NUTRIENT ASSESSMENT REPORT EAST MOCLETT

Author: [redacted]

Report date: 18 March 2021

Cooke Aquaculture Scotland

Crowness Road,
Hatston Industrial Estate,
Kirkwall,
Orkney,
KW15 1RG
T: [redacted]
www.cookeaqua .com

Table of Contents

Introduction

As part of the screening and scoping process, in relation to a proposed new fish farm site, East Moclett in Orkney, Cooke Aquaculture Scotland were requested to carry out an assessment of the potential water column impacts. With the site being a new development, details of the predicted nutrient enhancement likely to result from the discharge of the finfish site is to be provided.

An Equilibrium Concentration Enhancement (ECE) assessment using the open water model described by Gillibrand (2006) will be used to assess nutrient enhancement at the East Moclett site.

Cumulative impacts for the area will also be assessed due to operational sites in the waters west and south of the East Moclett site. The energetic nature of the surrounding waters could lead to increased nutrient loading in the area. This will compare the worst-case scenario to quantify the overall enrichment for the region and any potential adverse effects from the proposed development.

Background

Fish farms release dissolved inorganic nutrients through excretion from the fish (ammonia and phosphate), particulate organic nutrients through defecation, and dissolved organic nutrients through resuspension from the particulate fractions. The majority of the nitrogen (N) wastes are released to open waters (68% of total) in the form of ammonia. Whereas the majority of the phosphorus (P) is accumulated in sediments (63%). Dissolved inorganic nutrients are rapidly assimilated by phytoplankton and bacteria and are then transferred to the higher trophic levels in the planktonic food web (Olsen and Olsen, 2008).

These nutrients can enhance the growth of marine plants and algae within the water column. High nutrient levels may lead to algal blooms and depletion of oxygen in the water column. However, it is not easy to identify the causal links of harmful algal blooms and site productivity, as rapid dilution occurs. In the marine environment nitrogen is typically a limiting nutrient so its addition will dictate the amount of primary production (algal growth). Phosphorous is not considered a limiting nutrient for phytoplankton in marine waters and therefore is of less importance than nitrogen (Environmental Assessment Office, 1997). The Scottish Executive Review of environmental impacts of aquaculture concluded that the present level of fish farming only has a small effect on the numbers and growth rate of phytoplankton and that this effect should not be a cause of concern except in poorly flushed areas or areas of high farm density (Scottish Executive, 2002). It is also recognised in many rural areas, that nutrient inputs from agricultural land well exceeds those from fish farming operations.

A number of steps have been taken by the industry in recent years to reduce nutrient release into the marine environment through improvements in husbandry practices, feed technology and feed quality. However, the continuing increase in total production means that the release of nutrients to the sea from aquaculture has also increased (Gubbins, 2003a). Therefore, monitoring nutrient levels around fish farms is important to ensure impacts on the water column and organisms are reduced.

Site details

The proposed East Moclett development is located off the south east coast of Papa Westray, Orkney, 2.92km from the closest landfall in open water. The development is sited in North Sound, a water body situated between three islands - Westray, Eday and Sanday. The infrastructure proposed for the site is six cages, 160m in circumference arranged in a 2x3 grid configuration, orientated to 0°. Grids will be 110m^2, with a net depth at the site of 21m. The site centre of the proposed farm will be 59°19.223'N 02°49.907'W (HY 52757 48516). The proposed maximum biomass for the site will be 3,850 tonnes.

There are seven sites in the Westray area, five sites to the west (4 active/1 inactive) and one site to the south of the East Moclett site with the closest site to the East Moclett site located 3.55km south south-west, situated off the south east coast of Westray.

There has been no hydrographic data recorded at the Bay of Cleat South and Scarfhall Point sites, therefore, they cannot be included in the cumulative assessment. The four remaining sites Bay of Cleat North, Vestness, Ouseness and East of Skelwick Skerry will be considered in the cumulative assessment along with the East Moclett site.

The cumulative assessment will investigate whether the fish farms in the surrounding area may affect nutrient loading at the East Moclett site. Nutrient plume dimensions will be calculated for the sites using the open water model. Details and locations of all the fish farm sites including the East Moclett site can be found in Table 1 and illustrated in Figure 1.

