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Population growth in North Atlantic fin whales

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ABSTRACT

I use Bayesian modelling to analyse the population growth of fin whales across four areas in the North Atlantic. Each areas has three or four abundance estimates, and assuming density regulated growth it is estimated that North Atlantic fin whales have a msyr^{1+} of 6.1% (90% CI:2.1 − 9.6%). This estimate is examined for robustness to uncertainty in the priors for 1+ survival, fecundity and the msyr^{1+}, and I conclude that there is a 95% probability that the msyr^{1+} is higher than ≈ 2% in North Atlantic fin whales.

I use an age-structured and density regulated model to analyse the population growth of fin whales across four areas in the North Atlantic; ranging from West Greenland (WG), over East Greenland (EG) and West Iceland (WI) to East Iceland/Faroese waters (EI).

I use the abundance and catch data from the 2014 Implementation Review (IWC 2014), and my model is based on a Bayesian simulation framework that I have used in many earlier assessments (e.g., Witting 2011; Witting 2013). I do not fit the models to the complete catch histories; as density regulated growth tends to be unrepresentative of the long-term dynamics of baleen whale populations (Witting 2013). My models are instead initiated below the current carrying capacities and with a stable age-structure in 1978 to provide estimates of current growth; expressed as current values of the maximum sustainable yield rate (msyr^{1+}).

My priors were uninformative and uniform. Based on a point estimate of 0.96 from Allen (1980), and comparable survival estimates for humpback whales (e.g., Larsen and Hammond 2004; Zerbini et al. 2010), the prior on the yearly survival of one plus individuals was set from 0.9 to 0.995 following the range from IWC (2015). First year survival was solved from draws of the maximal birth rate, the age of maturity, 1+ survival, the msyr^{1+} and the msyl, assuming that first years survival is less than 1+ survival. For each draw of the msyr^{1+}, I resample the other parameters up til 10.000 times, until a solution for the rate of first year survival is possible. If a solution is not possible, I draw a new value of the msyr^{1+} and resample the other parameters 10.000 times for a solution, etc.

A range from 5 to 15 for the age of maturity (first reproduction) were obtained from Lockyer and Sigurjonsson (1992) following IWC (2015), and a range from 0.4 to 0.76 for the maximum rate of reproduction in mature females were set from Lockyer and Sigurjonsson (1992), Gunnlaugsson et al. (2013), and IWC (2015). This is somewhat higher than the 0.3 to 0.6 range suggested by IWC (2015), however, data from Iceland (Gunnlaugsson et al. 2013) find average pregnancy rates from 0.51 to 0.76 over four hunting periods between 1967 and 2010. While this sample might be biased in favour of females with no calfs, twins were also observed on a few occasions, and the maximal pregnancy rate is likely somewhat higher than the realised pregnancy that is observed in natural population. I therefore chose a lower bound of 0.4 - representing the average between the observed minimum pregnancy rate and a calf every third year, and an upper bound of 0.76 representing the upper bound of data.

The prior on the msyl was uniform from 0.55 to 0.65, and the prior on the msyr^{1+} was uniform from 0.001 to 0.10. The latter has a lower bound that is ten times smaller than the usual lower range of 1% considered by IWC, and an upper range that is within the prior limits of the life history parameters.

The abundance data are listed in Table 1, the priors in Table 2, the sampling-resampling statistics in Table 3, and the posterior parameter estimates in Table 4. The realised prior and posterior distributions are shown in Figures 1 to 4, and the estimated trajectories in Figure 5.

All models have more or less pronounced peaks in the posterior distributions of the current carrying capacities, but with only three to four abundance estimates the models were unable to estimate an upper bound on the carrying capacity. The posterior distributions were also unable to estimate upper bounds on the population dynamic growth rates, but they were able to distinguish lower bounds. This provided posterior estimates of the msyr^{1+} of 6.7% (90% CI:2.7 − 9.6%) for WG, 6.0% (90% CI:2.7 − 9.5%) for EG, 5.9% (90% CI:1.7 − 9.6%) for WI, and of 5.7% (90% CI:1.1 − 9.6%) for EI, with the average estimate across the four areas being 6.1% (90% CI:2.1 − 9.6%).

