NewDEPOMOD Modelling Report
Shapinsay (Veantrow Bay), Stronsay Firth

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1. Executive Summary

This report presents modelling undertaken by Scottish Sea Farms Ltd. for the proposed modification of the marine fish farm at Shapinsay (Veantrow Bay), Orkney (VEA1, CAR/L/1003931). The proposal would relocate the centre point 242m north, replacing the existing infrastructure with twelve 140m circumference pens and increasing the maximum biomass from 948t to 2,472.4t. Impact assessment followed current SEPA modelling guidance where solid and sea lice treatment discharges are simulated with NewDEPOMOD, initially configured as per the standard default approach, and later using a vertical dispersion coefficient (resuspension phase) that best represents the impact observed via the benthic monitoring at the existing site. Results indicate that the environmental impact from this proposal would meet all relevant EQS criteria. Proposed benthic sampling stations along four transects are detailed in the Environmental Monitoring Plan. Site details and recommended consent limits are summarised in Table 1.1.

Table 1.1 Proposal summary and recommended consent limits at Shapinsay (Veantrow Bay).

Infrastructure	Pen number and size: 12no. 140m circumference. Arrangement: 2x6 Pen separation: 100m Net depth: 7.5m
Biomass	A maximum biomass of 2,472.4t and stocking density 17.62kg/m^3
Emamectin benzoate (Slice)	A modelled maximum quantity of 26.83g equivalent to a Maximum Environmental Quantity (MEQ) of 19.36g.

2. Introduction

This document is a technical summary of an assessment undertaken by Scottish Sea Farms Ltd. using NewDEPOMOD and BathAuto for a proposed relocation and change to the configuration of the Shapinsay (Veantrow Bay) marine fish farm (hereafter referred to as Shapinsay). Information on the methodologies employed and in the accompanying modelling files are intended to support an application to the Scottish Environment Protection Agency (SEPA) under the Controlled Activities Regulations ((CAR) 2011) to vary the existing permit for the site by providing the proposed maximum biomass and quantity of the sea lice treatment Slice (active ingredient emamectin benzoate), in addition to defining an Environmental Monitoring Plan.

2.1 Site details

The Shapinsay marine fish farm is located within Veantrow Bay to the north of the island of the same name, on the southern side of Stronsay Firth, Orkney (Figure 2.1). The site is strongly influenced by tidal currents with a mean spring range of 2.5m (Tingwall), as well as being exposed to a large fetch to the north and northeast. The proposed relocation of the site increases the distance to the shore from 1.63 m to 1.70 m into more dispersive waters while slightly increasing the mean depth beneath the pens from approximately 17.8 mCD to 18.5 mCD. Details of the existing and proposed infrastructure are provided in Table 2.1.

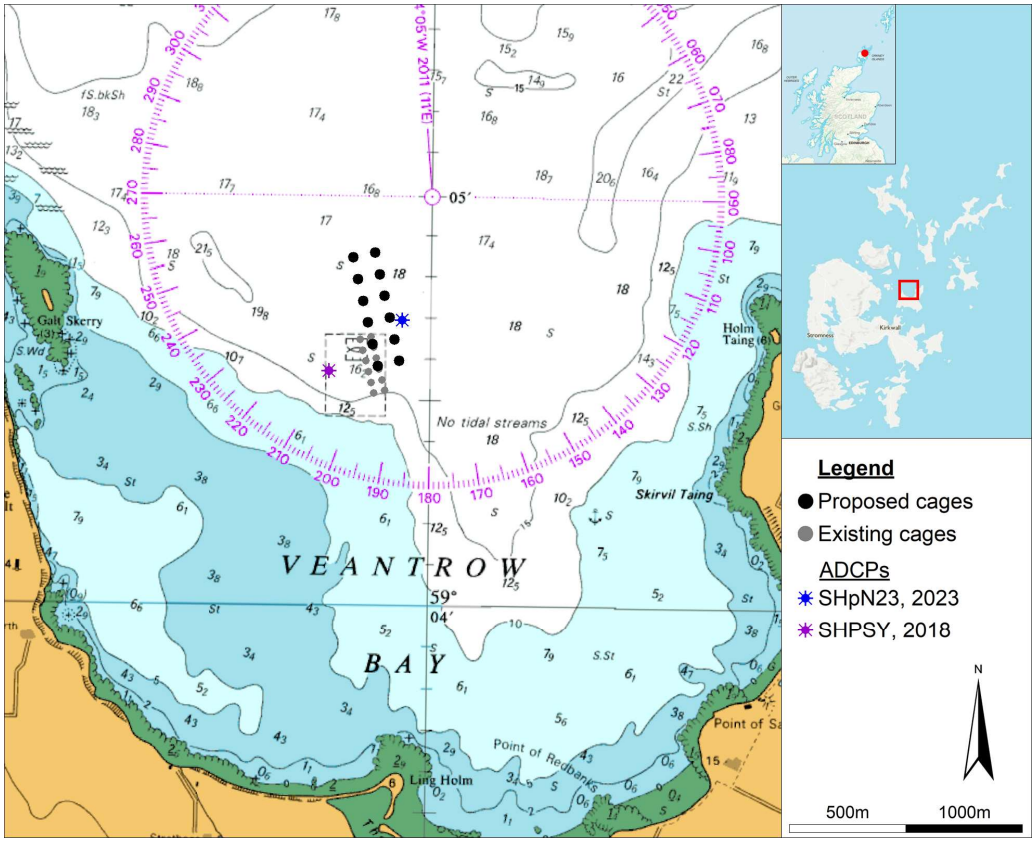

Figure 2.1 Location of the Shapinsay marine fish farm illustrating the ADCP deployments relative to the proposed and existing pens.

