Pressure-State relationships for Type 2 data

INDICATOR: Long-lived biomass fraction

Jochen Depestele, Jan Hiddink, Lorna McKellar, Daniel Van Denderen

15 January 2026

1 Biomass at longevity class for each sample

The biological data of each taxon was matched with the longevity trait and its four trait modalities (L1, L3, L10 and L10plus). Each trait modalities were multiplied with the respective biomass ($g\,m^{-2}$) for each species, and summed by station to estimate the total longevity biomass. The relative cumulative biomass ($Cumb_L$) for the first three longevity classes L was calculated as the ratio of the cumulative biomass of all longevity classes up to and including L to the total biomass:

$$Cumb_L = \frac{\sum_{L=1}^{i} B_L}{\sum_{L=1}^{4} B_L}, \quad i = 1, 2, 3$$

and modeled with a cumulative binomial regression

$$\mathrm{logit}(Cumb_L) = \alpha + \beta\, ll_L$$

where $ll_L = \log(L_{\mathrm{upper},L})$, and α and β are the intercept and slope, respectively, each individual sample station.

2 Explore longevity distributions

2.1 Matching station-specific longevity distribution with station info

Station information for pressure type *SAR* was added to the biological datatable which has slope and intercept of each sampling station. Station info was matched using the Excel filename, year and month when available in both the station and biological data worksheet. Note that station numbers did not provide and exact match for *NS_SilverPit_btrawling* because of the different years. Both were manually set to 2003. The *NS_Hinderbank_btrawling* stations did not match, because one dataset has *hi_* while the other did not. The Gotland station numbers were re-named to *GO* to be consistent between the station and biological data worksheet. Stations were excluded for *bobic_gulfofcadizsand_btrawling* except for 2015, for *bs_southernbaltic_oxygendepletion*, because the pressure type was 'oxygen depletion', and for *ns_hinderbanken_sandextr_and_btrawling* because the station info of 2012 was missing.

2.2 Exploration of sample-based cumulative biomass distribution

The cumulative biomass distribution at longevity was explored for 3 trawl and 12 grab studies (Figure 1). The fishing intensity (SAR or trawl index) differed between and within studies. Stations with low fishing intensities are expected to have a higher biomass at higher longevities (blue curves shifting to the right of the graph), while highly fished stations are except to be shifted towards lower longevities (red curves shifting to the left). Visual inspection suggested that some patterns are performing as expected, such as the *bs_gotland_btrawling*, while others are not, e.g. *bobic_gulfofcadizsand_btrawling*.

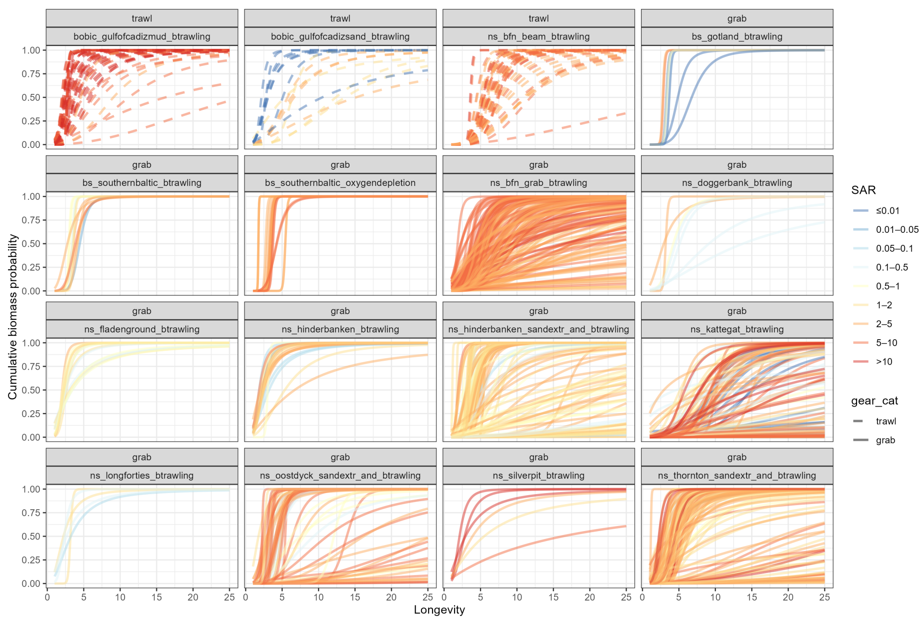

Figure 1: Cumulative biomass distribution at longevity for each input dataset and sampling gears. Colors are indicative of the level of trawling disturbance, SAR except for the NS Silverpit study which used a trawling index.

