Supplementary information for:

Effects of bottom trawling and hypoxia on benthic invertebrate communities.

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Supplementary Figures S1–S8

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Supplementary Text S1: Information on longevity of *Astarte elliptica*

Supplementary Text S2: Calculation of benthic impact from fishing

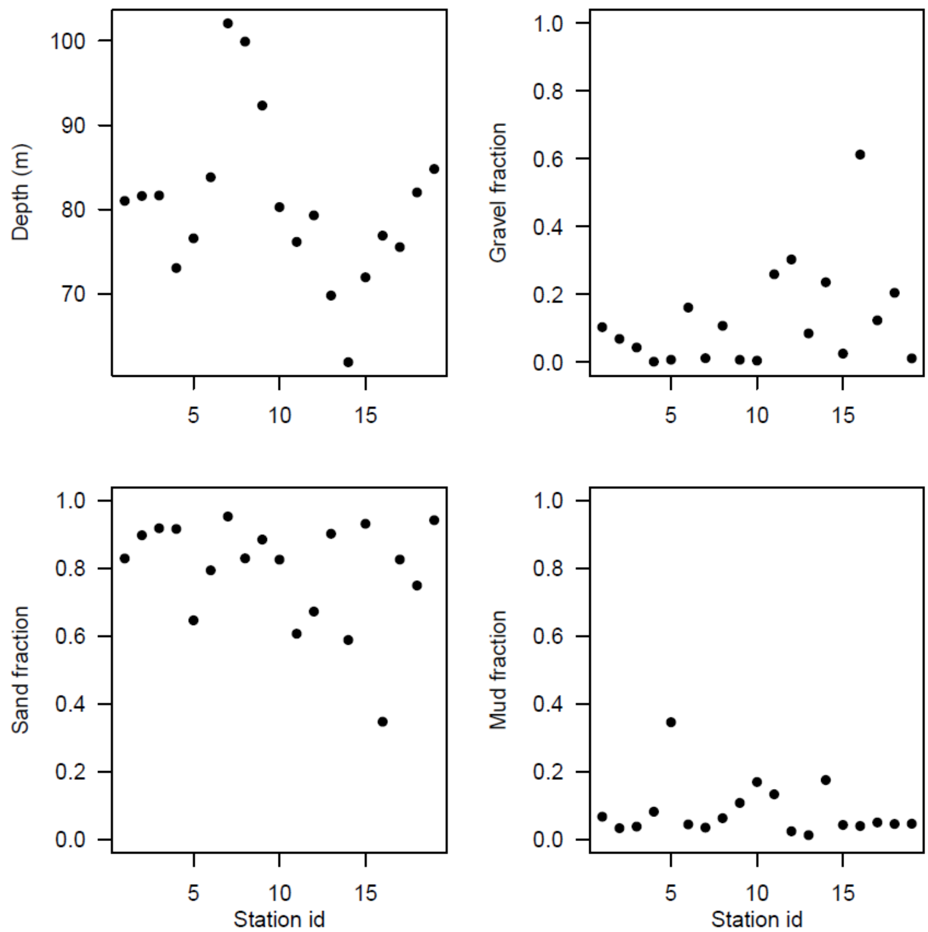

Figure S1. Sediment and depth data for each sampling station (station ID numbers correspond to Table S1). We verified that our results are robust against the removal of 1) Stations 5 and 16, which have a relatively high mud / gravel fraction, and 2) Stations 7–9 and 14, which have depths deeper than 90 m or shallower than 70 m. Since we obtained similar patterns and trends, it was decided to maintain all stations within the analysis.

