Isle of Rum, CAR/L/1152362

Waste Solids & In-feed Medicine Deposition Modelling Report

Mowi Scotland Ltd.

June 2022

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EXECUTIVE SUMMARY

Model simulations have been performed to assess the likely deposition of waste solids and in-feed medicine at a salmon farm site near the Isle of Rum. This report explains the application of the NewDepomod model to describe the deposition of waste solids and in-feed medicine beneath the pens and in the surrounding environment. The modelling procedure followed as far as possible guidance presented by the Scottish Environment Protection Agency (SEPA) in January 2022 (SEPA, 2022). Modelling of the cumulative waste solids deposition from Rum together with deposition from nearby site at Muck and proposed site at Canna is also presented using a coupled hydrodynamic model with Mowi's in-house particle tracking model *unptrack* (Gillibrand, 2021).

Results indicated that deposition at Rum will be minimal, with a maximum deposition of 791.1 g m^{-2} (Table 1). The footprint area, where the deposition exceeded the critical deposition rate of 250 g m^{-2}, was 0.16 km^{2}. The intensity of deposition, 378.1 g m^{-2} was less than the critical value of 2,000 g m^{-2}.

These results indicate that the proposed new layout at Rum and biomass increase will comfortably meet pertinent Environmental Quality Standards for salmon farm waste solids. Cumulative modelling indicated that the deposited wastes from Rum will not interact with solid wastes discharged from the neighbouring site at Muck and proposed new site at Canna.

Table 1. Site details & summary of results

Site Details	
Site Name:	Rum
Site Location:	Isle of Rum
Peak Biomass (T):	3,300
Feed Load (T/year):	8431.5
Pen Details	
Number of Pens:	8
Pen Dimensions:	160m Circumference
Working Depth (m):	15
Configuration:	2x4, 100m matrix
NewDepomod Results	
Allowable Mixing Zone (m^{2}):	177,068
Maximum Deposition (g m^{-2}):	791.1
Modelled Footprint (m^{2}):	160,000
Mean Footprint Deposition (g m^{-2}):	378.1

1 INTRODUCTION

This report has been prepared by Mowi Scotland Ltd. to describe the deposition of waste solids from a marine salmon farm near the **Isle of Rum** (Figure 1 and Figure 2). It explains the application of the NewDepomod model to describe the deposition of waste solids and in-feed medicine beneath the pens and in the surrounding environment. The modelling procedure followed as far as possible guidance presented by the Scottish Environment Protection Agency (SEPA) in January 2022 (SEPA, 2022). Modelling of the cumulative waste solids deposition from Rum together with deposition from nearby site at Muck and the proposed site at Canna is also presented using a coupled hydrodynamic model with Mowi's in-house particle tracking model *unptrack* (Gillibrand, 2021).

