‘Deep-sea ecosystems and Extreme environments’ PROMEX 5UM15

UPMC, Banyuls-sur-Mer, 17th December 2015 –13:30 to 14:30

Deep Sea Mining: Threats to deep-sea ecosystems posed by petrochemical drilling and metallic nodule mining

Autun Purser – Alfred Wegener Institute, Bremerhaven, Germany

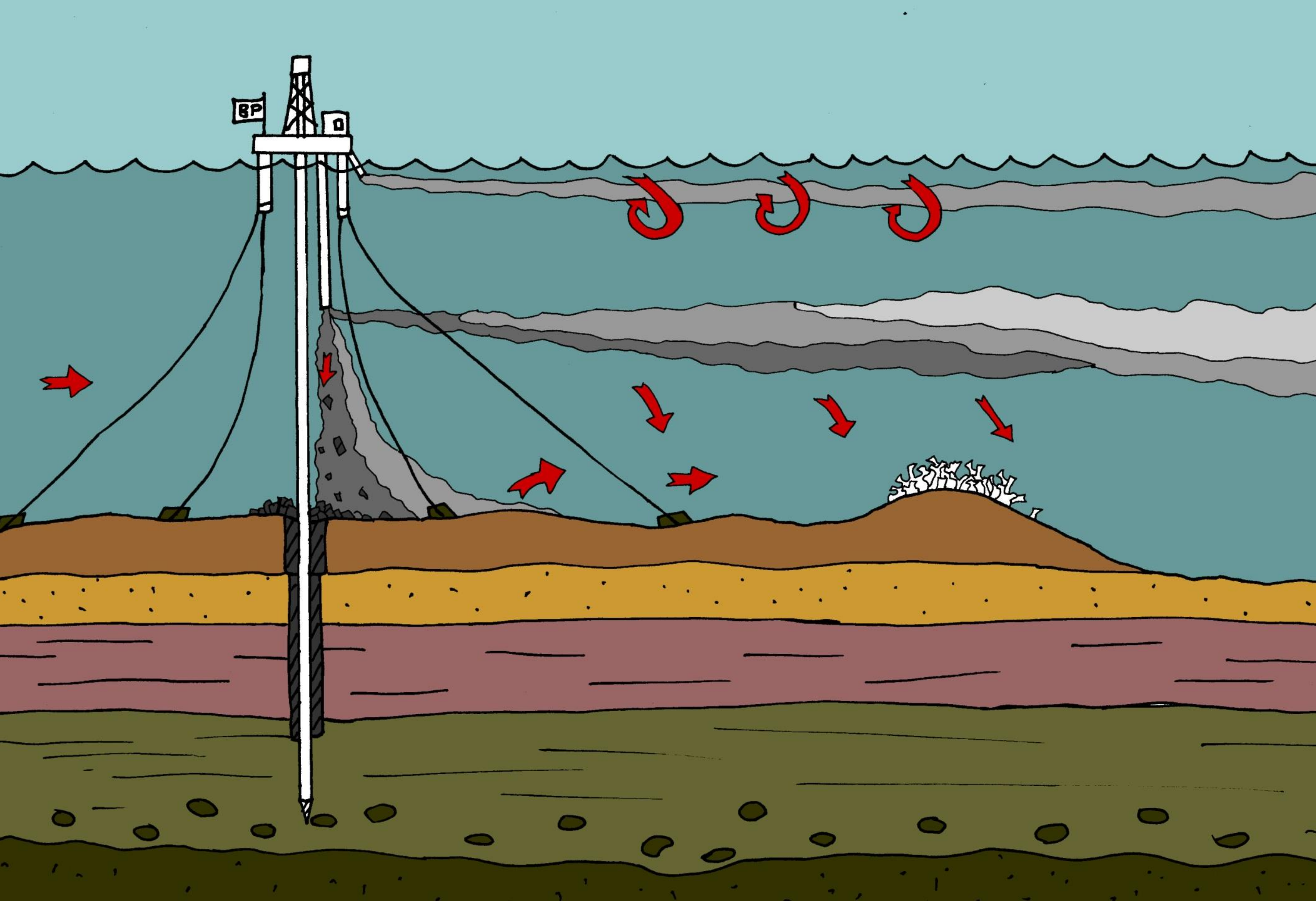
(a.purser@jacobs-university.de – please contact with questions etc)

I have spent the last 9 years studying deep-water reefs – during my PhD and postdoc.

Mostly the potential effects on reef communities of anthropogenic activity. Now I start work on nodule extraction…

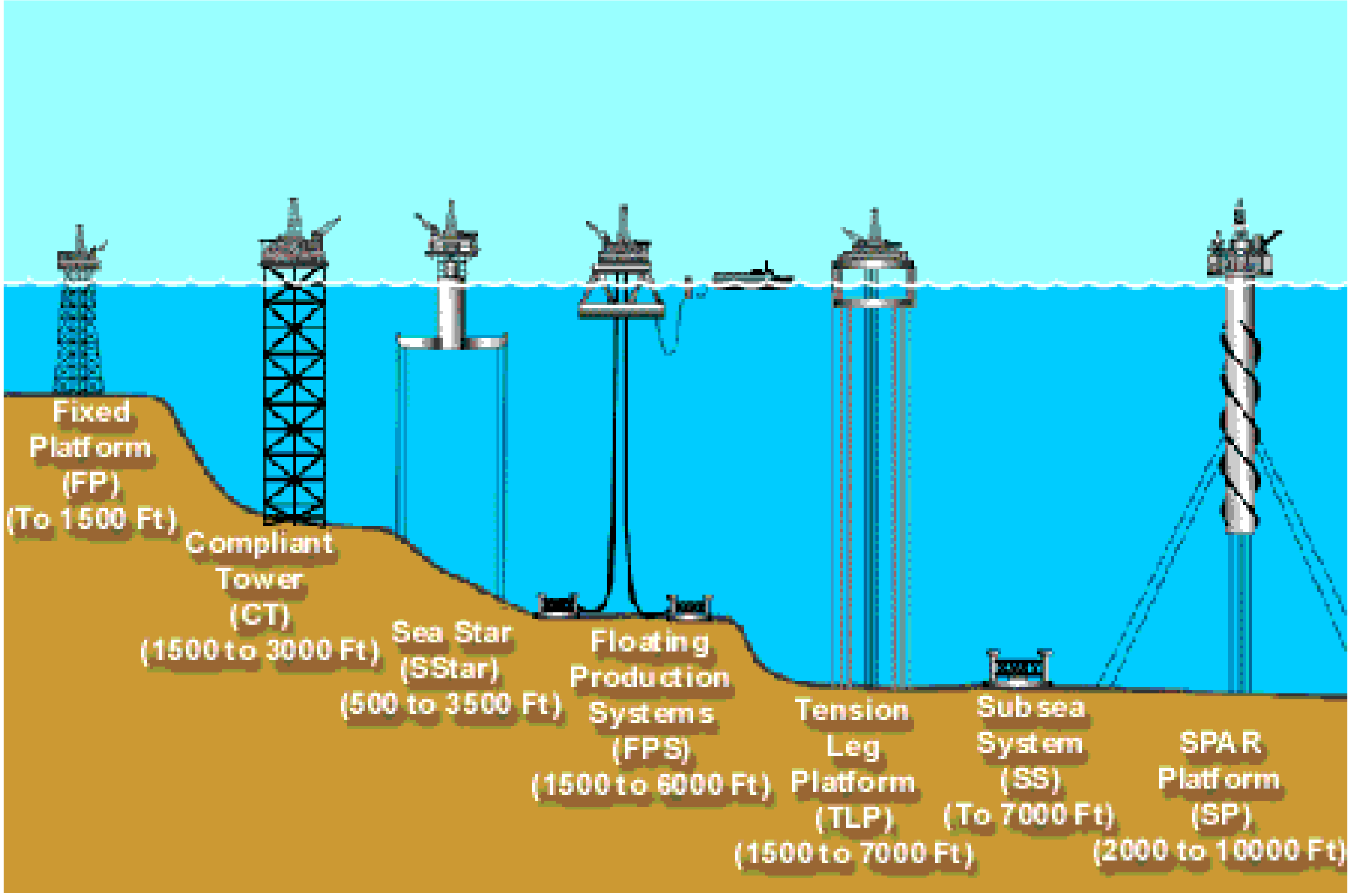
…Talk in two halves… 1) Threats posed by drilling 2) Threats posed by metallic nodule extraction.

The threat to deep-sea ecosystems posed by drilling.



What is deep sea drilling?

Deep sea drilling is primarily aimed at extracting oil and gas from buried rock strata.



SOURCE: http://ffden-2.phys.uaf.edu/212_spring2011.web.dir/kristine_odom/temp/10956/ftddrops/Homepage.html

What is deep sea drilling?

The drill is kept in action by drilling muds (to maintain positive pressure and to push up waste material) and produces drill cuttings… waste rock and mud fragments…

..if oil content low (usually is in European waters), these can be released to the sea.

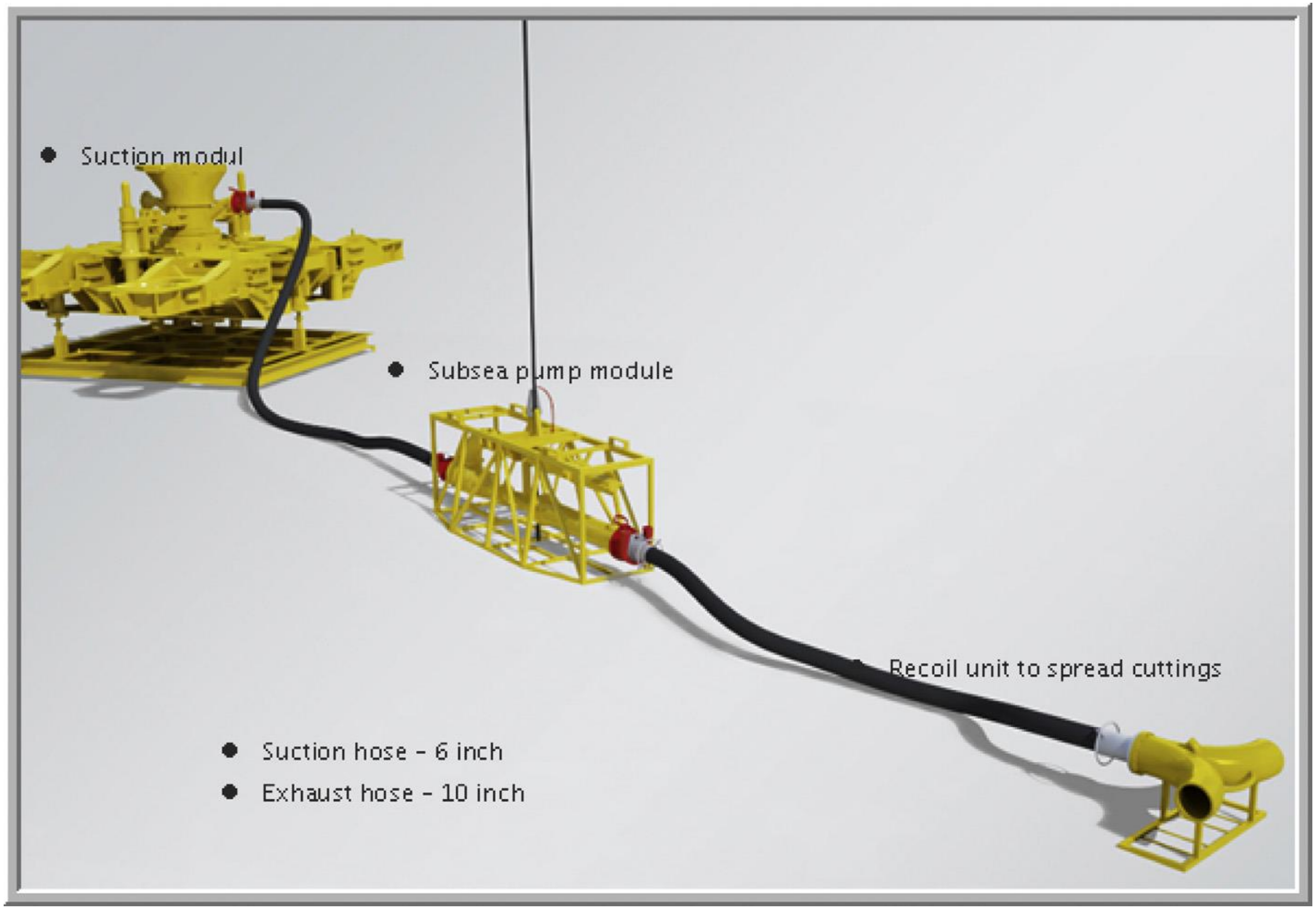
IMAGES: SINTEF

What are the direct physical threats of drilling?

Any ideas what these might be?   How big an area is affected?

What are the direct physical threats of drilling?

Localised drill hole plus immediate cuttings smothering, less than 50 m diameter.



Godo et al. (2014)

What are the secondary threats posed by drilling?

Any ideas? Magnitudes?

What are the secondary threats posed by drilling?

Various:

- Chemical exposure?   Metals?   Drilling mud components?
- Particles.   Fine grained, unnaturally sharp unusual material.
- Seafloor modification (sediment coverage).
- Later resuspension.
- Impacts on natural aggregation.

Reviewed in: Purser & Thomsen (2013

Extreme threats posed by drilling

SOURCE: wikipedia

Extreme threats posed by drilling

Deepwater Horizon.

Oil exposure and flocculants had clear, measurable effects on some fauna, such as gorgonian corals.

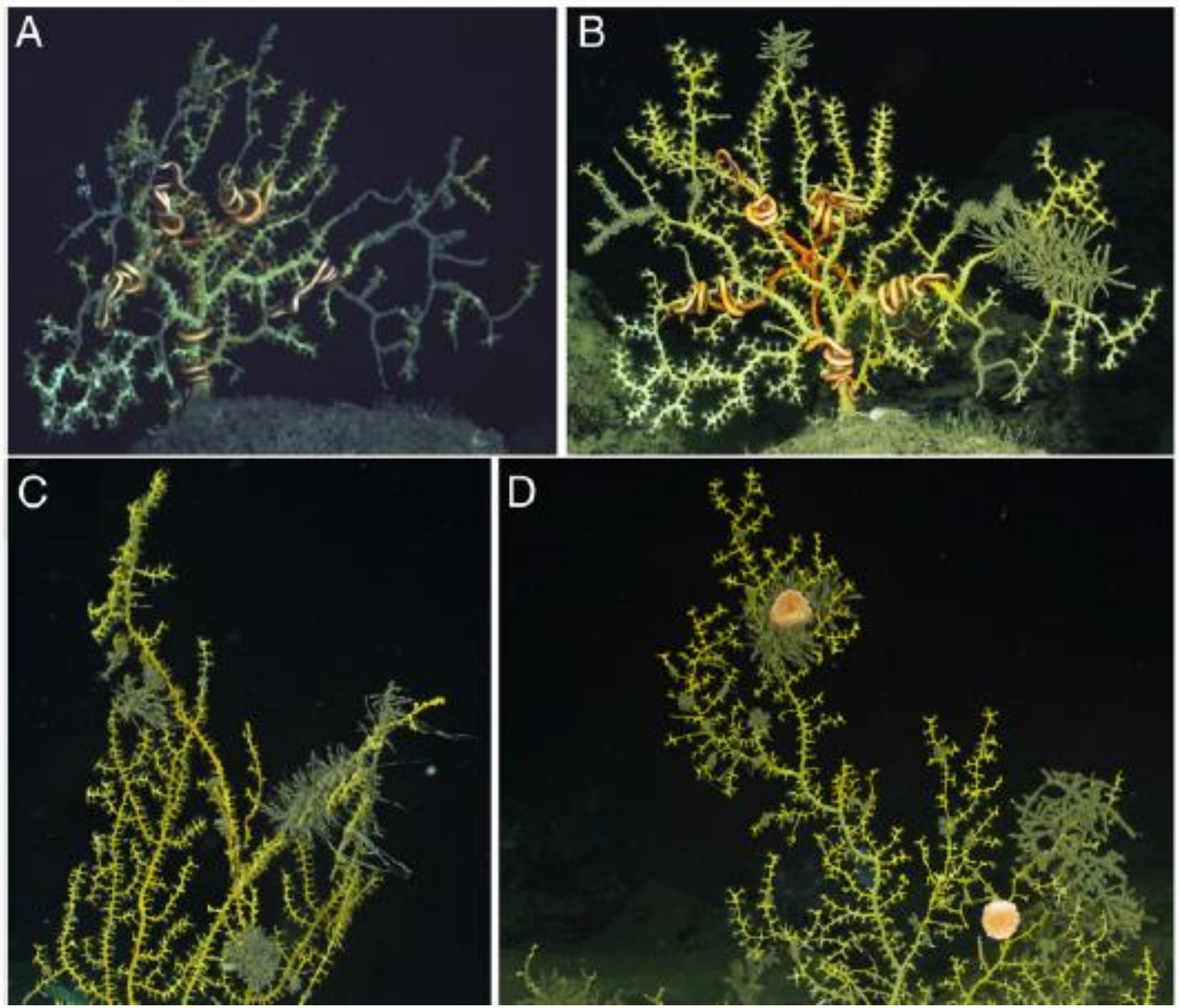
What about unmeasureable effects?

Fecundity?

Feeding?

Growth?

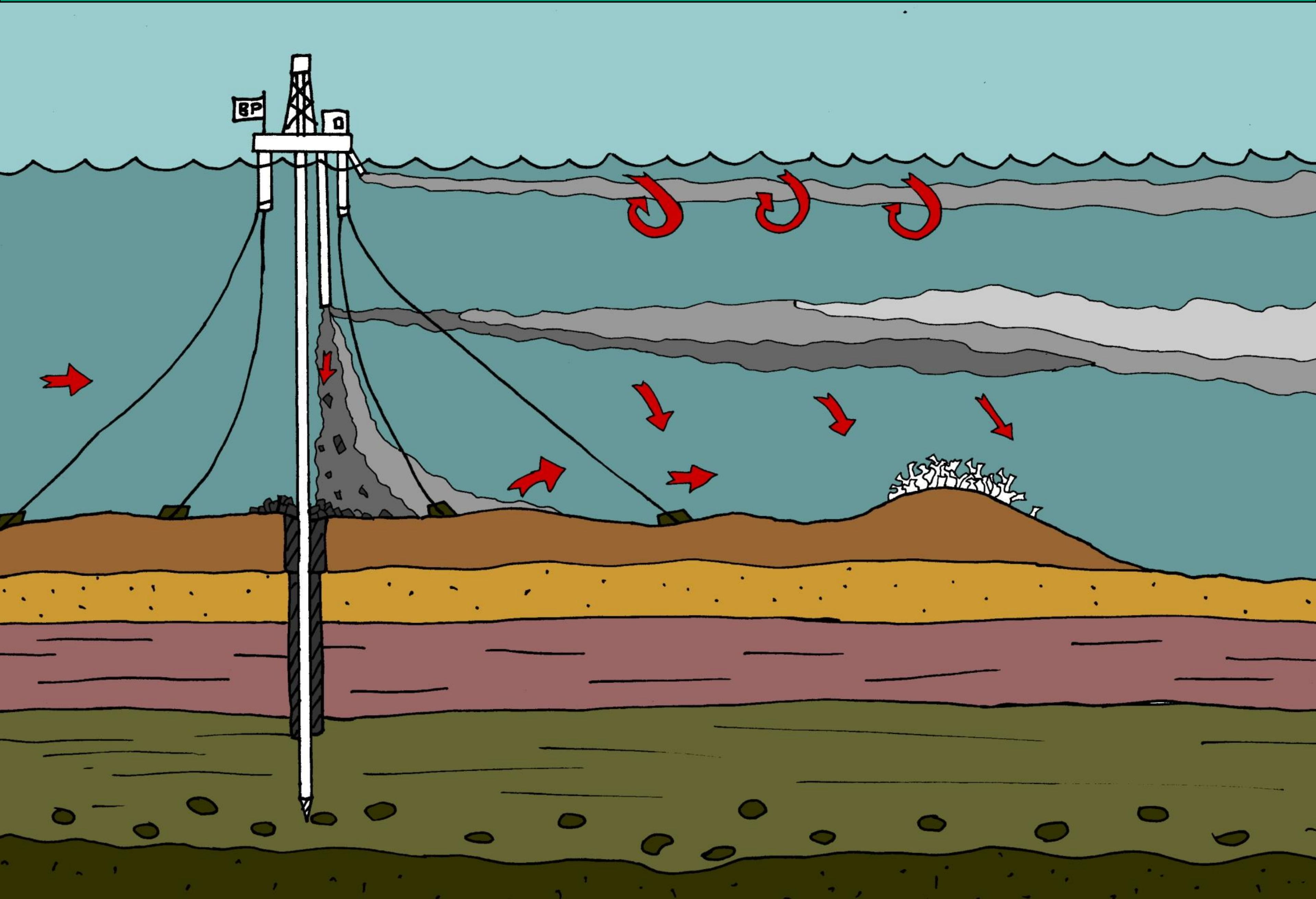
Important or not?



