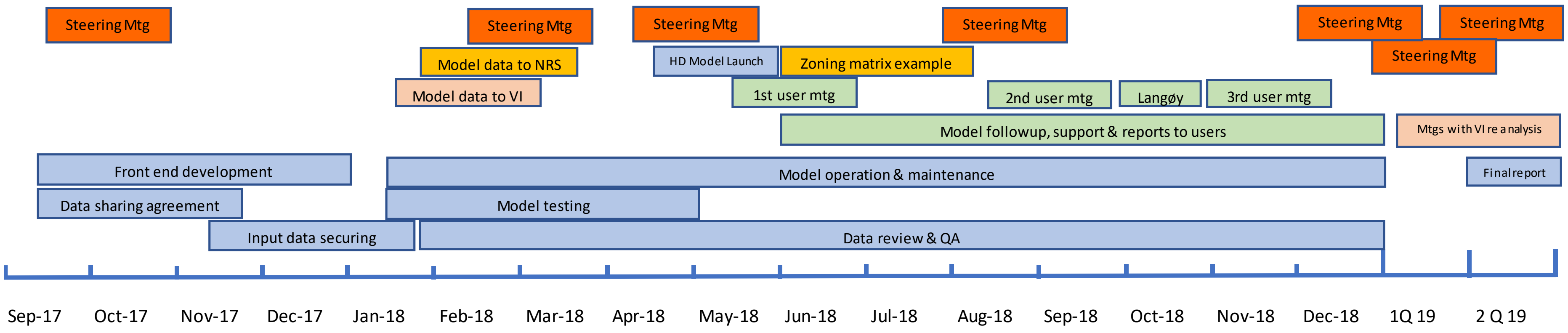


Figure 2 Simple Timeline of key milestones and deliveries

3.3.1 WP1 - Establish and operate "live" infectious larvae spread model / hydrodynamic model

The scope of work package includes establishing and operating the 3D hydrodynamic "live" infection pressure model and further includes tasks 1 to 10 in Table 2:

Effective data acquisition

Initially, the key to securing a reasonably reliable live model was dependent on securing delivery of input data from the various sites in Rogaland as soon as possible. A series of meetings were held with Fishtalk and Steinsvik to present the model, explain the data requirements and discuss the best approach for effectively transferring data on a daily basis. Several formats and simplifications were agreed in order to agree as simple and effective approach to data delivery as possible. The transfer of data was then initiated with a few sites before progressing to transfer data from all sites.

As part of the regular quality control follow up the input data were checked for consistency and completeness. There were quite often occasions where data were incomplete and cross checks were made to understand the reason and make corrections. Overtime the delivery of data became more reliable. However, there was still a need to quality control or respond to issues where sometimes whole datasets from producers did not get transferred. One important element was to encourage all the localities to register their latest records of the number adult female lice counted as soon as possible. In time it is expected that systems which provide automatic counting of lice will provide an even better source of input data to the model. Data were checked for consistency and completeness on daily basis during the project by Proactima and DHI's water modelling team. .

Illustration below of an early listing (later simplified) of the type of data required is shown in Figure 3.

Lokalitet	
Firma navn	
Navn på lokalitet	
Koordinater	
I drift Ja/Nei	
Type merd	

Laks mengde	
# laks på lokalitet	
Biomasse (Tonn)	
oppdatert ukentlig/med endring	

Lusstatistikk	
Lustelling dato	
# merder telt	
# laks telt	
# Fastsittende lus	
# Lus i bevegelige stadier	
# Hunnlus	
# Total lus per fisk	
oppdatert ukentlig	

Hydrodynamisk data	
Dato/tidspunkt	
Temp (°C) 3m	
Saltholdighet (PSU) 3m	
Strøm (m/s)	
Strøm retning	
Frekvens	Så ofte som mulig

Kjemikalsk behandling	
Kjemikalie brukt	
Antall merder behandlt	
Startdato	
Sluttdato	
Oppdatering - hver behandling	

Rensefisk	
Rensefisk type	
%/merd	
dato introdusert	
Oppdatert med endring	

Mekanisk behandling	
Behandlingsnavn	
Antall merder behandlt	
Startdato	
Sluttdato	
Oppdatering - hver behandling	

Forebygging	
Forebygging type eks skørt, tubenot, strøm gjerder	
Antall merder behandlt	
Startdato	
Sluttdato	
Oppdatering - hver gang	

Annen behandling	
Behandling Type - feks laser	
Startdato	
Sluttdato	
Oppdatering - hver behandling	

Figure 3 Illustration of early definition of data needs

Front end development

Parallel to securing and following up data input (mainly adult female lice numbers) the front end of the model was developed as a beta version. This was trialled within the project team and presented to the steering group before introduction to the functioning model.

As part of the development of the frontend for the live model consideration was given to the following:

- Model input data
- Access & security
- Model output – clear, consistent
- User types
    - People working at fish farm needing daily access
    - People needing a broader overview
    - Long term planning
- Ability for user to manoeuvre within model front end at different levels of detail
- Ability to display and animate model output from different layers
- Extraction of historical data to perform analyses
- Balance in complexity but maintaining a complete picture
- Feedback from users
- Low training threshold with clear graphics
- Etc.

Data security was a key issue during the front end development and acquisition of data. There was a clear understanding that sensitive data were not displayed in the front end. Access to the portal was provided via company specific usernames and passwords at the portal login page.

Design web interface for information exchange

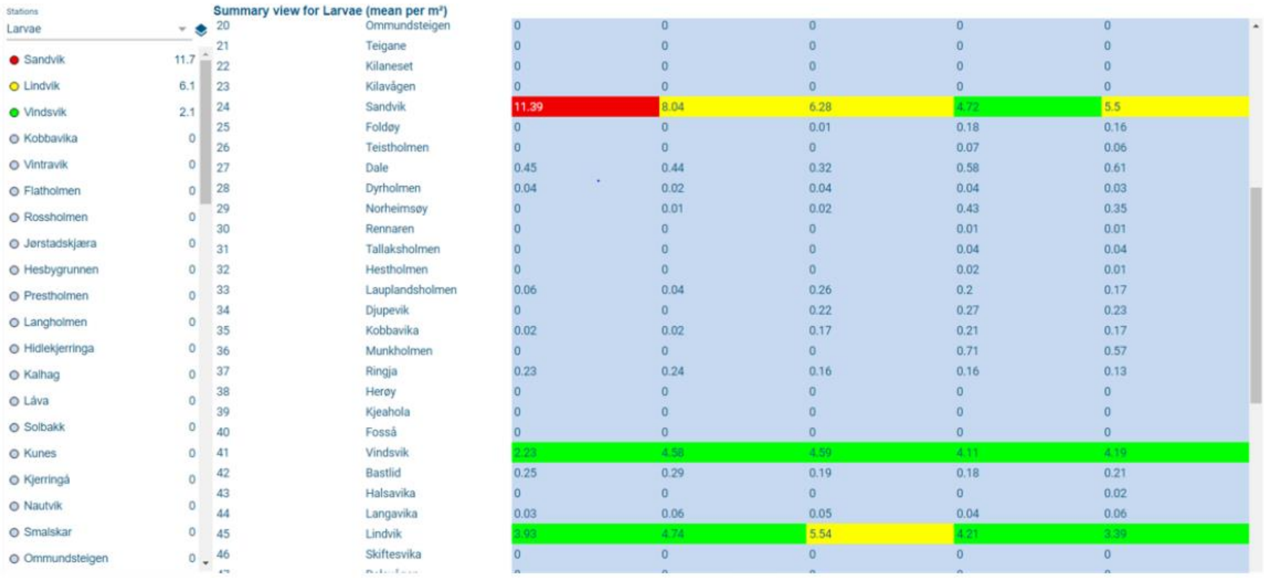
The users were considered to be several including workers at a farm, operational managers wanting an overview of their sites with recent and future exposure, strategic planners assessing relocation of biomass, analysing new or relocated sites.

The model frontend version 1.0 already contains several layers of data with the ability to review data in several formats or dimensions. There is also the ability for historical output data to be extracted where necessary in order to undertake more detailed studies.

The frontend does not have the capability to display all potential output data for example key parameters at different depths, though this could be a future function as the data are generated and stored in the model.

User feedback and training is dealt with in a separate section (3.3.4) later.

Figure 4 below illustrates one of the beta version screens developed for the frontend.



20	Ommundsteigen	0	0	0	0	0
21	Teigane	0	0	0	0	0
22	Kilaneset	0	0	0	0	0
23	Kilavågen	0	0	0	0	0
24	Sandvik	11.39	8.04	6.28	4.72	5.5
25	Foldøy	0	0	0.01	0.18	0.16
26	Teistholmen	0	0	0	0.07	0.06
27	Dale	0.45	0.44	0.32	0.58	0.61
28	Dyrholmen	0.04	0.02	0.04	0.04	0.03
29	Norheimsøy	0	0.01	0.02	0.43	0.35
30	Rennaren	0	0	0	0.01	0.01
31	Tallaksholmen	0	0	0	0.04	0.04
32	Hestholmen	0	0	0	0.02	0.01
33	Lauplandsholmen	0.06	0.04	0.26	0.2	0.17
34	Djupevik	0	0	0.22	0.27	0.23
35	Kobbavika	0.02	0.02	0.17	0.21	0.17
36	Munkholmen	0	0	0	0.71	0.57
37	Ringja	0.23	0.24	0.16	0.16	0.13
38	Herøy	0	0	0	0	0
39	Kjeahola	0	0	0	0	0
40	Fosså	0	0	0	0	0
41	Vindsvik	2.23	4.58	4.59	4.11	4.19
42	Bastlid	0.25	0.29	0.19	0.18	0.21
43	Halsavika	0	0	0	0	0.02
44	Langavika	0.03	0.06	0.05	0.04	0.06
45	Lindvik	3.93	4.74	5.54	4.21	3.39
46	Skiftesvika	0	0	0	0	0

Figure 4 Early version of front end

The resulting tested version of the model is illustrated below in Figure 5 to Figure 10.

