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ADS Environmental Services Sdn. Bhd.

Project South Stewart Island New Zealand

Volume III Depositional Modelling Report

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1 INTRODUCTION

Sanford is proposing to expand its salmonid farming operations offshore at 5 locations east of Foveaux Strait on the southern edge of Ruapuke and Green Islands (Project South farm areas). There are 6 major environmental factors that need to be assessed, namely: Regional Oceanography, Waves, Algal Blooms and Riverine Inputs, Sea Surface Temperature, Protected Areas, Seabed Communities and Sediment Types.

Specific site conditions were investigated with a field survey conducted by ADS in August 2019. This survey examined the epibenthic community and infaunal community and confirmed that the seabed at the proposed Farming Areas is composed of scoured, compacted sandy sediments. There was no indication of biogenic reefs present, nor any major epibenthic suspension feeding community that might be adversely impacted by farm deposition (see Volume 1 ADS 2019).

This report describes the depositional modelling undertaken to determine the spatial extent and magnitude of feed and faeces deposition to the seabed at the proposed Farming Areas. Depositional footprints (those areas of the seabed impacted by farming activities) associated with farms are often used as a basis for management. The local bathymetry and hydrodynamic regime are the primary drivers controlling the shape, extent, and concentration of the deposition field.

Depositional footprints associated with fish farms are typically skewed in an elliptical pattern, fanning out in the direction of the prevailing currents and with the greatest deposition usually observed directly under the farm pens (depending on the hydrodynamic forcing). Strong gradients in physiochemical conditions and ecological community composition/function occur along gradients in organic matter deposition. **Pearson and Rosenberg (1978) and others** describe the ecological shifts in benthic faunal communities associated with farming deposition.

Depositional modelling is used to predict organic carbon and solids deposition, resulting from feed wastage and fish faeces production. These tools have been widely used to predict seabed effects and the extended impact area of proposed farms across the globe (*i.e.* **Cromey *et al*. 2005, Keeley *et al.* 2013**).

Models presented in this report were performed using New DEPOMOD (SAMS 2017 [1]). DEPOMOD (**Cromey *et al.* 2002**) is a widely used and credible (**SEPA 2005**, **ASC 2012**) particle tracking model designed for predicting salmon farm deposition (**Cromey *et al.* 1998**, **Thetmeyer *et al.* 2003**, **Cromey and Black 2005**, **Cook *et al.* 2006**, **Magill *et al.* 2006**). This modelling tool requires background information from the subject area that includes the bathymetry, local current fields, and specific information regarding farming practices such as pen layouts, feed input, feed composition and stocking density.

Five discrete farm locations have been modelled, with each having a standing biomass of approximately 5,400 tonnes spread across 10 cages for a period of 12 months.

[1] New DEPOMOD: URL http://science.sams.ac.uk/trevor-carpenter/newdepomod/).

2 MODEL SET-UP

2.1 MODEL DOMAIN

The domains of the Project South depositional models consisted of bathymetric data provided by NIWA and interpolated to a resolution of 40m. The location of the 5 Farming Areas modelled is depicted in **Figure 1** below. It was necessary to configure each lease location with a unique domain as this minimized processing time. This is an appropriate approach, as the model results show that the individual depositional footprints did not overlap.

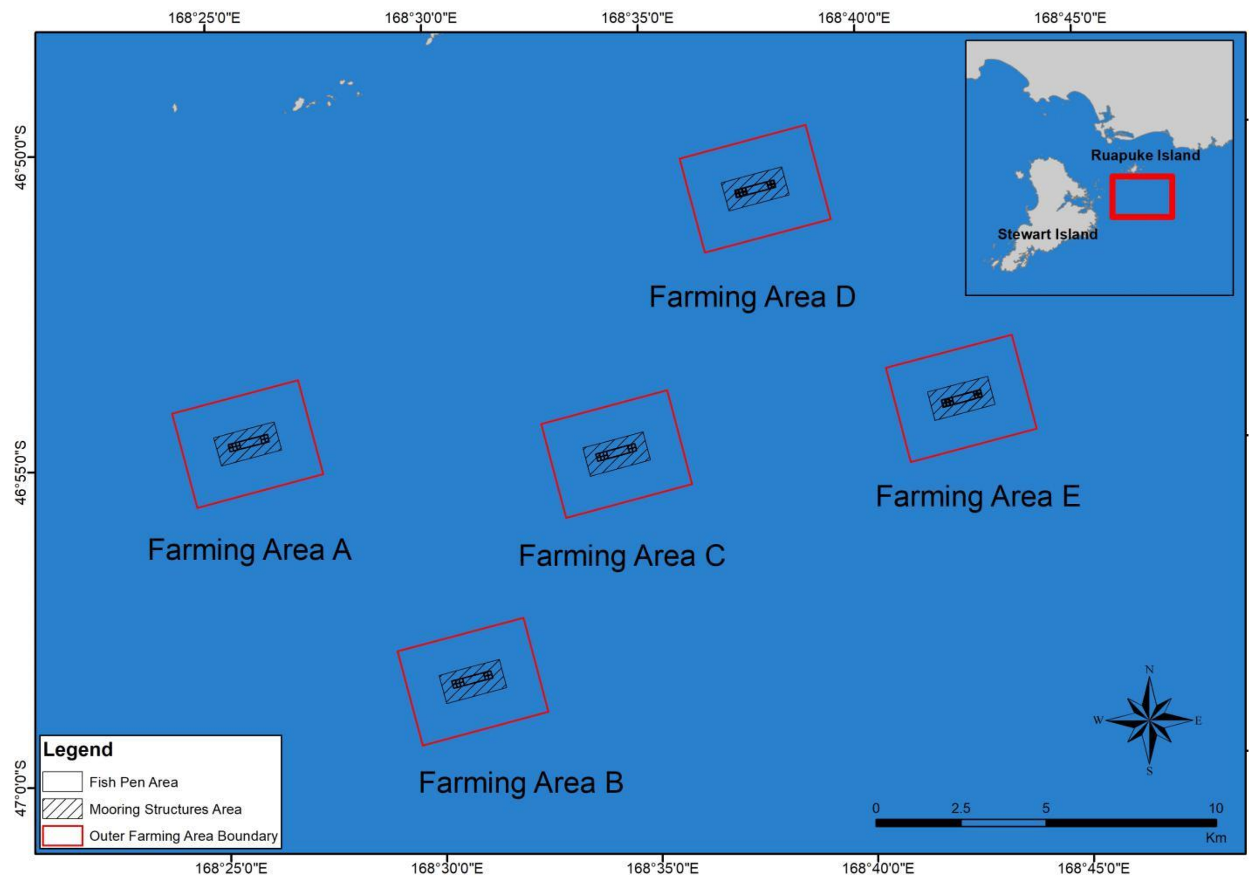

Figure 1: Depositional modelling farm locations.
Specific information regarding pen layout and positioning is referenced in Table 2.

2.2 FLOW CONDITIONS

The current flows within the proposed expansion area are not uniform and thus current fields experienced by farms within the proposed expansion area can vary depending on their position (Hydrodynamic Report Volume 2 ADS 2019). An example of a current rose from Farming Area C in presented in **Figure 2.** while roses representing the remainder of the Farmed Areas can be found in **Appendix 1**. These highlight the main two flow directions are to the WSW and ENE. At proposed Farming Area A the predominate flow direction is to the NNW. Note: Current rose plots indicate where the flow is coming from.

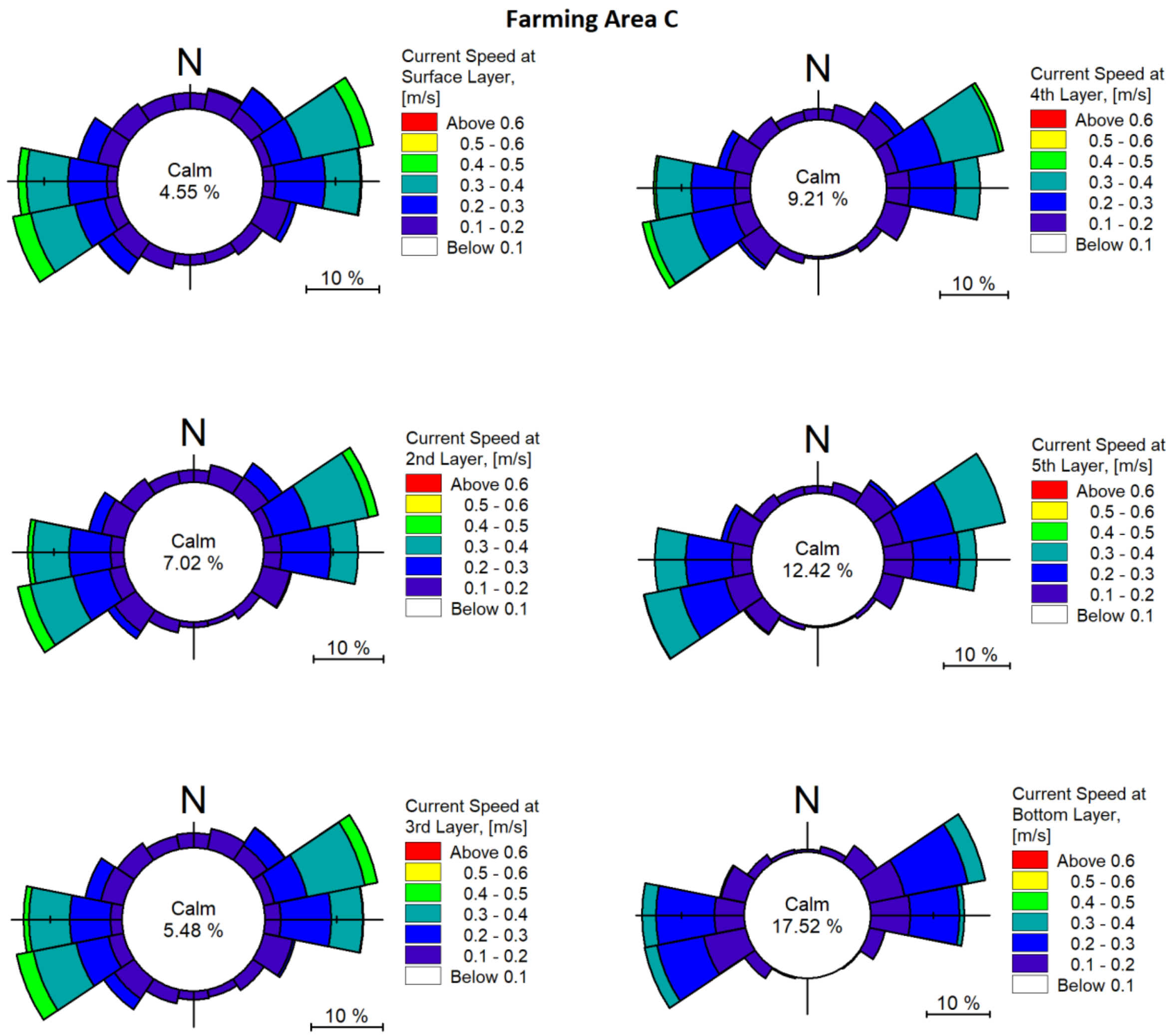

Figure 2: 3D Current rose from Farming Area C clearly indicating a moderate-strong ENE/WSW flow down the water column.

Modelling studies conducted by ADS show that median flows across the proposed Farming Areas are between 0.20 - 0.35 m s^{-1} with peak flows >0.55m/s though stronger flows >1.2 m sec^{-1} were also observed west of the proposed study area in the model and match those reported by **Stevens *et al.* (2019)**, **Cullen (1967)**, and **Cranfield (1968).**

The flows used to drive the depositional model are based on model extracts from ADS's hydrodynamic model. This model is a 3D model with 10 vertical layers that was run for a period of 1 year. An extract was taken from each of the 5 proposed farming Areas with the current speed and direction data presented in

Figure 2 above and **Appendix 1**. The depositional model takes current speed and direction data over this period approximately every 10 mins (from 10 layers down the water column). The median current speeds used in the model extracted fields ranged from approx. 0.23 to 0.31 m s^{-1} (**Figure 3**).

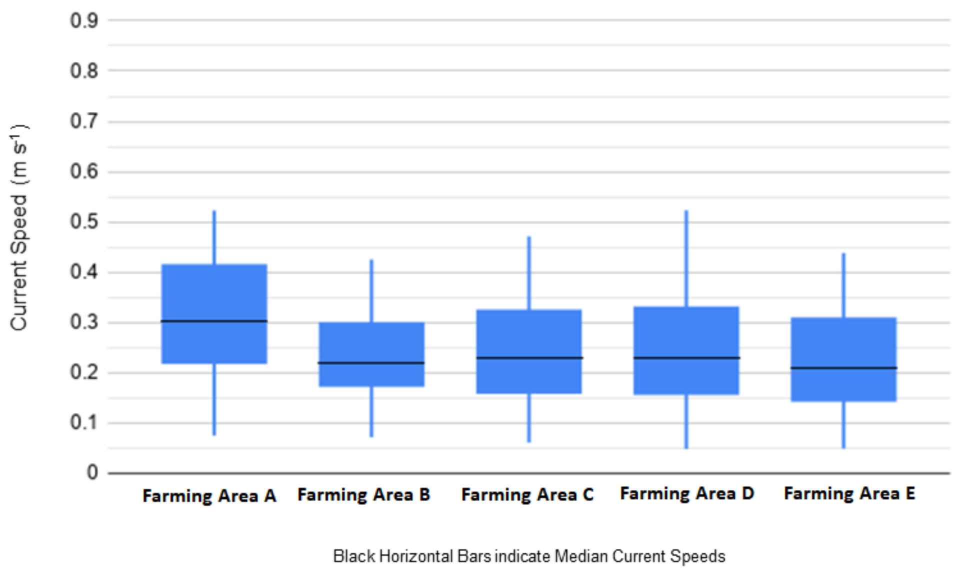

Figure 3: Box plots of current speeds used at each farm area for depositional modelling. Black lines indicate median current speed.

Current speeds greater than 0.09 m s^{-1} can redistribute feed and faeces wastes along the seabed, and sites experiencing those levels of flow can characterized as 'dispersive' (as discussed **Keeley *et al*. 2013**). The Farmed Areas modelled in this study clearly show dispersive characteristics according to the ADS model extracts and the published literature and deposited wastes are expected to be redistributed along the bottom in the direction of the predominant current flow along the seabed. NewDEPOMOD software accounts for this dispersion and resuspension of feed and faeces once they hit the seabed.

2.3 Pen Setup and Inputs for Deposition Modelling

This depositional model employed a submersible pen design, with a 120m circumference, 20m deep sidewalls (with a bottom cone extending to a depth of 25m) and a total pen volume of 27,000 m^3 (**Figure 4**). This pen design was common to the five locations modelled – see Figure 1. The pens are designed to sit in two preferred locations in the water column. Firstly, in the middle of the water column and secondly three meters below the surface (**Figure 5**). At each farm area the cages are broken into 2 cage groups separated by 640 meters (**Figure 6**). One cage group is 3x2 while the other is 2x2 and there is a feed barge between each set of cages.

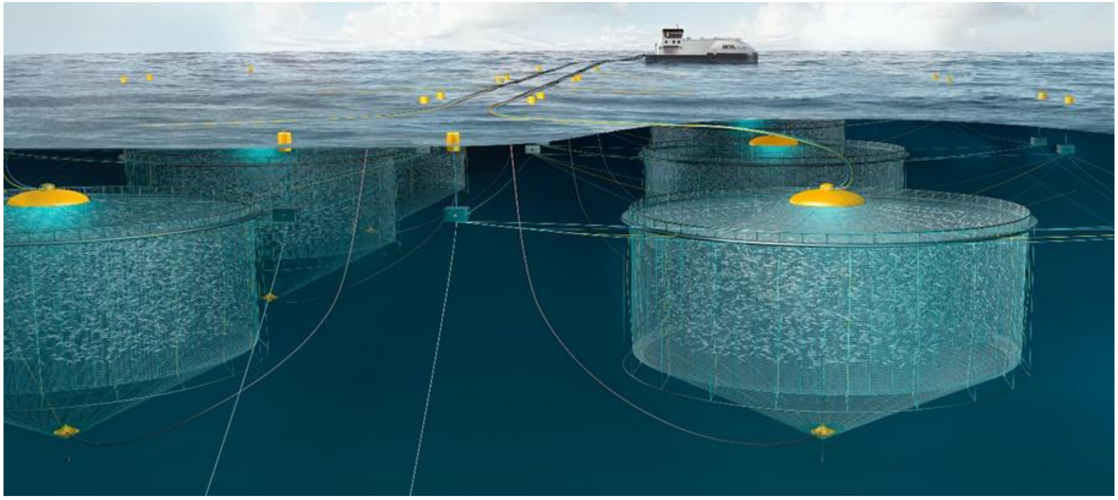

Figure 4: Sanford's Proposed Submersible Pen.

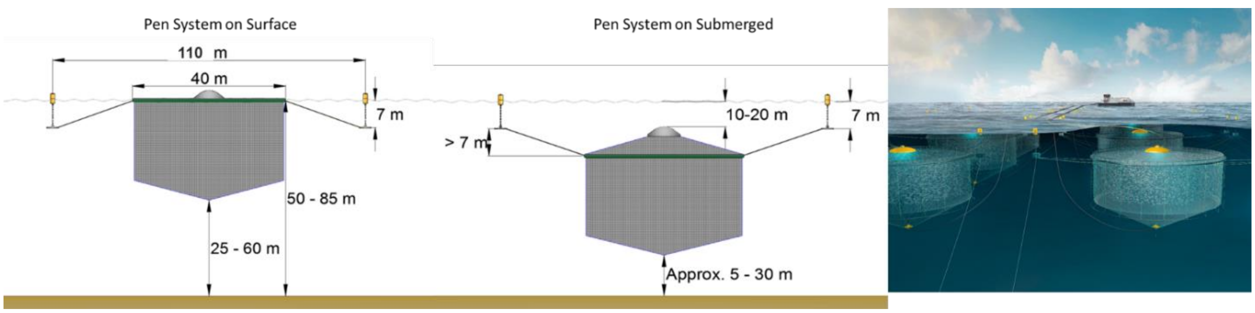

Figure 5: Diagram of Akva Atlantis 120m circumference pens sitting just below the surface and in the middle of the water column.

The NewDEPOMOD software models these pens as spheres and to obtain a final pen volume a sphere diameter of 37.22m was modelled. Specific farm locations and orientations can be found in **Table 1** below.

	Farming Area A		Farming Area B		Farming Area C		Farming Area D		Farming Area E	
X position	303635	304573	310203	311140	314435	315370	318522	319459	324595	325532
Y Position	4801463	4801711	4794515	4794765	4801187	4801441	4808937	4809188	4802774	4803026
layout (row x column)	2x3	2x2	2x3	2x2	2x3	2x2	2x3	2x2	2x3	2x2
Pen Diameter (m)	38	38	38	38	38	38	38	38	38	38
Pen Spacing (m)	110	110	110	110	110	110	110	110	110	110
Bearing (N°)	75	75	75	75	75	75	75	75	75	75
Total Volume (m^2)										

Table 1 - Pen designs, locations, layouts, and volumes used for this depositional model.
Pens locations are reported as they are entered into DEPOMOD (i.e. referencing the center of the top left pen before adjusting the bearing of the pen set). Coordinates are given in UTM NZGD 2000.