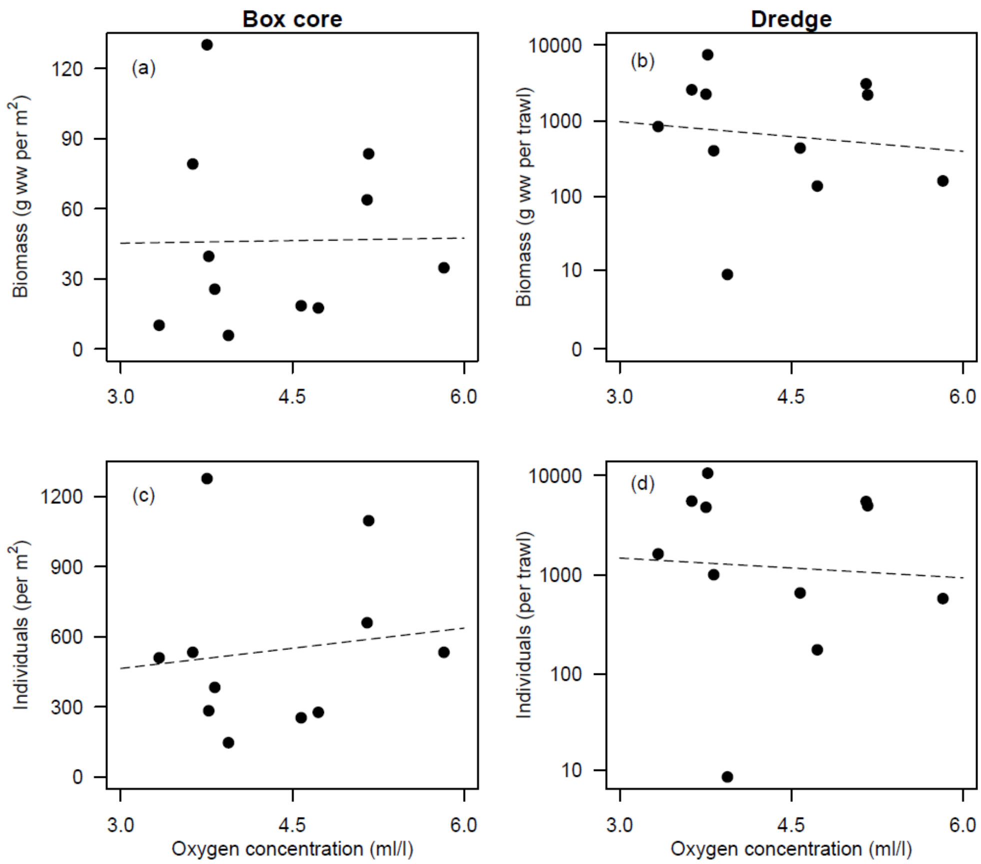

Figure S2. Relationships between oxygen and total faunal biomass and abundance collected using the box core (a, c) and dredge (b, d) for all sampling stations with oxygen concentrations above 3 ml l^{-1}. The relationships are all non-significant based on linear regression. We used the threshold value of 3 ml O_2 l^{-1} to examine the effect of bottom trawling in isolation (Fig. 5).

