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ADS Environmental Services Sdn. Bhd.

Project South Stewart Island New Zealand

Volume IV Nutrient Modelling Report

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1 INTRODUCTION

The hydrodynamic model is arguably the core of the numerical modelling and is used to simulate water movement across the proposed farming area and across the entire model domain.

Once a calibrated/validated hydrodynamic model has been finalised, extra modules can be added (*i.e.* to combine the flow field with nutrient release) in order to define the concentrations of the effluent released from the farms.

The hydrodynamic model was run for a period of one year (2017) to allow for full seasonal effects. Results of these simulations were also used to drive water movement within the water quality module.

For a description of the hydrodynamic modelling process, cf. Volume II – Hydrodynamic Modelling.

1.1 CHOICE OF NUTRIENT MODELLING PARAMETERS

The capacity of marine systems for fish farming (from a water quality perspective) is generally limited by 2 main parameters: nutrients and oxygen. Early modelling results indicated that the maximum draw down is approximately 0.1mg/l. This is not surprising Given the location of the site and the moderate to strong currents.

Feed composition is complex; however, the waste substances can be broken down into 3 main elements, Carbon (C), Nitrogen (N) and Phosphorus (P). In marine systems, the main limiting nutrient is Nitrogen (**Boynton *et al*. 1982**) and is the focus of this modelling study.

Solute N is released by the fish in the form of Total Ammonia Nitrogen (TAN), a term that corresponds to both the innocuous ionized version of Ammonia (NH_4^+) and the toxic variety (NH_3^-). Both coexist in the water column in quantities defined by an equilibrium equation.

Upon being released into the water column, TAN is subjected to a few potential environmental pathways. One of them is uptake by algae, while the second major pathway involves nitrification, a process in which TAN is transformed into nitrates (NO_3^-).

For the purpose of this modelling exercise we have taken the most conservative approach and assumed that all TAN released by the proposed farms remains in the form of TAN (i.e. without any being converted to nitrates a form of inorganic nitrogen which is usually more difficult to be up taken by the phytoplankton community and is far less toxic). A further description on the conversion from TAN to phytoplankton biomass is provided in Section 2 below.

2 WATER QUALITY MODEL SET-UP

2.1 MODEL DOMAIN

The modelling extent remains the same as the local hydrodynamic model (cf. Volume II – Hydrodynamic Modelling).

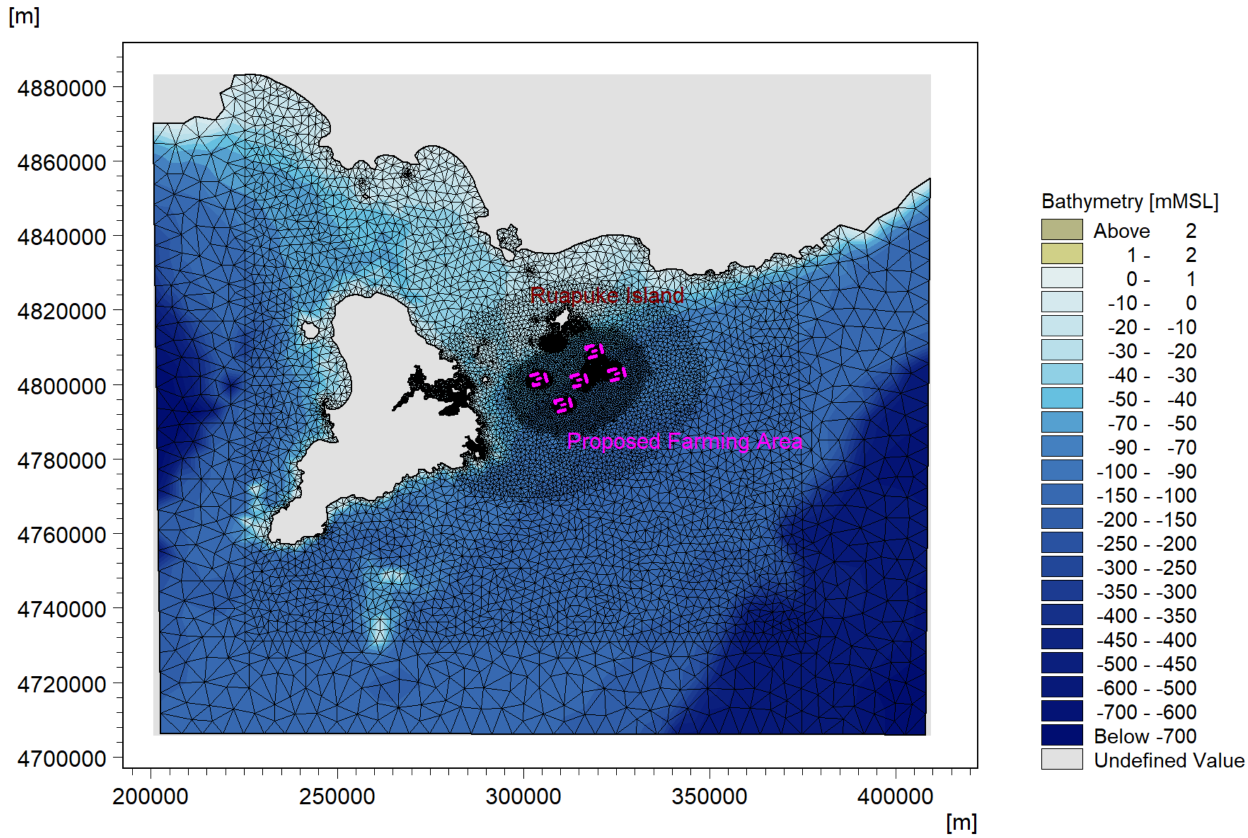

Figure 1 : Extent of regional model flexible mesh.

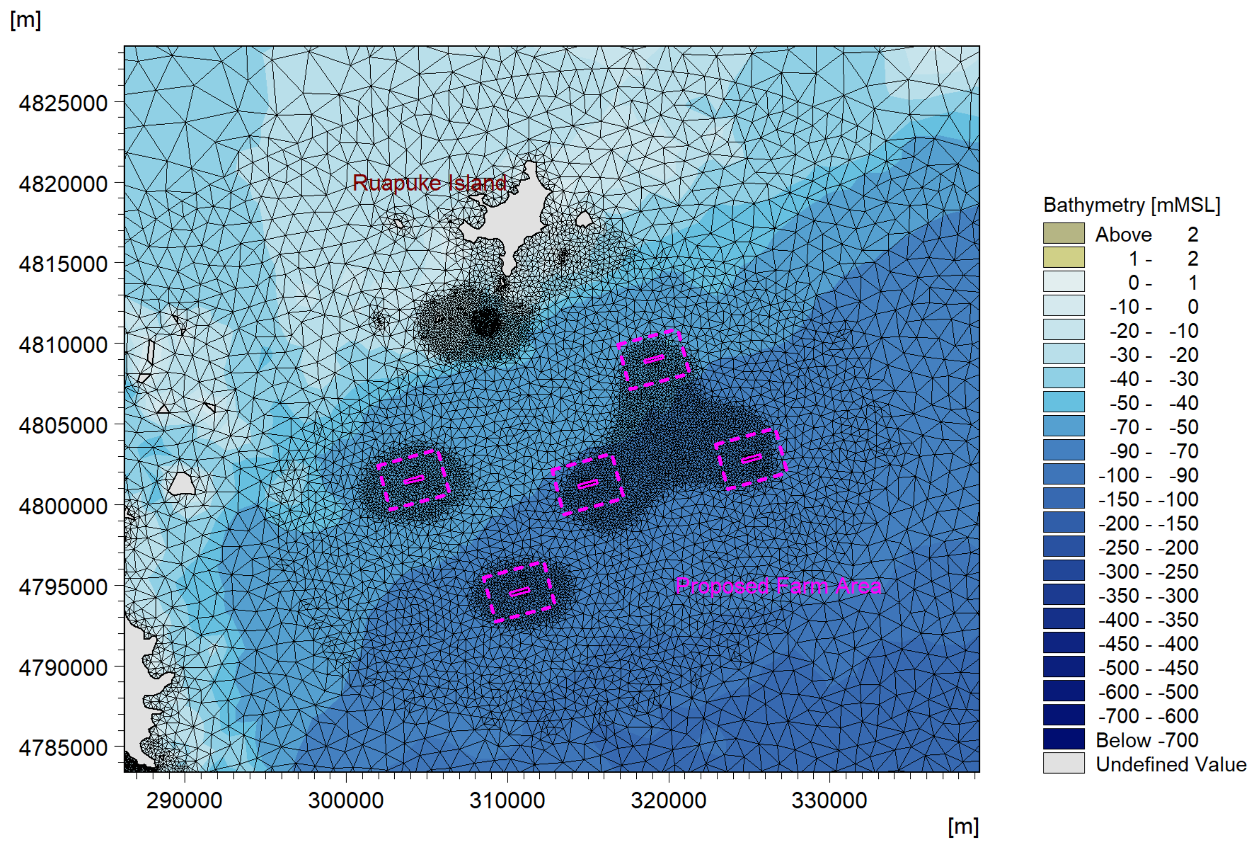

Figure 2: Extent of local flexible mesh for the proposed Farming Area locations.

2.2 Modelling Period

The modelling period remains the same as that of the hydrodynamic model and runs for all of 2017.

2.3 Boundary Conditions

2.3.1 TAN

As the model is using a conservative tracer, boundary conditions have been set to zero as the only source of the nutrients inside the model domain are the proposed farms. Accordingly, the modelling focusses on the excess in nutrients generated by the farms themselves and not what is already existing in the system.

2.4 Initial Conditions (inside the model domain)

In a tracer model, the aim is to simulate the excess concentrations of a particular discharge. Initial conditions (values that the model starts with) are typically set to 0 throughout the domain. This leads to a so-called “warm-up period” during which the model will adjust the start conditions towards a point at which the model is in “equilibrium”.

In order to account for this, the water quality models were run once with initial conditions set to zero, and then a second time with starting conditions taken the final time step of the first run (*i.e*. final day of each season presented, see below).

2.5 WATER QUALITY SCENARIOS AND LOAD INPUTS

2.5.1 Water Column Nutrient Release (TAN)

Table 1below highlights the pen setup used in the model as well as the cage stocking density and farm nutrient release mass. The stocking density was set to 20.0 kg m^{-3} for all FarmingAreas in order to model the maximum intended biomass. Each farming area consists of 10 pens each 270,000 m^3. All pens assume a stock to feed ratio (average daily feed input divided by the annual stocking) of 0.479. Feed and stock to feed ratio data was supplied by Skretting (the feed supplier to Sanford) along with the nitrogen content in the feed (6.1%) and the mass (soluble release from the cages and the release of inorganic nitrogen from the faeces) that will be released into the environment. Soluble nutrients were released from a source point within each cage (10 per farm area). Nitrogen released from seabed faeces deposition was also released beneath each cage and it was assumed all nitrogen deposited in the faeces and feed waste was released back into the water column as soluble TAN.

Table 1 – Nutrient model loading input parameters for each of the proposed Farming Areas.
Stock to Feed Ratio is defined as the average daily feed rate (tons day^{-1}) divided by the annual production (tons yr^{-1}).

	Farm A	Farm B	Farm C	Farm D	Farm E
***Pen Stocking Density** (kg m^{-3})*	20	20	20	20	20
Stock: Feed	0.479	0.479	0.479	0.479	0.479
***Feed Mass** (tons day^{-1})*	25.8	25.8	25.8	25.8	25.8
% Feed Wastage	3	3	3	3	3
% Feed Digested	85	85	85	85	85
% Water Content	9	9	9	9	9
N in faeces	99	99	49	49	49
Soluble N release year (ton)	331.5	331.5	331.5	331.5	331.5
Total N release per year into the water column (ton)	430.5	430.5	430.5	430.5	430.5
***Final Biomass** (ton)*	5400	5400	5400	5400	5400

The nutrient model assumes that all feed inputs and subsequent release of inorganic nitrogen into the water column are distributed evenly across all pens for the duration of the model simulation; in this case the model simulated 1 year of farm soluble nitrogen release and the release of nitrogen from the faeces. The model assumed the maximum biomass of 5400 tons at each Farming Area per year.

In practice feeding schedules and individual pen stocking will vary, with pens unevenly stocked throughout the growing season and feeding schedules adjusted to growth phase and the surrounding environmental conditions present at the farm. As such, the modelled scenario represents a situation that is very unlikely to occur in practice, and thus is conservative.

3 WATER QUALITY MODEL RESULTS

3.1 WATER QUALITY MODEL OUTPUTS DESCRIPTION

The model provides three dimensional maps of the predicted TAN within the entire domain. Results were aggregated and presented as two-dimensional seasonal averages (Spring, Summer, Autumn and Winter).

TAN maps are presented for both the surface and bottom layers of the model which represent approximately the top 5-8 and bottom 5-8 meters of the water column (depending on the water depth).

In order to illustrate the potential implications of an increase in TAN on phytoplankton, maps of a corresponding increase in chlorophyll-*a* were also created using those TAN outputs.

3.2 DESCRIPTION OF CHLOROPHYLL-A ASSUMPTIONS

As a conservative worst case, all TAN has been assumed to be converted to phytoplankton biomass and represented by an increase in the chlorophyll-*a* concentration.

In reality, only some TAN (inorganic nitrogen) will be used for plankton growth.

