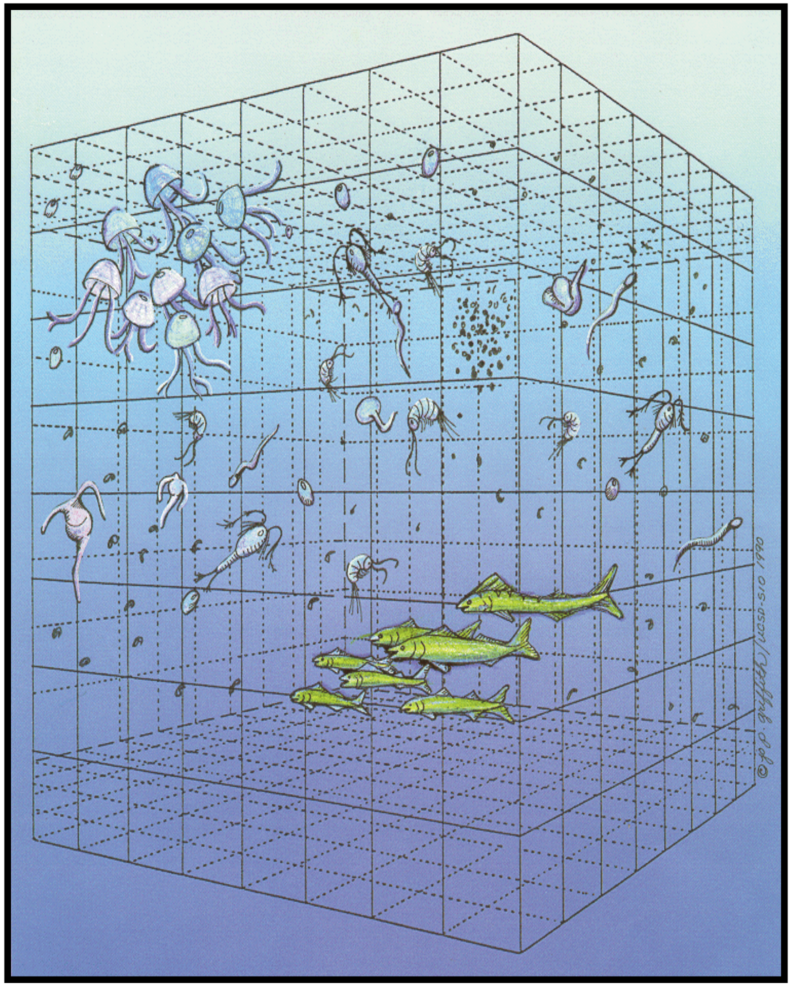
Deep-Sea Biology
Life Beyond the Blue

Ricardo Serrão Santos
Universidade dos Açores

Theme 1 - Coastal and Deep Sea Natural Resources knowledge
Sociedade Amor da Pátria, Horta, Açores, Portugal
21st of September, 2012

The Oceans
Huge & Diverse



- ***Huge*** 70% of the planet's surface and more than 90% of the available volume: 170 times more space available to life than all other combined ecosystems.
- ***Unknown*** In deep sea only a small area corresponding has actually been ground-truthed from a scientific point of view.
- ***Diverse*** A predicted number of marine species is 2.2 million, of which 91% still waiting description. A lot more Phyla represented when compared with terrestrial envoronments.
- ***Miscellaneous*** deep ocean is a miscellany with several levels of productivity and biomass.
- ***Rich*** In the seafloor and sub-seafloor there are abundant minerals, biominerals and energy deposits.

How Many Species in the Ocean?

Species	Earth			Ocean		
	Catalogued	**Predicted**	**±SE**	**Catalogued**	**Predicted**	**±SE**
Eukaryotes						
Animalia	953,434	7,770,000	958,000	171,082	2,150,000	145,000
Chromista	13,033	27,500	30,500	4,859	7,400	9,640
Fungi	43,271	611,000	297,000	1,097	5,320	11,100
Plantae	215,644	298,000	8,200	8,600	16,600	9,130
Protozoa	8,118	36,400	6,690	8,118	36,400	6,690
Total	1,233,500	8,740,000	1,300,000	193,756	2,210,000	182,000
Prokaryotes						
Archaea	502	455	160	1	1	0
Bacteria	10,358	9,680	3,470	652	1,320	436
Total	10,860	10,100	3,630	653	1,320	436
Grand Total	**1,244,360**	**8,750,000**	**1,300,000**	**194,409**	**2,210,000**	**182,000**

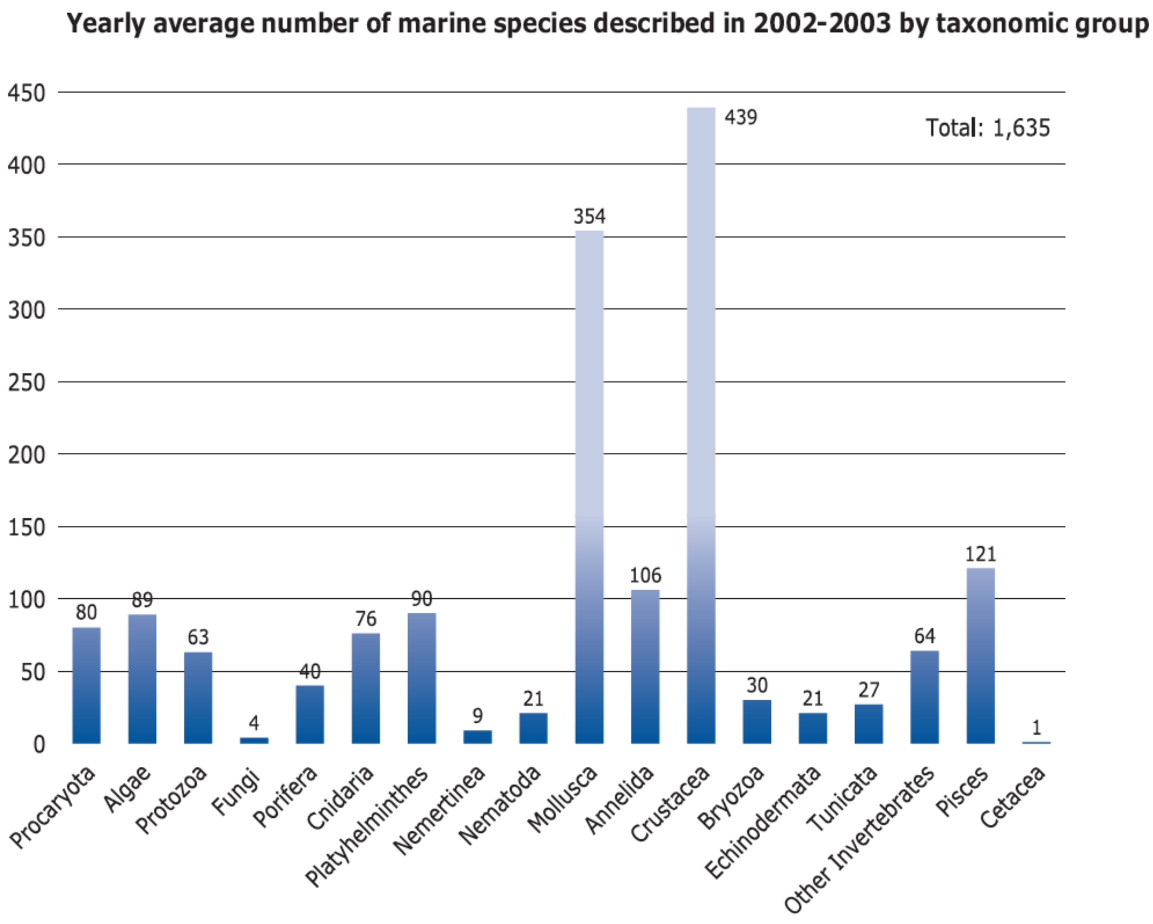
Predictions for prokaryotes represent a lower bound because they do not consider undescribed higher taxa. For protozoa, the ocean database was substantially more complete than the database for the entire Earth so we only used the former to estimate the total number of species in this taxon. All predictions were rounded to three significant digits.

doi:10.1371/journal.pbio.1001127.t002

91.3%
still left to discover

C Mora et al. PLoS Biology| August 2011 | Volume 9 | Issue 8 | e1001127

Average New Species / year



P. Bouchet 2006. The Magnitude of Marine Biodiversity

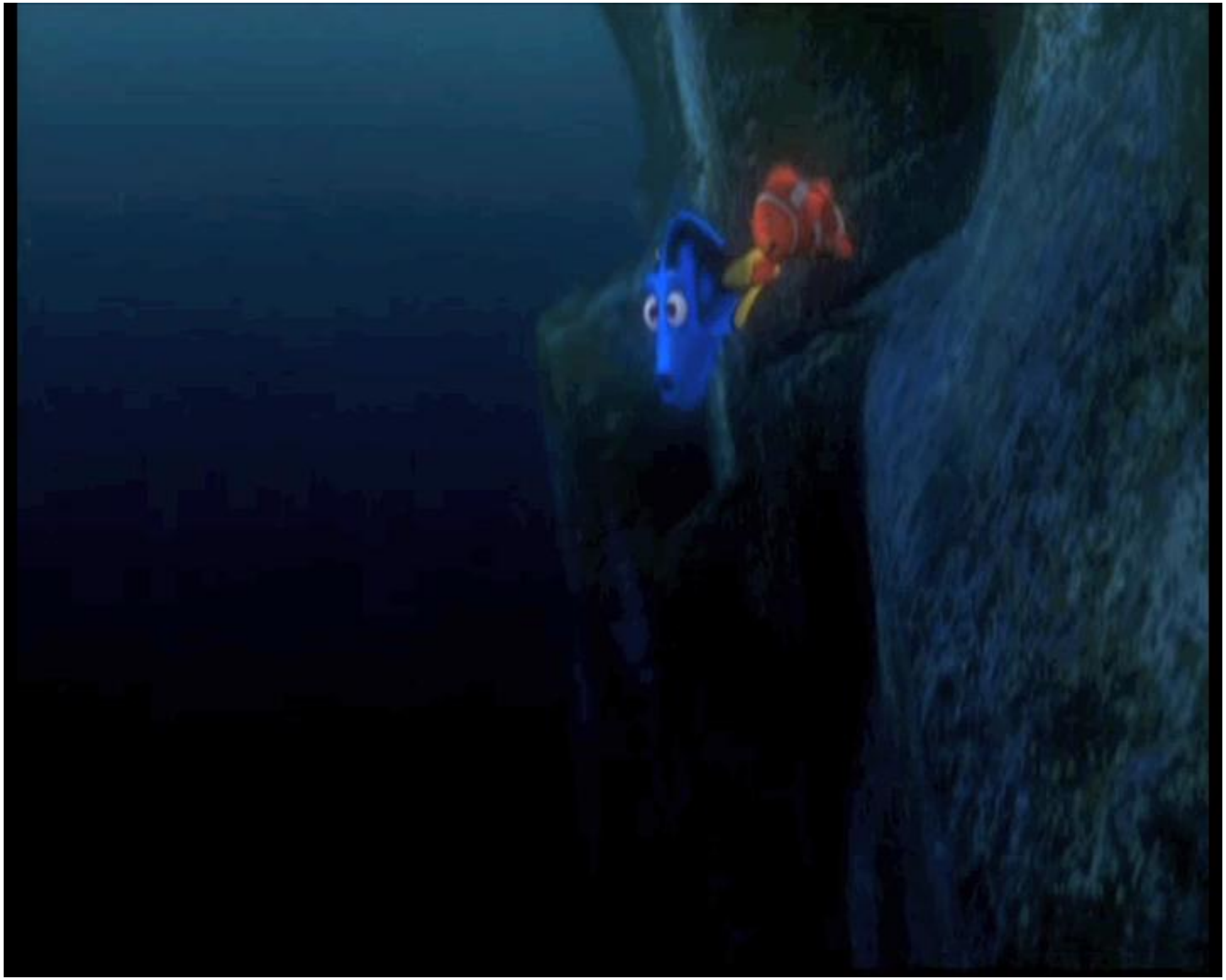
Most of Biodiversity Hidden in Hotspots

The majority of species that remain to be discovered are likely to be small-ranged occurring in hotspots and less explored areas such as the deep sea.

