# Physical disturbance by bottom trawling suspends particulate matter and alters biogeochemical processes on and near the seafloor

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## SUPPLEMENTARY INFORMATION

## Contents

# 1. Sampling positions

See also the map presented in Fig. 1 in the main paper

***Table S1.*** *Details of the acoustic transects. EM2040 = Kongsberg EM2040 0.4° x 0.7°, 200-400 kHz, multibeam echo-sounder. PS40 = Kongsberg Topas PS40, 24 channel, parametric sub-bottom profiler. ADCP = Acoustic Doppler Current Profiler; Workhorse Mariner, 600 kHz). SBP = sub-bottom profile*

| Type of Transect | Date | Start position | | End position | | Time (UTC) | Trawling status | Notes, including description of position relative to trawl track |
|---|---|---|---|---|---|---|---|---|
| | | Latitude (N) | Longitude (E) | Latitude (N) | Longitude (E) | | | |
| EM2040 | 2 May, 2018 | 58.826608 | 17.661242 | 58.828644 | 17.670113 | 11:13-12:18 | 5.5 months before trawling | Survey comprised of several tracks, approx. parallel to the trawl track. The part of the survey overlapping the trawl track is given by the start and end positions. |
| ADCP | 22 Oct, 2018 | 58.831349 | 17.682898 | 58.824581 | 17.670267 | 07:50 – 08:02 | c. 4h before trawling | NE to SW along track |
| EM2040 | 22 Oct, 2018 | 58.82529635 | 17.658810 | 58.844883 | 17.699953 | 12:11 – 13:05 | During trawling | Along whole length of track (SW to NE) |
| EM2040 | 22 Oct, 2018 | 58.82569784 | 17.660268 | 58.829449 | 17.679212 | 13:40-14:00 | 0.5-1.5h after trawling | Along half of track (SW to NE) |
| ADCP | 23 Oct, 2018 | 58.822831 | 17.66785 | 58.834302 | 17.688673 | 07:20 – 07:33 | 20h after trawling | SW to NE along track |
| ADCP | 25 Oct, 2018 | 58.834004 | 17.666691 | 58.82309 | 17.684161 | 08:32 – 08:43 | 3 days after trawling | NW to SE perpendicular to track |
| PS40 | 26 Oct, 2018 | 58.845761 | 17.700557 | 58.825396 | 17.6587856 | 08:52- | 4 days after trawling | (SBP 243) Along the entire trawl track (NE to SW) |
| PS40 | 26 Oct, 2018 | 58.84378945 | 17.691870 | 58.842910 | 17.700905 | 09:38- | 4 days after trawling | (SBP 805) Across the trawl track (W to E) |
| EM2040 | 7 Apr, 2020 | 58.82647054 | 17.661123 | 58.844932 | 17.699784 | 08:26-08:55 | 18 months after trawling | Along the entire trawl track (SW to NE) |

***Table S2.*** *Details of SVP, CTD casts and water sampling*

| Site | Date | Latitude (N) | Longitude (E) | Approx time (GMT) | Depth (m) | Water samples taken | Trawling status | Approximate position relative to trawl track |
|---|---|---|---|---|---|---|---|---|
| SVP01 | 22 Oct 2018 | 58.82476 | 17.67036 | 08:15 | 29.5 | N/A | 3h pre-trawling | c. 300 m SE of track |
| CTD01 | 22 Oct 2018 | 58.82476 | 17.67036 | 08:15 | 29.5 | Yes | 3h pre-trawling | c. 300 m SE of track |
| CTD02 | 22 Oct 2018 | 58.82936 | 17.67886 | 09:05 | 35 | Yes | 3h pre-trawling | directly above the track |
| CTD04 | 22 Oct 2018 | 58.8293 | 17.67892 | 14:00 | 35 | No | 2h after trawling | directly above the track (same as CTD02) |
| CTD05 | 22 Oct 2018 | 58.8284 | 17.67944 | 14:35 | 35.75 | Yes | 2h after trawling | 100 m SE of track |
| CTD06 | 22 Oct 2018 | 58.82714 | 17.68002 | 14:45 | 34 | Yes | 2h after trawling | 250 m SE of track |
| CTD07 | 22 Oct 2018 | 58.82452 | 17.68162 | 15:00 | 31.75 | Yes | 2h after trawling | 550 m SE of track |
| CTD08 | 23 Oct 2018 | 58.82452 | 17.68156 | 07:50 | 31.5 | Yes* | 20h after trawling | 550 m SE of track (same as CTD07) |
| SVP03 | 23 Oct 2018 | 58.82716 | 17.68002 | 08:25 | 33.75 | N/A | 20h after trawling | 250 m SE of track (same as CTD06) |
| CTD09 | 23 Oct 2018 | 58.82716 | 17.68002 | 08:25 | 33.75 | Yes* | 20h after trawling | 250 m SE of track (same as CTD06) |
| CTD10 | 23 Oct 2018 | 58.82948 | 17.6789 | 08:55 | 35.25 | Yes* | 20h after trawling | above the track (same as CTD02 and CTD04) |
| CTD11 | 23 Oct 2018 | 58.8307 | 17.6782 | 09:25 | 35 | Yes* | 20h after trawling | 150 m NNW of track |
| CTD24 | 25 Oct 2018 | 58.82068 | 17.68704 | 09:40 | 35.5 | Yes* | 3d after trawling | 1100 m SE of track |
| CTD25 | 25 Oct 2018 | 58.82288 | 17.68418 | 09:45 | 32 | No | 3d after trawling | 800 m SE of track |
| CTD26 | 25 Oct 2018 | 58.82498 | 17.68102 | 10:00 | 31.5 | No | 3d after trawling | close to CTD07/08 |
| CTD27 | 25 Oct 2018 | 58.82706 | 17.67776 | 10:20 | 31.5 | No | 3d after trawling | 250 m SSW of track |
| CTD28 | 25 Oct 2018 | 58.82952 | 17.67898 | 10:40 | 35 | Yes* | 3d after trawling | same site as 02/04/10 |
| CTD29 | 25 Oct 2018 | 58.83194 | 17.67658 | 11:15 | 33 | No | 3d after trawling | 500 m NW of track |
| CTD30 | 25 Oct 2018 | 58.8176 | 17.70236 | 11:55 | 33.5 | No | 3d after trawling | 1900 m SE of track |
| CTD31 | 25 Oct 2018 | 58.81942 | 17.69354 | 12:15 | 31.25 | No | 3d after trawling | 1400 m SE of track |
| CTD32 | 25 Oct 2018 | 58.81194 | 17.70606 | 12:35 | 32.5 | No | 3d after trawling | 2500 m SE of track |
| CTD33 | 26 Oct 2018 | 58.82948 | 17.67932 | 08:00 | 35.25 | Yes* | 4d after trawling | same site as 02/04/10/28 |

^ depth estimated from CTD cast data as maximum depth plus 0.5 m

* water samples only taken at two water depths (0.5 and 5 mab)

*__Table S3.__ Details of sediment sampling*

| Type of sampling, sample number | Date | Latitude (N) | Longitude (E) | Time (UTC) | Depth (m) | Type of analyses done on the cores | Trawling status | Position relative to trawl track |
|---|---|---|---|---|---|---|---|---|
| Multicore (MC) #12, 13, 15, 16 | 23 Oct 2018 | 58.827778 | 17.665283 | 10:45-12:45 | 26 | Porewater elements and methane. Sediment physical properties. | c. 24h after trawling | Casts taken on a c. 3m long transect across different parts of the trawl track |
| Multicore (MC) #18 | 23 Oct 2018 | 58.827303 | 17.666428 | 13:00 | 27 | Sediment physical properties. | c. 24h after trawling | c. 100m SE of the trawl track |
| Multicore (MC) #21 | 23 Oct 2018 | 58.827778 | 17.665283 | 12:00 | 26 | Flux incubations | c. 2 d after trawling | On the trawl track |
| Multicore (MC) #22 | 23 Oct 2018 | 58.827283 | 17.666140 | 12:30 | 27 | Flux incubations | c. 2 d after trawling | c. 100m SE of the trawl track |

# 2. Further details of investigations of the trawl tracks

## 2.1. Detailed methods of the acoustic mapping

Since the pre-trawl mapping was done about 5.5 months before the full-scale trawl experiment, two factors had to be considered when comparing multibeam bathymetric data from the two time points: 1) bottom sediment deposition or erosion over 5.5 months and; 2) sea level differences between the survey days. Accumulation and/or erosion of bottom sediment are likely minor, on the order of < 1 cm. Since the survey is carried out using RTK positioning, we referenced all surveys to the Swedish vertical reference system RH2000 using the geoid separation model SWEN08_RH2000 (Ågren, 2009). This implies that the uncertainties of the depths from the multibeam echosounder are influenced by the uncertainty of the vertical component of the RTK corrected positions, which commonly is on the order of 3-6 cm. While the Seapath 330+ GNSS reported slightly better positional accuracies during the surveys than 3-6 cm, the critical components are the final estimated uncertainties of the depths of the processed bathymetric CUBE surface, after propagation of all used sensors' uncertainties. The 95 % confidence interval of the CUBE surface depth values generally ranged between about ±1 and ±4 cm around the trawl tracks, and up to >±10 cm within the trawl tracks.