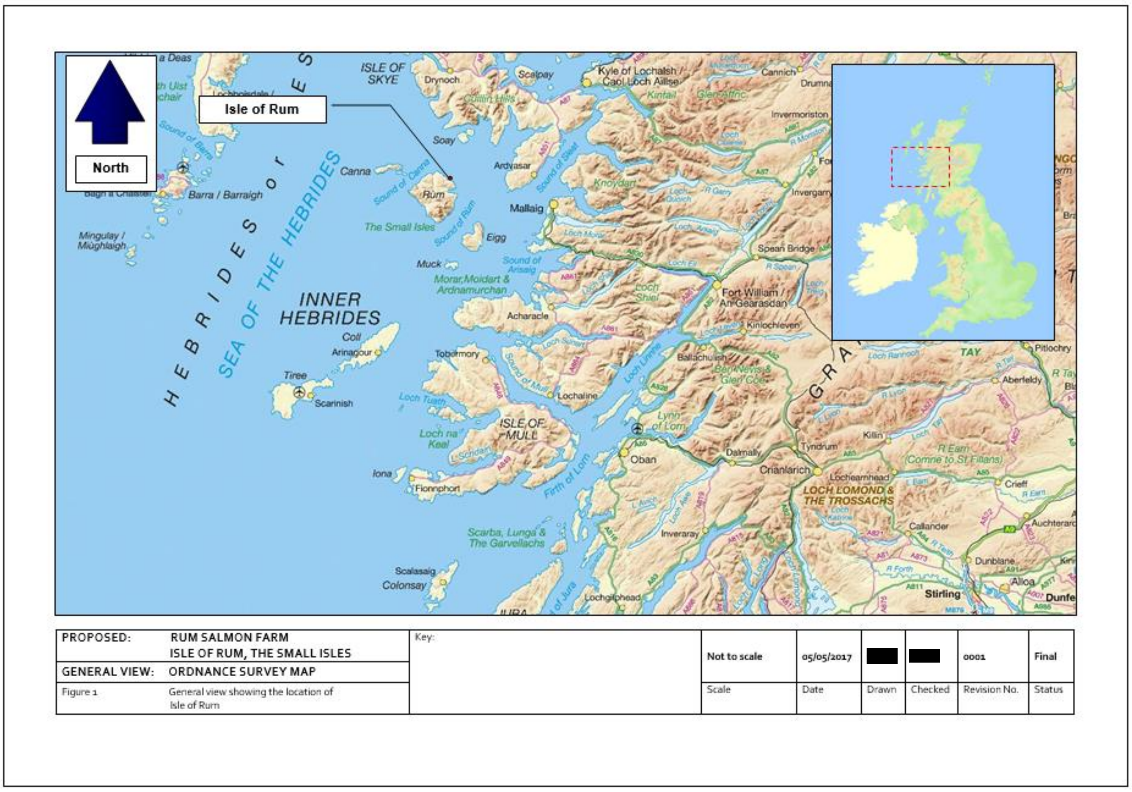

Figure 1. Location of the Isle of Rum Site

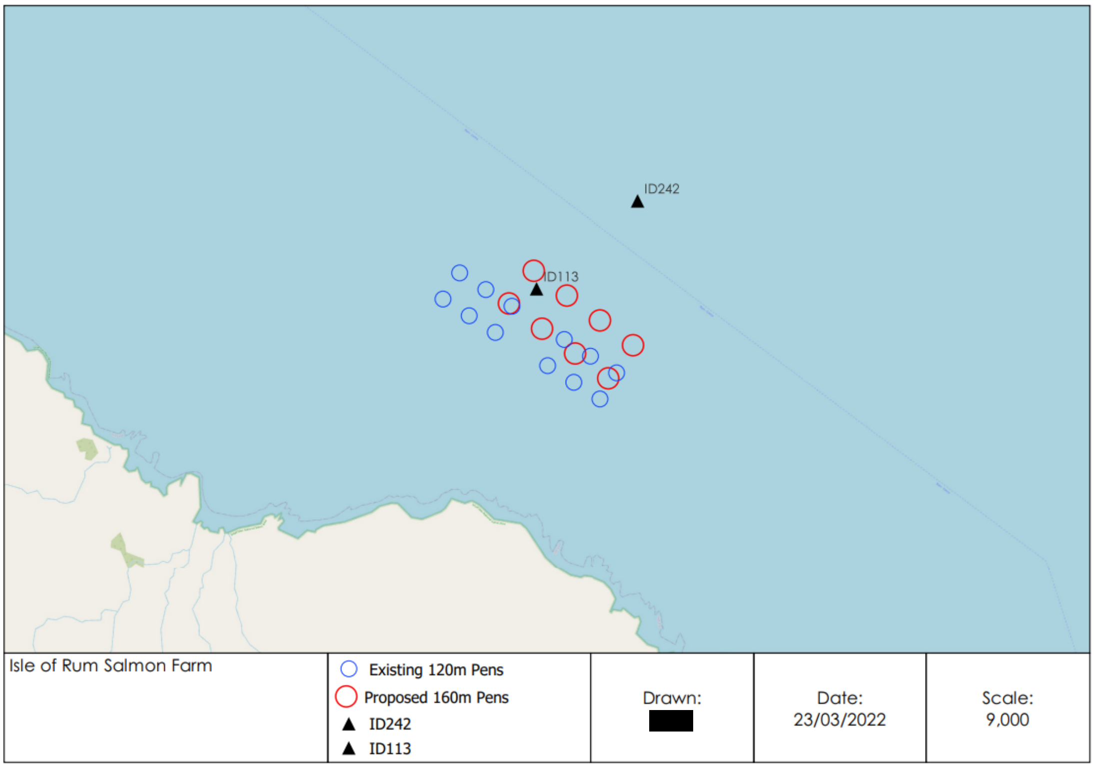

Figure 2. Existing (blue) and proposed (red) layouts at the Isle of Rum salmon farm. ADCP deployment locations are also marked with a black triangle

Table 2. Summary of hydrographic data from near bed currents

Hydrographic Summary	**ID113**	**ID242**
Deployment Date	Aug-Oct 2016	Aug-Nov 2018
Easting	141101	141338
Northing	803023	803238
Mean Speed (m/s)	0.119	0.132
Residual Speed (m/s)	0.040	0.042
Residual Direction (°G)	313	321
Tidal Amplitude Parallel (m/s)	0.186	0.206
Tidal Amplitude Normal (m/s)	0.055	0.065
Major Axis (°G)	315	315

1.1 Site Details

The existing site is situated off the north-east of the Isle of Rum (Figure 1 and Figure 2). Details of the site and hydrographic summary are provided in Table 1 and Table 2. The receiving water is defined as open water. The pen center locations are given in Table 3. These locations were used in the computer modelling (Section 2).

Table 3. Details of the individual pen centre locations and net depths used in the modelling for Rum.

Cage	Easting	Northing	Net Depth (m)
1	141087	803069	15
2	141027	802990	15
3	141167	803009	15
4	141107	802929	15
5	141247	802949	15
6	141187	802869	15
7	141327	802889	15
8	141267	802809	15

The most recent seabed compliance survey at Rum was carried out in December 2021 and has been sent to our consultant laboratory for analysis. Once received this will be reported to SEPA for classification.

Previous compliance seabed surveys were carried out in July 2019 at 96.5% of peak biomass and April 2020 at 35% of peak biomass both of which have been fully analysed and submitted to SEPA for classification. To date SEPA have not formally responded; however, both of these surveys meet pen edge and mixing zone environmental standards.

2 MODEL DETAILS

Three sets of simulations were performed. The first and second set focussed on localised deposition of waste solids and in-feed medicine beneath the proposed 160m pens and utilised the NewDepomod model, configured in the default parameter values specified by SEPA and using measured flow data to force the model. The third set investigated the cumulative deposition arising from the site at Rum together with that from neighbouring Small Isles site at Muck and the proposed site at Canna; for this set, flow fields from a hydrodynamic model, RiCOM, were used to force a particle tracking deposition model, *unptrack*.

2.1 Local Deposition: NewDepomod

NewDepomod is a bespoke modelling software designed to simulate the dispersion of particulate wastes from salmon farms. The model (SAMS, 2021) has been developed by the Scottish Association for Marine Science (SAMS) and is supplied under licence. The version used for the modelling described here was:

library version:
numerics version: Final 1.20220131164515.1643647287
datatypes version: Final 1.20220131164505.1643647287
util version: v1.4.0-final-(SEPA)

A regular model grid was prepared. The grid covered a 4km x 4km area, with a 25m grid spacing in both directions. The grid size was 160 x 160 cells. The water depth was 35.68 m, the minimum depth recorded during the ID113 deployment. The flowmetry file combined the data from ID113 and ID242; after merging the length of the combined record was 90 days in total. The same grid size, grid spacing and water depth was used for the Emamectin Benzoate modelling.

2.1.1 Waste Feed and Faeces

The model was configured exactly as specified by SEPA in the modelling guidance published in January 2022 (SEPA, 2022). The site was modelled for a maximum biomass of 3300 tonnes with a feed load of 7 kg/tonne/day. This configuration of the model produces a conservative estimate of the benthic footprint, with a deposition rate of 250 g m^{-2} equating approximately to an Infaunal Quality Index (IQI) of 0.64 (the boundary between moderate and good status). Work by SEPA has shown that footprints predicted by this “standard default” configuration broadly match the footprint area derived from seabed samples, although there is a great deal of variability from site to site.

Following the standard default approach, NewDepomod was used to simulate one year of deposition at the maximum farm biomass. Results were analysed over the final 90 days of the simulation, with the mean deposition rate across the model domain being calculated and the footprint area being delimited by the 250 g m^{-2} contour (SEPA, 2022). The results are presented in Section 3.1.

2.1.2 In-feed Medicine Modelling

Rum salmon farm has a current EMBZ consent of 12g. To check that the proposed 8 x 160m pens do not negatively affect the deposition, the in-feed medicine model of NewDepomod was used. It was run for 118 days, with hourly results over the final two days (Days 116 – 118) saved to file. This approach followed that of the standard default modelling approach outlined in the SEPA Regulatory Modelling Guidance (SEPA 2022). The mean concentrations of Emamectin Benzoate were calculated from this output for comparison with the EQS value of 11.75 ng/kg (wet weight, equivalent to 23.5 ng/kg dry weight), which is the current interim position standard.

