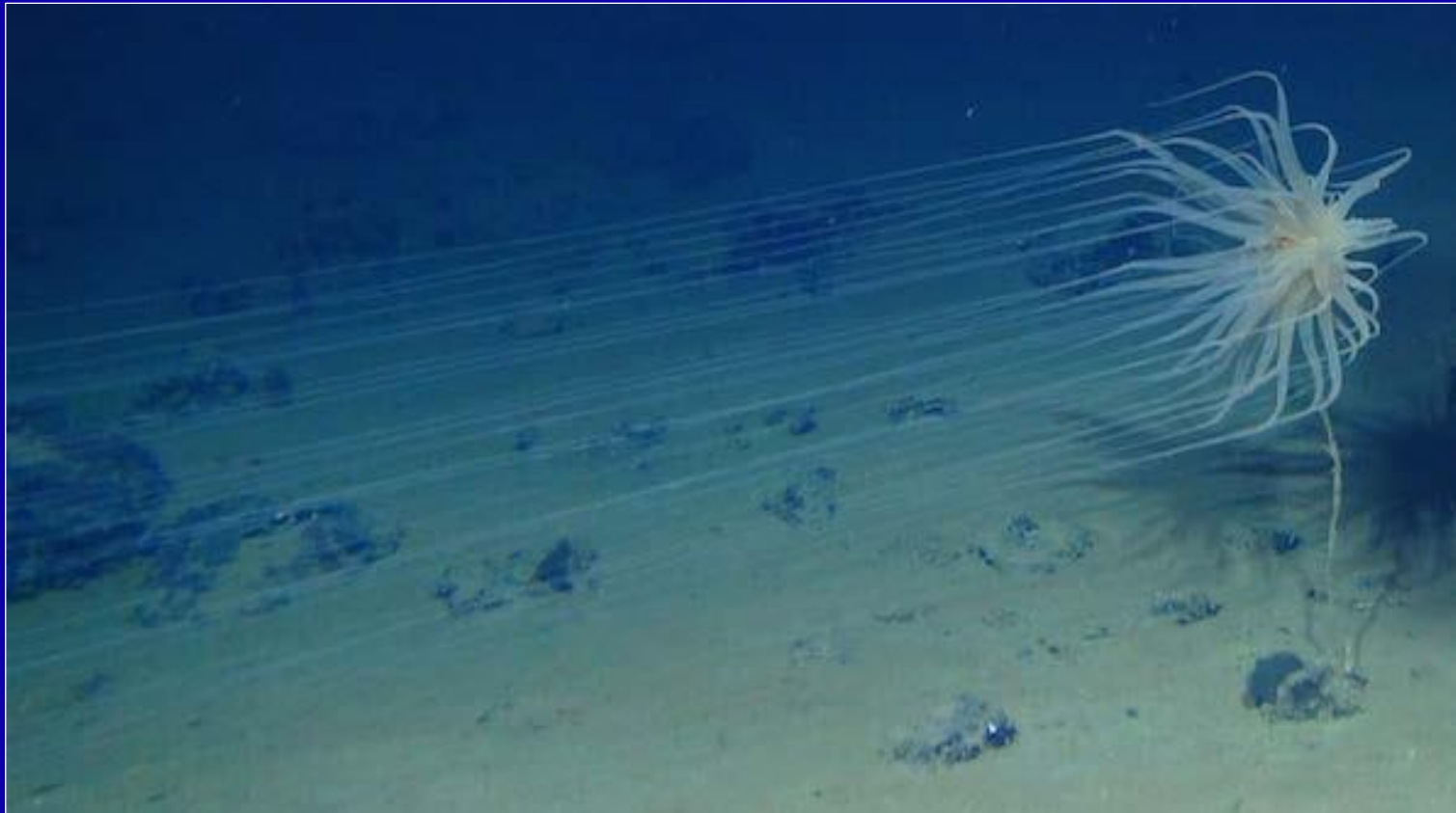


# Ecosystem Characteristics of Abyssal Nodule Fields, Especially the CCZ, Relevant to IRZs - PRZs

*Craig R. Smith<sup>1</sup>, Diva Amon<sup>1</sup>, Iris Altamira<sup>1</sup>, Andreas Thurnherr<sup>2</sup>, with input from many others*

<sup>1</sup>University of Hawai'i at Manoa, Honolulu, HI, USA, [craigmi@Hawaii.edu](mailto:craigmi@Hawaii.edu); <sup>2</sup>LDEO



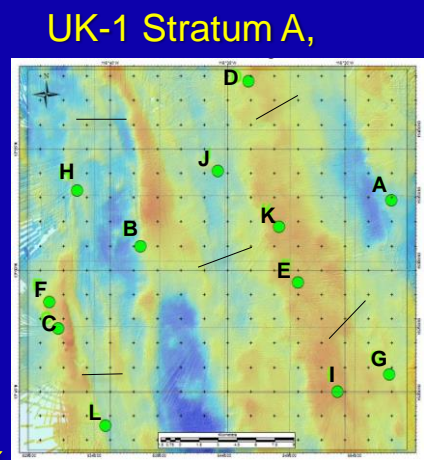
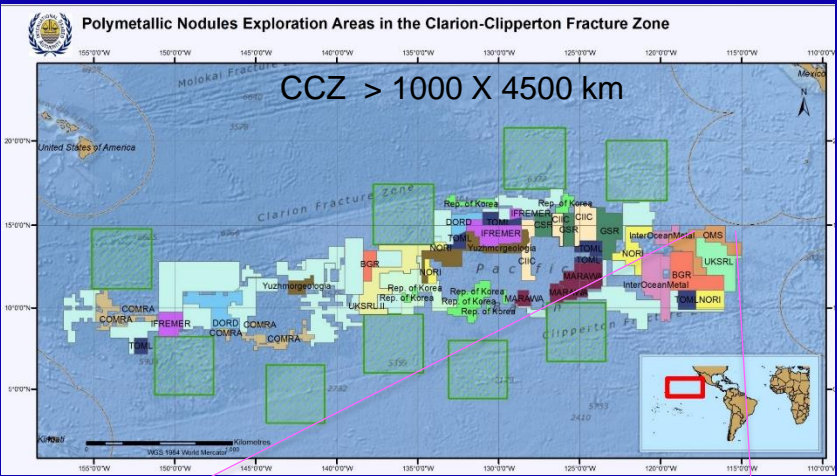
# Characteristics of Nodule Ecosystems

## Outline:

- 1) Physical Characteristics
- 2) Ecological Characteristics
- 3) Regional Patterns
- 4) Suggestion for PRZ Design

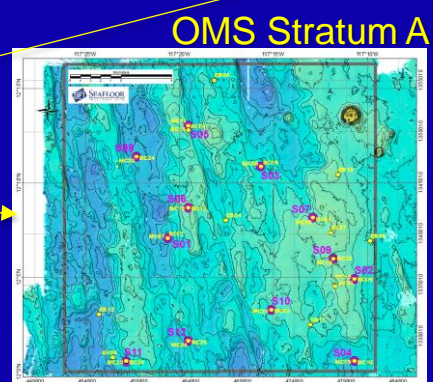
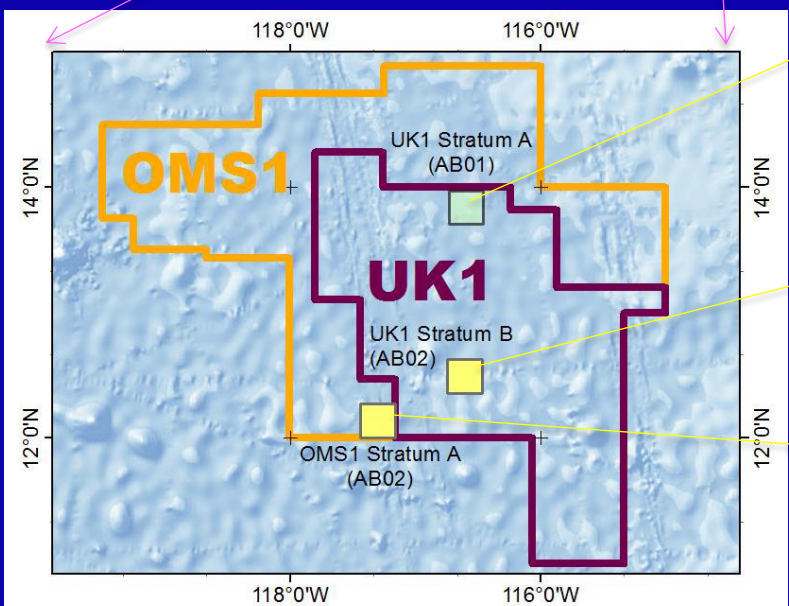
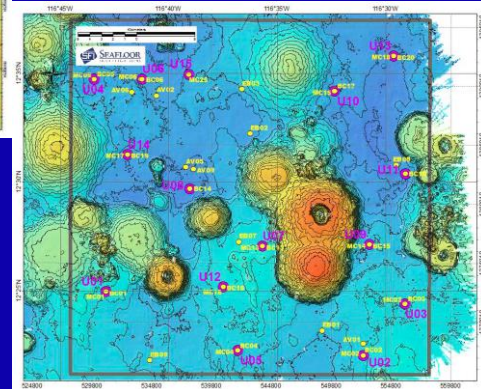
# 1) Physical characteristics – Heterogeneous on multiple scales

**Topography:** Vast expanse of rolling ridges/troughs at 3800–5500 m depths punctuated by volcanic seamounts, outcrops, transform faults



*E.g., 30 x 30 km strata in UK-1 and OMS claims*

UK-1 Stratum B



- Substantial topographic heterogeneity on scales of 10 – 100 km

**Abyssal Seafloor** mostly silt-clay sediments (away from seamounts/faults) with heterogeneous occurrence of nodules (1 m – >10 km); can be substantial vertical sediment heterogeneity (“soupy” surface, backfilled burrows, etc.)



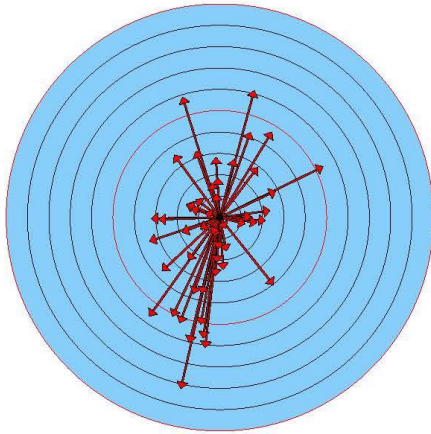
**Conclusion:** *To be physically (and ecologically) representative, IRZs and PRZs must integrate and replicate the full range of seafloor physical heterogeneity (and resultant habitat quality) over scales up to 100 km (e.g., with a nested design for IRZs).*

155W 150W 145W 140W 135W 130W 125W 120W 115W 110W 105W

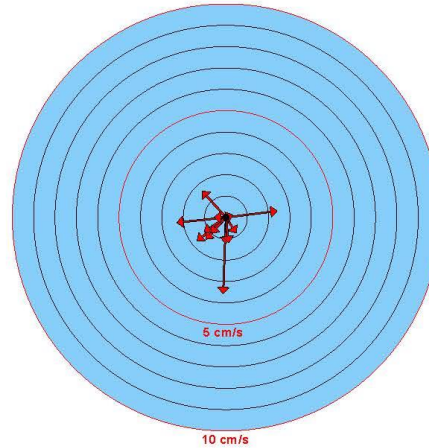
Hydrodynamically, the CCZ seafloor ecosystem is low-energy and stable