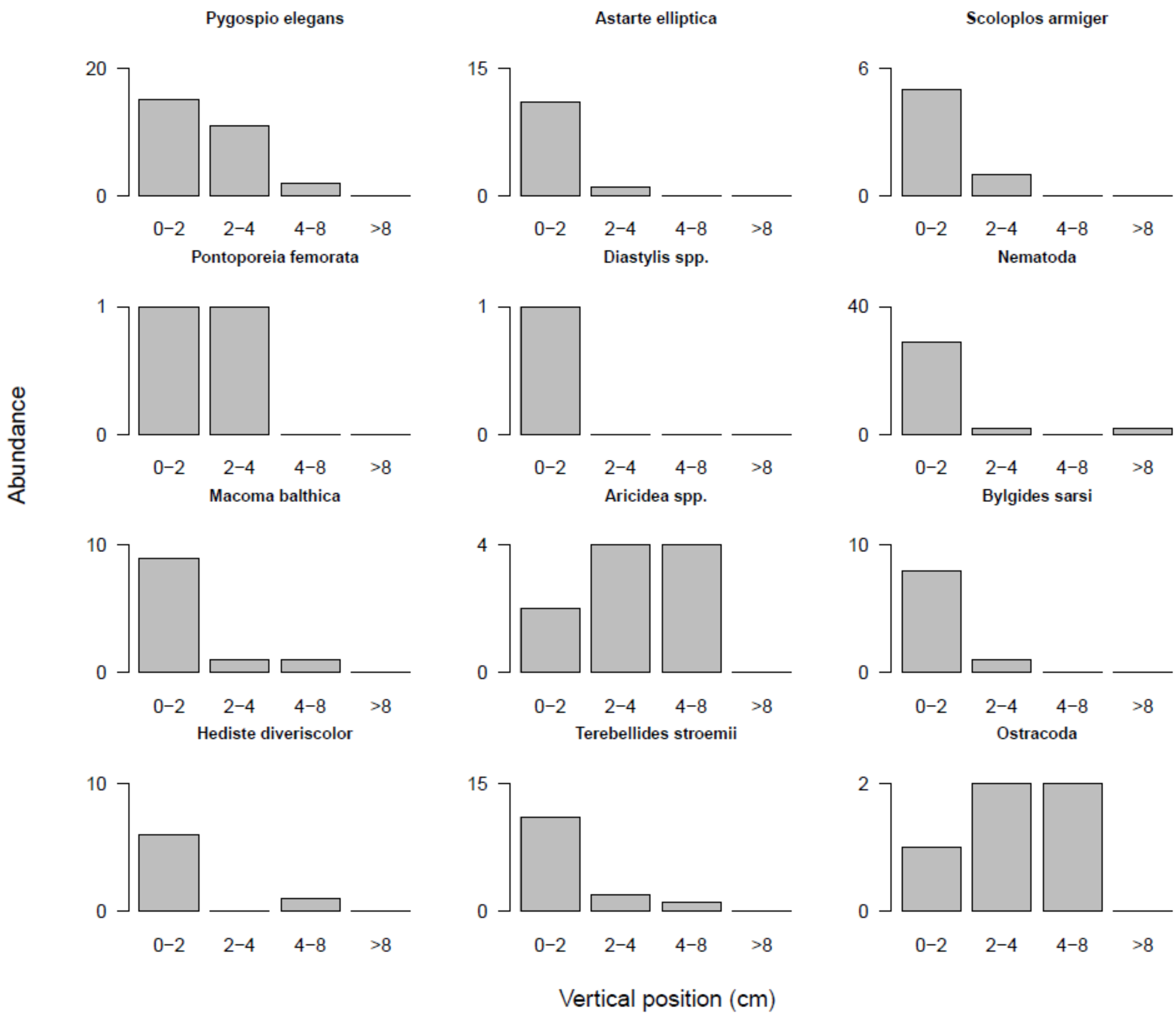

Figure S3. Vertical abundance distribution of species in the sediment (showing the sum of all individuals across all stations). The vertical distribution was estimated using three 4.5 cm diameter sub-cores up to a maximum depth of 17 cm from the first two intact box core samples per station.