The difference between the overlapping parts of the survey seafloor before and after the trawling should show the depth of the trawl marks and the height of material which has been ploughed up on the sides of the main furrow. This is also clearly the case (Fig. 3 in main paper). By looking at the statistic (mean/median) of the depth differences between the entire overlapping area of the seafloor surveyed before and after the trawling we can tell if there are systematic depth biases in the surveys that relate to parameters that we not have been able to remove when referencing the surfaces to the RH2000 level (*D*=Depth):

$$\Delta D = D_{before} - D_{after} \qquad \text{(Equation 1)}$$

Applying Equation 1 to the entire overlapping areas between the surveys assumes that the actual trawl track is spatially so small that it does not affect the statistics much, which was tested by comparing the area surrounding the seafloor impacted by the trawling only. Figure S1 shows distribution of the depth difference. A mean and median difference of +2 cm is apparent, showing that the survey during the trawling is systematically 2 cm deeper. We used this value and adjusted that survey with 2 cm before estimating the sediment volume disturbed by the trawling.

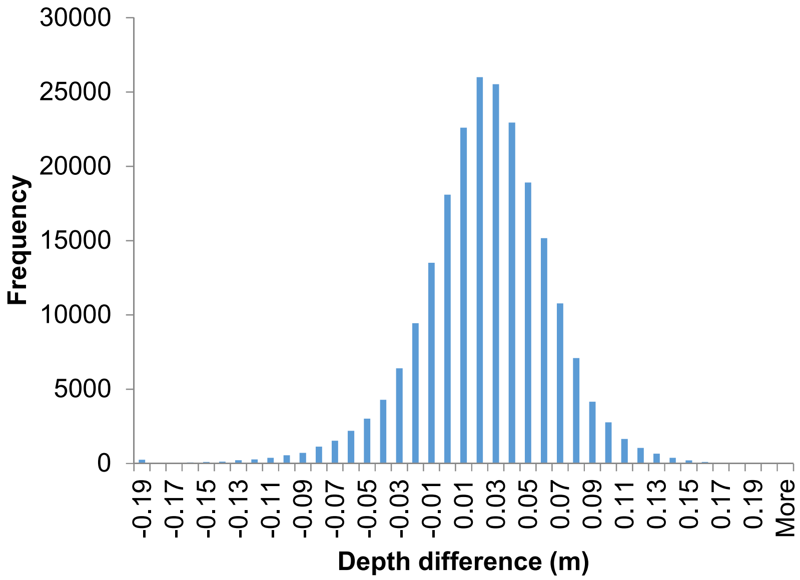



***Figure S1.*** *Histogram showing the depth differences between the multibeam surveys carried out May 02 and October 22, 2018, i.e. before and after trawling experiments. The mean and median differences are +2 cm, implying that the survey following the trawling experiment is systematically 2 cm deeper (see Eq. 1). This bias was corrected for prior to the analyses of the trawling impact on the seafloor.*

## 2.2. Additional data and dimensions of the trawl track features and their use in calculations

The distance between the two trawl tracks created by the trawl doors was measured at intervals of 100 m along the track (Table S4), beginning 50 m after the trawl doors established regular paths on the seafloor and over a 900 m long stretch (Fig. 3 in main text)

***Table S4.*** *Distances between the two trawl doors, from multibeam analysis.*

| Distance from start of trawl track (m, DS in Fig. 3 in paper). | Distance between trawl doors (m, WB in Fig. 3 in paper). |
|---|---|
| 50 | 31.8 |
| 150 | 32.9 |
| 250 | 32.9 |
| 350 | 33.1 |
| 450 | 33.2 |
| 550 | 34.4 |
| 650 | 34.5 |
| 750 | 34.2 |
| 850 | 33.5 |
| 950 | 33.9 |
| **Mean** | **33.4** |
| **Median** | **33.4** |
| **SD** | **0.8** |

Ten boxes were identified along the door tracks as being suitable for more detailed analysis. By suitable we mean stretches where the multibeam was of high quality and the trawl track was clearly distinguished without disturbances. Of these, Boxes 2 and 7 were of particularly good quality (between-survey differences were close to zero outside the tracks).

***Table S5.*** *Estimated volumes of the furrows and sediment piles produced by the trawl doors. Summary values are expressed as $m^3$ per m of single furrow (cf. some later calculations which are expressed as $m^3$ per m of whole trawl track). Areas refer to boxes and corridors shown in Fig. 3 in the main paper. Boxes 2 and 7 were used for more detailed bathymetric analysis.*

| **Area analysed** | **Sediment pile ($m^3$)** | **Furrow ($m^3$)** |
|---|---|---|
| Box 1 | 2.58 | 1.37 |
| Box 2 | 1.68 | 1.78 |
| Box 3 | 3.43 | 0.93 |
| Box 4 | 2.63 | 3.70 |
| Box 5 | 0.43 | 5.58 |
| Box 6 | 0.99 | 4.94 |
| Box 7 | 2.33 | 0.89 |
| Box 8 | 0.12 | 8.46 |
| Box 9 | 0.43 | 8.77 |
| Box 10 | 0.82 | 6.99 |
| North corridor | 48.03 | 47.87 |
| South corridor | 27.77 | 68.05 |
| Average from Boxes 1-10 ($m^3$ $m^{-1}$) | 0.08 | 0.22 |
| Average from Boxes 2 and 7 ($m^3$ $m^{-1}$) | **0.10** | **0.07** |
| Average from North Corridor ($m^3$ $m^{-1}$) | **0.12** | **0.12** |

| | | |
|---|---|---|
| Average from South Corridor ($m^3$ $m^{-1}$) | **0.07** | **0.17** |

## 2.3. Additional details for the calculations of area, volume and mass of disturbed sediment on the seabed

From multibeam measurements, each trawl door furrow was assumed to be c. 1.4 m wide (based on mean/median furrow width of 1.6/1.6 and 1.2/1.2 m from Boxes 2 and 7). The distance between the furrows was assumed to be 33.4 m (mean/median distance was 33.4 (SD 0.8)(Table S4)). Thus the furrows represent 7.7 % of the total area disturbed (=2.8/(2.8+33.4)), and groundgear the remaining 92.3% of the area.

Volumes of sediment excavated (furrows) or displaced (sediment piles) per m or $m^2$ of track were obtained from analysis of multibeam data. These values differed along the trawl track; in the following calculations, the ranges of the averages of the values for the North and South corridors (Table S5) were used: for the furrows, 0.12 – 0.17 $m^3$ $m^{-1}$; for the sediment piles, 0.07 - 0.12 $m^3$ $m^{-1}$). Since these values were for only one of the trawl door tracks (one furrow plus displaced sediment), they were multiplied by two to get a value per m or $m^2$ of entire trawl track (2 furrows plus displaced sediment). These were also expressed as kg removed per m or $m^2$, using a bulk sediment density of 0.52 mgDW $ml^{-1}$ (average of values from top 9 cm of 4 sediment cores sliced at 1cm intervals; the average was 0.52 gDW $ml^{-1}$ wet sediment (SD 0.15, n=36)). Similar calculations were done for the volume and mass of sediment displaced into piles at the sides of the furrows. Values were expressed as volume (or mass) displaced per m (or $m^2$) of excavated furrow, using the same assumption of a furrow width of 1.4 m.

Groundgear was assumed to penetrate 2 cm into the sediment since shallow parallel furrows were visible in ROV images but rarely with the multibeam which had a difference contour of c. 2 cm. Assuming a uniform disturbance across the whole central area, the groundgear was calculated to disturb 0.67 $m^3$ $m^{-1}$ of trawl track (= 33.4 m width x 0.02 m depth x 1 m length of track). As a percentage of the total volume disturbed, this is 70 % (=0.29/(0.69+0.29)) (range 66 - 74% using the range of door disturbance values).

## 2.4. Further details of backscatter and sub-bottom results

Sub-bottom profile SBP 243 runs along the entire trawl track and captures stratigraphic variations of the uppermost c. 40 m of unconsolidated sediments (Fig. 1 and S2). Previous studies of the area, including sub-bottom profiling and coring, revealed that the acoustically well-stratified sediment layers draping the underlying bedrock topography are comprised of varved glacial clay, while the uppermost layers consist of soft clay to gyttja clay (Jakobsson et al 2020) (Fig. S2). SBP 805 clearly shows the relationship between the underlying glacial clay unit draping the bedrock topography and the upmost softer sediment unit (Fig. S2b).

The locations of the trawl tracks in sub-bottom profile SBP 805 coincide with acoustically transparent spots (Fig. S2b,c), which commonly appear where layered sediments are disturbed. Although several other small acoustically transparent spots are visible along the profile, it would seem to be more than coincidental that these match the trawl track locations. The vertical resolution of the sub-bottom profiles is on the order of 10-20 cm, so it is not impossible that the tracks, with their vertical topography of c. 20 cm, might be visible in this way.

The acoustic backscatter maps (Fig. S3), compiled from the multibeam data, show that the surface sediments are rather uniform along the trawl track, apart from in three distinct areas characterized by higher backscatter values. These areas are marked BS2, BS3 and BS4 in Fig. S2 and S3. SPB 243 reveals that these areas coincide with locations where the underlying glacial clay outcrop, or is very close to outcrop, at the seafloor (Fig. S2a). It should be noted that none of the sediment samples are retrieved from the areas with higher backscatter, i.e. they are all from the softer surface sediments (Fig. S3). The bottom inspections with divers and the ROV also occurred away from the areas with higher backscatter.