Impacted corals from Deepwater Horizon oil…..And flocculants.

Fisher et al., 2014.

Procedural threats posed by drilling



Elevated particulate exposure

How might exposure to particles impact on seafloor organisms?

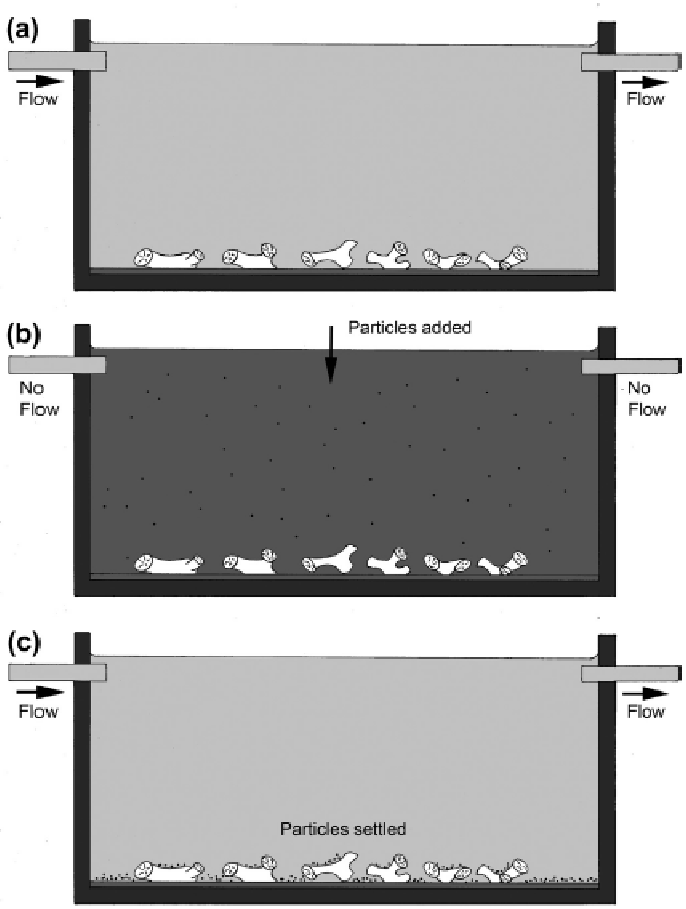
Elevated particulate exposure

How might exposure to particles impact on seafloor organisms?

- Clogging feeding?
- Damaging skin?
- Removing substrate?
- Bioaccumulating within food web?
- Triggering energy intensive behaviour in fauna?
- Smothering?
- Does duration of exposure matter?
- DO WE KNOW ALL THE ANSWERS TO THESE QUESTIONS!?!?!?!
- Etc etc etc etc

Elevated particulate exposure - smothering

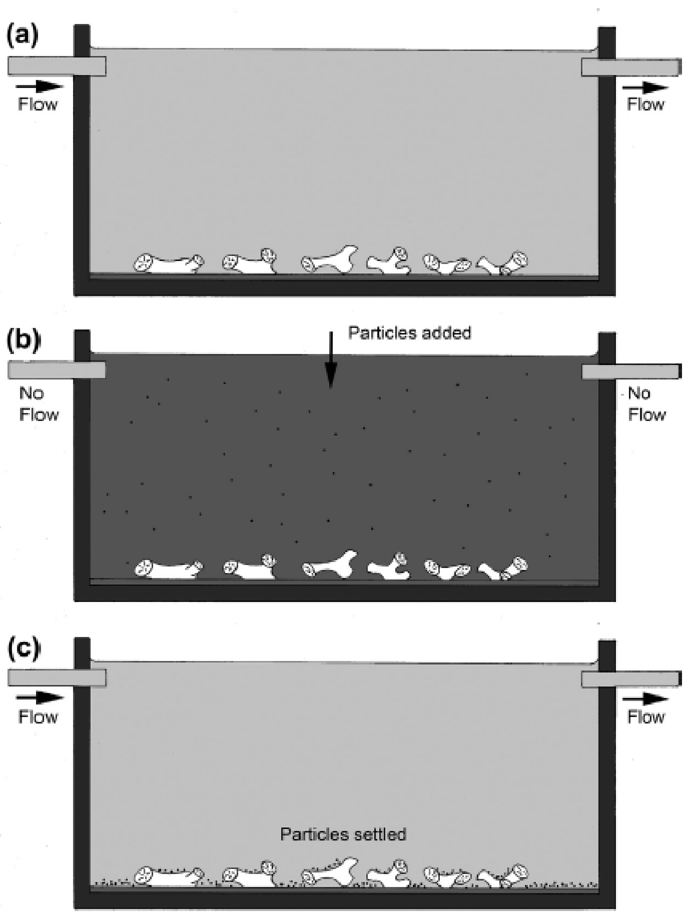
Fine material settling onto a sessile animal can suffocate it if the layer cannot be removed and inhibits oxygen exchange.



Reference: Allers et al. (2013)

Elevated particulate exposure - smothering

Fine material settling onto a sessile animal can suffocate it if the layer cannot be removed and inhibits oxygen exchange.



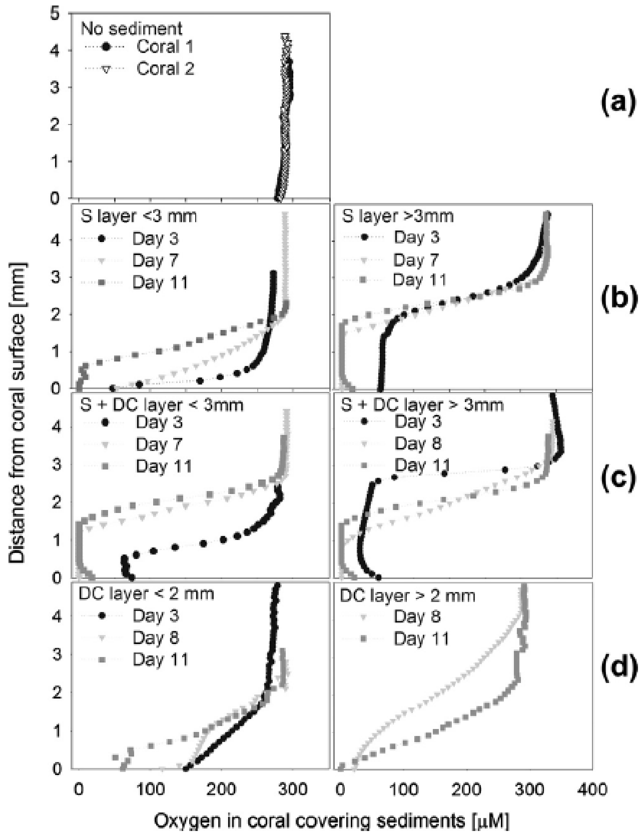
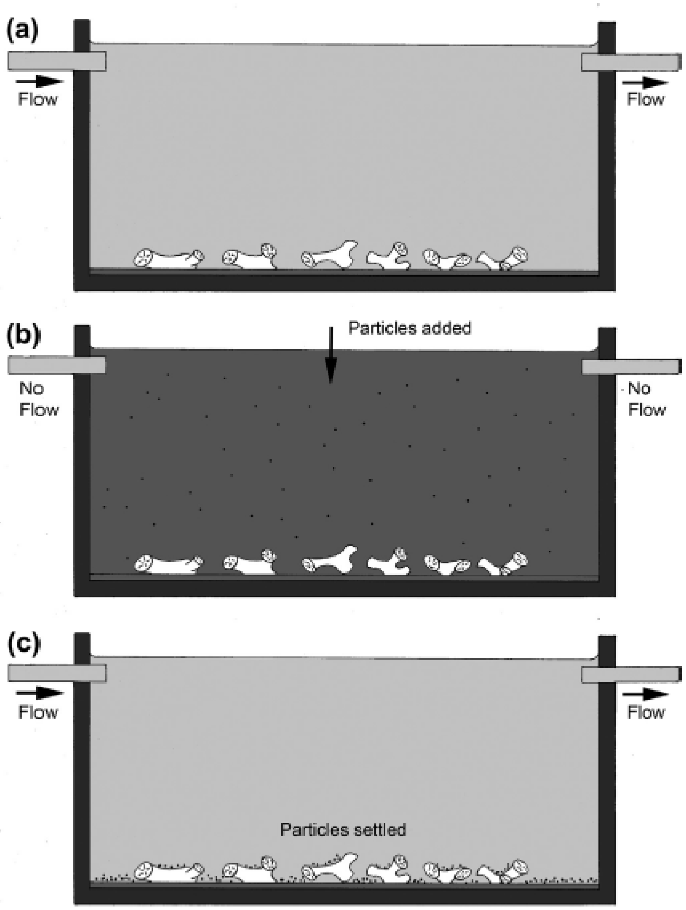


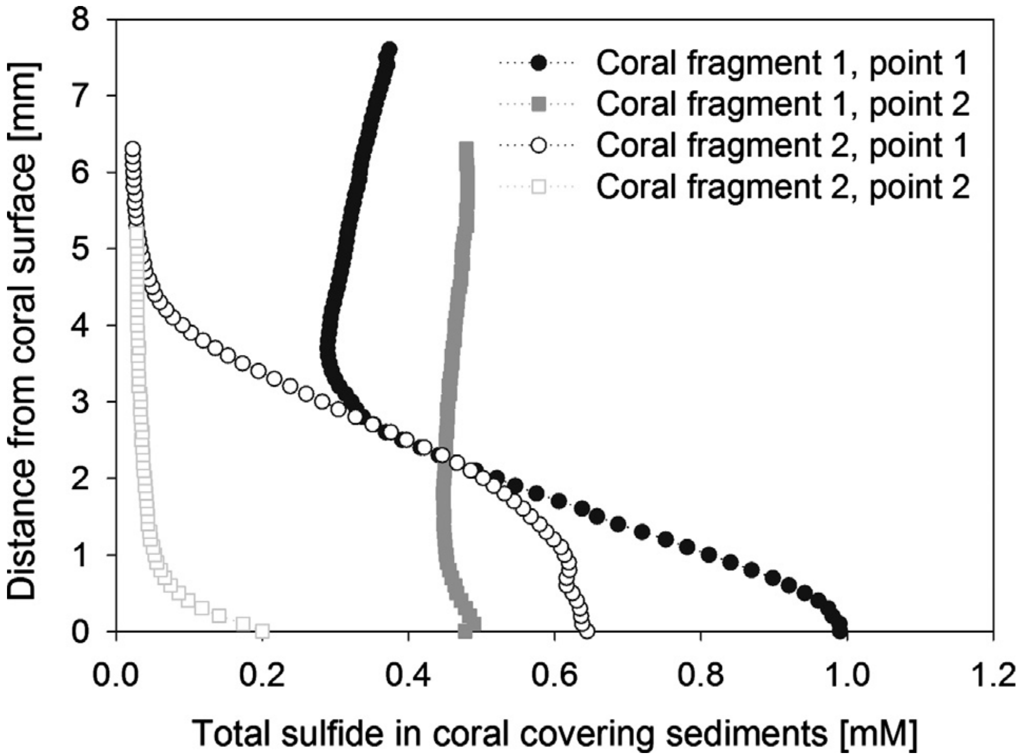
Fig. 3. Representative oxygen profiles from the coral surface (0 mm) through the sediment horizon (7× nominal sediment cover) and towards the free water: (a) Control without sediment, (b) thin and thick layers of reef sediment (S), (c) thin and thick layers of mixed reef sediment and drill cuttings (S + DC), (d) thin and thick layers of drill cuttings (DC).

Reference: Allers et al. (2013)

Elevated particulate exposure - smothering

In tropical corals, such coverage can lead to sulfide reduction damage to the coral – this is unlikely the case in CWC environments… temperatures slow down the process.





Sulfide can build in concentration (after 11 days above) but damage minimal

Elevated particulate exposure - smothering

…repeated settling pulses may slowly, slowly kill coenosarc tissue…

…limitations of a particular experimental design must always be considered, especially when making recommendations to regulators etc.

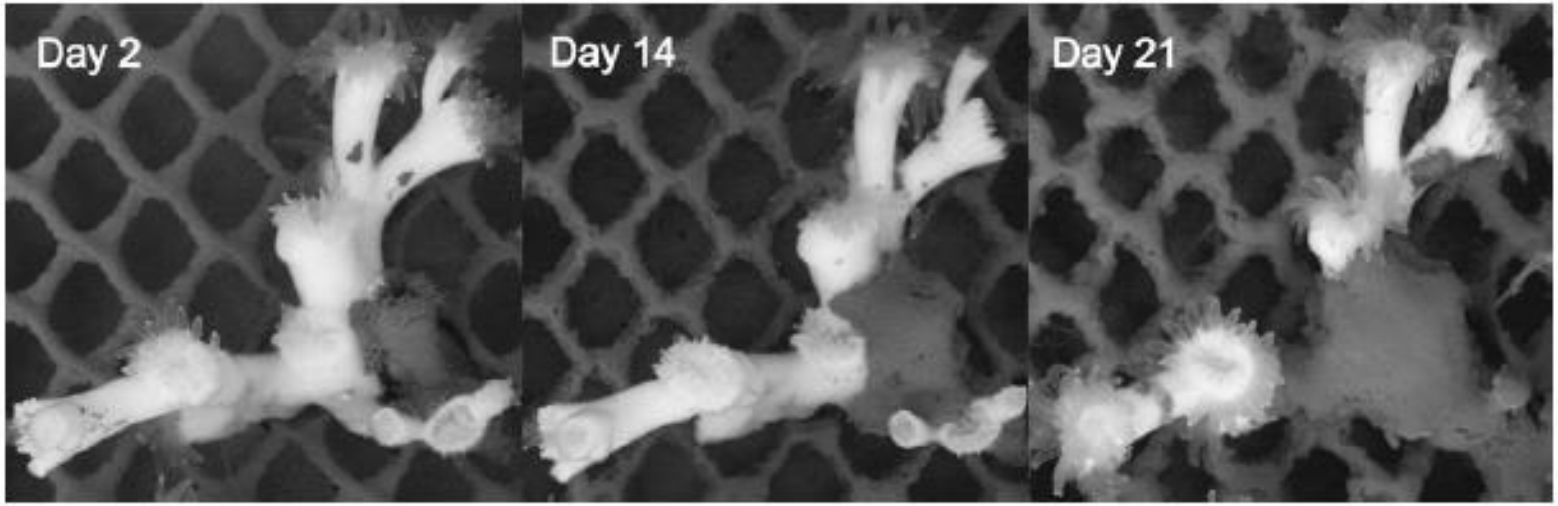


Fig. 6. Example of polyps and tissue smothered by accumulated drill cuttings. The total sediment load was 19 mm added in portions during 3 weeks.

Reference: Larsson and Purser (2011)

Elevated particulate exposure – Algal aggregation

…much in the water column is sticky…

- phytoplankton detritus
- faecal pellets
- plastics
- naturally settling inorganic material

..these can and do all aggregate, and can do so with waste drilling material

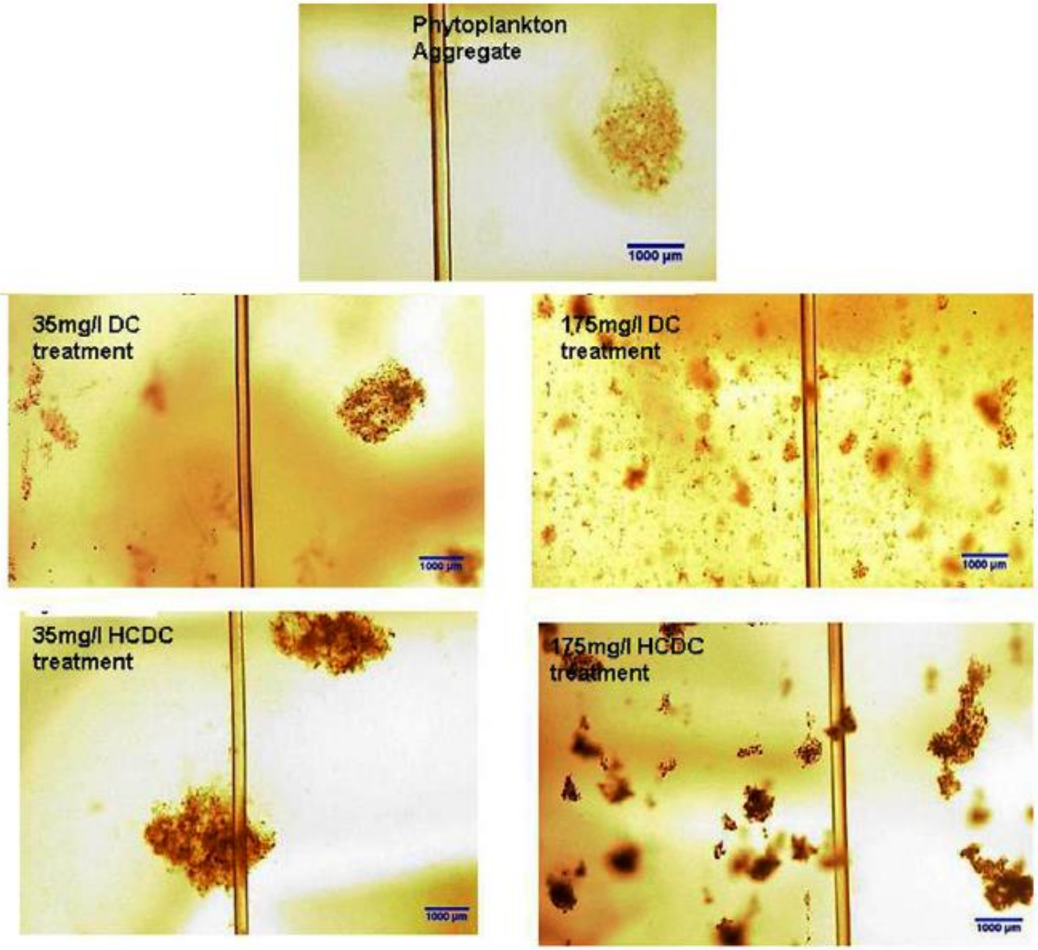


Fig. 6. Photographs of a selection of phytodetrital aggregates and aggregates exposed to drill cuttings of various concentrations and compositions.

Reference: Pabortsava et al.(2011)

Elevated particulate exposure – Algal aggregation

..settling behaviour of these aggregates differs from naturally occuring agreggates – may also vary throughout the year.