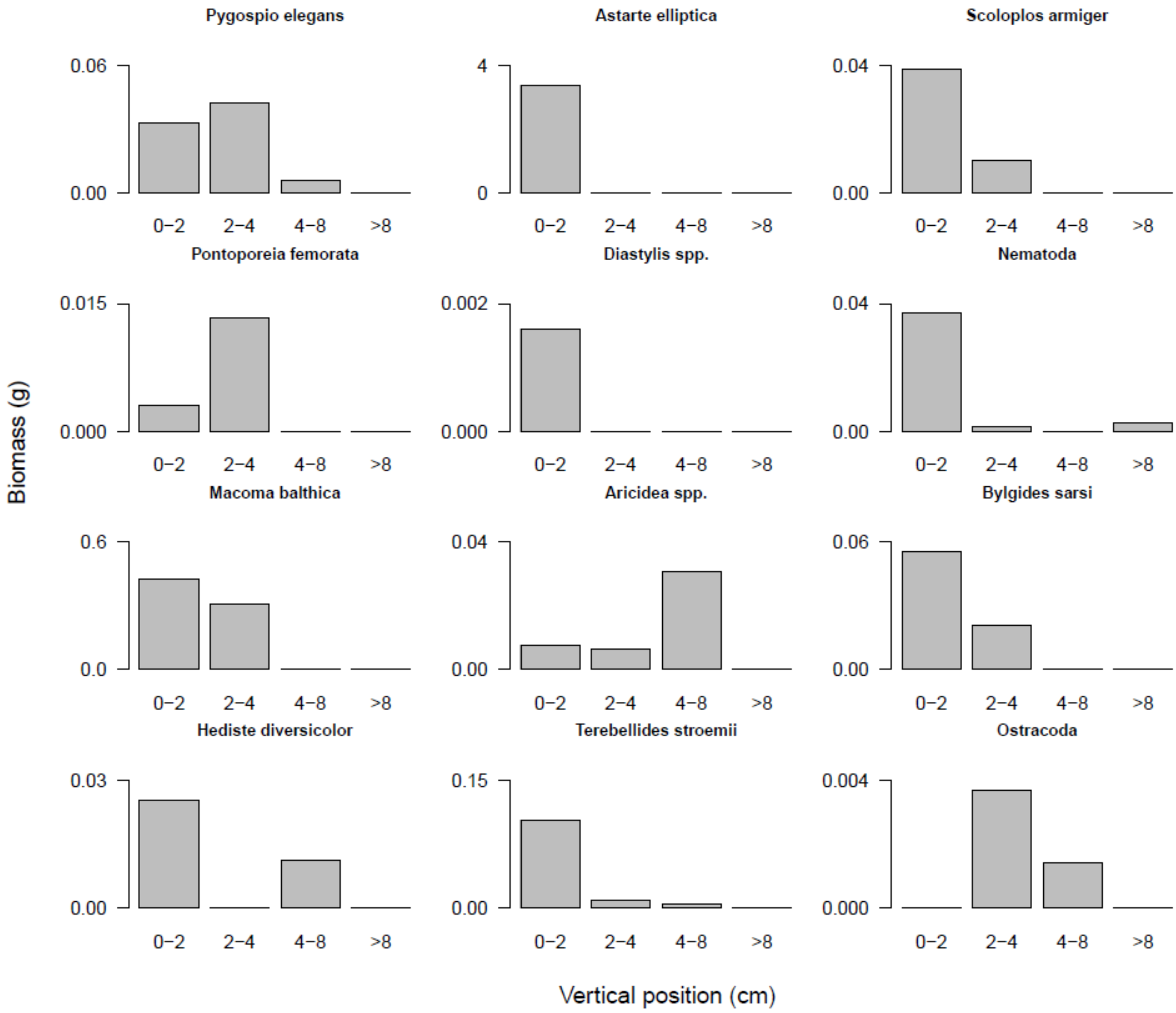

Figure S4. Vertical biomass (gram wet weight) distribution of species in the sediment (showing total biomass across all stations). The vertical distribution was estimated using three 4.5 cm diameter sub-cores up to a maximum depth of 17 cm from the first two intact box core samples per station. Note that for some species and depth layers, e.g. *Astarte elliptica* in 2–4 cm, biomass is practically zero although there was an individual present (see Figure S3).

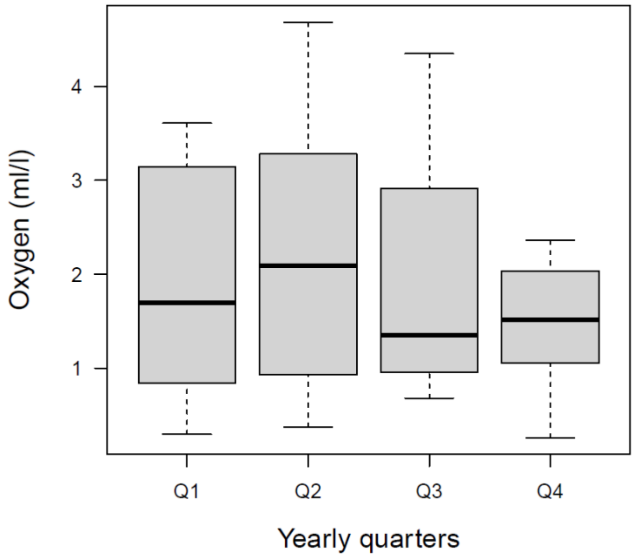

Figure S5. Boxplot of oxygen concentrations for each seasonal quarter based on all data points in Fig. 3a, indicating lower median oxygen concentrations in quarter 3 and 4. Data used were obtained from HELCOM secretariat and based on ICES dataset on Ocean Hydrography.

