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The biodiversity and ecology of deep-sea ecosystems

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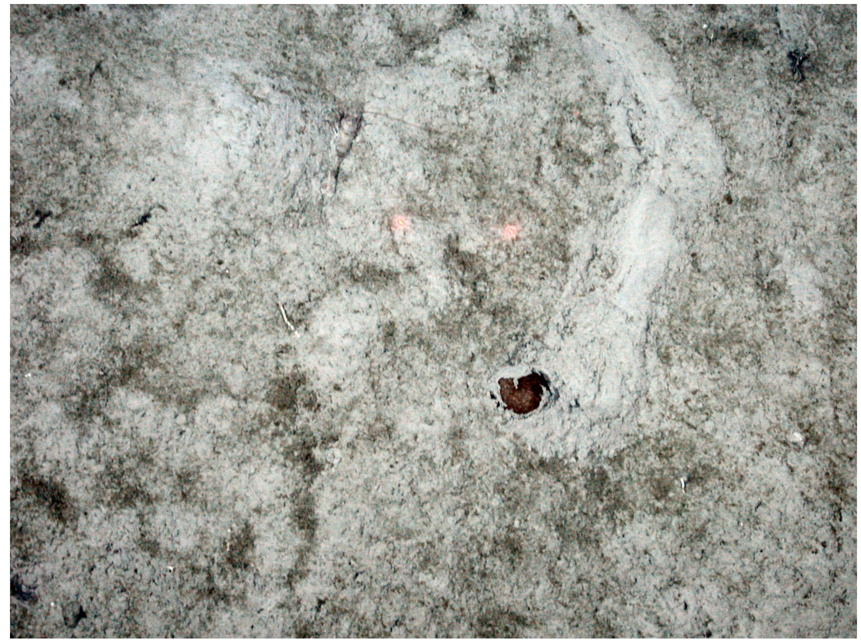
The deep-seabed: mud – lots of it!



Types of sediment

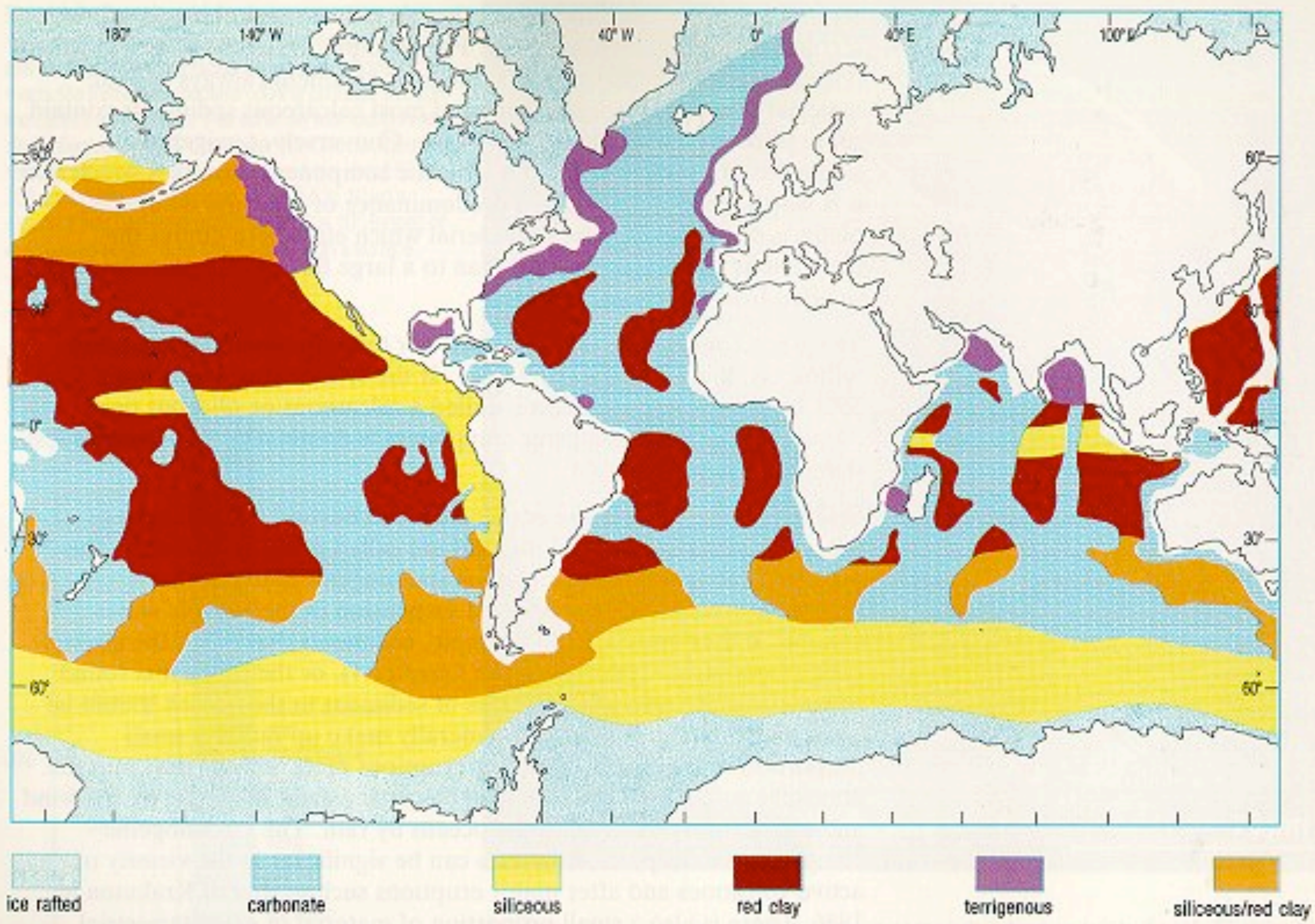
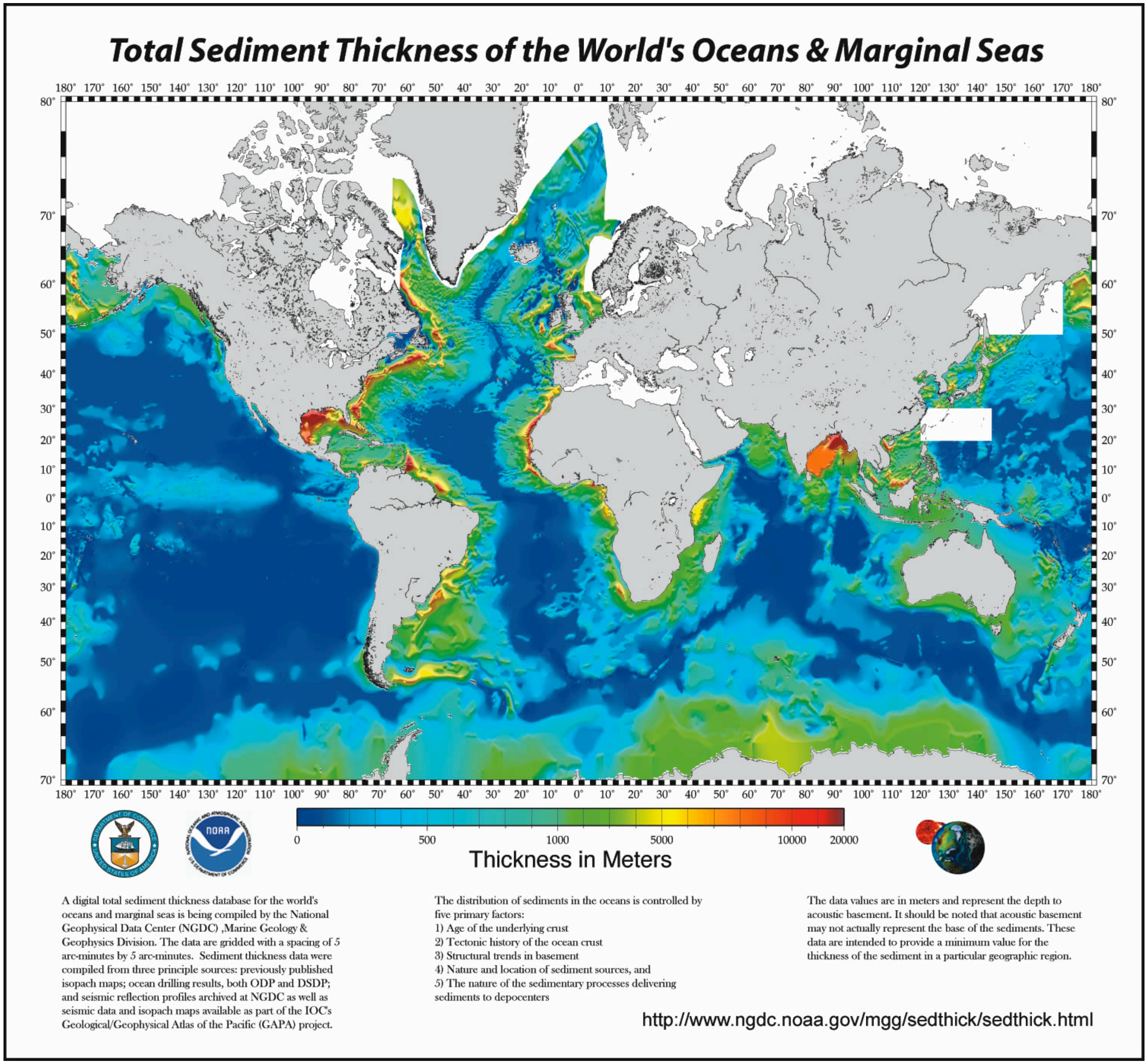
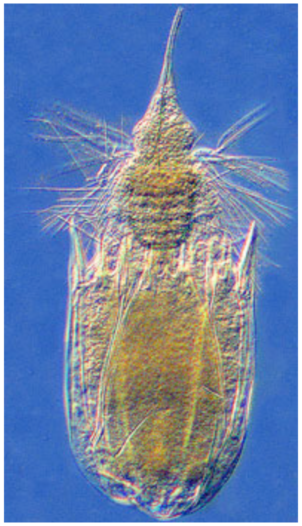


Figure 1.4 Distribution of dominant sediment types on the floor of the present-day oceans. Note that red clays are also terrigenous sediments.

