Impact of deep-sea polymetallic nodule mining on benthic microbial community and mediated biogeochemical functions

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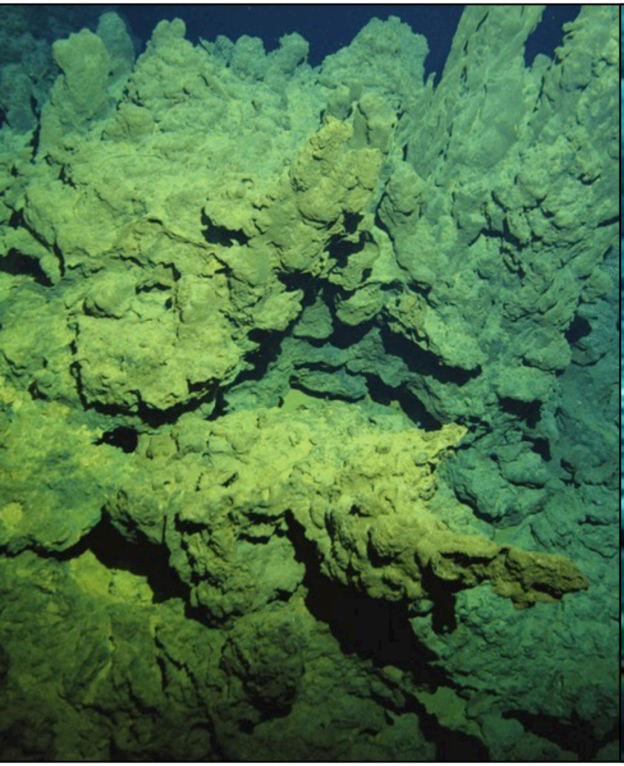
Logo: Autun Purser

Where to carry out mining in the deep-sea and for what?

Massive sulfide deposits

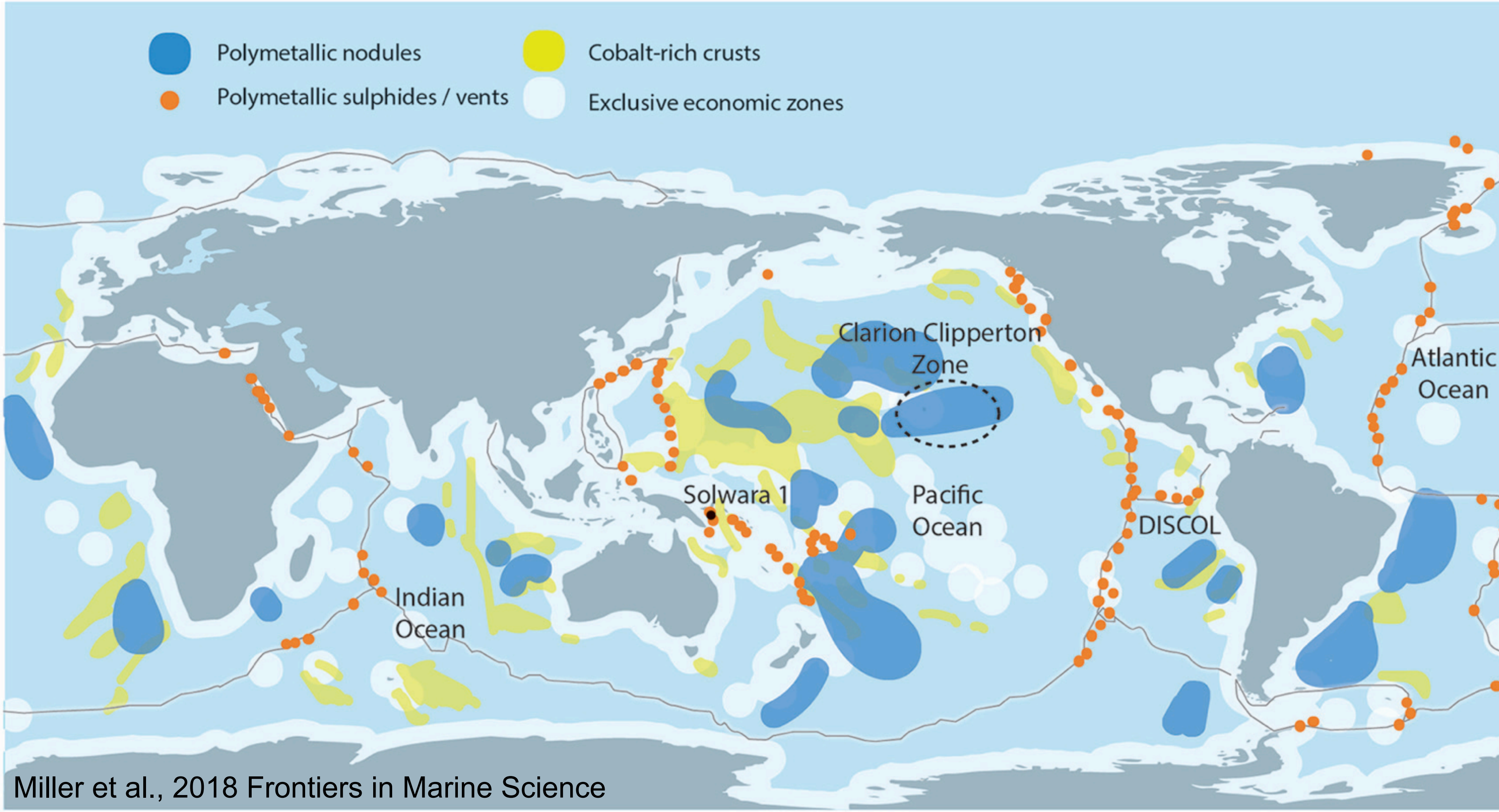


Cobalt-rich crust

Manganese nodule fields

Metal resources include: arsenic, copper, cobalt, nickel, lithium, platinum, tellurium, zinc, lead, barium, gold, silver and rare earth elements

Where to carry out mining in the deep-sea and for what?

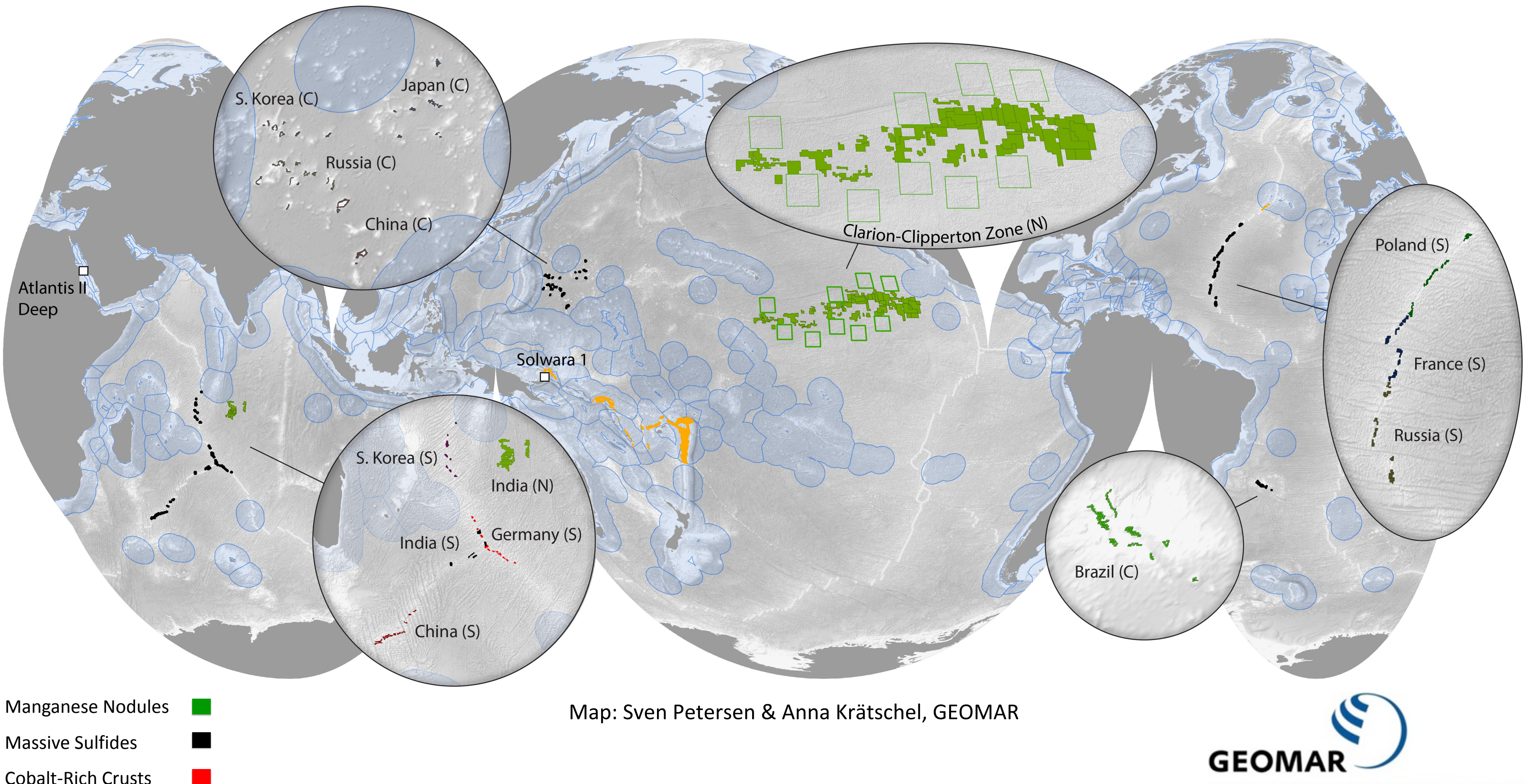


Miller et al., 2018 Frontiers in Marine Science

Metal resources include: arsenic, copper, cobalt, nickel, lithium, platinum, tellurium, zinc, lead, barium, gold, silver and rare earth elements

Is deep-sea mining ready to start?

International Seabed Authority (ISA) has approved 28 exploration contracts in the Pacific, Indian, and Atlantic oceans – covering more than 85,000 km^2 of deep-sea area

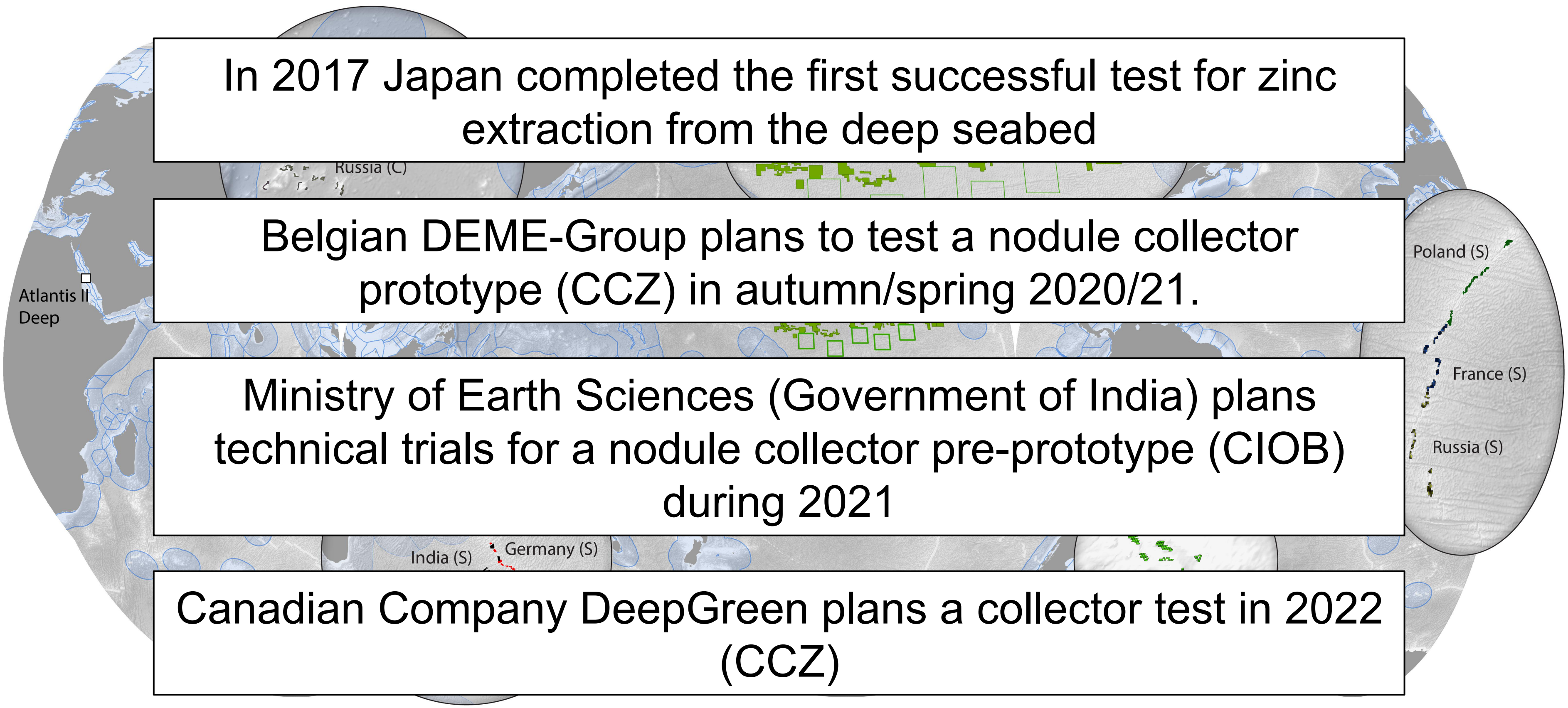


Map: Sven Petersen & Anna Krätschel, GEOMAR

GEOMAR Helmholtz Centre for Ocean Research Kiel

Is deep-sea mining ready to start?

