Modelling chance and necessity in natural systems
Supplementary material
Model parametrization for the Barents Sea

Benjamin Planque
Institute of Marine Research, Tromsoe, Norway
benjamin.planque@hi.no

Christian Mullon
Paris, France
christian.mullon@ird.fr

We provide below information about input parameters and observations used in the Barents Sea CaN food-web model. Most parameters are derived from Lindstrøm *et al.* (2017).

1 Trophic groups

1.1 Trophic groups composition

Trophic groups are provided in table 1.

Table 1: Trophic groups in the Barents Sea. Exploited species are in italic.

Trophic group	Species
Primary production (phytoplankton)	Diatoms, Prymnesiophytes, Flagellates, Monads.
Herbivorous zooplankton	Mesozooplankton $< 2000 \mu m$.
Omnivorous zooplankton	Mesozooplankton $> 2000 \mu m$, *Euphausiids*, Amphipods.
Benthos	Epifaunal filter feeders (sea lilies, crinoids, urchins, etc.), Infaunal filter feeders (bivalves, detritophages and polychaetes), Other macrobenthos (predators, omnivores and carrion eaters, plant eaters and scrapers), Meiofauna.
Pelagic fish	*Juvenile herring*, *Capelin*, *Polar cod*, *Blue Whiting*.
Demersal fish	*Cod*, *Haddock*, *Saithe*, *Redfishes*, *Wolffishes*.
Marine mammals	Fin whale, Humpback whale, *Minke whale*, White beaked dolphin, Sperm whale, White whale, *Harp sea*l, Ringed seal, Walrus, Bearded seal.
Birds	Northern fulmar, Black-legged kittiwake, Glaucous gull, Common murre, Thick-billed murre, Razorbill, Atlantic puffin, Black guillemot, Little auk, Other birds.

1.2 Datasets for trophic groups

The following data table regroups the data used by the CaN model. Estimates of biomasses and landings have been extracted from the report of the Working Group on the Integrated Assessments of the Barents Sea (ICES, 2017). Estimates of primary production since 1998 come from Dalpadado *et al.* (2014). Prior to 1998, primary production has been assumed to be around 1.000,000,000t/y. There are no available time series for the biomasses of benthos, marine mammals and birds. These are assumed to be around 105,000t, 560,000t and 11,000t respectively. Landings are assumed to be known without uncertainty. These data are summarized together with their uncertainty in figure 2 of the paper.

Table 2: Barents Sea. Primary production. Biomasses (observations and estimations). Landings (observations)

Year	Primary pr.	Herbivorous p.	Omnivorous p.	Benthos	Pelagic	Demersal	Mammals	Birds	Benthos	Pelagic	Demersal	Mammals
1988	1000000	16608	16864	105000	576	1472	560	11	48.68	114.24	545.88	10.79
1989	1000000	27872	13616	105000	1200	1376	560	11	62.74	123.01	414.01	6.51
1990	1000000	23504	7695	105000	6304	1392	560	11	81.16	95.94	274.27	6.32
1991	1000000	21776	14640	105000	8304	2112	560	11	74.86	1036.32	403.92	6.29
1992	1000000	26816	7008	105000	7231	2976	560	11	68.56	1271.2	588.49	5.97
1993	1000000	37440	13008	105000	3776	3728	560	11	56.31	792.4	677.21	7.06
1994	1000000	71408	17552	105000	2368	3647	560	11	28.28	153.05	918.92	7.45
1995	1000000	57296	16784	105000	1136	3440	560	11	25.22	191.67	892.68	6.33
1996	1000000	38752	19536	105000	1184	3584	560	11	34.51	192.14	918.17	7.77
1997	1000000	45024	16191	105000	1584	3360	560	11	35.73	151.42	924.99	7.67
1998	799240	40496	17744	105000	3215	3072	560	11	55.79	157.82	707.64	4.28
1999	747073	35008	13104	105000	4960	3008	560	11	75.66	273.07	579.4	7.45
2000	1052786	41616	12736	105000	7088	2928	560	11	83.17	585.52	493.97	8.54
2001	1170272	31168	13104	105000	6272	3456	560	11	57.53	745.05	534.01	8.73
2002	1109194	35088	12224	105000	3904	3904	560	11	61.48	843.37	656.99	8.1
2003	874724	31776	17184	105000	2304	4000	560	11	39.22	482.89	693.52	9.12
2004	1071634	36480	25344	105000	4992	4015	560	11	42.73	166.23	769.5	2.18
2005	909010	41616	17392	105000	4816	4128	560	11	42.61	201.96	807.5	6.5
2006	1096430	45808	21152	105000	4656	3872	560	11	29.62	229.12	724.3	5.14
2007	946826	39184	27392	105000	4224	4192	560	11	29.93	229.9	668.72	4.23
2008	872083	35360	19392	105000	6064	4784	560	11	28.18	204.94	632.7	4.05
2009	931335	33520	22992	105000	5056	5392	560	11	27.27	485.85	733.3	2.18
2010	1129906	37616	28639	105000	5344	6256	560	11	25.19	545.23	871.1	2.18
2011	1232387	32048	20832	105000	4880	6016	560	11	30.22	536.21	1042.8	2.62
2012	1108070	41104	20784	105000	4448	5776	560	11	24.75	456.96	1053.69	2.25
2013	1190710	31088	8880	105000	4928	5568	560	11	19.24	308.81	1169.2	2.95