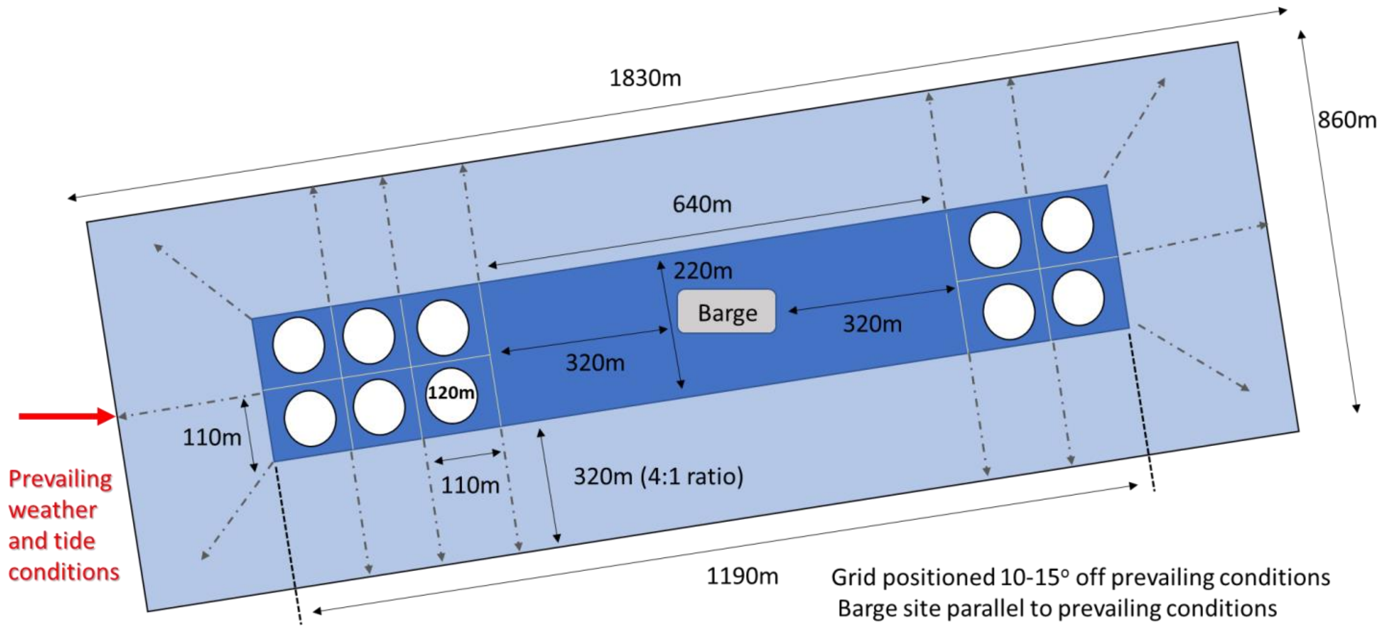

Figure 6: Atlantis 120m circumference pens with 80m pen bays and 4:1 mooring lines as used in the depositional modelling.

2.3.1 Farming Inputs and Discharge Scenarios

Table 2 below highlights the pen setup used. The stocking density was set to 20.0 kg m^{-3} (equivalent to 5,400 tonnes per farm) at all Farming Areas in order to model the maximum intended biomass. 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 DEPOMOD software computes the feed mass inputs and biomass for the pen internally based on pen volume, stocking density, and stock to feed ratio. Each of the proposed farms was computed to have a daily feed input of approximately 25.8 tons (**Table 2**). Specific feed loadings, C content, and other input parameters can be found in **Table 2** below.

Table 2 - Depositional model loading input parameters.
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
Feed % C	49	49	49	49	49
Faeces % C	30	30	30	30	30

***Final Biomass** (ton)*	5400	5400	5400	5400	5400

DEPOMOD assumes that all feed inputs are distributed evenly across all pens for the duration of the model simulation; in this case the model simulated 1 year of farm faeces and feed waste deposition assuming the maximum biomass of 5400 tonnes per Farming Area.

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.

Offshore fish farming may require pens to be submerged for extended periods of time. Compared to surface pens, submerging the pens has the potential to focus depositional footprints into a smaller area, increasing the concentration of surplus feed and faeces within the new footprint. We have thus modelled two scenarios for each Farming Area within the proposed farm expansion area:

1. Surface Scenario: Pens operating three meters from the surface of the water column.
2. Submerged Scenario: Pens operating at approximately half of the water column depth (referencing the middle of the pen) (**Table 3**).

Table 3 – Approximate modelled waste release depths for submerged pen scenarios

	Farm A	Farm B	Farm C	Farm D	Farm E
Submerged Pen Depth (m)	28	40	28	30	40

2.4 Deposition Results

Results are expressed in kilograms of carbon per square metre per year (kg C m^{-2} yr^{-1}) and total mass of feed and faeces in kilograms per square metre per year (kg m^{-2} yr^{-1}). By way of context, a number of studies have observed the impact of organic deposition on macrobenthic communities. **Cromey *et al.* (2001)** observed macro-faunal community responses at carbon deposition rates of approximately 3.3g m^{-2} day^{-1}. Other studies such as **Hargrave (1994)** and **Gilibrand *et al.* (2002)**, concluded that long term benthic loading of approximately 2g m^{-2} day^{-1} of carbon deposition would start to have some impact on benthic conditions.

Total carbon and solid mass released for both scenarios during the year are shown in **Table 4** below. The specific patterns and concentrations of those wastes along the seabed (the depositional footprint) are described below.

Table 4 - Depositional model outputs in terms of C and Solids (feed and faeces).
Carbon and Solid release numbers were provided by Skretting.

	Farm A	**Farm B**	**Farm C**	**Farm D**	**Farm E**
Carbon Released (tons/year)	501.6	501.6	501.6	501.6	501.6
Solids Released (tons/year)	1508.7	1508.7	1508.7	1508.7	1508.7

2.4.1 Farming Area A

Figure 7 to **Figure 10** below show the depositional footprint from both surface and submerged pen scenarios at Farming Area A. Zoomed in figures of each model simulation can be found in Appendix 2.

In general, farm discharges at Farming Area A are predicted to scattered more than 2.5km NNW of the pen set for both surface and submerged pen modelled depositional scenarios. Carbon deposition from surface situated pens is predicted to reach up to 0.25 kg m^{-2} yr^{-1}, while submersed pens deposit up to 0.7 kg m^{-2} yr^{-1}. Solids deposition from surface pens reaches 1.0 kg m^{-2} yr^{-1}, while subsurface pens deposit up to 2 kg m^{-2} yr^{-1} in small patches a few hundred meters from the farming area with lower concentrations observed up to 3.0 km to the NNW.

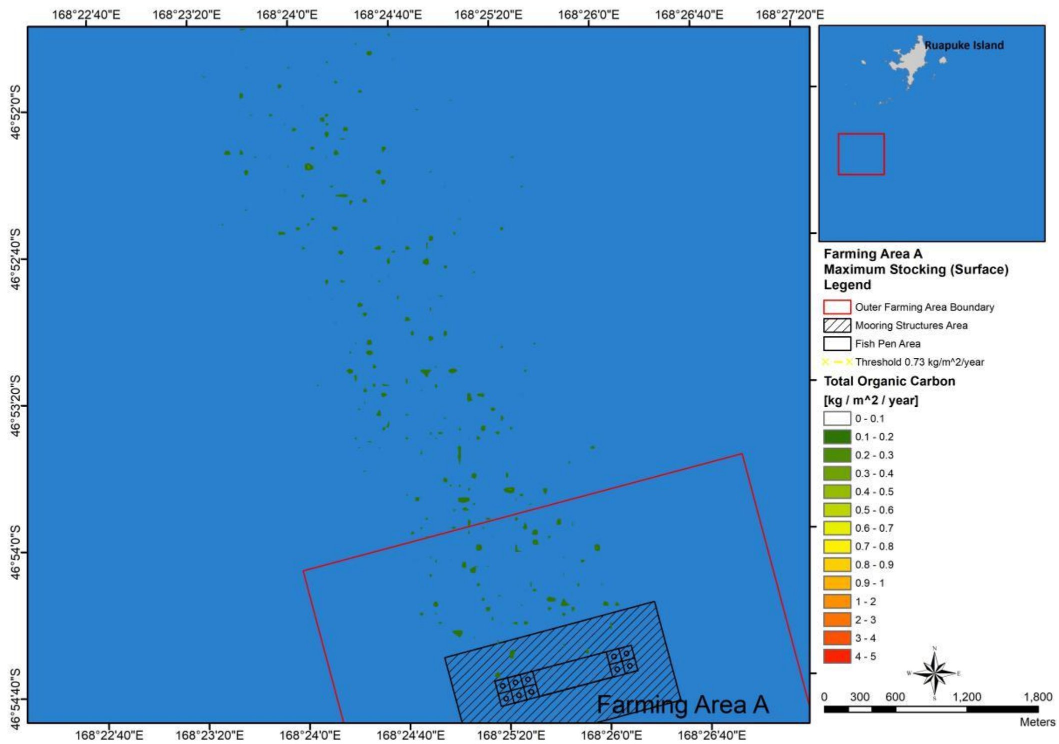

Figure 7: Farming Area A carbon deposition Surface Pen Scenario.

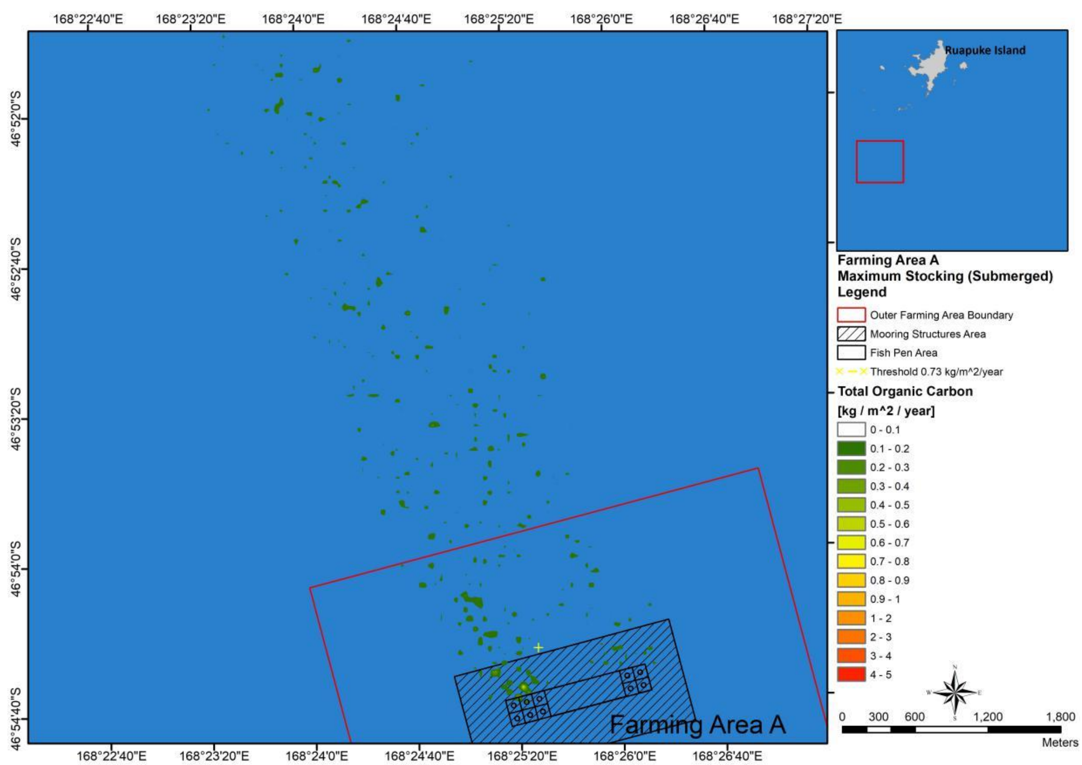

Figure 8: Farming Area A carbon deposition Submerged Pen Scenario.

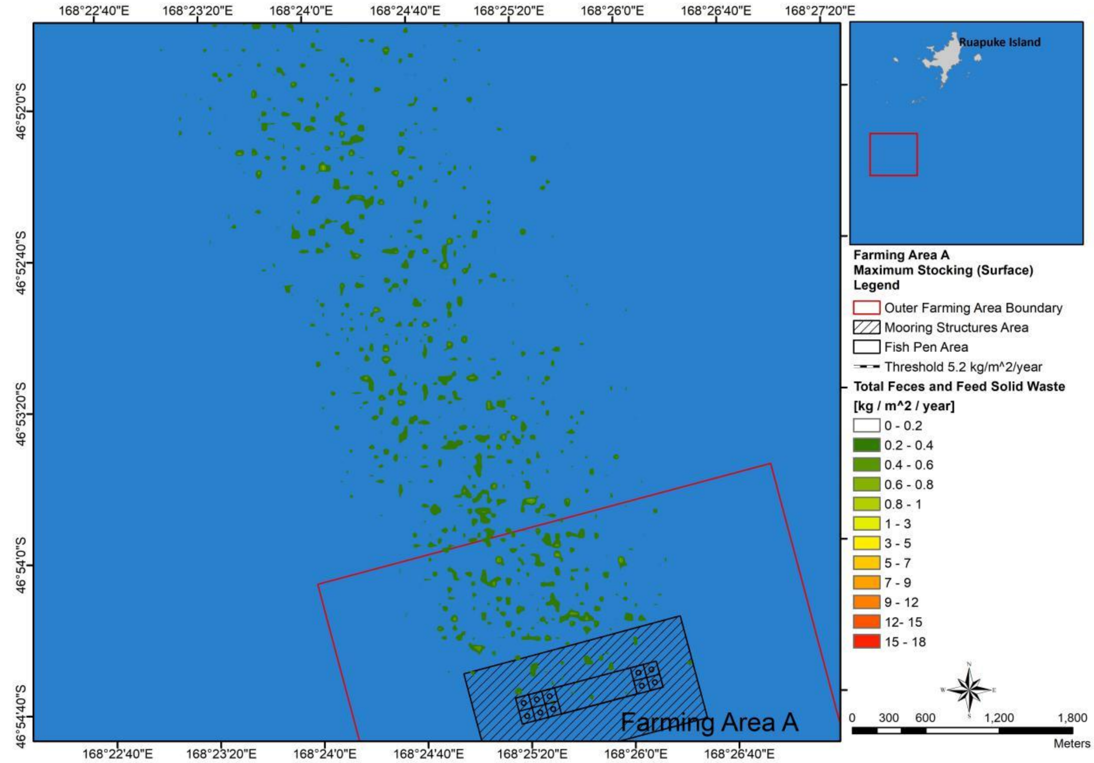

Figure 9: Farming Area A feed and faeces solids deposition Surface Pen Scenario.

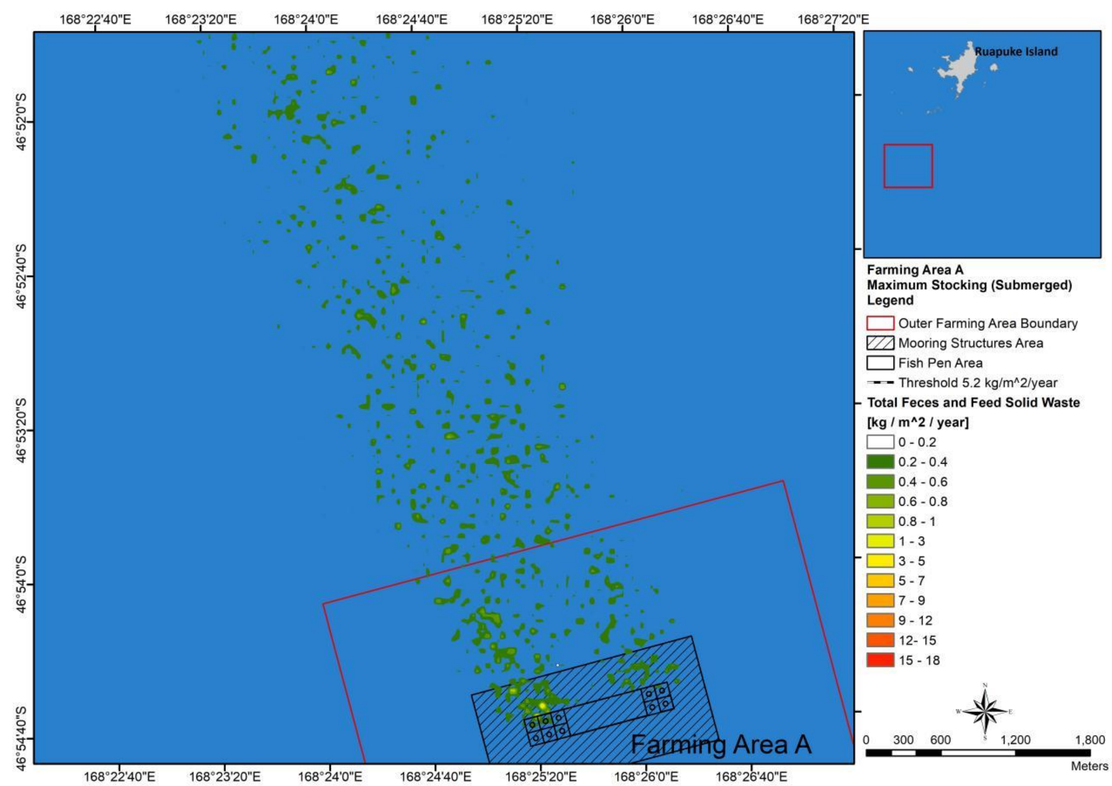

Figure 10: Farming Area A feed and faeces solids deposition Submerged Pen Scenario.

2.4.2 Farming Area B

Figure 11 to **Figure 14** below show the depositional footprint from both surface and submerged pen scenarios at Farming Area B. Zoomed in figures of each model simulation can be found in Appendix 2.

In general, farm discharges at Farming Area B are predicted to scattered approx. 1.5 km W of the pen set for surface pens and submerged pen model scenarios. Carbon deposition from surface situated pens is predicted to reach up to 1.25 kg m^{-2} yr^{-1}, while submersed pens deposit up to 3.0 kg m^{-2} yr^{-1} in isolated patches directly under the pens and a few hundred meters to the west (but well within the mooring structure area). Solids deposition from surface pens reaches over 4.0 kg m^{-2} yr^{-1}, while subsurface pens deposit more than 5.2 kg m^{-2} yr^{-1} at scattered locations under the pens and a few hundred meters to the W.

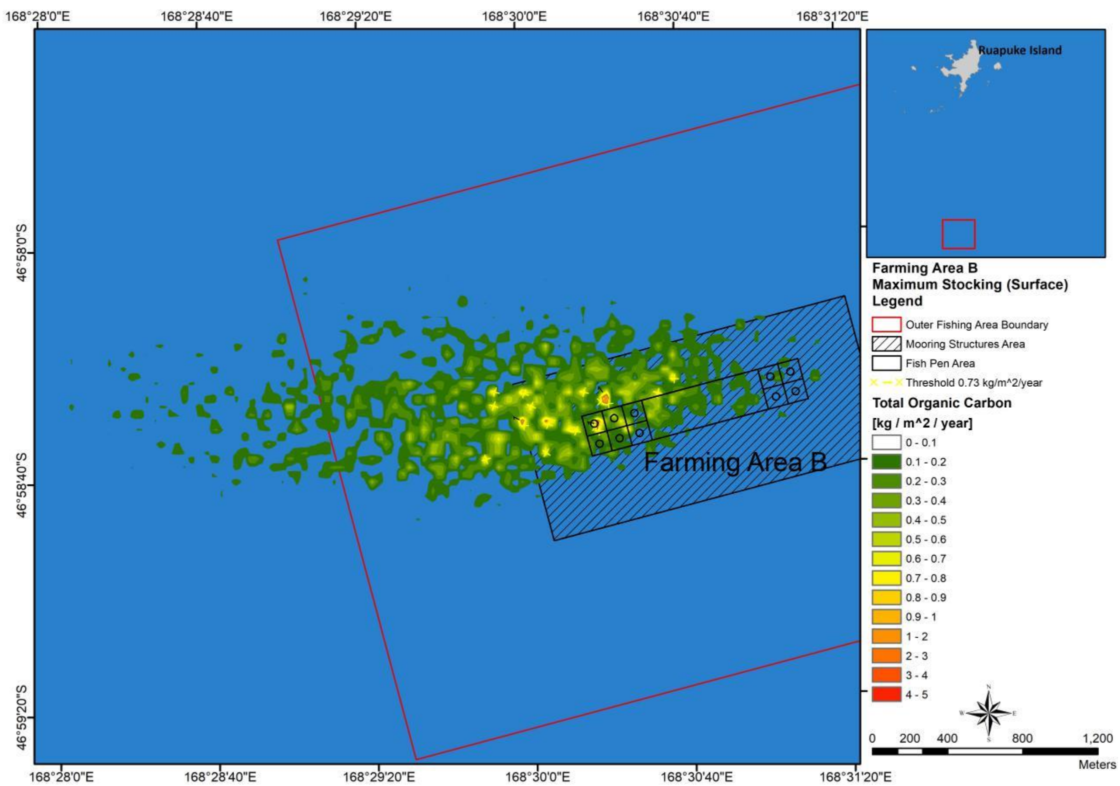

Figure 11: Farming Area B carbon deposition Surface Pen Scenario.