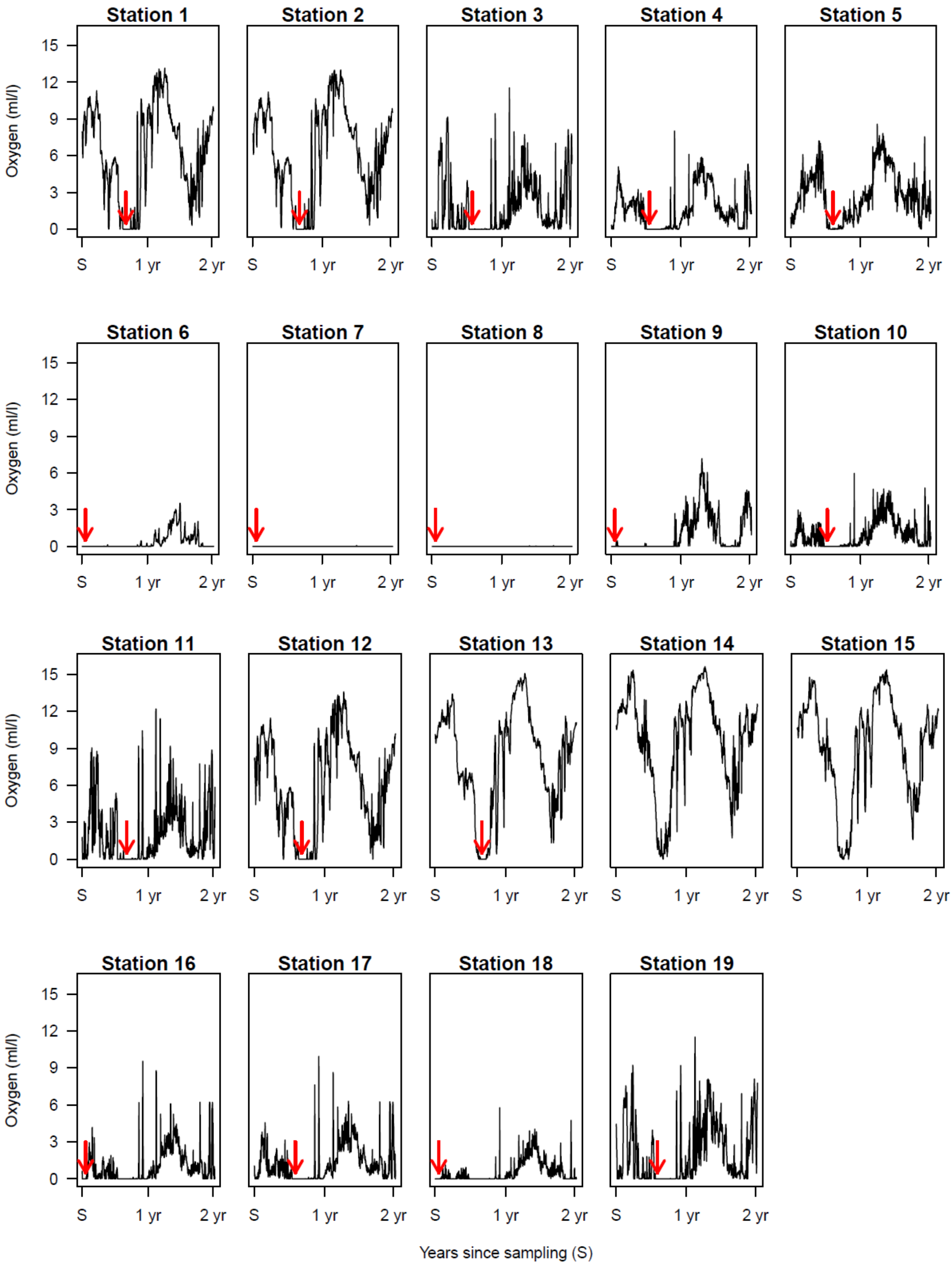

Figure S6. Simulated daily oxygen concentrations for each sampling station. S describes the day of sampling. The red arrow shows the most recent hypoxia event with high likelihood of mass-mortality pre-sampling (i.e. where simulated oxygen concentrations were below 0.5 ml l^{-1} for 20 consecutive days).

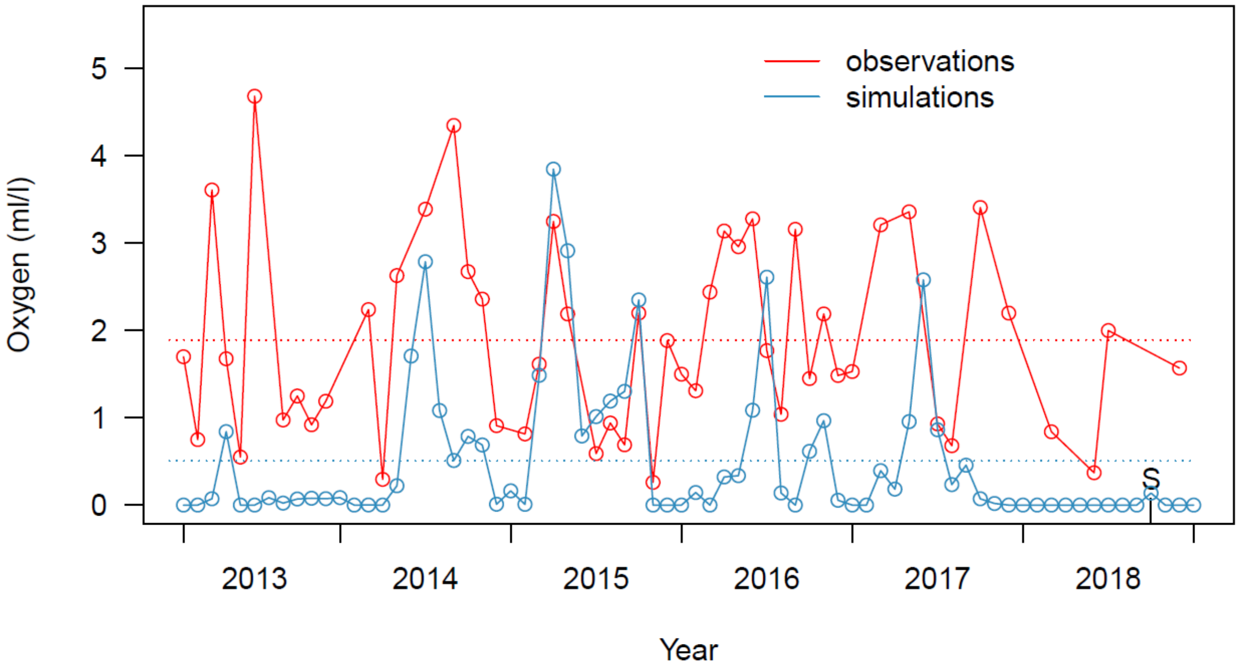

Figure S7. Comparison of time series of near-bed oxygen concentrations with model simulations at the same location from 2013 to 2018. The letter "S" indicates when we sampled the study area. Both observations and simulations were averaged per month. The dotted lines show the average oxygen levels over the whole period.