3 Pressure-state response curves

3.1 Longevity for low-disturbed samples

Low-disturbance samples were identified for each dataset using the 15 % quantiles of the pressure values (Figure 2). The cumulative biomass distribution curves were estimated by dataset for the low-disturbance samples only. 10 datasets had low-disturbance samples with SAR-values below or equal to one ($SAR \leq 1$), while the following 4 datasets (bobic_gulfofcadizmud_btrawling, ns_bfn_beam_btrawling, ns_bfn_grab_btrawling, ns_thornton_sandextr_and_btrawling) had high *reference* SAR-values: 6.97, 2.89, 2.85, 1.32. A cumulative biomass distribution function was fitted through the low-disturbance samples from which the longevity of the top 10 % biomass was estimated (Table 1).

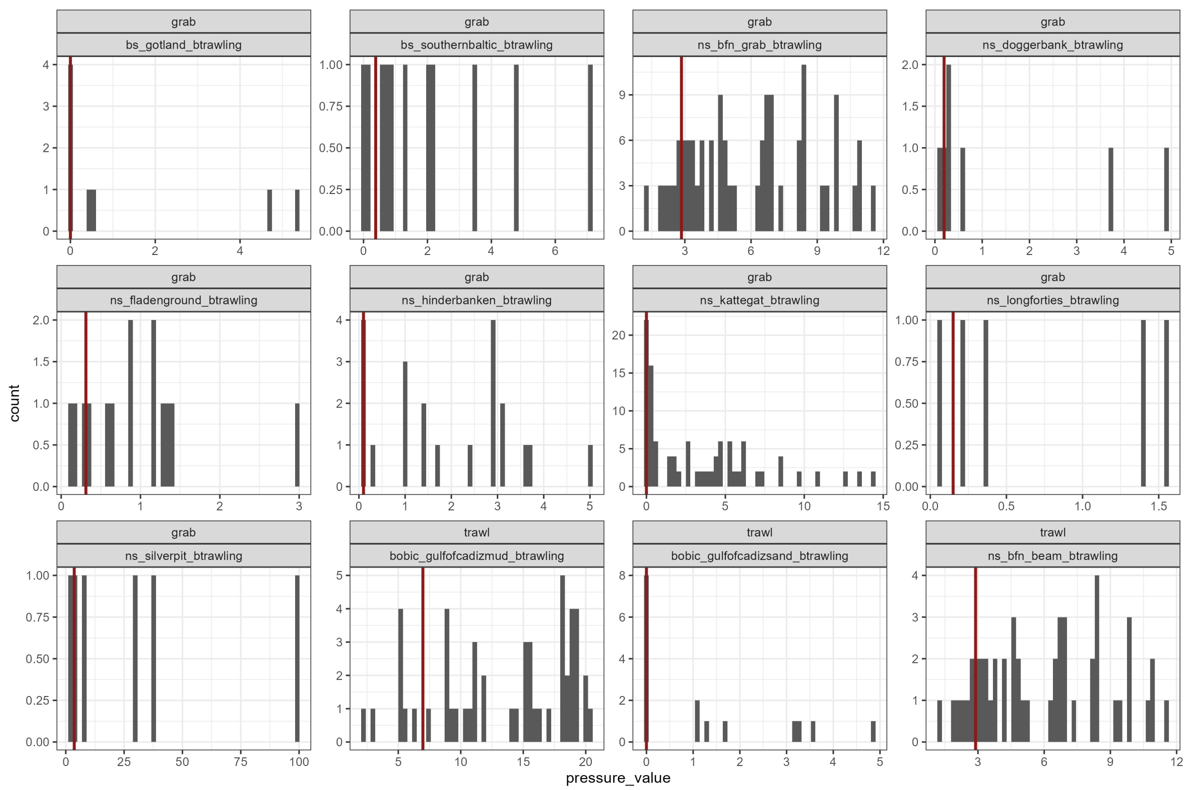

Figure 2: Histograms of the pressure values by dataset with one pressure. All datasets used SAR except for the NS Silverpit study which used a trawling index and bs_southernbaltic which represents oxygen concentrations .