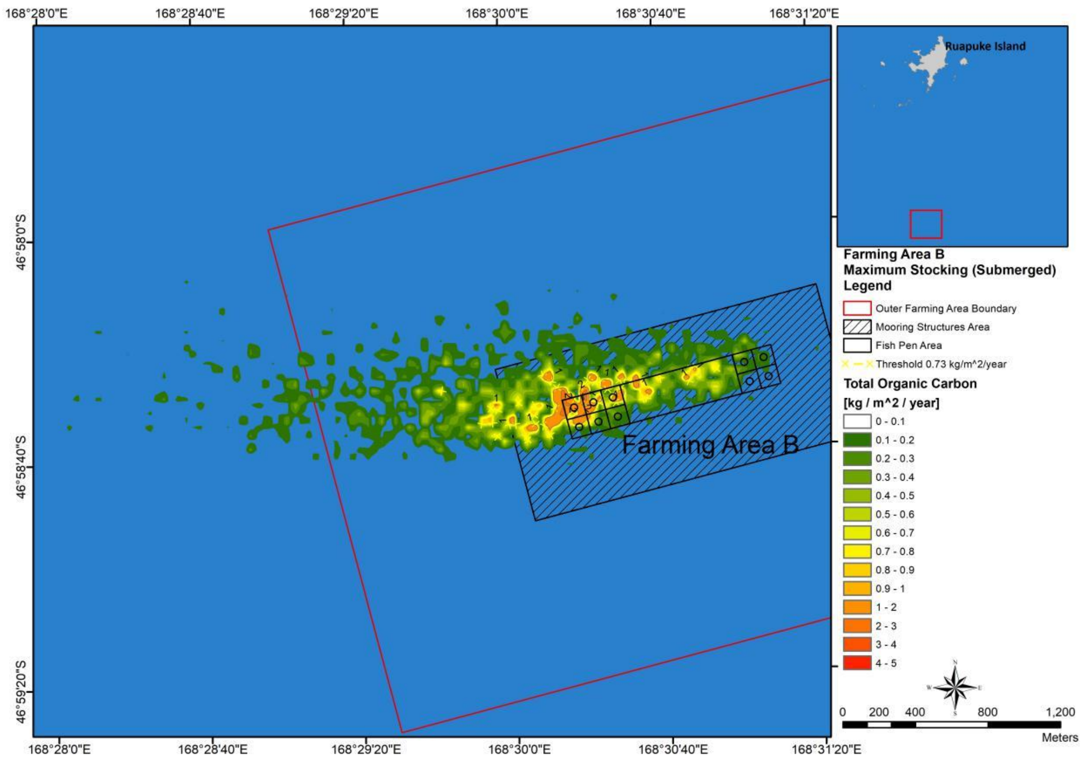

Figure 12: Farming Area B carbon deposition Submerged Pen Scenario.

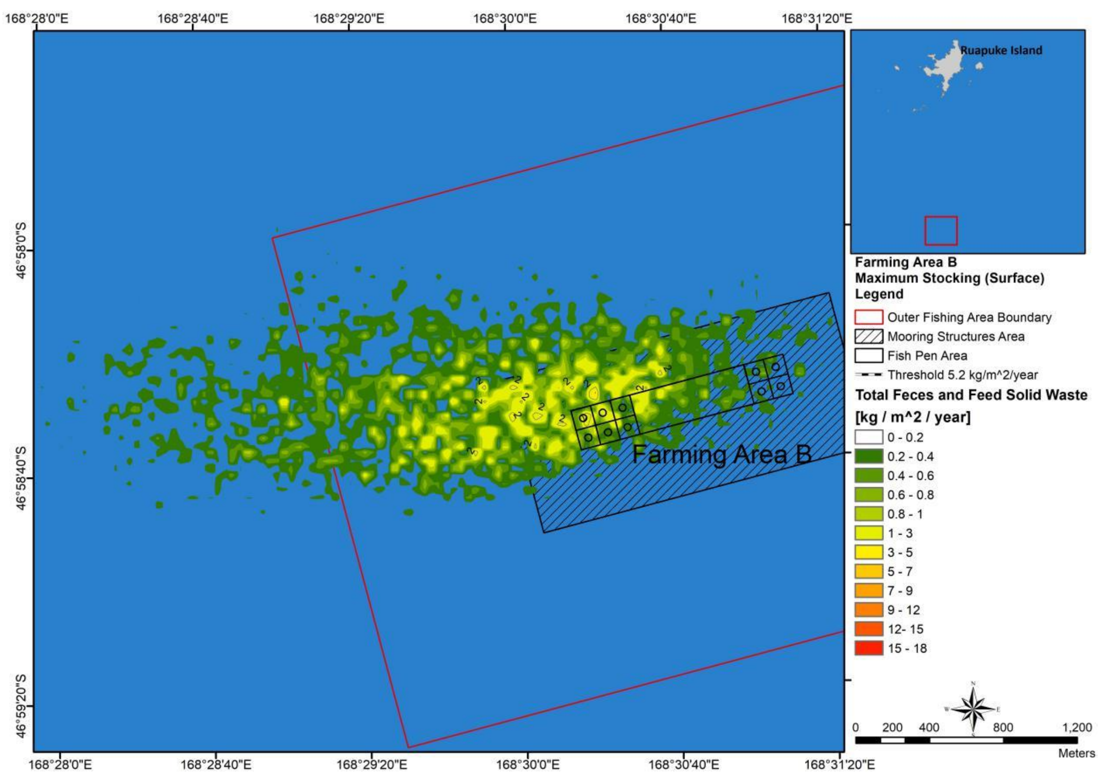

Figure 13: Farming Area B feed and faeces solids deposition Surface Pen Scenario.

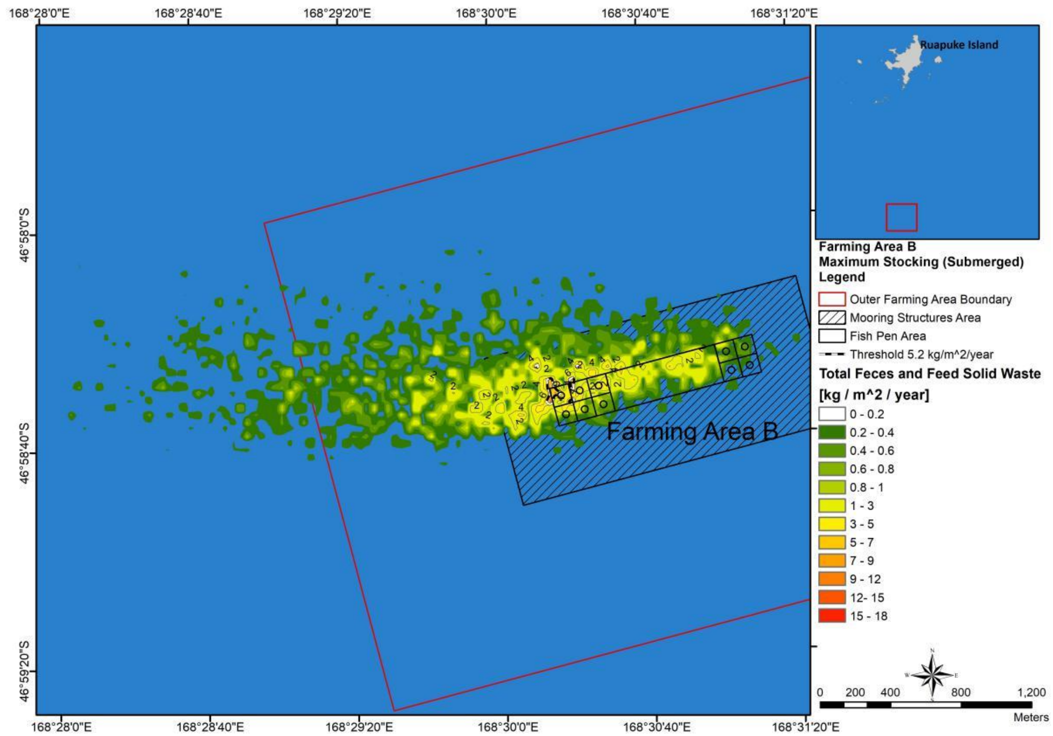

Figure 14: Farming Area B feed and faeces solids deposition Submerged Pen Scenario.

2.4.3 Farming Area C

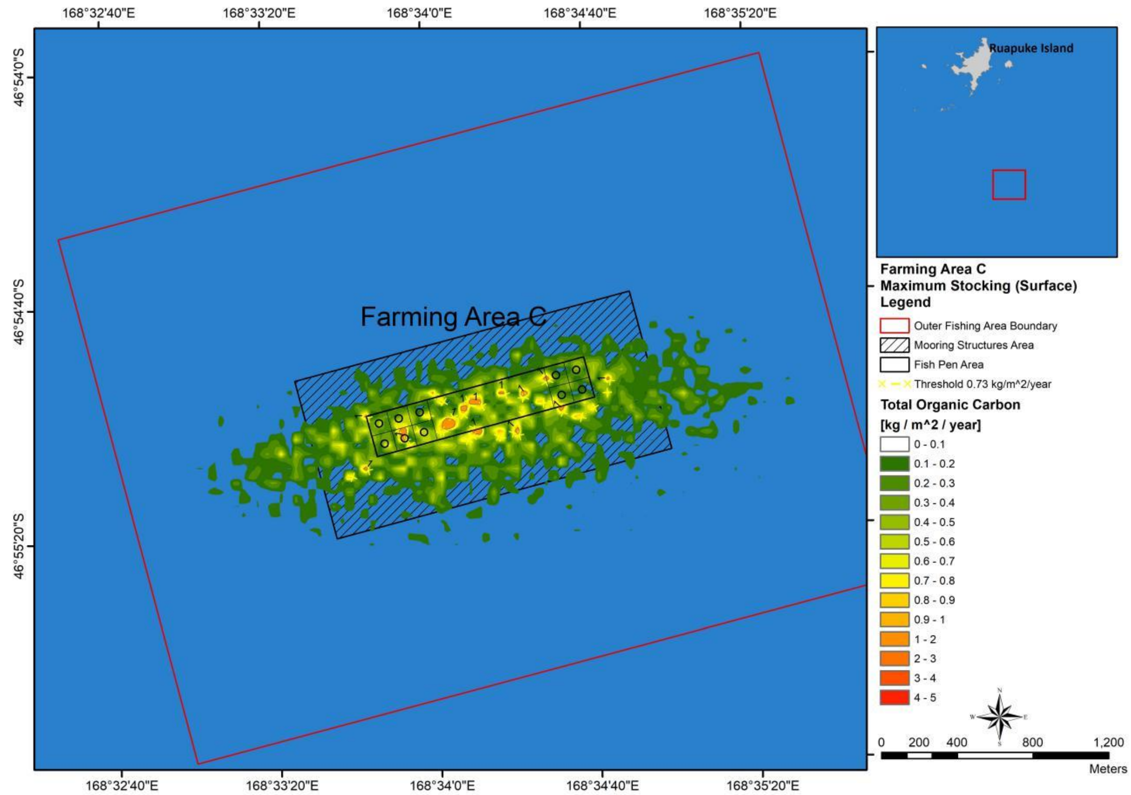

Figure 15 to **Figure 18** below show the depositional footprint from both surface and submerged pen scenarios at Farming Area C. Zoom in figures of each model simulation can be found in Appendix 2.

Unlike the depositional footprints of Farming Aea A and B, farm discharges at Farming Area C are predicted to scatter in an ellipse around the pen sets approx. 800m NE and SW of the pen set during the surface pen scenario, and approx. 500m ENE and 300m WSW for submerged pens.

Carbon deposition from surface situated pens is predicted to reach up to 1.0 kg m^{-2} yr^{-1}, while submersed pens deposit up to 2.0 kg m^{-2} yr^{-1} in isolated patches within the fish pen area. Solids deposition from surface pens reaches up to 3.0 kg m^{-2} yr^{-1} and higher values >5 kg are observed under the cages during the submerged scenario.

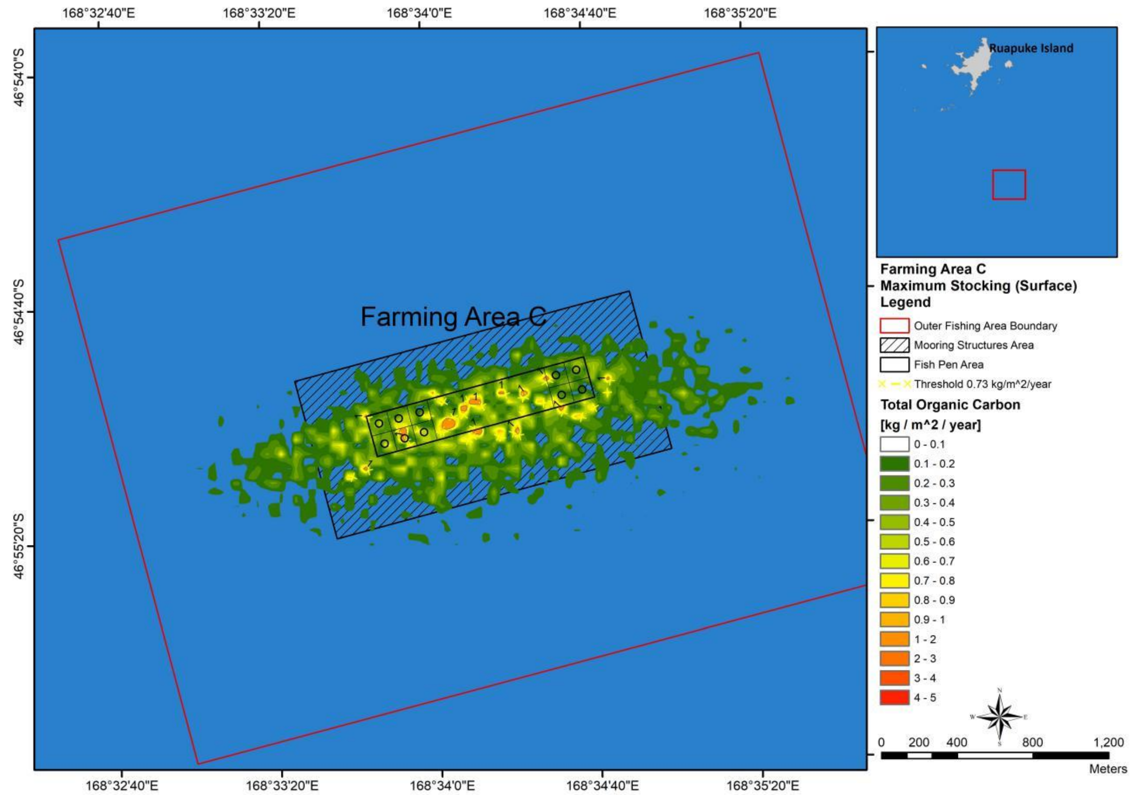

Figure 15: Farming Area C carbon deposition Surface Pen Scenario.

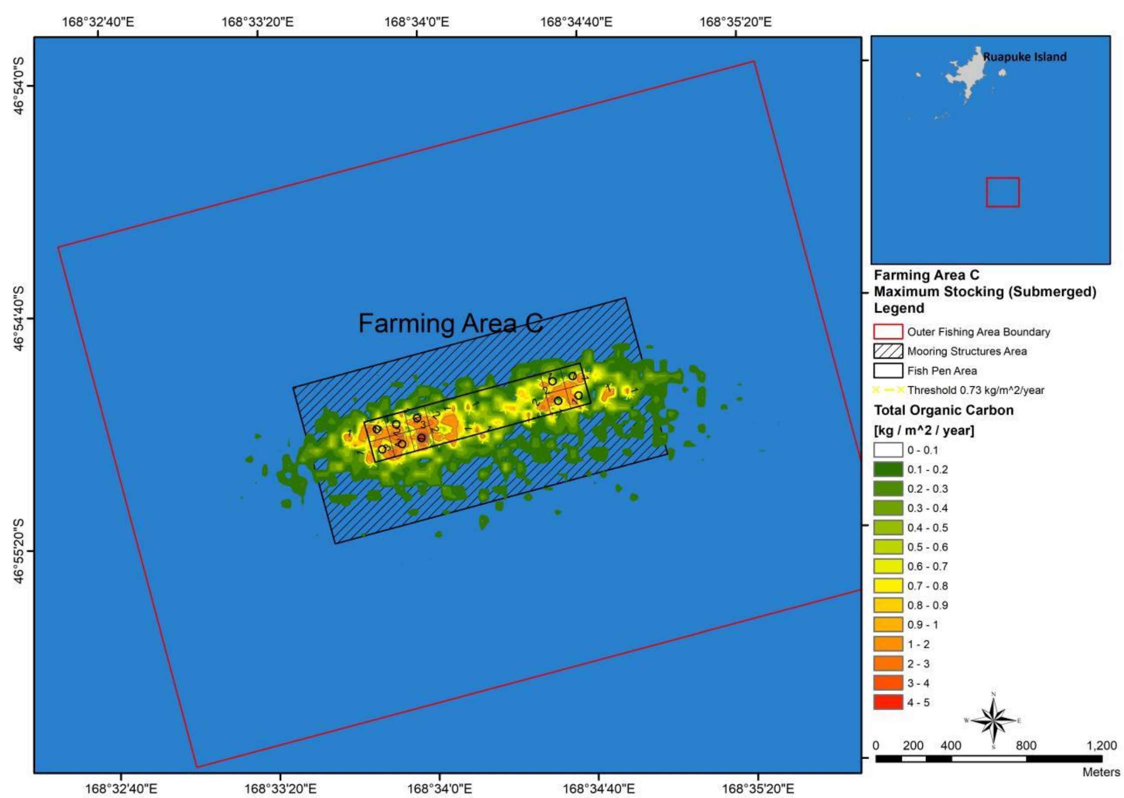

Figure 16: Farming Area C carbon deposition Submerged Pen Scenario.

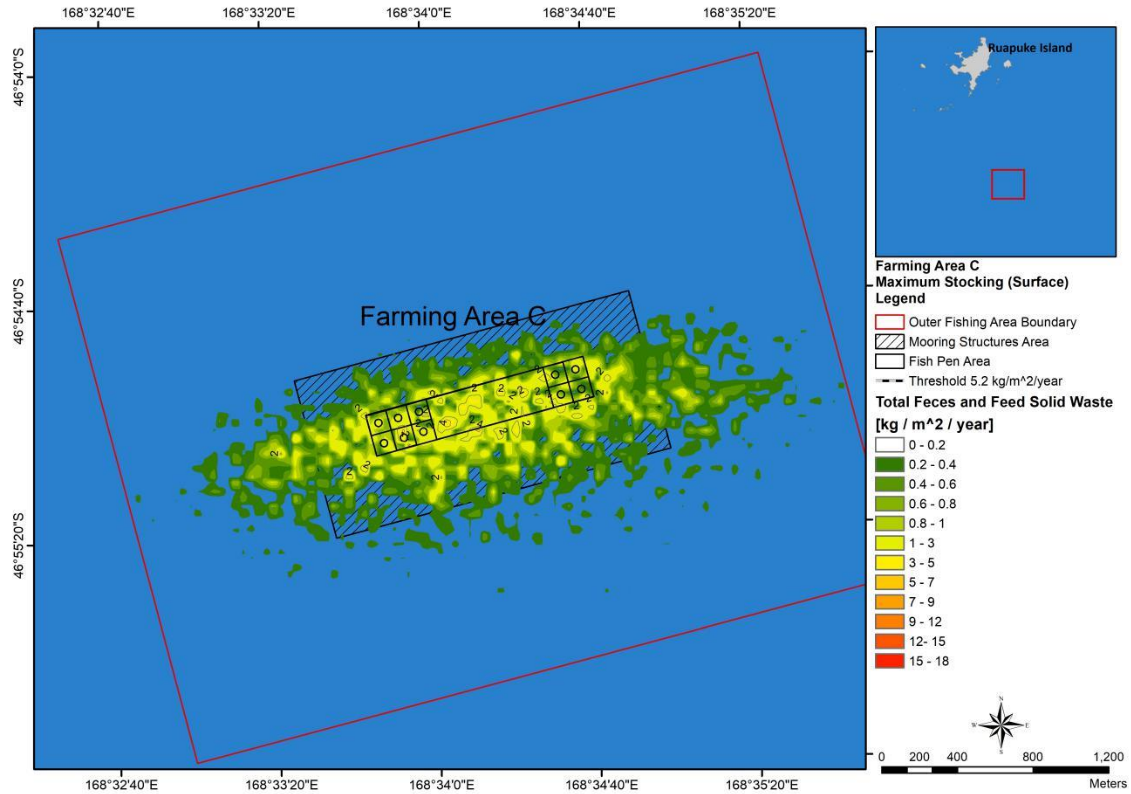

Figure 17: Farming Area C feed and faeces solids deposition Surface Pen Scenario.