To examine the robustness of these estimates I ran sensitivity analyses based on alterative priors. The upper bound of 0.995 for adult survival is certainly in the upper range of the possible, and to examine the consequences for our estimates if this limit is indeed too large, I ran alternative models with a uniform survival prior from 0.9 to 0.98. This resulted in msyr^{1+} estimates that were essentially identical with the base case, with the sensitivity estimates being 6.6% (90% CI:2.7 − 9.6%) for WG, 6.0% (90% CI:2.6 − 9.5%) for EG, 5.8% (90% CI:1.7 − 9.6%) for WI, and of 5.7% (90% CI:1.2 − 9.6%) for EI, with the average estimate across the four areas being 6.0% (90% CI:2.1 − 9.6%).

A second sensitivity run was based on fin whale data from Gunnlaugsson et al. (2013), with a max birth rate prior from 0.51 to 0.76, and an age of maturity prior from 5 to 35 as 2010 catches included seven animals with zero corpora with apparent ages from 18 to 34 years. This provided msyr^{1+} estimates that were practically identical with the base case: 6.7% (90% CI:2.7 − 9.6%) for WG, 6.1% (90% CI:2.7 − 9.5%) for EG, 5.8% (90% CI:1.6 − 9.6%) for WI, and of 5.7% (90% CI:1.1 − 9.6%) for EI, with the only difference in the average estimate 6.1% (90% CI:2.0 − 9.6%) being a lower limit of 2.0% instead of 2.1%.

It is concluded that the estimated lower bound for msyr^{1+} of the base case is robust to uncertainty in the priors of the underlying life history parameters.

The bounds on the uniform prior of the msyr^{1+}, however, will naturally affect the estimates of the msyr^{1+} as the updating from the data is anything but strong, except for the very low growth rates in three of the areas. With a lower bound of 0.1% there seems to be no risk that the lower bound is too high; the 0.1% may instead bias the estimate downward. With no strong updating in the upper range, it is somewhat unclear where the upper limit on the growth rate should be. I have chosen a msyr^{1+}

of 10% as the upper bound, as this is within the limits of the life history prior, and as it is unlikely that the msyr^{1+} is much larger than this. The 10% limit on the msyr^{1+} suggests that there is a 95% probability that the maximal growth rate in North Atlantic fin whales is below 12%.

If instead the upper limit on the msyr^{1+} is set to 9%, it is estimated that there is a 95% probability that the maximal growth rate in North Atlantic fin whales is below 10.5%. This provides msyr^{1+} estimates that are slightly smaller: 6.2% (90% CI:2.4 – 8.7%) for WG, 5.7% (90% CI:2.5 – 8.6%) for EG, 5.3% (90% CI:1.6 – 8.6%) for WI, and of 5.1% (90% CI:0.9 – 8.6%) for EI, with the average estimate across the four areas being 5.6% (90% CI:1.9 – 8.6%). The estimated lower bound of 1.9% is 0.2% lower than the 2.1% of the base case. Hence, given the data, it is concluded that there is approximately a 95% probability that the msyr^{1+} in North Atlantic fin whales is larger than 2%.

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Year	WG	EG	WI	EI
1987	–	–	–	5260 (28)
1988	1100 (35)	5270 (22)	4240 (23)	–
1995	–	8410 (29)	6800 (22)	6650 (29)
2001	–	11700 (19)	6560 (19)	7490 (26)
2005	3230 (44)	–	–	–
2007	4360 (45)	12200 (20)	8120 (26)	–

Table 1: **The abundance** estimates with CV in parenthesis (given in %). WG:West Greenland; EG:East Greenland; WI:West Iceland; EI:East Iceland/Faroese waters. Data from IWC (2014).

