Hydrodynamic drag as a main component in explaining concentrations of nutrients and particle loads at different heights of a fisheries trawl plume

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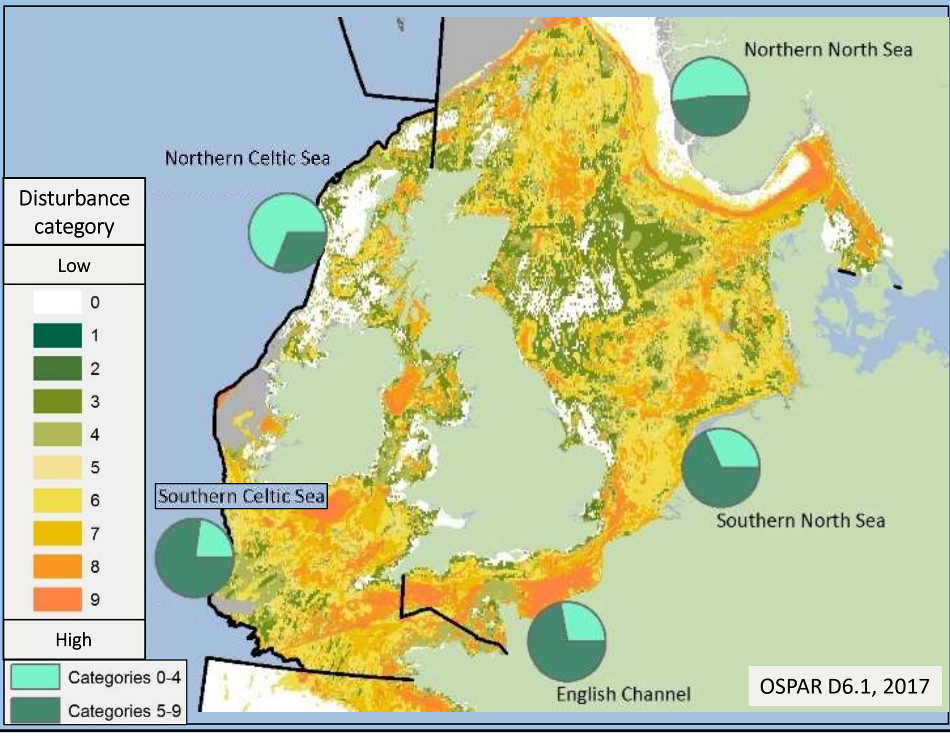
Trawling effects on the West European shelf



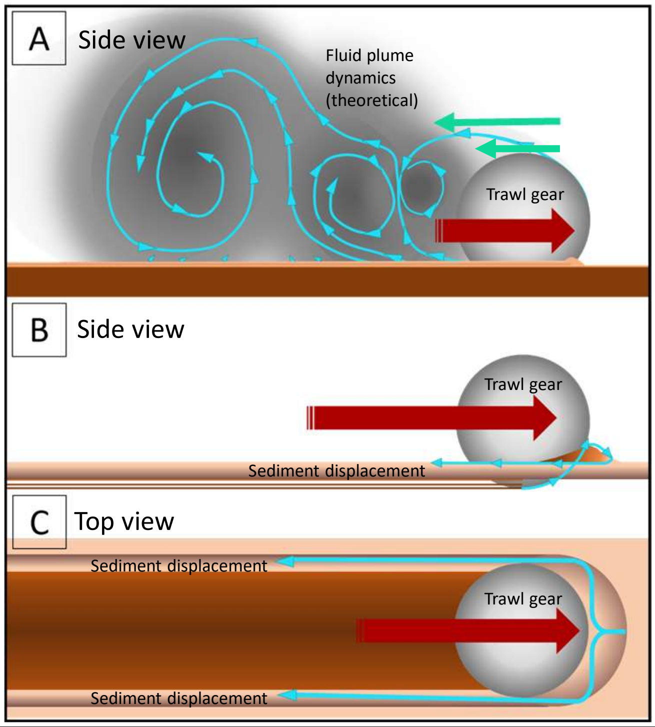
Shelf seas provide 50% of total ocean primary production, which in turn drives secondary production: feeding and breeding grounds of commercial fishing stock.