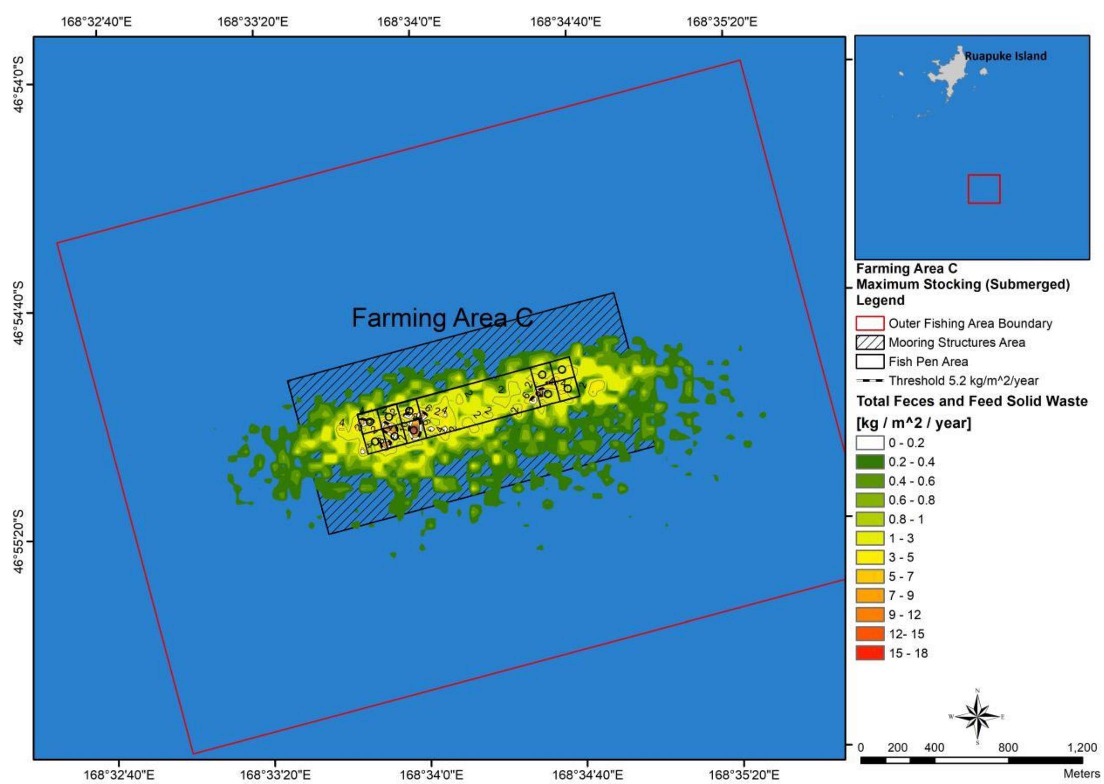

Figure 18: Farming Area C feed and faeces solids deposition Submerged Pen Scenario.

2.4.4 Farming Area D

Figure 19 to **Figure 22** below show the depositional footprint from both surface and submerged pen scenarios at Farming Area D. Zoomed in figures of each model simulation can be found in Appendix 2.

Farm discharges at Farming Area D are predicted to scatter to the NE over 2.5 km from the pen set during surface and submerged depositional scenarios.

Carbon deposition from surface situated pens is predicted to reach up to 0.5 kg m^{-2} yr^{-1} several 1000 meters from the pens (small patches only) while submersed pens deposit over 3.0 kg m^{-2} yr^{-1} in isolated patches directly under the pens. Solids deposition from surface pens reached over 2 kg m^{-2} yr^{-1} in a couple of isolated patches only. Subsurface solids concentrations are predicted to accumulate at more than 5 kg m^{-2} yr^{-1} under the farm and a few small patches a few hundred meters to the NE.

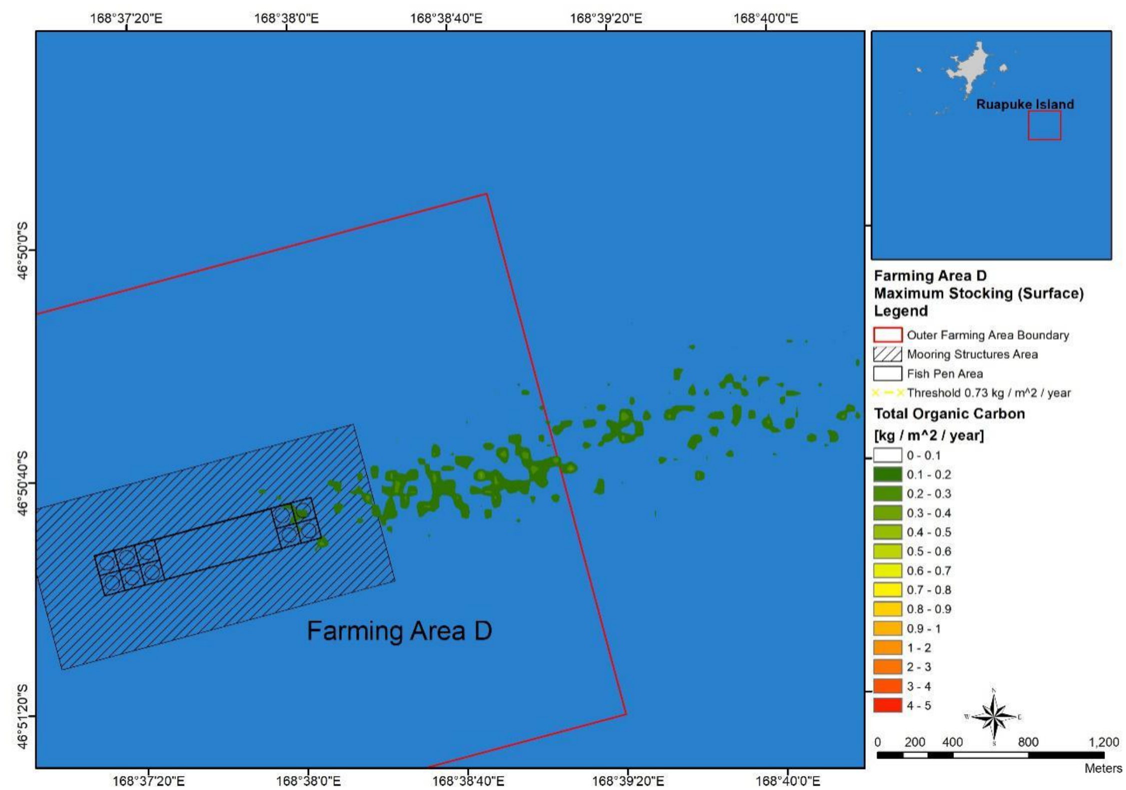

Figure 19: Farming Area D carbon deposition Surface Pen Scenario.

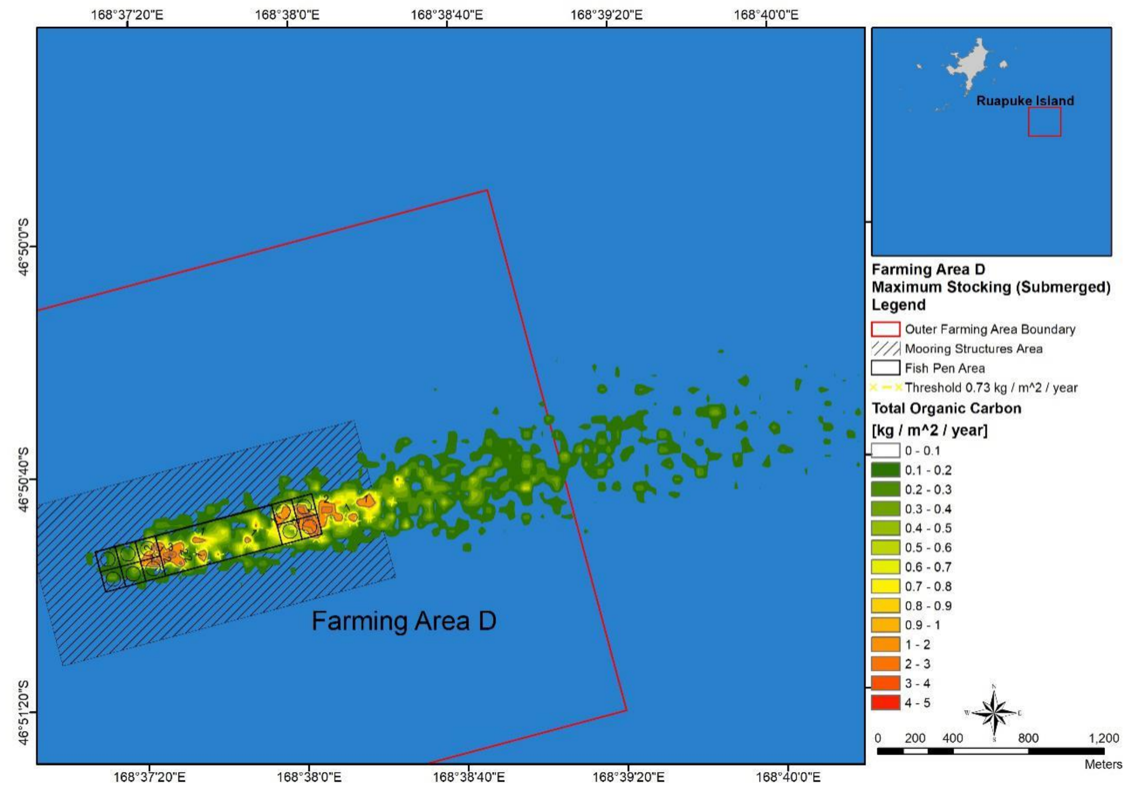

Figure 20: Farming Area D carbon deposition Submerged Pen Scenario.

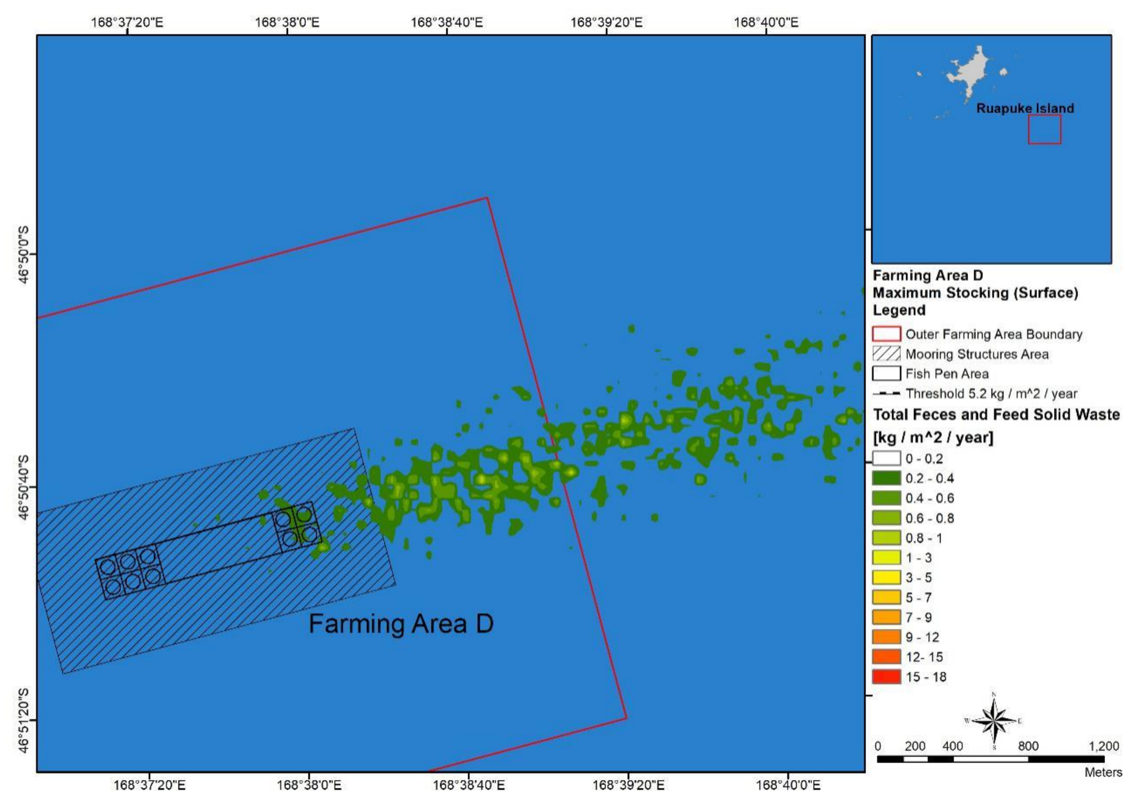

Figure 21: Farming Area D feed and faeces solids deposition Surface Pen Scenario.

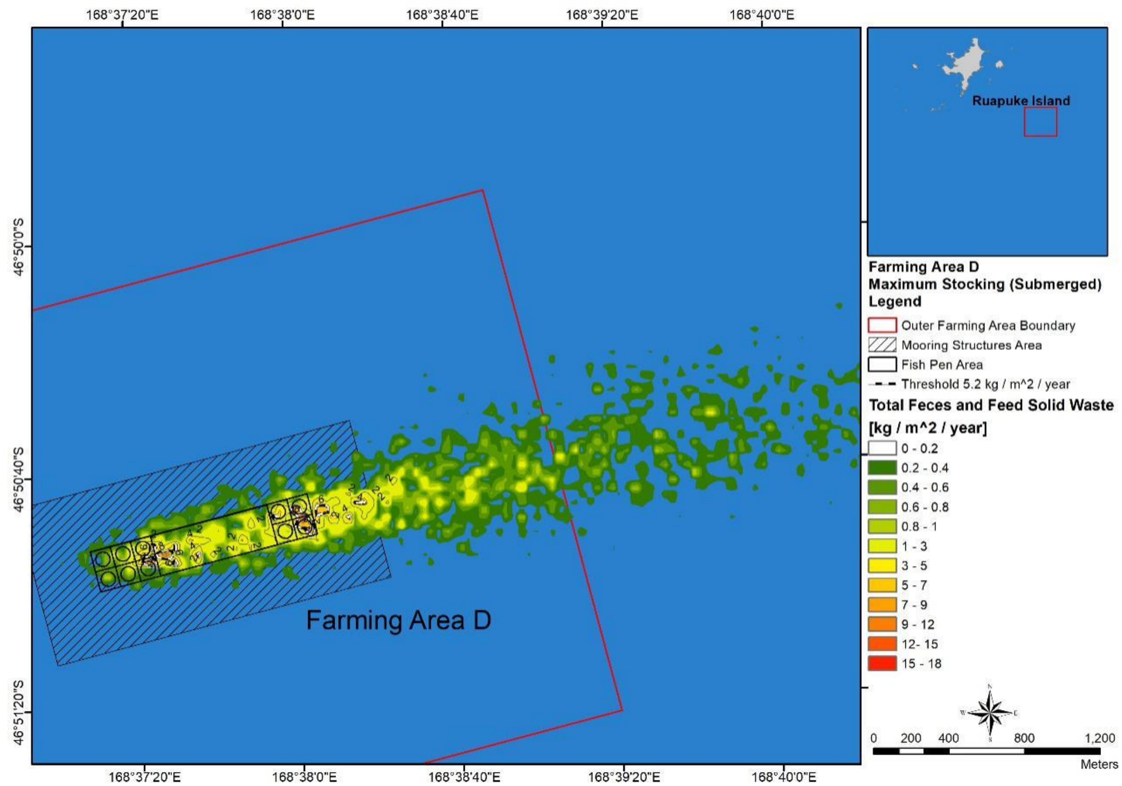

Figure 22: Farming Area D feed and faeces solids deposition Submerged Pen Scenario.

2.4.5 Farming Area E

Figure 23 to **Figure 26** below show the depositional footprint from both surface and submerged pen scenarios at Farming Area E. Zoomed in figures of each model simulation can be found in Appendix 2.

Like Farming Area C, farm discharges at Farming Area E are predicted to scatter in an ellipse around the pen set, in a predominantly NE and SW orientation.

Carbon deposition from surface situated pens is predicted to reach up to 2 kg m^{-2} yr^{-1}, while submersed pens deposit over 4 kg m^{-2} yr^{-1} in isolated patches directly under the pen. Solids deposition from surface pens reaches over to 5 kg m^{-2} yr^{-1} in a couple of isolated patches only, while the subsurface scenario shows a more concentration patch of solids deposition directly within the fish pen area.

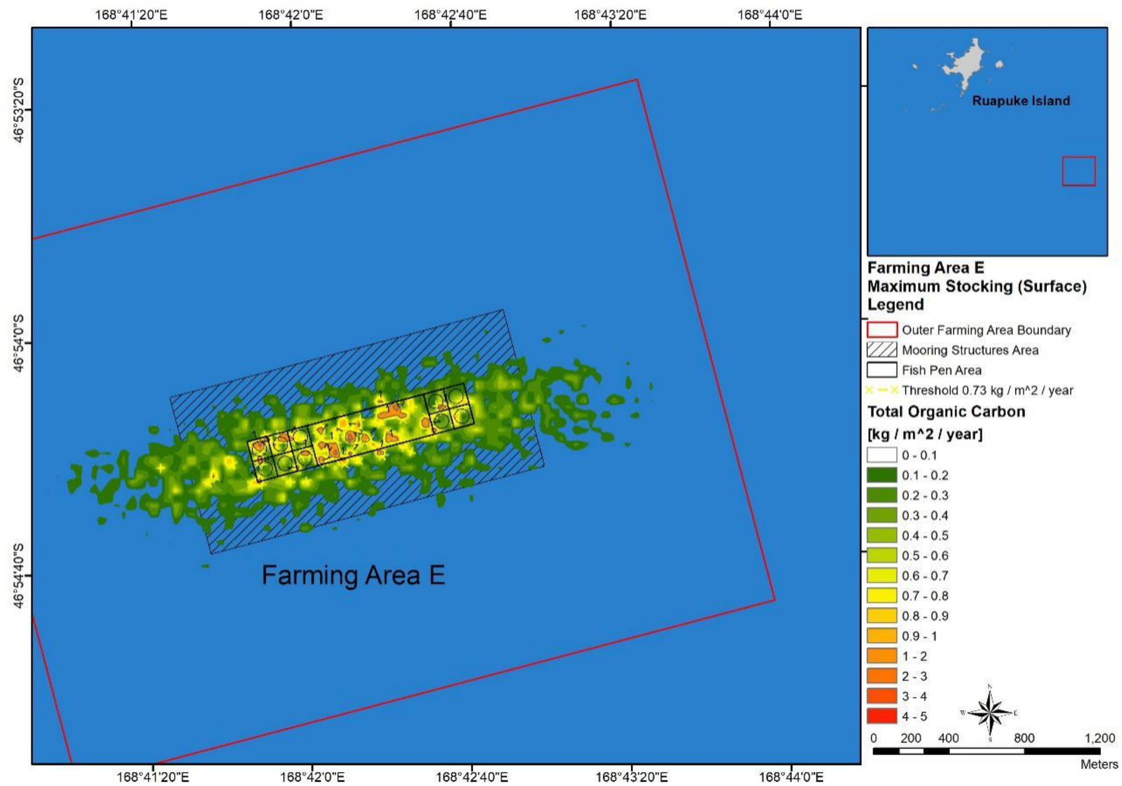

Figure 23: Farming Area E carbon deposition Surface Pen Scenario.

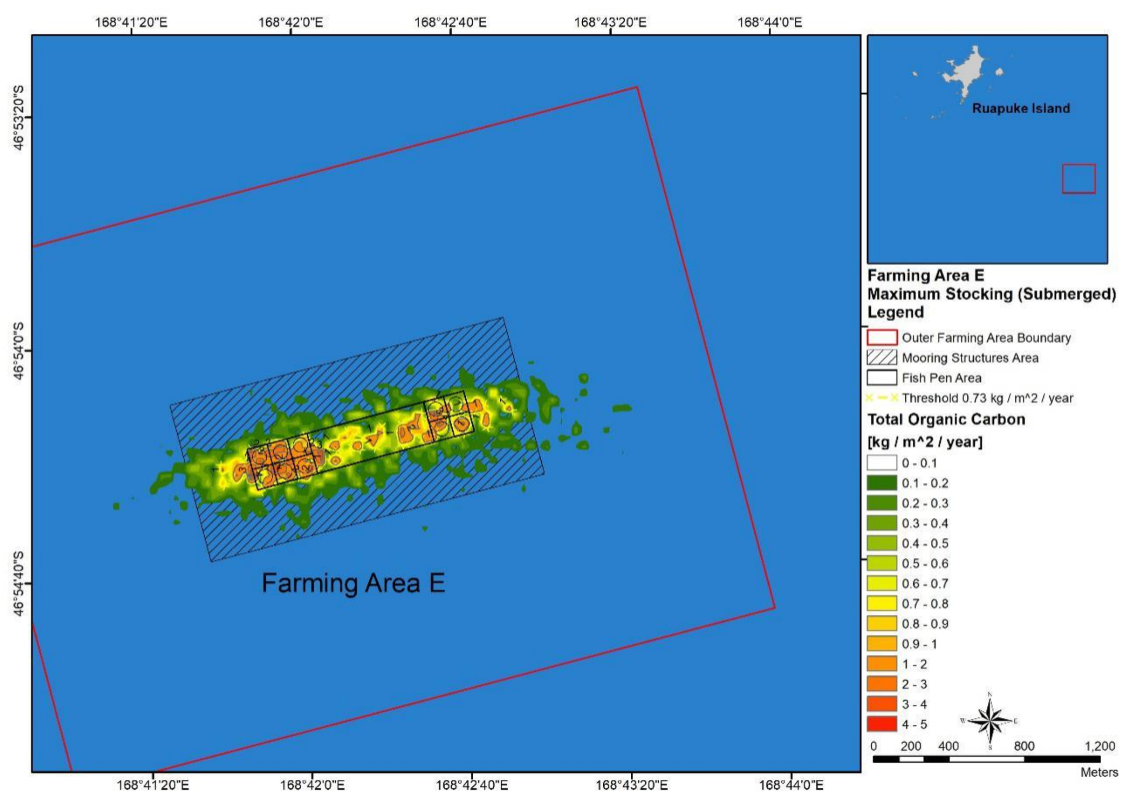

Figure 24: Farming Area E carbon deposition Submerged Pen Scenario.

