Deposition Marine Modelling Report

Billy Baa, Scalloway, Shetland

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1 Summary

This report describes simulations of deposition based on the outputs of a hydrodynamic model which was developed for Scalloway Bay, Shetland. The aim of the investigation was to provide a risk assessment for deposition resulting from a proposed new development 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	Billy Baa
SEPA ID	BLYB1
Locality	Scalloway, Shetland
Pen centre (OSGB easting/northing, m)	435899, 1145874
Biomass (T)	4091 (applied for)
Configuration	
Number of pens (configuration)	10
Pen size	9 x 160 m + 1 x 120 m circumference
Pen group distance to shore	335 m (centre)
Pen grid orientation	16.25^{o}
Depth (m)	44.95 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 new site in new site at Billy Baa, Scalloway, Shetland ("BLYB1"; Figure 3.1), and in particular to predict the dispersal of waste feed and faeces from the proposed 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 Insitute 2022).

The modelling procedure follows the current version SEPA marine modelling guidance as available at April 2023, as far as possible.

This configuration is composed of 10 pens on a 125m grid, with centre-point of cage grid at (OSGB 435922, 1145858) m. Key data relating to the site are summarised in Table 1.1.

3 Methodology

3.1 Hydrodynamic model

The hydrodynamic model used in this work was the DHI MIKE 3 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 3 is a three-dimensional model which can account for density variation, currents and tidal elevation (Danish Hydraulic Insitute 2017).

MIKE 3 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.

Hydrodynamic fields covering the required time period were extracted from output generated using a hindcast implementation of Scottish Sea Farms' Scalloway area hydrodynamic model (Danish Hydraulic Insitute 2021b). This is a higher resolution subdomain of a larger model which covers the whole of the Shetland Isles. Model output covers the entirety of the south west of Shetland, reaching Foula in the west and has been validated at multiple locations throughout the domain, including the proposed Billy Baa site 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 01/11/2017-01/11/2018, 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 in (Danish Hydraulic Insitute 2021b) and the accompanying HD model validation report.

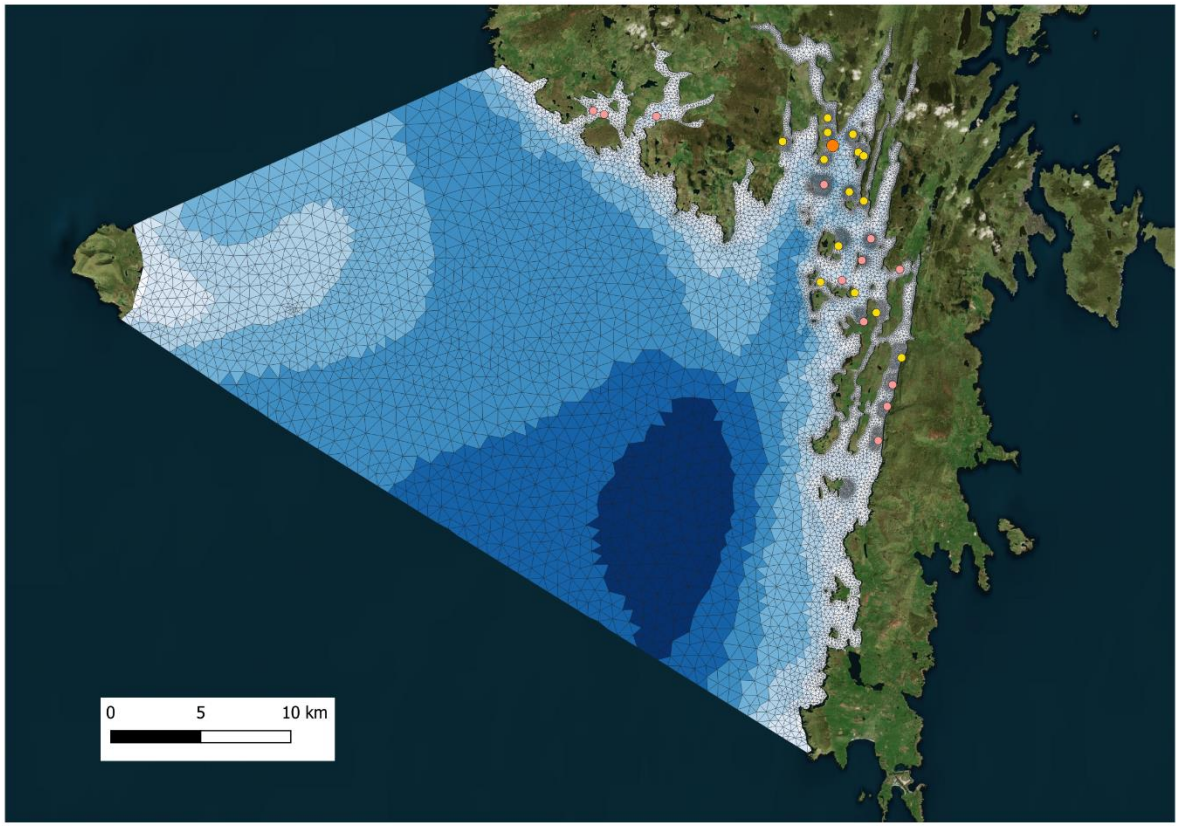

Figure 3.1: **Mesh for hydrodynamic model, showing the full extent of the spatial domain, which focusses on the Scalloway Bay area of Shetland. Active farm sites are indicated by pink discs, inactive sites by yellow discs, and the Billy Baa current meter location by an orange disc.**

3.2 Particle Tracking model

Particle tracking was also carried out using the DHI MIKE software suite (Danish Hydraulic Insitute 2021a). Flow fields (U/V/W velocities) generated by MIKE 3 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 default critical erosion threshold of 0.02 N m^{-2}. The default bed roughness of 0.001 m was used for the main simulations (tuning and final).

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 (covering the focal site and the two Category 1 waterbodies to the northeast, Sandsound and Weisdale Voes), element side length is around 40 m, and element area is around 500 m^2 (i.e. smaller than the default grid size in NewDepomod).

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.

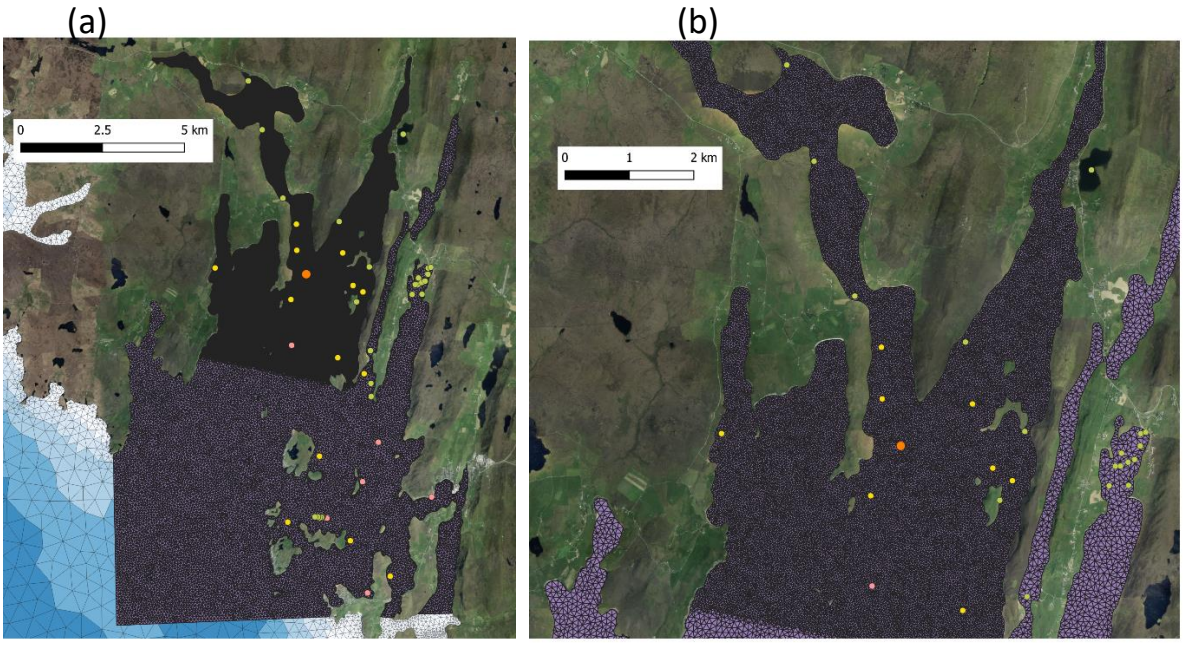

Figure 3.2 **Mesh used for particle tracking, covering inner Scalloway area at high resolution. (a) Whole mesh. (b) Close-up view of Sandsound and Weisdale voes.**

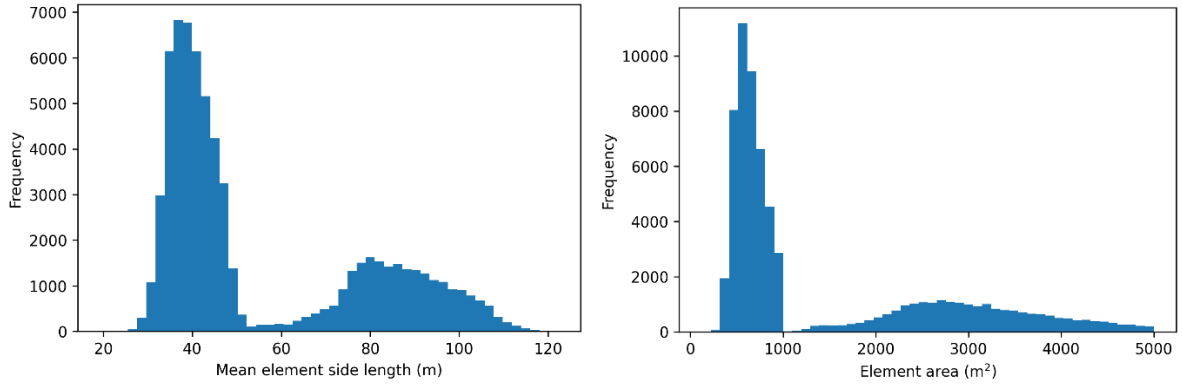

Figure 3.3 **Histograms of properties of the mesh used for impact assessment particle tracking. (a) Element side length (mean of the three sides of an element), and (b) element area.**

3.3 Waste deposition model study

3.3.1 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 BLYB1, in addition to other existing sites identified in the SEPA risk screening report for the site (Scottish Environmental 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)

= 4,091,000 * 0.007 * 0.91 * 0.03

= 781.8 kg

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

= 4,091,000 * 0.007 * 0.91 * 0.97 * 0.15

= 383.1 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 2023).

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 (Scottish Environment Protection Agency 2023).

Assessment was made of the predicted cumulative impacts of several different site configurations, on the assumption of maximum permissible biomass being held at the sites used for release:

1. stocking of all existing sites/CAR licence locations (the current “worst case”);
2. stocking of proposed Billy Baa site, and relinquishment of sites to be made as a condition of the new site being granted (the SEPA requested future configuration);

These scenarios are indicated in the columns at the right hand side of Table 3.1. Results relating to scenario 2 are presented within the main body of the document, with some additional figures and supporting information relating to other sites/scenarios provided in the Appendix.

Table 3.1 Sites simulated, with stocked biomass and calculated quantities for release (per day, and per model timestep. The two scenarios considered in cumulative impact analysis (described in Section 3.3.1) are also indicated, with site included in each scenario mark with a cross.

Site Code	Site Name	Easting	Northing	Biomass (tonnes)	Last Production Cycle	Waste feed mass (kg d^-1)	Faeces mass (kg d^-1)	Waste feed mass (kg step^-1)	Faeces mass (kg step^-1)	S1	S2
BLYB1	Billy Baa	435922	1145858.4	4091	Proposed	781.8	3791.7	3.257	15.799		x
BUR1	West of Burwick	438123	1140625	1922.6	Currently Stocked	367.4	1781.9	1.531	7.425	x	x
CLI4	North of Papa	436565	1138287	1332	Currently Stocked	254.5	1234.5	1.061	5.144	x	x
EHIL3	East of Hildasay	436517	1140594	1500	Fish last on site Nov 08	286.7	1390.3	1.194	5.793	x	x
ELAN1	East of Langa	437692	1139455	1642.8	Currently Stocked	313.9	1522.6	1.308	6.344	x	x
ESH1	Easter Score Holm	435402	1143485	3919.61	Currently Stocked	749.0	3632.8	3.121	15.137	x	x
NHAV1	North Havra	436965	1143086	1496	Fish last on site Aug 17	285.9	1386.5	1.191	5.777	x	x
PVOE1	Punds Voe (Marine Hatchery)	438900	1138900	960	Fish last on site Nov 13	183.5	889.8	0.764	3.707	x	x
SANDA1	Sanda Stour	435550	1142030	1500	Fish last on site Sep 07	286.7	1390.3	1.194	5.793	x	x
SEL3	Selivoe	433310	1146000	963	Fish last on site Dec 07	184.0	892.5	0.767	3.719	x	x
SPO1	Spoose Holm	435334	1138344	1500	Fish last on site Sep 17	286.7	1390.3	1.194	5.793	x	x
STRO1	Stromness Voe	438200	1144000	150	Not stocked since 2007	28.7	139.0	0.119	0.579	x	x
STRO2	Binnaness	437649	1142440	1500	Fish last on site Jan 09	286.7	1390.3	1.194	5.793	x	x
BGEO1	Brei Gei Offshore	435726	1146673	2635	Fish last on site Oct 08	503.5	2442.2	2.098	10.176	x	
BGEO2	Brei Geo Inshore	435680	1147320	1209	Fish last on site Oct 07	231.0	1120.5	0.963	4.669	x	
FOR2	Foreholm	435490	1145040	1650	Fish last on site Jun 17	315.3	1529.3	1.314	6.372	x	x
SAND1	Sandsound Voe	435200	1150000	100	Not stocked since records began (2002)	19.1	92.7	0.080	0.386	x	
SBIX1	Sand Sound, Bixter	435000	1148900	1000	Fish last on site Mar 02	191.1	926.8	0.796	3.862	x	
SHOY1	Sound of Hoy	437700	1145000	1190.5	Fish last on site Jan 09	227.5	1103.4	0.948	4.597	x	x
WEI2	North of Hoy	437500	1145430	1190.5	Fish last on site Jan 09	227.5	1103.4	0.948	4.597	x	x
WEI3	Flotta	437090	1146320	1221	Fish last on site Jan 09	233.3	1131.7	0.972	4.715	x	x
WEIA1	Weisdale Voe A	438300	1147700	100	Not stocked since records began (2002)	19.1	92.7	0.080	0.386	x	x
WEIB1	Weisdale Voe B	437400	1147800	250	Not stocked since records began (2002)	47.8	231.7	0.199	0.965	x	x

3.3.2 Output statistics

Output statistics were generated for all particle dispersion simulations in accordance with the current version of SEPA guidance (Scottish Environment Protection Agency 2023).

Specifically, this 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, at the 250 g m^{-2} contour;
- 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 Priority Marine Features, due to the presence of horse mussel, seagrass, blue mussel and maerl (Table 3.2). A shapefile representing the PMF locations was downloaded from the Scottish Government NMPI website and trimmed to the domain of interest. A small number of PMF locations were outside the hydrodynamic model domain (located on the coastline, or in one case, a small side loch not represented in the model). For these locations, points representing them were placed within the nearest hydrodynamic model element (and in the side loch case, on the seaward side of the connecting inlet.

A visual seabed survey on the area around the proposed site indicated the presence of a small number of horse mussel beds (Table 3.3). Additional sensitive locations were identified during the risk screening, in the form of fish (Table 3.4) and shellfish farms (Table 3.5). All features are shown on a map in Figure 4.3.

For each of these locations, timeseries of concentration within were generated. Mean values and number of non-zero values over the last 90 days of the simulation were calculated, in addition to vertical profiles of concentration over the last 90 days, where concentration was sufficiently high.

Table 3.2 PMF locations in the proximity of the proposed site, extracted from the NMPI database. Numbering here is used in later plots presenting results of impact calculations. Starred items were slightly outside model domain and points representing them were placed within the nearest model element.

ID	Type	Easting	Northing
1	Horse mussel beds	593298.7	6670498
2	Horse mussel beds	593292.7	6670898
3	Horse mussel beds	593277.5	6671898
4	Horse mussel beds*	592854.8	6673392
5	Seagrass beds	594851.7	6673623
6	Seagrass beds	594551.7	6673618
7	Seagrass beds	594727.2	6673921
8	Seagrass beds	594647.2	6673920
9	Blue mussel beds	594846.3	6673982
10	Seagrass beds	594945.6	6674024
11	Seagrass beds	594744.1	6674121
12	Seagrass beds	595042.6	6674226
13	Seagrass beds	595032.5	6674235
14	Seagrass beds	595039.6	6674426
15	Seagrass beds*	595119.3	6674447
16	Blue mussel beds*	595119.3	6674447
17	Horse mussel beds	593244.3	6674458
18	Horse mussel beds	593244.3	6674458
19	Horse mussel beds	592323	6675845
20	Horse mussel beds	590606.4	6676559
21	Horse mussel beds	590606.4	6676559
22	Seagrass beds*	594277.5	6678515
23	Seagrass beds*	594277.5	6678515
24	Horse mussel beds	589974.6	6678650
25	Blue mussel beds	589551.9	6680143
26	Maerl beds	591823.5	6666826
27	Maerl beds	591812.4	6666826
28	Maerl beds	591805.8	6666826
29	Maerl beds	591794.4	6666814
30	Maerl beds	591782.4	6666803
31	Maerl beds	591728.8	6666790
32	Maerl beds	591670.2	6666800
33	Maerl beds	591602.4	6666821
34	Maerl beds	591669.6	6666822
35	Maerl beds	591584.7	6666820

Table 3.3: Sensitive features identified during visual seabed survey of site.

ID	Type	Easting	Northing
1	Horse mussel beds	591020.7	6673938
2	Horse mussel beds	590969.9	6673925
3	Horse mussel beds	590893.6	6673882
4	Horse mussel beds	591034.3	6673768

Table 3.4: Fish farms identified as sensitive features at risk from sediment interaction in the SEPA risk screening report.

ID	Feature Name	Feature Type	Easting	Northing
1	BLYB1	Fish Farm	591262.5	6674326
2	BUR1	Fish Farm	593519	6668999
3	CLI4	Fish Farm	592020.6	6666764
4	EHIL3	Fish Farm	591937.6	6669071
5	ELAN1	Fish Farm	593129.8	6667949
6	ESH1	Fish Farm	590702.1	6671928
7	NHAV1	Fish Farm	592347.9	6671569
8	PVOE1	Fish Farm	594346.1	6667413
9	SANDA1	Fish Farm	590933.8	6671492
10	SEL3	Fish Farm	588648.9	6674428
11	SPO1	Fish Farm	590788.8	6666803
12	STRO1	Fish Farm	593568.9	6672502
13	STRO2	Fish Farm	593041.6	6670934
14	WHI2	Fish Farm	594396.2	6670714

Table 3.5: Shellfish farms identified as sensitive features at risk from sediment interaction in the SEPA risk screening report.