2.2 Cumulative Deposition: Hydrodynamic and Particle Tracking Models

The cumulative deposition modelling approach utilised a coupled hydrodynamic and particle tracking method, whereby water currents in the region, modelled using a calibrated hydrodynamic model, advected particles representing waste solids around the model domain. Deposition from existing sites at Rum and Muck was modelled as well as deposition from the proposed site at Canna.

The hydrodynamic modelling approach is described in full in the accompanying report (Mowi, 2022) and is only summarised here. Flow fields were calculated using RiCOM (River and Coastal Ocean Model). RiCOM is a general-purpose hydrodynamics and transport model, which solves the standard Reynolds-averaged Navier-Stokes equation (RANS) and the incompressibility condition, applying the hydrostatic and Boussinesq approximations (Walters and Casulli, 1998). It has been tested on a variety of benchmarks against both analytical and experimental data sets. The model has been previously used to investigate the inundation risk from tsunamis and storm surge on the New Zealand coastline, the effects of mussel farms on current flows, and, more recently in Scotland to study tidal energy resource and the effects of energy extraction on the ambient environment (McIlvenny et al., 2016; Gillibrand et al., 2016b).

The mathematical equations are discretized on an unstructured grid of triangular elements which permits greater resolution of complex coastlines, such as typically found in Scotland. Therefore greater spatial resolution in near-shore areas can be achieved without excessive computational demand.

For the particle tracking component, Mowi's in-house model "*unptrack*" (Gillibrand, 2021) was used. The model used the hydrodynamic flow fields from the RiCOM model simulations. This model has been used previously to simulate sea lice dispersal (Gillibrand & Willis, 2007), the development of a harmful algal bloom (Gillibrand et al., 2016a) and the dispersion of cypermethrin from a fish farm (Willis et al., 2005). The approach for particulate wastes is the same as for living organisms, except that medicine has no biological behaviour but instead has a prescribed settling velocity: numerical particles represent either waste feed pellets or faecal waste. Particles are released continuously at pen locations, with initial particle positions distributed randomly through the pen volumes. The particles are then subject to advection, from the modelled flow fields, and horizontal and vertical diffusion. The prescribed settling velocity means particles rapidly settle onto the seabed, from where they can be resuspended back into the water column if the seabed stress exceeds a critical value, or where they may remain in place.

2.2.1 Model Domain and Boundary Conditions

The unstructured mesh used in the modelling was adapted from the East Coast of Lewis and Harris (ECLH) sub-model mesh of the Scottish Shelf Model (SSM; MS, 2016). Model resolution was enhanced in the Small isles region, particularly around the Mowi sites at Rum and Muck. The domain and mesh is shown in Figure 3, with the area around Rum shown in Figure 4. The spatial resolution of the model varied from 25m in some inshore waters to 5km along the open boundary. In total, the model consisted of 76,452 nodes and 144,971 elements.

Given that the SEPA standard default approach with a flat bathymetry was used in the NewDepomod simulations, detailed bathymetry for the marine model was deemed unnecessary. Bathymetry was taken from the European Marine Observation and Data Network (EMODnet).The bathymetry in the original EMODnet model is acceptable in the Cuillin Sound area where the model is focussed (Figure 5 and Figure 6).