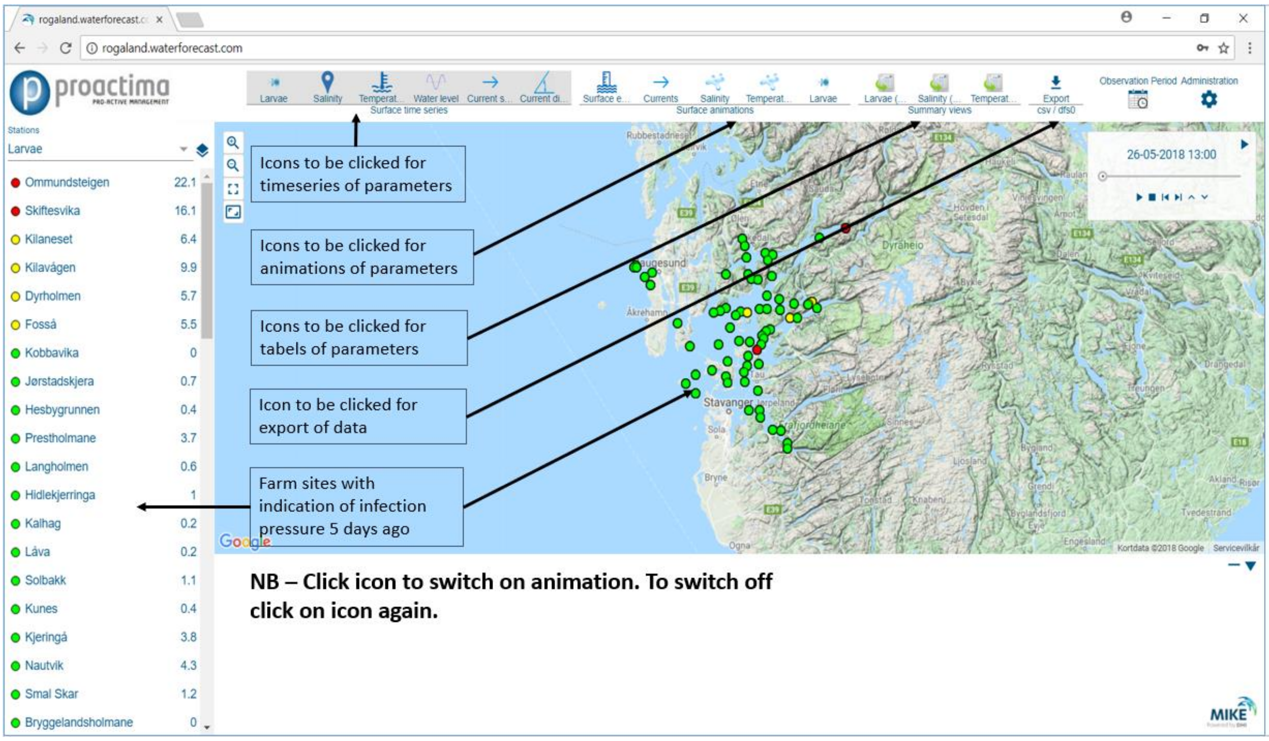


Figure 5 Front End overall view of Rogaland and sites

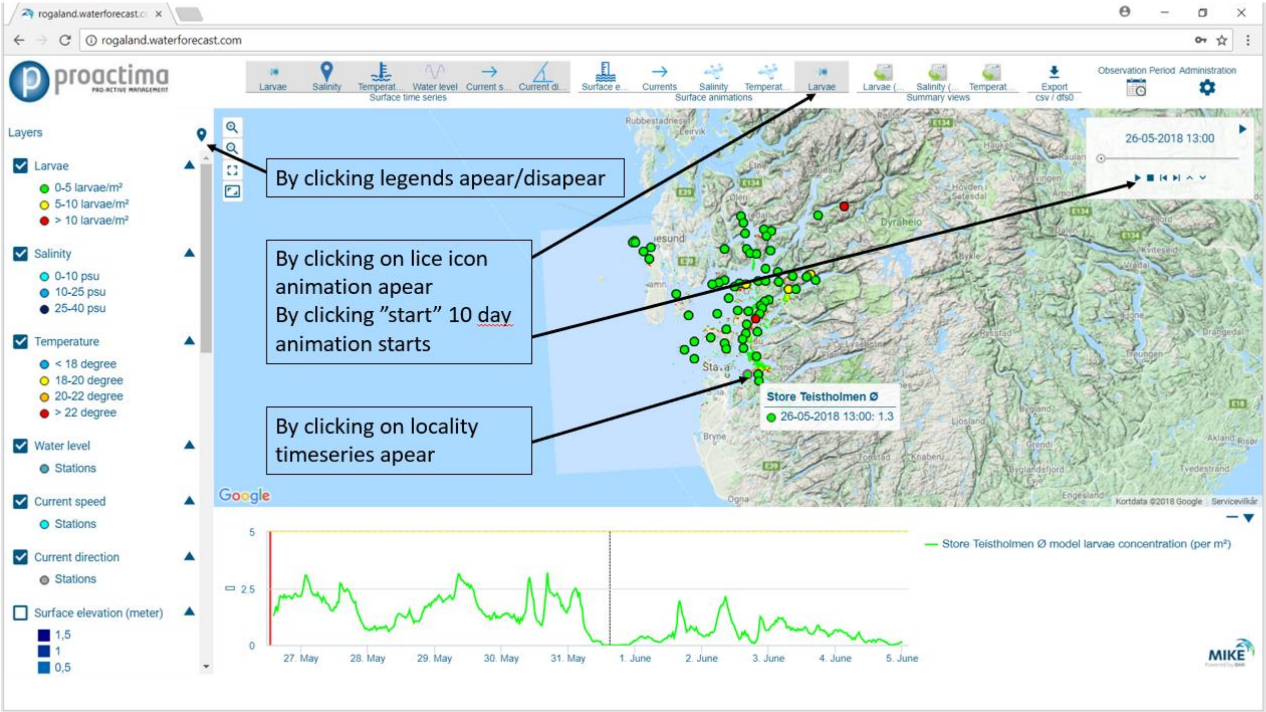
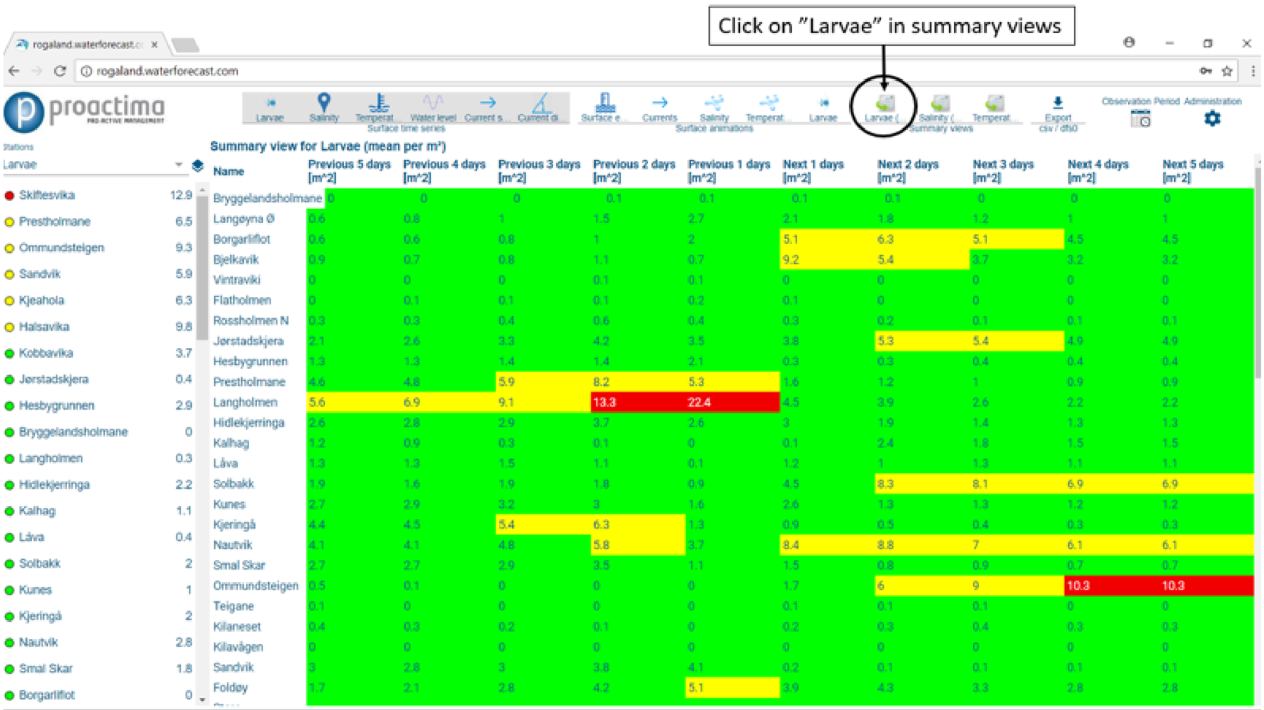


Figure 6 One site 5 day forecast for infectious larvae concentration



Name	Previous 5 days [m^2]	Previous 4 days [m^2]	Previous 3 days [m^2]	Previous 2 days [m^2]	Previous 1 days [m^2]	Next 1 days [m^2]	Next 2 days [m^2]	Next 3 days [m^2]	Next 4 days [m^2]	Next 5 days [m^2]
Bryggelandsholmane	0	0	0	0.1	0.1	0.1	0.1	0	0	0
Langøyna Ø	0.6	0.8	1	1.5	2.7	2.1	1.8	1.2	1	1
Borgarliflot	0.6	0.6	0.8	1	2	5.1	6.3	5.1	4.5	4.5
Bjelkavik	0.9	0.7	0.8	1.1	0.7	9.2	5.4	3.7	3.2	3.2
Vintraviki	0	0	0	0.1	0.1	0	0	0	0	0
Flatholmen	0	0.1	0.1	0.1	0.2	0.1	0	0	0	0
Rossholmen N	0.3	0.3	0.4	0.6	0.4	0.3	0.2	0.1	0.1	0.1
Jørstadskjera	2.1	2.6	3.3	4.2	3.5	3.8	5.3	5.4	4.9	4.9
Hesbygrunnen	1.3	1.3	1.4	1.4	2.1	0.3	0.3	0.4	0.4	0.4
Prestholmane	4.6	4.8	5.9	8.2	5.3	1.6	1.2	1	0.9	0.9
Langholmen	5.6	6.9	9.1	13.3	22.4	4.5	3.9	2.6	2.2	2.2
Hidlekjerringa	2.6	2.8	2.9	3.7	2.6	3	1.9	1.4	1.3	1.3
Kalhag	1.2	0.9	0.3	0.1	0	0.1	2.4	1.8	1.5	1.5
Låva	1.3	1.3	1.5	1.1	0.1	1.2	1	1.3	1.1	1.1
Solbakk	1.9	1.6	1.9	1.8	0.9	4.5	8.3	8.1	6.9	6.9
Kunes	2.7	2.9	3.2	3	1.6	2.6	1.3	1.3	1.2	1.2
Kjeringå	4.4	4.5	5.4	6.3	1.3	0.9	0.5	0.4	0.3	0.3
Nautvik	4.1	4.1	4.8	5.8	3.7	8.4	8.8	7	6.1	6.1
Smal Skar	2.7	2.7	2.9	3.5	1.1	1.5	0.8	0.9	0.7	0.7
Ommundsteigen	0.5	0.1	0	0	0	1.7	6	9	10.3	10.3
Teigane	0.1	0	0	0	0	0.1	0.1	0.1	0	0
Kilaneset	0.4	0.3	0.2	0.1	0	0.2	0.3	0.4	0.3	0.3
Kilavågen	0	0	0	0	0	0	0	0	0	0
Sandvik	3	2.8	3	3.8	4.1	0.2	0.1	0.1	0.1	0.1
Foldøy	1.7	2.1	2.8	4.2	5.1	3.9	4.3	3.3	2.8	2.8

Figure 7 Tabular form showing 24 larvae concentrations at all locations

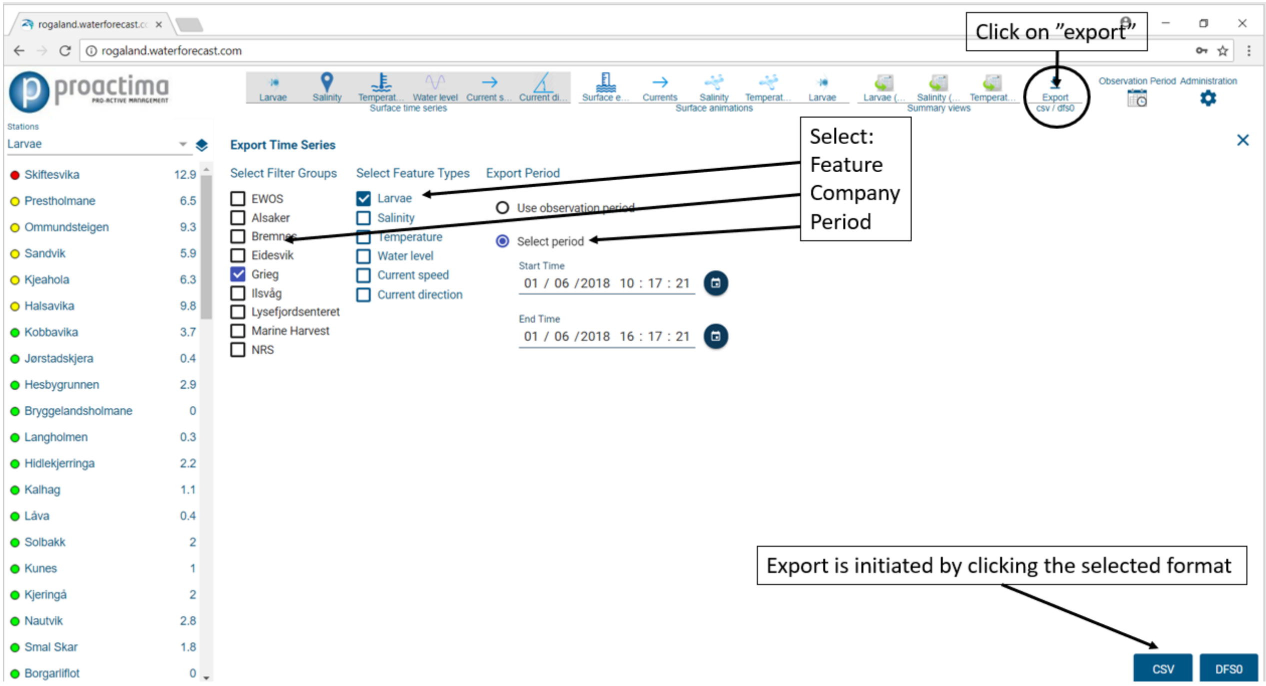


Figure 8 Screenshot for export of data

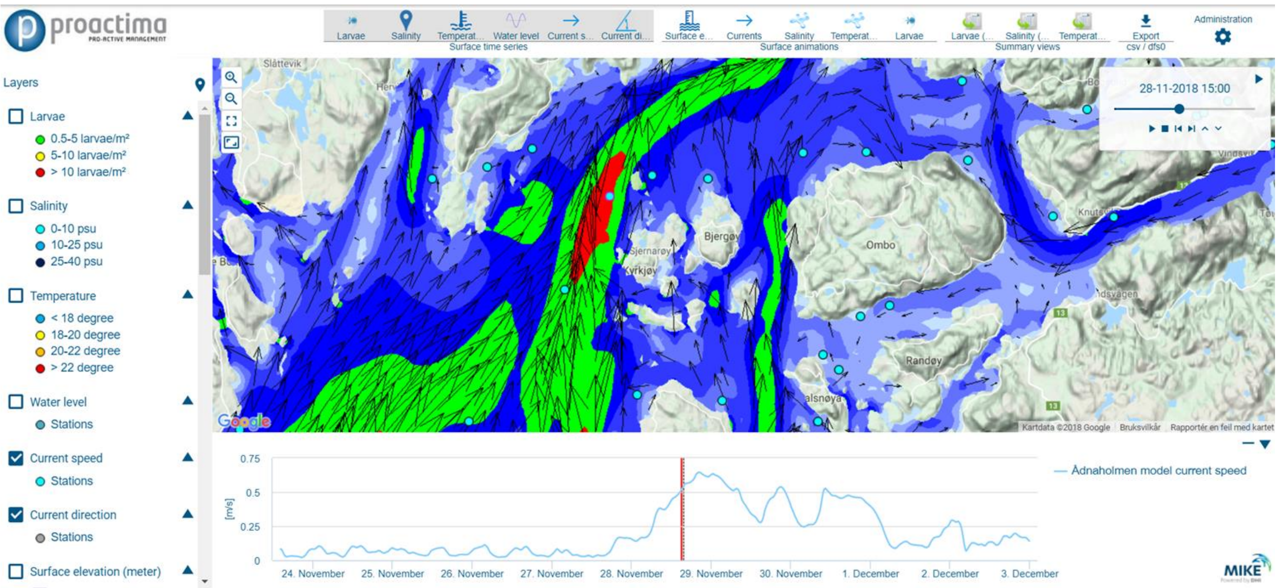


Figure 9 User interface showing site specific and area current forecast

In the above figure current direction and speed is illustrated by arrows. The overall current speed is also illustrated with a coloured layer relating to different speed bands. The line graph underneath is for a specific selected site (Adneholmen) and shows the current speed for the five previous days as well as the current speed forecast for the coming five days.

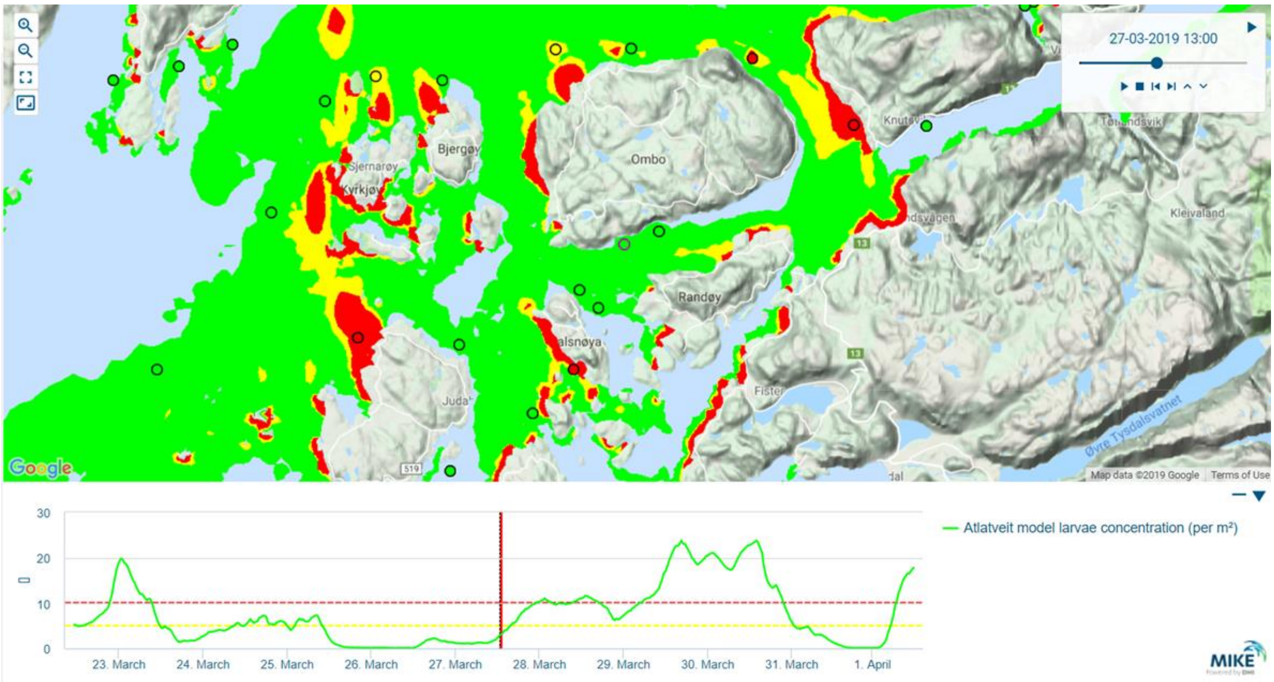


Figure 10 User interface showing site specific and are infectious larvae forecast

In the above figure a snapshot of the concentration of infectious larvae is shown for the time and date shown in the box in the upper right corner. The graph underneath shows both the historical concentration of infectious larvae for the past 5 days at the selected site (Atlatveit) and the forecast for the coming 5 days. In this figure it is possible to see that there is a distinct increase in exposure to infectious lice forecast in the coming 3 days. Both intermediate (5) and high (10) threshold criteria are breached during this period.

What is of particular note in the above figure is the tendency for infectious larvae to concentrate along particular coast lines, depending on the prevailing current and coastal geography. These concentrations can suddenly "breakout" due to a change in current or merely spread out to infest farms located close to the shore. Others have reported a higher concentration of infectious lice in shallower water along coastal areas. The reason for this higher concentration of infectious larvae in specific areas relate to:

- Lower current speed along the shore or in secluded areas.
- Winds cause lice to be pushed towards the shore
- Lice tend to be attracted to water areas which are less deep where there is better light penetration – "positively phototactic"

Modification of the model – issues

The live model was operated on a continuous basis and monitored against actual hydrodynamic measurements from locations where available. The model performed well in practice as reported below by users. However, in the course of the summer 2018 it was detected by the ongoing monitoring and trending exercises performed by the project team that the model was showing higher temperatures than practice. Once this was identified the model algorithms were adjusted. It is worth noting that during the summer of 2018 the region experienced a prolonged period of well above average warm weather.