Yeti crab & Michel Segonzac IFREMER

P Bouchet 2006. The Magnitude of Marine Biodiversity

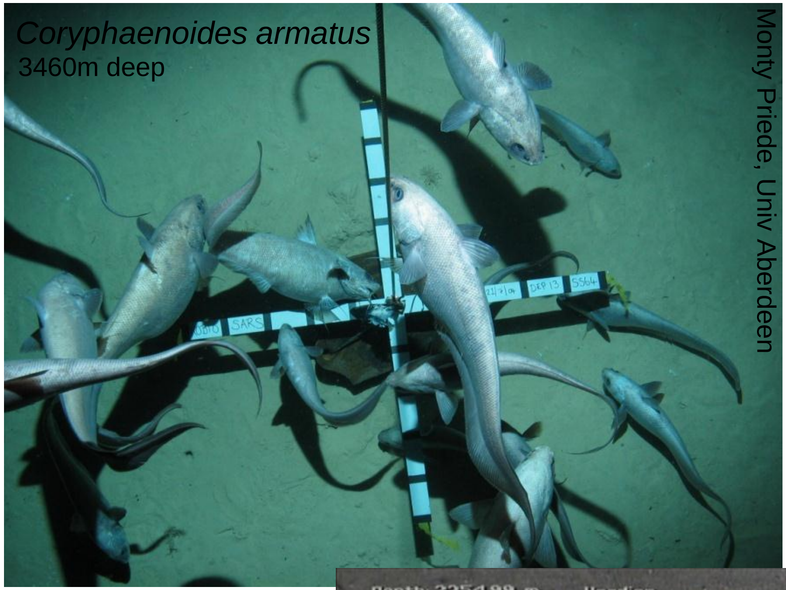
Beyond the Blue



Finding Nemo © Walt Disney Pictures & PIXAR Studios

Changing perceptions of the Deep Sea

- Until around the first half of the 20th century
  - The deep-sea floor was seen as an kind of empty and monotonous environment with low richness
- Actually the deep-sea floor is seen as an heterogeneous and changing environment
  - Large animals move, feed and reproduce there creating mounds, depressions and trails
  - Water currents move sediment surface around
  - Large carcasses sink to the bottom and create food hot-spots
  - Occasionally slides of sediment, like underwater avalanches, sweep everything away
  - In terms of life there are big expectations in new bio-molecules
  - Microbial diversity is the higher in the planet, and the sub seafloor only recently is being search for genetic resources
  - Rich in biodiversity, new molecules and new chemistry.
  - Rich in mineral resources

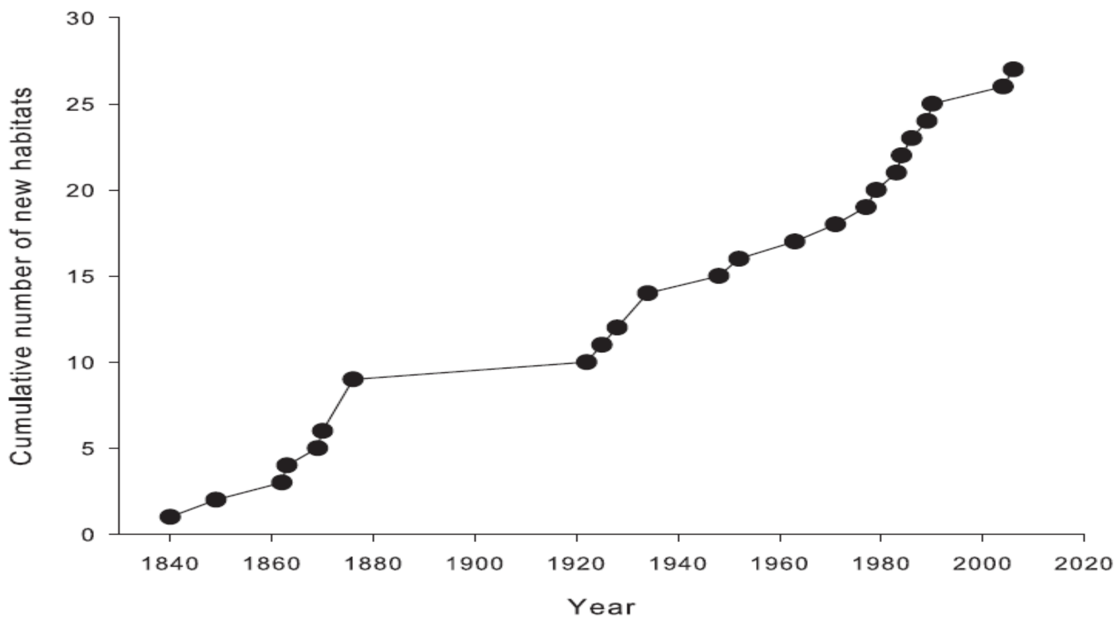


Holland et al. 2005 (Nature)

Dimension of our ignorance

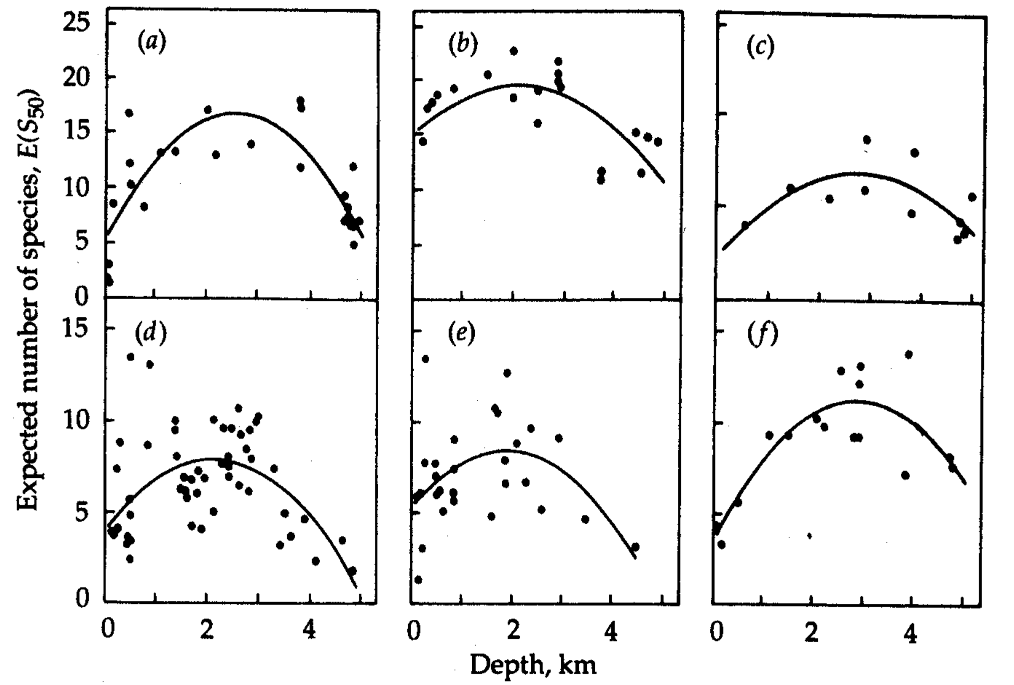
The deep-sea is the major environment on Earth but one of the least studied

It includes a unique variety of habitats, with a great number of discoveries during the last 50 years

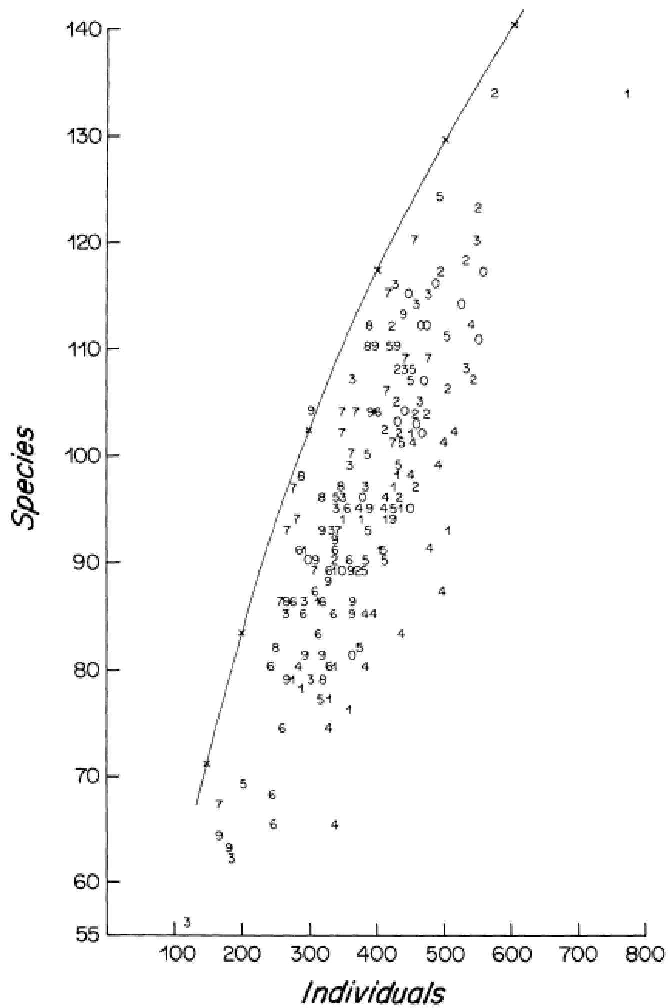


Diversity with depth

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)



High local diversity, many rare species



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)

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

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

No single species >10% of sample

10 species made up ~ 42% of samples

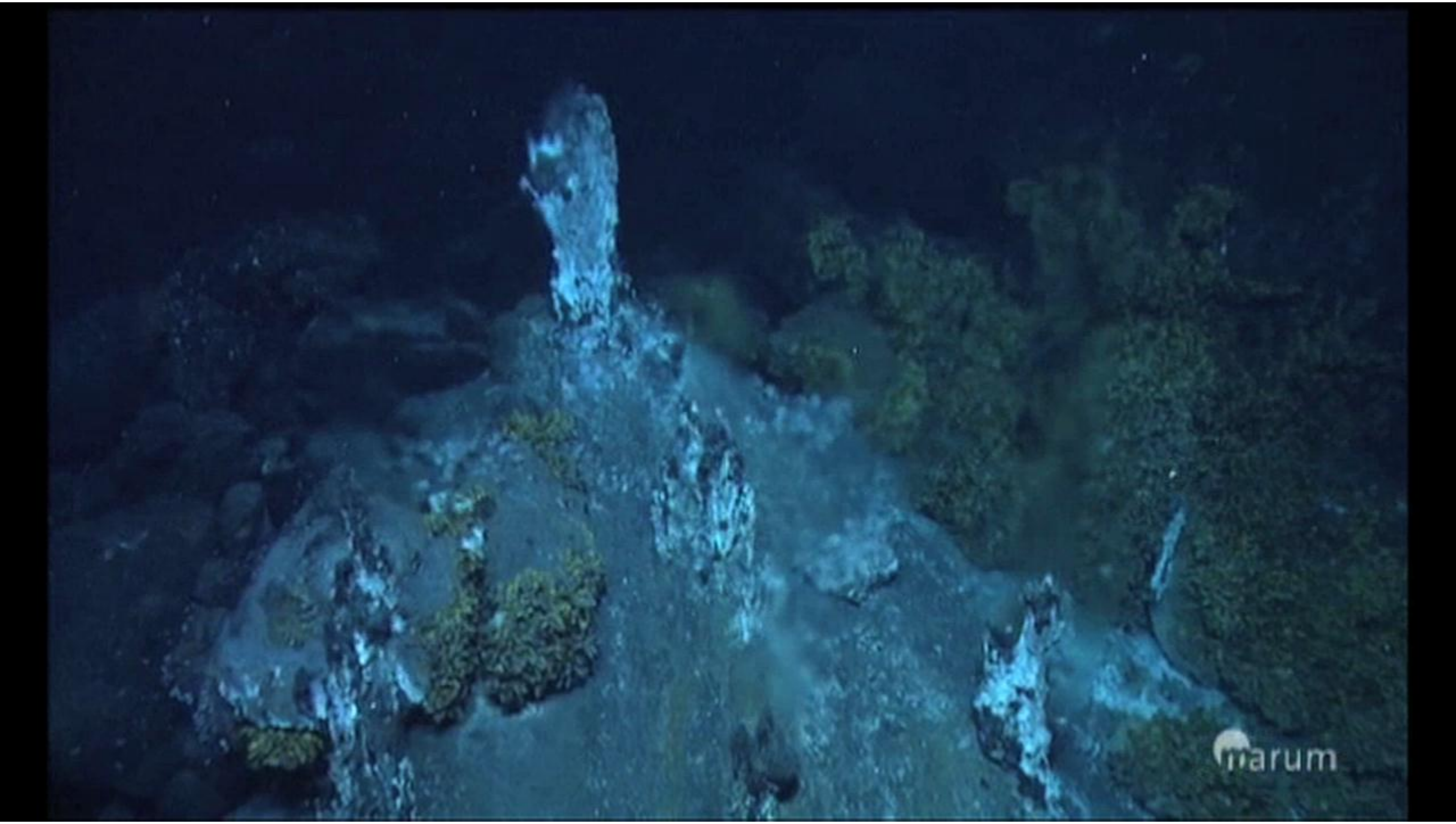
Many rare species

Life at Extreme Conditions
Structurally Unique Molecules

- Deep-sea organisms survive under:
  - absence of light, low levels of oxygen, intensely high pressures, increasingly low temperatures
- At volcanic active areas, where hydrothermal vents exist generating chemosynthetic communities life proliferate under
  - low pH, toxic metals, high temperature, low oxygen, seismic activity, radio-active elements.
- Deep-sea fauna are expected to have a greater genetic diversity, than their shallow-water counterparts, and a higher probability of containing structurally unique molecules with potential application in biotechnology.