ID	Name	Type	Easting	Northing
1	South of Ness of Bixter	Shellfish farm	588861.6	6679532
2	The Firth (Tresta North)	Shellfish farm	589557	6679842
3	The Firth (Tresta South)	Shellfish farm	589466.1	6679241
4	Northwest of Lunga	Shellfish farm	590267.6	6679153
5	Lungness	Shellfish farm	590381.2	6678255
6	Sandsound South	Shellfish farm	590191.9	6677552
7	Mid Noost	Shellfish farm	594258.3	6679814
8	NE of Vedri Geo Weisdale	Shellfish farm	593297.7	6677199
9	Olligarth	Shellfish farm	593611.4	6676303
10	Kirkaward	Shellfish farm	592709.9	6676390
11	Oxa Geo	Shellfish farm	592220.5	6675682
12	NW Greena, Weisdale Voe	Shellfish farm	592920.5	6675693
13	North Flotta	Shellfish farm	593432.6	6674900

4 Results

4.1 NewDepomod comparison

Results from the final NewDepomod simulation for the Billy Baa site are shown in Figure 4.1. The impacted area above the 250 g m^{-2} contour for this final passing simulation was estimated as 310,000 m^2 (counting cells), and the mean flux within this zone was estimated at 3976.5 g m^{-2} yr^{-1} (counting cells). Results are described in more detail in the accompanying NewDepomod modelling report.

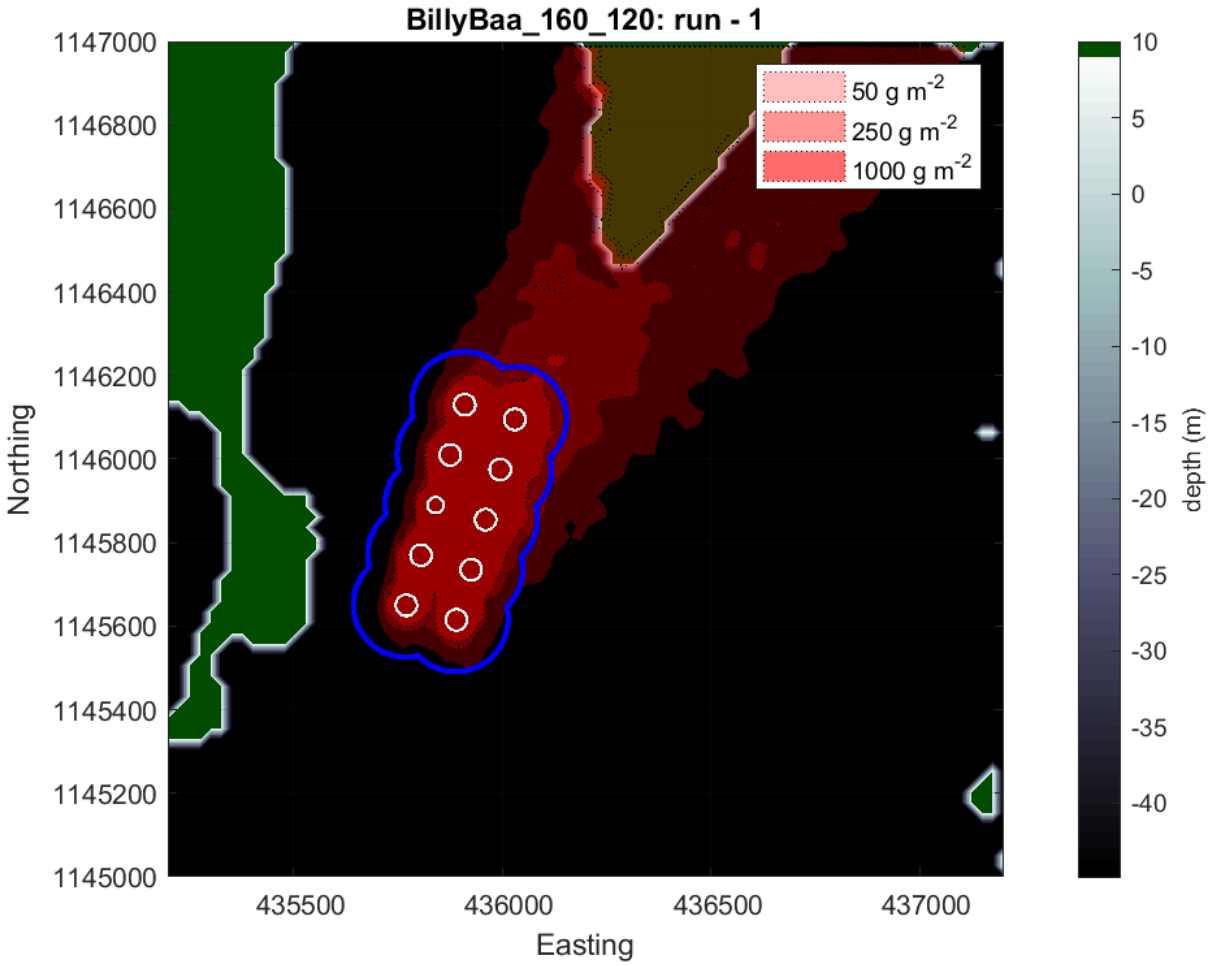

Figure 4.1: Map of deposition predicted by NewDepomod using the standard default configuration.

In terms of overall intensity and extent, the results arising from the MIKE simulation with the default critical erosion (0.02 N m^{-2}) and bed roughness (0.001 m) parameters appear reasonably close to the Depomod simulation, even though the plume of dispersed material is oriented somewhat differently. The most intense area of the footprint is also co-located with that predicted by Depomod. For the Billy Baa site, the MIKE simulation with this parameter has a 250 g m^{-2} contour with extent 287,995 m^2, and average intensity 5,056 g m^{-2}; both of which are close to the Depomod prediction (a slightly smaller and more intense footprint).

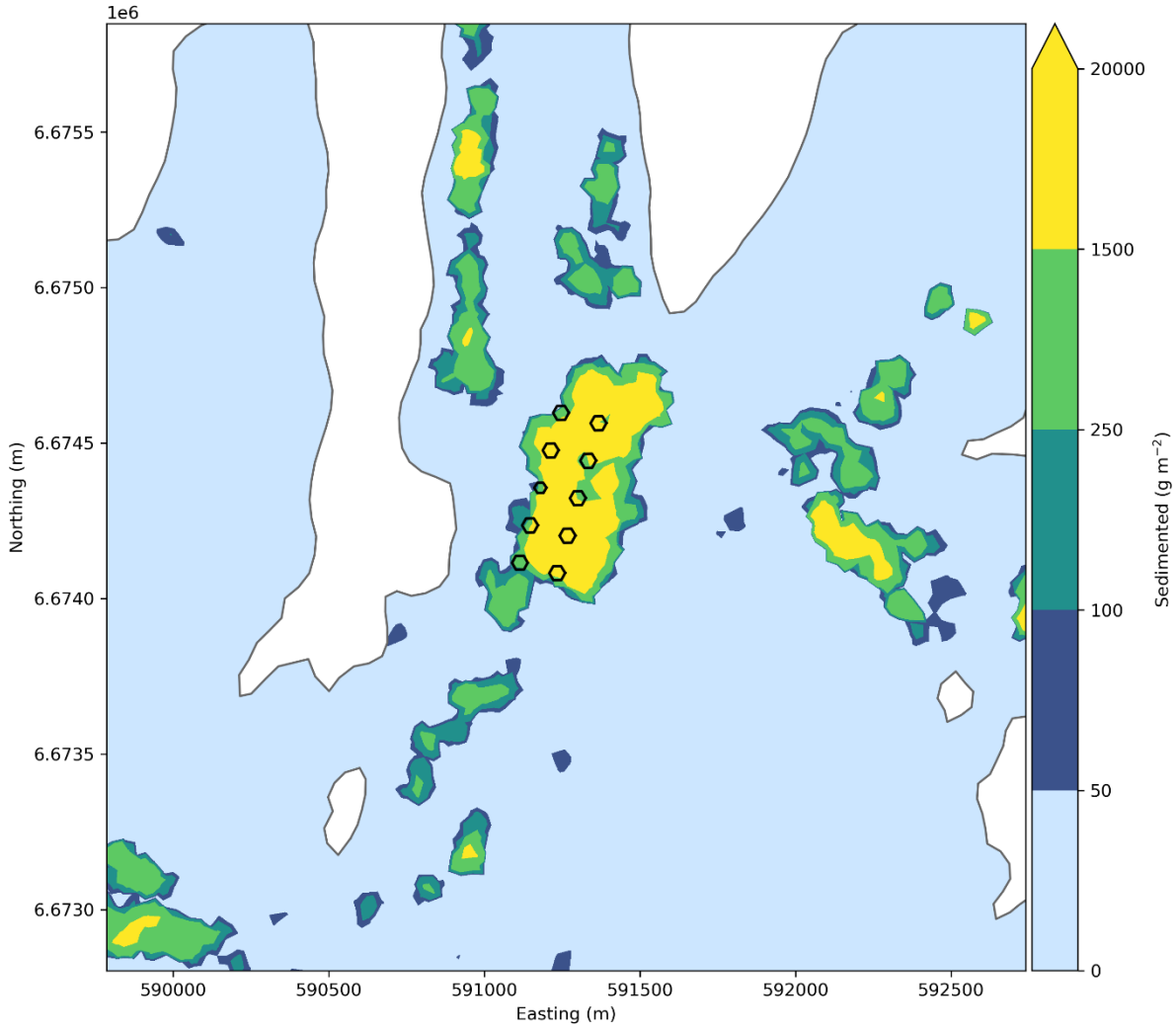

Figure 4.2: MIKE prediction of deposition at Billy Baa site, using default parameters.

Slight improvements in match to area and intensity were obtained by adjusting the bed roughness parameter to 0.01 m and retaining the default critical erosion threshold (extent 315,015 m^2, average intensity 4,179 g m^{-2}), but was a qualitatively worse match to the NewDepomod footprint for this site (Appendix Figure A1). A map showing predicted deposition from Billy Baa across the broader area of Scalloway, using the default parameters, is shown in Appendix Figure A5.

It was therefore considered appropriate to carry out cumulative deposition simulations for all sites using the default MIKE parameterisation.

4.2 Extent and concentration of impact over final 90 days

4.2.1 Suspended sediment

A map of suspended sediment concentration, averaged over the last 90 days of the simulation, are shown in Figure 4.3. Maps showing each of the 4 scenarios noted in Section 3.3.1, and individual site releases, are provided in Appendix Figure A2.

The concentration is generally predicted to be low throughout the domain, only reaching any notable level on some western shores of the voes, 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.

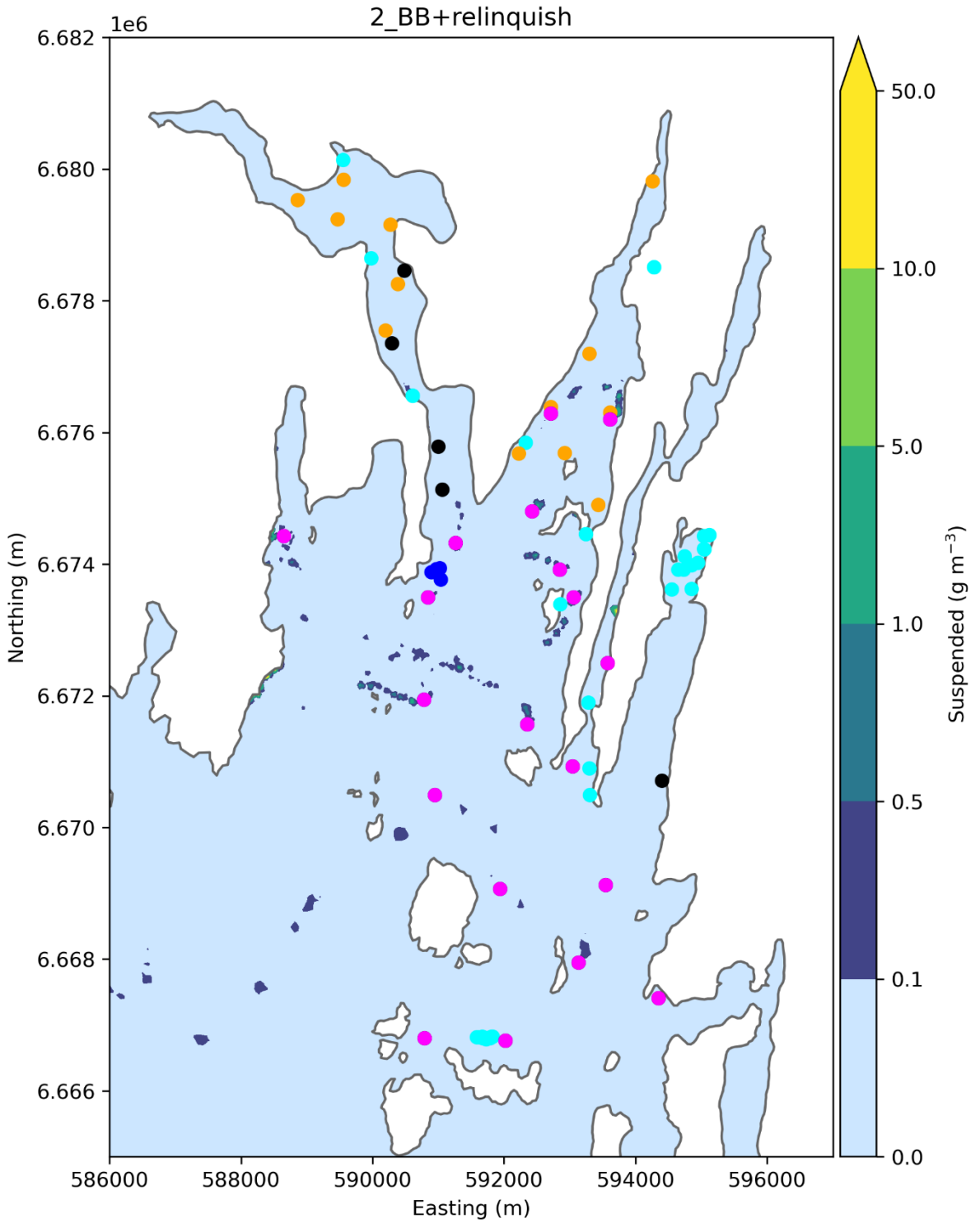

Figure 4.3 **Map of average suspended sediment concentration of the final 90 days of the simulation for scenario 2 (proposed Billy Baa + relinquishment). Magenta points indicate farm locations included as release points in the simulation. Cyan points indicate PMF locations for impact assessment, dark blue points the location of sensitive features found during visual survey, and black/orange points other fish/shellfish farms identified for impact assessment.**

4.2.2 Deposited sediment

Maps of deposited sediment concentration, including all source sites in the SEPA risk assessment and averaged over the last 90 days of the simulation, are shown in Figure 4.4. Again, maps showing each of the 4 scenarios noted in Section 3.3.1, and individual site releases, are provided in Appendix Figure A3.

Summary statistics for the extent and intensity of the 250 g m^{-2} impacted area are given in Table 4.1. BLYB1 has the largest predicted area over 250 g m^{-2}, with average intensity within this intermediate of the other sites.

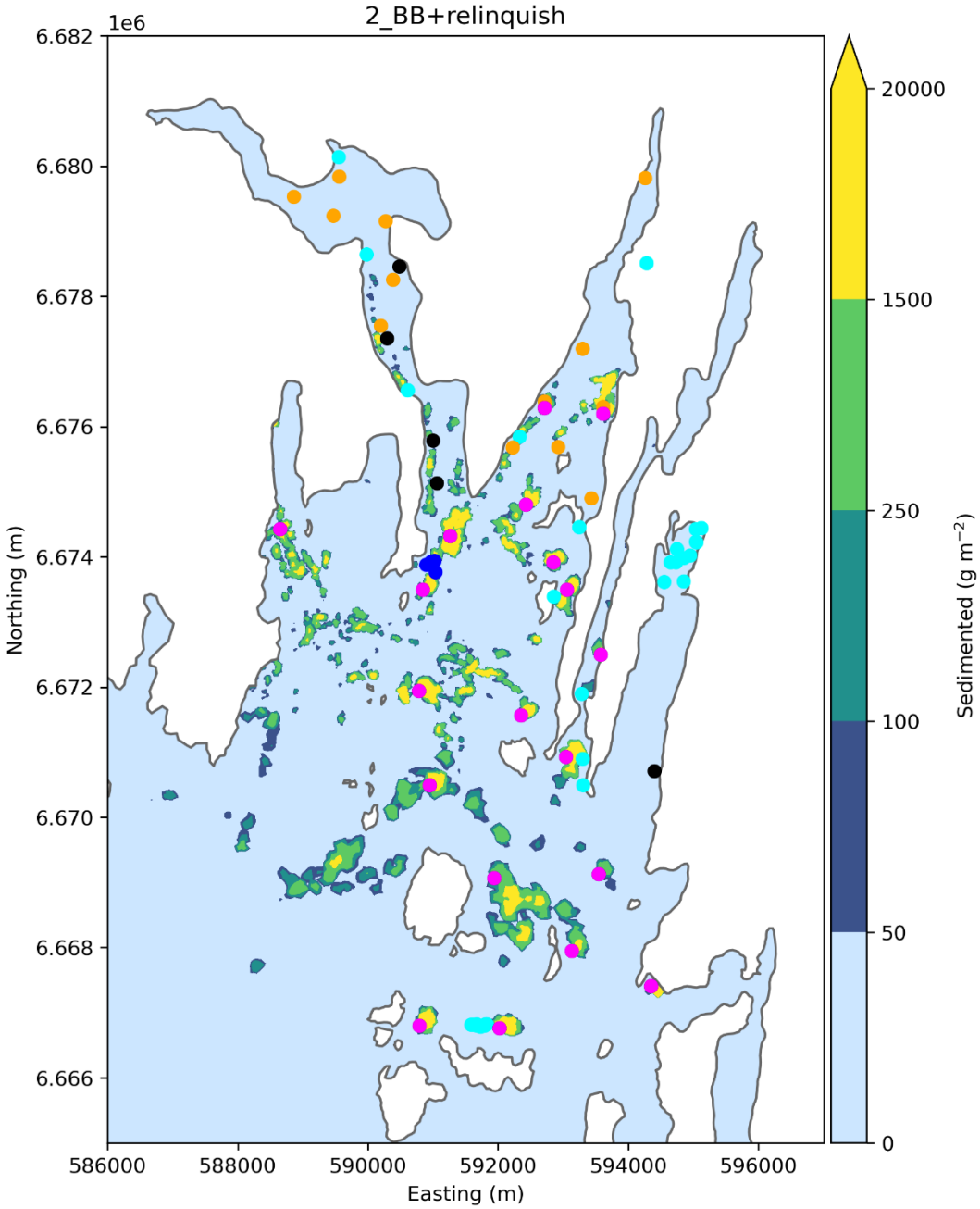

Figure 4.4 **Map of average deposited sediment concentration of the final 90 days of the simulation for scenario 2 (proposed Billy Baa + relinquishment). Magenta points indicate farm locations included as release points in the simulation. Cyan points indicate PMF locations for impact assessment, dark blue points the location of sensitive features found during visual survey, and black/orange points other fish/shellfish farms identified for impact assessment.**

Table 4.1: Summary statistics for individual site releases, showing the size and average intensity of the area above 250 g m^{-2}, over the last 90 days of the simulation.

Site	Extent > 250 g m^{-2}	Average > 250 g m^{-2}
BLYB1	287995	5056
BUR1	221532	1559
CLI4	52517	8995
EHIL3	181499	2003
ELAN1	160272	3076
ESH1	150405	9290
NHAV1	127420	4051
PVOE1	22504	15229
SANDA1	109100	3255
SEL3	99448	3406
SPO1	38133	13989
STRO1	21458	2481
STRO2	66016	7765
BGEO1	179695	5172
BGEO2	111697	3789
FOR2	52953	11156
SAND1	22528	1286
SBIX1	75073	4716
SHOY1	51937	8273
WEI2	66547	6377
WEI3	82020	5186
WEIA1	65720	34296
WEIB1	28106	3013

4.3 Maximum concentrations over (full run)

4.3.1 Suspended sediment

Suspended sediment concentrations in the simulation are broadly increasing over the first half of the year, before becoming more stable. Maximum concentration at a given time is highly dependent on the state of the tide, and this is reflected in the raw timeseries which indicate a high level of short term variability (not shown). The overall pattern of maximum concentration (and the conservative upper bound) is seen more clearly in the timeseries of the 72 hr rolling maximum (Figure 4.5).

