Improved deep-sea biodiversity assessments inform sustainable management of seamounts

Telmo Morato

&
many others

Okeanos, University of the Azores, Portugal

Blue Azores / Fundação Oceano Azul

OKEANOS

iAtlantic
INTEGRATED ASSESSMENT OF ATLANTIC MARINE ECOSYSTEMS IN SPACE AND TIME

atlas

OCEANO AZUL fundação

AÇORES 2020

GOVERNO DOS AÇORES

PORTUGAL 2020

UNIÃO EUROPEIA
Fundo Europeu de Desenvolvimento Regional

MISSION STATEMENT

Increase our **understanding**

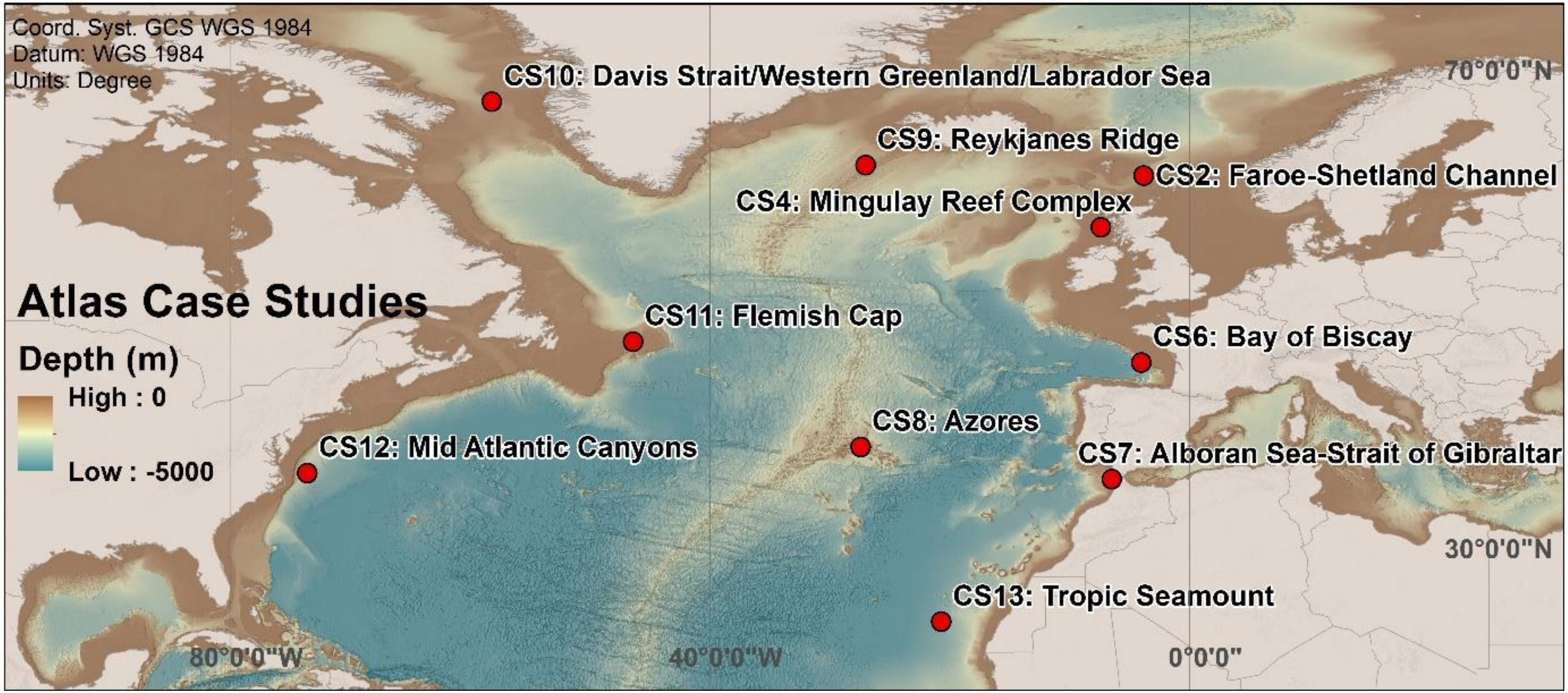
of the **deep-sea** in the north Atlantic & Azores