Table 2.1 Shapinsay site infrastructure and consent details.

Parameter	Existing	Proposed
Pens group centre location (OSGB36)	350153E, 1021387N	350176E 1021628N
Number of pens	12	12
Pens circumference	100m	140m
Net depth	10m	7.5m
Mooring grid spacing	50m	100m
Orientation	349.7°	347.4°
Layout	2 x 6	2 x 6
Average water depth	17.8mCD	18.5mCD
Distance to shore (site centre)	1.63km	1.70km
Maximum biomass	948.0t	2472.4t
Emamectin benzoate	TAQ[1]: 2,048.2g	MEQ: 19.36g
Azamethiphos[2]	3hr: n/a, 24hr: 191g	3hr: 455.5g, 24hr: 1,366.5g
Deltamethrin[2]	3hr: 13.48g	3hr: 55.0g
Stocking density	9.93kg m^{-3}	17.62kg m^{-3}

[1]The Total Allowable Quantity (TAQ), now known as the 'modelled max quantity', is equivalent to a Maximum Environmental quantity (MEQ) of 1,478.3g.
[2]Refer to the accompanying *Bath Dispersion Marine Modelling Report* for derivation of the proposed quantities.

3. Model input details

3.1 Proposal

NewDEPOMOD version 1.4.2-rc02 final was configured according to the "standard default" approach as outlined by SEPA (SEPA, 2023a). The project was named *ShapinsayC2023* and was generated using the user interface with the input, physical, configuration and model properties files subsequently modified according to the aforementioned guidance.

The proposed site has a predicted Wave Exposure Index of 2.93 at the ADCP location (Marine Scotland, 2014). As this is greater than 2.8, to meet the extent EQS the total area impacted with deposition above 250g m^{-2} should not exceed 120% of the calculated 100m Mixing Zone area (using the standard default approach). The mean deposition within the Mixing Zone should not exceed 4,000g m^{-2} to satisfy the intensity EQS. Assessment is based the mean deposition over the final 90-days of output from the model run.

3.1.1 Hydrographic data

The standard default approach requires a uniform flow field from one or more current meter deployments with a combined duration of at least 90-days. A hydrographic survey was undertaken at the proposed site in 2023 and these data are used to create the 90-day flowmetry. Full details regarding data collection, processing, and summary statistics can be found in the accompanying document *Shapinsay (Veantrow Bay), Modelling Data Collection Report*, March 2024. These data have been approved by SEPA to use in a modelling assessment.

Summary statistics for the 90-day flowmetry are repeated in Table 3.1. Located where Veantrow Bay meets Stronsay Firth the site is significantly influenced by the strong tidal streams present in the latter. Currents are primarily bi-directional through the water column along a NW-SE axis. Some variation is observed in the vertical profile with a greater influence of currents to the SE present nearer the seabed. The flow field across the 4 km^2 model domain is expected to show variation in current speed and direction with slower velocities in the southern part and more energetic conditions to the north. This is corroborated by other ADCP records from the bay and by the flow fields derived from the validated hydrodynamic model (Danish Hydraulic Institute, 2022).

Table 3.1 Summary statistics for the 90-day flowmetry at Shapinsay (SHpN23 deployment).

Position and depth (m)	350293E 1021578N, 19.18mCD		
	Near-bed	**Cage-bottom**	**Sub-surface**
Height above seabed (m)	2.7	12.7	15.7
Mean velocity (m s^{-1})	0.101	0.118	0.120
Min velocity (m s^{-1})	0.000	0.001	0.002
Max velocity (m s^{-1})	0.417	0.468	0.503
Ranked percentage 0.095 m s^{-1}	55.7%	45.8%	43.7%
Major axis (°G)	110	115	120
Amplitude anisotropy	2.35	2.39	2.11
Residual velocity (m s^{-1})	0.052	0.071	0.072
Residual velocity as % of mean	51.4%	60.6%	60.1%
Residual direction (°G)	119.6	126.4	123.4
Parallel Residual (m s^{-1})	0.051	0.070	0.072
Normal Residual (m s^{-1})	0.009	0.014	0.004
Parallel tidal amplitude (m s^{-1})	0.141	0.160	0.160

Continued…

Table 3.1 continued.

Normal tidal amplitude (m s^{-1})	0.060	0.067	0.076
	Min	**Max**	**Range**
Depth (m)	19.0	22.1	3.1

The residual current in the near-bed layer is 51.4% of the mean velocity, exceeding the threshold defined by SEPA whereupon the residual component should be removed from the flow data used in the standard default approach to determine maximum biomass. Comparative runs were also undertaken with the full flow flowmetry.

The vertical dispersion coefficient for the resuspension phase ($\sigma_{z,r}$) is defined using the mean flow speed (u) in the near-seabed layer from the 90-day dataset according to:

$$\sigma_{z,r} = 0.0003\ u^{-0.762}$$

Table 3.2 details the vertical dispersion coefficients for the flowmetries used.

Table 3.2 Flowmetry specific vertical dispersion coefficients (σz,r).

Flowmetry	Near-bed mean speed (m s^{-1})	Vertical dispersion coefficient (m^2 s^{-1})
Full Flow	0.101	0.001722721
No residual	0.091	0.001870205

3.1.2 Bathymetry

The area is well represented in the local Admiralty Chart (ref. 2584-0 *Approaches to Kirkwall*, 1:25,000) however due to a lack of survey coverage on the UKHO Marine Data Portal, a bathymetry survey was undertaken in the bay in 2018. The model domain is a 2 km x 2 km regular grid made up of 25 m grid cells with the following bounding coordinates:

Domain.spatial.minX= 349190
Domain.spatial.maxX= 351190
Domain.spatial.minY= 1020600
Domain.spatial.maxY= 1022600

As there is no land boundary in the model domain the uniform bathymetry array required under the standard default approach configuration was created using the ADCP depth (-19.18m). Apart from to the southwest where the seabed shoals towards the shore, this depth is representative of most of the model domain.