So far not a single request for an exploitation license was handed in, but ISA is working on the regulations and the contractors on the technical preparations:



In 2017 Japan completed the first successful test for zinc extraction from the deep seabed

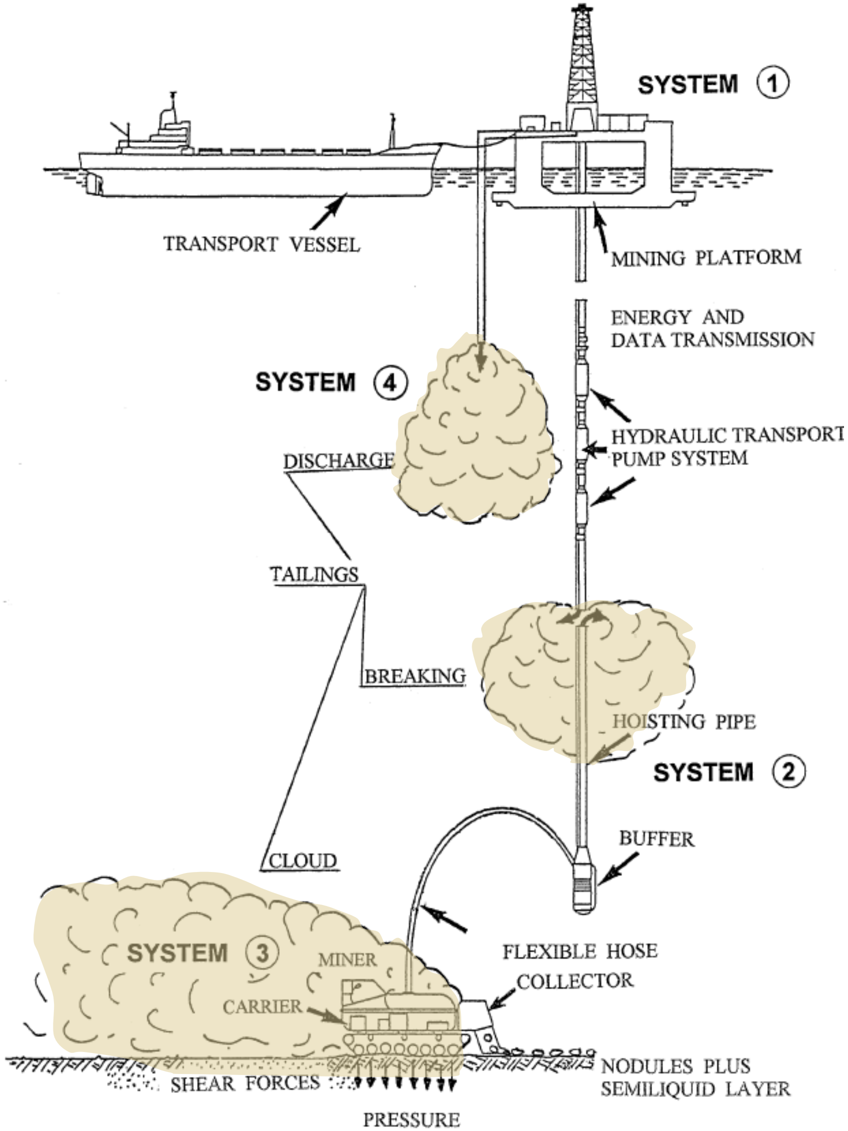
Belgian DEME-Group plans to test a nodule collector prototype (CCZ) in autumn/spring 2020/21.

Ministry of Earth Sciences (Government of India) plans technical trials for a nodule collector pre-prototype (CIOB) during 2021

Canadian Company DeepGreen plans a collector test in 2022 (CCZ)

Manganese Nodules
Massive Sulfides
Cobalt-Rich Crusts

Impacts of polymetallic nodule mining



Oebius et al. (2001) DSR II 48

Physical Impacts

- Removal of nodules & 10 cm of seafloor
- Generation of sediment plume that will resettle & blanket the seafloor
- Discharge of sediment waste from surface platform / riser pipe

Potential effect on ecosystems

- Loss of habitat integrity
- Loss of species & genetic diversity
- Loss of ecosystem structure & functions

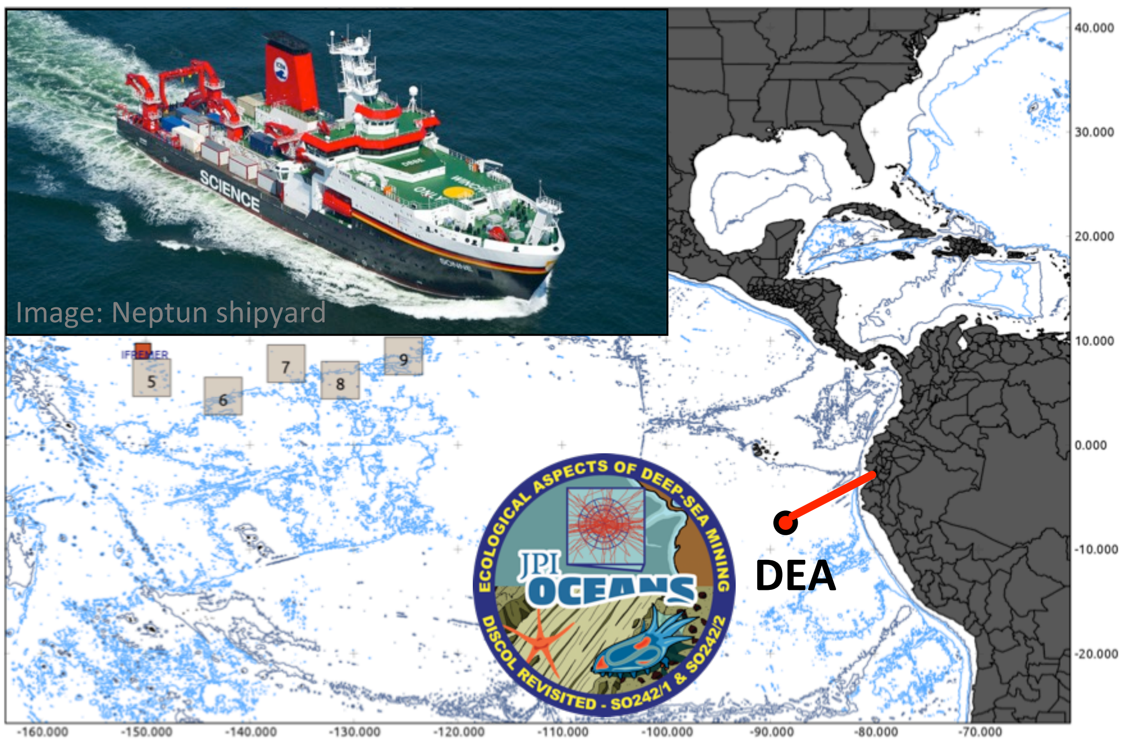
Study Aims

JPIO MiningImpact (2015-2018)

Overall Goal:
Assessing the long-term impacts of nodule mining on deep-sea ecosystems

Motivation and study focus

- Observations of microbial communities and functions are missing in assessments of deep-sea mining impacts

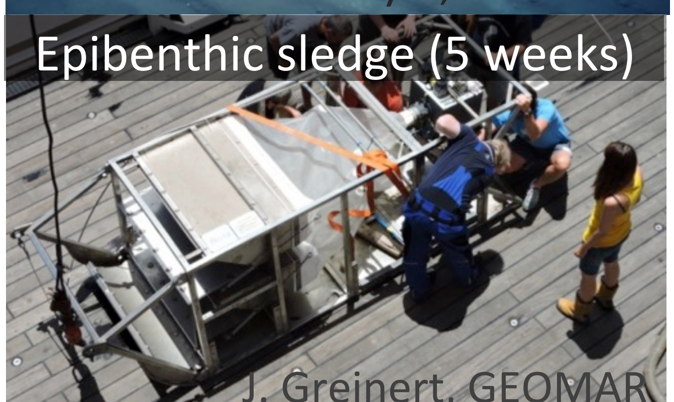


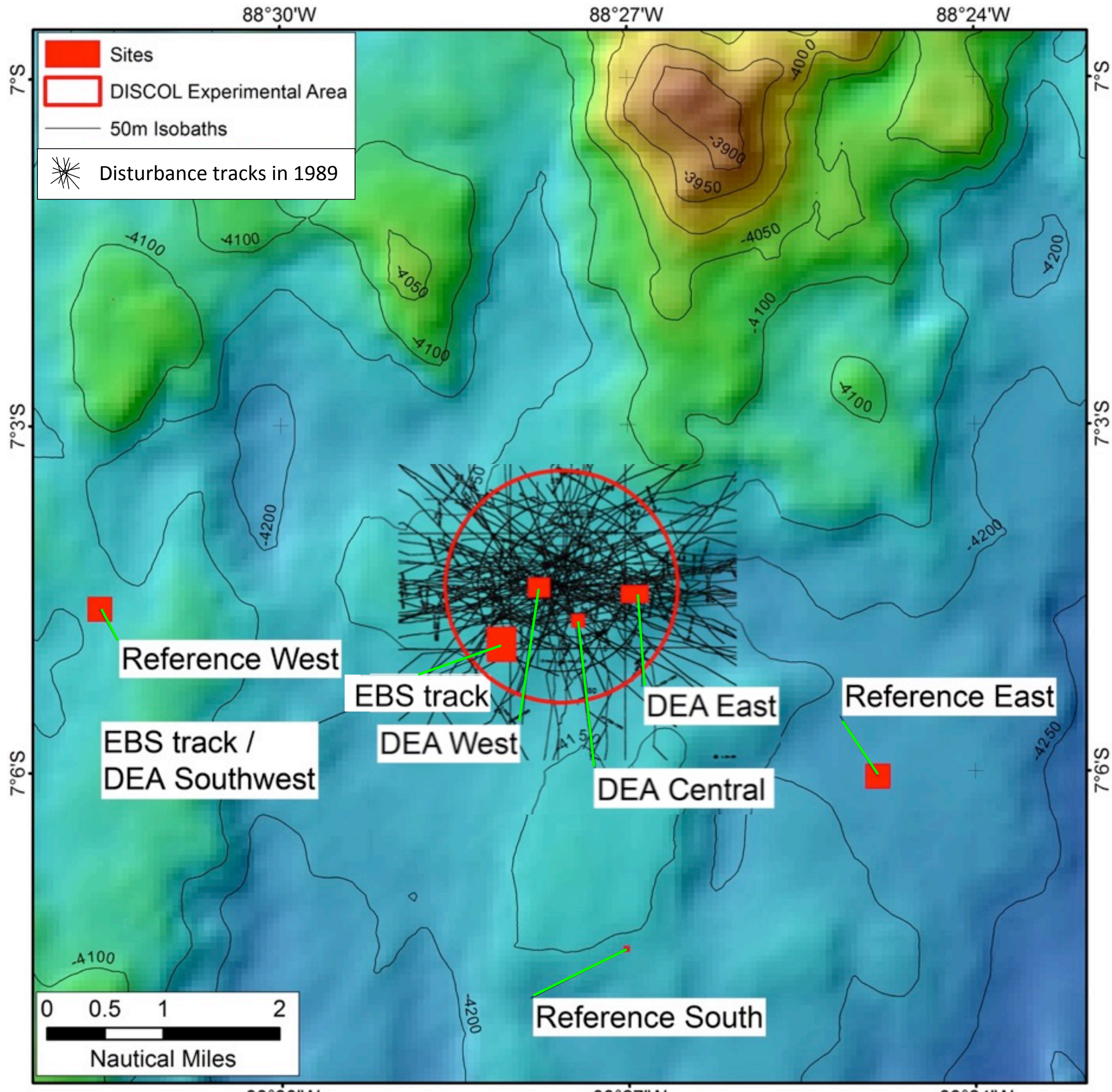
Key research questions

- can we identify disturbance effects on microbial community structure, activities, and biogeochemical functions?
- are effects scaling with disturbance intensity?
- at what time scales are communities and functions recovering?