1.3 Original parameters

We reproduce below the parameters used in the original study by Lindstrøm *et al.* (2017).

The original input parameters are defined as follows:

- γ: the proportion of ingested prey that is assimilated by the predator
- κ: a digestibility correction factor which accounts for variations in prey energy content.

The product of the potential assimilation efficiency by the digestibility correction factor is the absorption efficiency (the proportion of prey biomass digested and absorbed)

- μ: a mortality coefficient that account for other losses, i.e. metabolic losses and other mortality not accounted for explicitly in the model.
- α: inertia, i.e. a parameter that bounds biomass variations between a maximum growth rate and a maximum mortality rate.
- σ: satiation, the maximum consumption rate per unit biomass of the predator.

Table 3: Characteristics of trophic groups. From Lindstrøm *et al.* (2017)

Group	Primary pr.	Herbivorous p.	Omnivorous p.	Benthos	Pelagic	Demersal	Mammals	Birds
Assimilation γ		1.	1.	0.94	0.9	0.93	1.	0.84
Digestibility κ	0.65	0.9	0.9	0.6	0.9	0.85		
Losses μ		8.4	5.5	1.5	2.85	1.65	5.5	60.
Satiation σ		128.	42.	25.	13.5	5.5	10.9	123.
Inertia ρ		7.6	3.1	0.74	0.9	0.25	0.11	0.81

2 Parameters

2.1 Parameters for mass conservation equation of trophic groups

Notations are those of appendix B.2 of the main text. To get the parameters express the mass conservation equation, we use the same method as Lindstrøm *et al.* (2017). They assume that:

1. For a trophic group i, biomass change due to an incoming trophic flow f is related to the assimilation coefficient γ_i and the digestibility coefficient of its prey $\kappa_{o(f)}$; total change due to the predation it exerts is:

$$\gamma_i \sum_{f|e(f)=i} \kappa_{o(f)} F_{f,t}$$

2. Instantaneous losses of biomass due to predation are, with similar notations:

$$\sum_{f|o(f)=i} F_{f,t}$$

3. Instantaneous losses of biomass due to other losses (such as somatic maintenance, mortality not related to predation, etc.) that are considered as linearly related to the amount of biomass. With a trophic loss coefficient μ_i, they are: $\mu_i B_{i,t}$.