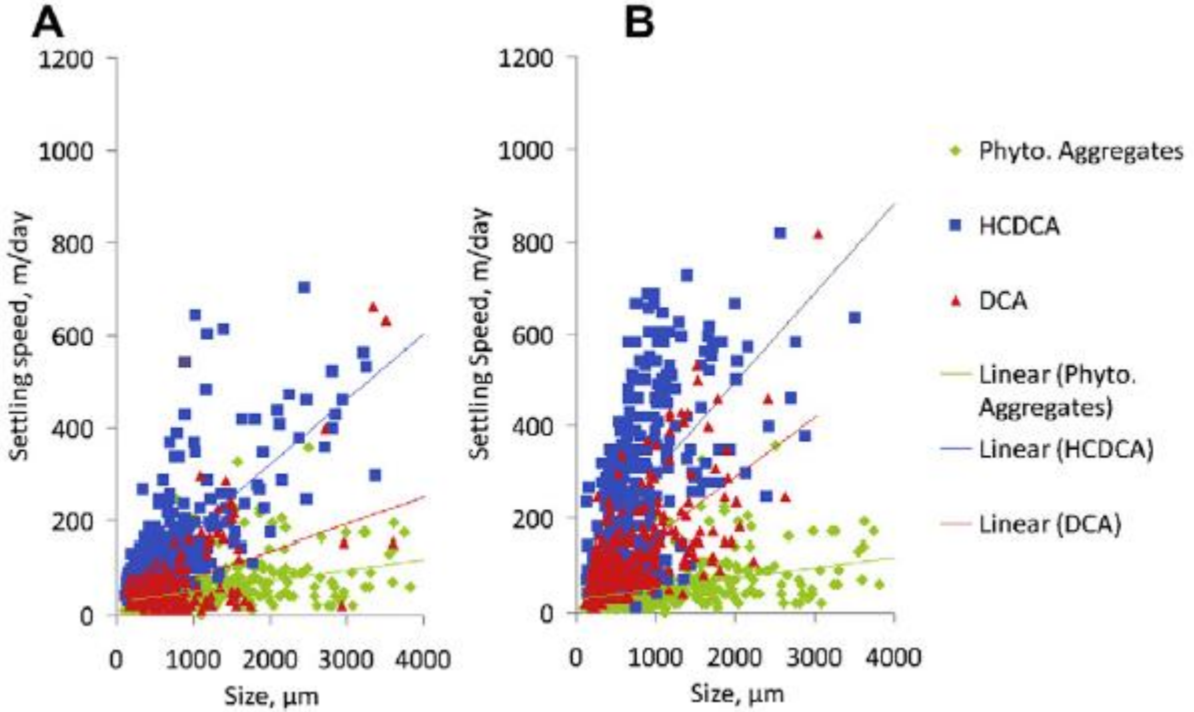


Fig. 5. Settling rates of phytoplankton aggregates, and aggregates exposed to DC and HCDC cuttings: (A) 35 mg l^{-1} treatment; (B) 175 mg l^{-1} treatment.

Elevated particulate exposure – long term exposures

Marine Pollution Bulletin 70 (2013) 176–188

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Tolerance to long-term exposure of suspended benthic sediments and drill cuttings in the cold-water coral *Lophelia pertusa*

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Keywords:
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Sediment exposure
Drill cuttings
Growth
Larval survival

ABSTRACT

The cold-water coral *Lophelia pertusa* was exposed to suspended particles (<63 µm) for 12 weeks. Skeletal growth was significantly lower under exposure concentrations of ~25 mg l^{-1} than ~5 mg l^{-1} and there was a trend of lower growth rates when exposed to water-based drill cuttings than to natural benthic sediment. Polyp extension was less in corals exposed to higher material concentrations, which provides a possible explanation for observed skeletal growth differences between particle concentrations. Particle exposure had no significant impact on respiration or proportions of tissue and fatty acids in corals. The volume of additional cleaning mucus released by exposed corals was low and release did not significantly affect coral energy expenditure. Our results indicate that *L. pertusa* polyps can deal comparatively well with enhanced particle deposition rates and suspended matter concentrations. However, a small pilot experiment indicated that coral larvae might be particularly vulnerable to high particle concentrations.

Reference: Larsson et al. (2013)

Elevated particulate exposure – long term exposures

Constant exposure for weeks in flowthrough aquaria (required by fussy CWC corals) can be problematic – but is a requirement to simulate realistic continued exposure to concentrations reflecting realistic drilling events.

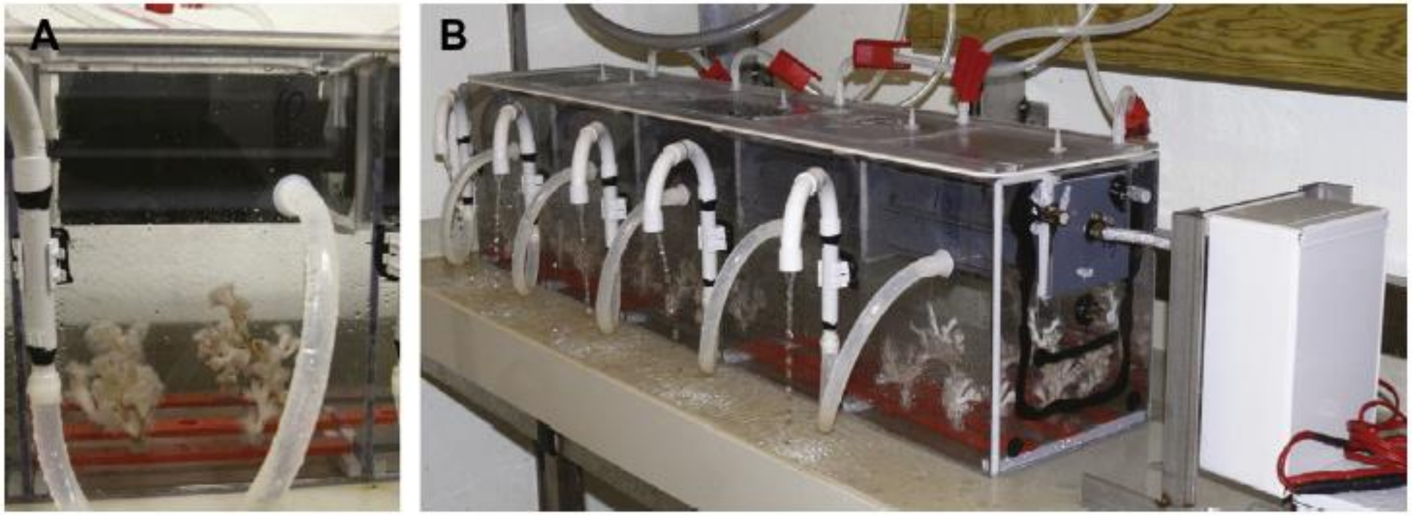

Fig. 1. Aquaria used for exposure of *Lophelia pertusa* to suspended sediments and for respiration measurements. (A) Mounting of coral fragments in a single aquarium. (B) Whole set of aquaria with common motor and paddle wheel axis.

Elevated particulate exposure – long term exposures

Coral branch starting health very important when gauging effects… large number of replicates is required for accuracy and confidence in results.

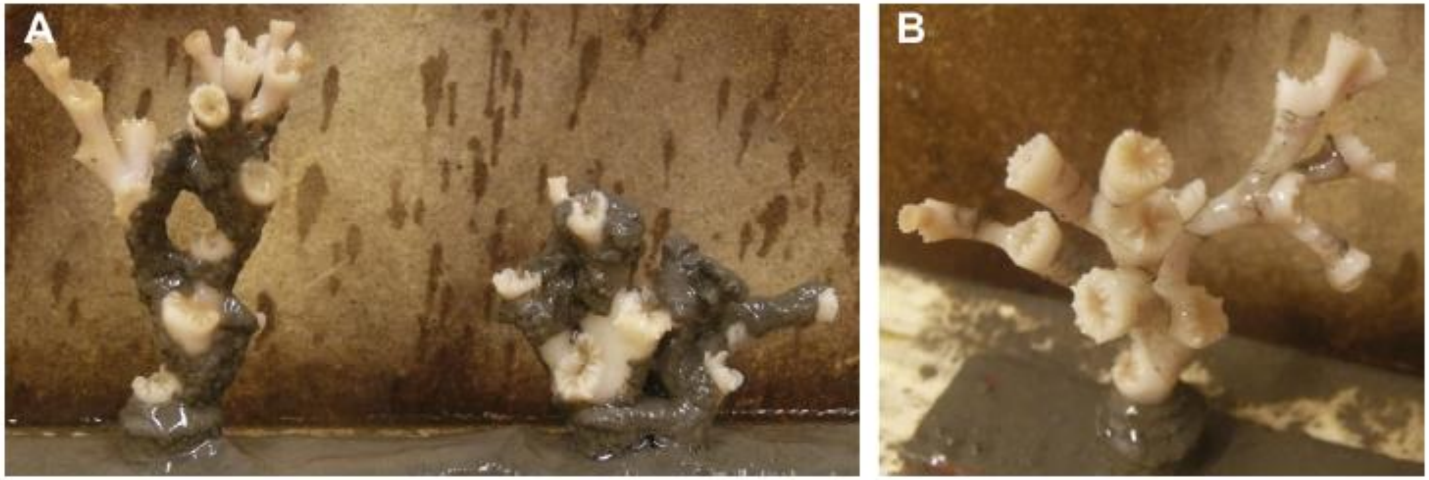

Fig. 2. *Lophelia pertusa* fragments after 8 weeks of continuous exposure to suspended sediments without cleaning. Sediments were continuously added during 12 weeks except for a few days 4 weeks into the experimental period when fragments were cleaned for respiration measurements. (A) Example of rather high coverage of drill cuttings resulting from the high exposure treatment. (B) Example of a coral fragment with high coverage of coenosarc where the drill cuttings are removed with aid of mucus.

Reference: Larsson et al. (2013)

Elevated particulate exposure – long term exposures

Experimental results may be…

…unexpected…

…annoying…

…difficult to explain…

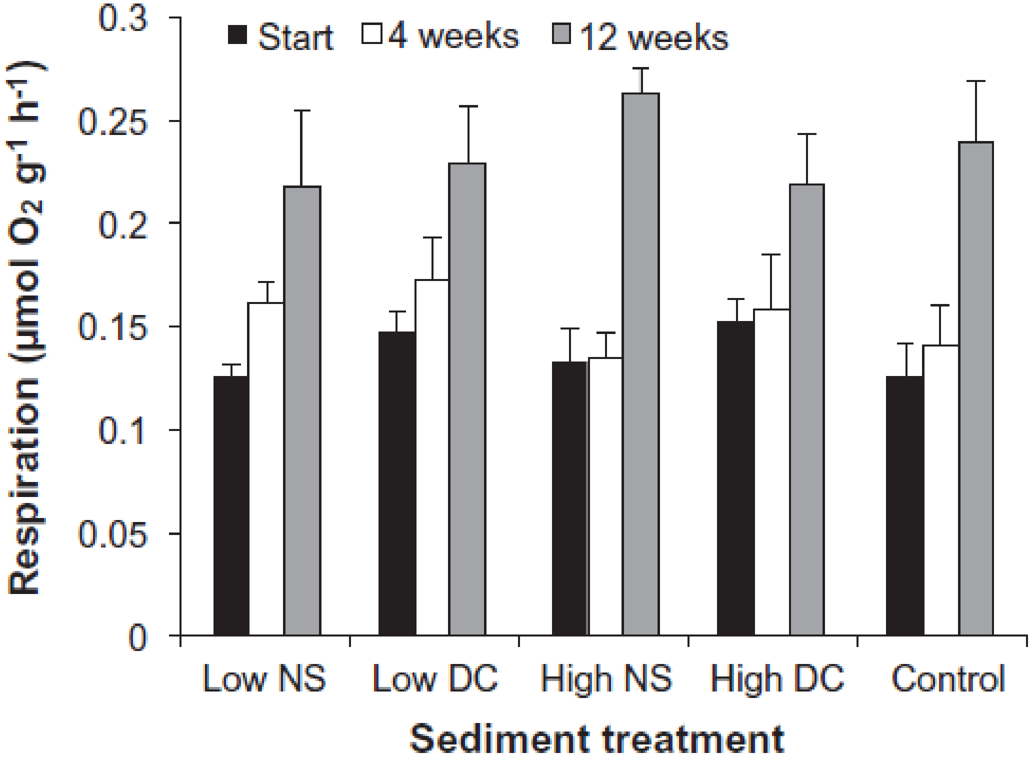

Fig. 3. Effect of sediment exposure on respiration in *Lophelia pertusa*. The respiration rate is normalised to the total dry weight of coral. Respiration was measured prior to experimental start, after 4 weeks of sediment exposure and after finalisation of the 12 weeks long experimental exposure. Bars are average ± SE, $n = 3$ replicate aquaria with six coral fragments in each. Result from the statistical analysis is presented in Table 3.

Reference: Larsson et al. (2013)

Elevated particulate exposure – long term exposures

Particule concentration does seem to have some sub-lethal effects on coral functioning when continued over 12 weeks.

Is this important?

A drilling event is 12 weeks on average…

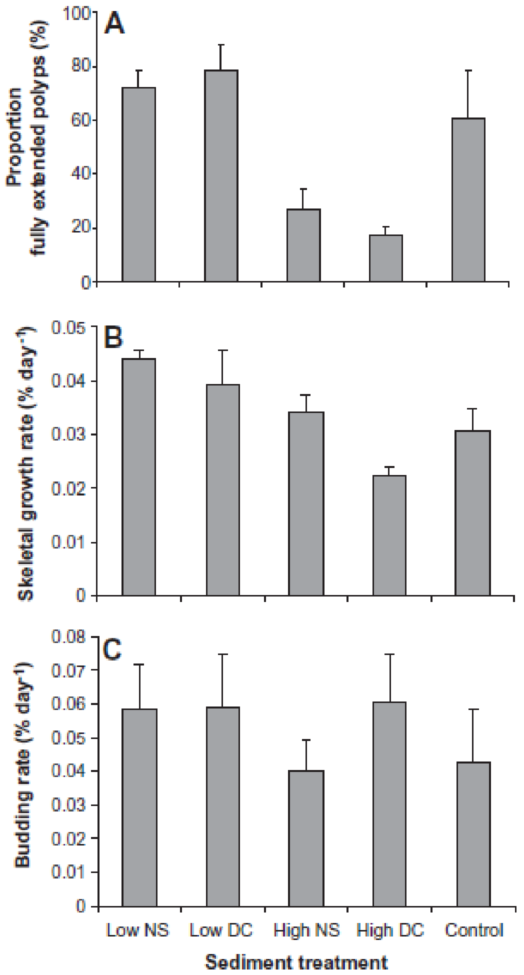

Fig. 4. (A) Effect of exposure to suspended sediment on polyp activity in *Lophelia pertusa*. The proportion of fully or close to fully extended polyps out of the total number of polyps is given. (B and C) Effects of 12 weeks exposure to suspended sediments on coral growth. (B) Skeletal growth rates as estimated by change in buoyant weight. (C) Rates of production of new polyps normalised to number of initial polyps. Bars are average ± SE, $n = 3$ replicate aquaria with six coral fragments in each. Diagrams show untransformed data and results of the statistical analyses for (A and B) are presented in Table 4.

Reference: Larsson et al. (2013)

Deep water drilling and the regulatory framework(s)

A mishmash of national regulations.

In European waters, the PRECAUTIONARY APPROACH is dominant, coupled with an ease in acquiring exploration and exploitation licenses if the company is shown to be developing the science and applied science related to ist activities.

STATOIL and TOTAL are examples of companies benefiting from this approach.

Monitoring during drilling campaigns

After two decades of reasonably deep drilling, there are the first attempts to monitor drilling during operations. Here pictured an image of corals exposed to drill cuttings pulses during Morvin drilling in 2009.

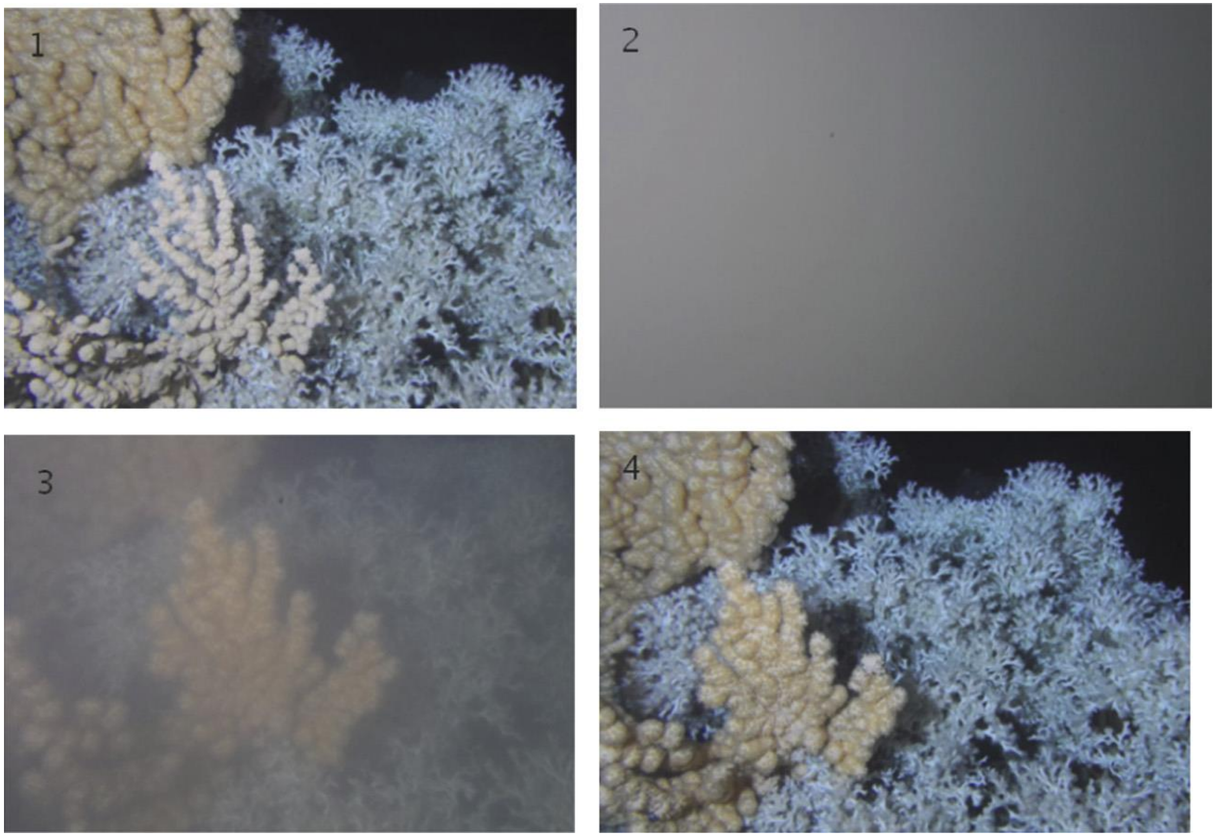

Fig. 7. Photo sequence at the monitored coral reef before, during and after an episode of particle exposure (turbid water). The sequence representing a 3 h interval. Apparently the polyps are active during the whole period.