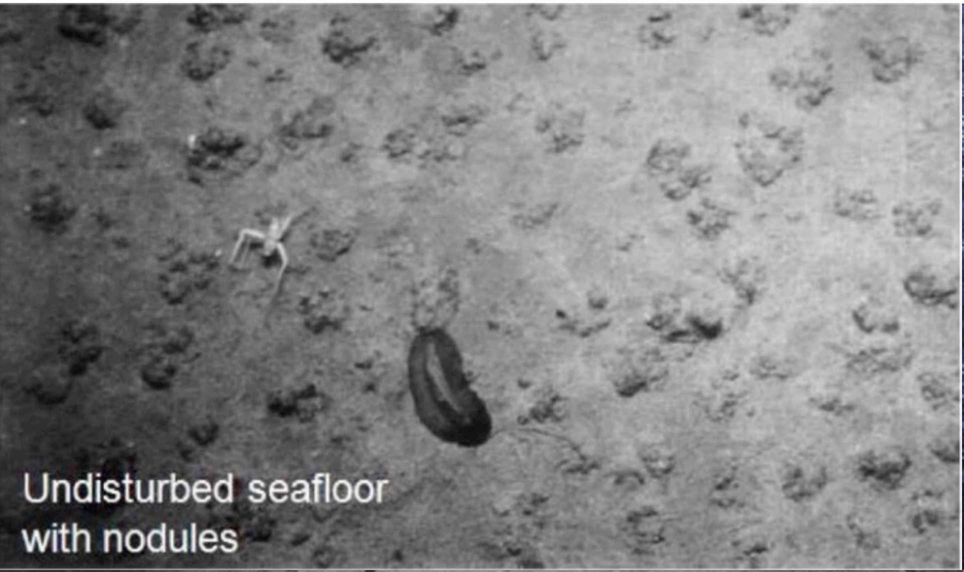
Discol Experimental Area (1989 BMBF project)

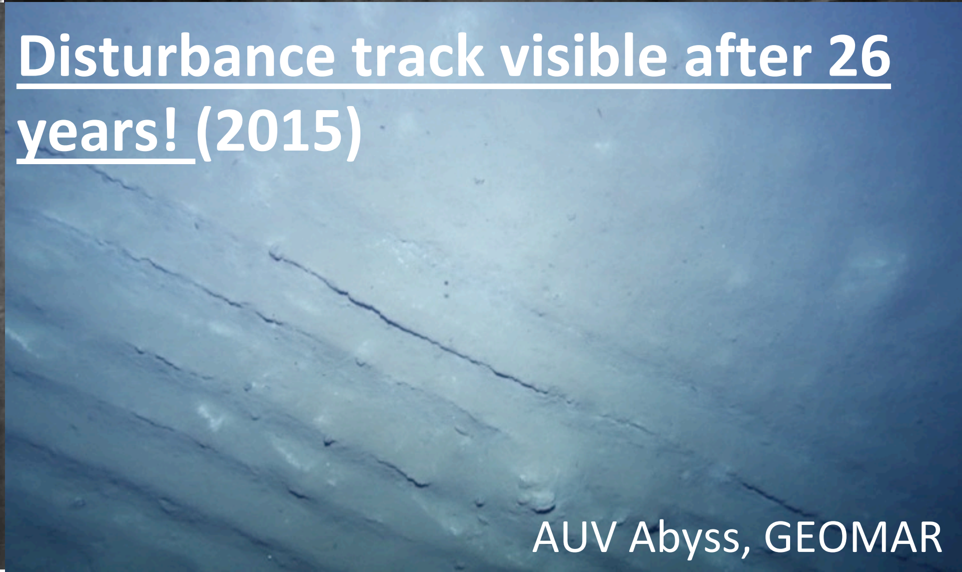
SO242/1 | DEA (Aug. 2015; J. Greinert), **SO242/2 | DEA** (Sep. 2015; A. Boetius)





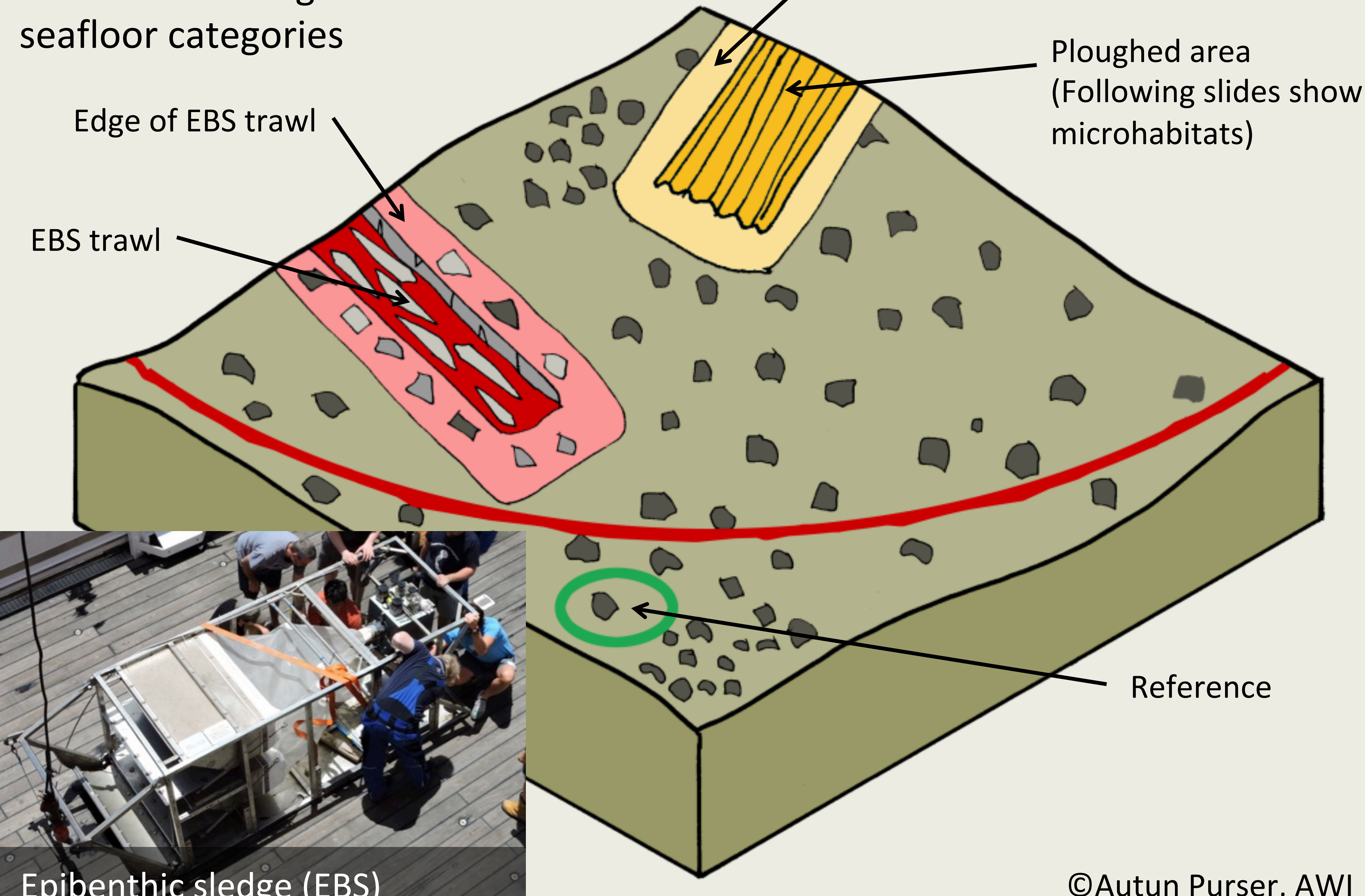
Comparing areas in/outside 26y old plough tracks to reference areas outside DEA





Sampling Strategy

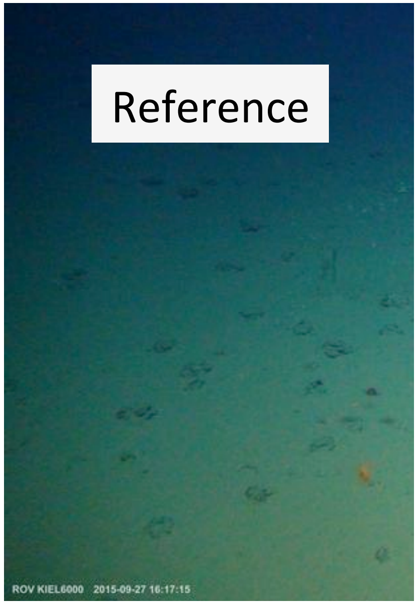
DISCOL – Investigated seafloor categories



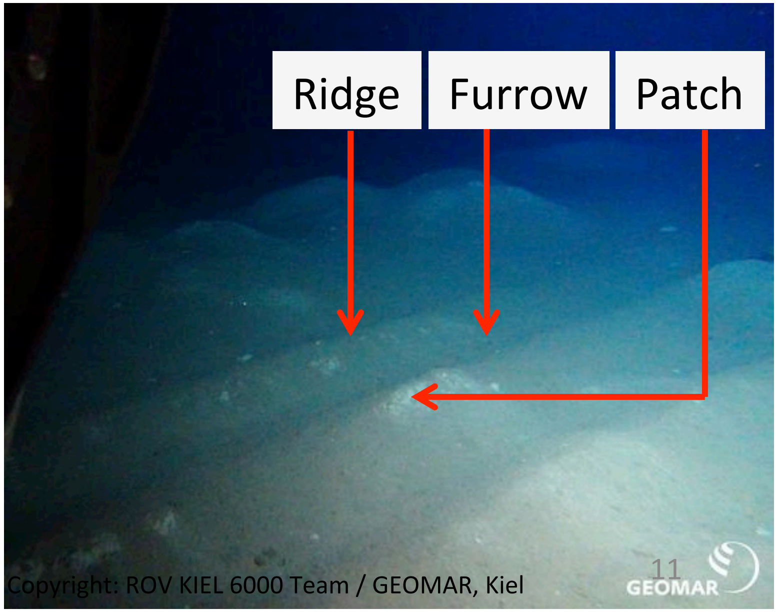
Epibenthic sledge (EBS)

Identified disturbance area microhabitats

- **Furrows**
  > surface sediments redistributed (removed?) upon ploughing
- **Ridges**
  > surface sediments redistributed (piled up?) upon ploughing
- **Subsurface patch**
  > deeper sediment exposed on sediment surface
- **Epibenthic trawl (EBS) track**
  > fresh disturbance created during first leg (5 weeks before sampling)



DEA: plough harrow

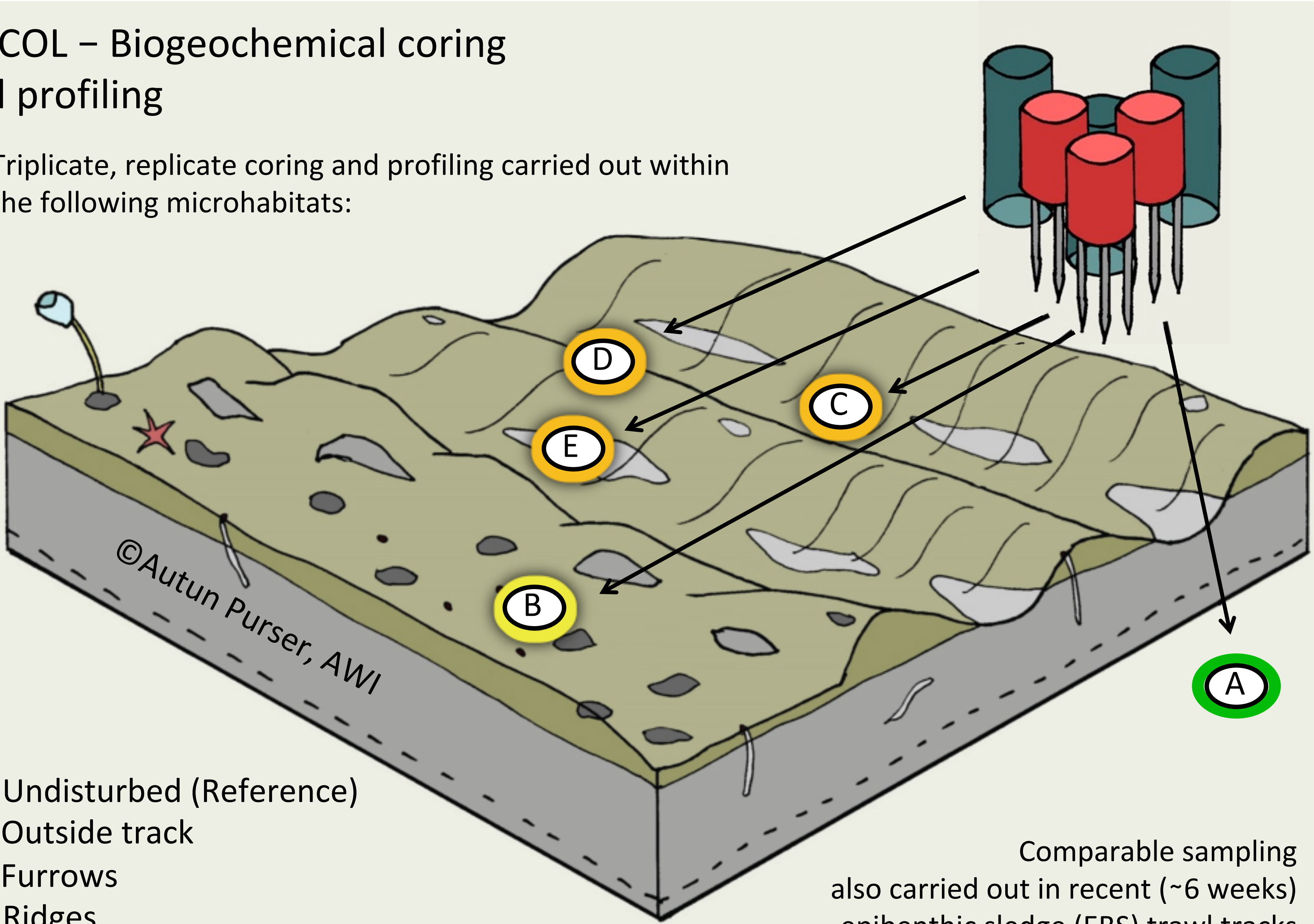


EBS

Sampling Strategy

DISCOL – Biogeochemical coring and profiling

Triplicate, replicate coring and profiling carried out within the following microhabitats:



A – Undisturbed (Reference)
B – Outside track
C – Furrows
D – Ridges
E – Subsurface patch

Comparable sampling also carried out in recent (~6 weeks) epibenthic sledge (EBS) trawl tracks made by SO242/1

Sediment biogeochemistry: quantify / classify impact intensities

Microbial abundance in Sediments:

Total cell counts (AODC)

Microbial community structure and diversity in Sediments & Nodules:

Illumina sequencing of 16S rRNA gene:

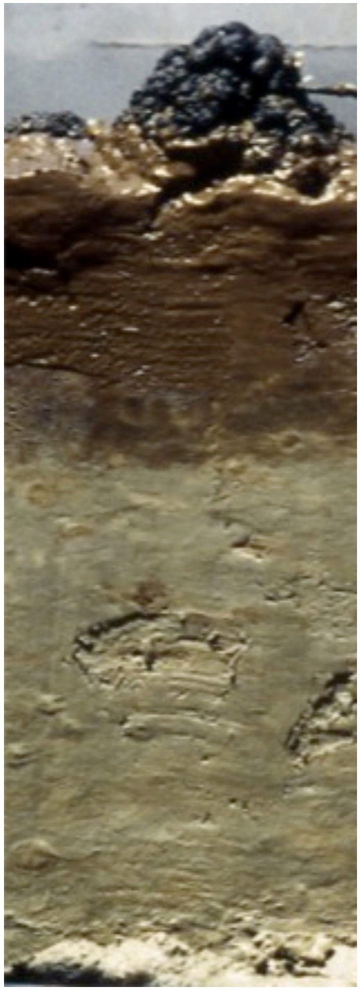
Bacteria V3-V4 region

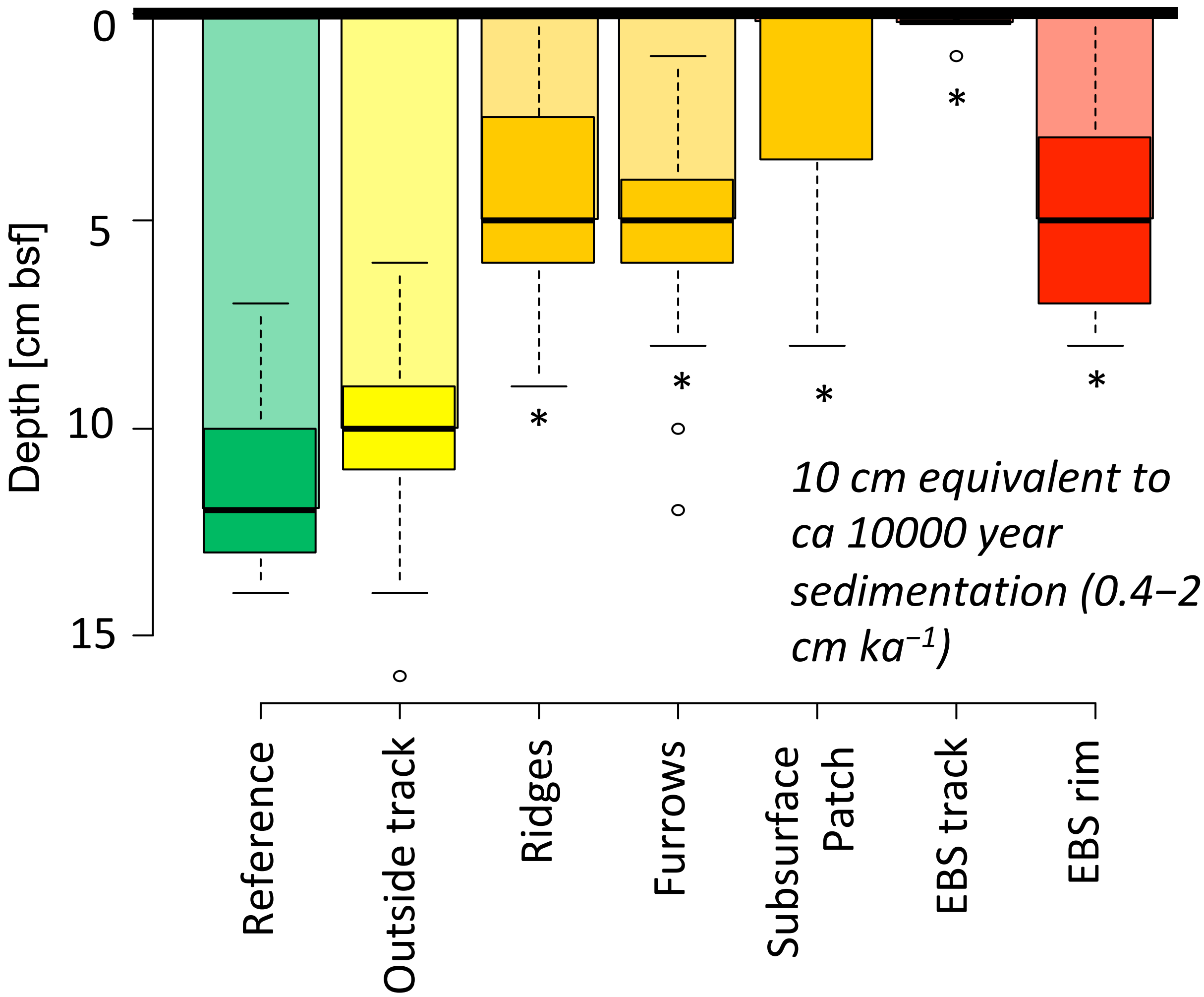
Archaea V3-V5 region

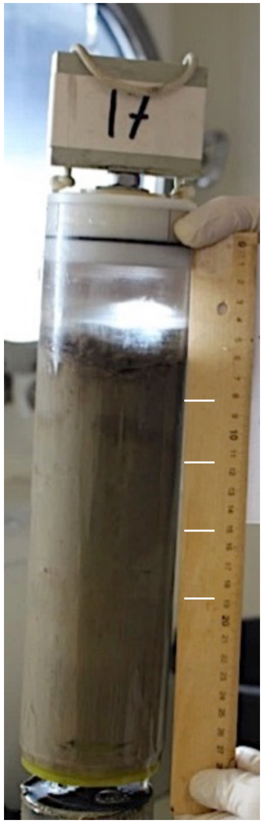
Microbial activity in Sediments

- Potential OM degradation: extracellular enzymatic activity (EEA)
- OM remineralization: in situ O_2 microsensor sediment profiles and chamber incubations
- Substrate uptake rates: ^{14}C-bicarbonate (DIC) and ^{3}H-leucine
- Biomass production: empirical DIC and leucine to C conversion factors

- Disturbance & loss of reactive surface layer



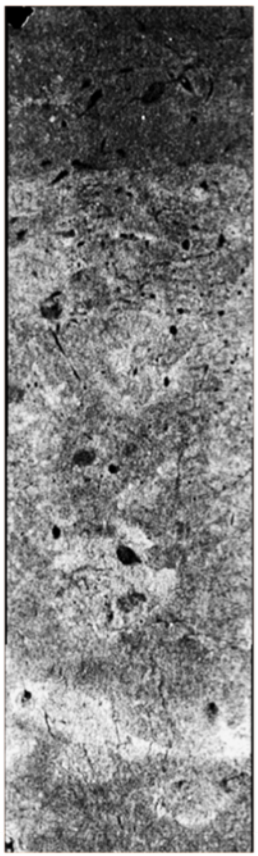


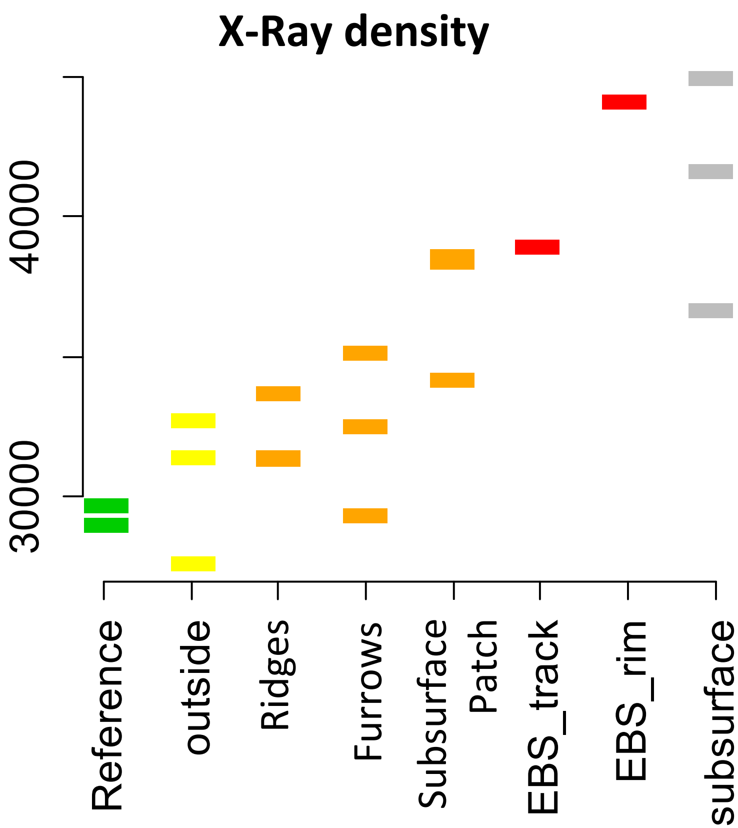


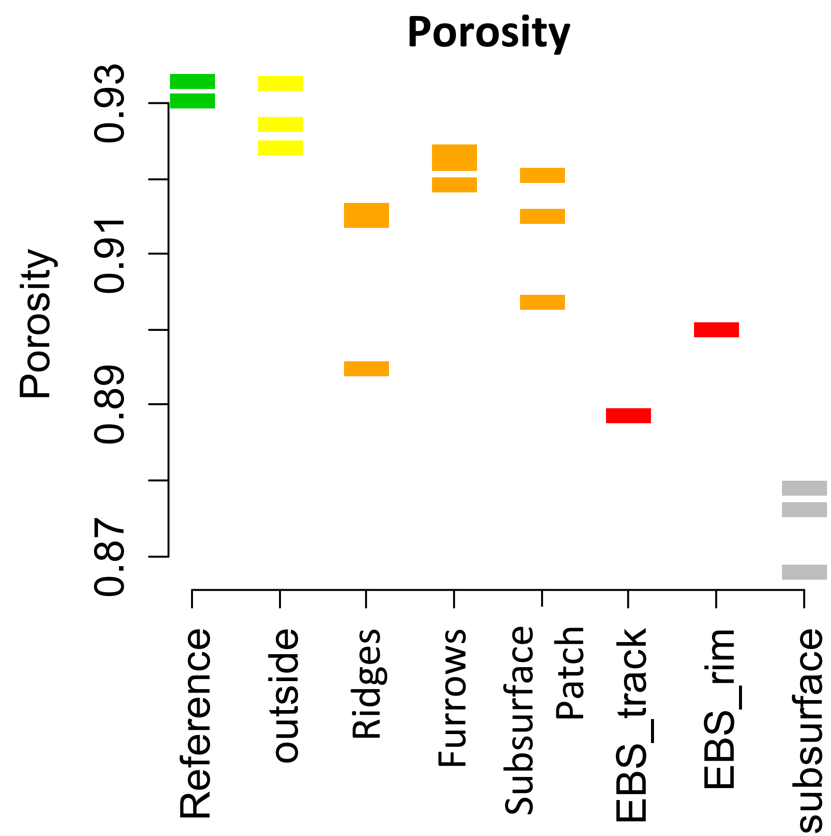
Vonnahme et al., Science Advances. DOI: 10.1126/sciadv.aaz5922

Changes in seafloor properties due to ploughing

- Stiffer, more compacted sediment exposed => difficult to recolonize => low bioturbation activity