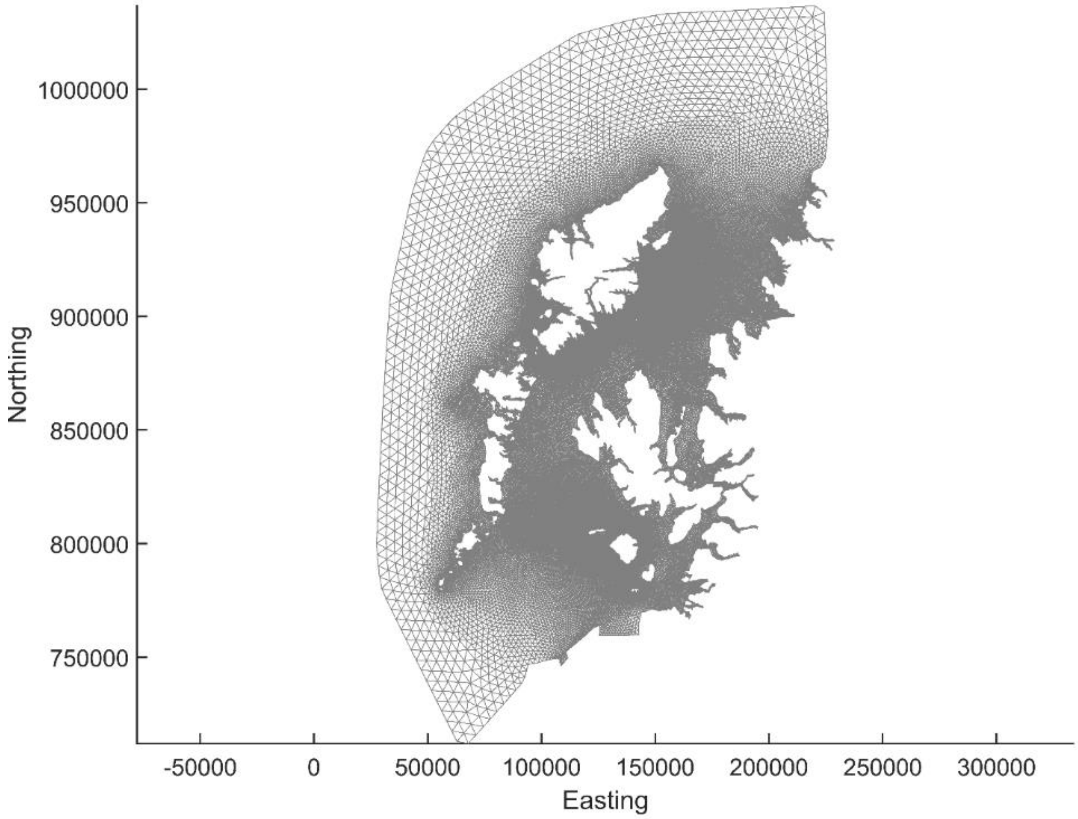

Figure 3. The modified ECLH domain and mesh used in the Rum modelling

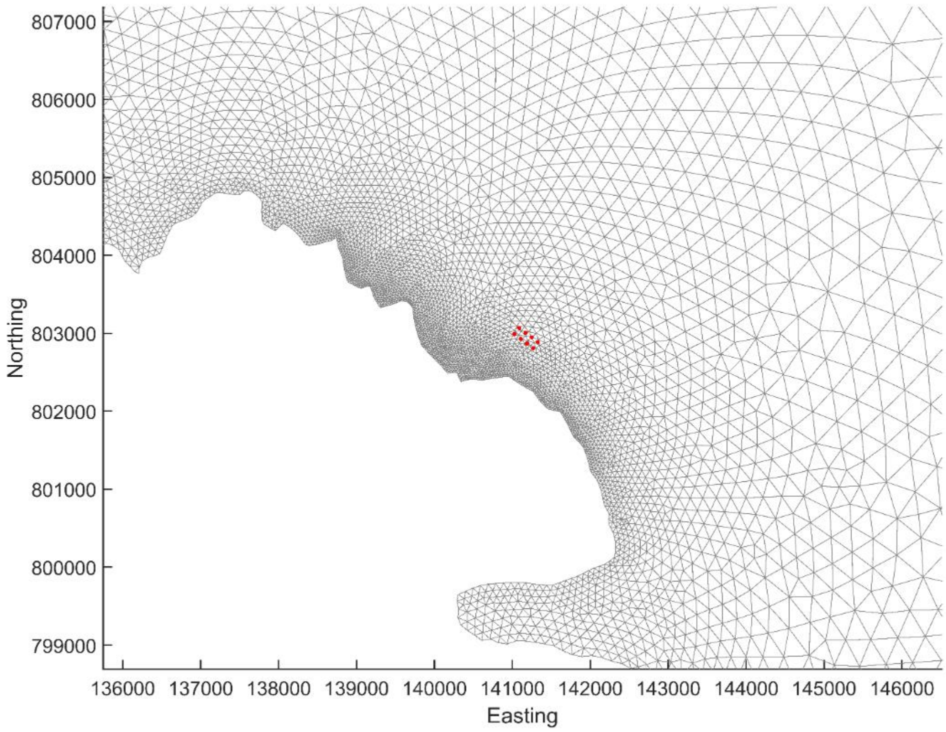

Figure 4. The unstructured mesh around the Rum site. The pen locations are indicated (○).

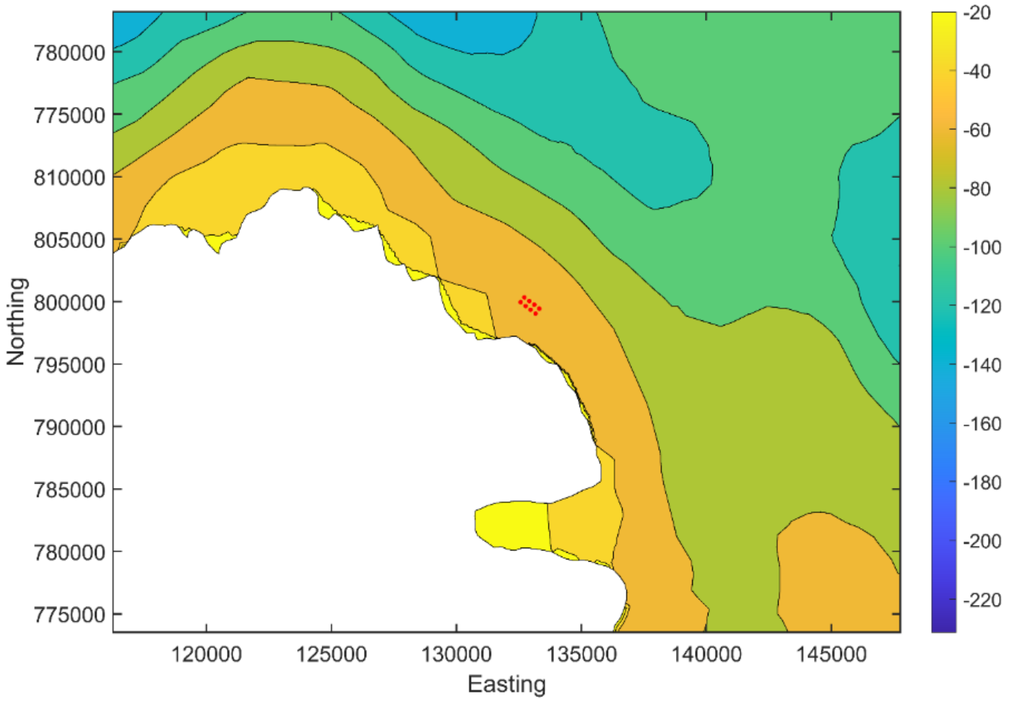

Figure 5. Localised bathymetry (m) around Rum from the modified model.

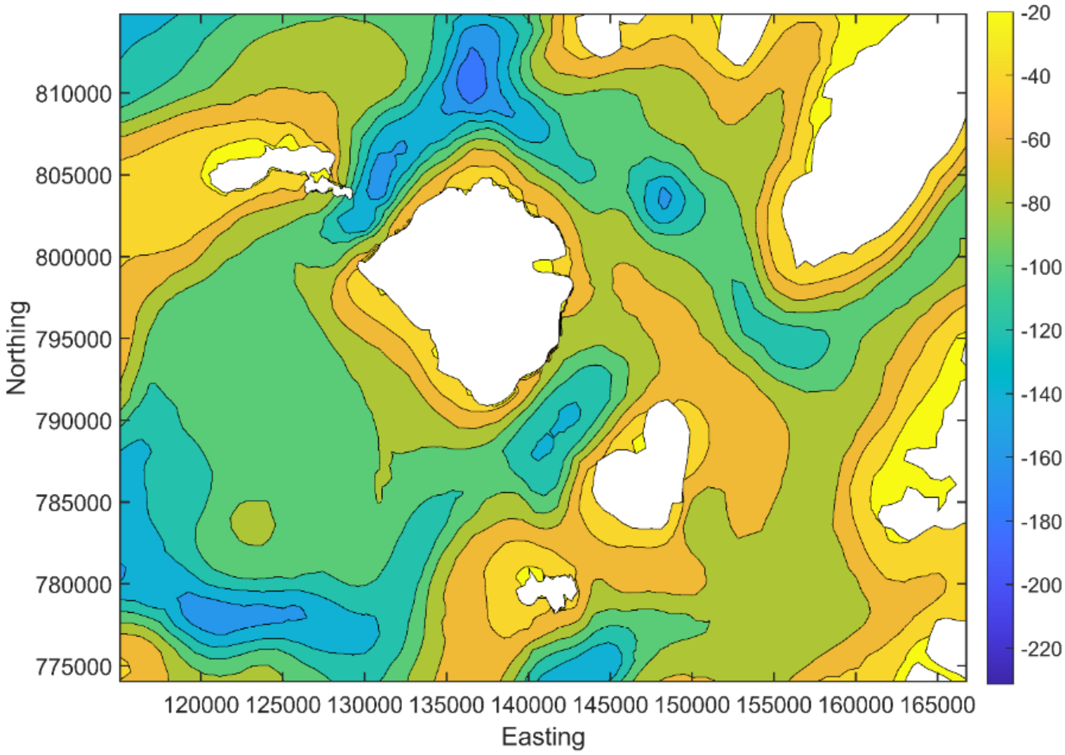

Figure 6. Localised water depths (m) around the Small Isles in the modified model domain.