Due to the relatively large biomass, the proposed site is at the upper end of the modelled sites in terms of the maximum concentration of suspended sediment resulting from its operation.

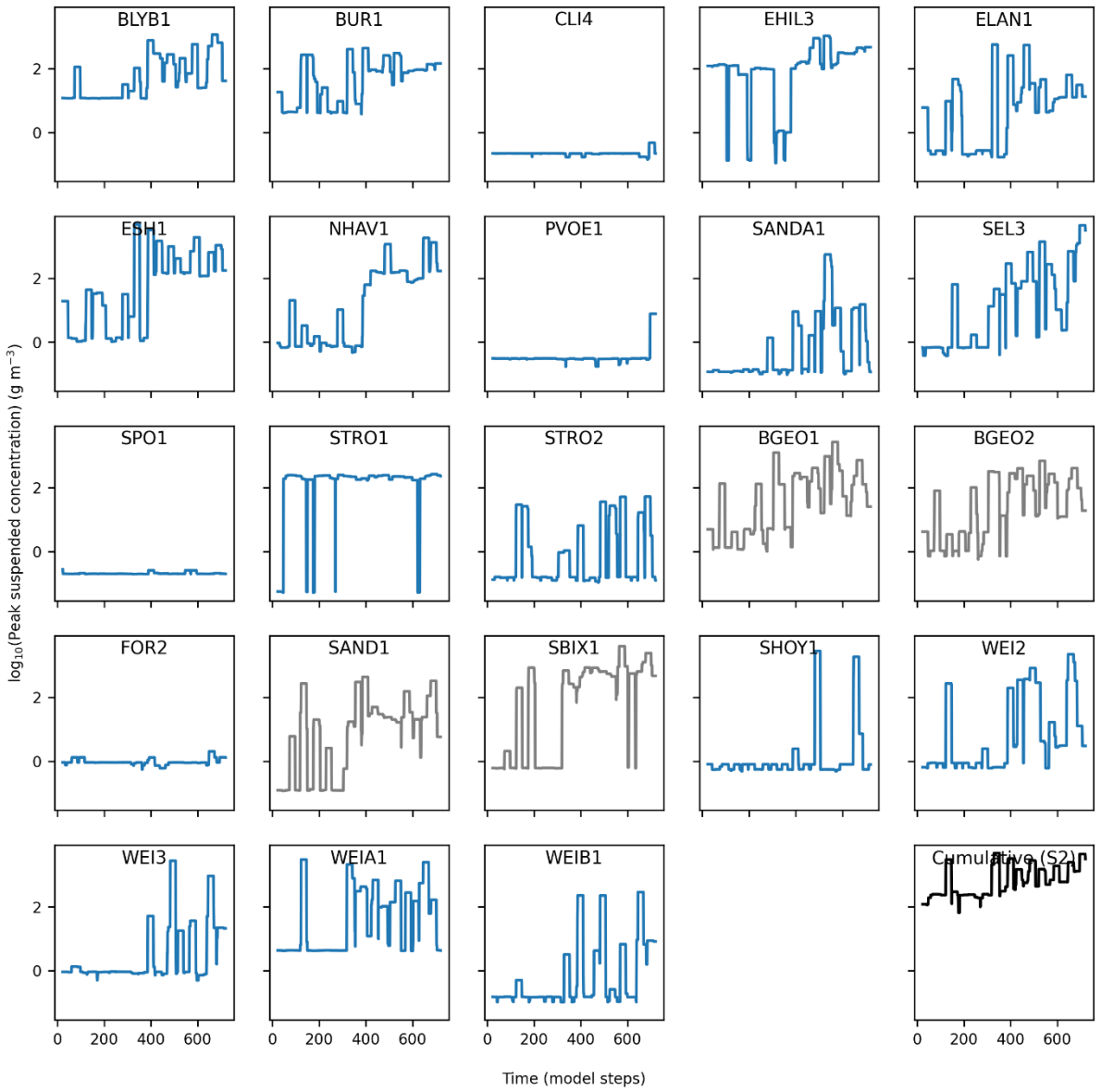

Figure 4.5 **Maximum concentration of suspended sediment (rolling maximum over 72 hrs) in relation to each source farm, and cumulative total for the proposed scenario 2. Sites included in the proposed scenario are shown with blue lines, and those excluded with grey. Values are plotted on a logarithmic scale.**

4.3.2 Deposited sediment

For most of the simulated sites, maximum concentration of deposited sediment fluctuates somewhat less than does maximum suspended sediment. Timeseries of individual site and overall (cumulative) maxima are shown in Figure 4.6.

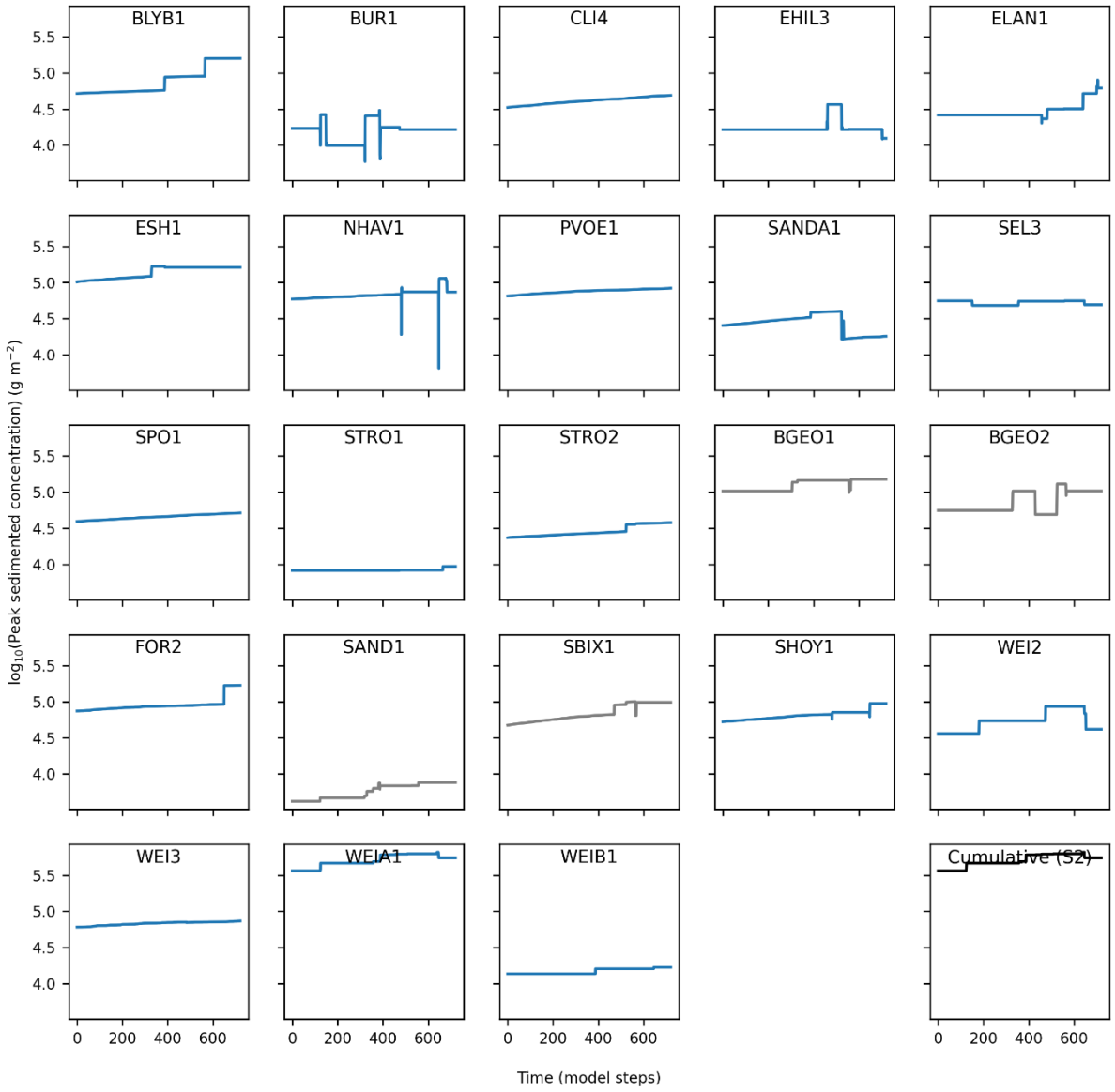

Figure 4.6 **Maximum concentration of deposited sediment (raw values) in relation to each source farm, and cumulative total for scenario 2. Sites included in the proposed scenario are shown with blue lines, and those excluded with grey. Values are plotted on a logarithmic scale.**

4.4 Average concentrations (full run)

4.4.1 Suspended sediment

The patterns of average suspended sediment concentration predicted over the duration of the simulation are similar to those seen in the maximum concentrations. Again there are high levels of fluctuation in concentration, and the proposed site is comparable to the others included in the simulation (Figure 4.7).

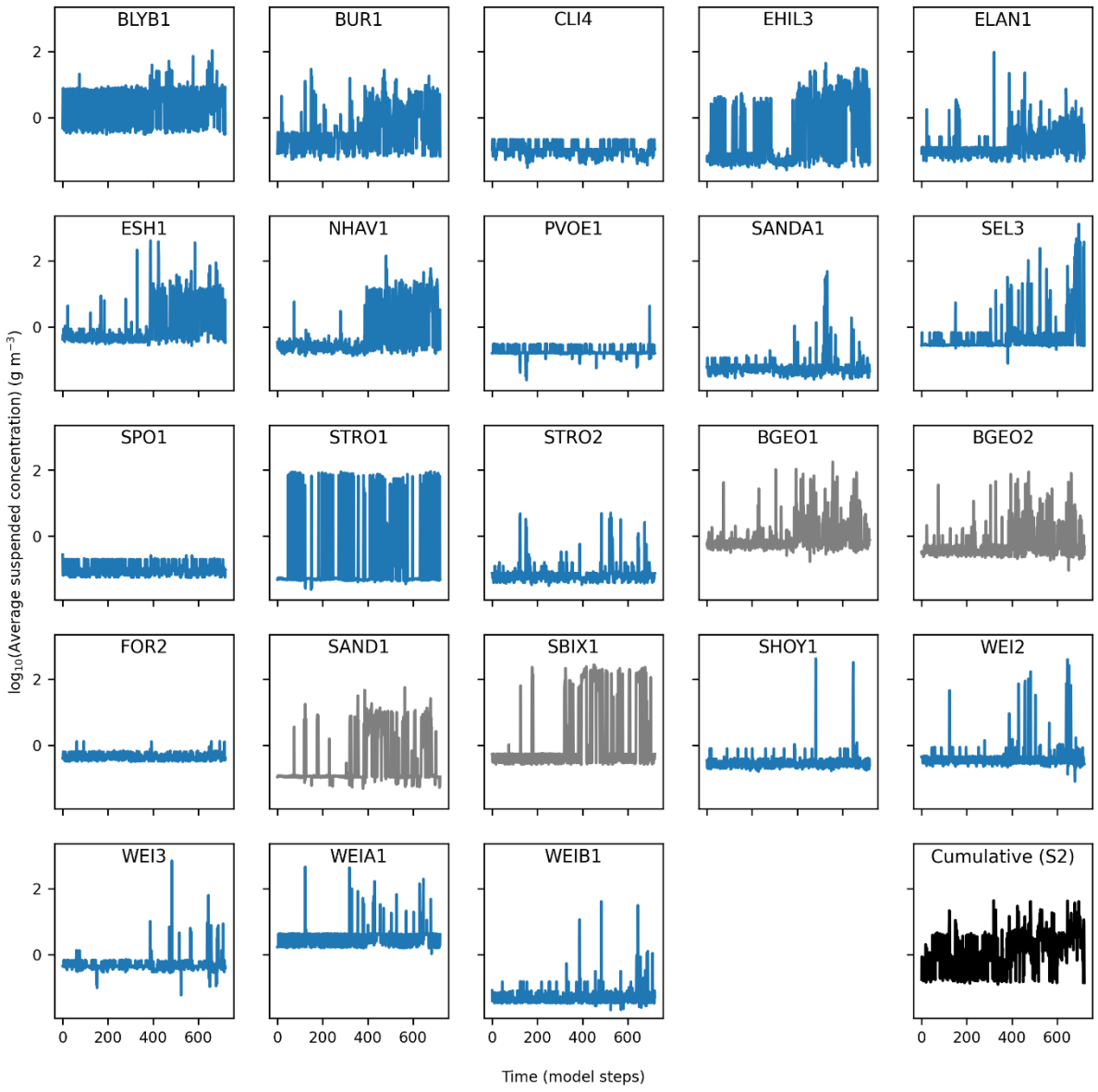

Figure 4.7 **Average concentration of suspended sediment (raw values) in relation to each source farm, and cumulative total for scenario 2. Sites included in the proposed scenario are shown with blue lines, and those excluded with grey. Values are plotted on a logarithmic scale.**

4.4.2 Deposited sediment

The patterns of average deposited sediment concentration predicted over the duration of the simulation are similar to those seen in the maximum concentrations. Moderate levels of fluctuation were observed (generally lower than for suspended sediment), and the proposed site is one of the highest (though not the highest) included in the simulation (Figure 4.8).

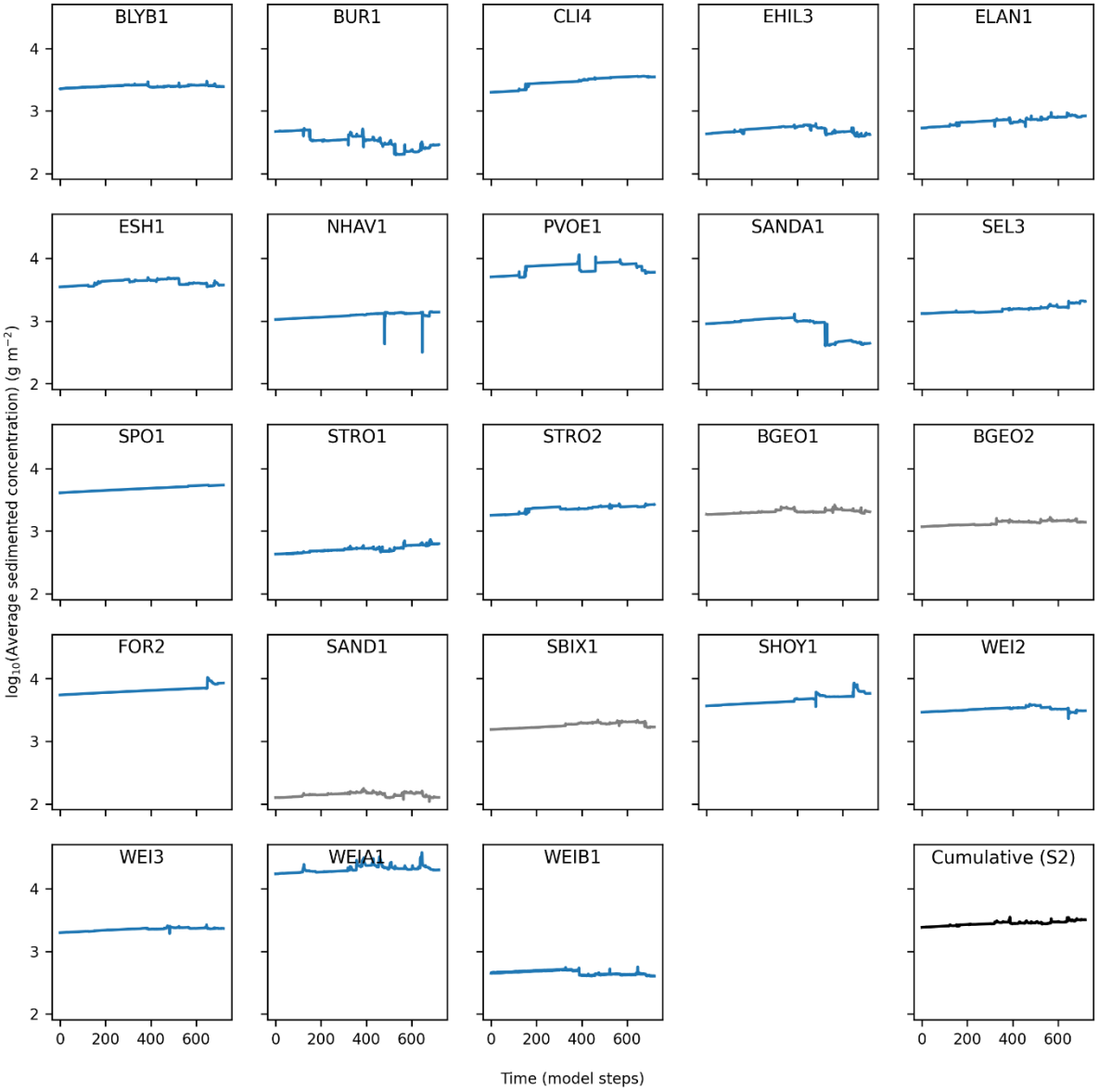

Figure 4.8 **Average concentration of deposited sediment (raw values) in relation to each source farm, and cumulative total for scenario 2. Sites included in the proposed scenario are shown with blue lines, and those excluded with grey. Values are plotted on a logarithmic scale.**

4.5 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. Due to its large spatial extent, BLYB1 generated a larger area over the threshold deposited mass than did other sites in the assessment (Figure 4.9).