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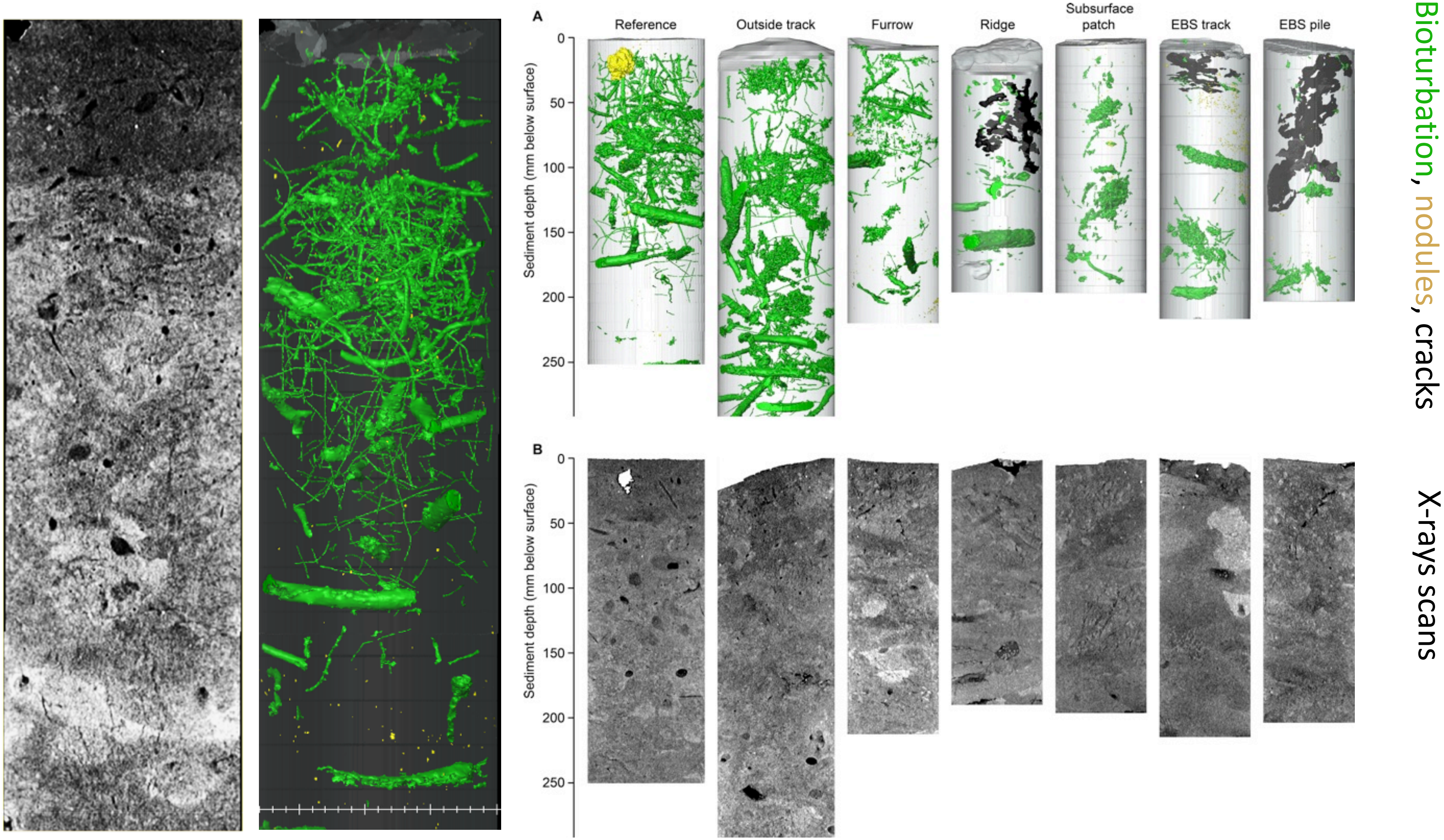
Impacts on bioturbation (DEA)

- X-rays show no / little recovery of bioturbation activity in 26 year old tracks
- exposed stiffer subsurface sediments difficult to colonize



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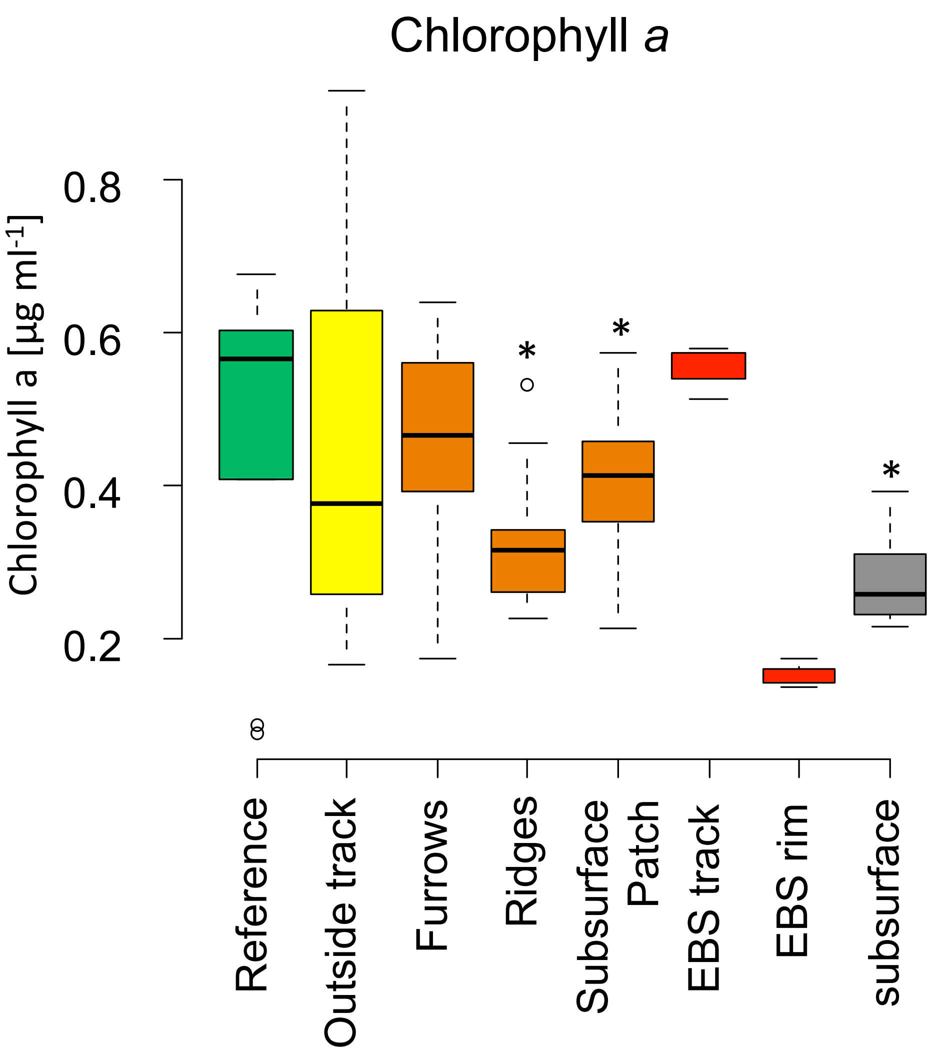
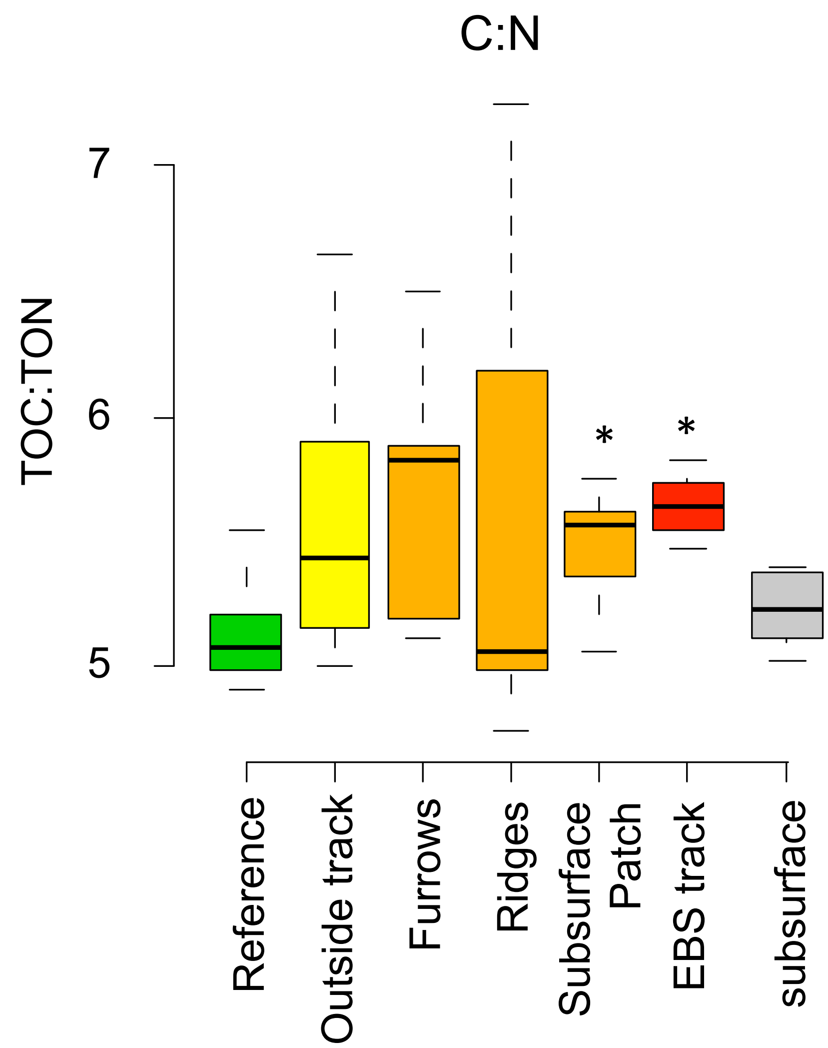
Loss of labile organic matter (DEA)

- Fresh detritus & nitrogen-rich organic matter is still reduced 26 y after disturbance