Table 1: Longevities associated with the top 10 long-lived biomass in low-pressure samples

ID data set	Sampling gear	Pressure type	Threshold low pressure	Longevity of top 10 biomass
ns_kattegat_btrawling	grab	SAR	0.00	45.877941
ns_bfn_grab_btrawling	grab	SAR	2.85	33.569337
ns_silverpit_btrawling	grab	trawl_index	3.62	26.014159
bobic_gulfofcadizmud_btrawling	trawl	SAR	6.97	25.949412
ns_bfn_beam_btrawling	trawl	SAR	2.89	11.153422
ns_longforties_btrawling	grab	SAR	0.15	9.036932
ns_fladenground_btrawling	grab	SAR	0.31	8.421408
ns_doggerbank_btrawling	grab	SAR	0.19	8.115840
bs_gotland_btrawling	grab	SAR	0.00	7.833533
bobic_gulfofcadizsand_btrawling	trawl	SAR	0.00	7.786705
bs_southernbaltic_oxygendepletion	grab	O2_depl	5.82	6.017775
bs_southernbaltic_btrawling	grab	SAR	0.38	5.658958
ns_hinderbanken_btrawling	grab	SAR	0.10	5.409517

3.2 Relative long-lived biomass over a fishing gradient

The sample-based long-lived biomass was estimated using the the sampled-based cumulative biomass distributions (Figure 1) and the longevities of the top 10 % long-lived biomass estimated for low-disturbance samples (Table 1). The sample-based long-lived biomass fractions were divided by the mean long-lived biomass fraction of the low-disturbed samples to enable comparisons across datasets, and used as response variable for the pressure-state relationships.

The pressure-state relationships were estimated by fitting a log-normal model with the logarithm of relative long-lived biomass as a linear function of pressure:

$$\log(\text{RelativeLonglivedBiomass}) = \beta \cdot \text{pressure} + \varepsilon$$

with $\varepsilon_i \sim \mathcal{N}(0, \sigma^2)$.

The slope of the pressure-state response curves was negative in 11 out of 12 datasets, and significant at $P \leq 0.05$ for 6 datasets (Table 3, Figure 3).

The thresholds of the long-lived biomass fractions (Lf_{thr}) were estimated for each dataset from the threshold-models developed for infauna and epifauna using Type-1 data (Table 2), the sample-specific depths and the longevity estimates of the reference samples (Table 1). The median threshold of the long-lived biomass fraction (related to RBS sensitivity) was calculated as $Lf_{thr} = \text{Threshold}_{0.50} = Q_{0.50}(\text{Beta}(\alpha, \beta))$, where $Q_{0.50}$ denotes the 50th percentile of the beta distribution, or 50 % of being in good state.

The thresholds of long-lived biomass fraction (Lf_{thr}) and the pressure-state relationships of each dataset (Figure 3) were used to estimate the associated SAR-thresholds with 95 % Confidence Intervals using the 95 % CI from the pressure-state relationships. SAR-thresholds wtih

95 % CI were only estimated when inverted fitted relationships were significant ($P \leq 0.05$) using $\text{Pressure}_{\text{thr}} = \log(\text{Biomass}_{thr})/\beta$ with β being the slope parameters (Table 3).

Table 2: Beta regression results for thresholds

component	term	estimate	std.error	statistic	p.value
mean	(Intercept)	0.691	0.292	2.366	0.018
mean	log10(depth.m)	0.269	0.107	2.505	0.012
mean	lifespan.int	-1.541	0.643	-2.397	0.017
precision	(phi)	8.144	1.968	4.137	0.000

Table 3: Slopes of pressure-state curves and pressures/SAR thresholds inferred from long-lived biomass thresholds estimated using Type-1 data

