Bath Medicine Dispersion Report
Fish Holm, Shetland Islands

Report To Prepared for	Scottish Environmental Protection Agency Dingwall Registry, Scottish Environment Protection Agency, Graesser House, Fodderty Way, Dingwall, IV15 9XB
Status	Version 5.3
Date	January 28, 2025

Scottish Sea Farms Ltd
Barcaldine Hatchery
Barcaldine
Argyll
PA37 1SQ
Company Reg No. 93192
Email: modelling@scottishseafarms.com

Contents

1 Executive Summary 3
2 Introduction 3
3 Methodology 4
3.1 Hydrodynamic and particle tracking models 4
3.2 Model domain and boundary conditions 5
3.3 Model validation 8
3.4 Medicine dispersion modelling - Azamethiphos 9
3.4.1 Approach 9
3.4.2 Mass limit assessment 10
3.4.3 Output statistics 11
3.4.4 Dispersion study 11
3.5 Deltamethrin modelling 11
3.6 Impact on Sensitive Features 11
3.7 Removal of Coastline Elements and Shallow Depths 14
4 Results 15
4.1 Azamethiphos EQS and MAC 15
4.1.1 3 hr EQS – Baseline neap/spring simulations 15
4.1.2 72 hr MAC and EQS – Baseline neap/spring simulations 18
4.1.3 Sensitivity 20
4.2 Deltamethrin EQS 24
4.3 Impact on Sensitive Features 27
4.3.1 Azamethiphos 27
4.3.2 Deltamethrin 32
4.3.3 Summary statistics at EQS times 37
5 Discussion and Conclusions 39
6 References 40
7 Appendix 41
7.1 BathAuto calculations 41
7.2 Seabed concentrations at sensitive features 42
7.2.1 Azamethiphos 42
7.2.2 Deltamethrin 45

1 Executive Summary

This report describes simulations of bath treatment releases based on the outputs of a hydrodynamic model which was developed for the East coast of Shetland. The aim of the investigation was to understand what consented level of the medicines Azamethiphos and Deltamethrin for bath treatment at Scottish Sea Farms's proposed Fish Holm site (details in Table 1.1) could be safely used while maintaining satisfaction of SEPA Maximum Allowable Concentration (MAC) and Environmental Quality Standard (EQS) criteria [7].

A range of different treatment scenarios were investigated, in addition to sensitivity to horizontal dispersion (observed to be similar to the default SEPA value in the locality of the site [6]) and release time/tide state.

For Azamethiphos, simulations indicated that a medicine mass of 500 g could be safely consented as a 3 hr limit, and combined treatments and sensitivity analysis in a realistic multi-day scenario suggest a 24 hr limit of 1500 g. For Deltamethrin, simulations indicated that 90 g would be an appropriate limit for a single pen treatment.

Table 1.1: Summary of site details and model results.

Proposed Site Details	
Name	Fish Holm
Location	Yell Sound, Shetland
Site centre (Latitude, Longitude)	60.44599, -1.12258
Proposed Biomass (T)	6000
Configuration	
Number of Cages	12
Cage Circumference (m)	160
Net Depth (m)	15.7
Pen Group Distance to Shore	610 m (centre)
Group Layout	2 x 6
Pen Orientation	27°
Depth (m)	60 m
Azamethiphos	
Recommended consent (3 hr)	500 g
Recommended consent (24 hr)	1500 g
Deltamethrin	
Recommended consent (6 hr)	90 g

2 Introduction

This report has been prepared by Scottish Sea Farms Ltd (SSF) to meet the requirements of the Scottish Environmental Protection Agency (SEPA) for an application for the consented use of topical sea lice medicines at the proposed Fish Holm aquaculture site (OSGB 448381, 1173899; Figure 3.1 and 3.2).

The report describes the application of coupled hydrodynamic and particle tracking models to estimate the spread of bath medicines following treatment events, and to evaluate quantities of medicine which may be used in compliance with SEPA Environmental Quality Standards.

The modelling procedure follows the current version SEPA marine modelling guidance as available in January 2024 [7].

The site configuration is composed of 12 x 160m cages, with centre-point of cage grid at (448381, 1173899) m (OSGB Easting/Northing). Key data relating to the site are summarised in Table 1.1.

3 Methodology

3.1 Hydrodynamic and particle tracking models

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 variations in density, currents and tidal elevation [4]. Setup of the model and validation for its use in assessing bath medicines at the Fish Holm site are described in the accompanying reports [3] [8].

Particle tracking was also carried out using the DHI MIKE software suite. 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 by currents, horizontal and vertical diffusion (described by a random walk formulation) at fixed rates as defined in SEPA guidance. Each particle was assigned to represent a specific mass of medicine at the moment it was released, equal to total treatment mass, divided by the number of particles per release. For Azamethiphos mass is considered to decline exponentially over time at a fixed rate governed by the chemical half-life prescribed by SEPA. Presently the SEPA default value of half-life for Azamethiphos is 5.6 days [2].

3.2 Model domain and boundary conditions

The model domain used for this study covers the East coast of Shetland Mainland (Figure 3.1). 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 HD model mesh in this case was adapted to have a high resolution in the area around the proposed site, and lower resolution elsewhere. The mesh used for hydrodynamic modelling is shown in Figures 3.1 and 3.2.

Particle tracking was carried out using a higher resolution mesh representing the area around the proposed site development (Figure 3.3). This mesh has a fine resolution over an extended area in order to represent trajectories of particles more precisely. Median element area within a 3 km box centred on the proposed site location is 630.8 m^2 (95% interval = [399.3, 952.8] m^2).

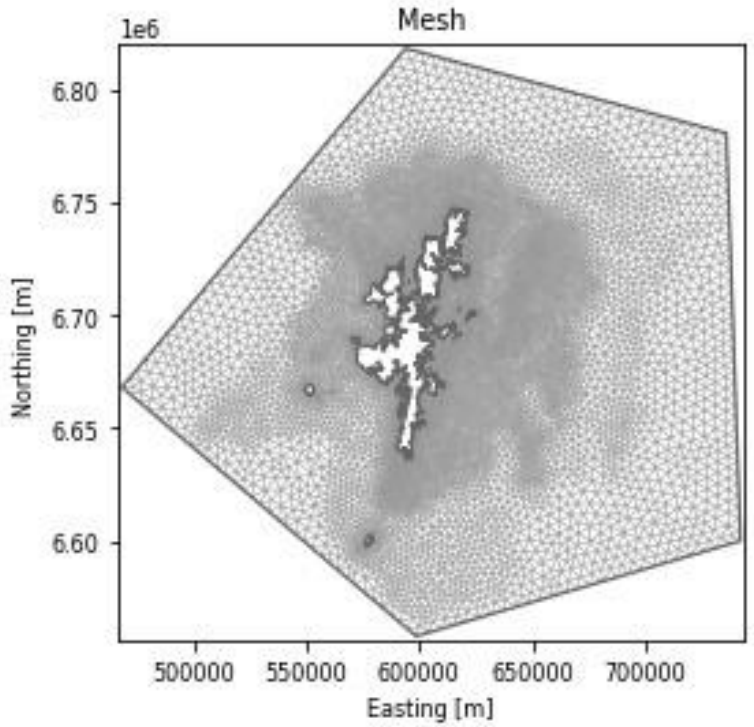

Figure 3.1: Mesh for hydrodynamic model, showing the full extent of the spatial domain, which covers the entirety of the Shetland Islands. [3]. Map coordinates are UTM zone 30N.

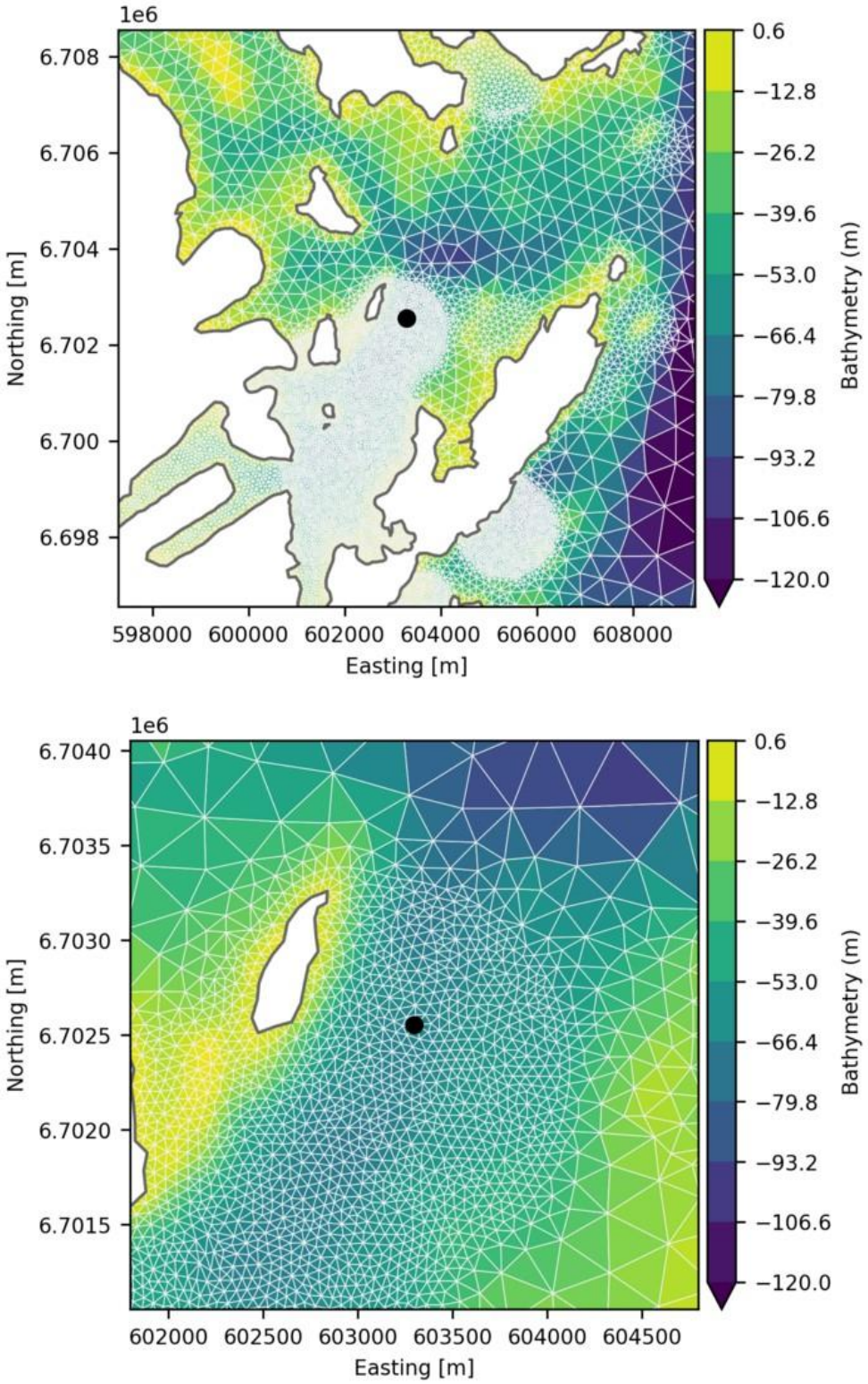

Figure 3.2: Close-up view of the area around Fish Holm and the mesh and bathymetry used for hydrodynamic modelling. Map coordinates are UTM zone 30N.

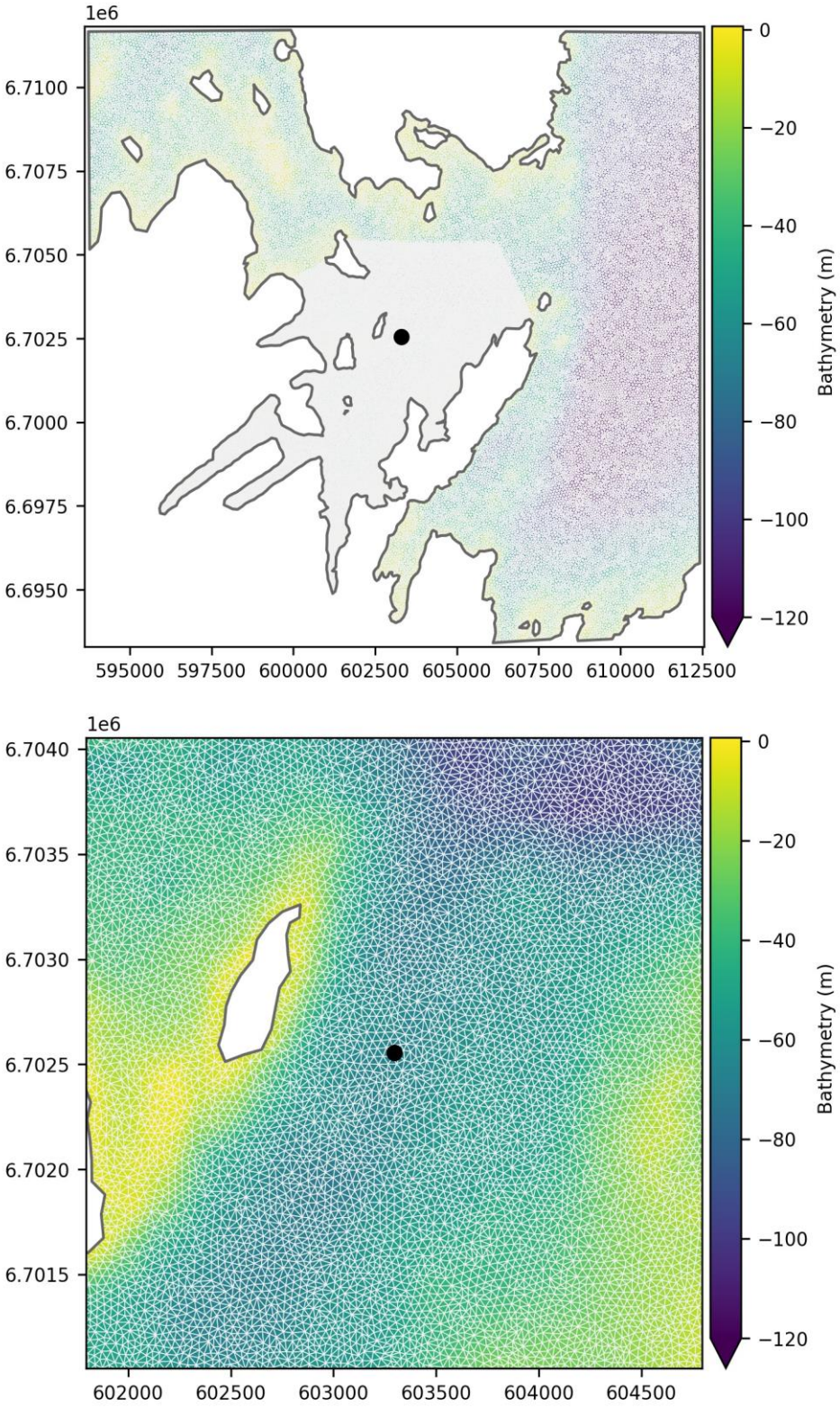

Figure 3.3: Close-up view of the area around Fish Holm and the mesh/bathymetry used for particle tracking. Map coordinates are UTM zone 30N.

3.3 Model validation

The hydrodynamic model validation was carried out using a current meter record collected at the site over a period between 21/04/2022 and 25/07/2022.

Accompanying this study is a detailed report on the hydrodynamic model validation process undertaken as part of this study [8]. This study indicated that the model matched the current meter record well in direction, though was likely to give slightly conservative predictions with respect current speed in the area.

Table 3.1: Current meter data used for model calibration/validation.

Position (OSGB m)	448317, 1173770
Depth at location (m)	66.98m
Surface bin height above sensor (m)	58.73
Cage-bottom bin height above sensor (m)	47.93
Bottom bin height above sensor (m)	2.93
Start date	21/04/2022
End date	25/07/2022
Duration (days)	95
Interval (minutes)	20
Purpose	Validation

3.4 Medicine dispersion modelling - Azamethiphos

3.4.1 Approach

For particle tracking simulations where releases of Azamethiphos were modelled at the site, two release (treatment completion) times were selected from the hydrodynamic model output:

- 10/07/1993 (release during NEAP tide)
- 19/07/1993 (release during SPRING tide)

Sensitivity to the specific release time for neap and spring period dispersal was estimated by adjustment to the particle tracking simulation start time of +/- 6 hrs about the baseline value.

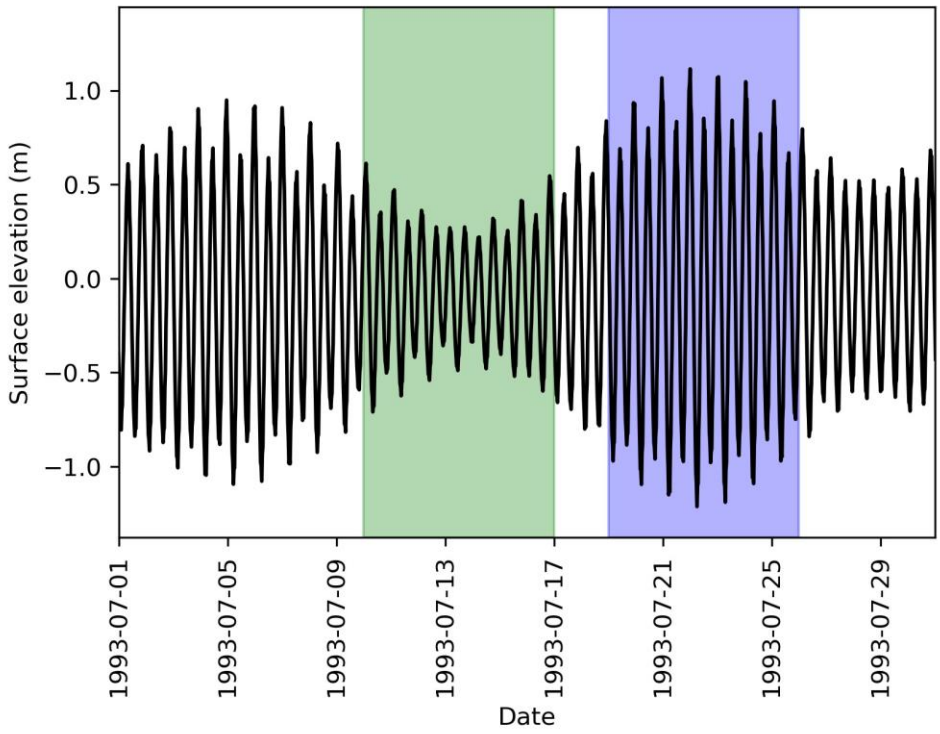

Figure 3.4: Surface elevation at Fish Holm from climatology model output of the SSF East Shetland HD model, indicating the time windows used for neap (green) and spring (blue) tide particle releases.