D. Skropeta 2008. Natural Product Reports
R. K. Pettit 2011. Marine Biotechnology

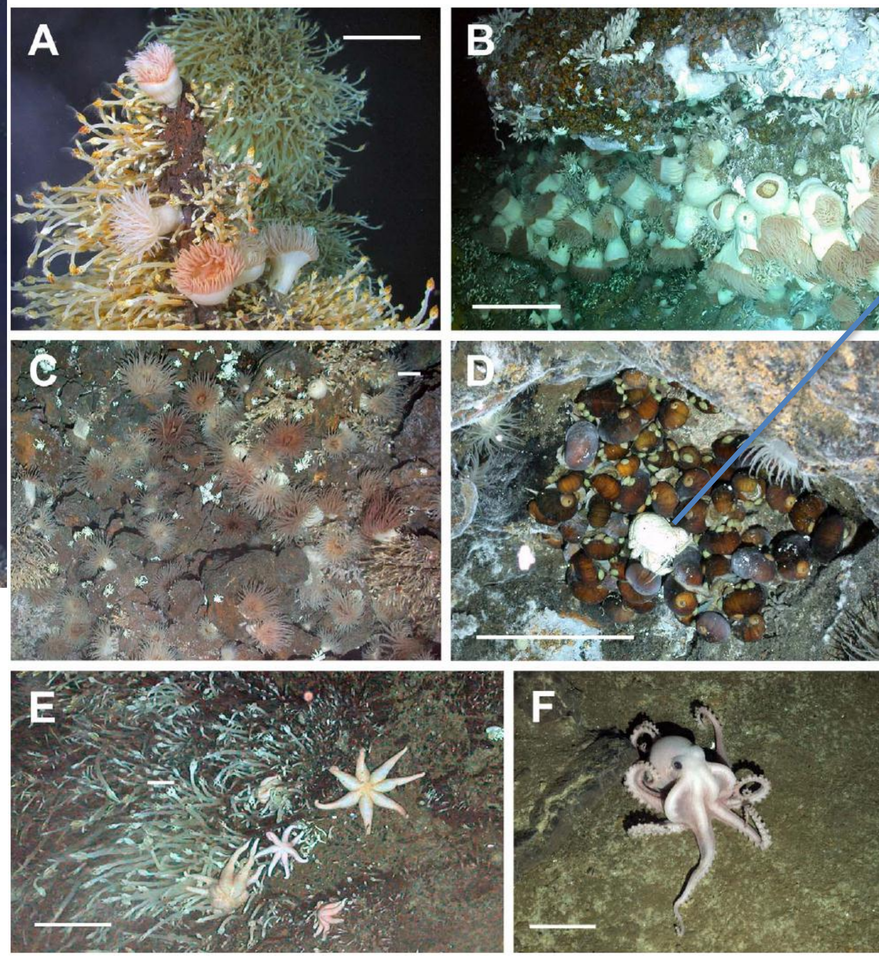
Deep-sea Vents



Antarctic Hydrothermal Vent

ca. - 2400 m deep

2009 -2010



Undescribed peltospiroid gastropod surrounding **undescribed** single Kiwa n. sp. and partially covered by Lepetodrilus **n. sp.**

An **undescribed** seven-arm sea star predatory on the stalked barnacles cf. Vulcanolepas

Unidentified octopus

Rogers et al. 2012 PLoS Biology | Januay, 2012 | vol. 107 | Issue 1

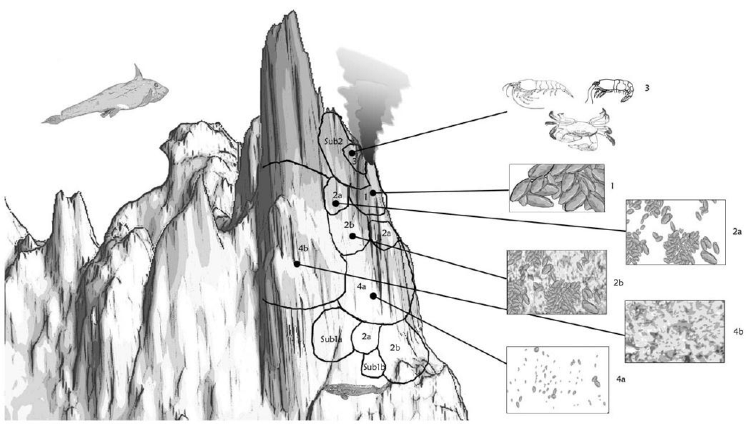
Farming Bacteria for Food

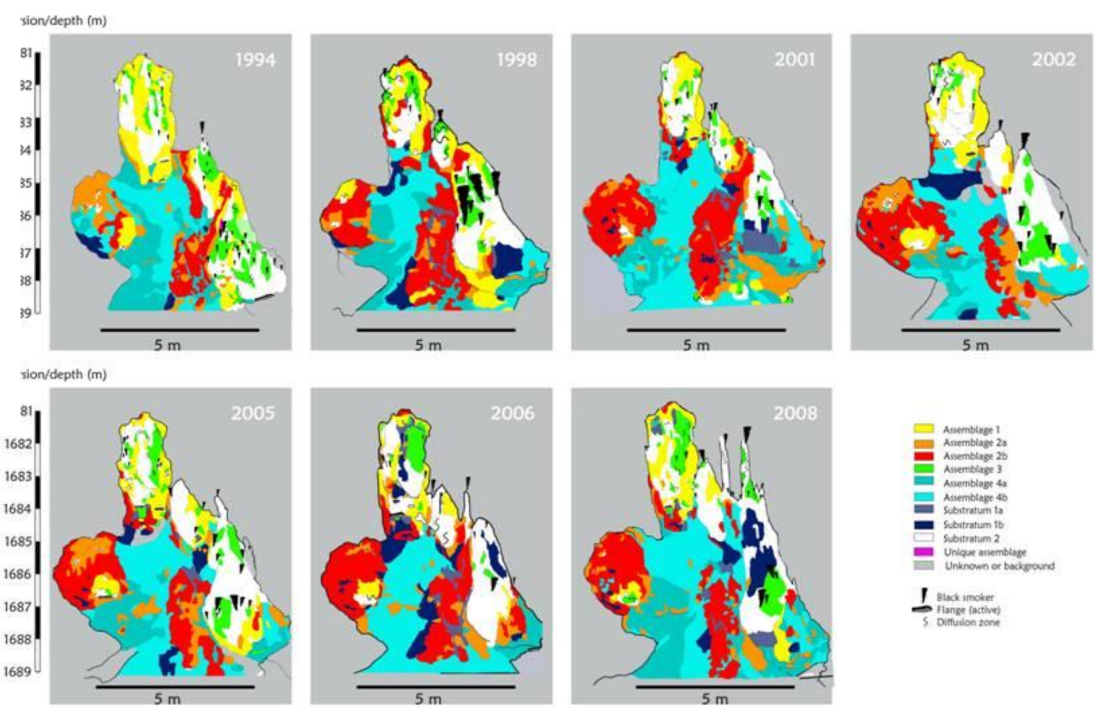
This species of yeti crab "farms" colonies of bacteria on its claws. To help them grow, it waves its pincers over methane and sulfide vents, fertilizing the bacteria and making them good enough to eat.

Thurber AR et al. 2011 PLoS one | November 2011 |Volume 6 | Issue 11 | e262431

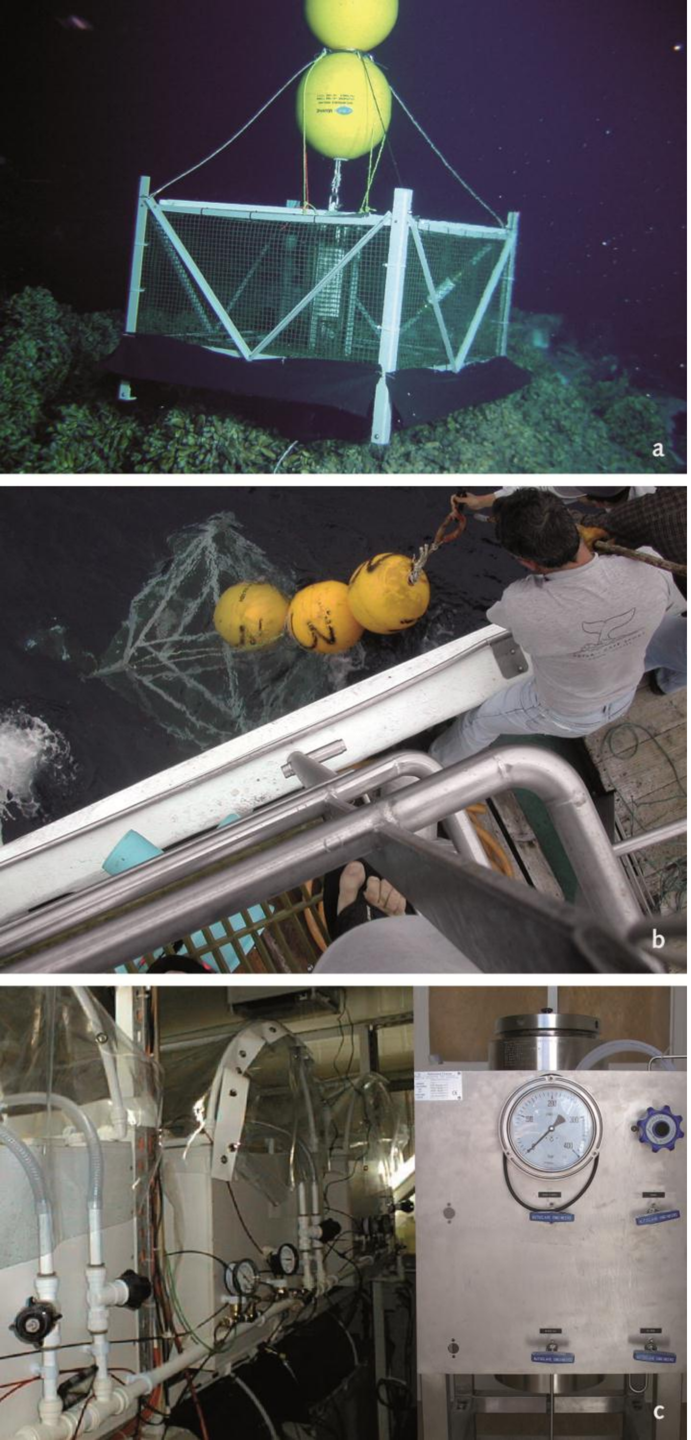
Rate of change in community dynamics at a slow-spreading ridge

- small fluctuations in the rather constant overall percentage coverage (~50%) were explained by subtle changes in hydrothermal activity.
- time was shown not to be a structuring factor,
- rate of change is (…) slower than that observed on sulfide edifices from faster-spreading ridges in the North-East Pacific.





Cuvelier et al. DSRII 2010 & *L&O 2011*



*Lab*Horta – "*Large Scale Facility*" For Experimental Studies with deep-sea Vent Organisms

a) Acoustic Retrievable Cage with Vent Mussels at the Hydrothermal Vent Field Menez Gwen: - 870 metres deep. ©Ifremer-ATOS2001

b) Recovery of Cage with RV Arquipélago ©*Imag*DOP;

c) Inside Acclimatised LabHorta with Pressured Chambers and Sulphide / Methane Chemically Controlled Seawater Aquaria. ©*Imag*DOP

ICES Journal of Marine Science (2011), 68(2), 349–356. doi:10.1093/icesjms/fsq120

LabHorta: a controlled aquarium system for monitoring physiological characteristics of the hydrothermal vent mussel *Bathymodiolus azoricus*

Ana Colaço et al. 2011

Bettencourt *et al. BMC Genomics* 2010, **11**:559
http://www.biomedcentral.com/1471-2164/11/559

BMC Genomics

RESEARCH ARTICLE **Open Access**

High-throughput sequencing and analysis of the gill tissue transcriptome from the deep-sea hydrothermal vent mussel *Bathymodiolus azoricus*

Raul Bettencourt[1,2*], Miguel Pinheiro[3], Conceição Egas[4,5], Paula Gomes[4], Mafalda Afonso[2], Timothy Shank[6], Ricardo Serrão Santos[1,2]

86065 potential genes were sequenced from which 44000 proteins were identified

New genes were identified, like the genes involved on immunological and inflammatory reactions of the mussels.

