ANDERSON MARINE SURVEYS

Report To: Scottish Sea Farms

Issued By: *SJA*

Date: 16 October 2023

ASSESSMENT OF POTENTIAL NUTRIENT ENHANCEMENT BY PROPOSED SALMON FARMING AT BILLY BAA, SHETLAND

SANDSOUND CATEGORY 1 AREA

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 The Deeps, northwest of Scalloway, Shetland; including development of a site at Billy Baa close to the entrance to Sandsound Voe.

The proposed peak biomass at Billy Baa is 4091T.

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).

In the vicinity of the proposed Billy Baa site, Sandsound, Weisdale and Stromness Voe are designated as Category 1; Selivoe and Whiteness Voe as Category 3 (Figure 1).

[1] https://www.gov.scot/publications/authorisation-of-marine-fish-farms-in-scottish-waters-locational-guidelines/ accessed 04/08/2023

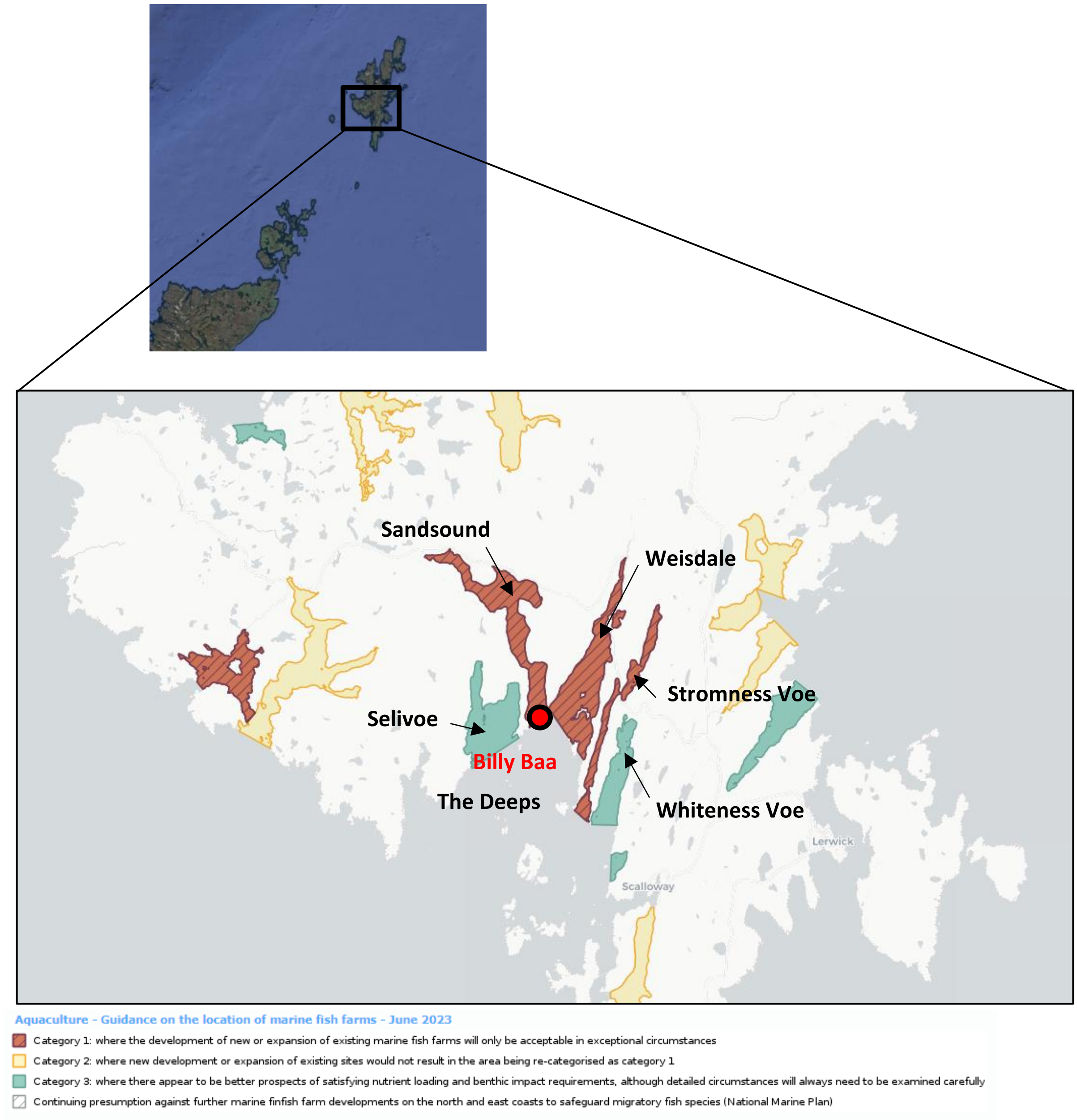
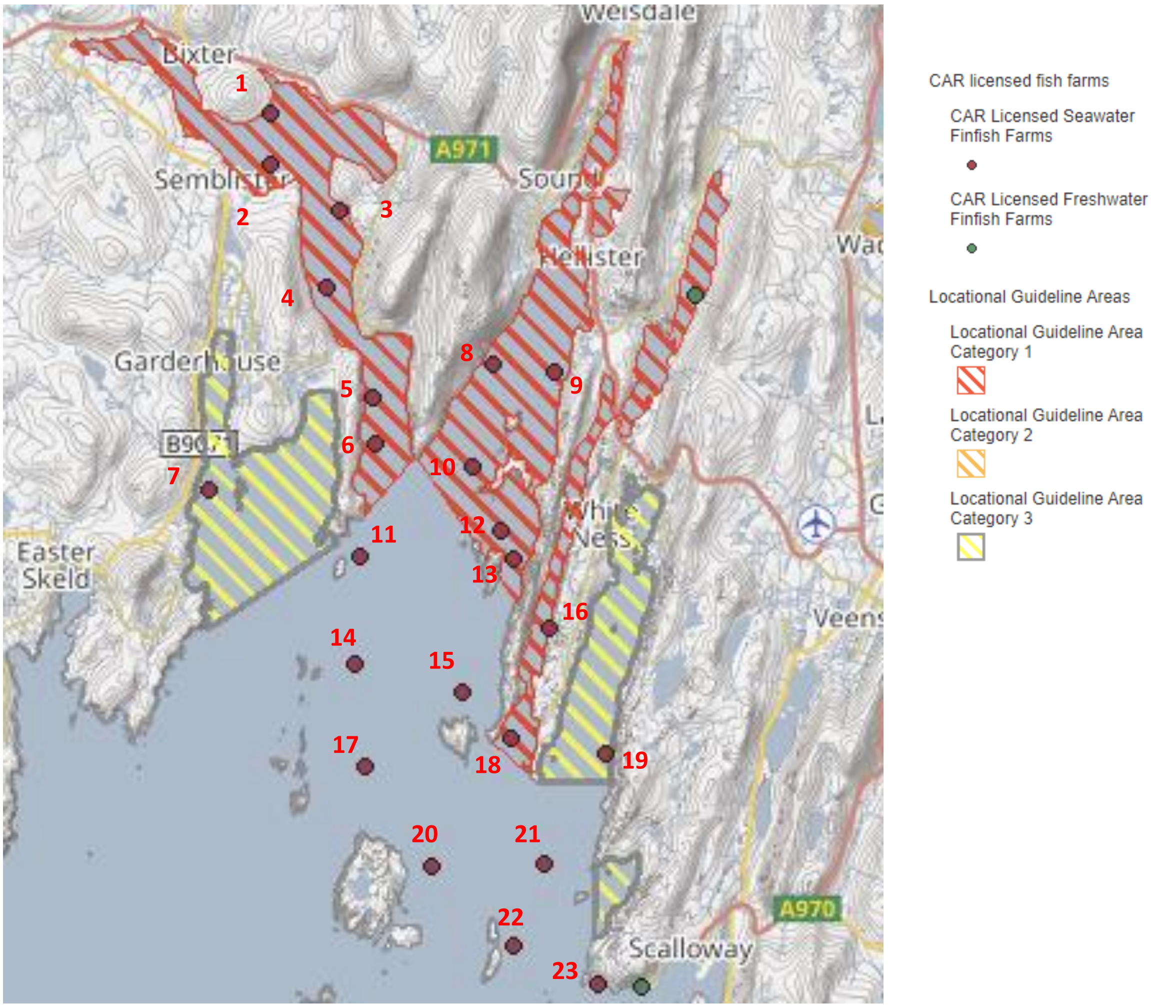


Figure 1. Billy Baa general location and Locational Guidelines areas
(source: https://marinescotland.atkinsgeospatial.com/nmpi/default.aspx?layers=530)