Trawling is the most intense form of benthic disturbance, globally. Trawl gears are purpose built to capture target species with limited consideration for habitat effects.

Disturbance to the system may affect primary and therefore secondary production.

- Shelf seas highly productive – account for 50% of ocean primary production which drive the high biomass and biodiversity of shelf ecosystems
- The fishing industry directly benefits from this productivity with global industry bringing in £39bn in 2000 and landing an average 400,000 tonnes of fish
- Coastal and island communities rely on employment and economic activity related to the fishing industry, however employment directly linked to fishing has fallen by 6% since 2008
- The common fisheries policy aims to safeguard sustainability of fisheries by introducing quotas, fishing effort and equipment that can be used.
- Currently, equipment is heavily destructive, churning up sediment, altering biogeochemical pathways and potentially reducing the effectiveness of benthos to cycle biodegradable matter.
- Ultimately this not only results in potential reduction of food (and economic) availability but also increases the potential for increased nutrients in the surface, leading to increased plankton blooms.

Trawl gear interaction with the sea bed



A] Trawl gears are a barrier to the flow of water, and as such will create friction between the gear surface and the water it is in contact with. Inflowing water is incrementally slowed by the slower plane below it, introducing turbulence in the wake of the gear.

B] Gears dig into the sediment, resuspending material and aerating layers that may have been anaerobic until this disturbance event. Subsequently, sediment biogeochemistry is altered and nutrients and particulate matter are thrown into the water column.

C] Peaks and troughs are created in the sediment, altering the topography and habitat type of the surface.

Trawl gear is depicted as a sphere as a representation of a body moving through sediment.
Panel A is a schematic based on O'Neil et al, 2015.

Hypotheses:

Levels of drag influence the plume size and shape

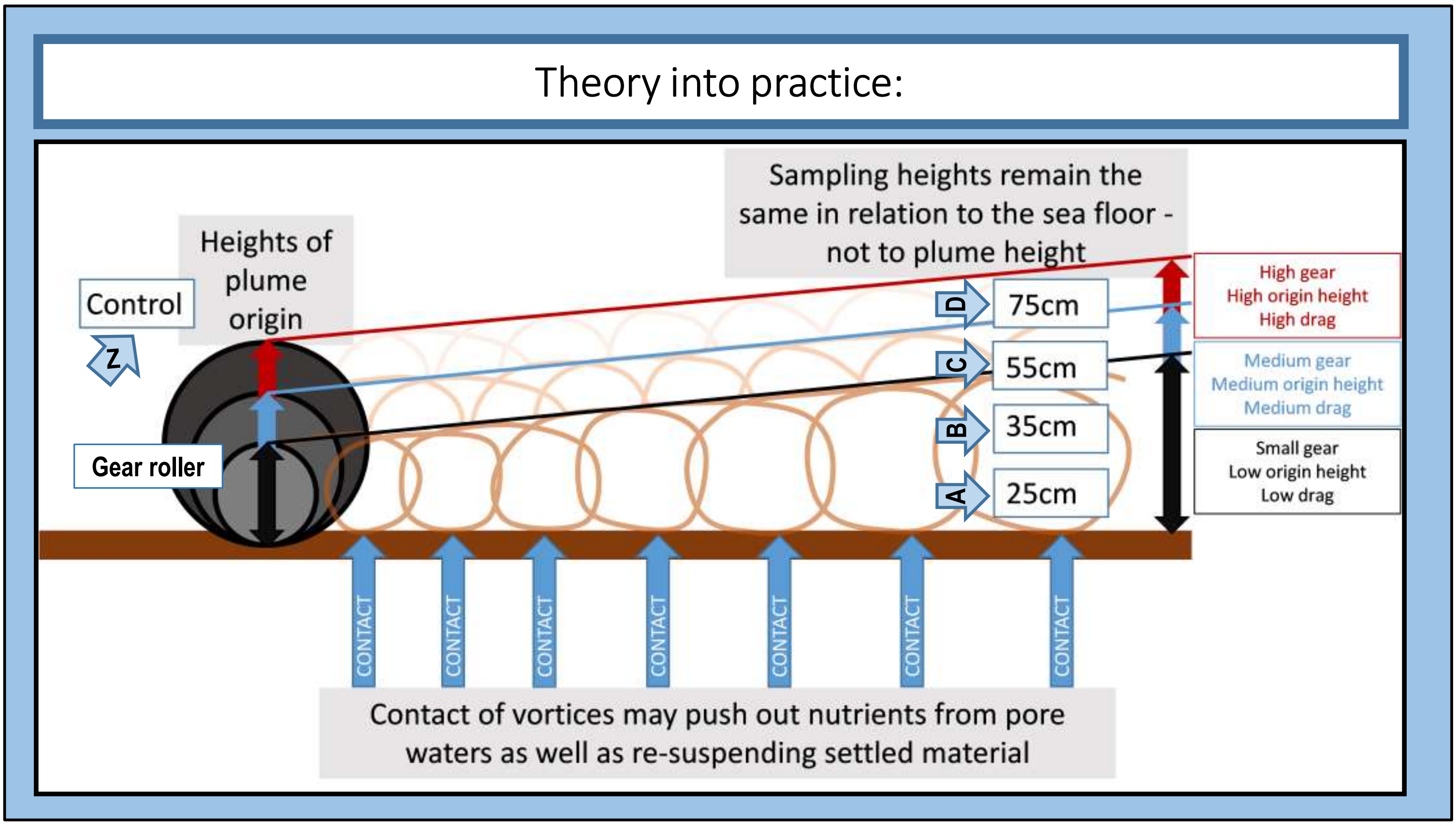
Trawl plume dynamics influence the resuspended nutrient concentrations and Particle Size Distribution(PSD)

The aim of the project is to quantify the concentrations of particulate matter and nutrients into the overlying water column within a trawling event.

In order to do this, the effects of drag were tested and the nutrient and particulate response measured.

For both, particles and nutrients, the same questions are being asked:

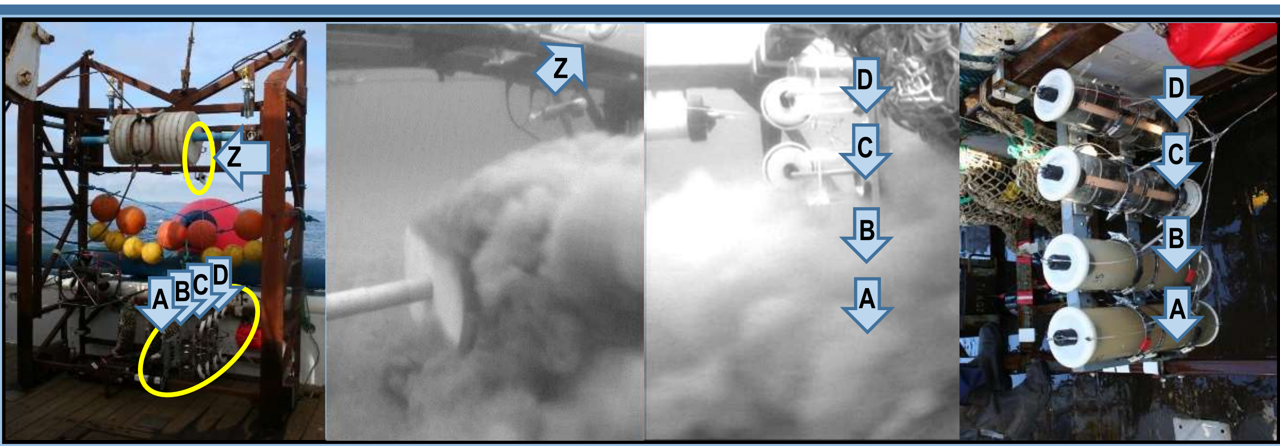
1) Do different levels of drag change nutrient and PSD (Particle Size Distribution) responses?
2) Is the composition of particulate matter and nutrient concentration different at different heights of the trawl plume?