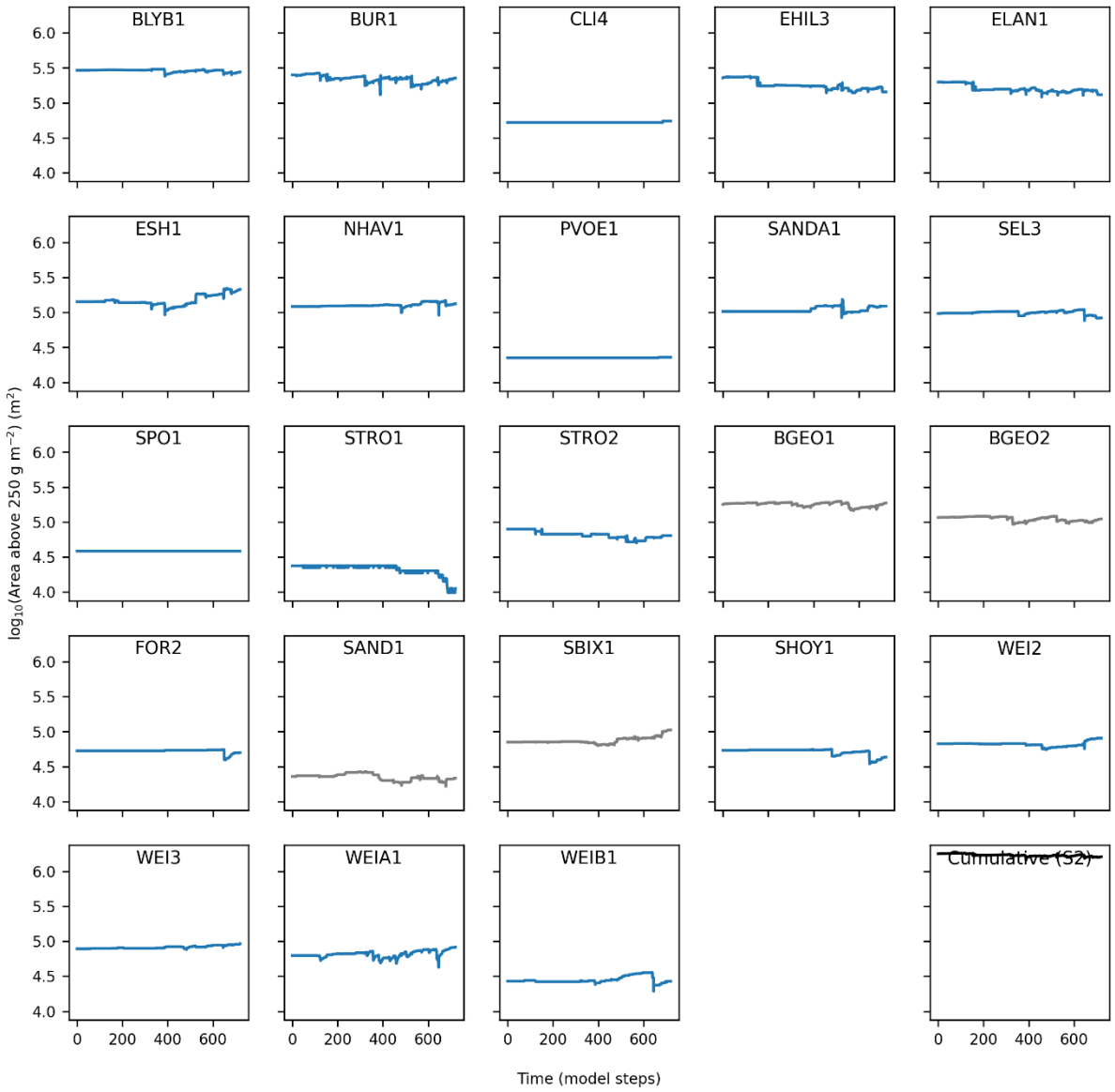

Figure 4.9 **Areal extent of suspended sediment concentration over 250 g m^{-2}, in relation to each source farm, and cumulative total for scenario 2. Sites included in the proposed scenario are shown with blue lines, and those excluded with grey. Values are plotted on a logarithmic scale.**

4.6 Concentrations at sensitive features

Within this section, suspended and sedimented concentrations are considered together for each feature type.

4.6.1 PMF locations

At the identified PMF locations, average concentrations of suspended sediment were predicted to be zero (

Table 4.2). This is evident in the timeseries plot (Figure 4.10), which indicates concentrations were zero for the entire duration of the simulation.

Concentrations of deposited sediment were zero at all PMF locations throughout the last 90 days of the simulation, excepting a single location (with two associated records) where occasional spikes were predicted, and a single location with a sustained high deposited sediment concentration (Figure 4.11). Both locations are recorded as horse mussel beds, to the NNW and NE of Billy Baa site respectively. The mean deposited sediment concentration at the former location is 114.2 g m^{-2}, originating largely from Billy Baa in the proposed scenario (Brei Geo and Sandsound sites were also predicted to contribute – see Appendix Table A1 - but they are not included in the scenario). At the latter location, the predicted deposited sediment concentration is 9,976.8 g m^{-2}, which is almost entirely derived from WEIB1, with a lesser contribution from WEI3 (both currently shellfish farms with no planning permission for fish farming activity). This area was surveyed as part of the visual seabed survey and while horse mussels were identified the density and percentage cover was not considered to represent a horse mussel bed and therefore no longer a PMF.

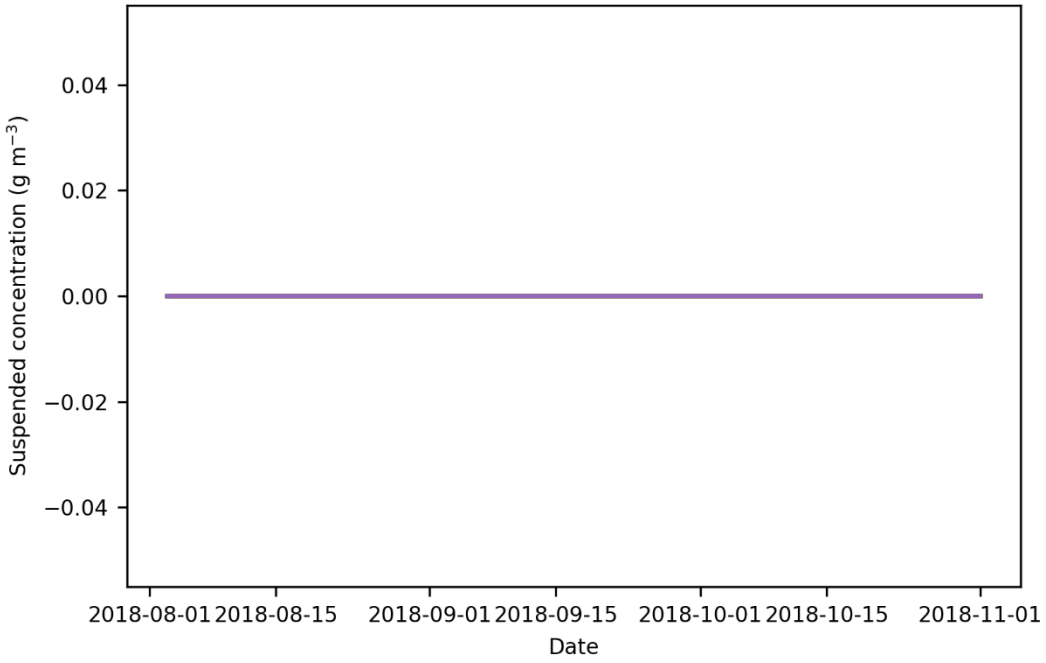

Figure 4.10: Timeseries of suspended sediment concentration at PMF locations, extracted from the nearest element centre location on the model mesh for each point, including all "scenario 2" farm sites as sources.

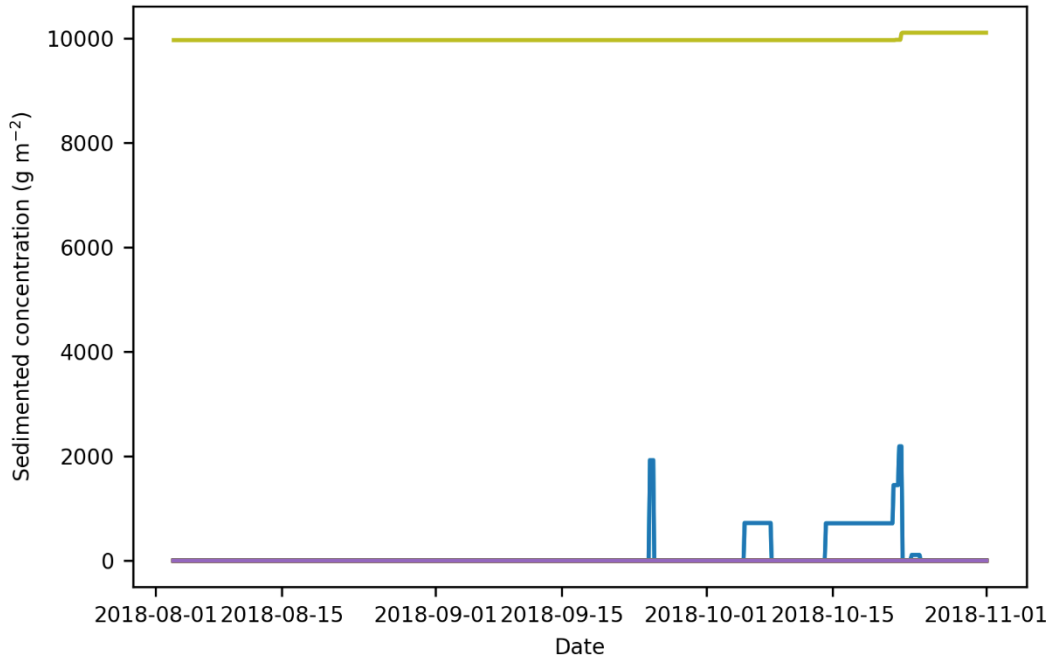

Figure 4.11: **Timeseries of deposited sediment concentration at PMF locations, extracted from the nearest element centre location on the model mesh for each point, including all specified farm sites as sources.**

Table 4.2: Summary of average suspended/sedimented concentrations at PMF locations, in addition to the number of individual hourly time points at which concentration was non-zero (of a possible 720 hours) over the last 90 days of the simulation. See Appendix Table A1 for a breakdown of source locations.

ID	Type	Easting	Northing	Suspended average (g m^{-3})	Suspended non-zero count	Sedimented average (g m^{-2})	Sedimented non-zero count
1	Horse mussel beds	593298.7	6670498	0	0	0	0
2	Horse mussel beds	593292.7	6670898	0	0	0	0
3	Horse mussel beds	593277.5	6671898	0	0	0	0
4	Horse mussel beds	592854.8	6673392	0	0	0	0
5	Seagrass beds	594851.7	6673623	0	0	0	0
6	Seagrass beds	594551.7	6673618	0	0	0	0
7	Seagrass beds	594727.2	6673921	0	0	0	0
8	Seagrass beds	594647.2	6673920	0	0	0	0
9	Blue mussel beds	594846.3	6673982	0	0	0	0
10	Seagrass beds	594945.6	6674024	0	0	0	0
11	Seagrass beds	594744.1	6674121	0	0	0	0
12	Seagrass beds	595042.6	6674226	0	0	0	0
13	Seagrass beds	595032.5	6674235	0	0	0	0
14	Seagrass beds	595039.6	6674426	0	0	0	0
15	Seagrass beds	595119.3	6674447	0	0	0	0
16	Blue mussel beds	595119.3	6674447	0	0	0	0
17	Horse mussel beds	593244.3	6674458	0	0	0	0
18	Horse mussel beds	593244.3	6674458	0	0	0	0
19	Horse mussel beds	592323	6675845	0	0	9976.799	720
20	Horse mussel beds	590606.4	6676559	0	0	114.1852	104
21	Horse mussel beds	590606.4	6676559	0	0	114.1852	104
22	Seagrass beds	594277.5	6678515	0	0	0	0
23	Seagrass beds	594277.5	6678515	0	0	0	0
24	Horse mussel beds	589974.6	6678650	0	0	0	0
25	Blue mussel beds	589551.9	6680143	0	0	0	0
26	Maerl beds	591823.5	6666826	0	0	0	0
27	Maerl beds	591812.4	6666826	0	0	0	0
28	Maerl beds	591805.8	6666826	0	0	0	0
29	Maerl beds	591794.4	6666814	0	0	0	0
30	Maerl beds	591782.4	6666803	0	0	0	0
31	Maerl beds	591728.8	6666790	0	0	0	0
32	Maerl beds	591670.2	6666800	0	0	0	0
33	Maerl beds	591602.4	6666821	0	0	0	0
34	Maerl beds	591669.6	6666822	0	0	0	0
35	Maerl beds	591584.7	6666820	0	0	0	0

4.6.2 Sensitive features identified during visual survey

At the sensitive features identified during the visual survey carried out at the site, average concentrations of suspended sediment were predicted to be zero in all cases (Table 4.3, Figure 4.12).

Concentrations of deposited sediment were predicted to be zero at all but one of these locations, where the mean concentration was 24.5 g m^{-2} (Figure 4.13). The deposition in this case is derived exclusively from Foreholm (FOR2) site (Appendix Table A2).

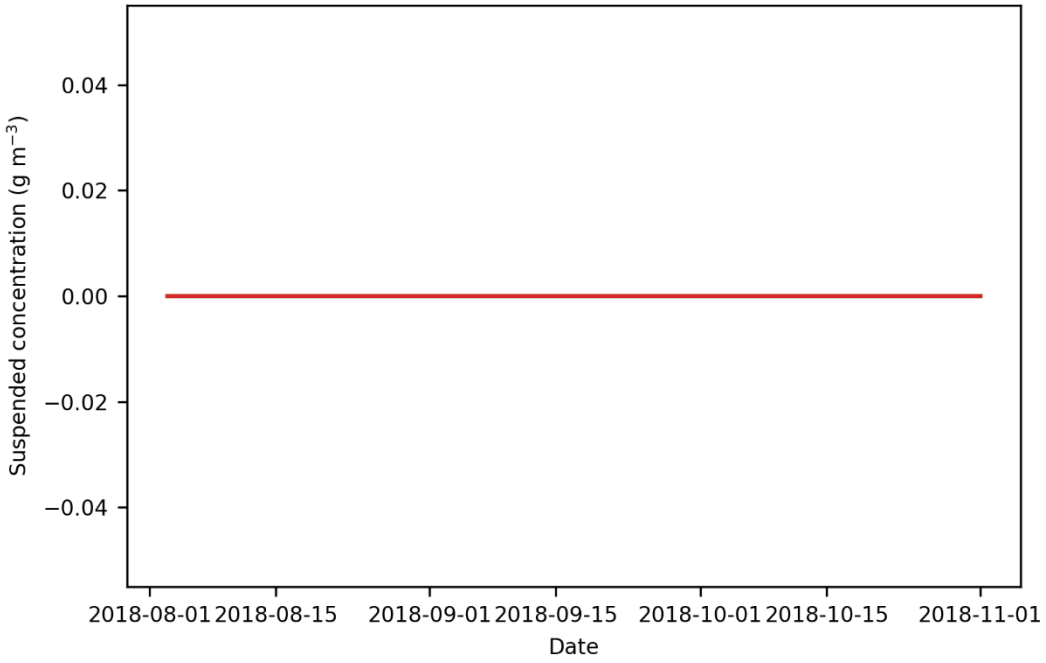

Figure 4.12: Timeseries of suspended sediment concentration at the location of sensitive features identified during the visual seabed survey, extracted from the nearest element centre location on the model mesh for each point, including all "scenario 2" farm sites as sources.

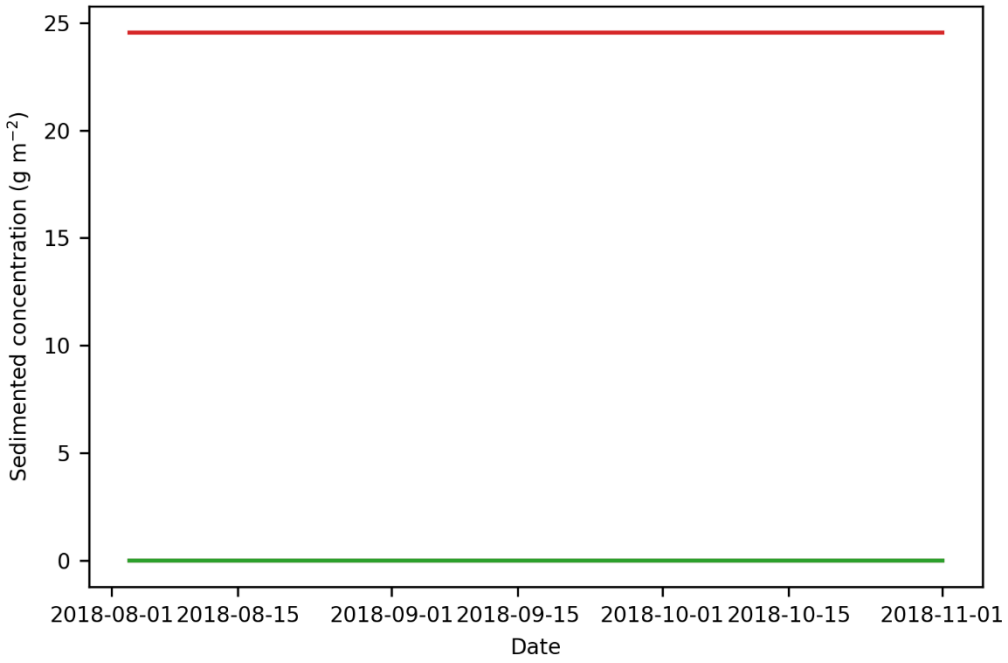

Figure 4.13: Timeseries of deposited sediment concentration at the location of sensitive features identified during the visual seabed survey, extracted from the nearest element centre location on the model mesh for each point, including all specified farm sites as sources.

Table 4.3: Summary of average suspended/sedimented concentrations at the location of sensitive features identified during the visual seabed survey, in addition to the number of individual hourly time points at which concentration was non-zero (of a possible 720 hours) over the last 90 days of the simulation. See Appendix Table A2 for a breakdown of source locations.

Type	Easting	Northing	Suspended average (g m^{-2})	Suspended non-zero count	Sedimented average (g m^{-2})	Sedimented non-zero count
D2	591020.7	6673938	0	0	0	0
D5	590969.9	6673925	0	0	0	0
D6	590893.6	6673882	0	0	0	0
D9	591034.3	6673768	0	0	24.54082	720

4.6.3 Fish farm locations

As might be anticipated, concentrations of both suspended and deposited sediment are higher at fish farm centre locations than at PMF locations (Table 4.4).

Within the last 90 days of the simulation, peaks of suspended sediment concentration remain fairly low, and non-zero values are very infrequently observed at most sites. The proposed site BLYB1 has the highest predicted mean concentration of suspended sediment (0.041 g m^{-3}) and highest frequency of non-zero values (41/720 = 5.7%). In general, any presence of suspended sediment tends to be dominated by occasional peaks rather than persistent presence (Figure 4.14).

With respect to sedimented concentration, most fish farm sites have non-zero values at a high proportion of time points. Of these, BLYB1 has the highest predicted sediment concentration (34262 g m^{-2} at site centre sample point). Along with several other sites, sediment is predicted to be present at almost all time points at BLYB1. Sedimented concentration is governed more by accumulation over time (Figure 4.15).

The suspended and deposited sediment concentrations predicted within this section were generally derived from the target site. That is, the main source of sediment present at most fish farm sites were the sites themselves (Appendix Tables A3 and A4).

Predicted sediment concentration at sites is sensitive to the precise location sampled, and also to erosion parameters such as bed roughness and critical erosion threshold. The simulations which provided the best fit to Depomod predictions of BLYB1 250 g m^{-2} area and intensity (higher bed roughness, as described in Section 4.1) predicted a much lower intensity at the sample point (6493 g m^{-2}).

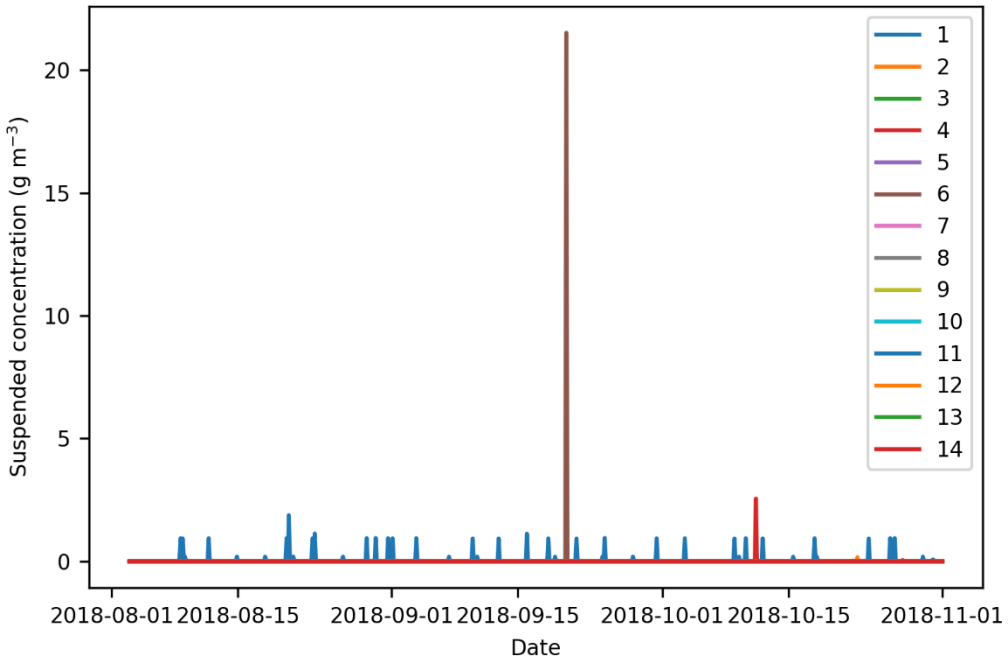

Figure 4.14: Timeseries of suspended sediment concentration at fish farm locations, extracted from the nearest element centre location on the model mesh for each point, including all specified farm sites as sources.

