SUPPLEMENT 1

1. ASSUMPTIONS FOR PARAMETER k_D

The parameter k_D (scaling stomach evacuation rate) was used to calibrate the model to fit with adult surplus energy requirements inferred from data. In our modelling framework, surplus energy needs to cover costs associated with both growth and reproduction. Slotte, 1999, shows that for NSS herring a 28 cm and 38 cm fish spends about 15 g and 25 g fat, respectively, on their spawning migration. Using the energy value for fat commonly used in the literature of 39.75 kJ g^{-1}, this represents approximately 596.25 and 993.75 kJ. We also used the mean (for 1995 and 1996) from equations of length-specific ovary weights (1995: $W_o = 0.805e^{0.13L}$ for 1995; 1996: $W_o = 1.79e^{0.104L}$ for 1996; with the energy density of ovaries of 8 kJ g^{-1}) in Slotte, 1999, to estimate the energy of spawning products for a herring of 28 and 38 cm. To account for the energy required to build gonads, we assumed the total energy expenditure for gonad production to be twice the energy of gonads (i.e. 508.71 kJ for 28 cm, and 1645.30 kJ for 38 cm). From the data on NSS herring used in this study, growth for individuals above 33 cm (all individuals mature) is approximately 16 g yr^{-1}. We assume that a mixed diet gives 10 kJ g^{-1} and that the cost of growing equals the cost of the actual growth, i.e. 320 kJ. Altogether, this means that our estimate of the surplus energy for a herring of 28 cm should around 1425 kJ, and that for a 38 cm herring should be around 2959 kJ and we scaled k_D to match our predictions to these values. For herring of body lengths 28 and 38 cm our model predicts surplus energy values of 1708 and 3131 kJ, respectively.

2. DIETS OF NORWEGIAN-SPRING SPAWNING ANF NORTH SEA HERRING

We assumed the diet of NSS herring to consist of 60% *Calanus finmarchicus* and 40% euphausiids and amphipods, as this is the approximate wet weight ratio observed in stomach content data from summer samples (Dalpadado et al. 2000, Gislason & Astthorsson 2002, Dommasnes et al. 2004, Bachiller et al. 2016). Summer stomach content data for North Sea herring are scarce, but their diet appears to consist primarily of *C. finmarchicus* and *Calanus helgolandicus*, with the remainder being mainly post-larval stages of fish (Last, 1989). To simplify interpretation of the results and to account for some feeding outside of the main foraging season, we assumed a wet weight ratio in the diet of North Sea herring of 60% *C. finmarchicus* and *C. helgolandicus*, and 40% larger prey (Last, 1989). For the default scenarios these ratios were obtained by scaling the predicted stomach content so that it corresponds to stomach data, and the same scaling factors were used in the sensitivity analyses. According to observations, we characterized *C. finmarchicus* in the North Sea simulation by a slightly smaller prosome length than in the Norwegian Sea simulation (Boxshall & Schminke, 1988; Skjoldal, 2004; Jónasdóttir *et al.*, 2005; Jonasdottir & Koski, 2011). Furthermore, due to the lack of discernible size differences between *C. finmarchicus* and *helgolandicus* in the North Sea (Wilson *et al.*, 2015), these species were modelled as one prey type. For generality, the 'larger prey' fraction in the diet of North Sea herring was parameterized as for euphausiids and amphipods in the Norwegian Sea simulation. NSS herring mainly forage in the upper 50 m during the main feeding season (Nøttestad et al. 2004). We defined one foraging depth for each prey type in the Norwegian Sea (30 m for the 'smaller prey' and 60 m for the 'larger prey'), and set the foraging depth to 20 m in the North Sea to account for shallower and less clear waters. Seasonal prey abundance distributions were modelled and parameterized to fit with observations (see section 4.2; North Sea, Colebrook, 1979; Norwegain Sea, Varpe & Fiksen, 2010). Section 4 contains values and references used to parameterize prey characteristics.