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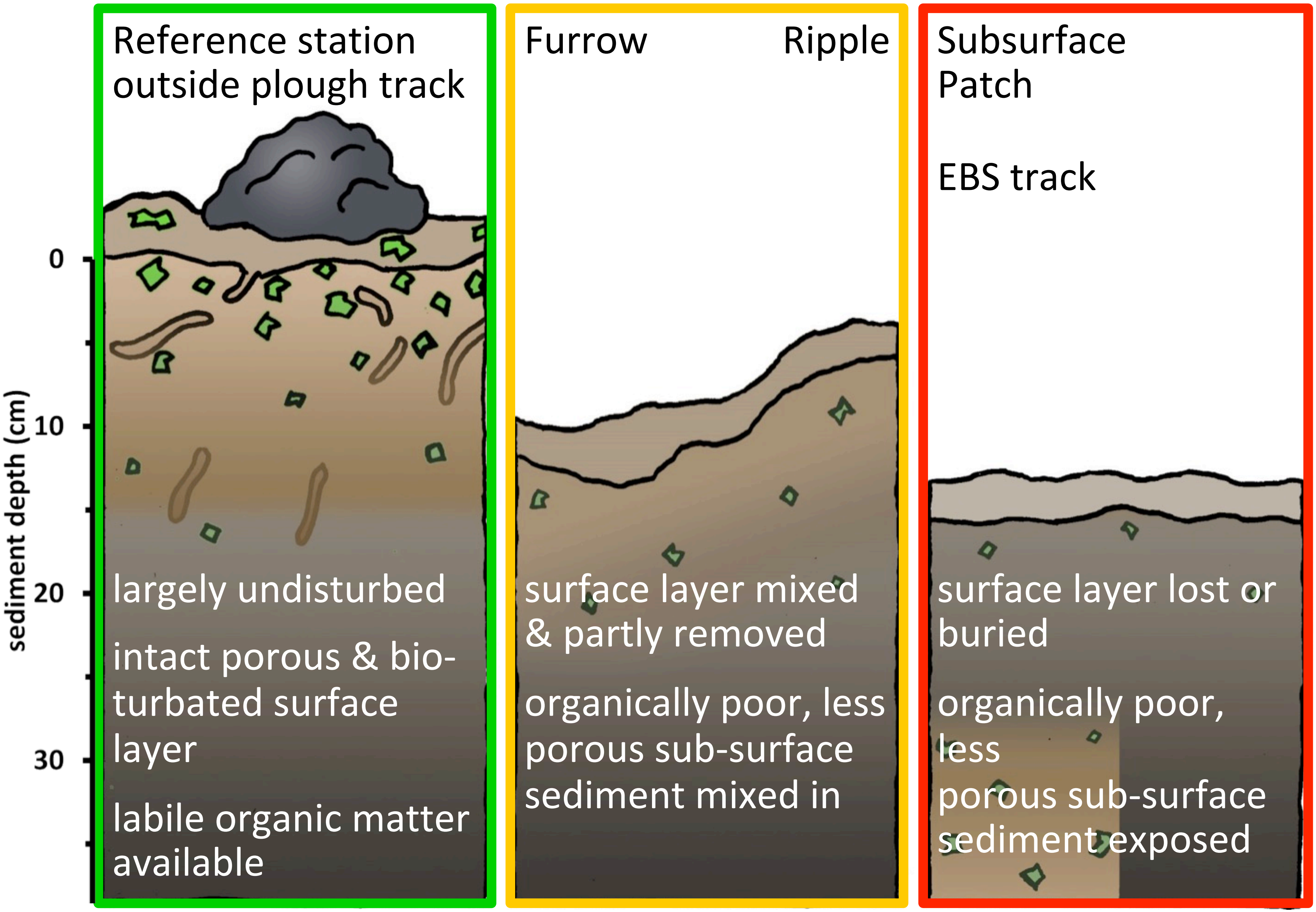
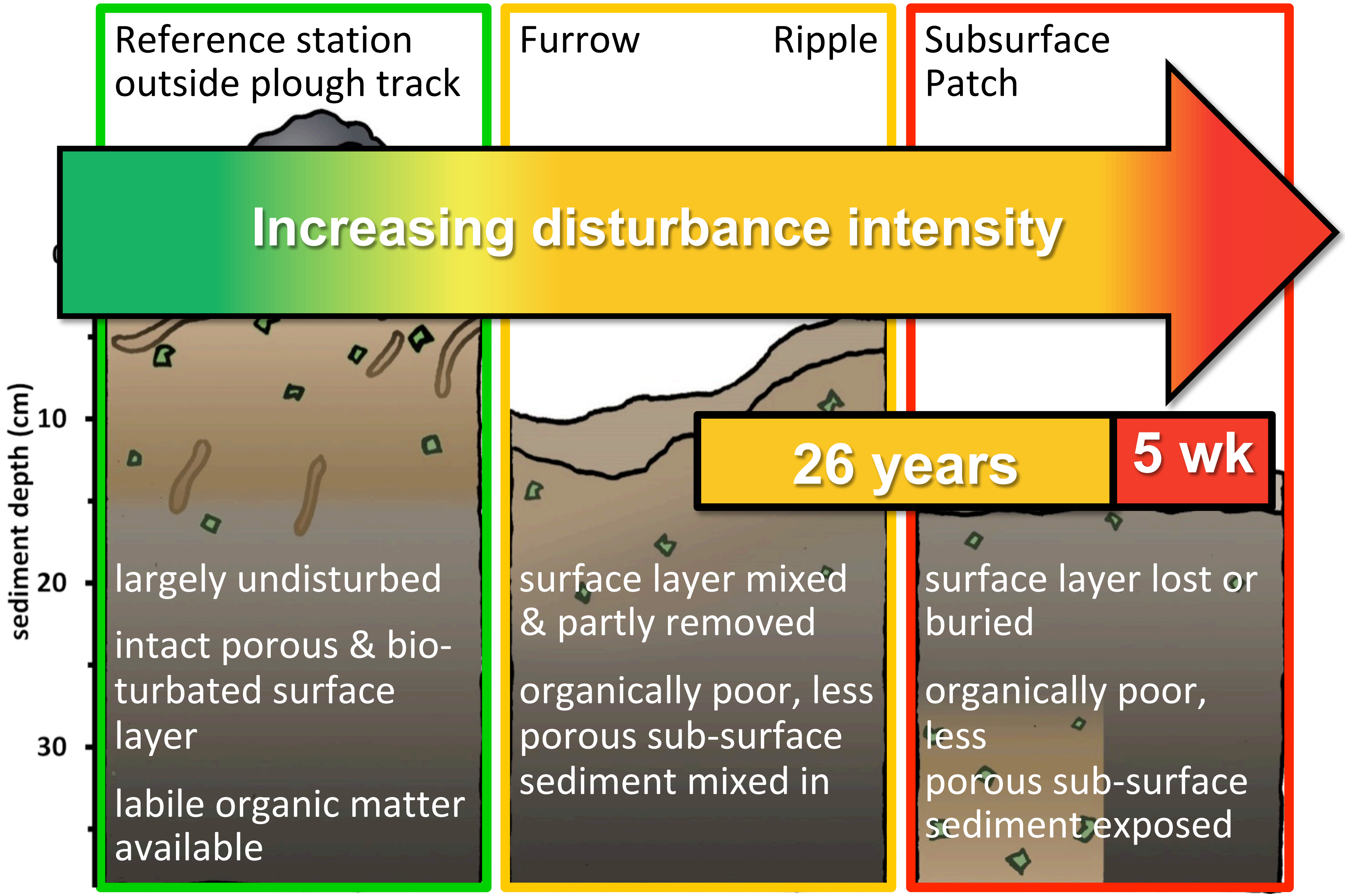
Results | Disturbance Classes

Disturbance intensity gradient scheme (Vonnahme et al. 2020, Science Advances)

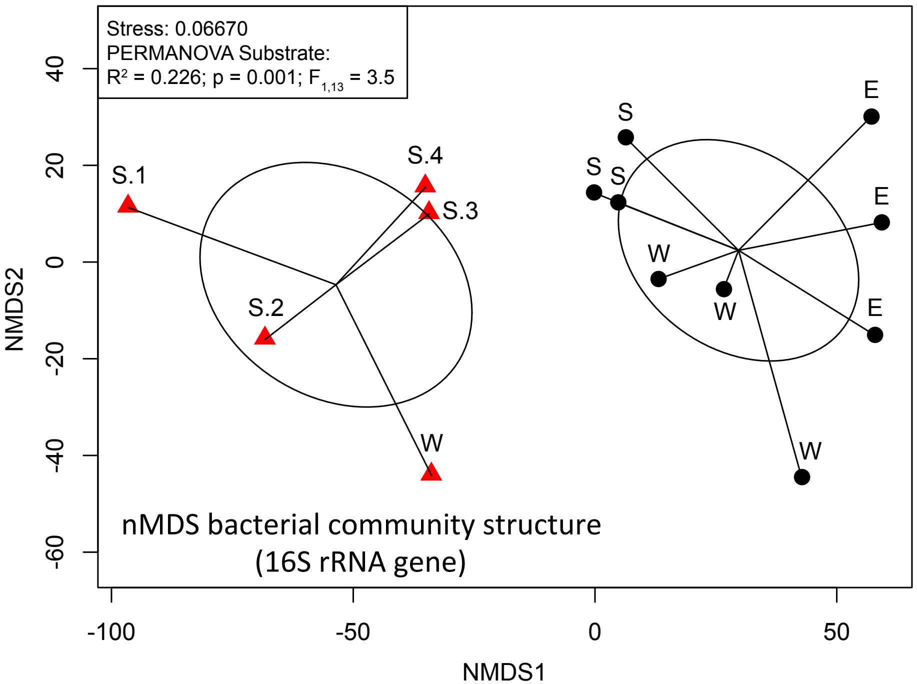


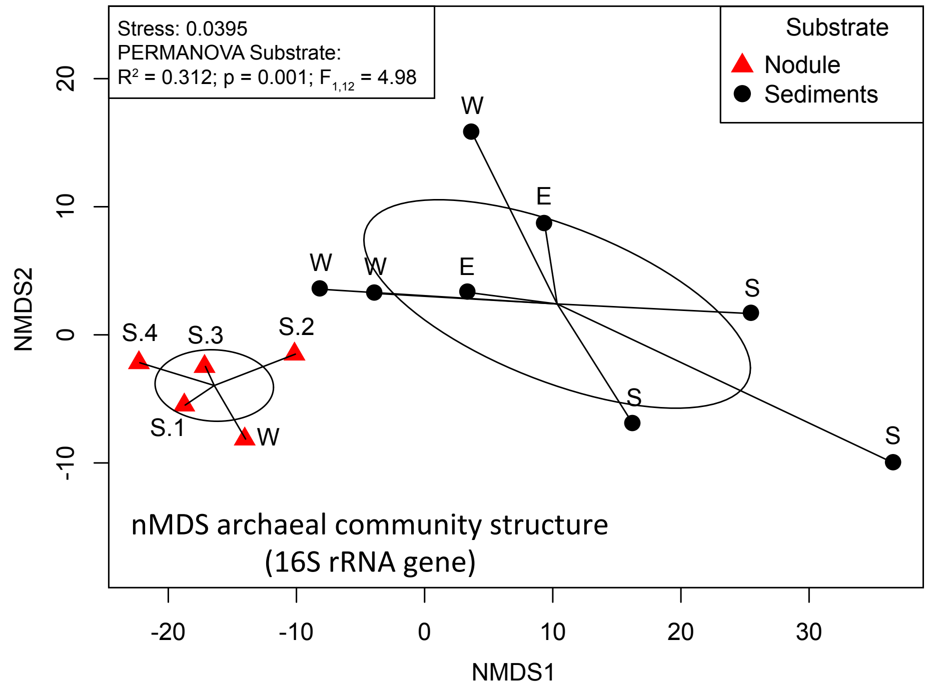
Disturbance intensity gradient scheme (Vonnahme et al. 2020, Science Advances)



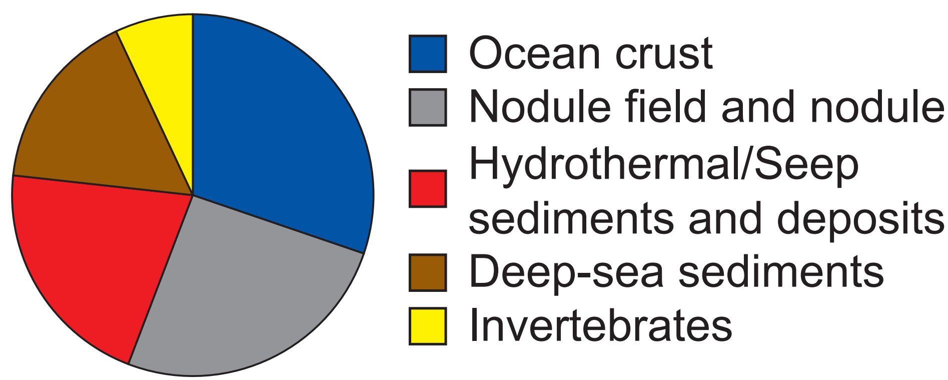
Results | Impact on bacterial diversity and community by nodules removal

- Nodules and sediments host distinct bacterial and archaeal communities



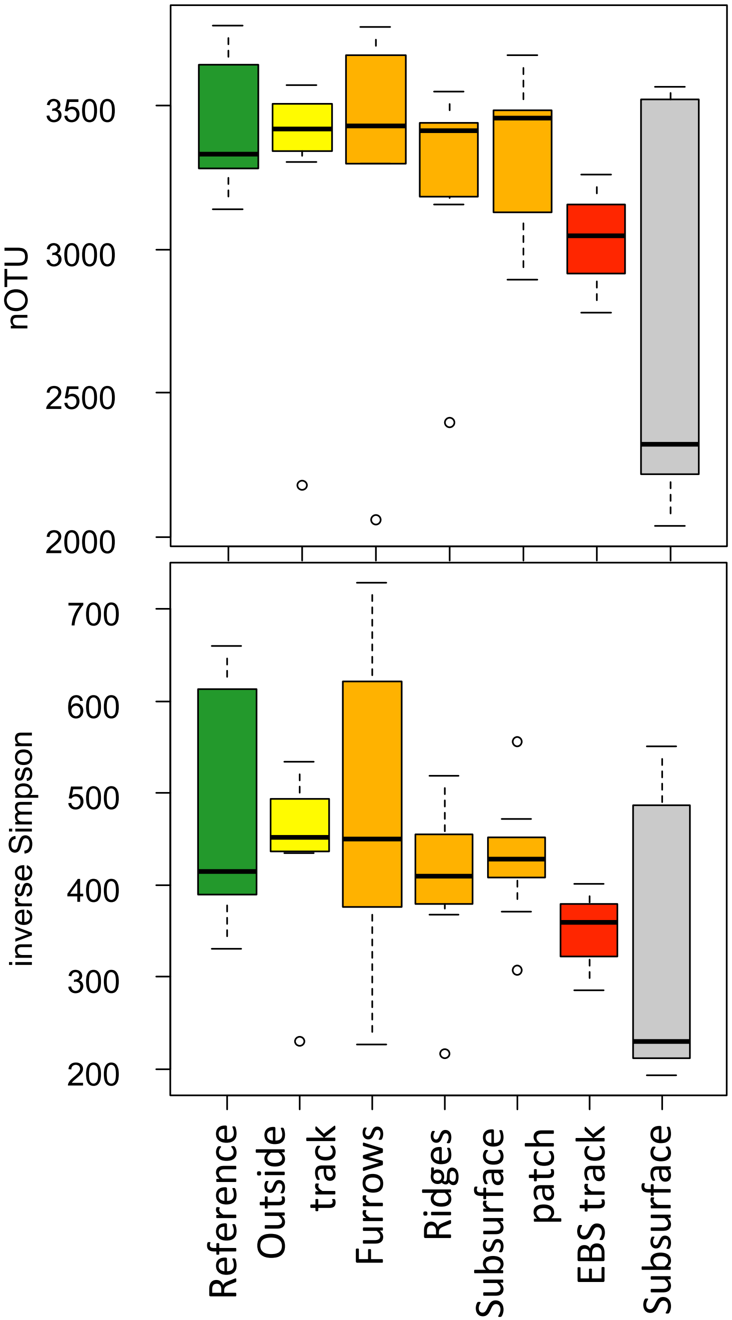


- Nodules are enriched in:
  - potential metal-cycling bacteria (i.e. Magnetospiraceae, Hyphomicrobiaceae
  - bacterial and archaeal nitrifiers (i.e. *AqS1*, unclassified Nitrosomonadaceae, *Nitrosopumilus*, *Nitrospina*, *Nitrospira*)
  - unclassified bacterial sequences found in ocean crust, others nodule fields, hydrothermal deposits and sessile fauna.