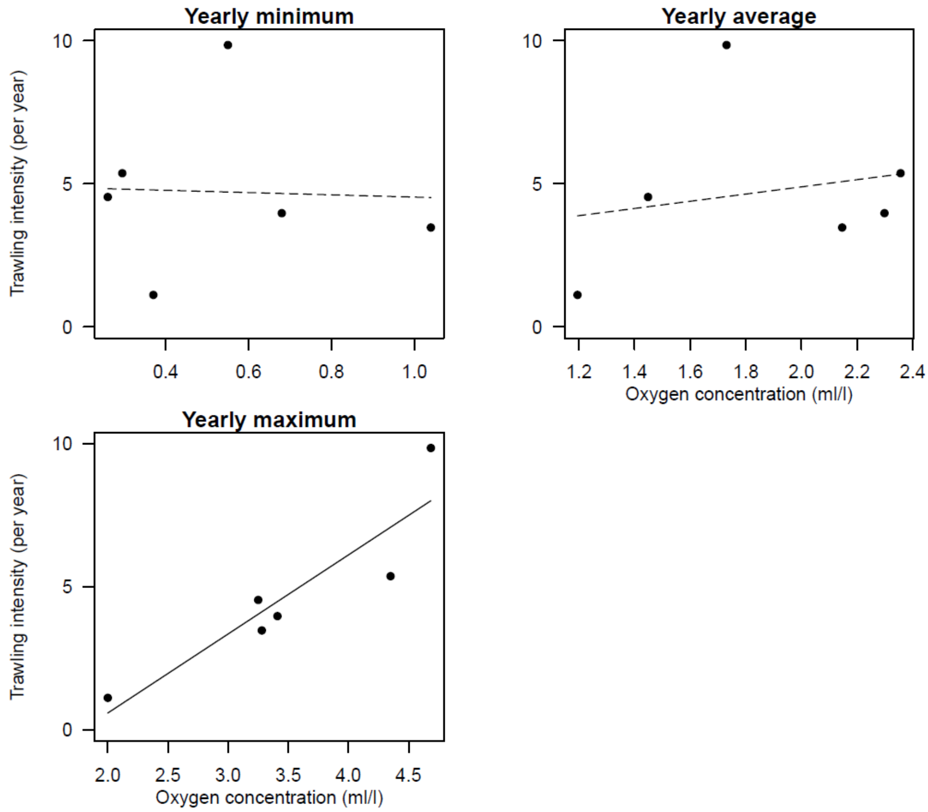

Figure S8. Relationship between annual trawling intensities at Station 9 and the minimum, average and maximum yearly near-bed oxygen concentration (as measured 3.7 km from Station 9, see Fig. 1 and 3). There is a significant and positive relation between trawling intensity and the maximum oxygen concentration (linear model shows a p-value of 0.01 and an adjusted R^2 of 0.78). No relation is found between trawling intensity and the minimum or average oxygen conditions.

Table S1. Overview of environmental conditions. Trawling intensity is average annual swept-area-ratio (SAR) for the period 2013 to 2017. Three sediment classes were included: mud (< 63 µm), sand (63 µm – 2 mm) and gravel (>2 mm) and sediment fractions were based on weight of the sediment classes. Temperature, salinity, and oxygen saturation (%) were measured from three replicate water samples at each station, except for the first seven stations where only a single measurement was taken (see *). Temperature, salinity, and oxygen saturation (%) were used to estimate the oxygen concentration in ml O_2 l^{-1}.