Godo et al., (2014)

Monitoring during drilling campaigns

I was given unique access to everything STATOIL did in the way of monitoring and modelling a drilling campaign…

PLOS | ONE

RESEARCH ARTICLE

A Time Series Study of *Lophelia pertusa* and Reef Megafauna Responses to Drill Cuttings Exposure on the Norwegian Margin

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OPEN ACCESS

Citation: Purser A (2015) A Time Series Study of *Lophelia pertusa* and Reef Megafauna Responses to Drill Cuttings Exposure on the Norwegian Margin. PLoS ONE 10(7): e0134076. doi:10.1371/journal.pone.0134076

Editor: Stephen J. Johnson, University of Kansas, UNITED STATES

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Published: July 28, 2015

Abstract

As hotspots of local biodiversity in the deep sea, preservation of cold-water coral reef communities is of great importance. In European waters the most extensive reefs are found at depths of 300 – 500 m on the continental margin. In Norwegian waters many of these reefs are located in areas of interest for oil and gas exploration and production. In this study drilling was carried out in the Morvin drill field in proximity to a number of small *Lophelia pertusa* coral reefs (closest reefs 100 m upstream and 350 m downstream of point of waste drill material release). In a novel monitoring study, ROV video surveys of 9 reefs were conducted prior, during, immediately after and >1 year after drilling operations. Behavior of coral polyps inhabiting reefs exposed to differing concentrations of drill cuttings and drilling fluids (waste drilling material) were compared. Levels of expected exposure to these waste materials were determined for each reef by modelling drill cutting transport following release, using accurate in-situ hydrodynamic data collected during the drilling period and drill cutting discharge data as parameters of a dispersal model. The presence / absence of associate reef species (*Acesta excavata*, *Paragorgia arborea* and *Primnoa resedaeformis*)

Purser (2015)

Monitoring during drilling campaigns

..allowing me to suffer for years on my most hellish manuscript to date!

- No clear monitoring plan.
- Poor environmental assessment
- before drilling.
- 5 different ships.
- 5 different ROV teams.
- Poor revisit protocol.
- Many, many different cameras…
- …Different zooms….
- ..RELABELLING SIGNS……..
  AAAAAAAAARRRRRRRRRRGGG!!!!!

Purser (2015)

Monitoring during drilling campaigns

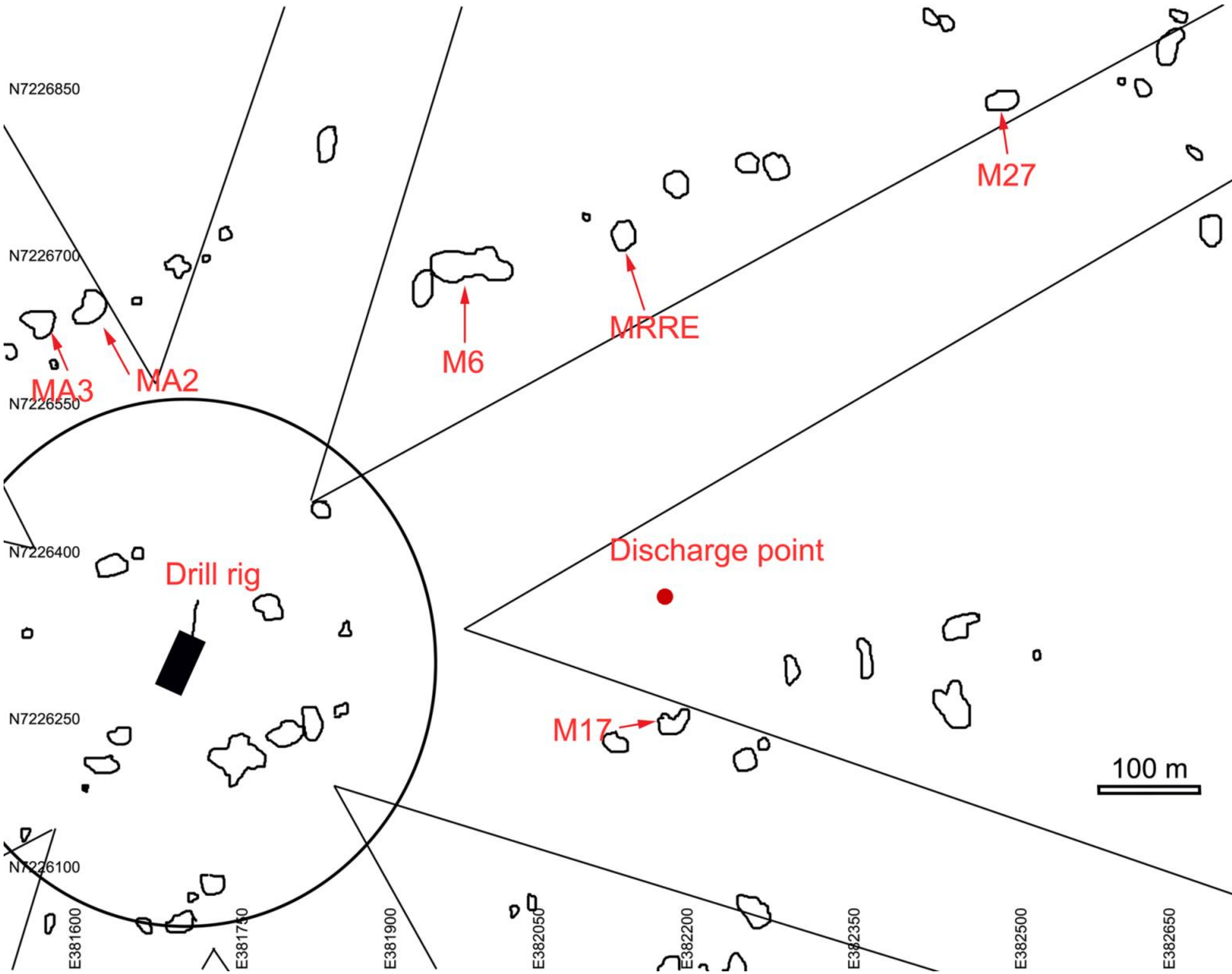
Different reefs.

Different orientations and distances from drill cutting release point.

Revisited and reimaged over time.

Flow meters, sediment traps, cameras in place, plus Remote Operated Vehicle.

…Nothing was ‚off the shelf‘ or operating well…

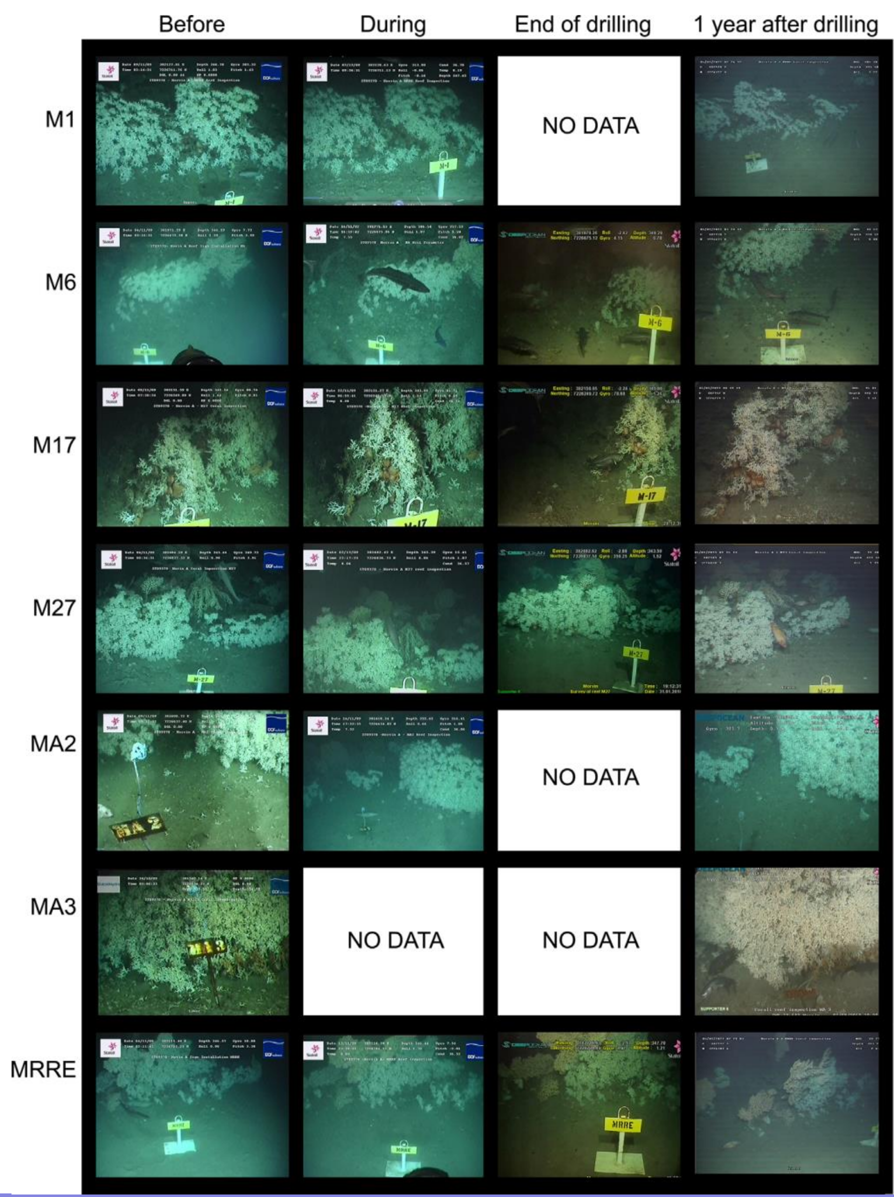


Monitoring during drilling campaigns

Reefs repeatedly visited an imaged. Some areas of reef reasonably revisited (here)… others much less representatively imaged.

Various things checked:

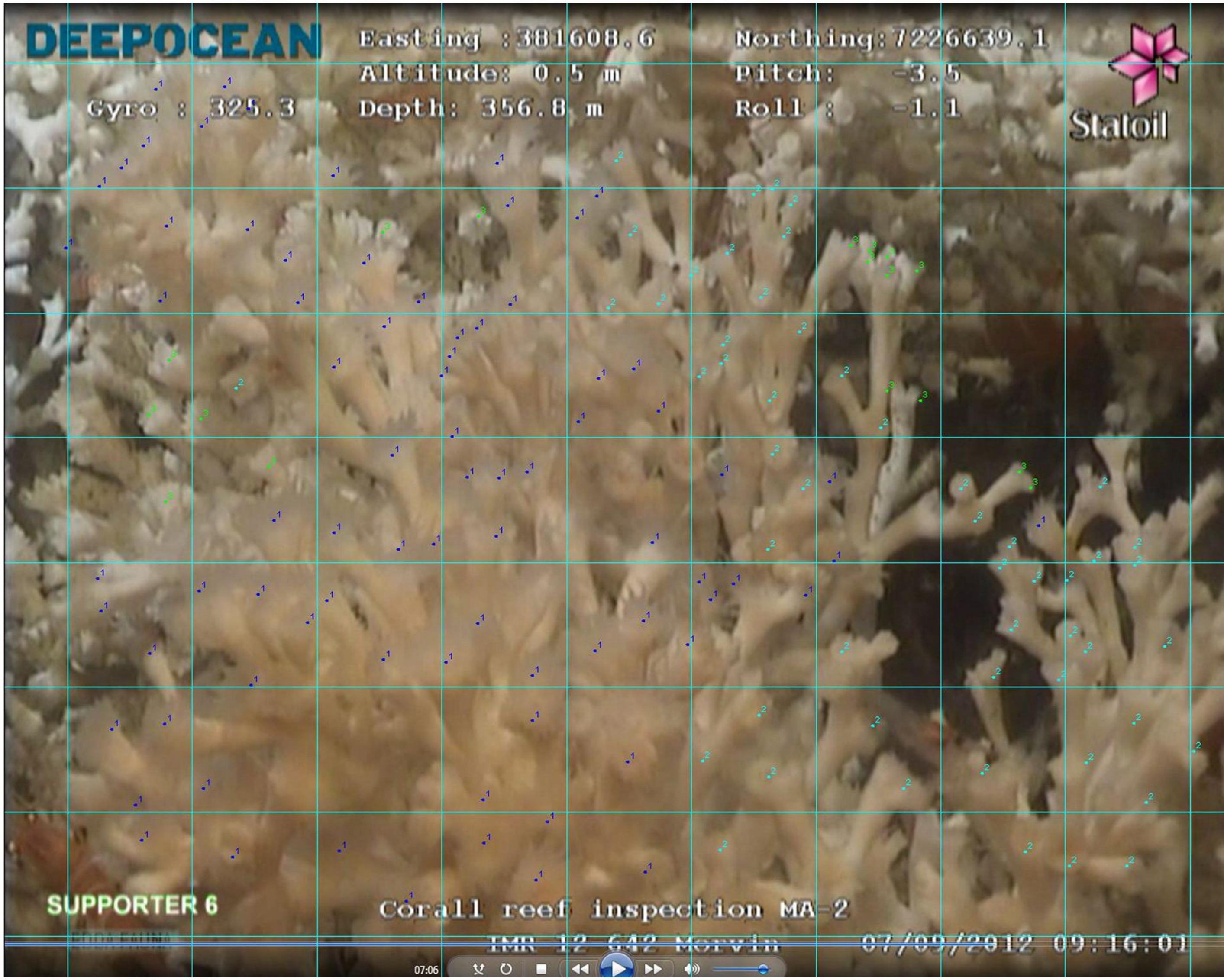
- Polyp activity.
- Presence/absence of new sediment
- Associate fauna.



Purser (2015)

Monitoring during drilling campaigns

Coral activity checked.



Monitoring during drilling campaigns

Coral activity checked.

EXTENDED

RETRACTED **VISIBLE**

Purser unpublished.

Monitoring during drilling campaigns

Predictive modelling can give an indication of likely transport of material, based on hydrodynamic knowledge of material and ecosystem.

For this campaign, was fairly accurate (though pre-study wholly incorrect)… realtime flow metering helped here.

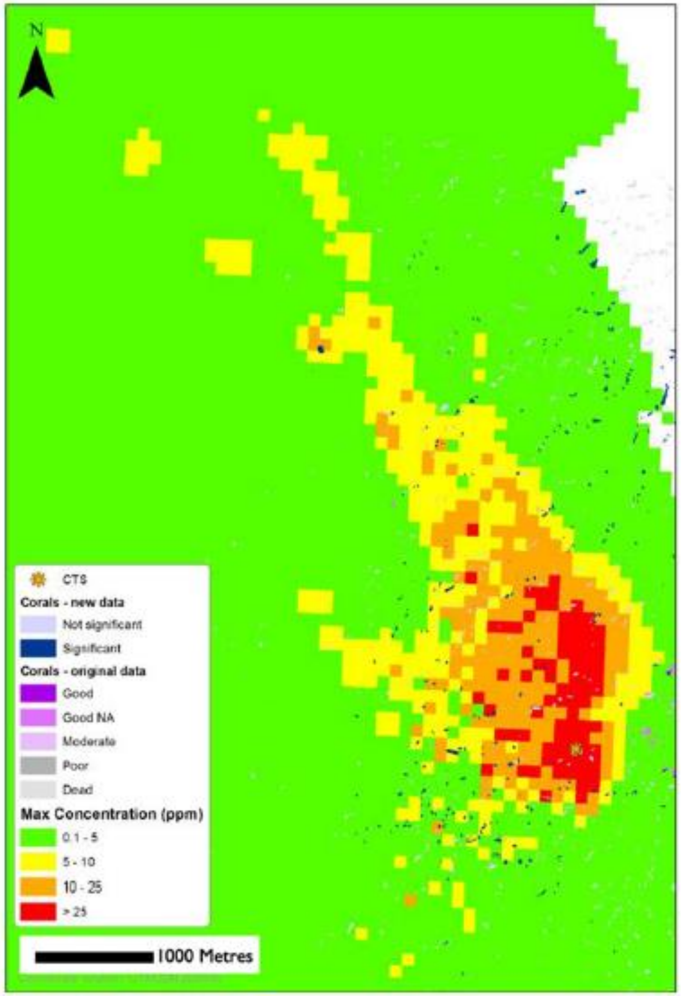
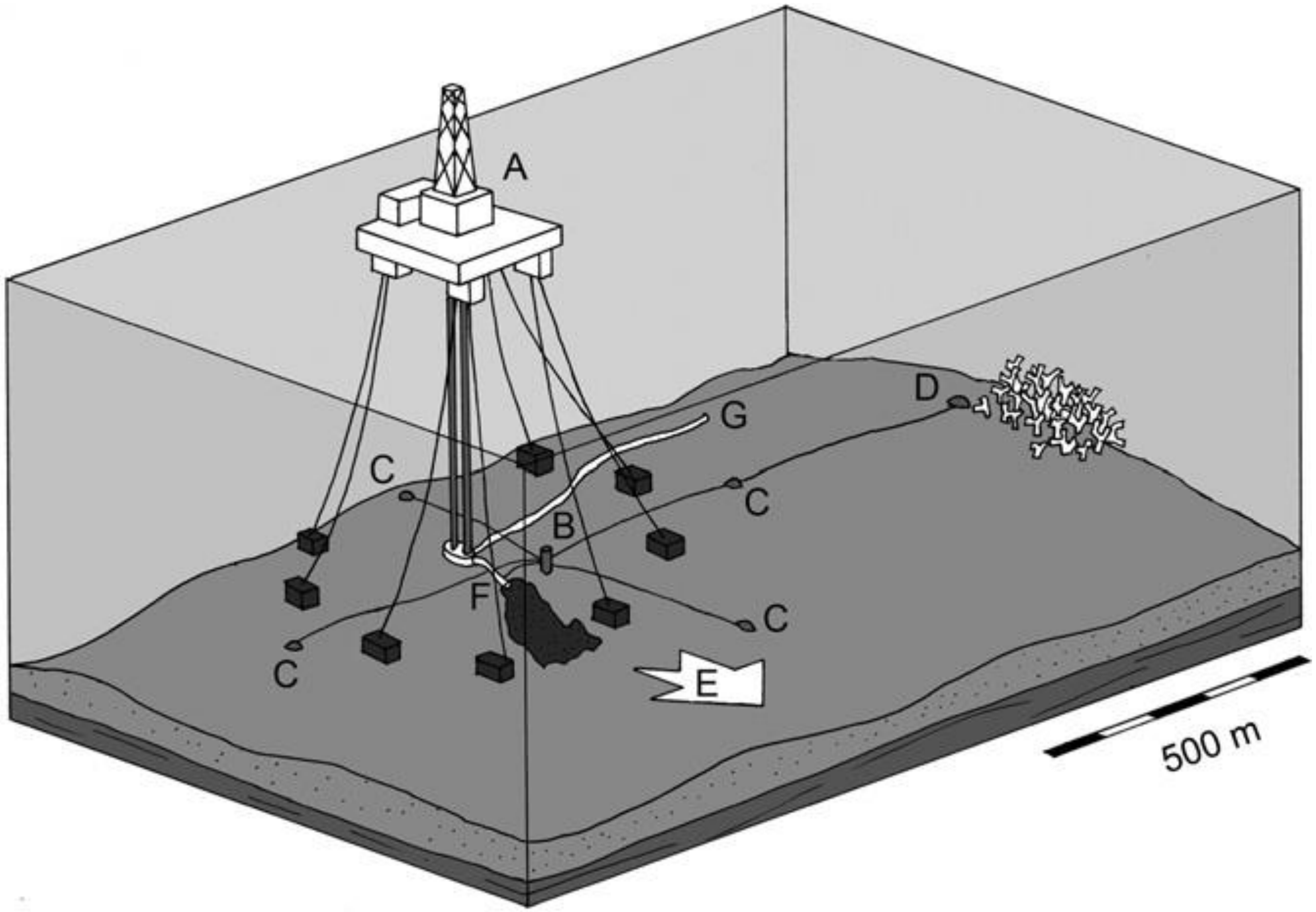


Fig 6. Modelled suspended particle concentrations within the vicinity of drilling during the monitoring period. 'CTS' represents the point at which drill cuttings were released to the ocean. The 'Corals-New data' are coral reefs visited by ROV within the year prior to drilling, whereas 'Corals-original data' are previously reported reefs. 'Max concentration' is the maximum concentrations of suspended drill cutting particles modelled to be transported to each grid square at some point during the drilling period.

Mitigation of drilling threats

To be attractive, ideally cost effective for the company: LOW COST, HIGH SUCCESS, GOOD PUBLICITY.



Can we say drilling of minor threat to Cold Water Coral?