## Abyssal Eulerian Mean Velocities

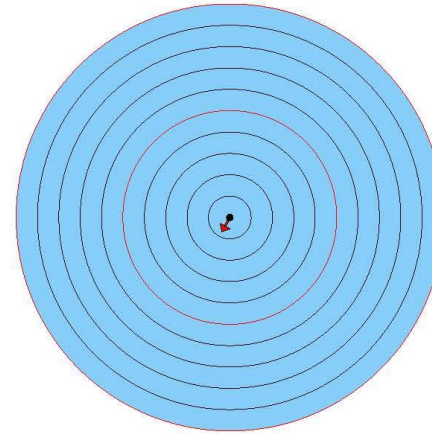
Weekly Averaged Velocities



Monthly Averaged Velocities



Yearly Averaged Velocities



A. Thurnherr, pers. comm.

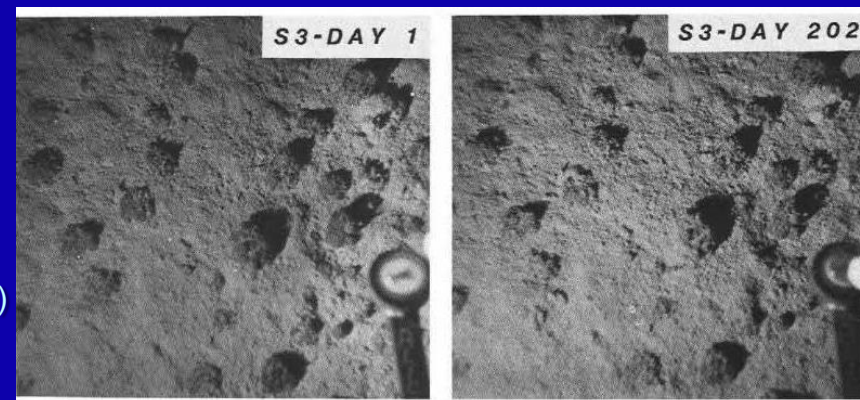
- Max short-term velocities at 4-20 m above abyssal seafloor  $\leq 20$  cm/s, i.e., **less than sediment critical-erosion velocity** (no change in turbidity from min to max flow)
- Over weeks to months, Eulerian mean velocities can be in any direction
- Weekly averaged speeds are dominated by mesoscale eddies (abyssal “storms”)  $\Rightarrow$  mean weekly flow several  $\text{cm} \cdot \text{s}^{-1}$  typical --- **NOT Benthic Sediment Storms!**
- Longer averages of net advection yield smaller speeds; yearly averages often  $< 1$   $\text{cm} \cdot \text{s}^{-1}$

## Consequences:

- 1) Large-scale benthic sediment storms (major erosion/deposition events) unrecorded and likely absent in abyssal CCZ over ecological times scales (major erosion/deposition events = **myth**).
- 2) Sediment-water interface very stable over ecological (decadal +) time scales –

Indicated by –

- Lack of current-related turbidity events recorded in deep current meter + transmissometer + time-lapse camera moorings (e.g., Gardner et al., 1984; A. Vink, pers. comm.; Leitner et al. 2017)
- Lack of major sediment events recorded in long-term, near-bottom sediment traps in CCZ (C. Smith, unpub. data).
- Clear bottom waters in tens of thousands of benthic images and hundreds of ROV/AUV dives throughout CCZ over many decades
- Persistence of intact dredge tracks (cm-scale structure) for decades (26 - 36 y) across CCZ (e.g., Miljutin et al., 2011; Vanreusel et al., 2016)



*Central CCZ floor at 4873 m – after 202 days*



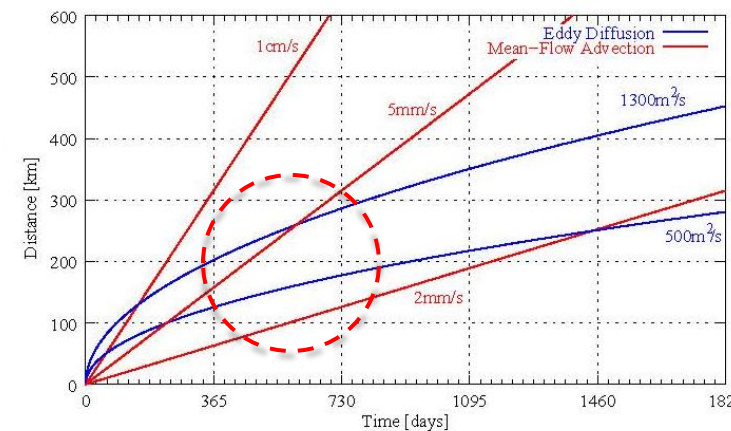
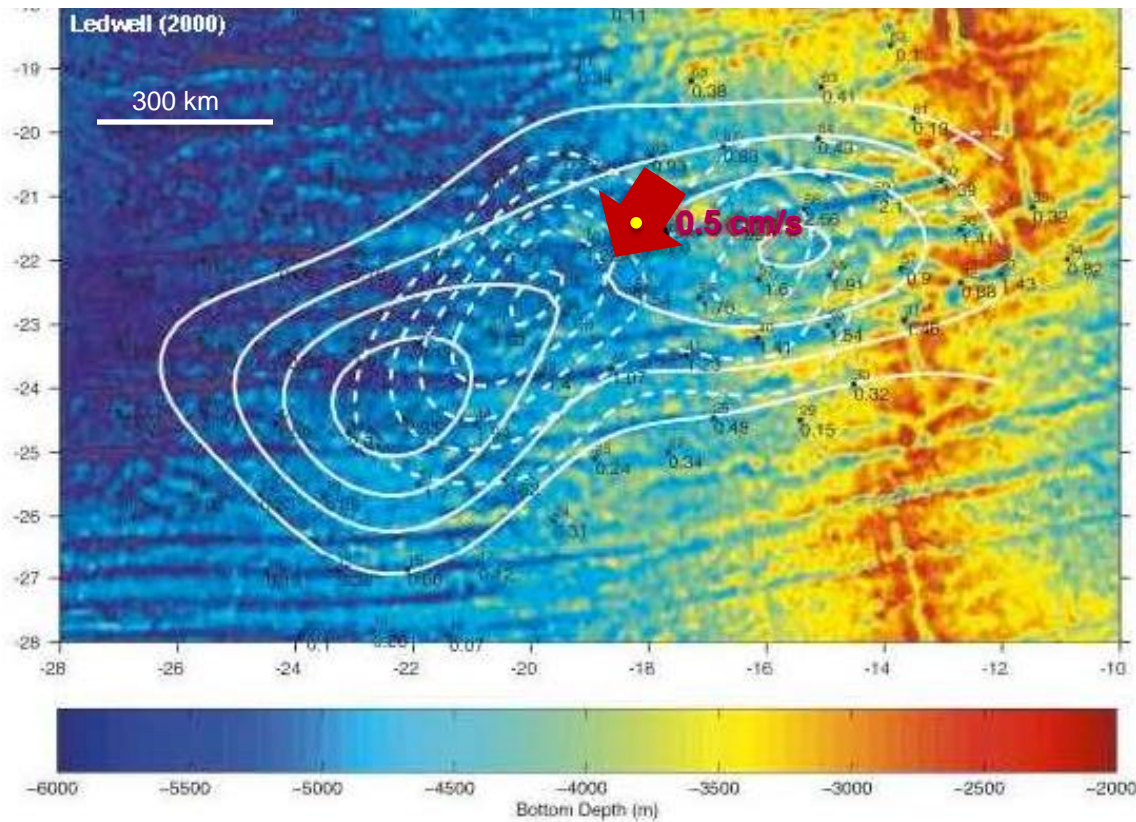
*26-y old test mining track 4800 m  
central CCZ*

# Example of Abyssal Dispersal Over 26 months

Plume dispersal is dominated by eddy diffusion (spreading over 100's of km) with very slow mean advection (0.5 cm/s):

**Everywhere is downstream!**

Sulphur hexafluoride distribution 12 months (dashed) and 26 months (solid) after release at yellow dot near abyssal seafloor

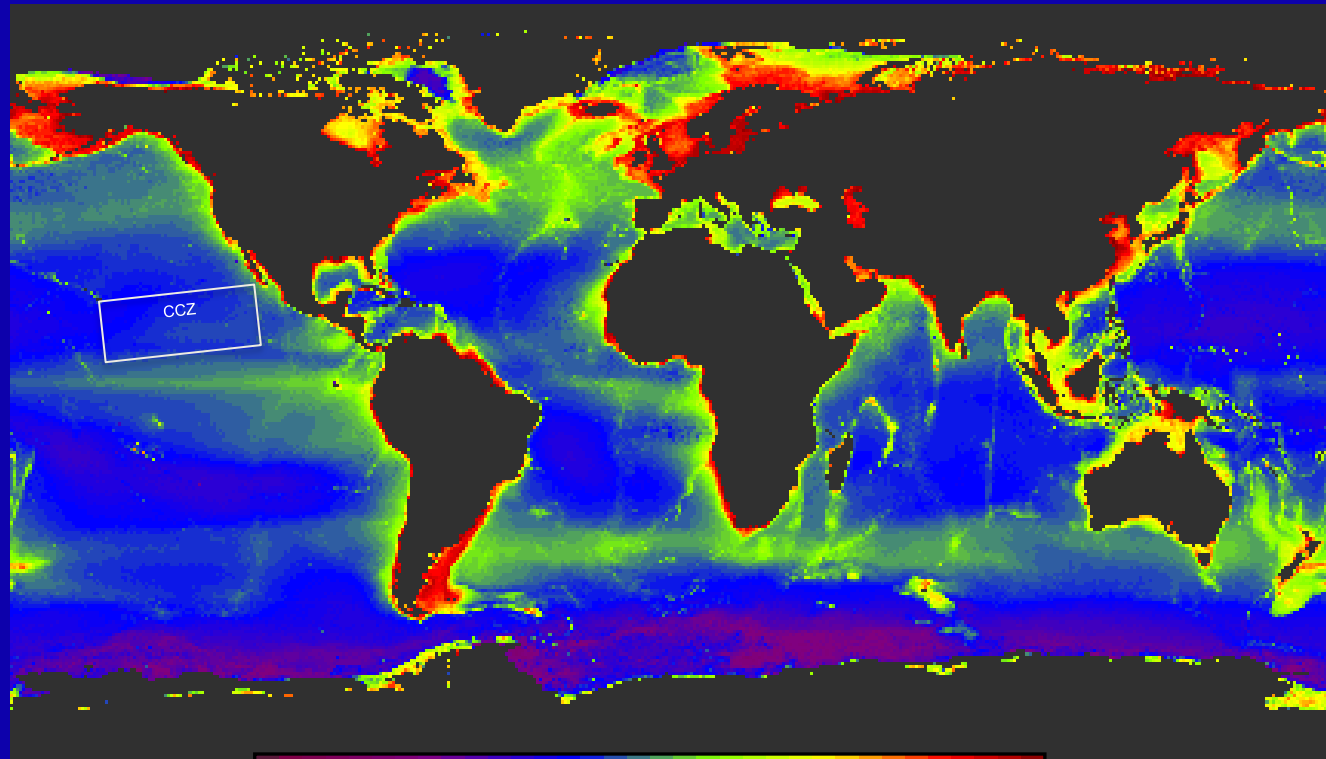
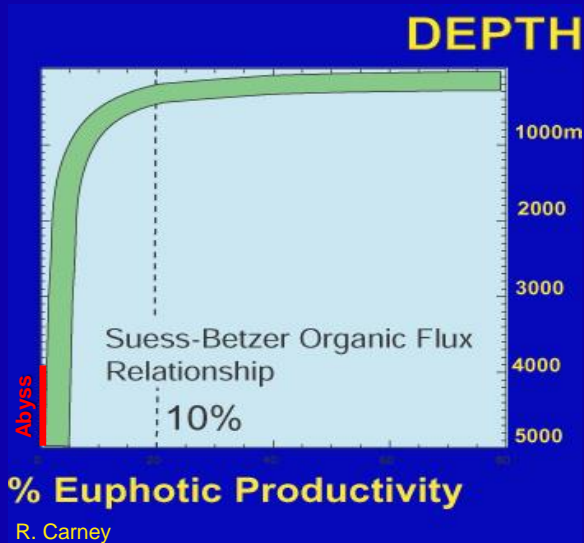