3.3.2 Exchange of historical modelling data and modelling of lice numbers as a function of infection concentration (WP2) and Lice calculator (WP3)

As part of the project there was a requirement to deliver output data from the Rogaland Water Forecast Model. Specific data format was defined together with VI/NR and the data prepared and exported to VI and NR.

Based on the Rogaland Water Forecast the average concentration of lice larvae around each fish farm in the Rogaland region was calculated for each month for a period of 2 years. In addition, salinity and temperature for each location were calculated. The results were sent to VI in the agreed format. An illustration of a limited selection of the data transferred is shown in Figure 11 illustrating a sample of data transferred for monthly average concentrations. It is worth noting that in the course of a month there is considerable variation in both direction and current speed which would be mostly lost using monthly averages.

		Copepodids originate from localities listed on the HORIZONTAL AXES							
Monthly average of the sum of copepodids in the top 15 meters of the water column (Copepodids/m2) for January 2013		Company	Alsaker	Alsaker	Alsaker	Alsaker	Alsaker	Alsaker	Alsaker
		Zone	Haugesund	2	1	1	1	Haugesund	2
		ID	11435	13055	15796	11930	11925	19336	12003
		Locality	Bryggeland	Langøy	Borgali	Bjelkavik	Vintravik	Flatholmen	Rossholmen
		X coordinate	5.0964	5.7133	5.9247	5.9919	6.0205	5.1145	5.7226
		Y Coordinate	59.4290	59.2983	59.3892	59.4517	59.3994	59.4293	59.0643
Locality	ID	Unit							
Bryggeland	11435	Copepodids/m^2	5.1	0	0	0	0	1.2	0.35
Langøy	13055	Copepodids/m^2	0	0.2	1.75	0.3	0.4	0	0
Borgali	15796	Copepodids/m^2	0	0	6	2.1	0.95	0	0
Bjelkavik	11930	Copepodids/m^2	0	0	0.25	2.35	0	0	0
Vintravik	11925	Copepodids/m^2	0	0	0	0	0.15	0	0
Flatholmen	19336	Copepodids/m^2	1.55	0	0	0	0.1	1.65	1
Rossholmen	12003	Copepodids/m^2	0	0	0	0	0	0	0.45
Jørstadskjæra	30036	Copepodids/m^2	0	0.15	0.2	0	1.95	0	0
Hesbygrunnen	22596	Copepodids/m^2	0	0	0	0	0	0	0.1
Prestholmen	11972	Copepodids/m^2	0	0	0	0	0	0	0
Langholmen	24715	Copepodids/m^2	0	0	0	0	0	0	0.35

Figure 11 Illustration of average monthly data provided to VI and NR

During 2019 Proactima had several meetings to discuss the ongoing model comparisons which VI undertook. During these discussions VI noted that the Rogaland Water Forecast provided better correlation for higher densities of infectious larvae. The Rogaland Water Forecast model illustrated that some sites were exposed to greater concentrations of infectious larvae due to their close proximity to land. Furthermore it was noted by VI that the VI Lice Calculator might be revised to take account of the fish farms distance from land.

3.3.3 WP4 Scenario Modelling

Initially it was discussed that the Rogaland Water Forecast model would provide analyses of infection between sites through the development of contact matrices between sites. An illustration of a contact matrix was developed for one month and is shown below in Figure 12. The intent here was to group sites with higher contact levels in order to optimise zoning. However, it was decided by Norges Regnesentral and the Steering Group that contact matrices would not add significantly to Scenario Modelling and further work on this was not pursued

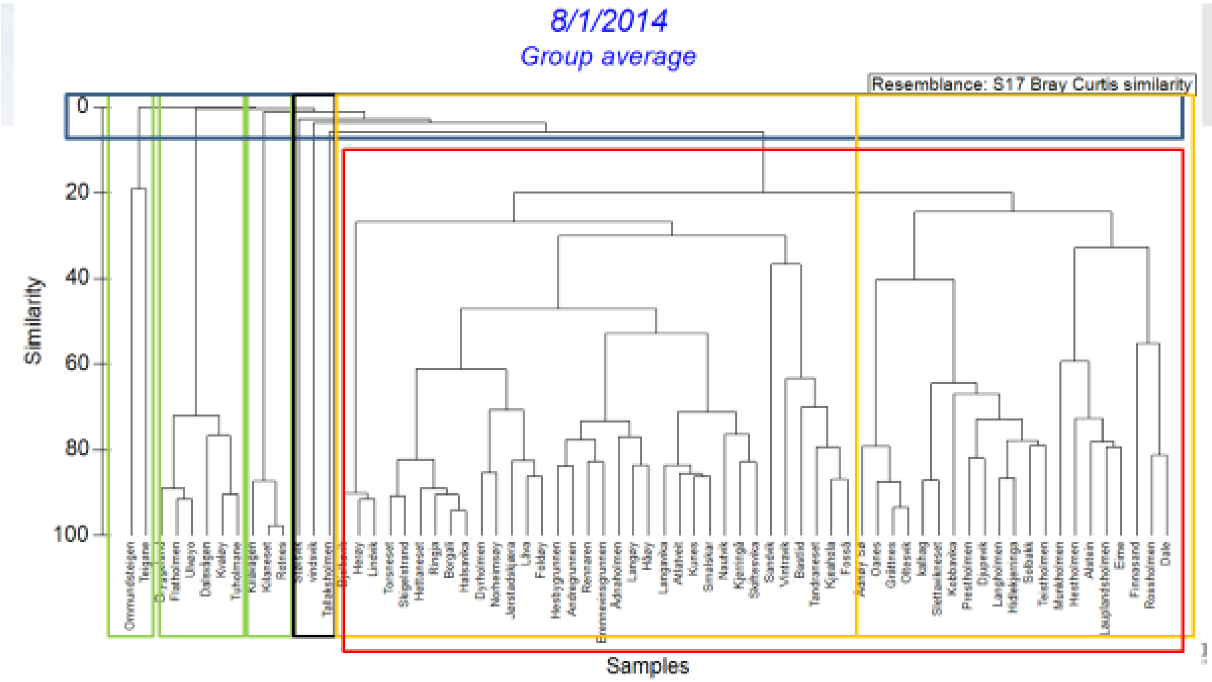


Figure 12 Illustration of contact matrix (one month only) showing grouping of sites based on contact

3.3.4 WP5 Communication

Following development and testing the live version of the hydrodynamic and lice model portal for Rogaland was released in May 2018. This provided updates twice a day, and provided a 5 day forecast for parameters including current (direction and speed and infectious larval concentrations at all farm locations 5 days in advance).

Access to the live model «Rogaland Waterforecast» was provided via username and password. Following a steering group meeting various users were proposed from the various producers. The users suggested were primarily in operational roles. Others were also provided access to the model.

In order to introduce the user group to the model and its functions an initial user group meeting was arranged. A summary of the main elements of the meeting included:

An introduction to the user forum explained the background and reasons for the model that has been developed and the commitment from all producers in the Rogaland area. The aim is to support the management of the lice issue in Rogaland such that a "green light" can be achieved.

An overview of the current FHF project was also provided for the users. The background and development history to the model was presented for the 3D hydrodynamic/infectious larvae model.

The Live portal for the 3D Hydrodynamic model Rogaland was presented for all the users present and user instructions distributed. A session of user "hands-on" training, where access to the portal was gained by all users via their PC and the various functions tested out. Note that the model has been designed for best performance using Google Chrome. Some users also tested out model access via their phone which it was not designed for and suggested there could be long term benefit in having a smartphone friendly version.

Once the users were comfortable with accessing and navigating through the functions there was some discussion about how the model could be used. It was decided to let the users get more familiar with the model and to have another user meeting after the summer.

It was agreed that Proactima would provide a regular summary for some selected sites, highlighting the key hydrodynamic output from the model and field data where available. This report also included site recent history of exposure, lice count data and the predicted exposure 5 days ahead.

A restricted Facebook group was established for all users and other project members showing interest. The regular reports were posted to Facebook and also emailed to users. Support between user meetings was provided to users as and when needed either by email or phone.

The second user meeting was arranged for 6th September where the discussion focused on initial experience with the model. One of the participants had tried to take some water samples during a period of predicted high infectious concentration. However, following discussion it was realised that the sample size would have been too small to have a significant chance of capturing larvae. The possibility of obtaining satisfactory water samples including techniques and analysis methods were discussed with members of the project group.

Following the second user meeting a visit to Langøy was arranged for 24 October to discuss the model with personnel at the cage level and to consider how water samples could be taken. Note: taking and analysing water samples was not part of the scope and was not proceeded with. The operations team at Langøy were very engaged with the potential for the model and recognised the immediate benefit of using the current forecast to plan the coming 5 days activities. Experience with the current aspect was extremely positive and a permanent screen was set up for viewing the model live for use as a planning tool – see **Figure 12**.

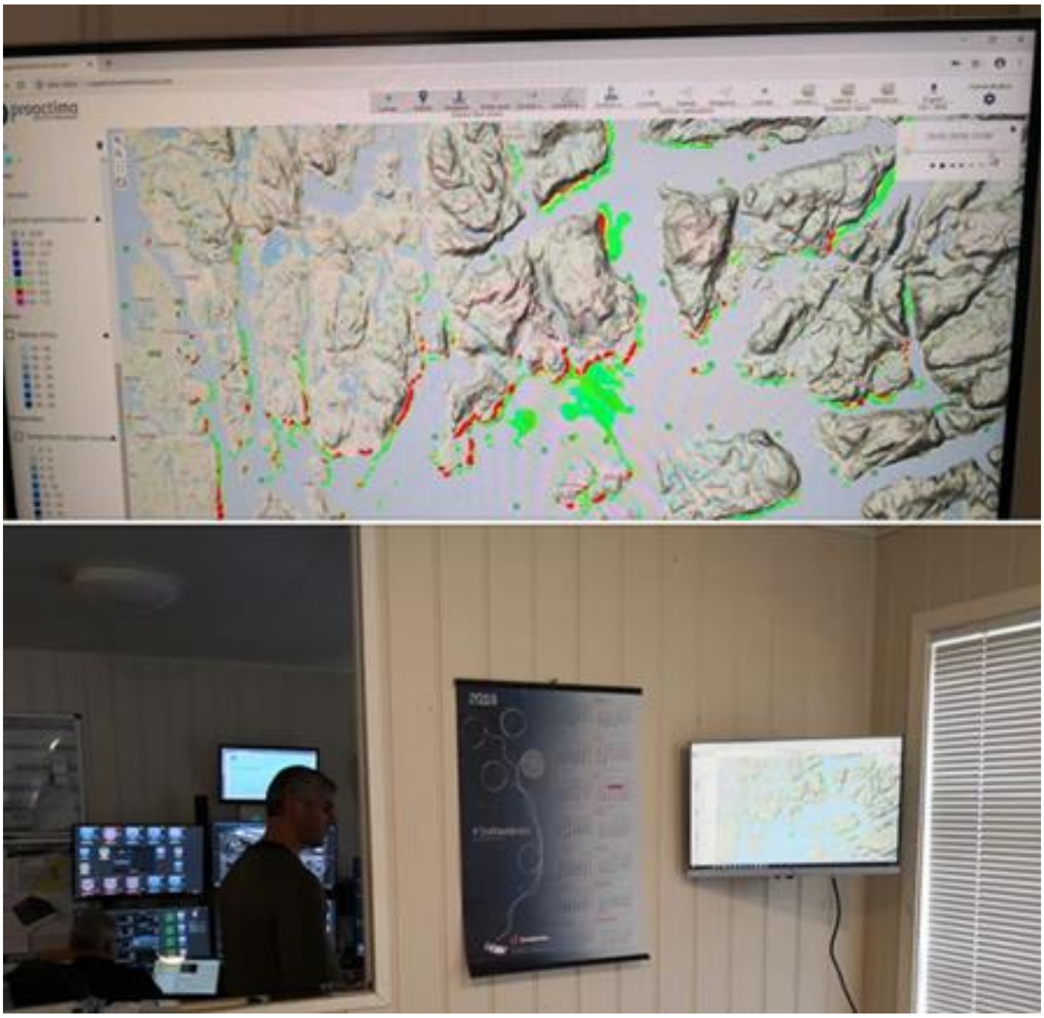


Figure 13 Screen at Langøy control room used for planning

A third user forum meeting was arranged for 7th November to further discuss experience with the model and discuss suggestions for a revised version. These suggestions are summarised below:

- Possibility to switch language (English to Norwegian)
- Ability to select only one specific producer or zone etc.
- Given high infectious pressure – indicate options available for reducing impact
- Include possibility to display actual measured local hydrodynamic date eg temperature
- Automatic generation of predefined reports
- Ability to have automatic warning of pending high infection pressure sent by email/text message
- Risk estimate for exceeding a specific female lice value based on infection pressure
- Include information regarding conducted treatments
- Include percentage of cleaner risk by week per locality
- Adjust colour coding
- Design for access by phone as well as existing PC solution
- Indication of depth where larvae are expected to be
- Include access to the water quality module (currently not available online)
- Ability for user to make adjustments to report content

The model also has the capability to include a layer for illustrating the spread of pathogens (ref FHF Project 901005). The water quality module combined with the hydrodynamic module also provide the basis for monitoring the development and spread of algae bloom.

There was also a simple overview prepared on the value and ease of implementation for further functionality see Figure 14 below.

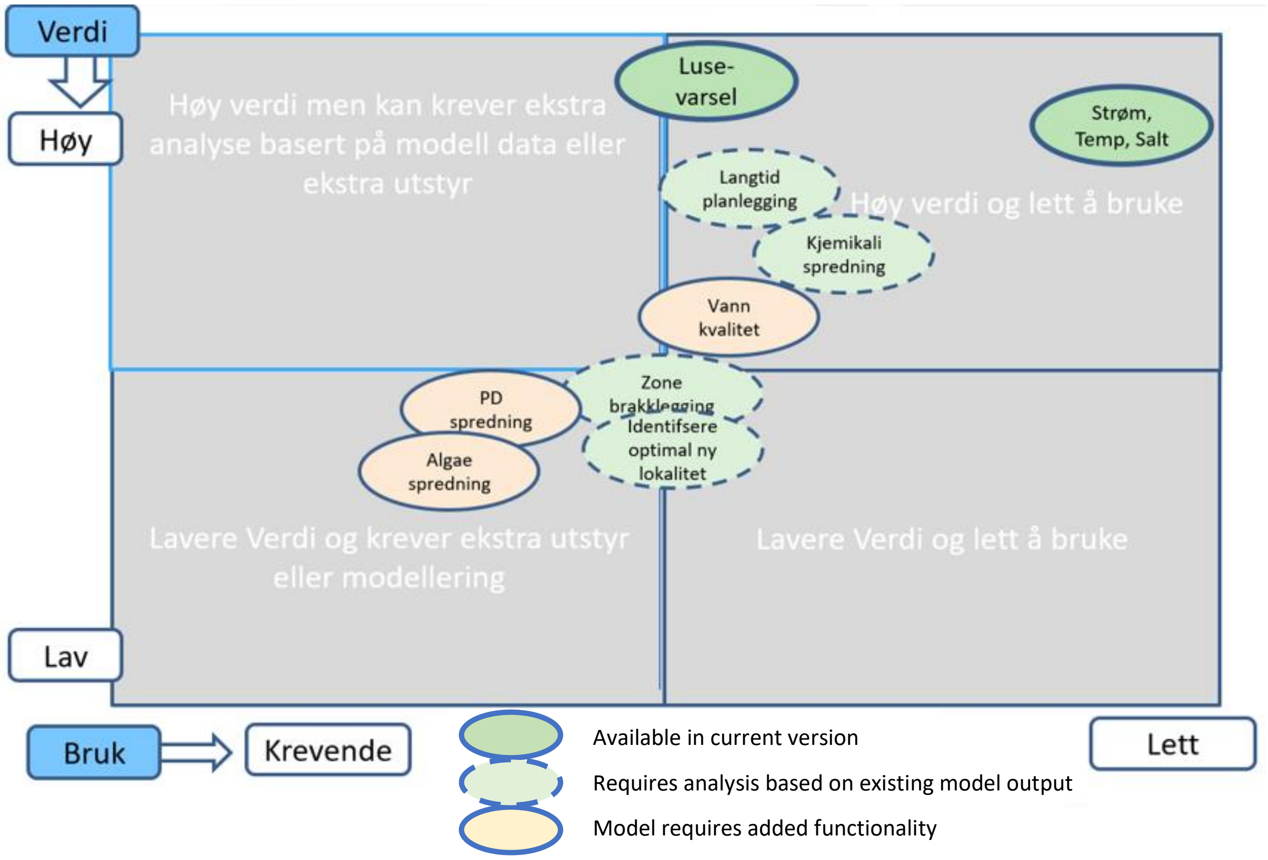


Figure 14 Illustration of function value vs ease of current implementation

The above figure is also represented in a textual format in Table 3 below.