Table 1 Details of the fish farm sites.

CAR licence number	Site name	Maximum biomass (tonnes)	Site centre position		Distance to East Moclett (km)
			WGS 84	NGR	
-	East Moclett	3,850[1]	59°19.223'N 02°49.907'W	352757 1048516	-
CAR/L/1151722	East of Skelwick Skerry	2,500	59°17.314'N 02°50.213'W	352422 1044977	3.55
CAR/L/1002996	Vestness	720	59°19.640'N 02°54.888'W	348042 1049352	4.79
CAR/L/1004213	Bay of Cleat North	960	59°18.678'N 02°55.657'W	347288 1047577	5.55
CAR/L/1003957	Bay of Cleat South	165	59°18.445'N 02°55.886'W	347065 1047148	5.85
CAR/L/1002997	Ouseness	500	59°19.841'N 02°56.502'W	346517 1049747	6.36
CAR/L/1003958	Scarfhall Point[2]	165	59°19.110'N 02°57.815'W	345252 1048408	7.51

[1] Proposed biomass
[2] Inactive sites

Figure 1 Fish farm locations.

Nutrient Modelling

Nutrient enhancement of a water body can be estimated by using two types of models. The first is used for assessing semi enclosed water bodies, described by Gillibrand (2002). This model is a technique used by Marine Scotland in the ‘Locational Guidelines for Authorisation of Marine Fish Farms in Scottish Waters’ issued to aid marine fish farm planning. This model is based on a semi enclosed loch scenario, with exchange of the water body achieved through the ebbing and flooding tide. This flushing allows a constant nutrient input, while maintaining a steady state concentration.

The second model is used to assess sites which are located in open water (Gillibrand 2006). Length and width of nutrient plumes are defined by parameters extracted from hydrographic survey data, where current velocities have been resolved to along shore and across shore components.

The standard ECE model described by Gillibrand (2002) is designed for enclosed loch systems and is not suited to open water and large water bodies. As the proposed East Moclett site is not located within a water body listed in Marine Scotland Science ‘Locational Guidelines for Authorisation of Marine Fish Farms in Scottish Waters’ and the site is located offshore in open water, the use of the open water model is more appropriate to use in this situation. The site is classed as highly resupensive, strongly flushed and very dynamic with a large proportion of the material released from the site being exported in a north west direction towards Papa Westray.

Due to the presence of other fish farm sites located within a nearby proximity (<10km) to the proposed site and its dynamic nature, fish farms located in the Papa Sound and North Sound water bodies will be considered in the cumulative impact assessment.

ECE modelling methodology

The ECE model is a simple box model used to predict the level of enhancement of soluble nutrient nitrogen from fish farming sources, treating nitrogen as a conservative substance. The model is a function of the flushing rate of a sea loch or voe, nitrogen source rate and total consented biomass within a defined area.

The nutrient considered by the model is nitrogen, mainly in the form of dissolved ammonia, however, nitrogen emitted as particulate waste is also considered as it is re-dissolving into the water column from the seabed. The combined source of nitrogen from dissolved and particulate wastes is 48.2kg N per tonne of salmon produced. This value is derived from a mass balance model used to estimate the release of dissolved and particulate nitrogenous waste from cultivated salmon (Davies, 2000). Such an estimate is dependent on details such as stocking, feeding and harvesting strategies employed during cultivation. This information was derived from the records of a major salmon producer in Scotland averaged over a large number of their on-growing sea cage sites. Total nitrogen discharge rate is therefore the sum of the dissolved and particulate rates.

The ECE models predict the relative levels of nutrient enhancement. The results of the models are scaled 0-5 to give a nutrient enhancement index (Table 2). Areas with higher ECE values are considered to be the most environmentally sensitive to further fish farming development due to high predicted levels of nutrient enhancement.