*Conclusion: PRZs will need buffer zones of order 50-100 km on all sides; IRZs will need to address impacts over large scales (10-100 km)*

## 2) Ecological Characteristics of CCZ

### a) Stable, Food-Poor Environment with Low Rates/Resilience

Benthic communities rely on attenuated rain of POC from euphotic zone



Lutz et al., 2007

Annual Seafloor Flux ( $\text{g C}_{\text{org}} \text{m}^{-2} \text{yr}^{-1}$ )



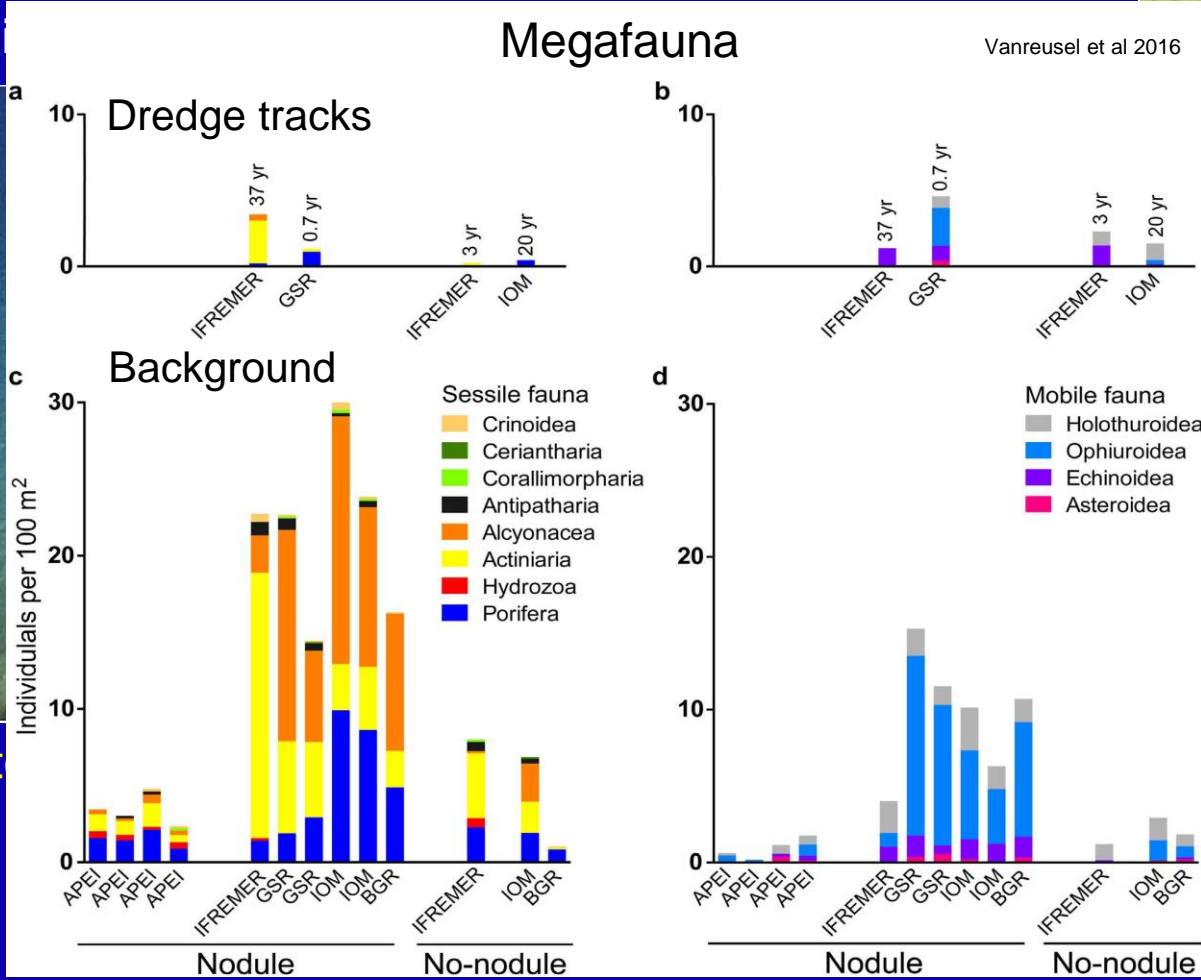
Because of high stability and low POC flux/sedimentation rates –  
 Seafloor ecosystems in CCZ are physically fragile and slow to recover from disturbance -

- Much of habitat structure biogenic (delicate) or nodules
- Soft sediment habitats/communities easily disrupted and



26 y old t

requi

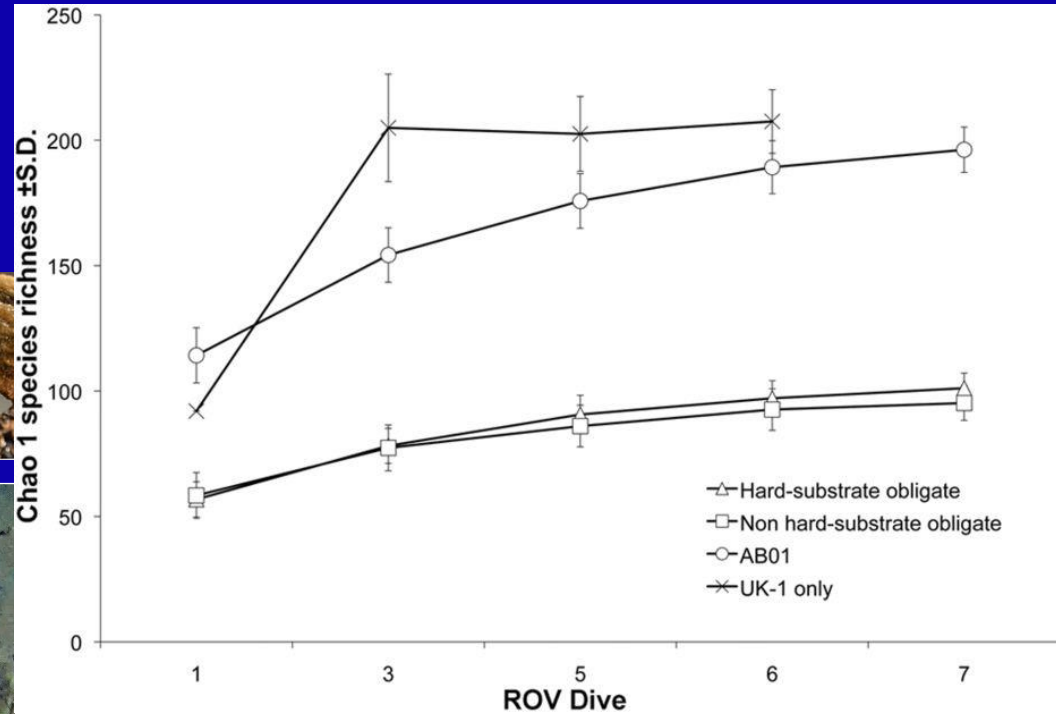
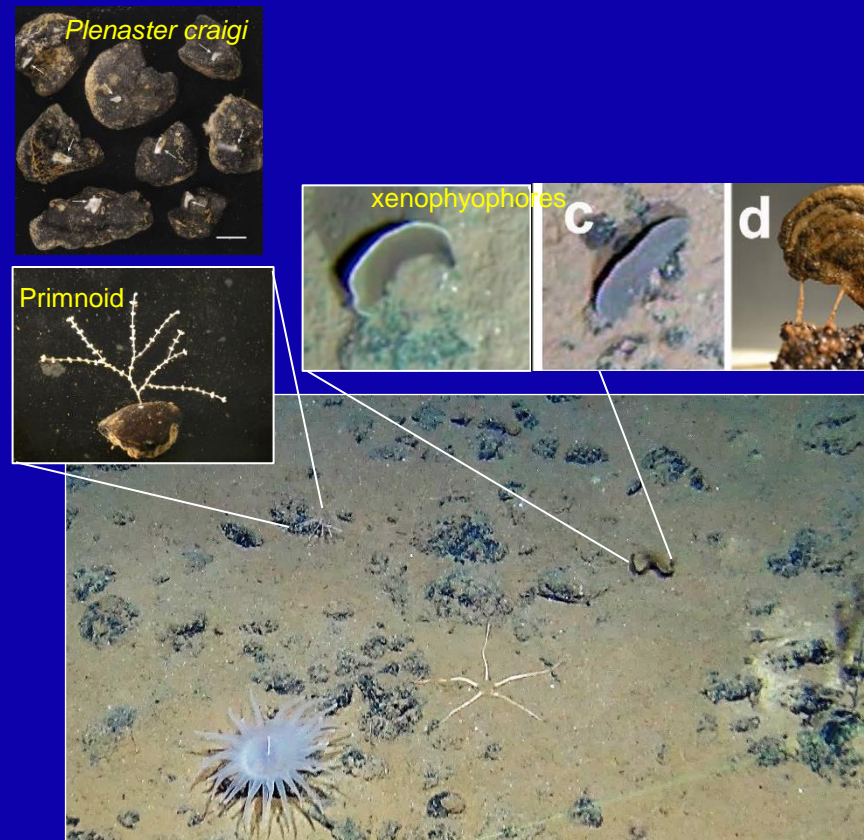


Amon and Smith, ABYSSLINE  
 4200 m eastern CCZ

Nematode abundance and diversity still reduced in tracks after 26 y (Miljutin et al. 2011)

Also true for megafauna (Vanreusel et al., 2016)