Table 3 Value and degree of implementation effort

Model Use	User Perceived Value	Current usability Easy-Medium - Demanding	Comment
Current speed and direction forecast	High value	Easy	Can be used immediately for weekly activities planning
Infectious larvae – copepoditt warning	High value	Medium	Early warning easy to understand. Many locations do not have immediate counter measures (eg skirts) to reduce exposure based on a high infection warning
Optimising Fallow Zones (period with no production)	Medium value	Medium	A specific analysis using model output is required. There are also many other factors (cost, politics) which have to be taken into consideration.

Model Use	User Perceived Value	Current usability Easy-Medium - Demanding	Comment
Long term planning of localities	High to Medium value	Medium to Easy	Optimise production across locations. A specific analysis using model output is required.
Optimise use and disposal of chemicals	High to Medium value	Medium to Easy	Possible to mode using todays model A specific analysis using model output is required. eg hydrogen peroxide
Spread of Pathogens – PD	Low value	Medium to Demanding	There is an existing module for PD spread (developed forTrondelag) which could be added to the Rogaland model
Algae, development and spread	Low (rating before recent outbreak)	Demanding	A model for algae development and spread is dependent on the water quality model being in operation
Water quality	Medium to high value	Medium	A water quality model was included in the Validation Project in 2017. This could be implemented as an extra layer in the Rogaland model
Choice of optimal locations	Medium value	Medium	The model value increases over time as and the optimisation of existing and new localities can be analysed and tested.

The user group was requested to provide feedback on their views of the model and these are summarised below and were also presented at FHF Lusekonferansen 2019 and presented below in Table 4.

Table 4 Summary User Group Feedback

Theme	Summary user group member feedback
Organisation and communication with user group	Several user meetings organized to gather experience, ideas and suggestions. In addition to meetings, communication went through private Facebook group, email and phone. Objective and quick follow-up from personnel at Proactima and Blue Planet to questions about the model.
Front end /User interface	The visual impression of the model is clear and tidy. Many different layers of different colours make it easy to find the parameter one wants to study more closely, such as lice infection, temperature, current etc. By pressing the symbol one can get many different environmental effects, or remove them to find one specific parameter. The model is regularly updated so that the program operates continuously, to show continuous development of lice infection and environment 120 hours ahead. The parameters are made with different colors and shades so it is easy to separate. Easy to zoom in and out to see development for the entire Rogaland, or in the individual area or locality.
Current prediction	• Current forecasts are quite good at all locations besides Hestholmen, which is strongly influenced by ocean currents. Hestholmen has always been difficult to predict, also in relation to lunar phases and floods / springs. I consider the current forecast is good outside Hestholmen. • Specifically, feeding was stopped one afternoon due to high infection larvae warning at the time the larval belt moving through the location.

	Planned treatment at the site was postponed for 24 hours due to predicted strong current from the model. It turned out reality agreed wit the model prediction for a strong current from the reported direction. The treatment was started a day later, and was completed in good (as predicted) current conditions. • Observations of current from the model: Was reported as a strong current in model, also proved to be in reality. • On several occasions we have verified high current period over short and longer period which lead to stopping operations and feeding at the sites. • By viewing the model on Mondays, operating personnel and crews on service boats have planned work operations five days ahead, especially regarding net replacement and treatments. Especially the latter has been a useful tool out on the sites • Regarding the planning of activities: it will vary between farmers to hat extent the model is used, depending on how one is set up at localities with personnel and equipment. For our part, who has a chartered the service boat, we have not yet used it in operational planning. Forecast on current and weather can be useful. • Generally, the model shows a good connection between model and reality in daily life. A good aid in planning operations such as net shift, delivery and debugging. Avoid unnecessary stress and starvation of fish, it is about getting the most growth as quickly as possible. One gets the job done without interruption, and does not let people and service boats stay on hold without getting the job they are hired for. A win-win situation for salmon and people.
Infectious larvae prediction	• The model gives very accurate movement of the larvae, especially from land with changing current or wind, and gives a good picture of the spread of infection. • Some sites do not have lice skirts or tubenot, and base proactive prevention only on clean fish. Here, the model could help us with better planning of cleaning fish stocks with a view to addressing increased larvae concentrations, but it requires the model to continue collecting data in order to have a better statistical basis. • The model works very well during periods when the infection pressure of lice larvae is low and moderate. In periods where the intensity of infection increases and periods between treatments became shorter, we had difficulty distinguishing internal from external infection. At temperatures above 13 degrees, the maturing of lice is so intensive that it is difficult to use data from the model, especially between locations that are very close to each other. • The forecast for 5 days can say something about lice infection at sites, but has little to say for operative lice control. Of course, a forecast / notice that

	extends more than than 5 days (for infectious larvae / copepods) would make the models more useful for operational planning. • To show the likelihood of lice infection in e.g. An application can be a useful tool for the larva forecast. We have used analyzes from the model to support some applications. • The model can also become interesting with long-term operational planning.
Summary	We have good experience with both the model and the collaboration with Blue Planet and Proactima, so the hope is that the development and digitization of the operations on the sites will be continued.

Apart from the regular interaction with the user group and steering group there have been several other communications at a wider level some of which are listed below:

- Presentation at FHF Annual Lice Conference 2019 – "Erfaring fra Rogaland"
- Article in Tekfisk, Jan 24, 2019 based on the FHF presentation,
- Article on iLaks.no, 29 Nov, 2018 - Lusevarsling – grunnlaget for neste generasjon lusebekjempelse - Prof Ragnar Tveterås og Bård Misund
- Article - Lusevarsling – En økonomiske analysis (to be published) -Bård Misund, førsteamanuensis, & Ragnar Tveterås, professor, Handelshøyskolen ved Universitetet i Stavanger
- Presentation of FHF project & HD/Lice model at INNAKVA/Fjordlab Workshop Jun 2019

4 Results

The project has delivered a 3D hydrodynamic model of the Rogaland area (PO2 plus Karmøy) complete with a model of the spread of eggs as they develop to become infectious larvae and look to attach themselves to salmon. The model is presented via a secure access portal with a relatively user friendly interface to allow selection of a wide range of output data at site or producer level. Output data are presented in a variety of ways which can be both static and animated. The model presents a 5 day forecast for various parameters including current, temperature, salinity and infectious lice concentration which enable critical activities to be planned better and provide early indication of potential increase in adult lice due to high infection pressure.

The model has been tested with a range of users representing the producers in the area and positive feedback received.

Output from the model has been provided to VI and NR in the format requested for them to undertake analyses. After completion of the Proactima/DHI element there were some discussions with VI regarding aspects of the model output and how there might be differences with the VI distance model and where there were potential areas of improvement.

The Proactima/DHI team has delivered and contributed to activities where required.

The model has been reviewed and used by a user group drawn from the various producers in the Rogaland region. Positive feedback and suggestions for further development have been gathered.

5 Conclusion and actions

The most important conclusion from this element of the project is the actual user feedback provided in Table 4 within Section 3.3.4. Although all users had a hectic daily level of activities they found time to consider in various ways the functionality available and to even test out the model output and predictions with reality.

All users reported the interface and output was relatively easy to use and understand. There were also many contributions as to how the user interface could be further improved and what functionality they would like to see.

Several users reported that the most usable function was to provide a reliable forecast of high current speeds which could disrupt critical activities. Using the forecast provided them with a short term planning and decision support tool.

Although several users experienced increases in adult lice at sites following exposure to high concentrations of infectious lice, the feedback was that they did not have the equipment readily available to make an intervention to reduce exposure to the infectious larvae before they came in contact with salmon.

The users brought forward many suggestions including actively sampling sufficient quantities of seawater to identify the presence of copepodids. Users with sites closers to shore, where the model shows higher concentrations were particularly interested in this phenomenon. It has been previously reported that copepodids have shown a tendency to aggregate close to shore (á Norði & Simonsen et al., 2015; Amundrud & Murray, 2009; McKibben & Hay, 2004; Penston & McKibben et al., 2004). Also Norði et al. (2015) showed that wind driven currents had a strong influence on the dispersal of planktonic L. salmonis, pushing the copepodids towards shallow waters (á Norði & Simonsen et al., 2015).

Veterinær Institutt also reported that during their analysis of the different models proximity to shore of sites was seen to be a significant factor – see separate report under this project from Veterinær Institutt.

An immediate action which has resulted from this project is to establish a project team (FHF project 901568) to test the use of easily deployable skirts based on the Rogaland model forecast of high concentrations of infectious larvae (copepodids). The intention is to deploy skirts at some selected cages for periods of predicted high exposure and monitor both fish health and comparative levels of lice for cages without the skirt protection. The project details are currently being finalised.

There may be a case for analysing water samples in locations predicted to have high concentrations in order to support the optimisation of locating producing sites i.e. that some producing sites are relatively close to areas where infectious larvae accumulate.

Proactima/DHI would also like to include in this report that they have not been directly involved in undertaking the comparison with the other models. Model output data, in specific formats, were requested and provided. Data from the other models was not reciprocated to Proactima/DHI.

6 References

á Norði, G., Simonsen, K., Danielsen, E., Eliasen, K., Mols-Mortensen, A., Christiansen, D., et al. (2015). Abundance and distribution of planktonic Lepeophtheirus salmonis and Caligus elongatus in a fish farming region in the Faroe Islands. Aquaculture Environment Interactions, 7(1), 15-27.

Amundrud, T., & Murray, A. (2009). Modelling sea lice dispersion under varying environmental forcing in a Scottish sea loch. Journal of fish diseases, 32(1), 27-44.
McKibben, M. A., & Hay, D. W. (2004). Distributions of planktonic sea lice larvae
Lepeophtheirus salmonis in the inter-tidal zone in Loch Torridon, Western Scotland in relation to salmon farm production cycles. Aquaculture Research, 35(8), 742-750.

Appendix A 3D Hydrodynamic model

(3D Hydrodynamic model Flow Model FM (Flexible Mesh) for Rogaland)

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A.1 Model objective

The Rogaland model is a high-resolution local modelling tool to assess transport, connectivity and population dynamics of sea lice in Rogaland and intended to apply to the management, planning and operation of marine fish farms in the area.

A.2 Background

The hydrodynamic model MIKE 3 Flow Model FM (Flexible Mesh) simulates the variation in time and space of parameters such as:

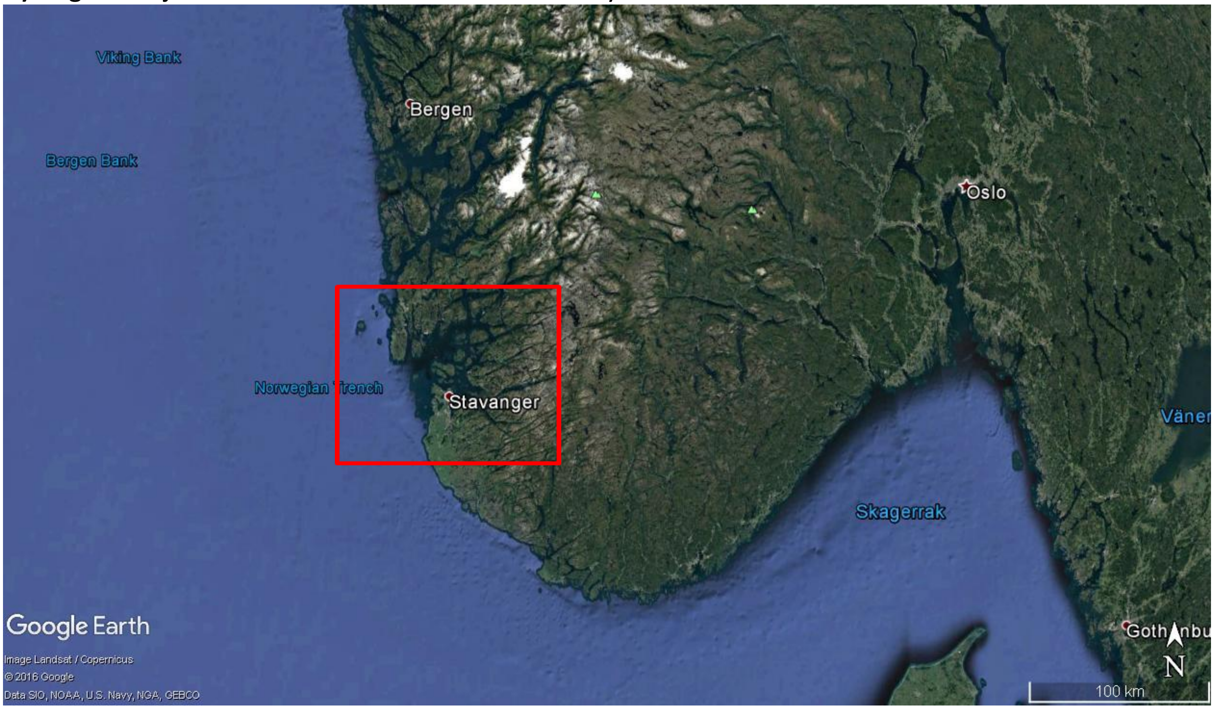
- Water level;
- Current speed and direction;
- Salinity; and
- Water temperature.

These parameters are both important in their own right, but they also form the basis for the subsequent **A**gent **B**ased sea lice **M**odelling (**ABM**), since hydrodynamic components affect the behaviour and fertility of sea lice and the movement and behaviour pelagic sea lice larvae. A general description of the MIKE 3 HD model can be found in references **Error! Reference source not found.** and **Error! Reference source not found.**.

In addition, a wave model is applied to simulate parameters such as wave heights and directions. The wave parameters are relevant to reflect physical conditions at the concessions.

The hydrodynamic processes in the Rogaland fjord model (**Figure 1**) and surrounding coastal areas are affected by outflowing river water and inflowing oceanic water being mixed by such processes as tide, wind and heat exchange with the atmosphere. To describe these processes, the hydrodynamic modelling needs to resolve both the area of interest (the local area where the concessions are located) and the area of influence. This is done by the large scale MIKE 3 HD Norwegian Seas model (**Figure 2**) which stretches from the English Channel all the way to the Kara Sea in in Russia, providing boundary conditions for a high resolution local scale model.