3. INPUT DATA

3.1 Prey size, energy density and concentration

Table S1. Parameter values and references for prey characteristics

Prey type	**Parameter**	**Value**	**Reference**
Norwegian Sea			
Calanus finmarchicus	Length	3.0 mm	Castellani & Edwards, 2017
	Weight	0.1523 mg dw	Using length-weight formula adapted from Uye (1982)[1].
	Energy density	6400 cal/g dw	Laurence, 1976
	Max concentration	600 prey/m^3	Varpe & Fiksen, 2010
Amphipods and euphasiids[2]	Length	14.4 mm	Lindley, 1978, 1982; Lindley et al. 1999; Kraft et al. 2012
	Weight	7.6896 mg dw	Using length-weight formula adapted from Uye (1982)[1].
	Energy density	5200 cal/g dw	Percy & Fife, 1981; Kulka & Corey, 1982
	Max concentration	3 prey/m^3	See 4.1.1
North Sea			
Calanus finmarchicus and *helgolandicus*	Length	2.6 mm	Jónasdóttir et al. 2005; Jonasdottir & Koski, 2011
	Weight	0.1065 mg dw	Using length-weight formula adapted from Uye (1982)[1].

	Energy density	6400 cal/g dw	Laurence, 1976; Kattner & Krause, 1989
	Max concentration	473 prey/m^3	See 4.1.1
Larger prey	Length	14.4 mm	Assume same value as for amphipods and euphausiids in the Norwegian Sea.
	Weight	7.6896 mg dw	Using length-weight formula adapted from Uye (1982)[1].
	Energy density	5200 cal/g dw	See text above.
	Max concentration	2 prey/m^3	See 4.1.1

[1]Prey weight (mg dry weight) = $10^{2.5\log(1000 l_p)-6.51} 10^{-3}$; Adapted from Uye (1982)
[2]Mean for *Themisto abyssorum* and *compressa*, *Meganyctiphanes norvegica*, and *Thysanoessa inermis* and *longicaudata*.