# The nodule habitat is also fragile, & harbors a distinct & abundant **obligate** fauna -



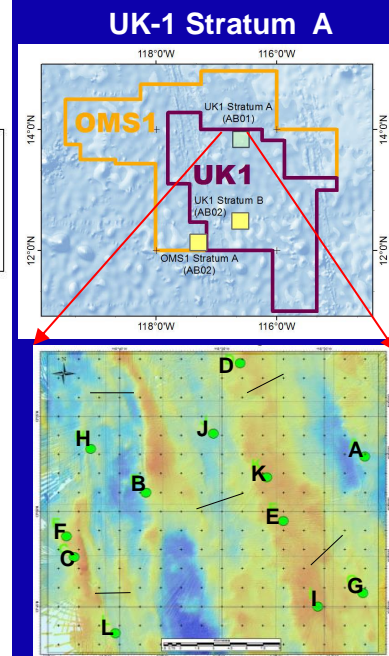
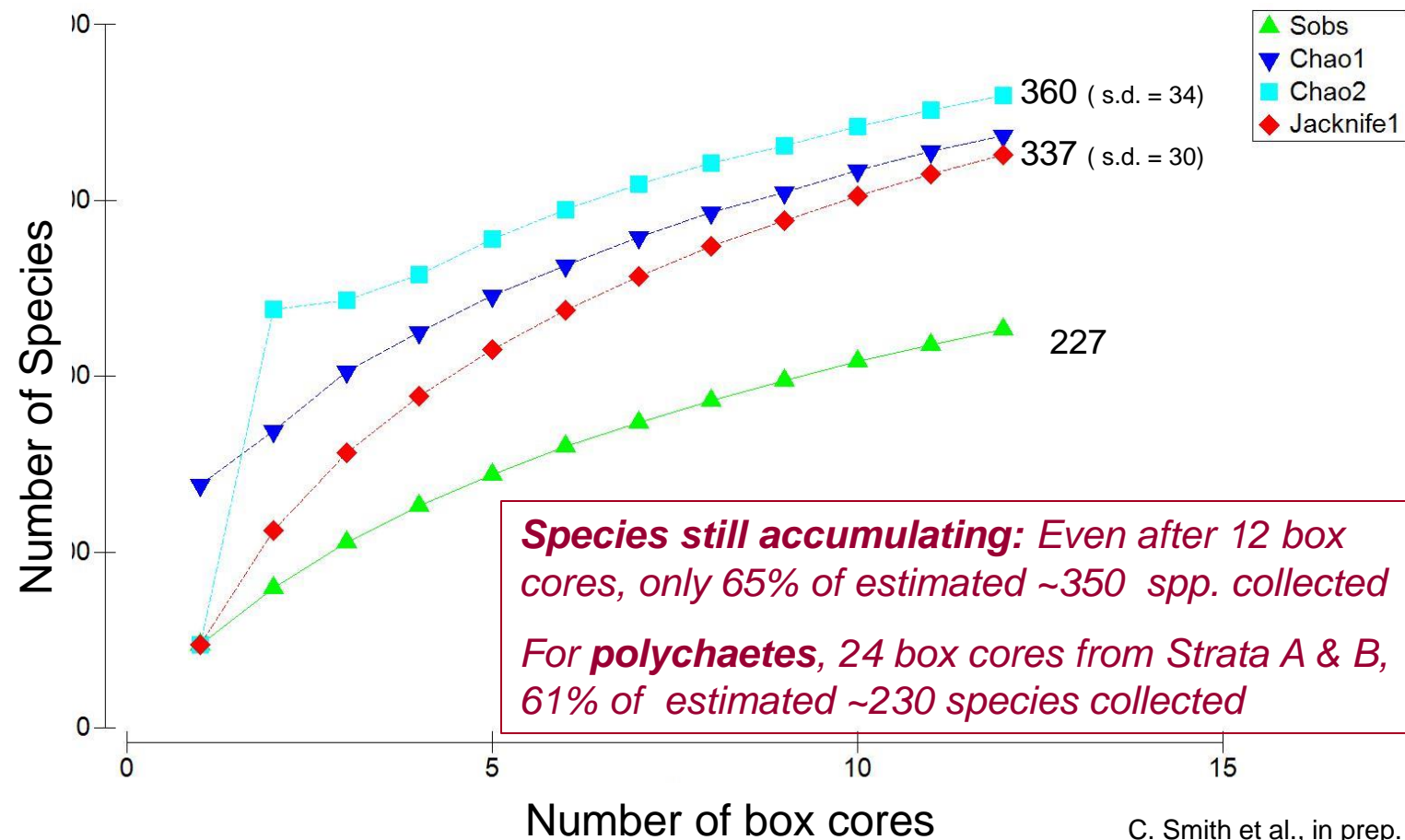
In UK-1 claim, 50% of megafaunal species richness and abundance occur only on nodules (Amon et al., 2016)

*Conclusion: To evaluate sediment community recovery, IRZ's and PRZ's will need to be monitored for decades. (For nodule fauna, even longer – nodule formation requires  $> 10^6$  years)*

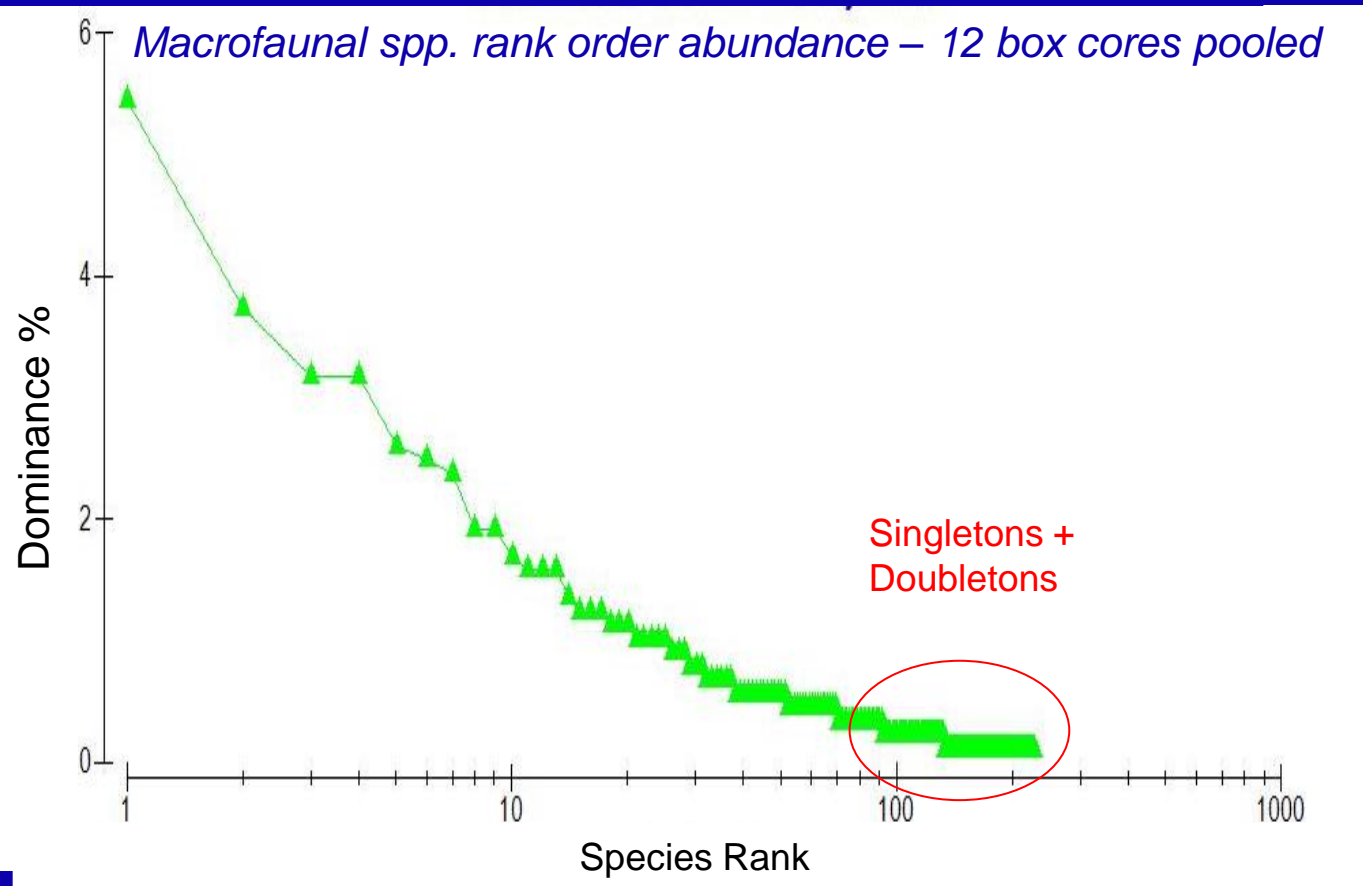
b) The best studied CCZ communities have high local diversity in all benthic size classes - microbes to megafauna

E.g., total sediment macrofauna in 30 X 30 km UK-1 Stratum A: 12 box cores, 880 individuals, 227 species collected!

Macrofaunal species accumulation (green) and species richness estimates in Stratum A



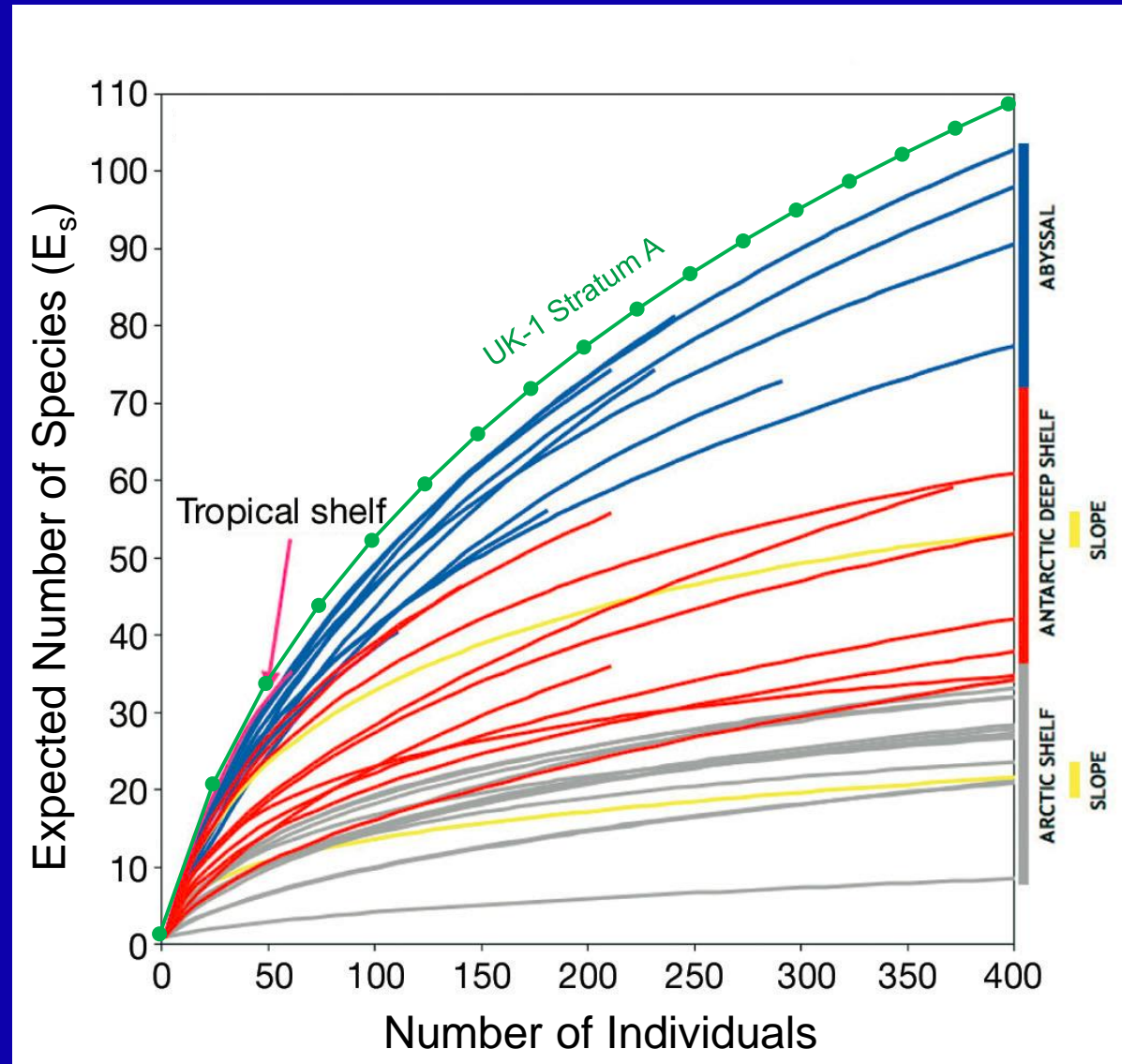
# Why still accumulating species after 12 - 24 box cores in UK-1? Very long tail of rare, undescribed species.



