ANDERSON MARINE SURVEYS

Report To: Grieg Seafoods

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ASSESSMENT OF POTENTIAL NUTRIENT ENHANCEMENT BY PROPOSED SALMON FARMING AT EASTER SCORE HOLMS, SHETLAND

The soluble nutrients ammonia, nitrate and phosphate are released from marine cage aquaculture in the form of excreta and waste feed, with releases both directly to the water column and following mineralisation of organic material deposited in the cage "footprint". This assessment considers potential effects of a proposed increase in consented peak biomass from 2500 to 3919.6 T from at an existing cage site Easter Score Holms, northwest of Scalloway. Overall, Grieg Seafoods also intend to increase production in the area at West of Burwick (1922.6 to 3438.25 T) and to relinquish production at North Papa (1332T), East of Papa (1500T) and Spoose Holm (1500T), an overall reduction of 1396.75T.

Nutrient release is of concern because of the potential for eutrophication leading to increased abundance of phytoplankton, in some cases causing Harmful Algal Blooms (HABs). In Scottish coastal waters under most conditions, the nutrient element that most limits phytoplankton growth is nitrogen, and the influence of phosphorus can safely be discounted (Tett and Edwards 2002).

Category 1, 2 and 3 areas for the Scottish Government Locational Guidelines[1]), have been designated on the basis of Marine Science Scotland (MSS) predictive modelling to estimate nutrient enhancement and benthic impact in sea lochs or similar water bodies supporting aquaculture. Modelling of nutrient enhancement is based on a simple box model originally developed by Gillibrand *et al* (2002) – see box. The model expresses nutrient enhancement as predicted Equilibrium Concentration Enhancement (ECE). Around 5% of lochs have ECE values which are more than 25% of the background levels of N and P. The worst case loch has an ECE value of half of background levels of nitrogen (Fisheries Research Scotland, cited by Tett and Edwards 2002).

The site location (The Deeps) has not been included in the list of loch systems assessed by MSS (December 2020). This assessment therefore applies a similar methodology to assess potential effects of the proposed increase in biomass at

[1] https://www.gov.scot/publications/authorisation-of-marine-fish-farms-in-scottish-waters-locational-guidelines/ accessed 22/04/2021

Easter Score Holms between The Deeps and Weisdale Voe (Figure 1). The assessment is for a maximum consentable biomass of 3919.6T.