	N_0	N^*	msyr	p	b	a_m	ϑ	msyl
WG	$.15,3^U$	$1,12^U$	$.001,.1^u$	$.9,1^u$	$.4,.76^u$	$5,15^u$	.5	$.55,.65^u$
EG	$.8,8^U$	$7,30^U$	$.001,.1^u$	$.9,1^u$	$.4,.76^u$	$5,15^u$	.5	$.55,.65^u$
WI	$1,10^U$	$3,15^U$	$.001,.1^u$	$.9,1^u$	$.4,.76^u$	$5,15^u$	.5	$.55,.65^u$
EI	$.8,10^U$	$3,15^U$	$.001,.1^u$	$.9,1^u$	$.4,.76^u$	$5,15^u$	.5	$.55,.65^u$

Table 2: **Prior distributions.** N_0 is the initial abundance, N^* the population dynamic equilibrium abundance, msyr the maximum sustainable yield rate, p the yearly survival, b the birth rate, a_m the age of the first reproductive event, ϑ the female fraction at birth, and msyl the maximum sustainable yield level. Abundance is given in thousands. The prior probability distribution is given by superscripts; p: fixed value, u: uniform (min,max), and U: log uniform (min,max).

	n_S	n_R	Unique	Max
WG	1000	10	9721	4
EG	1000	10	9599	3
WI	1000	10	9508	3
EI	1000	10	9804	4

Table 3: **Sampling statistics.** The number of parameter sets in the sample (n_S) and the resample (n_R), the number of unique parameter sets in the resample, and the maximum number of occurrences of a unique parameter set in the resample. n_S and n_R are given in thousands.

		N_0	N^*	r	msyr	p	p_0	b	a_m	γ	msyl	N_t	d_t
	$x_{.5}$	.53	4.8	.082	.067	.98	.75	.65	7.1	2.5	.61	3.8	.9
	$x_{.05}$	.26	2.3	.035	.027	.94	.35	.45	5.2	1.7	.56	2.1	.36
WG	$x_{.95}$	1.4	11	.12	.096	.99	.94	.75	13	3.4	.65	6.6	1
	$x_{.5}$	2.5	14	.074	.06	.98	.72	.64	7.2	2.5	.61	13	.99
	$x_{.05}$	1.4	9.8	.035	.027	.94	.34	.45	5.2	1.7	.56	9.7	.56
EG	$x_{.95}$	5.2	27	.12	.095	.99	.94	.75	13	3.4	.65	18	1
	$x_{.5}$	4.1	7.6	.073	.059	.98	.71	.64	7.3	2.5	.6	7.3	1
	$x_{.05}$	2.5	5.8	.022	.017	.93	.27	.44	5.2	1.7	.56	5.8	.67
WI	$x_{.95}$	6.7	13	.12	.096	.99	.93	.75	13	3.4	.65	10	1
	$x_{.5}$	3.4	7.6	.071	.057	.98	.71	.64	7.5	2.5	.61	7.3	1
	$x_{.05}$	1.6	5.4	.015	.011	.93	.25	.44	5.2	1.7	.56	5.3	.69
EI	$x_{.95}$	6.4	13	.12	.096	.99	.94	.75	14	3.4	.65	11	1

Table 4: **Parameter estimates**. Estimates are given by the median ($x_{.5}$) and the 90% credibility interval ($x_{.05}$ - $x_{.95}$) of the postreior distributions. Abundance is given in thousands.