Even with 12 box cores and 900 individuals, **60% of species collected** are singletons or doubletons

*This pattern is common across CCZ*

Macrofaunal species diversity in eastern CCZ is high compared to other deep-sea localities – e.g., Hurlbert rarefaction curve for UK-1 *polychaetes* lies above curves from other soft-sediment localities sampled similarly -



Estimates of polychaete diversity on a multi-sample scale from deep-sea and high-latitude shelf environments made using comparable sampling devices (sediment corers). Other data are from Neal et al. (2011).

# Other size fractions also show high local diversity of poorly described fauna in UK-1 Claim (and rest of CCZ?)

**Bacteria and Archaea** - 113,000 prokaryotic molecular OTUs (16SrRNA genes) with 97,000 only in sediments + nodules, 94% of the MOTUs are new (Shulse et al. 2016)

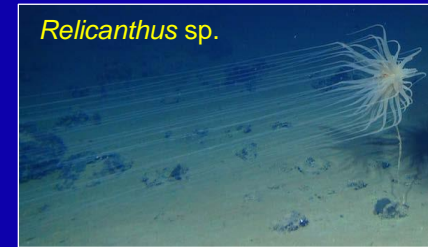
**Xenophyophores** - 29 morphospecies, 28 new to science, = **30%** of known **global** species richness of xenophyophores! (Gooday, Goineau, et al. 2015)



xenophyophore

**Benthic macrofauna** – DNA studies indicate >300 MOTUs of crustaceans, polychaetes, etc., many/most new, with many apparently cryptic species (Glover, Dahlgren and Wicklund; Morhbeck, Martinez, et al.)

**Epibenthic megafauna** – >200 species estimated in UK-1 area, including many new species, e.g., *Relicanthus* sp. in a new suborder of Cnidaria (Amon et al. 2016)

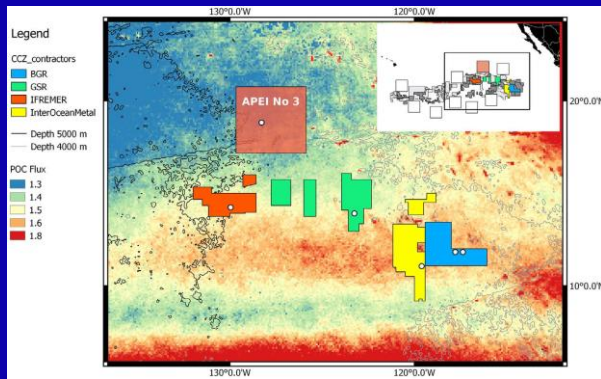


**Mobile scavenging megafauna** – Higher species richness (20) in UK-1 area than on margins of California (7) or Hawaii (12) at similar depths (Leitner et al. 2017)

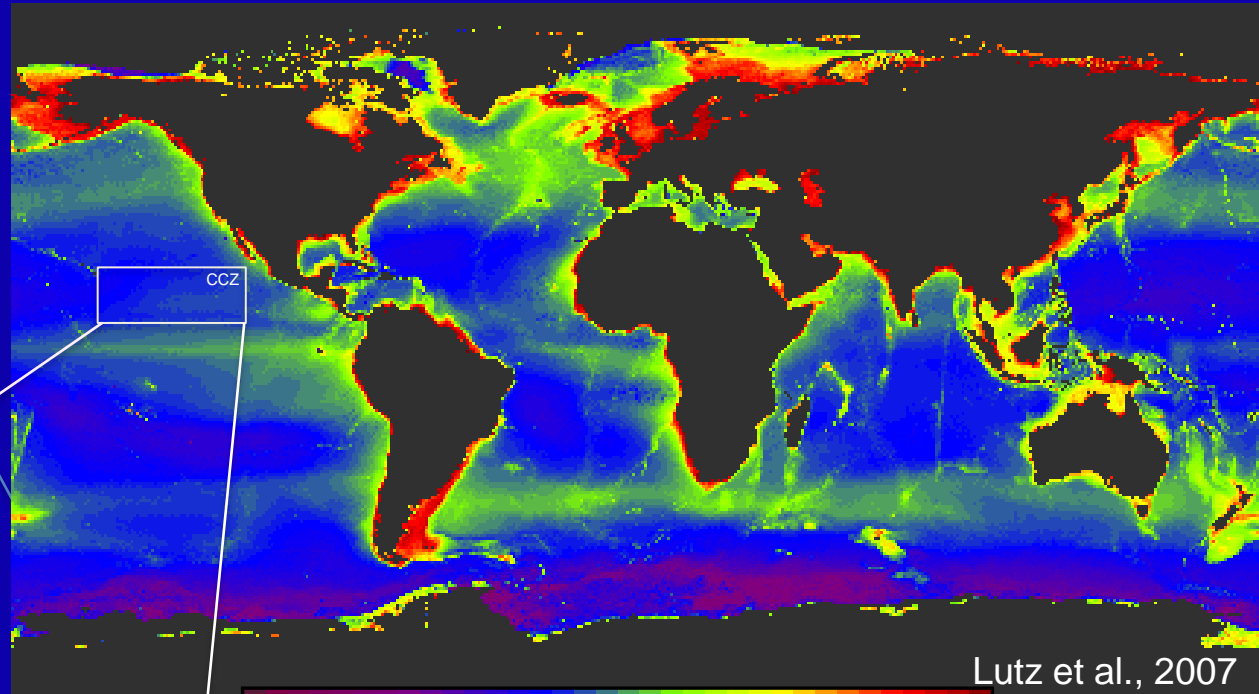
*Conclusion: High diversity and long list of rare species will require intensive sampling (e.g.,  $\geq 50$  box cores at each time pt.) to fully assess local diversity and to track any changes*

### 3) Regional patterns (100 – 4000 km scale)

- POC flux varies substantially (>2X) along and across CCZ



Vanreusel et al. 2016

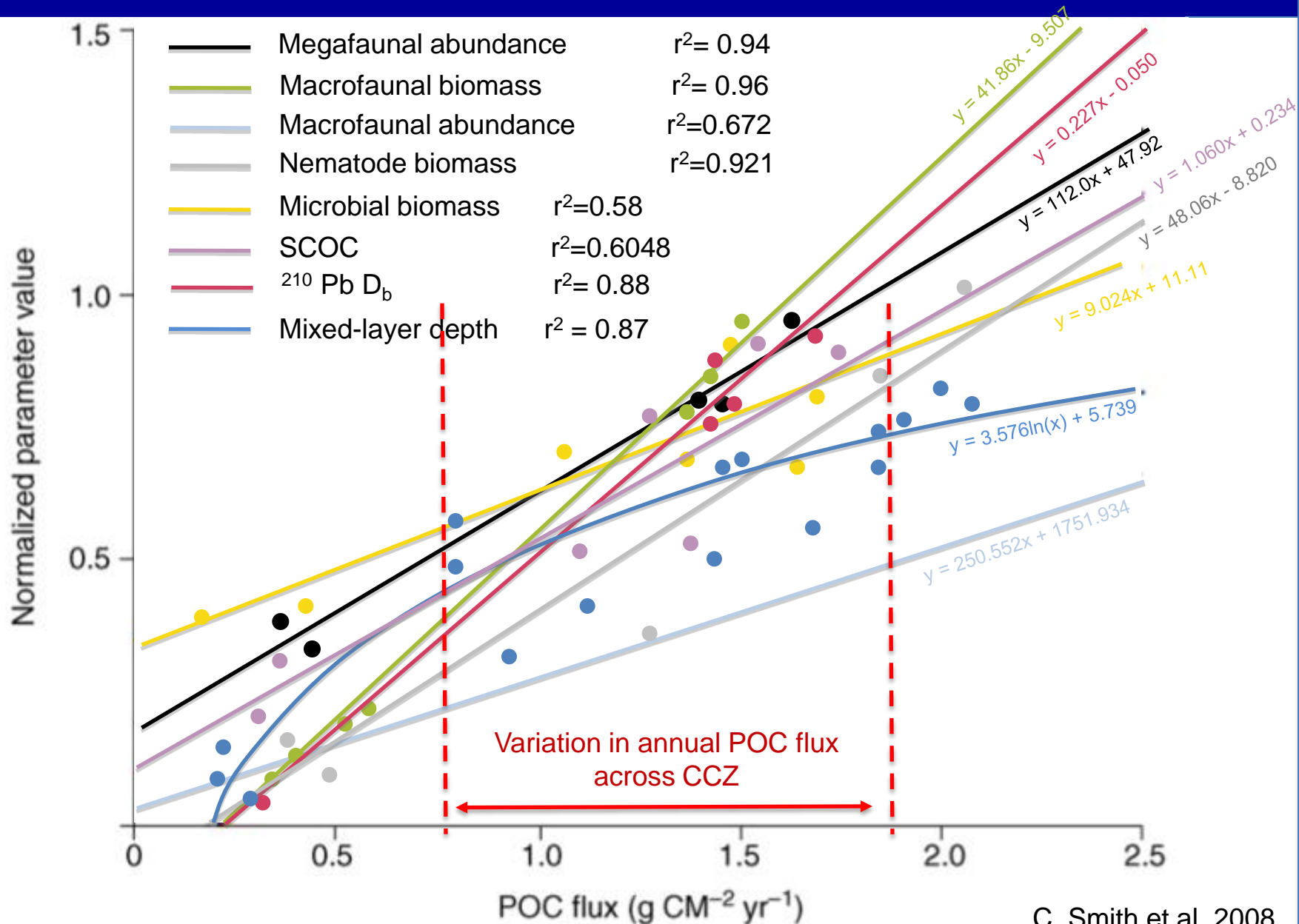


Annual Flux (g C<sub>org</sub> m<sup>-2</sup> yr<sup>-1</sup>)