A scenario for particle release was defined in order to simulate the most intensive treatment which would be likely to be carried out on the site. In this scenario, 3 cages were treated on the four consecutive days, at 3 hour intervals within each day, giving releases at 0, 3, 6, 24, 27, 30, 48, 51, 54,72, 75 and 78 hours).

Bath treatment events were simulated using a release of 50,000 model particles per cage treated, with each particle representing an equal proportion of the total treatment mass (total 600,000 particles per simulation when including all cages). Particles were released randomly within a cage's lateral area and over the top 5 m of the water column. The initial treatment mass was taken to be 500 g, determined as a reasonable amount of

azamethiphos to treat the specified cage size, and to be scaled down if the results were found not to comply with SEPA standards.

Simulated particles were passive, neutrally buoyant, and subject to both horizontal and vertical advection (derived from hydrodynamic model flow fields) and dispersion (set to fixed constant values; by default 0.1 $m^2 s^{-1}$ horizontally and 0.001 $m^2 s^{-1}$ vertically). As per present SEPA guidance, half-life for particles was set to 5.6 days (via a mass decay rate of 1.43 x 10^{-6} s^{-1}).

Dispersion studies close to the farm location have identified that dispersion is comparable at the proposed Fish Holm site to the default parameter values suggested in the SEPA guidance [6]. Sensitivity to horizontal dispersion was tested regardless, with simulations using horizontal dispersion coefficients of 0.05, 0.1, and 0.5 $m^2 s^{-1}$, for both neap and spring release times.

The set of dispersion simulations carried out is summarised in Table 3.2.

Table 3.2: Summary of Simulations carried out for Azamethiphos modelling. Also, individual simulations using the same parameters as ID 1 and 6 were undertaken for each release at each cage (an additional 24 simulations).

ID	Tide	Dispersion	Timing adjustment (hr)
1	Neap	0.1	0
2	Neap	0.1	-6
3	Neap	0.1	+6
4	Neap	0.05	0
5	Neap	0.5	0
6	Spring	0.1	0
7	Spring	0.1	-6
8	Spring	0.1	+6
9	Spring	0.05	0
10	Spring	0.5	0

3.4.2 Mass limit assessment

Adjustments were made to the total mass released per treatment in conjunction with assessment of compliance with Maximum Allowable Concentration (MAC) and Environmental Quality Standard (EQS) criteria.
This allowed determination of:

- A recommended maximum mass for release within a 3 hr window. For this purpose a range of increased treatment masses were applied to each individual cage release within the main sensitivity set of runs, ensuring that none of these releases exceeded the 3 hr EQS threshold. The highest treatment mass which complied with this was chosen.
- A recommended maximum mass for release within a 24 hr window. For this purpose a range of increased treatment masses were applied to each run within the main sensitivity set of runs, ensuring that the mass chosen complied with the 72 hr MAC and EQS thresholds.

3.4.3 Output statistics

Output statistics were generated for all particle dispersion simulations in accordance with the current version of SEPA guidance [7]. The following values were calculated, based on concentrations within the top 5 m of the water column, as per SEPA guidelines:

- Timeseries of area >3 hr EQS (threshold 250 ng l^{-1})
- Timeseries of area >72 hr EQS (threshold 40 ng l^{-1})
- Timeseries of maximum concentration vs 72 hr MAC (threshold 100 ng l^{-1})

The 3 hr Azamethiphos EQS area was derived from the SEPA MATLAB scripts provided to SSF that recreate the BathAuto mixing zone ellipse calculations (Appendix 7), and was determined to be 255,460m^2. Plots of medicine mass distribution at the specific EQS times were generated.

3.4.4 Dispersion study

A study was carried out at the Fish Holm site location to derive dispersion coefficients at Fish Holm and for validation against the HD model [6]. The study details eight releases, between the 22nd and 25th April 2024, each consisting of a dye plume and 4 GPS drifting buoys, corresponding to various stages of the tidal cycle. The report detailing the results of this study was submitted to SEPA alongside this report. The horizontal dispersion coefficient estimated here was comparable to the SEPA default value of 0.1 $m^2 s^{-1}$, with a mean of 0.101 $m^2 s^{-1}$. Sensitivity of model results to this parameter was still demonstrated through sensitivity testing in the simulations.

3.5 Deltamethrin modelling

Modelling for Deltamethrin was also undertaken using the same setup as for Azamethiphos, though without a decay constant, as recommended in SEPA guidance [7]. Cage releases were modelled at the same times as Azamethiphos both at neap and spring tides, though each model was only for one cage release following SEPA guidance to ensure compliance of each individual cage with the Deltamethrin 6 hr EQS, given as an area above a concentration of 6 ng l^{-1}.

The results of each cage were compared to ensure that each complied with this standard. The 6 hr area EQS value was determined using the same MATLAB script as for Azamethiphos: this value was calculated to be 722,540m^2 (Appendix 7).

Empirical assessment of dispersion at the site indicated that the horizontal dispersion coefficient here is similar to the SEPA default value [6]. Sensitivity testing for this parameter was not tested for Deltamethrin, as it was expected that testing for Azamethiphos would be sufficient.

3.6 Impact on sensitive features

SEPA identified shellfish farms and priority marine features (PMFs) which were classed as at risk from bath medicine release at the Fish Holm proposed site (Tables 3.3 and 3.4). A visual seabed survey was carried out as part of the risk assessment work for this site development, full results of which are detailed in a separate report

[9]. A number of potential PMF locations were identified during this survey; these are detailed in Table 3.5. The possible impacts on each of these, hereafter referred to as sensitive features were assessed through the model results at their locations to ensure the concentration of Azamethiphos and Deltamethrin at each was not significant at the relevant EQS timesteps.

Several of the sensitive features (the shellfish farms and one PMF location for maerl) cover larger areas, and so a region was assessed rather than an individual point (Figure 3.5). For these, the maximum concentration within the region at each timestep of azamethiphos and deltamethrin was used to determine the impact of these medicines on these sensitive features.

Table 3.3: Shellfish farm locations listed in the SEPA risk identification report. Though listed as points here, the entire region encompassed by these farms was assessed.

ID	Feature Name	Easting (OSGB)	Northing (OSGB)
1	Cul Ness	447700	1169300
2	North West of Cul Houb	446500	1168200
3	Inner Collafirth, Delting	443600	1169400
4	West Taing	444000	1170900
5	South Side, Dales Voe	443000	1170200
6/7	Scarva Ayre 1/1b	442100	1169900
8	Scarva Ayre 2	442800	1170600
9	Maerl	450116	1173741

Table 3.4: PMF locations included in the SEPA risk identification report. An additional maerl bed, covering a region of greater spatial extent and shown in Figure 3.5, was also identified and assessed in the same manner as shellfish farm locations.

ID	Feature Name	Easting (OSGB)	Northing (OSGB)
1	Horse Mussel	444602	1178546
2	Kelp and seaweed communities	447475	1170225
3	Kelp and seaweed communities	449785.1	1173843
4	Kelp and seaweed communities	449757.3	1173916
5	Kelp and seaweed communities	453142.2	1173820
6	Kelp beds	452216.9	1172464
7	Kelp beds	452383.8	1172909
8	Kelp beds	453274.4	1173493
9	Kelp beds	453434.4	1173660
10	Kelp beds	453114.4	1173744
11	Kelp beds	453708.4	1177498
12	Kelp beds	453587.8	1179613
13	Tide swept algal communities	449747.8	1173926
14	Tide swept algal communities	449768	1173894
15	Tide swept algal communities	449825.4	1173829
16	Maerl or coarse shell gravel with burrowing sea cucumbers	450540.3	1173772
17	Maerl or coarse shell gravel with burrowing sea cucumbers	450609.9	1173760
18	Maerl or coarse shell gravel with burrowing sea cucumbers	453107.7	1173704

Table 3.5: PMF locations identified during the site visual survey. Transect number indicates that from the report from that study. Transect section length relates to the portion of transect summarised by the easting/northing point location (mid-point of transect section).

ID	Transect	Type	Easting (UTM30N)	Northing (UTM30N)	Transect section length (m)
1	3N	Brittle star	603526	6702932	103.5
2	3S	Brittle star	603029	6701970	91.4
3	4S	Brittle star	602866	6702195	64.2
4	4N	Brittle star	603291	6703033	9.3
5	4N	Brittle star	603286	6702993	72.2
6	5	Brittle star (possible horse mussels)	603234	6703369	83.6
7	5	Brittle star (possible horse mussels)	603226	6703298	62.6
8	5	Brittle star (possible horse mussels)	603209	6703224	88.0
9	5	Brittle star (possible horse mussels)	603195	6703144	76.5
10	5	Brittle star (possible horse mussels)	603178	6703073	67.9
11	5	Brittle star (possible horse mussels)	603162	6703022	40.2
12	6	Brittle star	603576	6702565	102.0
13	6	Brittle star	603623	6702656	102.5

Figure 3.5: Map showing all sensitive features identified in the SEPA risk screening report, including fish farms (dark blue discs, SEPA ID label), PMF points (orange discs, small number labels), and shellfish/maerl polygons (dark grey, large number labels). Numbering on PMFs and polygons relates to the number within the summary Tables 3.3 and 3.4.

3.7 Removal of coastline elements and shallow depths

In previous bath medicine modelling assessments carried out by SSF using MIKE PT, accumulations of released particles occurred at model elements adjacent to the coastline and at elements with shallow depth. These accumulations were believed to be artefacts resulting from the numerical methods used for particle transport in the model [1]. For this reason, elements on the coastline were excluded from the main results of the bath medicine impact analysis.

Areas of shallow depth have also been identified as sometimes being problematic during low tides. As the EQS is assessed for the first 5 m of the water column, depth lower than this can lead to artificially high concentrations for EQS assessment. Therefore, all elements where the depth was less than half the tidal range (2.6 m, determined from the maximum and minimum surface elevation from the model) +5 m were also excluded from presented results.

Although these locations are excluded from the main statistic timeseries calculations, any locations with MAC exceedances in the unfiltered results are shown in the 72 hr Azamethiphos maps for reference.

4 Results

4.1 Azamethiphos EQS and MAC

Initial modelling for 500 g releases of Azamethiphos at each pen were found to comply with the SEPA EQS and MAC standards, and these results are presented here.

4.1.1 3 hr EQS – Baseline neap/spring simulations

This section assesses compliance for baseline cage releases under neap and spring tidal conditions, with the 3 hr EQS threshold area over 250 ng l^{-1}, that is 0.255 km^2.

Timeseries of area above the 3 hr EQS threshold concentration for the first pen release in the baseline neap and spring simulations are shown in Figure 4.1. Times are given relative to the initial release time for each simulation, aligning timeseries to a common start point. Initial trajectories of the areal extent of the plume are similar for the first hour after release, then some variability arises.

In addition to the variation in spatial extent of dispersion, the overall pattern of patch movement varies between the simulations, and indeed between cage releases. However, in all cases, the main body of the plume is moved over the first 3 hours post release NW out of the voe and into the wider Yell Sound area (Figures 4.2 and 4.3).

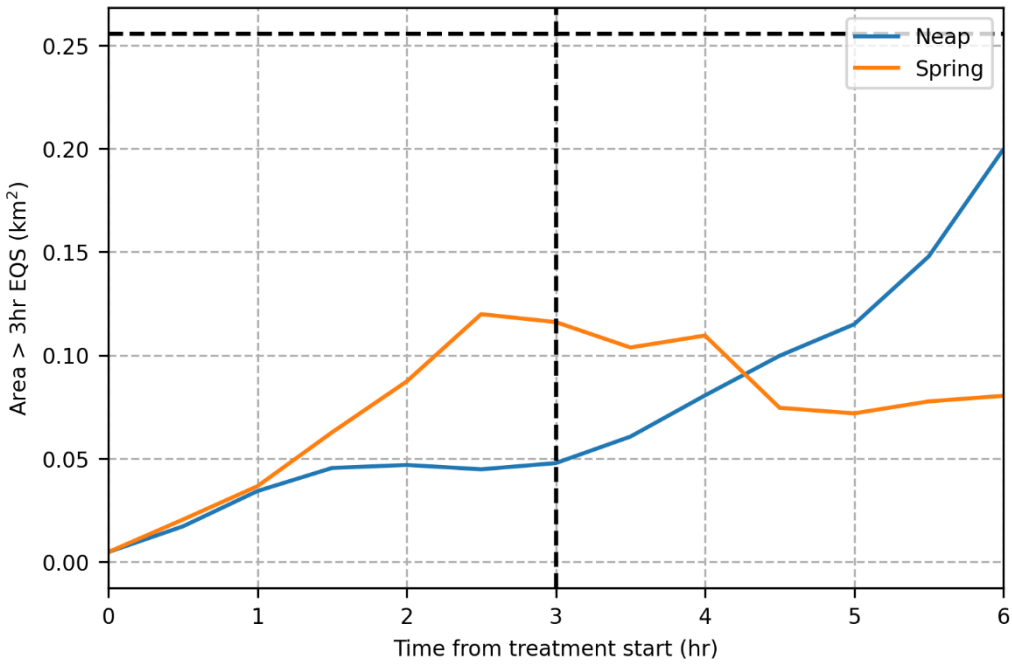

Figure 4.1: Baseline neap and spring tide simulations of 500 g Azamethiphos released from the first pen in the group; area above the 3 hr EQS concentration threshold (250 ng l^{-1}). Horizontal dotted line indicates the allowable 3 hr EQS ellipse area.

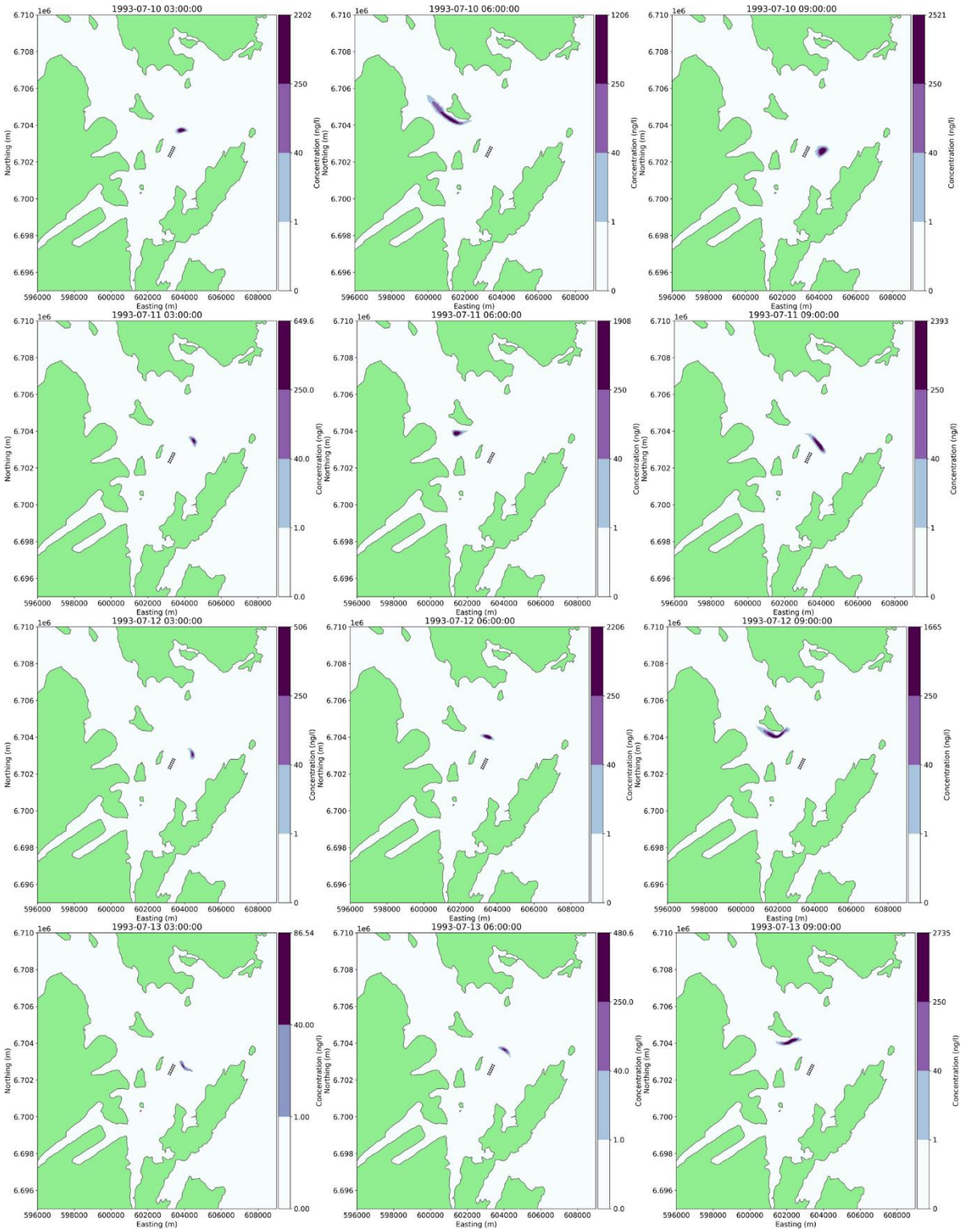

Figure 4.2: Predicted concentration at 3 hrs post release, for individual cage treatments 1-12 under NEAP tide conditions (plumes from each cage shown in isolation, in rows from top left), with release of 500 g azamethiphos at each cage. Contours are shown at EQS concentration thresholds.