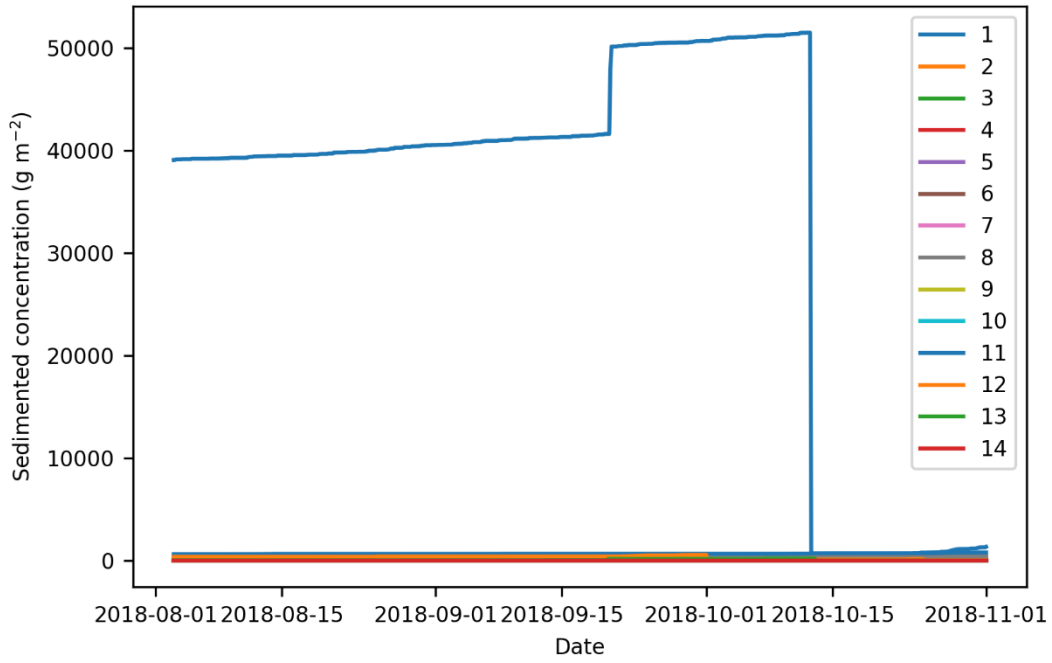

Figure 4.15: Timeseries of deposited sediment concentration at fish farm locations, extracted from the nearest element centre location on the model mesh for each point, including all specified farm sites as sources.

Table 4.4: Summary of average suspended/sedimented concentrations at fish farm locations, in addition to the number of individual hourly time points at which concentration was non-zero (of a possible 720 hours) over the last 90 days of the simulation. See Appendix Tables A3 and A4 for a breakdown of source locations.

Name	Type	Easting	Northing	Suspended average (g m^-2)	Suspended non-zero count	Sedimented average (g m^-2)	Sedimented non-zero count
BLYB1	Fish Farm	591262.5	6674326	0.040686	41	34262.25	717
BUR1	Fish Farm	593519	6668999	0.000235	1	0.074027	7
CLI4	Fish Farm	592020.6	6666764	0	0	237.5899	720
EHIL3	Fish Farm	591937.6	6669071	0.003691	4	96.94403	699
ELAN1	Fish Farm	593129.8	6667949	0	0	9.949714	603
ESH1	Fish Farm	590702.1	6671928	0.029883	1	0	0
NHAV1	Fish Farm	592347.9	6671569	0	0	48.11994	720
PVOE1	Fish Farm	594346.1	6667413	0	0	402.6952	720
SANDA1	Fish Farm	590933.8	6671492	0	0	0	0
SEL3	Fish Farm	588648.9	6674428	0	0	0	0
SPO1	Fish Farm	590788.8	6666803	0.00011	1	665.8063	720
STRO1	Fish Farm	593568.9	6672502	0	0	282.9963	719
STRO2	Fish Farm	593041.6	6670934	0	0	51.88065	568
WHI2	Fish Farm	594396.2	6670714	0	0	0	0

4.6.4 Shellfish farm locations

Concentrations of suspended sediment are predicted to be zero at shellfish farm locations at all time points in the last 90 days of the simulation (Figure 4.16, Table 4.5).

Concentration of deposited sediment in the last 90 days of the simulation is predicted to be zero at all shellfish farms, excepting a single location (Figure 4.17) where the average concentration is 1,565 g m^{-2}. The predicted concentration at this location is however predicted to be derived almost entirely from site WEIA1, with a tiny contribution from WEIB1 (Appendix Table A5).

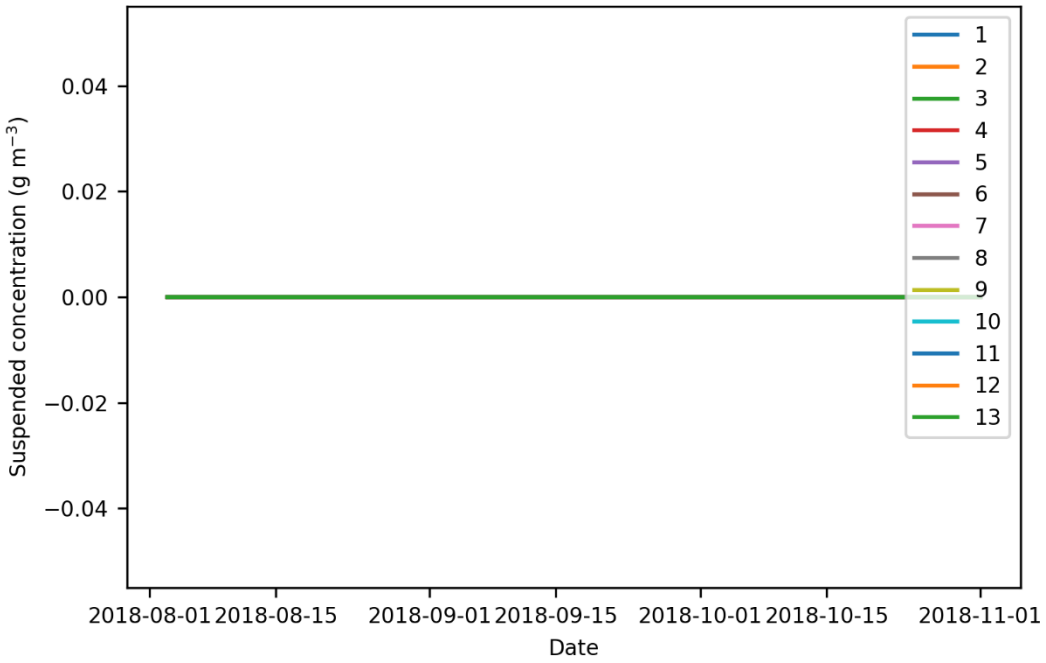

Figure 4.16: Timeseries of suspended sediment concentration at shellfish farm locations, extracted from the nearest element centre location on the model mesh for each point, including all specified farm sites as sources.

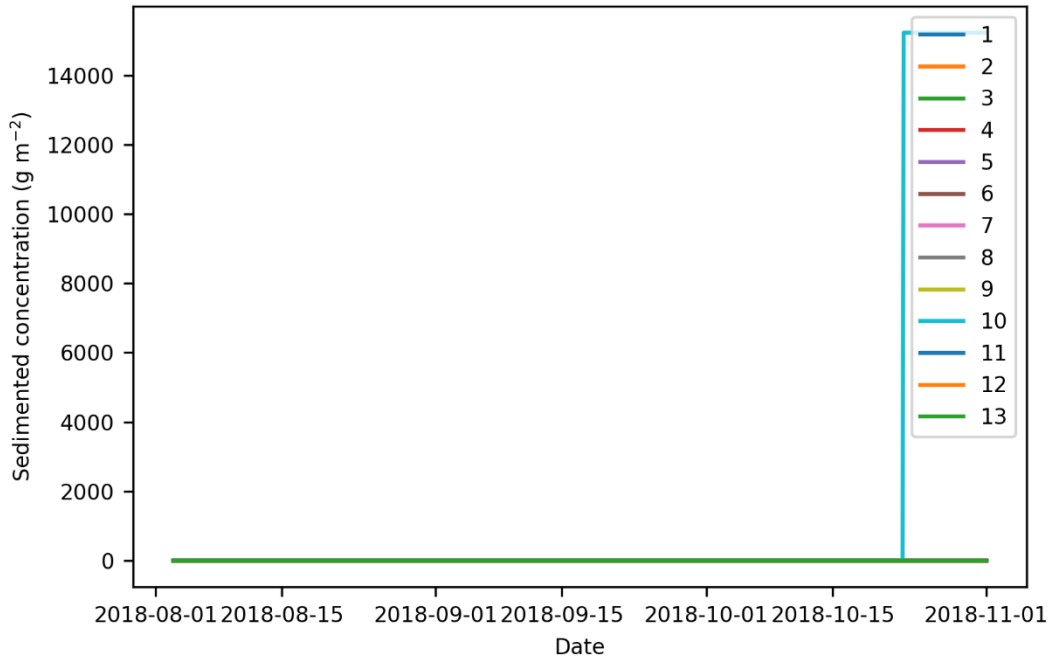

Figure 4.17: Timeseries of deposited sediment concentration at shellfish farm locations, extracted from the nearest element centre location on the model mesh for each point, including all specified farm sites as sources.

Table 4.5: Summary of average suspended/sedimented concentrations at shellfish farm locations, in addition to the number of individual hourly time points at which concentration was non-zero (of a possible 720 hours) over the last 90 days of the simulation. See Appendix Table A5 for a breakdown of source locations.

ID	Name	Type	Easting	Northing	Suspended average (g m^{-2})	Suspended non-zero count	Sedimented average (g m^{-2})	Sedimented non-zero count
1	South of Ness of Bixter	Shellfish farm	588861.6	6679532	0	0	0	0
2	The Firth (Tresta North)	Shellfish farm	589557	6679842	0	0	0	0
3	The Firth (Tresta South)	Shellfish farm	589466.1	6679241	0	0	0	0
4	Northwest of Lunga	Shellfish farm	590267.6	6679153	0	0	0	0
5	Lungness	Shellfish farm	590381.2	6678255	0	0	0	0
6	Sandsound South	Shellfish farm	590191.9	6677552	0	0	0	0
7	Mid Noost	Shellfish farm	594258.3	6679814	0	0	0	0
8	NE of Vedri Geo Weisdale	Shellfish farm	593297.7	6677199	0	0	0	0
9	Olligarth	Shellfish farm	593611.4	6676303	0	0	0	0
10	Kirkaward	Shellfish farm	592709.9	6676390	0	0	1565.4	76
11	Oxa Geo	Shellfish farm	592220.5	6675682	0	0	0	0
12	NW Greena, Weisdale Voe	Shellfish farm	592920.5	6675693	0	0	0	0
13	North Flotta	Shellfish farm	593432.6	6674900	0	0	0	0

5 Discussion and Conclusions

The proposed site is larger than other sites presently within the Scalloway Bay area. As a result it has a larger predicted impacted area, but intermediate sediment intensity. In common with the NewDepomod model prediction, the HD-driven deposition model predicted the footprint of the site to lie largely to the north of the site, although with an increased focus on Sandsound Voe than seen in NewDepomod. This reflects the greater variability seen in near-bed flow in the HD model versus the current meter record, and the spatial variation in flow in the HD model. The predicted scale and intensity of footprint is similar with both models, which accords with previous studies using the models at sites where current speeds are not too high.

The predicted influence of farm sites (including that proposed) on PMF locations is minimal, with a single location predicted to be influenced by deposited sediment from the BLYB1 site. No influence of suspended sediment was predicted.

Some additional sensitive features (horse mussel beds) were identified during a visual survey of the site location. Only one of these locations was predicted to experience any interaction with released sediment, and this was not derived from the BLYB1 site.

Deposited sediment was predicted to be present at many of the salmon farm sites within the area, generally related to the source site itself. Suspended sediment was predicted to be present at many salmon farm sites at a much lower frequency and intensity. In both cases, the greatest sediment influence on sites was predicted to come from those sites themselves.

Shellfish farms were not predicted to be influenced by suspended or deposited sediment from BLYB1, or any other salmon farm sites.

6 References

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

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

Danish Hydraulic Insitute (2021b) Shetland Aquaculture Modelling: Hydrodynamic Climatology Model.

Scottish Environment Protection Agency (2023) Interim Marine Modelling Guidance for Aquaculture Applications.

Scottish Environmental Protection Agency (2023) Aquaculture Modelling Screening & Risk Identification Report: Billy Baa (BLYB1).

7 Appendices

7.1 Adjusting critical erosion threshold and bed roughness

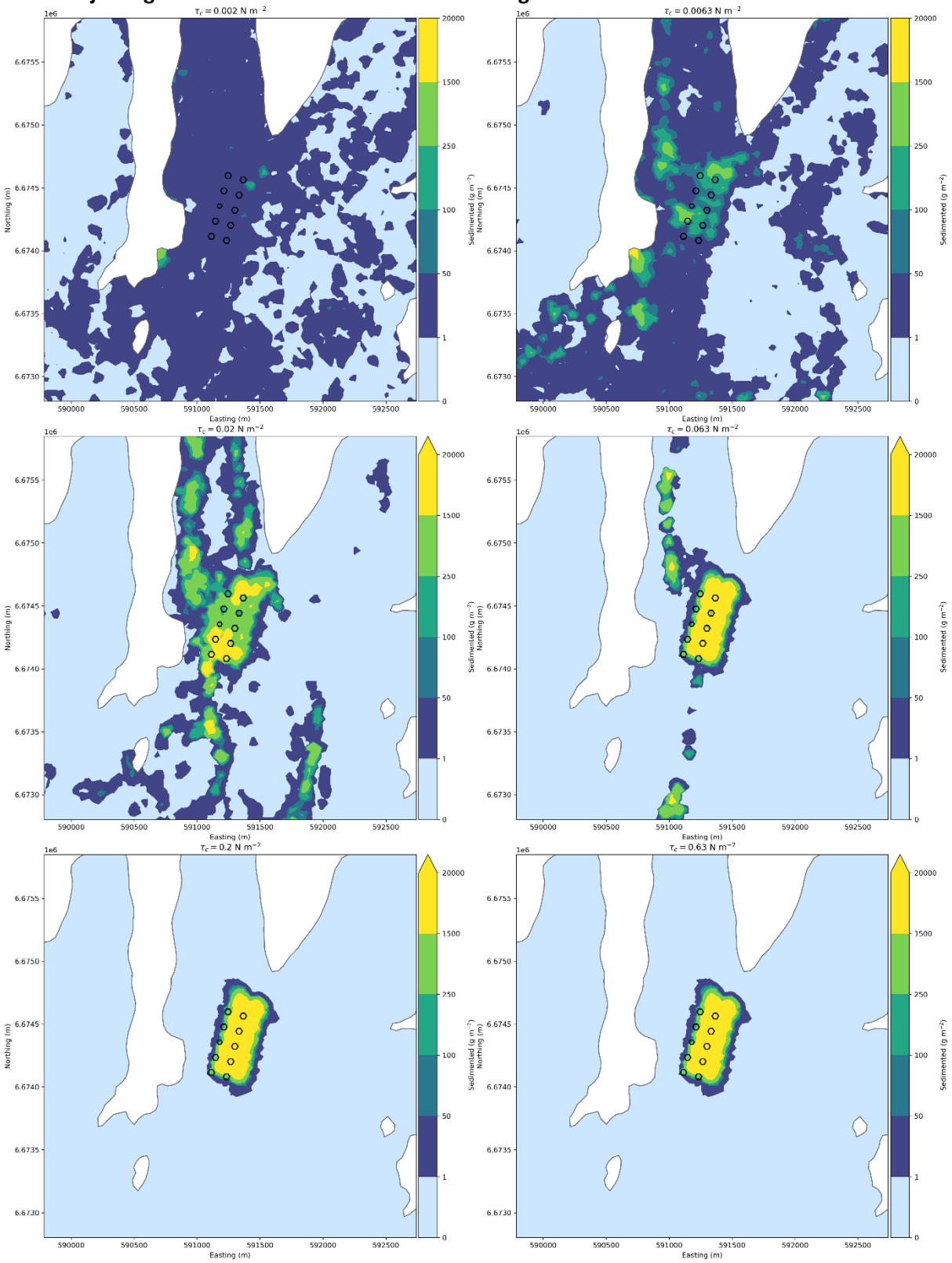


Figure A1: Effect of altering critical erosion threshold in MIKE particle tracking, showing altered footprint prediction from the proposed site at Billy Baa (bed roughness = 0.01 m, critical erosion threshold indicated in title). Best fit run was that using τ_c = 0.02 N m^{-2}.

