Deposition Marine Modelling Report

Shapinsay (Veantrow Bay), Orkney

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1 Summary

This report describes simulations of deposition based on the outputs of a hydrodynamic model which was developed for the Orkney Isles, with a focus on the Veantrow Bay area to the north of the island of Shapinsay. The aim of the investigation was to provide a risk assessment for deposition resulting from a proposed site expansion within the bay (details in Table 1.1), in addition to potential interaction with footprints from other nearby sites.

A single scenario involving feeding at a fixed rate while stocking at peak biomass for a full year was simulated. This provides an upper limit on the anticipated impact.

Table 1.1 Summary of site details and model results

Site details	
Site Name	Shapinsay (Veantrow Bay)
SEPA ID	VEA1
Locality	Orkney Isles
Pen centre (OSGB easting/northing, m)	350176, 1021628
Biomass (T)	2472.4 (applied for)
Configuration	
Number of pens (configuration)	12 (100 m grid, 2 x 6)
Pen size	140 m circumference
Pen group distance to shore	1700 m
Pen grid orientation	347.4^{o}
Depth (m)	19.18 m

2 Introduction

This report has been prepared by Scottish Sea Farms Ltd. to meet the requirements of the Scottish Environmental Protection Agency (SEPA) for an application for a site expansion in Veantrow Bay, Shapinsay, Orkney Islands ("VEA1"; Figure 2.1 and Figure 2.2), and in particular to investigate the movement of waste feed and faeces released from the site.

The report describes the application of a particle tracking model to estimate the spread of waste material from the proposed site and its neighbours. The particle tracking model is forced by the outputs of a hydrodynamic model which was developed specifically for this work. Full details of the development, calibration and validation of the hydrodynamic model are given in a dedicated report (Danish Hydraulic Institute 2022).

The modelling procedure follows the current version of SEPA marine modelling guidance as available at January 2022, as far as possible.

The site configuration is composed of 12 x 140 m pens on a 100 m grid, with centre-point of cage grid at (OSGB 350176, 1021628) m. Key data relating to the site are summarised in Table 1.1.

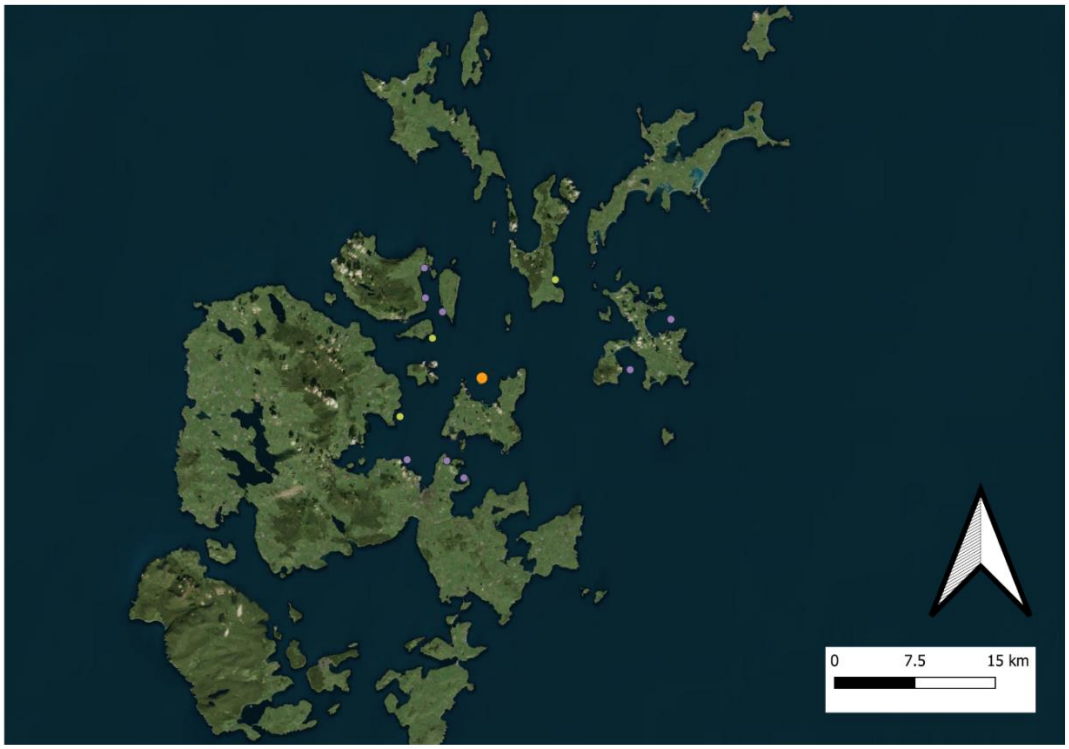


Figure 2.1 **Map showing broad location within Orkney Islands (Shapinsay site: orange disc; other salmon farms: green (SSF) and mauve (Cooke) discs).**

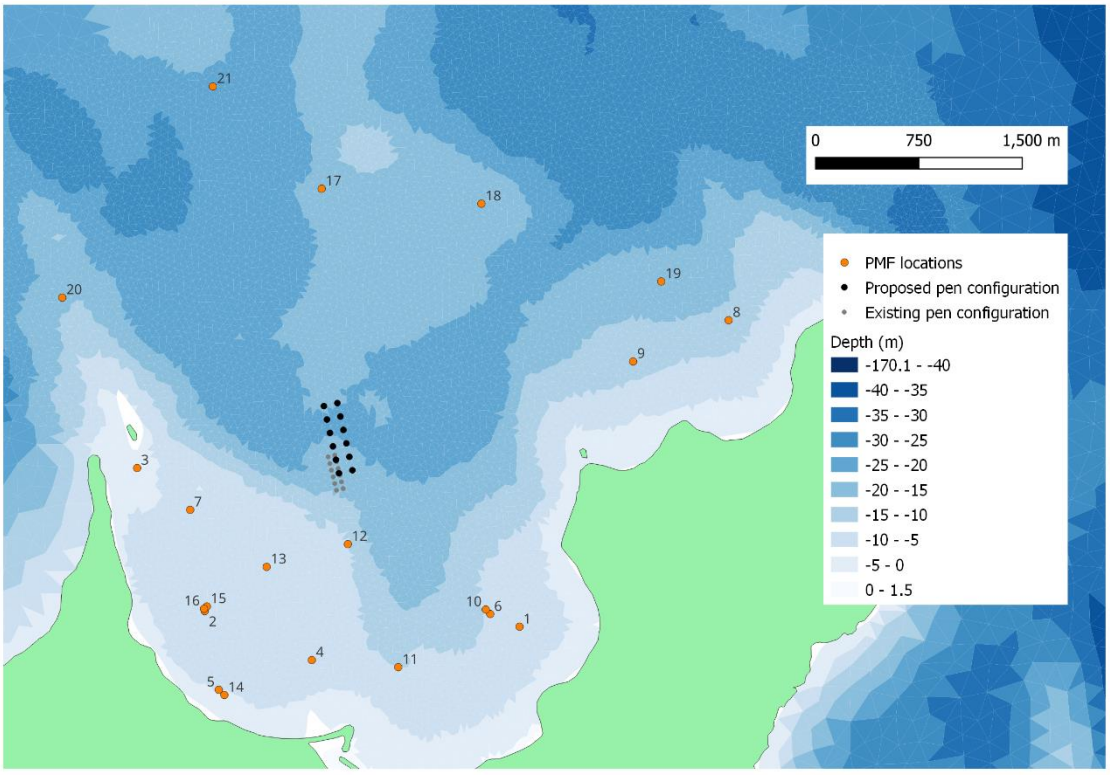


Figure 2.2 **Map of site location, showing proposed and existing site layouts (black/grey discs), and the locations of sensitive Priority Marine Feature (PMF) records identified by SEPA in their Risk Identification Report for the site (orange).**

3 Methodology

3.1 Dye and drogue study

A dye and drogue study was commissioned with Anderson Marine Surveys Limited (AMSL). This study was carried out in the proximity of the proposed site location, with the dual objectives of i) identifying horizontal dispersion parameters in the locality, and ii) checking that the movements predicted by the particle tracking model were realistic.

The dye/drogue study is described in detail elsewhere (Anderson Marine Surveys 2022) and key results and comparison with model predictions are described in the hydrodynamic modelling validation report.

3.2 Hydrodynamic model

The hydrodynamic model used in this work was the DHI MIKE 21 FM numerical modelling system, which has been developed for general simulation of water flows in estuaries, bays and coastal areas, in addition to wider ocean domains. MIKE 21 is a three-dimensional model which can account for density variation, currents and tidal elevation (Danish Hydraulic Institute 2017).

MIKE 21 is a finite volume hydrodynamic model, using an unstructured spatial mesh formulation which allows representation of fine scale features in coastline and bathymetry while retaining computational efficiency through a coarser mesh in simpler areas. Horizontal elements in the model can be triangular or quadrilateral; the model described here used exclusively triangular elements. This approach is particularly important for complex coastal regions such as the Scottish west coast. A similar method is used by other current hydrodynamic models such as FVCOM (Chen et al. 2013). This allows simulation of spatial domains that were not possible with earlier regular-grid models such as POLCOMS and ROMS, which were developed with wider ocean regions in mind.

The hydrodynamic model domain extended from the Moray Firth in the south to the Shetland Isles in the North, with the highest resolution areas focused on the Orkney Isles and in particular the focal site in Veantrow Bay (Figure 3.1). The hydrodynamic simulations covered two periods: i) a “climatological” year (25-year average meteorological and oceanographic forcing from 1993-2017), and ii) a 13-month period 01/06/2017-01/07/2018, which was validated against available current meter observations for the focal site and other nearby sites. The outputs of the latter (specific time period) simulation were applied here. The HD model output timestep was 30 minutes. Full details of the development, calibration and validation of the hydrodynamic model are given elsewhere (Danish Hydraulic Institute 2022, and in the HD model validation report submitted with this application).

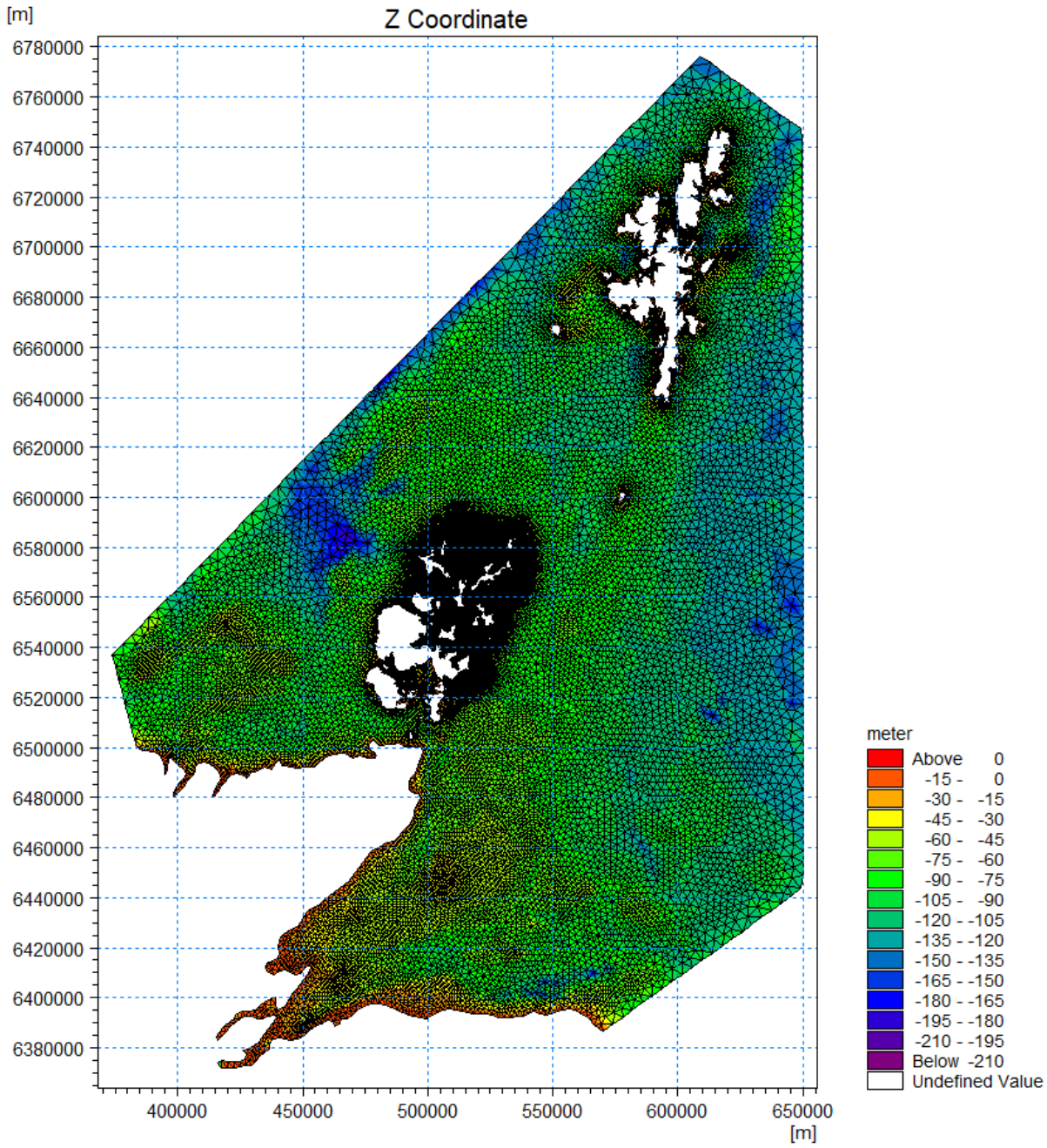


Figure 3.1: **Mesh for hydrodynamic model, showing the full extent of the spatial domain, which covers Orkney, Shetland, and a portion of the Scottish mainland coast. Resolution is highest around Orkney, in particular Veantrow Bay.**

3.3 Particle Tracking model

Particle tracking was also carried out using the DHI MIKE software suite (Danish Hydraulic Institute 2021). Flow fields (U/V/W velocities) generated by MIKE 21 were used to drive the movement of passive particles (no active horizontal or vertical movement) in the water column. Particles were subject to advection due to currents, and horizontal and vertical diffusion (described by a random walk formulation) at fixed rates of 0.1 and 0.001 $m^2 s^{-1}$ respectively. Current speeds at all depths were taken to be uniform and equal to the 2D depth averaged velocity computed by the HD model.

Separate simulations were carried out for waste feed and faeces, with specific sinking rates being applied to each class of particle:

- Waste feed = 0.095 m s^{-1}
- Waste faeces = 0.032 m s^{-1}

Particles were allowed to settle on the seabed but no consolidation was included in the model. Erosion and resuspension from the seabed was modelled using a critical erosion threshold of 0.02 N m^{-2}. Based on direct guidance from SEPA (email 06/07/2022), no bed shear profile was included, meaning that the depth averaged velocities were applied directly in calculating shear stress (and erosion) at the sea bed. This provides an upper bound on the distance travelled by waste material but has the effect of reducing intensity of the local footprint and generating accumulations at more distant locations with lower HD model flows.