3.1.3 NewDEPOMOD inputs

As per standard default approach requirements the waste discharge timeseries was based on the site constantly being at the proposed maximum biomass for a 365-day simulation period. This is generated using the parameters outlined in SEPA 2023a, namely a feed rate of 7 kg per tonne biomass per day, a waste feed rate of 3%, feed water content at 9% and feed digestibility of 85%. The infeed treatment emamectin benzoate (EMBZ) is modelled over a 118-day simulation period using the recommended dose rate of 50 µg of EMBZ per kg of biomass per day for the 7-day treatment period, with 97% of the medicated feed consumed and 3% associated with waste feed. Of the consumed feed 10% of the EMBZ load is excreted immediately with the remaining 90% excreted at an exponential rate according to an excretion half-life of 36 days.

3.2 Existing site

A second project named *Veantrow2022* was created in order to perform a basic calibration of the modelled impact here against the benthic survey monitoring data. This is largely configured according to the standard default approach with departures from this detailed below.

Pen positions for the existing site are derived from Google Earth aerial imagery (2021).

3.2.1 Hydrographic data

A hydrographic survey was undertaken at the existing site in 2018 (identifier; SHPSY) and these data are used to create the uniform flowmetry. With a duration of 64-days this survey falls short of the 90-days required, however the clear tidal signature at this location mitigates any impact of this. A full survey description is also included in the modelling data collection report. These data have been approved by SEPA for use in this assessment.

The residual current in the near-bed layer is 7% of the mean velocity therefore the residual component need not be removed from the flow data.

The second variation on the standard default approach involves running the simulation with various vertical dispersion coefficients to find the value where the total area impacted with deposition above 250g m^{-2} is equal to the IQI 0.64 area observed during the 2022 benthic monitoring survey (74,402m^2). A total of 27 values for the vertical dispersion coefficient were considered (Table 3.3).

Tabel 3.3 SHPSY Vertical dispersion coefficients considered.

Value	Vertical dispersion coefficient (m^2 s^{-1})
Minimum	0.000600000
Maximum[3]	0.002344766
Mean increment	0.000067106
Optimal	0.000645000

[3]Equates to the value calculated from the near-bed mean speed from the SHPSY dataset.

3.2.2 Bathymetry

The 2 km x 2 km modelling domain is bounded by the following coordinates:

Domain.spatial.minX= 349158
Domain.spatial.maxX= 351158
Domain.spatial.minY= 1020377
Domain.spatial.maxY= 1022377

The uniform bathymetry array uses the SHPSY ADCP depth (-17.22m).

3.2.3 NewDEPOMOD inputs

Inputs for solids waste representing the existing licenced maximum biomass at this site (948t) remain as per standard default approach detailed in Section 3.1.3.

3.3 Emamectin benzoate (EmBZ)

To establish the maximum permissible quantity of emamectin benzoate for the proposal, compliance is assessed against the requirements outlined in current SEPA guidance (SEPA, 2023a) and the interim position statement for emamectin benzoate (SEPA, 2023b). The latter, with respect to changes to the layout of fish pens, applies to the proposal as both the centre-to-centre distance and the overall increase in site length exceed 180m.

For proposals at existing sites the intention is that the risk of environmental harm is not increased which requires that the existing infrastructure is modelled at the presently licenced EmBZ quantity to establish the extent of deposition at the interim EQS (272 ng kg^{-1} dry weight sediment/136 ng kg^{-1} wet weight sediment). This is based on a modelled maximum quantity of 2,048.2g which for the proposal is an initial overtreatment factor of 2.37. A quantity of emamectin benzoate for the proposal is determined by lowering the overtreatment factor until the degree of non-overlap resulting from the proposal is not considered significant; namely that the seabed impacted by new areas of deposition is below 15% of the existing impact. This must be demonstrated for both standard default and calibrated modelling approaches. This assessment requires that both modelling domains have the same extents, therefore the bathymetry for the proposal is redefined to have the same bounding coordinates as the existing site as given in Section 3.2.2.

3.4 NewDEPOMOD run details

All runs are undertaken with 10 particles and are detailed in Table 3.4 below.

Table 3.4 Model run details.

ShapinsayC2023 (Proposed site)			
Identifier	**Run type**	**Flowmetry**	**Vertical dispersion coefficient (m^2 s^{-1})**
2	Biomass	SHpN23 – Full flow	0.001722721
3	Biomass	SHpN23 – No residual	0.001870205
10.1 to 10.3	Biomass (calibrated)	SHpN23 – No residual	0.000645000
12	EmBZ	SHpN23 – No residual	0.001870205
13	EmBZ (calibrated)	SHpN23 – No residual	0.000645000
Veantrow2022 (Existing site)			
5.1 to 5.3	Biomass (calibrated)	SHPSY – Full flow	0.000645000
7	EmBZ	SHPSY – Full flow	0.002344766
8	EmBZ (calibrated)	SHPSY – Full flow	0.000645000

4. Modelling Results

4.1 Biomass results

4.1.1 Standard default approach

Output was analysed using MATLAB with scripts derived from SEPA on the average surface of the final 90 days of the model run. EQS compliance is achieved at a maximum biomass of 2,472.4t with deposition covering 67% of the allowable Mixing Zone area (expanded) and at a level of 8% of the intensity standard (Table 4.1, Figure 4.1).