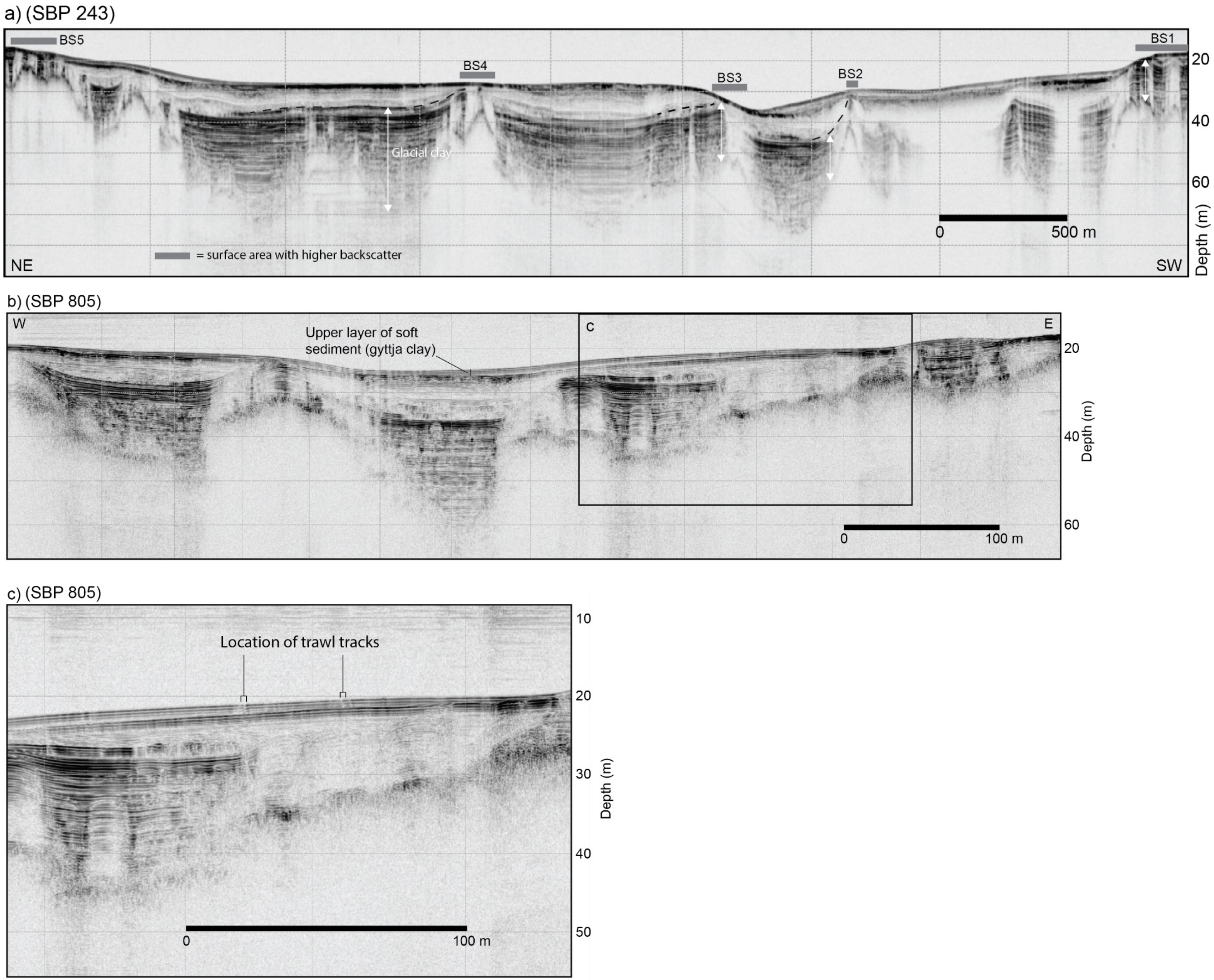

a) (SBP 243)
BS5
BS4
BS3
BS2
BS1
Glacial clay
= surface area with higher backscatter
NE
SW
0
500 m
20
40
60
Depth (m)
b) (SBP 805)
W
E
c
Upper layer of soft sediment (gyttja clay)
0
100 m
20
40
60
Depth (m)
c) (SBP 805)
Location of trawl tracks
0
100 m
10
20
30
40
50
Depth (m)

***Figure S2****: Sub-bottom profiles showing the uppermost c. 40 m of the sediment stratigraphy in the trawled area. a) Profile SBP 243 running along the entire trawl track from NE to SW. Seafloor areas BS1-BS5 with higher backscatter values are marked by grey boxes. These are shown on the backscatter maps in Fig. S3. Note that the areas with higher backscatter coincide with outcropping, or close to outcrop, glacial clay that underlay the uppermost unconsolidated to loosely consolidated sediments. None of the analysed sediment samples were taken from the areas with outcropping glacial clay. b) Profile SBP 805 crossing the trawl track perpendicularly. c) Enlargement of SBP 805 over the area where the trawl tracks are located (marked on the profile). A hint of acoustic blanking is seen at the locations of the trawl tracks*.

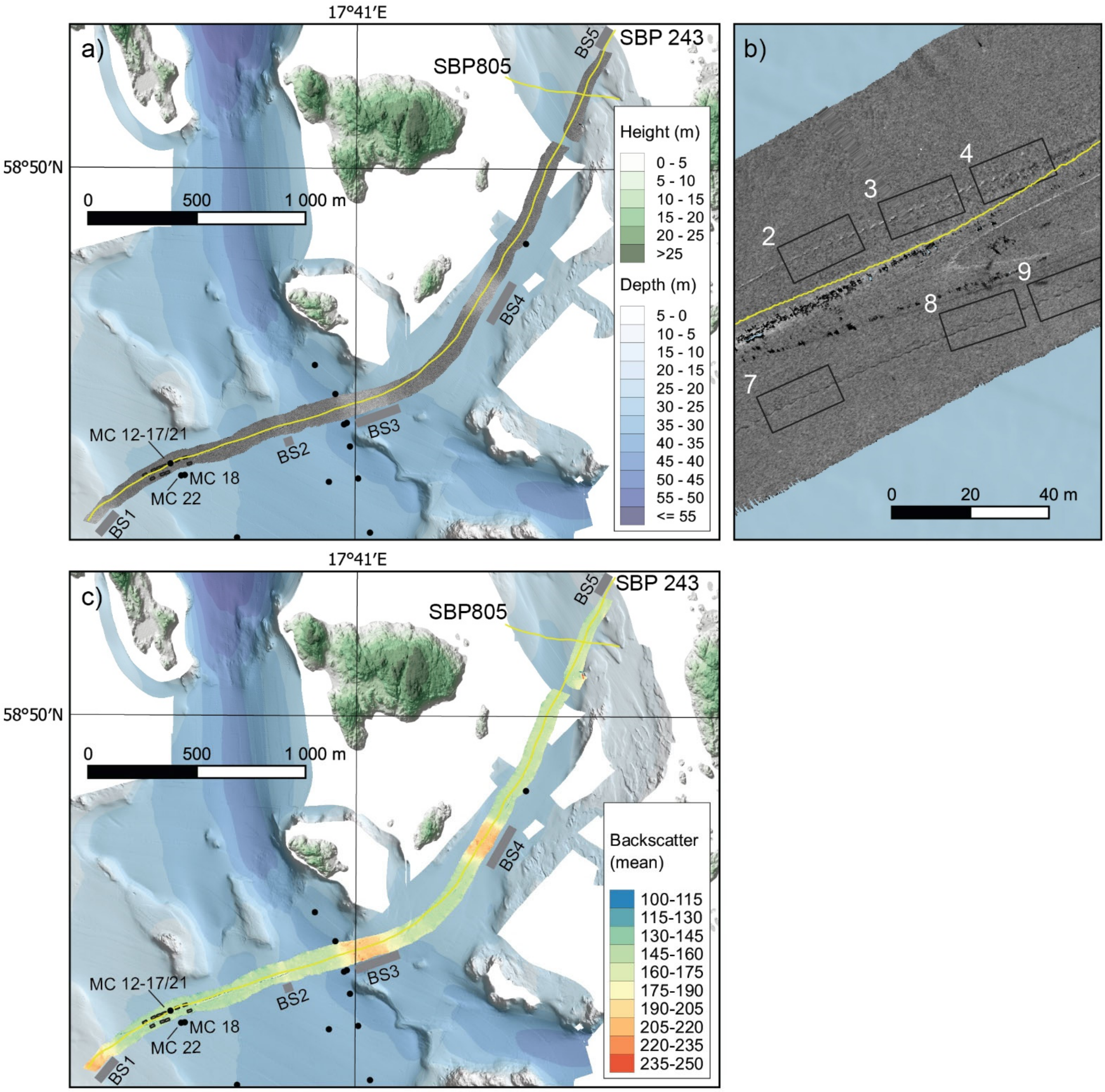



***Figure S3***. *Multibeam backscatter from the survey line along the trawl track acquired when following closely behind the trawling vessel.* ***a)*** *Grey scale image of the backscatter values gridded at a resolution of 9 x 9 cm. Areas displaying higher backscatter values are marked by the grey boxes BS1-5. These coincide with outcropping of glacial clay (Fig. S2).* ***b)*** *Close-up of the backscatter image from the beginning of the trawl track in the SE. The plough marks from the trawl doors are clearly visible. The locations of the boxes for which the difference in bathymetry before and after trawling has been analysed are shown as well as the sub-bottom profile location (yellow line). Black dots are artefacts (see Fig. S4c).* ***c)*** *Multibeam backscatter as in a), but colour coded mean values over a binned size of 1.8 x 1.8 m. The black dots are showing all sample stations displayed in Fig. 1 as a reference.*