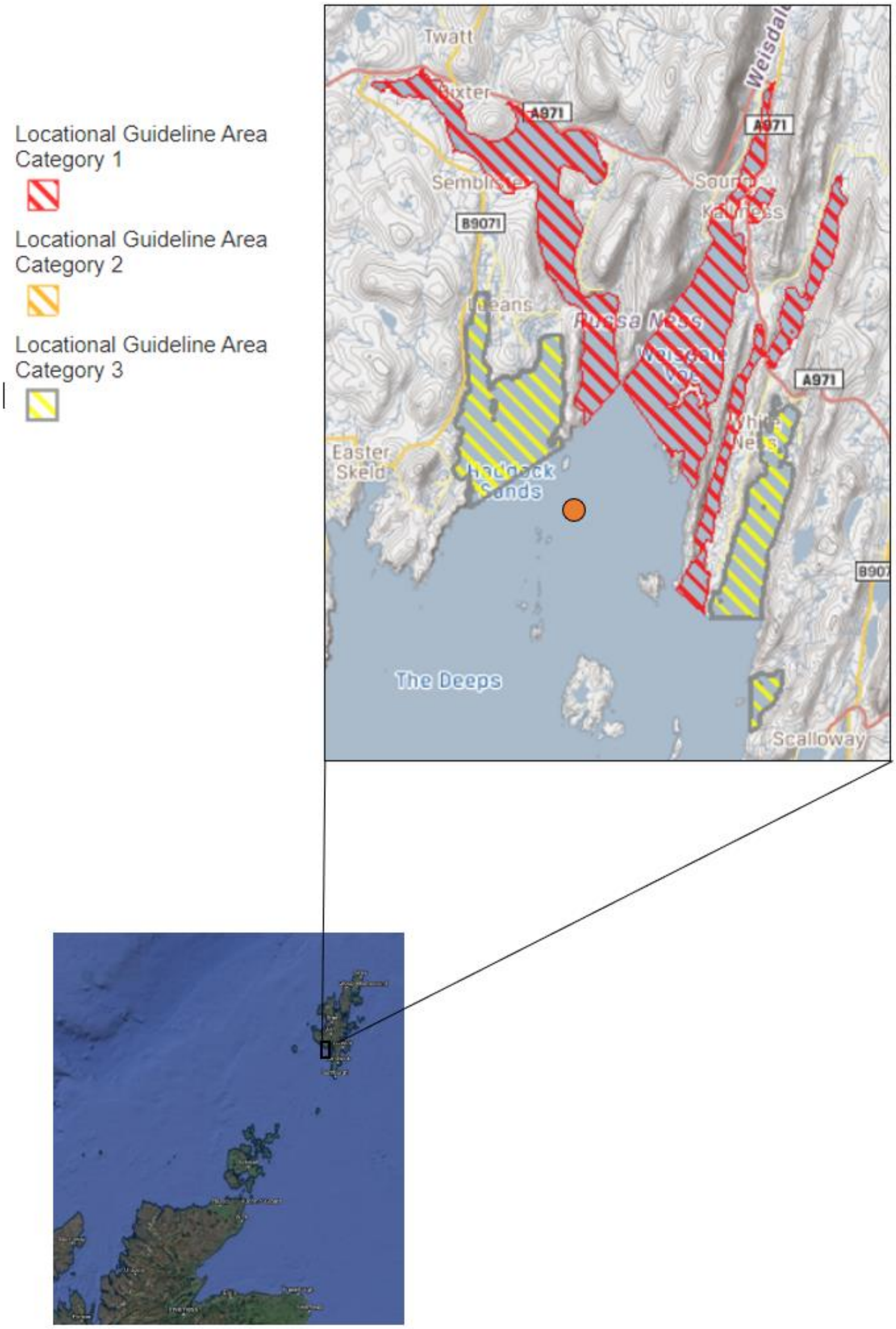

Figure 1. Easter Score Holms general location and locational guidelines areas (source: http://aquaculture.scotland.gov.uk/map/map.aspx)

Methods

The Gillibrand *et al* (2002) model (see box) has been applied to site area, extending from Hildasay to the entrances to Sand Voe and Weisdale Voe (grid centre OSGB 435435 1143374).

In view of the open nature of the area to the north and south, the concept of a topographically defined box is of limited value. The extent of the box was therefore assessed by examination of surface tidal amplitude and ellipses for representative spring (19 Dec 2020 and 13 Feb 2021) and neap (26 Dec 2020 and 20 Feb 2021) tides during the 93-day site hydrographic survey (Figure 2). Over the survey period, surface amplitude parallel to the major axis (025°G) was 0.114m/s giving an average tidal excursion (6.25h) of 2564m. Lateral amplitude was 0.081m/s giving an excursion of 1815m. These values were consistent with single tide ellipses showing maximum flood excursions of 2911m (spring) and 865m (neap); and ebb excursions of 2084m (spring) and 1231m (neap).

Flushing rate (Q) was therefore estimated from a volume estimate derived from bathymetric data within a box of 5128 x 3630m (i.e. corresponding to average 6.25h amplitude excursion in each direction), orientated to the major tidal axis (see Figure 2).

Mean High Water Springs was -1.6mCD and spring tidal range was 1.1m; derived from Admiralty Chart No. 3294, Harbours in Southern Mainland. Proposed peak biomass was set at 3919.6T.

MHWS volume of the box was estimated using SURFER analysis of digitised bathymetric data; giving values of:

Box dimensions (m)	Box area below MHWS (m^2)	Box volume below MHWS (m^3)	Average box depth (mCD)
5128 x 3630	1.61E+07	6.09E+08	36.3