3.2 Seasonal prey abundance distributions

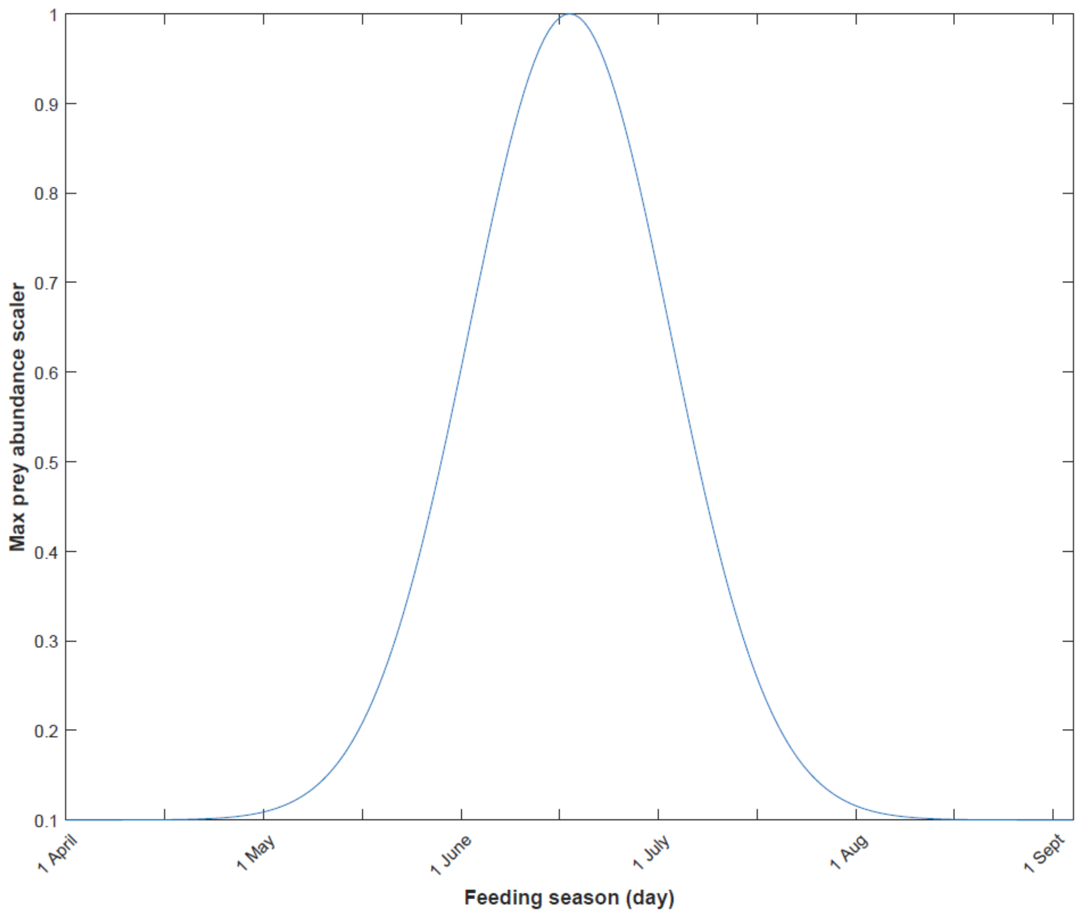

Figure S1. Seasonal prey biomass distribution s_d used to scale the maximum prey abundance $N_{\max,p}$ for the Norwegian Sea (see Equation 10 in Table 1)