The horizontal mesh used for particle tracking was finely resolved over a larger spatial extent than the mesh used to simulate the hydrodynamics. Resolution of hydrodynamic model mesh is constrained by computational processing capacity, and the need to obtain a balance between resolution and spatial extent of the model domain, which also has an impact on accuracy of predictions. High horizontal resolution in areas of deeper water requires a very short hydrodynamic model timestep, which is not feasible for a model of this spatial and temporal extent. The mesh used to carry out particle tracking simulations is shown in Figure 3.2, and histograms of mesh statistics are shown in Figure 3.2. In the highest resolution areas (extending 2-3 km around all sites), element side length is around 50 m, and element area is around 1100 m^2.

A timestep of 180 s (3 minutes) was used for particle tracking. Half-hourly hydrodynamic model velocities were interpolated temporally horizontally onto the particle tracking model mesh by the software during the model simulation.

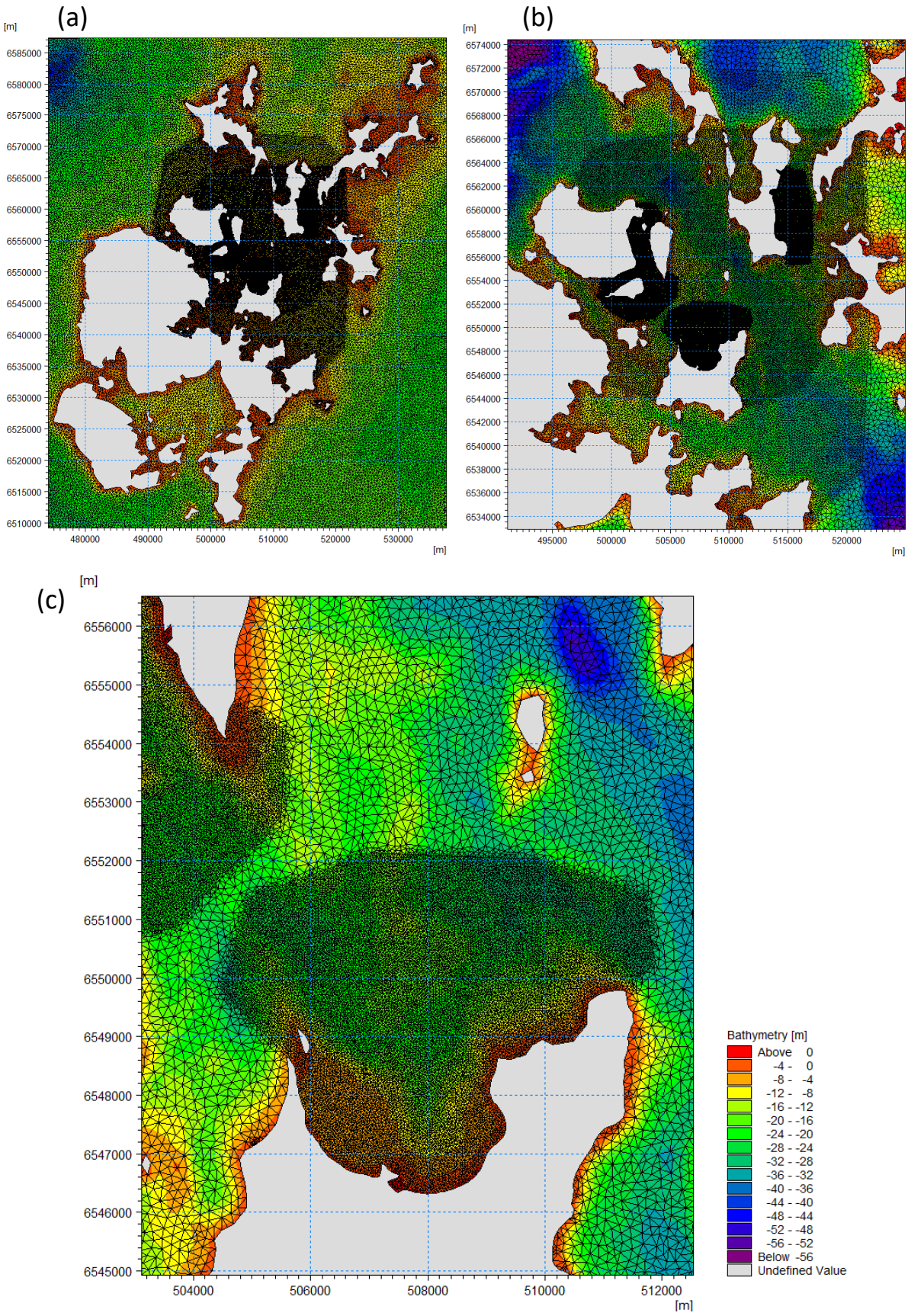


Figure 3.2 **Mesh used for particle tracking, covering the Orkney Islands at high resolution. (a) Whole mesh. (b) Expanded view of North Orkney area. (c) Close-up view of Veantrow Bay area (vertical scale only applies to this view).**

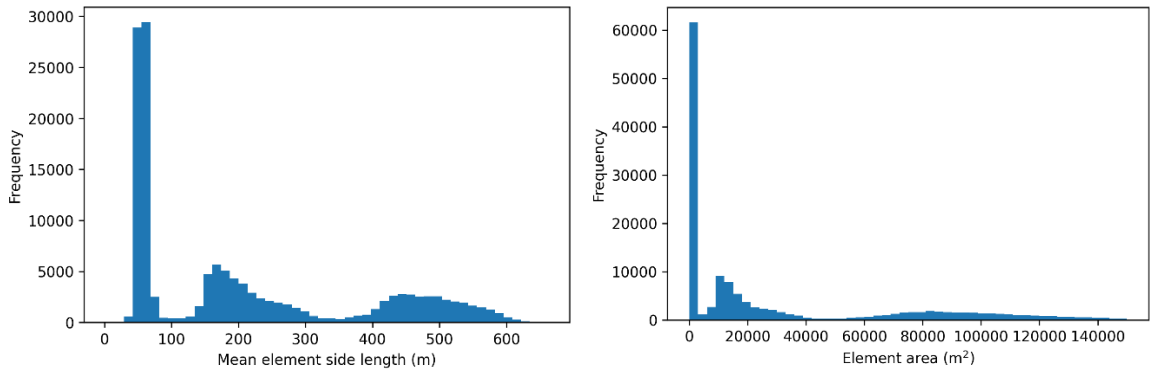


Figure 3.3 **Histograms of properties of the mesh used for impact assessment particle tracking. (a) Element side length (mean of the three sides of an element), and (b) element area.**

3.4 Waste deposition model study

3.4.1 Approach

For particle tracking simulations, separate results were stored for waste feed and faeces. Each simulation covered a period of 365 days, using HD model hindcast output for the period 15/06/2017 00:00 to 15/06/2018 00:00.

Simulations were carried out for the proposed site VEA1, in addition to other existing sites identified in the SEPA risk screening report for the site (Scottish Environment Protection Agency 2023).

Using the proposed site as an example, the quantity of material released per day was:

Feed mass = Biomass (kg) * Feed requirement (proportion) * (1-Feed water content) (proportion) * Feed waste level (proportion)

= 2,472,300 * 0.007 * 0.91 * 0.03

= 472.5 kg

Faeces mass = Biomass (kg) * Feed requirement (proportion) * (1-Feed water content) (proportion) * (1-Feed waste level) (proportion) * (1-Feed absorption level) (proportion)

= 2,472,300 * 0.007 * 0.91 * 0.97 * 0.15

= 2291.4 kg

where the values used for each parameter (other than biomass) are the SEPA default values as per the latest version of the guidance (Scottish Environment Protection Agency 2024).

Details of the sites used, and the calculated mass release rates, are given in Table 3.1.

One particle was released at each particle tracking model timestep (once every 3 minutes; 20 particles per hour. The mass represented by each particle released was thus calculated as the daily feed (or faeces) mass, multiplied by 180/86400.

Carbon mass represented by each feed or faeces particle were calculated using multipliers of 0.49 and 0.30 respectively.

Table 3.1 Sites simulated, with stocked biomass and calculated quantities for release.

				Model material per day (kg d^{-1})				Model material per timestep (kg per step)			
Site Name	**Location (OSGB Easting, Northing)**	**Biomass (t)**	**Last Production Cycle**	**Waste feed mass**	**Waste feed carbon**	**Faeces mass**	**Faeces carbon mass**	**Waste feed mass**	**Waste feed carbon**	**Faeces mass**	**Faeces carbon mass**
VEA1 (proposed expansion ; "ShapC")	350176, 1021628	2472.3	Currently stocked (since Apr 21)	472.5	231.5	2291.4	687.4	0.984	0.482	4.774	1.432
VEA1 (existing)	350151, 1021391	948	Currently stocked (since Apr 21)	181.2	88.8	878.6	263.6	0.377	0.185	1.830	0.549
BOH1	344954, 1031915	187.5	Fish last on site June 2018	35.8	17.6	173.8	52.1	0.075	0.037	0.362	0.109
BOH2	345016, 1029123	500	Currently stocked (since Apr 21)	95.6	46.8	463.4	139.0	0.199	0.098	0.965	0.290
BOV1	346598, 1027654	1000	Currently stocked (since Feb 21)	191.1	93.6	926.8	278.1	0.398	0.195	1.931	0.579
EDA1	357083, 1030800	1908.54	Currently stocked (since Nov 21)	364.7	178.7	1768.9	530.7	0.760	0.372	3.685	1.106
GAIR1	345558, 1025279	1909.7	Currently stocked (since Nov 21)	364.9	178.8	1770.0	531.0	0.760	0.373	3.687	1.106
MILL1	357200, 1033200	800	Fish last on site May 2003	152.9	74.9	741.5	222.4	0.319	0.156	1.545	0.463

3.4.2 Output statistics

Output statistics were generated for all particle transport simulations in accordance with the current version of SEPA guidance (Scottish Environment Protection Agency 2024). Concentration fields of suspended and deposited solids were output from the model at 3 hr intervals.

Specific output statistics included (for suspended and deposited solids):

- Plots showing the extent and concentration of impact, as an average, taken over the last 90 days of the model run;
- Areal extent and average concentration, averaged over the last 90 days of the model run;
- Time series of maximum and average concentrations for the entire model run period;
- Time series of areal extent at the 250 g m^2 contour of deposited material.

Several points in the locality of the farm have been identified as locations where sensitive Priority Marine Features have been previously recorded, primarily due to the presence of maerl, and were identified in SEPA's screening risk identification report (summarised in Figure 2.2 and Table 3.2). For each of these locations, timeseries of concentration within were generated, in addition to vertical profiles of concentration at EQS time points.

A visual seabed survey of the area around the site was carried out, identifying the presence of maerl in additional locations and confirming the presence or absence of maerl in locations of previous records. These locations are shown visually in Figure 3.4, classified according to the percentage cover of maerl at each location. Maerl beds as a PMF need to be 20% cover of maerl but for the purposes of this assessment all locations with maerl cover greater than 5% have been included (see Appendix 7.1 Table T1), and predicted concentration of deposited and suspended sediment extracted from the model.

Table 3.2 **PMF record locations in the proximity of the proposed site, extracted from the GEMS database. Numbering here is used in later plots presenting results of impact calculations.**

Number	Type	Easting (UTM30N)	Northing (UTM30N)
1	Maerl beds	508735	6547467
2	Maerl beds	506448	6547546
3	Seagrass beds	505942	6548578
4	Maerl beds	507231	6547202
5	Maerl beds	506559	6546976
6	Maerl beds	508521	6547556
7	Maerl beds	506332	6548280
8	Maerl beds	510219	6549716
9	Maerl beds	509530	6549406
10	Maerl beds	508488	6547588
11	Maerl beds	507859	6547160
12	Maerl beds	507480	6548048
13	Maerl beds	506893	6547874
14	Maerl beds	506600	6546939
15	Maerl beds	506463	6547580
16	Maerl beds	506443	6547563
17	Maerl beds	507251	6550627
18	Maerl beds	508412	6550536
19	Maerl beds	509726	6549990
20	Maerl beds	505380	6549808
21	Maerl beds	506450	6551358

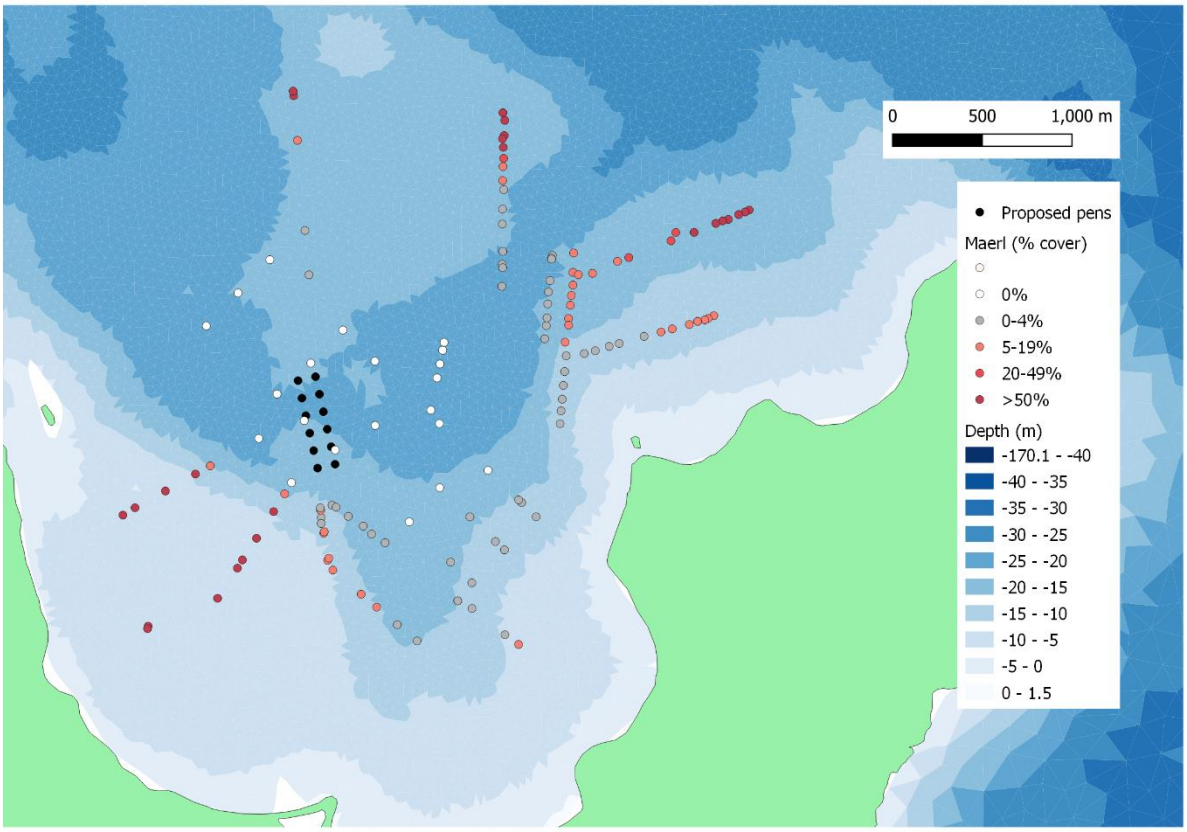


Figure 3.4: Visual survey locations and percentage cover of maerl on the seabed (shaded discs white to red). The location of the proposed pens is shown by black discs, and depth of the water by blue background.