CCZ

0.8 – 1.9 g C<sub>org</sub> m<sup>-2</sup> yr<sup>-1</sup>

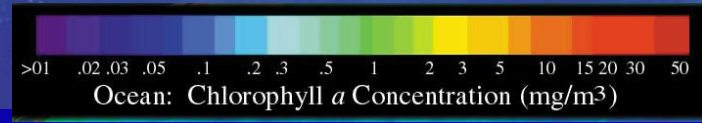
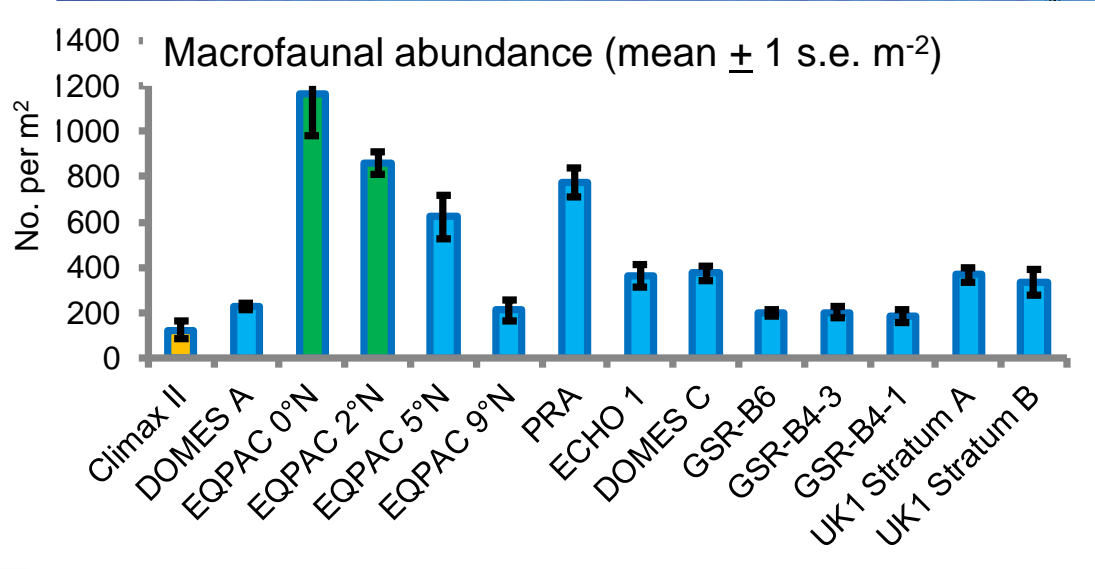
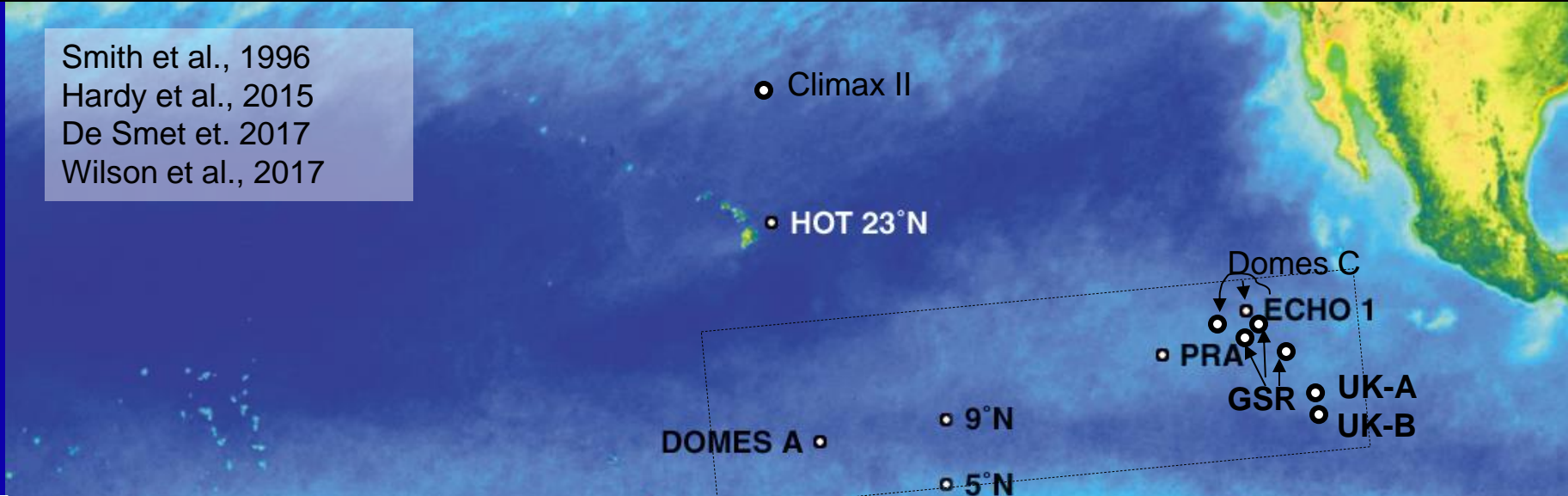
# Abyssal ecosystem structure/function is correlated with annual POC flux and thus also will vary along and across CCZ





# E.g., Macrofaunal abundance varies dramatically (~3X) N-S and E-W within the CCZ

Smith et al., 1996  
 Hardy et al., 2015  
 De Smet et. 2017  
 Wilson et al., 2017

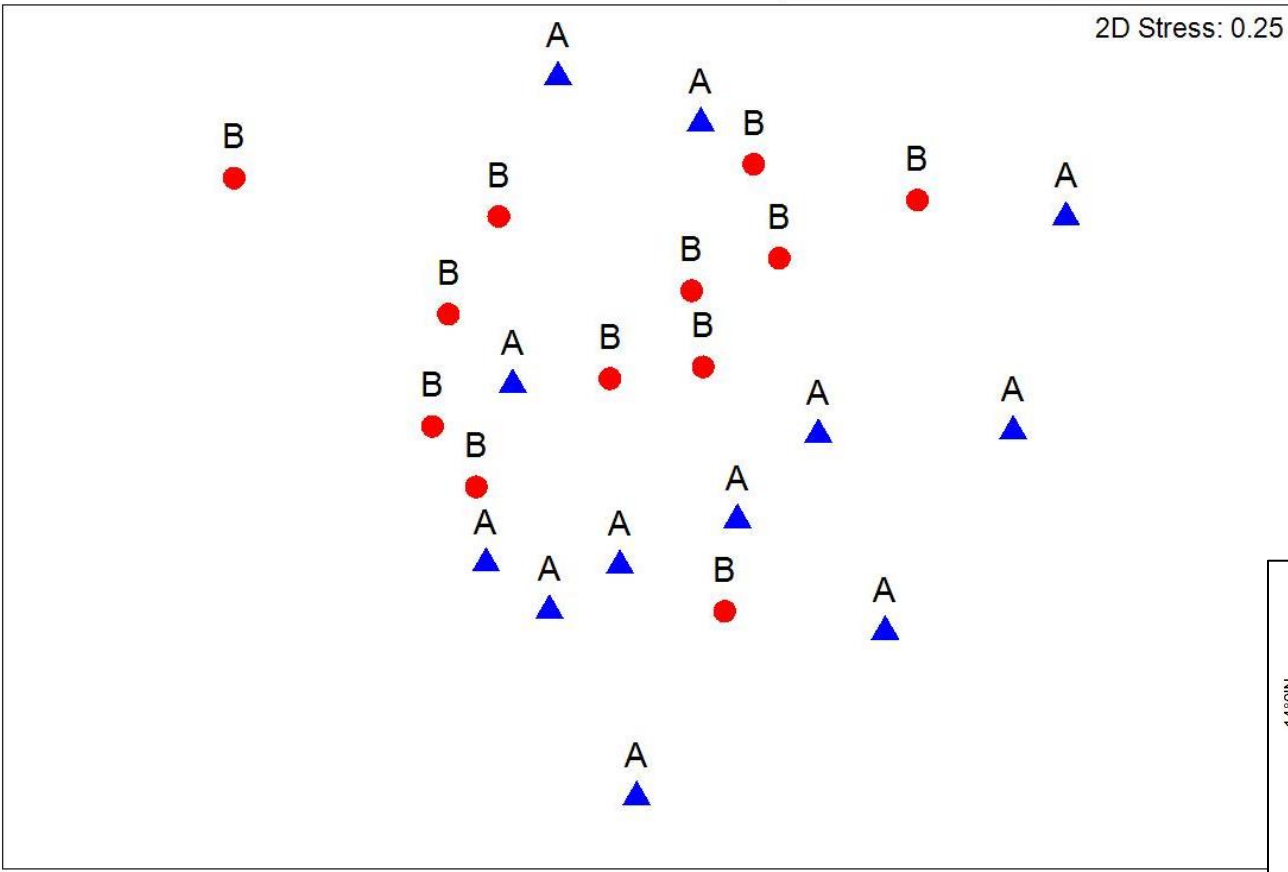


# How does community structure vary regionally?

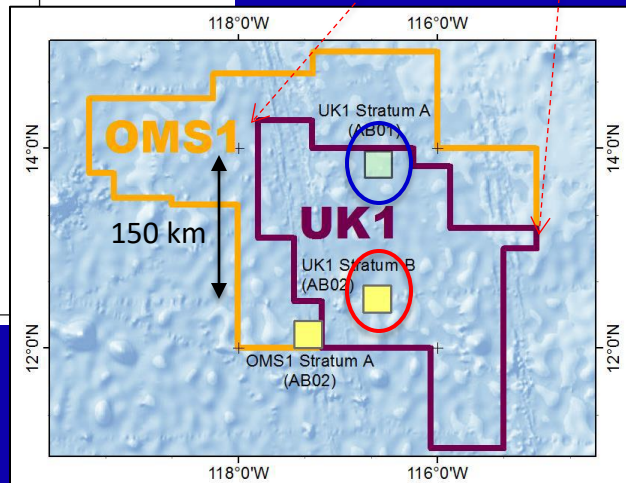
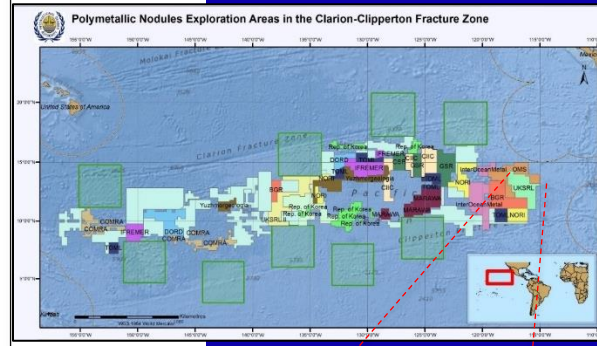
Relatively similar over scales of ~150 of kilometers

*NMDS Polychaete Species-Level Community Resemblance  
UK-1 Strata A & B*

Transform: Fourth root  
Resemblance: S17 Bray Curtis similarity



**Stratum**  
▲ A  
● B



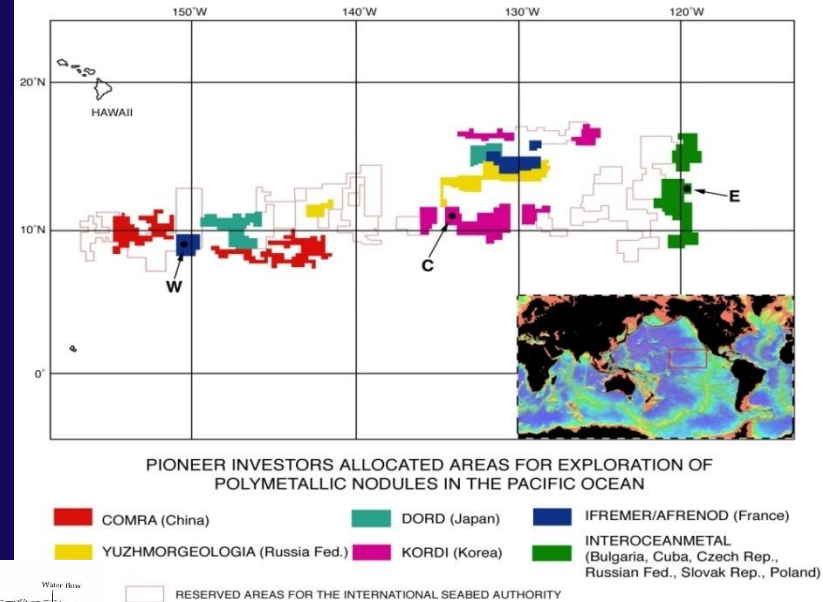
Similar pattern for megafauna (Amon et al., 2017), and for macrofauna in GSR claim area (De Smet et al. 2017)

On scales of 1000 km CCZ fauna and community structure vary -

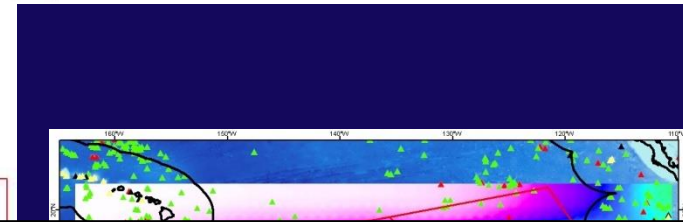
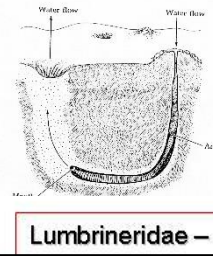
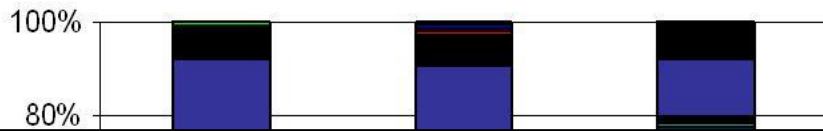
*E.g., three sites in CCZ (~1500 km apart)*

*- Major differences in polychaete fauna at family level (Kaplan Project, Smith et al. 2007)*

*- Likely driven by productivity gradient*



### Polychaete families



### Conclusion:

*Sampling intensity, design, and even “indicator species”, for monitoring IRZs/PRZs will need to vary across CCZ due to differences in faunal abundance and community structure.*

*E.g., to obtain a given level of statistical power, more samples will be needed in sparser communities.*

**Species Ranges?** We see a recurrent pattern:

Positive range-abundance relationships across size classes – prokaryotes to megafauna – (e.g., Bienhold et al. 2016 for bacteria; Glover et al., 2002 for polychaetes, Leitner et al. 2017 for mobile scavengers)

*I.e., rare species are detected at one to a few localities, abundant species often are more broadly distributed.*

**Is this a sampling problem (pseudo-endemism)?**

Or a real characteristic of species distributions (as in terrestrial ecosystems; Gaston 1996)?