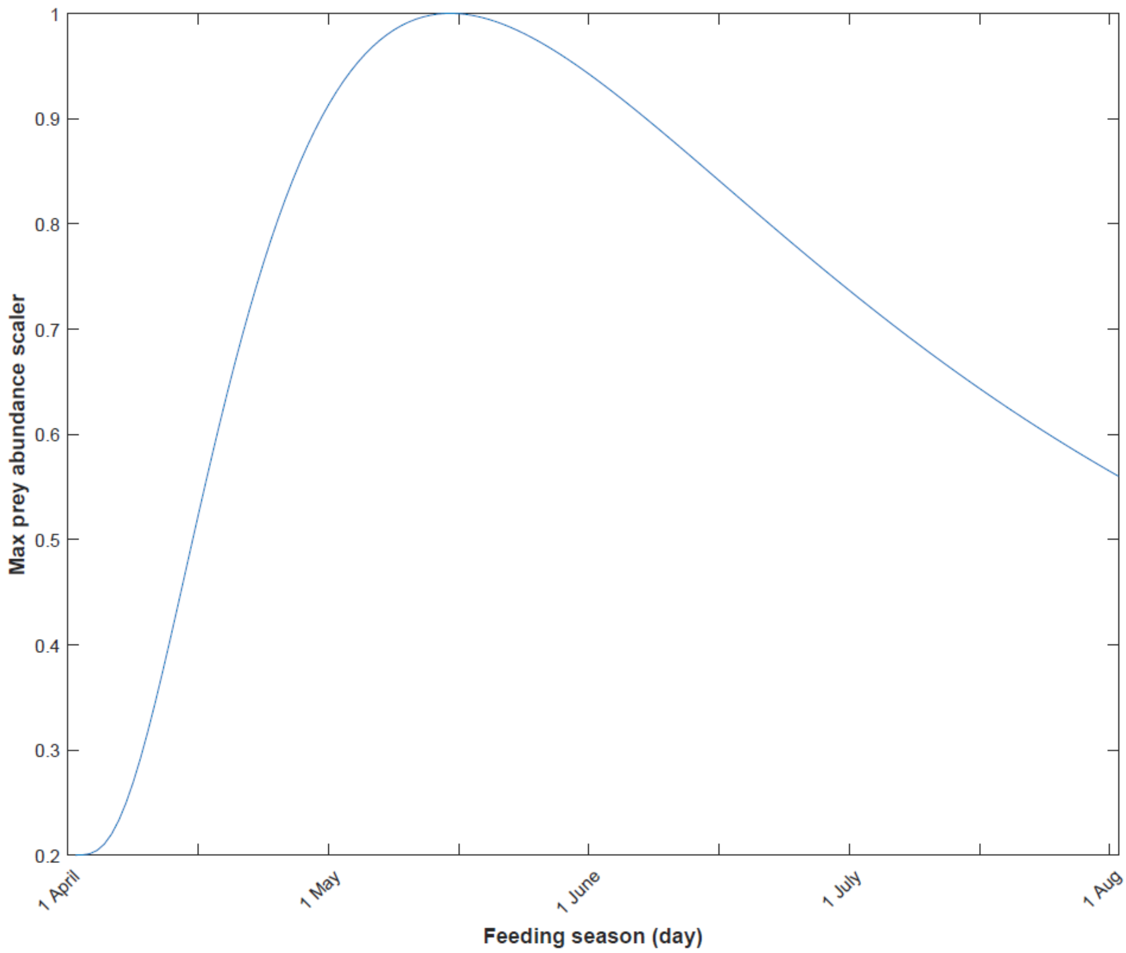

Figure S2. Seasonal prey biomass distribution s_d used to scale the maximum prey abundance $N_{\max,p}$ for the North Sea (see Equation 10 in Table 1)

4. ASSUMPTIONS AND CALCULATIONS

4.1 Prey biomass fractions

4.1.1 Predicting optimal body size in two herring populations

NORWEGAIN SEA

Approximation of biomass fractions by mesh size (dry weight; data obtained from Cecilie Broms, IMR):

<1 mm = 43 %

1-2 mm = 45 %

>2 mm = 12 %

Assumptions:

- *Calanus finmarchicus* constitute 45 % of the prey field
- Peak *C. finmarchicus* biomass concentration is 0.70 g/m^3 (600 prey/m^3; Varpe & Fiksen 2010) using prey dry weight from Table S1 and a dry weight to wet weight ratio of 0.13 (Rudstam 1988)
- Amphipods and euphausiids constitute 12 % of the prey field
- This yields a peak biomass concentration for amphipods and euphausiids of 0.18 g/m^3 (3 prey/m^3)

NORTH SEA

Approximation of biomass fractions by mesh size (dry weight; Falkenhaug, 2016):

<1 mm = 50 %

1-2 mm = 40 %

>2 mm = 10 %

Assumptions:

- Biomass ratio North Sea and Norwegain Sea = 5.7/9.2 (Broms 2016, Falkenhaug 2016), assume the same ratio between *C. finmarchicus* and *helgolandicus*
- *C. finmarchicus* and *helgolandicus* constitute 40 % of the prey field

- This yields a peak biomass concentration for *C. finmarchicus* and *helgolandicus* of 0.39 g/m^3 (473 prey/m^3)
- Larger prey constitute 10 % of the prey field
- This yields a peak biomass concentration for larger prey of 0.12 g/m^3 (2 prey/m^3)

4.1.2 Drivers of optimal body size in Norwegian spring-spawning and North Sea herring

NORWEGAIN SEA

- For this analysis default prey size (3 mm and 14.4 mm) is varied by ±20%
- Assuming a constant biomass concentration (see 4.1.1; Norwegian Sea) for all prey sizes yields peak prey concentrations for 3 mm ±20% prey of 750 prey/m^3 and 500 prey/m^3 for smaller and larger size, respectively
- Assuming constant biomass concentration (see 4.1.1; Norwegian Sea) for all prey sizes yields peak prey concentrations for 14.4 mm ±20% prey of 3.75 prey/m^3 2.5 prey/m^3 for smaller and larger size, respectively

NORTH SEA

- For this analysis default prey size (2.6 mm and 14.4 mm) is varied by ±20%
- Assuming constant biomass concentration (see 4.1.1; North Sea) for all prey sizes yields a peak concentration for 2.6 mm ±20% prey of 591 prey/m^3 and 394 prey/m^3 for smaller and larger size, respectively
- Assuming constant biomass concentration (see 4.1.1; North Sea) for all prey sizes yields a peak concentration for 14.4 mm ±20% prey of 2.5 prey/m^3 and 1.67 prey/m^3 for smaller and larger size, respectively