7.2 Suspended sediment – scenarios

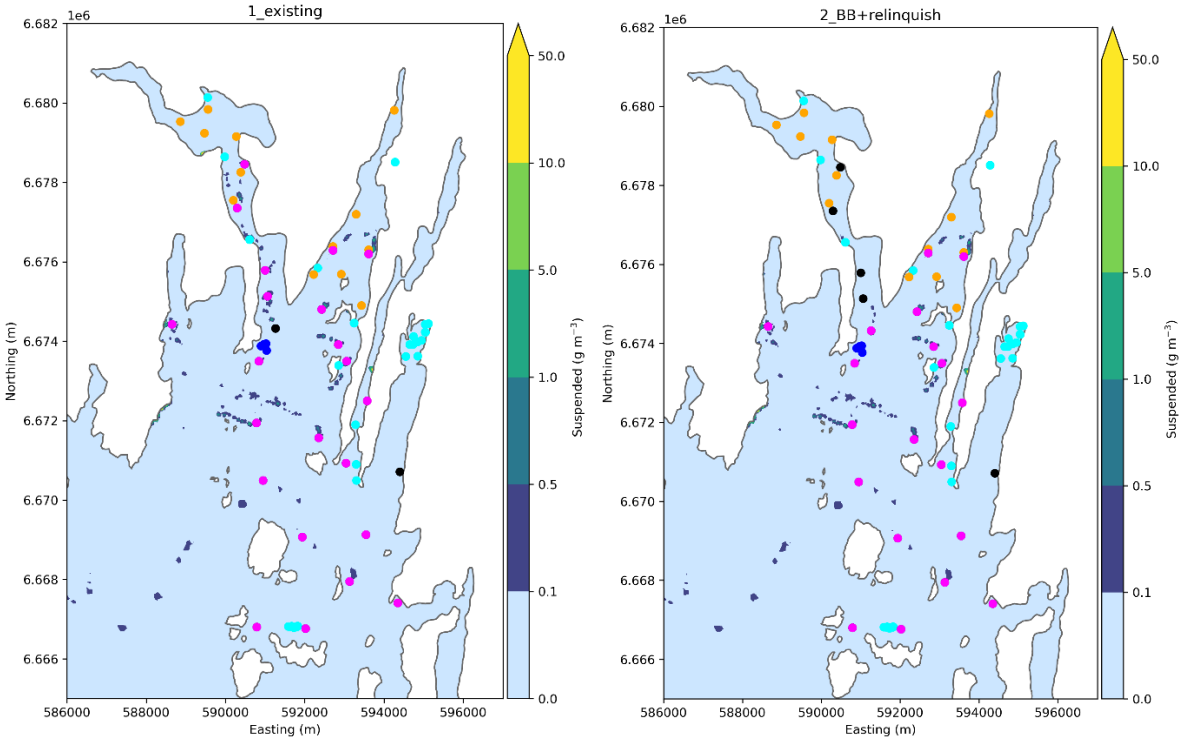
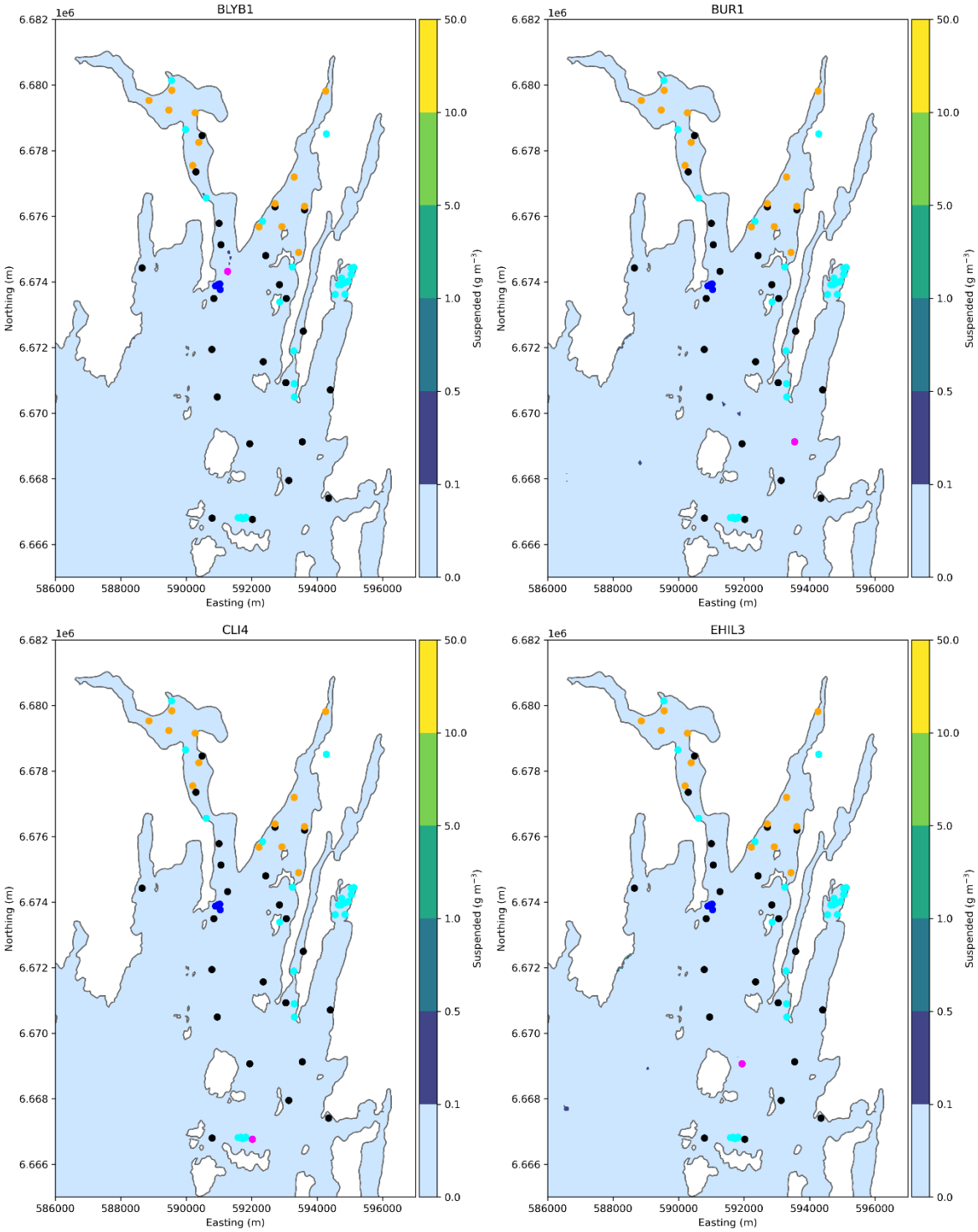
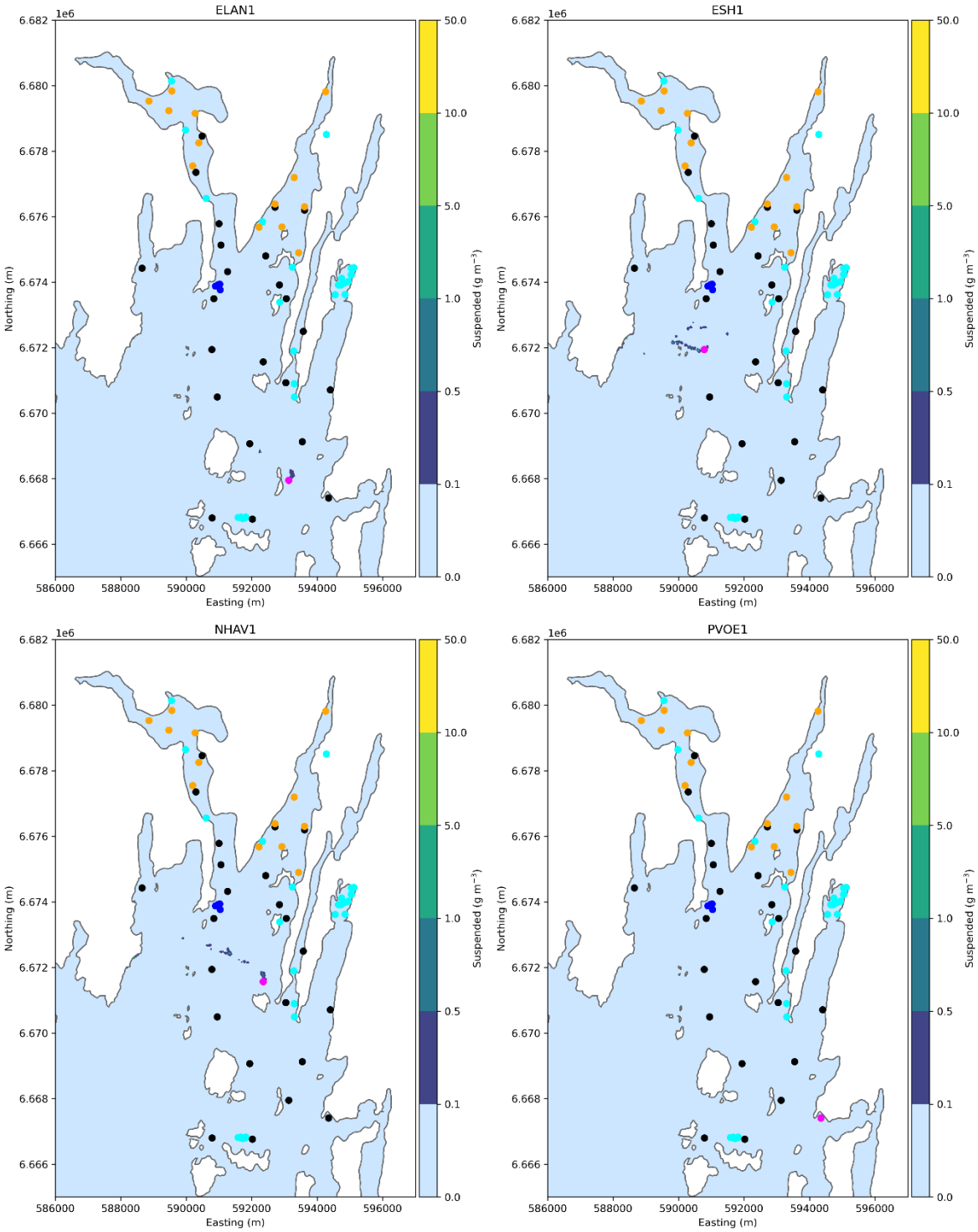


Figure A2: Map of average suspended sediment concentration of the final 90 days of the simulation (cumulative site release scenarios). Magenta points indicate farm locations included as release points in the simulation. Cyan points indicate PMF locations, blue points indicate additional sensitive features identified by visual seabed survey, and black/orange points indicate other fish/shellfish farms identified for impact assessment.

7.3 Suspended sediment – individual sites

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NHAV1
PVOE1
1e6
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6.680
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6.676
6.674
6.672
6.670
6.668
6.666
Northing (m)
586000
588000
590000
592000
594000
596000
Easting (m)
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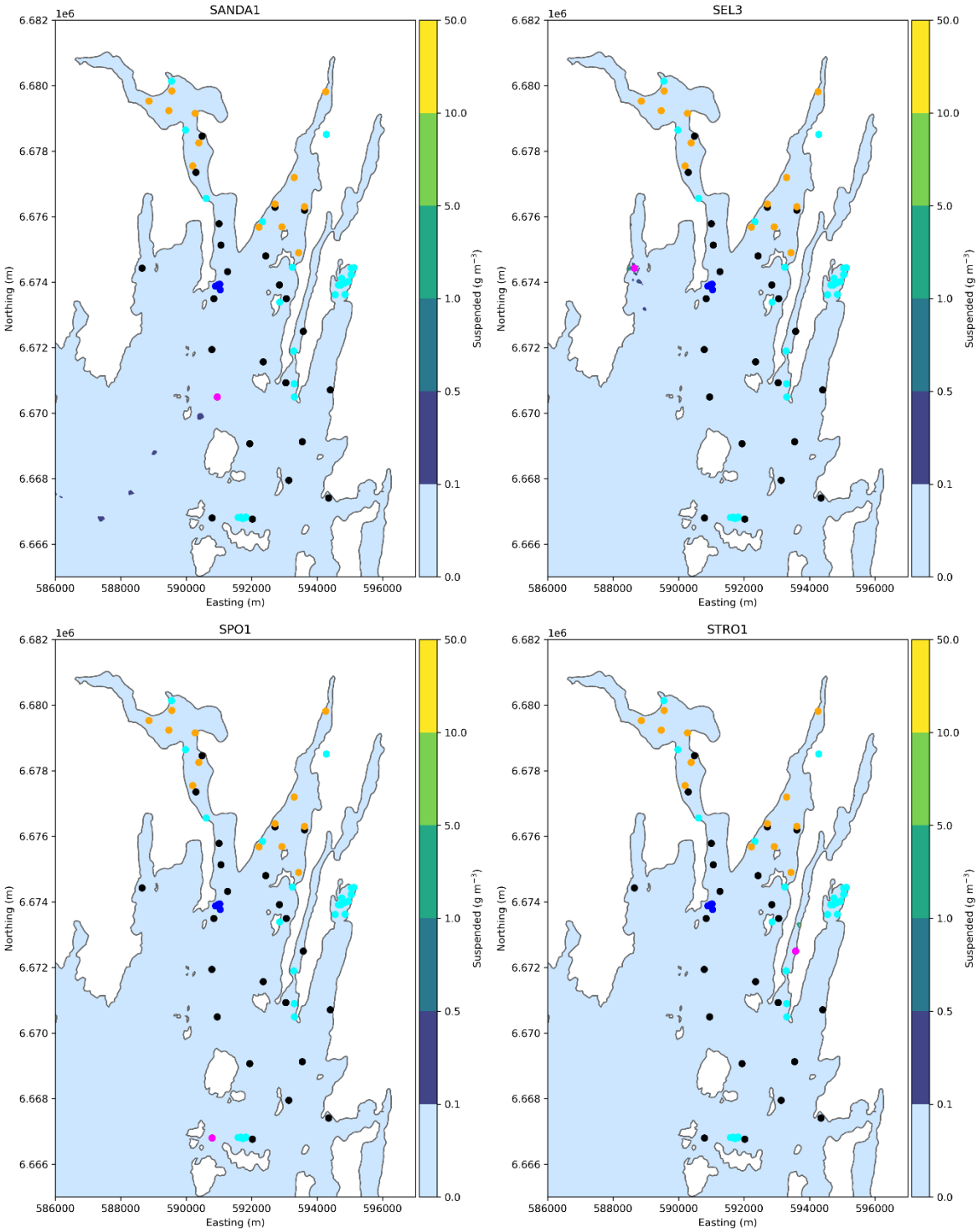
10.0
5.0
1.0
0.5
0.1
0.0
Suspended (g m^{-3})


SANDA1
SEL3
SPO1
STRO1
1e6
Northing (m)
Easting (m)
Suspended (g m^{-3})
6.682
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6.678
6.676
6.674
6.672
6.670
6.668
6.666
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1.0
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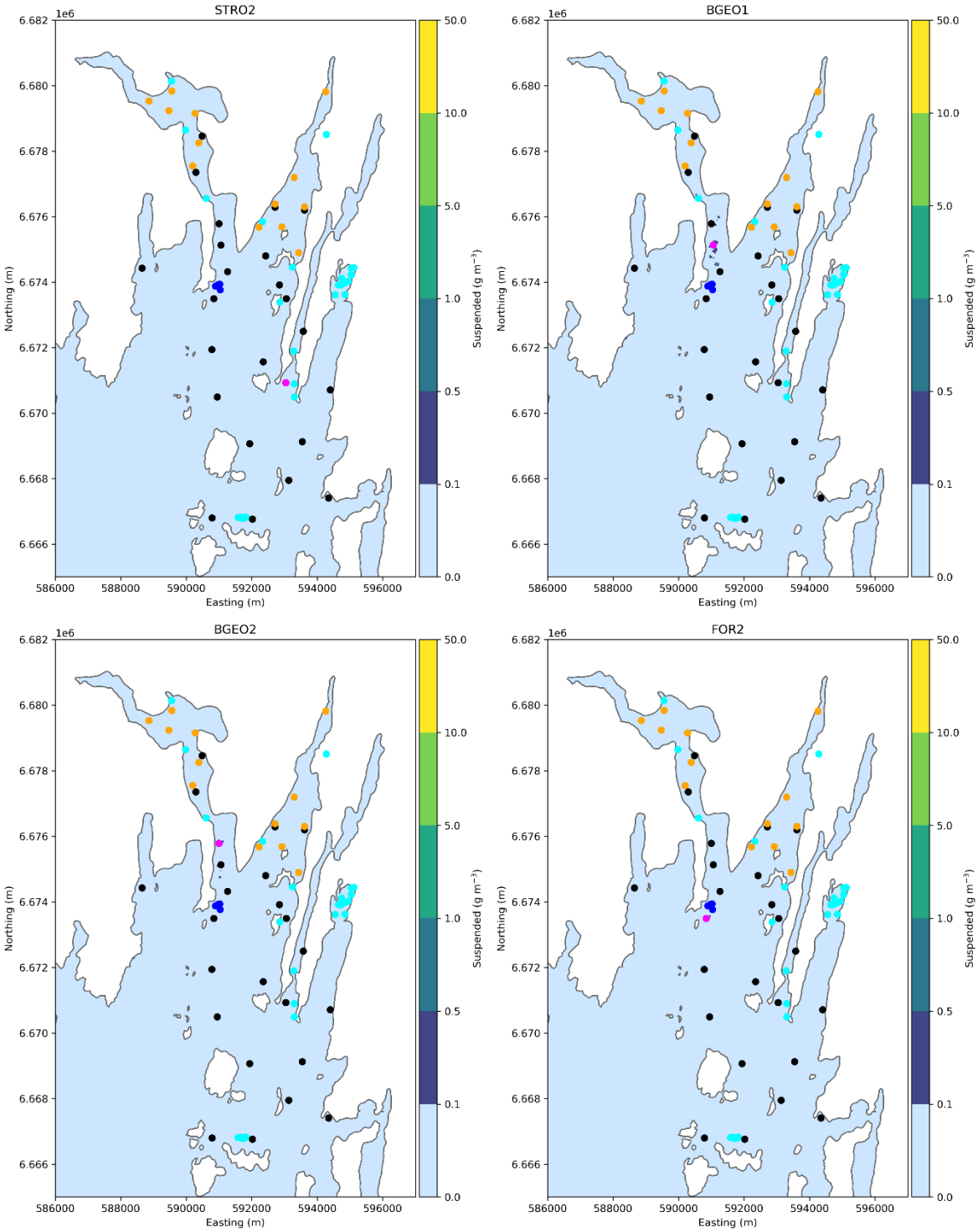
0.0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Northing (m)
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588000
590000
592000
594000
596000
Easting (m)
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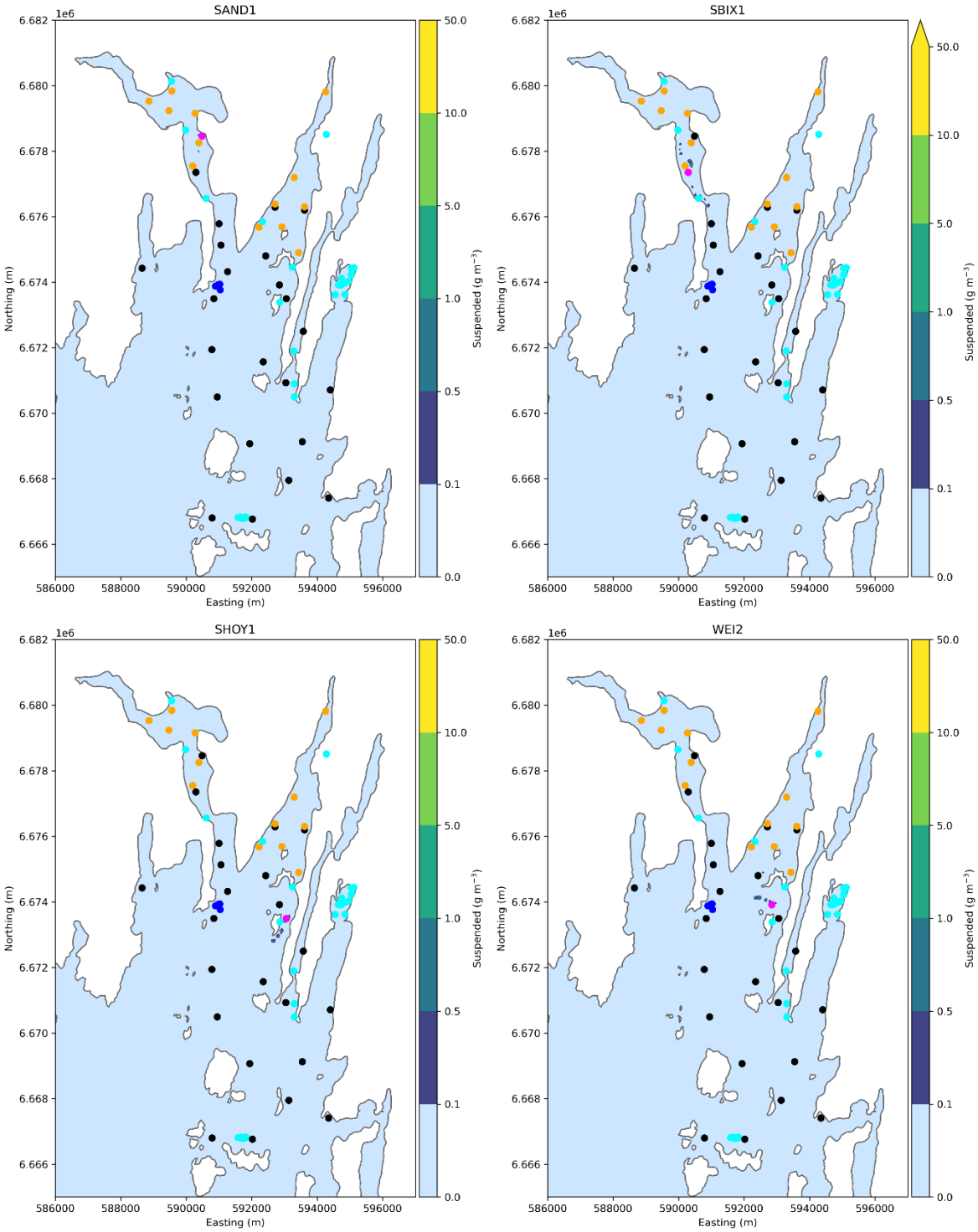
10.0
5.0
1.0
0.5
0.1
0.0
Suspended (g m⁻³)