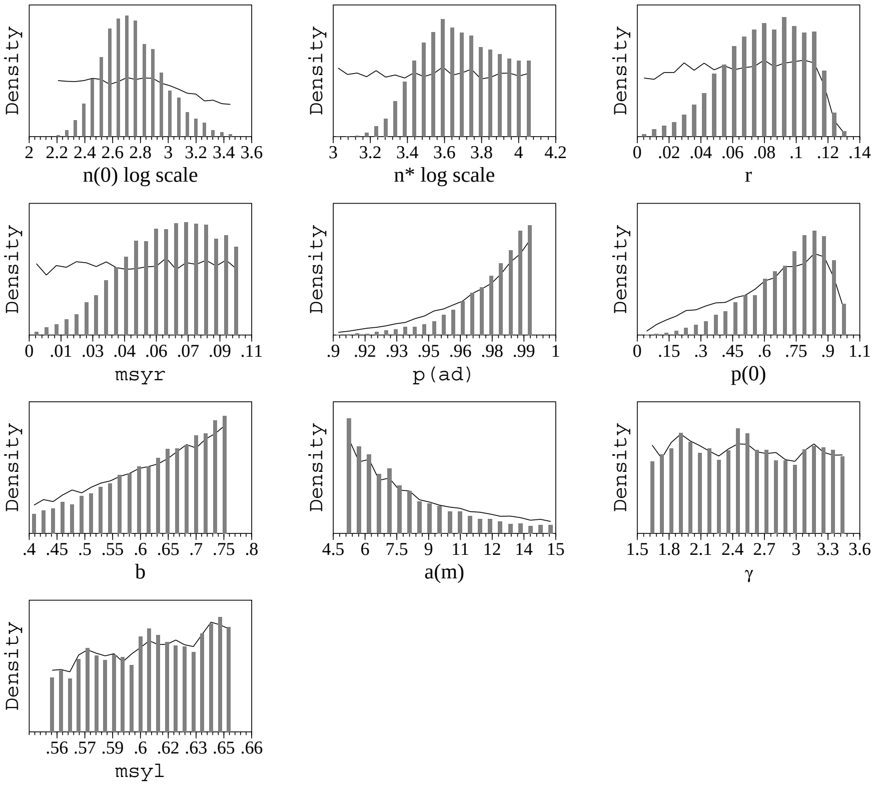

Figure 1: Realised prior (curve) and posterior (bars) distributions for West Greenland.

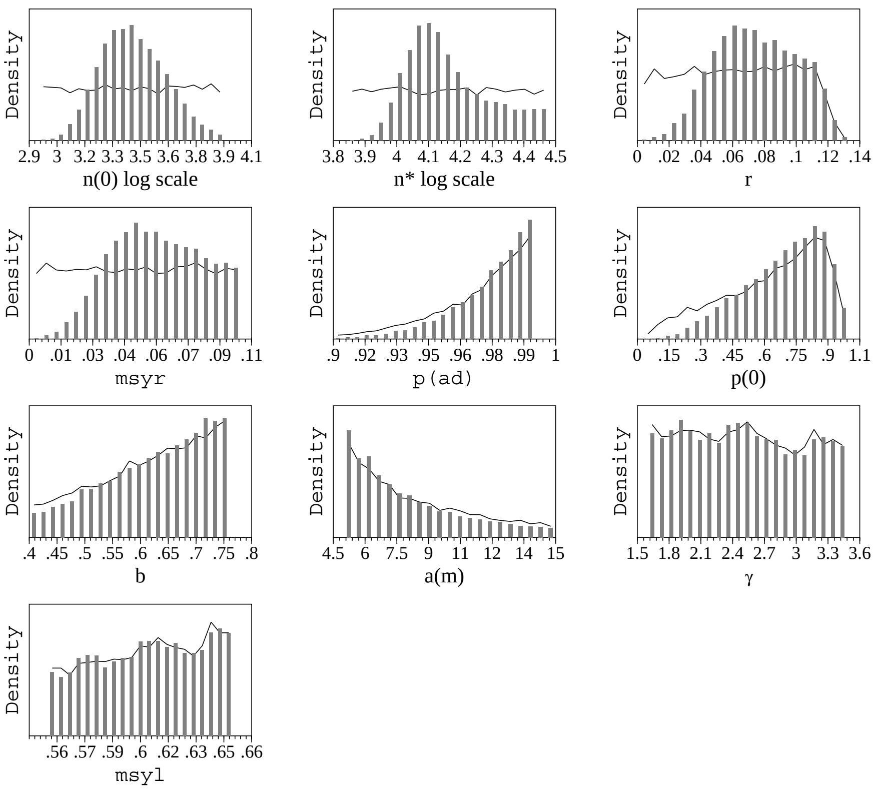

Figure 2: Realised prior (curve) and posterior (bars) distributions for East Greenland.