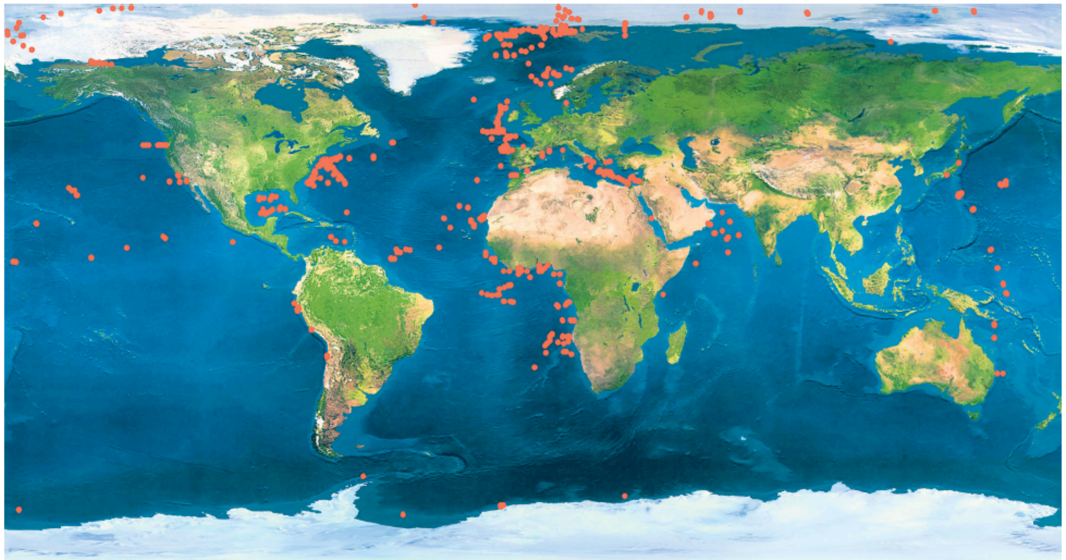
Sediment thickness

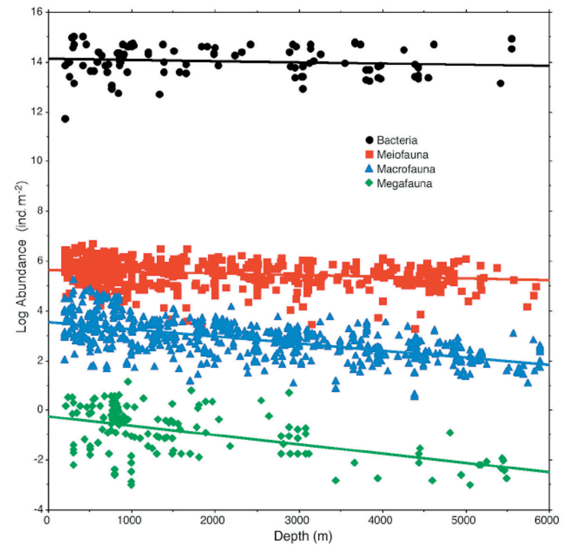


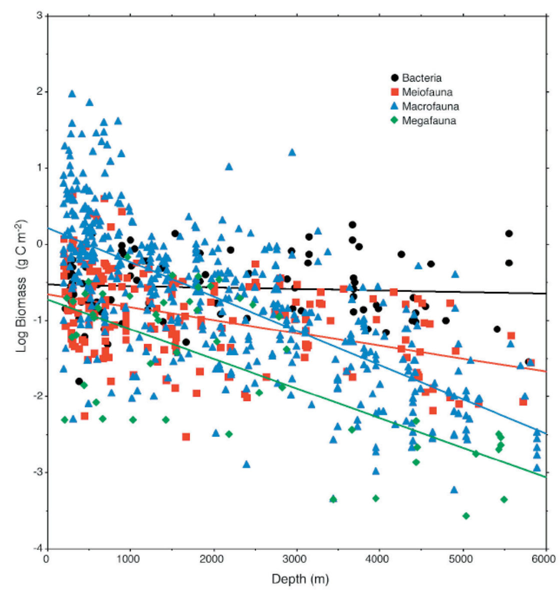
Macrofauna & meiofauna



Global patterns of abundance and biomass with depth







Trend of decreasing abundance and biomass with depth is a global pattern.

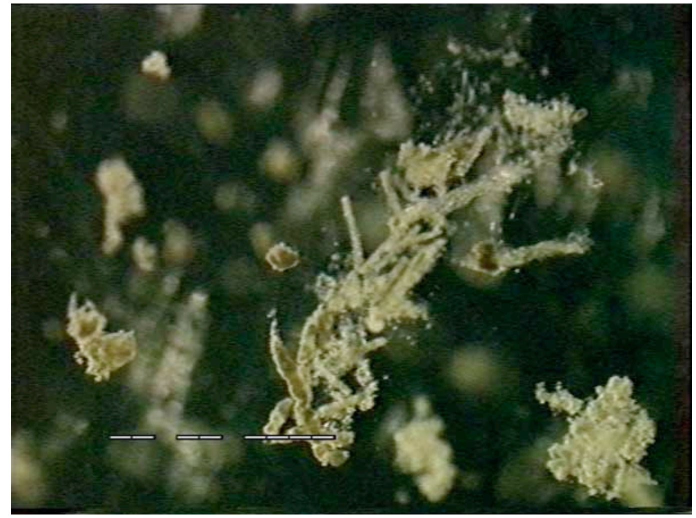
It holds for megafauna, macrofauna and meiofauna but not bacteria.

Rex et al. 2006 Mar Ecol Prog Ser 317: 1-8

Decreasing food supply with depth

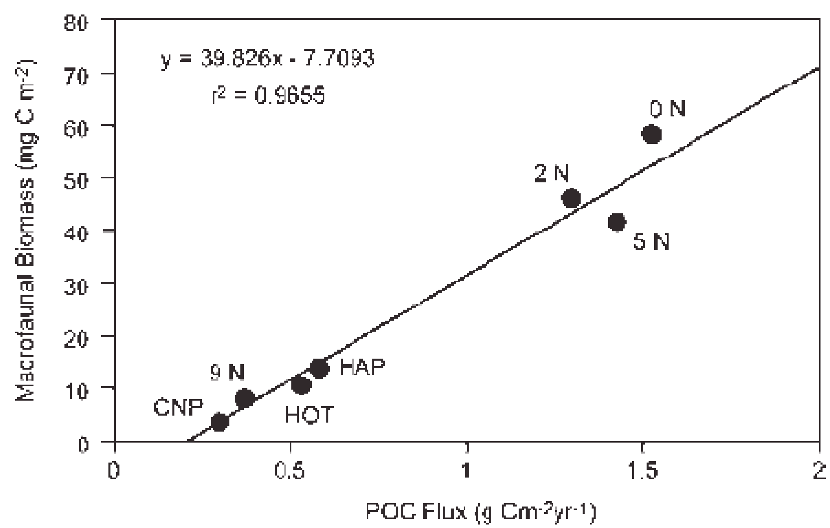
Most deep-sea ecosystems rely on the sinking of organic material from the surface water layers for food.

Marine snow (particulate organic carbon).



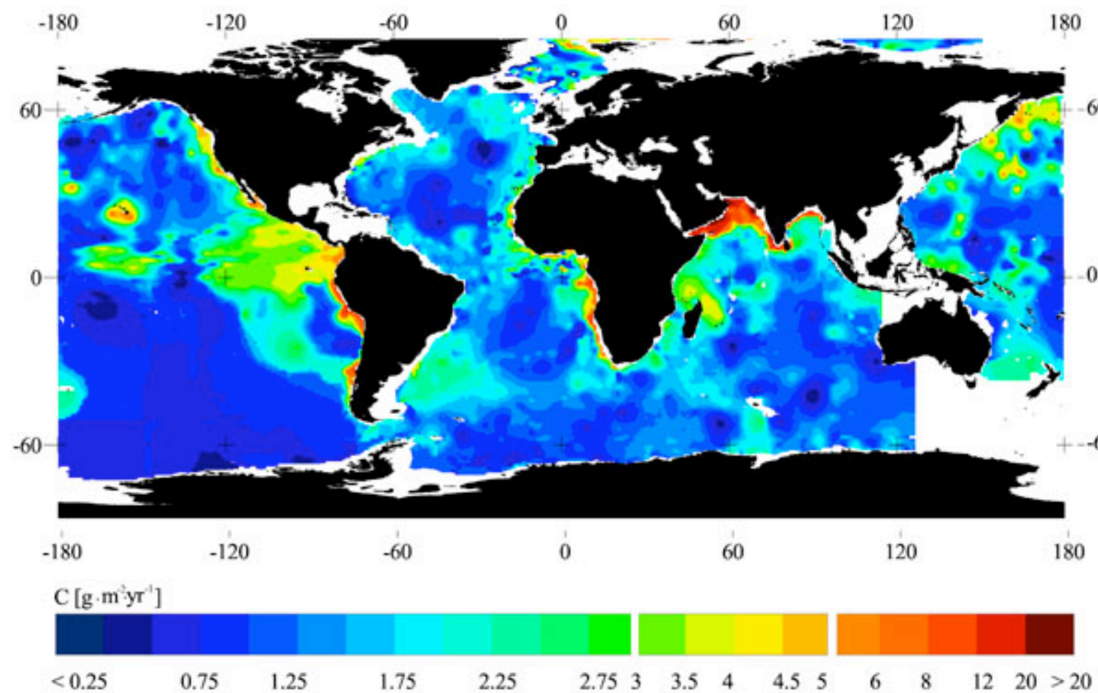
Decrease in biomass and abundance is related to the exponential decrease in the rate of nutrient input from sinking phytodetritus with increasing depth and distance from productive coastal waters.

Standing stock of organisms can be predicted by rates of particulate organic carbon flux or chloroplastic pigment equivalents in sediments