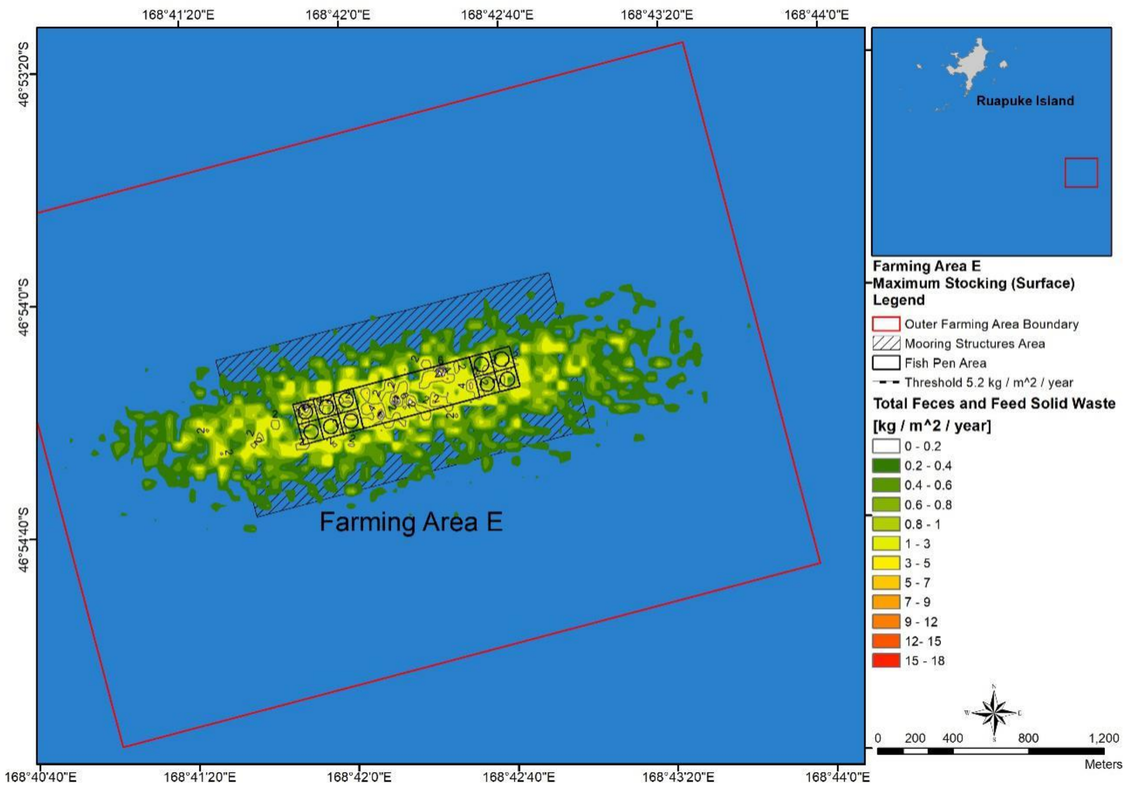

Figure 25: Farming Area E feed and faeces solids deposition Surface Pen Scenario.

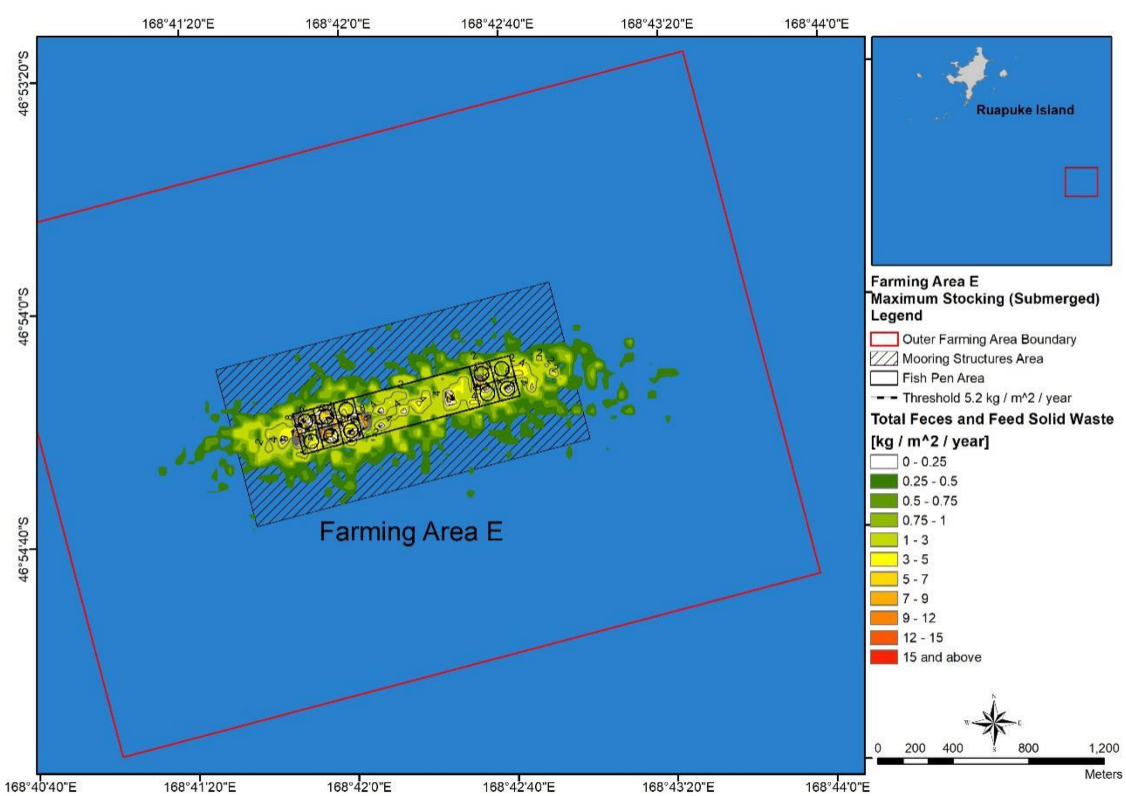

Figure 26: Farming Area E feed and faeces solids deposition Submerged Pen Scenario.

3 CONCLUSION / DISCUSSION

- The deposition model using 1-year current velocity extractions (from 2017) from the ADS hydrodynamic model show that faeces and solids deposition from the proposed farms will generally be deposited in the direction of the predominant current. The current fields at each Farming Area do differ though most have a predominately SW and NW flow direction.
- At some Farming Areas (A, B, and D) the depositional footprint can skew more than 2 km from the pen sets. Because the discharged material is scattered at such distances, the concentrations of waste predicted to accumulate at any one given location are relatively low. However, some deposition (defined here as breaches in the carbon and solids thresholds of 0.73kg/m2/year and 5.2kg/m2/year respectively) is predicted to occur in small patches outside the boundaries of the individual cage areas but usually within the mooring areas and certainly within the proposed outer farming area boundary.
- The model predictions presented in this report were derived from the New DEPOMOD software which assumes all pens within a farm are farmed uniformly and that feeding schedules are constant throughout the year. It relies on water current data extracted from model results driven by forcing's for 2017 (i.e. wind). Sporadic extreme weather events that may briefly increase dispersal and resuspension of farm wastes may alter the predicted footprints especially if accompanied by large waves which may generate strong seabed orbital flows not modelled in this study.
- Mass loading during the submerged scenario indicates that the depositional footprint is more concentrated.
- The data from August field sampling suggested that epibenthic fauna is sparse at these Farming Areas in numbers that would strongly suggest the absence of sensitive biogenic reef communities. Infaunal results also show generally low abundance and richness across all 5 proposed farming areas.
- Several hours of splash camera footage taken across 35 locations (see ADS Volume 1) within the proposed farming areas highlighted a generally scoured seabed indicating relatively moderate-strong currents or wave generated flows. These observations are supported by model resulting which are mostly greater than 0.09 m s^{-1}, which is generally considered the speed in which deposited faeces can be scattered along the seabed (*i.e.* dispersive current flows).

4 REFERENCES

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APPENDIX 1 : CURRENT ROSE PLOTS FROM EACH PROPOSED FARMING AREA

A1.1 FARMING AREA A

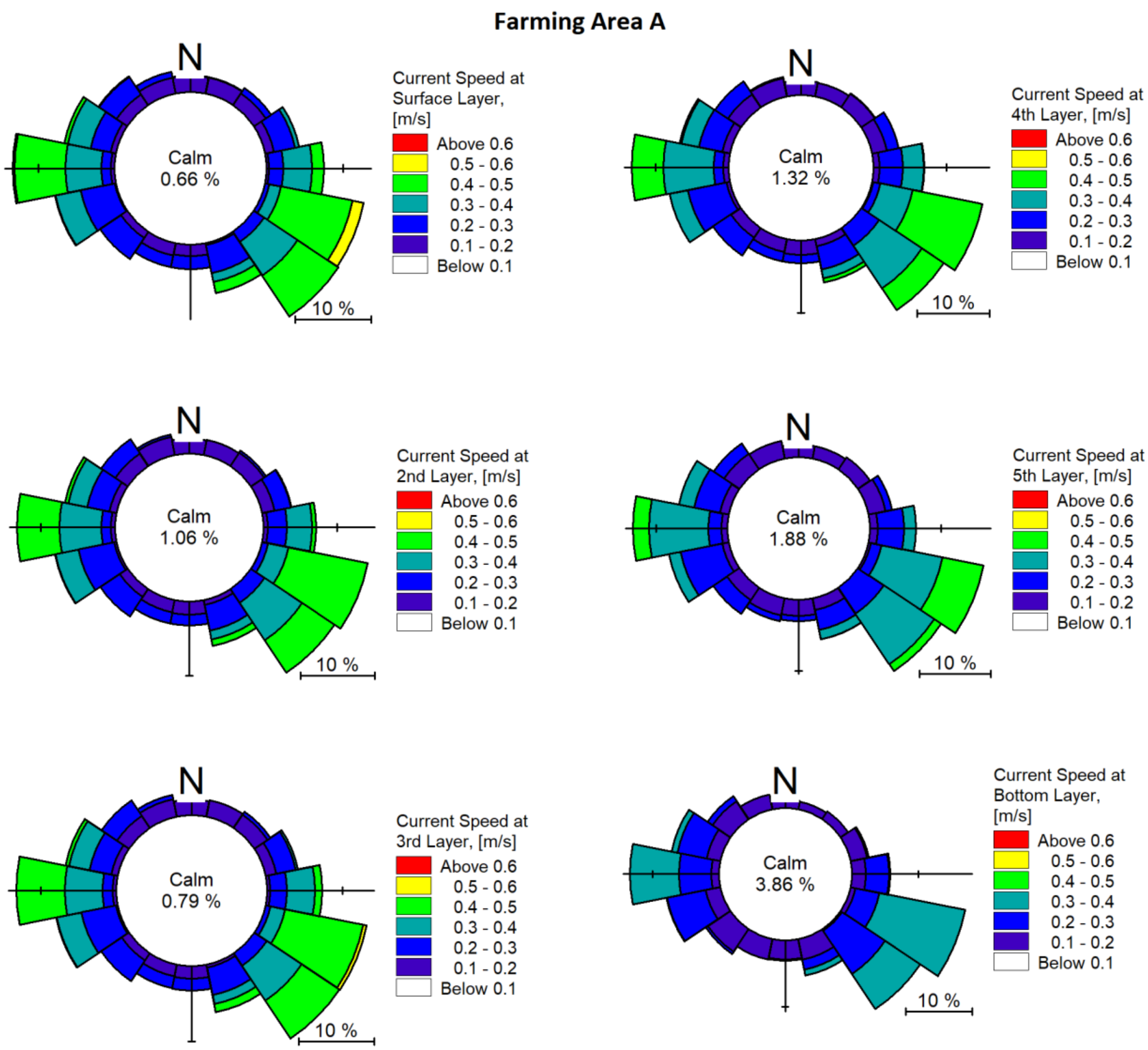

Figure 27: 3D Current rose from Farming Area A clearly indicating a moderate-strong SE/W flow down the water column. Current speed and direction extraction were taken in the center of the proposed Farming Area.

A1.2 FARMING AREA B

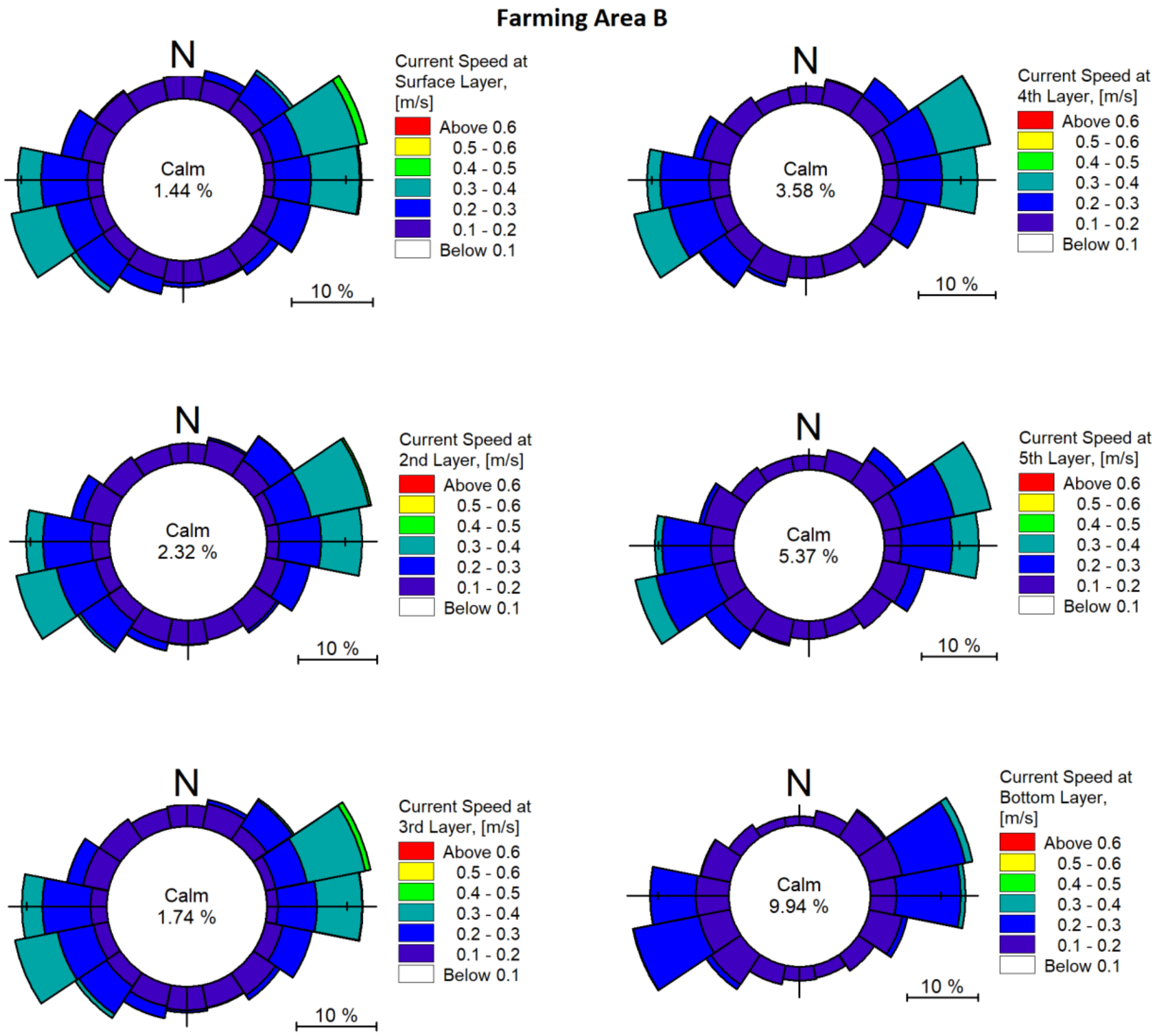

Figure 28: : 3D Current rose from Farming Area B clearly indicating a moderate ENE/WSW flow down the water column. Current speed and direction extraction were taken in the center of the proposed Farming Area.

A1.3 FARMING AREA C

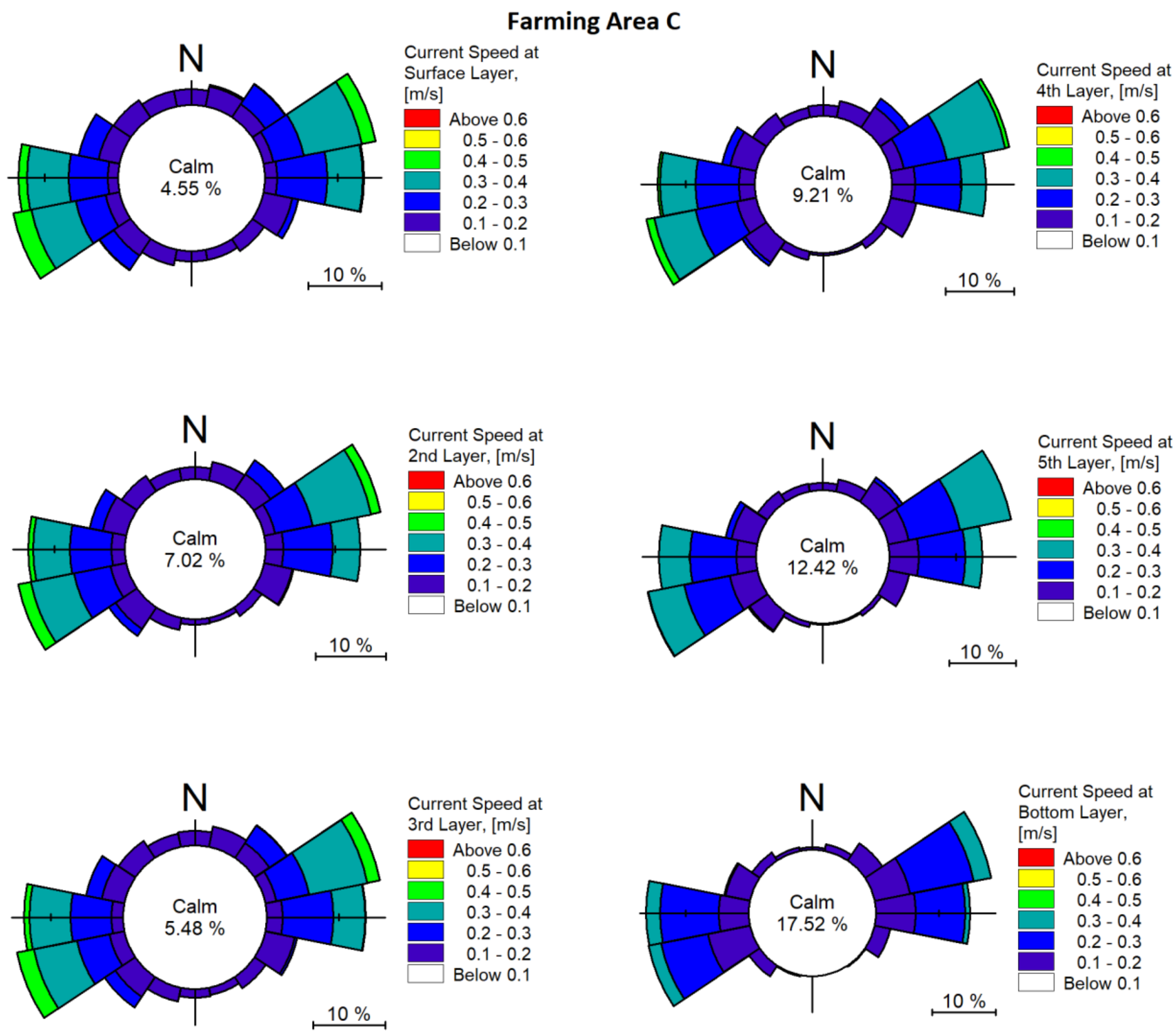

Figure 29: : 3D Current rose from Farming Area C clearly indicating a moderate-strong ENE/WSW flow down the water column. Current speed and direction extraction were taken in the center of the proposed Farming Area.