4 Results

4.1 Extent and concentration of impact over final 90 days

4.1.1 Suspended sediment

A map of suspended sediment concentration, including all source sites in the SEPA risk assessment and averaged over the last 90 days of the simulation, is shown in Figure 4.1. Suspended sediment released from individual sites, averaged over the same period, is shown in Appendix 7.2.1.

The concentration is generally predicted to be low throughout the domain, only reaching any notable level in isolated coastal locations, where some accumulations are predicted. Similar aggregations have been observed in previous projects, and may be an artefact of model configuration and the manner in which particles interact with the coastline.

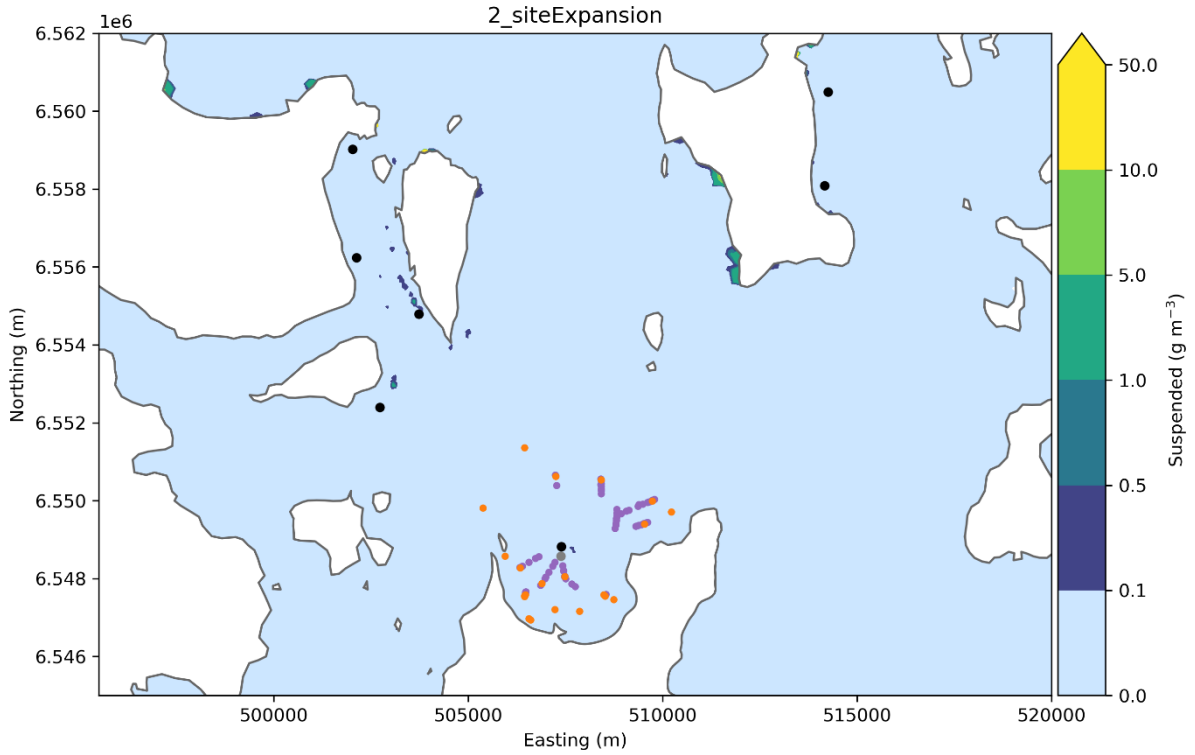


Figure 4.1 **Map of average suspended sediment concentration of the final 90 days of the simulation. The map indicates farm locations included in the simulation (black points), maerl and seagrass PMF locations identified in the SEPA risk assessment (orange points) and visual survey locations with over 5% coverage of maerl (purple points). The grey point indicates the centre of the existing VEA1 site, which was not included in the mapped results.**

4.1.2 Deposited sediment

A map of deposited sediment concentration, including all source sites in the SEPA risk assessment and averaged over the last 90 days of the simulation, is shown in Figure 4.2. Deposited sediment released from individual sites, averaged over the same period, are shown in Appendix 7.2.2.

Levels are generally low across the model domain, with isolated footprint areas predicted to be present within Veantrow bay (largely arising from the VEA1 site), in Rousay Sound to the north (largely arising from Cooke sites located there), and at GAIR1 site (arising from that site). These footprint areas are relatively small and low intensity (Table 4.1).

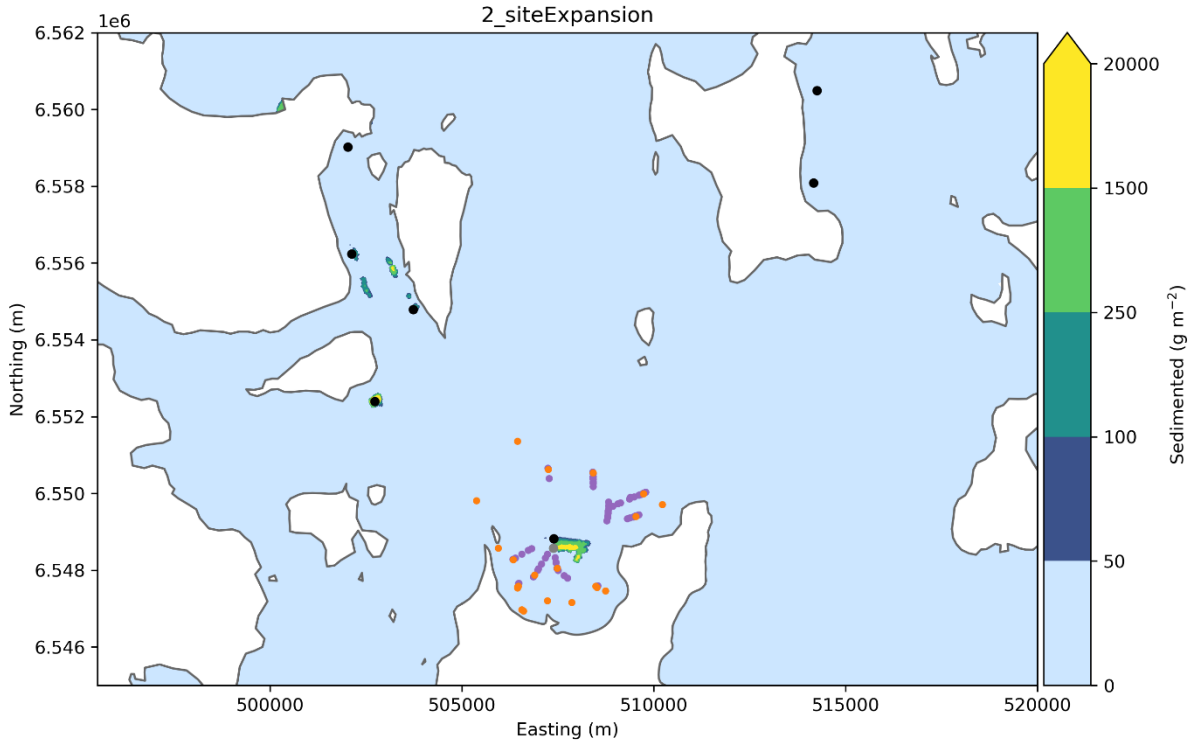


Figure 4.2 **Map of average deposited sediment concentration of the final 90 days of the simulation. The map indicates farm locations included in the simulation (black points), maerl and seagrass PMF locations identified in the SEPA risk assessment (orange points) and visual survey locations with over 5% coverage of maerl (purple points). The grey point indicates the centre of the existing VEA1 site, which was not included in the mapped results.**

4.2 Areal extent of 250 g m^{-2} contour (full run)

The areal extent of the 250 g m^{-2} sedimented material contour generated by most individual sites was fairly small, due to the high levels of resuspension and dispersion occurring in the model runs. The intensity of deposition over this threshold was also very low for most sites (Table 4.1).

The current configuration of the Shapinsay VEA1 site generates a higher predicted area over the threshold deposited mass (63454.5 m^2) than the other sites modelled here, but intermediate intensity over that level (1318.5 g m^{-2}). The proposed site expansion causes an increase in extent of the 250 g m^{-2} contour to 97662 m^2, and intensity to 2338.7 g m^{-2}. However, in the context of sites in other areas, this is a relatively small and low intensity footprint.

Table 4.1: Extent and concentration of (deposited sediment) footprint arising from each site, averaged over the last 90 days of the simulation.

Site	Extent > 250 g m^{-2}	Average > 250 g m^{-2}
ShapC (VEA1 expansion)	97662.0	2338.7
VEA1 (existing)	63454.5	1318.5
BOH1	1180.8	341.0
BOH2	13527.0	663.1
BOV1	25136.3	1325.7
EDA1	154.0	42.3
GAIR1	36845.3	7163.6
MILL1	10.4	5.3

4.3 Concentrations at sensitive features

4.3.1 Suspended sediment

At the identified PMF locations, concentrations of suspended sediment were generally predicted to be very low. This is evident in the timeseries plot (Figure 4.3), which indicates concentrations were near zero for almost the entire duration of the simulation. For clarity of labelling, PMF locations where concentration never exceeded 0 g m^{-3} are omitted from the plot. At those locations where larger concentrations were predicted, those concentrations were only ever present for a very short period of time, indicated by sharp peaks in concentration in the plots.

Considering the last three months of the simulation, average concentrations at (or close to) any of the PMF locations were close to zero over this period, and occurrence of non-zero values was only seen on a tiny fraction of timesteps (<1%; Table 4.2).

Considering the visual survey locations where maerl coverage was greater than 5%, again only transient spikes in suspended sediment concentration were predicted by the model, with only 3 instances of spikes over 10 g m^{-3} during the whole simulation, and none in the last 3 months (Figure 4.4; Table 4.3).

Due to the very low concentration and frequency of occurrence of suspended sediment (<1% of model timesteps) at the database PMF and visual survey maerl locations, vertical transects are not included here.

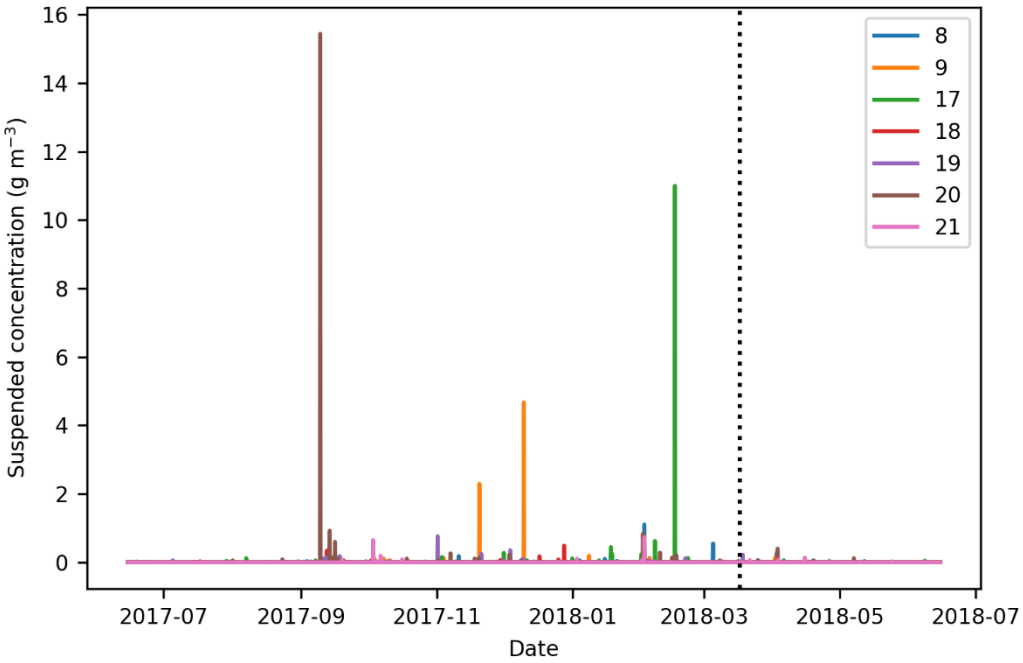


Figure 4.3: Timeseries of suspended sediment concentration at PMF locations, extracted from the nearest location on the model mesh for each point. Source locations were all farms together, with VEA1 at newly proposed stocking level. All locations with at least one record over 0 g m^{-3} are shown. Vertical dotted line indicates the beginning of the 90 day window over which statistics are calculated.

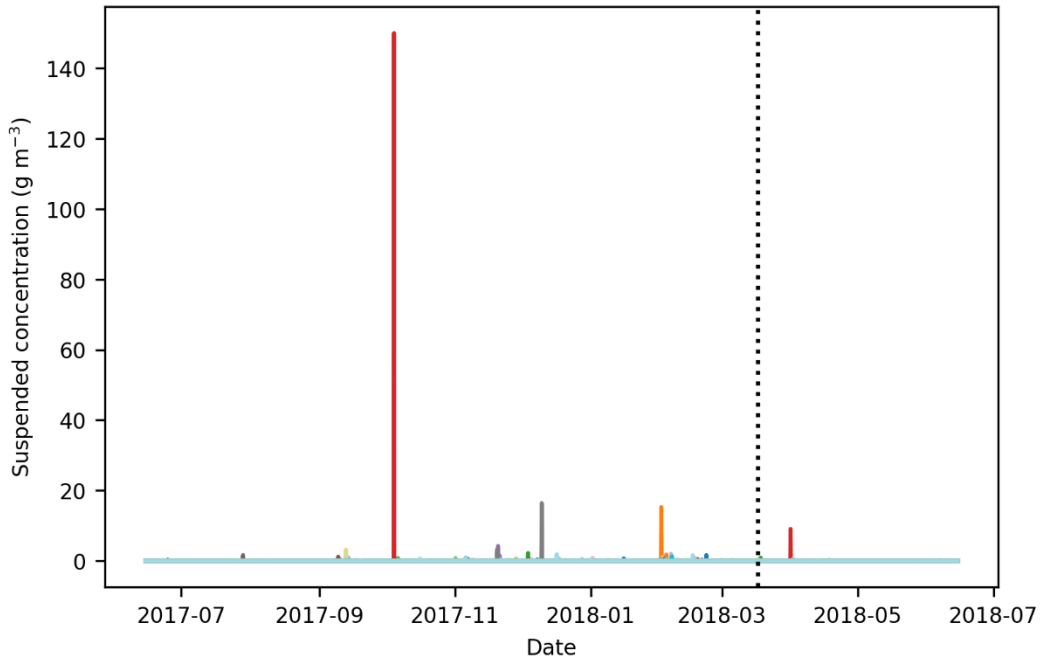


Figure 4.4: Timeseries of suspended sediment concentration at visual survey locations with over 5% cover of maerl, extracted from the nearest location on the model mesh for each point. Source locations were all farms together, with VEA1 at newly proposed stocking level. All locations with at least one record over 0 g m^{-3} are shown. Individual points are not labelled here; refer to Table 4.3 for maximum and average statistics for specific locations. Vertical dotted line indicates the beginning of the 90 day window over which statistics are calculated.

