ANDERSON MARINE SURVEYS

Report To: Scottish Sea Farms

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ASSESSMENT OF POTENTIAL NUTRIENT ENHANCEMENT BY PROPOSED SALMON FARMING AT FISH HOLM, 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 relocation of farmed biomass in Yell Sound, Shetland; including increased production at Fish Holm close to the eastern end of Yell Sound.

The proposed peak biomass at Fish Holm is 6000T.

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).

[1] https://www.gov.scot/publications/authorisation-of-marine-fish-farms-in-scottish-waters-locational-guidelines/ accessed 11/06/2024

In the vicinity of the proposed Fish Holm site, Swinister Voe is designated as Category 2 (Figure 1). To the south of Lunna, Vidlin Voe is designated as Category 1, but is unlikely to be hydrographically connected to Fish Holm.

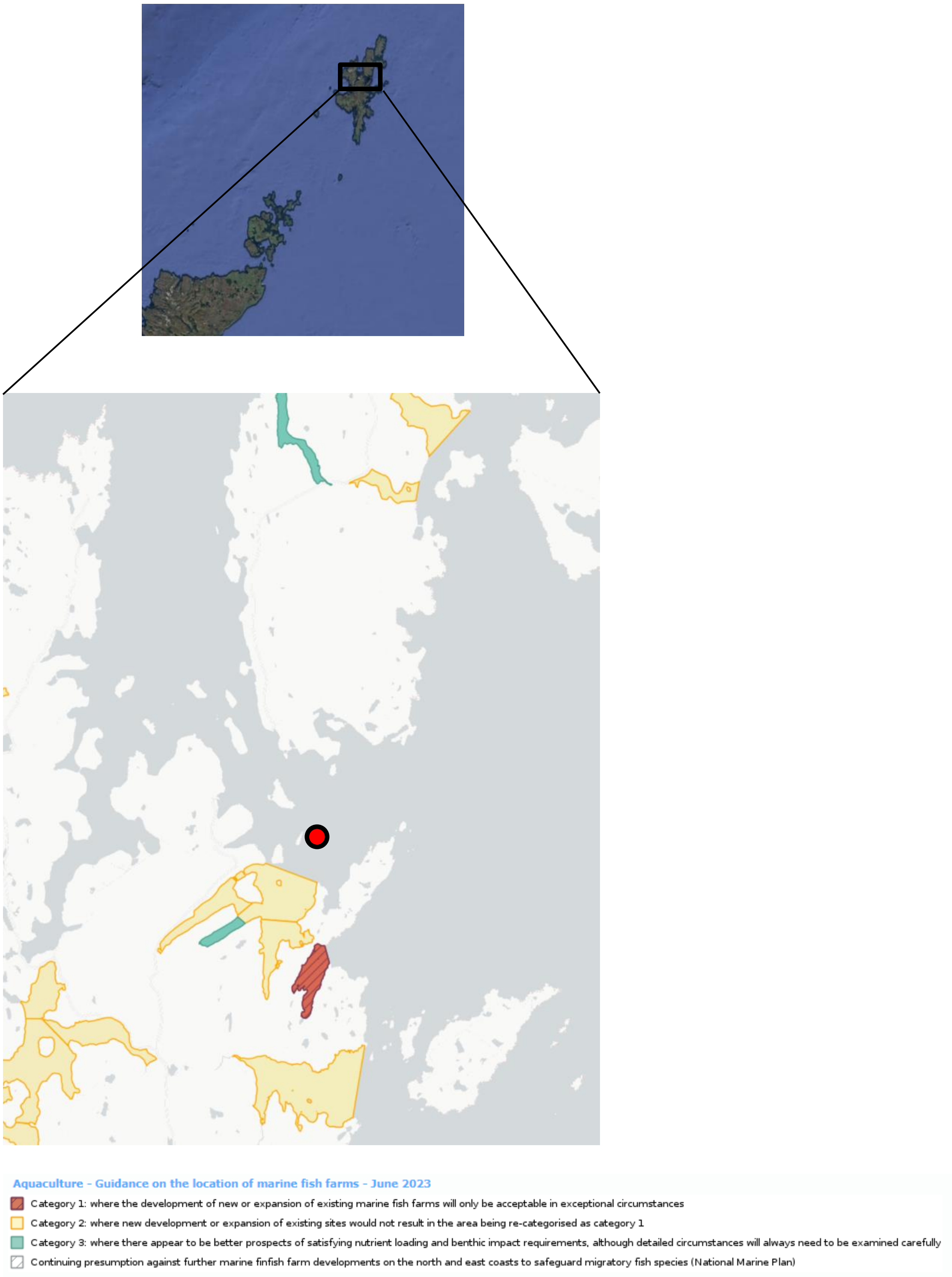

Figure 1. Fish Holm general location and Locational Guidelines areas
(source: https://marinescotland.atkinsgeospatial.com/nmpi/default.aspx?layers=530)

Existing sites in the area are shown in Figure 2:

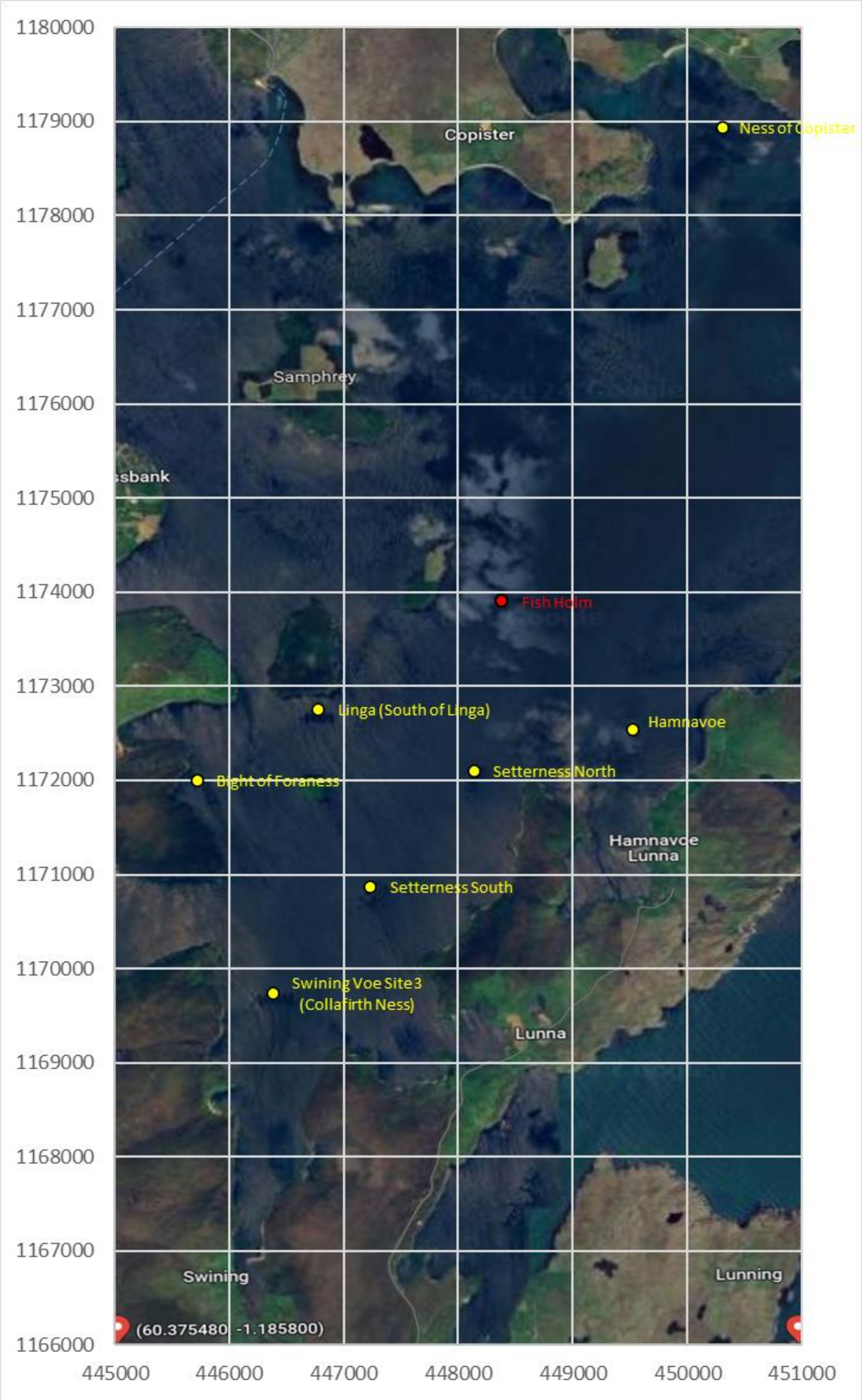

Figure 2. Existing production sites in south-east Yell Sound (two sites in Vidlin Voe, south of Lunna, are not shown)

SEPA's Screening Risk and Identification Report for the site, namely that due to the close proximity to the Swinister Voe Category 2 area, requires demonstration that any increase in nutrients does not cause degradation causing it to be recategorized as Category 1. This could happen if the 'Nutrient enhancement' index rose to 4, i.e. from an ECE >3 umol/l, pushing the combined index to 7.

Code	Loch	Maximum biomass (tonnes)	Total biomass (tonnes)	'Nutrient enhancement' index	'Benthic impact' index	'Combined' index
9	Swinister Voe	13227	13227	3	3	6

The Swinister Voe Category 2 area contains 9 CAR licences totalling 13,227 tonnes biomass and covers the 3 tributary categorised areas Dales Voe, Colla Firth & Swining Voe, as well as the large area at the confluence of these. The locational guidelines also state values for Flushing Time (Tf) and Flushing Rate (Q) for this area:

Loch name	Length (km)	Area (km^2)	Volume (Mm^3)	Tidal range (m)	Tf (days)	Q (Mm^3 $year^{-1}$)
SWINISTER VOE	6.3	14.9	367.5	1.8	4.9	27377

The three scenarios considered are:

Scenario 1 - Baseline

Potentially half of the soluble release from Fish Holm could be transported into the category 2 area, evidenced by the proportion of drogue paths and dye plumes that track to the south. This is backed up by the tracks of the modelled bath treatment plumes derived from hydrodynamic simulations.