A1.4 FARMING AREA D

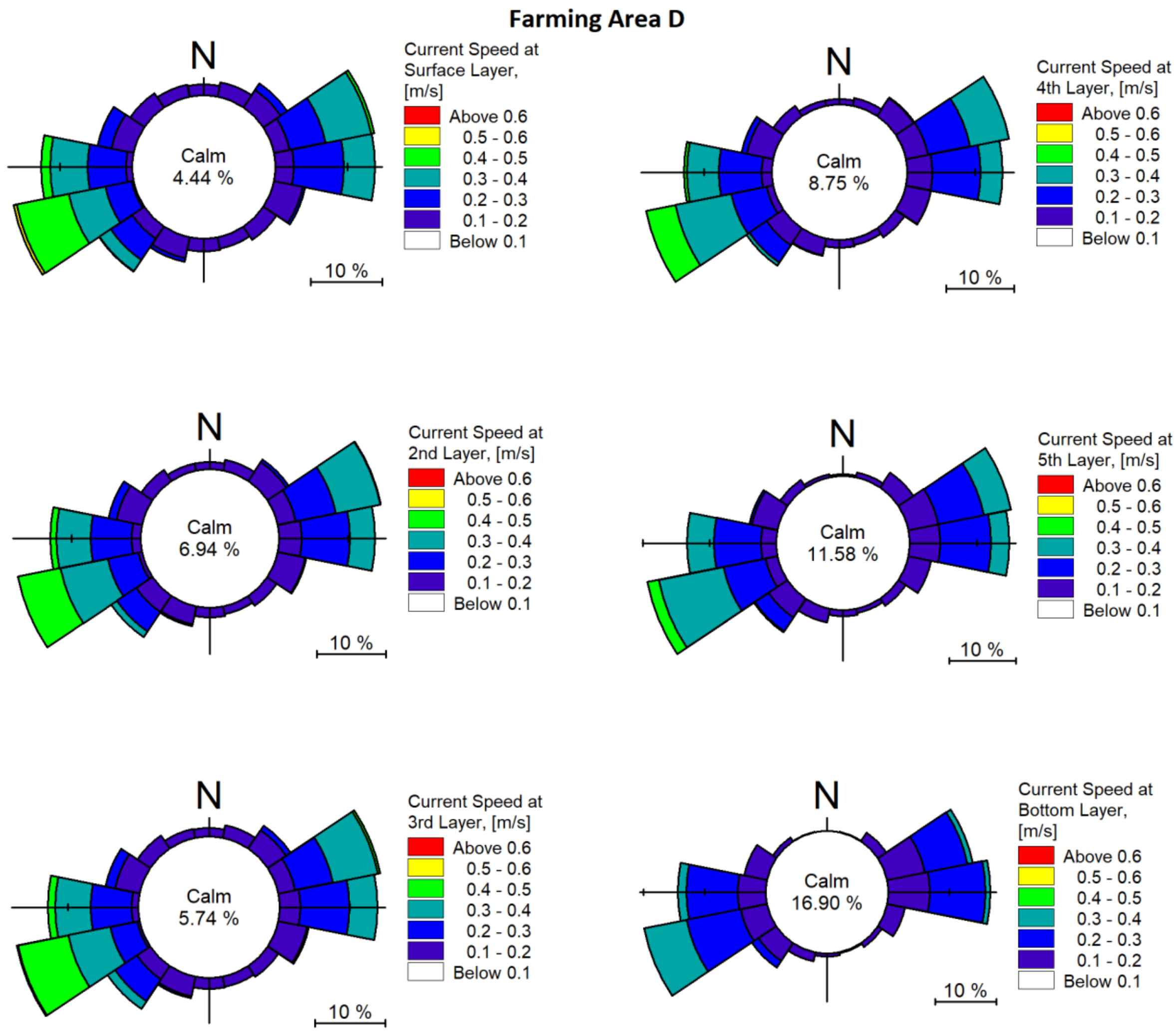

Figure 30: 3D Current rose from Farming Area D clearly indicating a moderate-strong ENE/WSW flow down the water column Current speed and direction extraction were taken in the center of the proposed Farming Area.

A1.5 Farming Area E

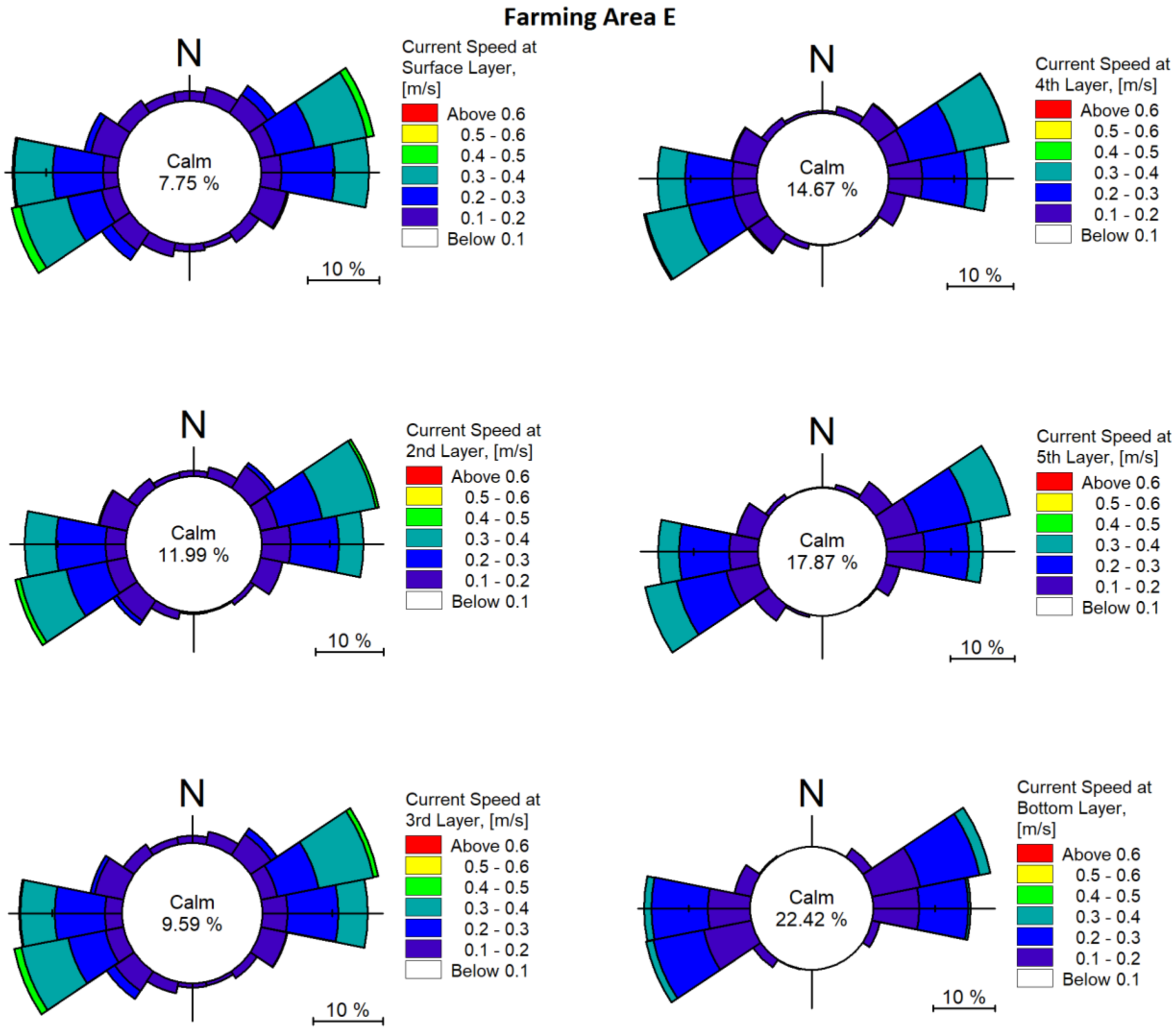

Figure 31: 3D Current rose from Farming Area E clearly indicating a moderate ENE/WSW flow down the water column. Current speed and direction extraction were taken in the center of the proposed Farming Area.

APPENDIX 2: ZOOMED IN CARBON AND SOLID DEPOSITIONAL PLOTS FROM EACH PROPOSED FARMING AREA

A2.1 FARMING AREA A

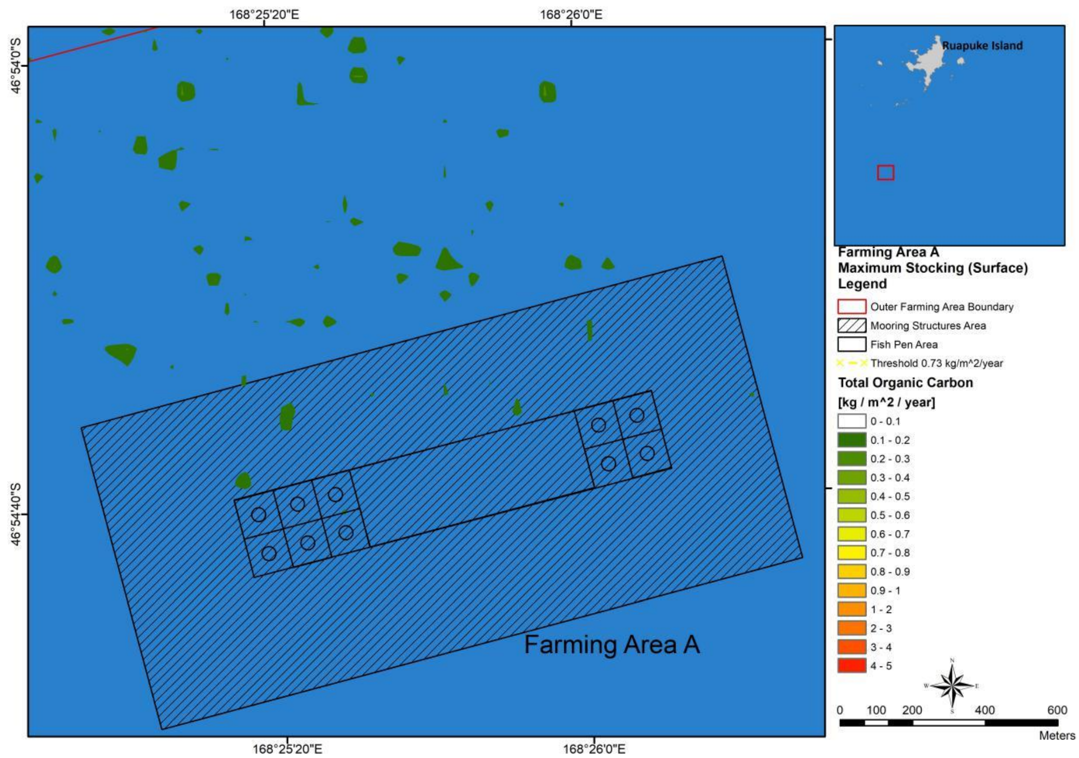

Figure 32: Farming Area A carbon deposition Surface Pen Scenario (Zoomed in).

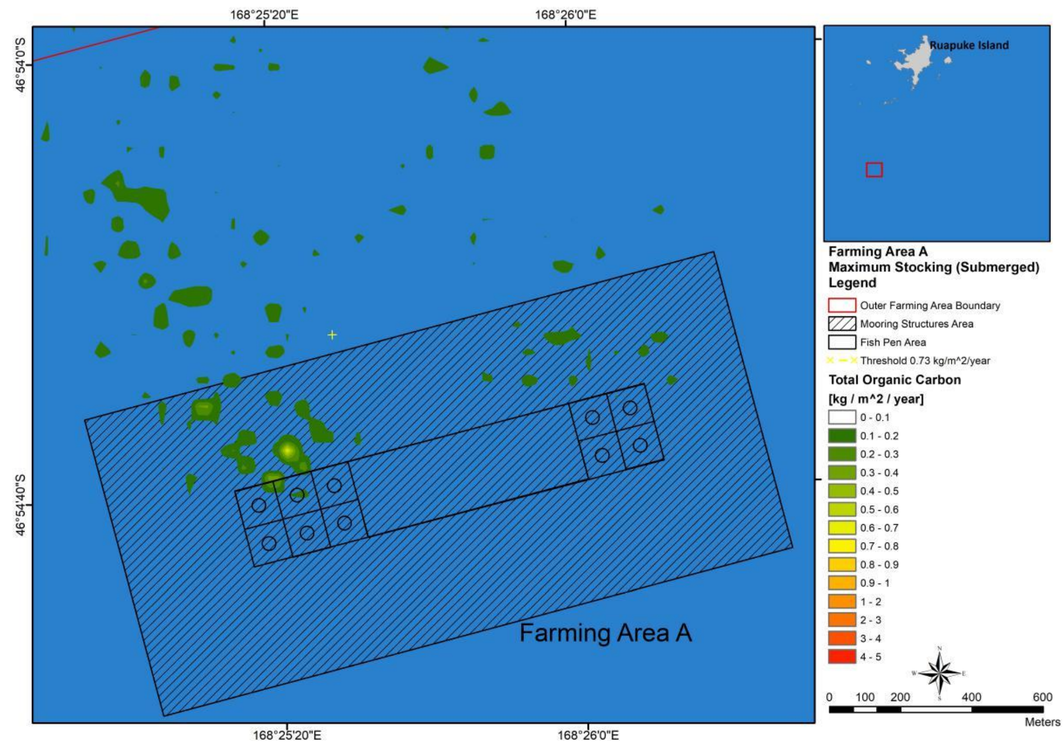

Figure 33: Farming Area A carbon deposition Submerged Pen Scenario (Zoomed in).

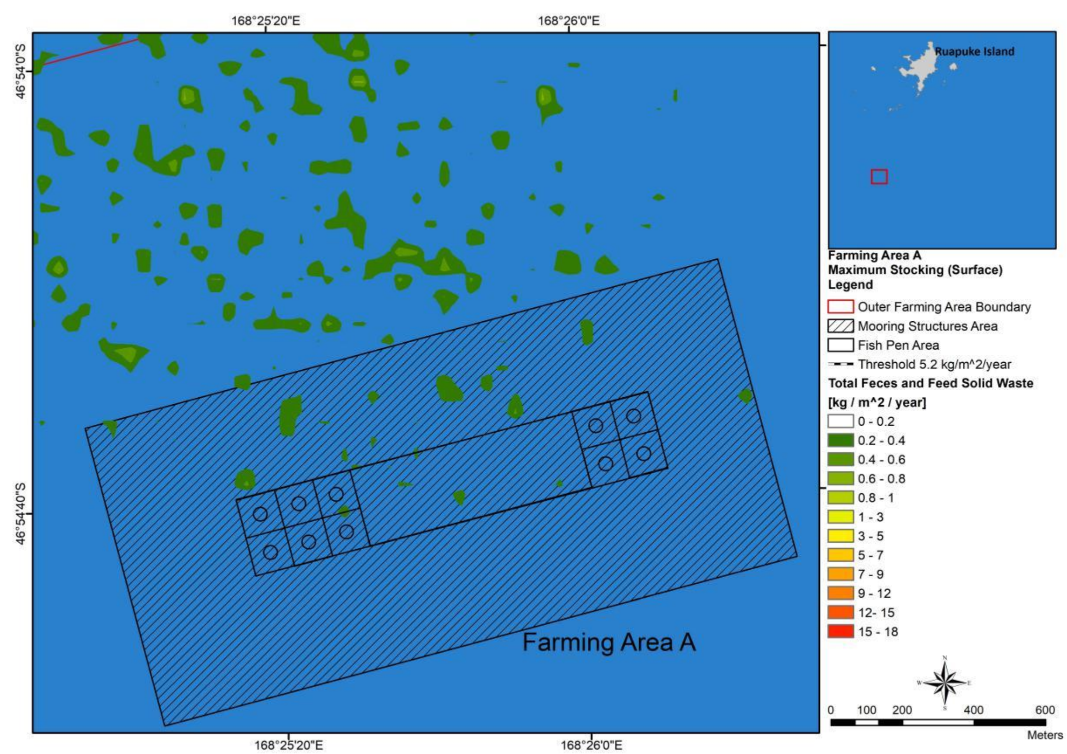

Figure 34: Farming Area A feed and faeces solids deposition Surface Pen Scenario (Zoomed in).

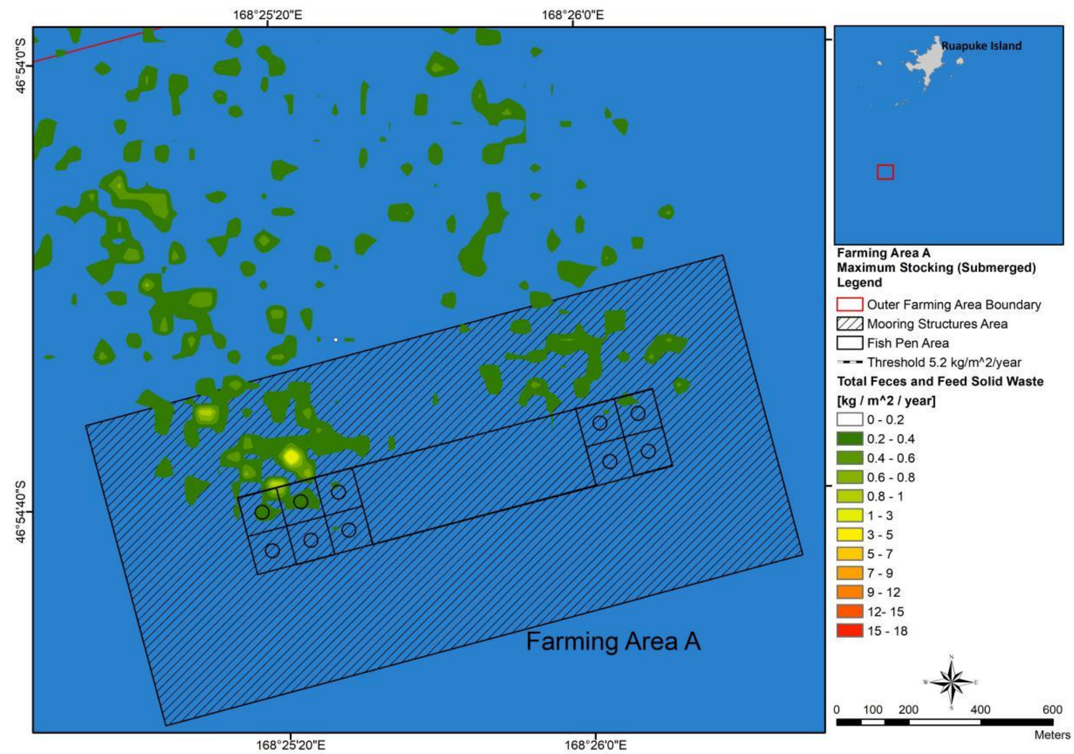

Figure 35: Farming Area A feed and faeces solids deposition Submerged Pen Scenario (Zoomed in).

A2.2 FARMING AREA B

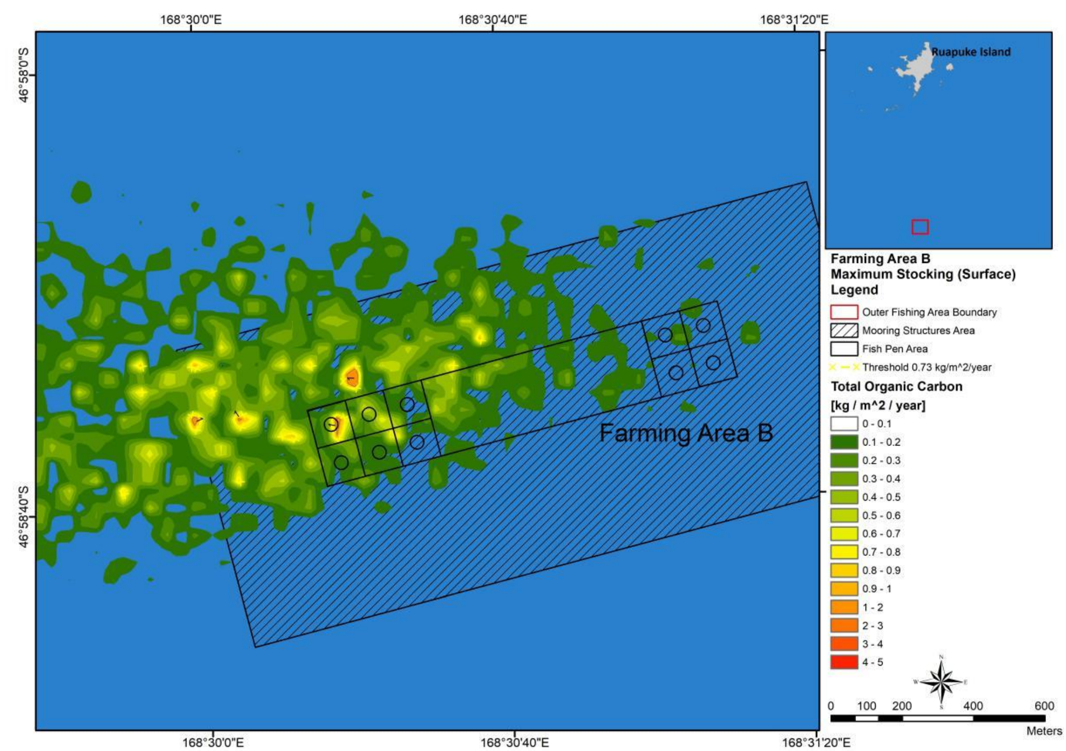

Figure 36: Farming Area B carbon deposition Surface Pen Scenario (zoomed in).