4.3.2 Deposited sediment

Timeseries of deposited sediment over the duration of the model run show a similar story to that for suspended sediment. Concentrations at PMF locations are generally close to zero, with only occasional peaks of sediment concentration being large enough to be visible. These peaks are all much lower than the level assumed to relate to a shift away from good environmental status (250 g m^{-2}). Again, for clarity, locations where a level of 0 g m^{-2} was never exceeded are omitted from the plot.

Considering the last three months of the simulation, average concentrations at (or close to) any of the PMF locations were close to zero over this period, and occurrence of non-zero values was only seen in a tiny fraction of timesteps (0.42%; Table 4.2).

Considering the visual survey locations where maerl coverage was greater than 5%, only transient spikes in suspended sediment concentration were predicted by the model, with none at concentrations or over durations that would generally be considered to raise concerns (Figure 4.6; Table 4.3).

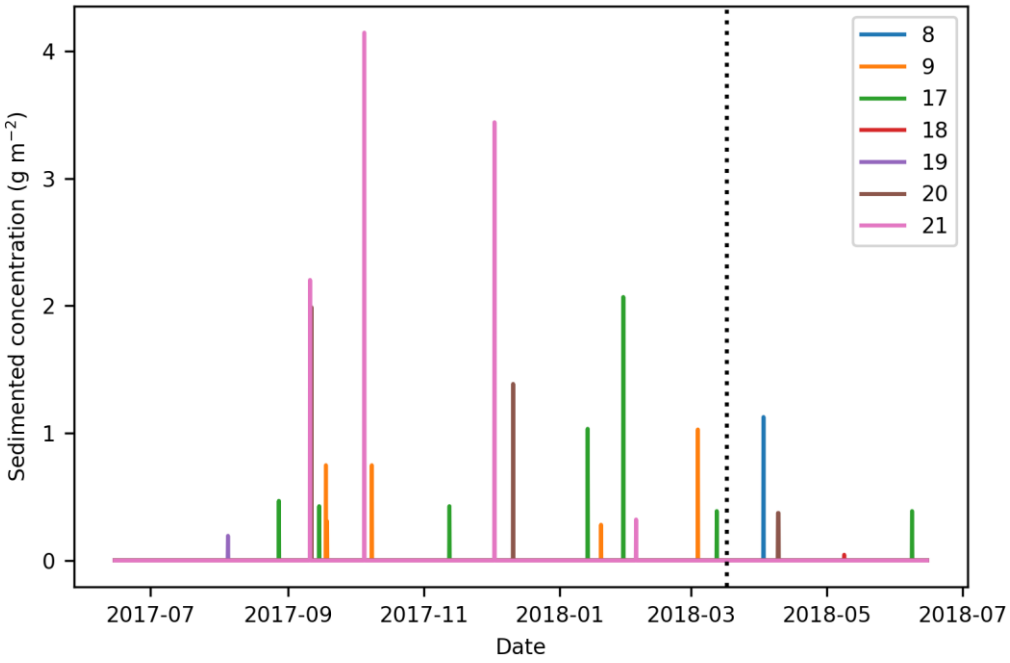


Figure 4.5: Timeseries of deposited sediment concentration at PMF locations, extracted from the nearest location on the model mesh for each point. Source locations were all farms together, with Shapinsay at newly proposed stocking level. All locations with at least one record over 0 g m^{-2} are shown.

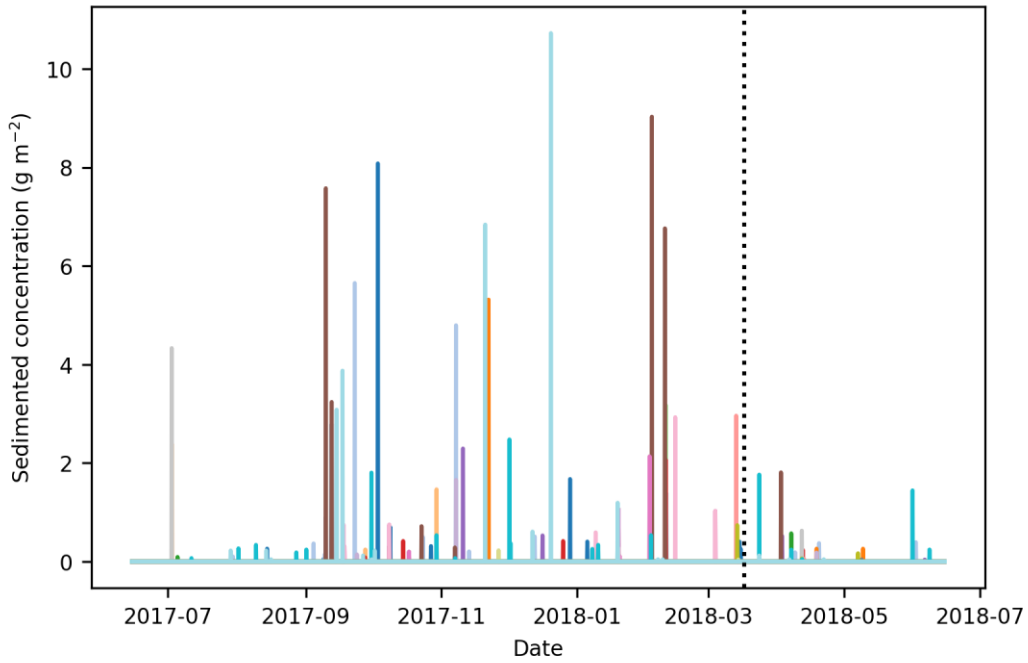


Figure 4.6: Timeseries of deposited sediment concentration at visual survey locations with more than 5% cover of maerl, extracted from the nearest location on the model mesh for each point (over the full simulated duration). Source locations were all farms together, with Shapinsay at newly proposed stocking level. All locations with at least one record over 0 g m^{-2} are shown. Individual points are not labelled here; refer to Table 4.3 for maximum and average statistics for specific locations.

Table 4.2: Average concentration of suspended and deposited sediment at each PMF record location over the last 90 days of the simulation, in addition to the percentage of model timesteps in which the predicted value was non-zero.

ID	Type	Easting (UTM30 N)	Northing (UTM30 N)	Suspended average (g m^{-2})	Suspended maximum (g m^{-2})	Suspended non-zero values	Sedimented average (g m^{-2})	Sedimented maximum (g m^{-2})	Sedimented non-zero values
1	Maerl beds	508735	6547467	0	0	0	0	0	0
2	Maerl beds	506448	6547546	0	0	0	0	0	0
3	Seagrass beds	505942	6548578	0	0	0	0	0	0
4	Maerl beds	507231	6547202	0	0	0	0	0	0
5	Maerl beds	506559	6546976	0	0	0	0	0	0
6	Maerl beds	508521	6547556	0	0	0	0	0	0
7	Maerl beds	506332	6548280	0	0	0	0	0	0
8	Maerl beds	510219	6549716	0.000428	0.273	0.28%	0.00156	1.12	0.14%
9	Maerl beds	509530	6549406	0.000303	0.146	0.56%	0	0	0
10	Maerl beds	508488	6547588	0	0	0	0	0	0
11	Maerl beds	507859	6547160	0	0	0	0	0	0
12	Maerl beds	507480	6548048	0	0	0	0	0	0
13	Maerl beds	506893	6547874	0	0	0	0	0	0
14	Maerl beds	506600	6546939	0	0	0	0	0	0
15	Maerl beds	506463	6547580	0	0	0	0	0	0
16	Maerl beds	506443	6547563	0	0	0	0	0	0
17	Maerl beds	507251	6550627	0.000284	0.0621	0.97%	0.000539	0.388	0.14%
18	Maerl beds	508412	6550536	1.84E-05	0.00519	0.56%	6.22E-05	0.0448	0.14%
19	Maerl beds	509726	6549990	0.000399	0.220	0.69%	0	0	0
20	Maerl beds	505380	6549808	0.00092	0.396	0.69%	0.00155	0.373	0.42%
21	Maerl beds	506450	6551358	0.000479	0.137	0.83%	0	0	0

Table 4.3: Average concentration of suspended and deposited sediment at visual survey locations with over 5% cover of maerl over the last 90 days of the simulation, in addition to the number of model timesteps (out of a possible 720) in which the predicted value was non-zero.

ID	Easting	Northing	Maerl Density	Suspended average (g m^{-3})	Suspended maximum (g m^{-3})	Suspended non-zero values	Sedimented average (g m^{-2})	Sedimented maximum (g m^{-2})	Sedimented non-zero values
14	508817	6549783	5-19%	7.70E-05	0.033463	0.56%	0	0	0
15	508815	6549675	5-19%	0.00039	0.231026	0.69%	7.52E-05	0.054157	0.14%
16	508816	6549604	5-19%	0.000372	0.222431	0.97%	0.001376	0.391985	0.56%
17	508808	6549546	5-19%	0.000157	0.080234	0.42%	8.07E-05	0.05814	0.14%
18	508803	6549492	5-19%	4.44E-06	0.0032	0.14%	0.000725	0.260963	0.28%
19	508794	6549417	5-19%	0	0	0	0	0	0
20	508795	6549380	5-19%	0.000304	0.218793	0.14%	0	0	0
21	508777	6549285	5-19%	3.70E-05	0.01924	0.42%	0	0	0
28	509792	6550037	>50%	0.001413	0.888658	0.42%	0	0	0
29	509770	6550026	>50%	6.70E-05	0.020854	0.56%	0	0	0
30	509734	6550011	>50%	0.000573	0.397271	0.42%	0	0	0
31	509677	6549983	>50%	0.000362	0.154833	0.97%	0.000796	0.573183	0.14%
32	509645	6549974	>50%	0.01291	9.049812	1.11%	0	0	0
33	509607	6549960	>50%	0.001465	0.927042	0.83%	0.000323	0.232794	0.14%
34	509487	6549908	>50%	1.91E-05	0.013767	0.14%	0	0	0
35	509385	6549906	20-49%	0.000221	0.090596	0.83%	0	0	0
36	509359	6549859	20-49%	0.000692	0.157381	0.83%	7.86E-05	0.056598	0.14%
37	509125	6549762	20-49%	0.000292	0.103756	0.69%	0.000778	0.519585	0.28%
38	509062	6549740	5-19%	0.000124	0.078648	0.28%	0.000253	0.182307	0.14%
39	508924	6549671	5-19%	0.000213	0.147761	0.42%	0	0	0
40	508845	6549662	5-19%	0.000664	0.229587	1.11%	0	0	0
41	509604	6549445	5-19%	5.82E-06	0.00419	0.14%	0.002513	1.809697	0.14%
42	509572	6549429	5-19%	0.001264	0.483521	0.97%	0	0	0
43	509554	6549421	5-19%	0.001264	0.483521	0.97%	0	0	0
44	509514	6549412	5-19%	0.000303	0.146341	0.56%	0	0	0
45	509514	6549412	5-19%	0.000303	0.146341	0.56%	0	0	0
46	509468	6549394	5-19%	0.000714	0.47697	0.42%	0	0	0
47	509373	6549368	5-19%	0.000301	0.119708	0.42%	0	0	0
48	509311	6549350	5-19%	5.23E-05	0.026868	0.42%	0	0	0
54	508411	6550559	>50%	0.000208	0.109964	0.97%	0	0	0
55	508422	6550517	>50%	1.84E-05	0.005189	0.56%	6.22E-05	0.04481	0.14%
56	508420	6550432	>50%	0.000395	0.129206	0.97%	0.000871	0.626943	0.14%
57	508411	6550414	>50%	0.000117	0.03487	0.97%	0	0	0
58	508416	6550366	>50%	0.000147	0.088857	0.28%	8.84E-05	0.063643	0.14%
59	508419	6550305	20-49%	0.000185	0.057468	0.97%	0	0	0
60	508416	6550259	5-19%	2.61E-05	0.015506	0.28%	0.000233	0.167969	0.14%
61	508415	6550181	5-19%	0.000115	0.038987	0.56%	0	0	0
75	508543	6547596	5-19%	0	0	0	0	0	0
83	507447	6548200	5-19%	0	0	0	0	0	0
84	507471	6548049	5-19%	0	0	0	0	0	0
85	506476	6547667	>50%	0	0	0	0	0	0

ID	Easting	Northing	Maerl Density	Suspended average (g m^{-3})	Suspended maximum (g m^{-3})	Suspended non-zero values	Sedimented average (g m^{-2})	Sedimented maximum (g m^{-2})	Sedimented non-zero values
86	506473	6547653	>50%	0	0	0	0	0	0
111	507748	6547792	5-19%	0	0	0	0	0	0
112	507661	6547863	5-19%	0	0	0	0	0	0
113	507501	6547995	5-19%	0	0	0	0	0	0
114	507477	6548061	5-19%	0	0	0	0	0	0
115	507450	6548208	5-19%	0	0	0	0	0	0
116	507428	6548328	5-19%	0	0	0	0	0	0
118	506861	6547828	>50%	0	0	0	0	0	0
119	506969	6547998	>50%	0	0	0	0	0	0
120	506996	6548044	>50%	0	0	0	0	0	0
121	507073	6548166	>50%	0	0	0	0	0	0
122	507166	6548316	>50%	0	0	0	0	0	0
123	507226	6548416	5-19%	0	0	0	0	0	0
125	506326	6548284	>50%	0	0	0	0	0	0
126	506393	6548326	>50%	0	0	0	0	0	0
127	506561	6548422	>50%	0	0	0	0	0	0
128	506727	6548519	>50%	0	0	0	0	0	0
129	506809	6548566	5-19%	0	0	0	0	0	0
133	507268	6550388	5-19%	0.000532	0.141783	1.11%	0.000746	0.24342	0.42%
134	507243	6550636	>50%	0.000237	0.098816	0.83%	0.004457	1.764677	0.28%
135	507240	6550662	>50%	0.000273	0.118314	1.11%	0.0003	0.123034	0.42%

5 Discussion and Conclusions

The location of the proposed expanded Veantrow Bay site is in an area of slightly higher flows in comparison with the existing site location. The dominant flow is towards the east, and most material appears to form a footprint within the bay, to the east. The currents predicted by the HD model corresponded well to observed current meter records (Danish Hydraulic Institute 2022).

The predicted footprint was larger than those generated by other sites in the study, and at the higher end of the intensity range. However, in comparison with sites in other areas, the footprint was neither particularly large or intense.