The model is forced at the outer boundaries by 8 tidal constituents (M_2, S_2, N_2, K_2, O_1, K_1, P_1 and Q_1) which were derived from tidal analysis (Pawlowicz et al., 2002) of the sea surface elevations at the closest nodes from the Scottish Shelf Model climatology (Marine Scotland, 2016). Spatially- and temporally-varying wind speed and direction data are taken from the ERA5 global reanalysis dataset (ECMWF, 2021) for the required simulation periods.

Stratification is relatively weak in this location, given the strong tidal flows in the area, and the model was run in 2D vertically-averaged mode.

Full details of the calibration and validation of the hydrodynamic model are given in the Hydrodynamic Model Description (Mowi Scotland Ltd, Rum Hydrodynamic Model Description, 2022).

2.2.2 Hydrodynamic Model Calibration

The RiCOM model has previously been calibrated against sea level and current meter data from the north of Scotland (Gillibrand et al. 2016b). For the current study, the model was further calibrated and validated against hydrographic data collected in the region of the farm site from 2016 and 2018. The data are described in the relevant hydrographic reports. In August 2016, an Acoustic Doppler Current Profiler (ADCP) was deployed close to the farm site (Figure 2 & Table 2) until October 2016 (ID113). A second ADCP deployment, ID242, was collected between August and November 2018. The ADCP deployments provided both current velocity and seabed pressure data which were used to calibrate and validate modelled velocity and sea surface height.

The following main simulations were performed, corresponding with the dates of the ADCP deployments:

1. 15th August 2016 – 9th October 2016 (ADCP deployment ID113)
2. 30th August 2018 – 22nd November 2018 (ADCP deployment ID242)

The calibration process and results are described fully in the accompanying hydrodynamic modelling report (Mowi, 2022).

2.2.3 Particulate Waste Deposition Modelling

The particulate deposition modelling, performed using the *unptrack* model (Gillibrand, 2021), simulated the settling of waste solids (waste feed and faeces) discharged from pens during a production cycle. In addition to the pens at Rum, wastes were released from the site at Muck and the proposed site at Canna at the proposed biomass (Table 4) with pen locations at Muck and Canna given in Table 5. Particles were discharged continuously, with each numerical particle representing 5 kg of particulate waste. Feed and faecal particles were assigned settling velocities within the range of 0.095 m s^{-1} ±10% and 0.032 m s^{-1} ± 10% respectively, the same as the values used by NewDepomod. The particle tracking model used the simulation from August – November 2018 (ID242) as this was the longest hydrodynamic model run, at 84 days.

Table 4. Modelled biomass and feed rate for the cumulative modelling

Sites	Modelled Biomass (T)	Feed Rate (kg/T/day)
Rum	3300	7
Muck	4069	7
Canna	2500	7

Table 5. Pen centre locations for the Muck and Canna sites used in the modelling

	Muck		Canna	
Pen	Easting	Northing	Easting	Northing
1	143200	780207	128371	805494
2	143295	780238	128283	805514
3	143169	780302	128391	805581
4	143264	780333	128303	805602
5	143138	780397	128411	805669
6	143233	780428	128323	805689
7	143107	780492	128431	805757
8	143202	780525	128343	805777

When a particle reaches the seabed due to its settling velocities, it may be resuspended into the water column and be subject again to advection and diffusion. Resuspension is modelled using a stochastic approach, whereby a probability of resuspension is specified for each settled particle every time step. In the present simulations, the probability of resuspension, P, was calculated by:

$$P = c_r(\tau_b - \tau_{bc})e^{-t/\lambda}$$

where $\tau_b = \rho u_*^2$ is the bed shear stress derived from the local modelled current speed, τ_{bc} is the minimum critical shear stress required to erode particles off the seabed, c_r is a resuspension constant, and λ is a consolidation time scale. With this approach, the probability of particle erosion decreases as particles age, as it becomes more likely that the particle is consolidated into the seabed sediment. The parameters c_r, τ_{bc} and λ are tunable coefficients that can be used to calibrate the deposition model. A bed roughness scale of z_0 = 0.01 m was used to calculate the bed shear stress from the local current speed.

3. RESULTS

3.1 Local Deposition: NewDepomod

3.1.1 Waste Feed and Faeces

The modelled footprint for the Rum farm using the SEPA standard default method is shown for the proposed biomass (Figure 7). The area of the footprint, as defined by the deposition rate of 250 g m^{-2}, was 160,000 m^2 (Table 6). The maximum 90-day mean deposition was 791.1 g m^{-2}. The intensity of deposition was 378.1 g m^{-2} which is well below the critical value of 2,000 g m^{-2}. These results indicate that the proposed equipment change and biomass increase will comfortably meet pertinent Environmental Quality Standards for salmon farm waste solids.