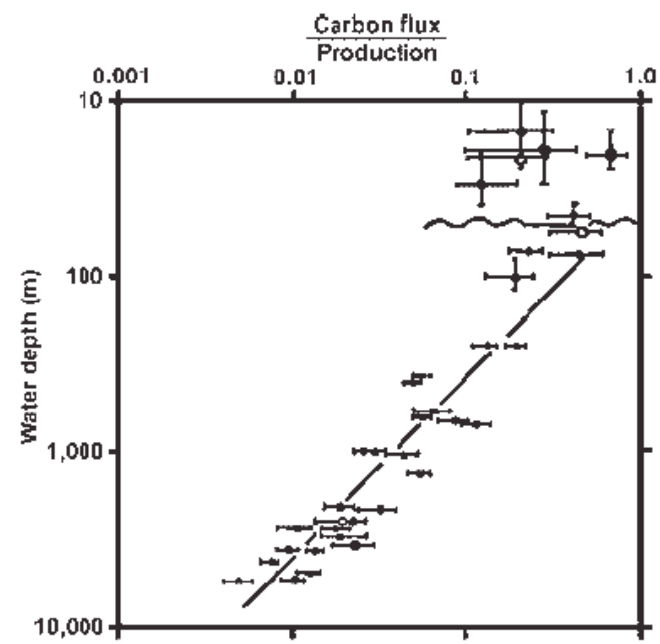


Macrofaunal biomass vs annual flux of POC
In sediment traps. Smith & Demopoulos

Rate of particulate organic carbon flux to the seafloor

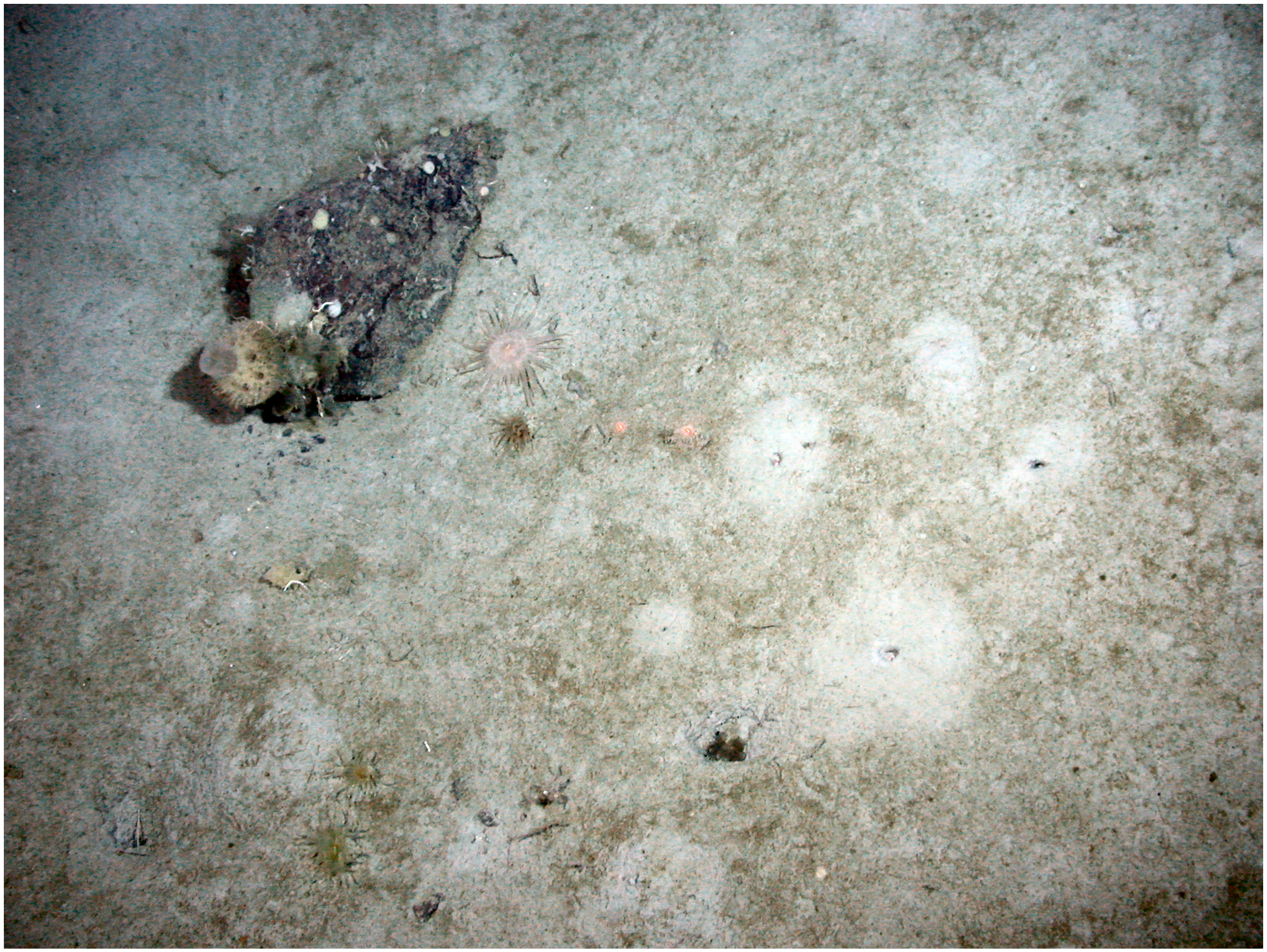


Global patterns of flux of POC

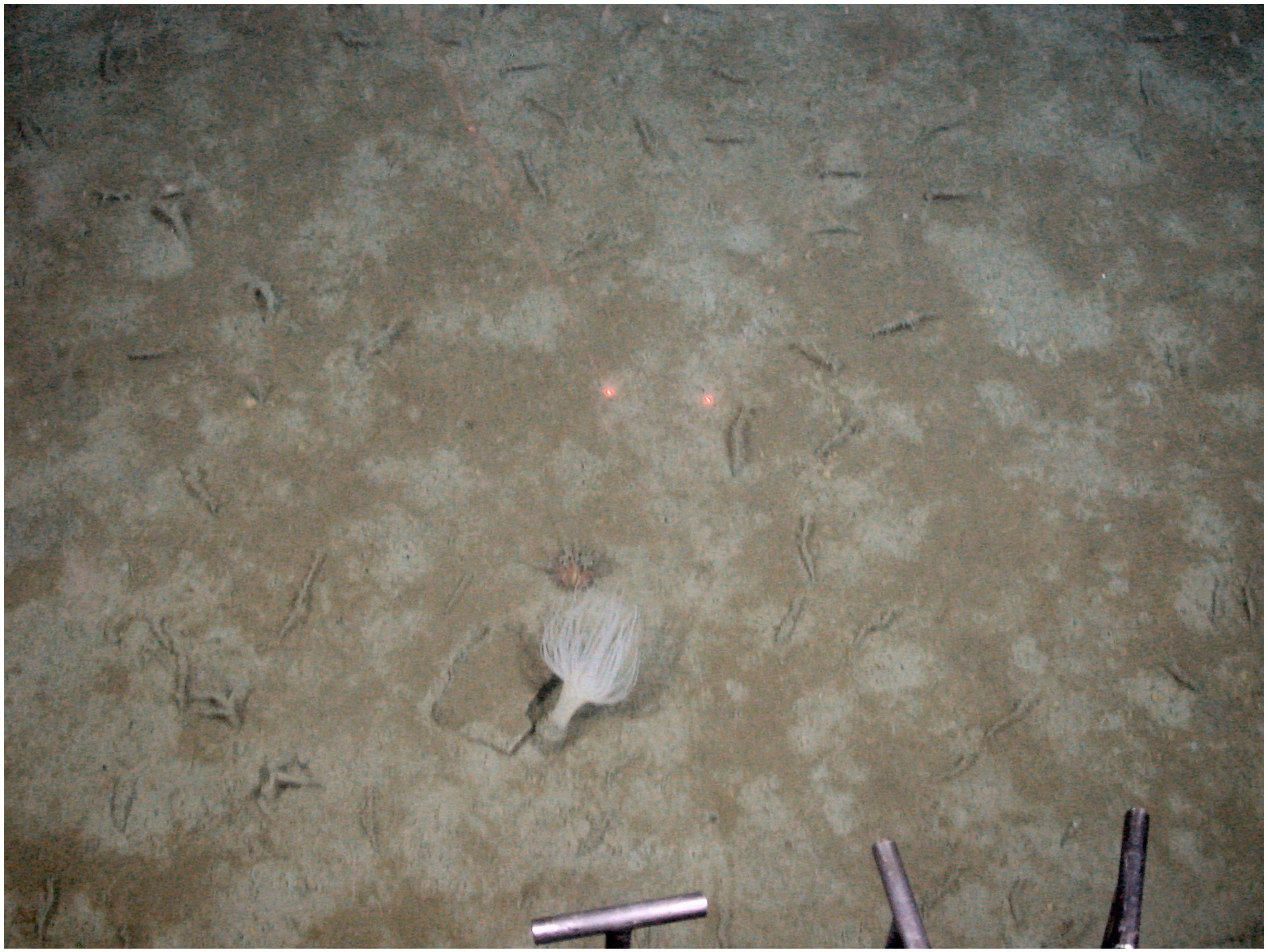


Ratio of sinking flux of POC to primary production in euphotic zone

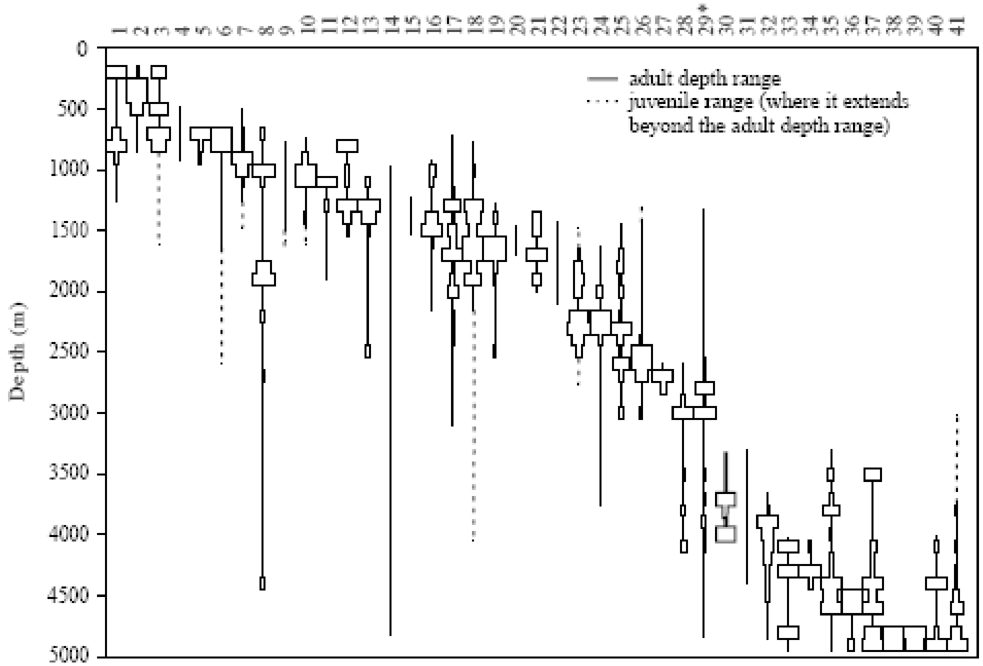
“Fluff” or phytodetritus

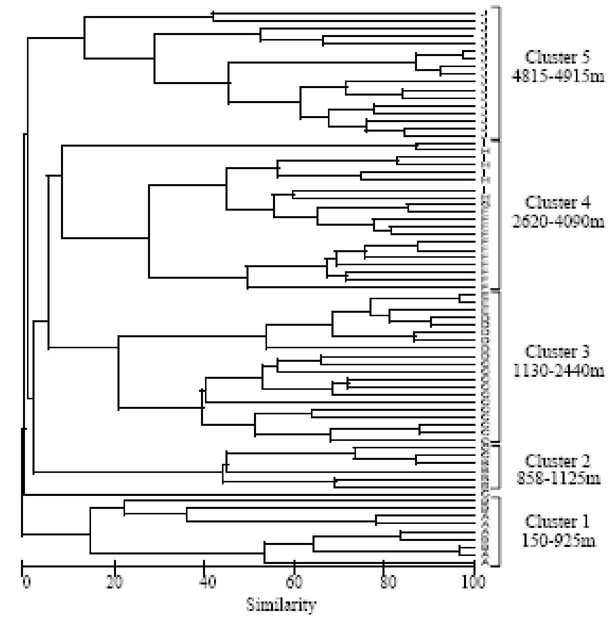


"Fluff" or phytodetritus



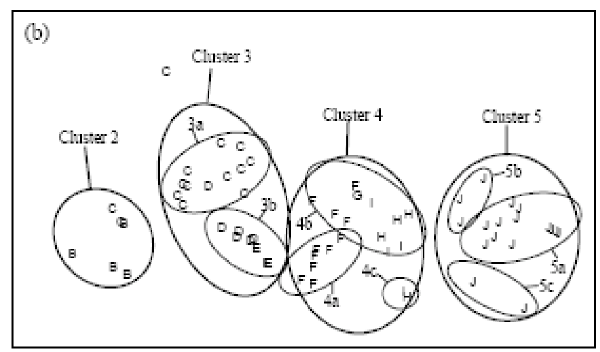
Species zonation with depth





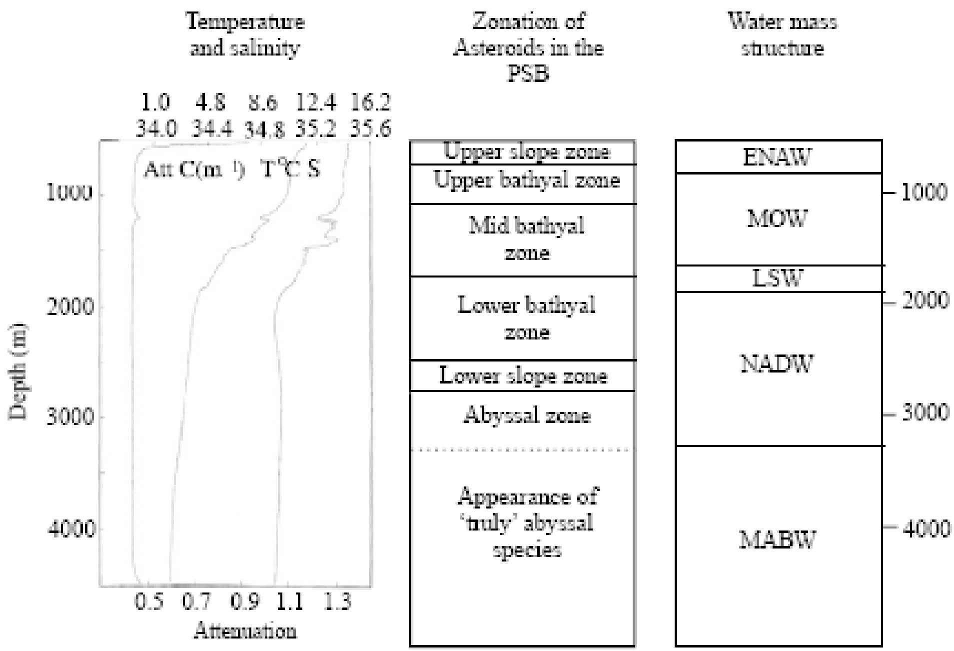
Vertical distribution pattern of seastars with depth, Porcupine Seabight.

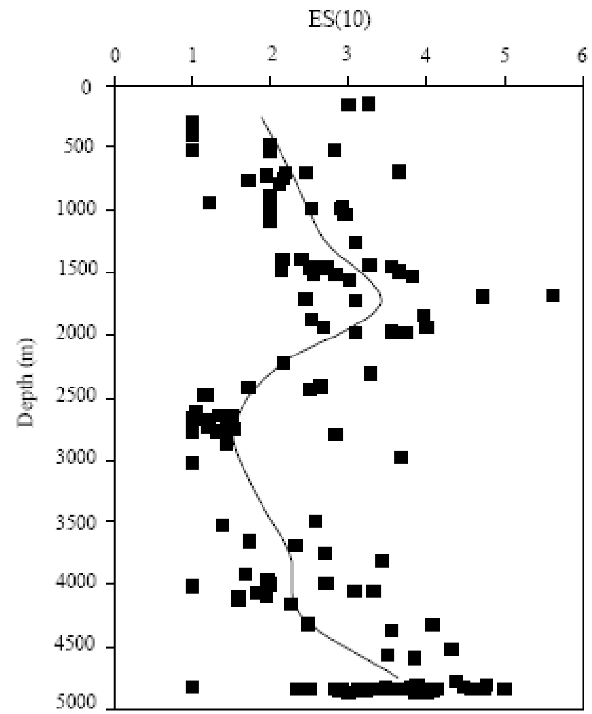
(i) Many species have a specific depth range
(ii) Juveniles often broader than adults
(iii) Communities cluster by depth



(Howell et al.2002 Deep-Sea Research I 49: 1901-1920).