Only a very limited interaction with PMFs (or locations with >5% maerl coverage identified during the visual survey conducted as part of this application) was predicted, in terms of either suspended or deposited sediment. Presence at these locations was limited to occasional spikes of quite low intensity, and was zero for almost the entirety of the simulated period (>99% of model timesteps in the analysis period, covering the last 90 days).

6 References

Anderson Marine Surveys (2022) NE Shapinsay, Orkney: Dye dispersion study.

Chen C, Beardsley RC, Cowles G (2013) An Unstructured Grid, Finite-Volume Coastal Ocean Model: FVCOM User Manual, 4th Edition.

Danish Hydraulic Institute (2017) MIKE 21 & 3 Flow Model FM Hydrodynamic and Transport Module Scientific Documentation.

Danish Hydraulic Institute (2021) MIKE 21 Flow Model FM - Particle Tracking Module User Guide.

Danish Hydraulic Institute (2022) North Orkney Aquaculture Modelling Hydrodynamic Climatology and Hindcast Models.

Scottish Environment Protection Agency (2023) Aquaculture Modelling Screening & Risk Identification Report: Shapinsay, Veantrow Bay (VEA1).

Scottish Environment Protection Agency (2024) Interim Marine Modelling Guidance for Aquaculture Applications.

7 Appendices

7.1 Visual survey PMF locations

Table T1: Locations identified during the visual seabed survey at which greater than 5% cover of maerl was identified.

Seabed Image ID	Transect ID	Easting	Northing	Depth (m)	Biotope Designation	Estimated Maerl Density (% cover)	Transect description, biota observed	SACFOR
HD-T300001	T3-1	508817	6549783	21	SS.SMx.CMx	5-19%	Sandy sediments with scattered deposits of shell debris and gravel. Small quantities of live and dead maerl observed amongst the gravel and shell debris. Gravelly sediment areas more extensive that those observed in Transect 2 with slightly higher proportions of maerl fragments present.	
HD-T300002	T3-2	508815	6549675	19	SS.SMx.CMx	5-19%	Coarser, shelly sediment types and areas of rocky seabed observed in shallower, southern part of transect.	
HD-T300003	T3-3	508816	6549604	19	SS.SMx.CMx	5-19%	Seaweed - primarily Laminaria spp. (including L. saccharina), abundance increasing in shallower waters to the south.	O-F
HD-T300004	T3-4	508808	6549546	19	SS.SMx.CMx	5-19%	Starfish (Asterias rubens)	R
HD-T300005	T3-5	508803	6549492	18	SS.SMx.CMx	5-19%	Urchins (Echinus esculentus)	R
HD-T300006	T3-6	508794	6549417	18	SS.SMx.CMx	5-19%		
HD-T300007	T3-7	508795	6549380	17	SS.SMx.CMx	5-19%		
HD-T300008	T3-8	508777	6549285	15	SS.SMp.KSwSS	5-19%		
HD-T400001	T4-1	509792	6550037	18	SS.SMp.Mrl.Pcal	>50%	Maerl bed habitat observed at the eastern end of transect gradually becoming more patchy and less dense to the west where higher proportions of gravelly and shelly sediments become more prevalent.	
HD-T400002	T4-2	509770	6550026	18	SS.SMp.Mrl.Pcal	>50%	High abundance of seaweed cover was observed along the entire transect - primarily Laminaria spp. (including L. saccharina).	C-F
HD-T400003	T4-3	509734	6550011	18	SS.SMp.Mrl.Pcal	>50%	Starfish (Asterias rubens and Luidia ciliaris)	R

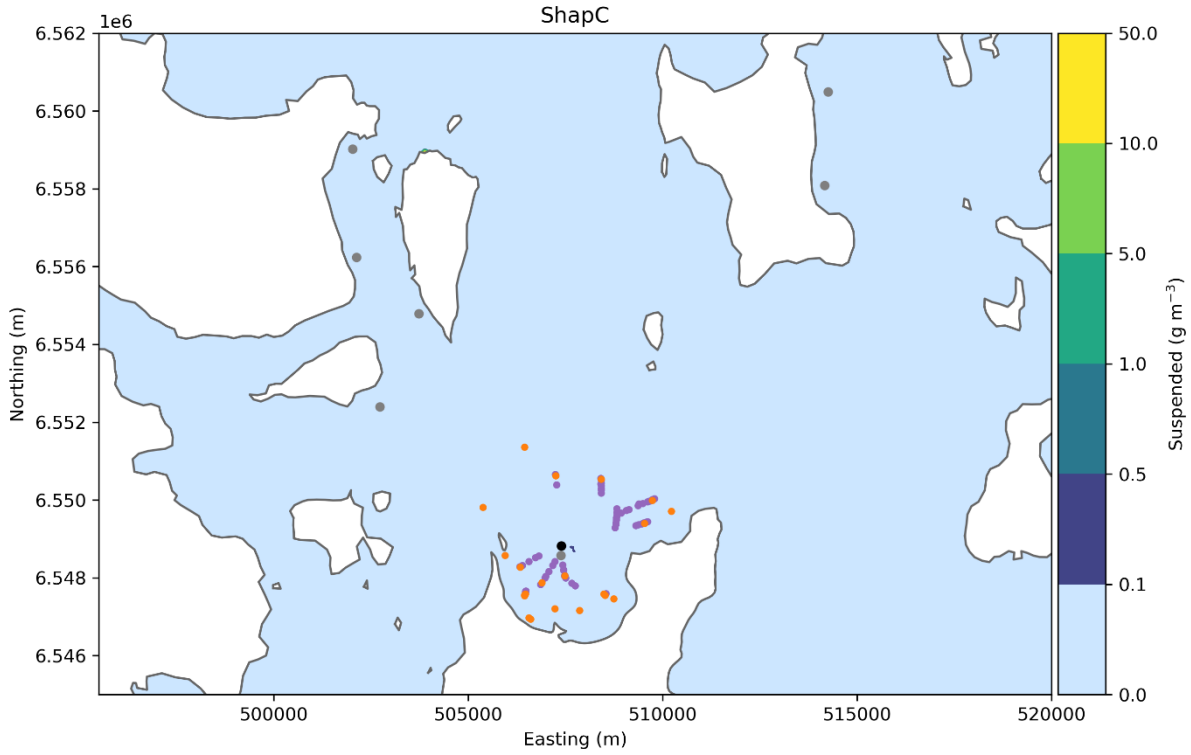
Seabed Image ID	Transect ID	Easting	Northing	Depth (m)	Biotope Designation	Estimated Maerl Density (% cover)	Transect description, biota observed	SACFOR
HD-T400004	T4-4	509677	6549983	17	SS.SMp.Mrl.Pcal	>50%	Urchins (Echinus esculentus)	R-O
HD-T400006	T4-6	509645	6549974	16	SS.SMp.Mrl.Pcal	>50%	Brittle star (Amphipholis squamata) - R overall but C-A patches of at western end of transect.	R
HD-T400014	T4-14	509607	6549960	18	SS.SMp.Mrl.Pcal	>50%		
HD-T400013	T4-13	509487	6549908	18	SS.SMp.Mrl.Pcal	>50%		
HD-T400012	T4-12	509385	6549906	17	SS.SMp.Mrl.Pcal	20-49%		
HD-T400011	T4-11	509359	6549859	16	SS.SMp.Mrl.Pcal	20-49%		
HD-T400010	T4-10	509125	6549762	16	SS.SMp.Mrl.Pcal	20-49%		
HD-T400009	T4-9	509062	6549740	16	SS.SMp.KSwSS	5-19%		
HD-T400008	T4-8	508924	6549671	16	SS.SMp.KSwSS	5-19%		
HD-T400007	T4-7	508845	6549662	17	SS.SMp.KSwSS	5-19%		
HD-T500001	T5-1	509604	6549445	12	SS.SMp.KSwSS	5-19%	Mixed sandy sediments with patches of shell debris and gravel. Small quantities of live and dead maerl observed amongst the gravel and shell debris. Mearl density highest in eastern part of transect.	
HD-T500002	T5-2	509572	6549429	12	SS.SMp.KSwSS	5-19%	High abundance of seaweed cover was observed along the entire transect - primarily Laminaria spp. (including L. saccharina).	C-F
HD-T500003	T5-3	509554	6549421	12	SS.SMp.KSwSS	5-19%	Starfish (Asterias rubens)	R
HD-T500004	T5-4	509514	6549412	12	SS.SMp.KSwSS	5-19%	Urchins (Echinus esculentus)	R
HD-T500005	T5-5	509514	6549412	12	SS.SMp.KSwSS	5-19%		
HD-T500006	T5-6	509468	6549394	12	SS.SMp.KSwSS	5-19%		
HD-T500007	T5-7	509373	6549368	13	SS.SMp.KSwSS	5-19%		
HD-T500008	T5-8	509311	6549350	13	SS.SMp.KSwSS	5-19%		
HD-T600001	T6-1	508411	6550559	15	SS.SMp.Mrl.Pcal	>50%	Maerl bed habitat and gravelly, shelly sediments observed at the northern end of transect gradually becoming more patchy and less dense to the south where rippled fine sandy sediments become more prevalent with occasional patches of shell debris and gravel.	
HD-T600002	T6-2	508422	6550517	15	SS.SMp.Mrl.Pcal	>50%	High abundance of seaweed cover was observed along in the northern part of the transect decreasing in the south - primarily Laminaria spp. (including L. saccharina).	O-F
HD-T600003	T6-3	508420	6550432	16	SS.SMp.Mrl.Pcal	>50%	Starfish (Asterias rubens and Luidia ciliaris)	R
HD-T600004	T6-4	508411	6550414	17	SS.SMp.Mrl.Pcal	>50%	Urchins (Echinus esculentus)	R
HD-T600005	T6-5	508416	6550366	18	SS.SMp.Mrl.Pcal	>50%	Burrowing anemones observed in Mearl bed habitat in the north	P
HD-T600006	T6-6	508419	6550305	18	SS.SMp.Mrl.Pcal	20-49%		
HD-T600007	T6-7	508416	6550259	19	SS.SSa.CFiSa	5-19%		
HD-T600008	T6-8	508415	6550181	19	SS.SSa.CFiSa	5-19%		
HD-T7B-0007	T7B-7	508543	6547596	8.9	SS.SMp.KSwSS	5-19%	Mixed muddy sediments becoming more mixed in shallower water. Burrowed polychaetes. Patches of live and dead maerl fragments observed becoming denser/more frequent in the shallower water – in depths of approx. 9-12 m.	

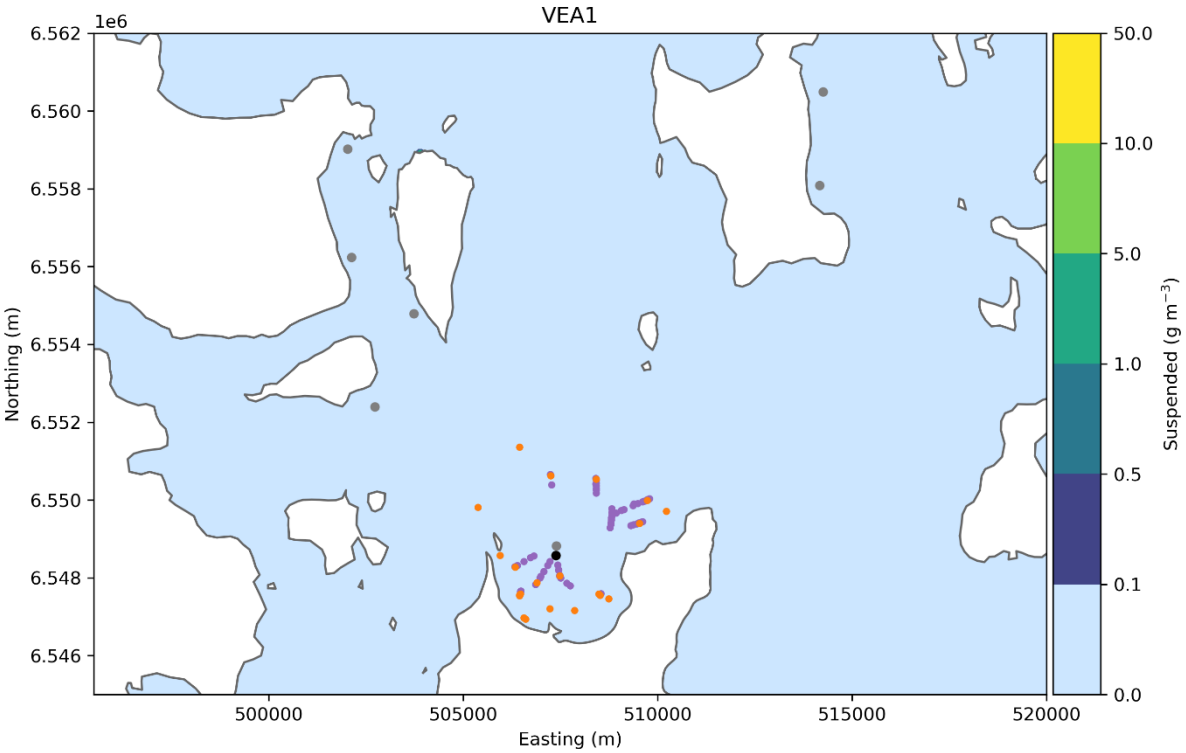
Seabed Image ID	Transect ID	Easting	Northing	Depth (m)	Biotope Designation	Estimated Maerl Density (% cover)	Transect description, biota observed	SACFOR
HD-T8-0004	T8-4	507447	6548200	10.9	SS.SMp.KSwSS	5-19%	Urchins (Echinus esculentus)	R
HD-T8-0005	T8-5	507471	6548049	9.9	SS.SMp.KSwSS	5-19%		
HD-T9-0001	T9-1	506476	6547667	7.6	SS.SMp.Mrl.Pcal	>50%	High abundance of seaweed cover was observed along the entire transect – primarily bootlace weed (Chorda filum) and Laminaria spp. (including L. saccharina).	
HD-T9-0002	T9-2	506473	6547653	7.4	SS.SMp.Mrl.Pcal	>50%	Based on limited observations of seabed beneath seaweed cover, substrate is mixed sediment containing live and dead maerl and shell debris.	
153011_1	C07-3	507748	6547792	12	SS.SMp.KSwSS	5-19%	Urchins (Echinus esculentus)	P
153542_1	C07-4	507661	6547863	10	SS.SMp.KSwSS	5-19%		
154412_1	C07-5	507501	6547995	7	SS.SMp.KSwSS	5-19%		
155128_1	C08-1	507477	6548061	7	SS.SMp.KSwSS	5-19%	Mixed muddy sediments. High seaweed/algae coverage – including Laminaria spp. Some dense patches of maerl recorded in southern part of transect becoming more scattered in the north.	
155715_1	C08-2	507450	6548208	8	SS.SMp.KSwSS	5-19%	Starfish (Asterias rubens)	P
160222_1	C08-3	507428	6548328	10	SS.SMp.KSwSS	5-19%	Urchins (Echinus esculentus)	P
135236_1	C09-1	506861	6547828	4	SS.SMp.Mrl.Pcal	>50%	High abundance of seaweed cover was observed in water depths of less than approx. 10 m – primarily bootlace weed (Chorda filum) and Laminaria spp.	
140400_1	C09-2	506969	6547998	4	SS.SMp.Mrl.Pcal	>50%	Seabed beneath seaweed cover, primarily composed of live maerl in shallow waters gradually becoming less dense as depth increased.	
140653_1	C09-3	506996	6548044	4	SS.SMp.Mrl.Pcal	>50%	Mixed muddy sediments with scattering of maerl recorded in deeper waters in the east of the transect.	
141422_1	C09-4	507073	6548166	5	SS.SMp.Mrl.Pcal	>50%		
142223_1	C09-5	507166	6548316	8	SS.SMp.Mrl.Pcal	>50%		
142745_1	C09-6	507226	6548416	12	SS.Sa.CMuSa	5-19%		
125154_1	C10-1	506326	6548284	4	SS.SMp.Mrl.Pcal	>50%	High abundance of seaweed cover was observed in water depths of less than approx. 10 m – primarily bootlace weed (Chorda filum) and Laminaria spp.	
125747_1	C10-2	506393	6548326	4	SS.SMp.Mrl.Pcal	>50%	Seabed beneath seaweed cover, primarily composed of live maerl in shallow waters gradually becoming less dense as depth increased.	
130805_1	C10-3	506561	6548422	5	SS.SMp.Mrl.Pcal	>50%	Mixed muddy sediments with scattering of maerl recorded in deeper waters in the east of the transect.	
131828_1	C10-4	506727	6548519	8	SS.SMp.Mrl.Pcal	>50%		
132357_1	C10-5	506809	6548566	12	SS.Sa.CMuSa	5-19%		
173840_1	C11-3	507268	6550388	17	SS.SSa.CFiSa	5-19%	Fine sandy sediments becoming more mixed as water depth decreased to the north with occasional patches of shell debris and gravel. Maerl more frequent at the as water depth decreases becoming dense at the northern end of the transect.	
174828_1	C11-4	507243	6550636	14	SS.SSa.CFiSa	>50%		
175032_1	C11-5	507240	6550662	14	SS.SSa.CFiSa	>50%		