## 2.5. Appearance of the track after 1.5 years

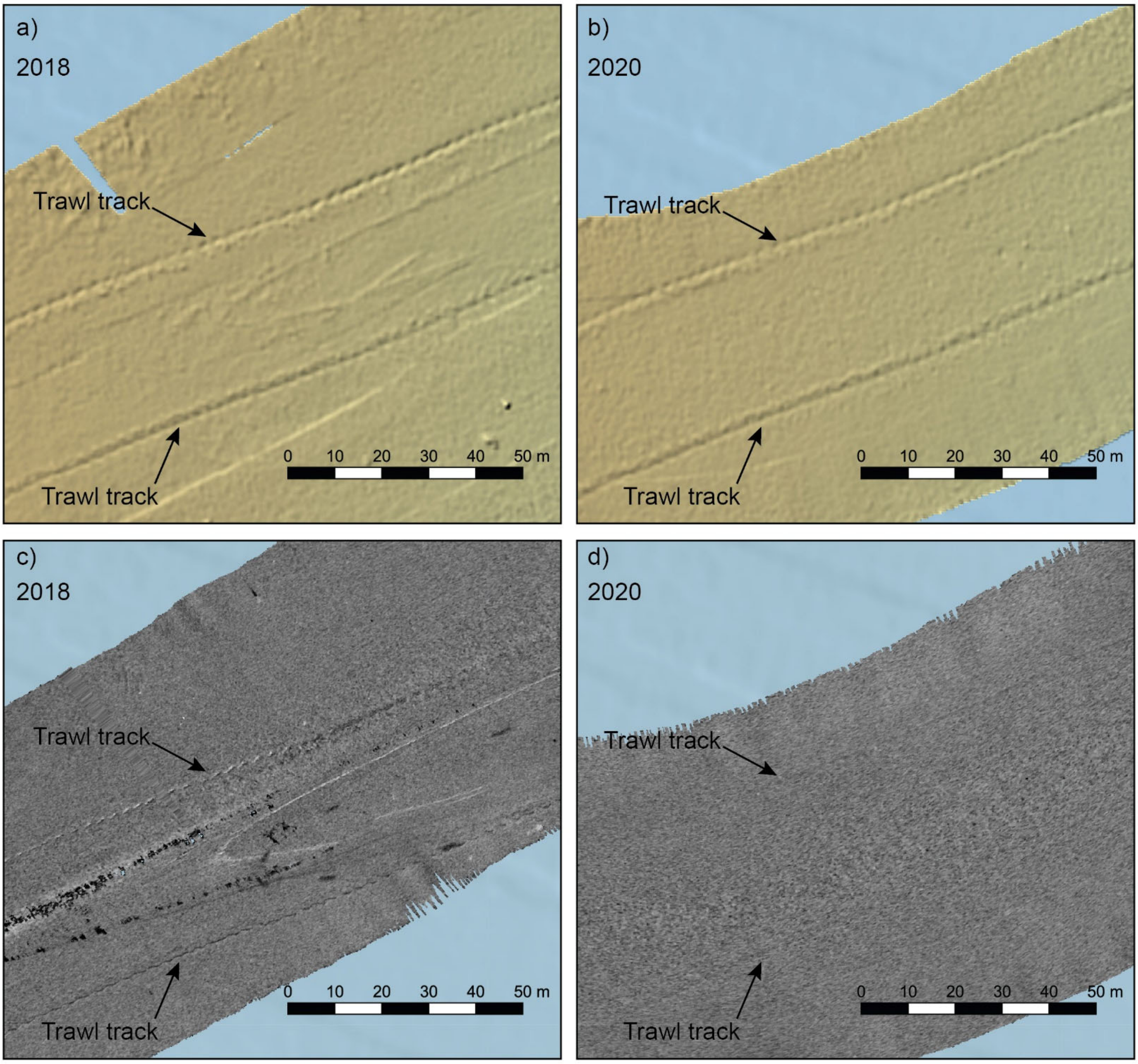



***Figure S4.*** *Multibeam bathymetry **(a, b)** and backscatter **(c, d)** from the trawled area acquired directly in conjunction with the trawling in October 2018 **(a, c)** and 18 months after in April 2020 **(b, d)**. The panels show a segment from the beginning of the trawl track in the southeast. The multibeam bathymetry clearly reveals the tracks from the trawl doors 18 months after the trawling **(b)**, while the tracks are not as distinct in the backscatter images **(d)**. The black speckles in **c)** are outliers in the backscatter values because of scattering from the trawl net.*

In April 2020, ie. 1.5 years after trawling, a repeat multibeam survey was done and divers inspected the seabed in the same area as the ROV survey had been performed in October 2018 (see Fig. 1). The parallel trawl door tracks were still clearly visible in the multibeam bathymetry (Fig. S4b), but were far less clear in the backscatter images (Fig. S4d) compared to when the tracks were fresh (Fig. S4c).

Divers accessed the trawl track area via a buoy placed c. 10 m to the north of the trawl track. Despite swimming an appropriate distance in the direction of, and crossing, the trawl door track, as well as performing standardized searches for 30 min in the area, the track was not observed. Analysis of photos and videos taken by the divers did not reveal any obvious features. The clear furrows and mounds of sediment observed in the ROV images in 2018 had apparently been smoothed out and/or filled in, making them invisible to divers while still visible in the multibeam bathymetry, presumably due to persistent differences in the sediment properties that still affect the acoustic signal.

## 2.6. Sediment perturbations

One day after trawling, sediment cores were taken with a multicorer a few hundred metres outside the trawl track and also in the general area of the trawl door track. The exact position of the cores relative to (e.g.) sediment piles and furrows is not known, but could often be estimated by the appearance of the surface sediment in the cores; those that showed most disruption were assumed to have been disturbed by the trawling and were used to produce the ‘on track’ data in Fig. S5 and S6. A range of parameters were estimated in sediment slices taken from these cores (see Sections 2.5 and 2.6 in the main text). Due to the low replication, these data and figures should be interpreted cautiously. However, the general trends shown in Figs S5 and S6 support the assumption that trawling has disrupted the physical and chemical structure of at least the upper 5 cm or so.

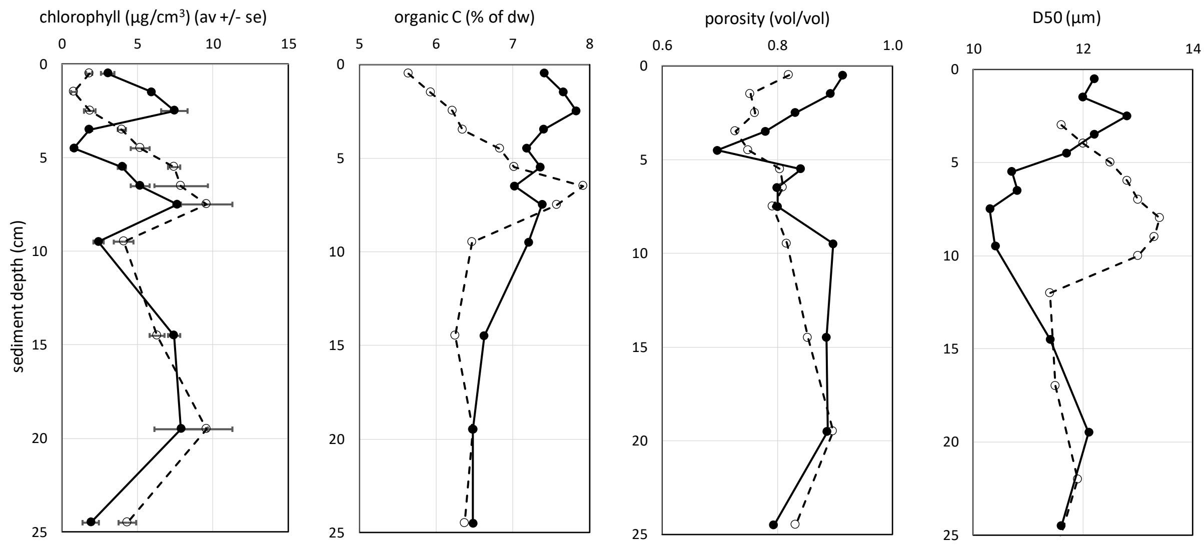



***Figure S5.*** *Sediment profiles 24 h after trawling; one core from the trawl track (dashed line, open circles) and one core c. 100 m away from the track (solid line, filled circles). From left to right: chlorophyll (µg cm$^{-3}$) (mean +/- SD* *three replicates from each sediment slice); organic carbon content (% of dry weight, through loss on ignition), porosity (vol/vol) and median grain size (D50, µm).*