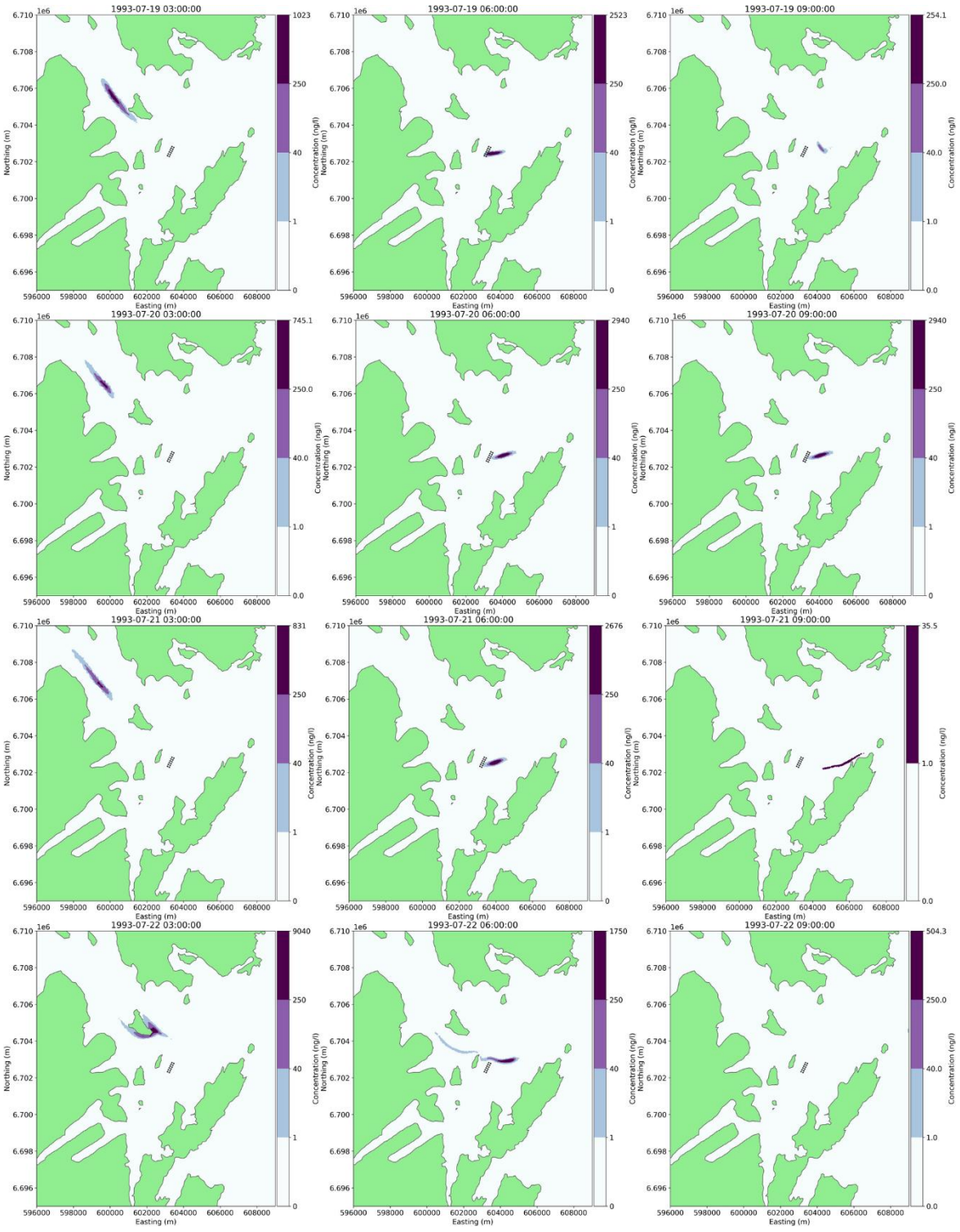

Figure 4.3: Predicted concentration at 3 hrs post release, for individual cage treatments 1-12 under SPRING tide conditions (plumes from each cage shown in isolation, in rows from top left), with release of 500 g azamethiphos at each cage. Contours are shown at EQS concentration thresholds.

4.1.2 72 hr MAC and EQS – Baseline neap/spring simulations

This section assesses compliance with the 72 hr MAC and EQS for baseline cage releases under neap and spring tidal conditions. The 72 hr MAC is 100 ng l^{-1}, and the 72 hr EQS threshold for area 40 ng l^{-1} concentration is 0.5 km^2.

In the case of maximum concentration (Figure 4.4), this decreases rapidly after treatment, falling below the 72 hr MAC within around 12 hours of final treatment in both spring and neap tide cases, and continues to decrease, with only some small spikes that do not exceed the EQS after 72 hr post-treatment.

In the case of the EQS 40 ng l^{-1} 72 hr (after final treatment) area threshold of 0.5 km^2 (Figure 4.5), it is clear from the figure that this requirement is easily met. Within around 20 hours of treatment ending, the area above this concentration is generally close to zero.

Figure 4.6 shows concentration at 72 hours after release across the domain for the neap simulation, indicating that only very low quantities of Azamethiphos remained at this time. Some isolated shallow and coastal locations did exhibit peaks above the MAC. These locations are considered to present model artefacts which do not reflect reality, and were not included in the timeseries plots.

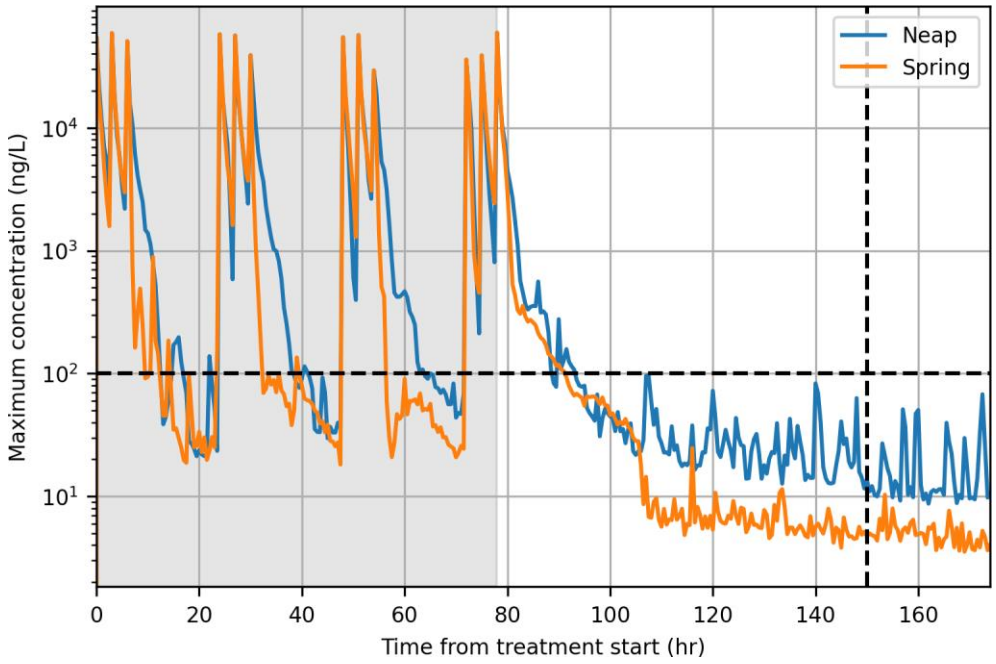

Figure 4.4: Peak concentration for baseline simulations (neap tide: blue; spring tide: orange). Timeseries of predicted maximum concentration within the domain, allowing comparison against MAC (horizontal dashed line) at 72 hrs after the final treatment release (vertical dashed line). Time is given relative to the time of initial release, to enable direct comparison of results.

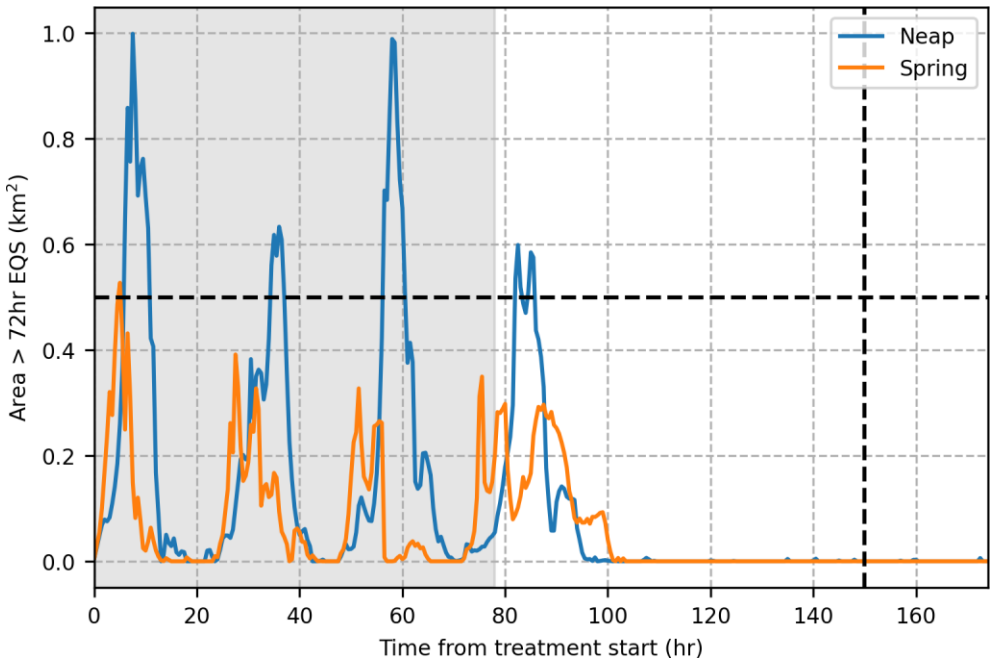

Figure 4.5: Area above 72 hr EQS of 40 ng l^{-1} for baseline simulations (neap tide: blue; spring tide: orange). Timeseries of predicted area with concentration higher than the 72 hr EQS concentration, allowing comparison with the allowable areal extent of that concentration (horizontal dashed line) at 72 hrs after the final treatment release (vertical dashed line). Time is given relative to the time of initial release, to enable direct comparison of results.

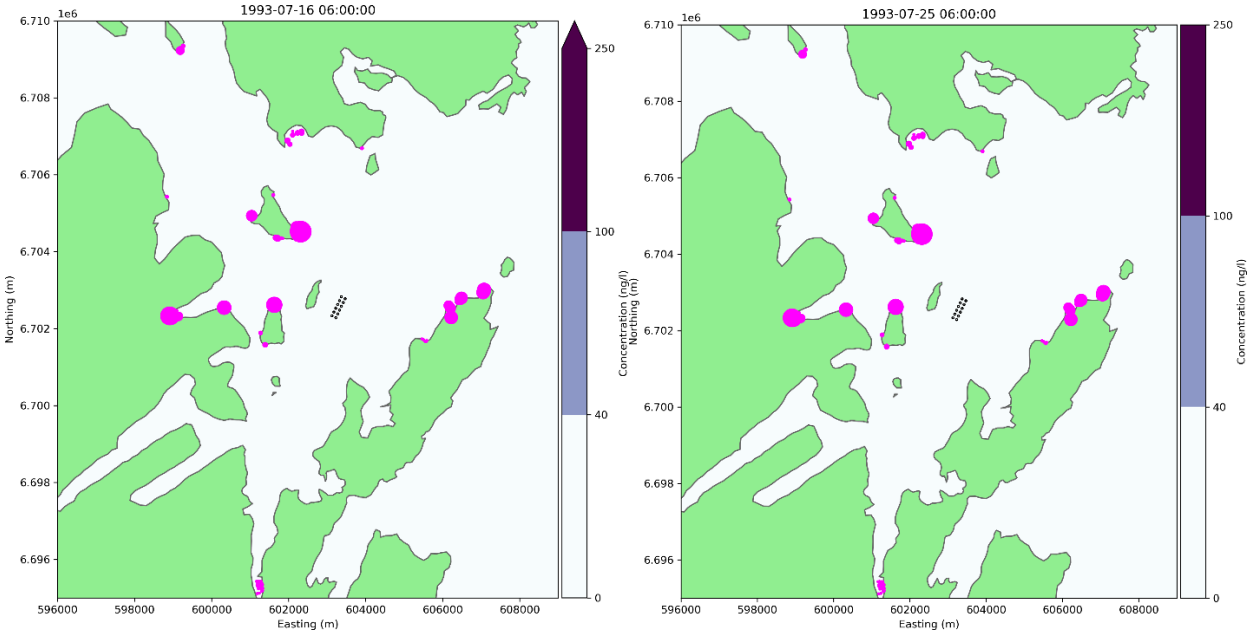

Figure 4.6: Neap (left) and Spring (right) baseline simulation predicted concentration at 72 hours after treatment is complete. Contours at EQS concentration thresholds. Magenta points indicate the locations where MAC exceedances were identified, prior to removal of coastline and shallow elements (size proportional to relative number of occurrences).

4.1.3 Sensitivity

Release time

The impacts of adjusting release time by 6 hours before and after the baseline time for neap and spring scenarios are shown in Figure 4.7 and Figure 4.8 respectively. Early dynamics in the statistics are closely related to the timing of the releases, particularly notable in the 72 hr area EQS plot. However, by around 36-48 hours after the final treatment, patterns in maximum concentration appear to be governed more by general water movements, following a similar pattern in each case, with the dispersal occurring gradually and concentrations of medicine dropping below the EQS. As in the baseline neap and spring period simulations, the 3 and 72 hr area EQS criteria are both easily met in the simulations, and the MAC is also met though by a smaller margin (isolated spikes in neap case), with this continuing to decrease after the EQS time.

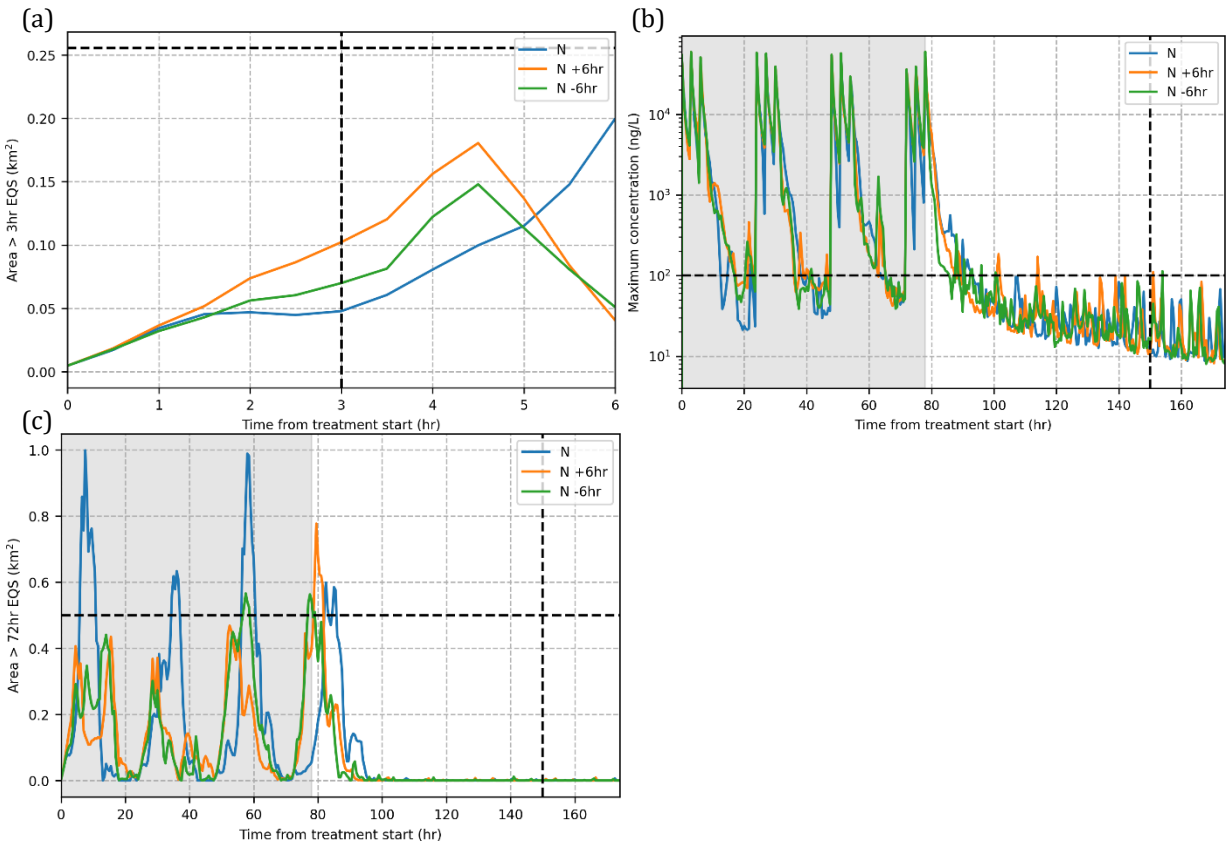

Figure 4.7: Sensitivity to release time for NEAP tide conditions, showing the effect of adjusting release time +/-6 hrs from the baseline time. (a) Area of plume with concentration greater than 250 ng l^{-1} (3 hr EQS level), up to 3 hrs, for the first cage treated. (b) Maximum concentration anywhere within the domain. (c) Area of plume with concentration greater than 40 ng l^{-1} (72 hr EQS level). Horizontal dashed lines indicate EQS/MAC maximum allowable thresholds, and vertical lines indicate the relevant time for assessment. Time is given relative to the time of initial release, to enable direct comparison of results.