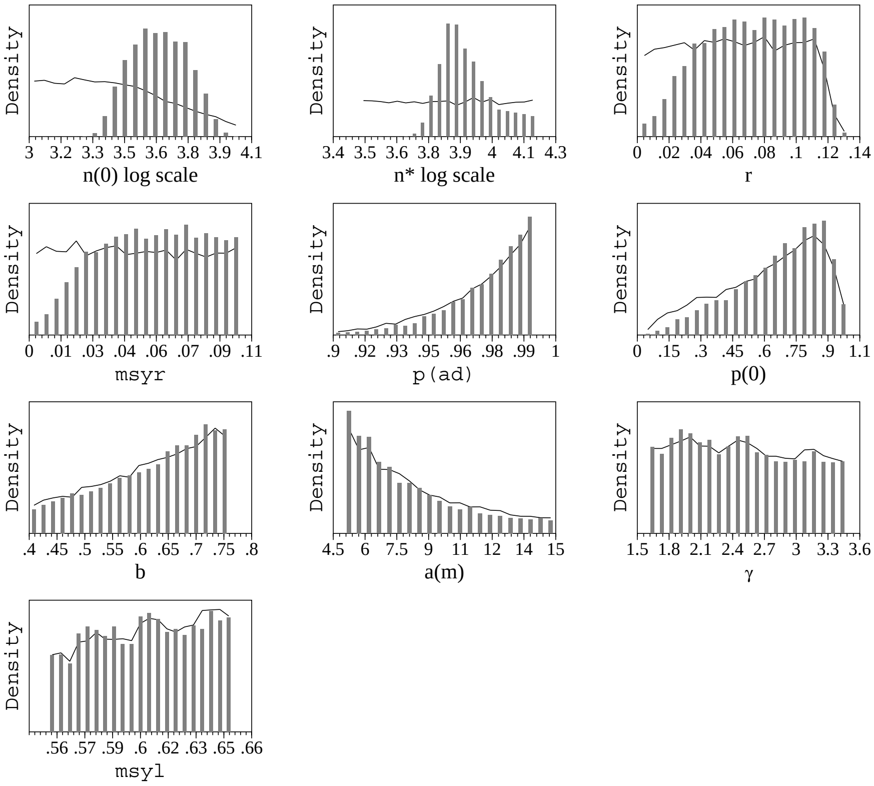

Figure 3: Realised prior (curve) and posterior (bars) distributions for West Iceland.