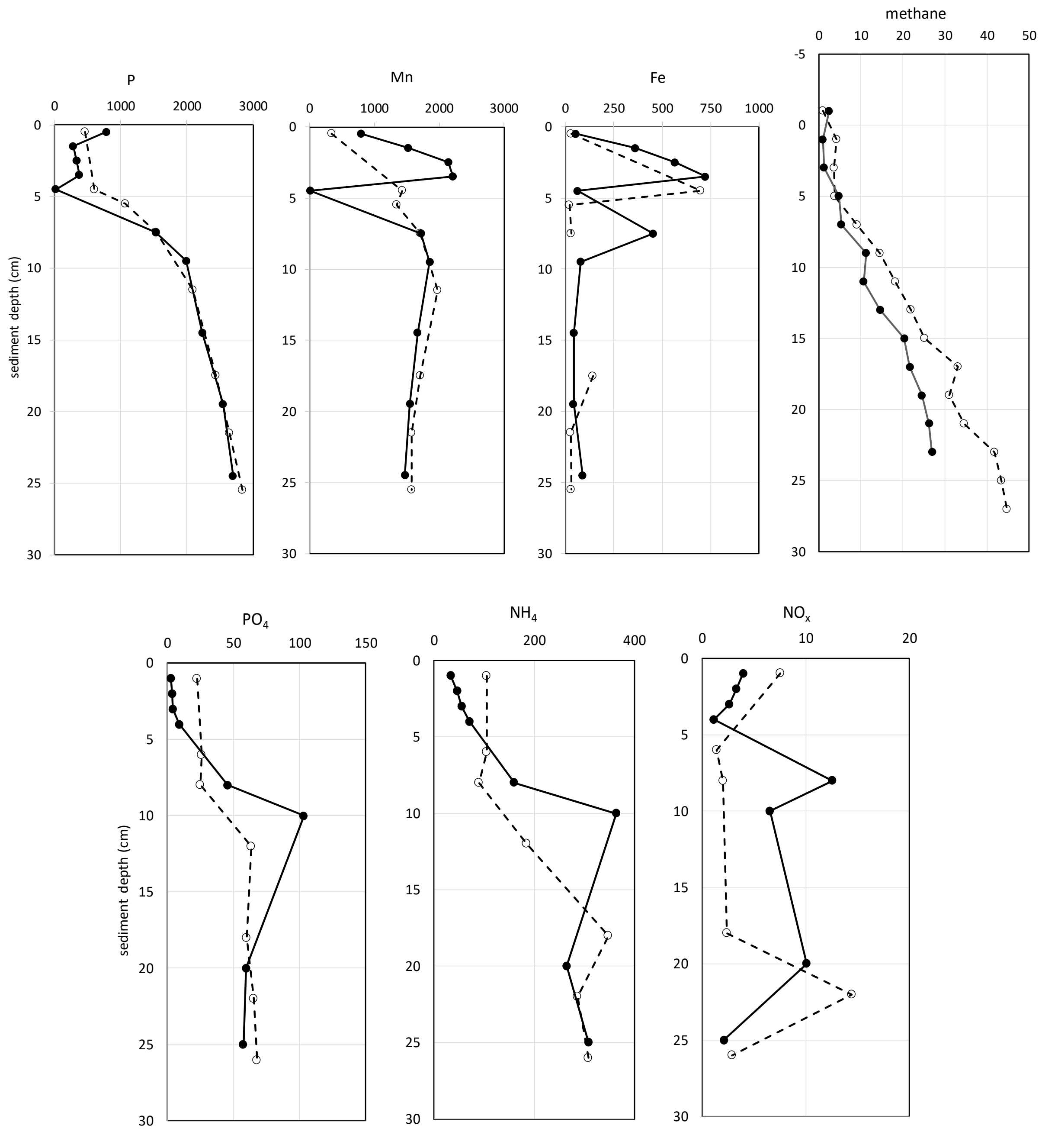



***Figure S6.*** *Sediment porewater concentrations 24 h after trawling. Profiles of one core from the trawl track (dashed line, open circles) and one core from c. 100 m away from the track (solid line, filled circles). Top row, left to right: porewater P, Mn and Fe (µg $L^{-1}$) and methane (µmol $L^{-1}$). Bottom row, left to right: porewater $PO_4$, $NH_4$ and $NO_x$ (µmol $L^{-1}$).*

# 3. Suspended sediment, particulate and dissolved substances

## 3.1. Water currents in the study area

In order to determine the likely direction of suspended sediment transport from the trawl track, water current velocity data were acquired using a hull-mounted Teledyne RDI Workhorse Mariner (600 kHz) Acoustic Doppler Current Profiler (ADCP) at a ping rate of about 0.25 pings per second with a vertical bin size of 1 m, and at a vessel speed of about 3 m $s^{-1}$. The data presented here were collected along three ADCP transects (see Table S1), two along the approximate line of the trawl track (4 h before and 20 h after trawling (22 and 23 October 2018, respectively) and one perpendicular to the track, 3 d after trawling (25 October). We first averaged vertically within three bins (0-5, 5-10 and 10-15 m.a.b) and subsequently averaged horizontally within three equidistant subsections along each transect (Figure S7).

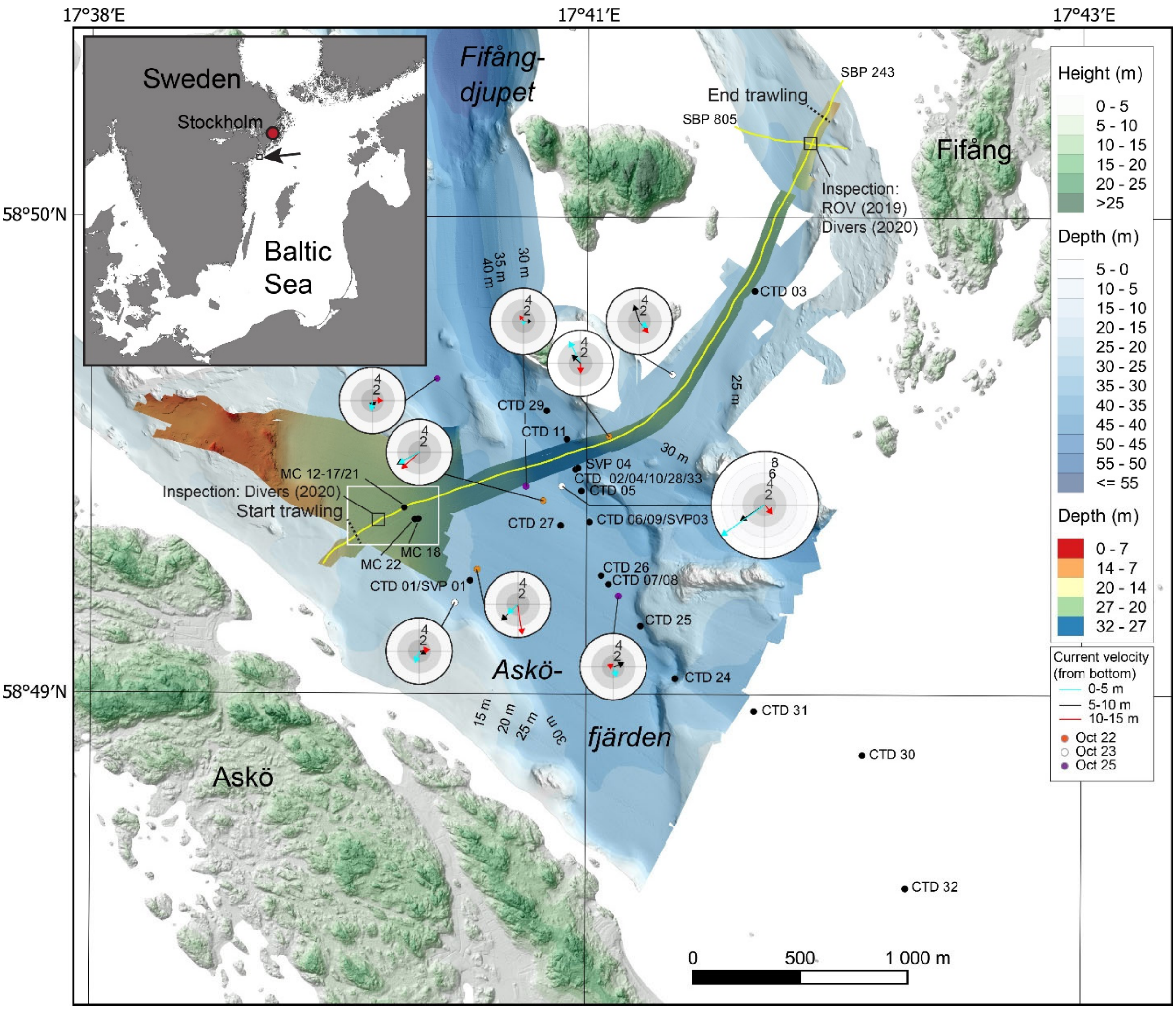


*Figure S7*: *Water current velocities and directions overlaid on the overview map (Fig. 1, main text). Data were obtained from three ADCP transects (orange, white and purple dots, sampled on October 22, 23 and 25, respectively – ie. 4 h pre-trawling and 20 h and 3 d post-trawling). Rose diagrams show averaged current velocities and directions for three depth horizons (0-5 m.a.b. (blue), 5-10 m.a.b. (black) and 10-15 m.a.b. (red). The arrow length is proportional to current velocity. Numbers in roses represent cm/s. Data are horizontally averaged along the transect, dots mark the centre location of averaging*

Water current directions and speeds varied both spatially (along the ADCP transects and with water depth) and temporally (between the three time points) and current speeds were generally low (< 6 cm $s^{-1}$), as might be expected in this non-tidal area (Fig. S7). Variable directions were likely due to variable weather and wind directions during the sampling week (data not shown), as well as local seafloor topography between the islands. This is in agreement with previous measurements taken from a benthic lander placed near the island of Fifång (see Fig. 1) for several days (Fig. S8). However, during the 4 days in which we followed the development of the sediment plume post-trawling, the dominant bottom current direction was to the SW or SE (Fig. S7).