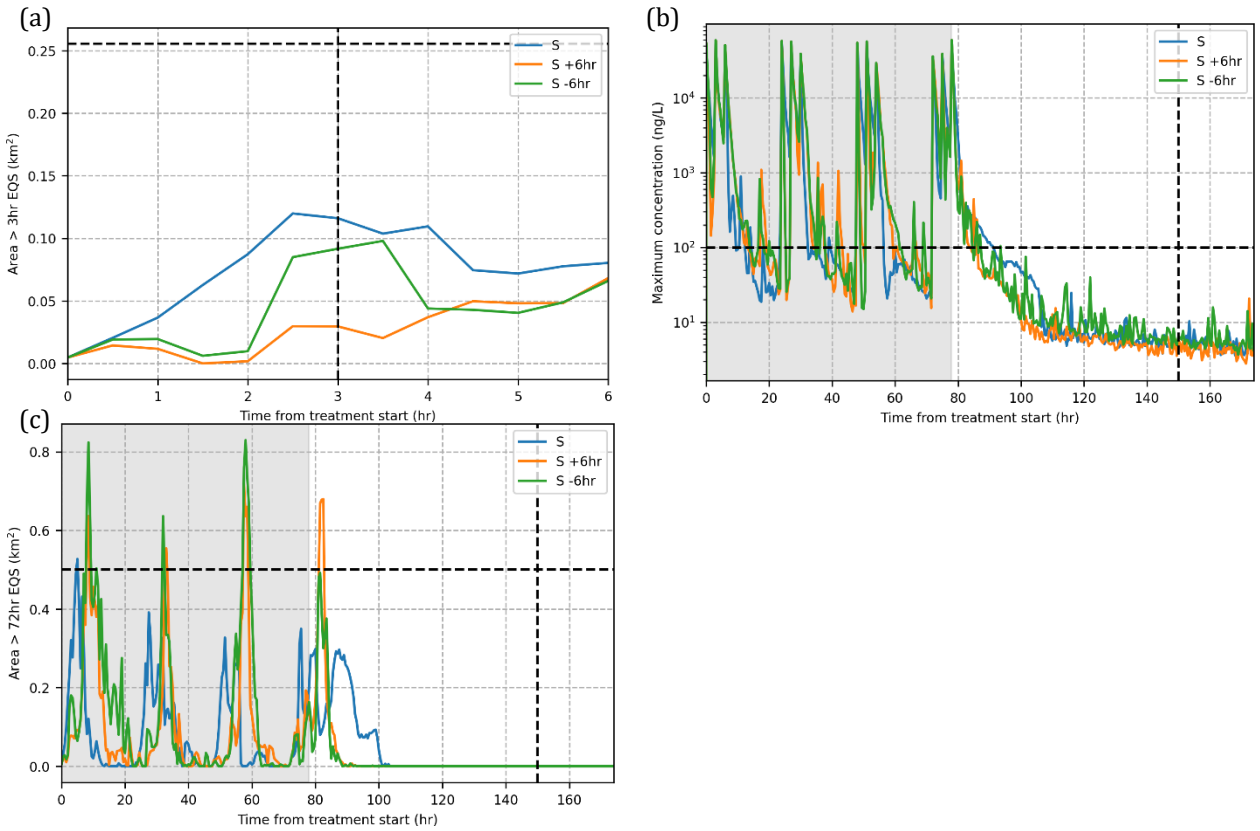

Figure 4.8: Sensitivity to release time for SPRING tide conditions, showing the effect of adjusting release time +/-6 hrs from the baseline time. (a) Area of plume with concentration greater than 250 ng l^{-1} (3 hr EQS level), up to 3 hrs, for the first cage treated. (b) Maximum concentration anywhere within the domain. (c) Area of plume with concentration greater than 40 ng l^{-1} (72 hr EQS level). Horizontal dashed lines indicate EQS/MAC maximum allowable thresholds, and vertical lines indicate the relevant time for assessment. Time is given relative to the time of initial release, to enable direct comparison of results.

Dispersion coefficient

Results relating to simulations with adjusted diffusion coefficients are shown in Figure 4.9 and Figure 4.10. Increasing the diffusion coefficient in simulations leads to i) more rapid initial reduction in maximum concentration within the model domain, and ii) greater/faster initial increase in area above a given concentration, and then faster decrease in this area later. The latter effect is particularly noticeable in the area-based 3 hr EQS with initial increase in areal extent, and in the later stages of the 72 hr run where areal extent decreases earlier in the higher dispersion run.

For the later MAC/EQS times closer to the 72 hr EQS the dynamic nature of the local hydrodynamic regime dominates, leading to similar patterns at all parameter values.

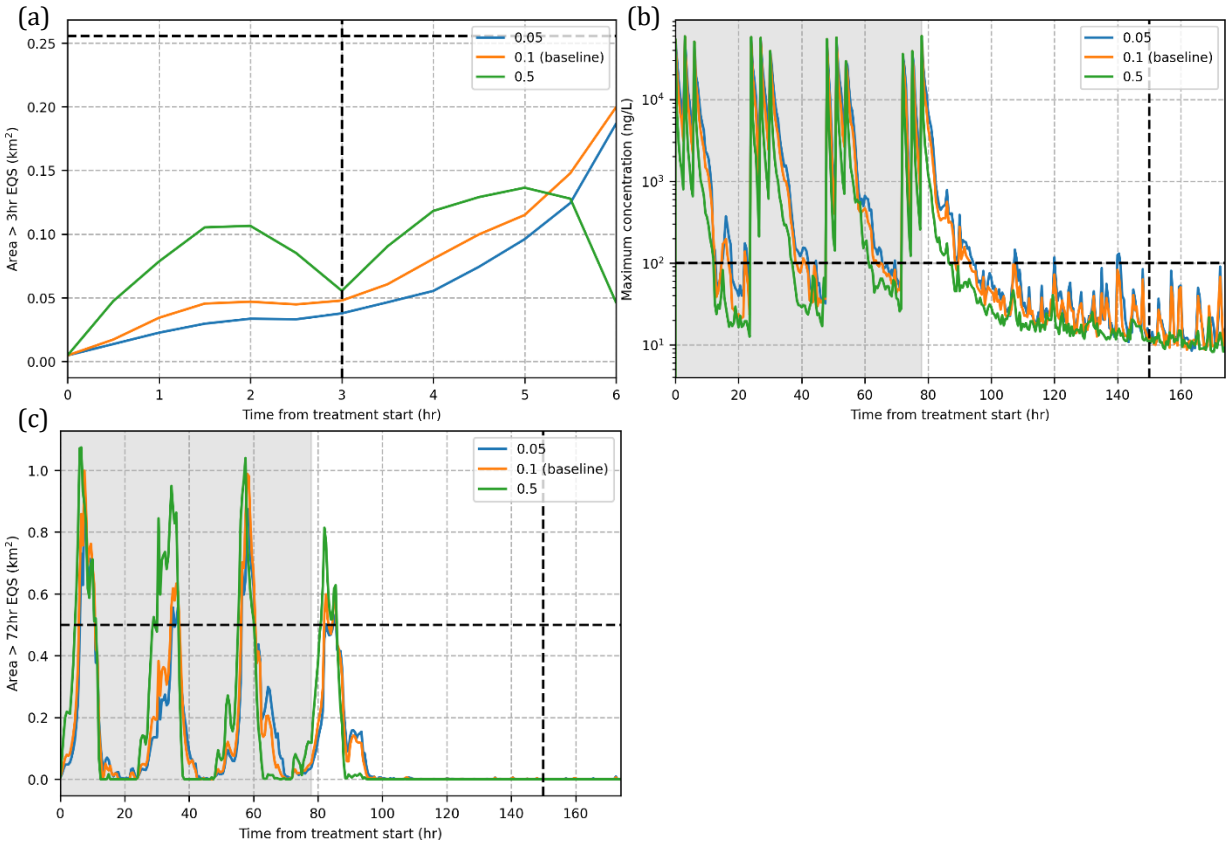

Figure 4.9: Sensitivity to dispersion coefficient, under NEAP tide conditions. (a) Area of plume with concentration greater than 250 ng l^{-1} (3 hr EQS level), up to 3 hrs, for the first cage treated. (b) Maximum concentration anywhere within the domain. (c) Area of plume with concentration greater than 40 ng l^{-1} (72 hr EQS level). Horizontal dashed lines indicate EQS/MAC maximum allowable thresholds, and vertical lines indicate the relevant time for assessment.

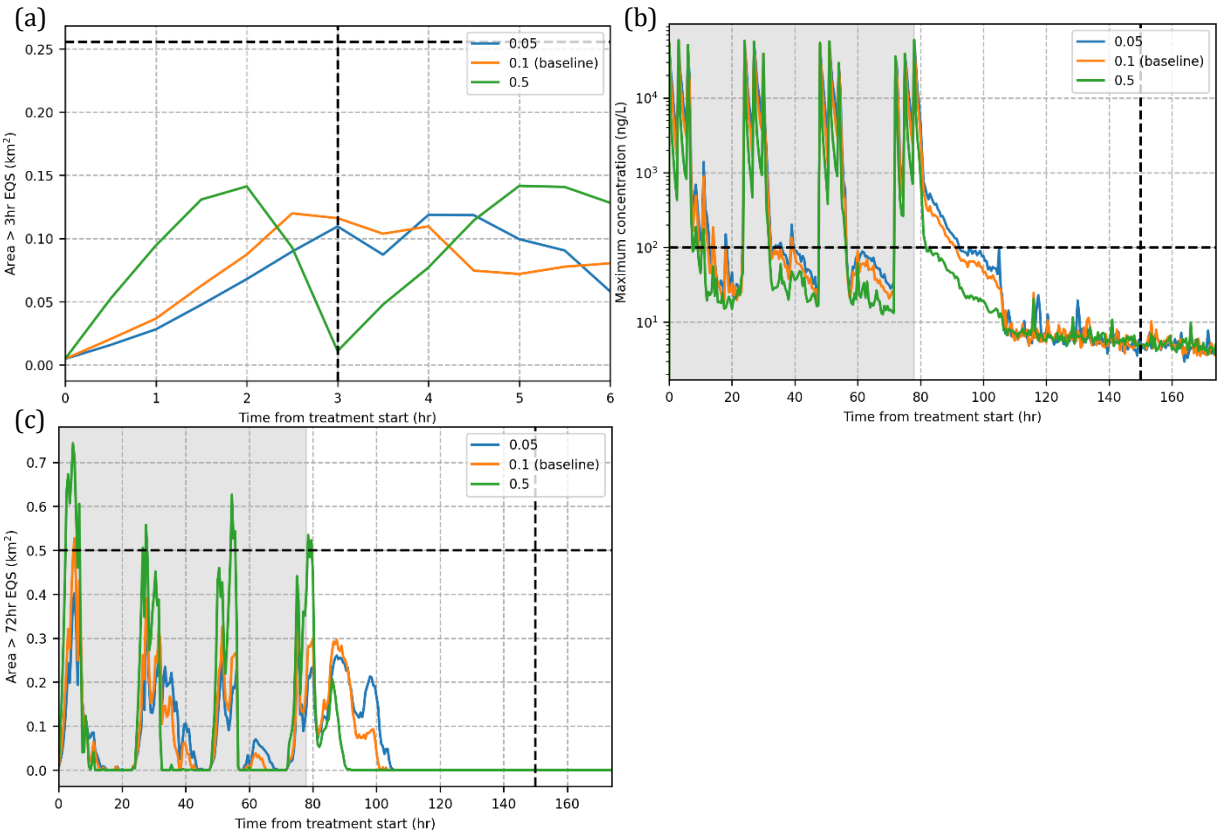

Figure 4.10: Sensitivity to dispersion coefficient, under SPRING tide conditions. (a) Area of plume with concentration greater than 250 ng l^{-1} (3 hr EQS level), up to 3 hrs, for the first cage treated. (b) Maximum concentration anywhere within the domain. (c) Area of plume with concentration greater than 40 ng l^{-1} (72 hr EQS level). Horizontal dashed lines indicate EQS/MAC maximum allowable thresholds, and vertical lines indicate the relevant time for assessment.

4.2 Deltamethrin EQS

This section assesses compliance with the 6 hr EQS for Deltamethrin over the baseline cage releases under neap and spring tidal conditions.

The 6 hr EQS threshold for area over 6 ng l^{-1} concentration, derived using MATLAB scripts provided by SEPA using a mean surface current speed at the site of 0.162 m s^{-1}, was 0.723 km^2. Further details for the calculation of this value provided in Appendix 7.1.

Timeseries of area above the 6 hr EQS threshold concentration for the first pen release in each of neap and spring tide simulations are shown in Figure 4.11. The areal extent of the plume meets the EQS criteria in both cases. Similarly to Azamethiphos results, the main body of the bath plume is transported out of the enclosed voe area and into the broader area of Yell Sound in all cases (Figure 4.12 and 4.13).

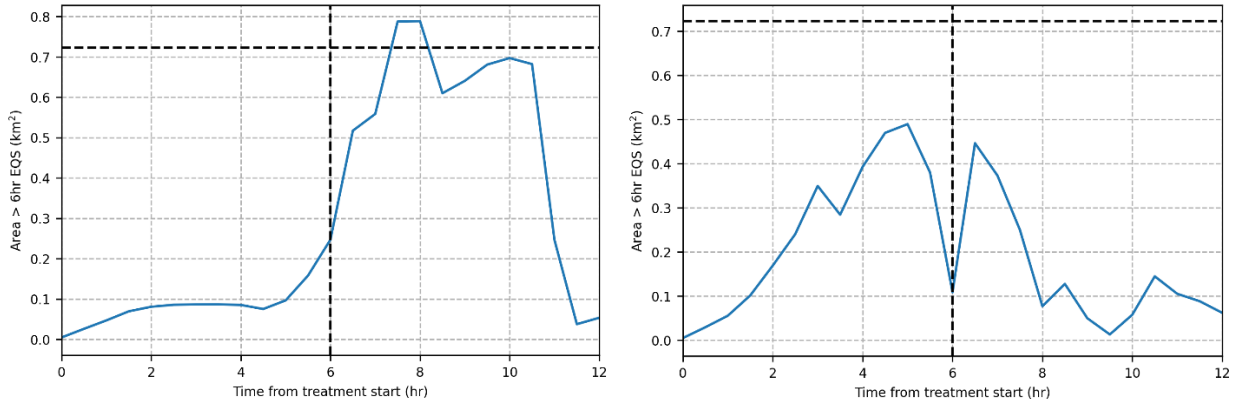

Figure 4.11: Individual cage releases of 90 g deltamethrin. Area above the 6 hr EQS concentration threshold (6ng l^{-1}) for Pen 1 under the baseline (a) neap and (b) tide scenarios. Horizontal dotted line indicates the derived 6 hr ellipse area.

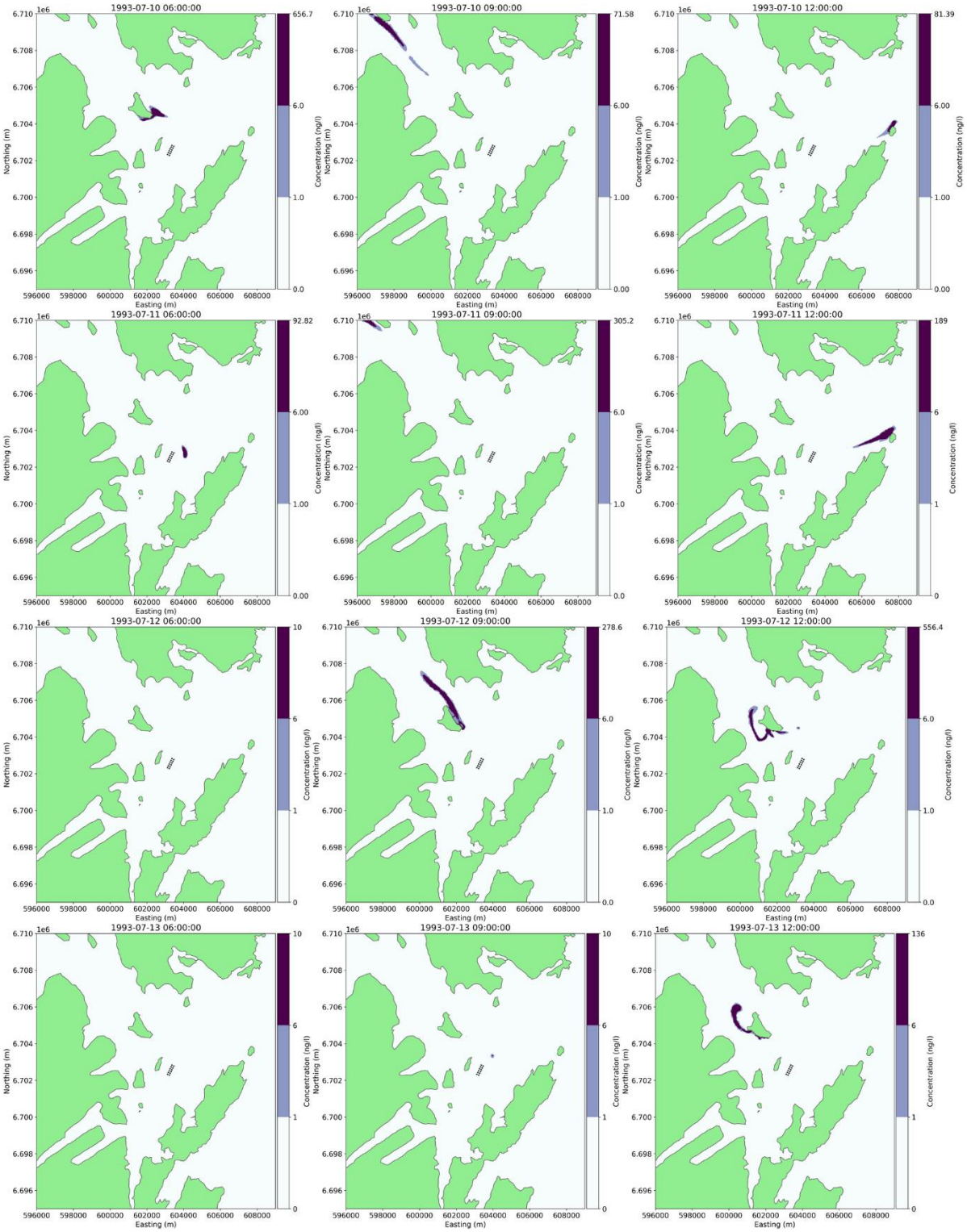

Figure 4.12: Predicted concentration at 6 hrs post release, for individual pen treatments 1-12 under NEAP tide conditions (plumes from each pen shown in isolation, in rows from top left), with release of 90 g Deltamethrin at each pen. Contours are shown at EQS concentration thresholds.