ID data set	Type 1 informed thresholds	Pressure type	slope	p-value	lower limit SAR	SAR at threshold	upper limit SAR
ns_bfn_grab_btrawling	0.7381898	SAR	-0.55	0.0000000	0.67	0.55	0.47
bobic_gulfofcadizmud_btrawling	0.7533699	SAR	-0.50	0.0000000	0.68	0.57	0.48
ns_kattegat_btrawling	0.7301130	SAR	-0.39	0.0000008	1.29	0.81	0.59
ns_bfn_beam_btrawling	0.6913460	SAR	-0.32	0.0000188	1.97	1.16	0.82
ns_fladenground_btrawling	0.7266256	SAR	-2.16	0.0000984	0.23	0.15	0.11
ns_silverpit_btrawling	0.7483729	trawl_index	-0.08	0.0036659	5.77	3.57	2.58
bs_gotland_btrawling	0.6696796	SAR	-2.99	0.0644986	-	-	-
ns_longforties_btrawling	0.7118171	SAR	-5.05	0.0940093	-	-	-
ns_doggerbank_btrawling	0.6608123	SAR	-1.36	0.1160256	-	-	-
bobic_gulfofcadizsand_btrawling	0.6792932	SAR	0.41	0.1583269	-	-	-
ns_hinderbanken_btrawling	0.6396863	SAR	-0.27	0.2433920	-	-	-
bs_southernbaltic_btrawling	0.6525376	SAR	-0.32	0.6272518	-	-	-

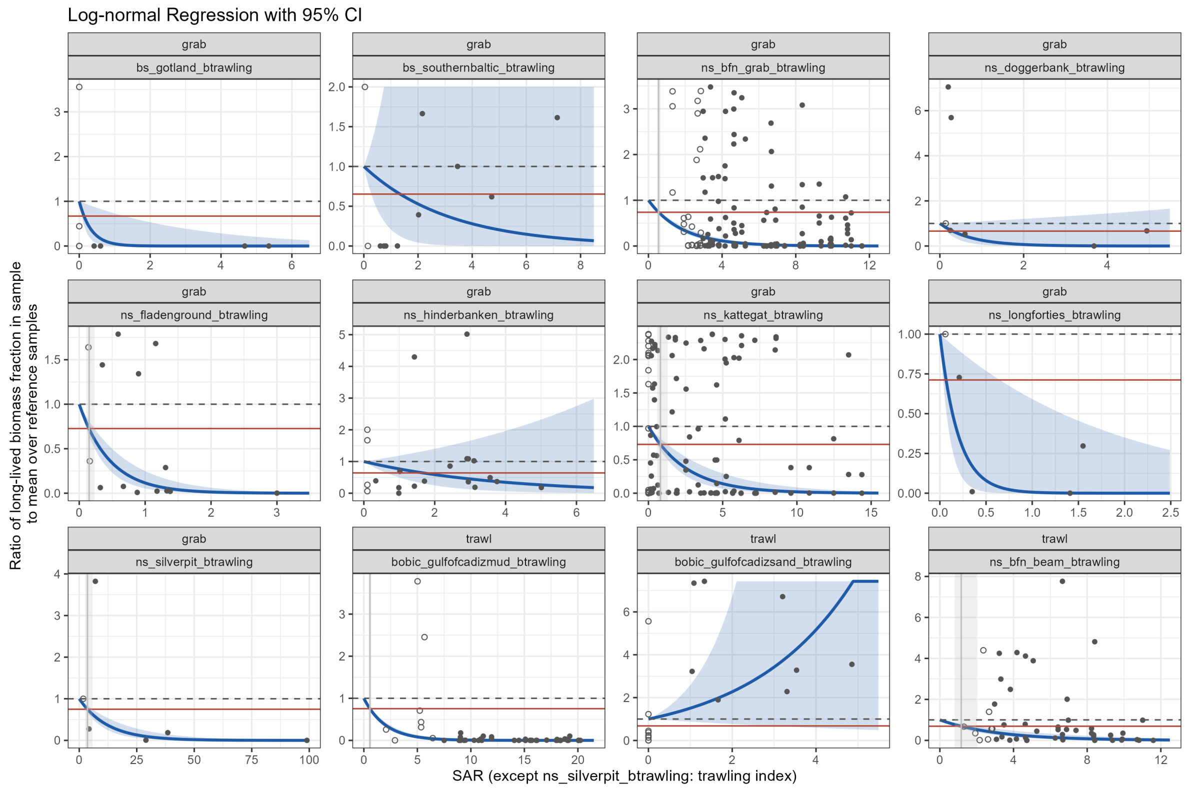

Figure 3: Relative response curve by submitted Type-2 dataset over a trawling gradient.