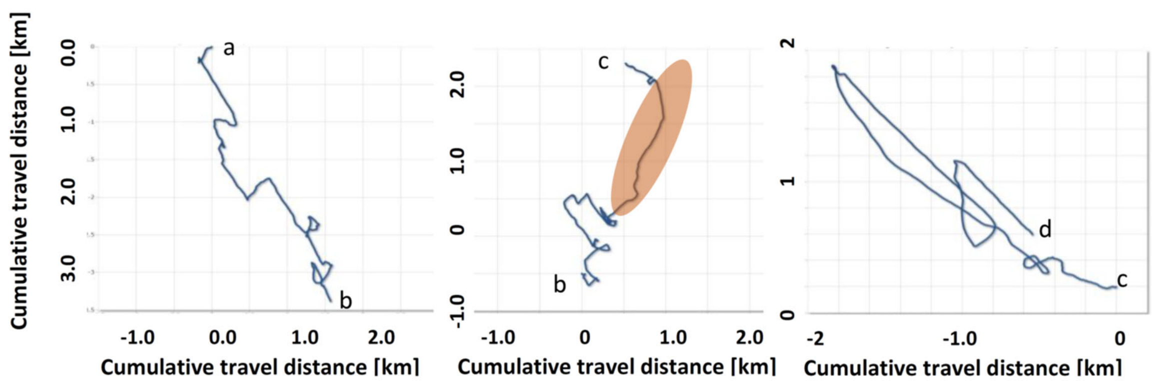



***Figure S8.*** *Progressive vector path showing how a particle starting at* ***a*** *would travel through* ***b*** *and* ***c****, ending up at* ***d,*** *based on measurements from a benthic lander over two consecutive days in August 2018. In time a-b represents 16:01 – 20:25, b-c represents 20:27 – 00:51 and c-d represents 00:54 – 09:00 (from Fredriksson, 2018, M.Sc thesis, Stockholm University).*

## 3.2. Suspended sediment and particulate substances

### 3.2.1. Details of calculations

NTU values from CTD casts and TSM from filtered water collected in Niskin bottles at the same depths during the same CTD casts (n = 73) were used to determine the relationship SPM (mgdw $L^{-1}$) = 1.42*NTU + 0.78 ($R^2$ = 0.82).

Background turbidity was calculated as the average of measurements from two CTD casts (CTD01, CTD02) taken 3 h prior to trawling. Average values were calculated at 5 different depths above the seabed; 0.5, 2.5, 5, 7.5, 10 m.a.b. (Table S6). At each of these depths, averages were taken including the values 0.25 m to either side of the actual depth measurement, in order to reduce the effect of single values (for 0.5 m.a.b., an average of values from 0.5 and 0.75 m.a.b. was used). Similar turbidity values were calculated for four CTD casts take 2h post-trawling (CTD04-07) and excess turbidity was calculated as the difference between these and the pre-trawl values for each depth (Table S6).

***Table S6.*** *Background turbidity (3 h pre-trawling), measured and increase in (excess) turbidity after 2 h. Each value is an average of 3 measurements around a given depth. Where excess values were negative, they were set to zero*

| | **Measured NTU** | | | | | **Excess NTU** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **3h pre-trawling** | **2h post-trawling** | | | | **2h post trawling** | | | |
| **Metres above bottom (mab)** | Average of CTD01 and CTD02 (above track) | CTD04 (above track) | CTD05 (100m SE of track) | CTD06 (250m SE of track) | CTD07 (550m SE of track) | CTD04 (above track) | CTD05 (100m SE of track) | CTD06 (250m SE of track) | CTD07 (550m SE of track) |
| **10** | 0.90 | 1.78 | 2.29 | 1.23 | 0.69 | 0.88 | 1.39 | 0.33 | 0 |
| **7.5** | 1.05 | 1.77 | 2.88 | 1.36 | 1.01 | 0.72 | 1.83 | 0.31 | 0 |
| **5** | 1.03 | 1.90 | 2.49 | 1.88 | 1.46 | 0.87 | 1.47 | 0.85 | 0.44 |
| **2.5** | 2.58 | 3.26 | 3.70 | 3.94 | 2.19 | 0.68 | 1.12 | 1.35 | 0 |
| **0.5** | 2.99 | 3.72 | 4.06 | 4.02 | 2.18 | 0.72 | 1.07 | 1.03 | 0 |

Next, we calculated the total amount of sediment suspended per $m^2$ and per m track, and the relative contribution of the trawl doors and ground gear. All calculations were done for a 1 m 'swathe' across the whole trawl track (width 36.2 m), and the 1 m wide water column 'downstream' of it (ie. along the CTD transects (Fig. 1).

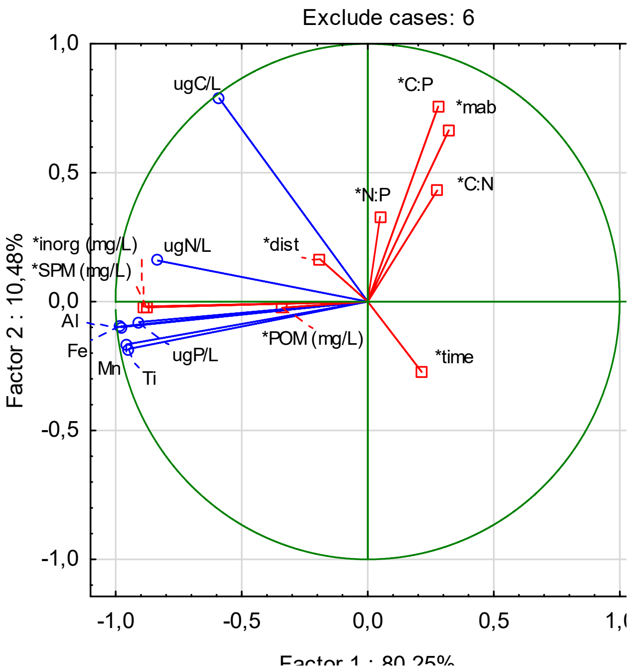
The 1m wide downstream water column was divided into compartments according to available data points at 2h after trawling: horizontally - 0-50 m away (CTD04), 50-175 m away (CTD05), 175-400 m away (CTD06) and 400-700 m away (CTD07); vertically – 0-0.5 m.a.b., 0.5-2.5 m.a.b., 2.5-5 m.a.b., 5-7.5 m.a.b., 7.5-10 m.a.b. The volume of each compartment was calculated. Turbidity measured at the top of each vertical compartment was applied to the whole of the compartment below (e.g. NTU at 0.5 m.a.b. was applied to 0-0.5 m.a.b., NTU at 2.5 m.a.b. applied to 0.5-2.5 m.a.b., etc).

The pre-trawl turbidity values were subtracted from each post-trawl values at each corresponding depth and expressed as mgDW $m^{-3}$. The value for each water compartment were multiplied by its volume to get mgDW per compartment. These were summed to give the total mgDW sediment in the entire downstream sediment plume suspended from a 1 m wide slice of trawl track (ie. kgDW $m^{-1}$ trawl track). The mass suspended per $m^2$ track was calculated by dividing by the area (36.2 $m^2$) of the track slice, assuming suspension was equal across the entire track. Using the relative proportions of disturbance produced by the doors vs groundgear (30% vs 70% on a volume basis, 7.7% vs 92.3% on an areal basis; see Section S2.3), the relative contribution of each to the total suspension was calculated both in kgDW $m^{-1}$ and kgDW $m^{-2}$. Results are shown in Table 2 in the main paper.

Finally, the total amount (gDW) of sediment suspended was used to estimate the total amounts of various particulate elements suspended. Ratios of particulate element concentrations (mg $L^{-1}$) to TSM (mgdw $L^{-1}$) to were calculated based on averages of measurements from 0.5 m.a.b. and 5 m.a.b., 2 h after trawling at 100, 250 and 550 m downstream (ie. the same CTD casts as used to estimate sediment suspension). These ratios were multiplied by the total mass of sediment suspended to obtain total masses of particulate elements suspended per m or $m^2$ of trawl track. The relative contribution of the trawl doors and groundgear was estimated in the same way as described above. Results are shown in Table 2.