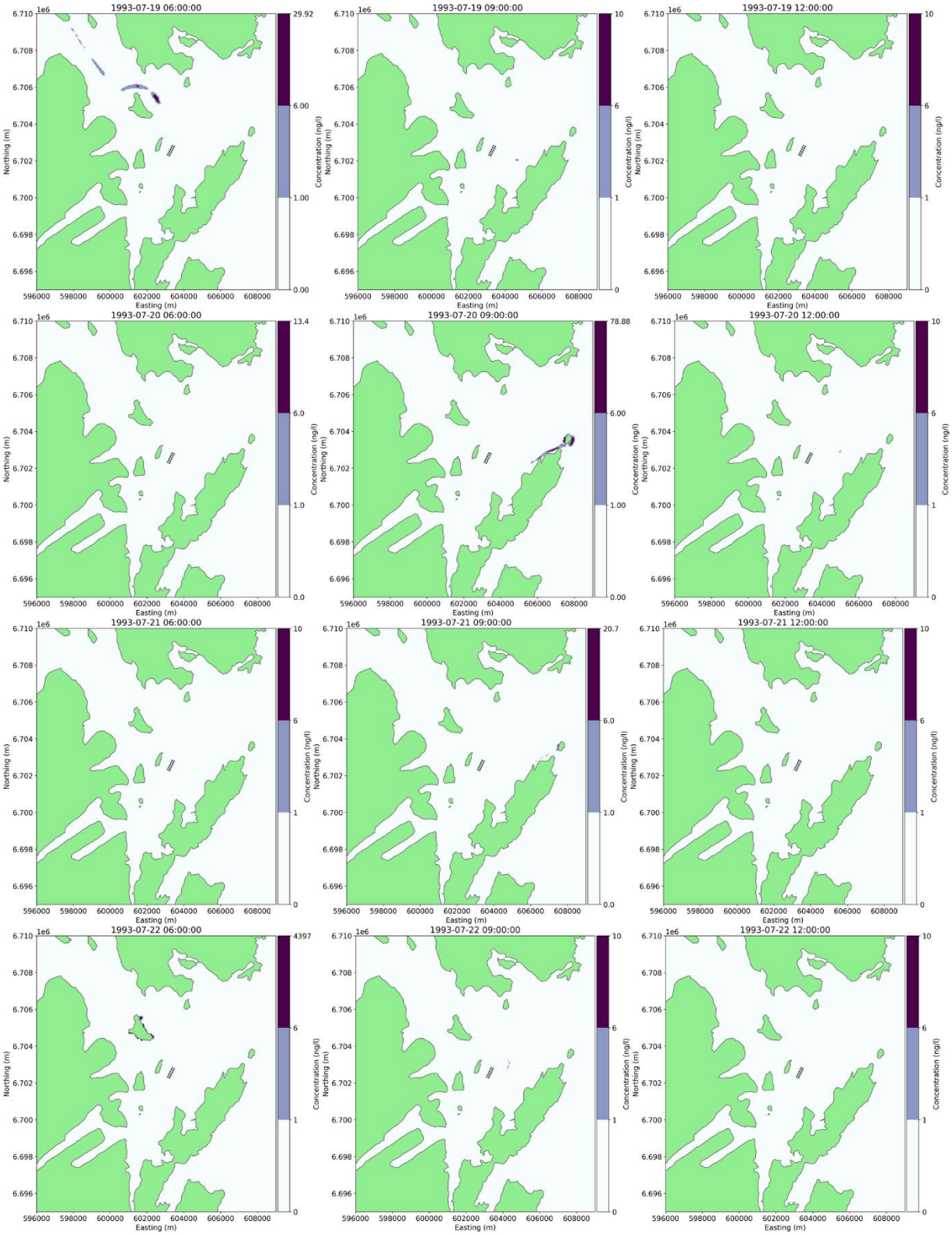

Figure 4.13: Predicted concentration at 6 hrs post release, for individual pen treatments 1-12 under SPRING tide conditions (plumes from each pen shown in isolation, in rows from top left), with release of 90 g Deltamethrin at each pen. Contours are shown at EQS concentration thresholds.

4.3 Impact on sensitive features

4.3.1 Azamethiphos

Figures 4.14 to 4.17 show how concentrations of Azamethiphos are predicted to vary at PMF locations, shellfish farms and fish farms, as a result of bath treatments at FISH1 site. In order to provide precaution, and following current SEPA guidance, concentrations are given as an average over the top 5 m (since this is where chemicals are released, and therefore where their concentrations are expected to be highest over the short duration considered).

In general, the figures indicate a generally low level of interaction between Fish Holm and the local sensitive features. Any significant concentrations (that is, above or close to EQS thresholds) occur as short spikes; no persistent high concentrations are predicted. Even in the "worst" cases for locations identified by SEPA (the maerl polygon to the NE of the site, and some of the algal communities), average concentrations over the treatment period are an order of magnitude below the 72 hr EQS threshold. The exception to this is the release site FISH1 itself, which obviously has a high peak at the time of/soon after treatment, and zero values at most other times (this is omitted from the fish farm time series plot to clarify results for other locations).

Isolated spikes in concentration are seen at several individual visual survey PMF locations during each of the neap and spring tide simulations (Figure 4.15). Due to the proximity of these locations to the release point, this is not unexpected, but the concentration is non-zero only for a single time point in each case, and is the concentration at the surface, not the seabed. Near-bed concentrations are much lower. Spikes never exceed EQS levels for any sensitive feature, except in the case of the peak value within the maerl polygon, which goes over EQS levels momentarily (for a single timestep) on two occasions shortly after the completion of the treatment schedule. Timeseries plots of near-bed concentrations of Azamethiphos at benthic sensitive features (and shellfish farms) are presented in Appendix Section 7.2.1.

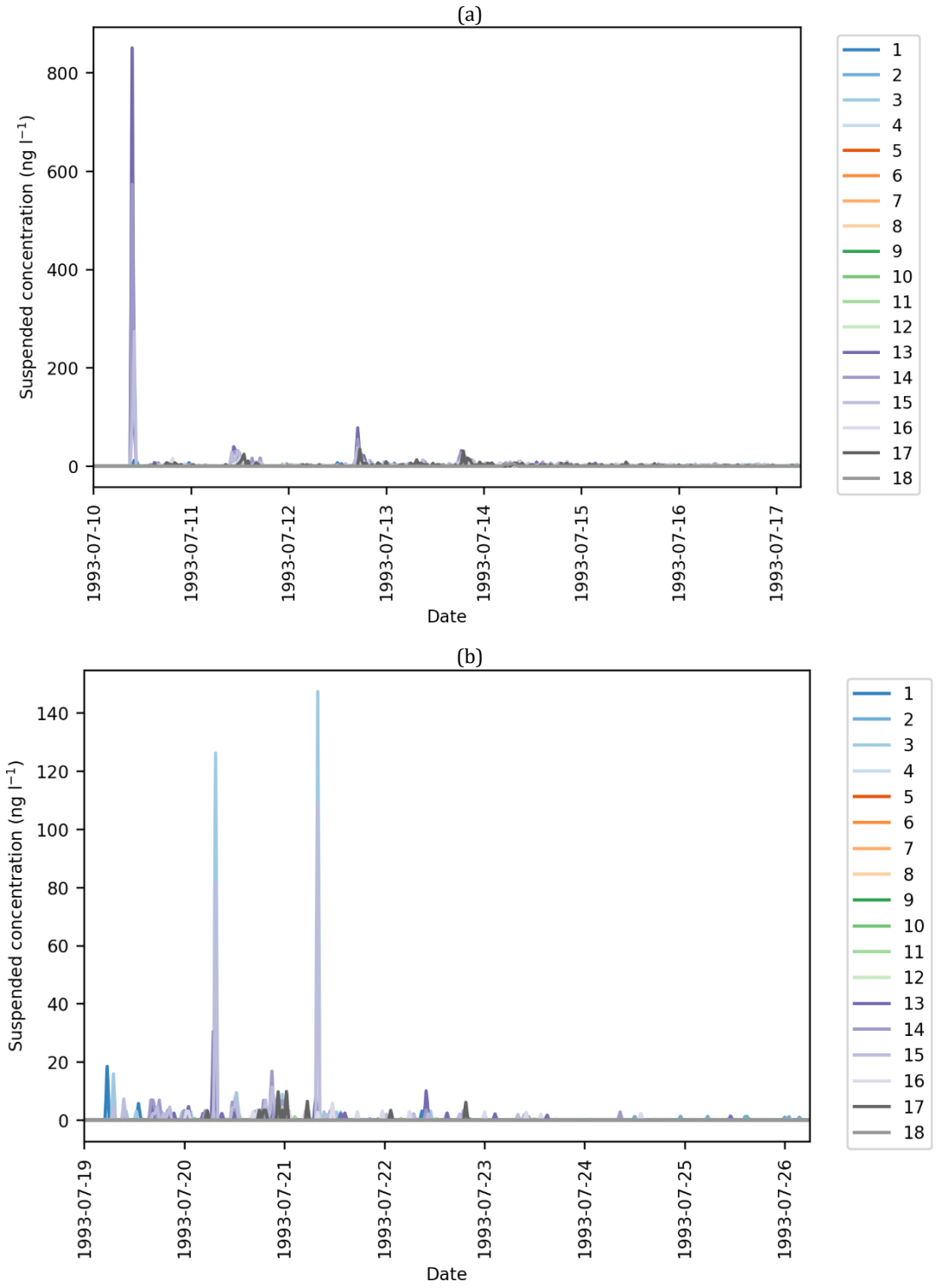

Figure 4.14: Near-surface (top 5 m) concentration of Azamethiphos at each sensitive feature (PMF) point identified by SEPA, through time series of the (a) neap and (b) spring baseline simulations. Legend numbers correspond to sensitive feature numbers in Table 3.4.

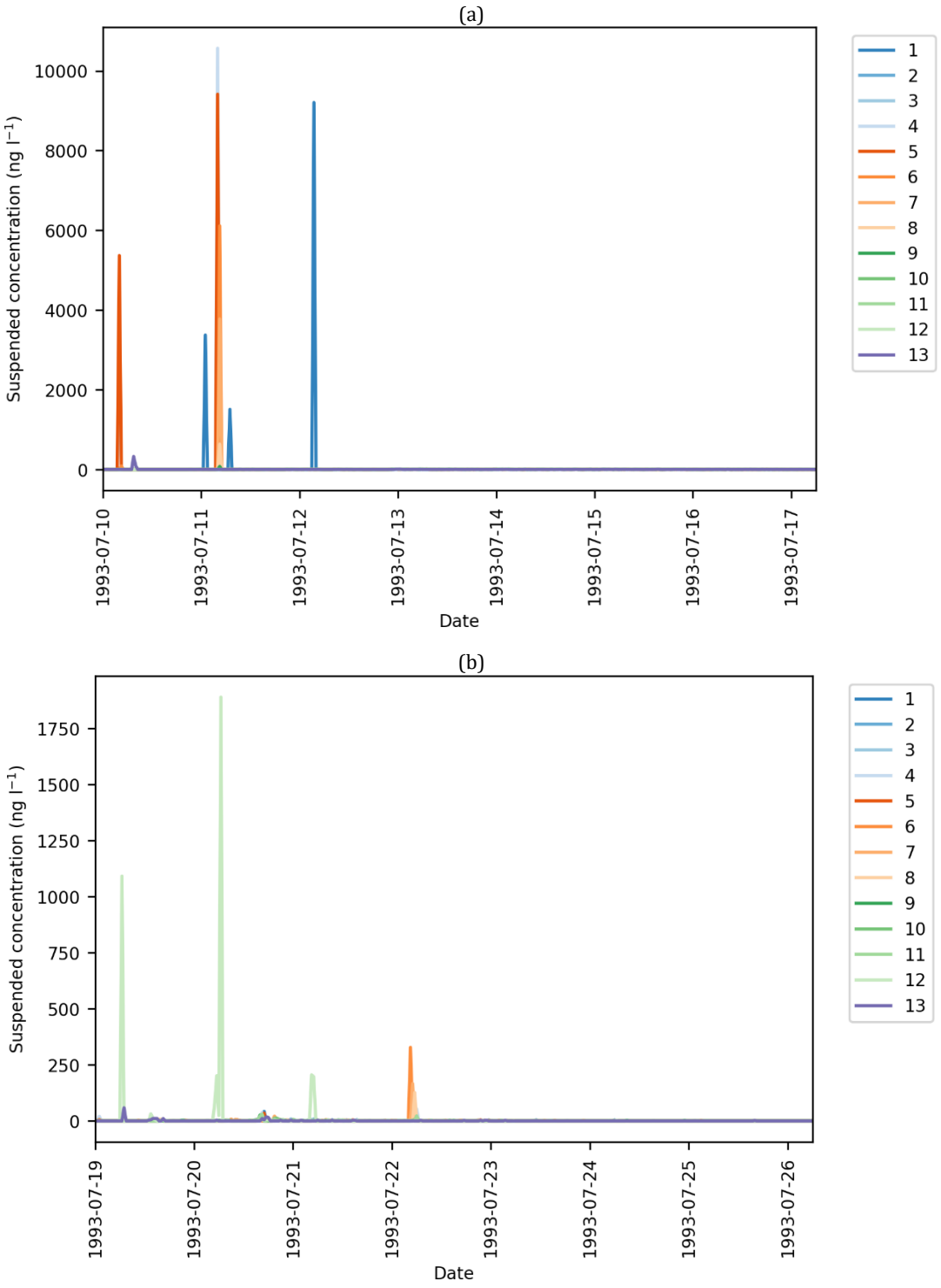

Figure 4.15: Near-surface (top 5 m) concentration of Azamethiphos at each sensitive feature (PMF) location identified during the visual survey, through time series of the (a) neap and (b) spring baseline simulations. Legend numbers correspond to sensitive feature numbers in Table 3.5.

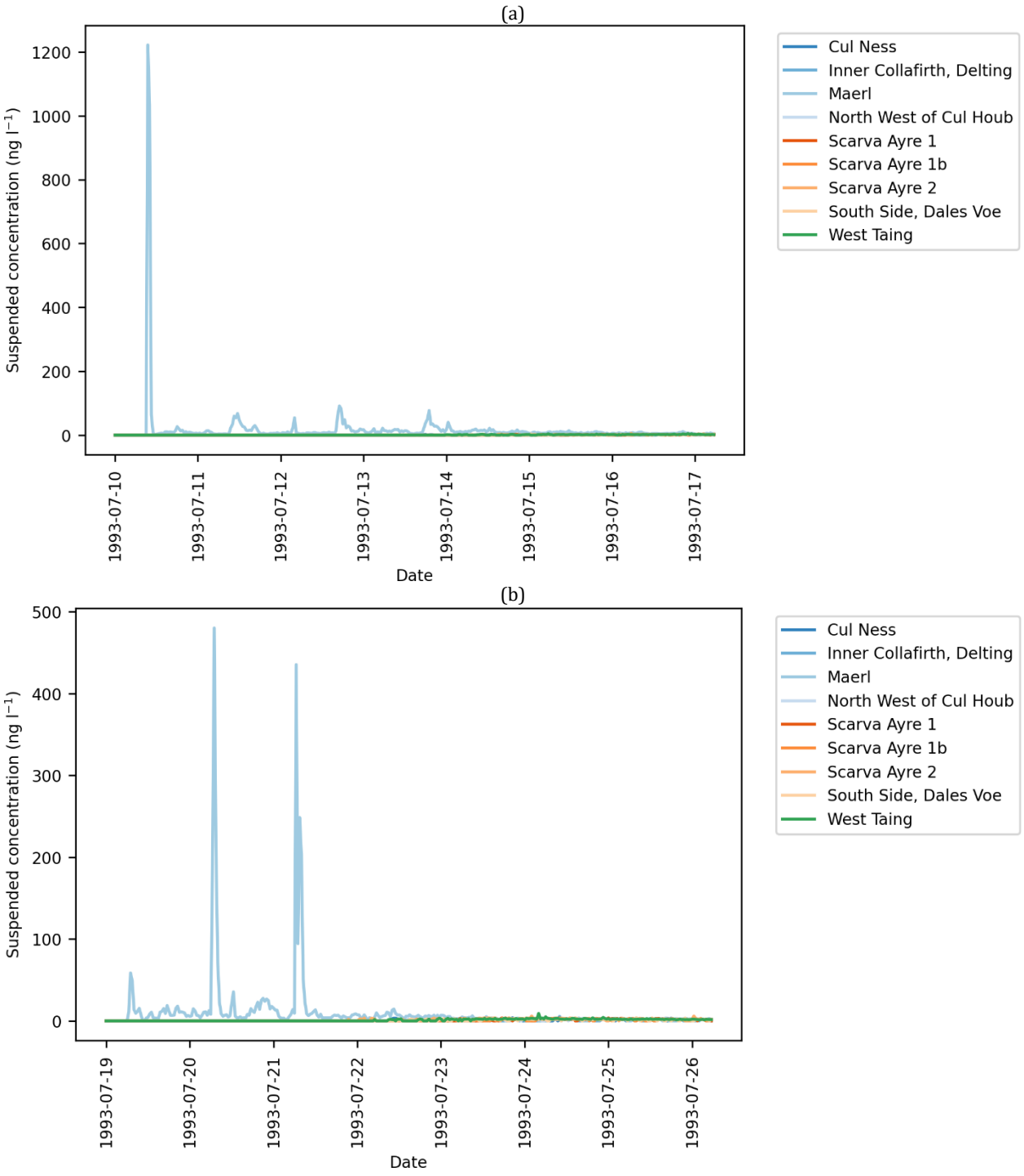

Figure 4.16: Maximum near-surface (top 5 m) concentration of Azamethiphos across all elements encompassing each sensitive feature polygon (maerl beds and shellfish farms) through time series of the (a) neap and (b) spring baseline simulations.