Bettencourt R et al. 2010. BMC Genomics, 11

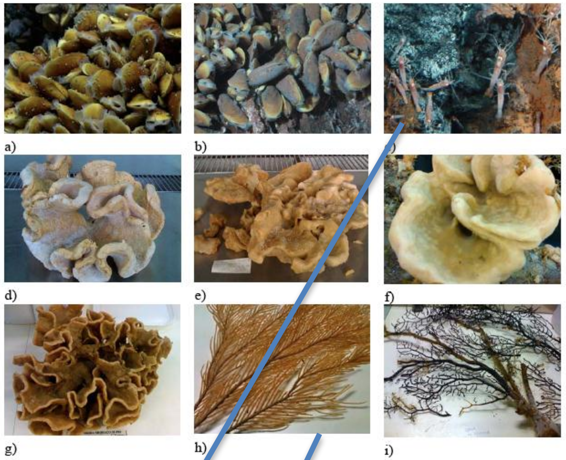
Mar. Drugs **2012**, *10*, 1765-1783; doi:10.3390/md10081765

OPEN ACCESS
Marine Drugs
ISSN 1660-3397
www.mdpi.com/journal/marinedrugs

Article

The Transcriptome of *Bathymodiolus azoricus* Gill Reveals Expression of Genes from Endosymbionts and Free-Living Deep-Sea Bacteria

Conceição Egas [1,†,*], Miguel Pinheiro [1,†], Paula Gomes [1], Cristina Barroso [1] and Raul Bettencourt [2]



OPEN ACCESS
Marine Drugs
ISSN 1660-3397
www.mdpi.com/journal/marinedrugs

Short note

First evaluation of antimalarial properties of lipid marine extracts from Azores deep-sea invertebrates

Silvia Lino [1,*], Ana Colaço [1], Ricardo S. Santos [1], Vírgilio do Rosário[3], Marta Machado[2] and Dinora Lopes[2]

Type of sample (specie)	Origin (depth)	IC50 (µg/ml) ± SD			Selectivity Index	
		P. falciparum 3D7	*P. falciparum* Dd2	HepG2 cells	HepG2/3D7	HepG2/Dd2
Gills from mussel (*Bathymodiolus azoricus*)	*Lucky Strike* hydrothermal vent (1700 m)	59,67 ± 3,28	71,84 ± 1,64	259,26 ± 9,63	4,34	3,61
Digestive Glands from mussel (*Bathymodiolus azoricus*)	*Lucky Strike* hydrothermal vent (1700 m)	100,38 ± 4,97	107,91 ± 6,7	95,26 ± 10,8	0,95	0,88
Muscle from mussel (*Bathymodiolus azoricus*)	*Lucky Strike* hydrothermal vent (1700 m)	158 ± 11,03	155,6 ± 2,4	331,3 ± 19,65	2,10	2,13
Bristle worm (*Amathys lutzi*)	*Lucky Strike* hydrothermal vent (1700 m)	86,97 ± 1[illegible],97	91,66 ± 11,97	266,2 ± 27,51	3,06	2,90
Shrimp (*Mirocaris fortunata*)	*Lucky Strike* hydrothermal vent (1700 m)	76,64 ± 6,33	78,28 ± 1,79	515,06 ± 24,61	6,72	6,58
Sponge (*Neophrissospongia nolitangere*)	Terceira Island (102 m)	83,2 ± 7,65	66,915 ± 3,94	304,85 ± 11,87	3,66	4,56
Sponge 1 (*Petrosia* sp.)	Faial Island (21[illegible] m)	115,85 ± 6,71	100,53 ± 0,96	56,68 ± 7,66	0,49	0,56
Sponge 2 (*Petrosia* sp.)	Princesa Alice seamount (300 m)	116,5 ± 17,11	105,01 ± 10,88	483,02 ± 22,3	4,15	4,60
Sponge (*Leiodermatium* cf. *pfeifferae*)	Açores seamount (384 m)	56,57 ± 3,79	62,44 ± 0,41	107,58 ± 8,35	1,90	1,72
Gorgonia (*Callogorgia verticillata*)	Açores seamount (409 m)	44 ± 6,1	46,57 ± 7,64	268,57 ± 35,6	6,10	5,77
Gorgonia (*Dentomuricea* sp.)	Condor seamount (193 m)	60,07 ± 12,8	59,33 ± 5	281,8 ± 17,61	4,69	4,75

Highest antimalarial activity

SCIENCE VOL 331 25 MARCH 2011

GLOBAL GENETIC RESOURCES

Marine Biodiversity and Gene Patents

Sophie Arnaud-Haond,[1,*] Jesús M. Arrieta,[2] Carlos M. Duarte[2,3]

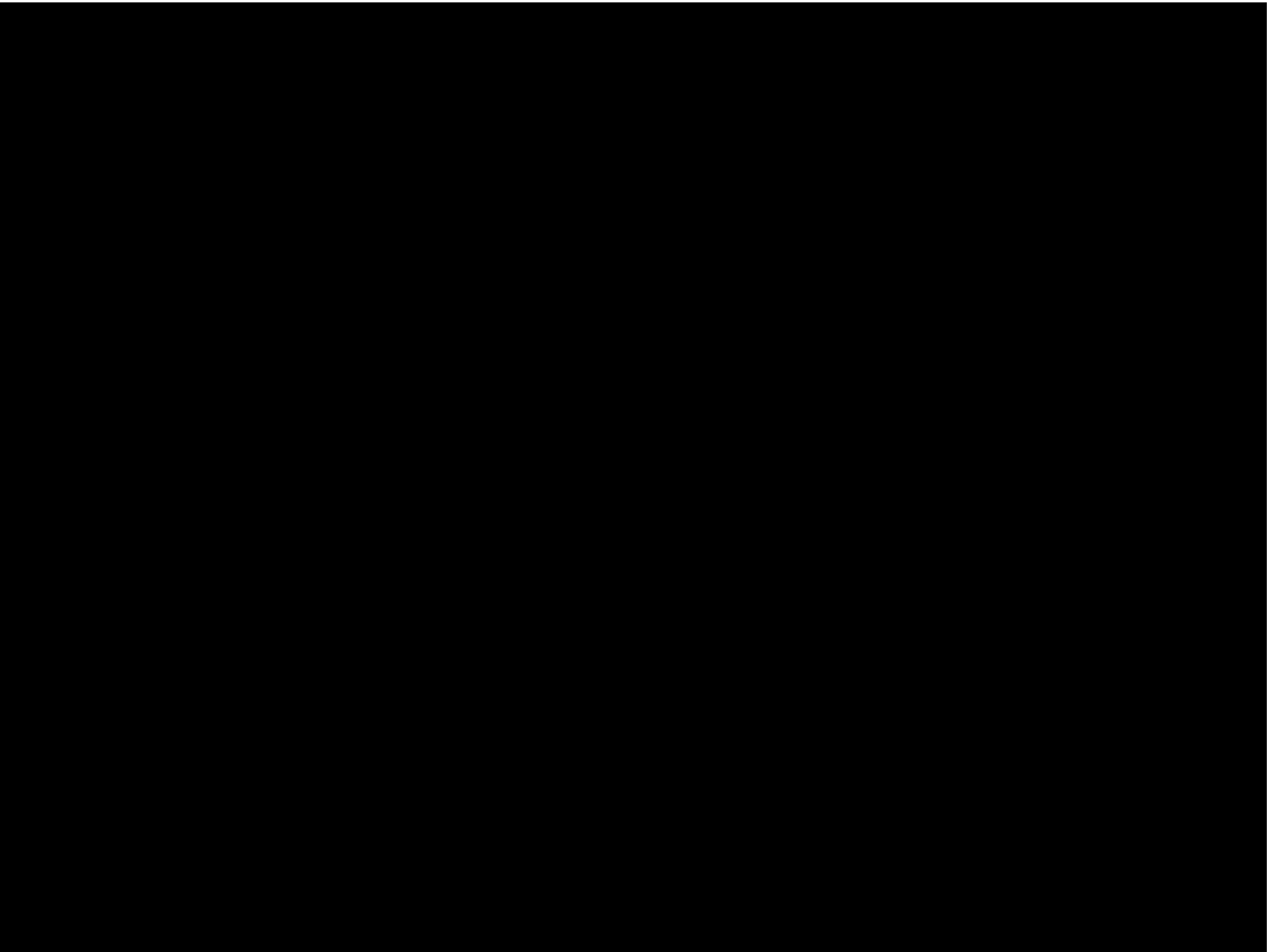
PATENT CLAIMS FOR A GENE OF MARINE ORIGIN WITH SOURCE

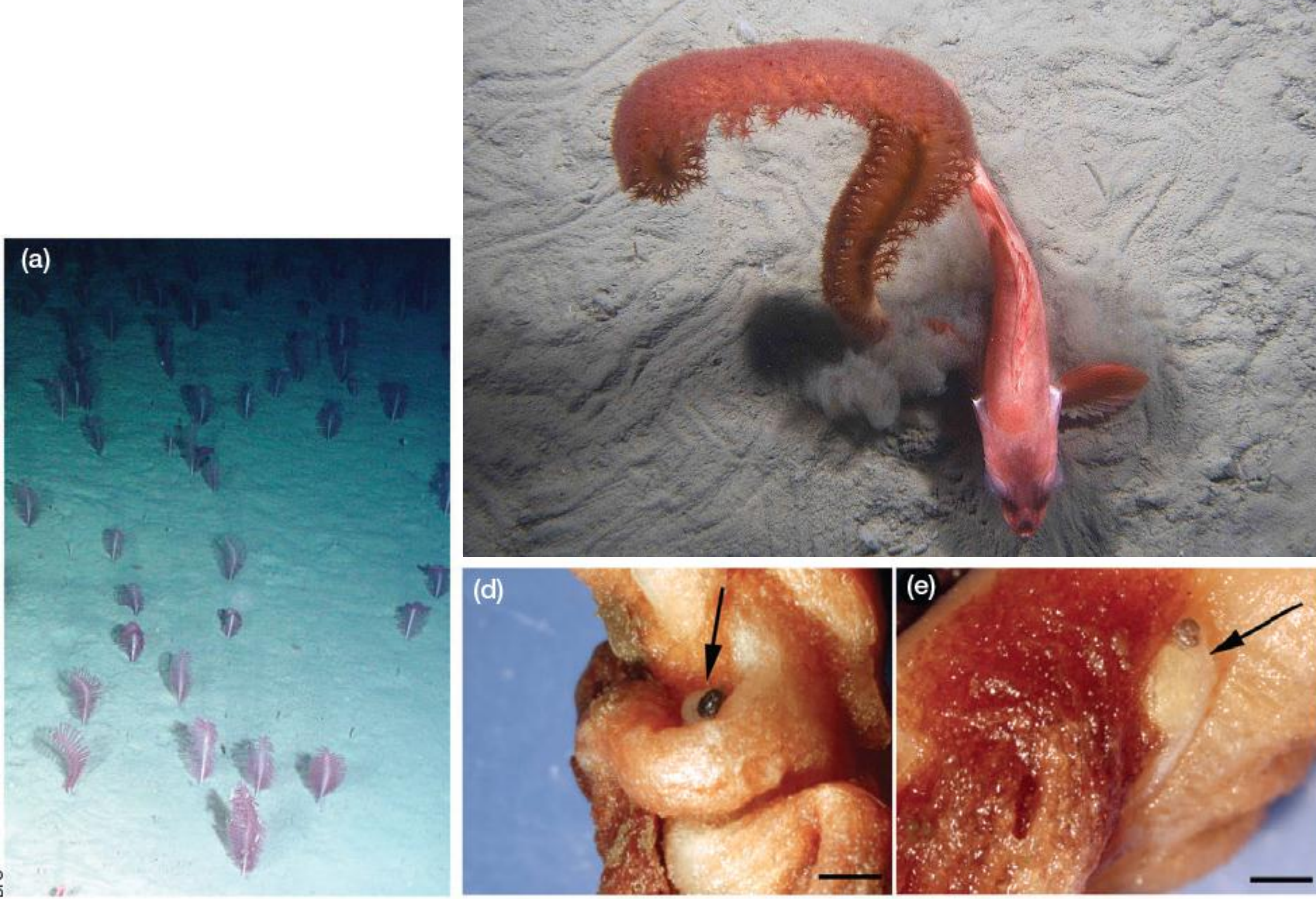
Country	Marine organism patent claims
USA	199
Germany	149
Japan	128
France	34
United Kingdom	33
Denmark	24
Belgium	17
Netherland	13
Switzerland	11
Norway	9

Of the genes associated with WIPO patents, 17% are of **unknown taxonomic origin**, and almost none of the patent claims examined **disclosed** the **geographic origin** of material.

Although states compromised in promoting establishment of sharing agreements under CBD, this is not a legally binding agreement and so does not imply that companies will necessarily comply.