### 3.2.2. Relationship between particulate substances and the sediment plume

A PCA analysis was performed using concentrations of particulate nutrients (µgC $L^{-1}$, µgN $L^{-1}$, µgP $L^{-1}$) and elements (Al, Fe, Mn, Ti, in µg $L^{-1}$) from 2 h, 20 h, 3 d and 4 d post-trawling, at water depths of 0.5 and 5 m.a.b., along transects extending up to 2.5 km away from the trawl track. Data from 20 h post-trawling, 0.5 m.a.b. (CTD10) was omitted due to unfeasibly high concentrations of most elements (ie. contamination) in this sample. The PCA was based on a correlation matrix derived from the concentration data and was scaled (standardised). SPM, organic matter concentration, inorganic matter concentration, C:N:P ratios, time, distance from trawl track and metres above bottom (m.a.b.) were included as supplementary variables and superimposed on the PCA plots. The supplementary variables' relationships with the element and nutrient concentrations were determined using separate multiple correlation analyses.




| | PC 1 | PC 2 | PC 3 | PC 4 |
|---|---|---|---|---|
| Eigen-value (%) | 5.62 (80.3%) | 0.73 (10.5%) | 0.35 (5.1%) | 0.21 (3.0%) |
| µgC $L^{-1}$ | 0.06 | 0.85 | 0.08 | 0.01 |
| µgN $L^{-1}$ | 0.12 | 0.03 | 0.76 | 0.01 |
| µgP $L^{-1}$ | 0.15 | 0.01 | 0.03 | 0.73 |
| µgAl $L^{-1}$ | 0.17 | 0.01 | 0.00 | 0.09 |
| µgFe $L^{-1}$ | 0.17 | 0.01 | 0.00 | 0.07 |
| µgMn $L^{-1}$ | 0.16 | 0.04 | 0.09 | 0.00 |
| µgTi $L^{-1}$ | 0.16 | 0.05 | 0.03 | 0.10 |

***Figure S9.*** *PCA plot of concentrations of particulate elements in water at 0.5 and 5 metres above the seabed (m.a.b.) from 2h- to 4d-post-trawling, together with total SPM (mg $L^{-1}$), inorganic and organic concentrations (mg $L^{-1}$), nutrient ratios and the factors time since trawling, distance from trawl track and m.a.b. Variables in blue are active variables used in the PCA analyses, those in red are supplementary and are superimposed on to the PCA plots based on correlations. The table shows the relative contributions of the active variables to each of the four principle components (factors) in the PCA.*

***Table S7.*** *Correlation matrix:* ***particulate*** *elements, SPM and inorganic and organic fractions at 0.5 and 5 m.a.b., 2 h to 4 d post-trawling. The first seven variables are those that were used as the active variables in the PCA analysis shown in Fig. S9. The other variables were those used as supplementary variables in that analysis. Pink/red indicates correlation coefficients > 0.75, yellow/orange = 0.5 – 0.75.*

| | ugC/L | ugN/L | ugP/L | Al | Fe | Mn | Ti | *time | *dist | *mab | *SPM (mg/L) | *POM (mg/L) | *inorg (mg/L) | *C:N | *C:P | *N:P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ugC/L** | | | | | | | | | | | | | | | | |
| **ugN/L** | 0.53 | | | | | | | | | | | | | | | |
| **ugP/L** | 0.48 | 0.71 | | | | | | | | | | | | | | |
| **Al** | 0.50 | 0.81 | 0.84 | | | | | | | | | | | | | |
| **Fe** | 0.50 | 0.81 | 0.85 | 0.99 | | | | | | | | | | | | |
| **Mn** | 0.46 | 0.69 | 0.90 | 0.94 | 0.96 | | | | | | | | | | | |
| **Ti** | 0.44 | 0.71 | 0.84 | 0.95 | 0.95 | 0.94 | | | | | | | | | | |
| ***time** | -0.34 | -0.19 | -0.43 | -0.11 | -0.14 | -0.22 | 0.00 | | | | | | | | | |
| ***dist** | 0.21 | 0.29 | 0.08 | 0.18 | 0.18 | 0.07 | 0.21 | 0.06 | | | | | | | | |
| ***mab** | 0.45 | -0.49 | -0.35 | -0.37 | -0.37 | -0.32 | -0.33 | -0.02 | -0.04 | | | | | | | |
| ***SPM (mg/L)** | 0.48 | 0.78 | 0.85 | 0.86 | 0.85 | 0.81 | 0.82 | -0.30 | 0.34 | -0.35 | | | | | | |
| ***POM (mg/L)** | 0.09 | 0.56 | 0.27 | 0.38 | 0.32 | 0.15 | 0.33 | 0.18 | 0.62 | -0.38 | 0.53 | | | | | |
| ***inorg (mg/L)** | 0.51 | 0.73 | 0.88 | 0.86 | 0.86 | 0.86 | 0.83 | -0.37 | 0.24 | -0.30 | 0.98 | 0.36 | | | | |
| ***C:N** | 0.32 | -0.59 | -0.24 | -0.31 | -0.31 | -0.17 | -0.27 | -0.14 | -0.20 | 0.90 | -0.30 | -0.55 | -0.21 | | | |
| ***C:P** | 0.46 | -0.16 | -0.53 | -0.28 | -0.28 | -0.38 | -0.33 | 0.19 | 0.10 | 0.72 | -0.33 | -0.19 | -0.32 | 0.51 | | |
| ***N:P** | 0.12 | 0.38 | -0.36 | 0.00 | -0.01 | -0.23 | -0.11 | 0.38 | 0.29 | -0.14 | -0.08 | 0.34 | -0.16 | -0.42 | 0.55 | |

## 3.3. Release of dissolved substances

### 3.3.1. Methane calculations

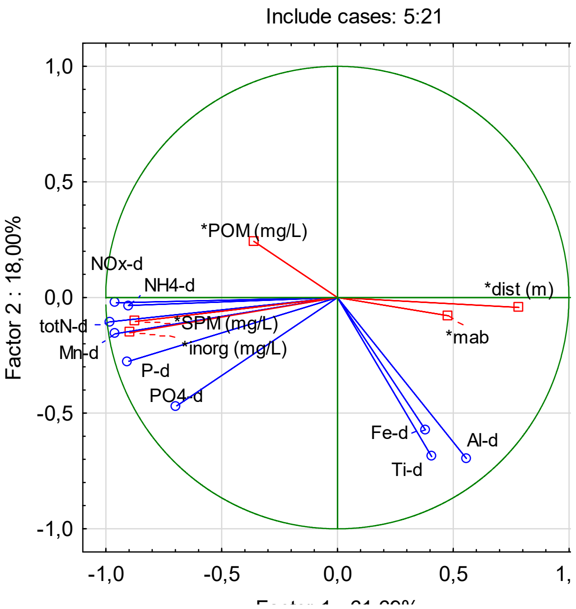
The method for calculating the amount of dissolved methane that could be released from the disturbed sediment in the trawl track, and its potential contribution to the overlying water concentrations downstream, is given in the main paper. The concentration of dissolved methane (mM) in a sediment sample was calculated as:

$$CH_4(mM) = \frac{CH_{4\,hsp} \cdot V_{hsp}}{1000 \cdot 24.148 \cdot V_{sed} \cdot \rho} \qquad \text{(Equation 2)}$$

where $CH_{4_{hsp}}$ is the concentration of methane in the headspace of the sample vial (ppm), $V_{hsp}$ is the volume of the headspace (L), $V_{sed}$ is the volume of the sediment sample (L), ρ is sediment porosity, and 24.148 (L $mol^{-1}$) is the molar volume of gas at standard pressure 100 kPa and 298 K. The reproducibility of the method has been tested at a station in the Stockholm archipelago by replicating methane sampling on multiple sediment cores. Concentrations in multiple cores deviated by about 10%.

### 3.3.2. Relationship between dissolved substances and the sediment plume

A PCA analysis was performed using concentrations of dissolved nutrients and elements, in the same way as for particulate substances (Section S3.2.2). Concentrations (µg/L) at 0.5, 1, 2, 3 and 5 m.a.b. were used, but only for 2 h post-trawling, since at 20 h no obvious correlations could be seen. Thus, time was not included as a supplementary variable in this analysis and the maximum distance from the trawl track was 550 m.




| Eigen-value (%) | PC 1 | PC 2 | PC 3 | PC 4 |
|---|---|---|---|---|
| | 5.55 (61.7%) | 1.62 (18.0%) | 0.79 (8.8%) | 0.53 (5.9%) |
| NH4-d | 0.15 | 0.00 | 0.00 | 0.26 |
| PO4-d | 0.09 | 0.14 | 0.00 | 0.43 |
| NOx-d | 0.17 | 0.00 | 0.00 | 0.01 |
| totN-d | 0.17 | 0.01 | 0.00 | 0.01 |
| Al-d | 0.06 | 0.30 | 0.00 | 0.22 |
| Fe-d | 0.03 | 0.20 | 0.62 | 0.00 |
| Mn-d | 0.17 | 0.02 | 0.00 | 0.07 |
| P-d | 0.15 | 0.05 | 0.00 | 0.00 |
| Ti-d | 0.03 | 0.29 | 0.37 | 0.00 |

***Figure S10.*** *PCA of dissolved concentrations (µg $L^{-1}$) up to 5 metres above the seabed (mab) and 550 m away from the trawl tracks, 2 h after trawling. Total SPM (mgDW $L^{-1}$), concentrations of particulate inorganic and organic matter (mgDW $L^{-1}$) and the factors time since trawling, distance from trawl track and m.a.b. are also shown. Variables in blue are active variables used in the PCA analyses, those in red are supplementary and are superimposed on to the PCA plots based on correlations. The table shows the contributions of the active variables to the four principle components (factors) in the PCA.*