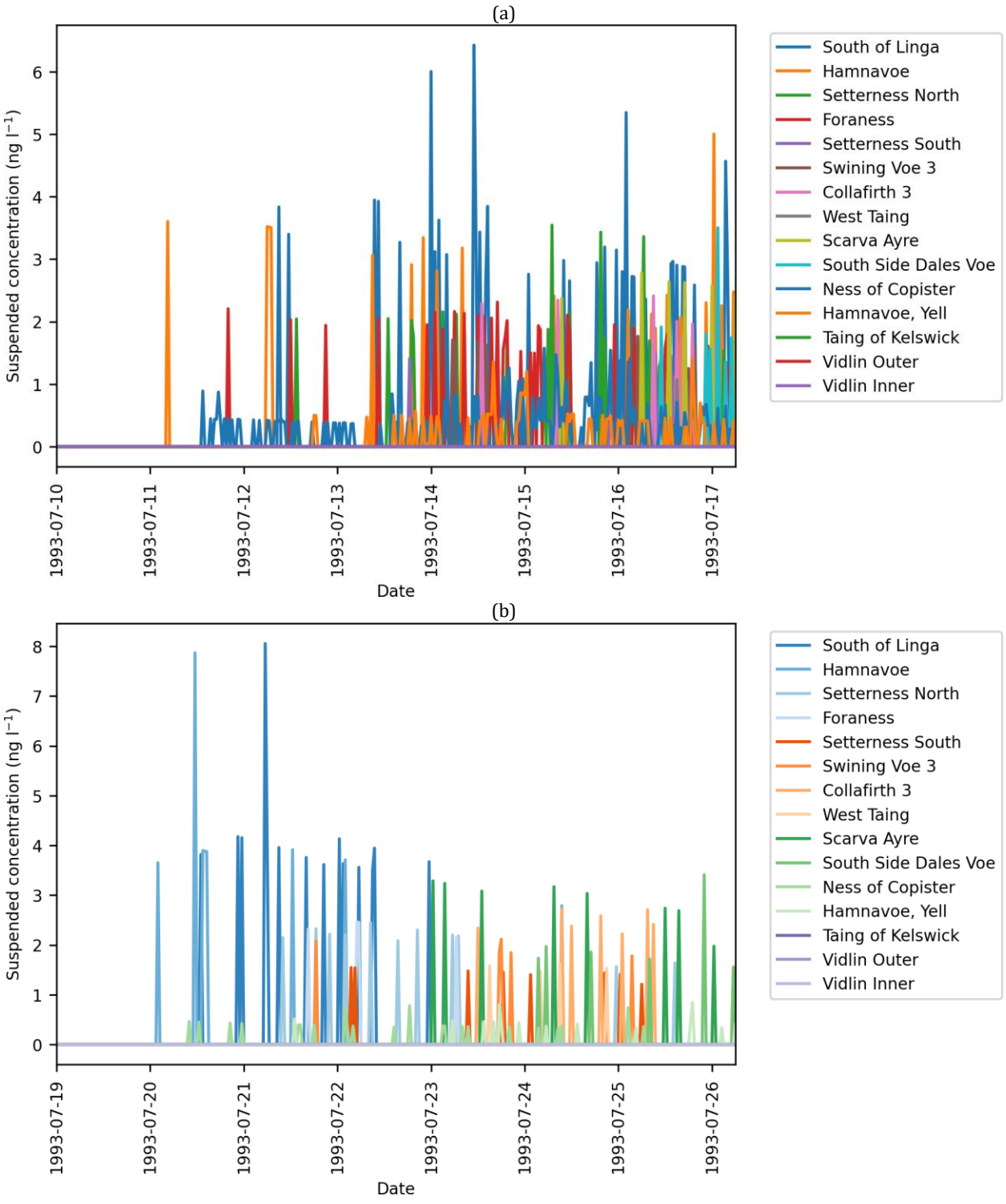

Figure 4.17: Near-surface (top 5 m) concentration of Azamethiphos at each fish farm location through time series of the (a) neap and (b) spring baseline simulations. As Fish Holm is assessed directly in the EQS section, it is omitted here to clarify the vertical axis.

4.3.2 Deltamethrin

As with the Azamethiphos results, concentrations of Deltamethrin at sensitive features are generally predicted to be very low in both spring and neap simulations (Figures 4.18 to 4.21). The 6 hr EQS level is not predicted to be exceeded at any sensitive feature.

Small spikes in concentration are seen at visual survey PMF location during each of the neap and spring tide simulations (Figure 4.19). Due to the proximity of these locations to the release point, this is not unexpected, but the concentration is non-zero only for a single time point, is the concentration at the surface.

Near-bed concentrations are generally lower than the surface concentrations. Timeseries plots of near-bed concentrations of Deltamethrin at benthic sensitive features (and shellfish farms) are presented in Appendix Section 7.2.2.

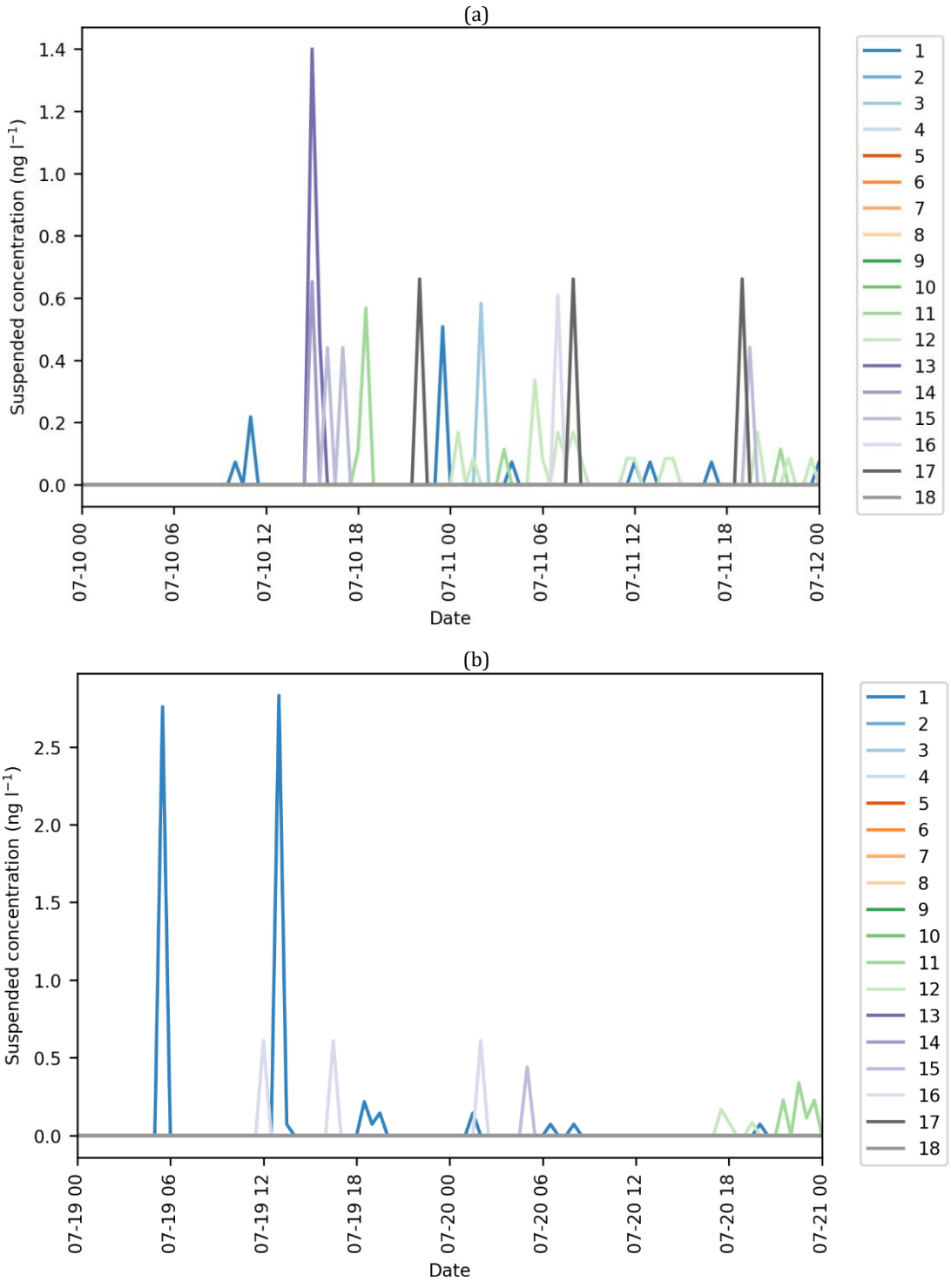

Figure 4.18: Mean near-surface (top 5 m) concentration timeseries of Deltamethrin at each PMF point identified by SEPA, during the (a) neap and (b) spring simulations of medicine release at cage 1. Legend numbers correspond to numbers in Table 3.4.

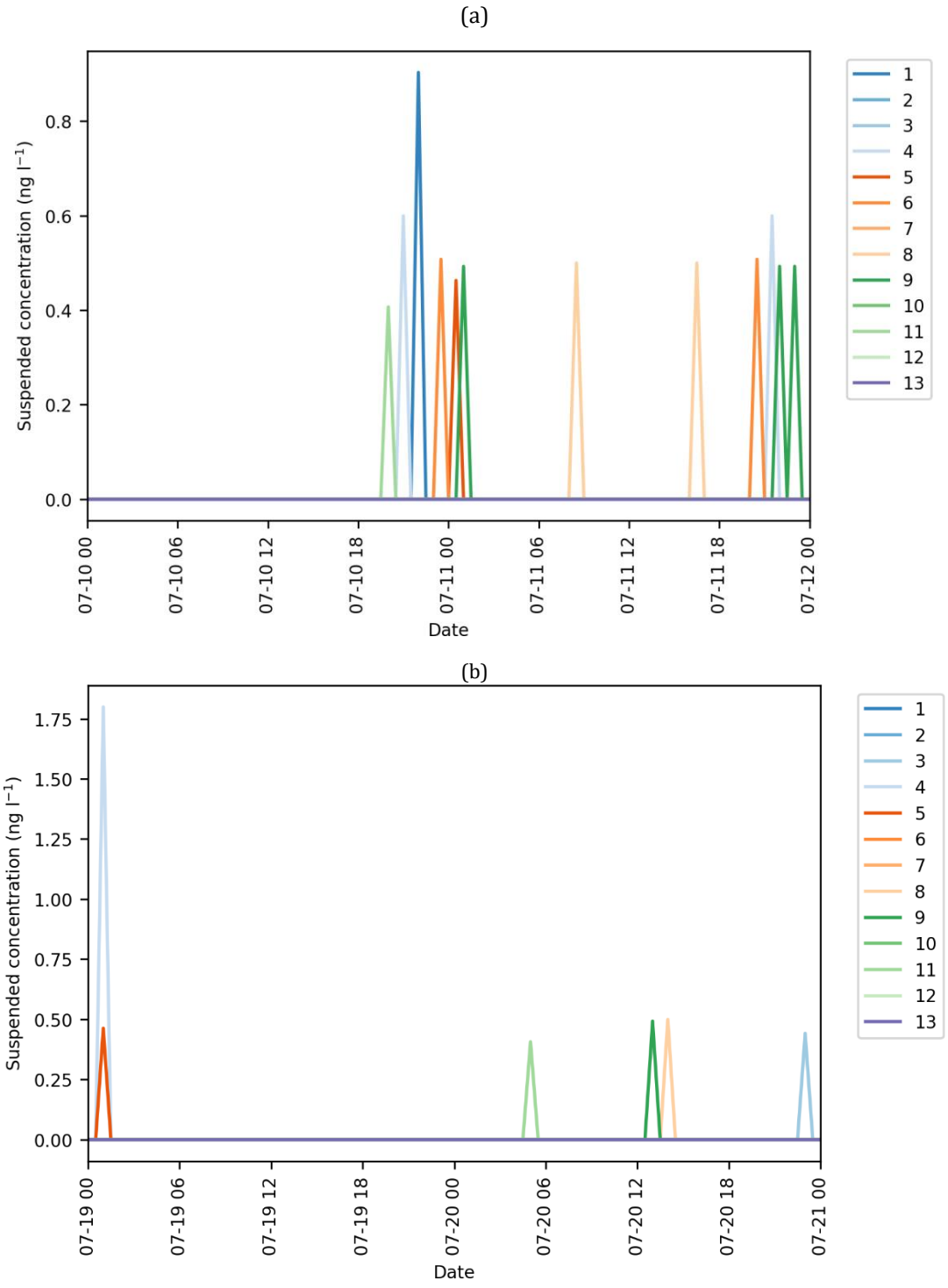

Figure 4.19: Mean near-surface (top 5 m) concentration timeseries of Deltamethrin at each PMF point identified in the visual seabed survey, during the (a) neap and (b) spring simulations of medicine release at cage 1. Legend numbers correspond to numbers in Table 3.4.

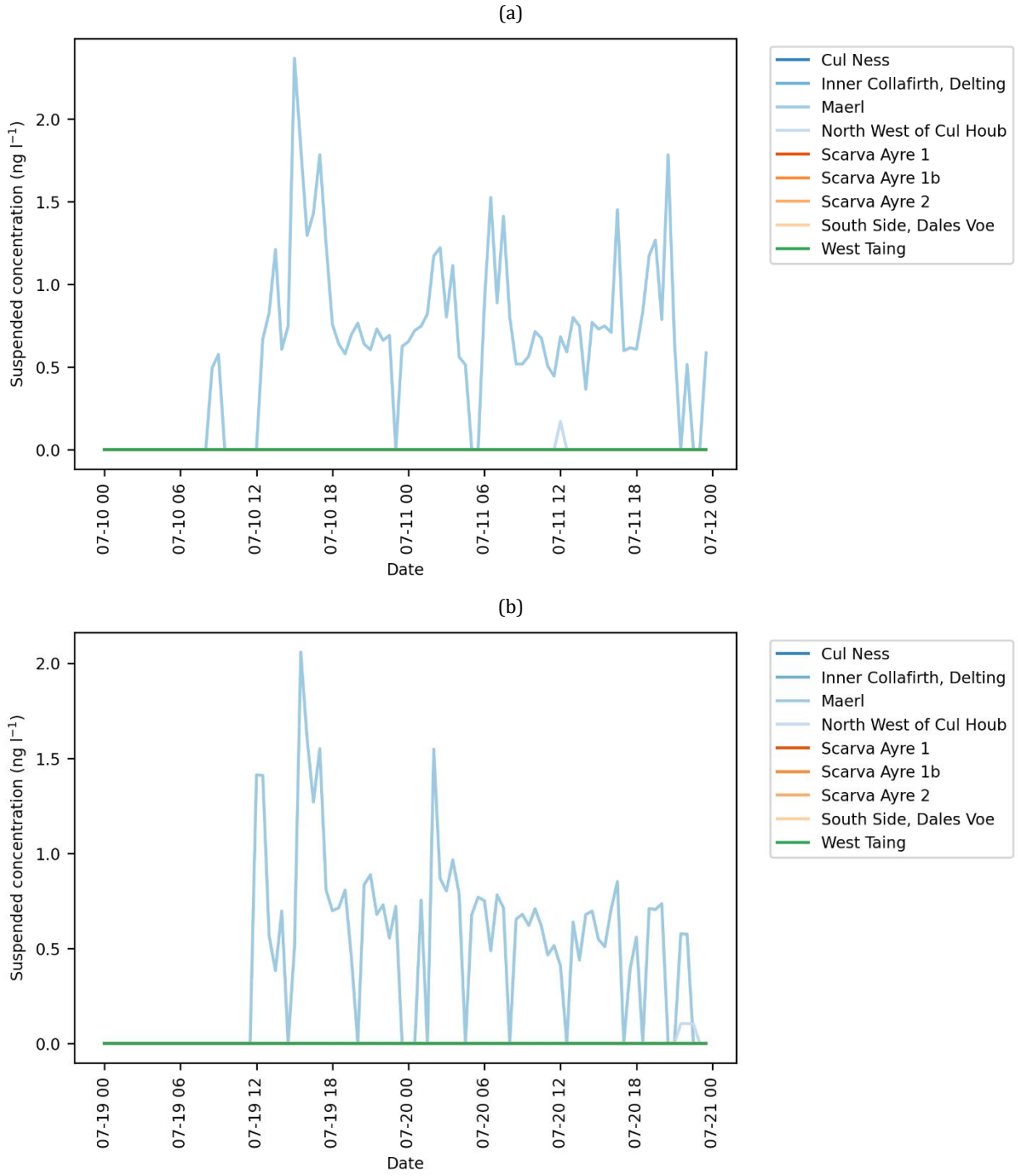

Figure 4.20: Maximum near-surface (top 5 m) concentration of Deltamethrin across each sensitive feature polygon (shellfish farms and a maerl bed) during the (a) neap and (b) spring baseline simulations of releases from cage 1.