SAND1
SBIX1
SHOY1
WEI2
1e6
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6.680
6.678
6.676
6.674
6.672
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6.668
6.666
Northing (m)
586000
588000
590000
592000
594000
596000
Easting (m)
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10.0
5.0
1.0
0.5
0.1
0.0
Suspended (g m⁻³)

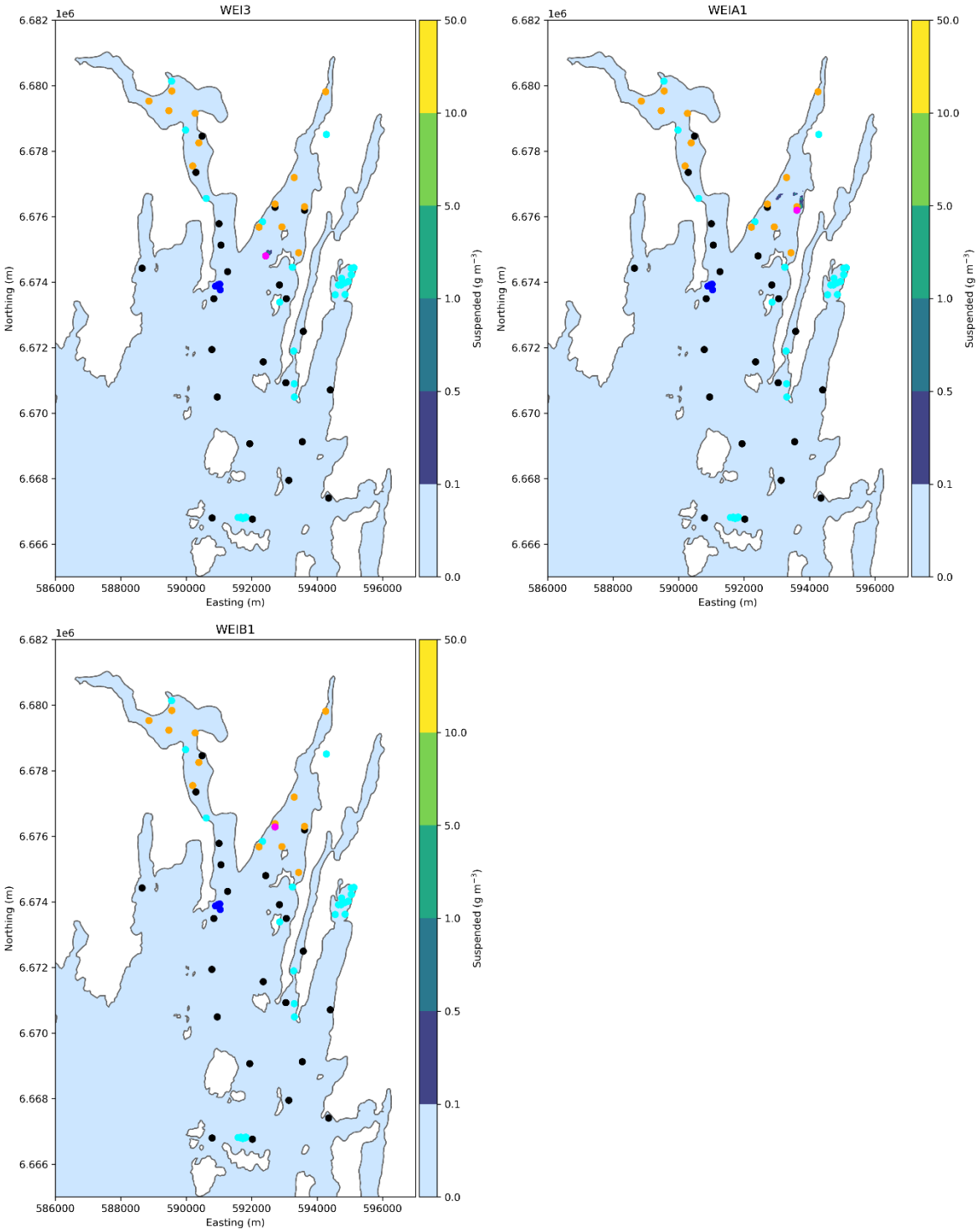


Figure A2: Map of average suspended sediment concentration of the final 90 days of the simulation (individual site releases). Magenta points indicate farm locations included as release points in the simulation. Cyan points indicate PMF locations, blue points indicate additional sensitive features identified by visual seabed survey, and black/orange points indicate other fish/shellfish farms identified for impact assessment.

7.4 Deposited sediment – scenarios

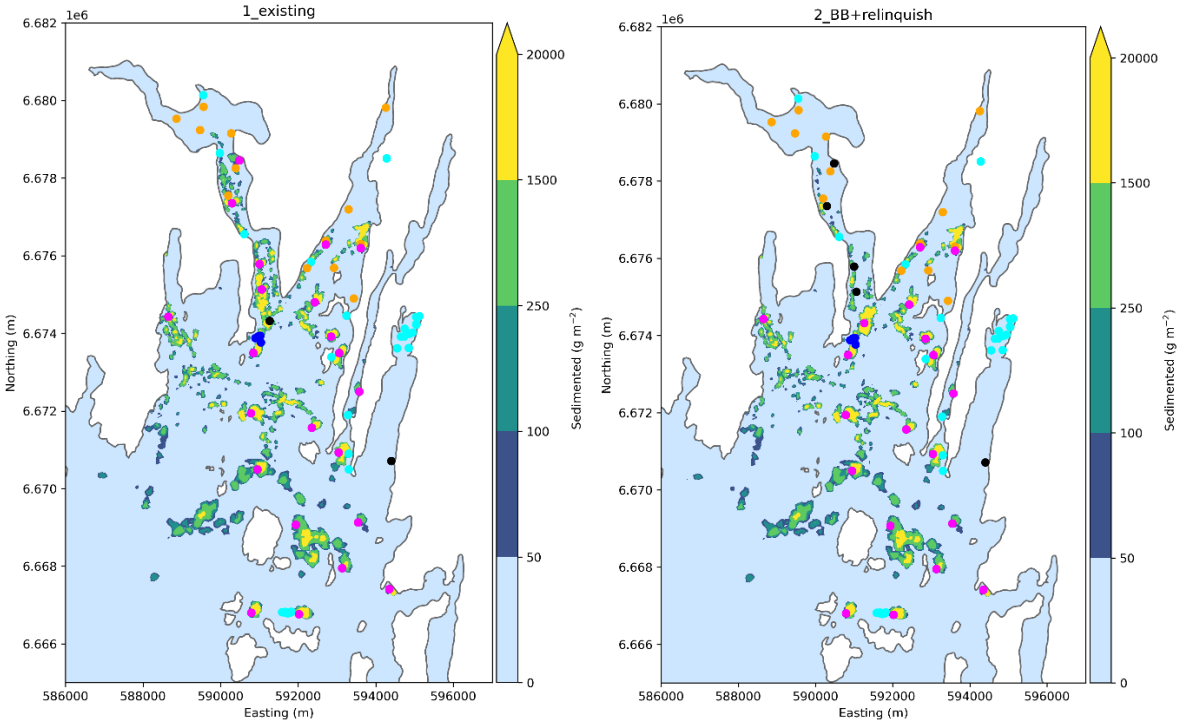
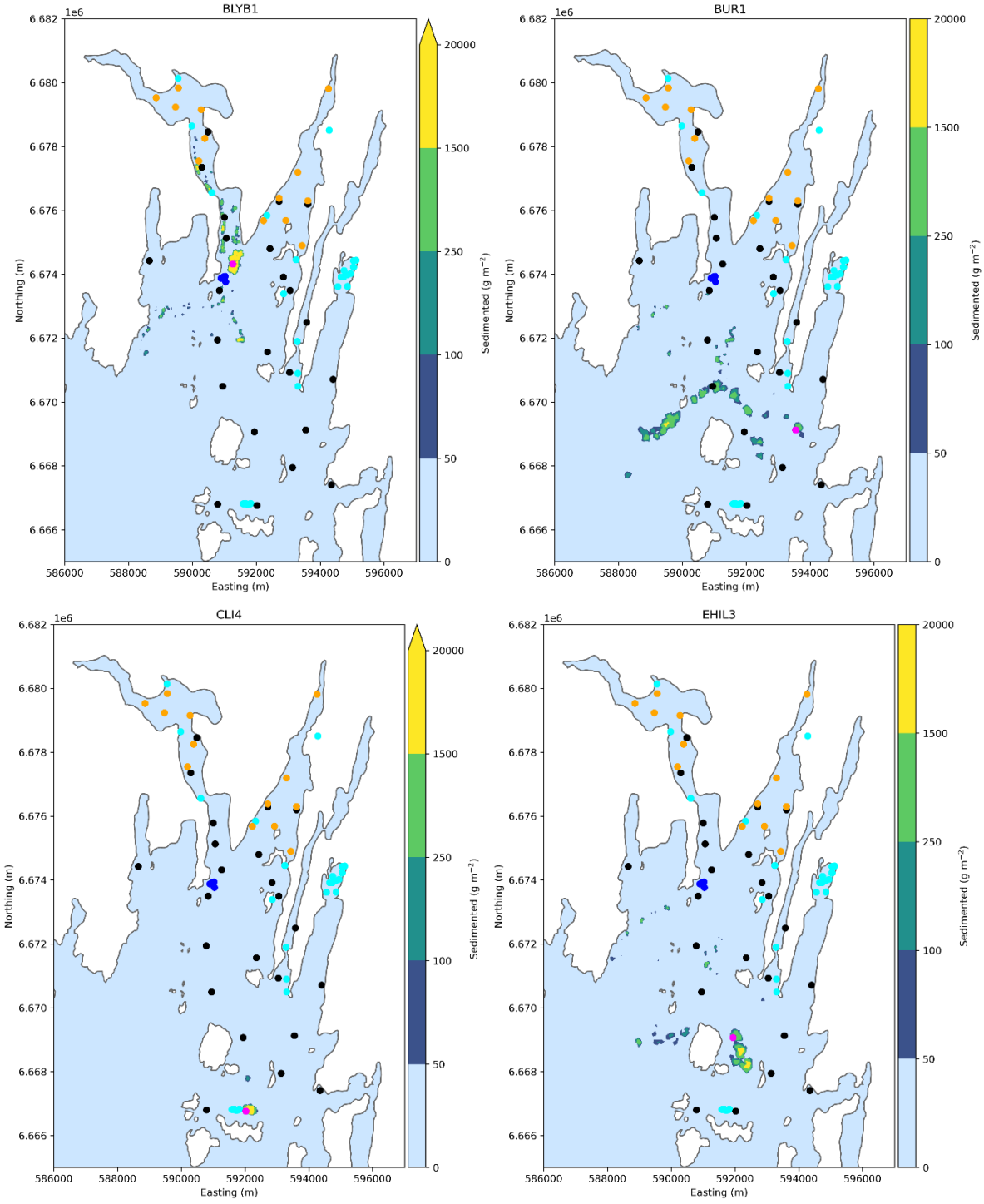
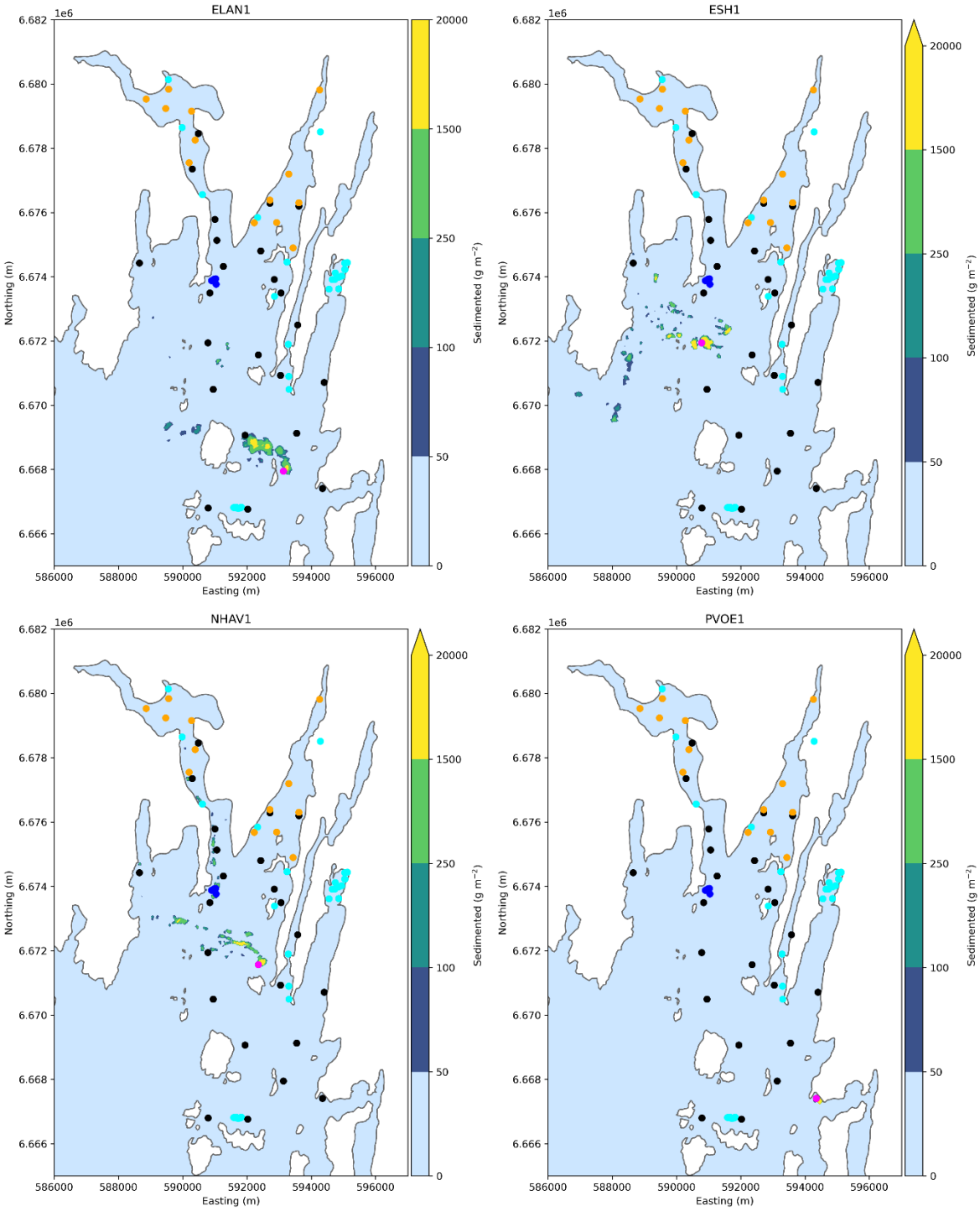


Figure A4: Map of average deposited sediment concentration of the final 90 days of the simulation (cumulative site release scenarios). Magenta points indicate farm locations included as release points in the simulation. Cyan points indicate PMF locations, blue points indicate additional sensitive features identified by visual seabed survey, and black/orange points indicate other fish/shellfish farms identified for impact assessment.

7.5 Deposited sediment – individual sites

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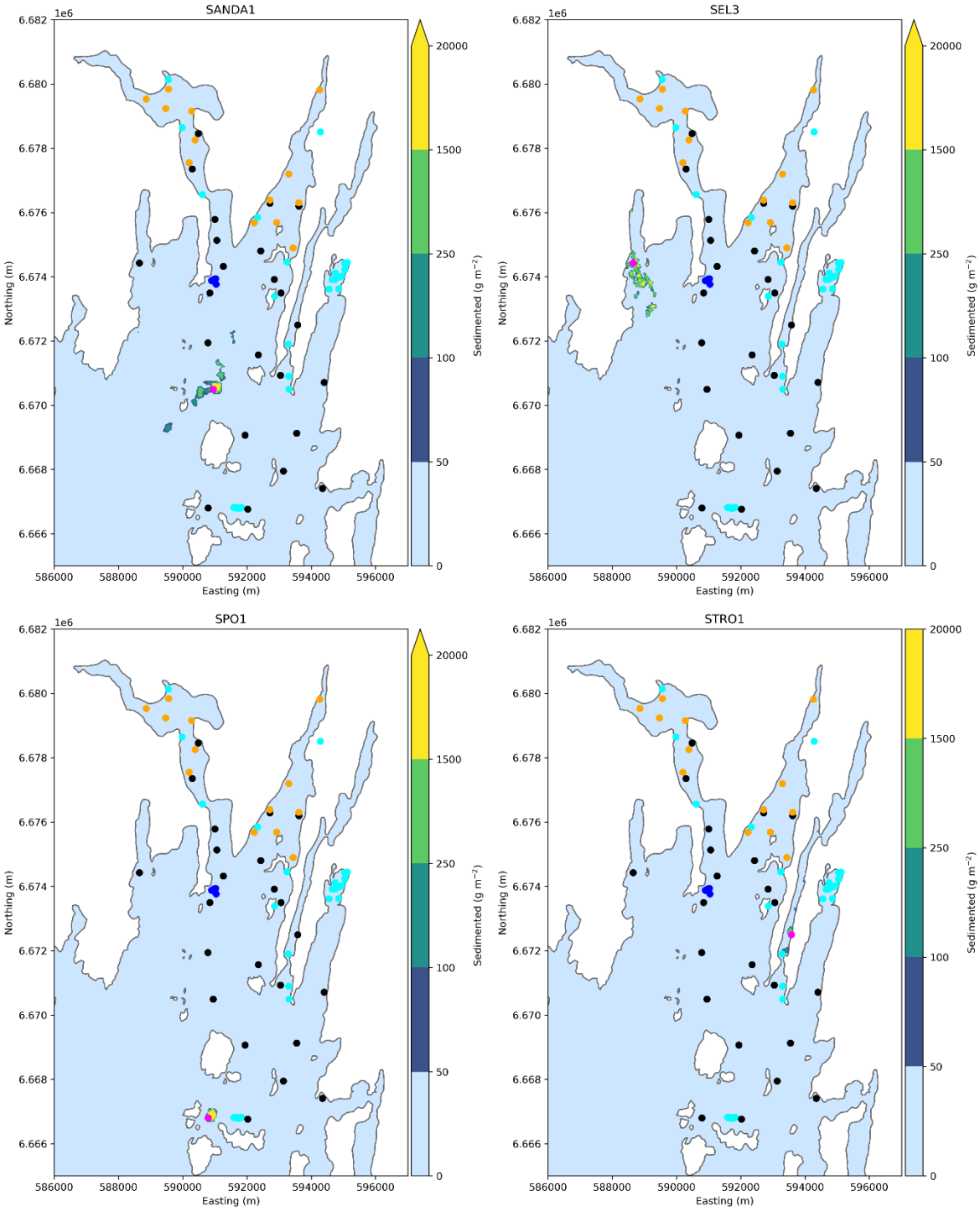
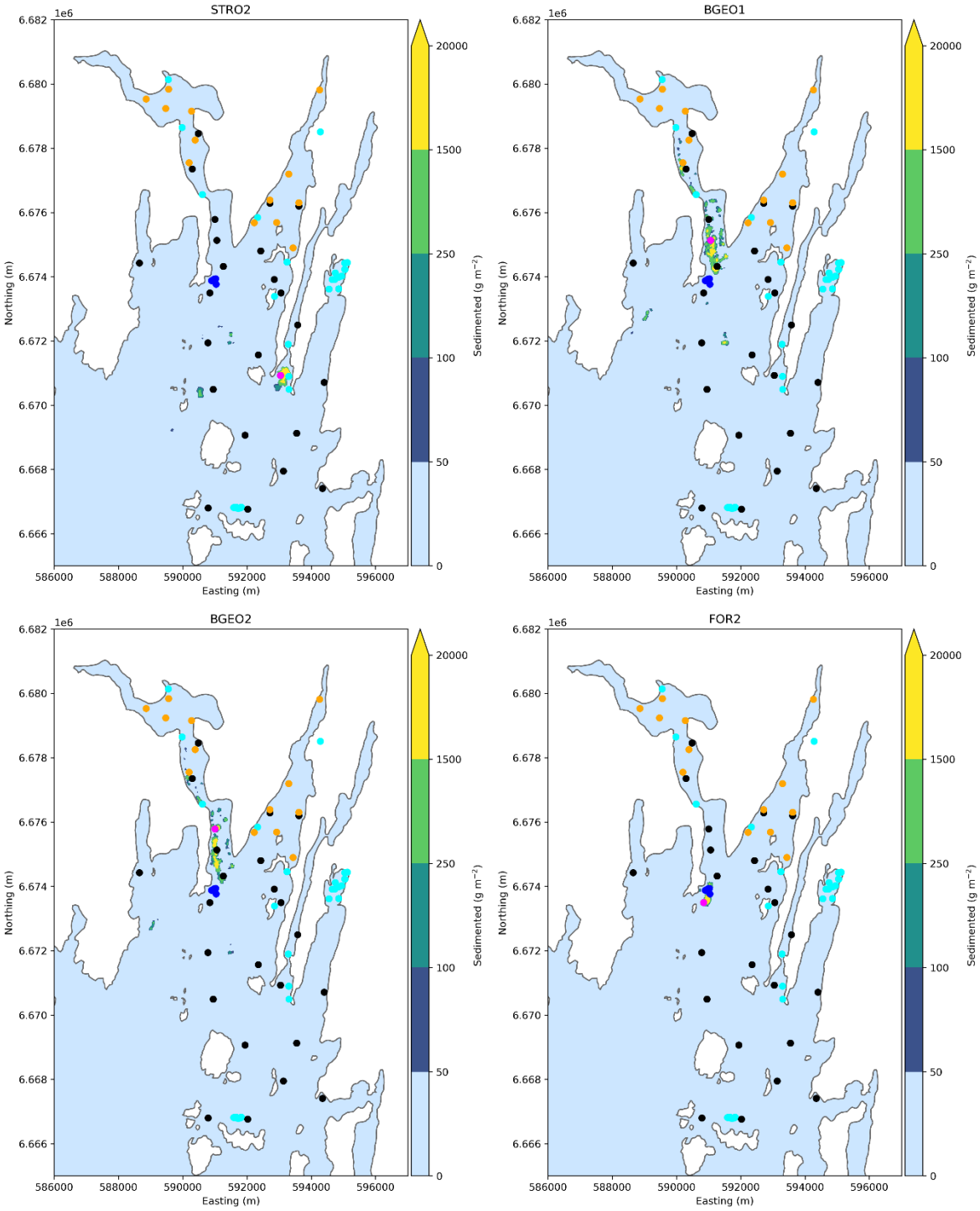
ESH1
NHAV1
PVOE1
1e6
6.682
6.680
6.678
6.676
6.674
6.672
6.670
6.668
6.666
Northing (m)
586000
588000
590000
592000
594000
596000
Easting (m)
20000
1500
250
100
50
0
Sedimented (g m⁻²)