*Conclusions:*

*Rare species constituting most of diversity and possibly with highest extinction risk (i.e., with narrow ranges) will be most difficult to monitor.*

*Common species may be generalists with wide distributions and poor indicators of extinction risk for most of biodiversity in CCZ.*

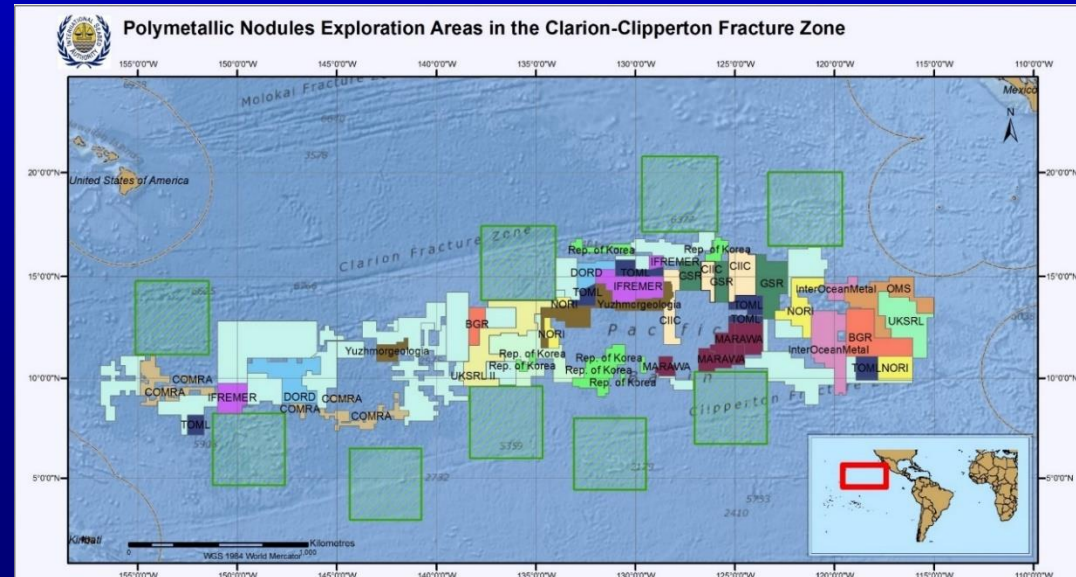
# Recommendations for PRZ design in CCZ:

1) To maintain biodiversity, need core area large enough to integrate full habitat diversity and maintain sustainable populations, i.e., 200 km across (Wedding et al. 2013; Dunn et al. in prep.)

2) To insure protection from mining disturbance (plumes), need buffer zone of order 50-100 km (Wedding et al. 2013; Dunn et al. in prep.).

Cannot really fit such a 300 x 300 km PRZ within current exploration claims (many of which are smaller).

**One approach:** Each existing contiguous claim is divided into halves of equal habitat heterogeneity and resource quality: Half designated a PRZ, the other half mined (similar to establishment of “Reserved Areas”).



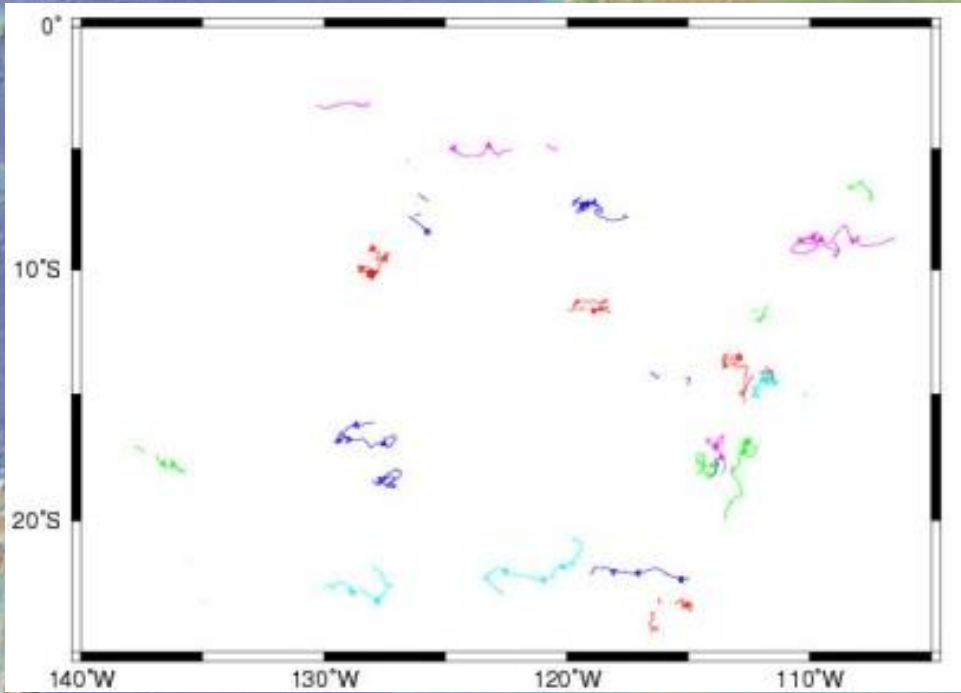


Show *Relicanthus* video if have 1 minute

mx1000



# Neutrally buoyant float movements in the abyss over 533 d plotted on an oceanic scale

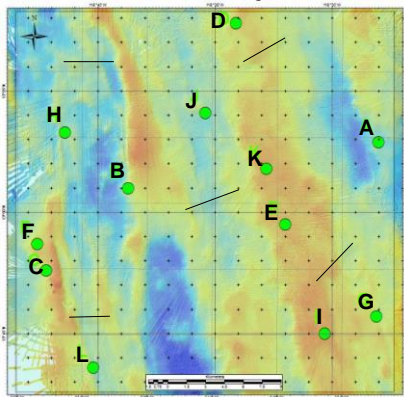


**Anderson-Fontana et al. (1992) – traces indicate dispersal over 533 days for individual floats at 2500 m (n = 40)**

135°E 150°E 165°E 180°E 165°W 150°W 135°W 120°W 105°W 90°W 75°W 60°W 45°W

45°N  
30°N  
15°N  
0°  
15°S  
30°S  
45°S

Within a 30 x 30 km area (UK-1 Claim), and across entire CCZ, nodule abundance highly variable – 2 to 55% cover

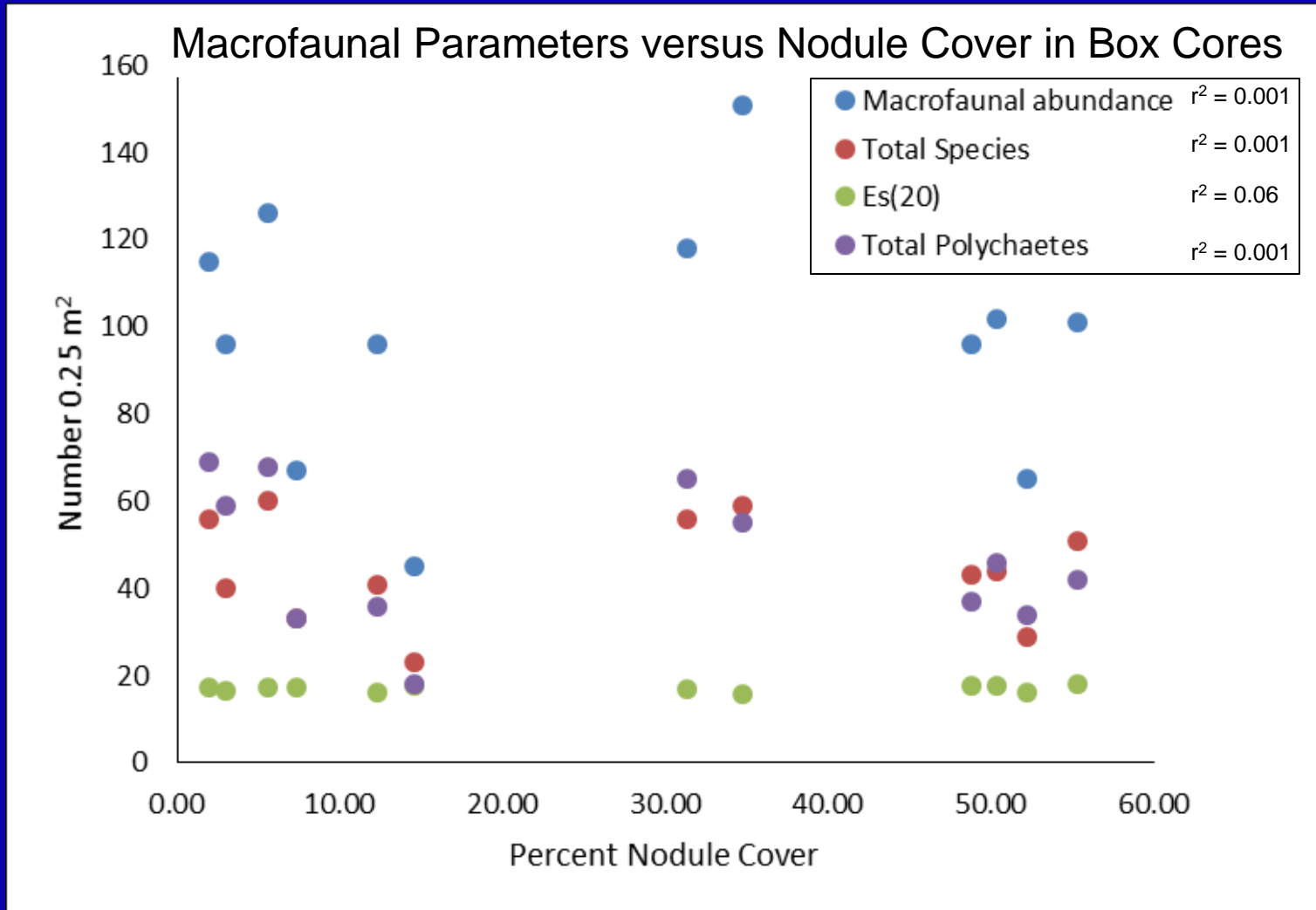


UK-1 Stratum A

Box Core ID	Total # Nodules	Nodule Cover (%)	Average Area per nodule (cm <sup>2</sup> )	Average nodule Feret Diameter (cm)
AB01-BC01	26	5.55	5.34	3.15
AB01-BC04	277	34.79	3.14	2.36
AB01-BC05	251	50.33	5.01	3.01
AB01-BC06	15	14.55	24.25	6.53
AB01-BC07	66	52.17	19.76	6.04
AB01-BC08	58	31.38	13.53	5.19
AB01-BC09	32	7.31	5.71	3.06
AB01-BC10	260	55.34	5.32	3.17
AB01-BC11	8	3.01	9.39	3.52
AB01-BC12	17	12.29	18.08	5.38
AB01-BC13	14	1.91	3.41	2.39
AB01-BC14	236	48.79	5.17	3.12
<i>Mean</i>	<i>105</i>	<i>26.5</i>	<i>9.8</i>	<i>3.9</i>
<i>S.E.</i>	<i>32.7</i>	<i>6.1</i>	<i>2.1</i>	<i>0.4</i>



How do macrofaunal parameters compare to nodule cover in Stratum A?  
Surprisingly, no sig. relationships over broad range of nodule cover (2 – 55%)



We hypothesize that POC flux, rather than soft-sediment habitat space, may control the abundance and diversity of sediment macrofauna in Stratum A.