Table 2 Index of nutrient enhancement, derived from predicted levels of equilibrium concentration enhancement (ECE) for nitrogen

Predicted ECE for nitrogenous nutrients arising from fish farming (µmol l-1)	Nutrient enhancement index
>10	5
3-10	4
1-3	3
0.3-1	2
<0.3	1
0	0

ECE Calculations

The calculations to determine the ECE values for the proposed East Moclett site and the cumulative assessment using the open water model are detailed in Gillibrand, 2006. A summary of the calculations used to assess nutrient impact are detailed below.

Nitrogen output (S) in kg/s is calculated using the equation –

$$S = \frac{\text{Max harvested biomass} * 48.2}{31{,}536{,}000}$$

Where:

-48.2kg is the value given to the combined source of nitrogen from dissolved and particulate wastes per tonne of salmon produced.

-31,536,000 is the number of seconds in a year to convert the nitrogen output from kg/yr to kg/s.

For the open water model, impacts resulting from nutrient discharges are considered over three spatial scales: Zone A is a region very close to the nutrient source; Zone B is the near field region, with residency times in the order of a few days and typically of the same spatial scale as a tidal excursion; Zone C is the far field region where residence time is the order of weeks to months. In Zone B phytoplankton may grow if conditions are favourable, therefore the model considers the exchange of water in the Zone B scale region. The model aims to predict the concentration of nutrients within Zone B, which represents the volume of water into which nutrients are released from the source and are rapidly mixed within a tidal cycle. The concentration in the body of water depends on the rate at which it is replaced or exchanged by uncontaminated water.

We must assume the flow at the site contains a tidal component and that the dominant tide is the semi diurnal lunar constituent. We also must assume that the vertical extent of the nutrient plume is bounded either by seabed or by a pycnocline and that the contaminant mixes evenly vertically through this surface layer.

The model uses site specific data from hydrographic surveys to calculate the rate of change of water within Zone B. The basic method of calculating the rate of change of water within Zone B is a simple calculation based on the current velocities of an average tide.

Zone B is determined by its length (L) and width (W) in metres, which are based on tidal excursion and calculated using the equations –

$$L = \frac{(\sqrt{2})\sigma_u T}{\pi} \qquad W = \frac{(\sqrt{2})\sigma_v T}{\pi}$$

Where:

σ_u is the standard deviation of "along shore" flow (m/s)

σ_v is the standard deviation of "across shore" flow (m/s)

T is the semi diurnal tidal period (s)

π=3.1415

We assume for simplicity that Zone B is rectangular with area (m^2) and volume (m^3) calculated using the equations –

$$A=LW \qquad V=AH$$

Where:

H is the water depth or pycnocline depth (m)

The concentration of effluent within the box (Zone B) is determined by the exchange rate (E), which is the inverse of the flushing time (Tf). The flushing time is defined as the time after which the mean concentration (C) in the box would have fallen to a value which is 37% of the initial concentration due to the action of physical exchange processes only.

In the model we define the exchange rate in seconds as:

$$E = E_A + Ex + Ey$$

Where:

E_A is the exchange rate due to advection (residual flow - U_R) and Ex and Ey are due to along shore and across shore diffusion respectively.

The exchange rate due to advection (E_A) is calculated by –

$$E_A = \frac{U_R}{L}$$

Where:

U_R is the residual flow (m/s)

Exchange rates due to diffusion are calculated by –

$$Ex = \frac{Kx}{2L^2} \qquad Ey = \frac{Ky}{2W^2}$$

Where:

Kx is the along shore diffusion coefficient

Ky is the across shore diffusion coefficient

The derivations of these equations to calculate the coefficients can be found in Sherwin (2001). This will give a Minimum (Min), Median and Maximum (Max) exchange rate. These exchange rates are then used to calculate Min, Median and Max flushing times (Tf) and effluent concentration (C) in Zone B.

