COMPLETED PROJECT CASE STUDY

EXPAND IN2 THE FUTURE: REALISING THE FULL CAPACITY OF THE SCOTTISH SALMON INDUSTRY

PARTNERS

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FUNDER

Sustainable Aquaculture Innovation Centre (SAIC)

BACKGROUND

The growing demand for sustainably produced Scottish salmon highlights the need for innovative solutions that balance aquaculture expansion with environmental stewardship. The NewDEPOMOD software remains the preferred tool for the Scottish Environment Protection Agency (SEPA), serving as a critical regulatory means of assessing new farm applications and evaluating the potential environmental impacts of existing aquaculture operations. Its development has represented a step-change in the advancement of environmental impact modelling for aquaculture.

By simulating the deposition and dispersion of organic waste – such as uneaten feed and fish faeces – on the seabed beneath and around fish pens, this modelling helps predict the potential impact of fish farming on the surrounding marine environment, allowing farmers and regulators to assess and manage benthic conditions. NewDEPOMOD improves on its predecessor by offering updated algorithms and enhanced accuracy in simulating the effects of currents and topography on waste dispersal.

The ExPAND2 project discussed in this case study aimed to bring together developers, researchers, and sector practitioners to collectively research and improve NewDEPOMOD and support its use in the Scottish salmon sector to its full potential. The project was led by Salmon Scotland, an industry body representing producers and other organisations working in the salmon sector in Scotland. Additional partners included the Scottish Association for Marine Science (SAMS), the University of Dundee, and the project was funded by the Sustainable Aquaculture Innovation Centre (SAIC). Salmon Scotland's role within the project facilitated the inclusion of modelling expertise from salmon production companies within Scotland. Although those companies were not formal partners within the project, they were integral to the project and its completion.

This work builds on the initial ExPAND project, for which a full case study can be accessed via this link.

AIMS

The work was divided into separate work packages (WP), each with its own objective to:

1. Quantify waste settlement characteristics;
2. Quantify seabed erosion thresholds and waste particle resuspension within controlled laboratory conditions;
3. Produce a comprehensive review on the necessity for, and the method to achieve, quantification of uneaten food, within the particulate waste emanating from a salmon pen;
4. Investigate implications on the depositional characteristics of new pen designs;
5. dentify improvements for maintaining NewDEPOMOD to be able to deliver efficient, flexible, and current modelling requirements;
6. Communicate with relevant stakeholders through regular workshops and discuss research, regulatory and industry issues around NewDEPOMOD.

> *EXPAND2 played a pivotal role in developing business capacity with the NewDEPOMOD package. This initiative provided a forum for production companies to work with the regulator and partner academic institutions to develop understanding and for the industry to grow within the regulatory environment. The ExPAND2 project facilitated true collaboration between our members, enabling meaningful peer engagement and professional development that has been continued since the close of the project.*
>
> *Johnny Coyle, Oceanography/Modeller, Salmon Scotland*

IMPROVEMENTS TO WASTE DISPERSION MODELLING AND CHARACTERISATION

Work packages 1 & 2 (WP1 and WP2, respectively), were aimed at improving the physical characterisation of settling and resuspension of particulate wastes, such as uneaten feed pellets and faecal matter, under environmentally relevant flow conditions.

The settling velocities of intact feed pellets and aquaculture waste samples were evaluated as part of WP1 within a bespoke, grid-stirred settling column to determine the impact of flow turbulence on particulate settling, as representative of typical hydrodynamic conditions at aquaculture farms in both sheltered and well-exposed coastal settings. This work was led by Dr Alan Cuthbertson at the University of Dundee's Environmental Fluid Mechanics Laboratory, where researchers directly measured the settlement of a range of waste types in the laboratory's experimental tank systems.

WP2 involved investigation of the erosion and resuspension of deposited wastes on different underlying sediment substrates. This work centred on the estimation of the critical shear stress required to resuspend the waste layer through the use of a benthic annular mini-flume in a controlled laboratory setting.

The third work package (WP3) sought to review existing research on the quantification of uneaten feed on the seabed. Historic research has largely focused on the combined impact of waste feed and faeces. Quantifying the waste feed aspect alone could result in more accurate predictions of the potential impact fish farms have on the marine environment and reduce the economic losses of wasted feed. WP3 was led by researchers at SAMS and resulted in a report evaluating and comparing the methods available for future research on waste feed quantification.

Due to several new pen designs being introduced into fish farms, the fourth work package (WP4), led by NewDEPOMOD developers at SAMS, addressed the updated characterisation parameters within the model for these novel pens. Various characteristics that may be used within the simulations include the height of the main enclosure, the depth of the main enclosure, the height of waste capture system arrangements, the depth of exit ports, the number and arrangement of exit ports, and more.

The fifth work package (WP5) was led by software developers at SAMS and improved the software, including enhancements or new features at the request of the project's technical working group, and rectified errors identified in existing code.