Station	Trawling intensity (yr^{-1})	Gravel fraction	Sand fraction	Mud fraction	Oxygen conc. (ml l^{-1})	Depth (m)	Temp. (°C)	Salinity (ppm)	Oxygen (%)
1*	2.16	0.10	0.83	0.07	3.63	81	7.4	10.7	45.8
2*	3.46	0.07	0.90	0.03	3.75	82	7.6	10.7	47.6
3*	4.72	0.04	0.92	0.04	3.82	82	7.9	11.3	49.0
4*	0.45	0.00	0.92	0.08	2.85	73	5.0	8.7	33.5
5*	0.51	0.01	0.65	0.35	0.76	76	5.8	9.5	9.1
6*	0.11	0.16	0.79	0.04	0.80	84	6.1	9.9	9.7
7*	0.07	0.01	0.95	0.04	0.97	102	6.5	10.6	12.0
8	0.11	0.11	0.83	0.06	1.12	99	6.5	10.5	13.8
9	5.44	0.01	0.89	0.11	1.34	92	6.6	10.5	16.5
10	2.34	0.00	0.83	0.17	2.91	80	6.6	10.6	36.0
11	0.74	0.26	0.61	0.13	3.77	76	6.8	10.6	46.8
12	2.02	0.30	0.67	0.02	5.17	79	6.9	10.1	64.2
13	0.61	0.08	0.90	0.01	5.15	70	6.2	9.3	62.6
14	0.15	0.24	0.59	0.18	4.73	62	5.7	8.8	56.5
15	0.04	0.03	0.93	0.04	5.82	73	5.8	9.2	70.0
16	1.24	0.61	0.35	0.04	4.58	77	7.3	10.7	57.7
17	0.81	0.12	0.83	0.05	3.94	76	7.4	11.3	49.9
18	3.47	0.20	0.75	0.05	2.12	82	6.2	10.1	25.9
19	7.14	0.01	0.94	0.05	3.34	85	7.5	11.2	42.3

Table S2. Wet weight (WW) to shell-free wet weight (SFWW) conversions for bivalve species.

Species	SFWW as fraction of WW	Source
Macoma balthica	0.41	1
Astarte elliptica	0.35	2
Mytilus trossulus	0.31	1

1 Rumohr H, Brey T, Ankar S (1987) A compilation of biometric conversion factors for benthic invertebrates of the Baltic Sea. The Baltic Marine Biologists Publication No. 9

2 Not available at species level. Value is based on the average of all bivalve observations in Brey, T. (2001): Population dynamics in benthic invertebrates. A virtual handbook, http://www.thomas-brey.de/science/virtualhandbook/

Table S3. Length-weight relationships for all species identified in the box corer: $\log_{10}(WW)$ = slope · $\log_{10}(L)$ + intercept. WW = wet weight in mg, L = length in mm.

Species	**Slope**	**Intercept**	**Source**
Ampharete spp.	2.550	-1.640	2
Aricidea spp.	2.550	-1.640	2
Astarte elliptica	2.878	-0.498	1
Bylgides sarsi	2.870	-1.727	1
Corophium spp.	2.989	-1.574	1
Diastylis bradyi	2.550	-1.640	2
Diastylis lucifera	2.550	-1.640	2
Diastylis spp.	2.550	-1.640	2
Halicryptus spinulosus	2.972	-1.419	1
Harmothoe spp.	2.870	-1.727	1
Hediste diversicolor	2.550	-1.640	2
Hydrozoa	2.550	-1.640	2
Lineus spp.	2.550	-1.640	2
Marenzelleria spp.	2.550	-1.640	2
Macoma balthica	3.049	-0.814	1
Monoporeia affinis	2.105	-1.123	1
Mytilus trossulus	2.326	-0.354	1
Nematoda	2.550	-1.640	2
Nemertea spp.	2.550	-1.640	2
Ostracoda	2.550	-1.640	2
Phascolion strombus	2.550	-1.640	2
Polynoidae spp.	2.550	-1.640	2
Pontoporeia femorata	2.662	-1.218	1
Pygospio elegans	2.550	-1.640	2
Saduria entomon	2.629	-1.43	1
Scoloplos armiger	2.550	-1.640	2
Spiophanes spp.	2.550	-1.640	2
Terebellides stroemii	2.407	-1.574	1
Unidentified	2.550	-1.640	2

1 Rumohr H, Brey T, Ankar S (1987) A compilation of biometric conversion factors for benthic invertebrates of the Baltic Sea. The Baltic Marine Biologists Publication No. 9

2 Unknown - based on polychaeta average (including for all observations that are not polychaetes)

Table S4. PerMANOVA analyses based on Bray-Curtis dissimilarities using longevity biomass data in four longevity groupings (<1, 1–3 and 3–10) in relation to changes in oxygen concentrations and trawling intensity. Results are based on an analysis using fractions of biomass per longevity group and sampling station, but similar results are obtained when absolute biomass values are used. Analyses are done for all sampling stations with fauna (n=14). Note that removal of one of the predictor variables does not affect the importance of the other.