Table 4.1 Shapinsay NewDEPOMOD biomass results assessment, ShapinsayC2023 Run 3.

Parameter	Value
Extent EQS	
100m allowable Mixing Zone area (m^2)	239,511
Extended Mixing Zone area (120%) (m^2)	287,413
Area of mean deposition ≥250g solids m^{-2} yr^{-1} (m^2)	186,875
Intensity EQS	
Mean Mixing Zone deposition standard (g m^{-2} yr^{-1})	4,000
Mean deposition within 250g m^{-2} yr^{-1} solids impact area (g m^{-2} yr^{-1})	316

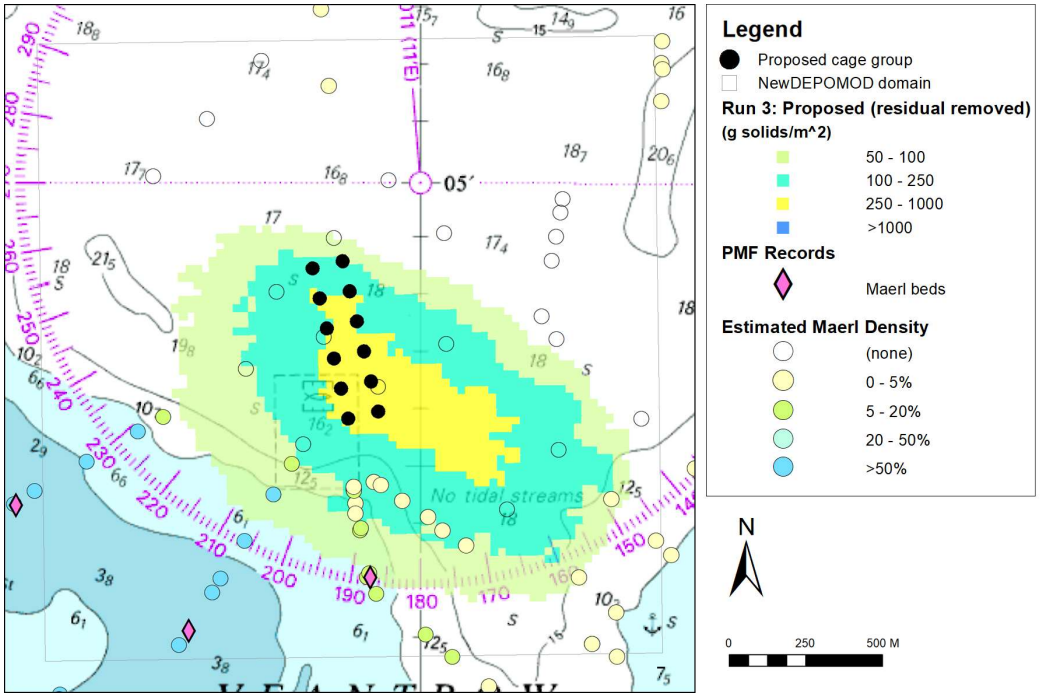

Figure 4.1 Mean solids deposition from the last 90-days of ShapinsayC2023 Run 3 with residual currents removed. Nearby maerl bed biotope Priority Marine Features (PMF) records are also plotted, along with estimated maerl density observations from the visual surveys conducted 2022-23.

Removing the residual component in the near-seabed layer allows for an improved estimate of the extent of benthic impact at the site. However, it is unlikely that this adequately represents the location where the impact forms. When compared to the run using the 'full flow' flowmetry (Run 2, Figure 4.2) it would appear that displacement of lighter deposition to the southwest results from the residual component being removed. As this has the potential to misrepresent impact to sensitive maerl habitats, recorded as Priority Marine Features (PMF) and estimates of maerl density from the baseline visual survey footage (Aquatera, 2023), the model was calibrated to reflect the benthic impact from the existing farm.

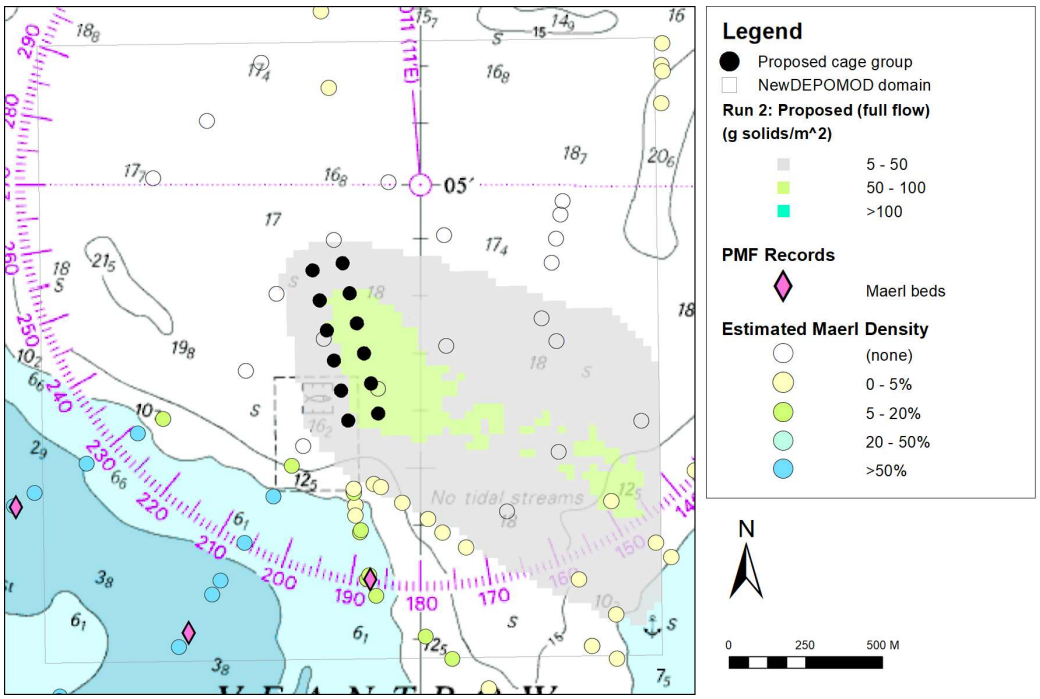

Figure 4.2 Mean solids deposition from the last 90-days of ShapinsayC2023 Run 2 including the residual component.