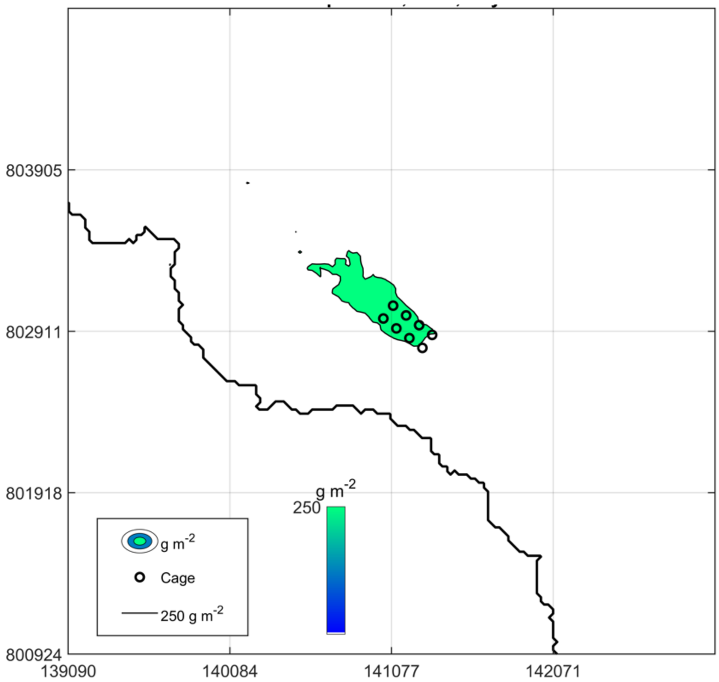

Figure 7. The modelled footprint for Rum for the proposed biomass increase to 3300 tonnes, using the SEPA standard default method.

Table 6. The modelled footprint area and mean footprint deposition for Rum for the proposed biomass increase, using the SEPA standard default method.

NewDepomod Results Summary	
Maximum Biomass (T)	3,300
Feed Load (T/year)	8431.5
Solid Waste Release Rate (kg/day)	3689.07
Allowable Mixing Zone (m^2)	177,068
Maximum Deposition (g m^{-2})	791.1
Modelled Footprint (m^2)	160,000
Mean Footprint Deposition (g m^{-2})	378.1

3.1.2 In-feed Medicine Modelling

The in-feed medicine model of NewDepomod was run using both the existing layout of 12 x 120m pens and the proposed 8 x 160m pens. This was done to determine whether the change in equipment would have an effect on the deposition shown from the site with the current consented EMBZ mass of 12g. The results show that the proposed layout increases the EMBZ footprint by more than the allowed 15% (Table 7) and is greater than the allowable mixing zone. Since the consented EMBZ mass at Rum is too small to treat the site effectively, it has not been utilised. Mowi Scotland may re-visit this consent in the future once UKTAG have released their report and recommendations on emamectin benzoate environmental quality standards.

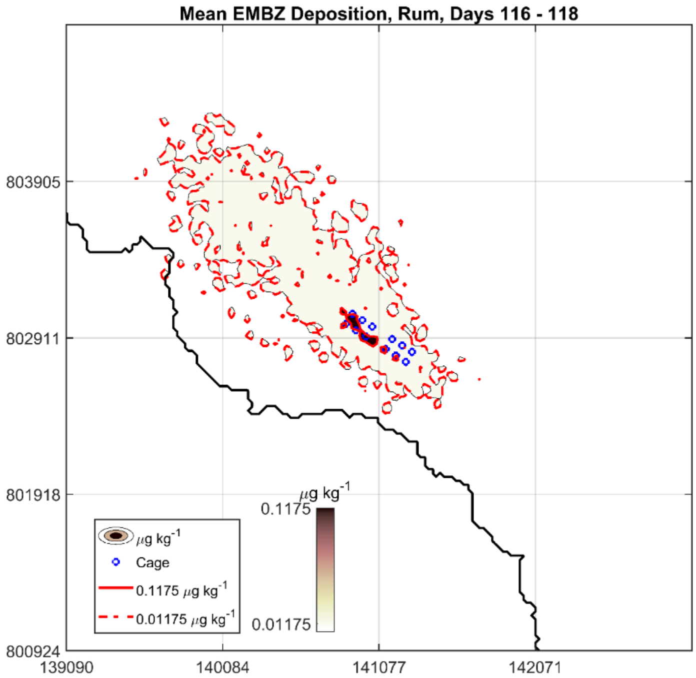

Figure 8: Predicted mean Emamectin Benzoate deposition over days 116 – 118 for the existing 12 x 120m pens at Rum following a consented treatment of 12g.

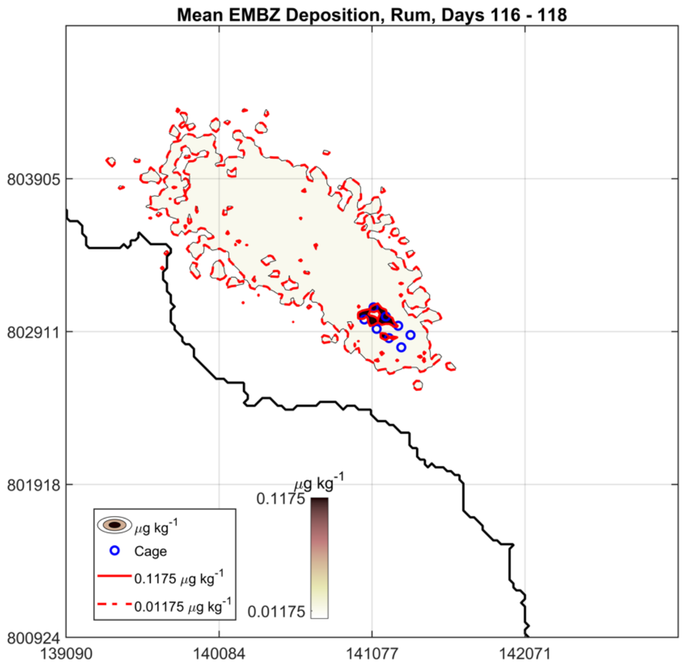

Figure 9: Predicted mean Emamectin Benzoate deposition over days 116-118 for the proposed 8 x 160m pens at Rum following a consented treatment of 12g.

Table 7: Percentage change in EMBZ footprint areas (km^2) from the existing and proposed pen layouts at Rum following a consented treatment of 12g.

Layout	Area > 0.01175 ug/kg (km^2)	Area > 0.1175 ug/kg (km^2)
Existing	1.145000	0.019375
Proposed	1.353750	0.023125
% change	+18.23%	+19.35%

3.2 Cumulative Predictions for the Small Isles

Cumulative particulate deposition arising from all three Small Isles sites was modelled using the maximum consented (or proposed) biomass at each site and the nominal feed rate (Table 4). Deposition was modelled for 365 days, and the mean deposition over the final 90 days calculated (Figure 10 and Figure 11). The results indicate that, as expected due to the dynamic nature of the sites, very small footprints (deposition exceeding 250 g/m^2) at all three sites were predicted. These results also confirm that the deposition footprints do not interact with each other.