Brown coils loosely represent plume dynamics and water movement behind the trawl gear (primary resuspension). Arrows indicating “contact” indicate areas of high pressure in the plume that come into contact with the sediment surface. Secondary resuspension may be introduced behind the trawl gear by the pressure of the turbulent water on the sediment. Gears of larger diameter will theoretically produce higher trawl plumes with potential for more internal mixing and secondary resuspension. The drag associated with each diameter of gear may result plumes with vortices of different sizes and energy. Height of resuspension and the retention time of material from the sediment (nutrients and particulates) varies according to the energy introduced and therefore the drag introduced.

Niskin array at the back of the rig (A-D) collected samples at designated sampling heights
Niskin bottle “control (Z)” collected background concentrations and was always outside the trawl plume
Trawl gear rollers with different diameters and thus, areas of contact might produce different levels of drag

Sample collection:



Data were collected in June 2015 at Dornoch Bay (Northern Scotland, UK)

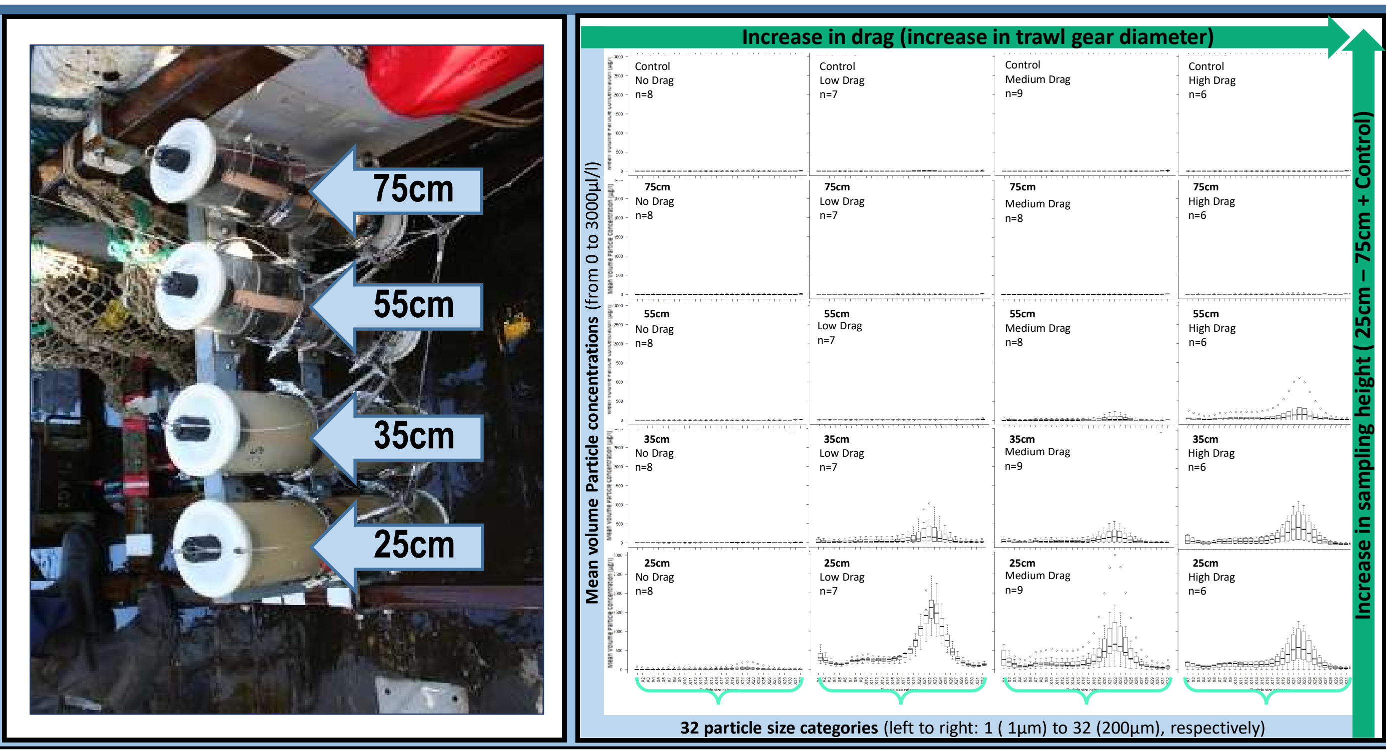
A novel trawl sledge with removable trawl gears representing low medium and high drag was deployed.
An array of niskin bottles mounted to a trawl sledge for continuous sampling at 25cm (A), 35cm (B), 55cm(C), 75cm (D) relative to the sea bed.
A fifth control niskin (Z) was mounted above and in front of the roller to collect background concentrations.