A) Rogaland fjord model domain relative to Norway



B) The model domain defines the area covered by the model

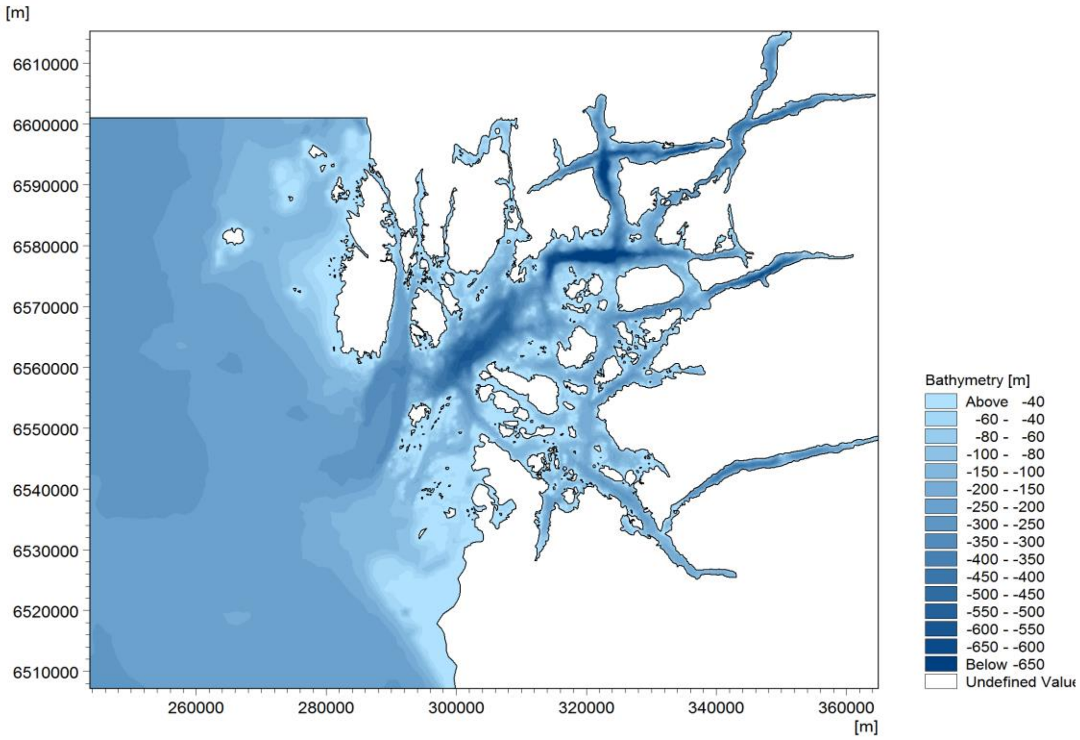
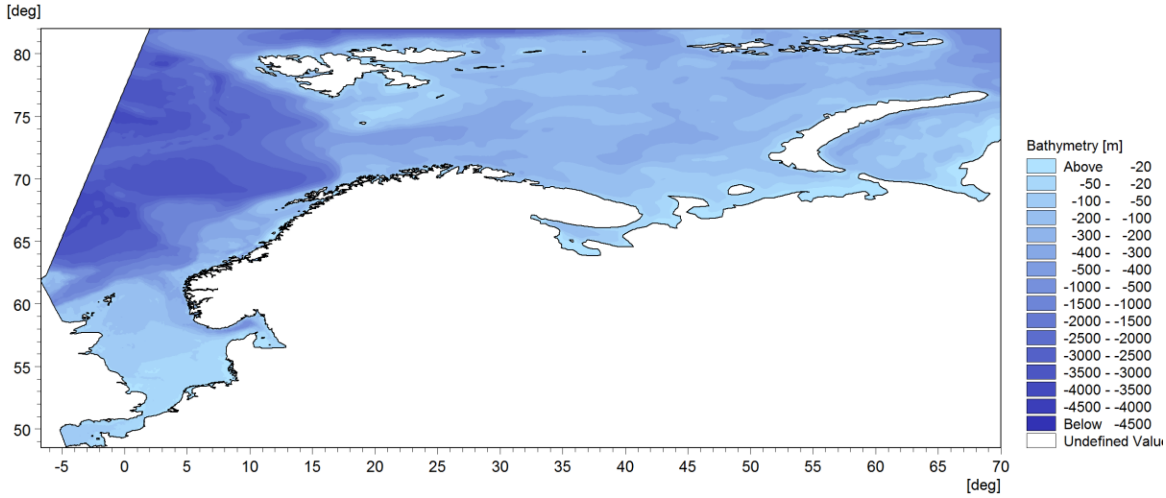


Figure 1. A) Rogaland fjord model domain relative to Norway. B) The model domain defines the area covered by the model.

A) Norwegian Seas regional model



B) Rogaland Fjord local model

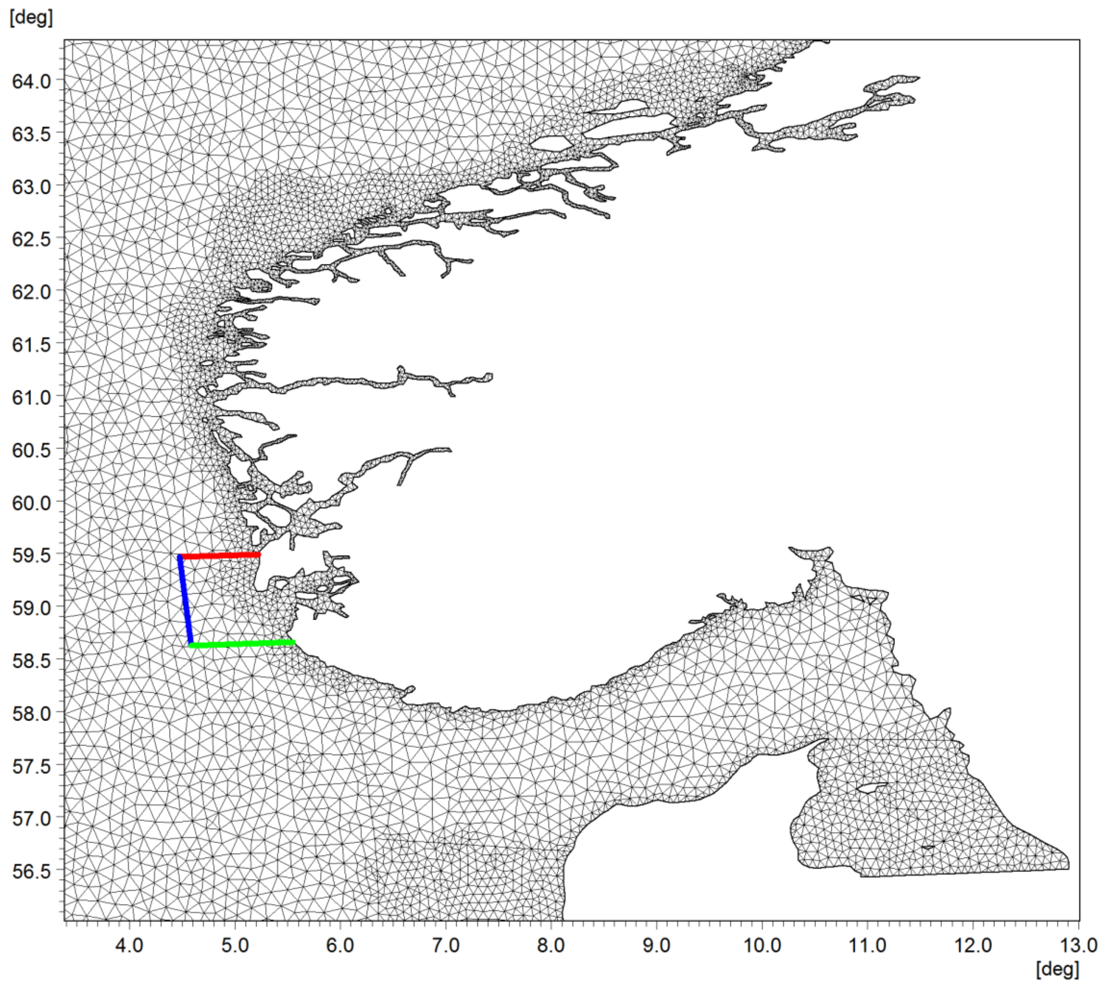


Figure 2. DHI´s Norwegian Seas regional model used to provide boundaries to the local Rogaland model (A) entire model domain above and (B) zoom-in mesh in the area of interest), and hence what passes "in to" the local Rogaland model from outside

To establish and run the Rogaland hydrodynamic fjord model different types of input data were required:

- Bathymetric and topographic data e.g. nautical charts, satellite images, bathymetric surveys;
- Meteorological data from meteorological models or local measurements;
- River run-off from local measurements or climatology;
- Tidal data from tide tables, local measurements or global tide models;
- Salinity and temperature profiles from measurements or climatology from regional sources.

Some of these data are already available in the large-scale model but are supplied with higher resolution data for the local area.

During calibration e.g. adjusting precisely and validating through comparison of modelled results with actual measurements the model, different types of comparison data have been applied:

- Local tidal data from measurements or tide tables (Stavanger - 5.73E, 58.98N, 0.0 MSL);
- Local measurements of salinity, currents and water temperature profiles and time-series from relevant farms and monitoring stations in the area.

Locally measured data from monitoring stations in Rogaland such as current and water level time-series, and salinity and water temperature profiles were used in 2016/17 to calibrate and validate the model. In the calibration and validation process, the results from the model were compared to measured data by statistical and visual evaluation. NB - validation data was not fed into the model to produce results.

A.3 Model domain, model period and model settings

The Rogaland hydrodynamic fjord numerical model covers the stretch of the Norwegian coast comprised between parallels 59° 30'N to the North and 58° 35'N to the South as shown in **Figure 3**.

The model includes the main islands such as Karmøy, Vestre Bokn, Kvitsøy, Rennesøy, Ombo, Finnøy, Mosterøy and the Sjernarøyane archipelago and the vast Boknafjorden with its many fjords branching off from it (**Figure 3**), such as Saudafjorden, Sandsfjorden, Vindafjorden, Hervikfjorden, Førresfjorden, Erfjorden, Jøsenfjorden, Årdalsfjorden, Idsefjorden, Høgsfjorden, Lysefjorden and Gandsfjorden. **Table 1** lists the surface area of the main fjords represented in the model.

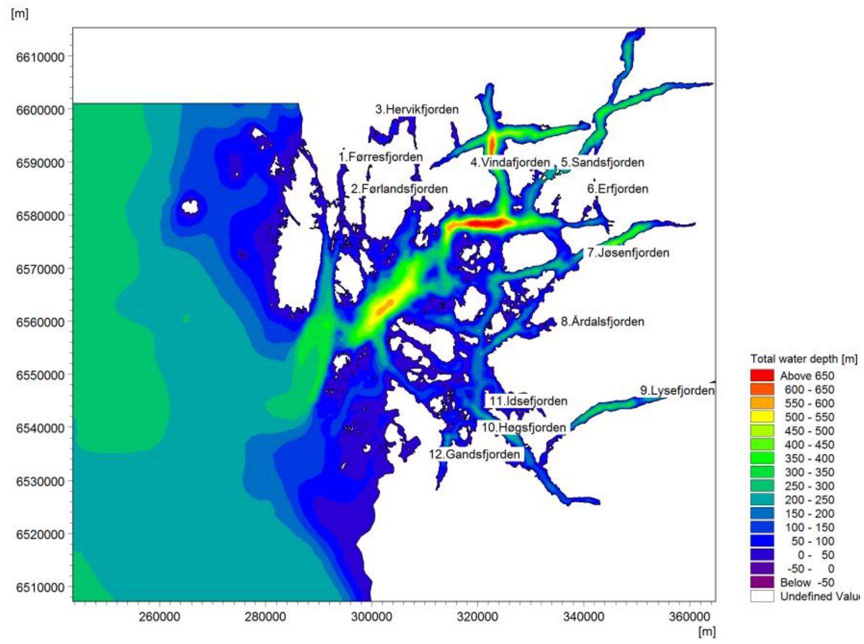


Figure 3 Rogaland numerical model domain and identification of the different fjords included

Table 1 Surface area in km² for the total model domain and the main fjords included in the model

	Surface area (km²)
Total model domain	6 222
1. Førresfjorden	16.6
2. Førlandsfjorden	5.1
3. Hervikfjorden	60.5
4. Vindafjorden	116.2
5. Sandsfjorden	96.9
6. Erfjorden	18.1
7. Jøsenfjorden	32.1
8. Årdalsfjorden	16.4
9. Lysefjorden	49.0
10. Høgsfjorden	60.7
11. Idsefjorden	29.0
12. Gandsfjorden	13.8

The model has been set up in MIKE 3 HD FM (Flexible Mesh), based on an unstructured flexible mesh using a finite volume solution technique. The mesh elements are triangles varying in size from 200m inside the fjords to 1500m in the offshore area, **Figure 4**. By using flexible mesh triangles, the setup allows for more precise calculations close to the coast and in the fjords while areas in the open ocean, which have less variation, don't require such fine calculations. This allows for faster simulation time. The model resolution can also be adjusted with relatively short notice on request. A refinement of the resolution (e.g. from 200 to 50 meter) will increase simulation time, while a coarser resolution will decrease simulation time.

DHI´s MIKE C-Map bathymetric data from 2016 has been used to generate water depths in the model domain (all elevations are applied relative to mean sea level). The bathymetry for the established model domain is generated from the interpolation of the scatter data into the applied mesh in the domain, **Figure 4**.

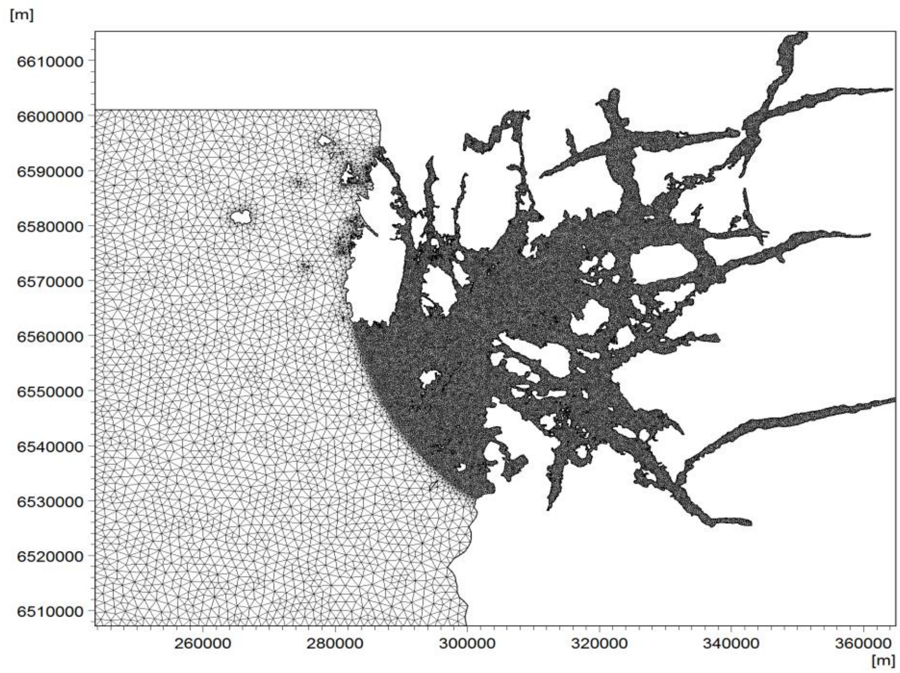
MIKE C-Map is a tool for extracting depth data from C-MAP Global Electronic Chart Database Professional+ (CM-93 Edition 3.0 technology) provided by Jeppesen Marine, Norway.

Vertically, the model applies a combined sigma/z-level mesh (**Table 2**), where 8 sigma layers are used from the free surface down to 20m, and below this depth, 18 z-level coordinates are used. Both sigma/z-level layers apply a layer thickness distribution where the thickness of each layer has been specified according to **Table 2**. At water depths below 20m the sigma layer thickness are decreasing with decreasing water depth. This means that the 8-sigma layers will be half the layer thickness at 10 m, compared to the thickness at 20m, and so on. At water depth below 20m the 18 z-level are not used.