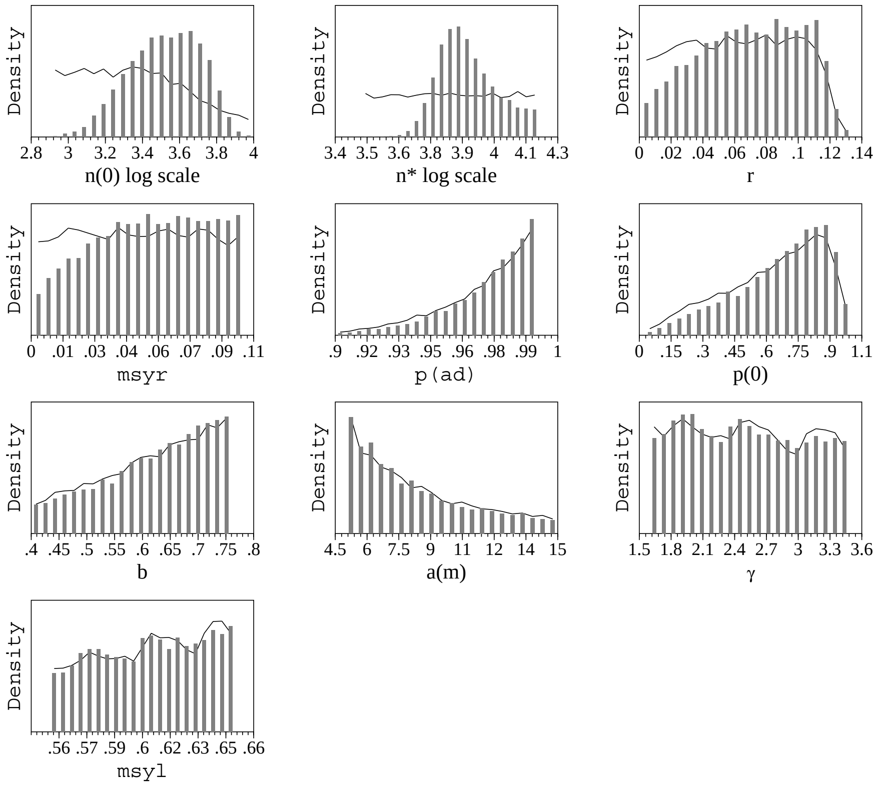

Figure 4: Realised prior (curve) and posterior (bars) distributions for East Iceland/Faroese waters.

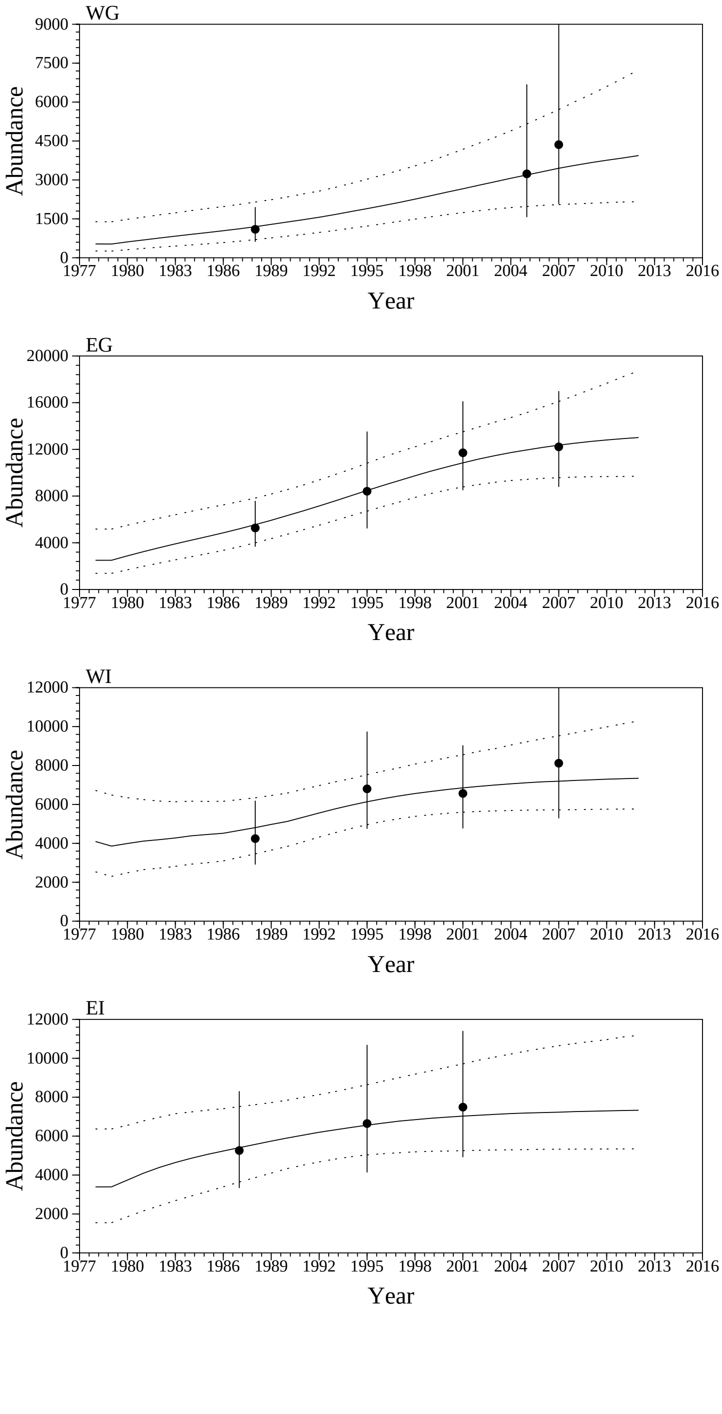

Figure 5: The projected median and 90% credibility interval of the different models.