7.2 Additional figures

7.2.1 Suspended sediment (individual sites)

Maps of average suspended sediment concentration of the final 90 days of the simulation, as released from individual farm sites. Each map indicates the farm location included in the simulation (black point), maerl and seagrass PMF locations identified in the SEPA risk assessment (orange points) and visual survey locations with over 5% coverage of maerl (purple points). The grey point indicates the location of other farm sites which are not included in the mapped results.

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510000
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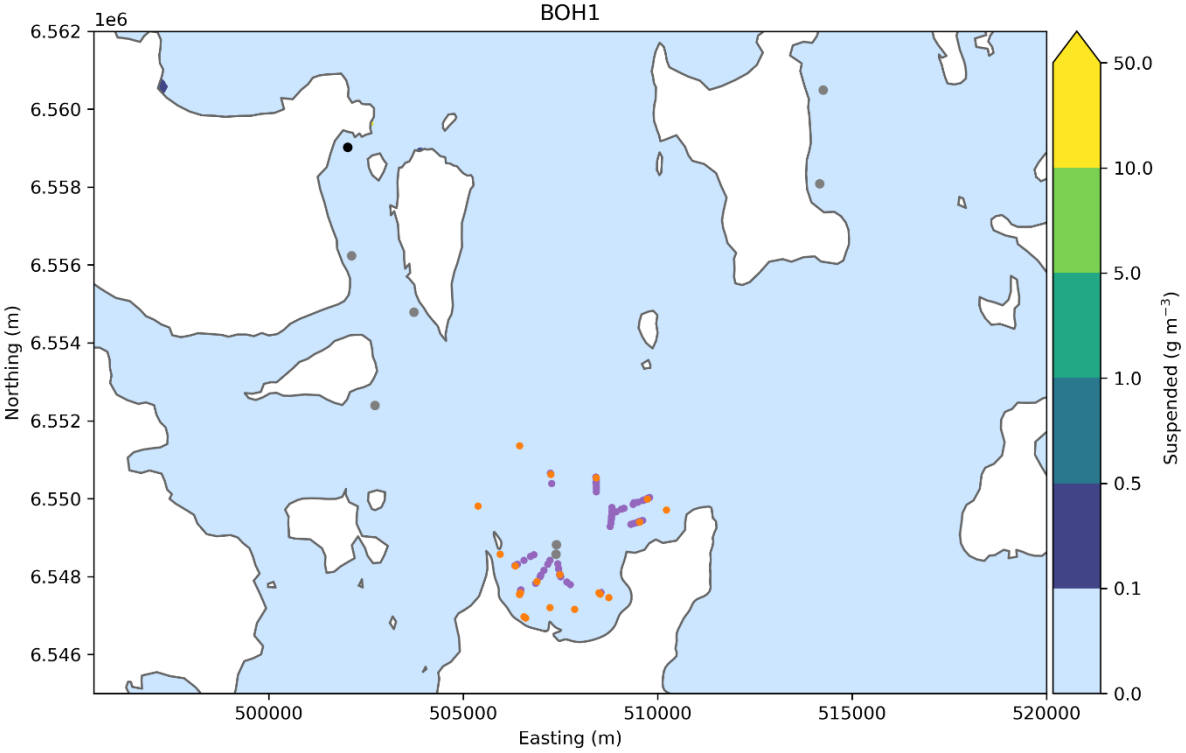
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505000
510000
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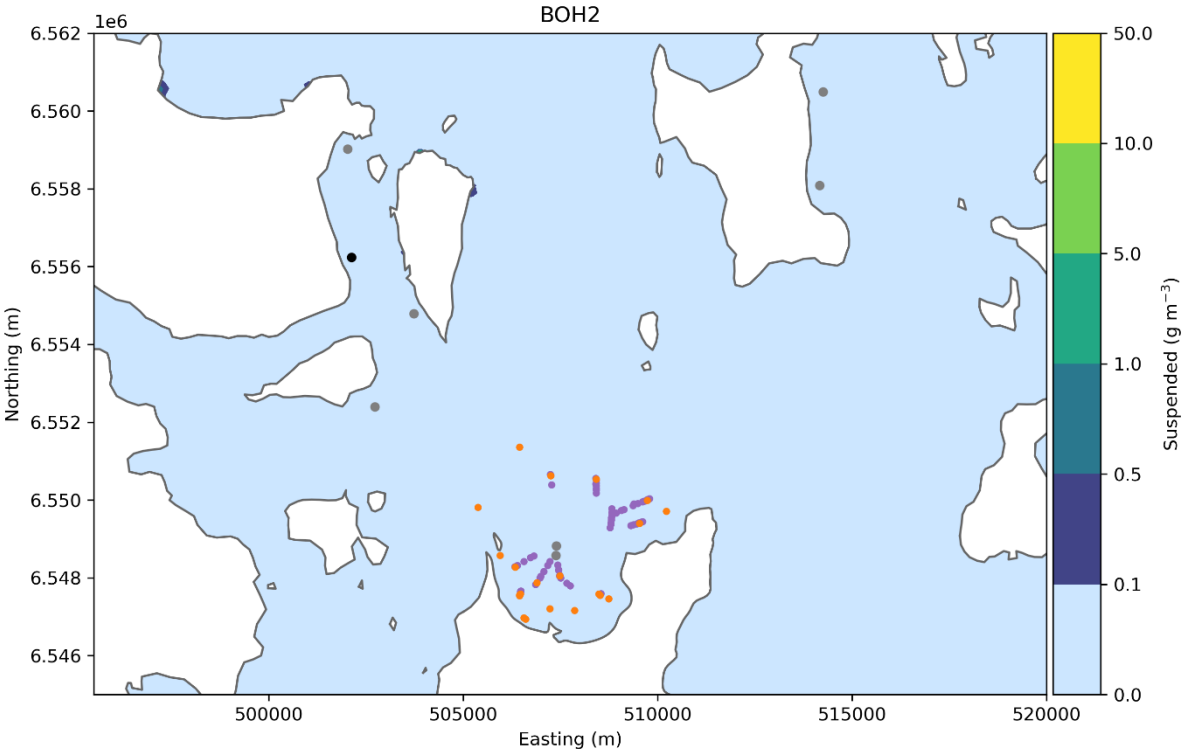
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Easting (m)
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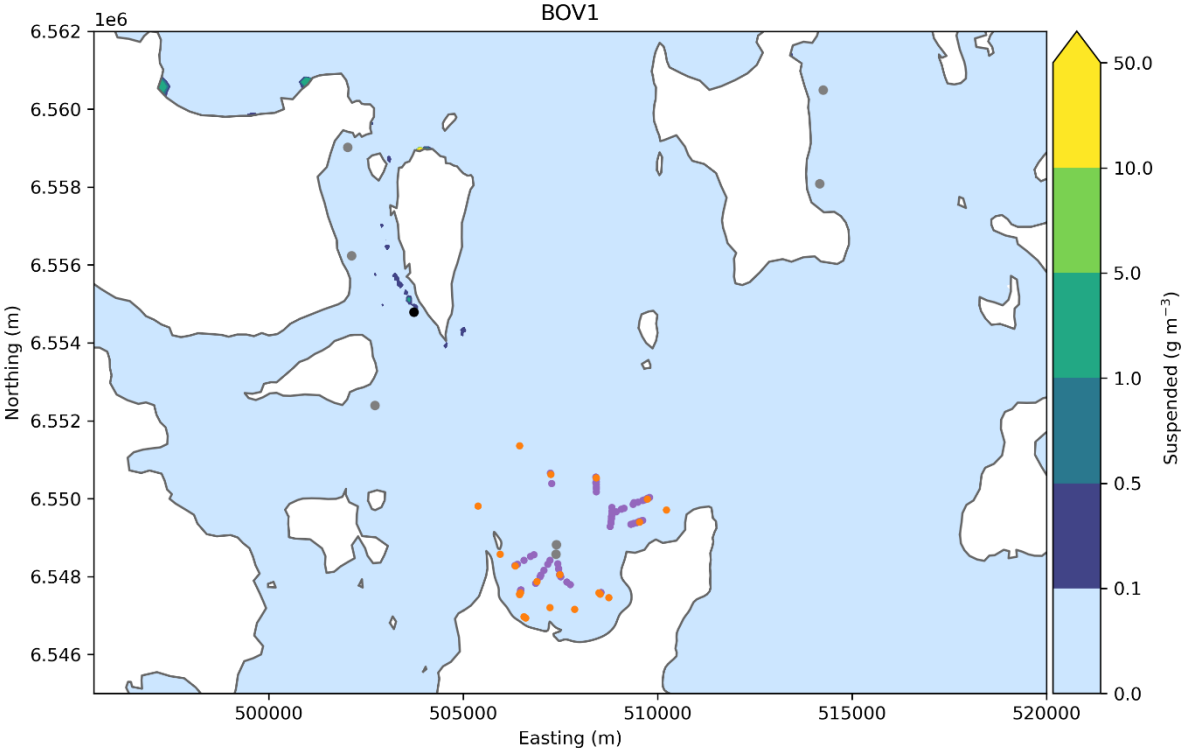
0.0
Suspended (g m^{-3})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505000