SANDA1
SEL3
SPO1
STRO1
1e6
6.682
6.680
6.678
6.676
6.674
6.672
6.670
6.668
6.666
Northing (m)
586000
588000
590000
592000
594000
596000
Easting (m)
20000
1500
250
100
50
0
Sedimented (g m⁻²)


STRO2
BGEO1
BGEO2
FOR2
1e6
6.682
6.680
6.678
6.676
6.674
6.672
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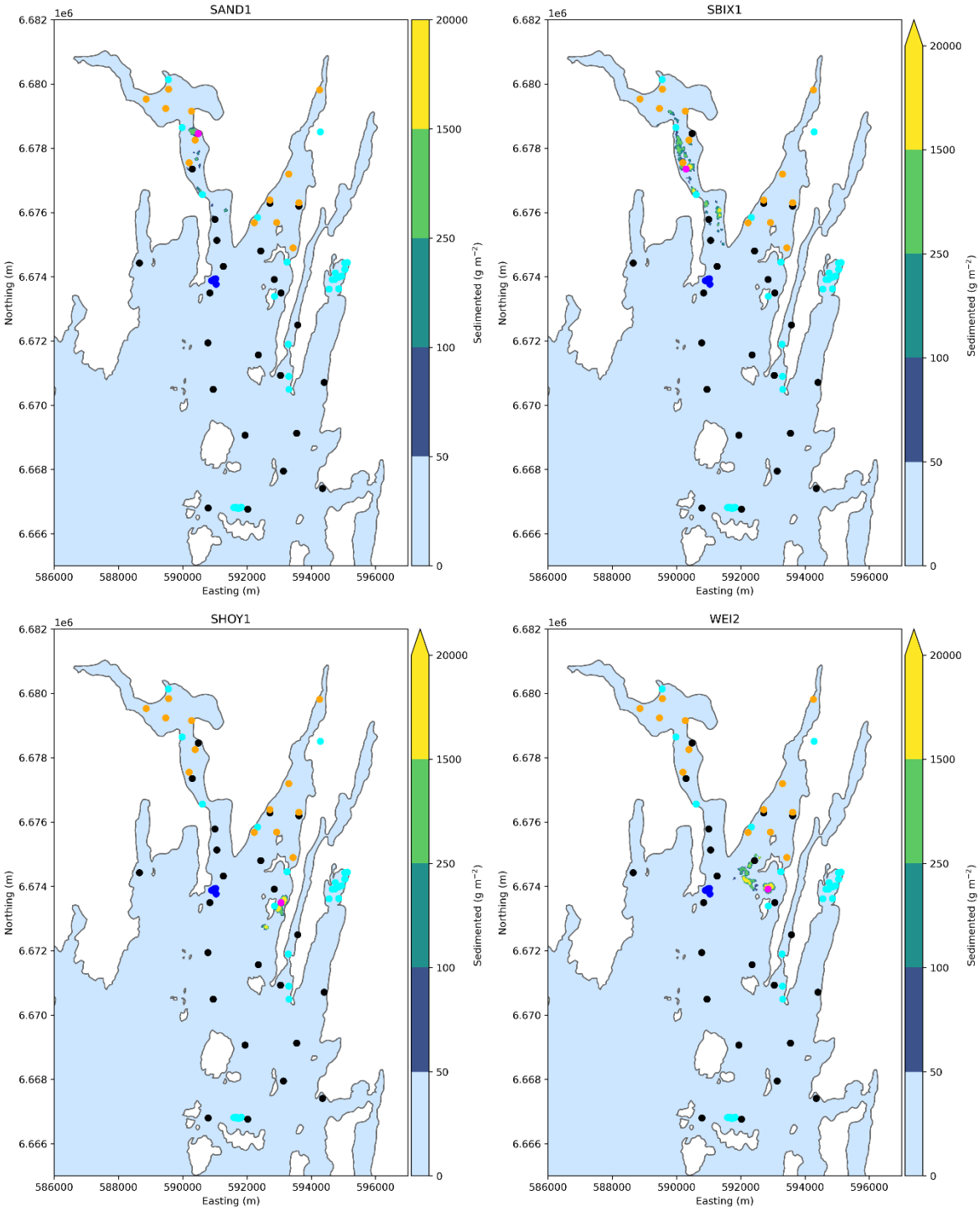
6.668
6.666
Northing (m)
586000
588000
590000
592000
594000
596000
Easting (m)
20000
1500
250
100
50
0
Sedimented (g m^{-2})


SAND1
SBIX1
SHOY1
WEI2
1e6
6.682
6.680
6.678
6.676
6.674
6.672
6.670
6.668
6.666
Northing (m)
586000
588000
590000
592000
594000
596000
Easting (m)
20000
1500
250
100
50
0
Sedimented (g m^{-2})

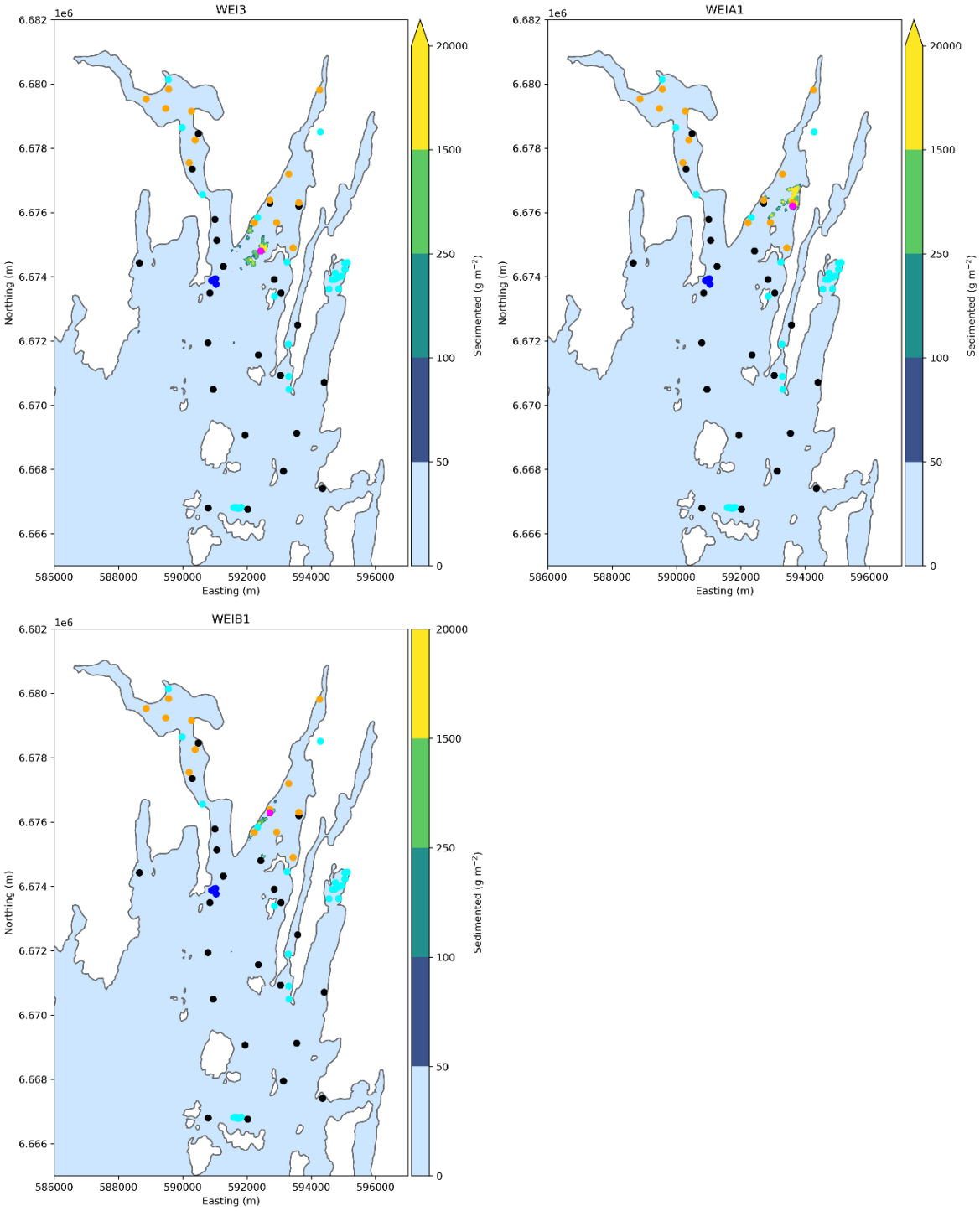


Figure A5: Map of average deposited sediment concentration of the final 90 days of the simulation (individual site releases). Magenta points indicate farm locations included as release points in the simulation. Cyan points indicate PMF locations, blue points indicate additional sensitive features identified by visual seabed survey, and black/orange points indicate other fish/shellfish farms identified for impact assessment.

7.6 Sensitive feature impacts – individual sites

This section contains site-by-site breakdowns of suspended and deposited sediment concentrations at those locations where overall concentrations are greater than zero. Not all sites in the table are included in the proposed scenario; some will have CAR licences relinquished as a condition of the application, and some no longer have planning permission for use as fish farm sites.

Table A1: Average concentration of deposited sediment at PMF locations, by source site (g m^{-2}).

PMF	Easting	Northing	BLYB1	BUR1	CLI4	EHIL3	ELAN1	ESH1	NHAV1	PVOE1	SANDA1	SEL3	SPO1	STRO1	STRO2	BGEO1	BGEO2	FOR2	SAND1	SBIX1	SHOY1	WEI2	WEI3	WEIA1	WEIB1
Horse mussel beds	593298.7	6670498	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Horse mussel beds	593292.7	6670898	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Horse mussel beds	593277.5	6671898	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Horse mussel beds	592854.8	6673392	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seagrass beds	594851.7	6673623	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seagrass beds	594551.7	6673618	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seagrass beds	594727.2	6673921	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seagrass beds	594647.2	6673920	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blue mussel beds	594846.3	6673982	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seagrass beds	594945.6	6674024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seagrass beds	594744.1	6674121	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seagrass beds	595042.6	6674226	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seagrass beds	595032.5	6674235	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seagrass beds	595039.6	6674426	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seagrass beds	595119.3	6674447	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blue mussel beds	595119.3	6674447	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Horse mussel beds	593244.3	6674458	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Horse mussel beds	593244.3	6674458	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Horse mussel beds	592323	6675845	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	302.7823	0	9674.016
Horse mussel beds	590606.4	6676559	110.3106	0	0	0	0	0	3.874597	0	0	0	0	0	0	85.24178	44.50262	0	3.879699	38.46609	0	0	0	0	0

Horse mussel beds	590606.4	6676559	110.3106	0	0	0	0	0	3.874597	0	0	0	0	0	0	85.24178	44.50262	0	3.879699	38.46609	0	0	0	0	0
Seagrass beds	594277.5	6678515	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seagrass beds	594277.5	6678515	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Horse mussel beds	589974.6	6678650	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blue mussel beds	589551.9	6680143	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maerl beds	591823.5	6666826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maerl beds	591812.4	6666826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maerl beds	591805.8	6666826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maerl beds	591794.4	6666814	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maerl beds	591782.4	6666803	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maerl beds	591728.8	6666790	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maerl beds	591670.2	6666800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maerl beds	591602.4	6666821	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maerl beds	591669.6	6666822	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maerl beds	591584.7	6666820	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A2: Average concentration of deposited sediment at sensitive features identified during the site visual survey, by source site (g m^{-2}).

ID	Easting	Northing	BLYB1	BUR1	CLI4	EHIL3	ELAN1	ESH1	NHAV1	PVOE1	SANDA1	SEL3	SPO1	STRO1	STRO2	BGEO1	BGEO2	FOR2	SAND1	SBIX1	SHOY1	WEI2	WEI3	WEIA1	WEIB1
D2	591020.7	6673938	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D5	590969.9	6673925	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D6	590893.6	6673882	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D9	591034.3	6673768	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24.5	0	0	0	0	0	0	0

Table A3: Average concentration of suspended sediment at fish farm locations, by source site (g m^{-3}).

Feature Name	Easting	Northing	BLYB1	BUR1	CLI4	EHIL3	ELAN1	ESH1	NHAV1	PVOE1	SANDA1	SEL3	SPO1	STRO1	STRO2	BGEO1	BGEO2	FOR2	SAND1	SBIX1	SHOY1	WEI2	WEI3	WEIA1	WEIB1
BLYB1	591262.5	6674326	0.040686	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

BUR1	593519	6668999	0	0.000235	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CLI4	592020.6	6666764	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EHIL3	591937.6	6669071	0	0.001808	0	0.001844	3.86E-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ELAN1	593129.8	6667949	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ESH1	590702.1	6671928	0	0	0	0	0	0.029883	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NHAV1	592347.9	6671569	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PVOE1	594346.1	6667413	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SANDA1	590933.8	6671492	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SEL3	588648.9	6674428	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPO1	590788.8	6666803	0	0	0	0	0	0	0	0	0	0	0.000011	0	0	0	0	0	0	0	0	0	0	0	0
STRO1	593568.9	6672502	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
STRO2	593041.6	6670934	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WHI2	594396.2	6670714	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A4: Average concentration of deposited sediment at fish farm locations, by source site (g m^{-2}).

Feature Name	Easting	Northing	BLYB1	BUR1	CLI4	EHIL3	ELAN1	ESH1	NHAV1	PVOE1	SANDA1	SEL3	SPO1	STRO1	STRO2	BGEO1	BGEO2	FOR2	SAND1	SBIX1	SHOY1	WEI2	WEI3	WEIA1	WEIB1
BLYB1	591262.5	6674326	34262.25	0	0	0	0	0	0	0	0	0	0	0	0	18478.08	0	0	0	0	0	0	0	0	0
BUR1	593519	6668999	0	0.074027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CLI4	592020.6	6666764	0	0	237.5899	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EHIL3	591937.6	6669071	0	48.74298	0	45.34636	2.854705	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ELAN1	593129.8	6667949	0	0	0	0	9.949714	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ESH1	590702.1	6671928	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NHAV1	592347.9	6671569	0	0	0	0	0	0	48.11994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PVOE1	594346.1	6667413	0	0	0	0	0	0	0	402.6952	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SAN DA1	590933.8	6671492	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SEL3	588648.9	6674428	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPO1	590788.8	6666803	0	0	0	0	0	0	0	0	0	0	665.8063	0	0	0	0	0	0	0	0	0	0	0	0
STRO1	593568.9	6672502	0	0	0	0	0	0	0	0	0	0	0	282.9963	0	0	0	0	0	0	0	0	0	0	0
STRO2	593041.6	6670934	0	0	0	0	0	0	0	0	0	0	0	0	51.88065	0	0	0	0	0	0	0	0	0	0
WHI2	594396.2	6670714	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A5: Average concentration of deposited sediment at shellfish farm locations, by source site (g m^{-2}).

Feature Name	Easting	Northing	BLYB1	BUR1	CLI4	EHIL3	ELAN1	ESH1	NHAV1	PVOE1	SANDA1	SEL3	SPO1	STRO1	STRO2	BGEO1	BGEO2	FOR2	SAND1	SBIX1	SHOY1	WEI2	WEI3	WEIA1	WEIB1
South of Ness of Bixter	588861.6	6679532	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
The Firth (Tresta North)	589557	6679842	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
The Firth (Tresta South)	589466.1	6679241	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northwest of Lunga	590267.6	6679153	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lungness	590381.2	6678255	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12.2691	0	0	0	0	0	0
Sandsound South	590191.9	6677552	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mid Noost	594258.3	6679814	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NE of Vedri Geo Weisdale	593297.7	6677199	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Olligarth	593611.4	6676303	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirkaward	592709.9	6676390	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1565.294	0.10482
Oxa Geo	592220.5	6675682	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NW Greena, Weisdale Voe	592920.5	6675693	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
North Flotta	593432.6	6674900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0