Predictor variables	**Df**	**Sum Sq**	**Pseudo-F**	**R^2**	**p-values**
Oxygen conc.	1	0.002	0.07	0.01	0.80
Trawling int.	1	0.014	0.47	0.04	0.52
Residual	11	0.330		0.95	
Total	13	0.347		1	

Df – degrees of freedom (1 for numeric variables), Sum sq – sum of squares, Pseudo-F – F value, R2 – variance explained, and p-values based on 999 permutations.

Table S5. PerMANOVA analyses based on Bray-Curtis dissimilarities using biomass (a) and abundance (b) data in four vertical sediment sections (0–2, 2–4, 4–8 and >8 cm) in relation to changes in oxygen concentrations and trawling intensity. Results are based on an analysis using fractions of abundance/biomass per sediment section and sampling station, but similar results are obtained when absolute values are used. Analyses are done for all sampling stations with fauna in the vertical sub-sections (n=15). Note that removal of one of the predictor variables does not affect the importance of the other.

Predictor variables	**Df**	**Sum Sq**	**Pseudo-F**	**R^2**	**p-values**
a) Biomass					
Oxygen conc.	1	0.011	0.07	0.01	0.94
Trawling int.	1	0.017	0.09	0.01	0.91
Residual	11	1.955		0.98	
Total	13	1.983		1	
b) Abundance					
Oxygen conc.	1	0.241	1.80	0.13	0.21
Trawling int.	1	0.076	0.57	0.04	0.58
Residual	12	1.600		0.83	
Total	14	1.916		1	

Df – degrees of freedom (1 for numeric variables), Sum sq – sum of squares, Pseudo-F – F value, R2 – variance explained, and p-values based on 999 permutations.

Text S1 – Information on longevity of *Astarte elliptica*

Astarte elliptica is a dominant species in the box core data, both in terms of biomass and abundance. Our longevity classification of *Astarte elliptica* is based on the classification by Bolam et al. (2014) for the genus *Astarte* and is 3–10 years (see van Denderen et al. (2019) github for species trait list). However, the longevity classification of *Astarte elliptica* is uncertain in our sampling region (see below) and this may influence the PerMANOVA result. For that reason, we re-analyzed the effect of trawling and oxygen concentration on longevity after re-classifying the maximum age of *Astarte elliptica*. This was done for two new scenarios: 1) longevity of *Astarte elliptica* is fuzzy coded and equally divided between 3–10 years and >10 years, 2) longevity of *Astarte elliptica* is >10 years. In both cases, the PerMANOVA analysis shows no support for a change in the biomass longevity composition of the community with changes in oxygen and/or trawling intensity (as also found in the main manuscript).

Longevity of Astarte

For the southwestern Baltic Sea, the maximum age of *Astarte elliptica* and *Astarte borealis* have been estimated to be more than 20 years (Trutschler & Samtleben 1988; Moss et al. 2021). However, salinity is higher in this area compared with our sampling region and this may affect longevity. Although no information is available for our region, a maximum age of 8.5 years is observed for *Astarte borealis* sampled near Gotland Deep (Gusev & Rudinskaya 2014).

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Text S2 – Calculation of benthic impact from fishing

We used the logistic growth model, as described by Pitcher et al. (2017), to estimate benthic impact from bottom fishing at a fishing intensity of 7 SAR per year and based on the longevity composition of our sampled stations. This was done with the following equation, which describes the relative state of the benthic community (the biomass relative to carrying capacity) at equilibrium conditions:

$$Community\ state = \frac{B}{K} = 1 - F\frac{d}{r}$$

In this equation, B is community biomass and K carrying capacity. F is the bottom trawling intensity per year which is set at 7. d is the proportional decline of benthic biomass caused by a single trawl pass which is set at 0.026 since all trawling in the area occurs with a demersal otter trawl (Hiddink et al., 2017; Rijnsdorp et al., 2020). Lastly, r is the intrinsic growth rate (or recovery rate) per year of the benthic community. r is shown to be dependent on benthic longevity and can be estimated based on the relation $r = H$ / longevity, with $H = 5.31$ (Hiddink et al., 2018). r was estimated for each longevity class (0–1, 1–3, 3–10, >10) using the median longevity value of each class (H/0.5, H/2, H/6.5, H/10).

We afterwards estimated the relative state of each longevity class at SAR = 7 per year. These predictions were multiplied with the biomass fractions in each class and summed to estimate the community state. Data on the longevity biomass fractions were taken as an average from our sampled stations. This average showed that 0.3% of the biomass is within the 0–1 longevity class, 18.8% within the 1–3 class and 79.9% within the 3–10 class. The resulting community state was 0.80, which corresponds to a 20% decline of community biomass relative to carrying capacity.

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