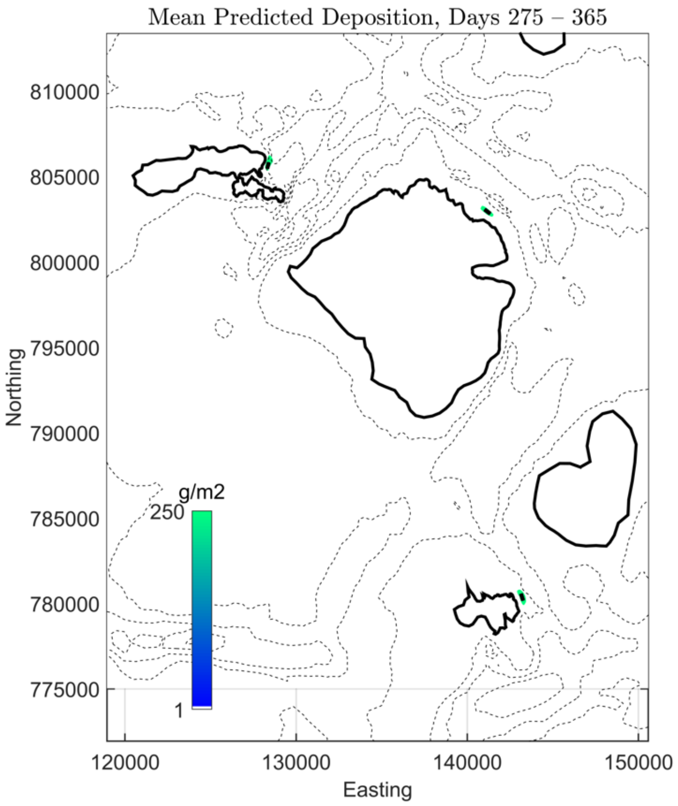

Figure 10. Predicted mean solids deposition over 90 days from the sites at Rum, Muck and the proposed site at Canna using the nominal feed rate (7 kg/tonne/day) at each site.

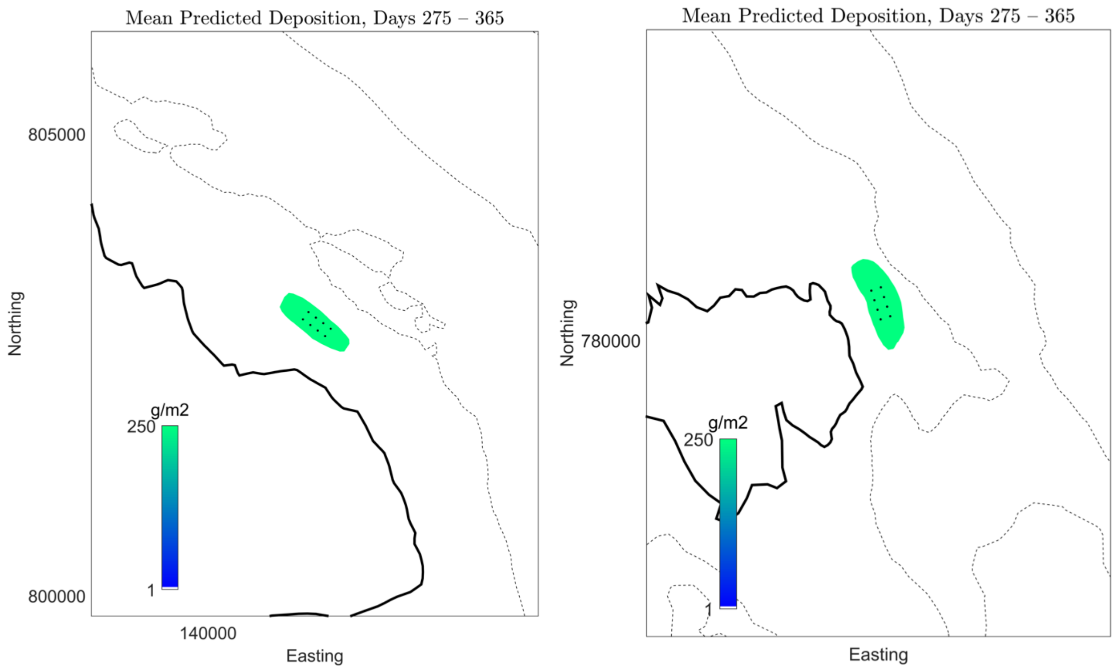

Figure 11. Modelled deposition footprints from the cumulative modelling at Rum (left) and Muck (right).

3.3 Solids Deposition and Sensitive Features

Several sensitive features have been identified (SEPA 2020) to be potentially at risk from sediment influence due to their proximity to the Isle of Rum site. The locations of these features are listed in Table 8. Figure 12 shows that the protected marine features (PMF) are not within the boundary of the modelled NewDepomod footprint. Figure 13 also shows that all PMF sites lie outwith the footprint generated from the marine modelling. The results indicate that the sensitive features should not be negatively impacted by sediment.

Table 8. Table of identified features close to the Rum site

Feature Name	Feature Type	Easting	Northing
Tall Sea Pen	PMF Species	139234	805633
		141455	806460
		141287	804755
Burrowed Mud	PMF Habitat	~3.8 km^2 area centered on 141999, 804130	