4.1.2 Calibrated modelling approach

Results from the December 2022 benthic monitoring indicate an impact area of 74,402m^2 at an IQI of 0.64, representing 60% of the allowable Mixing Zone for the existing site. Assuming the default conservative relationship that 250g solids m^{-2}yr^{-1} is a proxy for IQI 0.64 then basic tuning through altering the vertical dispersion coefficient for the resuspension phase can be undertaken until the modelled impact area at 250g solids m^{-2}yr^{-1} is approximately equal to 74,402m^2. Figure 4.3 illustrates the deposition using the optimal value for the vertical dispersion coefficient; 0.000645 m^2 s^{-1}, with individual run results detailed in Table 4.2. The footprint shows good visual agreement with the gradient of impact from the pens as indicated by the IQI scores.

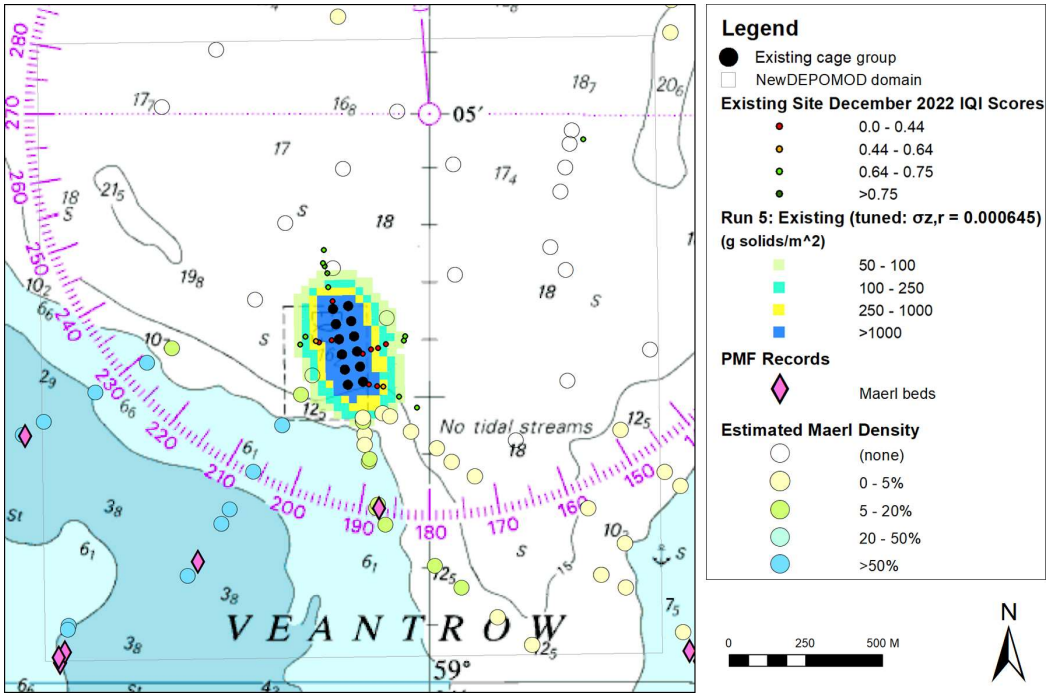

Figure 4.3 Mean solids deposition from the last 90-days of Veantrow2022 Run 5 (average surface of 3 runs) using the tuned vertical dispersion coefficient which equates to an impact area at 250g solids m^{-2}yr^{-1} of 75,208m^2. IQI scores from the December 2022 monitoring survey are overlain equivalent to an observed impact area of 74,402m^2.

Table 4.2 Existing site calibration results summary, Veantrow2022 Run 5.

Run	Area of mean deposition ≥250g solids m^{-2} yr^{-1} (m^2)	Mean deposition within 250g m^{-2} yr^{-1} solids impact area (g m^{-2} yr^{-1})
5.1	74,375	4,371
5.2	79,375	4,100
5.3	71,875	4,525
Mean	75,208	4,332

The vertical dispersion coefficient derived from calibration was applied to the proposal, replacing the value used in the standard default approach. Again, three replicate runs were undertaken. EQS compliance is achieved at the target biomass of 2,472.4t with deposition covering 94% of the allowable Mixing Zone area and at a level of 74% of the intensity EQS (Table 4.3, Figure 4.4). For calibrated modelling the latter is defined as being no greater than a 15% increase in mean deposition from the existing site configuration. The shape, displacement and intensity of the deposition are in accordance with that expected as demonstrated by the compliance monitoring at the existing site with limited interaction with maerl habitats to the south and southwest.

Table 4.3 Shapinsay calibrated NewDEPOMOD biomass results assessment, ShapinsayC2023 Run 10.