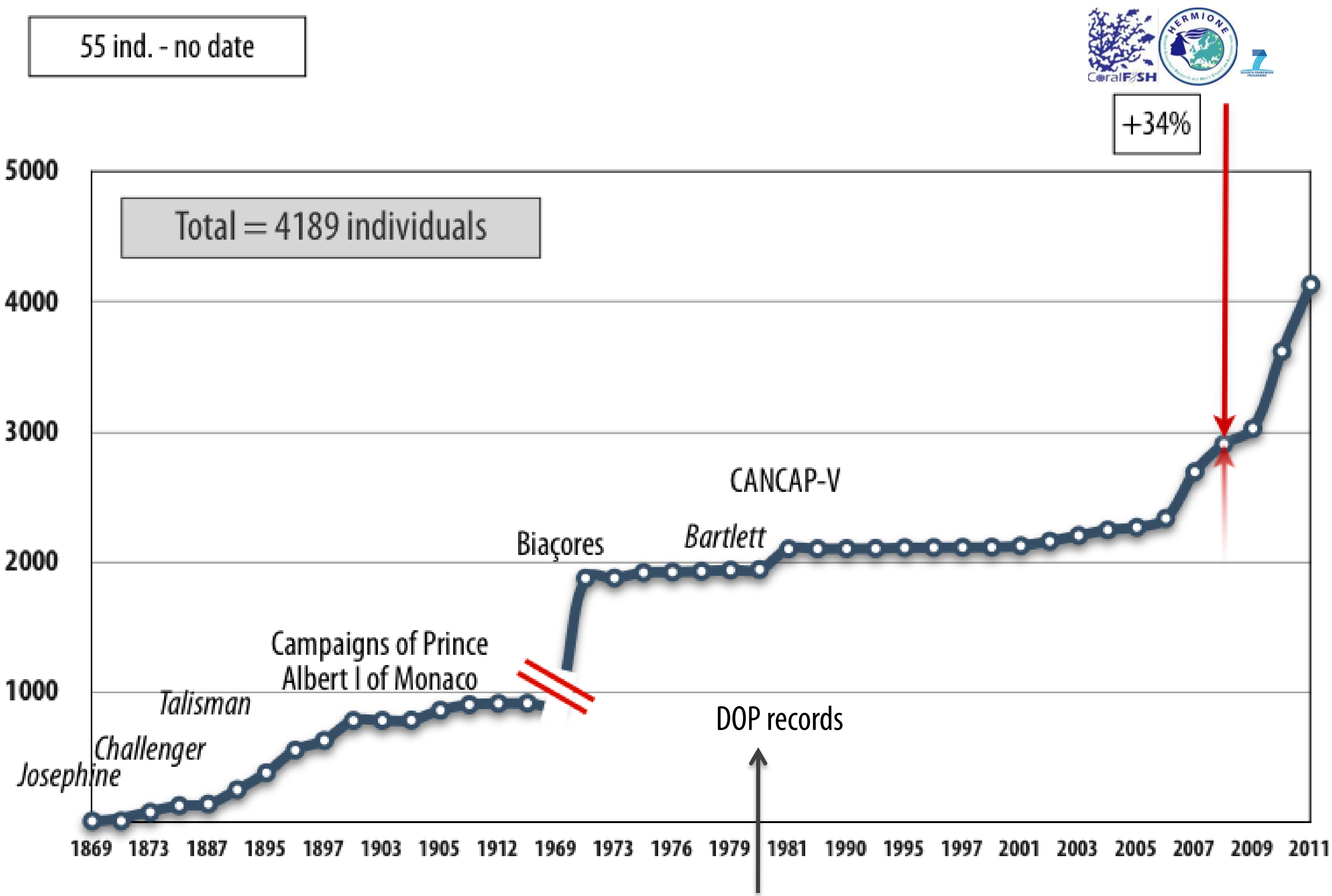
Seamounts





S. Baillon et al. 2012. Frontiers in Ecology and Environment

Number of coral specimens recorded vs time



A. Braga-Henriques et al. 2012. under submission

The long-living animal on the planet

Place of Birth: Azores

Year of Birth: -1392 c.e. (common era)

Year of Death: + 2008 c.e.

Age: 3400 years

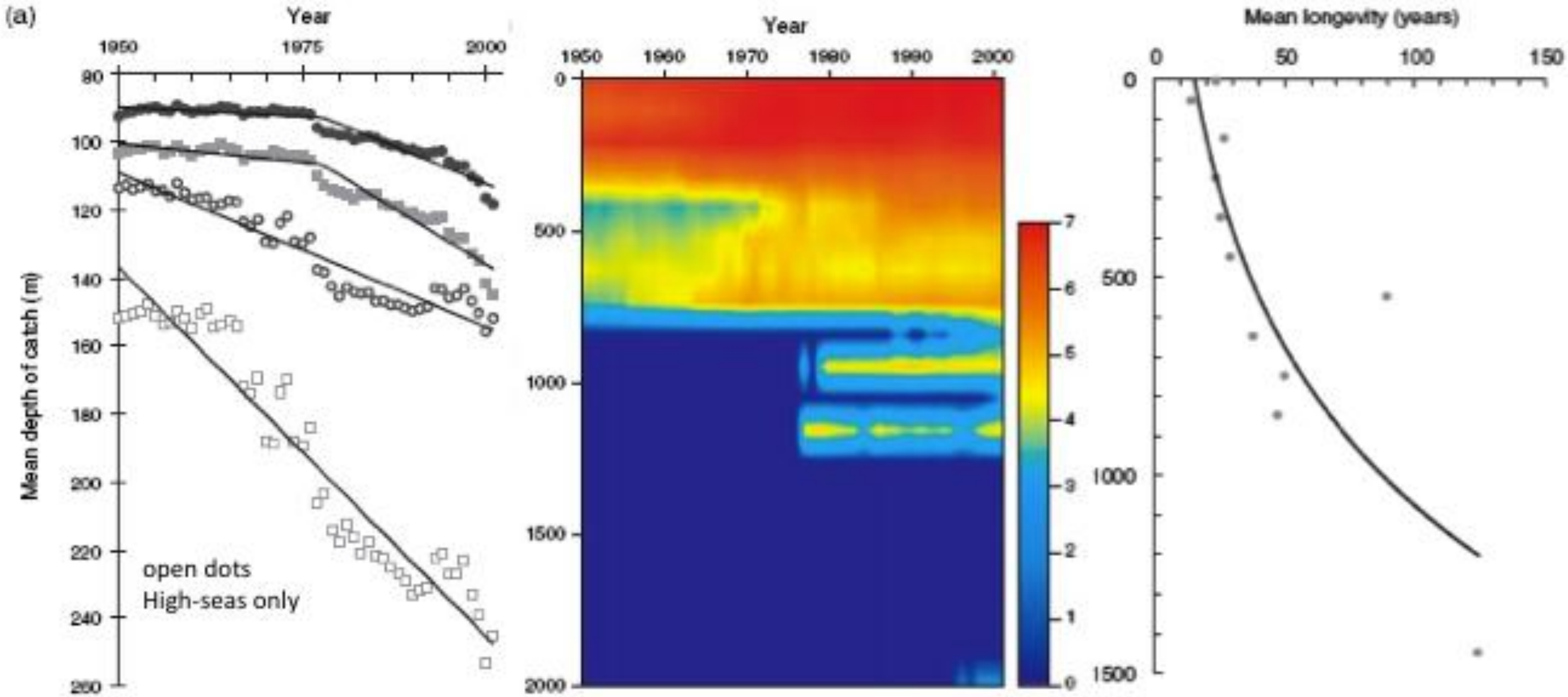
SEVENTH FRAMEWORK PROGRAMME

CoralFISH

HERMIONE

Hotspot Ecosystem Research and Man's Impact on European seas

Growing Interest on the Deep-sea Fisheries

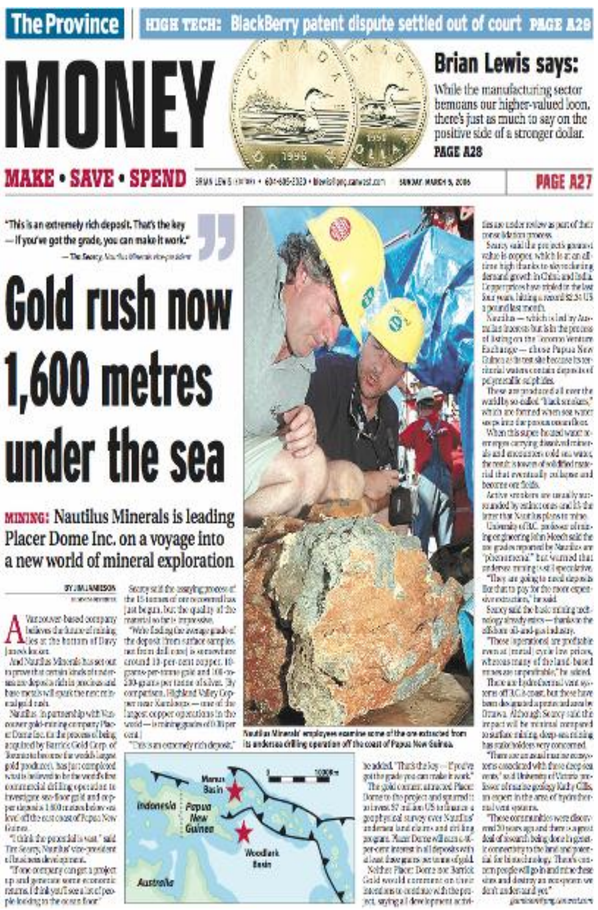


Global tendencies of mean depth in world fisheries from 1950 -2001

Morato T et al. 2006, Fish and Fisheries: Fishing down the deep
Serrão Santos R et al. 2012. Natural Resources, Sustainability and Humanity, Ch5. Springer

Serrão Santos R et al. 2012. Natural Resources, Sustainability and Humanity, Ch5. Springer

Growing Interest on the Deep-sea Mining of Minerals


The Province | HIGH TECH: BlackBerry patent dispute settled out of court PAGE A29

MONEY

MAKE • SAVE • SPEND

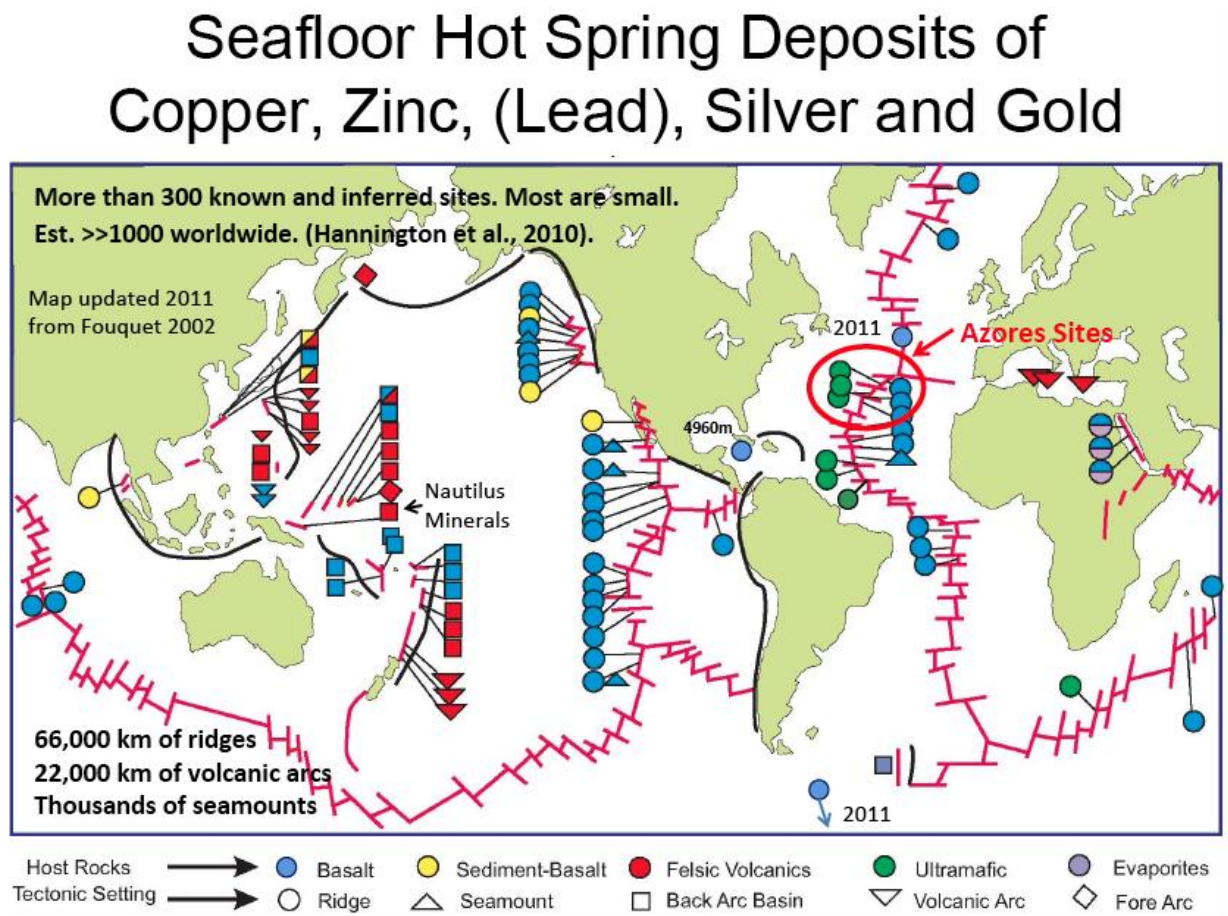
PAGE A27

Brian Lewis says: While the manufacturing sector bemoans our higher-valued loon, there's just as much to say on the positive side of a stronger dollar. PAGE A28

"This is an extremely rich deposit. That's the key — if you've got the grade, you can make it work."