510000
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Easting (m)
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5.0
1.0
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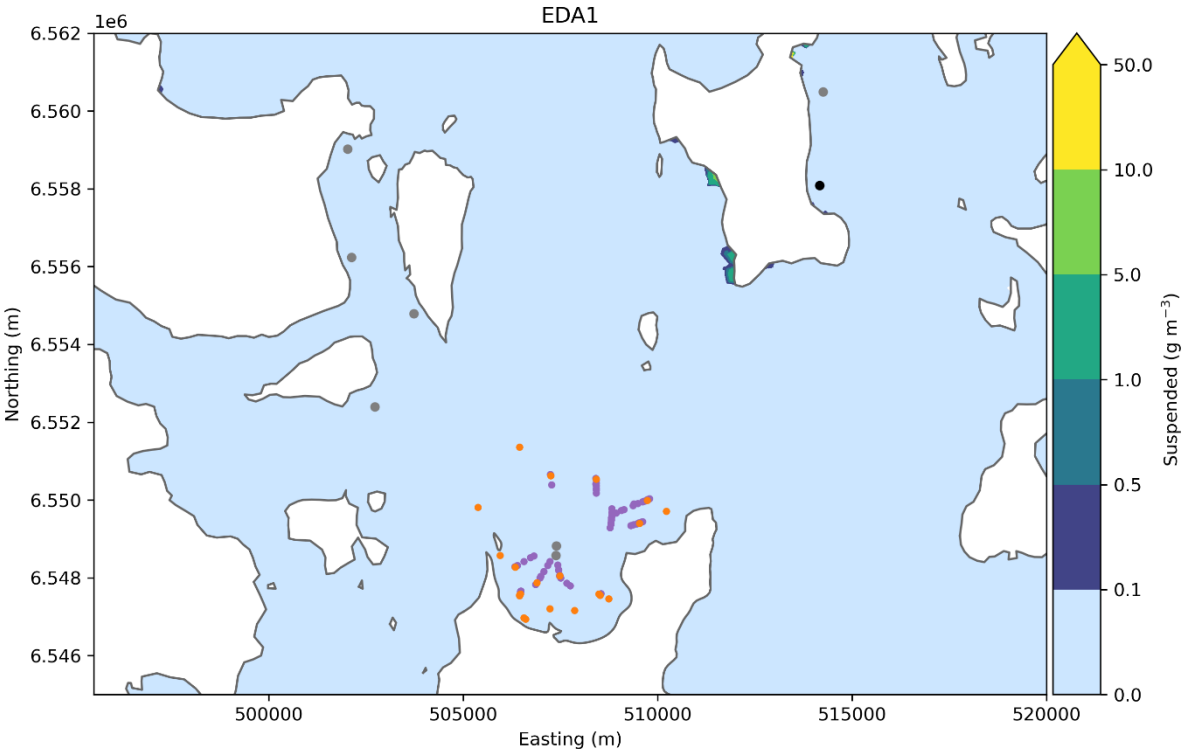
Suspended (g m^{-3})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Northing (m)
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510000
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520000
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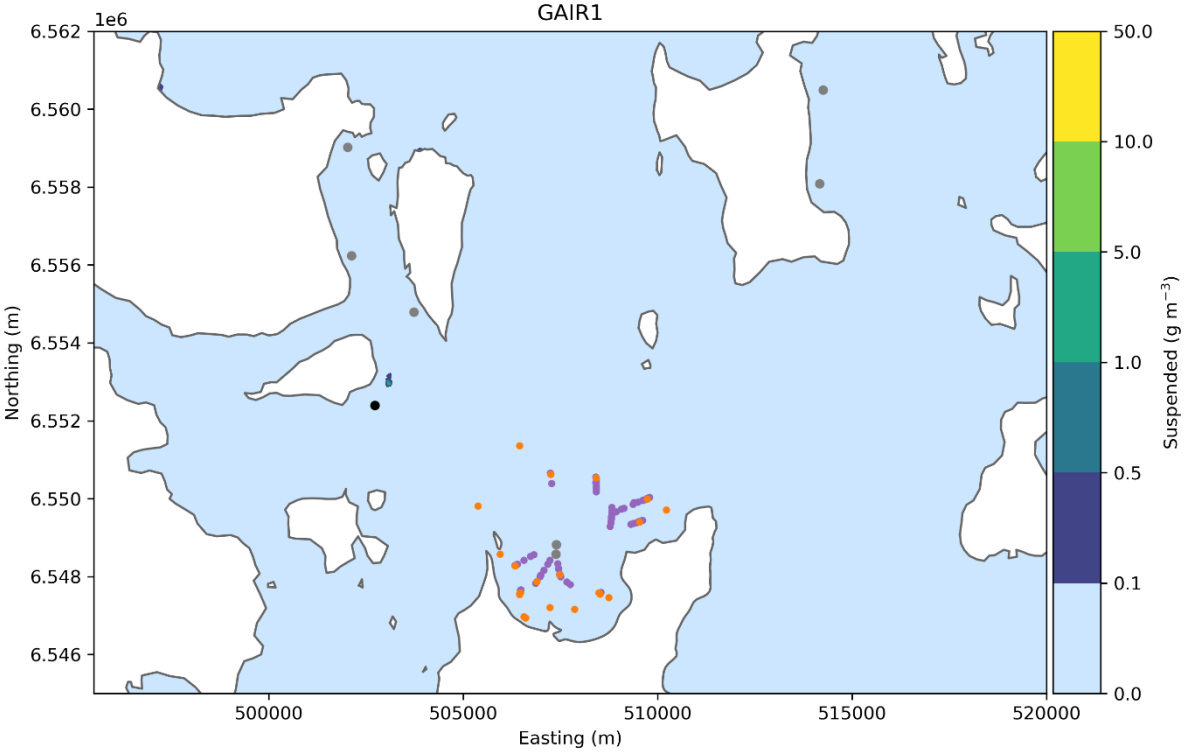
0.0
Suspended (g m^{-3})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Northing (m)
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505000
510000
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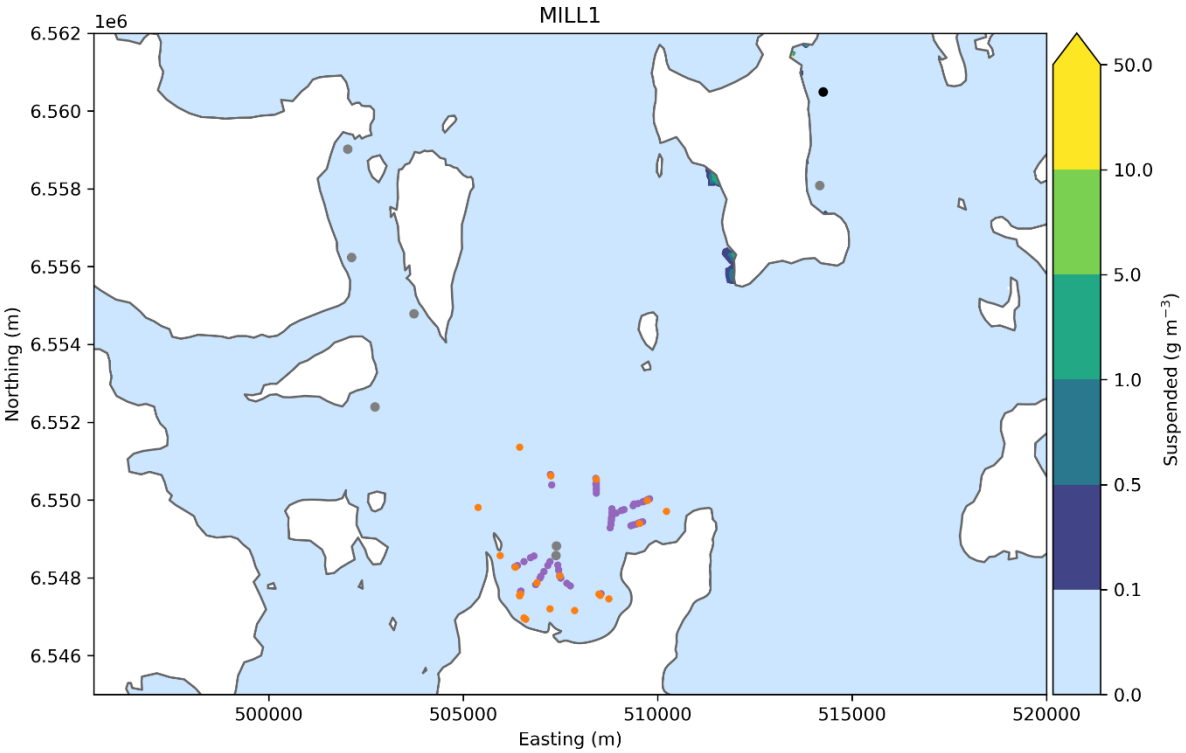
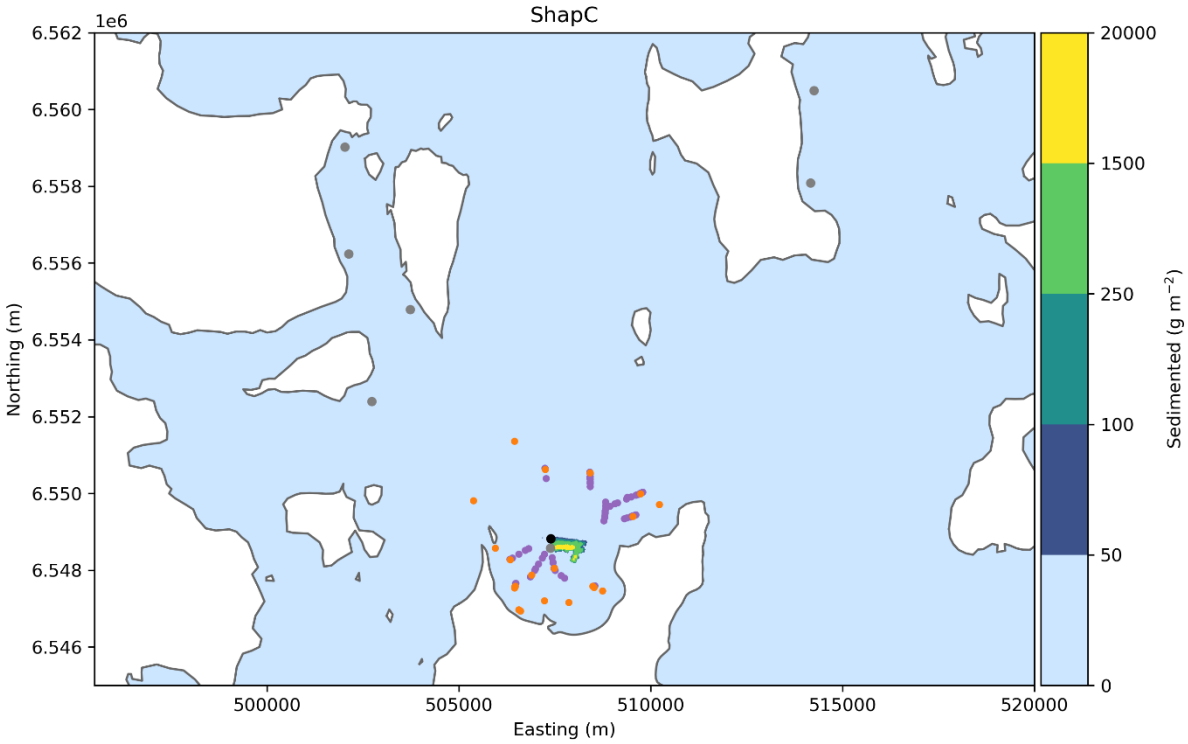
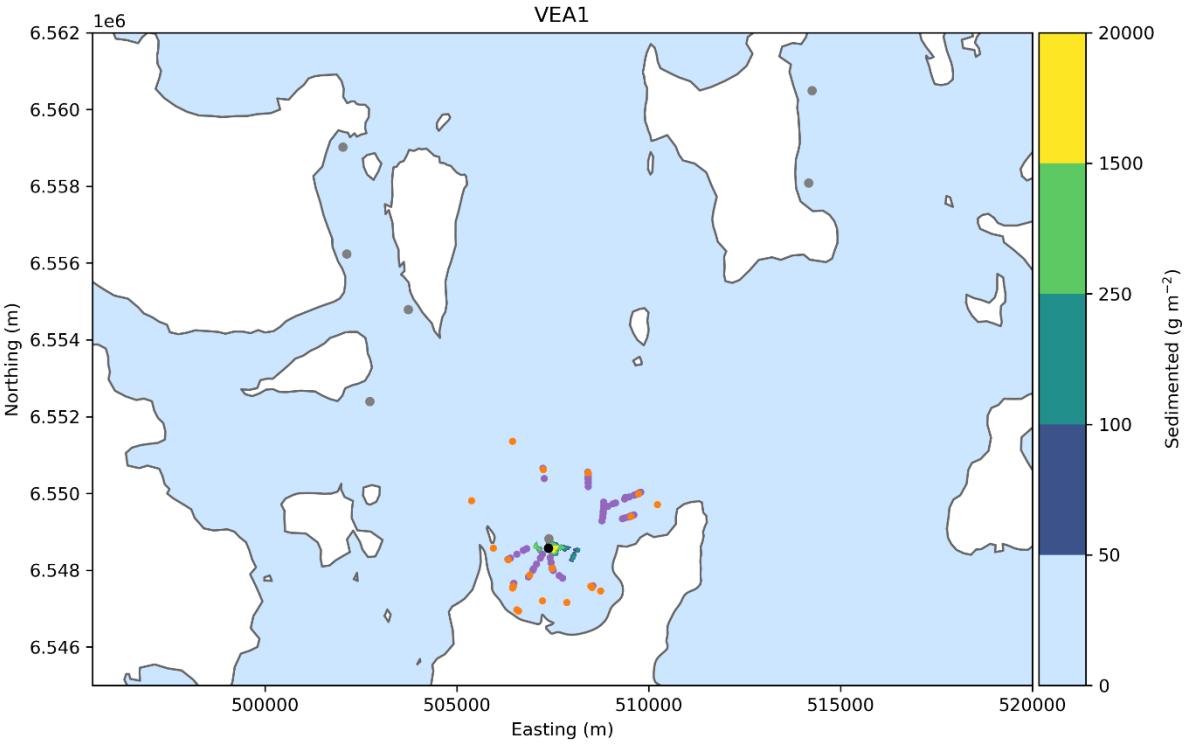
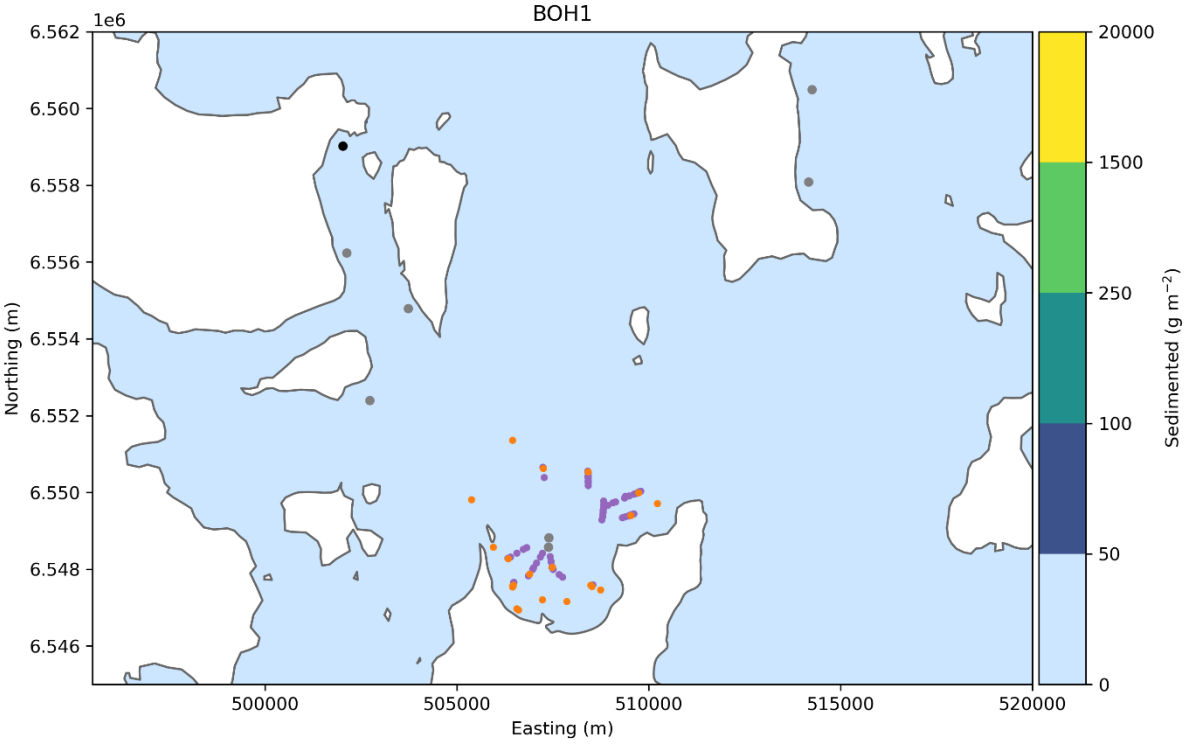

MILL1
1e6
6.562
6.560
6.558
6.556
6.554
6.552
6.550
6.548
6.546
Northing (m)
500000
505000
510000
515000
520000
Easting (m)
50.0
10.0
5.0
1.0
0.5
0.1
0.0
Suspended (g m^{-3})