Converting the TAN results from the model to chlorophyll-a was a 2 step process. First, the TAN (nitrogen) was converted to its C equivalent in plankton. This is done using the widely used Redfield ratio which corresponds to the statistical average composition of plankton in the sea, with a ratio of C to N of 106:16. The second step consists of calculating the amount of chlorophyll-a associated with algal C, using a C to Chlorophyll-*a* ratio for phytoplankton.

The C to Chlorophyll-*a* ratio is subject to significant variability. In the Marlborough Sounds, it was found to vary between 25 and 500 seasonally depending on the algal species composition (**Ren and Ross, 2005**). Data collected nearby in Big Glory Bay and to the west in Foveaux showed the ratio varied between 1 and almost 900. Given this large variability, a C:Chl-*a* ratio was applied that is representative of average conditions. In this regard, based on the work **Sathyendranath et al., 2005** and information granted limited at the site, a conservative ratio of 50 was chosen.

3.3 TAN AND CHLOROPHYLL RESULTS

3.3.1 Average TAN and Chlorophyll-*a*

Figure 3to **Figure 6**highlight the simulated seasonally averaged excess concentration of TAN at the surface and bottom across all 5 FarmingAreas. From these TAN results, seasonally averaged excess chlorophyll-*a* concentrations were estimated using the previously described assumptions (**Figure 7**to **Figure 10)**.

Modelled results show little difference between the surface and bottom layer TAN concentrations. Average TAN concentrations are in the 2-3 µg L^{-1} range, and chlorophyll-*a* concentrations are in the range of 0.2 to 0.6 µg L^{-1} in the vacinity of the farms. The greatest spread of TAN occurrs during Autumn where values of 1-2 µg L^{-1} are predicted well west of Ruapuke Island, though such concentrations are close to lab detection levels (i.e. 1 microgram per litre).

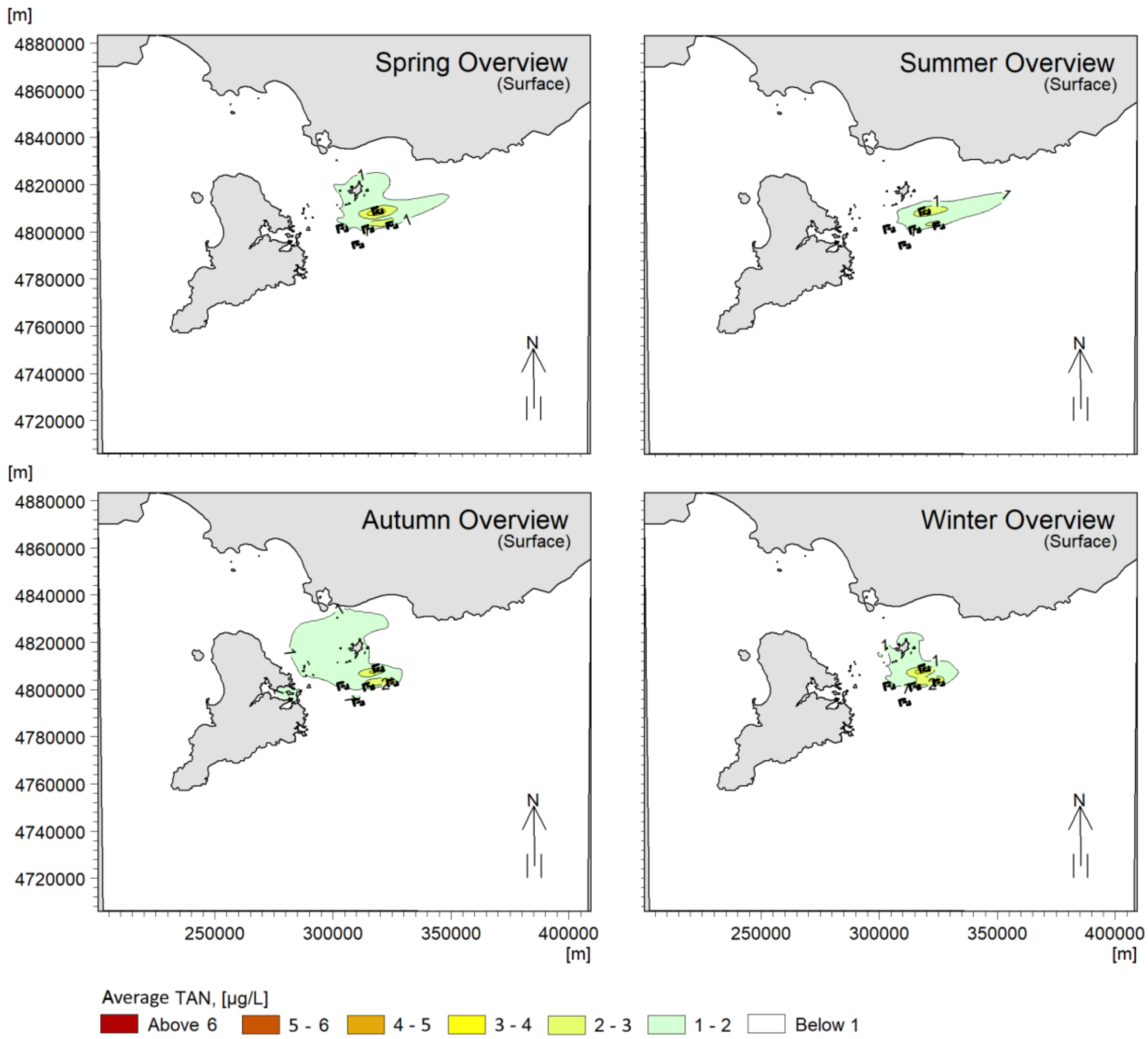

Figure 3: Seasonal average excess concentrations of total ammonia nitrogen (TAN) at the surface.

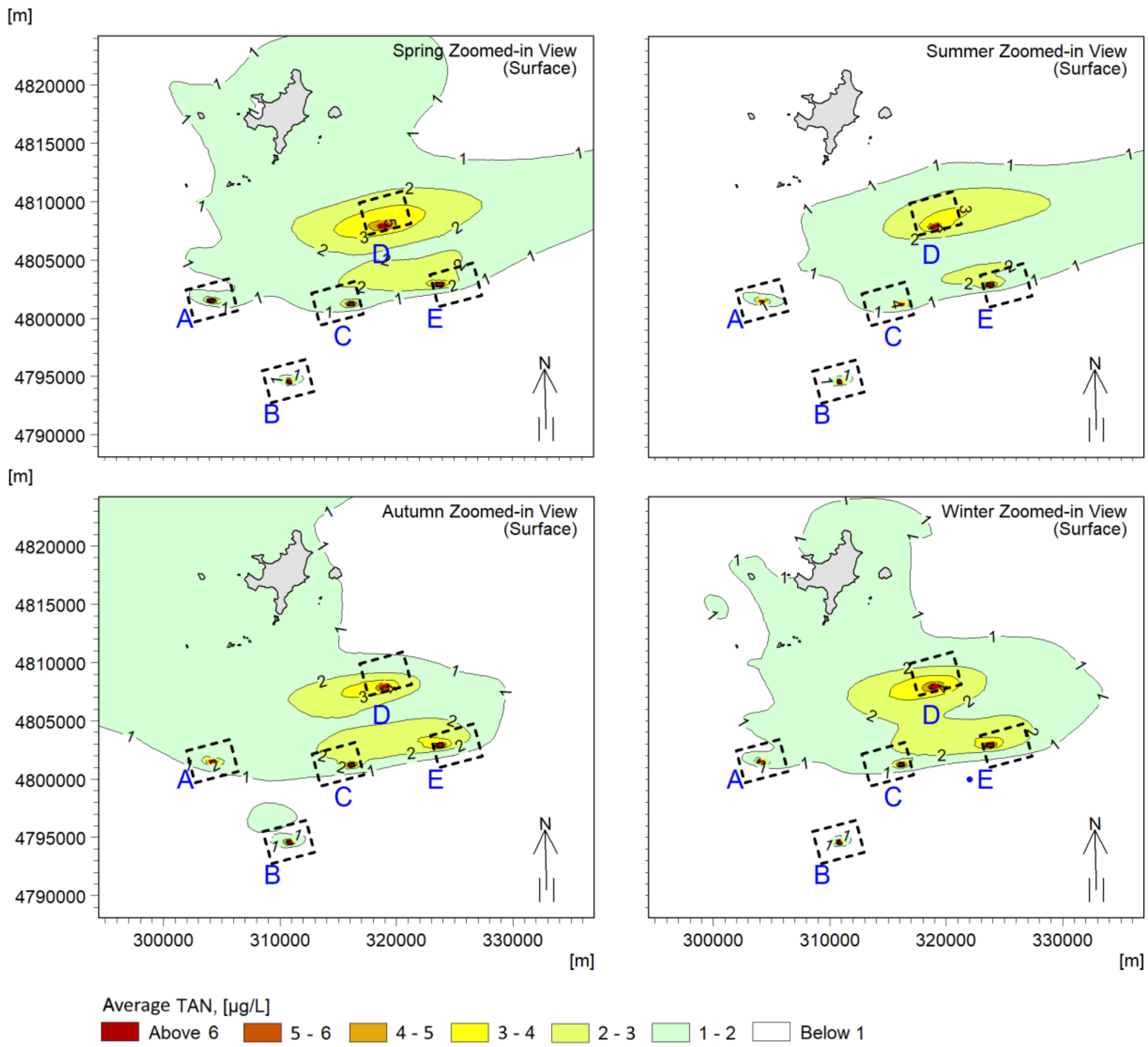

Figure 4: Seasonal average excess concentrations of total ammonia nitrogen (TAN) at the surface (Zoomed in).

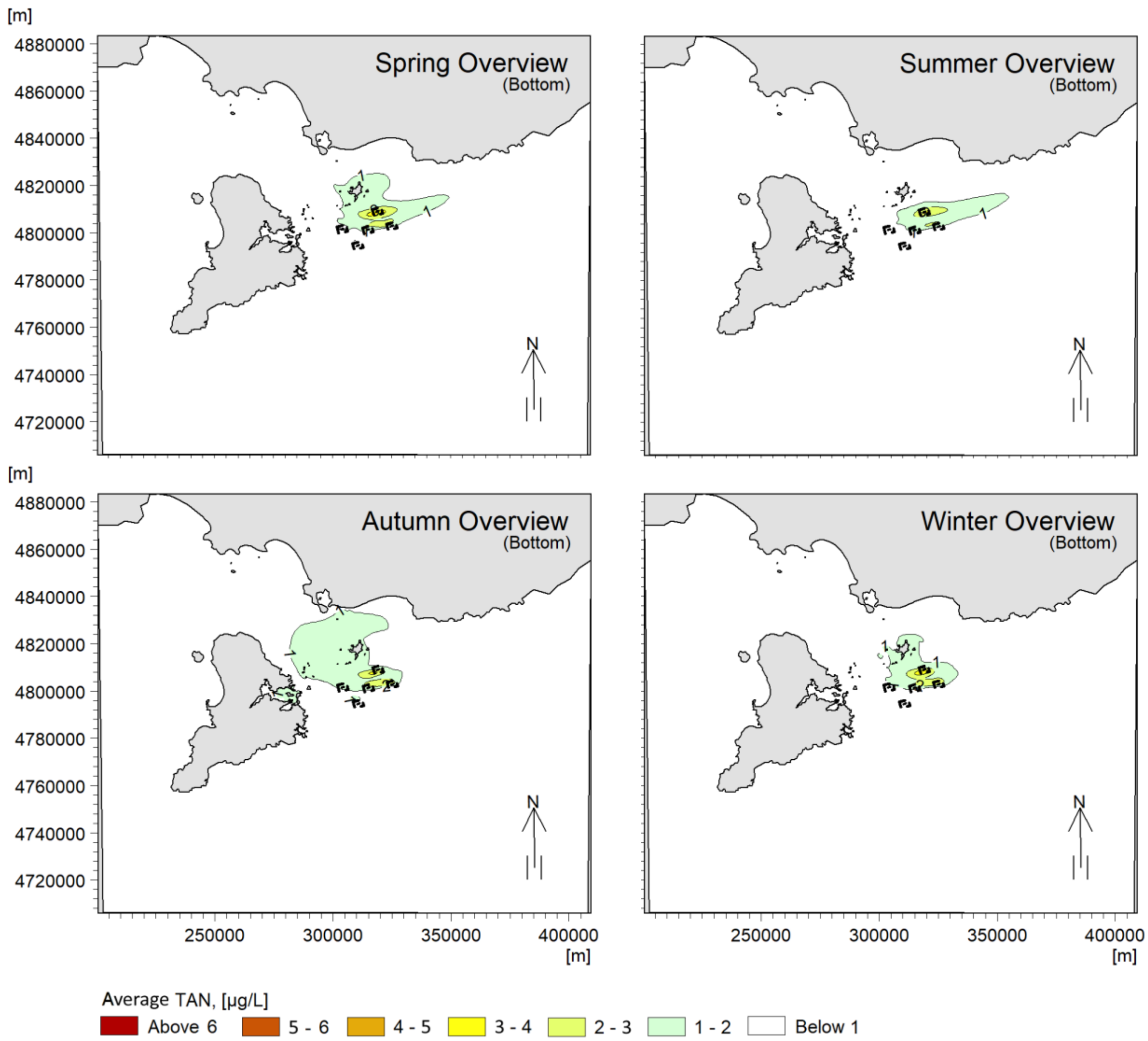

Figure 5: Seasonal average excess concentrations of total ammonia nitrogen (TAN) at the bottom.