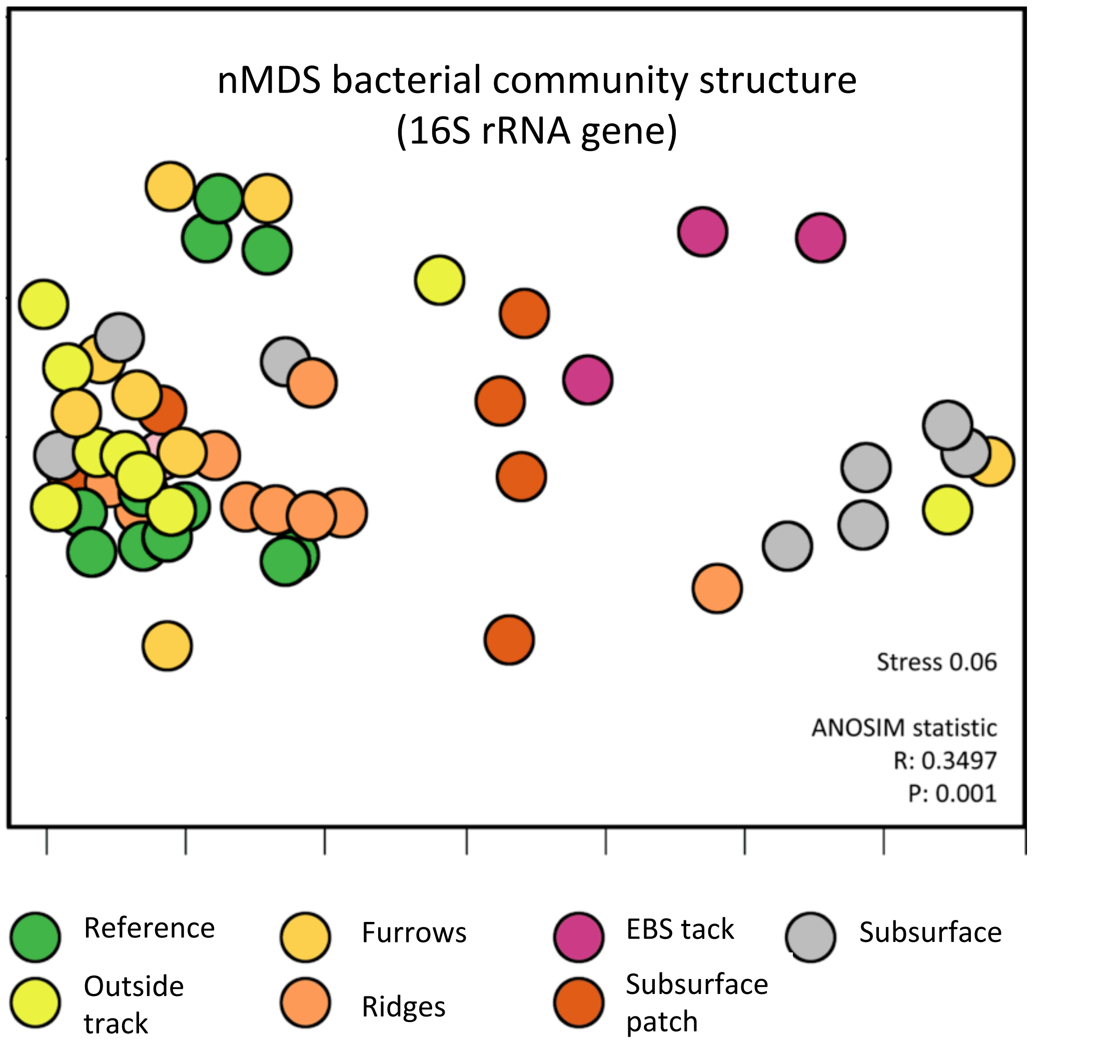


Molari et al., Biogeosciences Discussion. Doi.org/10.5194/bg-2020-11

Results | Impact on bacterial diversity and community



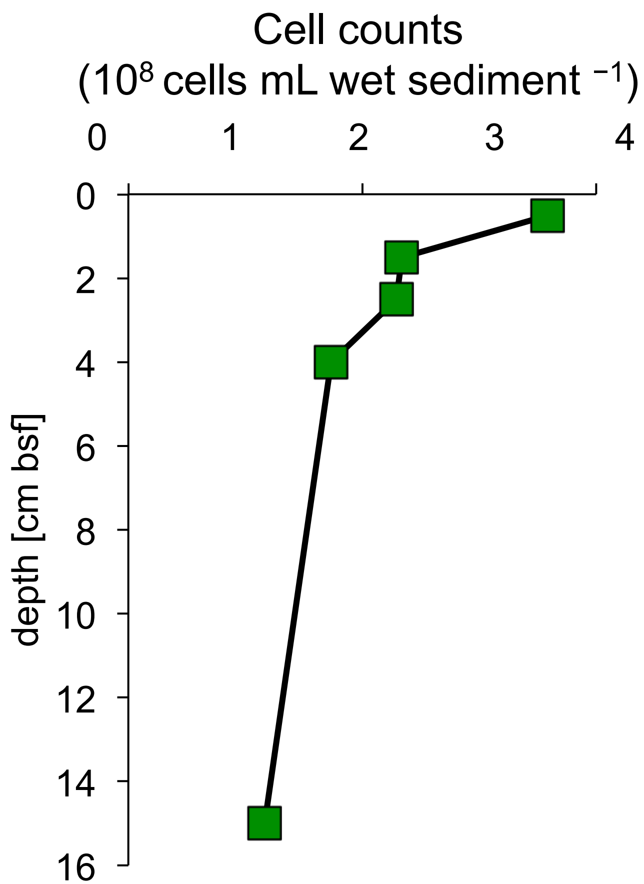
- Indications of disturbance related changes in microbial communities, but effects are hard to discriminate from pronounced spatial variability

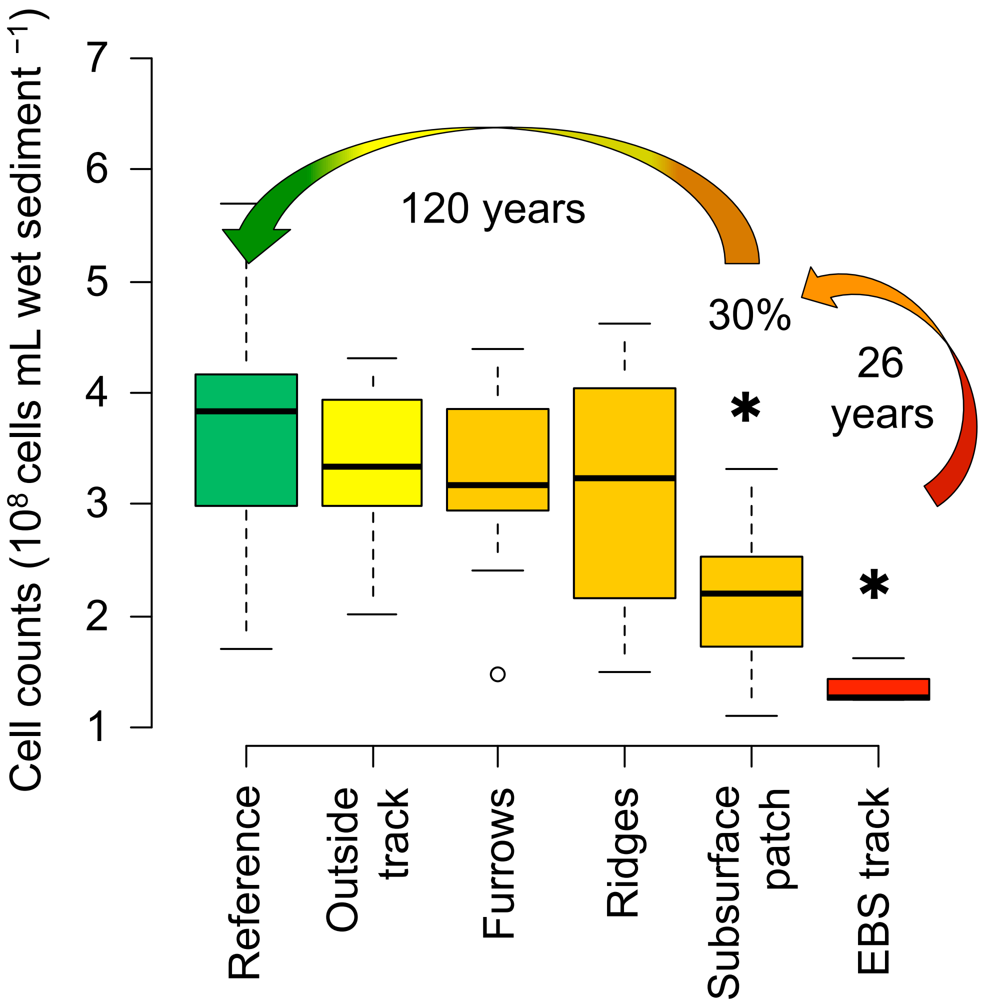


Vonnahme et al., Science Advance. DOI: 10.1126/sciadv.aaz5922

Results | Impact on microbial standing stock and activity

- Cell abundances are still reduced after 26 years in some microhabitats
- Recovery time estimated to be ~ 100 years





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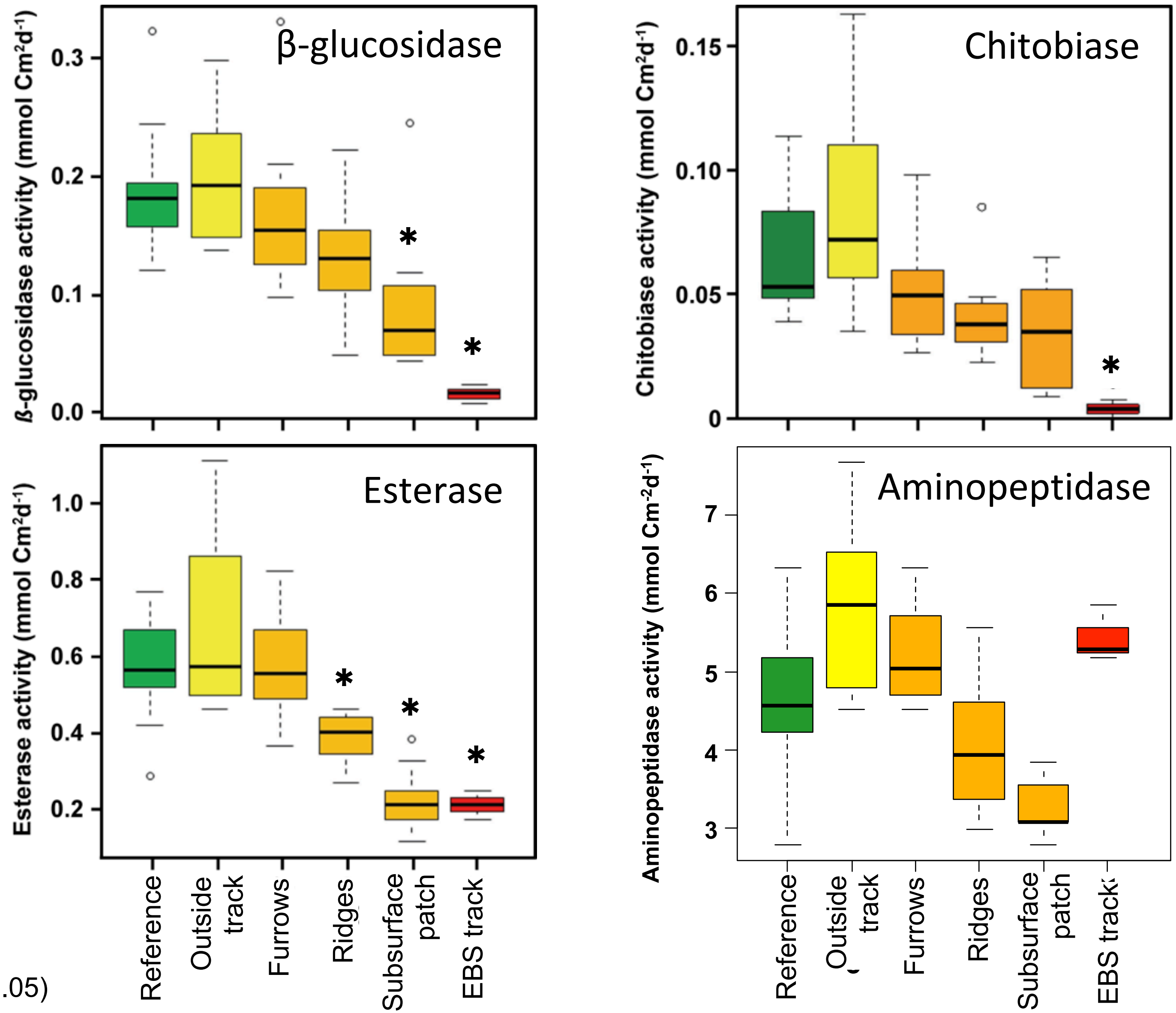
* kruskal wallis test, p<0.05