This vertical discretization is the result of the model calibration and makes it possible to reproduce the existing stratification of the fjords system.

The scientific description of the vertical discretization applied can be found in reference **Error! Reference source not found.**

A)



B)

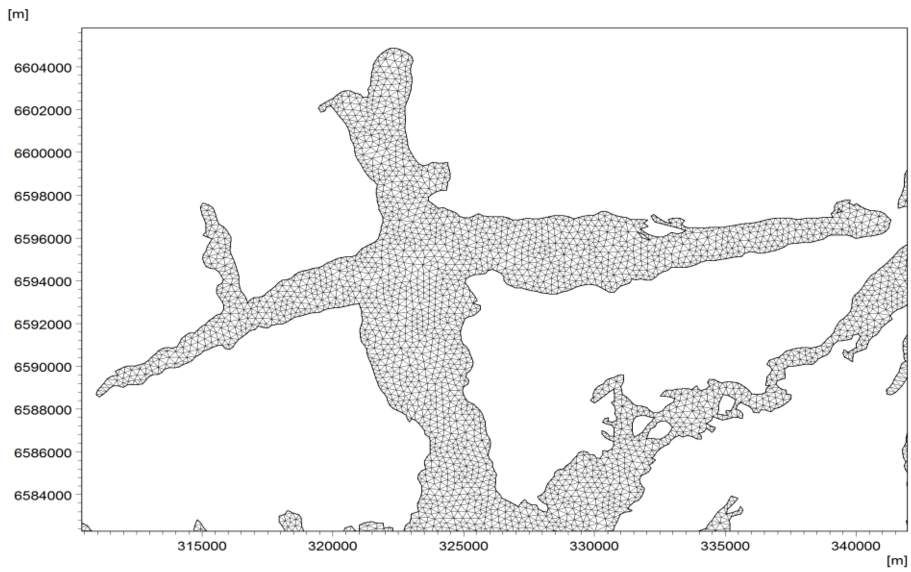


Figure 4. Horizontal discretization applied in the model domain (A) the domain and B) zoom-in). The discretization defines the individual computational elements of the model. The high resolution in the fjord is designed with respect to the bathymetrical and topographical complexity and aquaculture concessions while the lower resolution in the open ocean is designed with respect to the more uniform water masses.

Table 2 Vertical discretization of the domain is the result of the model calibration making it possible to reproduce the existing stratification of the fjords system.

Layer		Depth (m)	Layer Thickness (m)	Layer		Depth (m)	Layer Thickness (m)
Sigma	1	-1	1		-127	-127	32
	2	-2.2	1.2		-167	-167	40
	3	-3.8	1.6		-217	-217	50
	4	-5.8	2		-267	-267	50
	5	-8.2	2.4		-317	-317	50
	6	-11.2	3		-367	-367	50
	7	-15	3.8		-417	-417	50
	8	-20	5		-467	-467	50
Z Level	9	-27	7		-517	-517	50
	10	-37	10		-567	-567	50
	11	-51	14		-617	-617	50
	12	-70	19		-667	-667	50
	13	-95	25		-717	-717	50

A.4 Forcing conditions

The applied model domain has three connections to the open sea (**Figure 5**). Water level, currents, salinity and temperature from DHI's Norwegian seas model (**Figure 2**) have been extracted and applied at the open boundaries.

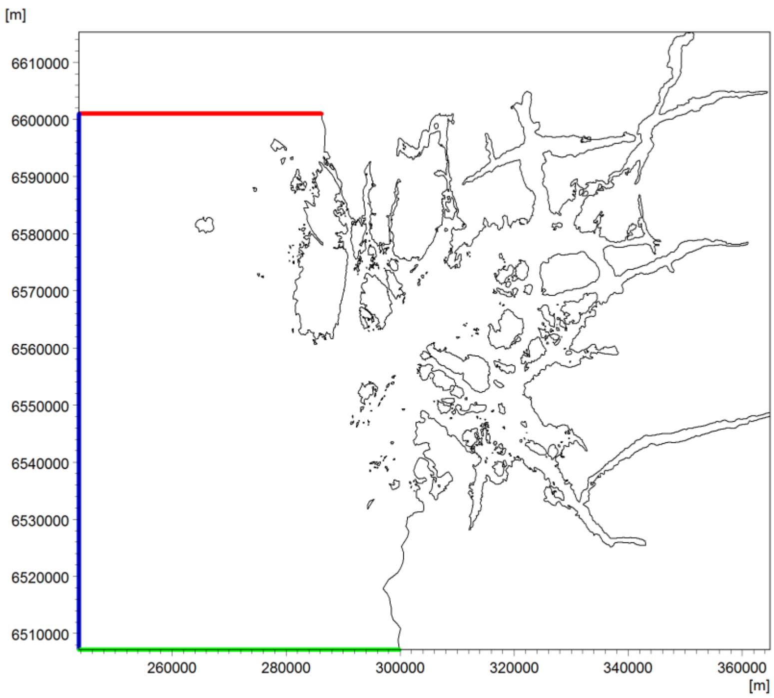


Figure 5 Open boundaries (coloured lines) of the model. The boundaries represent the border of the model.

A.4.1 Meteorological data

The model applies Storm Geo meteorological forcings as 2D time varying maps with a resolution of 0.1 degree (longitude/latitude):

- Wind speed and direction and air pressure
- Precipitation
- Air temperature
- Relative humidity
- Clearness coefficient

Time series of the meteorological variables in two locations within the model domain, **Figure 6**, are displayed in **Figure 8** to **Figure 13**.

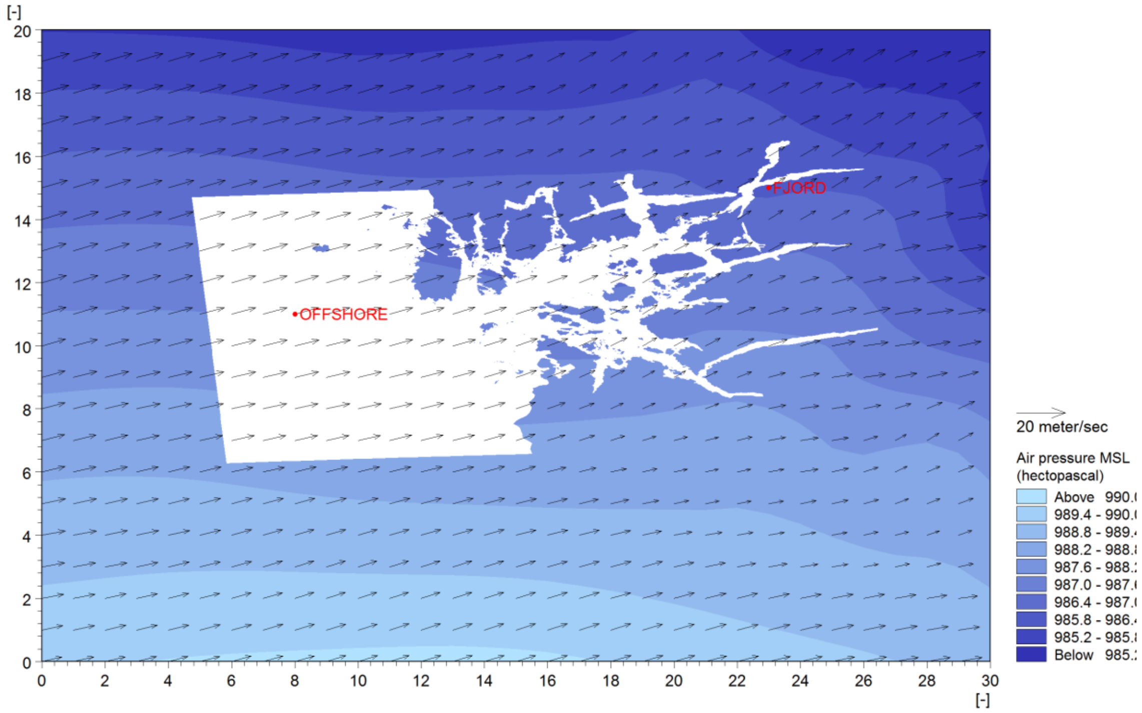


Figure 6. Snapshot of the 2D Storm Geo air pressure and wind field applied in the model.

The wind transfers energy to the upper layers of the water column, inducing vertical mixing and horizontal currents, while air temperature and precipitation/evaporation are variables affecting the heat exchange between the atmosphere and the water body, and are therefore directly related to the density variations in the system.

Measured wind in the inner fjords revealed that the Storm Geo 0.1 degree wind does not reflect the significant damping of the wind speed in the narrow fjords from the shelter induced by the surrounding topography, therefore the Storm Geo wind in these areas has been reduced by 25% and 50%, as shown in **Figure 8** . The reduction in wind is based on comparison of Storm Geo wind with actual wind observations from “Utsira”, “Kvitsoy” “Fister” and “Liarvatnen” (http://www.senorge.no/?p=klima).

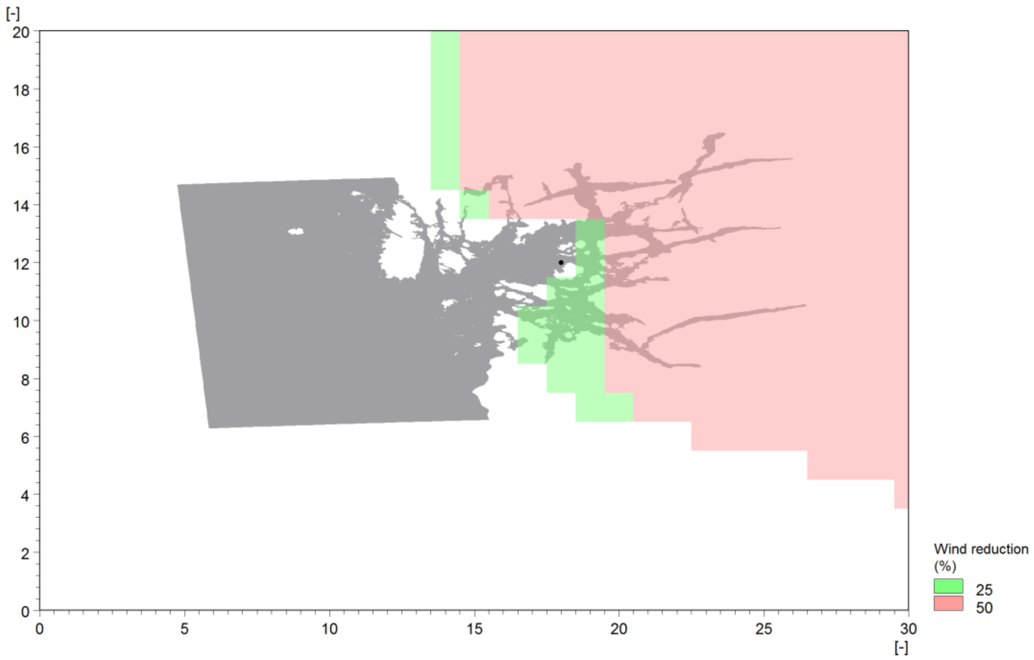


Figure 7. Reduction of the Storm Geo wind applied in the model. The reduction is based on comparison of Storm Geo wind and actual measured wind.

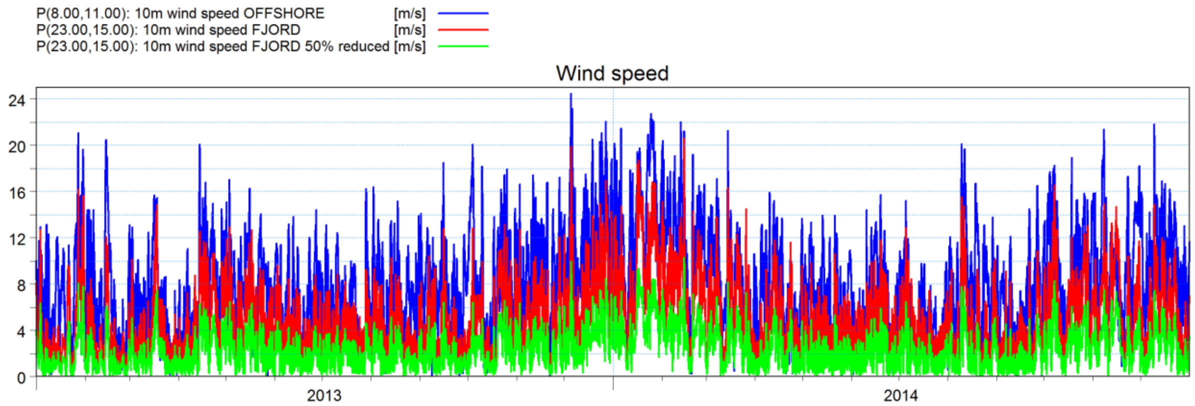


Figure 8 Wind speed time series from the Storm Geo 2D forcing applied in the model (offshore position in blue, and fjord position in red and green)

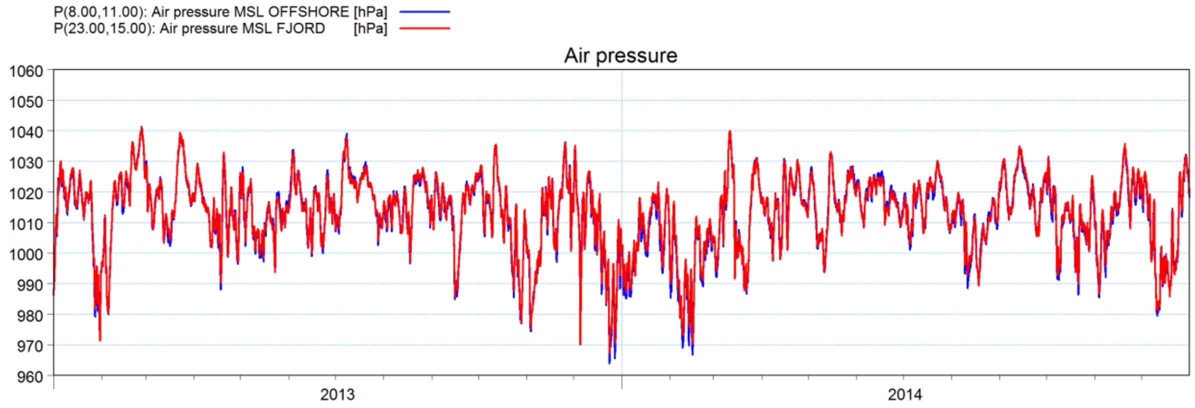


Figure 9. Air pressure time series from the Storm Geo 2D forcing applied in the model (offshore position in blue, and fjord position in red)

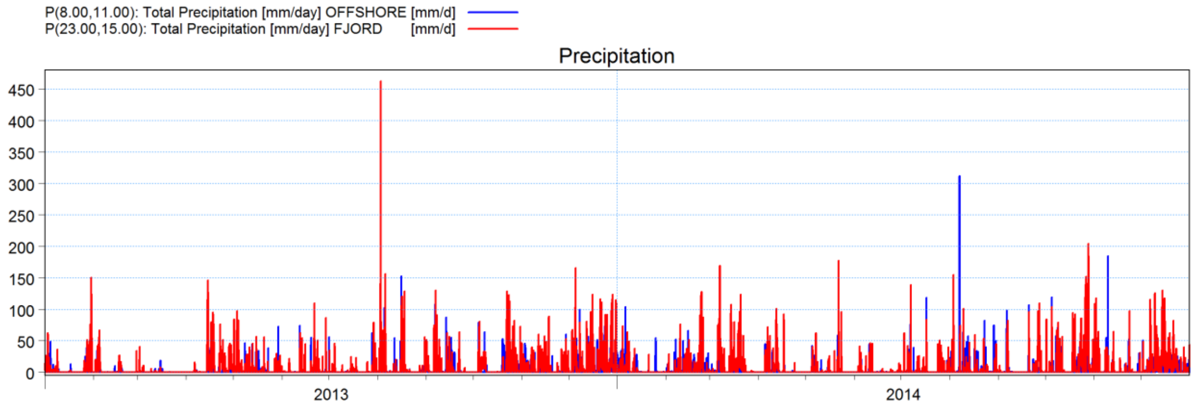


Figure 10. Precipitation time series from the Storm Geo 2D forcing applied in the model (offshore position in blue, and fjord position in red)