The categorisation of low, medium and high drag is arbitrary and used for the purpose of this study.

Generally – as you can see in the third image along:
Niskin D (75cm from the seafloor) generally sampled outside the trawl plume
Niskin C was sometimes inside and sometimes outside – depending on the plume height
Niskins A and B generally sampled the highest concentrations of particulate matter
Niskin Z was mounted in front of the roller, so was not affected by the sediment disturbance

Results

Particle Size Distribution (PSD) - Particles to Data:

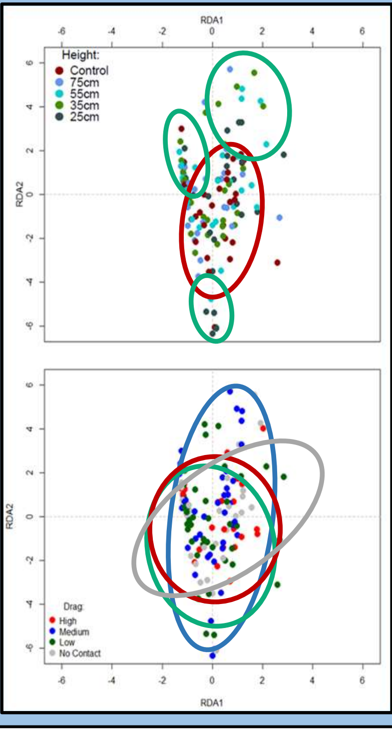


Raw data plots outlining Particle size distributions at each sampling height and drag category.
Panels read
Top to bottom – Control, 75cm, 55cm, 35cm, 25cm from the seafoor.
Left to right – No drag (No contact), Low drag, Medium drag, High drag

Each panel presents mean volume Particle concentrations (from 0 to 3000µl/l) by Particle size category (left to right: 1 (1µm) to 32 (200µm), respectively).

Main points:
High concentrations of particulate matter, high proximity to the sea floor
Low concentration, low proximity to the sea floor
Data suggest that an increase in drag results in an increase in plume height, as well as in PSD variability and concentration

Do the trawl plume dynamics influence Particle Size Distributions (PSD)?



Sampling Height:

•Data obtained from control samples appeared to group close to the origin (red circle)

•Samples collected at 25cm gave highest and most variable particle concentrations (Previous slide; green circle).

• Increased distance from sea floor, reduces the concentration and variation in PSD profiles.

•Data collected at 75cm from the seafloor and control data registered minimal PSD concentrations (Previous slide; red circle).

Drag:

•Data appeared to produce similar distributions, suggesting similar PSD concentrations at different levels of drag.