EQS	100m allowable Mixing Zone area (m^2)[4]	Mean Mixing Zone deposition standard[5]
Value	239,511	4,982
Run	**Area of mean deposition ≥250g solids m^{-2} yr^{-1} (m^2)**	**Mean deposition within 250g m^{-2} yr^{-1} impact area (g m^{-2} yr^{-1})**
10.1	226,250	3,688
10.2	228,750	3,641
10.3	220,625	3,778
Mean	225,208	3,703

[4]The extended, 120% allowable Mixing Zone area is not applicable to calibrated modelling.
[5]This value is 15% greater than the mean deposition of the existing calibrated configuration.

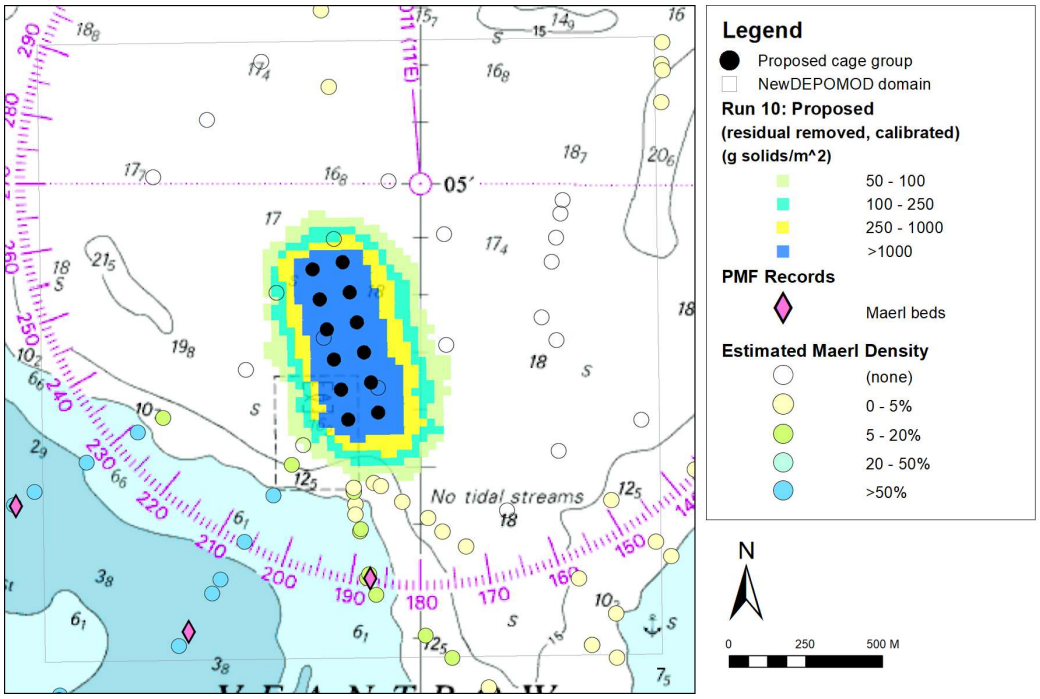

Figure 4.4 Mean solids deposition from the last 90-days of ShapinsayC2023 Run 10 with residual currents removed and using the vertical dispersion coefficient derived from calibrating the model to the benthic impact at the existing site.

4.1.3 Proposed Environmental Monitoring Plan

Biological sampling

Benthic monitoring transects and sampling stations are defined according to SEPA guidance (SEPA, 2022 & email SEPA, 2024) to inform the proposed Environmental Monitoring Plan submitted with this application. The default monitoring plan will be followed where four sampling transects are position running seaward from each side of the pen group. The two primary transects are aligned with the near-bed major axis of the tidal ellipse (110-290°). Minor transects are defined perpendicular to these to create an orthogonal arrangement (Table 4.4, Figure 4.5). Transect 2 to the southwest will overlap with residual impacts on the seabed from the operation of the farm in its pervious location.

Table 4.4 Shapinsay biological sampling transect details.

Transect	Bearing (°G)	Target length (m)
T1	110	240
T2	200	240
T3	290	180
T4	20	150

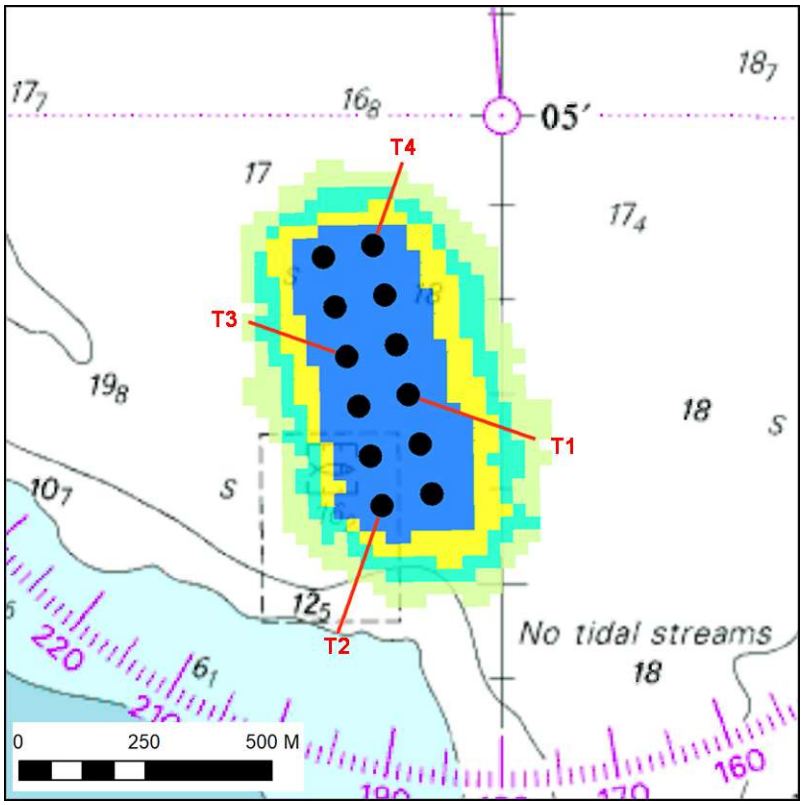

Figure 4.5 Shapinsay proposed biological sampling transects.