Community transition zones



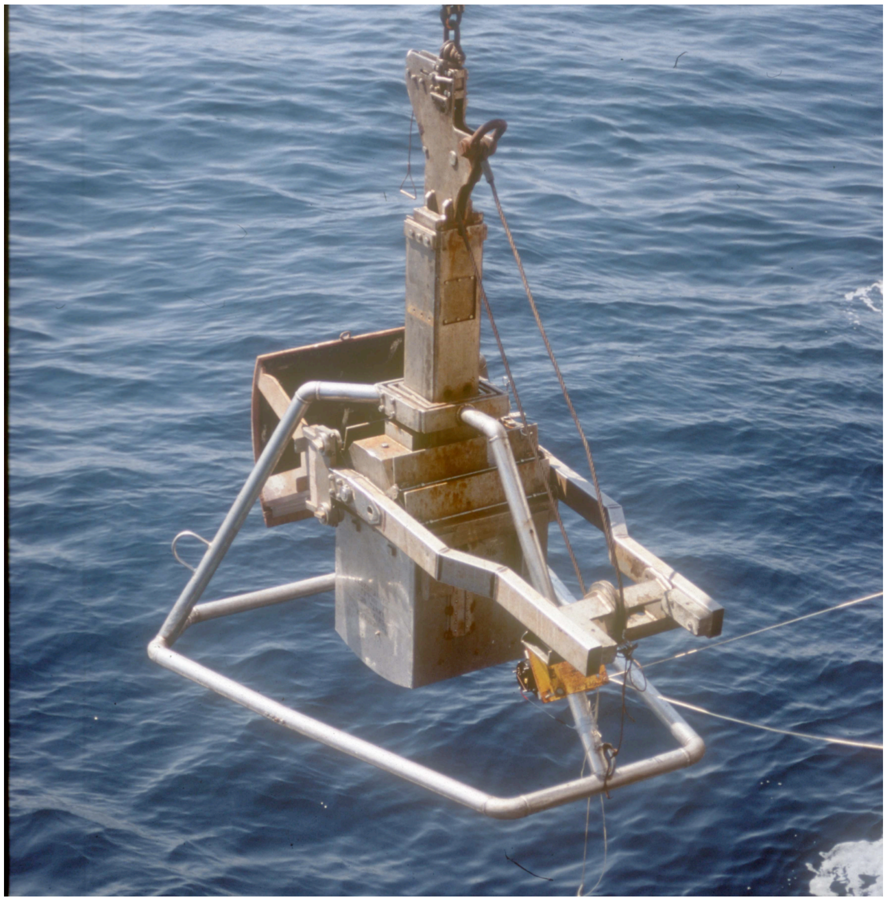


Asteroid community changes at 700m, 1100m & 1400m etc.

Physical environmental parameters thought to be important (temperature, pressure etc.)

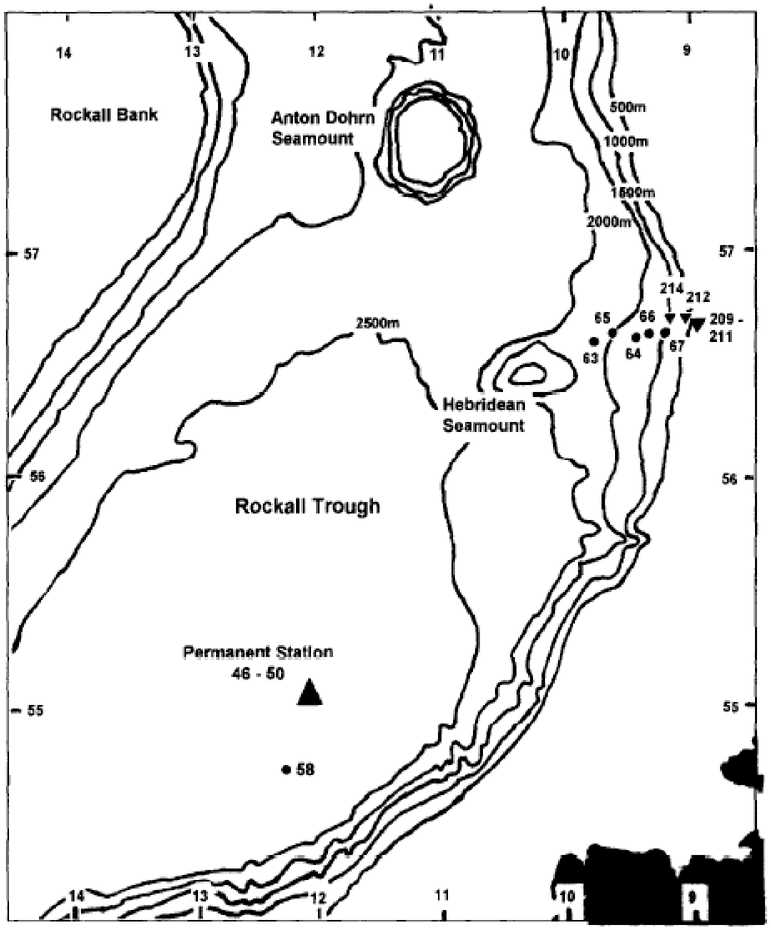
Overall diversity is greatest at 1,800m but also increases increases at >4,000m depth

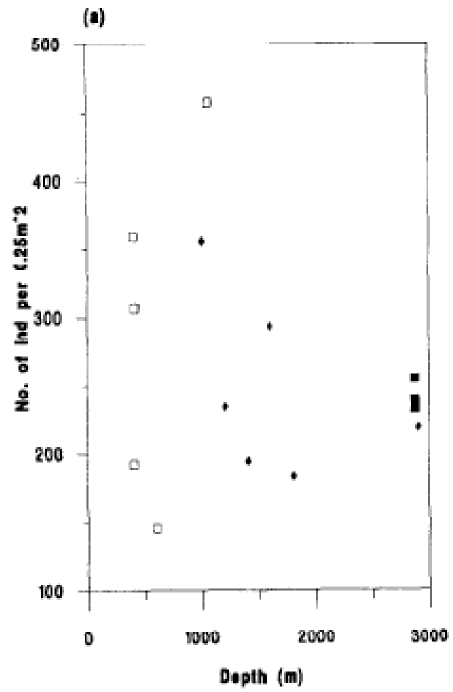
Quantitative sampling of the small stuff

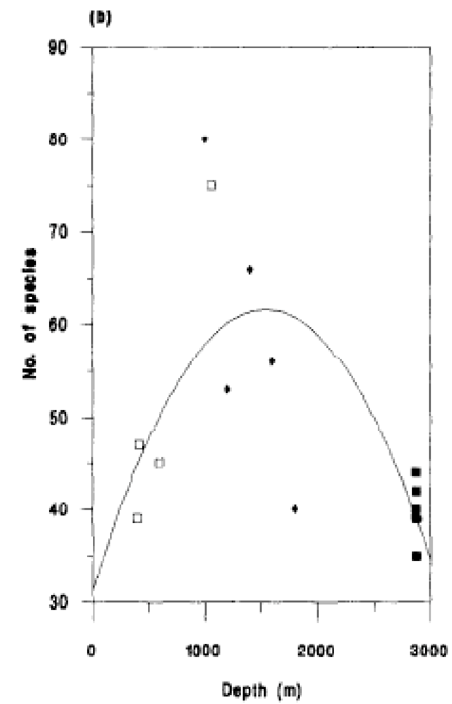


Species diversity with depth

Rockall Trough







Polychaete abundance & diversity with depth
Paterson & Lambshead 1995
Deep Sea Res. I 42 (7):1199-1214

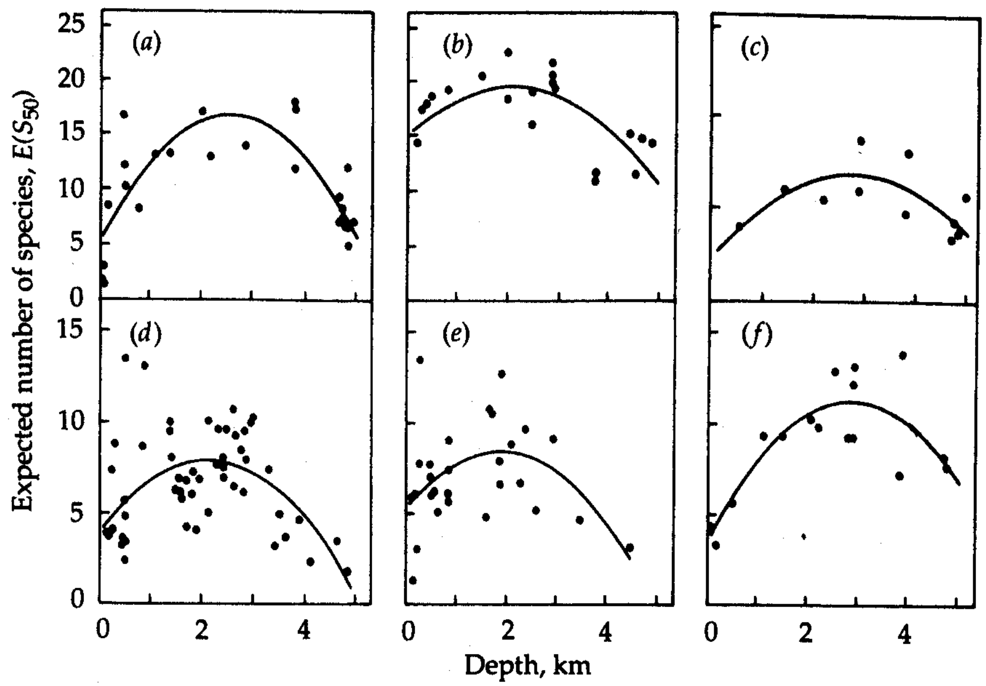
Peak in diversity at intermediate depths

Diversity with depth

Bathymetric patterns of expected species diversity (no. of species expected in random sample of 50 individuals).

(a) Gastropods
(b) Polychaetes
(c) Protobranch bivalves
(d) Cumaceans
(e) Invertebrate megafauna
(f) Fish

(Rex et al. 1981 Ann Rev Ecol Syst 12: 331-353)



Why is there high diversity at intermediate depths?

Explanations have centred around local-scale biophysical or ecological interactions:

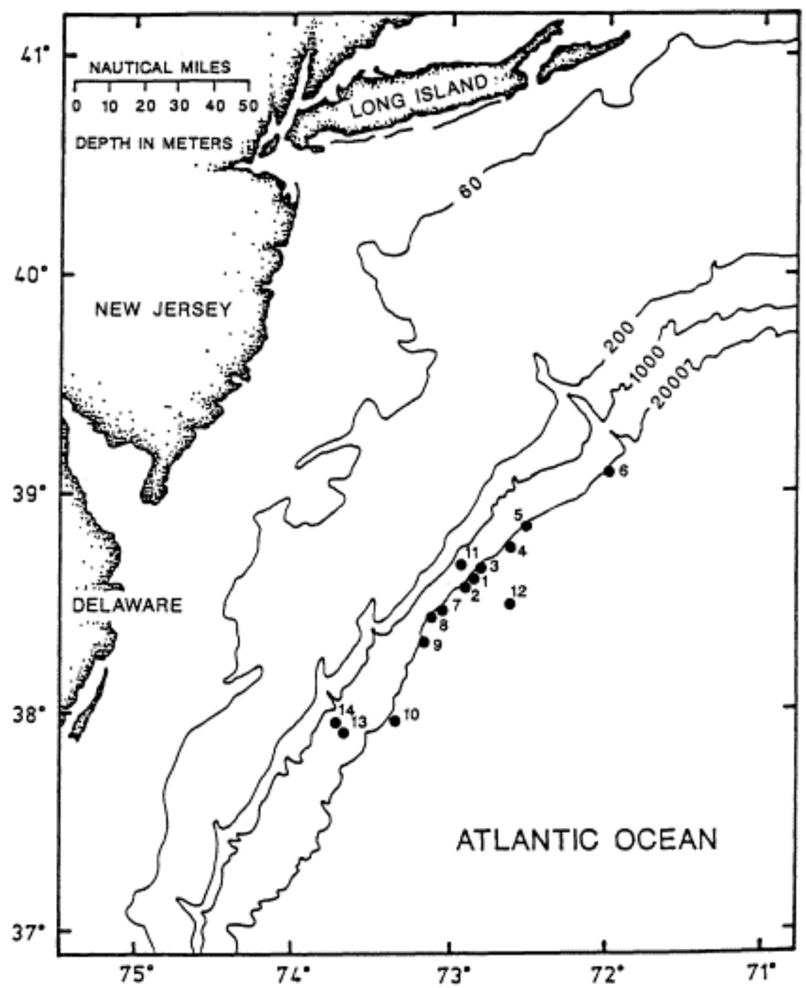
Sediment heterogeneity
Patchiness (spatial & temporal mosaic of patches/niches)
Food supply
Oxygen
Levels of catastrophic disturbance with slow recolonization

Intermediate disturbance models

Mid-domain effects
Randomly shuffled species' ranges free of environmental gradients will increasingly overlap towards the domain centre to create a richness peak.