•No contact data (grey circle) displayed different weightings to other drag categories (-ve RDA1 and 2 to +ve RDA1 and 2)

Sampling height (DF=4, F=11.7, p=0.001)
Drag(DF=2, F=3.7, p=0.003)

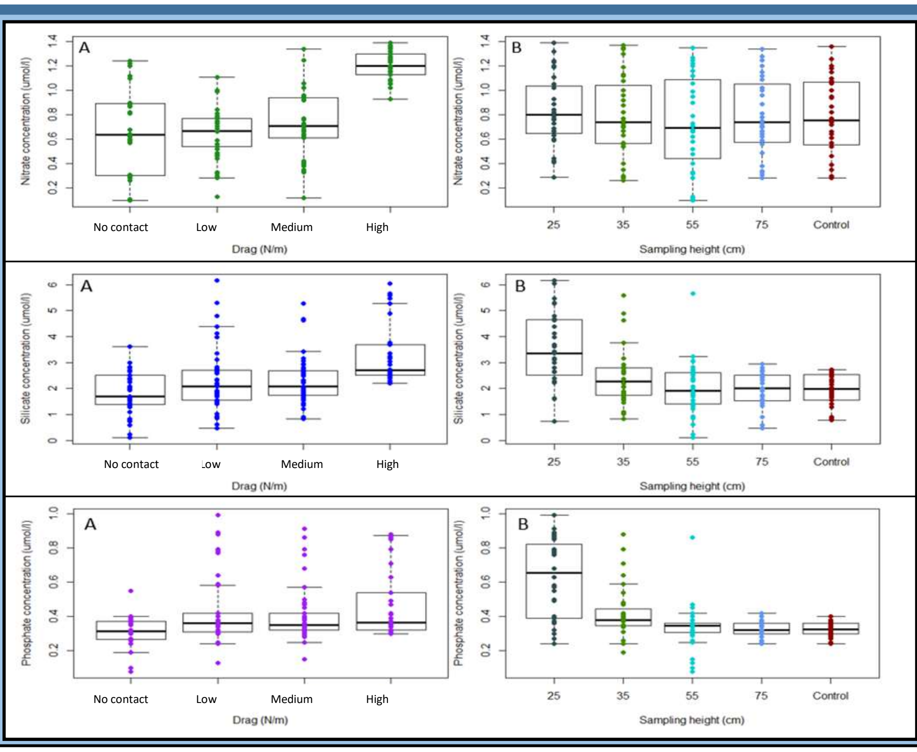
Model explains 33% of variation of which:
Sampling height: 28.7%
Drag: 4.3%

Data were analysed by redundancy analysis (RDA) to deal with the multivariate nature of the dataset.
The order of importance is important in an RDA as this represents the proportion of data explained from most to least.

Panels are presented in order of model show the spread of data allocated by the redundancy analysis across a biplot.
The top panel presents data points colour coded according to the sampling height at which data were collected.
The lower panel presents data colour coded according to the level of drag when data were collected.

Drag spreads the data, with samples from medium drag exhibiting the highest variability
- Could be due to the specific characteristics of that drag category

Do the trawl plume dynamics influence relative nutrient concentrations?

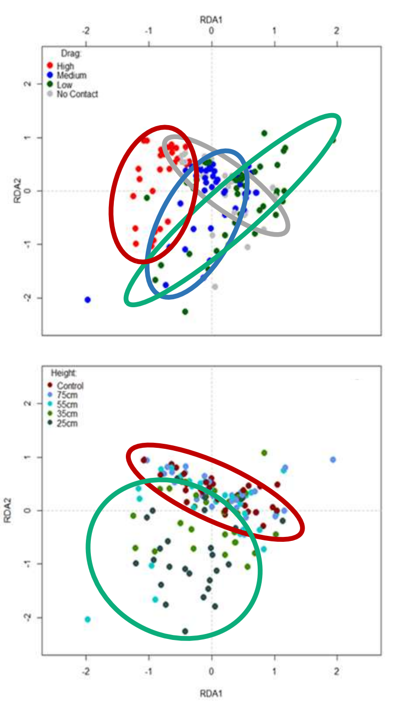


Nutrient species included in the model:
Nitrate
Nitrite
Ammonium
Silicate
Phosphate

Nutrients were converted to relative concentrations (percentage) across the sample before analysis.