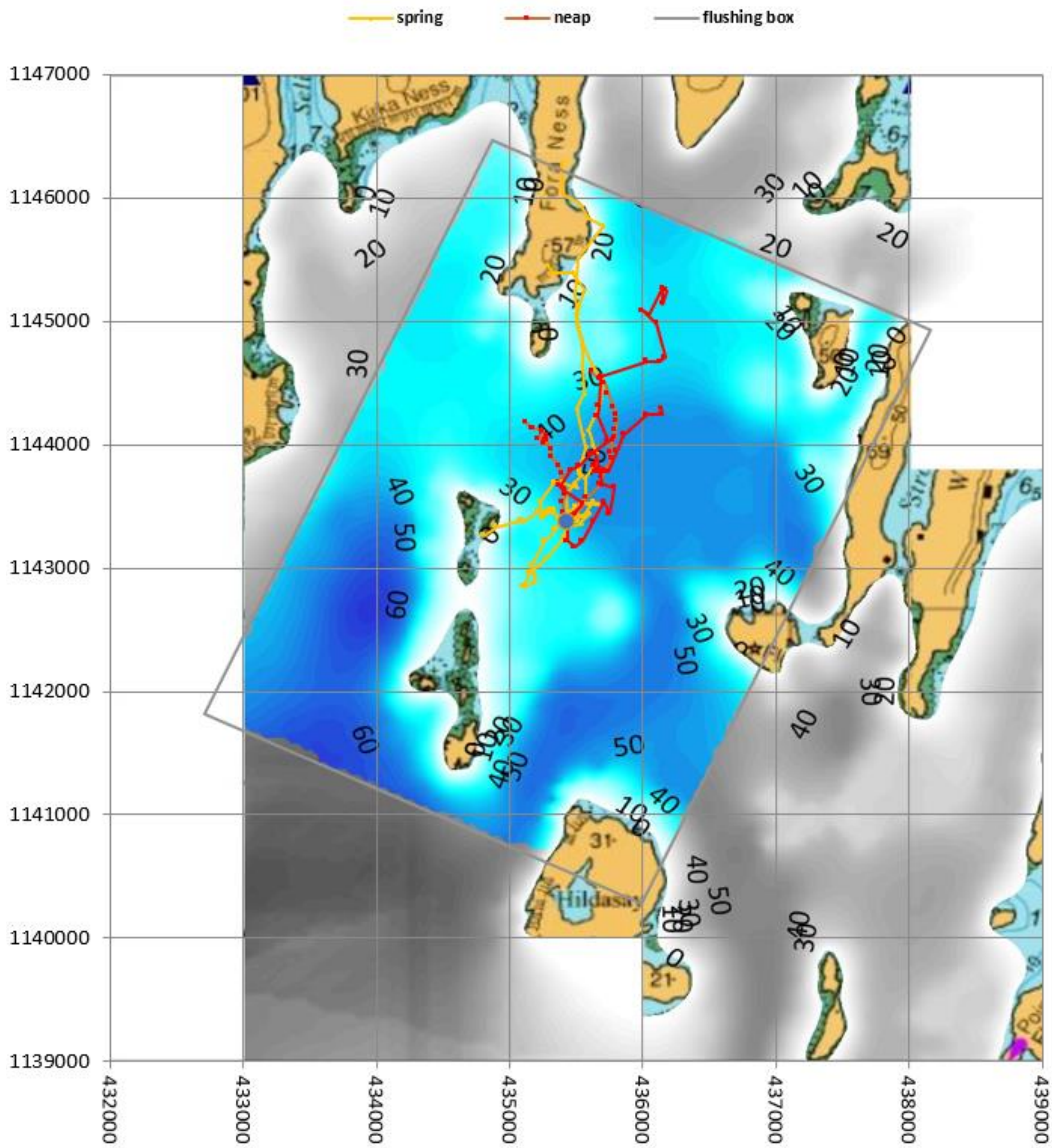

Figure 2. Tidal ellipses over two representative spring and neap 12.5h cycles

Results and discussion

Predicted flushing times, flushing rates, nitrogen ECEs and Nutrient Enhancement Index are

Flushing time (days)	Flushing rate, Q (m^3/year)	ECE (µmol/l)	Nutrient Enhancement Index
25.6	8.69E+09	1.55	3

(see also individual tabulated calculations below).