This scenario also includes include dissolved waste arising from the Hamnavoe site to the SE (HAML1, 1910T, last stocked 2016), with assumed total transport into the category 2 area. Total tonnage = 16092T.

Scenario 2 – Proposed

Expanding Fish Holm to 6000T, half of which is transported into the category 2 area while surrendering CAR licences at Collafirth Site 3 (COLL3, 1200t) and Hamnavoe (HAML1, 1910t). This should represent a decrease of 1,065 tonnes into the category 2 area. Total tonnage = 15027T.

Scenario 3 – Worst case

As scenario 2 but with total transport from the expanded Fish Holm site into the category 2 area. Total tonnage = 18027T.

SEPA ID No.	Site Name	Existing Biomass	Baseline Scenario 1	Proposed Scenario 2	Worst case Scenario 3
COLL3	Collafirth Delting Site 3	1,200	1,200		
LING1	Linga	2,299	2,299	2,299	2,299
SETN1	Setterness North	2,500	2,500	2,500	2,500
SETW1	Setterness West	2,357.6	2,358	2,358	2,358
SWI2	Bight of Foraness	2,100	2,100	2,100	2,100
COL3	Site 3, Collafirth Ness	1,920	1,920	1,920	1,920
DAL1	Dales Voe (South)	100	100	100	100
NWSCA1	Scarva Ayre	250	250	250	250
WTAI1	West Taing, Dales Voe	500	500	500	500
FISH1	FH existing	1,910	955		
FISH1	FH Proposed	6,000		3,000	6,000
HAML1	Hamnavoe	1,910	1,910		
		Total tonnage	16,091.6	15,026.6	18,026.6

Results and discussion

Predicted ECEs are:

	ECE (µmol/l)
Baseline scenario 1	2.02
Proposed scenario 2	1.89
Worst case scenario 3	2.27

(see also individual tabulated calculations below).

Environmental standards for discharges to surface waters (including marine) are given by SEPA Supporting Guidance (WAT-SG-53, April 2020); 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.

For the Swinister Voe category 2 area, the baseline (scenario 1) ECE, 2.02 µmol/l equivalent to 28.3 µg/l, which does not account for nitrification and other removal mechanisms, is approximately 11 % of the “good” standard and 17 % of the “high” standard. The predicted Nutrient Enhancement Index is 3. This is identical to the current status given by locational guidelines (NEI 3 for a biomass of 13227T).

Proposed (scenario 2) and worst case (scenario 3) ECEs, 1.89 and 2.27 µmol/l do not result in a change in the Nutrient Enhancement Index from 3 and therefore do not affect the overall classification of the area under Locational Guidelines. The predicted ECEs represent 10.5-12.6 % of the “good” standard and 15.8-18.9 % of the “high” standard.

Predicted ECEs are 13.4 – 16.1 % of the “typical” background nitrogen concentration in Scottish coastal waters (Loch Linnhe annual average, 14.06 µM 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.

Overall, these predictions are strongly indicative of no change to nutrient status resulting from proposed changes to production at Fish Holm and neighbouring SSF sites.

Tabulated calculation of ECE, using MSS model			**Swinister Voe Cat2**		
			baseline	**proposed**	**worst**
V	volume	m3	3.68E+08	3.68E+08	3.68E+08
A	surface area	m2	1.49E+07	1.49E+07	1.49E+07
R	spring tidal range	m	1.8	1.8	1.8
S	source rate	kg/t	48.2	48.2	48.2
M	peak forecast biomass	t	16,091.6	15,026.6	18,026.6
	total N release	t	775.6	724.3	868.9
TF	flushing time	days	4.90	4.90	4.90
Q	flushing rate	m3/y	2.74E+10	2.7377E+10	2.74E+10
ECE	enhancement	kg/m3	2.83E-05	2.65E-05	3.17E-05
		ug/l	28.33	26.46	31.74
		umol/l	**2.02**	**1.89**	**2.27**
	Nutrient Enhancement Index		**3**	**3**	**3**
	% "good" standard		**11.24**	**10.50**	**12.59**
	% "high" standard		**16.86**	**15.75**	**18.89**
	L Linnhe annual average	uM TN	14.06	14.06	14.06
	L Linnhe winter average	uM DAIN	7.80	7.80	7.80
	% of L Linnhe annual average		14.39	13.44	16.12
	% of L Linnhe winter average		25.94	24.23	29.06
	background chlorophyll	mg/m3	1.7	1.7	1.7
	enhancement	g chl / mo	1.1	1.1	1.1
	predicted chlorophyll increase	mg/m3	2.23	2.08	2.49
	predicted chlorophyll	mg/m3	**3.93**	**3.78**	**4.19**
	% of CSTT standard		39.3	37.8	41.9

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.