4. Then, instantaneous biomass changes is given by:

$$dB_{i,t} = \left(\gamma_i \sum_{f|e(f)=i} \kappa_{o(f)} F_{f,t} - \sum_{f|o(f)=i} F_{f,t} - \mu_i B_{i,t} \right) dt \tag{1}$$

5. Integration on interval $[t, t+1]$ gives a discrete equation:

$$B_{i,t+1} - B_{i,t} = \frac{1 - e^{-\mu_i}}{\mu_i} \left(\gamma_i \sum_{f|e(f)=i} \kappa_{o(f)} F_{f,t} - \sum_{f|o(f)=i} F_{f,t} - \mu_i B_{i,t} \right) \tag{2}$$

If, as usual $\delta_{i,j} = 1$ if $i = j$ and 0 else, we put :

$$\begin{aligned} H_i &= 1 - e^{-\mu_i} \\ N_{if} &= \frac{1 - e^{-\mu_i}}{\mu_i} \left(\gamma_i \kappa_{o(f)} \delta_{i,e(f)} - \delta_{i,o(f)} \right) \end{aligned}$$

we get the expected mass conservation equation:

$$B_{i,t+1} - B_{i,t} = \sum_f N_{if} F_{f,t} - H_i B_{i,t} \tag{3}$$

Values of vector H and matrix N that are obtained with the values in table 3 are given in table 4.

Table 4: Parameters H, N used in the CaN model of the Barents Sea for the expression of the mass conservation equation

		Herbivorous p.	Omnivorous p.	Benthos	Pelagic	Demersal	Mammals	Birds
B_0		16608	16864	105000	576	1472	560	11.2
H		0.9998	0.9959	0.7769	0.9422	0.808	0.9959	1.
N	{Benthos,Benthos}			-0.220				
	{Benthos,DemersalFish}			-0.518		0.273		
	{DemersalFish,DemersalFish}					-0.102		
	{DemersalFish,Fishery}					-0.489		
	{DemersalFish,Mammals}					-0.489	0.153	
	{HerbZooplankton,OmnivZooplankton}	-0.119	0.162					
	{HerbZooplankton,PelagicFish}	-0.119			0.267			
	{Mammals,Fishery}						-0.181	
	{OmnivZooplankton,Birds}		-0.181					0.0126
	{OmnivZooplankton,DemersalFish}		-0.181			0.409		
	{OmnivZooplankton,Fishery}		-0.181					
	{OmnivZooplankton,Mammals}		-0.181				0.162	
	{OmnivZooplankton,OmnivZooplankton}		-0.0181					
	{OmnivZooplankton,PelagicFish}		-0.181		0.267			
	{PelagicFish,Birds}				-0.330			0.0126
	{PelagicFish,DemersalFish}				-0.330	0.409		
	{PelagicFish,Fishery}				-0.330			
	{PelagicFish,Mammals}				-0.330		0.162	
	{PelagicFish,PelagicFish}				-0.0628			
	{PrimaryProduction,Benthos}			0.316				
	{PrimaryProduction,HerbZooplankton}	0.077						
	{PrimaryProduction,OmnivZooplankton}		0.118					

2.2 Parameters for constraints

To express the constraints detailed in the appendix 3, we need the values of α_i, σ_i, ν_i, λ_i. They are given in table 5.

Table 5: Constraints parameters on species used in the CaN model of the Barents Sea

		Primary pr.	Herbivorous p.	Omnivorous p.	Benthos	Pelagic	Demersal	Mammals	Birds
Inertia	ρ		7.6	3.1	0.74	0.9	0.25	0.11	0.81
Satiation	σ		128.	42.	25.	13.5	5.5	10.9	123.
Uncertainty bounds on observations (+)	ν	1.3	2.5	1.6	1.5	1.25	1.25	1.5	2.0
Uncertainty bounds on observations (-)	λ	0.7	0.4	0.6	0.6	0.8	0.8	0.6	0.5

References

Dalpadado, P., Arrigo, K. R., Hjøllo, S. S., Rey, F., Ingvaldsen, R. B., Sperfeld, E., van Dijken, G. L., Stige, L. C., Olsen, A., and Ottersen, G. (2014). Productivity in the barents sea-response to recent climate variability. *PloS one*, **9**(5), e95273.

ICES (2017). *Report of the Working Group on the Integrated Assessments of the Barents Sea (WGIBAR)*. ICES CM, 2017/SSGIEA:04: 191p.

Lindstrøm, U., Planque, B., and Subbey, S. (2017). Multiple patterns of food web dynamics revealed by a minimal non-deterministic model. *Ecosystems*, **20**(1), 163–182.