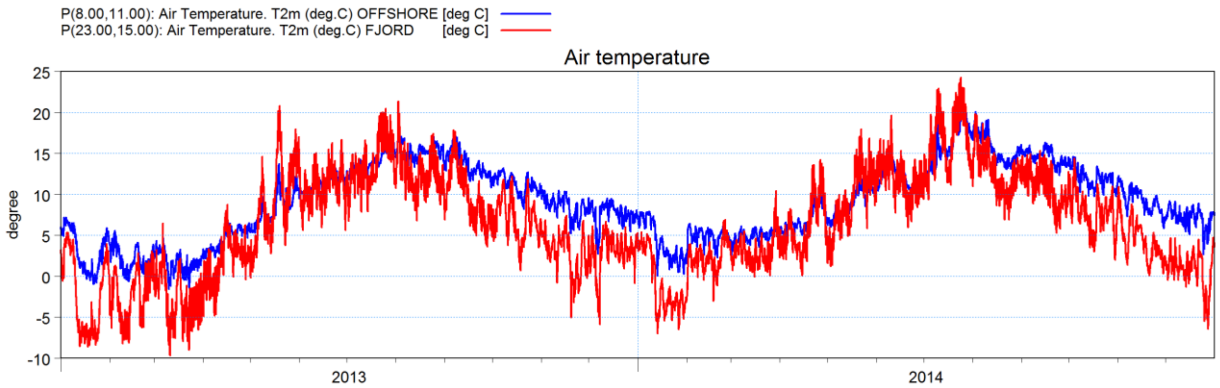


Figure 11. Air temperature time series from the Storm Geo 2D forcing applied in the model (offshore position in blue, and fjord position in red)

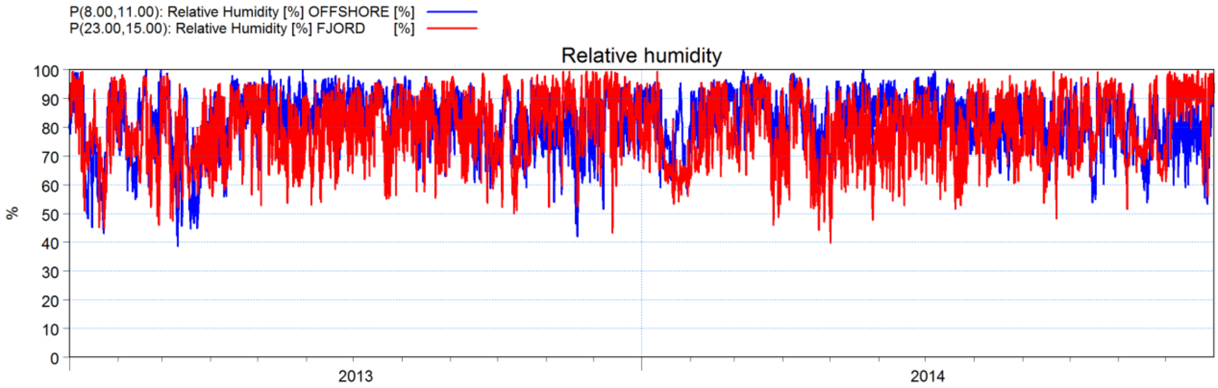


Figure 12. Relative humidity time series from the Storm Geo 2D forcing applied in the model (offshore position in blue, and fjord position in red)

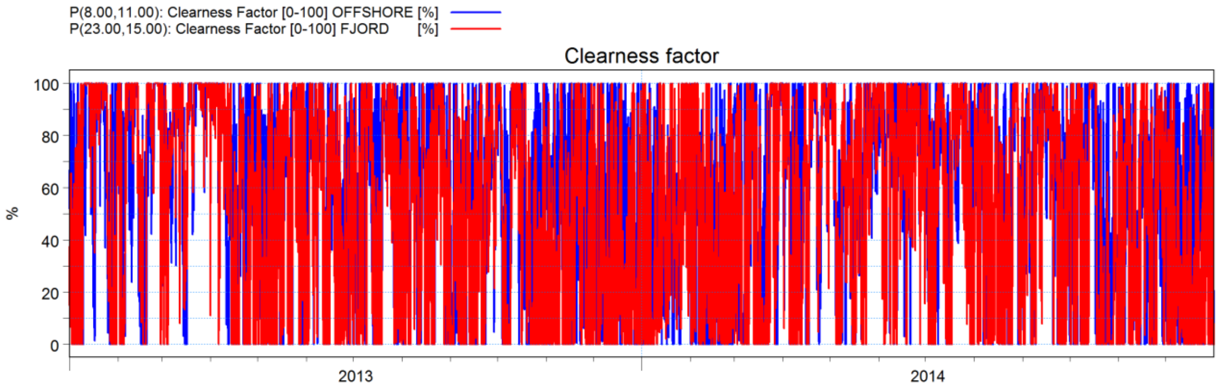


Figure 13. Clearness factor time series from the Storm Geo 2D forcing applied in the model (offshore position in blue, and fjord position in red)

A.4.2 River run-off

The effect of rivers and catchment runoff has been included in the simulation using point sources defined by the magnitude of the fresh water discharge to the system.

The flow and the distribution of the sources is based on runoff data to the sea from hydrological stations provided by the Norwegian Water Resources and Energy Directorate (NVE) and the location of the catchments defined in the NVE Atlas (http://atlas.nve.no), **Figure 14**.

A total of 84 sources has been included in the model, **Figure 15**, with a total yearly discharge to the system of around 20km^3. The three biggest discharges are located in the map and the time series flow displayed in **Figure 16**.

FHF «3D hydrodynamic and lice forecast model »,

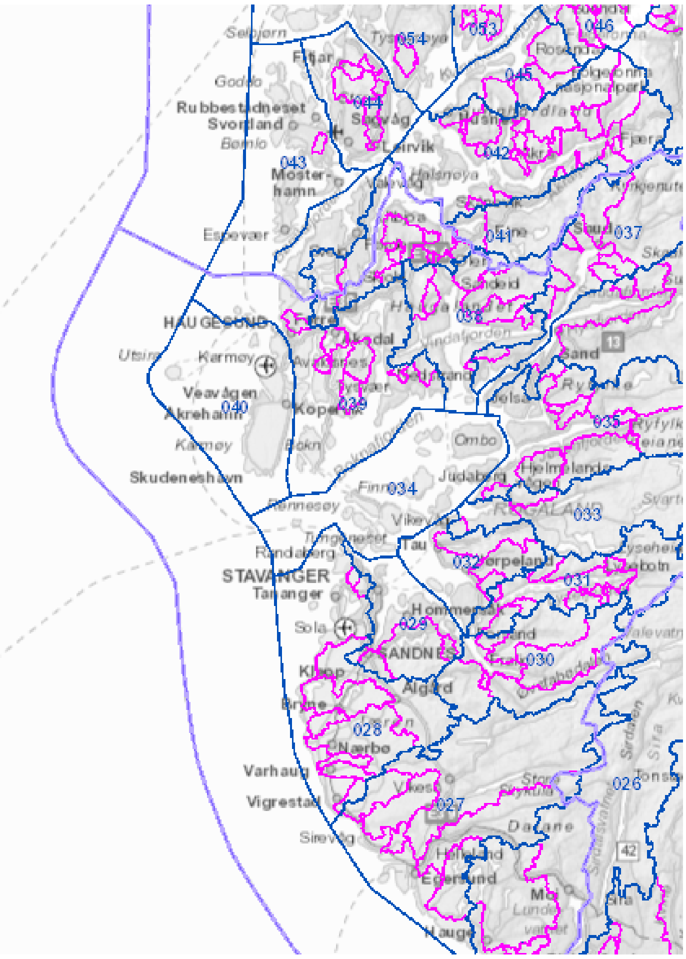


Figure 14 NVE Atlas (Nedbørfelt til havs)

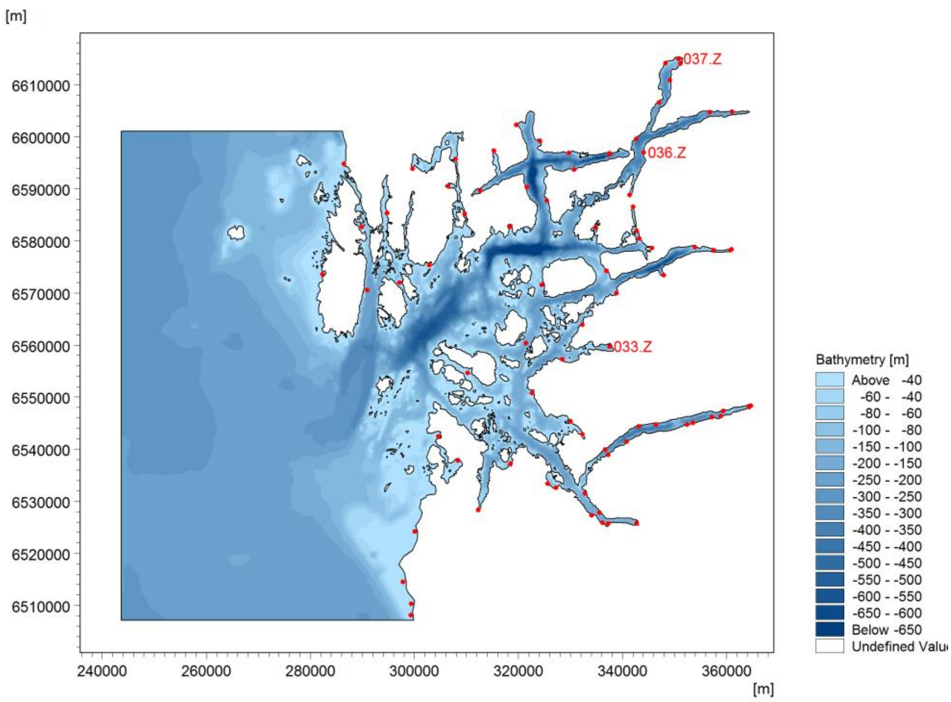


Figure 15. Fresh water point sources included in the model.

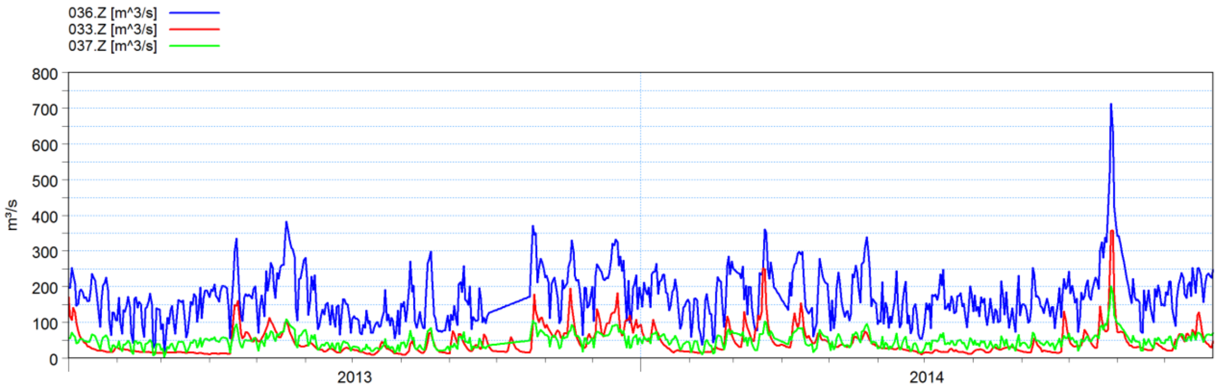


Figure 16. Discharge time series of the three biggest fresh water inflows e.g. Otra (blue), Sira (red) & Suldalsvassdraget (green) to the system

The model settings are summarized in **Table 3** and describe the setup as well as the data inputs used by the model.

Table 3 Summary of settings and input data used in the hydrodynamic model setup

Hydrodynamic Model Parameters		
Model	Rogaland fjord model	
Hydrodynamic modelling system	MIKE 3 FM HD	
Grid type	Flexible mesh	Allows for optimal and high efficient design of the mesh with the finest resolution in areas of special interest and high complexity and low resolution in areas of low complexity.
Horizontal resolution	200m	High horizontal resolution allowing for accurate modelling without compromising simulation time
Vertical grid	Combination of sigma-layers (bottom following) and z-layers (horizontal)	Vertical resolution allowing for accurate modelling without compromising simulation time
Period	2013-2014	The period with most data for validation of the model
Meteo forcing	StormGEO 0.1° (~8km)	

Hydrodynamic Model Parameters		
Offshore forcing	DHI's Norwegian seas model – 5 km	DHIs validated regional model
Hydrological forcing (run-off)	NVE hydrological model	Primary provider of runoff data in Norway
Hydrodynamic validation	Available water level Current measurements at 4 locations Salinity and temperature measurements at 12 stations (profiles and/or 4-5 depths)	
Current, salinity and temperature	From hydrodynamic model	

Appendix B ABM Salmon Lice Model

B.1 Introduction

As part of the project *"Blue Planet – Sea Lice Model Study – Rogaland"* DHI has developed and implemented an ABM (Agent Based Model) sea lice model in the area of Rogaland. The aim of the model is to describe the population dynamics of sea lice in the area. This document is a documentation document for the ABM sea lice/farm model. It is following the ODD protocol (Grimm et al. 2006, Grimm 2010), but extended/updated to the standard ECO Lab terminology.

B.2 Background

The purpose of the Sea Lice ABM is to simulate the planktonic life phase of sea lice (*Lepeophtherius salmonis)*, i.e. the first two non-infective naupili and the infective copepodid stages. The ABM works on top of a hydrodynamic model see (Eckroth J et al. (2017). Rogaland Helsenettverket - Rogaland Hydrodynamic Model).

The AMB model is used to describe and simulate the planktonic dispersal of sea lice to be able to identify dispersal path, networks and finally the infection pressure and risk at concessions.

The module can be used by its own to simulated dispersal patterns or in combination with a farm/cage ABM class of including population dynamics of sea lice in the farms to enable a full dynamic simulations.

B.3 Model description

B.3.1 Model entities

The spatial domain, environmental factors like flow fields etc. and the time step length are provided by the hydrodynamic model.

The Sea Lice module describes planktonic larvae stages by entities of an ABM class, representing one or more larvae (i.e. as kind of super-individual) in the same development stage and from the same release location. This state describes the current development stage of the particle. Each entity drifts passively with the current provided by the hydrodynamic module but is capable of adjust its vertical position due to salinity, light and temperature.

Table 4 Stages of larvae in the ABM model, from the first non-infective planktonic stage (Nauplius I) over the infective copepodid stage to the 1st sessile chalimus stage

Stage	Phase	Description
1	Naupilus I	First planktonic stage (non-infective)
2	Naupilus II	Second planktonic stage (non-infective)
3	Copepodid	Infective state
(4)	Chalimus	1st sessile stage, used as trigger to remove particle

B.4 Model concepts

B.4.1 Basic principles of the model

The Sea Lice ABM uses passive drifting particles to simulate the dispersal/distribution of entities representing the planktonic life stages of *Lepeophtherius salmonis*. Entities can move vertically in the water column, based on a hierarchical response to salinity, light and temperature. Switching of development stages is temperature dependent, based on a more complex model. Mortality is salinity and temperature dependent.