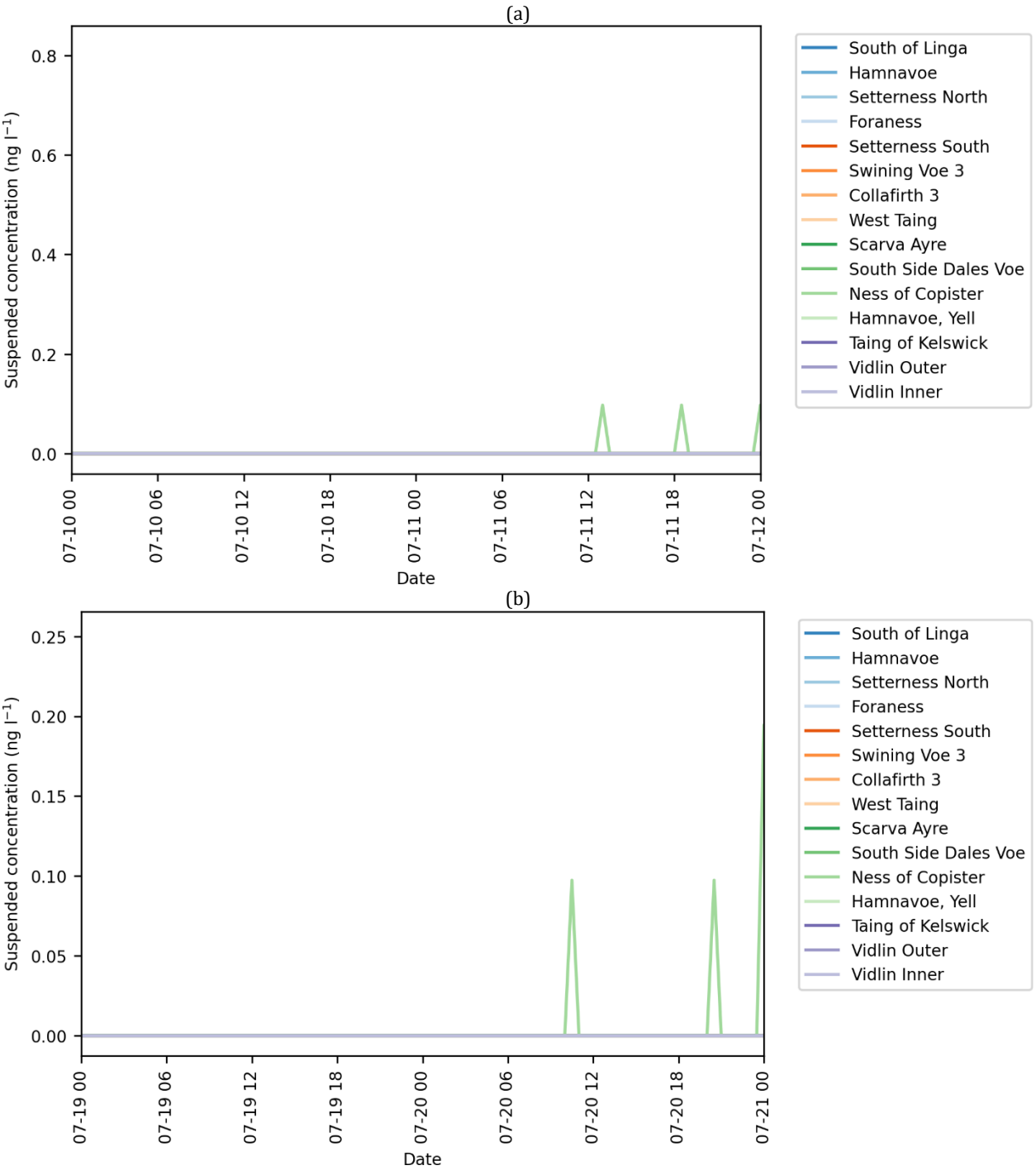

Figure 4.21: Maximum near-surface (top 5 m) concentration of Deltamethrin at each fish farm location during the (a) neap and (b) spring baseline simulations of releases from cage 1.

4.3.3 Summary statistics at EQS times

Table 4.1 details the mean concentration of both Azamethiphos and Deltamethrin at each sensitive feature at the relevant EQS times for the baseline runs. Concentrations arising from the farm bath treatment are far below the EQS levels in all cases, and the majority of values observed were zero values.

Due to the negligible/zero concentrations demonstrated in Table 4.1, vertical transects are not presented.

Table 4.1: Near-surface (top 5 m) concentrations of bath treatment medicines at EQS times, for all sensitive feature types. Concentrations are given in ng l^{-1}.

		Azamethiphos				Deltamethrin	
		Neap		Spring		Neap	Spring
ID	Type/Name	EQS 3hr	EQS 72hr	EQS 3hr	EQS 72hr	EQS 6 hr	EQS 6 hr
PMF (SEPA)							
1	Horse Mussel	0	0.51	0	0	0	0
2	Kelp and seaweed communities	0	1.09	0	0	0	0
3	Kelp and seaweed communities	0	0	0	0	0	0
4	Kelp and seaweed communities	0	1.22	0	0	0	0
5	Kelp and seaweed communities	0	0	0	0	0	0
6	Kelp beds	0	0	0	0	0	0
7	Kelp beds	0	0	0	0	0	0
8	Kelp beds	0	0	0	0	0	0
9	Kelp beds	0	0	0	0	0	0
10	Kelp beds	0	0	0	0	0	0
11	Kelp beds	0	0	0	0	0	0
12	Kelp beds	0	0	0	0	0	0
13	Tide swept algal communities	0	1.22	0	0	0	0
14	Tide swept algal communities	0	1.89	0	0	0	0
15	Tide swept algal communities	0	0	0	0	0	0
16	Maerl/burrowing sea cucumbers	0	0	0	0	0	0
17	Maerl/burrowing sea cucumbers	0	0	0	0	0	0
18	Maerl/burrowing sea cucumbers	0	0	0	0	0	0
PMF (visual survey)							
1	Brittle star	0	0	0	0	0	0
2	Brittle star	0	0	0	0	0	0
3	Brittle star	0	0	0	0	0	0
4	Brittle star	0	0	0	0	0	0
5	Brittle star	0	0	0	0	0	0
6	Brittle star (possible horse mussels)	3.58	0	0	0	0	0
7	Brittle star (possible horse mussels)	0	0	0	0	0	0
8	Brittle star (possible horse mussels)	0	0	0	0	0	0
9	Brittle star (possible horse mussels)	0	0	0	0	0	0
10	Brittle star (possible horse mussels)	0	0	0	0	0	0
11	Brittle star (possible horse mussels)	0	0	0	0	0	0
12	Brittle star	0	0	0	0	0	0
13	Brittle star	1.60	0	0	0	0	0
Shellfish/polygon							
1	Cul Ness	0	1.43	0	1.66	0	0
2	North West of Cul Houb	0	0	0	0	0	0
3	Inner Collafirth, Delting	0	7.94	0	0	0	0
4	West Taing	0	1.32	0	1.97	0	0
5	South Side, Dales Voe	0	1.72	0	2.95	0	0
6	Scarva Ayre 1	0	0	0	2.07	0	0
7	Scarva Ayre 1b	0	2.56	0	2.69	0	0
8	Scarva Ayre 2	0	1.56	0	2.10	0	0
9	Maerl	0	2.04	0	1.75	0	0
Fish farms							
1	FISH1	0	0	0	0	0	0
2	LING1	0	0	0	0	0	0
3	HAML1	0	0	0	0	0	0
4	SETN1	0	1.47	0	0	0	0
5	SWI2	0	0	0	0	0	0
6	SETW1	0	0	0	1.21	0	0
7	COL3	0	0	0	0	0	0
8	COLL3	0	0	0	0	0	0
9	WATI1	0	1.12	0	0	0	0
10	NWSCA1	0	2.78	0	0	0	0
11	DAL1	0	0	0	0	0	0
12	NCH1	0	0.37	0	0	0	0
13	HMNV1	0	0.42	0	0	0	0
14	VIDJ3	0	0	0	0	0	0
15	VIDM2	0	0	0	0	0	0
16	VIDM1	0	0	0	0	0	0

5 Discussion and Conclusions

The location of the proposed Fish Holm site is near to the opening of a system of voes into Yell Sound. The area is characterised by tidally dominated water movements and relatively fast current speeds. Residual flow from the site is to the north, into Yell Sound, and as such it is anticipated to be well suited to dispersal of bath medicine residues. The spread of released materials is expected to occur at a rate which will allow their areal extent to be quickly reduced and any environmental impact limited.

Sensitivity testing of bath medicine releases included several different release times as well as adjustments to the horizontal dispersion parameters after slight variation was found in an empirical study in the neighbourhood of the site [6]. Simulations carried out during sensitivity testing indicated that the SEPA area extent EQS thresholds for both azamethiphos and deltamethrin could be met comfortably at the applied treatment levels. The 72 hr areal extent EQS was met very comfortably by all Azamethiphos scenarios, suggesting rapid dispersal of particles after initial release to levels below and concern. Simulations also indicated that, once a small number of coastal model artefacts were removed, the SEPA MAC threshold was also achieved, with the maximum concentration being found to be an order of magnitude below the MAC.

The results presented in this document support the hypothesis that the Fish Holm proposed site is expected to be able to support the use of a 3 hr limit of 500 g Azamethiphos bath medicine for a single treatment (3 hr EQS), and a 24 limit of 2000 g for a full site treatment (72 hr MAC and EQS).

For Deltamethrin medicine releases, the results of these show that the 6 hr EQS for Deltamethrin was comfortably met with a release mass of 90 g. A single cage release of this mass was concluded to be supportable by the site over the 6 hr period.

The impact on sensitive features as a result of release of Azamethiphos and Deltamethrin at the Fish Holm site is not expected to be significant. Predicted concentration of chemicals at the sensitive features closest to the site only briefly exceeded EQS values in a small number of cases, and in general concentrations were zero or near-zero.

The SEPA risk identification report for the site indicated that results from bath medicine modelling may be used to support determination of risks relating to nutrient enhancement in the water body to the SW of the FISH1 site. The peak concentration area of the bath medicine plume is transported out of the enclosed water body and to the N into Yell Sound, in all individual pen releases for both chemicals and under both neap and spring tidal conditions. This provides a degree of confidence that dissolved nutrients released from the site would be subject to a similar fate, and not present a concern for enrichment.

6 References

[1] DHI. “Particle Tracking Module Scientific Documentation” (2015).

[2] Veterinary Medicines Directorate. “Summary of Product Characteristics: Salmosan Vet” (2022).

[3] DHI. “East of Shetland Aquaculture Modelling Hydrodynamic Climatology and Hindcast Models Model Setup Report” (2023).

[4] DHI. “MIKE 21 & 3 Flow Model FM Hydrodynamic and Transport Module Scientific Documentation” (2023).

[5] SEPA. “Interim Marine Modelling Guidance for Aquaculture Applications (published 14 April 2023)” (2023).

[6] Anderson Marine Surveys. *Fish Holm Dye and Drogue Dispersion Study*. Tech. rep. 2024.

[7] SEPA. “Interim Marine Modelling Guidance for Aquaculture Applications”. *(published January 2024)* (2024).

[8] SSF. *Fish Holm Hydrodynamic Model Validation Report*. Tech. rep. 2024.

[9] Tritonia Scientific. “Fish Holm, Shetland Isles: baseline seabed survey using multibeam echosounder and georeferenced 3D photogrammetry”. Report No: SSF-077075.

7 Appendix

7.1 BathAuto calculations

To determine the 3 hr and 6 hr EQS standards for Azamethiphos and Deltamethrin, a MATLAB script provided by SEPA was used.

% Azamethiphos 3h
% calculate by hand:
% calculate L and w:

% L [m]= half-length of the mixing zone L = 0.5*u*t % w [m] =
half-width of the mixing zone w = 0.5*4*sqrt(2*D*t) u
mean=0.162 % surface bin mean speed
% u mean=profile.Bins3.MeanSpeed
L = 0.5*u mean*10800 % for Cyp and Delt use 21600 s (3 h), for AZA use 10800 s (6 h) w =
0.5*4*sqrt(2*0.1*10800)
% area: A [m^2] area of mixing zone ellipse,
Area= pi*L*w

7.2 Seabed concentrations at sensitive features

7.2.1 Azamethiphos

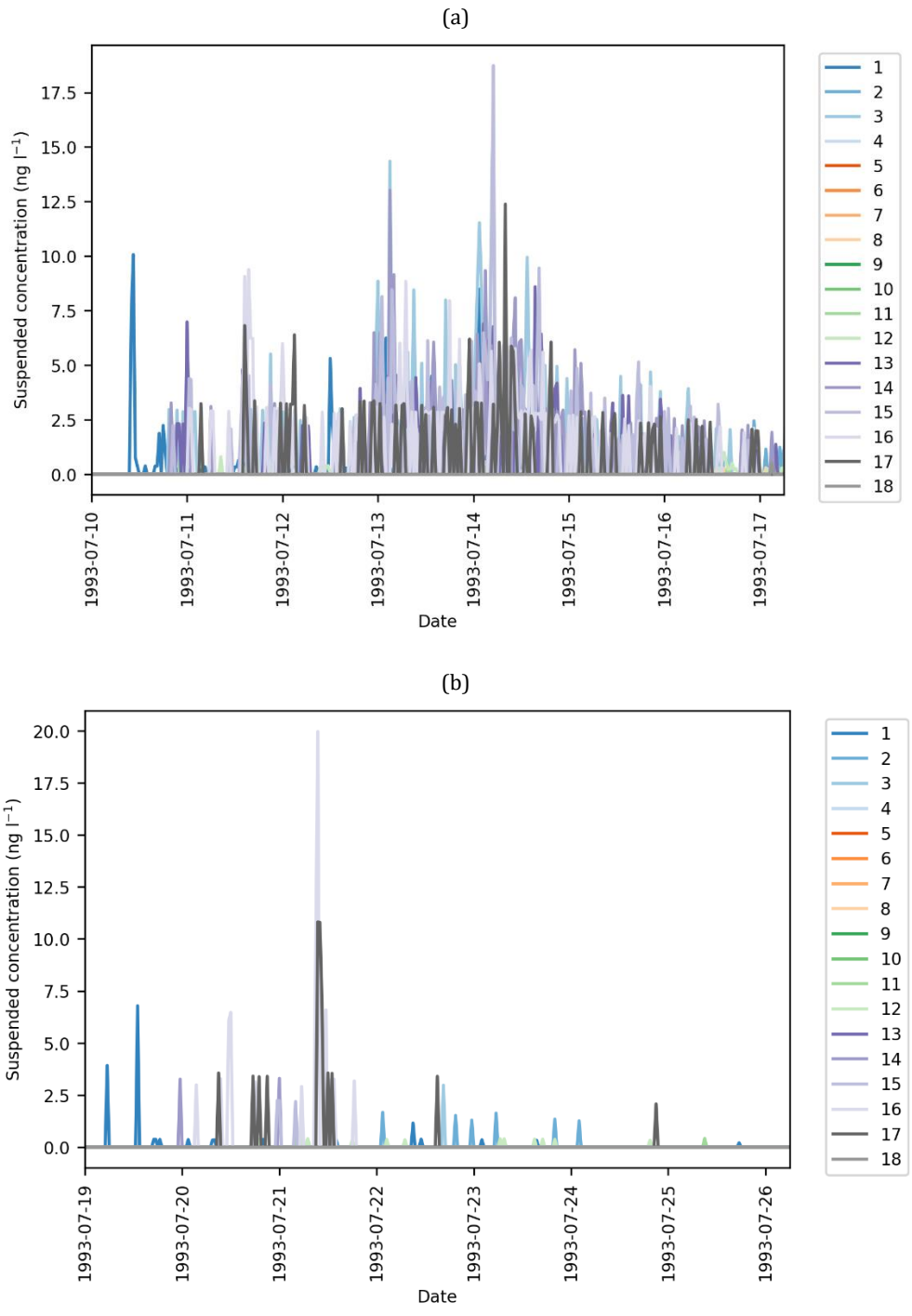

Figure 7.1: Near-bed (bottom 5 m) concentration of Azamethiphos at each sensitive feature (PMF) point identified by SEPA, through time series of the (a) neap and (b) spring baseline simulations. Legend numbers correspond to sensitive feature numbers in Table 3.4.

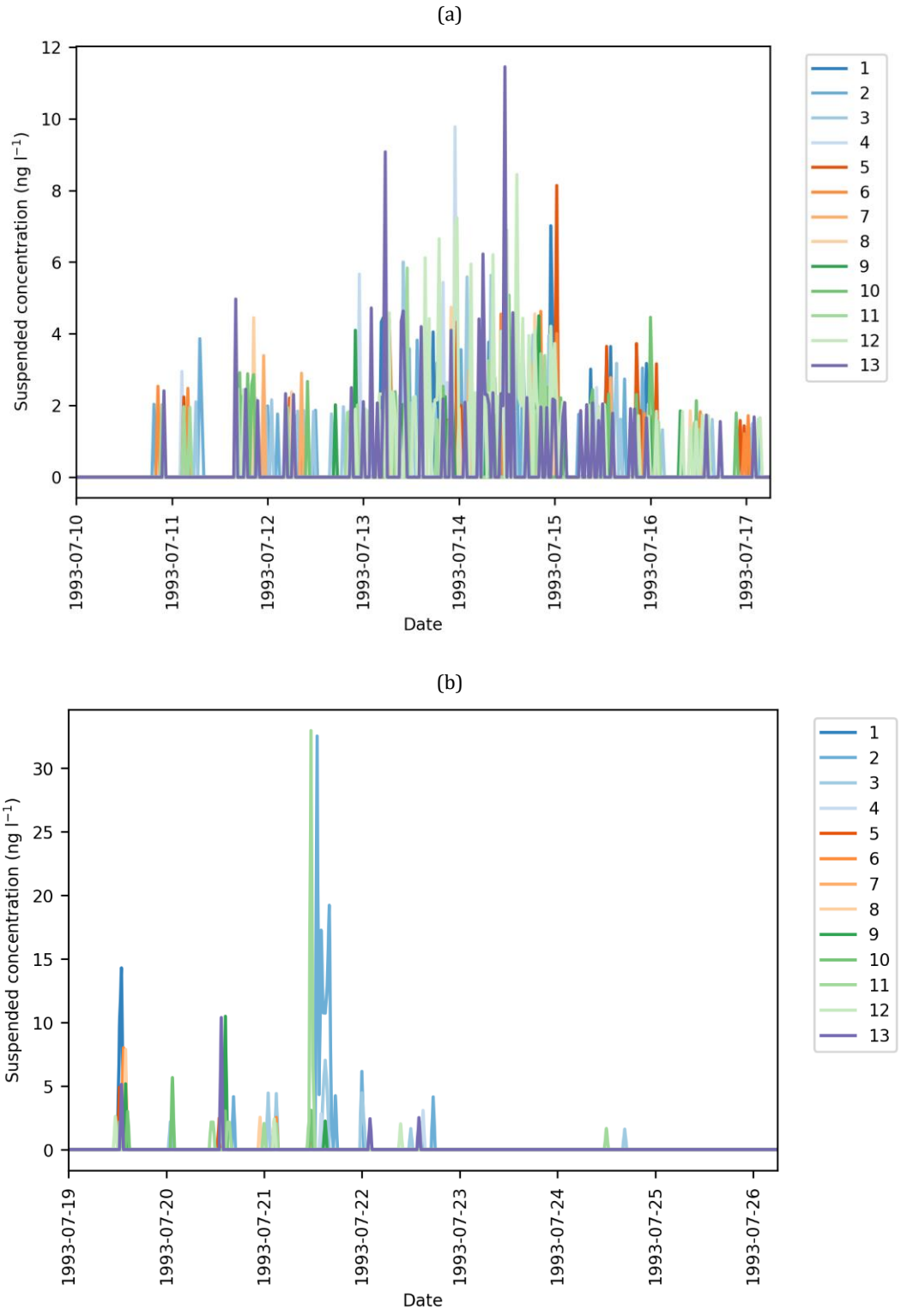

Figure 7.2: Near-bed (top 5 m) concentration of Azamethiphos at each sensitive feature (PMF) location identified during the visual survey, through time series of the (a) neap and (b) spring baseline simulations. Legend numbers correspond to sensitive feature numbers in Table 3.5.