Flushing time in hours is calculated using the equation –

Tf = ((1/E)/60)/60

Where the:

E_{MAX} value is used to calculate the Tf_{MIN} value

E_{MEDIAN} value is used to calculate the Tf_{MEDIAN} value

E_{MIN} value is used to calculate the Tf_{MAX} value

The effluent concentration in kg/m^3 is calculated by the equation –

$$C = \frac{S}{V(E+k)}$$

Where:

S is the nitrogen output or effluent source (kg/s)

k is the nutrient decay rate (s)

And the:

E_{MAX} value is used to calculate the C_{MIN} value

E_{MEDIAN} value is used to calculate the C_{MEDIAN} value

E_{MIN} value is used to calculate the C_{MAX} value

To convert the ECE value (C) from kg/s to µmol/l the following equation is used –

$$\frac{C*1000000}{14}$$

Results

East Moclett ECE

Model inputs

The reported hydrographic data for the near surface (NS), cage bottom (CB) and near bed (NB) layers for the East Moclett site are shown in Table 3, with the averaged hydrographic data required for the model shown in Table 4 below.

Table 3 Hydrographic data at the three reported water depths

Residual Current (U_R)			"along shore" flow (σ_u)			"across shore" flow (σ_v)		
NS	**CB**	**NB**	**NS**	**CB**	**NB**	**NS**	**CB**	**NB**
0.0781	0.078	0.0462	0.234	0.233	0.166	0.0691	0.0503	0.052

Table 4 Averaged hydrographic data for input into the model

Residual Current (U_R)	"along shore" flow (σ_u)	"across shore" flow (σ_v)	Vector Average Residual Direction (Degrees)
0.0674	0.211	0.0571	305

The production cycle for the East Moclett site is 22 months with 2 months fallowing. To adopt a precautionary approach and to follow the methods detailed in Gillibrand (2002) the source of nitrogen from dissolved and particulate wastes was set at 48.2kg Nitrogen per tonne of salmon produced.

Table 5 below shows the nitrogen data used to calculate the nitrogen output value for the East Moclett site which is subsequently used in the ECE model.

Table 5 Nitrogen data

Nitrogen (kg per tonne salmon)	48.2
Proposed maximum biomass on site (t)	3,850
Nitrogen output (kg/yr)	185,570
Nitrogen output (kg/s)	**5.884×10^{-3}**

Table 6 outlines the data inputs required to run the open water ECE model for the East Moclett site.

Table 6 ECE model inputs

Semi-diurnal tidal period (s)	T	45,000
Water depth (m)	H	54.8
Residual flow (m/s)	U_R	0.0674
Standard deviation "along-shore" flow (m/s)	σ_u	0.211
Standard deviation "across-shore" flow (m/s)	σ_v	0.0571
Nutrient decay rate (s-1)	k	0
Nitrogen output (kg/s)	S	5.884×10^{-3}

Model outputs

Area of impact (Zone B) is calculated using the hydrographic data. Table 7 details the area of impact for the East Moclett site.

Table 7 Zone B dimensions

Length (m)	4,275.8
Width (m)	1,156.8
Area (m^2)	4,946,411.9
Volume (m^3)	271,063,370.8

Exchange rates and flushing times for the East Moclett site are detailed in Table 8. The model determines a flushing time by calculating a refreshment rate. This is based on the size of Zone B and the residual currents in the area.

Table 8 Exchange rates and Flushing times

Minimum exchange rate (s-1)	E_{MIN}	1.57796×10^{-5}
Median exchange rate (s-1)	E_{MEDIAN}	1.59627×10^{-5}
Maximum exchange rate (s-1)	E_{MAX}	1.64202×10^{-5}
Minimum flushing time (hrs)	Tf_{MIN}	16.92
Median flushing time (hrs)	Tf_{MEDIAN}	17.40
Maximum flushing time (hrs)	Tf_{MAX}	17.60

The resultant open water ECE model outputs are detailed in Table 9 below for the East Moclett site.

Table 9 Equilibrium Concentration Enhancement

		(kg/m^3)	(µmol l-1)
Minimum ECE	C_{MIN}	1.32206×10^{-6}	0.09443
Median ECE	C_{MEDIAN}	1.35995×10^{-6}	0.09714
Maximum ECE	C_{MAX}	1.37573×10^{-6}	**0.09827**

The predicted maximum nutrient enhancement value for the East Moclett site is 0.098 µmol l-1, equivalent to nutrient enhancement index category 1. This is at the lower end of category 1.