Existing CAR-licensed sites in the area are shown in Figure 2:



		Maximum biomass (T)			Maximum biomass (T)
1	Firth of Bixter Site 1	94.5	13	Sound of Hoy	1190.5
2	Firth of Bixter Site 2	97	14	Easter Score Holm	3919.61
3	Sandsound Voe	100	15	North Havra	1496
4	Sand Sound, Bixter	1000	16	Stromness Voe	150
5	Brei Geo Inshore	1209	17	Sanda Stour	1500
6	Brei Geo Offshore	2635	18	Binna Ness	1500
7	Seli Voe (Trouts Ness)	963	19	Whiteness Voe	500
8	Weisdale Voe B	250	20	East of Hildasay	1500
9	Weisdale Voe A	100	21	West of Burwick	1922.6
10	Flotta	1221	22	East of Langa	1642.8
11	Fore Holm	1650	23	Punds Voe	960
12	North of Hoy	1190.5			

Figure 2. CAR licensed fishfarms in The Deeps area
(source: http://aquaculture.scotland.gov.uk/map/map.aspx)

This assessment is made on the basis of mixing within the Sandsound Voe Category 1 area only. Two scenarios were considered:

Assessment 1 – Sandsound Category 1 area

Scenario 1 – Considering the Category 1 area only assessing the nutrient impact of all CAR licences plus Billy Baa

Scenario 2 – Considering the Category 1 area only assessing the nutrient impact of Billy Baa plus all CAR licences which would not be relinquished

Scenario 1			Scenario 2		
Site	Grid ref	Tonnes	Site	Grid ref	Tonnes
Firth of Bixter Site 1	HU342514	95	Firth of Bixter Site 1	HU342514	95
Firth of Bixter Site 2	HU342507	97	Firth of Bixter Site 2	HU342507	97
Sandsound Voe	HU352500	100	Billy Baa		4091
Sandsound, Bixter	HU350489	1000		***Total***	***4283***
Brei Geo Inshore	HU357473	1209			
Brei Geo Offshore	HU357465	2635			
Billy Baa		4091			
	Total	***9227***			

Methods

The Gillibrand *et al* (2002) model has been applied to the designated Sandsound Voe Category 1 area (Figure 3) adjacent to the proposed Billy Baa cage site (OSGB 435978mE 1145767mN).