Environmental standards for discharges to surface waters (including marine) are given by SEPA Supporting Guidance (WAT-SG-53, Sep 2019); which transcribes The Scotland River Basin District (Surface Water Typology, Environmental Standards, Condition Limits and Groundwater Threshold Values) Directions 2009. The standards are based on the latest scientific understanding of the UK Technical Advisory Group (UKTAG) for the Water Framework Directive (WFD). The surface water standards for coastal and transitional waters are available in the Standards Directions 2014, Schedule 2, Part C, Sections 3 and 4.

For Dissolved Inorganic Nitrogen, standards for coastal waters are specified for mean winter salinities 30 to <34.5 ‰ and ≥34.5 ‰. The procedure for calculating DIN standard (by SEPA) is complex and requires data covering salinity and DIN concentration over the winter period; to calculate the arithmetic mean concentration of dissolved inorganic nitrogen at salinity 32 for the compliance assessment period. “Good” and “high” standards at salinity 32 ‰ range equate to 0.252 and 0.168 mg/l respectively.

The predicted ECE, 1.55 µmol/l equivalent to 21.7 µg/l, which does not account for nitrification and other removal mechanisms, is approximately 9% of the “good” standard and 13% of the “high” standard.

Predicted ECE is 11.0% of the “typical” background nitrogen concentration in Scottish coastal waters (Loch Linnhe annual average, 14.06µM TN, Rees *et al*. 1995). Nutrient concentrations in coastal waters are highly variable (partly as a result of algal blooms), and the predicted range of ECE is within the expected range of short-term variability.

In a different context (urban waste water discharges), assessment criteria for the consequences of nutrient enhancement in terms of phytoplankton growth (as chlorophyll concentration) have been established by the Comprehensive Studies Task Team (CSTT 1997). Tett and Edwards (2002) have applied this approach to predicting the bulk effects of nutrients derived from aquaculture to algal blooms in Scottish sea lochs. In this approach, receiving water is deemed to be potentially eutrophic if the chlorophyll concentration calculated by addition of chlorophyll produced by utilisation of the ECE to chlorophyll concentration in the water coming from the adjacent sea, exceeds a threshold of 10 mg/m^3, i.e.

potential maximum chlorophyll = summer background chlorophyll + ***q*** x maximum summer nutrient concentration

where ***q*** = the yield of chlorophyll from nitrogen
("standard" value = 1.1 g chl /mol N)

Mean observed summer chlorophyll concentration in surface water from typical west Scottish coastal water (outer Firth of Lorne) is 1.7 mg/m^3 (Grantham 1983, cited by Tett and Edwards 2002). The box model calculations indicate a potential maximum increase in chlorophyll concentration in the model box of 1.7 mg/m^3 associated with the proposed Easter Score Holms cage site; and a total chlorophyll concentration of 3.41 mg/m^3 (34% of CSTT standard).

Tidal vectors do not indicate a high likelihood of mixing of released nutrients into adjacent waters classified by MSS. However, the assessed mixing box includes two other cage sites in production: North Havra (consented 1496T) and Foreholm (consented 1650T); and a further site, Sanda Stour (consented 1500T) which has not reported production in the past three years[2].

The proposed increase in production at Easter Score Holms will result in an increase in Nutrient Enhancement Index from 2 to 3. Assuming that nutrient loads from all current production sites (total 7066T including the proposed increase at Easter Score Holms) are mixed within the box, Nutrient Enhancement Indices for these waters will remain unchanged at 3. However, if all currently consented sites are in production and production at Easter Score Holms is increased as proposed, the ECE within the mixing box will increase by 20% and the Nutrient Enhancement Index will increase to 4.

	Biomass (T)	Flushing time (days)	Flushing rate, Q (m^3/year)	ECE (µmol/l)	Nutrient Enhancement Index
Score Holms consented	2500	25.56	8.69E+09	0.99	2
Score Holms increased	3920	25.56	8.69E+09	1.55	3
All producing	5646	25.56	8.69E+09	2.24	3
All producing, SH increased	7066	25.56	8.69E+09	2.80	3
All consented	7146	25.56	8.69E+09	2.83	3
All consented, SH increased	8566	25.56	8.69E+09	3.39	4

With the same assumptions for total consented production plus increase at Easter Score Holms, dissolved inorganic nitrogen concentrations within the mixing box would be 28% of the "high" standard and total chlorophyll would be 54% of the CSTT standard.