Panels present boxplots of raw data for the three nutrients which appear to be driving distributions. Raw data plots presenting the nutrient concentrations which suggested trends by [A] Drag and [B] Sampling height (cm).
Nitrate, phosphate and silicate all indicated an increase in relative concentration with increasing drag.
Silicate and phosphate indicated high to low concentrations as distance from the seafloor increased.
Nitrate did not exhibit any clear trend with sampling height but suggested high variability at 55cm – the niskin which is sometimes at the edge of the trawl plume.

Do the trawl plume dynamics influence relative nutrient concentrations?



Drag level:

•Clear data separation between drag categories – control distributions (grey circle) are almost horizontal, as opposed to low, medium and high treatments (green, blue, red circles)

•Data clusters are concentrated and only show slight overlap

•Drag portion of the model appears to be driven by nitrogen, silicate and phosphate based nutrients

Sampling height:

•Low variability in control data and data from higher sampling heights and control (red circle)

•High variation at lower sampling heights (green circle)

•Height portion of the model appears to be driven by particle associated nutrients such as silicate and phosphate

Drag:
(DF=3, F=7.7, p=0.001)
Sampling height:
(DF=4, F=5.7, p=0.001)

Model explains 37.9% of variation of which:
Drag: 22.9%
Sampling height:15%

Left panel: Data are presented in order of importance according to the RDA model.
Top – data are coloured to show drag
Bottom – data are coloured to show sampling height (distance from the seafloor)

Drag:
Data separated into clusters by drag category:
No contact drag strongly indicates a difference between trawled and non-trawled (control) runs
As you might expect – low drag and high drag are at the extremes of the distribution, with a more variable medium drag in between
Nutrients in solution - which have dissolved fully into porewaters and are no longer associated with particulates – may be driving this data distribution. These nutrients would be following the fluid dynamics of the trawl plume - which is characterised by the size (surface area introducing friction in the water) of the trawl gear.
Additionally, areas of high pressure on the sediment surface caused by the vortices in the trawl plume may be pushing nutrients out of the pore waters after the trawl roller has passed (see slide 5 for a conceptual schematic)

Sampling height:
High concentration, high proximity to the sea floor; Low concentration, low proximity to the sea floor (see previous panel)
There is a separation in distributions - samples collected close to the sea floor (≤35cm) show high variability, with highly negative weightings being assigned to samples from 25cm along RDA2. Samples collected at heights ≥55cm, as well as the control, were clustered close to the origin and displayed strong overlap in distributions.

Nutrients which are particle associated (phosphate, silicate) might drive this separation in data. Would expect more phosphate to become decoupled from higher concentrations of particles as they adhere to surface minerals.
Silicate is, by its nature a particle. The more silicate particles are present, the higher the concentrations due to dissolution. Increased oxygen might kick-start dissolution in highly saturated pore waters that have reached saturation.

Conclusions

Do the trawl plume dynamics influence the nutrient concentrations and Particle Size Distribution(PSD)?

Particle size distributions and the relative abundances of nutrient species changed as sampling height increased

A drag effect was apparent in both nutrient and particle size distribution profiles

Fisheries trawling introduces higher concentrations of nutrients and particles into the overlying water column than are present in background concentrations

What changes the plume size and shape, and can trawl plumes be reduced ?

Data suggest that low drag gears would reduce the concentrations of particulate and nutrient concentrations, maintaining sediment integrity to some degree

Thank you for your time!