Ecotones
Transition zones between ecological assemblages
Gage JD 2004 Deep-Sea Res. II 51: 1689 - 1708

Hyperdiversity in the deep sea

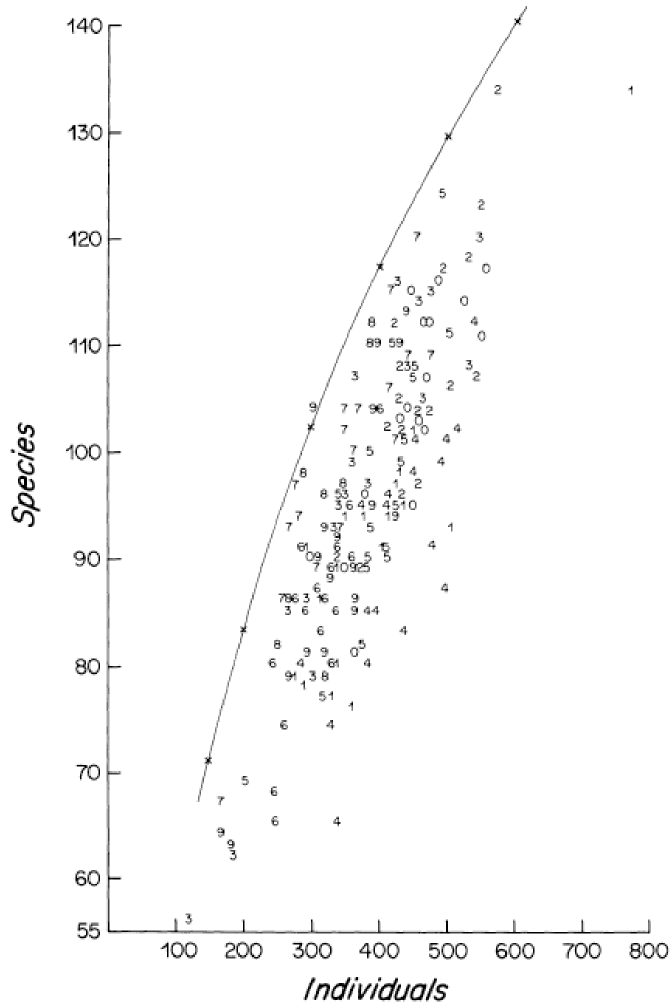


Grassle & Maciolek, 1992 Am. Nat 139 (2): 313-341

TAXONOMIC COMPOSITION OF SOFT-SEDIMENT BENTHOS FROM U.S. MID-ATLANTIC CONTINENTAL SLOPE SAMPLES

Species and Family	No. of Species	No. of Families
Cnidaria	19	10
Hydrozoa	6	3
Anthozoa	12	6
Scyphozoa	1	1
Nemertea	22	1
Priapulida	2	1
Annelida	385	49
Polychaeta	367	47
Oligochaeta	18	2
Echiurida	4	2
Sipuncula	15	3
Pogonophora	13	5
Mollusca	106	43
Bivalvia	45	18
Gastropoda	28	18
Scaphopoda	9	4
Aplacophora	24	3
Arthropoda:	185	40
Cumacea	25	4
Tanaidacea	45	8
Isopoda	59	11
Amphipoda	55	16
Pycnogonida	1	1
Bryozoa	1	1
Brachiopoda	2	1
Echinodermata	39	13
Echinoidea	9	2
Ophiuroidea	16	6
Asteroidea	3	3
Holothuroidea	11	2
Hemichordata	4	1
Chordata	1	1
Total	798	171

High local diversity, many rare species



PERCENTAGE CONTRIBUTION OF THE 10 MOST ABUNDANT SPECIES AT 2,100-M DEPTH

Species Ordered by Rank	All Samples Combined	Replicates and Times Combined, Averaged across Stations (%)	Replicates Combined, Averaged across Stations and Times (%)	Averaged across Stations, Times, and Replicates (%)
Aurospio dibranchiata (P)	7.1	7.2 (9.5)	7.7 (16.6)	8.3 (26.9)
Pholoe anoculata (P)	4.6	5.6 (17.4)	5.8 (19.2)	6.2 (21.9)
Spathoderma clenchi (A)	3.9	4.2 (19.5)	4.6 (18.8)	4.9 (18.1)
Tharyx sp. 1 (P)	3.8	3.6 (15.4)	3.9 (17.8)	4.2 (17.0)
Prionospio sp. 2 (P)	3.1	3.4 (17.6)	3.4 (15.4)	3.8 (15.9)
Tubificoides aculeatus (O)	3.0	3.1 (13.1)	3.2 (14.9)	3.4 (14.9)
Prochaetoderma yongei (A)	2.8	2.8 (12.3)	2.9 (14.1)	3.2 (14.9)
Aricidea tetrabranchia (P)	2.2	2.6 (10.2)	2.6 (13.5)	2.9 (14.3)
Glycera capitata (P)	2.1	2.4 (8.1)	2.4 (11.2)	2.7 (13.0)
Nemertea sp. 5 (N)	2.1	2.2 (5.4)	2.3 (11.4)	2.5 (13.5)

Very high local diversity – the more samples, the more species

No single species >10% of sample

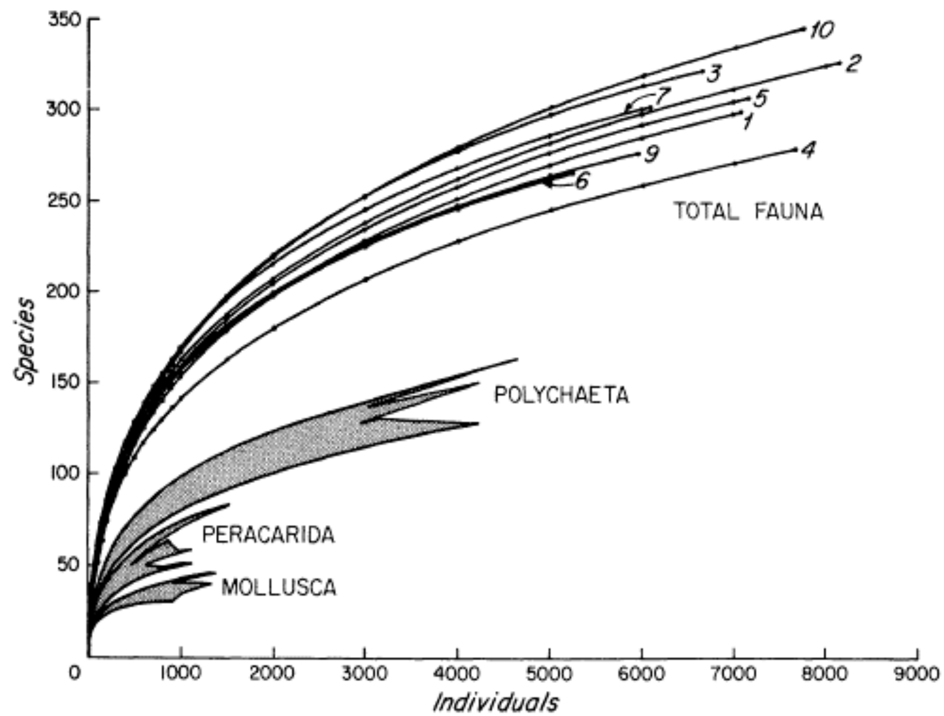
10 species made up ~ 42% of samples

Many rare species

Who are the most diverse groups?

Polychaetes most diverse, followed by peracarid crustacea and molluscs

(for meiofauna nematodes are most diverse)



The global estimate of species diversity

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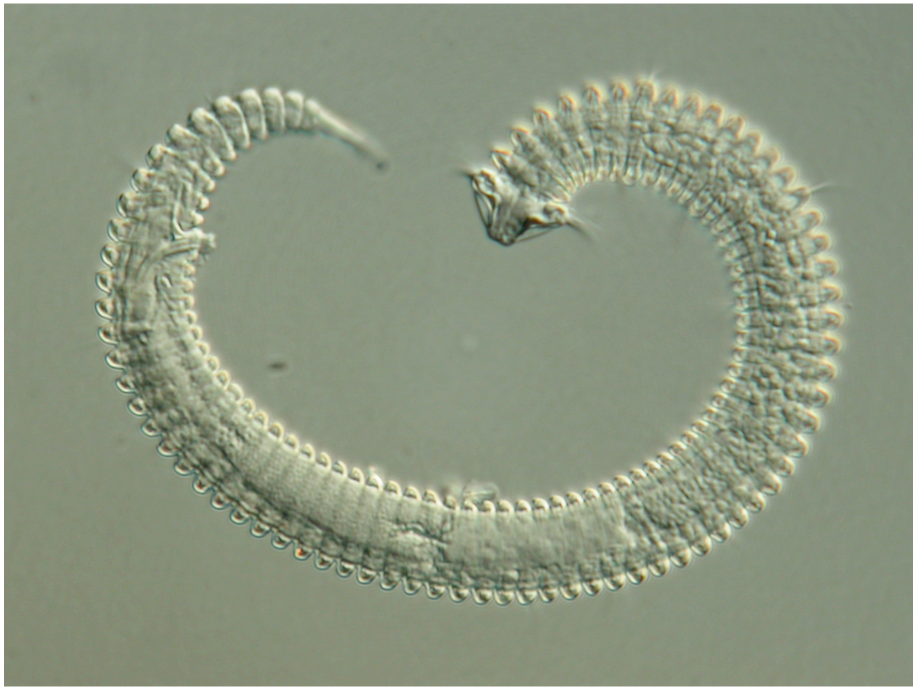
- 233 box cores taken from 10 stations across about 100km of the seabed (21 m^2 of the seabed)
- 90,677 specimens representing 798 species of animals
- Grassle & Maciolek found they added about 100 species for each 100km of the seabed they sampled (traversed)
- Extrapolated this figure to the rest of the deep ocean and estimated that there were certainly more than 1 million species and maybe as many as 10 million
- Thought to be conservative as they sampled along isobaths rather than across the depth gradient

Diversity with meiofauna

- Lambshead (1993) noted that the meiofauna were generally at least an order of magnitude more diverse than the macrofauna
- He suggested that there maybe as many as 100 million species in the deep sea

Obviously controversial but based on similar extrapolations for insects in tropical rain forests.