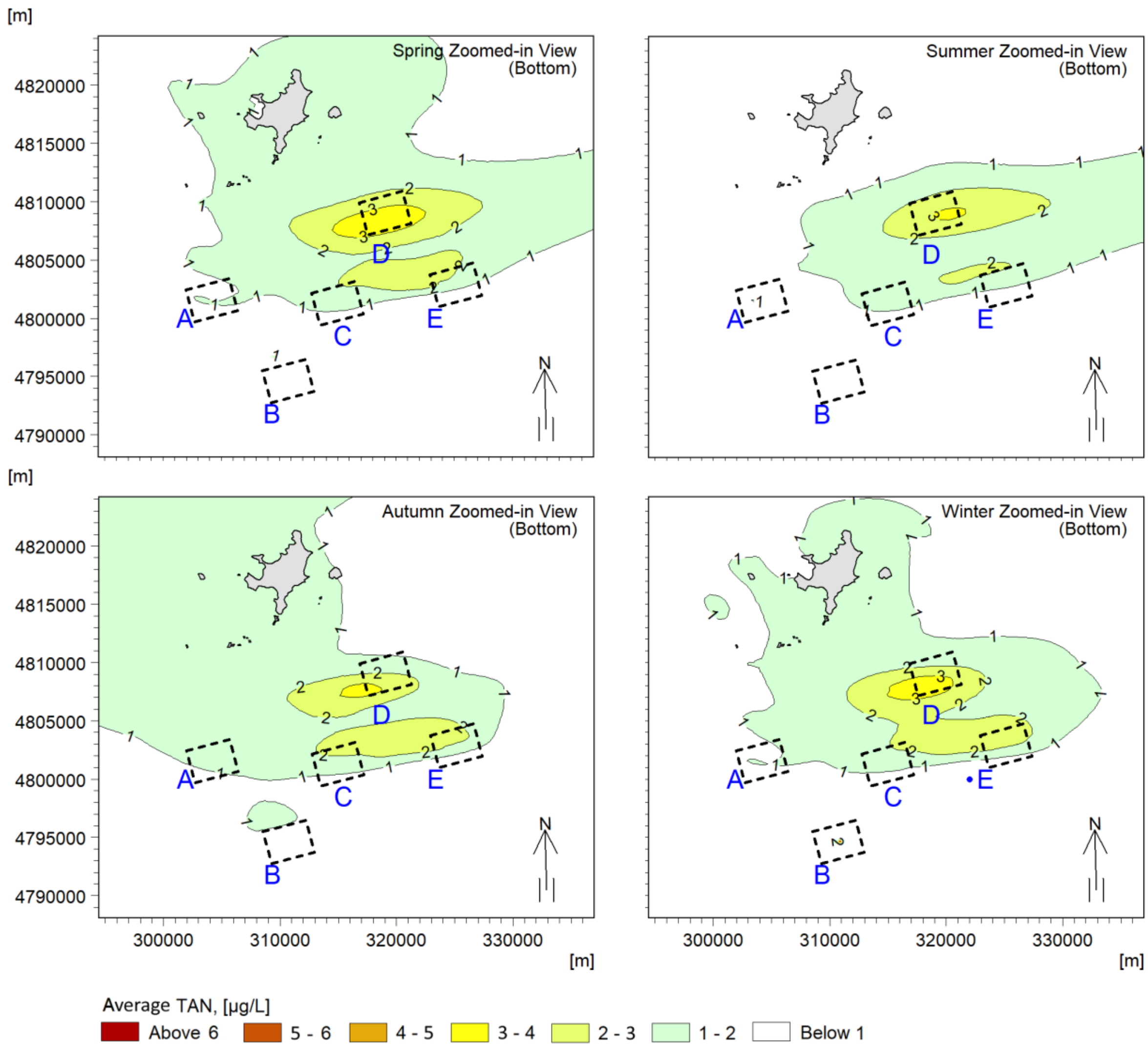

Figure 6: Seasonal average excess concentrations of total ammonia nitrogen (TAN) at the bottom (Zoomed in).

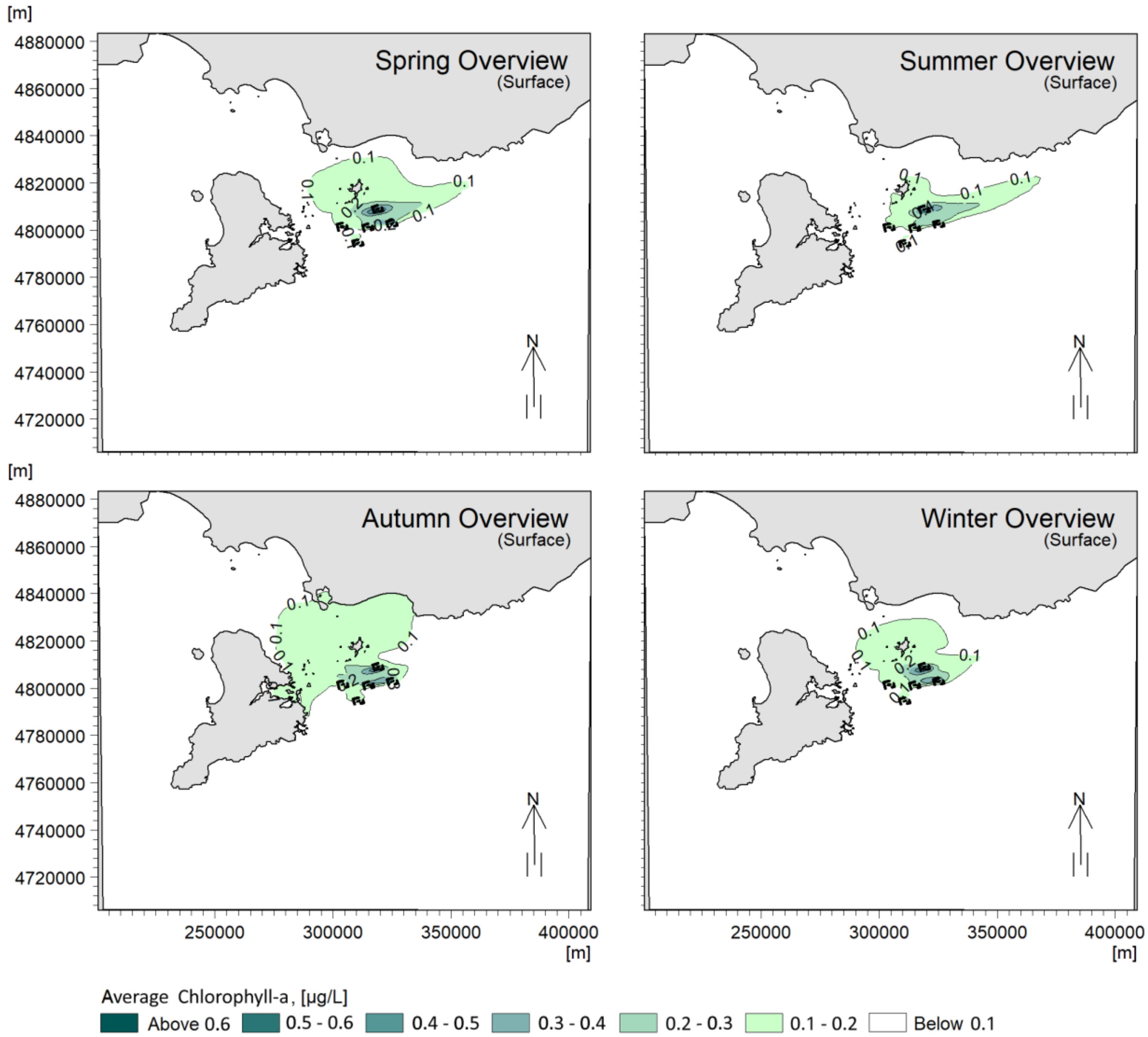

Figure 7: Seasonal average excess concentrations of chlorophyll-a at the surface.

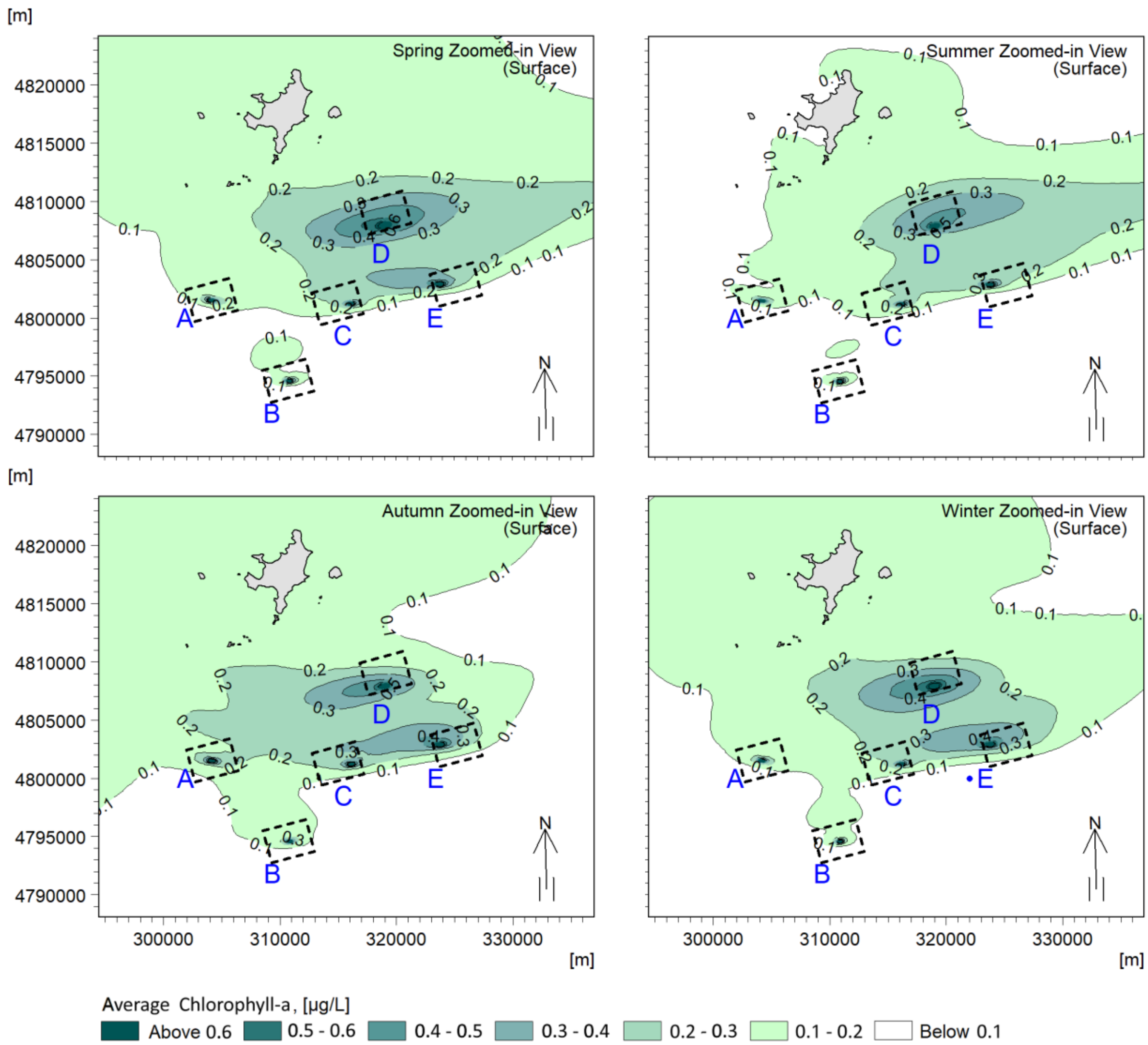

Figure 8: Seasonal average excess concentrations of chlorophyll-a at the surface (Zoomed in).