***Table S8.*** *Correlation matrix:* ***dissolved*** *elements, SPM and inorganic and organic fractions up to 5 m.a.b., at 2 h after trawling. The first nine variables are those used as the active variables in the PCA analysis shown in Fig. S10. The other variables were those used as supplementary variables in that analysis. Pink/red indicates correlation coefficients > 0.75, yellow/orange = 0.5 – 0.75.*

| | NH4-d | PO4-d | NOx-d | totN-d | Al-d | Fe-d | Mn-d | P-d | Ti-d | *mab | *dist (m) | *SPM (mg/L) | *POM (mg/L) | *inorg (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NH4-d** | | | | | | | | | | | | | | |
| **PO4-d** | 0.49 | | | | | | | | | | | | | |
| **NOx-d** | 0.82 | 0.69 | | | | | | | | | | | | |
| **totN-d** | 0.93 | 0.71 | 0.94 | | | | | | | | | | | |
| **Al-d** | -0.38 | -0.17 | -0.55 | -0.45 | | | | | | | | | | |
| **Fe-d** | -0.30 | -0.02 | -0.31 | -0.31 | 0.53 | | | | | | | | | |
| **Mn-d** | 0.94 | 0.65 | 0.90 | 0.97 | -0.38 | -0.29 | | | | | | | | |
| **P-d** | 0.77 | 0.73 | 0.85 | 0.90 | -0.32 | -0.21 | 0.92 | | | | | | | |
| **Ti-d** | -0.36 | 0.02 | -0.38 | -0.33 | 0.63 | 0.22 | -0.28 | -0.17 | | | | | | |
| ***mab** | -0.48 | -0.28 | -0.51 | -0.47 | 0.21 | -0.01 | -0.45 | -0.35 | 0.52 | | | | | |
| ***dist (m)** | -0.68 | -0.46 | -0.74 | -0.75 | 0.44 | 0.40 | -0.77 | -0.79 | 0.30 | 0.02 | | | | |
| ***SPM (mg/l** | 0.90 | 0.64 | 0.79 | 0.91 | -0.33 | -0.26 | 0.88 | 0.74 | -0.35 | -0.51 | -0.57 | | | |
| ***POM (mg/** | 0.59 | 0.00 | 0.26 | 0.42 | -0.16 | -0.41 | 0.37 | 0.10 | -0.30 | -0.31 | -0.06 | 0.63 | | |
| ***inorg (mg** | 0.89 | 0.70 | 0.82 | 0.93 | -0.34 | -0.22 | 0.90 | 0.79 | -0.33 | -0.50 | -0.61 | 0.99 | 0.53 | |

***Table S9.*** *Comparison of concentrations of dissolved substances 2 h post-trawling with 3 h pre-trawling (average of samples from two CTD casts). No data (n.d.) available for Al and Fe, 5 m.a.b., 3 h pre-trawling. For the post:pre ratios, orange-red = ratio >1, yellow/green = ratio <1.*

| | Al | | | Fe | | | Mn | | | Ti | | | P | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **m.a.b** | 100m | 250m | 550m | 100m | 250m | 550m | 100m | 250m | 550m | 100m | 250m | 550m | 100m | 250m | 550m |
| 5 | 0.74 | 1.05 | 1.70 | 0.67 | 1.36 | 1.60 | 17.02 | 10.61 | 10.99 | 0.59 | 0.62 | 0.76 | 33.30 | 28.60 | 30.04 |
| 3 | 1.15 | 0.83 | 1.89 | 1.27 | 0.90 | 2.22 | 21.91 | 24.60 | 11.52 | 0.68 | 0.63 | 0.69 | 34.06 | 33.68 | 29.57 |
| 2 | 0.71 | 0.61 | 1.82 | 0.85 | 0.73 | | 22.00 | 24.84 | 13.42 | 0.58 | 0.64 | 0.65 | 33.51 | 33.48 | 30.94 |
| 1 | 0.60 | 1.54 | 0.79 | 1.32 | 1.05 | 0.87 | 24.06 | 22.98 | 13.17 | 0.58 | 0.55 | 0.60 | 34.02 | 32.50 | 30.39 |
| 0.5 | 0.46 | 0.71 | 0.90 | 0.69 | 0.94 | 0.97 | 24.17 | 20.69 | 10.97 | 0.52 | 0.59 | 0.54 | 32.98 | 31.95 | 29.83 |
| **Dissolved concentrations (μg/L) in the bottom water 3 h pre-trawling** | | | | | | | | | | | | | | | |
| 5 | n.d. | | | n.d. | | | 19.6 | | | 0.98 | | | 33.97 | | |
| 3 | 1.58 | | | 1.27 | | | 23.5 | | | 0.57 | | | 34.46 | | |
| 2 | 1.13 | | | 1.14 | | | 26.1 | | | 0.62 | | | 34.58 | | |
| 1 | 0.59 | | | 1.12 | | | 27.0 | | | 0.57 | | | 35.09 | | |
| 0.5 | 0.98 | | | 1.06 | | | 18.5 | | | 0.59 | | | 32.18 | | |
| **Ratio of post:pre-trawling concentrations in bottom water** | | | | | | | | | | | | | | | |
| 5 | | | | | | | 0.87 | 0.54 | 0.56 | 0.61 | 0.64 | 0.78 | 0.98 | 0.84 | 0.88 |
| 3 | 0.73 | 0.53 | 1.19 | 1.00 | 0.71 | 1.75 | 0.93 | 1.05 | 0.49 | 1.19 | 1.10 | 1.21 | 0.99 | 0.98 | 0.86 |
| 2 | 0.63 | 0.54 | 1.61 | 0.74 | 0.64 | | 0.84 | 0.95 | 0.51 | 0.94 | 1.04 | 1.04 | 0.97 | 0.97 | 0.89 |
| 1 | 1.02 | 2.61 | 1.34 | 1.18 | 0.94 | 0.78 | 0.89 | 0.85 | 0.49 | 1.01 | 0.95 | 1.05 | 0.97 | 0.93 | 0.87 |
| 0.5 | 0.47 | 0.73 | 0.92 | 0.65 | 0.88 | 0.91 | 1.30 | 1.12 | 0.59 | 0.89 | 1.00 | 0.91 | 1.02 | 0.99 | 0.93 |

| | PO4 | | | NH4 | | | NOx | | | tot-N | | | CH4 (20h) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **m.a.b** | 100m | 250m | 550m | 100m | 250m | 550m | 100m | 250m | 550m | 100m | 250m | 550m | 100m | 250m | 550m |
| 5 | 25.95 | 22.60 | 24.10 | 3.87 | 3.91 | 2.29 | 25.60 | 19.70 | 19.75 | 29.5 | 23.6 | 22.0 | 0.74 | 0.62 | 0.86 |
| 3 | 30.90 | 26.30 | 22.95 | 5.92 | 7.48 | 2.33 | 29.65 | 26.45 | 19.30 | 35.6 | 33.9 | 21.6 | 0.78 | 0.65 | 0.93 |
| 2 | 28.30 | 28.95 | 26.40 | 5.80 | 8.23 | 3.42 | 26.65 | 30.80 | 22.10 | 32.4 | 39.0 | 25.5 | 0.72 | 0.86 | 0.94 |
| 1 | 24.60 | 25.35 | 25.20 | 8.11 | 8.80 | 4.40 | 27.35 | 26.15 | 23.35 | 35.5 | 35.0 | 27.8 | 0.69 | 0.78 | 0.93 |
| 0.5 | 26.55 | 24.35 | 25.10 | 7.24 | 7.19 | 2.65 | 31.75 | 28.25 | 22.15 | 35.4 | 31.8 | 24.8 | 0.72 | 0.72 | 0.89 |
| **Dissolved concentrations (μg/L) in the bottom water 3 h pre-trawling** | | | | | | | | | | | | | | | |
| 5 | 29.6 | | | 2.39 | | | 18.9 | | | 21.2 | | | 0.56 | | |
| 3 | 29.9 | | | 3.54 | | | 23.6 | | | 27.1 | | | 0.63 | | |
| 2 | 29.9 | | | 4.25 | | | 23.1 | | | 27.3 | | | 0.48 | | |
| 1 | 28.8 | | | 5.47 | | | 23.7 | | | 29.2 | | | 0.69 | | |
| 0.5 | 27.4 | | | 2.68 | | | 22.2 | | | 23.5 | | | 0.55 | | |
| **Ratio of post:pre-trawling concentrations in bottom water** | | | | | | | | | | | | | | | |
| 5 | 0.88 | 0.76 | 0.81 | 1.62 | 1.63 | 0.96 | 1.36 | 1.05 | 1.05 | 1.39 | 1.11 | 1.04 | 1.32 | 1.11 | 1.54 |
| 3 | 1.03 | 0.88 | 0.77 | 1.67 | 2.11 | 0.66 | 1.26 | 1.12 | 0.82 | 1.31 | 1.25 | 0.80 | 1.23 | 1.03 | 1.47 |
| 2 | 0.95 | 0.97 | 0.88 | 1.36 | 1.94 | 0.80 | 1.16 | 1.34 | 0.96 | 1.19 | 1.43 | 0.93 | 1.49 | 1.79 | 1.96 |
| 1 | 0.85 | 0.88 | 0.88 | 1.48 | 1.61 | 0.80 | 1.15 | 1.10 | 0.99 | 1.22 | 1.20 | 0.95 | 0.99 | 1.14 | 1.35 |
| 0.5 | 0.97 | 0.89 | 0.92 | 2.71 | 2.69 | 0.99 | 1.43 | 1.27 | 1.00 | 1.50 | 1.35 | 1.05 | 1.31 | 1.31 | 1.62 |

## 3.4. References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