Visual monitoring

Visual monitoring of maerl habitats to the south and southwest of the pen group is specified along three of the original baseline survey transect lines and at three reference locations. The first 100m of transects C08 and C09 will overlap with the farm in its pervious location. Transect identifiers preserve continuity with baseline survey naming convention (Table 4.5, Figure 4.6).

Table 4.5 Shapinsay visual monitoring transect details.

Transect	Origin	Bearing (°G)	Target length (m)
C08	Pen 1	171	500
C09	Pen 2	213	500
C10	Pen 4	241	700
Ref1	350634, 1020492	118	100
Ref2	349658, 1020700	213	100
Ref3	349116, 1021132	241	100

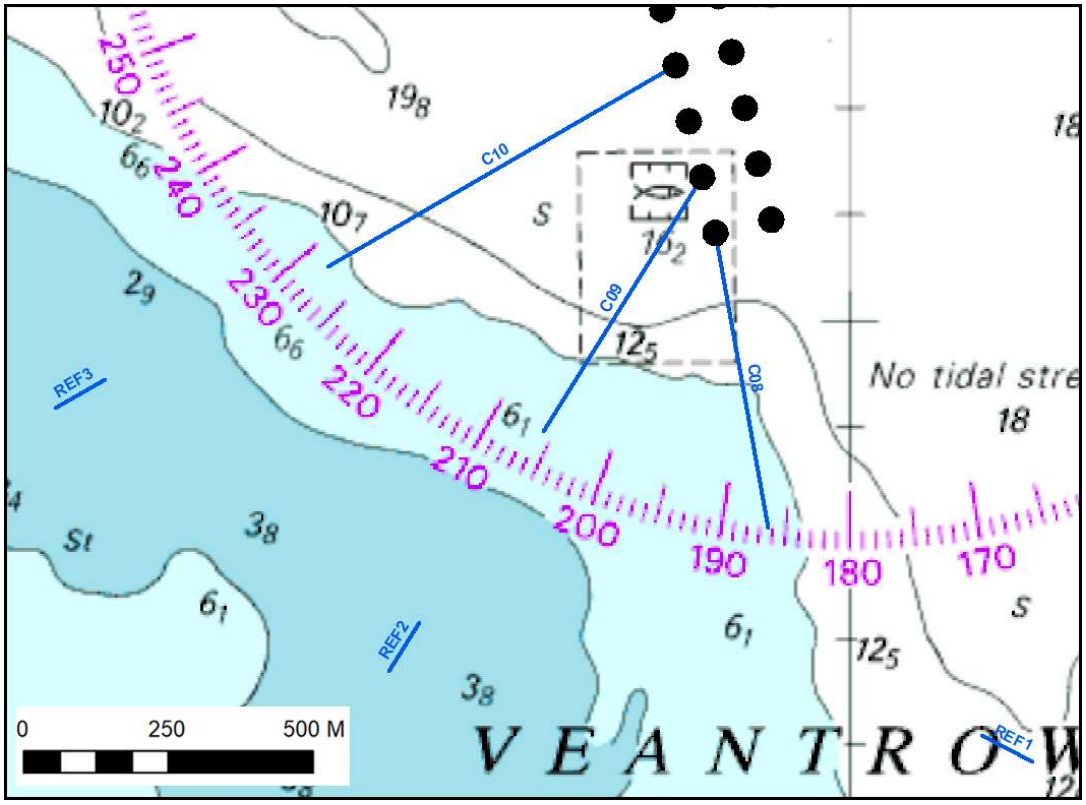

Figure 4.6 Shapinsay proposed visual monitoring transects.

4.2 Emamectin benzoate results

Output for the existing and proposed layouts were analysed using MATLAB with scripts derived from SEPA on the aggregate surface for the final 2 days of the model runs.

Initial runs modelled the licenced TAQ (2,048.2g) at the existing site and the proposal using both the standard default and calibrated modelling approaches. As the degree of non-overlap of the footprint was greatest for the calibrated model (96%) the overtreatment factor was reduced to seek the quantity that satisfied the assessment criteria. However, even using an overtreatment factor of 0.031 (the value which would be compliant with the EQS if the proposal were a new site) the degree of non-overlap was 23% (Table 4.6, Figure 4.7, right panel). Due to the greater dimensions of the proposed site compared to the existing pen group a degree of non-overlap below the 15% threshold is not possible using the calibrated model configuration. With the standard default settings, the area of deposition from the proposal is almost entirely within the predicted footprint from the existing site with a negligible degree of non-overlapping areas (0.1%).

Table 4.6 Shapinsay NewDEPOMOD emamectin benzoate results assessment.