Local vs regional diversity

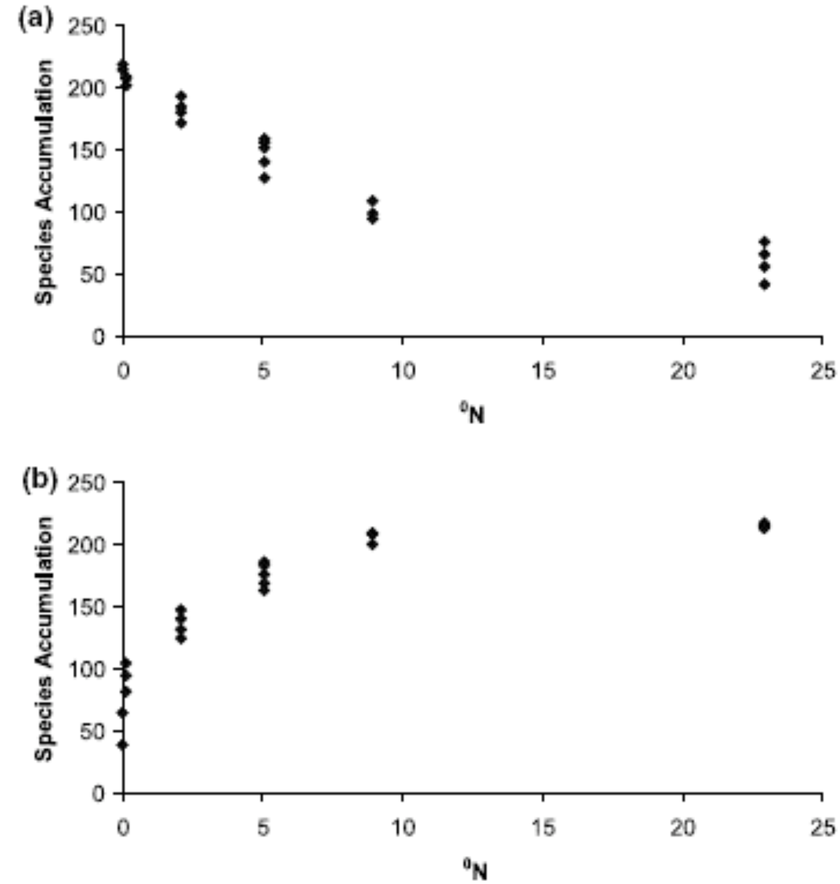
- Local species richness is rarely “saturated”
- The number of species co-existing locally can be determined to a large extent from inputs from the wider area
- In many cases, local species richness may reflect regional species richness.
- An effect of this is that continuous sampling at the local scale, within an ecosystem, will result in finding more and more species as you are sampling the regional fauna
- In the case of the deep sea this is a very large pool of species indeed

Supporting evidence

Nematodes: Clarion Clipperton Fracture Zone (3000km)

Species accumulation curve north to south – rapid accumulation to 0.1 species per Km^{2}.

Species accumulation curve running south to north, rapidly Goes to asymtote – 0.006 species Km^2



Difference in global species diversity 10^7 to 10^5

Decrease in organic C flux from south to north

Meiofauna & macrofauna - CCFZ

- Nematodes – 71% of species in northern region sampled in southern organically rich area

- Polychaete worms
- Core of 30-40 species dominated local to regional (3000km) scales of sampling
- Represent 70-90% of individuals

	Location	N	S	D	Dp	CFE	ICE
1	English Channel	12/1200	320	465	10–40	2103 (0.9987)	922
2	New Caledonia Lagoon	30/3000	333	10	6–16	1734 (0.9999)	702
3	Mersey Estuary	77/68426	323	22	Littoral	384 (0.9987)	327
4	Guadeloupe	10/997	140	85	0.5–5	871 (0.9972)	303
5	Central Equatorial Pacific Abyssal Plain	21/1877	218	3195	4301–4994	360 (0.9999)	281
6	HEBBLE North West Atlantic Abyssal Plain	18/2432	174	1	4626	623 (0.9999)	238
7	Irish Sea	15/9113	158	10	39–56	287 (0.9997)	221
8	Porcupine North East Atlantic Abyssal Plain	6/1211	119	1	4850	306 (0.9999)	160
9	Thames Estuary	40/6769	152	76	Littoral	230 (0.9999)	152
10	Fiji, Ono Reef	7/700	95	4	30	244 (0.9997)	138
11	Clyde Inland Sea Sandy Beach	16/8896	113	50	Low water spring	129 (0.9988)	133
12	Madeira North East Atlantic Abyssal Plain	6/576	71	1	4950	287 (0.9999)	106
13	San Diego Trough, Bathyal East Pacific	6/1381	98	0.5	1050	102 (0.9989)	100
14	Mangrove Swamp, Guyana	30/2997	65	2	Intertidal	131 (0.9992)	76
15	Moorea, Polynesia	7/700	42	0.1	1.6–3.1	56 (0.9998)	56
16	Mudflat, La Rochelle, France	36/3600	43	4	Intertidal	65 (0.9986)	49

N = No. samples/ individuals
S = species
D = distance between samples
Dp = Depth
CFE/ICE = species Estimators
Lambshead & Boucher 2003 J Biogeogr 30: 475-485

Source-sink hypothesis

The bathyal zone is thought to act as the “source” population for the abyssal plains that are viewed as a giant “sink” for propagules of bathyal origin

Requires that bathyal species must disperse over massive distances and vertically across depths

(Rex et al., 2005)

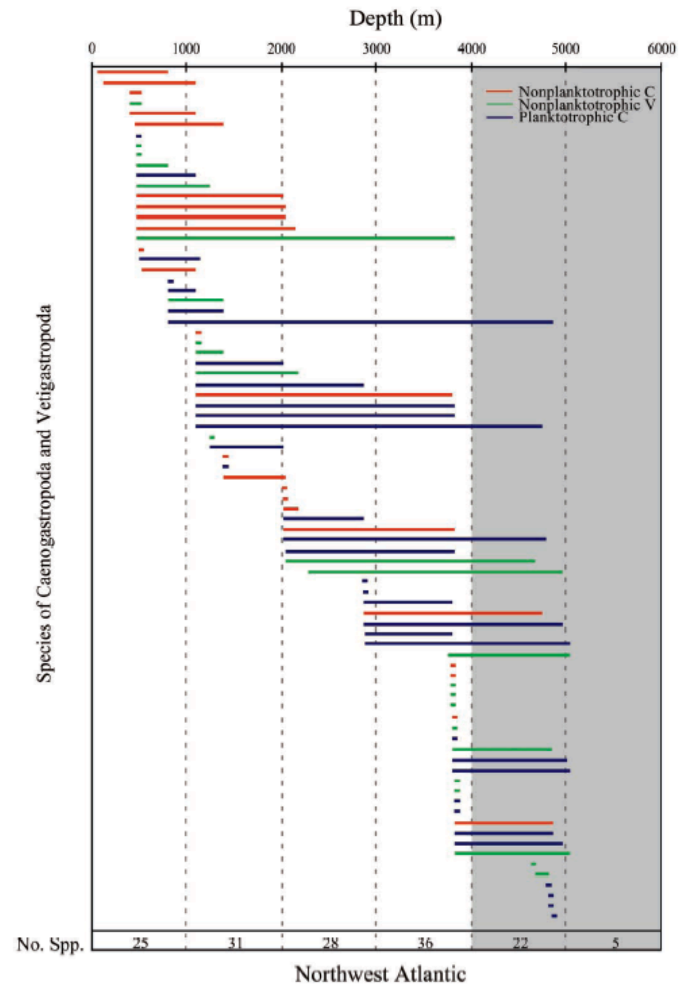


Figure 2: Bathymetric ranges and modes of larval development for deep-sea prosobranch gastropods collected south of New England in the western North Atlantic. The depth region of the abyssal plain is shaded. Data are from Rex and Warén (1982) with updated species names and locality

Depth range of snails along continental slope

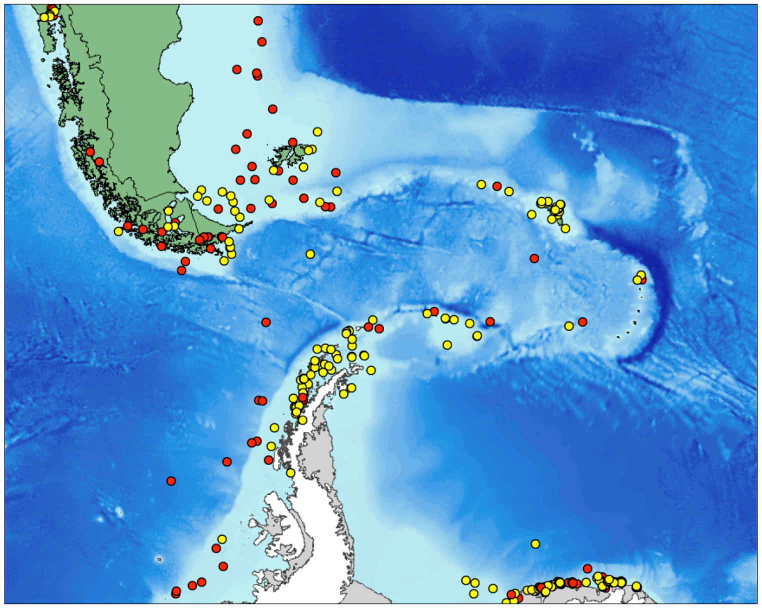
Supporting evidence

- For many groups of deep-sea animals, diversity is concentrated on the shelf or bathyal zone.
- Species of these groups tend to occur across wide depth bands with species ranges extending into the abyssal zone
- Include: the Echinoida (sea urchins), Polychaeta (segmented worms), Decapoda (crabs, lobsters and allies), Cirripedia (barnacles), Ophiuroidea (brittle stars), Cnidaria (corals, anemones and sea pens), Mollusca (clams and snails) and Sipunculida (peanut worms)
- Mollusca – main group on which Rex hypothesis was established.

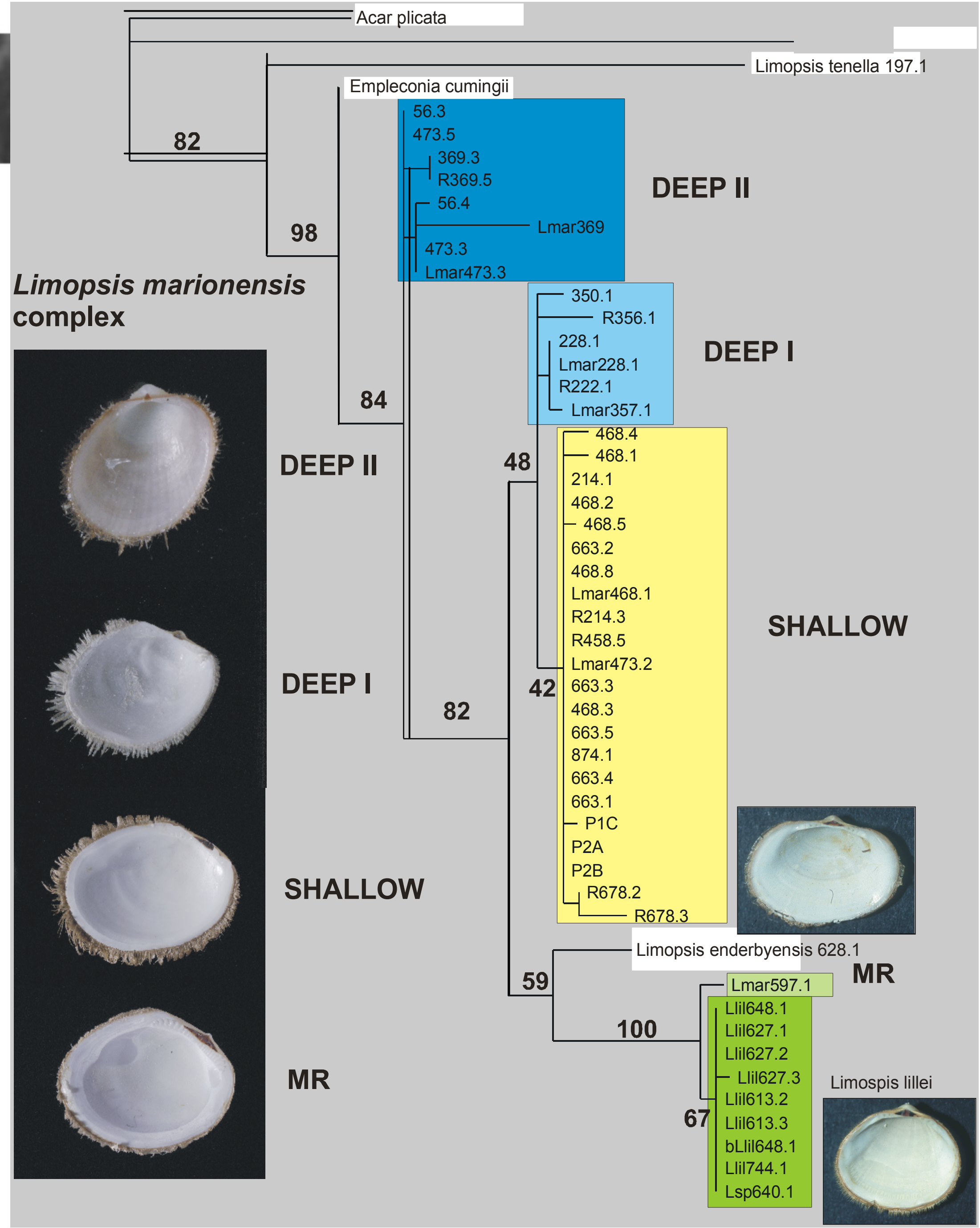
But….