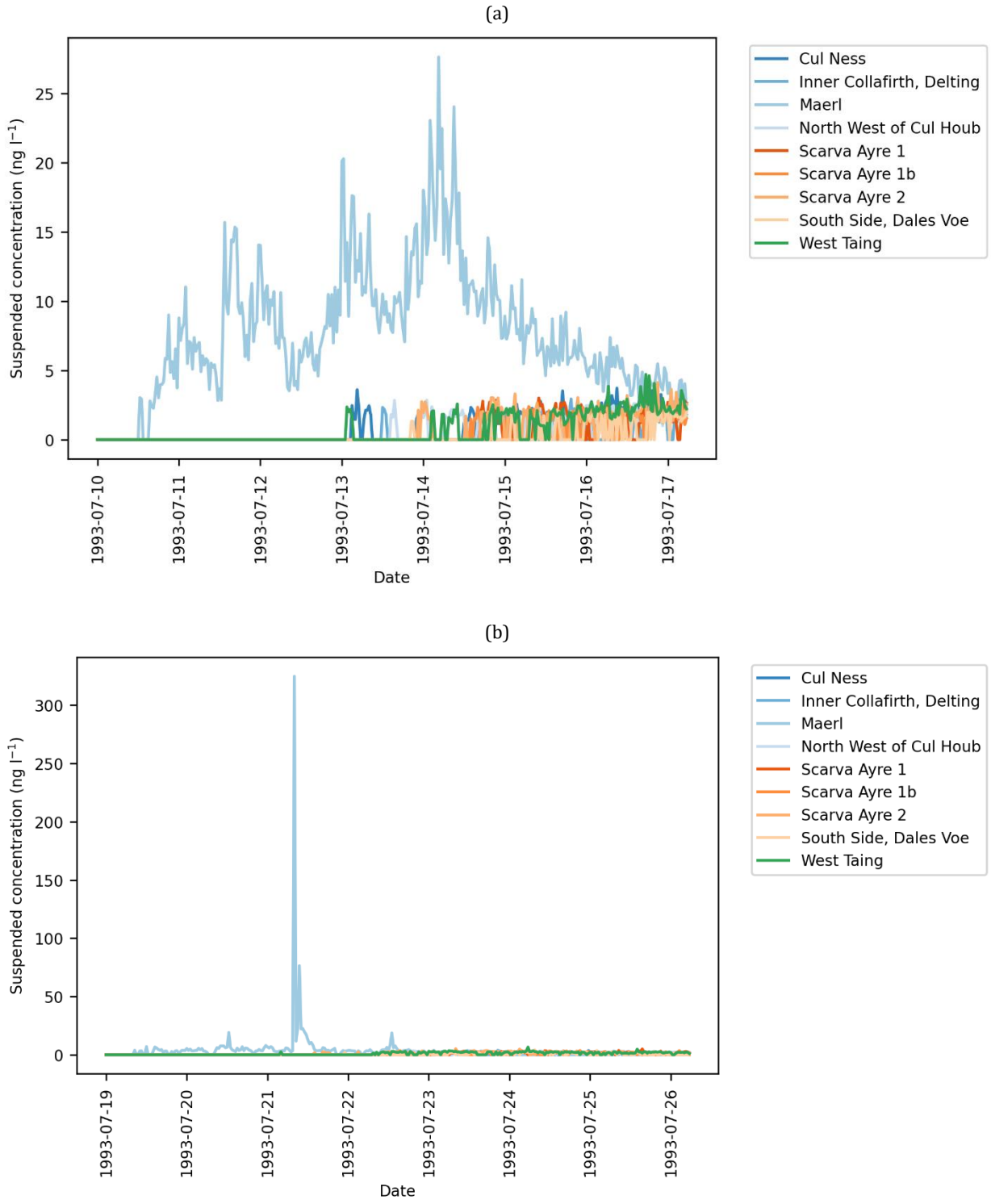

Figure 7.3: Maximum near-bed (top 5 m) concentration of Azamethiphos across all elements encompassing each sensitive feature polygon (maerl beds and shellfish farms) through time series of the (a) neap and (b) spring baseline simulations.

7.2.2 Deltamethrin

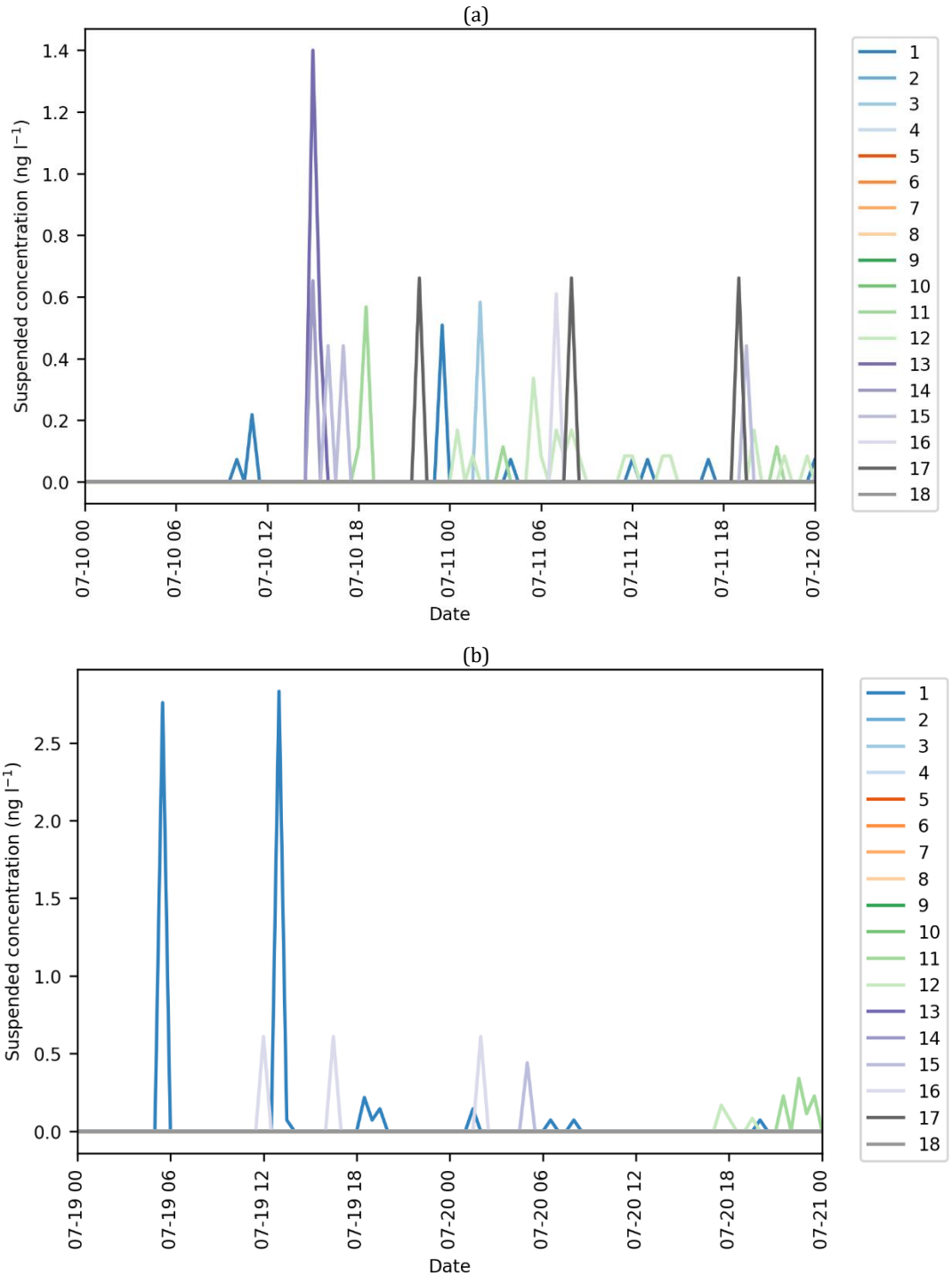

Figure 7.4: Near-bed (bottom 5 m) concentration of Deltamethrin at each sensitive feature (PMF) point identified by SEPA, through time series of the (a) neap and (b) spring baseline simulations. Legend numbers correspond to sensitive feature numbers in Table 3.4.

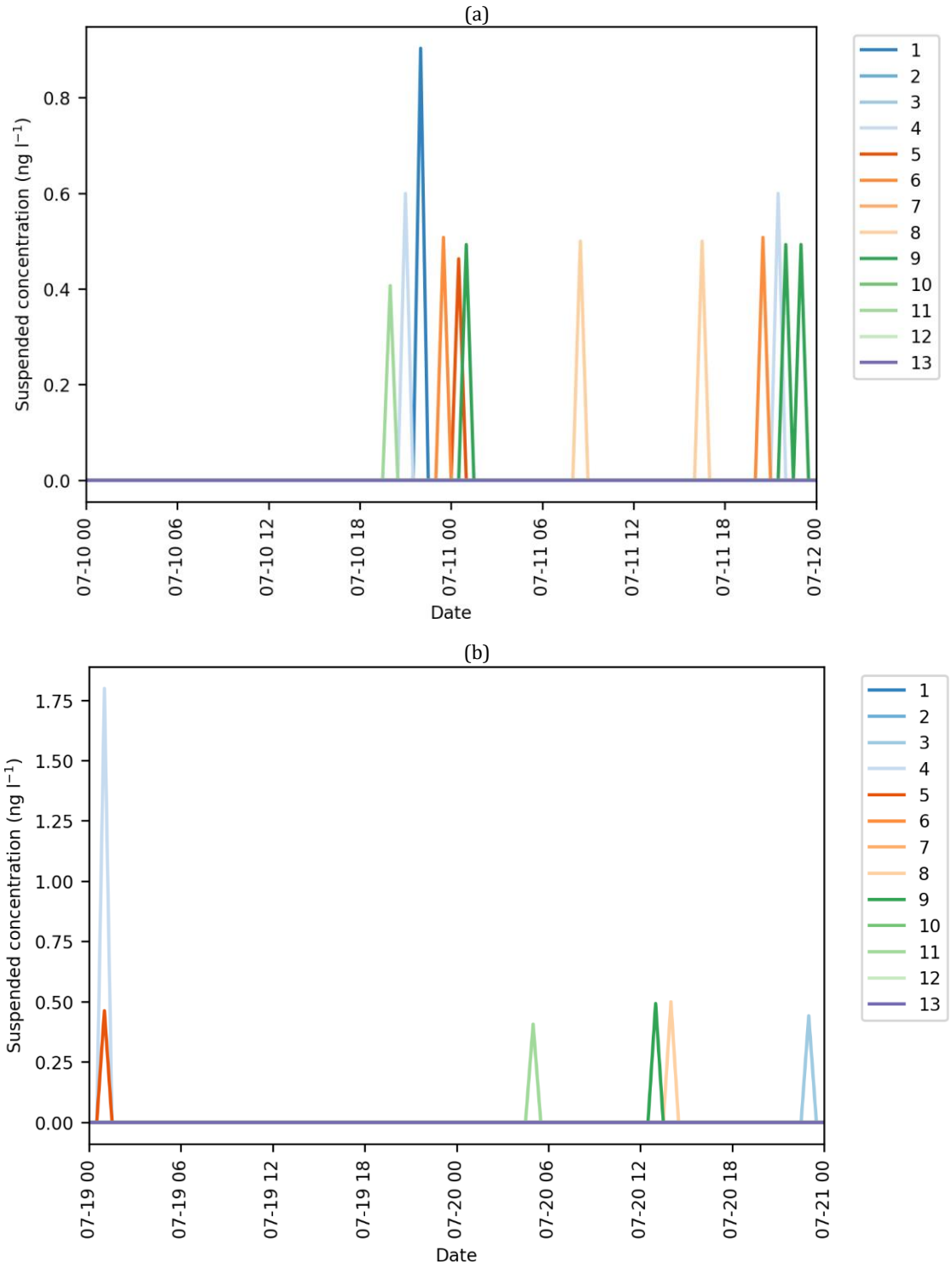

Figure 7.5: Near-bed (bottom 5 m) concentration of Deltamethrin at each sensitive feature (PMF) location identified during the visual survey, through time series of the (a) neap and (b) spring baseline simulations. Legend numbers correspond to sensitive feature numbers in Table 3.5.

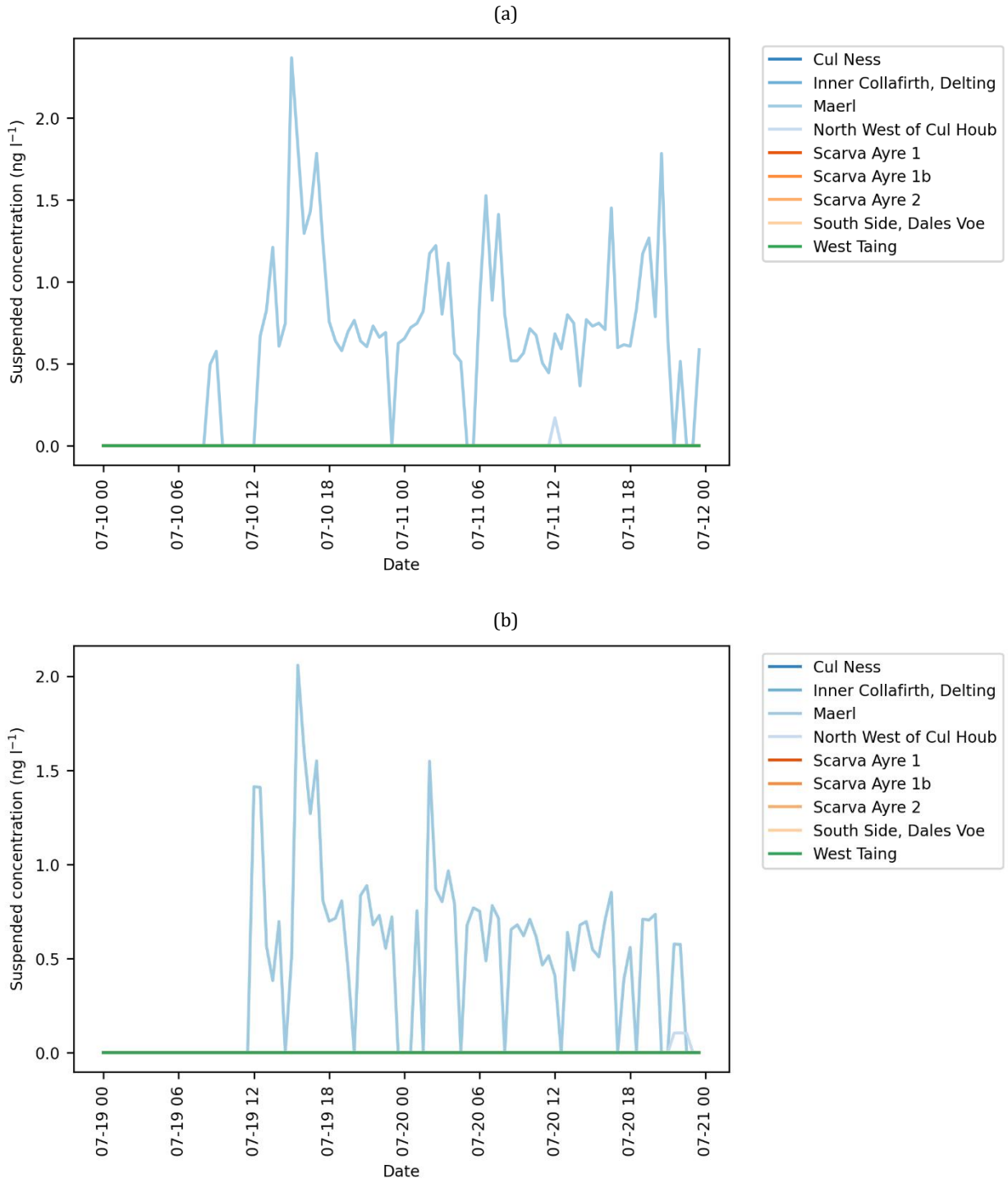

Figure 7.6: Maximum near-bed (bottom 5 m) concentration of Deltamethrin across all elements encompassing each sensitive feature polygon (maerl beds and shellfish farms) through time series of the (a) neap and (b) spring baseline simulations.