Cumulative Effects

An assessment of the cumulative effects of nutrients released from the sites in the waters surrounding the East Moclett site was undertaken.

There are six other fish farms in the Westray area, however only four of the sites have hydrographic data. No data has been recorded at the Bay of Cleat South and the Scarfhall Point sites. Due to the lack of hydrographic data for the two sites, only four sites are considered in the cumulative assessment (East of Skelwick Skerry, Bay of Cleat North, Vestness and Ouseness). The cumulative assessment is carried out using the open water model (Gillibrand 2006). The sites considered in the cumulative assessment are not located within areas categorised in the Locational Guidelines. This combined with their current regimes and topography, mean the open water model is applicable. Using the most recent hydrographic data for the sites, plume dimensions were calculated. The plumes were mapped using the vector averaged residual current directions to assess potential influence on nutrient loading at the East Moclett site.

Model inputs – Plume calculations

Three current velocity inputs are required to calculate the nutrient plume dimensions, with data obtained from hydrographic surveys at the four sites. Data from two or three reported water depths (NS-near surface, CB-cage bottom & NB-near bed layers) are shown in Table 10.

Table 10 Hydrographic data at the two or three reported water depths.

	Residual Current (U_R)			"along shore" flow (σ_u)			"across shore" flow (σ_v)		
	NS	**CB**	**NB**	**NS**	**CB**	**NB**	**NS**	**CB**	**NB**
East of Skelwick Skerry	0.029	0.031	0.023	0.145	0.144	0.102	0.04	0.033	0.033
Vestness	0.077	0.074	0.072	0.199	0.194	0.16	0.054	0.054	0.068
Bay of Cleat North	0.036	-	0.04	0.134	-	0.116	0.033	-	0.04
Ouseness	0.02	0.03	0.038	0.246	0.236	0.226	0.074	0.062	0.063

Table 11 outlines the data inputs required to calculate the nutrient plume dimensions including the averaged hydrographic data, depth and residual direction. Additional data inputs required to calculate the plume dimensions include the semi diurnal tidal period of 45,000 seconds which remains the same for all sites.

Table 11 Plume calculations - model inputs

	Residual Current (UR)	"along shore" flow (σu)	"across shore" flow (σv)	Water depth (m)	Vector Average Residual Direction (Degrees)
East of Skelwick Skerry	0.0278	0.1304	0.0353	52.39	211
Vestness	0.0745	0.1845	0.0588	16.31	353
Bay of Cleat North	0.0376	0.1245	0.0362	13.9	155
Ouseness	0.0292	0.2363	0.0662	11.0	213

Model outputs – Plume dimensions

Table 12 details the plume dimensions of the area of impact (Zone B) for the sites to the west and south of the East Moclett site. Figure 2 illustrates the nutrient plumes for all the sites including the proposed East Moclett site.

Table 12 Zone B plume dimensions

	Length (m)	Width (m)	Area (m^2)	Volume (m^3)
East of Skelwick Skerry	2,641.2	715.9	1,890,951.6	99,066,955.8
Vestness	3,737.1	1,191.6	4,453,009.9	72,628,590.7
Bay of Cleat North	2,522.8	733.9	1,851,554.8	25,736,611.6
Ouseness	4,786.8	1,340.7	6,417,459.3	70,592,052.8