Results | Impact on microbial standing stock and activity

- Strong effects on extracellular enzymatic activities in disturbance tracks (especially where surface sediments are buried or lost)

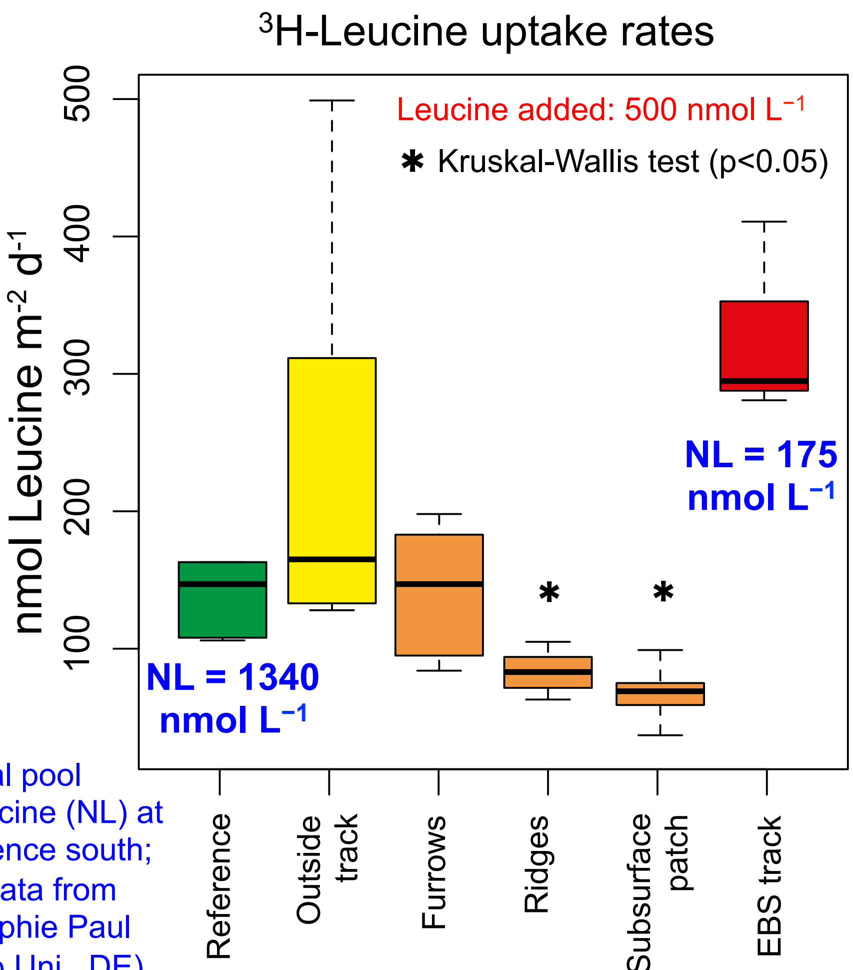


✱ ANOVA (p<0.05)

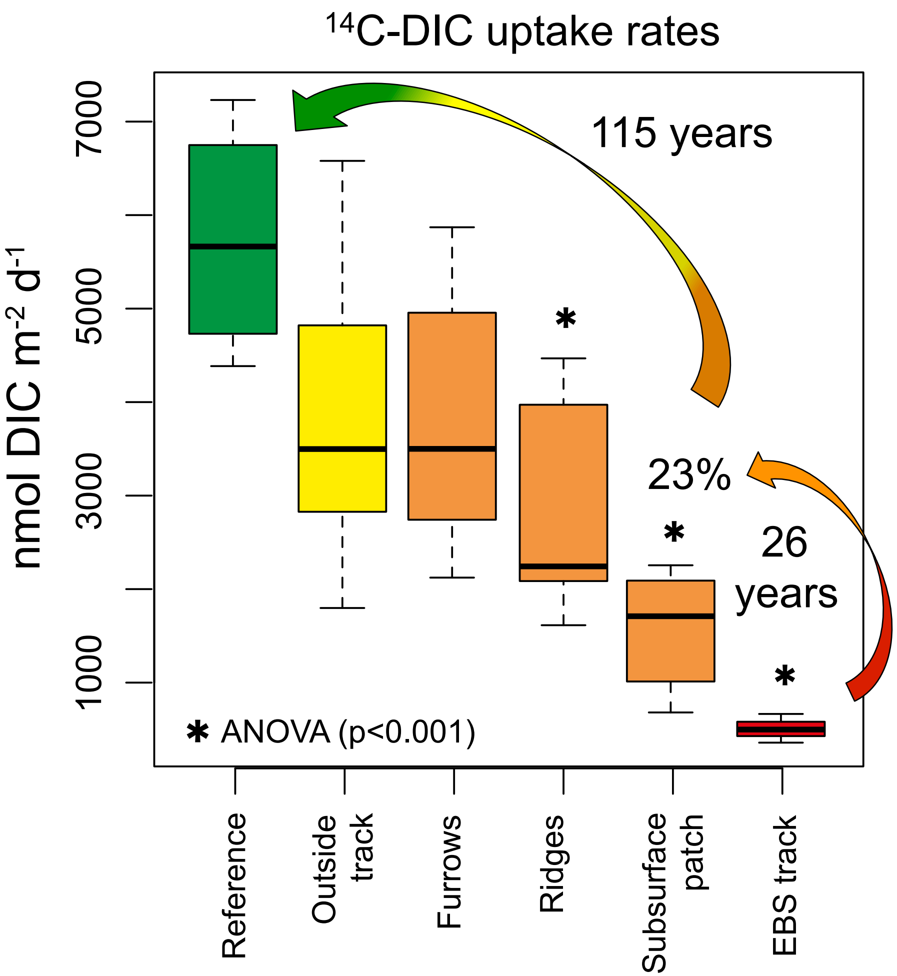
Vonnahme et al., Science Advance. DOI: 10.1126/ sciadv.aaz5922

Results | Impact on microbial standing stock and activity

- Strong effects also on biomass production (inorganic C and Leucine uptake)
- Recovery time estimated to be ~ 100 years
- Stimulation of Leucine uptake in EBS track suggests food limitation



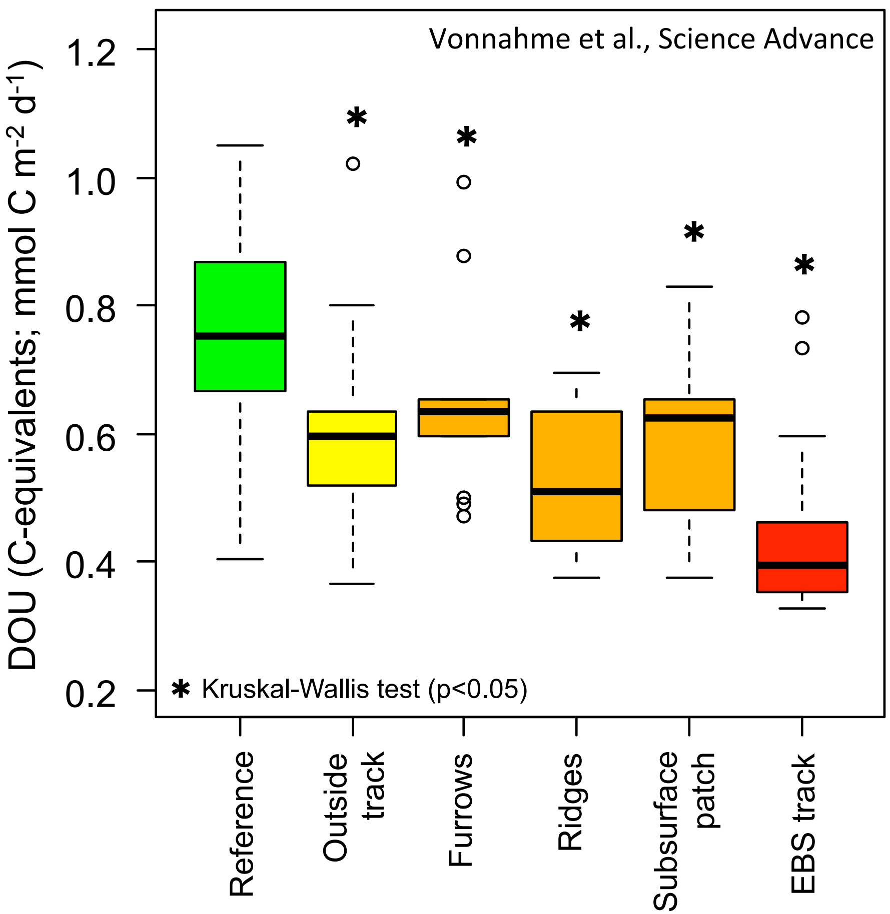
Natural pool of Leucine (NL) at Reference south; DAA data from Dr. Sophie Paul (Jacob Uni., DE)



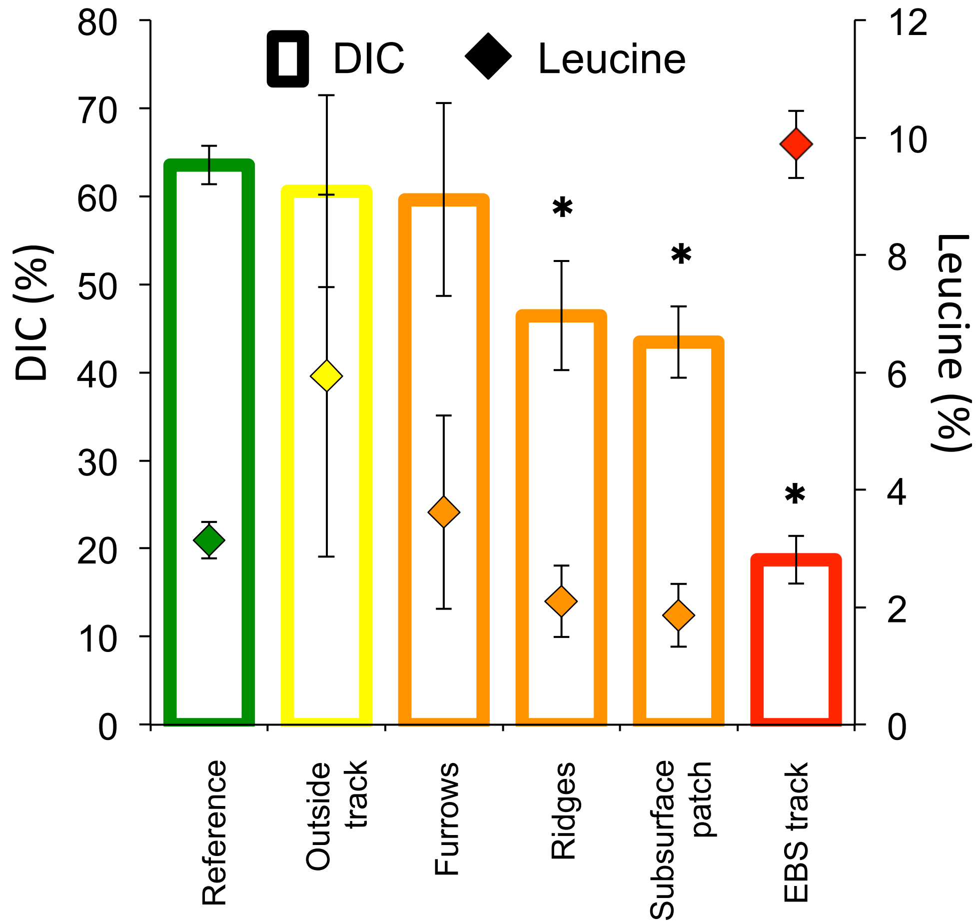
Natural pool of leuicne (NL) assessed with saturation curves at Reference East: 1150-1375 nmol/L

- Oxygen fluxes and grow efficiency generally decreasing with increasing disturbance intensity

O_2 respiration



Grow efficiency [BP/(BP+R)]



Empirical Leucine CF = 1.90 Kg C mol^{-1} Leu (this study, unpublished data)
[theoretical CF: 1.44 -1.55 Kg C mol^{-1} Leu; Simon and Azam (1989); Buesing and Marxsen (2004)]
Empirical DIC CF = 2.54 Kg C mol^{-1} DIC (this study, unpublished data)

Conclusions

- Ploughing created different microhabitats with characteristic changes in physical and biogeochemical conditions
- High spatial variability in microbial communities and activity require extensive baseline studies

  > *Reference / conservation areas need to match characteristics of mined areas (e.g. productivity, nodule coverage, topography) and replication during baseline studies and monitoring needs to cover local variability*

- Carbon cycle (OM degradation and remineralization, and C transfer to food web) is highly impacted and did not fully recover in 26 years (estimate time ca. 100 years)

  > *Identification of key active microbial taxa and processes would help monitoring the recovery of the ecosystem*

- Nodules represent a specific ecological niche (i.e. hard substrate, high metal concentrations, and sessile fauna), with a potentially relevant role in organic carbon degradation and in the cycling of elements.

  > *Assessment metabolic activities / Restoration experiments*

Acknowledgements

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