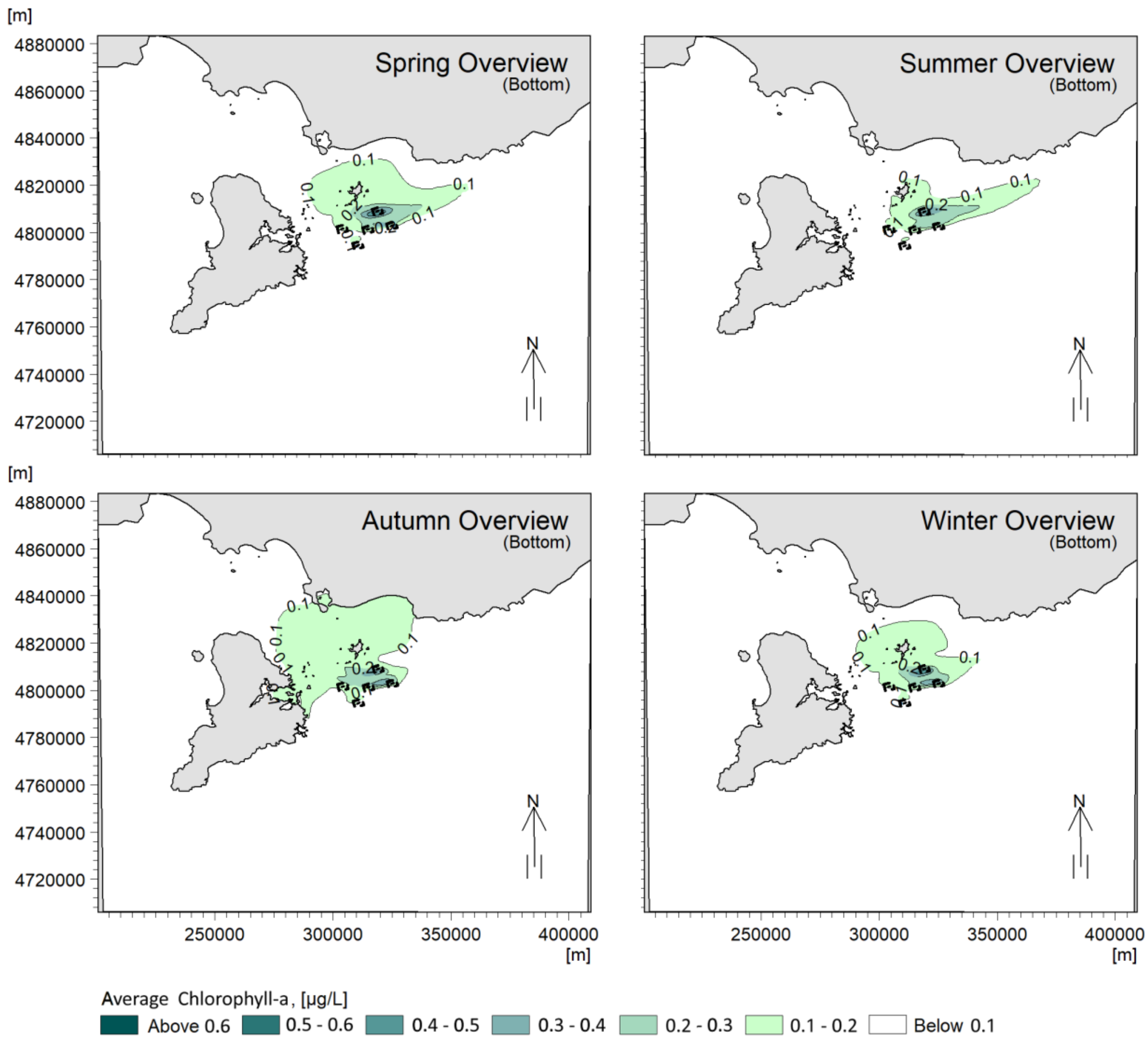

Figure 9: Seasonal average excess concentrations of chlorophyll-a at the bottom.

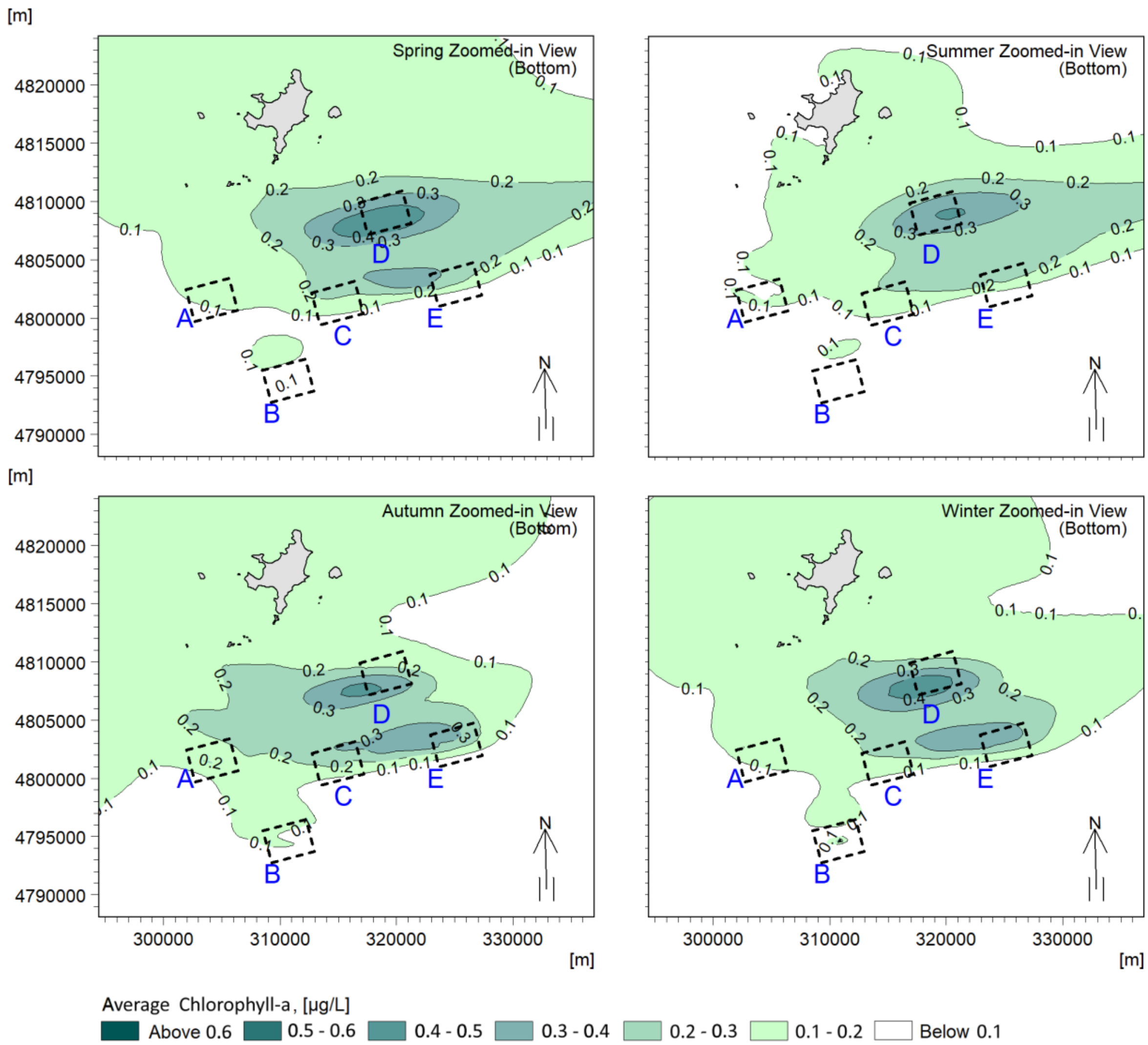

Figure 10: Seasonal average excess concentrations of chlorophyll-a at the bottom (Zoomed in).

3.3.2 Maximum TAN and Chlorophyll-*a*

Figure 11to **Figure 14**highlight the simulated maximum seasonal excess concentration of TAN at the surface and bottom across all 5 FarmingAreas. The maximum is defined as the highest value calculated during the simulation period (per season), for a single time step (10 minutes). From these TAN results, seasonally averaged excess chlorophyll-*a* concentrations were estimated using the previously described assumptions (**Figure 15**to**Figure 18)**.

Modelled results again showed little difference between the surface and bottom layer maximum TAN concentrations. Maximum TAN concentrations are in the order of 10-12 µg L^{-1} range within the proposed farming area, while maximum chlorophyll-*a* concentrations are in the range of 1.2 to 1.4 µg L^{-1} in the vicinity of the farms.

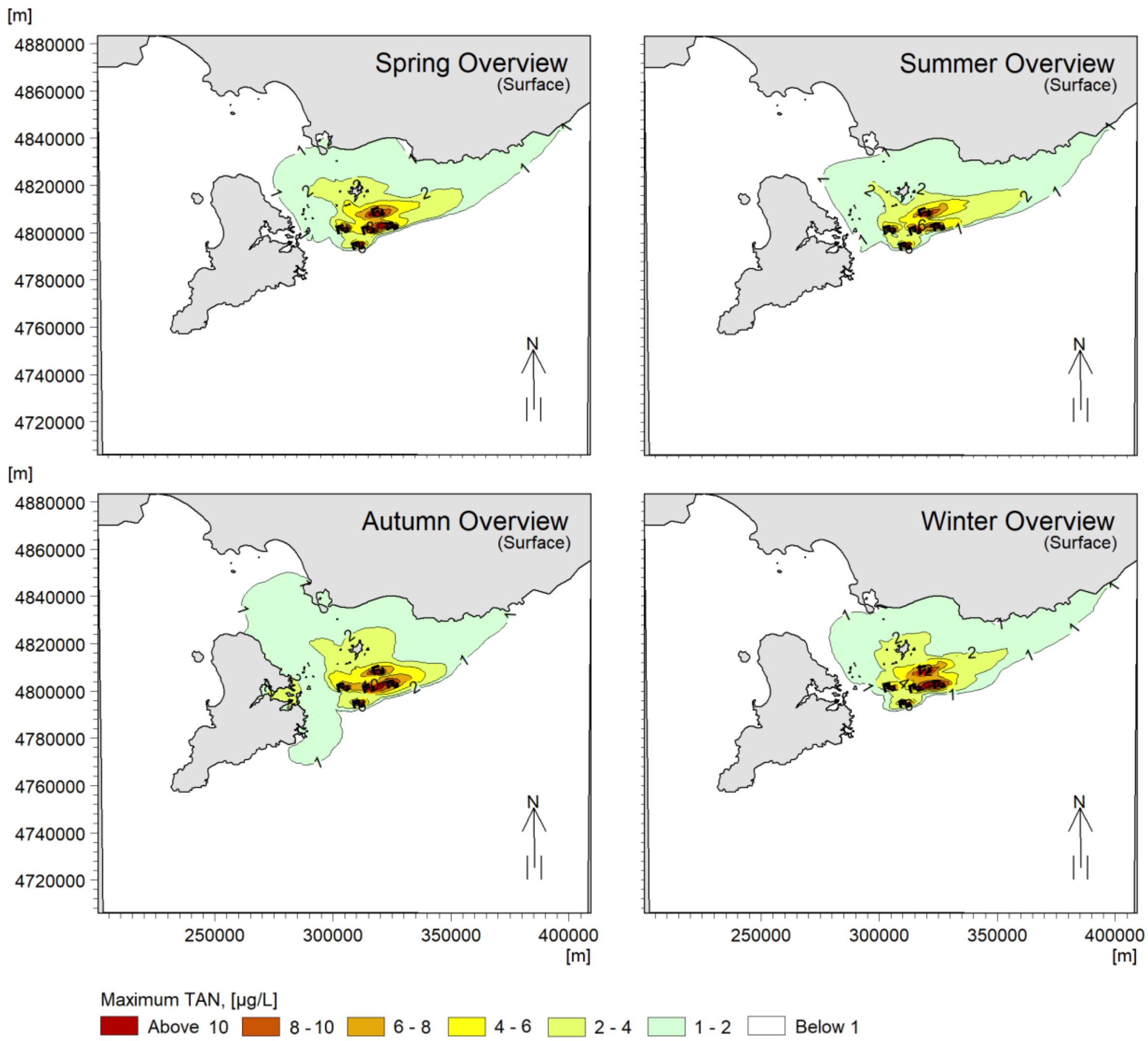

Figure 11: Seasonal maximum excess concentrations of total ammonia nitrogen (TAN) at the surface.

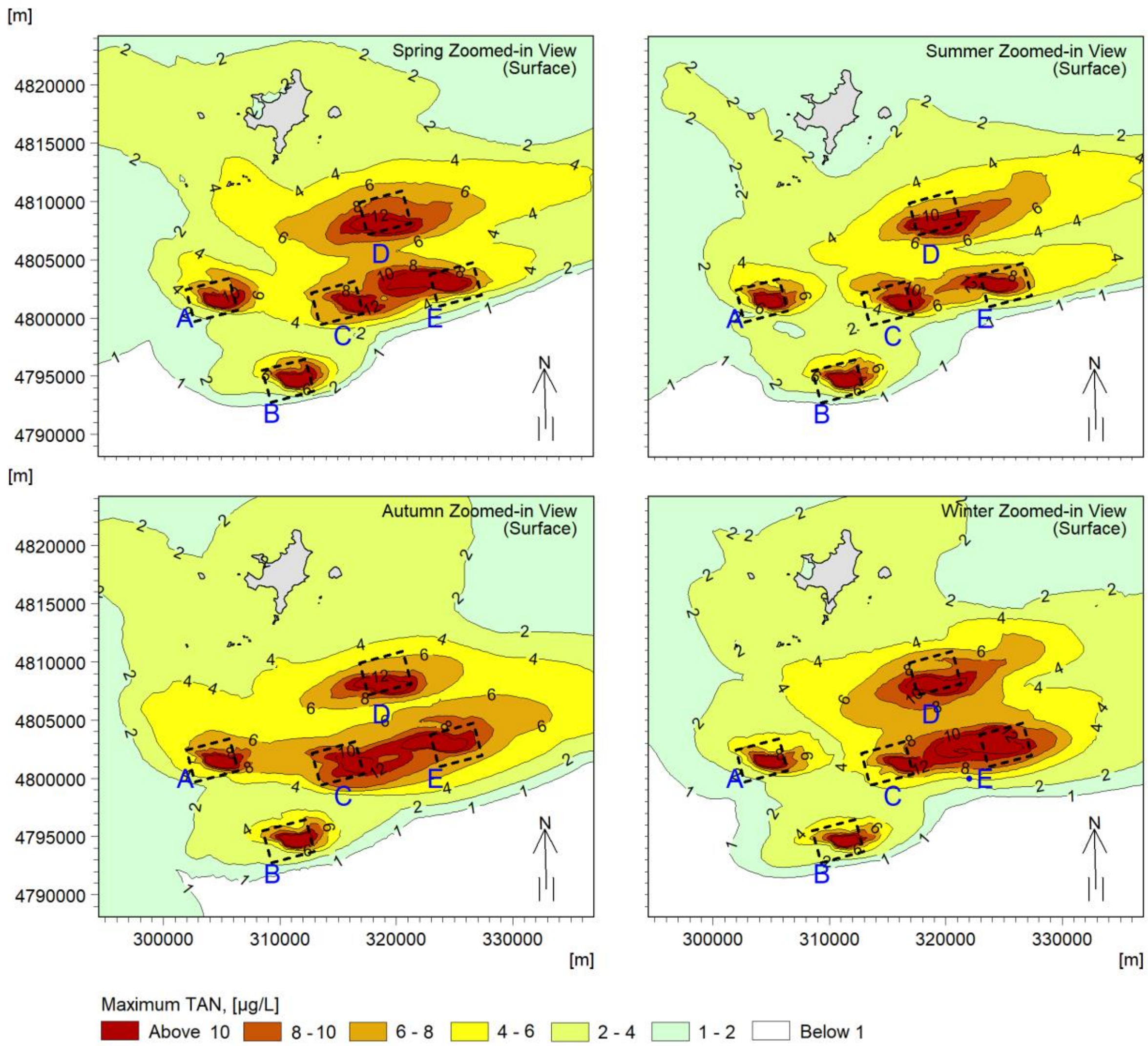

Figure 12: Seasonal maximum excess concentrations of total ammonia nitrogen (TAN) at the surface (Zoomed in).