Gold rush now 1,600 metres under the sea

MINING: Nautilus Minerals is leading Placer Dome Inc. on a voyage into a new world of mineral exploration



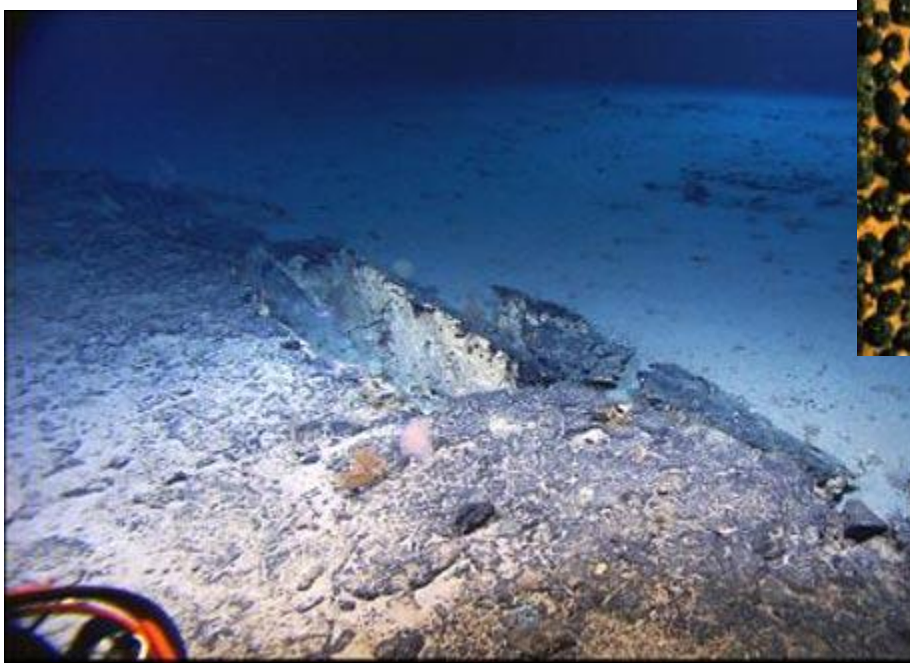
Map – Steve Scott courtesy

Serrão Santos R et al. 2012. Natural Resources, Sustainability and Humanity, Ch5. Springer

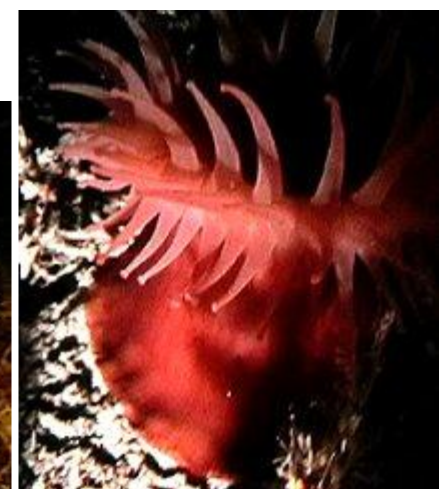
Crust and manganese nodules

Crusts and nodules are among the slowest-forming mineral deposits known: from 1 to 20 mm/million years. Crust thicknesses range from < 1 mm to as much as 240 mm (common between 20 and 40 mm in thickness) (Verlaan 1992)

Manganese nodules



Carbonate, with manganese crust

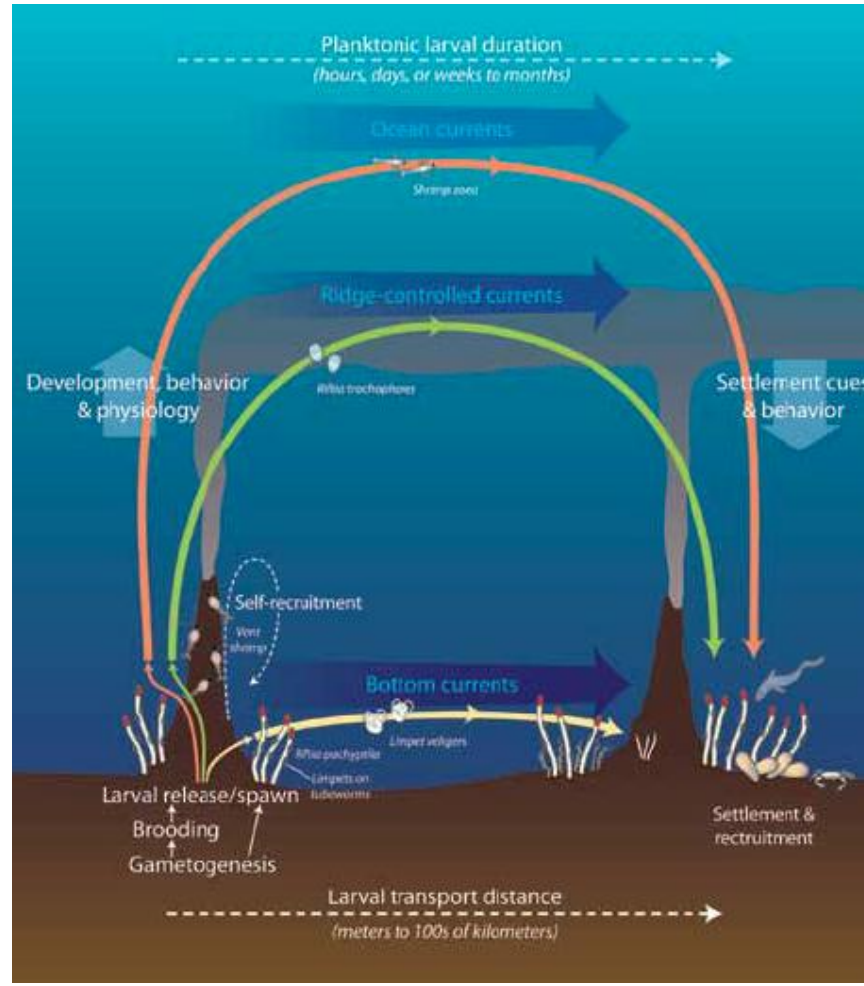


Anenome growing on manganese crust in the Great Australian Bight at a depth of about 1620 metres

Ramirez-Llodra E, Tyler PA, Baker MC, Bergstad OA, et al. (2011) Man and the Last Great Wilderness: Human Impact on the Deep Sea. PLoS ONE 6(8): e22588. doi:10.1371/journal.pone.0022588
http://www.plosone.org/article/info:doi/10.1371/journal.pone.0022588

PLoS one

Connectivity



Adams, D.K., S.M. Arellano, and B. Govenar. 2012. Larval dispersal: Vent life in the water column. *Oceanography* 25(1):256–268, http://dx.doi.org/10.5670/oceanog.2012.24.

Threaten Habitats

OSPAR Commission
Commission OSPAR

OSPAR CONVENTION FOR THE PROTECTION OF THE MARINE ENVIRONMENT OF THE NORTH-EAST ATLANTIC

MEETING OF THE OSPAR COMMISSION (OSPAR)

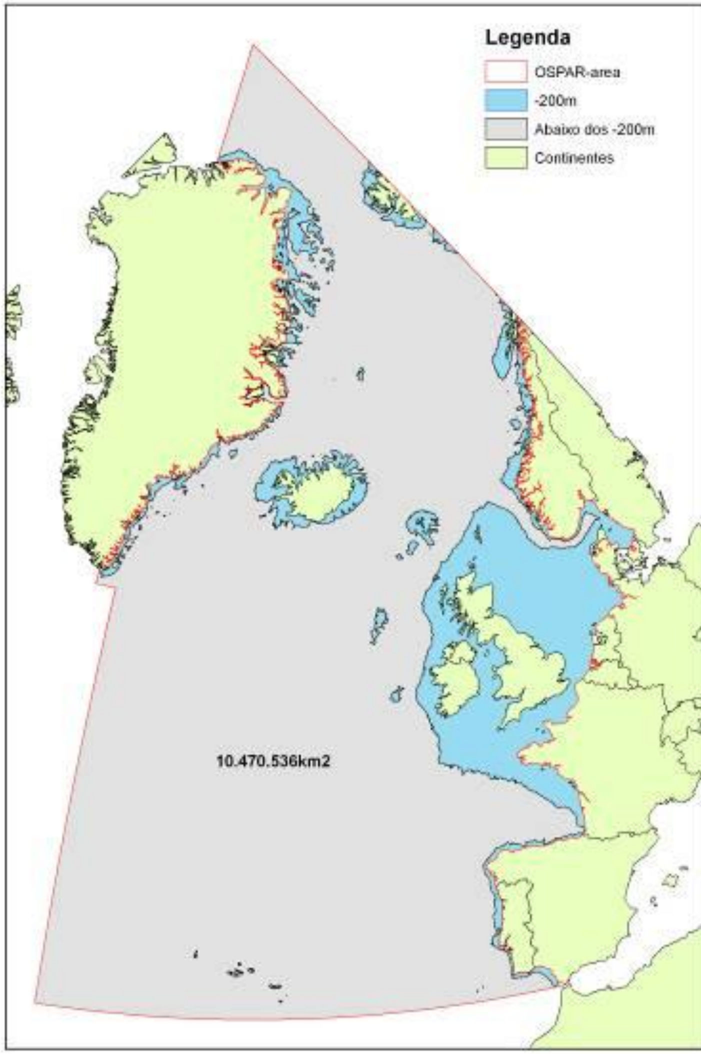
REYKJAVIK: 28 JUNE – 1 JULY 2004

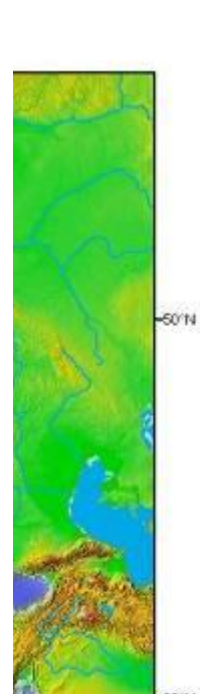
OSPAR List of Threatened and/or Declining Species and Habitats
(Reference Number: 2004-06)

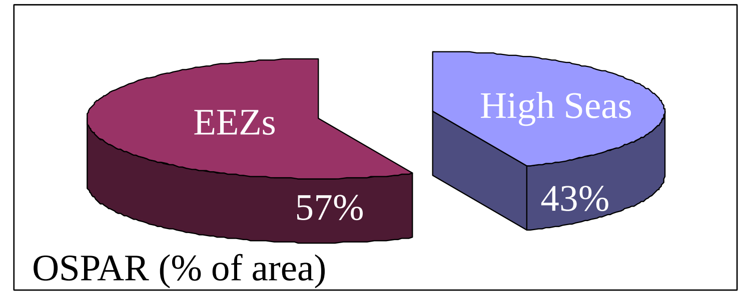
DESCRIPTION	OSPAR Regions where the habitat occurs	OSPAR Regions where such habitats are under threat and/or in decline
HABITATS		
Carbonate mounds	**I, V**	**V[7]**
Deep-sea sponge aggregations	**I, III, IV, V**	**All where they occur**
Oceanic ridges with hydrothermal vents/fields	**I, V**	**V**
Intertidal mudflats	**I, II, III, IV**	**All where they occur**
Littoral chalk communities	**II**	**All where they occur**
Lophelia pertusa reefs	**All**	**All where they occur**
Maerl beds	**All**	**III**
Modiolus modiolus beds	**All**	**All where they occur**
Intertidal *Mytilus edulis* beds on mixed and sandy sediments	**II, III**	**All where they occur**
Ostrea edulis beds	**II, III, IV**	**All where they occur**
Sabellaria spinulosa reefs	**All**	**II, III**
Seamounts	**I, IV, V**	**All where they occur[8]**
Sea-pen and burrowing megafauna communities	**I, II, III, IV**	**II, III**
Zostera beds	**I, II, III, IV**	**All where they occur**

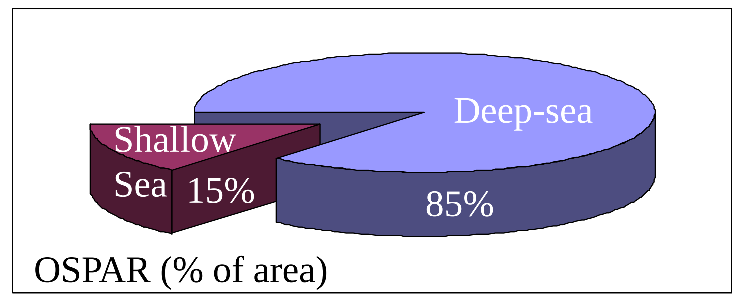
The Quantitative Relevance of the Deep-Sea

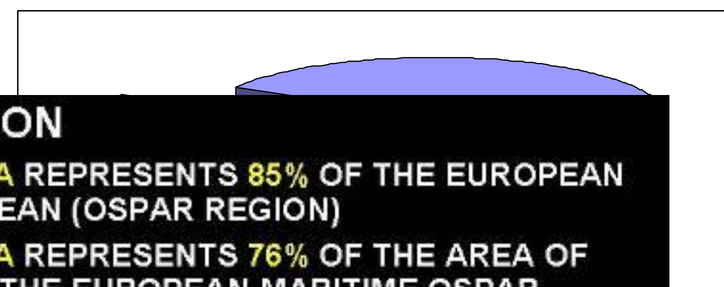
A View from the Atlantic: Our Seas in the OSPAR Area.