[2] http://aquaculture.scotland.gov.uk/data/site_details.aspx accessed 23/04/2021

The proposed net reduction in total consented peak biomass at sites operated by Grieg Seafoods (-1396.75T) is also noted in the context of overall nutrient release.

It can therefore be concluded that nutrient enhancement associated with increased production of cage aquaculture at the Easter Score Holms site is unlikely to make a significant contribution to nutrient enhancement or to the likelihood of harmful algal blooms.

FRS Box Model for Prediction of Nutrient Enhancement

A simple box model is used by FRS Marine Laboratory to predict the level of soluble nutrient nitrogen from fish farming sources, in order to provide advice on the environmental suitability of coastal areas for fish farming (Gillibrand *et al* 2002). The model treats nitrogen as a conservative substance, and is a function of the flushing rate of a sea loch, the total consented biomass of all the finfish farms in the loch and the nitrogen source rate. A mass balance model was used to estimate the rate of release of nitrogen at 48.2 kgN per tonne of salmon produced per year. These data are used to calculate an equilibrium concentration enhancement (ECE) for nitrogen, expressed in µmol l^{-1}.

The predominant exchange mechanism is assumed to be the semi-diurnal tide. The flushing time of the loch basin can be calculated by assuming that the water volume is replaced by the volume of water entering and leaving on each tide (the "tidal prism"), giving:

$$T_F = \frac{0.52V}{0.7A.R} \text{ days}$$

where V is the volume of the loch basin (m^3), A is the surface area of the loch (m^2) and R is the tidal range (m). The factor 0.52 is the number of days per tidal cycle (1 tidal cycle = 12.4 hours = 0.52 days), and the factor 0.7 approximates the mean tidal range from the spring tidal range, R (Edwards and Sharples 1986).

The nutrient enhancement is strongly dependent on the flushing rate, Q (m^3 y^{-1}), of the loch, which is given by

$$Q = 365.V / T_F$$

where the factor 365 converts the units from m^3 d^{-1} to m^3 y^{-1}. The flushing rate, then, is the total quantity of water that is exchanged over a year.

The nutrient considered by the model is nitrogen, mainly in the form of dissolved ammonia but also accounting for nitrogen emitted as particulate waste and re-dissolving into the water column from the seabed. This is equivalent to considering that seabed conditions at farms are generally not deteriorating with time. The combined source of nitrogen from dissolved and particulate wastes is S = 48.2 kgN per tonne of salmon produced. This value was derived from a mass balance model, used to estimate the release of dissolved and particulate nitrogenous waste from cultivated salmon (Davies, 2000).

Applying values for feed wastage of 5 % and assuming the diet is 90 % digestible, a farm producing 1000 tonnes of salmon over a 20 month production cycle was found to achieve a food conversion ratio (FCR) of 1.17 (on a wet weight basis). The mean nitrogen content of salmon diets (wet weight) is estimated at 7.2 %, and the bulk composition of farmed fish is estimated to contain 3.4 % (wet weight) nitrogen. Therefore, assuming a total mortality rate over the 20-month production cycle of 10 %, the amount of nitrogen released can be calculated as the difference between the amount input in the feed and that incorporated into fish growth. Using this method, the amount of dissolved nitrogen released is estimated at 35.6 kgN $tonne^{-1}$ production, and the amount in particulate waste (wasted feed plus undigested faecal material) is estimated at 12.6 kgN $tonne^{-1}$ production. The total nitrogen discharge rate is therefore the sum of the dissolved and particulate rates, which is 48.2 kgN $tonne^{-1}$ production.

The equilibrium concentration enhancement, ECE, is calculated by

$$ECE = S.M / Q$$

where M is the total consented biomass of all the finfish farms in the sea loch (tonnes), Q is the flushing rate (m^3 y^{-1}) and S the Source rate (total discharge of nutrient nitrogen, kg $tonne^{-1}$ production). The ECE units are converted from kg m^{-3} to µmol l^{-1}, since measurements of dissolved nutrients are traditionally presented in these units.

Nutrient enhancement index is calculated on a semi-logarithmic scale, as described by Gillibrand *et al* (2002):

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