The sixth work package (WP6), which was considered critical to the project, centred around stakeholder engagement, knowledge exchange, and creating opportunities for dialogue and liaison within the sector.

RESULTS

WP1 & WP2:

Larger feed pellets had higher settling rates, ranging from approximately 70 to 210 mm/s, depending on pellet size, while turbulent flow conditions reduced the average pellet settling rates and increased variability. In contrast, the settling rates of faecal matter and seabed material showed far more significant variability based on their composition, while the influence of low flow turbulence levels was less significant.

The findings suggest that current default NewDEPOMOD parameters for waste settling do not fully reflect the observed variability in settling rates for both feed and waste materials. Proposed improvements include adjusting settling rate calculations to account for organic and inorganic particle differences, and considering the effects of ambient flow turbulence.

Erosion tests of aquaculture waste were conducted using an annular mini-flume, revealing critical bed shear stress thresholds between approximately 0.017 and 0.050 N/m², consistent with previous field data. Erosion was found to occur as cohesive waste layers broke up into fragments. There was no systematic relationship between shear stress thresholds and waste properties like grain size or organic content. The study suggests varying the default minimum erosion stress threshold in NewDEPOMOD (currently set at 0.02 n/m2) between 0.01 to 0.05 N/m² to be able to capture a wider range of benthic conditions experienced at fish farms.

WP3:

Based on the review of existing methods of quantifying the amount of wasted food, there is currently no method available that could reliably differentiate between a 1-2% variance of uneaten feed. The most accurate suggested method was to collect the total waste from a farm over a set period. However, this method has its own set of challenges, as it risks the material becoming too damaged to identify feed particulates, as well as the risk of losing samples during retrieval. Further investigation is encouraged with the appropriate resources and experimental designs, as well as input from SEPA to ensure it meets the criteria for calibration of an individual farm.

WP4:

Several components were modified in NewDEPOMOD to handle new pen types and their parameters. A new user interface dialogue was developed to include the collection of all the new parameters. Improvements to the API (application programming interface) included modifications to the pen and group object representations to handle the new parameters and additional pen features. Furthermore, new pen shapes and features, such as the presence of exit ports, called for the release mechanism to be updated.

Pen designs evolve continuously. Therefore, future work will be required to keep the modelling software up to date, such as the development of time-dependent characteristics like the increase of biomass over time.

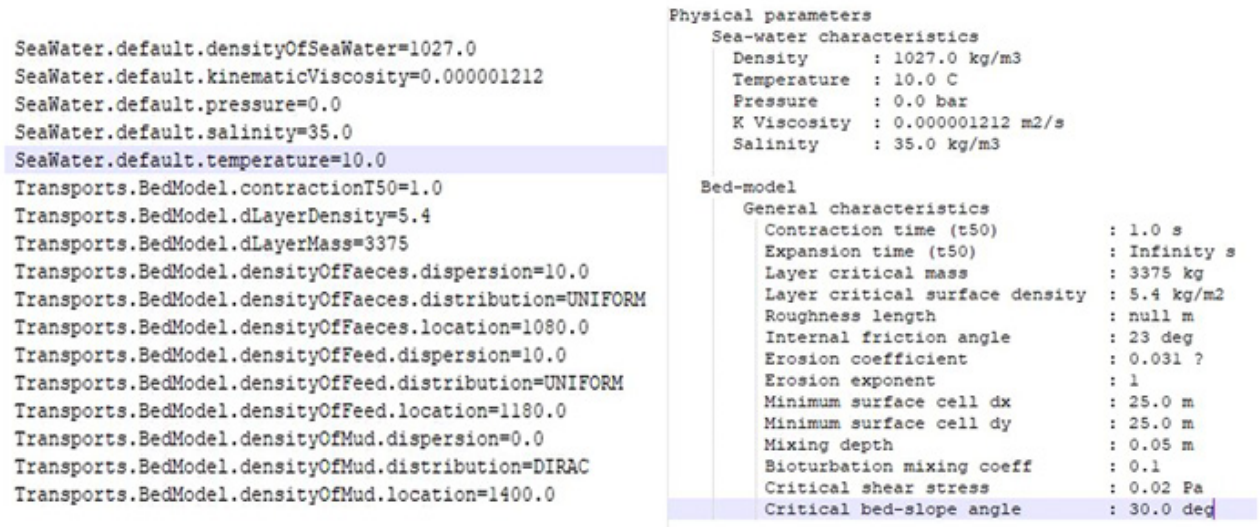
WP5:

Several projects were undertaken guided by the requirements of the Technical Working Group, such as importing pen definitions in CSV format. Another example includes formatting a run log to be readable by humans.

The current run log output file contains a set of keywords and values generated by the model simulation. These keywords are designed to be read by both the user interface and external scripts which extract the values of specific parameters. These are not particularly human-readable, including some with long names, and generally do not include measurement units.