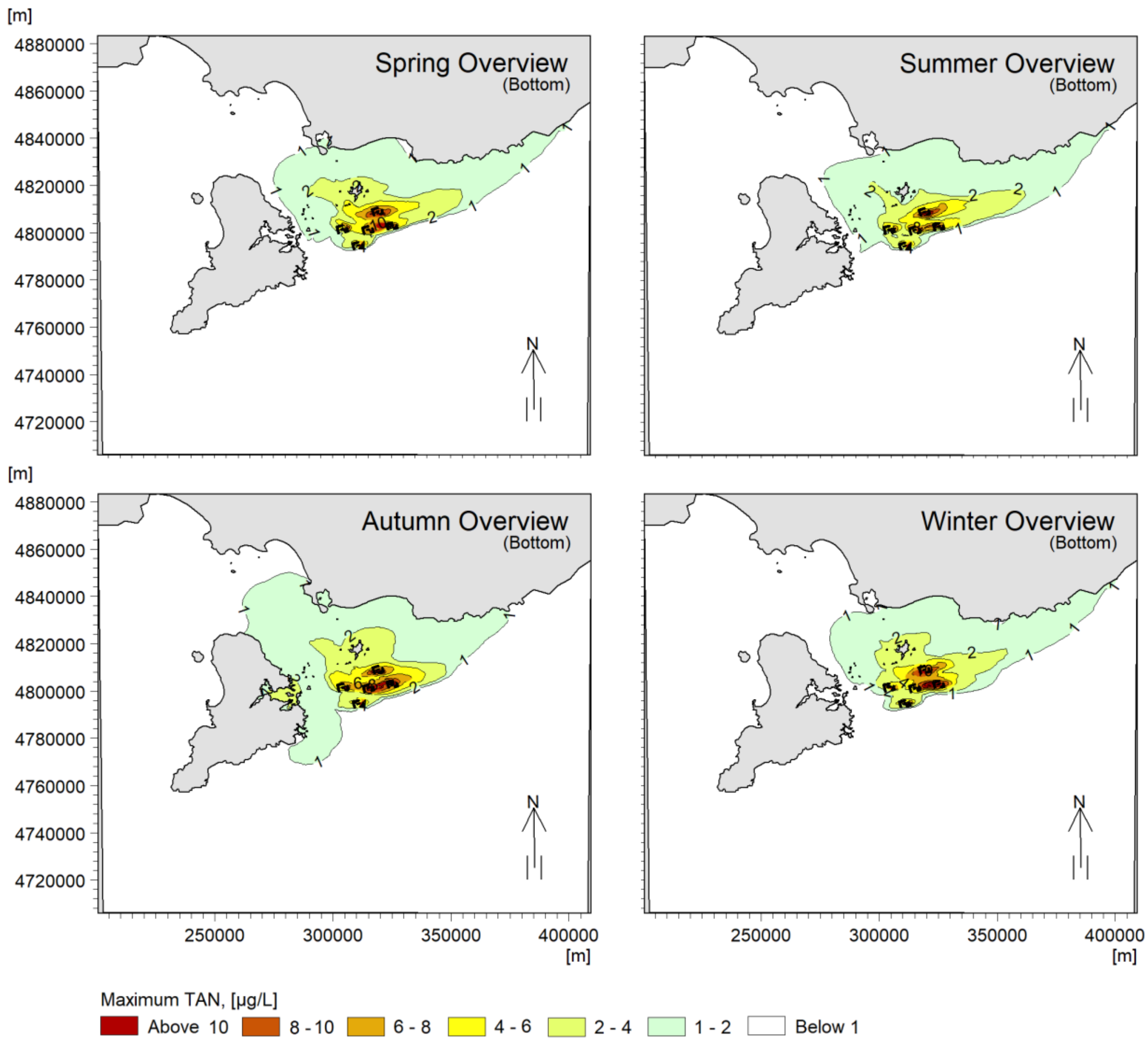

Figure 13: Seasonal maximum excess concentrations of total ammonia nitrogen (TAN) at the bottom.

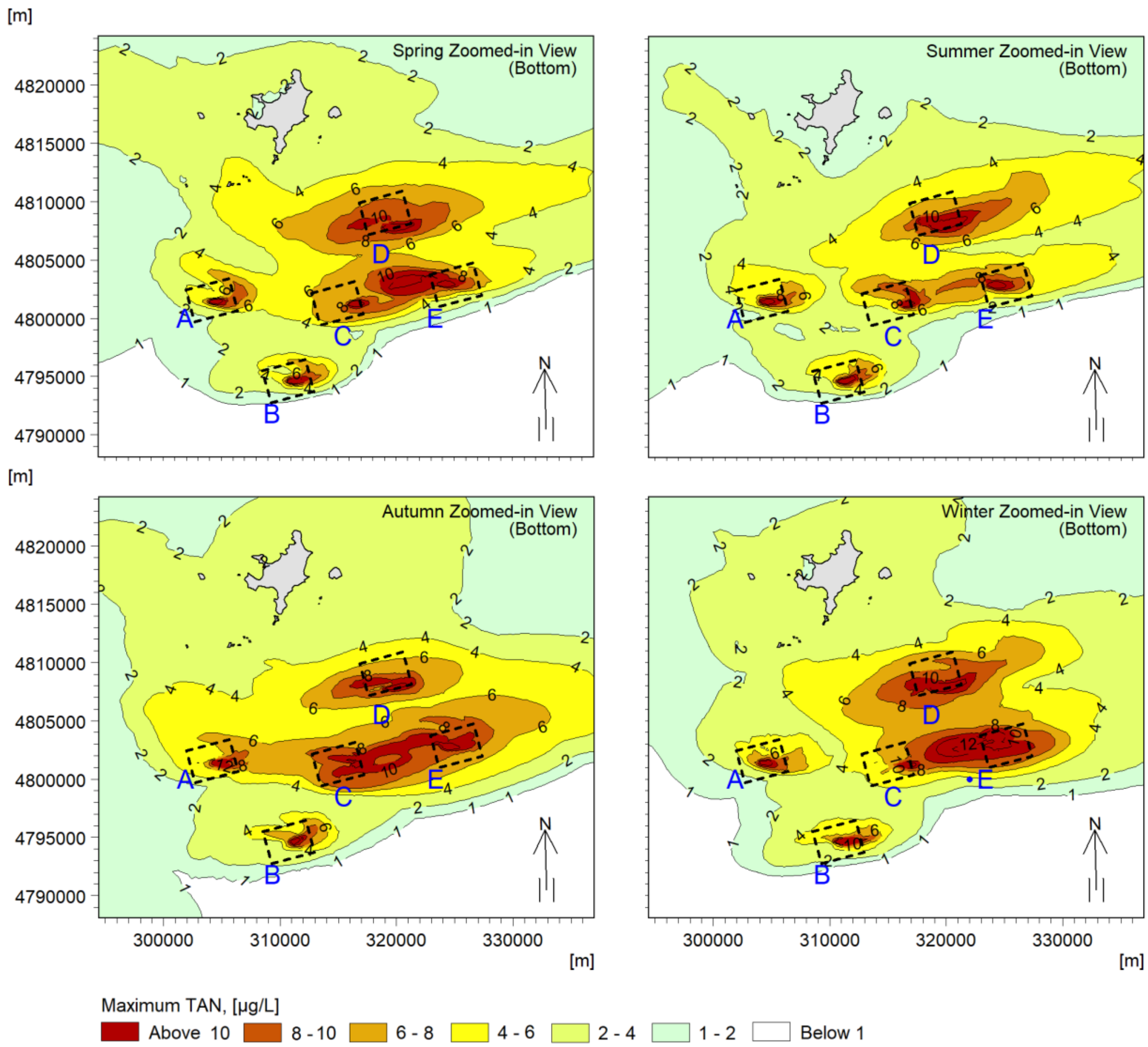

Figure 14: Seasonal maximum excess concentrations of total ammonia nitrogen (TAN) at the bottom (Zoomed in).

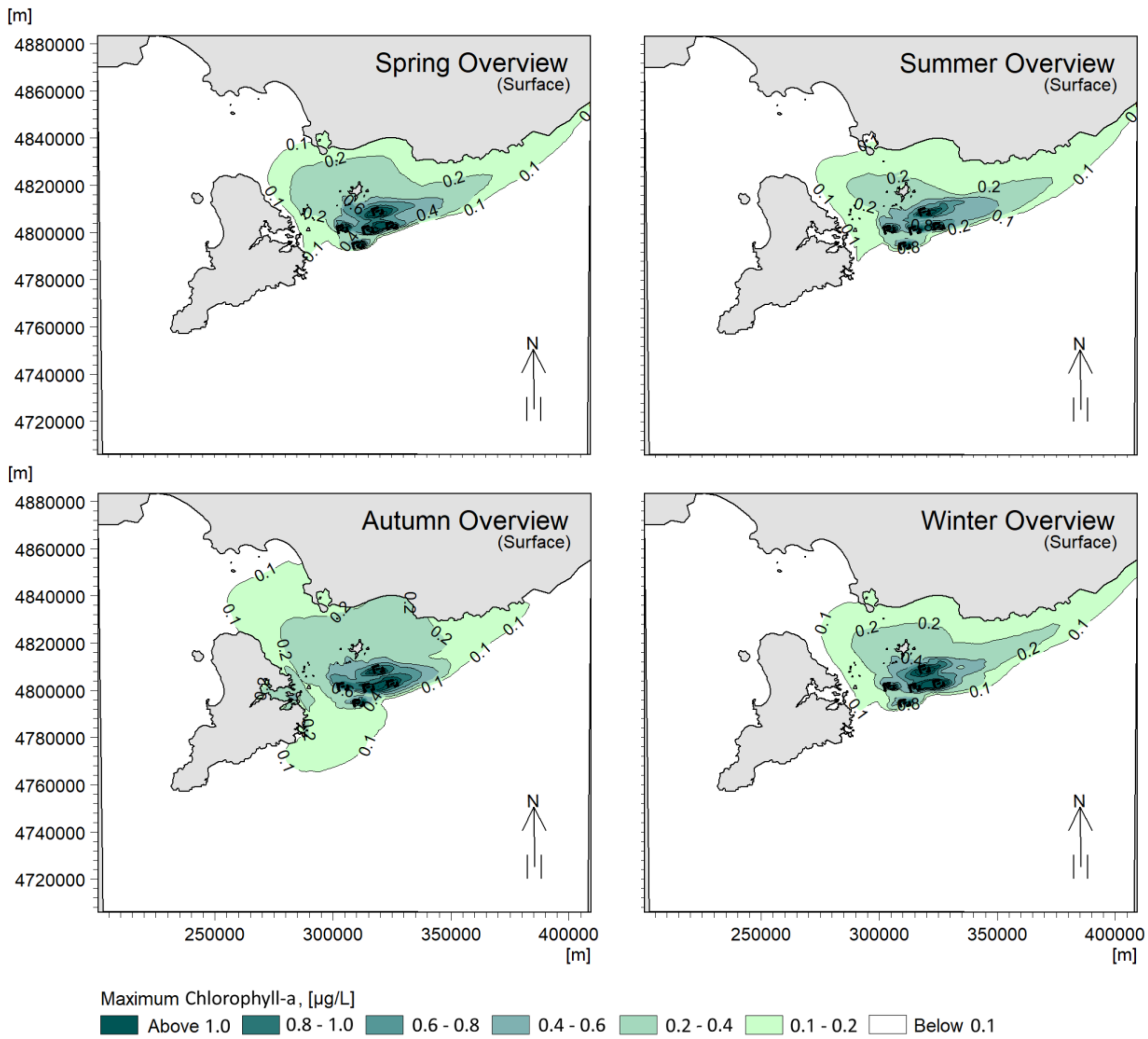

Figure 15: Seasonal maximum excess concentrations of chlorophyll-a at the surface.