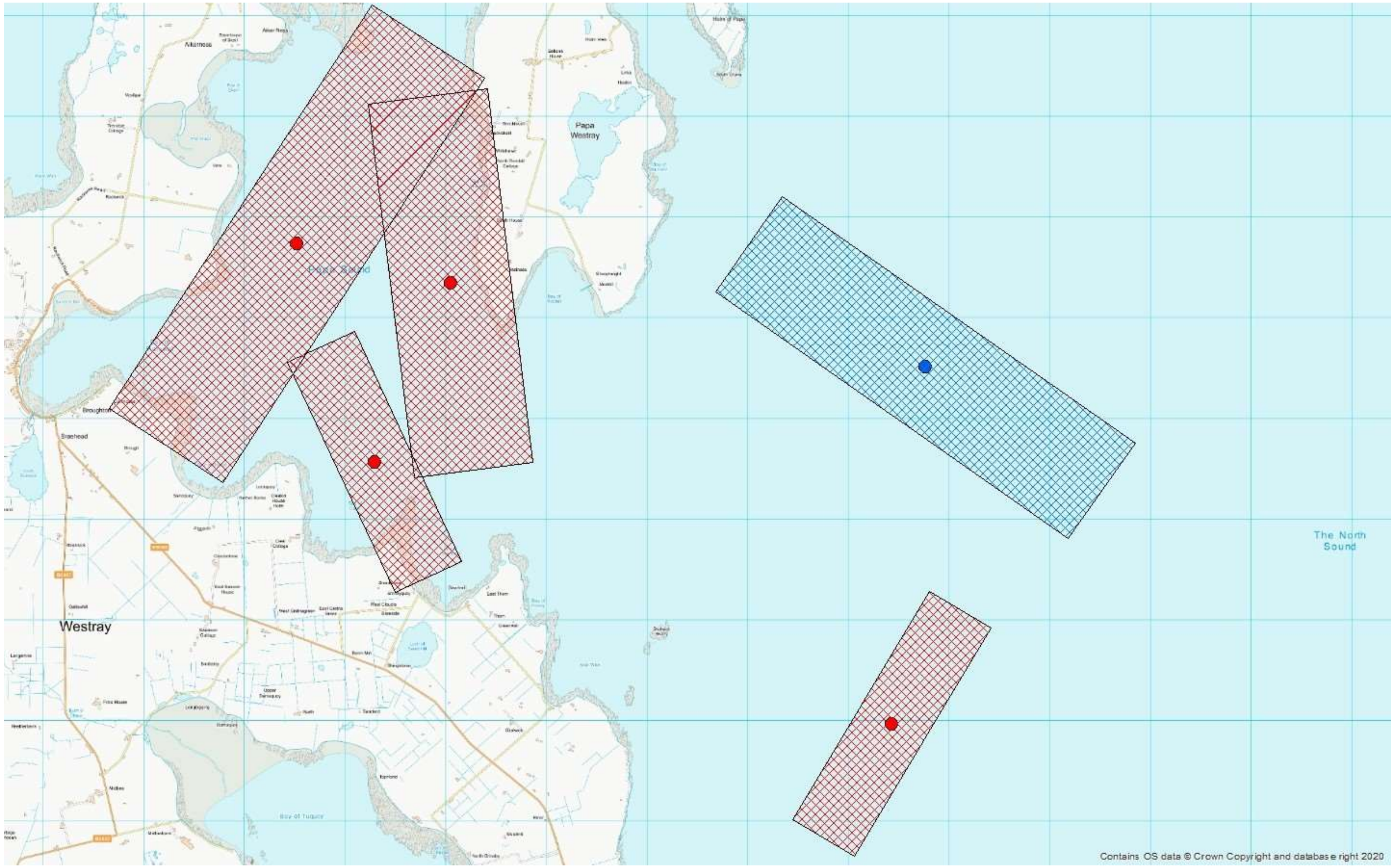

Figure 2 - Zone B areas.

Although the plumes in the Papa Sound area interact with one another, none of these plumes or the East of Skelwick Skerry plume interacts with the nutrient plume from the East Moclett site (blue).

Discussion

East Moclett ECE

For the ECE calculations the open water model was used to assess the East Moclett site. Due to the location of the site being classed as offshore in open water, and being relatively exposed to large tidal currents, the majority of exported material is well dispersed. As the site is not within a sea loch, the open water model was deemed to be the most appropriate model to calculate nutrient enhancement at the East Moclett site.

Using the open water ECE model, the East Moclett site has a maximum nutrient enhancement value of 0.098 µmol l-1. When stocked to the proposed maximum biomass this provides a nutrient enhancement index of 1. This remains at the lower end of the level 1 index with a range of <0.3 µmol l-1.