What do you think?

Can we say drilling of minor threat to Cold Water Coral?

We can say from our experimental and observational work that lethal impacts from regular activities are low on ADULT corals… Larvae and settling juveniles are something else again…

ALSO!! What about less obvious and pretty associate fauna?

Table 5
Effect of fine fraction drill cutting exposure on number of surviving *Lophelia pertusa* planulae between exposure day one and five. The two control treatments, i.e. the normal seawater control and the possibly contaminated control from water used to wash the drill cuttings, were pooled to a common control.

	Pooled controls	5 mg l^{-1}	25 mg l^{-1}
Survived	11	8	3
Died	0	1	6

The future of drilling and drill monitoring

Proposals in viewpoint papers highlight the need for repeatable, representative drilling and drill monitoring techniques.

..there is progress, but not unified by:

- Drill company
- National regulations
- Extraction type

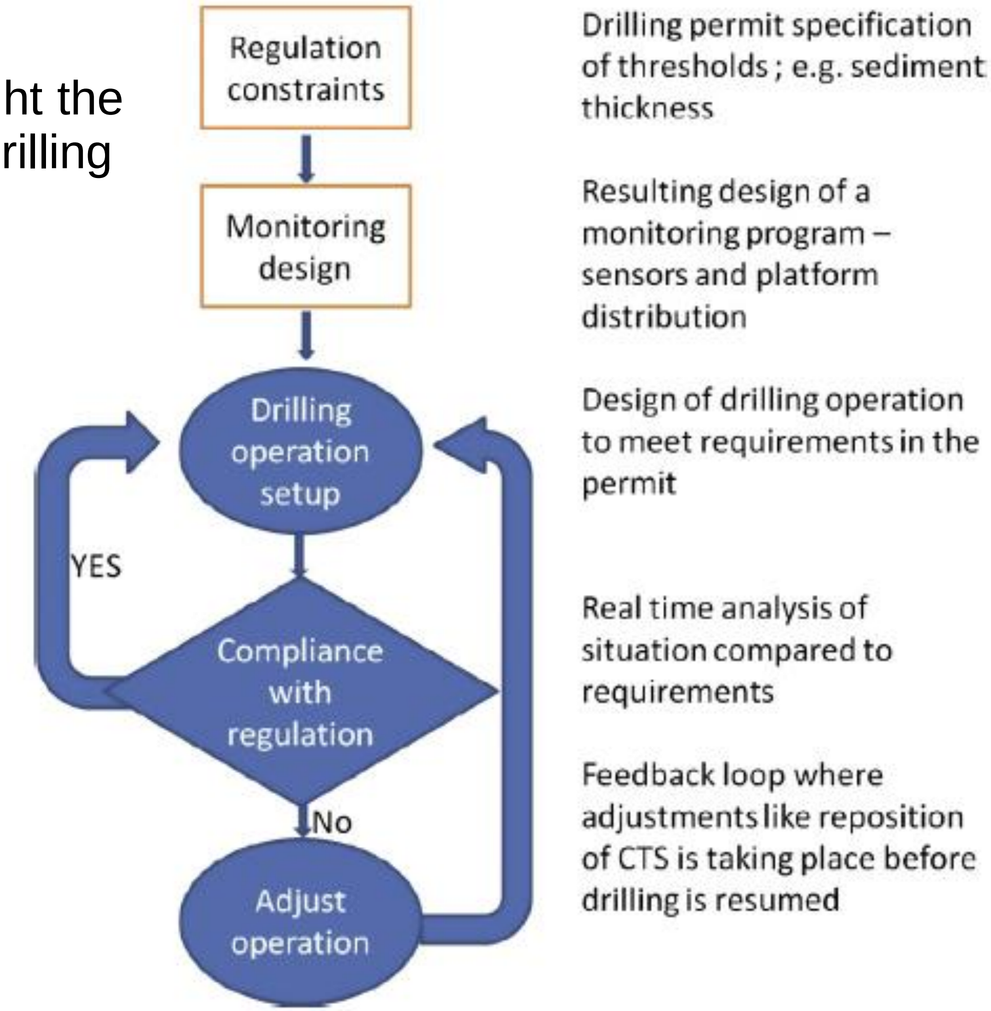


Fig. 10. Schematic illustration of the basic setup and flow of information and actions in a real-time monitoring case with feedback.

Deep sea Nodule extraction

IMAGE: Wikipedia

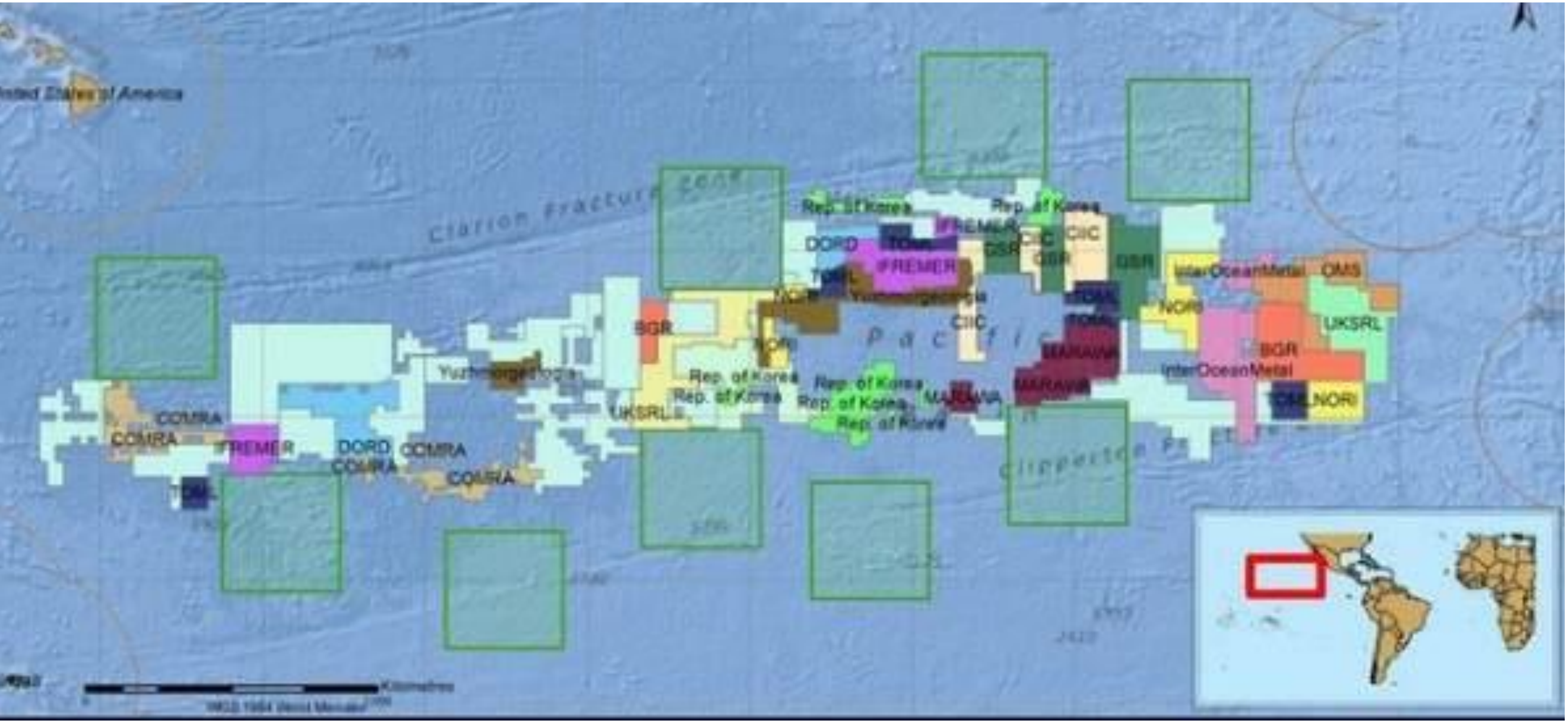
What are deep sea nodules?

A mic of high-tech metals.

94% of land sources are managed by China.

Increasing use is increasing the chance of deep sea exploitation.

Where are deep sea nodules?



Also in the Atlantic, South Pacific, Indian Ocean

How will nodule extraction occur?

…Uncertain. Massive sulfide removal macines look like this… nodule machines less certain…

IMAGE: Wikipedia

How do nodule fields look?

Vary in nodule size (a few cm to 30cm diameter) and density (scattered to almost total coverage).

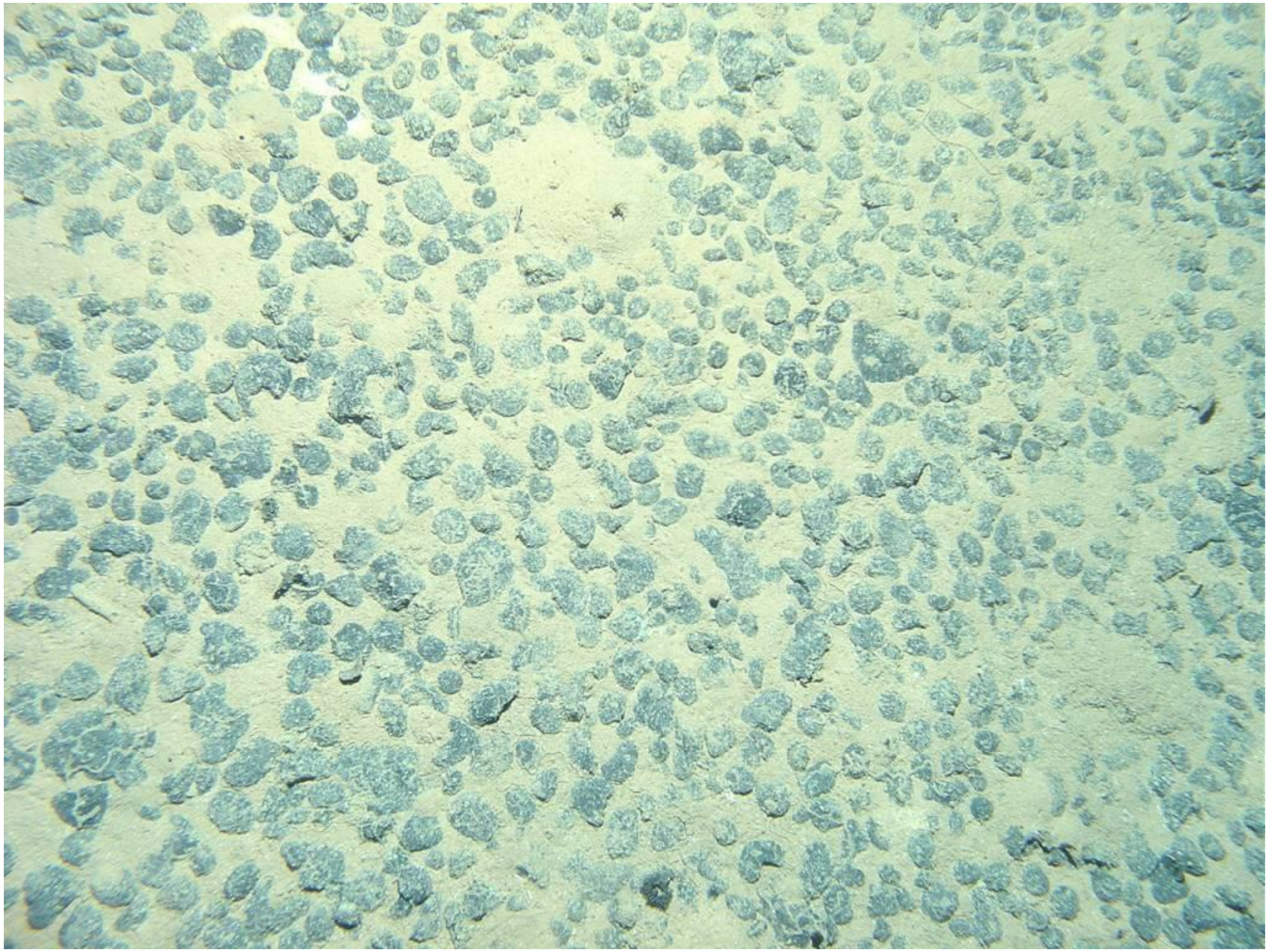


IMAGE: Wikipedia

What are the direct physical threats of nodule extraction?

Any ideas what these might be?   How big an area is affected?

What are the direct physical threats of nodule extraction?

Seafloor modification. Habitat loss (hard ground). Local smothering.

Extreme threats posed by drilling

Less clear than with drilling… no major blow outs possible.

What are the secondary threats posed?

Any ideas?   Magnitudes?

What are the secondary threats posed?

Various:

- Chemical exposure?   Metals?
- Particles.
- Seafloor modification (sediment coverage).
- Later resuspension.
- Impacts on natural aggregation.
- Long duration habitat heterogeniety loss.

Reviewed in: Purser & Thomsen (2013

Procedural threats posed by nodule mining

Seafloor stripped in a fashion similar to opencast mining on land.

IMAGE: Wikipedia

Elevated particulate exposure

How might exposure to particles impact on seafloor organisms?

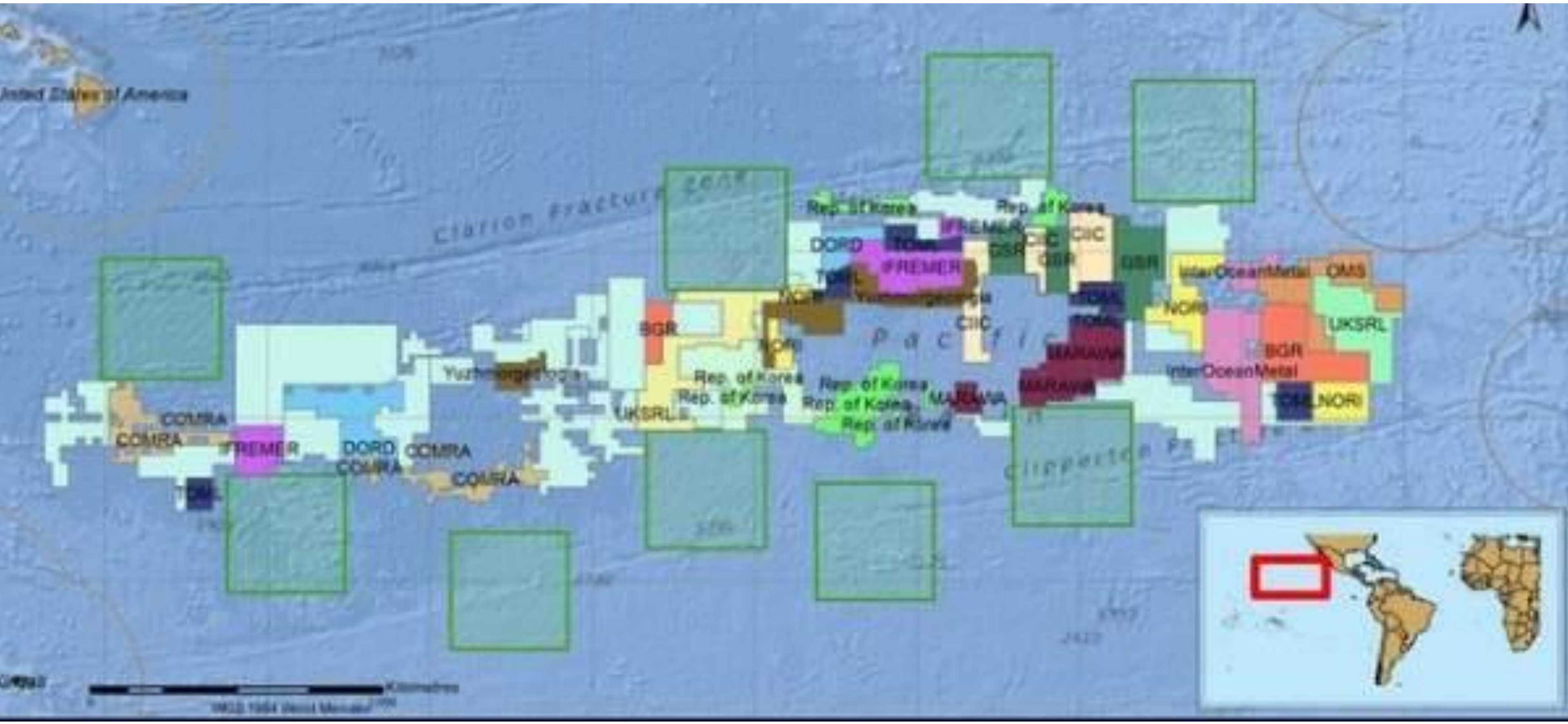
Elevated particulate exposure

How might exposure to particles impact on seafloor organisms?

- Clogging feeding?
- Damaging skin?
- Removing substrate?
- Bioaccumulating within food web?
- Triggering energy intensive behaviour in fauna?
- Smothering?
- Does duration of exposure matter?
- DO WE KNOW ALL THE ANSWERS TO THESE QUESTIONS!?!?!?!
- SIMILAR PROBLEM TO DEEP SEA MINING! NEW SPECIES TO CONSIDER!

Nodule extraction regulatory framework(s)

Areas of the seafloor have been put aside as reserves with no future drilling allowed (see map) – elsewhere, regulation is in the early stages of formulation.



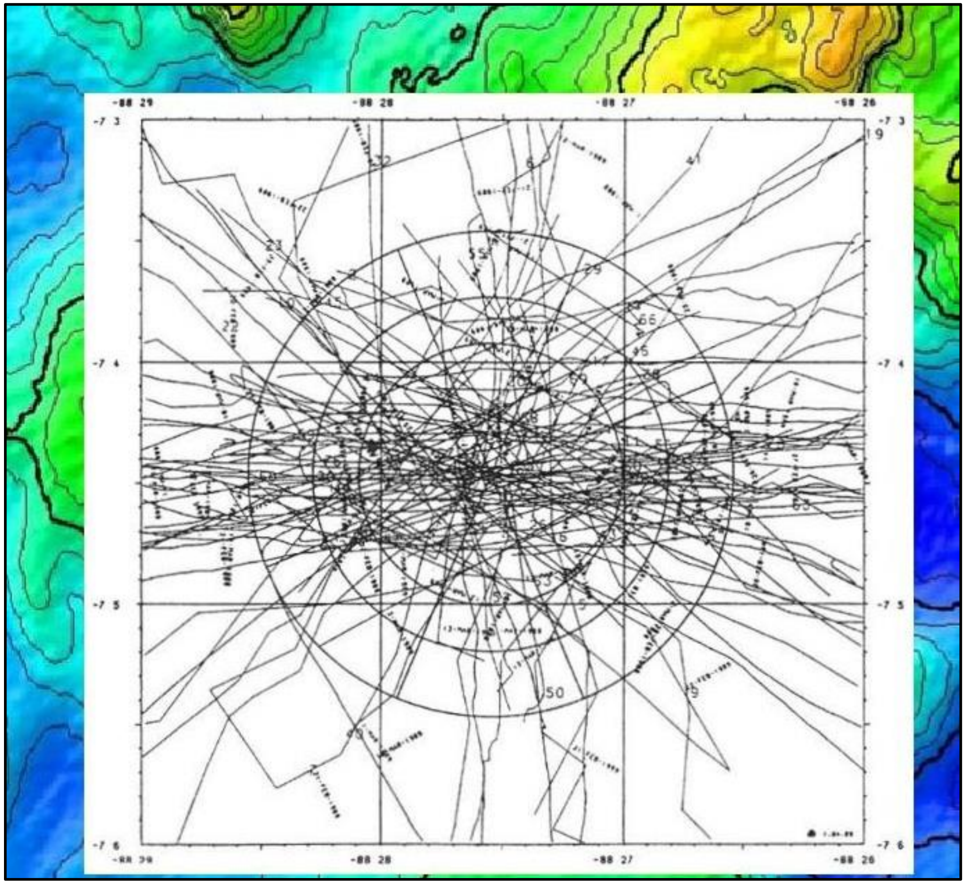
Deep sea Nodule extraction – What experiments to date?