**Species Ranges?** Poorly constrained due to undersampling of undescribed fauna.

## **Megafauna:**

– Abundant mobile species (e.g., fish, holothurians) distributed broadly across CCZ; rarer forms often collected at only one locality (including fish and shrimp)

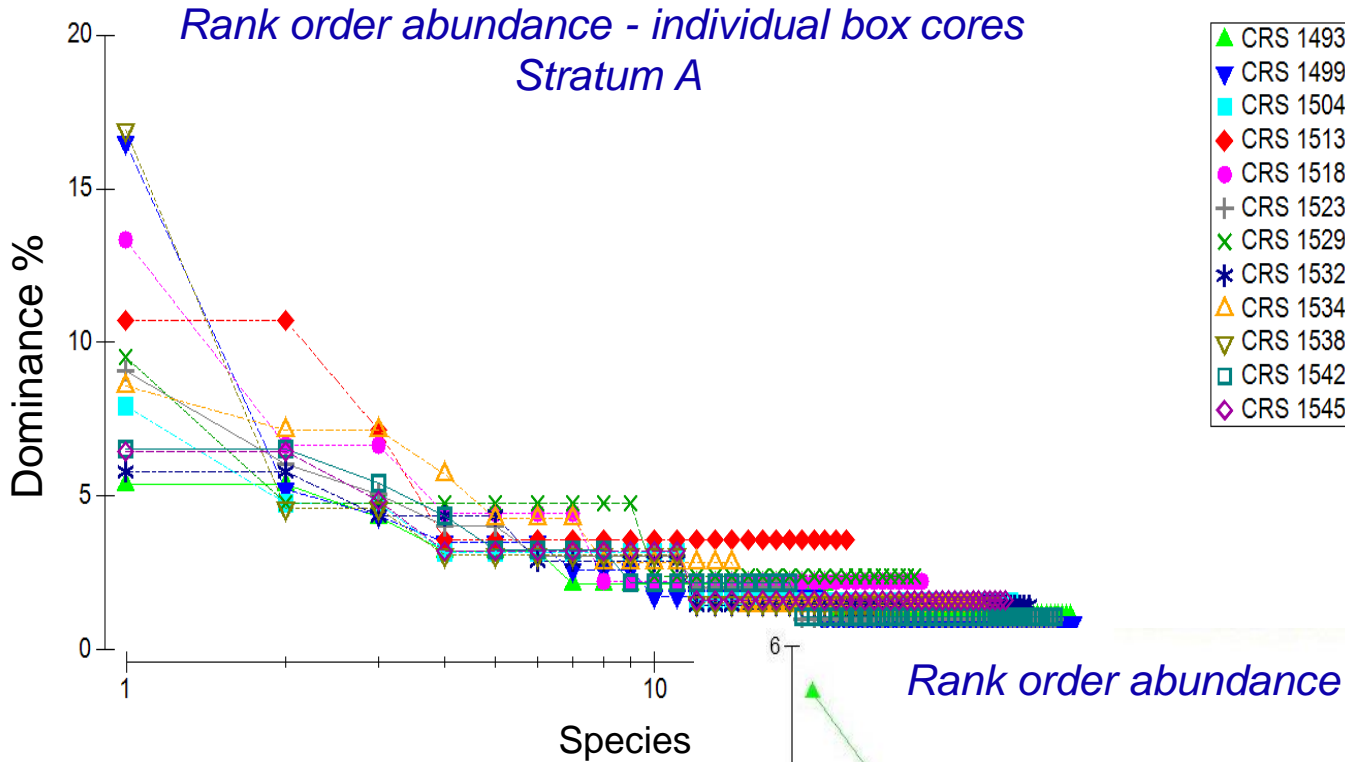
## **Macrofauna (based on morphology and bar coding):**

- Polychaetes, isopods, other taxa
  - Some common species broadly distributed (across claims, across CCZ) Jannsen et al., 2015; Wilson, 2017, work in progress)
- Rare species usually found at only one site (Jannsen et al., 2015)



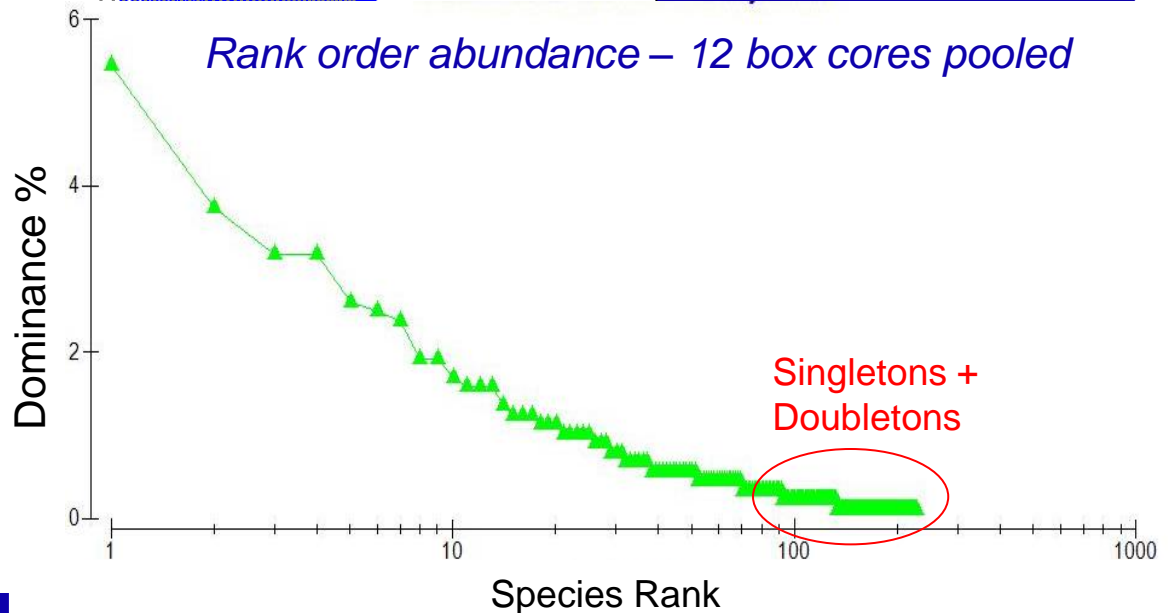
# Why still accumulating species after 12 - 24 box cores?

Very long tail of rare, undescribed species.



~ 90%  
macrofaunal  
of species  
new to  
science!

Even with 12 box  
cores pooled, **60% of  
species collected** are  
singletons or  
doubletons

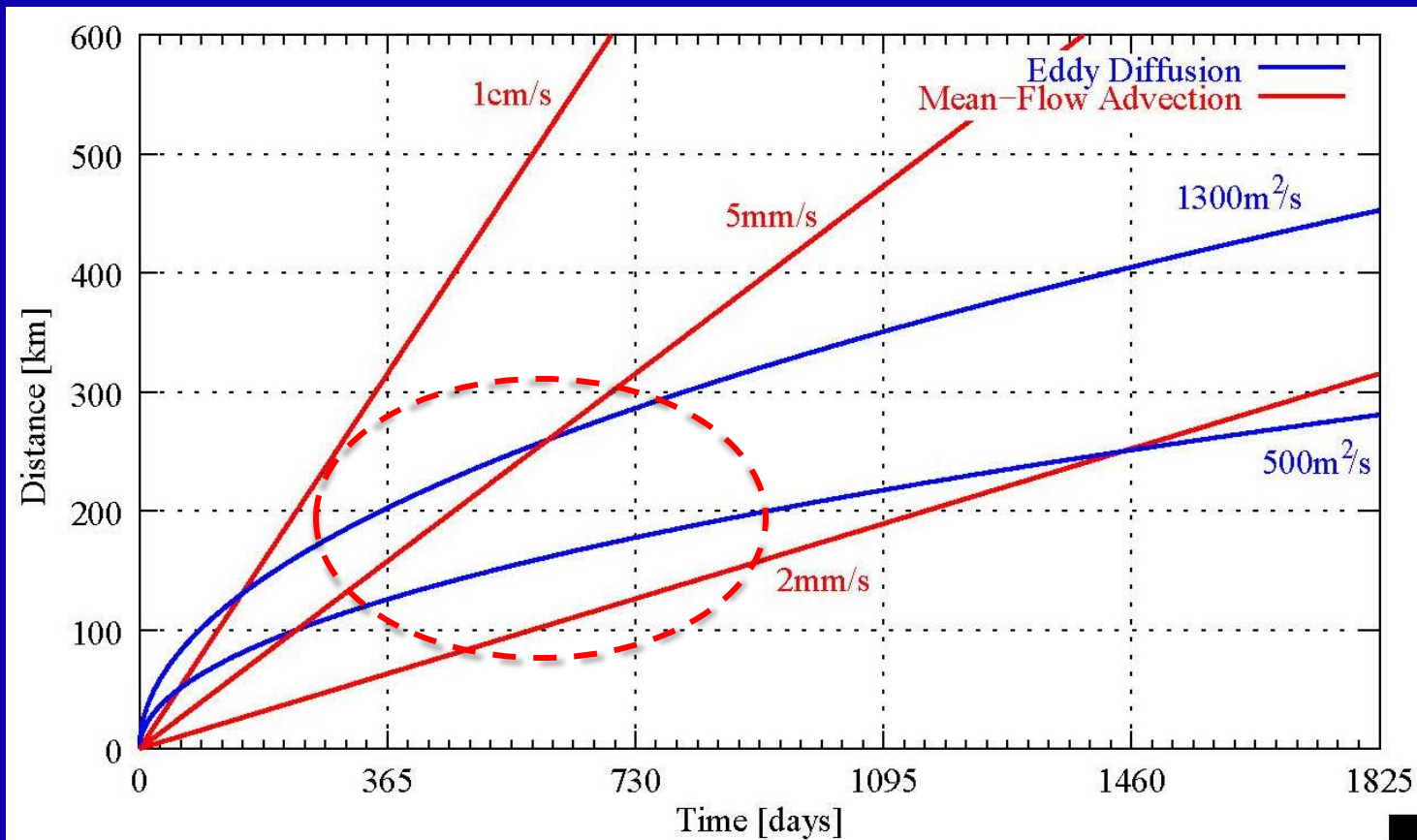


### 3) Dispersal of sediment particles (plumes) and larvae is combination of two effects:

- Advection by low-frequency (mean) flow

- Eddy diffusion (random walk)

- Dispersal on time scales of months to 2 years is often **diffusion dominated**  $\Rightarrow$  dispersal in all directions (everywhere is “downstream”)



# Polycheate Species Accumulation and Estimated Richness

## UK-1 Strata A & B