The output of the simulation is the spatial/temporal variation of planktonic *Lepeophtherius salmonis* life stages based on the HD flow field and the vertical movement that is dependent on the development stage. Especially the distribution of the last, infective planktonic life stage is of interest, since is used to estimate the risk of infecting and spreading pathways of between concessions.

B.4.2 Horizontal and vertical movement

The horizontal movement of entities is purely defined by the local current drift (including random walk properties). However, the vertical speed is actively influenced. Entities can react to avoid unfavourable salinities by sinking, show a positive phototaxis or based on temperature changes and seek a depth with a higher temperature (to optimise development time). The vertical movement module is based on published models (Johnsen et al. 2014; Sandvik et al. 2016), but modified so the temperature response is based on the temperature history instead of direct sampling of above/below layer temperatures. An additional ground avoidance is implemented to prevent particles to get stuck in the sea bed. The determination/response of the vertical movement is based on a simple, hierarchical decision tree.

The thresholds for some of the movement clues are dependent on the development stage (stage dependent thresholds).

B.4.3 Prediction of hydrodynamic conditions by sea lice

There is no prediction of any states or process into the future. All reactions/decisions occur on the base of current and past/historic information.

B.4.4 Sensing of hydrodynamic conditions by sea lice

Entities can sense the local flow field (current direction and speed) as well as local environmental and hydrodynamic parameters (light, salinity, temperature) directly.

B.4.5 Stochasticity of sea lice behaviour

The template uses a random variable (uniform) to test if an entity dies within a time step. Apart from this, each entity may see slightly varying environmental factors (in form of local flow conditions), dependent on the selected dispersion scheme. This will cause a standard, uncorrelated random walk component in the horizontal/and or vertical.

B.4.6 Temperature dependent development of sea lice larvae

The development of Lepeophtherius is temperature dependent. The ABM model includes two different submodels.

Constant temperature sum model

The constant temperature sum model assumes that a certain amount of degree-days is needed to switch from one state to the next. This constant degree sum model is used by Johnsen et al. (2014) and Sandvik et al. (2016).

Notably, Johnsen et al. (2014) derived the state durations from Stien et al. (2005), using a reference temperature of 10°C. Sandvik et al. (2016) refer to Samsing et al. (2016), probably also at a reference temperature of about 10°C.

Universal model of temperature dependence

Samsing et al. (2016) demonstrated that an exponential quadratic model can describe the temperature dependent development of Lepeophtherius. Samsing et al. (2016) give both coefficients for the stage durations in days and degree-days.

B.4.7 Mortality of sea lice larvae

The current model imcludes two different submodels for mortality. The first assumes a constant mortality in each development stage as also used by Johnsen et al. (2014) and Sandvik et al. (Brooks and Stucchi (2006) used a give a linear relationship, based on analysing the data of Johnson and Albright (1991).

B.4.7.1 Movement

B.4.7.1.1 Horizontal movement

The horizontal movement direction corresponds to the flow direction. The movement speed is the flow speed multiplied by a scaling factor to enable a reduced flow inside a cage/farm.

$$direction = FlowDirection$$

$$speed = FlowScalFactor * FlowSpeed$$

B.4.7.1.2 Vertical movement

The vertical movement speed is up to 1.55 mm/s (Gillibrandt and Willis 2007). The majority of drift models use a lower velocity in the range of 0.5 mm/s, corresponding to about 1 body length per second (Johnsen et al. 2014).

The individual triggers for a response/decision are simple threshold responses, i.e. the decision is made by:

1. If the salinity is below a given threshold particles sink

2. Else if the light is below a threshold particles move upward

3. Else if the a temperature change towards a colder vertical position is detected particles move into the direction of the higher temperature

4. Else if the distance to ground is lower than a threshold particles move upwards
5. Otherwise no movement

The individual thresholds are partially stage dependent.

This behaviour module is an adoption/extension of the model described by Johnsen et al. (2014) and Sandvik et al. (2016). The adoptions include a simple ground avoidance i.e. in absence of any other trigger entities will avoid to come closer to the bottom than a given distance (1 m by default).

B.4.7.1.3 Salinity response

Planktonic life stages of *Lepeophtherius* show an avoidance of low salinity area. The threshold seem to be in the range of 20-23 PSU ((á Norði et al. 2015; Peter Andreas Heuch et al. 1995; Johnsen et al. 2014).

B.4.7.1.4 Light response

Planktonic life stages of *Lepeophtherius salmonis* show a positive photo taxis. In Johnsen et al. (2014) and Sandvik et al. (2016) both naupili and copepodid stages are given a light response. Peter Andreas Heuch et al. (1995) reports a larger diurnal migration of copepodid stages than for naupili.

Light intensity

If the surface light module is disabled (UseSurfaceLight=0), the light intensity is read from a user supplied input. Otherwise, an entity either calculates the light intensity based on a surface intensity I_0 and a local

Light thresholds

Johnsen et al. (2014) use the following levels and refer to Novales Flamarique et al. (2000):

Naupili: $3.9*10^{-1}$ µmol photons s^{-1} m^{-2}

Copepodid: $2.06*10^{-5}$ µmol photons s^{-1} m^{-2}

However, it is not possible to relate these thresholds to the data of Novales Flamarique et al. (2000).

Novales Flamarique et al. (2000) give the following reaction thresholds (wave lengths 352-652nm, compare PAR=400-710 nm):

Table 5 Light reaction thresholds for nauplii and copepodids.

	Photons m^{-2} s^{-1}		
Stage	[N]	[mol]	[µmol]
1, Naupili I	4.24E+16	7.04E-08	7.04E-02
2, Naupili II	8.07E+12	1.34E-11	1.34E-05
3, Copepodid		($N/6.023*10^{23}$)	($mol*10^6$)

The thresholds used by Johnsen et al. (2014) are 5.5x (naupili) respective 1.5x (copepodid) higher. Neither is the relation (naupili::copepodid) similar ((Johnsen et al. 2014) $1.89*10^4$ vs. $5.25*10^3$ (Novales Flamarique et al. 2000)).

B.4.7.1.5 Temperature response

There is evidence that planktonic life stages of *Lepeophtherius salmonis* seek higher water temperatures to optimise development time (á Norði et al. 2015)

In (Johnsen et al. 2014; Sandvik et al. 2016) entities can sense the water temperature in direct adjacent layers above and below the current layer. As the authors note, this is mechanical unrealistic. We therefore added two state variables, representing a smoothed history value of the last temperature and vertical position. If the current temperature is below the smoothed history reference, entities move into the direction of the associated smoothed vertical position.

B.4.8 In situ data

In-situ data against which ABM model results are compared for validation of model were collected from salmon lice counts delivered by companies under BluePlanet. The data from the concessions include, weekly counts in 2013-2014 of sea lice. The overall distribution of the concessions applied for the model validation is included in Figure .

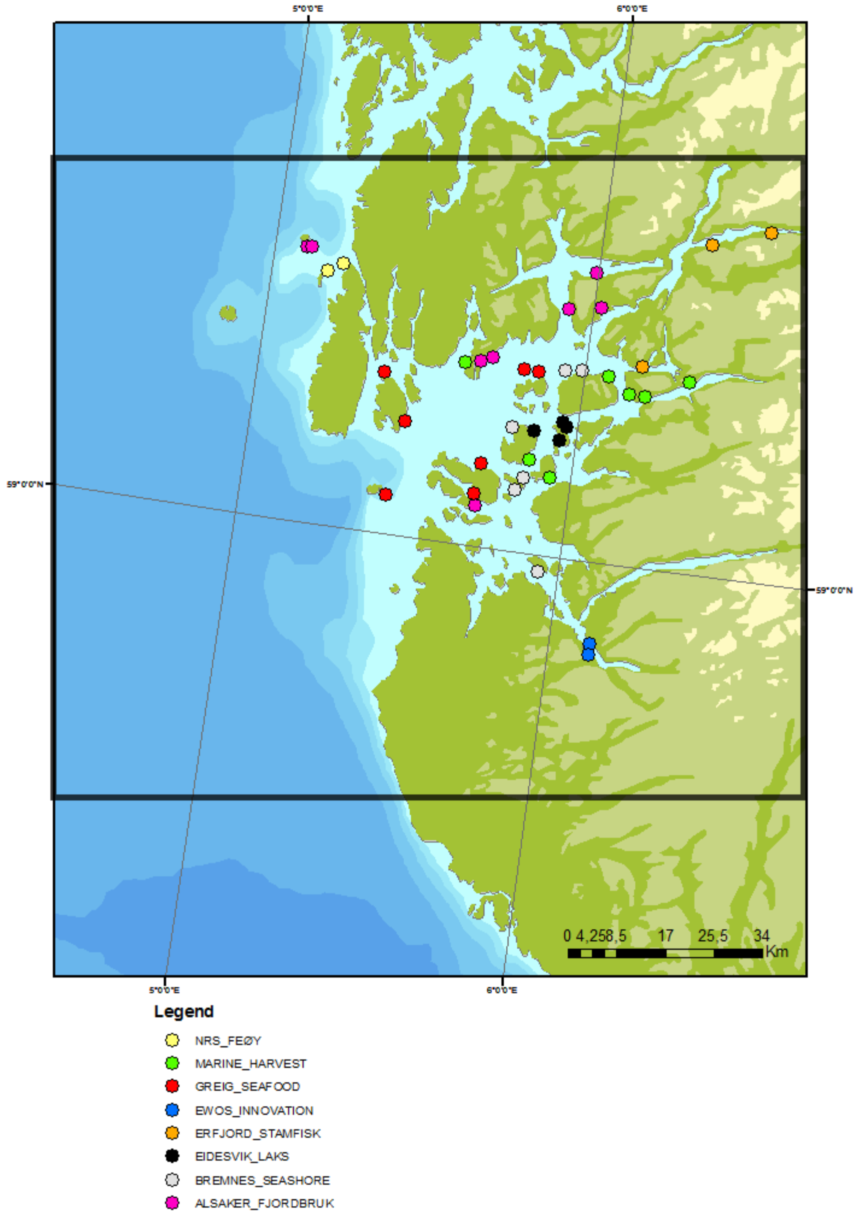


Figure 17 Location of fish farms in Rogaland. Each coloured point indicates a farm and company.

B.4.9 Model validation

The model validation is based on *in-situ* counts of adult female salmon lice at 57 concessions in Ryfylke, compared to model results of infectious copepodids from the combined hydrodynamic-salmon lice ABM model covering the period year 2013-2014.

Validation of the preliminary Sea Lice model was attempted by linear regression of log-transformed concentrations of infective copepodids passing a fish farm and corresponding observations of adult female sea lice (log-transformed) on salmon in farms.

The development time from the infective stage (modelled at a farm area) was estimated using a temperature function on modelled copepodids. During late summer (ca 12-15 °C) the delay from infective stage to adult was 25-30 days.

Overall, based on log-transformed modelled copepodid abundance and log-transformed observed adults 83% of all data was confined within 75% prediction bands parallel to the regression line.

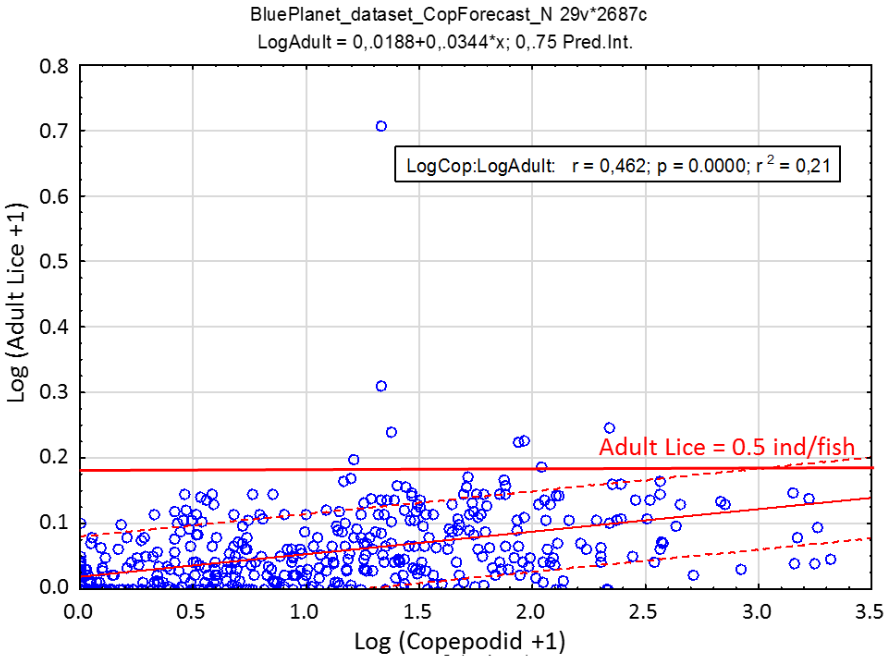


Figure 17 Scatter plot between log-transformed modelled copepodid abundance and corresponding log-transformed observed adult lice on fish.

Eight observations exceeding 0.5 adults/fish could not be predicted. An example is shown in Figure .

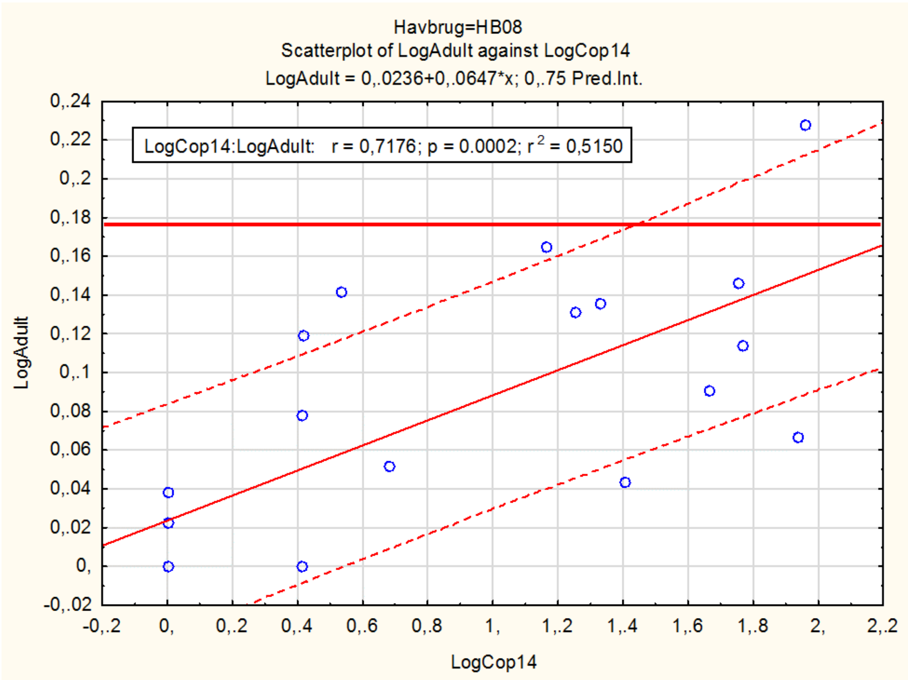


Figure 19 Example from Havbruk (HB08) where a salmon lice count > 0.5 adult female was not predicted by the model.

It is expected that introducing adult sea lice as a *state variable* will improve the predictive power of the model significantly - at present adult lice is tightly coupled to copepodids abundance passing a farm.

Hence, a peak in copepodid abundance results in peak in adult abundance (after a delay of 25-30 days) and after that peak adults are “eliminated”. Modelling adults as a state variable will allow “build-up” of adults fed by pulses of copepodids.

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