In1989 A 8 km2 diameter area of Pacific seafloor was subjected to artificial dodule removal.

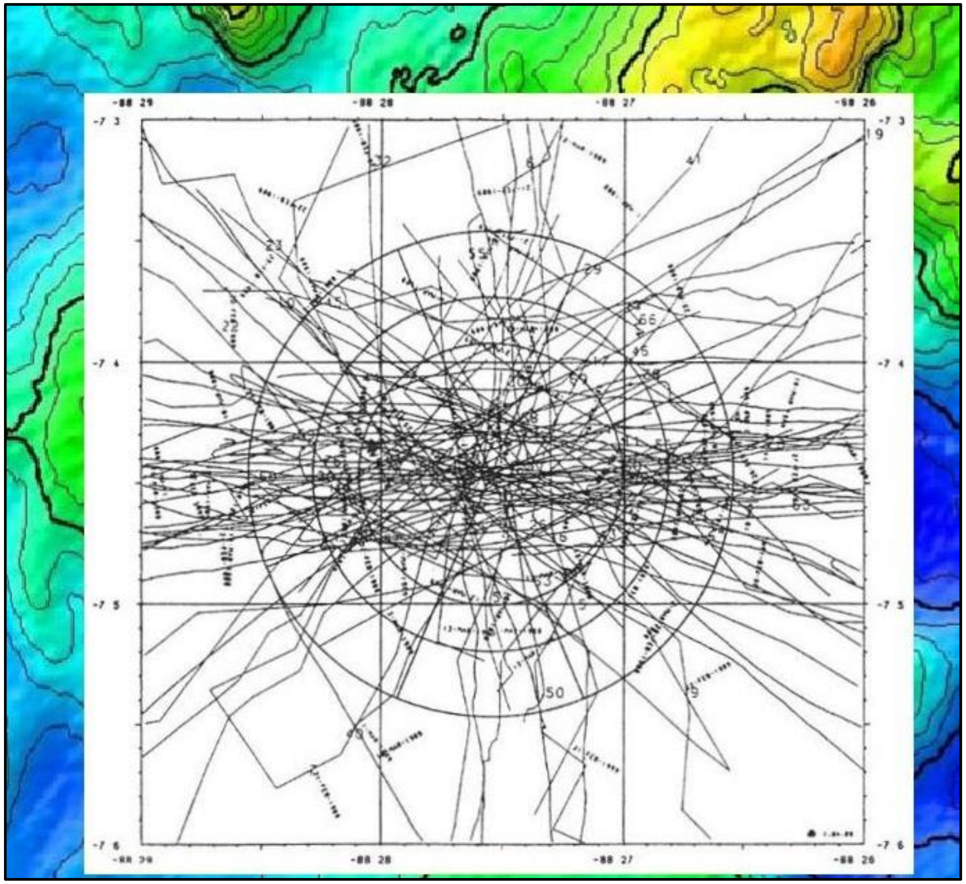
Repeated visits over 9 years showed impacts on key taxa.

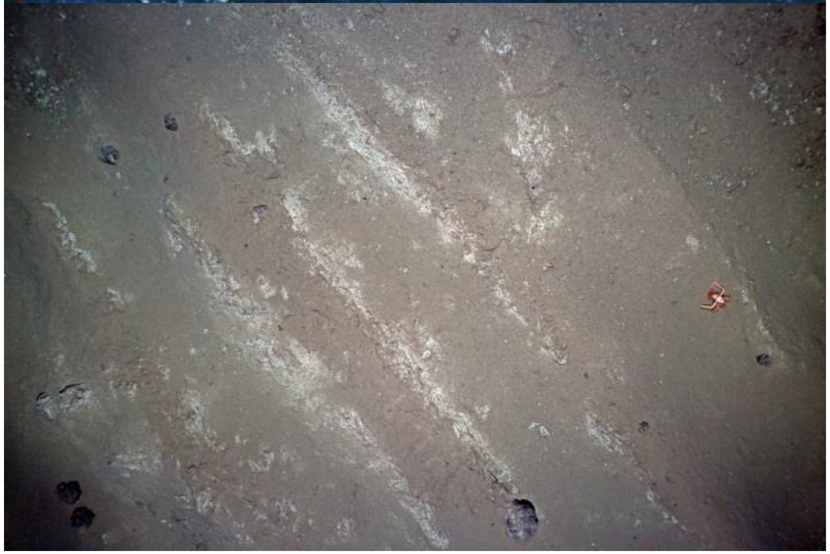
THIS YEAR the area was revisited. A paper on megafuana is underway:

Megafauna community structures at the DISCOL experimental disturbance site, 26 years after artificial disturbance.
First results from 'RV SONNE' cruise SO242-2 – August 2015

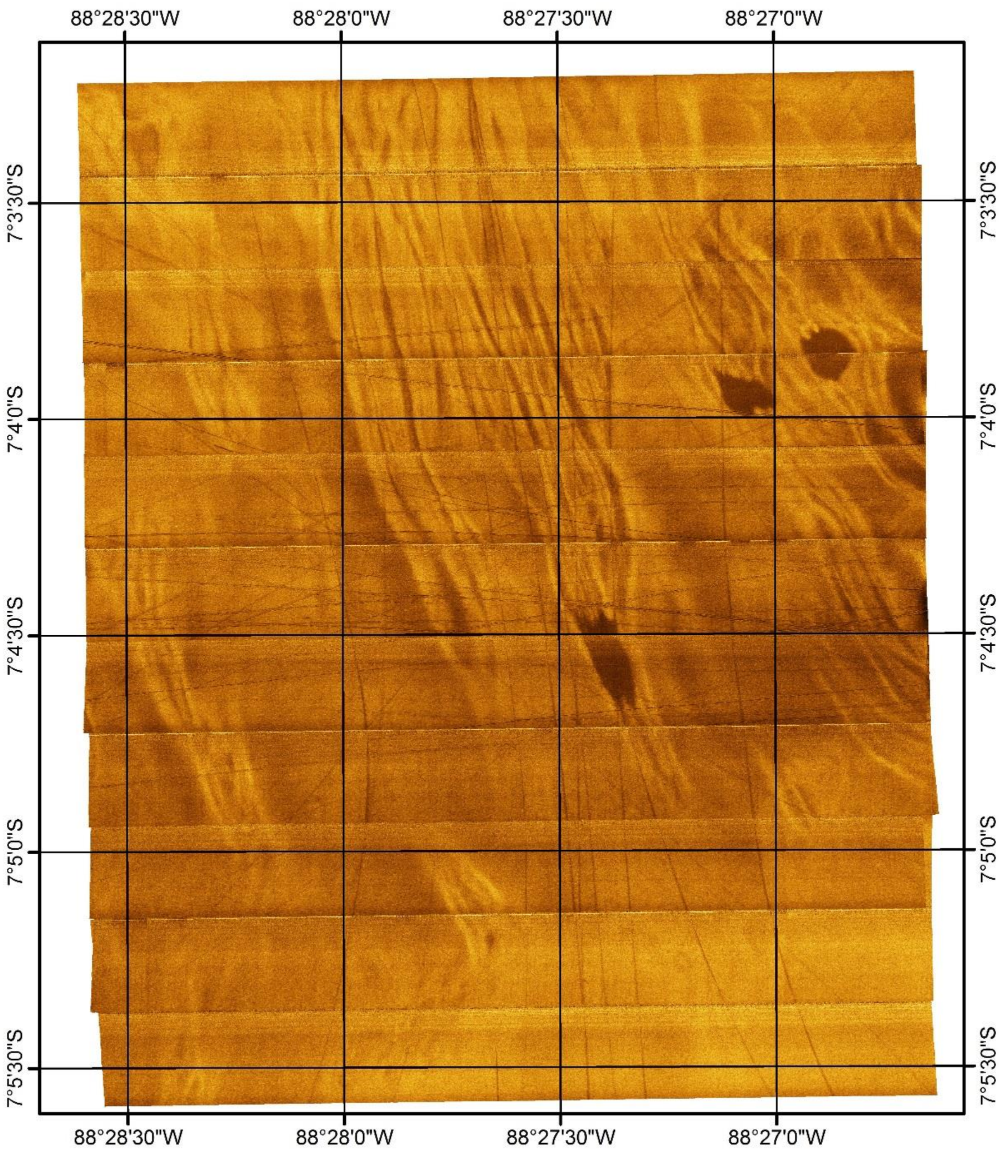


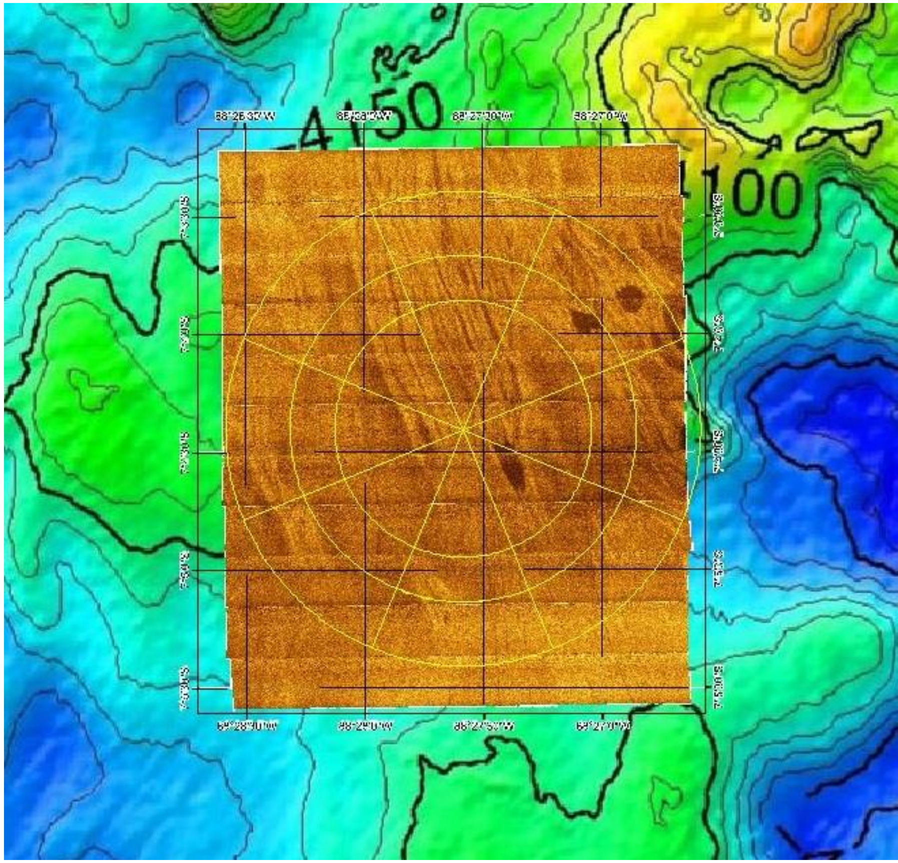
SO242-2 the second of two summer cruises to the DISCOL experimental area in 2015.





In 1989 an area of Pacific manganese nodules was artificially ploughed, in an effort to simulate the effects of deep sea mining.





SO242-2 utilised the fine sidescan maps provided by the SO242-1 team for localised study of areas of interest. HUGE THANKS TO JENS et al…!

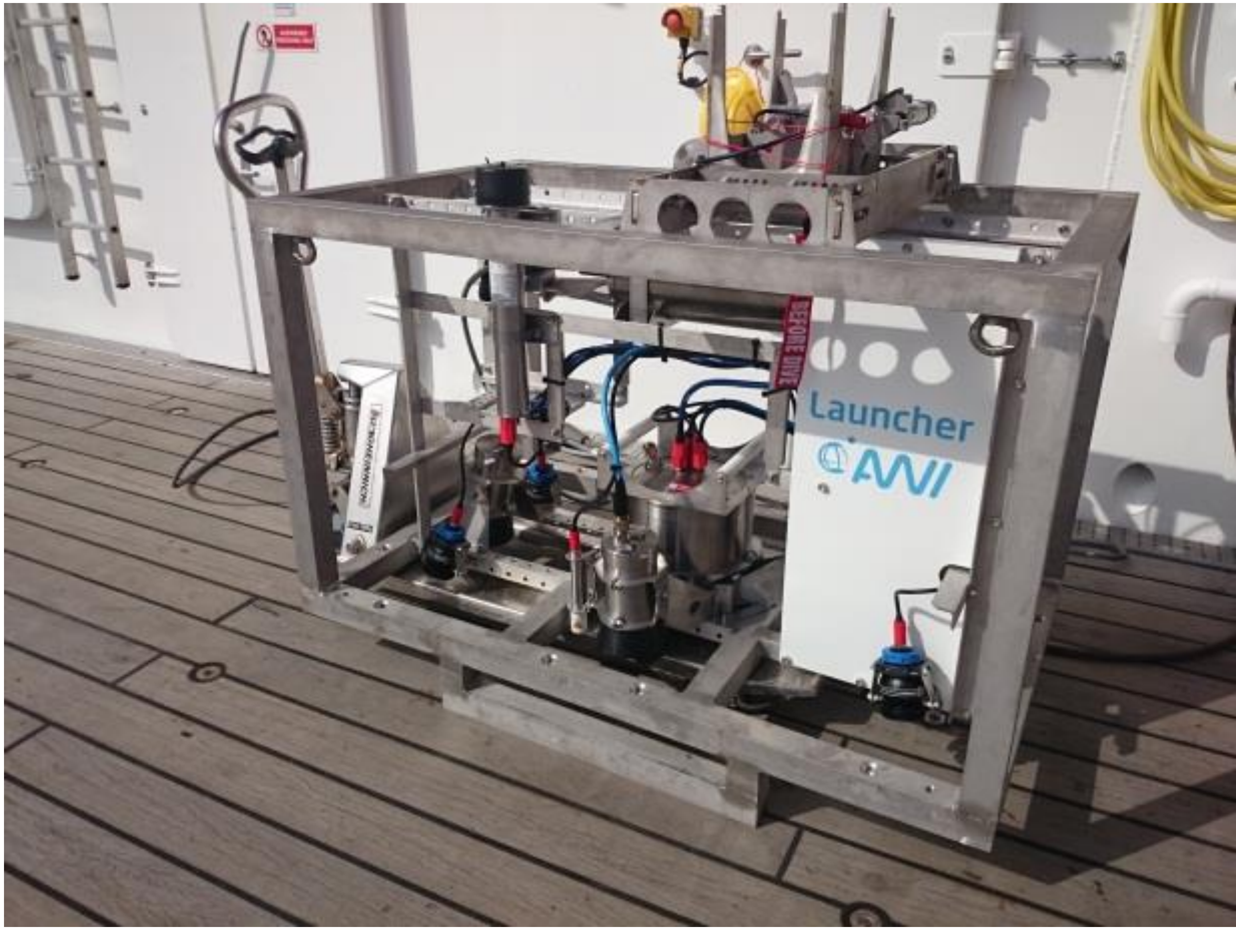
„Putting anything on the seafloor without a good map is bullsh*t" – Greniert, J. Nov 19th 2015.

For investigation of megafauna,
the AWI OFOS LAUNCHER was flown at a height of (usually) 1.5m to image seafloor with a 23 megapixel camera.

Regular ship speed 0.2-0.4 kts.

Video and still images collected (hotkey and timer)

Main aim of megafauna imaging: To collect image data to determine whether or not taxa reported in Bluhm, (2001), had returned to the ploughed regions or not…. 26 yrs after experimental ploughing.



OFOS survey design planned tc image roughly equal areas of habitats defined in previous DISCOL publications:

a) Nodule area within DEA (Undisturbed)

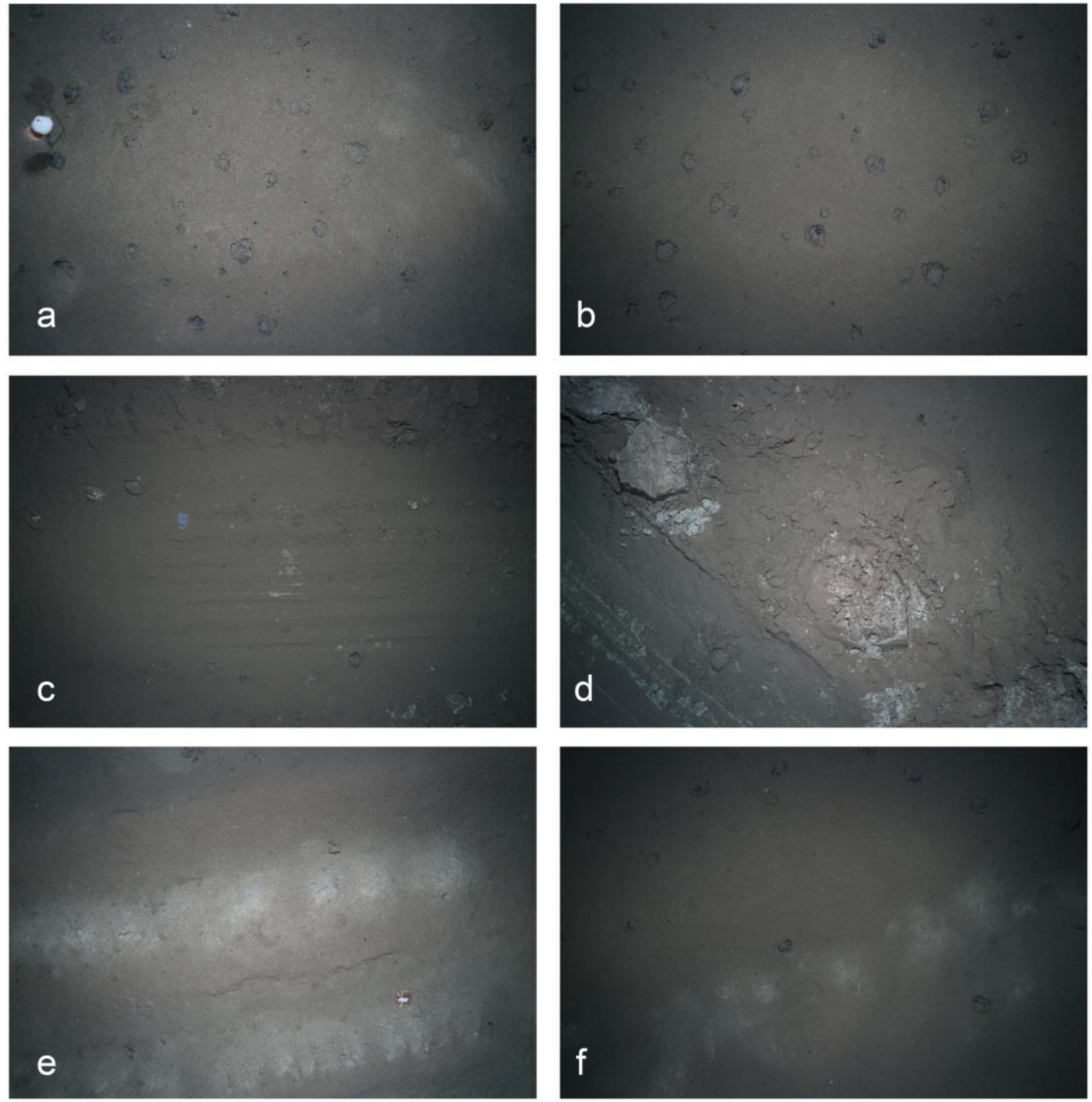
b) Nodule area outside DEA (Reference)

c) Epibenthic sled centre (new category)

d) Epibentic sled edge (new category))

e) Ploughmark (central plough)