There will be some nutrient enrichment in the vicinity of the development due to nutrient release from the fish farm. However, this is not considered to be significant in terms of the current regime of the North Sound waterbody, where the East Moclett site is located. The proposed site is unlikely to lead to any environmental impacts with the majority of the effluent from the site dispersed in the energetic waters that pass the site.

Cumulative assessment

Due to a number of sites in the Westray area and the energetic nature of the waters surrounding the East Moclett site, there was potential for nutrient plumes to overlap. This could potentially lead to increased nutrient loading. To address this, the cumulative effects of all sites in the area were investigated using the open water model.

There are six sites in this area, however, two sites were not included in the assessment, as there is no hydrographic data recorded. Of these two sites one is inactive and the other is consented for a very low tonnage (165 tonnes), therefore, the addition of nutrients from these sites would have been very minimal.

The East Moclett nutrient plume did not overlap with any of the other site's nutrient discharges, therefore, the potential for cumulative nutrient loading is low.

The closest site to the East Moclett fish farm is the East of Skelwick Skerry site, this is 3.55km south of the proposed site. However, the energetic nature of the North Sound water body, where both sites are located, would lead to rapid dispersal of nutrients in this area.

The modelling assumptions have considered a worst-case scenario. It has assumed that all sites are producing salmon and are at maximum biomass at one time. It is very unrealistic and impractical to have all sites running at maximum biomass. Cooke Aquaculture Scotland is the only salmon farming company operating in the Papa Sound/North Sound area, and due to the close proximity of the sites it is highly unlikely they would have all the sites running at one time in terms of management and environmental sustainability. Therefore, the actual amount of salmon harvested will be significantly lower than that of the modelled assumptions. This will result in less feed used and less nitrogen enrichment in the area than predicted.

Nutrient modelling of the proposed site showed low nutrient loading, where no nutrient plumes overlap as a result of the addition of the East Moclett site. Due to the hydrodynamic conditions at the site, any plumes that are created are quickly dispersed, allowing this site to be considered as very low risk.

Mitigation

In order to minimise nutrient input from the East Moclett site, measures are in place to reduce the amount of waste feed entering the water column and settling on the seabed. Improvements in feeding efficiency and feed quality could reduce waste entering the water column lowering the environmental impact.

Monitoring will be carried out in accordance with SEPA water quality monitoring procedures throughout the production cycle to detect nutrients entering the water column and to act as early warning of a potentially harmful bloom.

References

Davies, I.M. (2000). Waste production by farmed Atlantic salmon (*Salmo salar*) in Scotland. ICES CM 2000/O:01, 12 pp.

Environmental Assessment Office (1997). Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems. Evolving views over three decades 1997 Robert W. Howarth1 and Roxanne Marino.

Gillibrand P.A. (2006) Improving Assimilative Capacity Modelling for Scottish Coastal Waters: II. A Model of Physical Exchange for Open Water Sites. SAMS Marine Physics Report No. 168

Gillibrand P.A., Gubbins M.J., Greathead C. & Davies I.M. (2002) Scottish Executive Locational Guidelines for fish farming: predicted levels of nutrient enhancement and benthic impact. Scottish Fisheries Research Report Number 63. FRS, Aberdeen.

Gubbins, M.J., Gillibrand, P.A., Sammes, P.J., Miller, B.S. and Davies, I.M. 2003a. OSPAR eutrophication assessment of aquaculture hotspots in Scottish coastal waters. FRS Marine Laboratory Collaborative Report 07/03, 149 pp.

Olsen Y., Olsen L.M. (2008) Environmental impact of aquaculture on coastal planktonic ecosystems. In:Tsuka -moto K, Kawamura T, Takeuchi T, Beard TD Jr, Kaiser MJ (eds) Fisheries for global welfare and environment. Proc 5th World Fisheries Congress 2008, Terrapub, Tokyo, p 181−196.

Scottish Executive, (2002). Review and Synthesis of the Environmental Impacts of Aquaculture, The Scottish Association for Marine Science and Napier University.

Sherwin, T.J. (2001) The significance of residual currents in the interpretation of the EU Urban Wastewater Treatment Directive in coastal locations. Marine Pollution Bulletin, 40, 17-21.