Parameter	Value	
Overtreatment factor	0.031	
Modelled max quantity (g)	26.83	
Equivalent biomass (t)	76.64	
Maximum Environmental quantity (MEQ) (g)	19.36	
100m Allowable Mixing Zone area (m^2)	239,511	
Model configuration	Standard default	Calibrated
Area of mean deposition ≥136 ng kg^{-1} sediment (wet weight) (m^2)	225,000	213,125
Non-overlap (%)	0.1	23.0

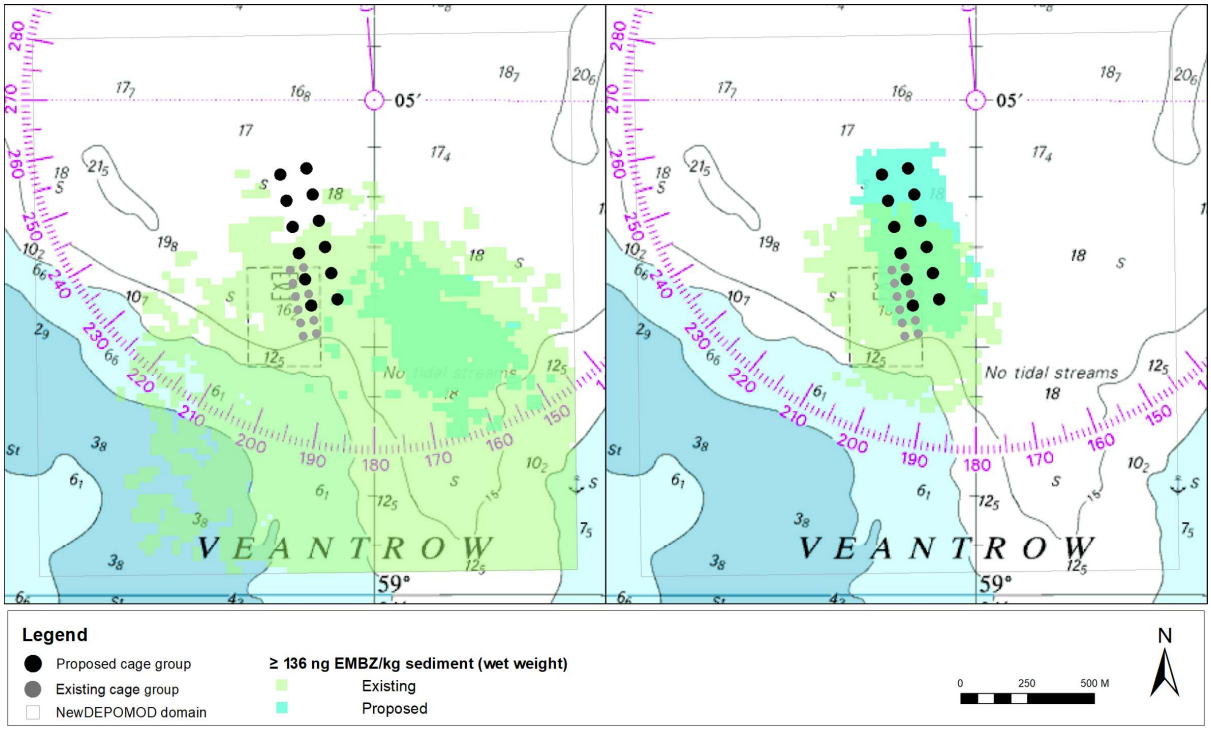

Figure 4.7 Mean emamectin benzoate deposition from the last 2-days of ShapinsayC2023. Left panel; standard default configuration (Run 12). Right panel; calibrated (Run 13).

As the area of new seabed affected by deposition above the EQS is greater than 15% of the existing impact area then the recommended quantity of emamectin benzoate is that where the area of mean deposition ≥136 ng kg^{-1} sediment (wet weight) does not exceed the allowable 100m mixing zone. Both standard default and calibrated modelling approaches satisfy this criteria and show comparable areas of deposition.

4.2.1 Proposed Environmental Monitoring Plan; chemical residues sampling

The proposed transects for emamectin benzoate residue sampling are the same as those outlined for biological sampling, with stations to be specified by SEPA in the CAR licence.

5. Conclusions

NewDEPOMOD simulations using the conservative standard default approach demonstrate that the proposed re-configuration of the Shapinsay fish farm would meet the relevant EQS criteria. At the proposed maximum biomass of 2,472.2 tonnes 67% of the available Mixing Zone area would be utilised at this moderately exposed site with the mean deposition within this area at level which is 8% of that permitted.

The standard default approach requires that the residual flow be removed from the near-seabed flowmetry to ensure that the extent of the impact is adequately represented. This influences the spatial distribution of the footprint, extending to the south and west towards maerl habitats in a direction not aligned with the tidal axis or the residual transport. Additionally, a large overall footprint characterised by a gentle flux gradient towards areas of lighter deposition are reflected in a very low mean intensity in the mixing zone. This is not consistent with the benthic impact observed through monitoring at the existing site which demonstrates that the footprint is more compact and contained to the vicinity of the pens.

NewDEPOMOD was therefore calibrated by adjusting the vertical dispersion coefficient until the extent of deposition ≥250g m^{-2} yr^{-1} at the existing site matches the monitored 0.64 IQI footprint here. This results in a greater mean intensity which is expected considering the pen edge IQI scores observed. When this tuned parameter is used to model the proposed site the extent and intensity EQS criteria remain satisfied, and the footprint is no longer predicted to influence sensitive maerl habitats.

Modelling emamectin benzoate according to the SEPA interim position statement predicts that the area of new seabed affected would be greater than 15% of the area already impacted at the present licenced quantity at the existing farm. This is despite reducing the quantity applied for to the level that meets the extent EQS for new farms. Equivalent to an overtreatment factor of 0.031, a modelled maximum quantity of 26.83g would be sufficient to treat 76.64t biomass.

An Environmental Monitoring Plan is proposed with four benthic sampling transects running seaward from each side of the pen group. Additionally visual monitoring of maerl habitats would be undertaken along three of the original baseline survey transect lines and at three reference locations.

6. References

Aquatera (2023). Veantrow Bay Benthic Video Surveys 2020 – 2023. October 2023.

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