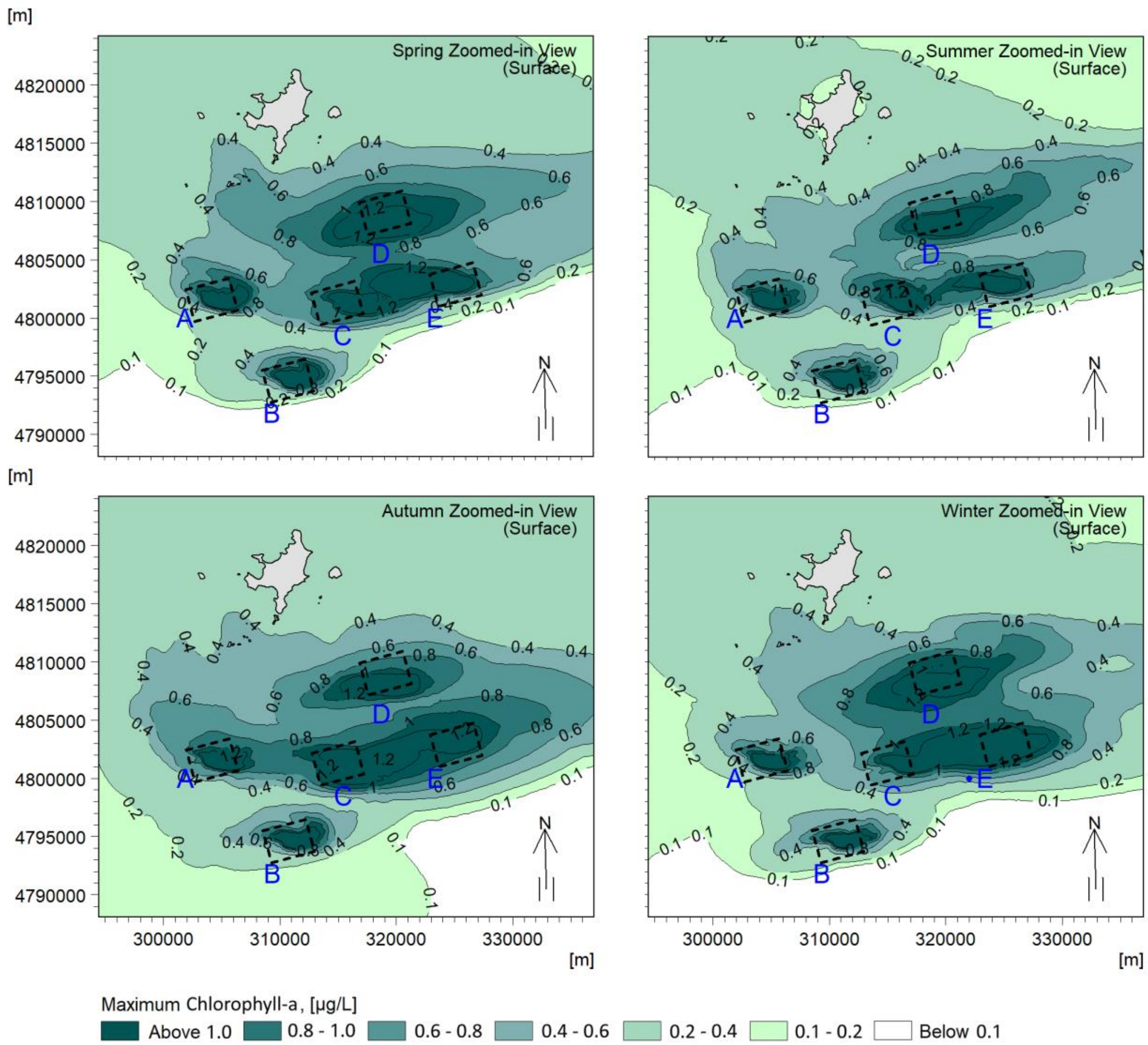

Figure 16: Seasonal maximum excess concentrations of chlorophyll-a at the surface (Zoomed in).

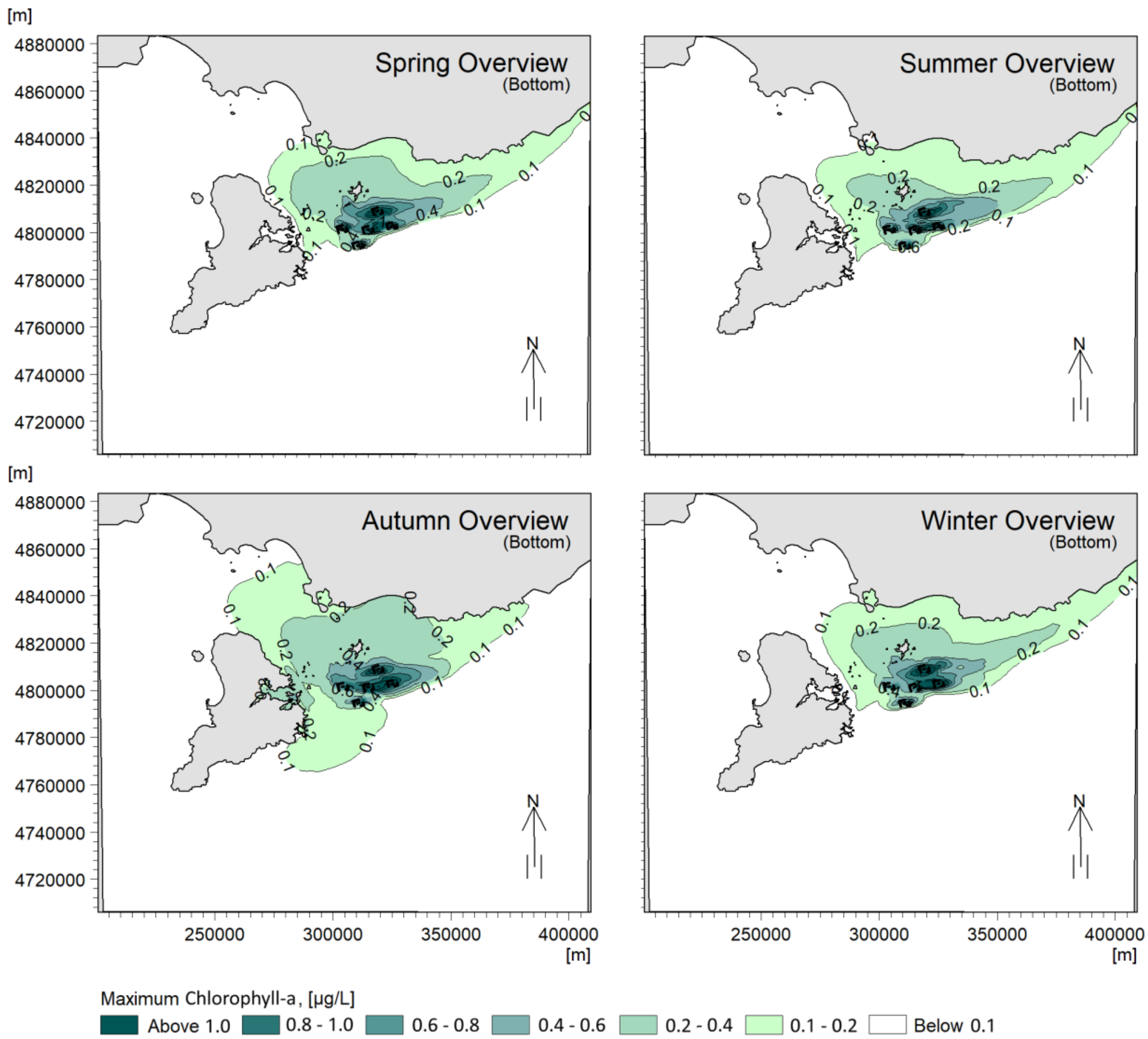

Figure 17: Seasonal maximum excess concentrations of chlorophyll-a at the bottom.

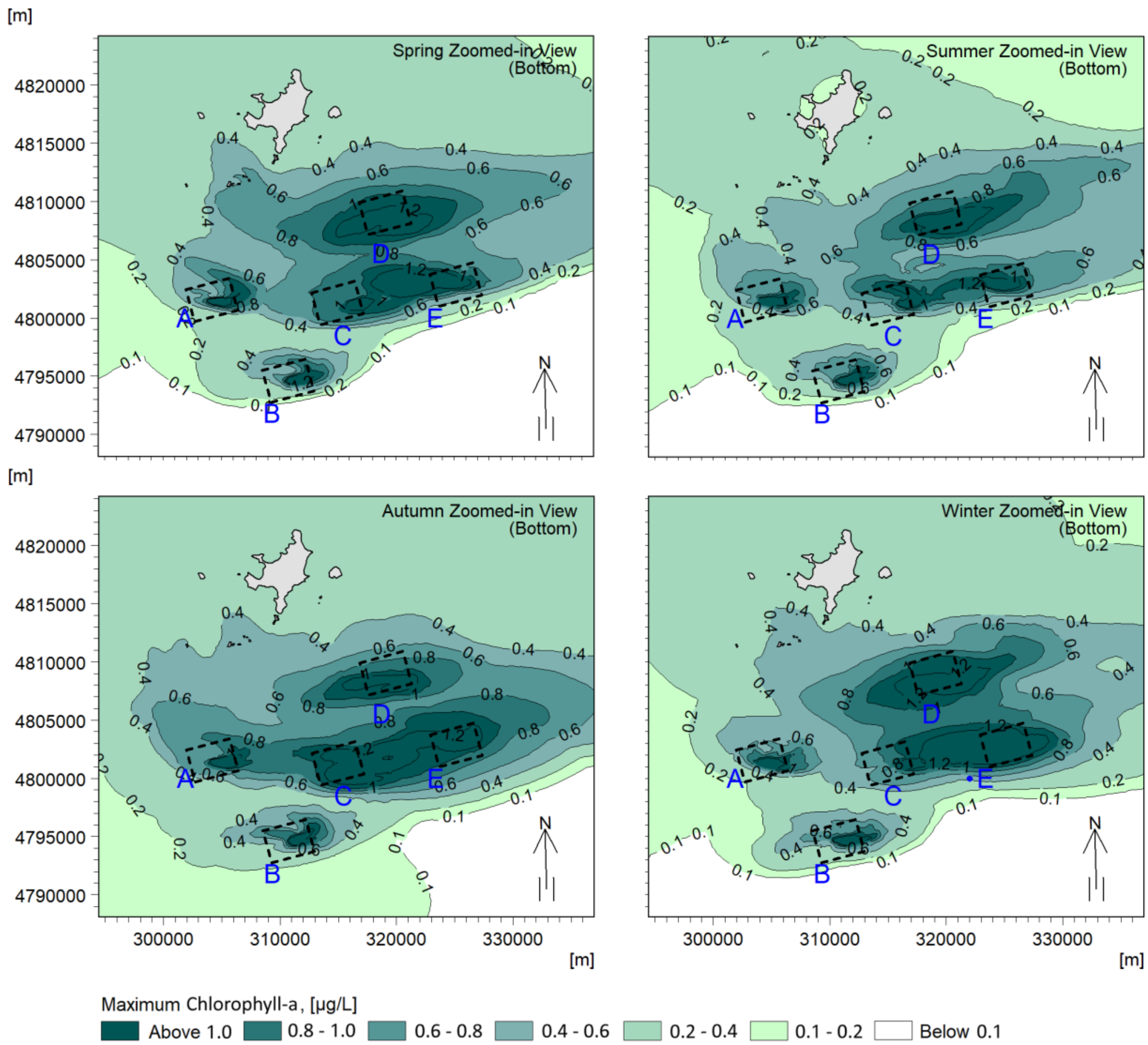

Figure 18: Seasonal maximum excess concentrations of chlorophyll-a at the bottom (Zoomed in).

3.3.3 Dissolved Oxygen

Modelling of oxygen impacts consists of subtracting quantities of oxygen in each farming area based on fish respiration. The oxygen drawdown was set to match a daily feeding schedule with feeding occurring twice daily for approximately 30 minutes. The rates of oxygen consumption are in line with values from the literature which were also used in the previous carrying capacity assessment (**ADS 2017**): 50 mgO_2 kg fish^{-1} hour^{-1} for non-feeding time and 450 mgO_2 kg fish^{-1} hour^{-1} during feeding. The high rates of oxygen consumption during feeding were adjusted to reflect the intense energy expenditure of the feeding process (fish swim faster).

Dissolved oxygen depletion was only observed in the immediate vicinity of the farms as ambient levels are rapidly reached further away from cages due to aeration and mixing from the moderate to strong currents observed within the proposed farming areas.Oxygen concentrations at the most are 0.3 mg L^{-1} lower in localized areas within the outer farming area boundary (.

Dissolved oxygen shows small differences between seasons that are related to the changes in temperature modifying the amount of oxygen water can hold or current speed (faster water movement results in less oxygen depletion).