During WP5, the run log code was enhanced with a FormattedLog generator, producing output detailing different sets of parameters:

- Model
- Configuration
- Physical
- Feed
- Common
- EQS results



```
SeaWater.default.densityOfSeaWater=1027.0
SeaWater.default.kinematicViscosity=0.000001212
SeaWater.default.pressure=0.0
SeaWater.default.salinity=35.0
SeaWater.default.temperature=10.0
Transports.BedModel.contractionT50=1.0
Transports.BedModel.dLayerDensity=5.4
Transports.BedModel.dLayerMass=3375
Transports.BedModel.densityOfFaeces.dispersion=10.0
Transports.BedModel.densityOfFaeces.distribution=UNIFORM
Transports.BedModel.densityOfFaeces.location=1080.0
Transports.BedModel.densityOfFeed.dispersion=10.0
Transports.BedModel.densityOfFeed.distribution=UNIFORM
Transports.BedModel.densityOfFeed.location=1180.0
Transports.BedModel.densityOfMud.dispersion=0.0
Transports.BedModel.densityOfMud.distribution=DIRAC
Transports.BedModel.densityOfMud.location=1400.0
```

```
Physical parameters
    Sea-water characteristics
      Density       : 1027.0 kg/m3
      Temperature   : 10.0 C
      Pressure      : 0.0 bar
      K Viscosity   : 0.000001212 m2/s
      Salinity      : 35.0 kg/m3

  Bed-model
      General characteristics
        Contraction time (t50)          : 1.0 s
        Expansion time (t50)            : Infinity s
        Layer critical mass             : 3375 kg
        Layer critical surface density  : 5.4 kg/m2
        Roughness length                : null m
        Internal friction angle         : 23 deg
        Erosion coefficient             : 0.031 ?
        Erosion exponent                : 1
        Minimum surface cell dx         : 25.0 m
        Minimum surface cell dy         : 25.0 m
        Mixing depth                    : 0.05 m
        Bioturbation mixing coeff       : 0.1
        Critical shear stress           : 0.02 Pa
        Critical bed-slope angle        : 30.0 deg
```

Figure 1: Before (left) and after (right) examples of the summary run log, an output file containing keywords and values generated by the model simulation.

Other improvements include the conversion and importation of data from hydrodynamic model outputs, varying critical erosion stress values, analysis of issues with the current bed model, and more. Additionally, more enhancements and bug fixes were carried out as a result of known and newly discovered issues, such as fixing a bug for the rotation of square pens.

WP6

The final work package (WP6), which aimed to provide opportunities for dialogue and engagements within the sector, was carried out by organising three regular and ongoing sets of meetings:

A monthly meeting with the project partners;
A quarterly meeting of the Steering Group made up of project partners, the environmental regulator and industry modellers from aquaculture organisations;
A quarterly in-person meeting of the Technical Working Group, which provided a valuable opportunity to congregate modellers from all salmon producing companies and regulator representatives to discuss how best to use NewDEPOMOD and the models needed to improve its usability.

It is a well-documented fact that in any sector across the globe, the relationship between lawmakers, regulators and industry can be challenging. An initiative that can build open, effective and fruitful collaboration between some or all of these parties is worthy of respect and recognition.

Dr Benedikte Ranum, Knowledge Exchange Manager, Sustainable Aquaculture Innovation Centre (SAIC)

IMPACT

The ExPAND2 project strengthened collaboration among software developers and researchers at SAMS and the University of Dundee, Salmon Scotland members, SEPA, and SAIC, and built on the ExPAND1 project's foundation. This collaboration fostered a platform for communication across sectors to ensure fish farm depositional modelling supports sustainable salmon farming in Scotland, meeting regulatory and sector needs.

ExPAND2 also created a forum for modellers from all the companies and partners to work together. This was a particular strength of this project, and had immediate impact for the sector. Salmon Scotland is keeping this momentum going by hosting meetings with all the modellers twice a year.

ExPAND2 addressed the need for improved modelling for the environmental regulator, combining fundamental research and applied knowledge to support sector growth. Key research achievements included collecting experimental data on waste behaviour, settlement, and resuspension using benthic grabs and settlement traps. This data improved the understanding of waste variability under different conditions, aiding model validation, calibration, and refining SEPA's default parameters. A report was also compiled on quantifying uneaten feed in particulate waste.

The project advanced NewDEPOMOD by incorporating novel pen designs, ensuring the model's adaptability to future farm designs. Ongoing code development, including migration to the JAVA platform, enhanced the model's flexibility and efficiency. Regular meetings facilitated effective knowledge exchange and collaboration across stakeholders, ensuring mutual benefits and open communication across the sector in Scotland.

The ExPAND2 project has led to tangible improvements in the NewDEPOMOD model itself and how it is utilised by industry, helping SEPA streamline its regulatory duties. The resulting collaboration between parties with differing priorities has helped progress our mutual ambition of an environmentally sustainable industry of great importance to Scotland.

Dr Ted Schlicke, Senior Specialist Scientist, Scottish Environment Protection Agency (SEPA)