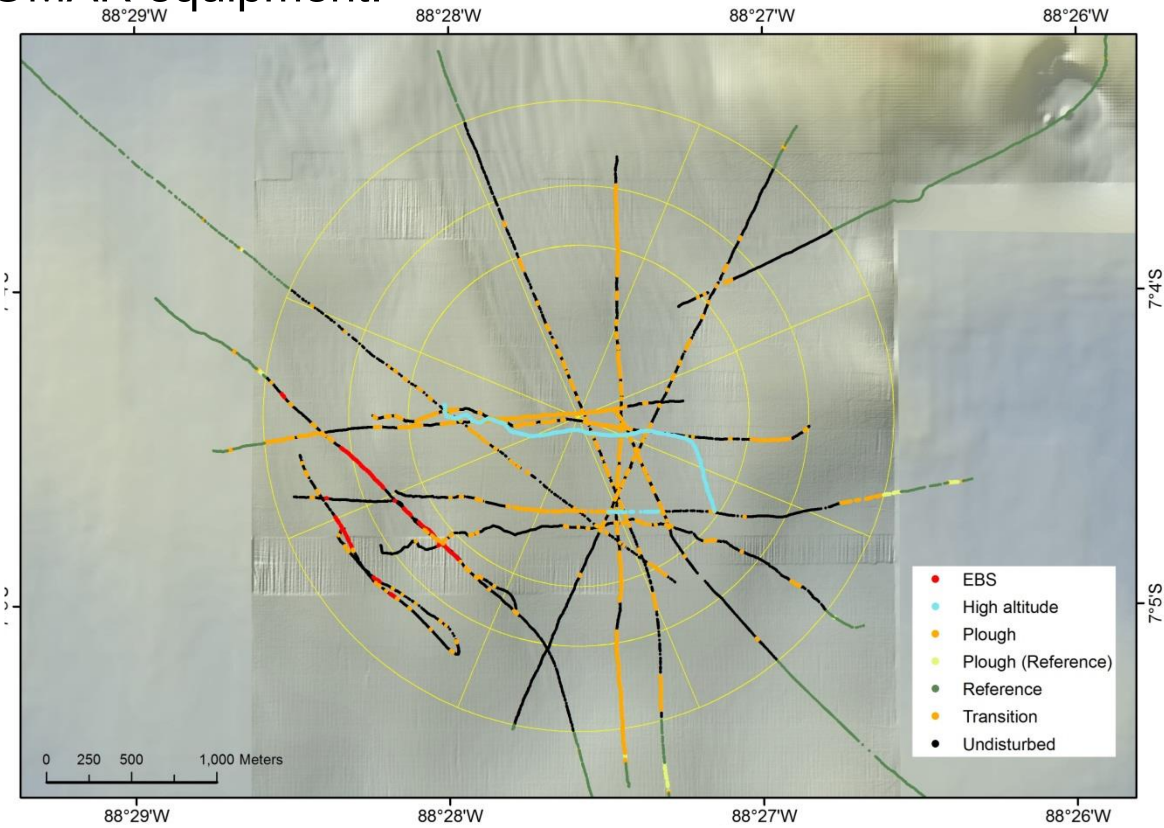
f) Ploughmark (transition)



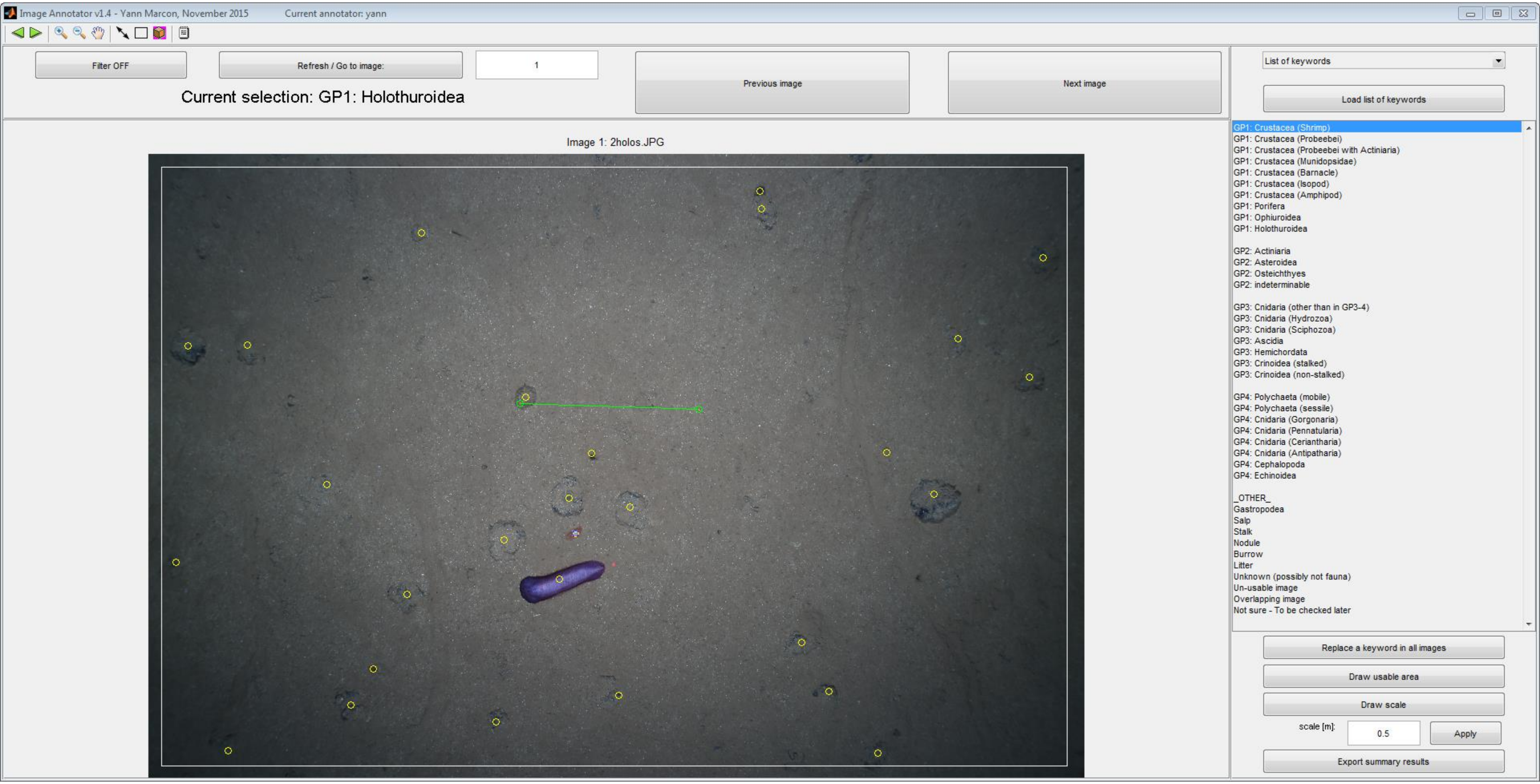
19.5 OFOS dives to support primarily the main objective.
1.5 OFOS dives to support AUV, historical OFOS and OFOS altitude methodology comparison.
1 OFOS dive to rescue lost GEOMAR equipment.

Total number of images: 15,442

Plough marks:	1,740
Epibentic Sled:	350
Transition:	1,065
Undisturbed DEA:	6,524
Reference:	5,763



Majority of publications reporting megafauna recolonisation of the DISCOL area report abundances of 16 taxa. We have continued with this approach. After 26 years, variation in abundances across the DEA habitat types differs with taxa. We have analysed approx. 20% of images.



Custom built software available! Multipurpose! Perfect for students!

PAPARA(ZZ)I

Program for Annotation of Photographs and Rapid Analysis (of Zillions and Zillions) of Images

hdl:10013/epic.46423

Group 1: Crustacea

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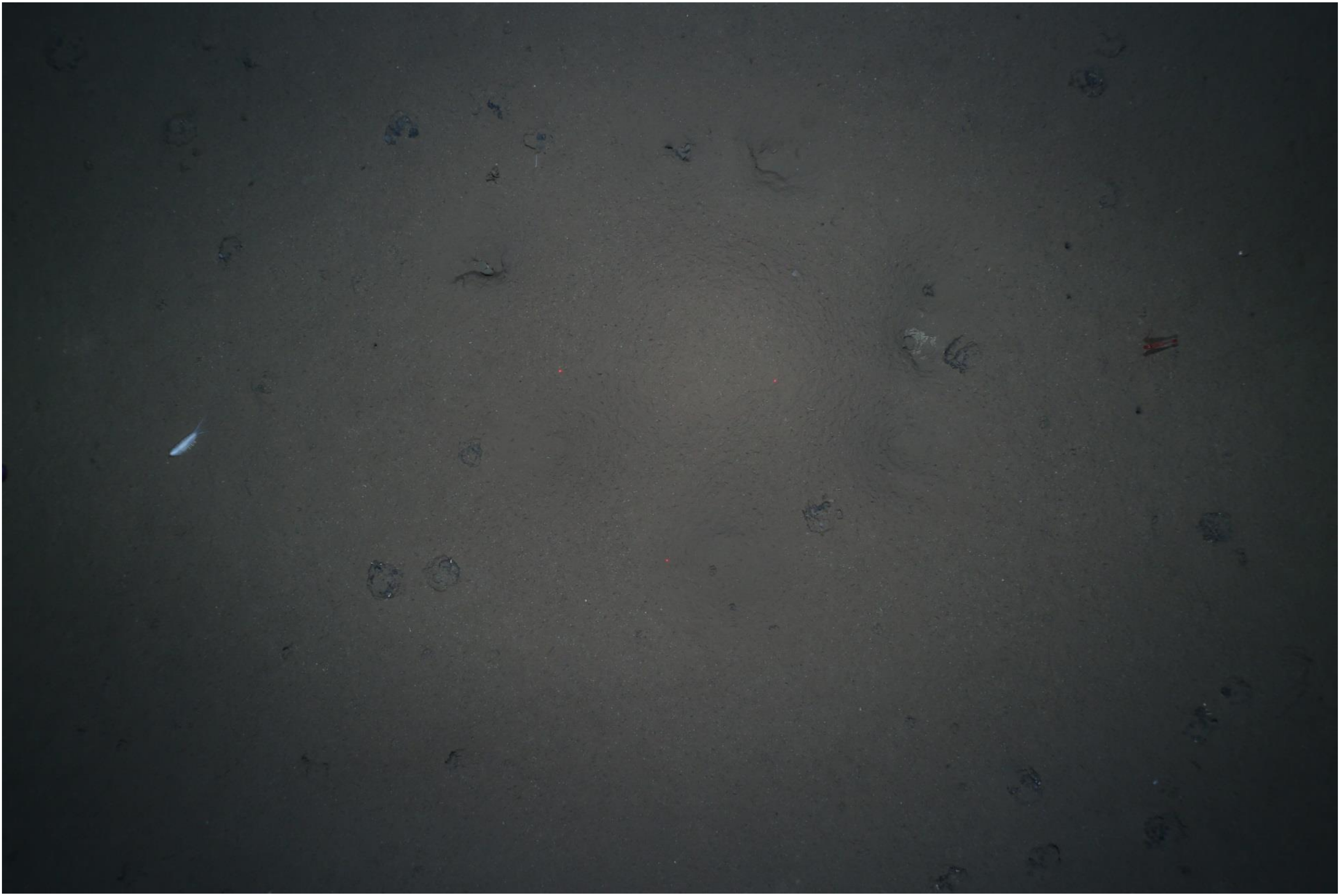
MIDAS is funded by the European Union's Framework 7 Programme
under the theme "*Sustainable management of Europe's deep sea and*

Group 1: Crustacea



Group 1: Porifera

Group 1: Porifera

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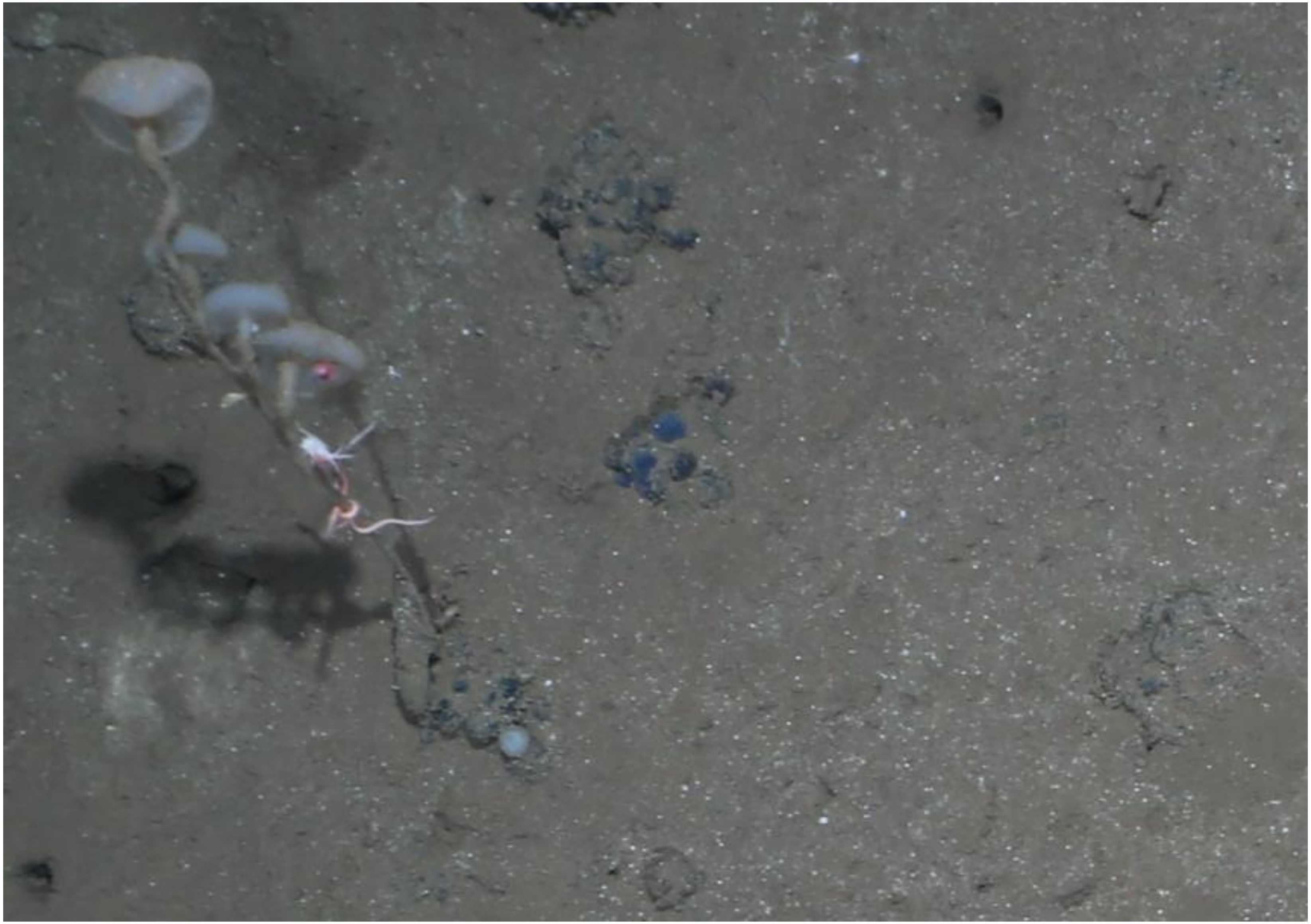
Group 1: Porifera