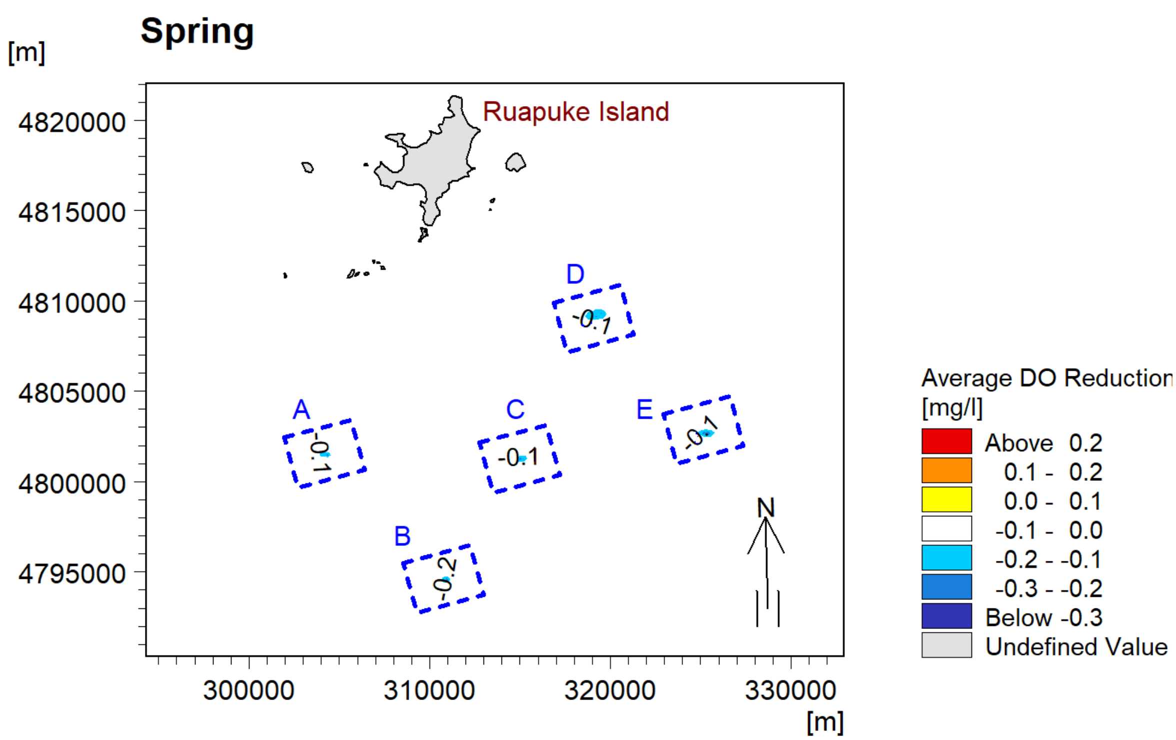

Figure 19: Spring maximum oxygen reduction within the proposed Farming Areas.

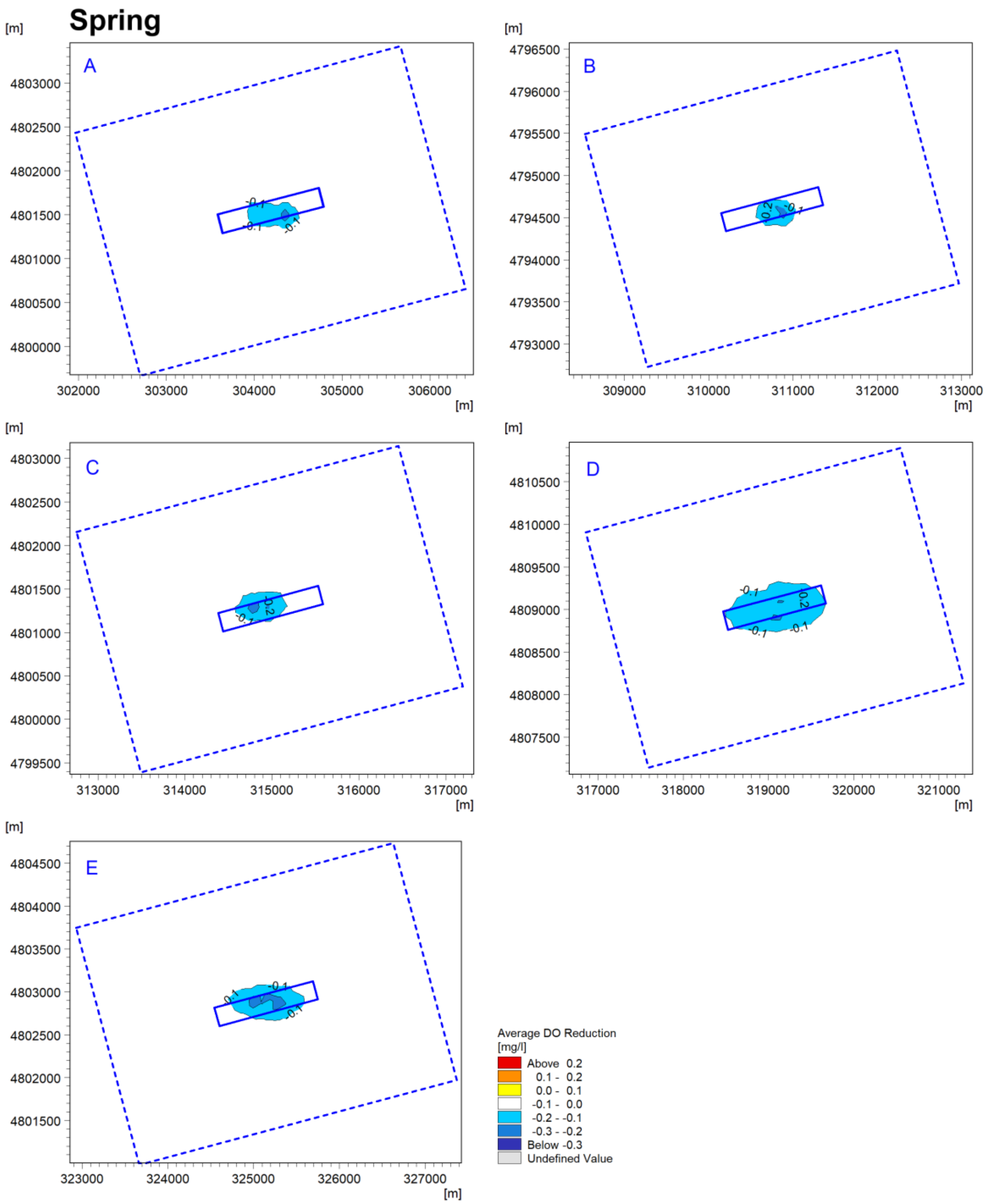

Figure 20: Spring maximum oxygen reduction zoomed in.

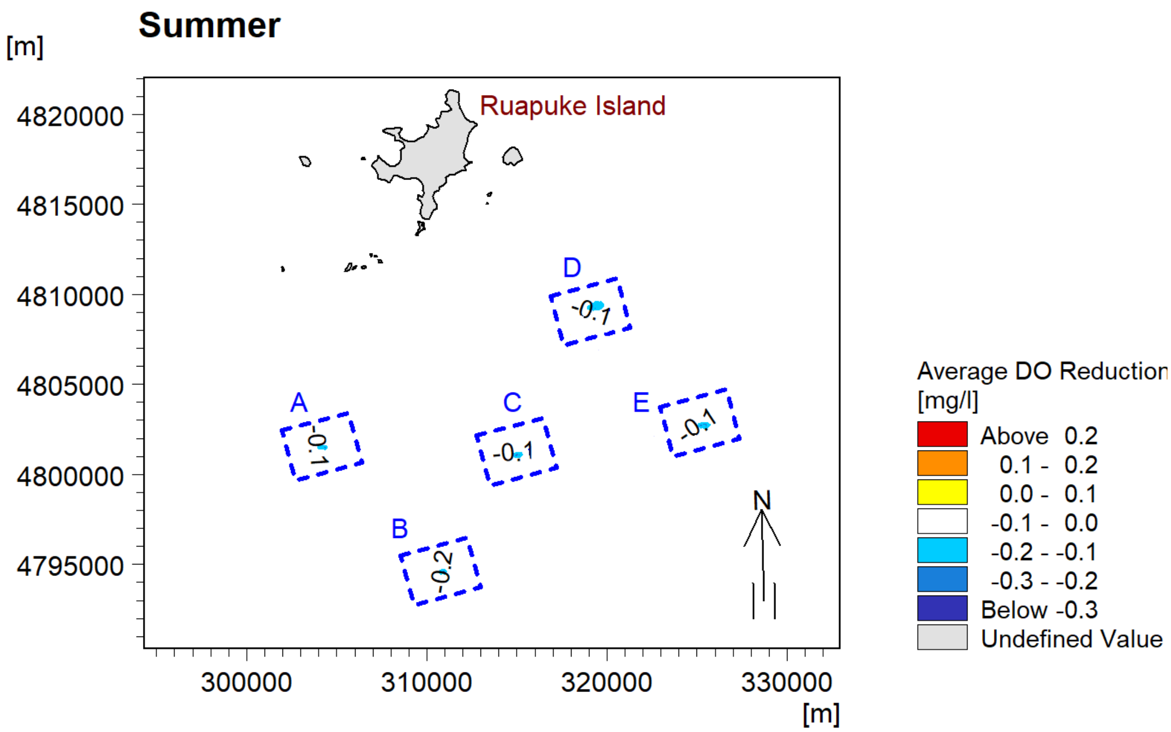

Figure 21: Summer maximum oxygen reduction within the proposed Farming Areas.

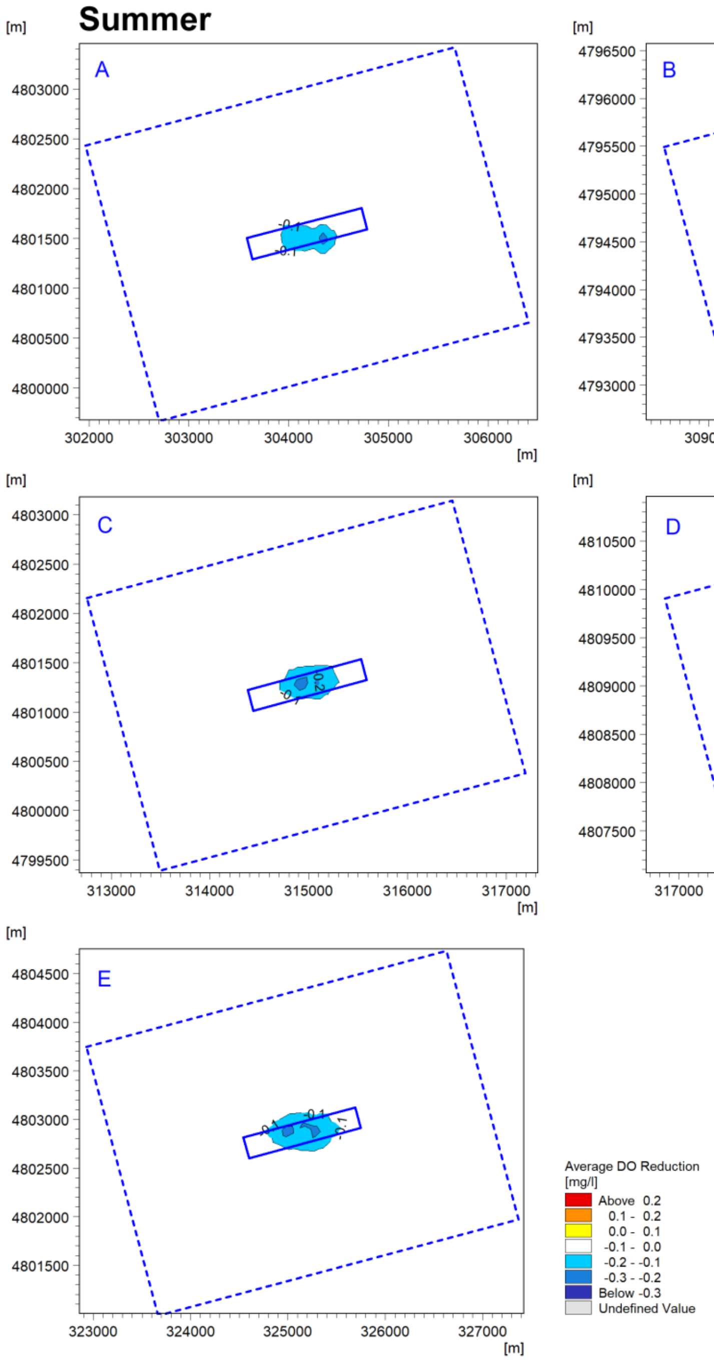

Figure 22: Summer maximum oxygen reduction zoomed in.