- A smaller group of animals have a much higher proportion of species that have narrow depth ranges and which are found on the abyssal plains and lower bathyal zone
- These include the Porifera (sponges), Isopoda (crustaceans resembling pill bugs), Asteroidea (starfish), Holothuroidea (sea-cucumbers), Echiura (proboscis worms) and Pogonophora (beard worms). In particular, the hexactinellid sponges, Asellota (isopods), Phanerozonia (asteroids) and Elasipoda (holothurians) are orders that are predominantly distributed in the abyssal zone.

Deep → shallow



Lissarca •
Limopsis •



Zoroaster fulgens

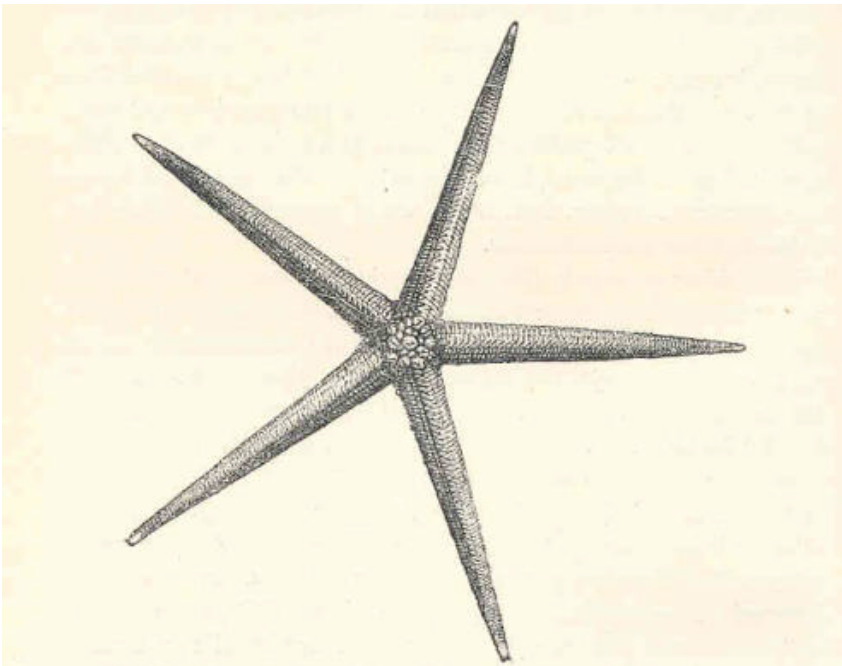
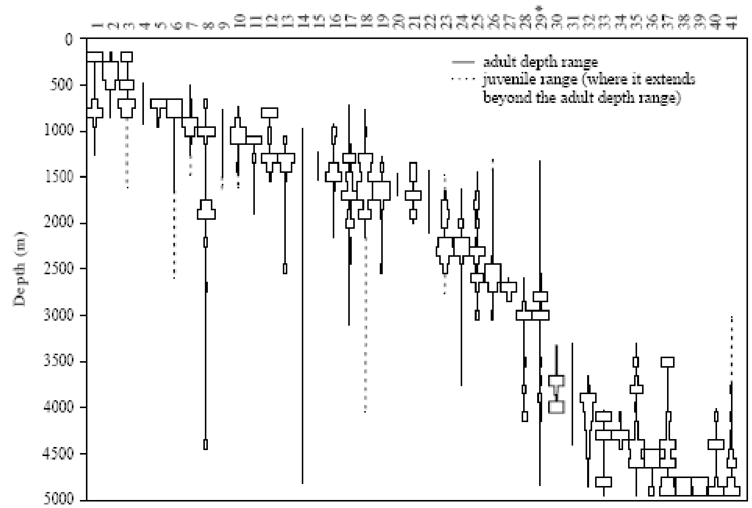


Fig. 177. — *Zoroaster fulgens*, Wyville Thomson, vu de dos. — Légèrement réduit



Many examples of cryptic species separated by depth…..

Antarctic octopods: invasion of the deep sea

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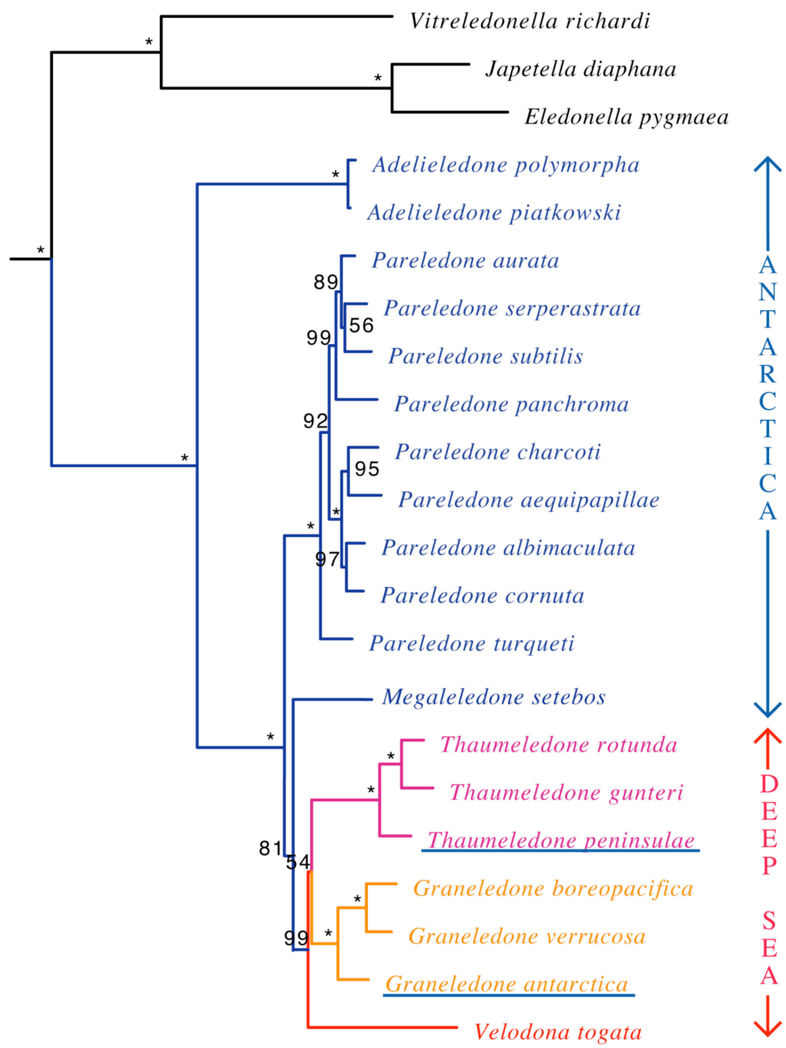
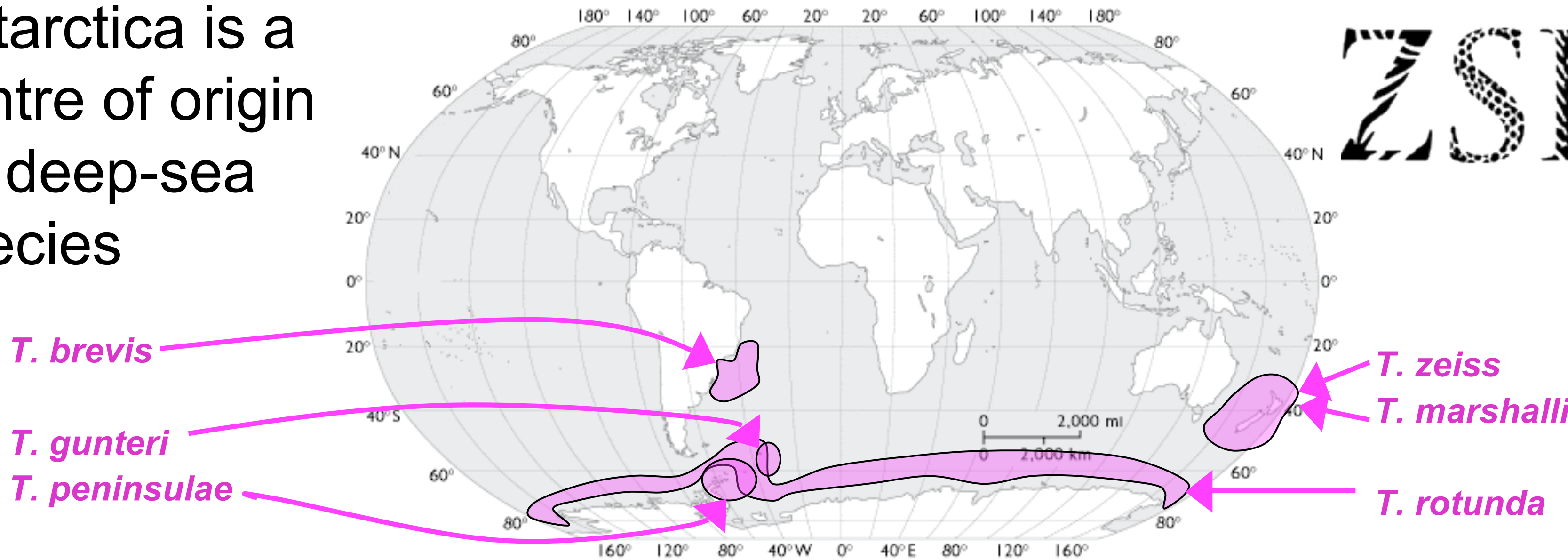
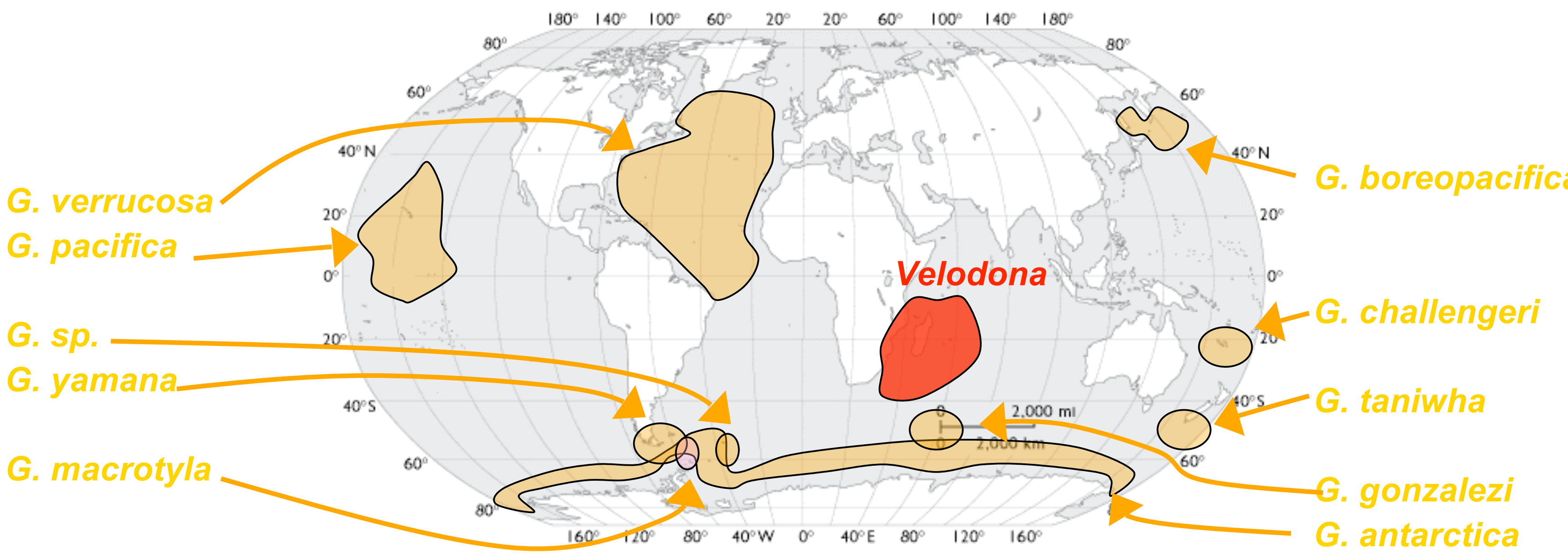
History!!