Group 1: Porifera

Group 1: Porifera



Group 1: Porifera

Group 1: Porifera

Group 1: Ophiuroidea

Group 1: Ophiuroidea

Group 1: Ophiuroidea

Group 1: Holothuroidea

Group 1: Holothuroidea

Group 1: Holothuroidea

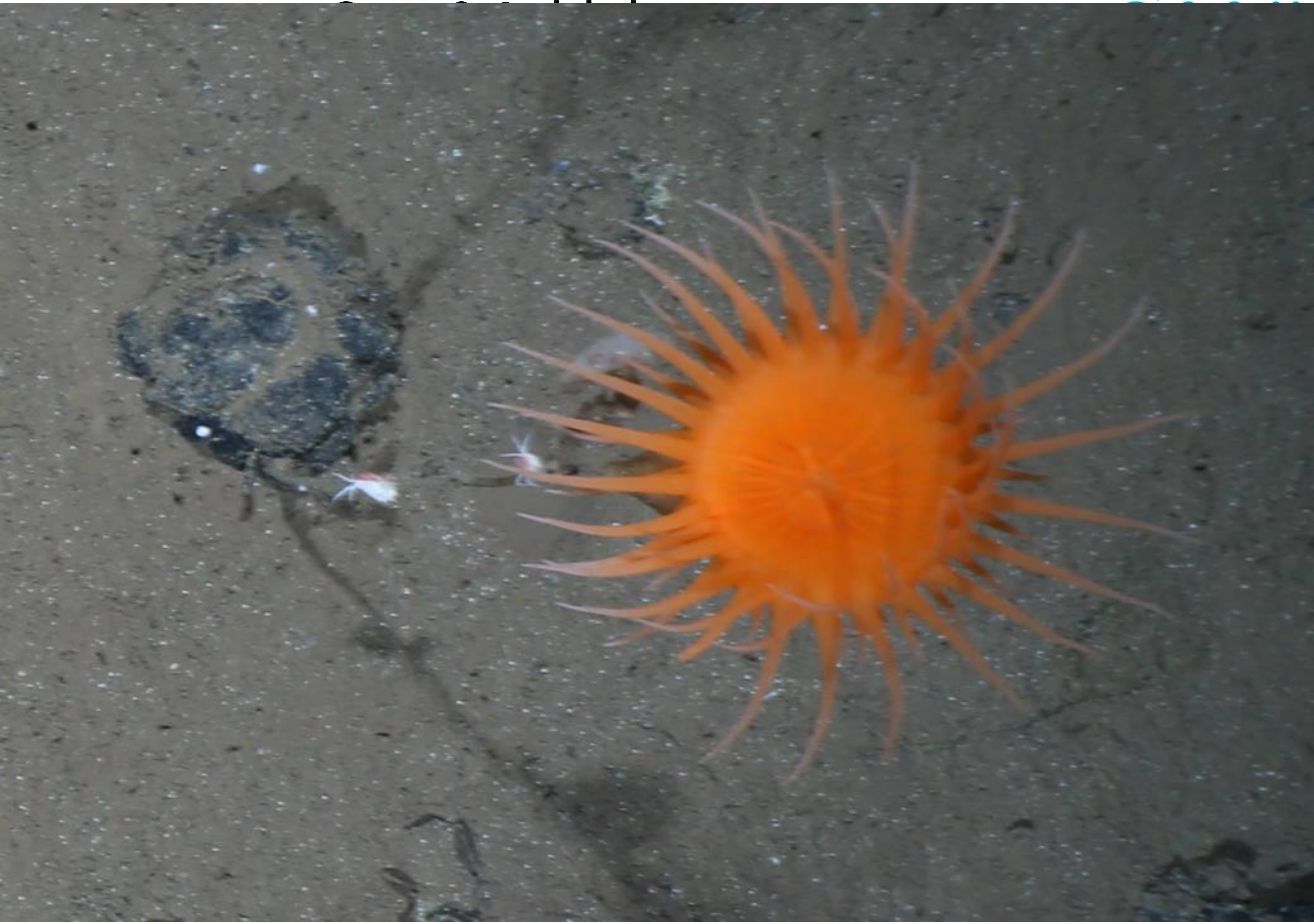
Group 1: Holothuroidea

Group 1: Holothuroidea

Group 2: Asteroidea

Group 2: Asteroidea

Group 2: Actiniaria



Group 2: Actiniaria

Group 2: Actiniaria

Group 2: Osteichthyes

Group 2: Osteichthyes

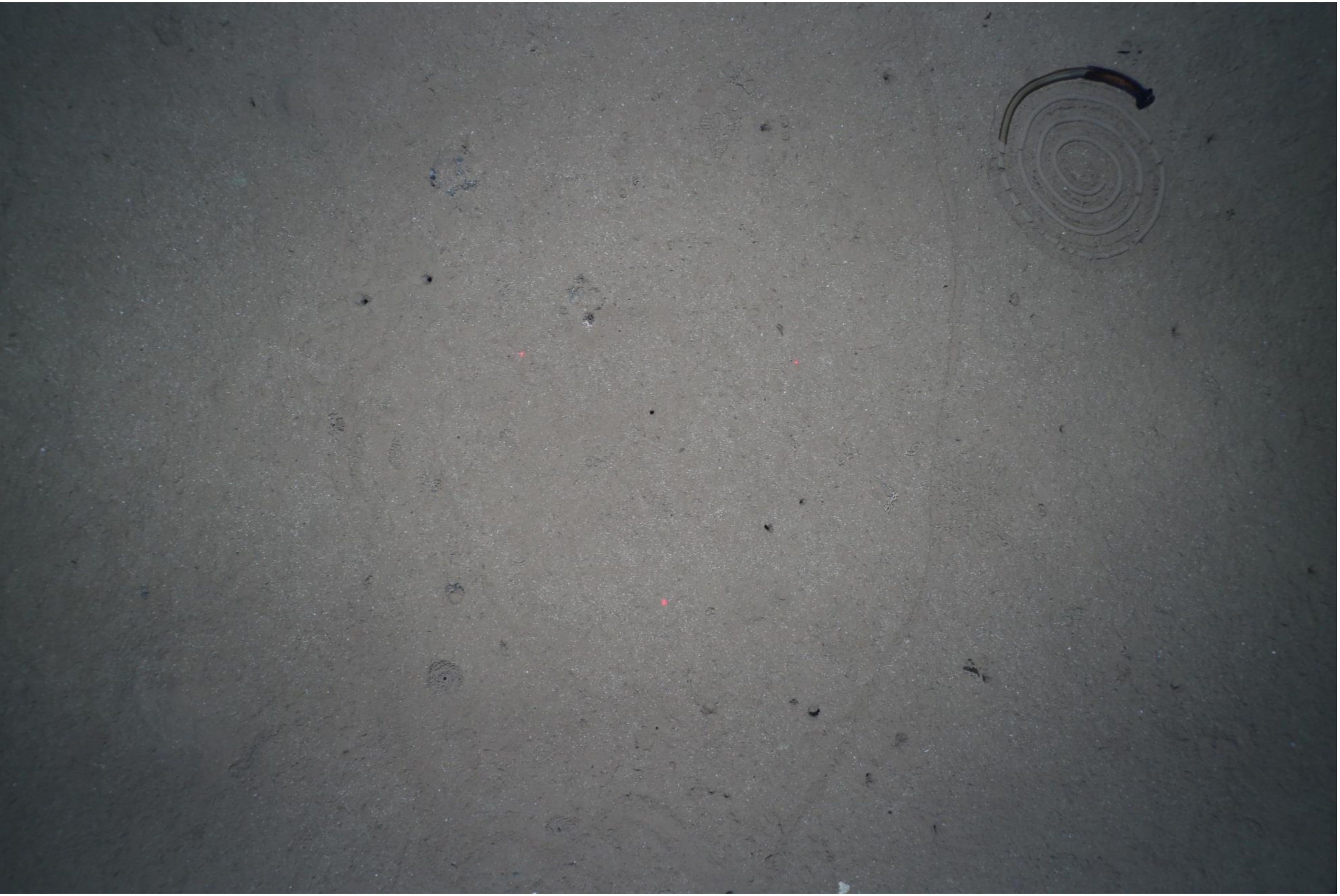
Group 2: Indeterminable

Group 3: Cnidaria (Hydrozoa and Schipozoa)

Group 3: Cnidaria (Hydrozoa and Schipozoa)

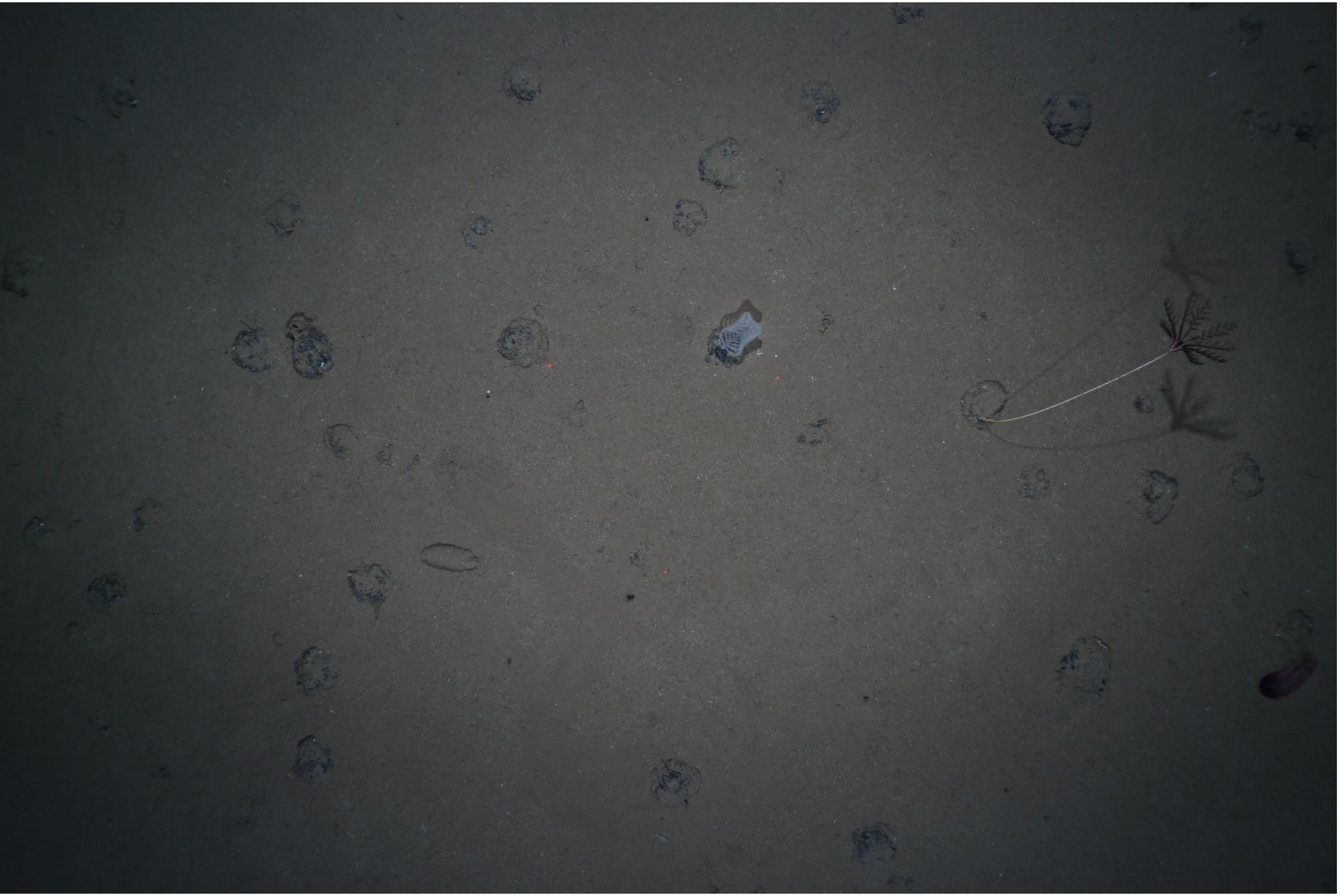
Group 3: Ascidia

Group 3: Hemichordata



Group 3: Hemichordata

Group 3: Crinoidea



Group 3: Crinoidea

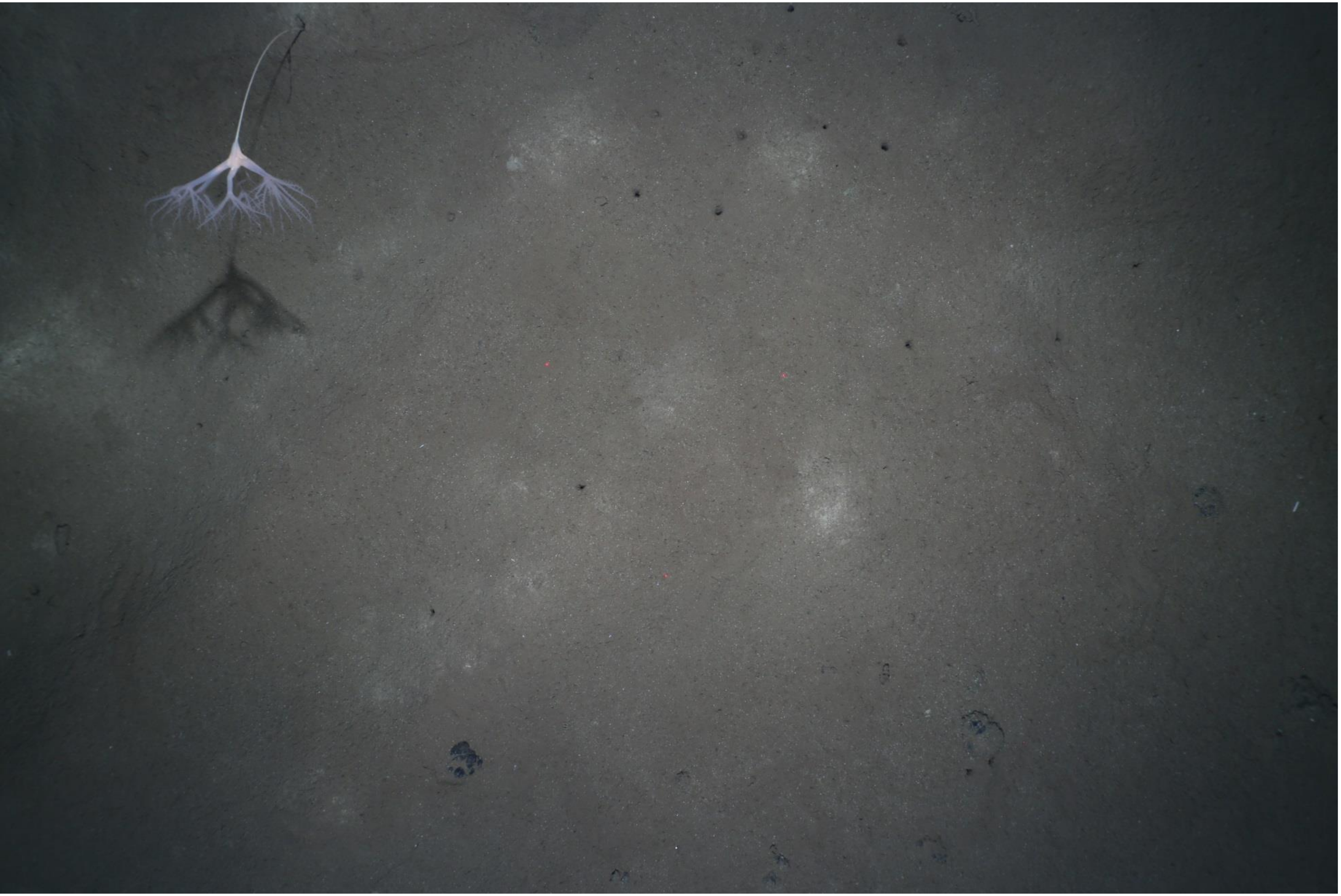
Group 3: Crinoidea

Group 4: Polychaeta

Group 4: Polychaeta

Group 4: Polychaeta

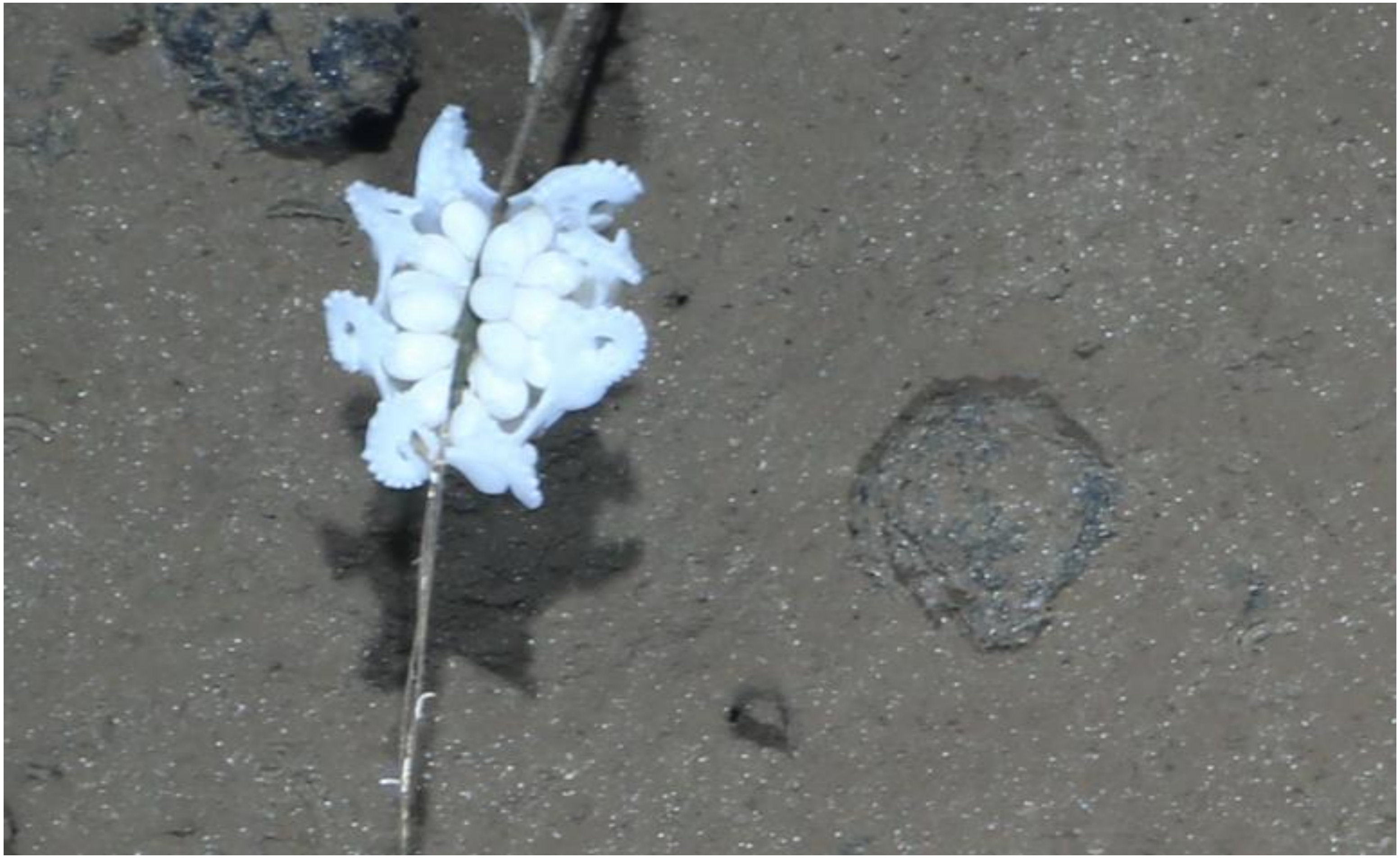
Group 4: Cnideria (Gorgonia, Pennatularia, Ceriantharia, Antipatharia)



Group 4: Cephalopoda

Group 4: Cephalopoda

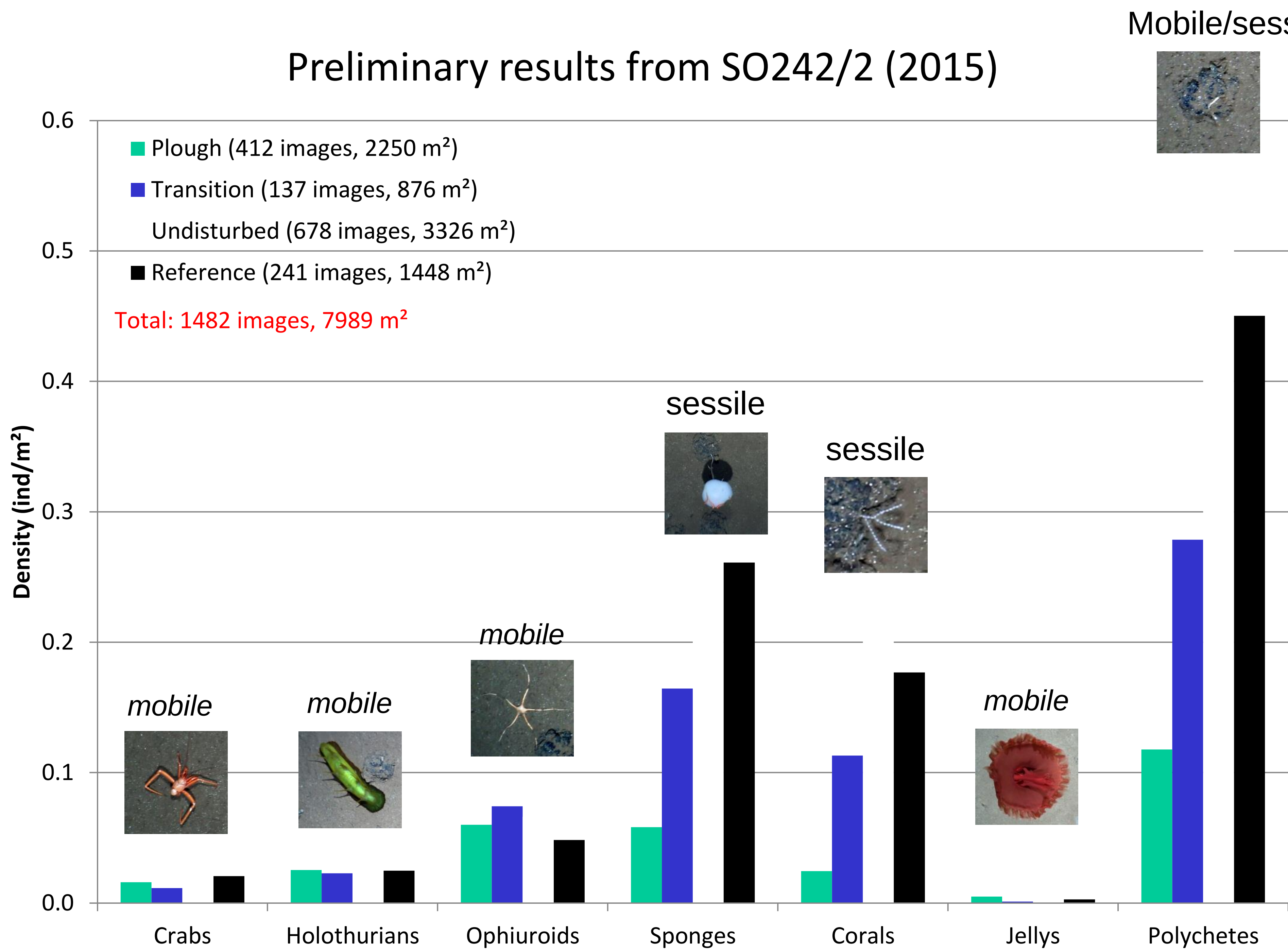
Group 4: Cephalopoda



Many, many surprises… Many, many Salp

Many, many surprises… Many, many Salp

Many, many surprises… Many, many Salp



Preliminary results from SO242/2 (2015)
Mobile/sess
Plough (412 images, 2250 m²)
Transition (137 images, 876 m²)
Undisturbed (678 images, 3326 m²)
Reference (241 images, 1448 m²)
Total: 1482 images, 7989 m²
Density (ind/m²)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
mobile
mobile
mobile
sessile
sessile
mobile
Crabs
Holothurians
Ophiuroids
Sponges
Corals
Jellys
Polychetes


Thank you for listening!

Thank you for listening!