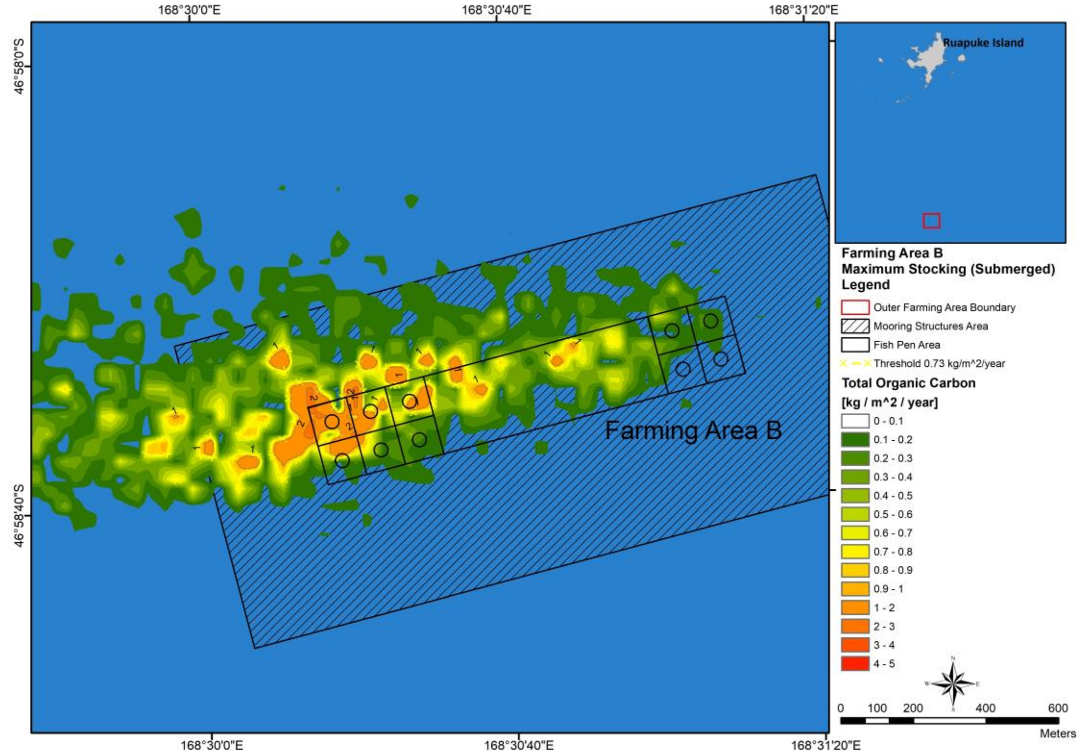

Figure 37: Farming Area B carbon deposition Submerged Pen Scenario (Zoomed in).

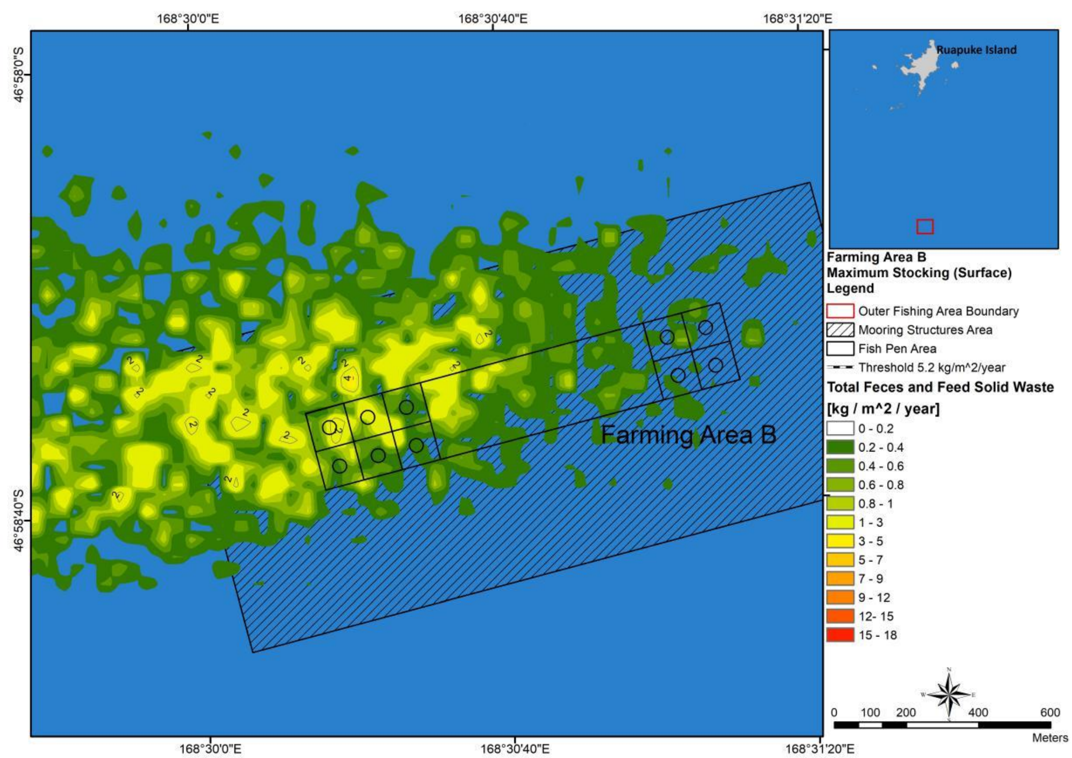

Figure 38: Farming Area B feed and faeces solids deposition Surface Pen Scenario (Zoomed in).

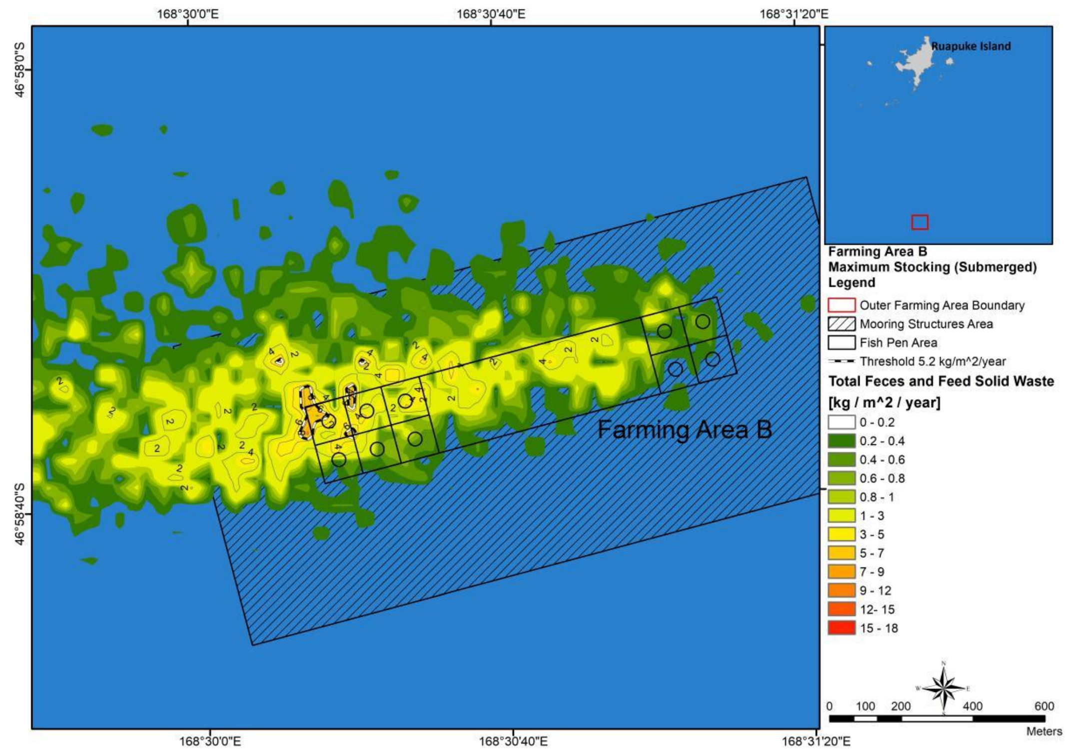

Figure 39: Farming Area B feed and faeces solids deposition Submerged Pen Scenario (Zoomed in).

A2.3 FARMING AREA C

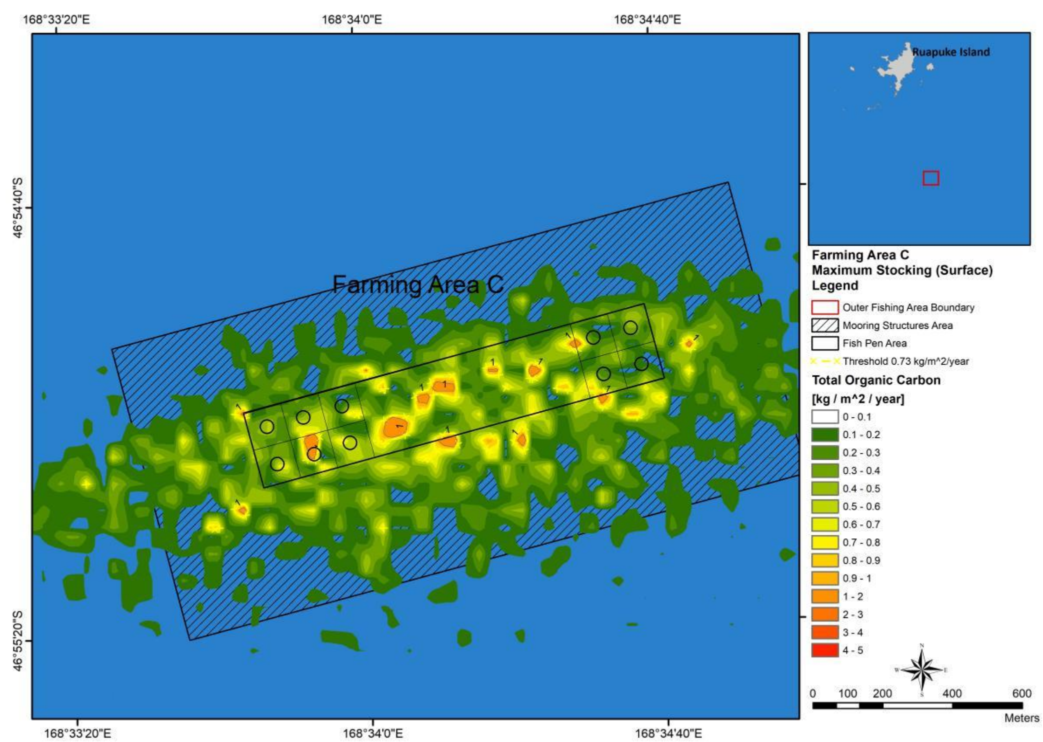

Figure 40: Farming Area C carbon deposition Surface Pen Scenario (zoomed in).

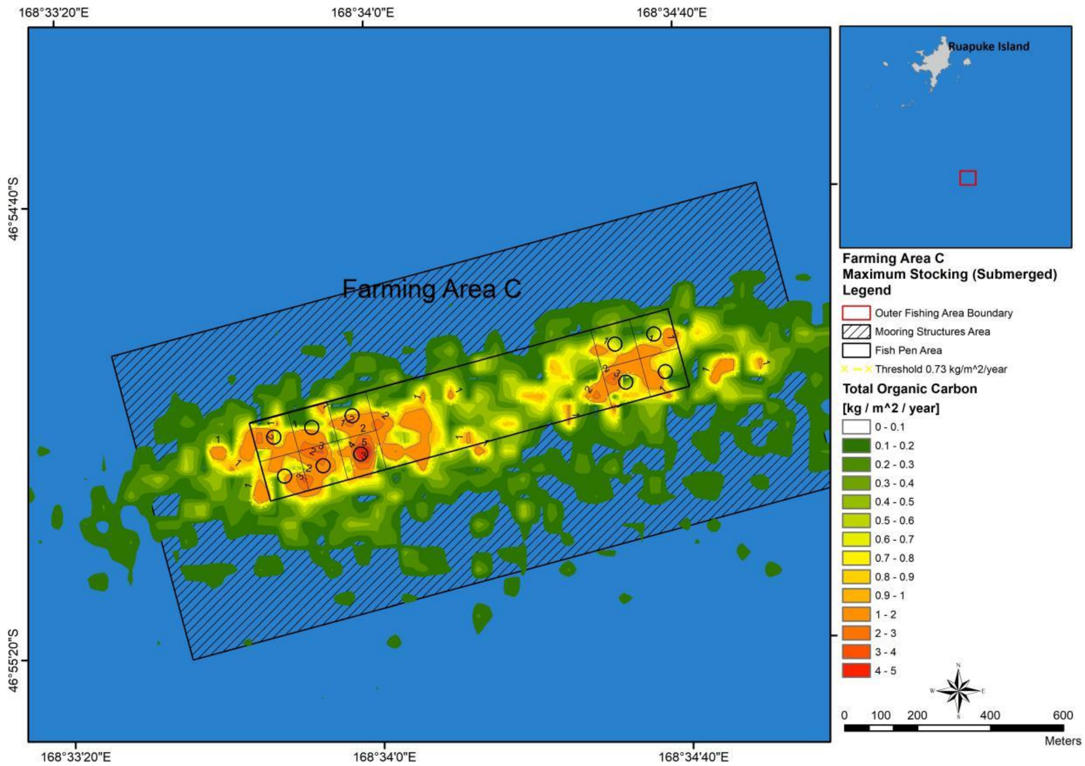

Figure 41: Farming Area C carbon deposition Submerged Pen Scenario (Zoomed in).

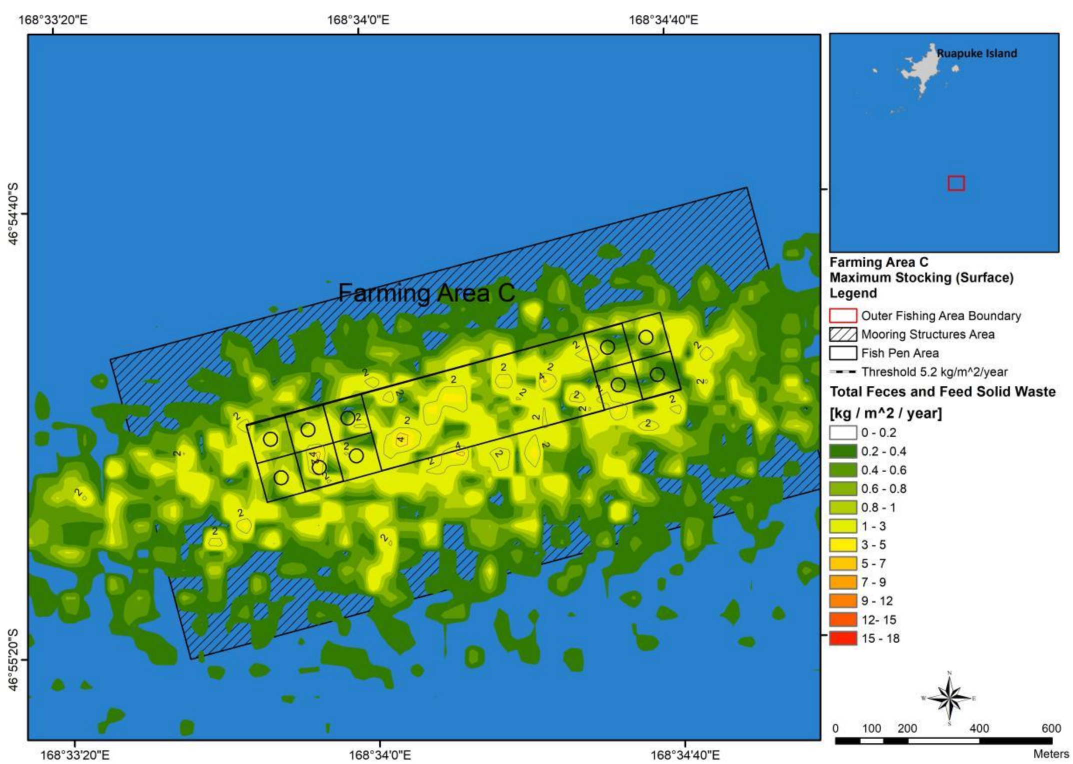

Figure 42: Farming Area C feed and faeces solids deposition Surface Pen Scenario (Zoomed in).

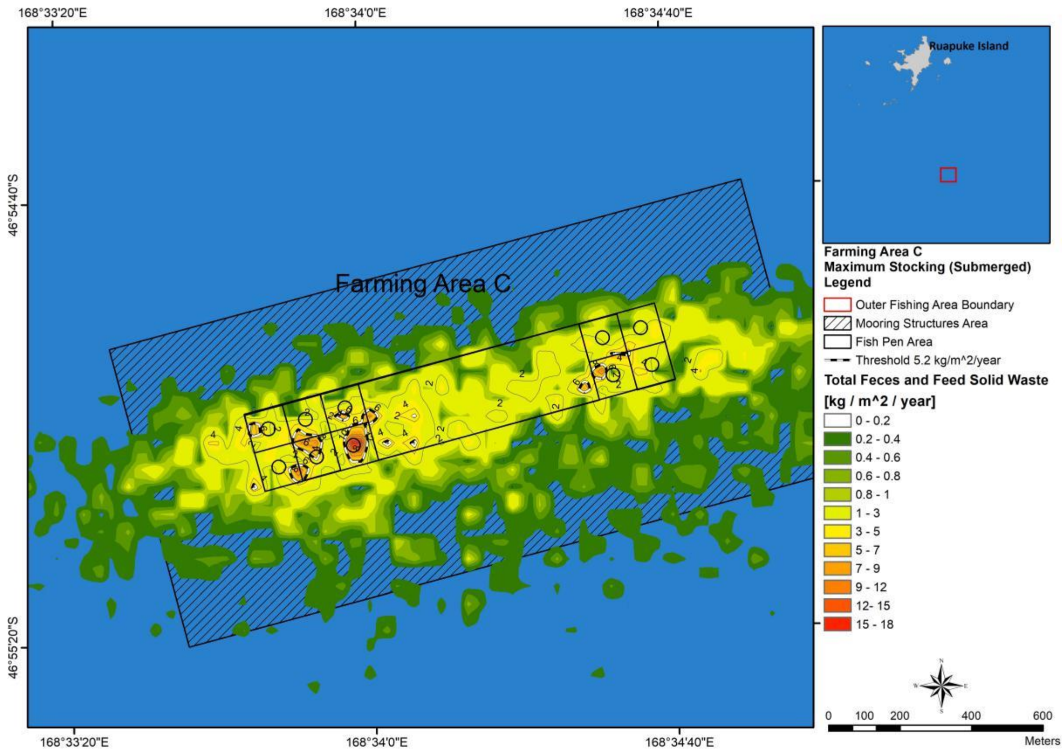

Figure 43: Farming Area C feed and faeces solids deposition Submerged Pen Scenario (Zoomed in).