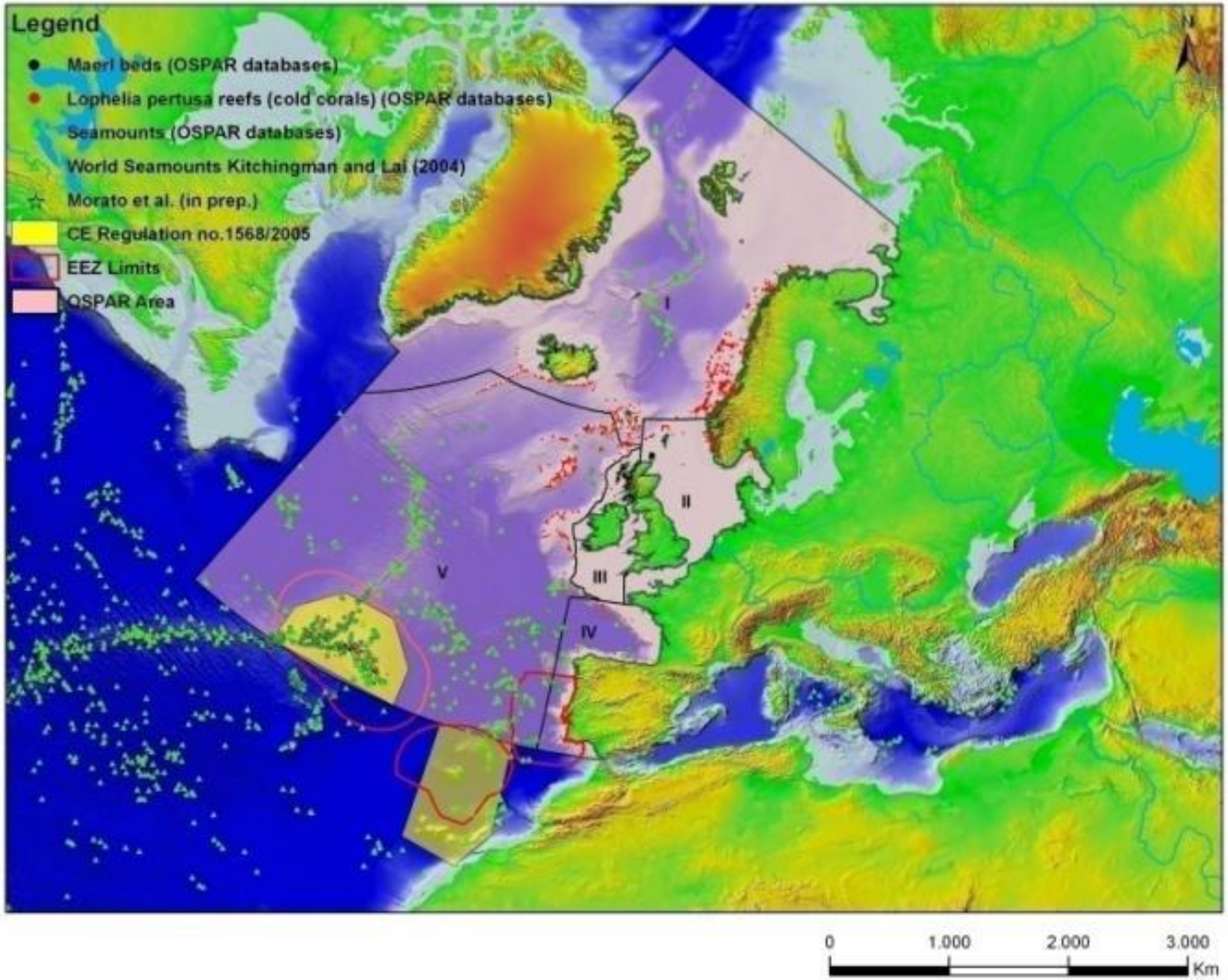




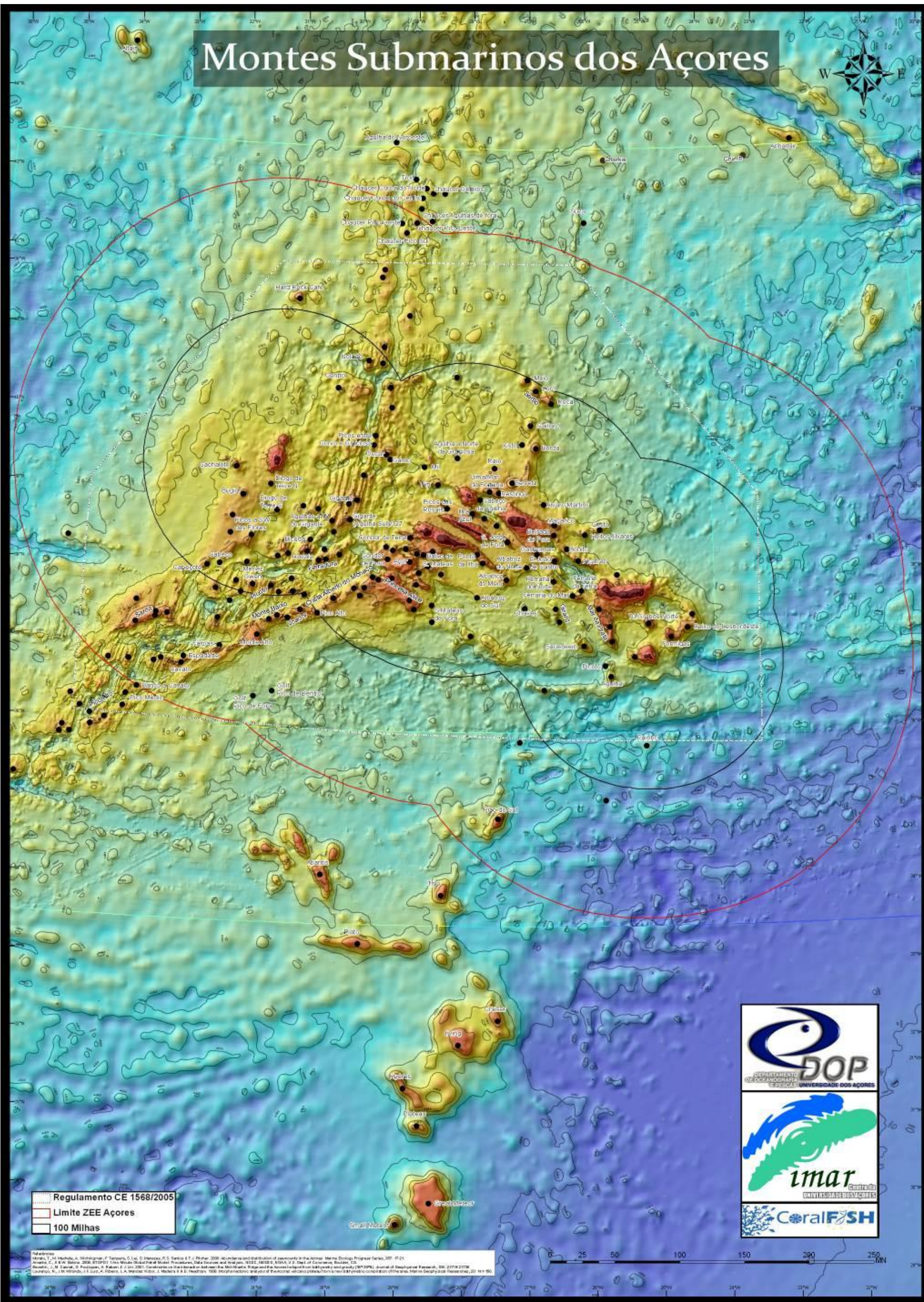


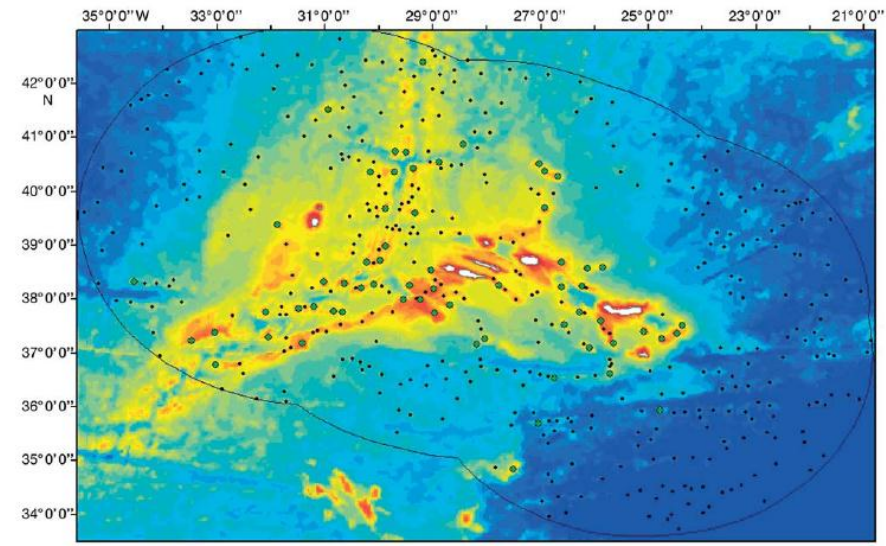


- IN CONCLUSION
  - THE DEEP SEA REPRESENTS 85% OF THE EUROPEAN ATLANTIC OCEAN (OSPAR REGION)
  - THE DEEP SEA REPRESENTS 76% OF THE AREA OF THE EEZS OF THE EUROPEAN MARITIME OSPAR COUNTRIES
  - THE DEEP SEA REPRESENTS 100% OF THE HIGH SEAS OF THE OSPAR REGION



Legend
Maerl beds (OSPAR databases)
Lophelia pertusa reefs (cold corals) (OSPAR databases)
Seamounts (OSPAR databases)
World Seamounts Kitchingman and Lai (2004)
Morato et al. (in prep.)
CE Regulation no.1568/2005
EEZ Limits
OSPAR Area
I
II
III
IV
V
0
1.000
2.000
3.000
Km