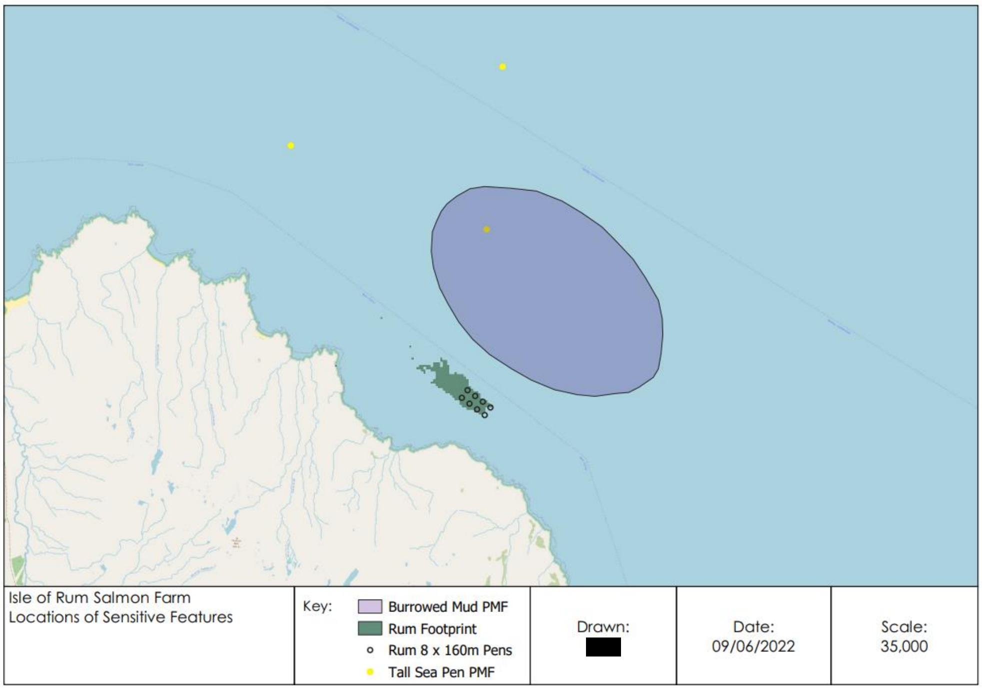

Figure 12. Identified PMF locations and the NewDepomod footprint for the proposed new layout at the Rum site. Locations of the Tall Sea Pen PMFs (●) and Burrowed Mud PMF (purple area) are indicated.

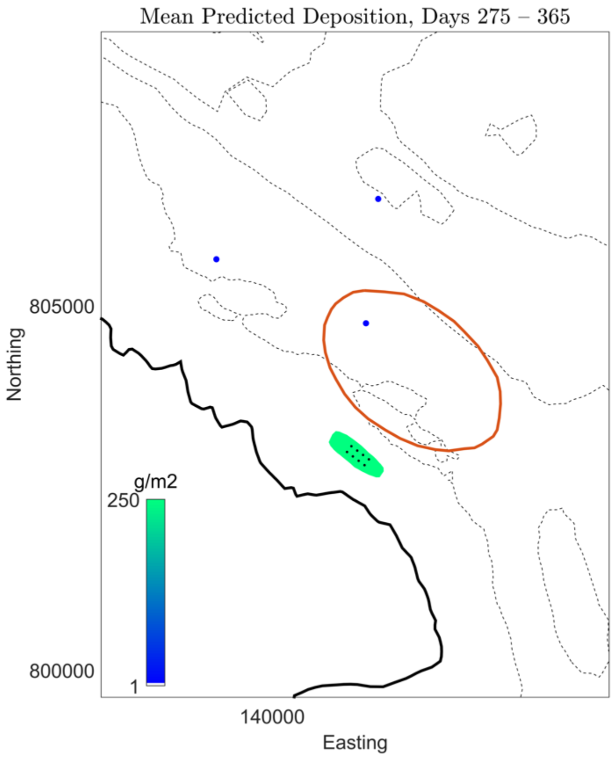

Figure 13. Identified PMF locations and the deposition footprint (shaded in green) predicted by marine modelling for the proposed new layout and biomass at the Rum site. Locations of the Tall Sea Pen PMFs (●) and Burrowed Mud PMF (red oval) are indicated.

4. SUMMARY AND CONCLUSIONS

The biomass of 3,300 tonnes requested for consent at the Rum site, and the associated feed loading (Table 9), has been shown to comfortably meet pertinent Environmental Quality Standards. The SEPA standard default method, which is designed to provide a conservative prediction of particulate deposition, suggested that deposition at the site will meet both mixing zone and deposition intensity criteria. The cumulative modelling also indicates that deposition from Rum will not interact with deposition from neighbouring sites at Muck and Canna, nor with nearby priority marine features.

Table 9. Summary of Results

Site Details	
Site Name:	Rum
Site Location:	Isle of Rum
Peak Biomass (T):	3,300
Feed Load (T/year):	8,431.5
Pen Details	
Number of Pens:	8
Pen Dimensions:	160m Circumference
Working Depth (m):	15
Configuration:	2x4, 100m matrix
NewDepomod Results	
Allowable Mixing Zone (m^2):	177,068
Maximum Deposition ($g\ m^{-2}$):	791.1
Modelled Footprint (m^2):	160,000
Mean Footprint Deposition ($g\ m^{-2}$):	378.1

5. REFERENCES

Gillibrand, P.A., 2021. *Unptrack* User Guide. Mowi Scotland Ltd., September 2021, 32 pp.

Gillibrand, P.A., B. Siemering, P.I. Miller and K. Davidson, 2016a. Individual-Based Modelling of the Development and Transport of a Karenia mikimotoi Bloom on the North-West European Continental Shelf. Harmful Algae, DOI: 10.1016/j.hal.2015.11.011

Gillibrand, P.A., Walters, R.A., and McIlvenny, J., 2016b. Numerical simulations of the effects of a tidal turbine array on near-bed velocity and local bed shear stress. *Energies*, vol 9, no. 10, pp. 852. DOI: 10.3390/en9100852

Gillibrand, P.A. and K.J. Willis, 2007. Dispersal of Sea Lice Larvae from Salmon Farms: A Model Study of the Influence of Environmental Conditions and Larval Behaviour. Aquatic Biology, 1, 73-75.

Marine Scotland, 2016. Scottish Shelf Model. Part 1: Shelf-Wide Domain. Available at https://data.marine.gov.scot/dataset/scottish-shelf-model-part-1-shelf-wide-domain

McIlvenny, J. , Tamsett, D., Gillibrand, P.A. and Goddijn-Murphy, L., 2016. Sediment Dynamics in a Tidally Energetic Channel: The Inner Sound, Northern Scotland. Journal of Marine Science and Engineering, 4, 31; doi:10.3390/jmse4020031

Mowi, 2022. Rum Hydrodynamic Model Description Report. Mowi Scotland Ltd, April 2022.

Pawlowicz, R.; Beardsley, B.; Lentz, S., 2002. Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE. Computers & Geosciences, 28, 929-937.

Scottish Association for Marine Science (SAMS), 2021, NewDEPOMOD Modelling Software. https://depomod.sams.ac.uk

SEPA, February 2020. Aquaculture Modelling Screening & Risk Identification Report: Rum RUM1. Scottish Environment Protection Agency, Air & Marine Modelling Unit

SEPA, 2022. Interim Marine Modelling Guidance for Aquaculture Applications. Scottish Environment Protection Agency, Air & Marine Modelling Unit, 25th January 2022.

Walters, R.A.; Casulli, V., 1998. A robust, finite element model for hydrostatic surface water flows. Comm. Num. Methods Eng., 14, 931–940.

Willis, K.J, Gillibrand, P.A., Cromey, C.J. and Black, K.D., 2005. Sea lice treatments on salmon farms have no adverse effect on zooplankton communities: A case study. *Marine Pollution Bulletin*, 50, 806 – 816.