Dr Jan Strugnall, British Antarctic Survey

Antarctica is a centre of origin for deep-sea species





Molecular barcoding work

- Box core samples from 1st Kaplan cruise: specimens from CRS 822, 825, 826, 829, 833 and 844 (97 individuals).
- Have sequenced ~500bp segment of 18S small subunit ribosomal RNA gene
- Total of 72 individual sequences generated.
- 72 sequences clustered into 53 distinct MOTU (2bp variation or less).
- Most common MOTU had 6 members.
- Majority of MOTU (45) had only a single representative.

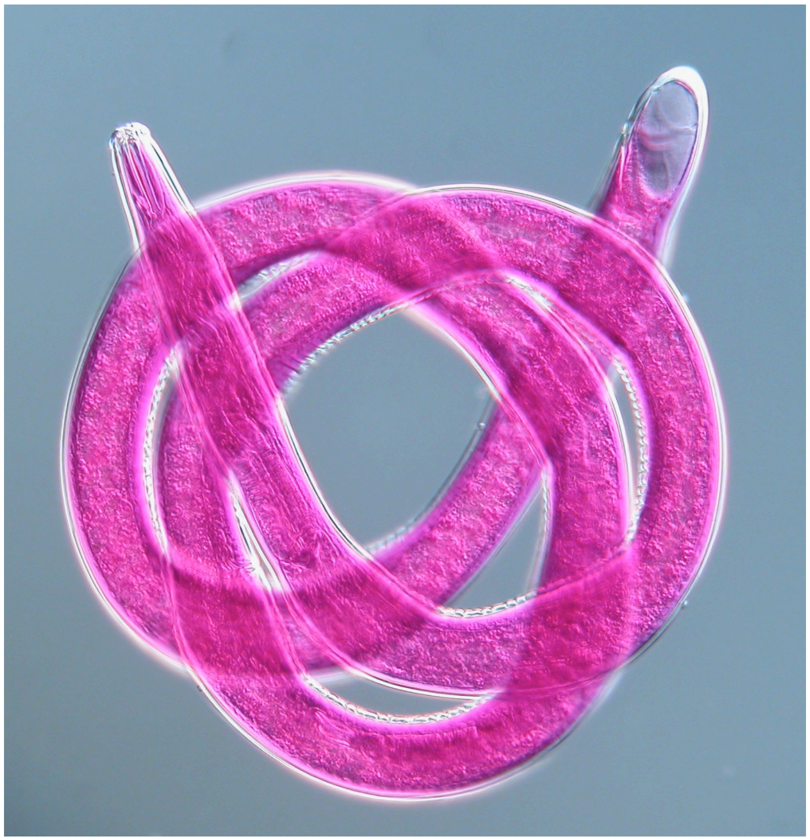
BLAST searches

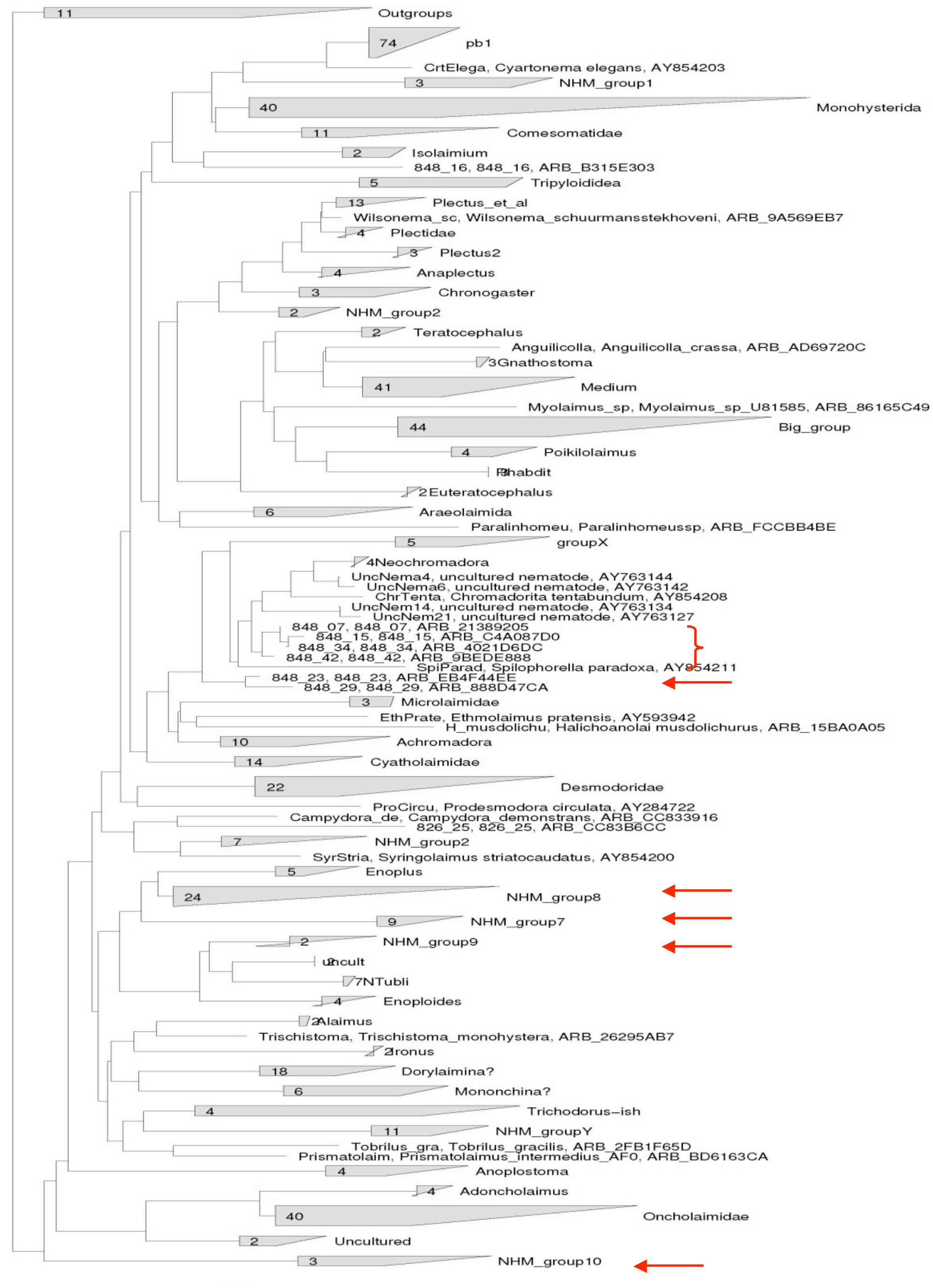
No sequences were found showing 100% identical matches to any known nematode. However, the following were found as common closest hits (90%+ identical)…

- *Enoplus brevis*
- *Trischistoma monohystera*
- *Enoplus anisospiculus*
- *Syringolaimus striatochaudatus*
- *Anaplectus* sp
- *Belondira apitica*
- *Sabatieria punctata*

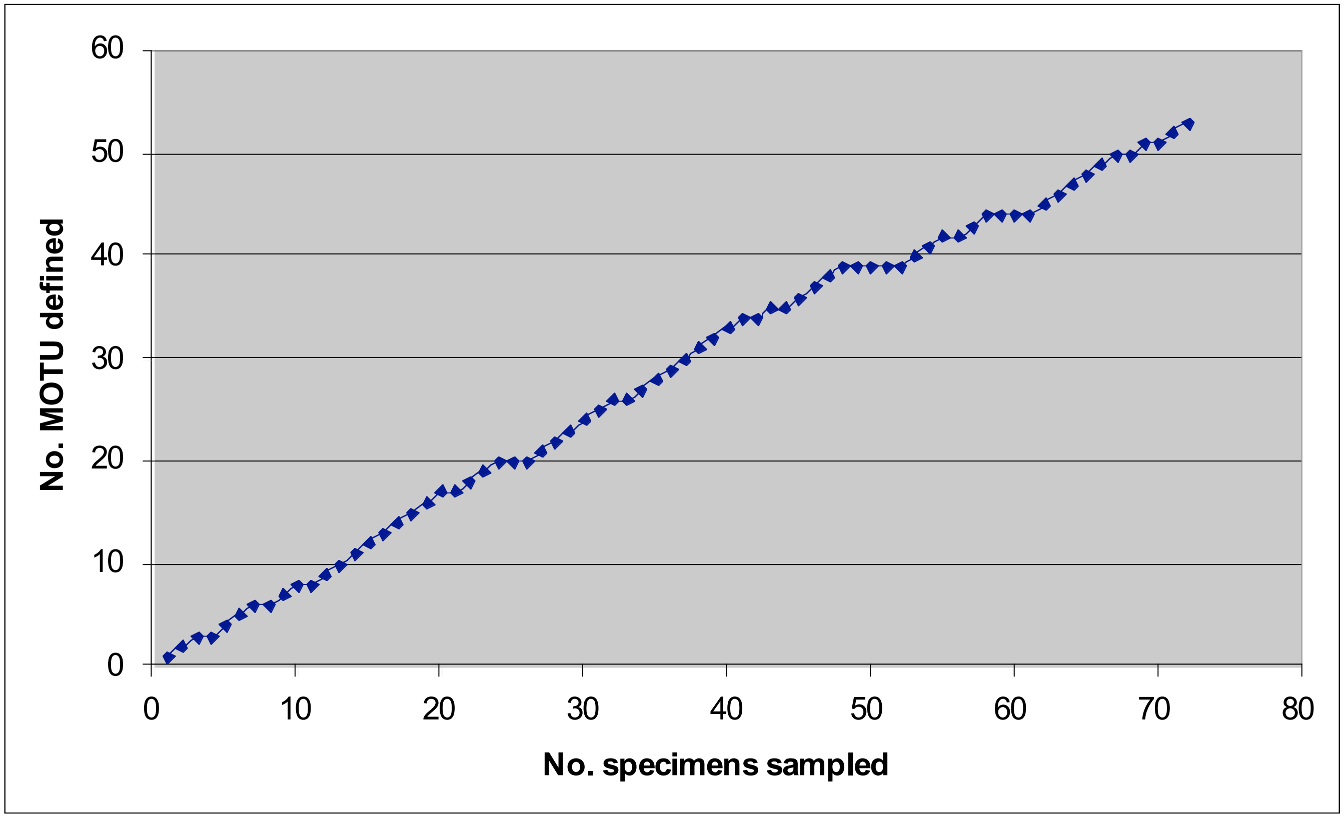
- *Pontonema vulgare*
- *Viscosia viscosa*
- *Tobrilus gracilis*
- *Campydora demonstrans*
- *Praeacanthonchus* sp
- *Enoploides brunettii*
- *Oncholaimus* sp

Unknown taxa?





M-OTU accumulation curve



Summary M-OTU diversity

Sample ID	No. sequences	No. MOTU
CRS 822	4	4
CRS 825	14	13
CRS 826	20	12
CRS 829	12	12
CRS 833	10	8
CRS 844	12	10

Summary

- Biodiversity does show patterns of distribution in the deep sea
- Decrease in abundance and biomass with depth
- Mid-slope peak in species richness (in Atlantic)
- Abyssal diversity comprises a low number of “common” species and many rare
- Likely that this represents sampling of the regional fauna
- Corroborated by central Pacific morphological studies
- Consistent with molecular data
- Are the “rare” species really rare?