4.1.3 Drivers of optimal body size in planktivores

Assumptions:

- Peak *C. finmarchicus* (3 mm prey) biomass concentration is 0.70 g/m^3 (600 prey/m^3; Varpe & Fiksen 2010)
- Assuming constant biomass concentration for all prey sizes yields a peak prey concentration for 2 mm prey of 1652 prey/m^3, and for 4 mm prey of 292 prey/m^3 (using the length-weight formula adapted from Uye (1982) and a and a dry weight to wet weight ratio of 0.13 (Rudstam 1988))

5. SENSITIVITY TO ALTERED SEASONAL PREY DISTRIBUTIONS

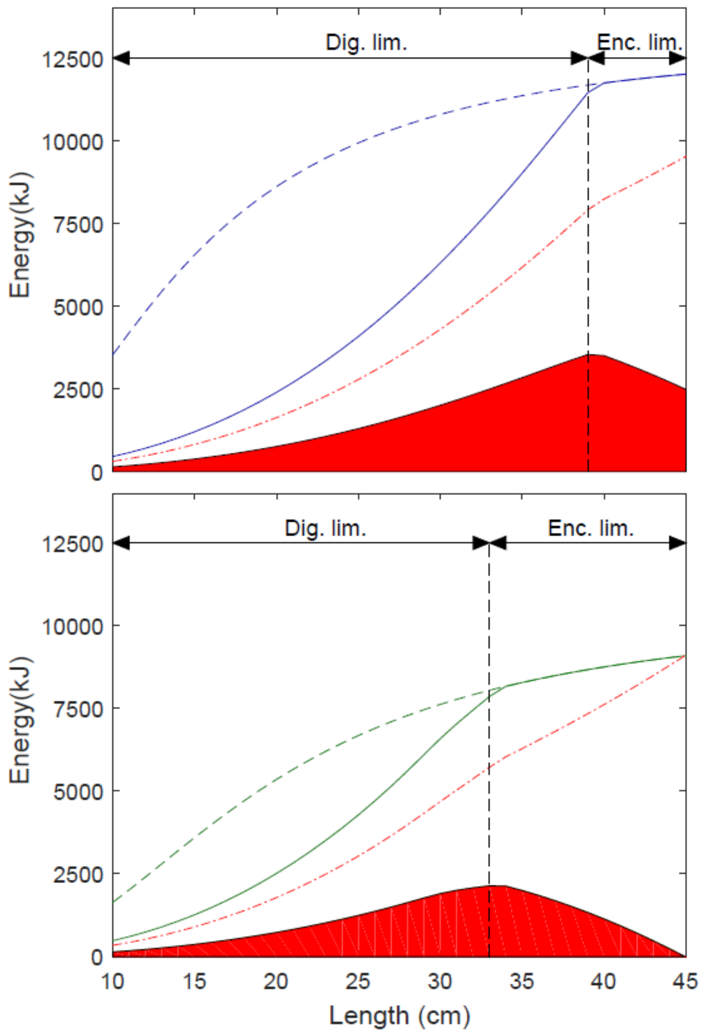

Figure S3. Predictions for the Norwegian Sea (top) using the seasonal prey abundance distribution for the North Sea (see Figure S2) and for the North Sea (bottom) using the seasonal prey abundance distribution for the Norwegian Sea (see Figure S3). Solid lines show digested food (kJ year^{-1}), dashed blue and green line show maximum potential food intake when there is no digestion limitation (sum of feeding rate; kJ year^{-1}), and red dotdash lines the metabolic cost (kJ year^{-1}). Red areas represent the difference between amount of digested food and the metabolic cost and thus represent annual surplus energy (kJ) of herring in the Norwegian Sea a) and the North Sea b). Dashed black lines show the predicted optimal size. 'Dig. lim.' and 'Enc. lim.' indicate the lengths at which digestion and prey encounters, respectively, limit energy acquisition.

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