A2.4 FARMING AREA D

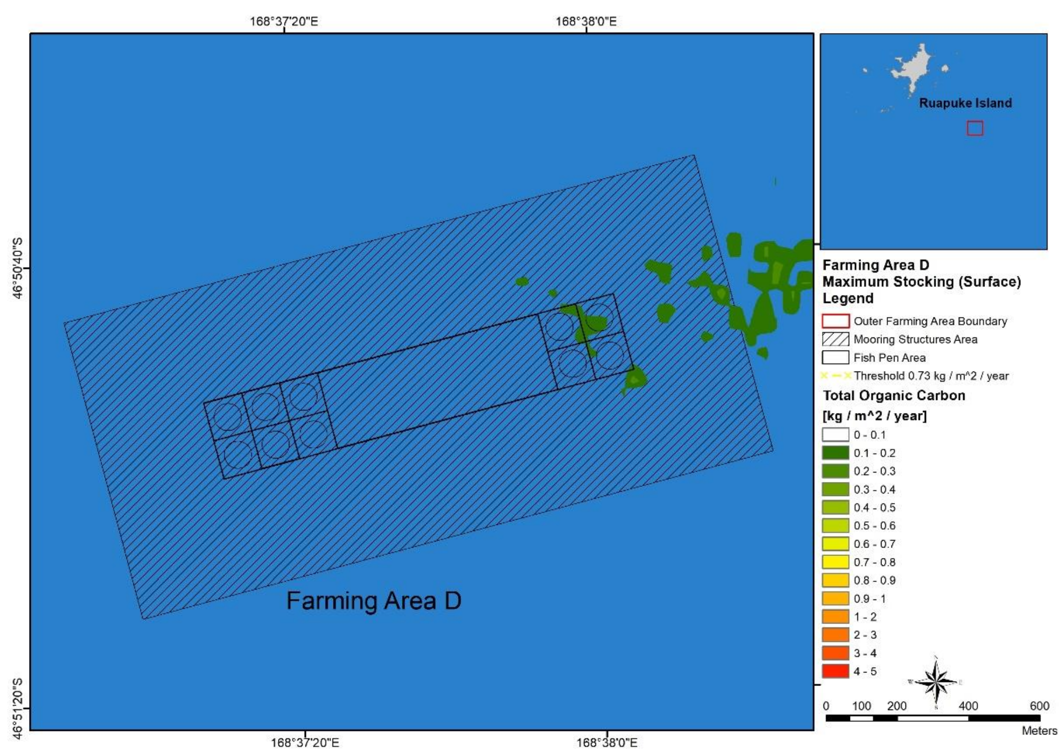

Figure 44: Farming Area D carbon deposition Surface Pen Scenario (zoomed in).

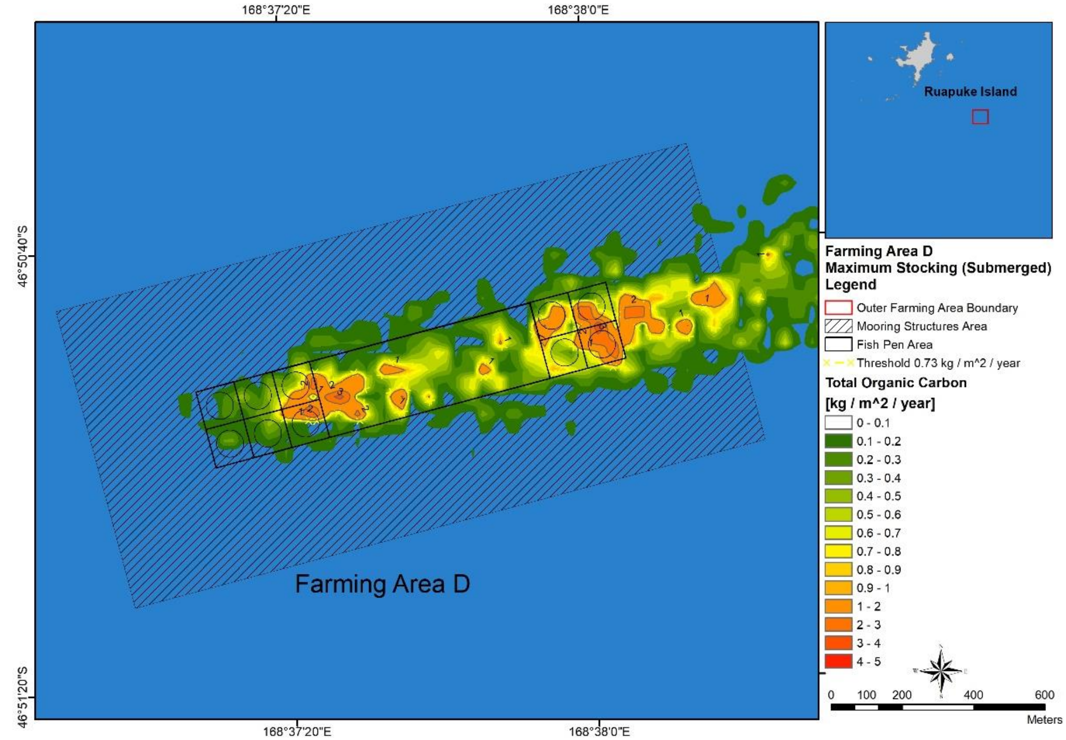

Figure 45: Farming Area D carbon deposition Submerged Pen Scenario (Zoomed in).

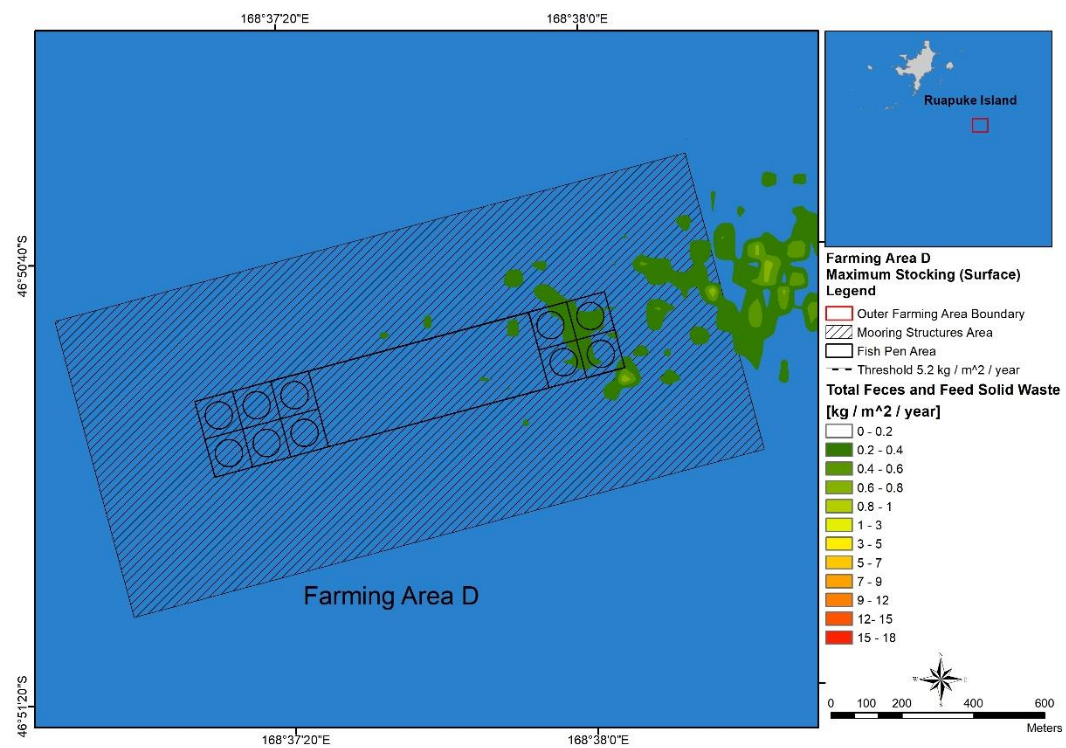

Figure 46: Farming Area D feed and faeces solids deposition Surface Pen Scenario (Zoomed in).

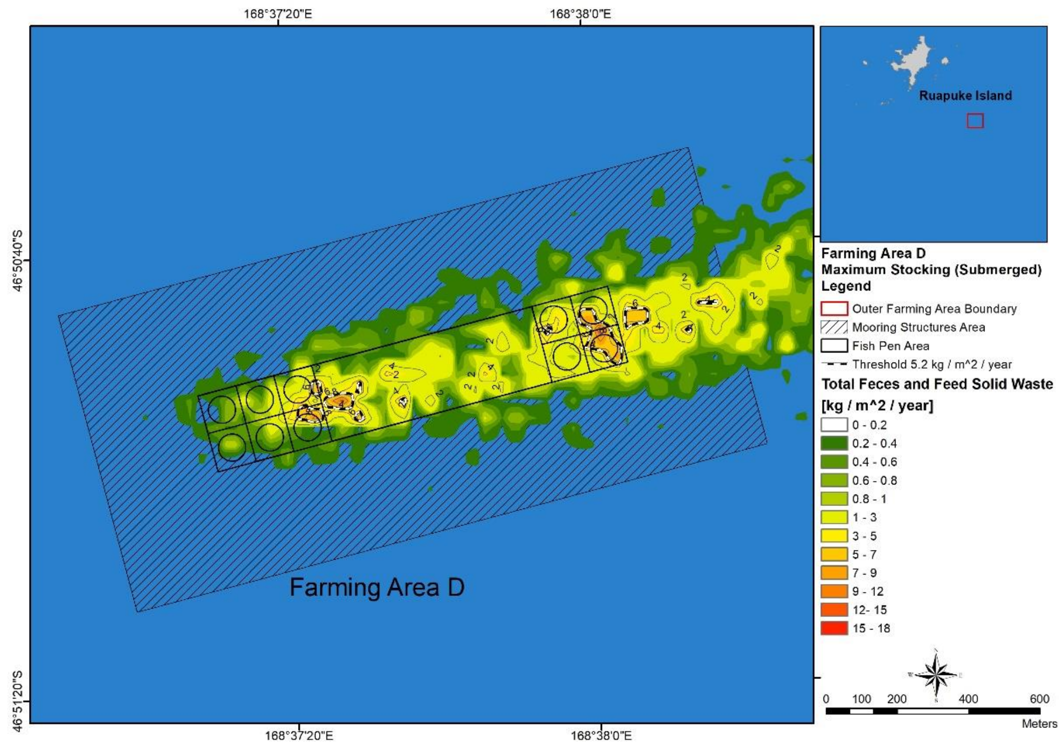

Figure 47: Farming Area D feed and faeces solids deposition Submerged Pen Scenario (Zoomed in).

A2.4 FARMING AREA E

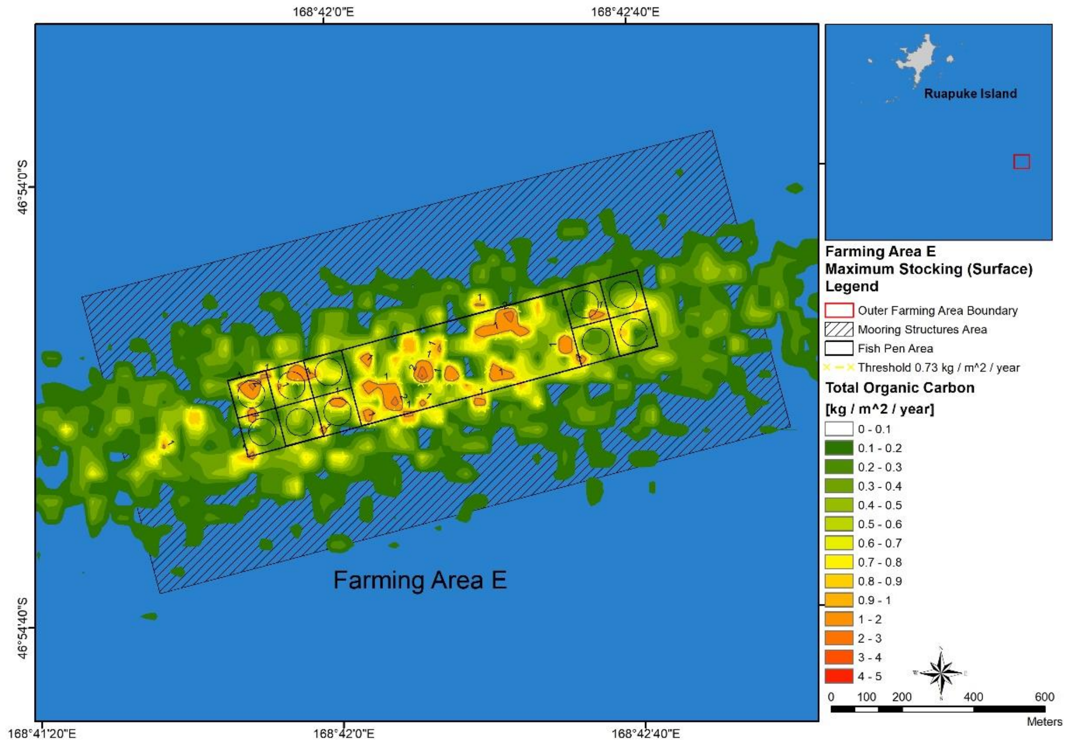

Figure 48: Farming Area E carbon deposition Surface Pen Scenario (zoomed in).

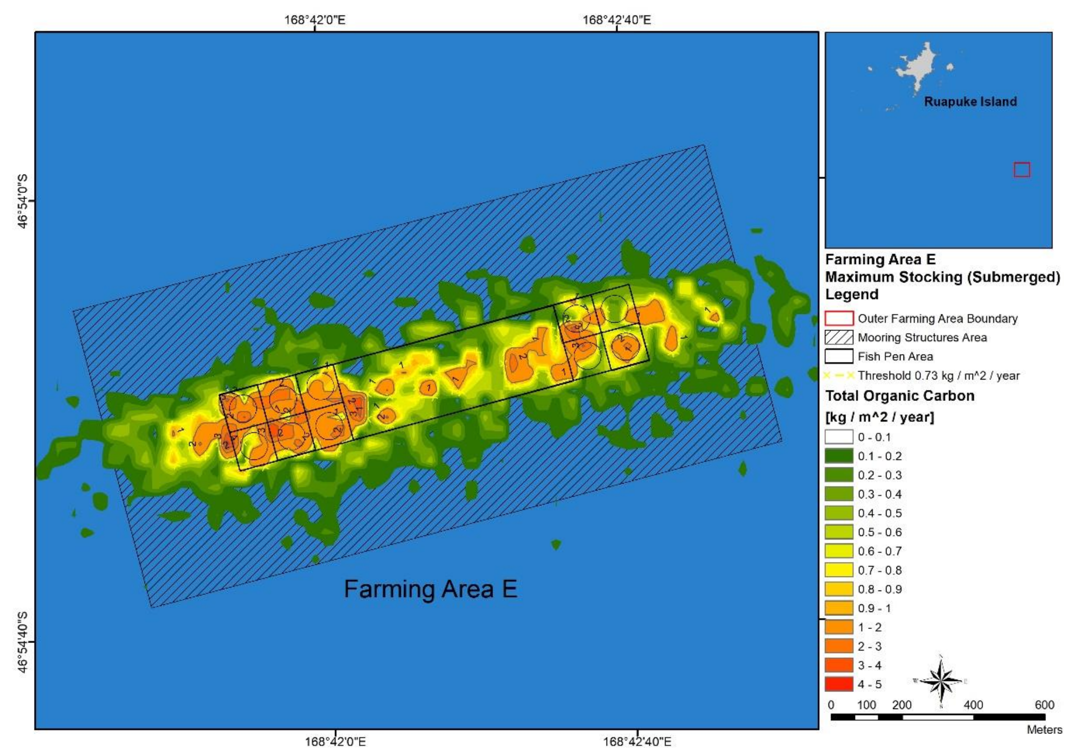

Figure 49: Farming Area E carbon deposition Submerged Pen Scenario (Zoomed in).

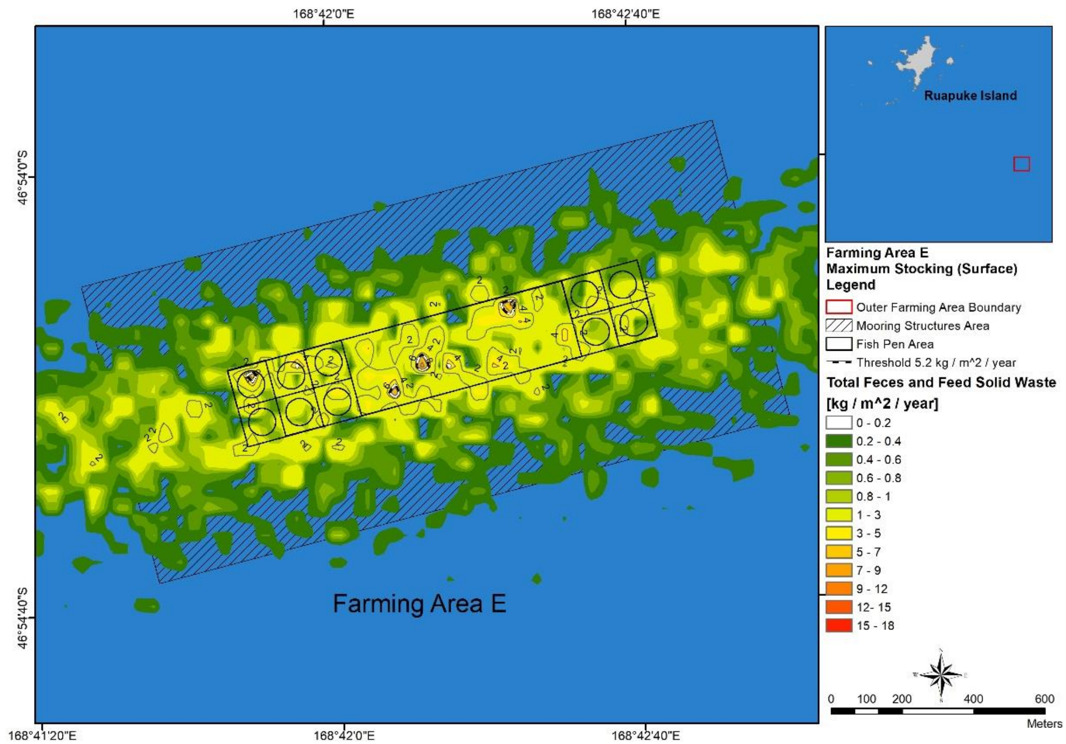

Figure 50: Farming Area E feed and faeces solids deposition Surface Pen Scenario (Zoomed in).

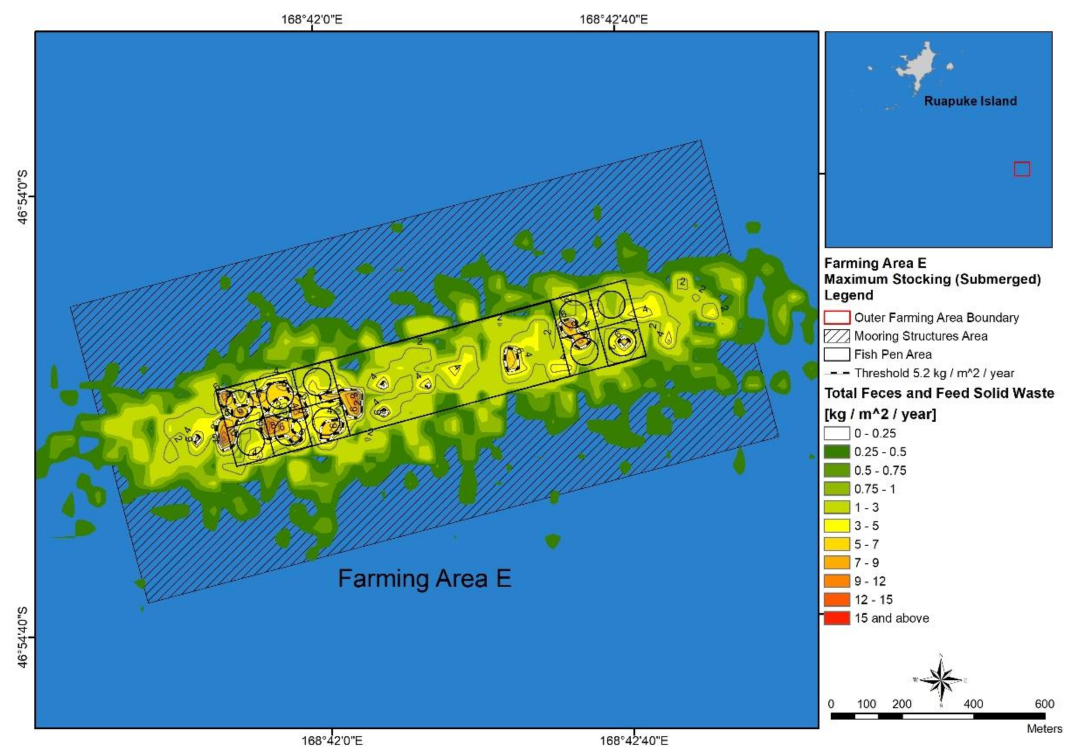

Figure 51: Farming Area E feed and faeces solids deposition Submerged Pen Scenario (Zoomed in).