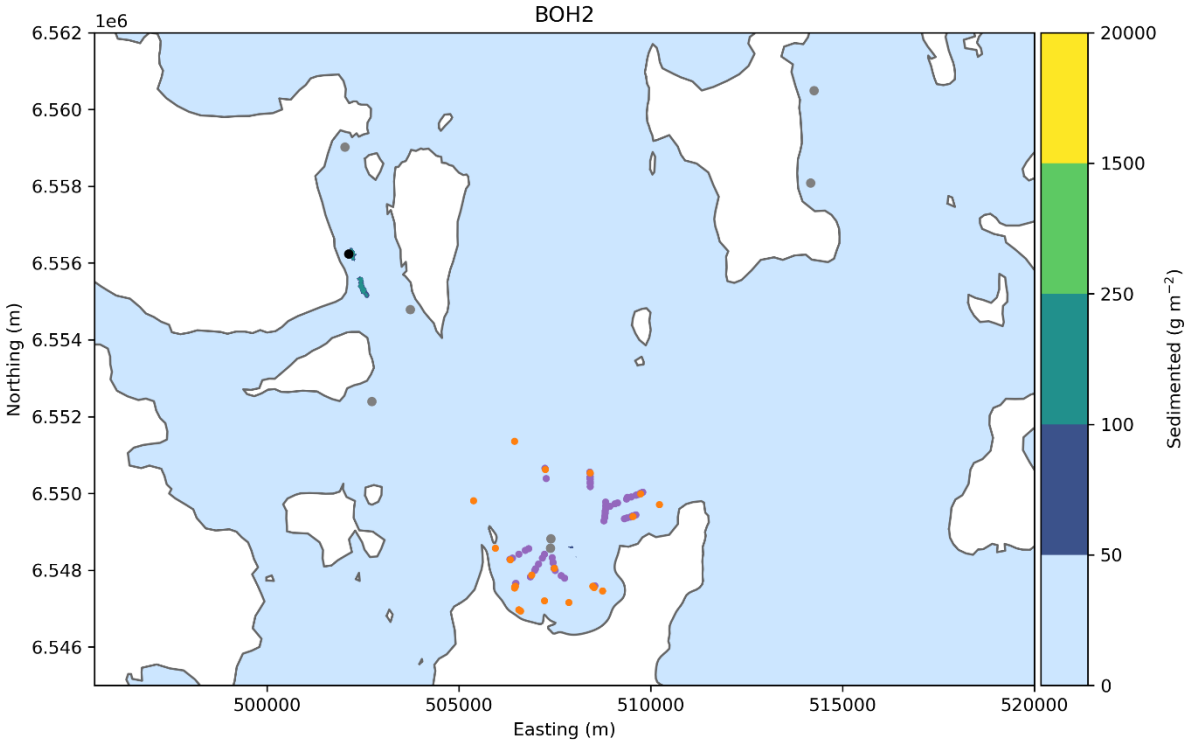
7.2.2 Deposited sediment (individual sites)

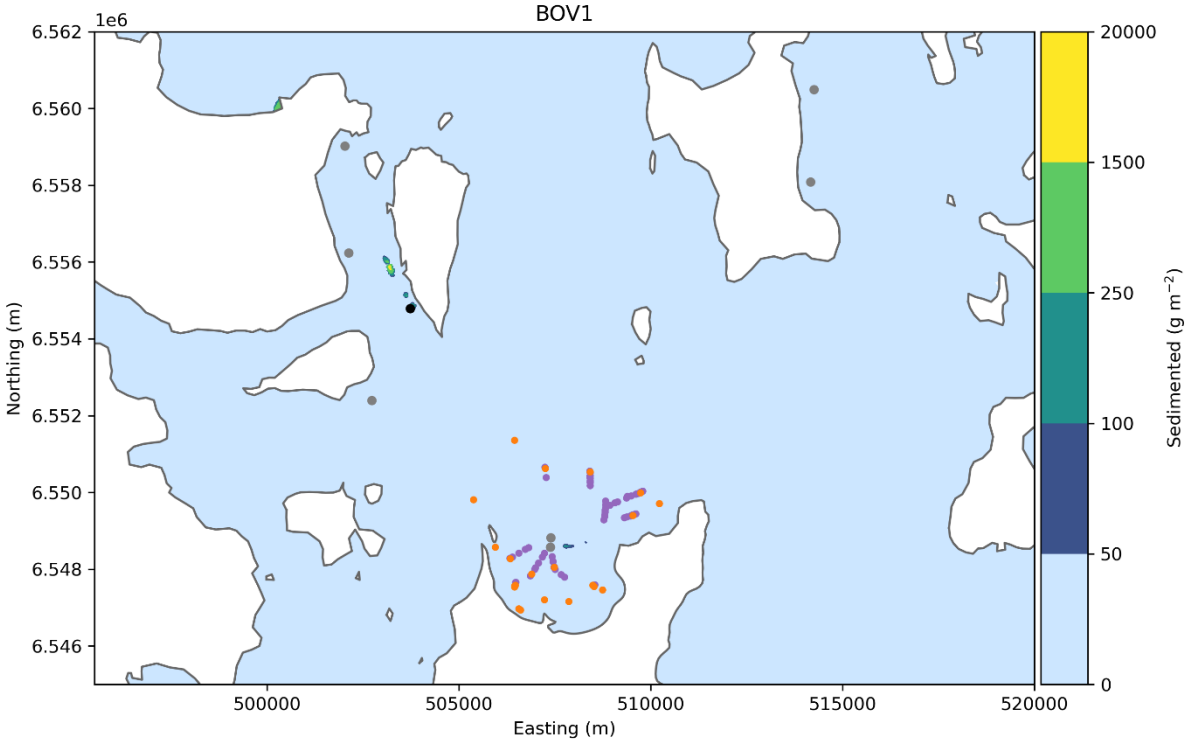
Maps of average deposited sediment concentration of the final 90 days of the simulation, as released from individual farm sites. Each map indicates the farm location included in the simulation (black point), maerl and seagrass PMF locations identified in the SEPA risk assessment (orange points) and visual survey locations with over 5% coverage of maerl (purple points). Grey points indicate the location of other farm sites which are not included in that particular map.

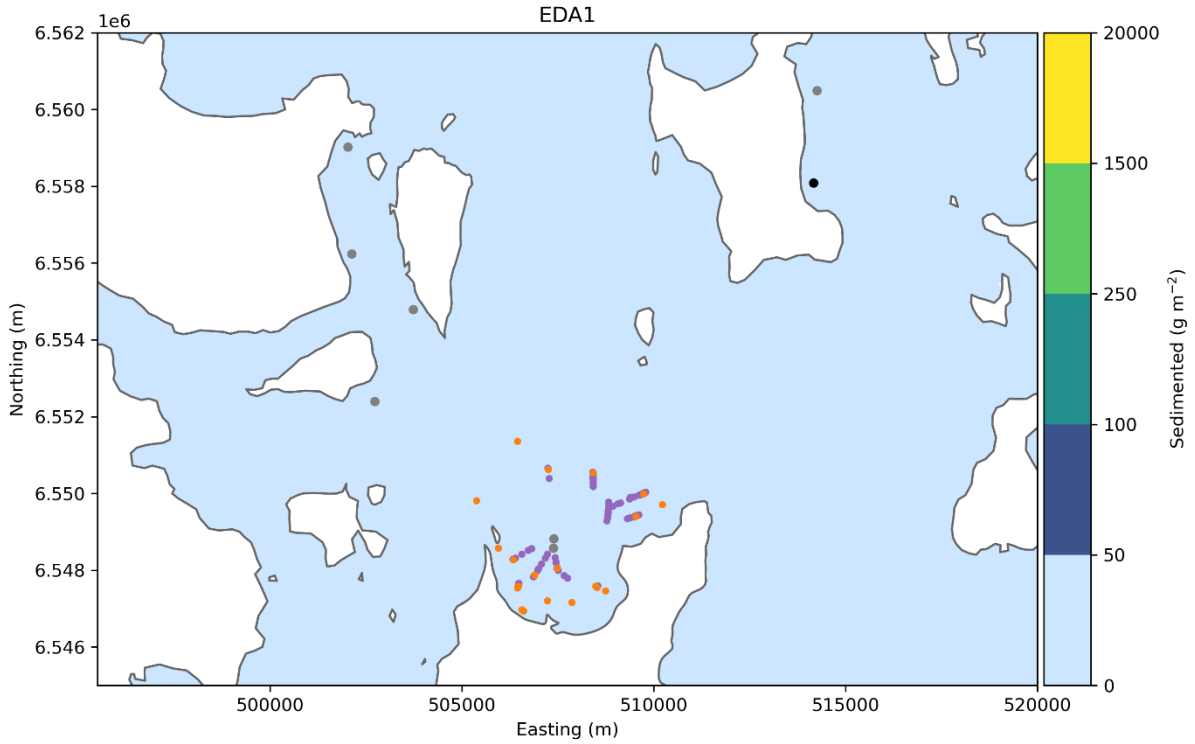


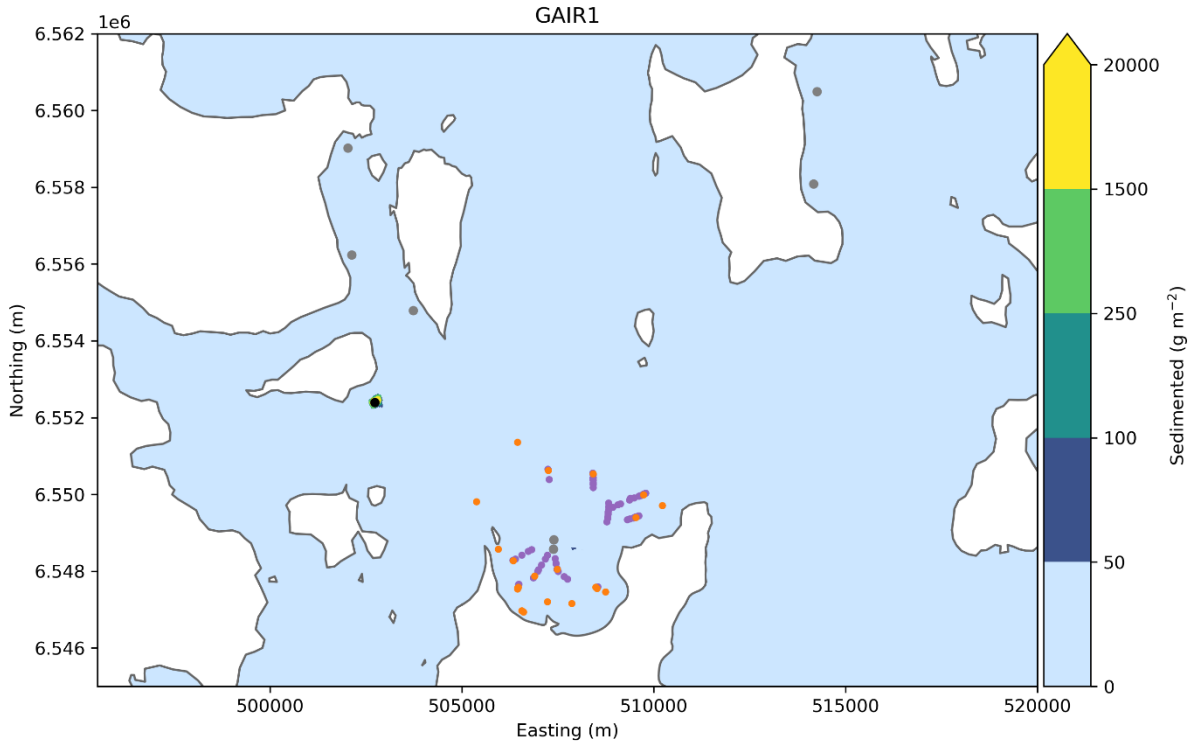

VEA1
1e6
6.562
6.560
6.558
6.556
6.554
6.552
6.550
6.548
6.546
Northing (m)
500000
505000
510000
515000
520000
Easting (m)
20000
1500
250
100
50
0
Sedimented (g m^{-2})

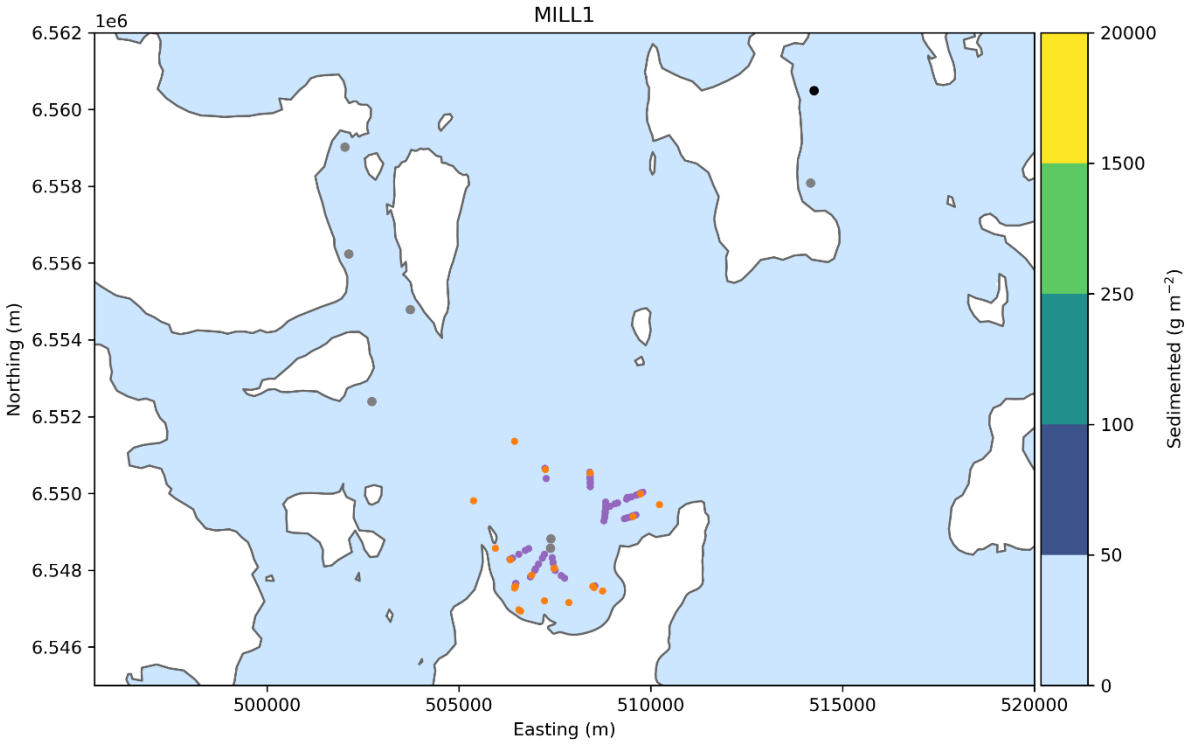

BOH1
1e6
6.562
6.560
6.558
6.556
6.554
6.552
6.550
6.548
6.546
Northing (m)
500000
505000
510000
515000
520000
Easting (m)
20000
1500
250
100
50
0
Sedimented (g m^{-2})


BOH2
1e6
6.562
6.560
6.558
6.556
6.554
6.552
6.550
6.548
6.546
Northing (m)
500000
505000
510000
515000
520000
Easting (m)
20000
1500
250
100
50
0
Sedimented (g m^{-2})


BOV1
1e6
6.562
6.560
6.558
6.556
6.554
6.552
6.550
6.548
6.546
Northing (m)
500000
505000
510000
515000
520000
Easting (m)
20000
1500
250
100
50
0
Sedimented (g m^{-2})


EDA1
1e6
6.562
6.560
6.558
6.556
6.554
6.552
6.550
6.548
6.546
Northing (m)
500000
505000
510000
515000
520000
Easting (m)
20000
1500
250
100
50
0
Sedimented (g m^{-2})


GAIR1
1e6
6.562
6.560
6.558
6.556
6.554
6.552
6.550
6.548
6.546
Northing (m)
500000
505000
510000
515000
520000
Easting (m)
20000
1500
250
100
50
0
Sedimented (g m^{-2})


MILL1
1e6
6.562
6.560
6.558
6.556
6.554
6.552
6.550
6.548
6.546
Northing (m)
500000
505000
510000
515000
520000
Easting (m)
20000
1500
250
100
50
0
Sedimented (g m^{-2})