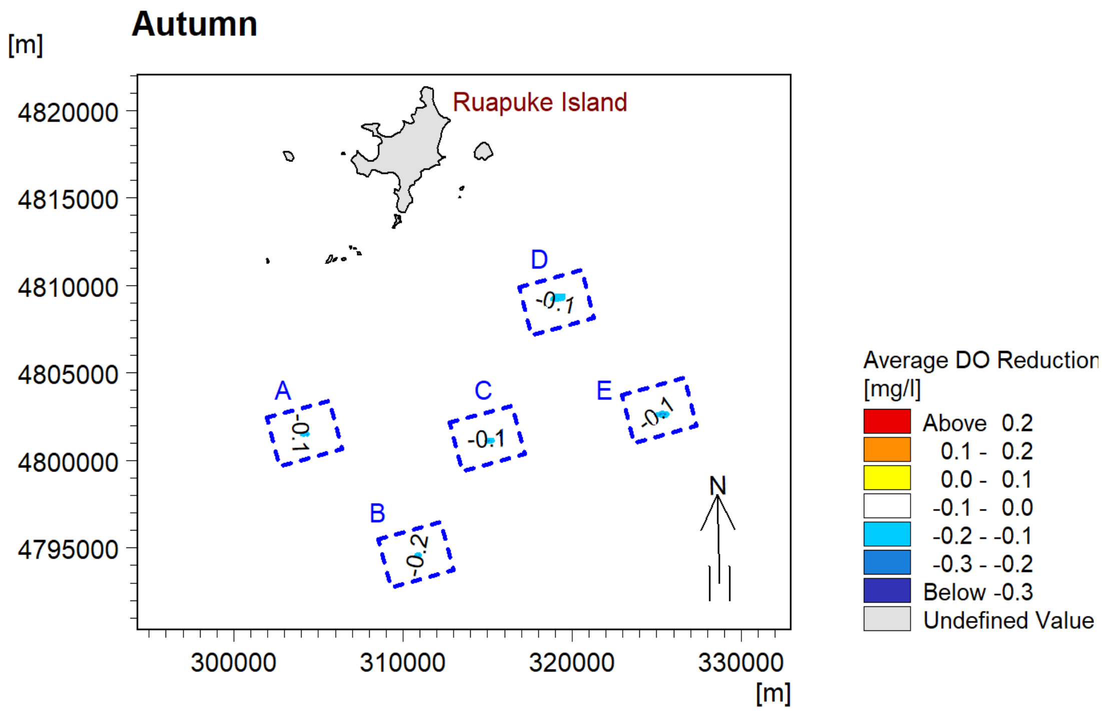

Figure 23: Autumn maximum oxygen reduction within the proposed Farming Areas.

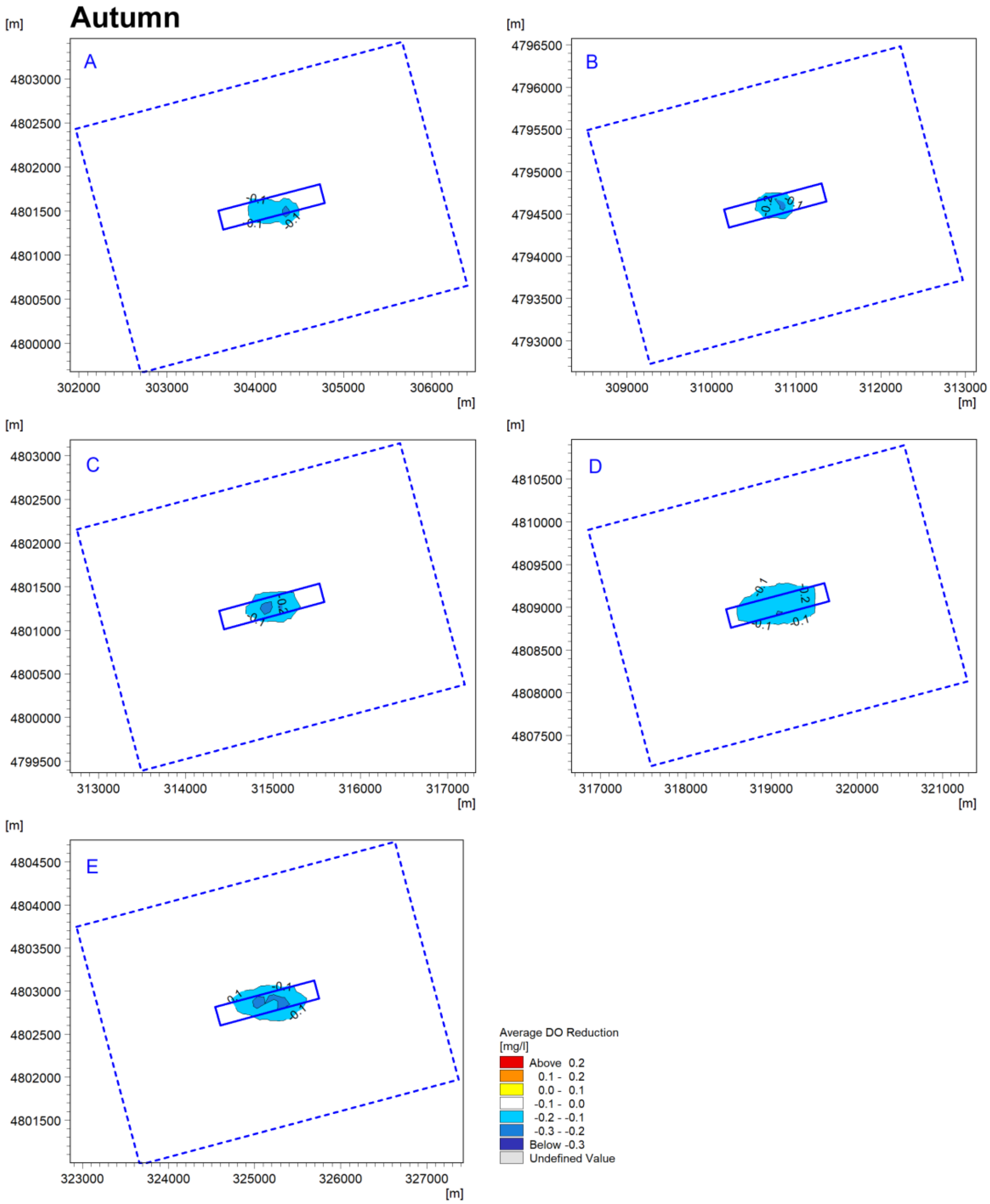

Figure 24: Autumn maximum oxygen reduction zoomed in.

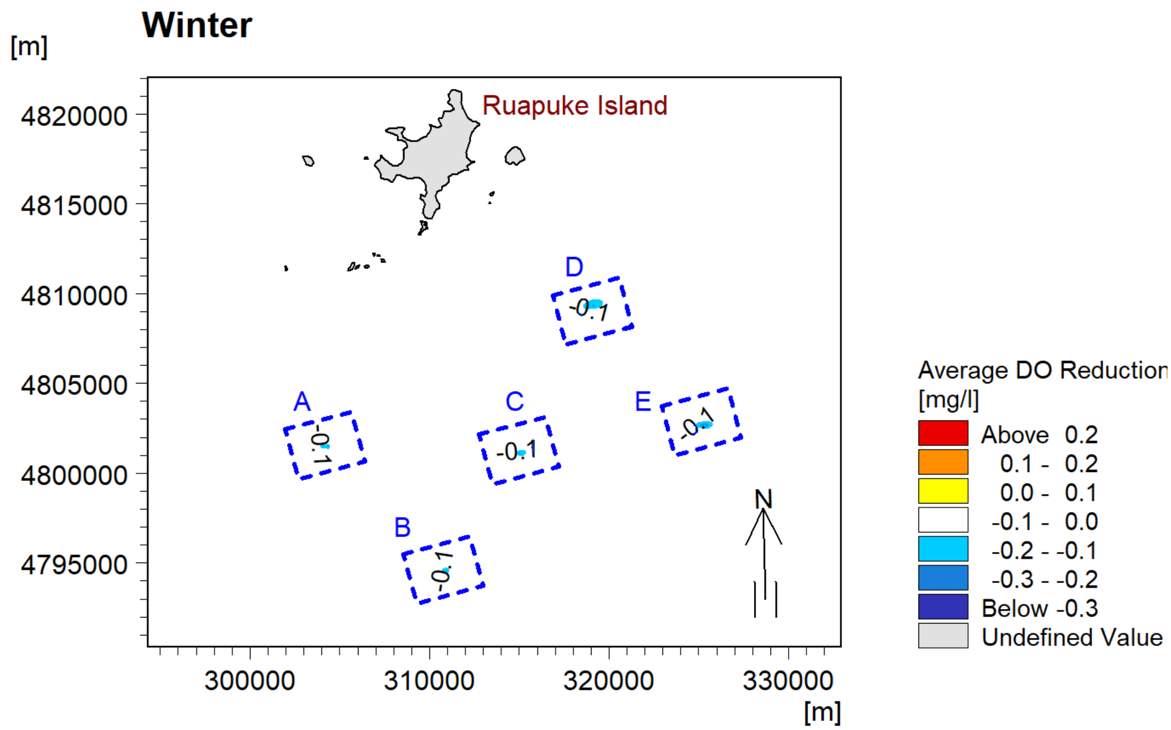

Figure 25: Winter maximum oxygen reduction within the proposed Farming Areas

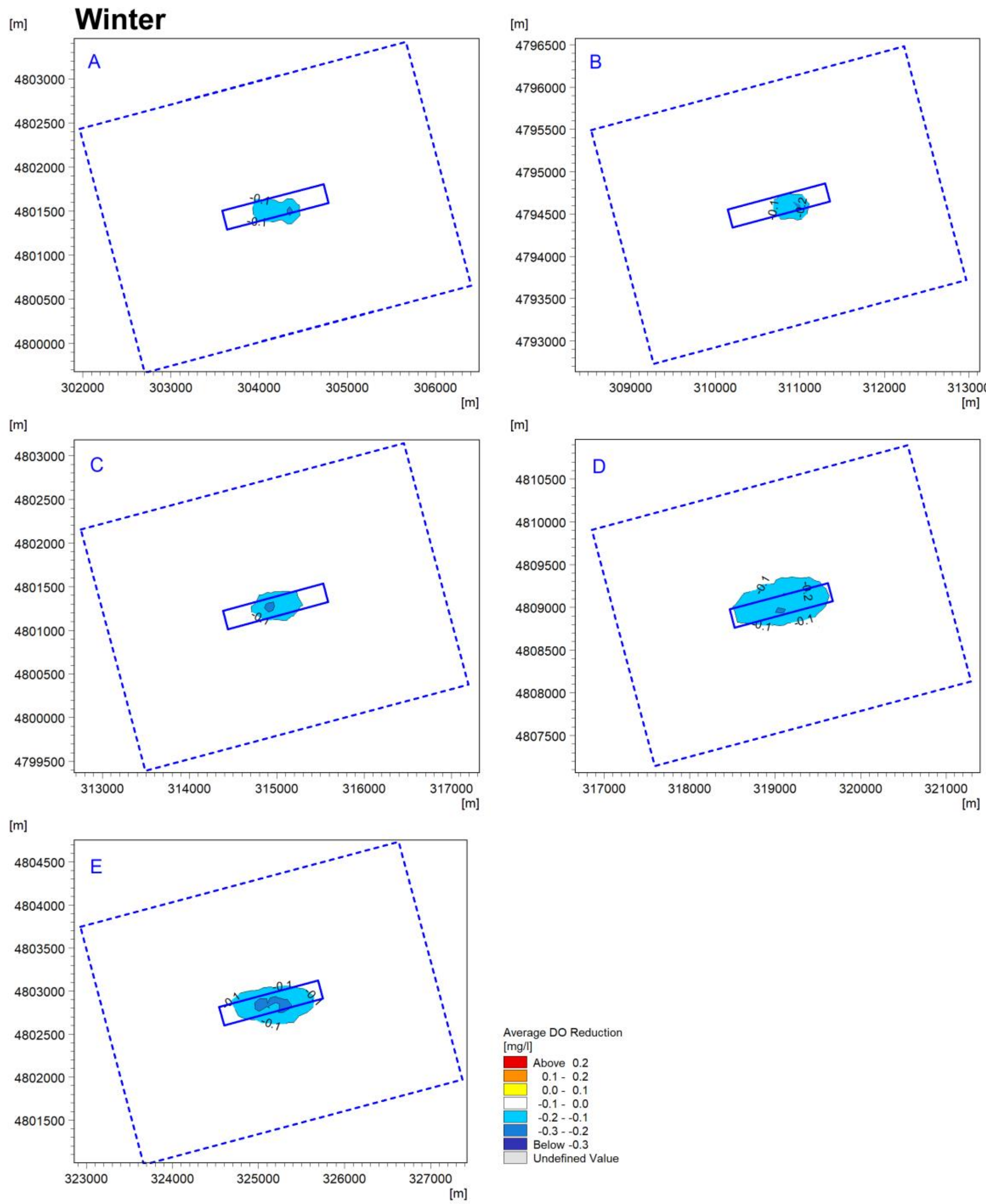

Figure 26: Winter maximum oxygen reduction zoomed in.

4 CONCLUSIONS

The water quality modelling indicates that average TAN levels are predicted to increase across the proposed farming area by 2-3 µg L^{-1} with a maximum increase (but extremely short-lived) increases of 10-12 µg L^{-1}.

Increases in average TAN extend some distance from the proposed farming area but at low concentrations <2 micrograms per litre at distances more than 5km from the proposed farms.

As a result of the release of TAN into the water column, average chlorophyll-*a* levels are predicted to increase by up to 0.4 µg L^{-1} with a maximum of 1.4µg L^{-1}, with such increases being localised to the farming area.

The predicated increases in TAN concentrations and the corresponding maximum potential increase in Chlorphyll-a are small when compared to those predicated at other farming sites both within New Zealand and around the world (i.e. NZKS water quality modelling report 2012, Storm Bay EIS 2017). Such low concentrations are to be expected, due to the stronger flows found at this site that act to dilute the release of TAN into the water column.

Oxygen reduction is localised and predominately less than 0.1 mg/l with a maximum reduction of up to 0.3 mg/l. within the cage areas.

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