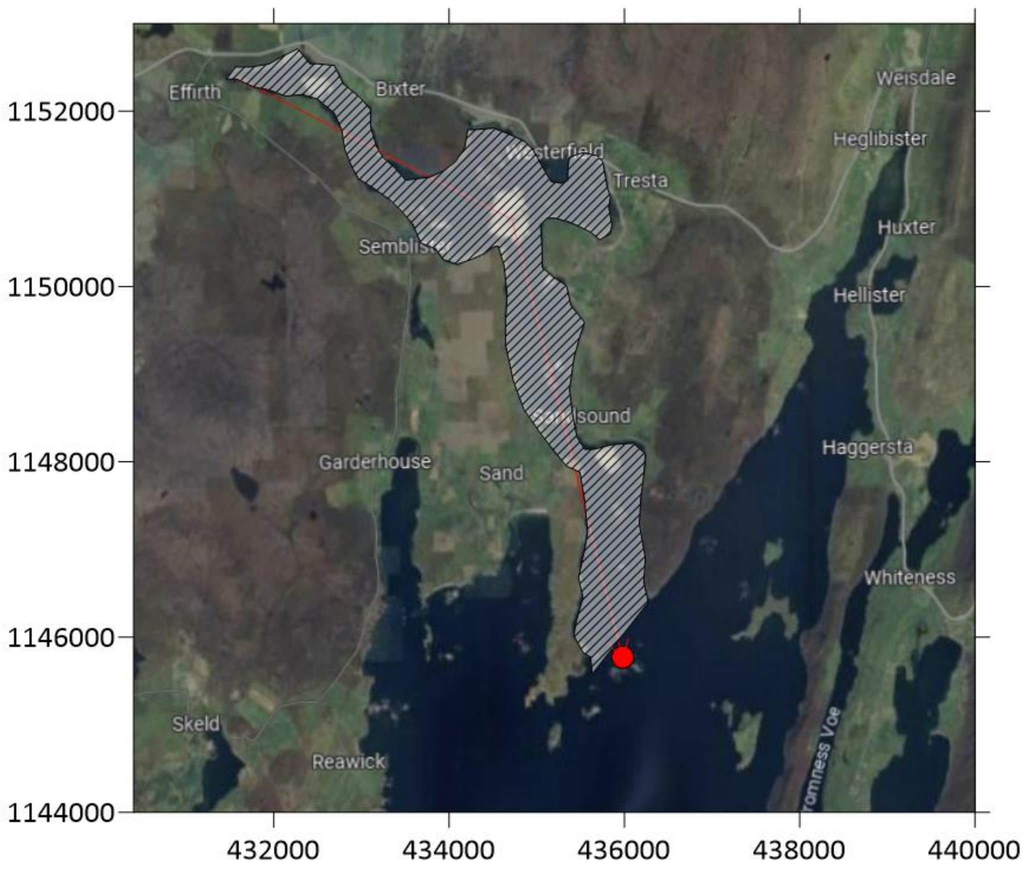


Figure 3. Proposed Billy Baa location and Sandsound Voe Category 1 area

Flushing rate (Q) was therefore estimated from volume and surface area estimates derived from Locational Guidelines 2023:

Loch Name	Length (km)	Area (km^2)	Volume (Mm^3)	Tidal Range (m)	Tf (days)	Q (Mm^3yr^{-1})
Sandsound	8.6	6.0	69.7	1.1	7.9	3219

Mean High Water Springs was -1.6mCD and spring tidal range was 1.1m; derived from Admiralty Chart No. 3283, Scalloway.

Results and discussion

Predicted flushing times, flushing rates and nitrogen ECEs are

Flushing time (days)	Flushing rate, Q (m^3/year)	ECE (µmol/l)
7.85	3.24E+09	Scenario 1: 9.80 Scenario 2: 4.55

(see also individual tabulated calculations below).

Environmental standards for discharges to surface waters (including marine) are given by SEPA Supporting Guidance (WAT-SG-53, Dec 2015); 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 scenario 1, the predicted ECE, 9.80 µmol/l equivalent to 137.1 µg/l, which does not account for nitrification and other removal mechanisms, is approximately 54 % of the “good” standard and 82% of the “high” standard. The predicted Nutrient Enhancement Index is 4.

For scenario 2, the predicted ECE, 4.55 µmol/l equivalent to 63.7 µg/l, is approximately 25 % of the "good" standard and 38% of the "high" standard. The predicted Nutrient Enhancement Index is also 4.

Predicted ECEs are 70% and 32% 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.

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 10.78 mg/m^3 for scenario 1; and a total chlorophyll concentration of 12.48 mg/m^3 (125% of CSTT standard).

For scenario 2, increase in chlorophyll concentration is 5.00 mg/m^3; with a total chlorophyll concentration of 6.70 mg/m^3 (67% of CSTT standard).

Tabulated calculation of ECE, using MSS model

			Sandsound S1	Sandsound S2
V	volume	m3	6.97E+07	6.97E+07
A	surface area	m2	6.00E+06	6.00E+06
R	spring tidal range	m	1.1	1.1
S	source rate	kg/t	48.2	48.2
M	peak forecast biomass	t	9227	4283
	total N release	t	444.7414	206.4406
TF	flushing time	days	7.85	7.85
Q	flushing rate	m3/y	3.24E+09	3.24E+09
ECE	enhancement	kg/m3	1.37E-04	6.37E-05
		ug/l	137.14	63.66
		umol/l	**9.80**	**4.55**
	Nutrient Enhancement Index		**4**	**4**
	% "good" standard		**54.42**	**25.26**
	% "high" standard		**81.63**	**37.89**
	L Linnhe annual average	uM TN	14.06	14.06
	L Linnhe winter average	uM DAIN	7.8	7.8
	% of L Linnhe annual average		69.67	32.34
	% of L Linnhe winter average		125.59	58.30
	background chlorophyll	mg/m3	1.7	1.7
	enhancement	g chl / mc	1.1	1.1
	predicted chlorophyll increase	mg/m3	10.78	5.00
	predicted chlorophyll	mg/m3	**12.48**	**6.70**
	% of CSTT standard		124.8	67.0

estimated V (m3) and A (m2) from Locational Guidelines March 2023	
Sandsound	
V	6.97E+07
A	6.00E+06
average depth	10.0

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.