Azores seamounts
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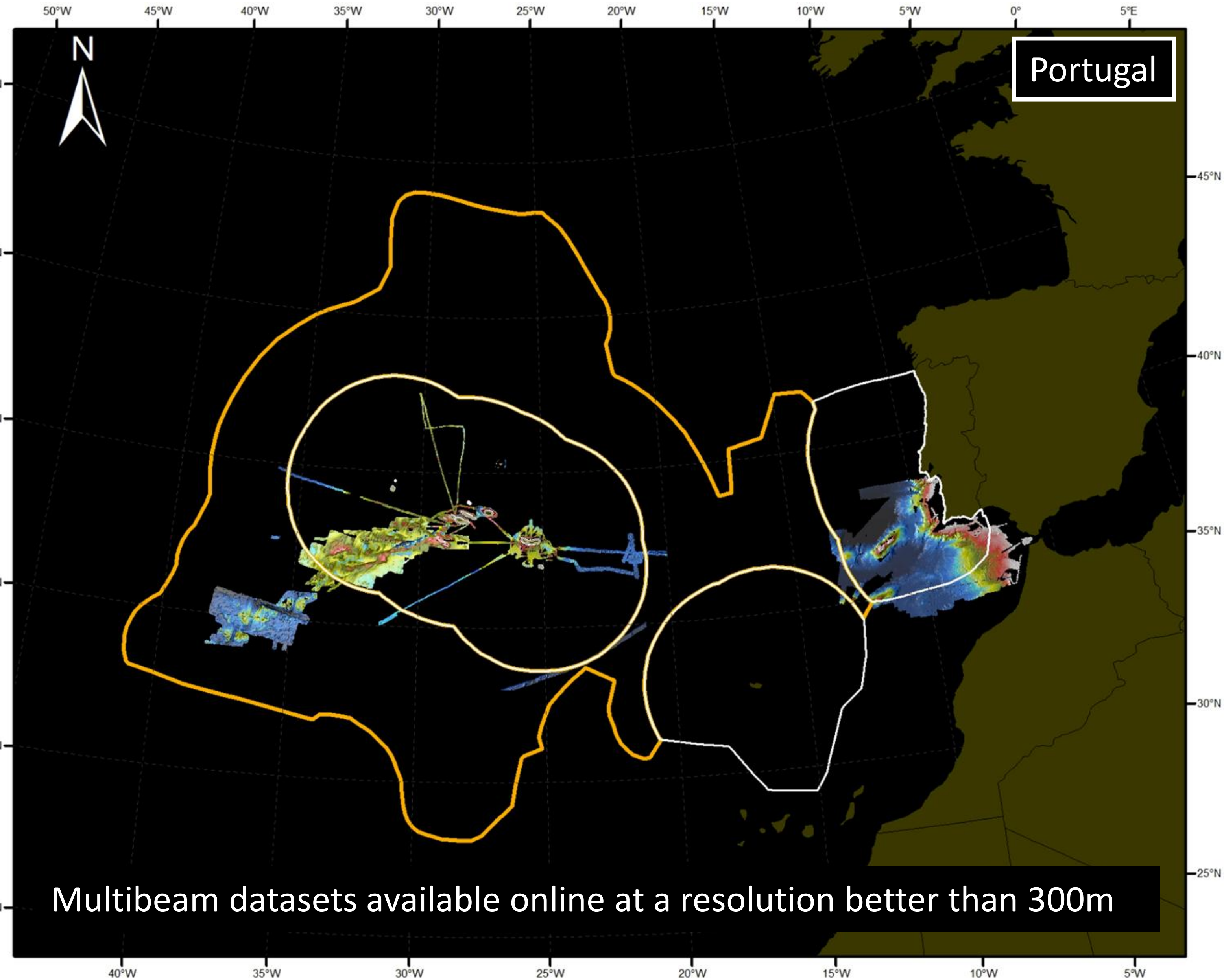
Abundance and distribution of seamounts in the Azores

Telmo Morato[1,2,*], Miguel Machete[1], Adrian Kitchingman[2], Fernando Tempera[1], Sherman Lai[2], Gui Menezes[1], Tony J. Pitcher[2], Ricardo S. Santos[1]

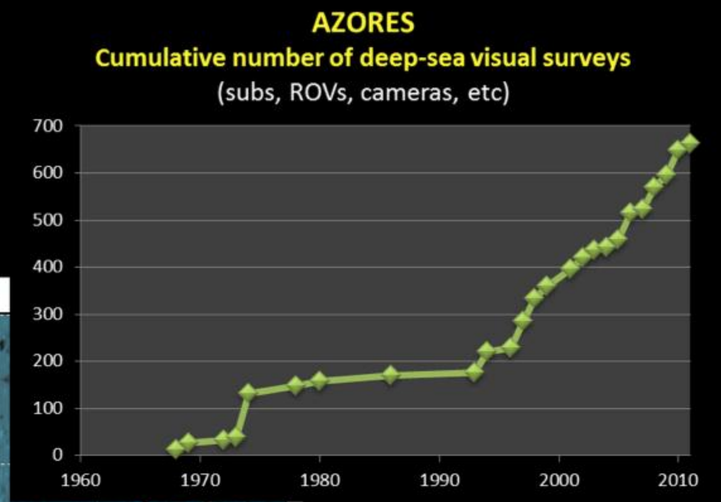
[1]Departamento de Oceanografia e Pescas, Universidade dos Açores, 9901-862, Horta, Portugal
[2]Fisheries Centre, Aquatic Ecosystems Research Laboratory, 2202 Main Mall, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada

Ground-truth mapping

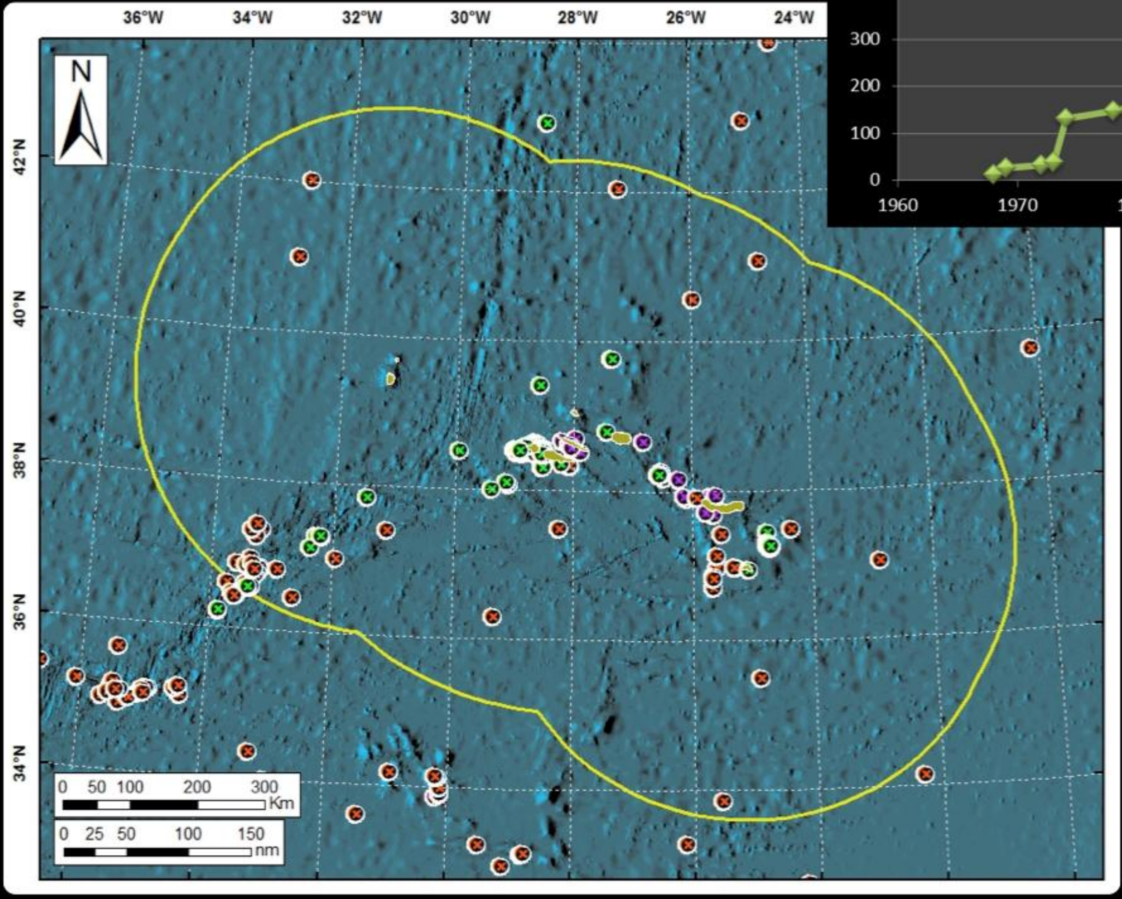


F Tempera *Imag*DOP

Groundtruthing surveys by visual methods



courtesy F Tempera



Island shelves

Island slopes

Seamount slopes

Mid-depth seamount summits

Abyssal plains

Deep-sea hydrothermal vents

Smaller elevations

OSPAR Priority Habitats Inventory
Azores EEZ sub-area

OSPAR Commission
Commission OSPAR

Habitat	No of records
Seamounts (height ≥1000m)	434 (4 MPAs) all under EC resol. 1568/ 2005
Lophelia reefs (+ *Madrepora*)	1 type 28 records
Deep sea sponge aggregations	14 types 136 records
Coral gardens	[166 spp] – 23 assemblages 223 records
Hydrothermal vents	3 types 10 sites (3 MPAs)
Maerl	15 records

F. Tempera et al. 2011. Bulletin of the Geological Society of Finland

Future directions

Açores 2010 © MARUM

The North-Eastern Atlantic provides a basis for an increasing range of economic interests in the deep-sea

There is a need for continued research on the identification of vulnerable marine ecosystems and clear assessment and mitigation of impacts

MSFD establishes that the seafloor remain healthy and productive for future generations

High-resolution map of seabed morphology and habitats is essential to underpin the European integrated maritime policy

Cooperation in the establishment of a European Atlantic Seabed Mapping.

We need to know a lot more about connectivity, ecosystem functioning and services.

Acknowledgements to Co-Workers

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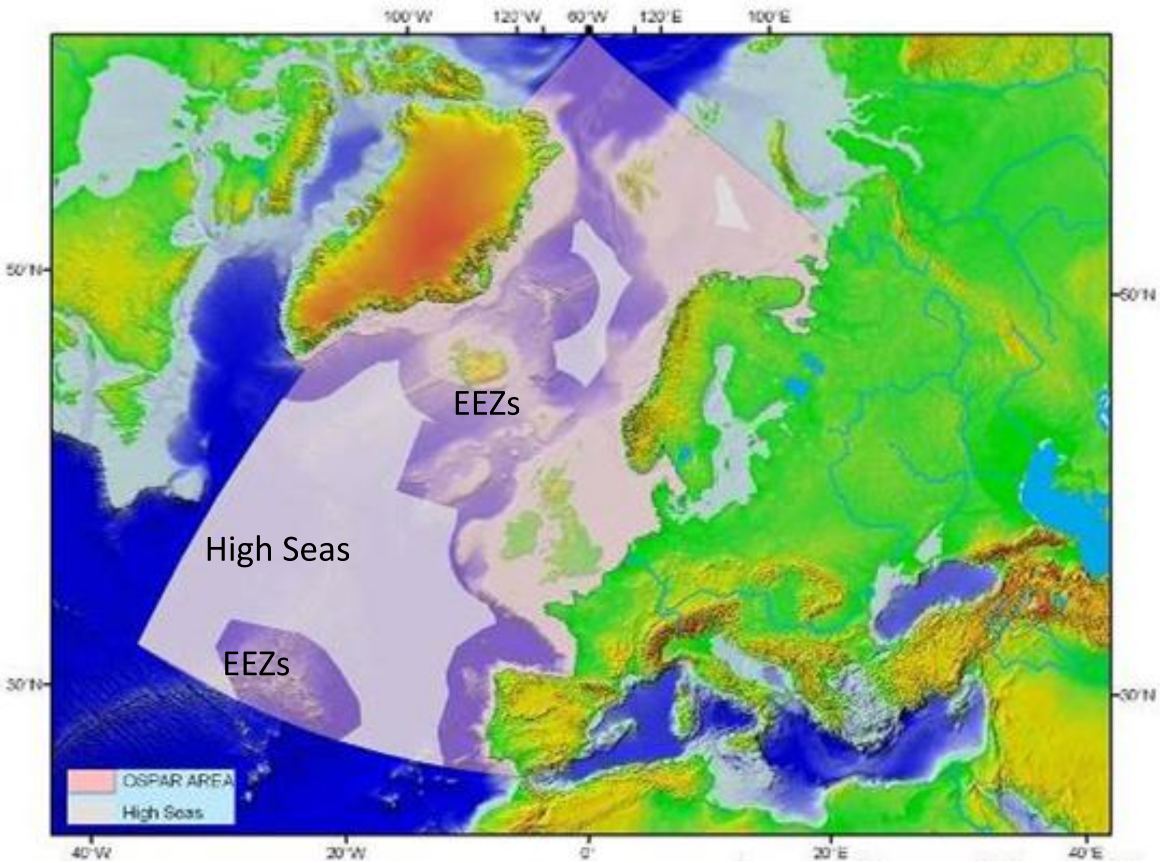
- Gui Menezes
- Telmo Morato
- Filipe Porteiro
- Virginie Riou
- Fernando Tempera

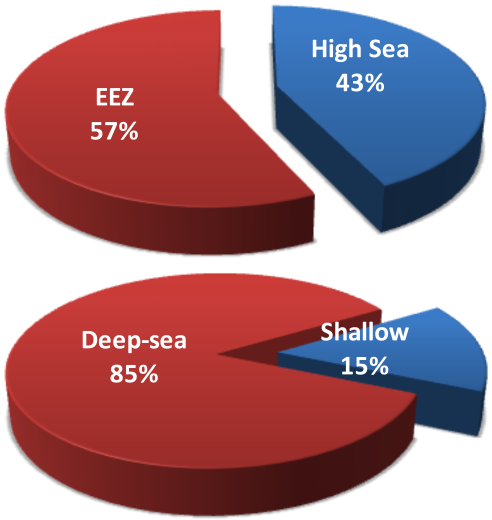
... and many others

A view from the Atlantic: the OSPAR Area

Mean depth of the seafloor in the OSPAR region: 2 159m



% OSPAR area



% EEZ area