in a **changing planet**,

to inform **conservation** & **sustainable use**

for current and **future** generations

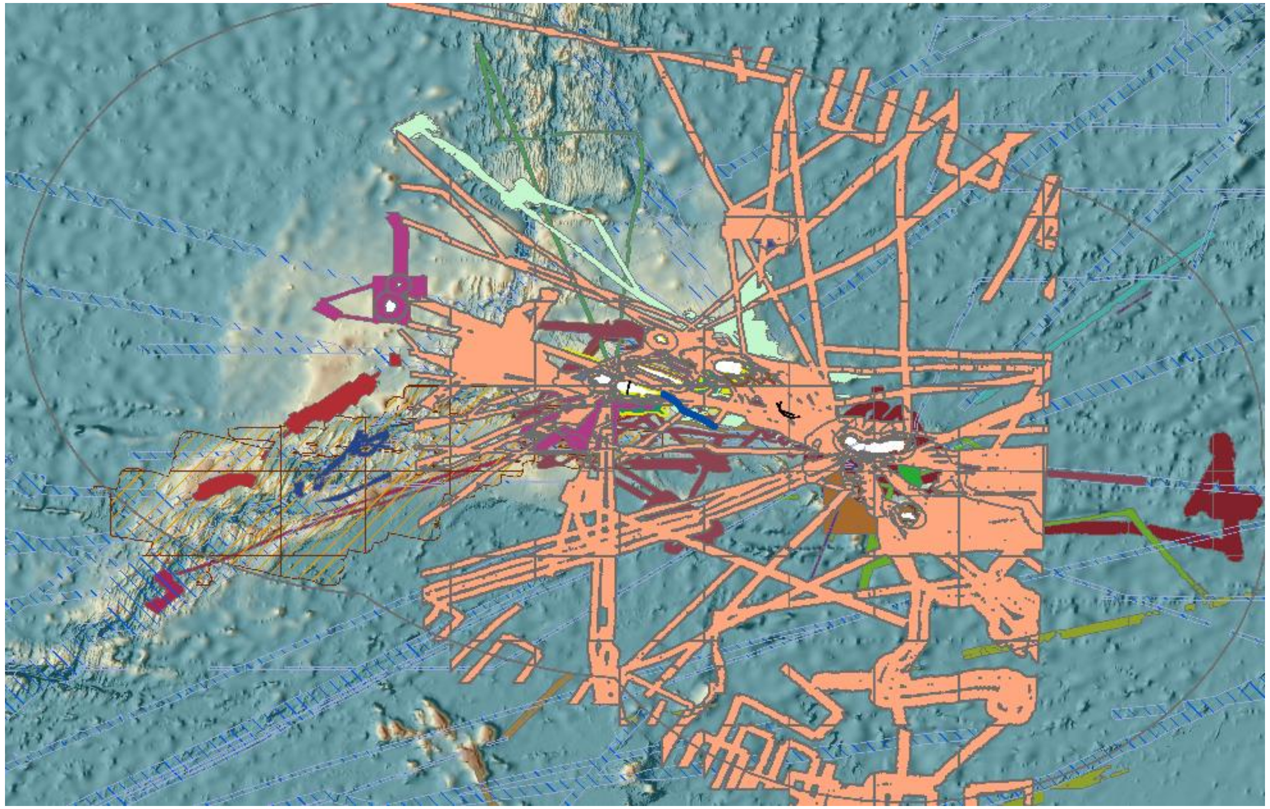
Ocean basin- and regional- scales



AZORES DEEP-SEA RESEARCH

GEOMORPHOLOGY OF THE SEABED

Azores EEZ (baseline information)



Geomorphology:

Compile/collect multibeam bathymetry data

Improve spatial definition of geomorphological structures (e.g., seamounts)

Identify **Geomorphology management units**

Support analyses **of small and meso scale species distribution** patterns

Support development of **HSMs**

Plan **field-work**

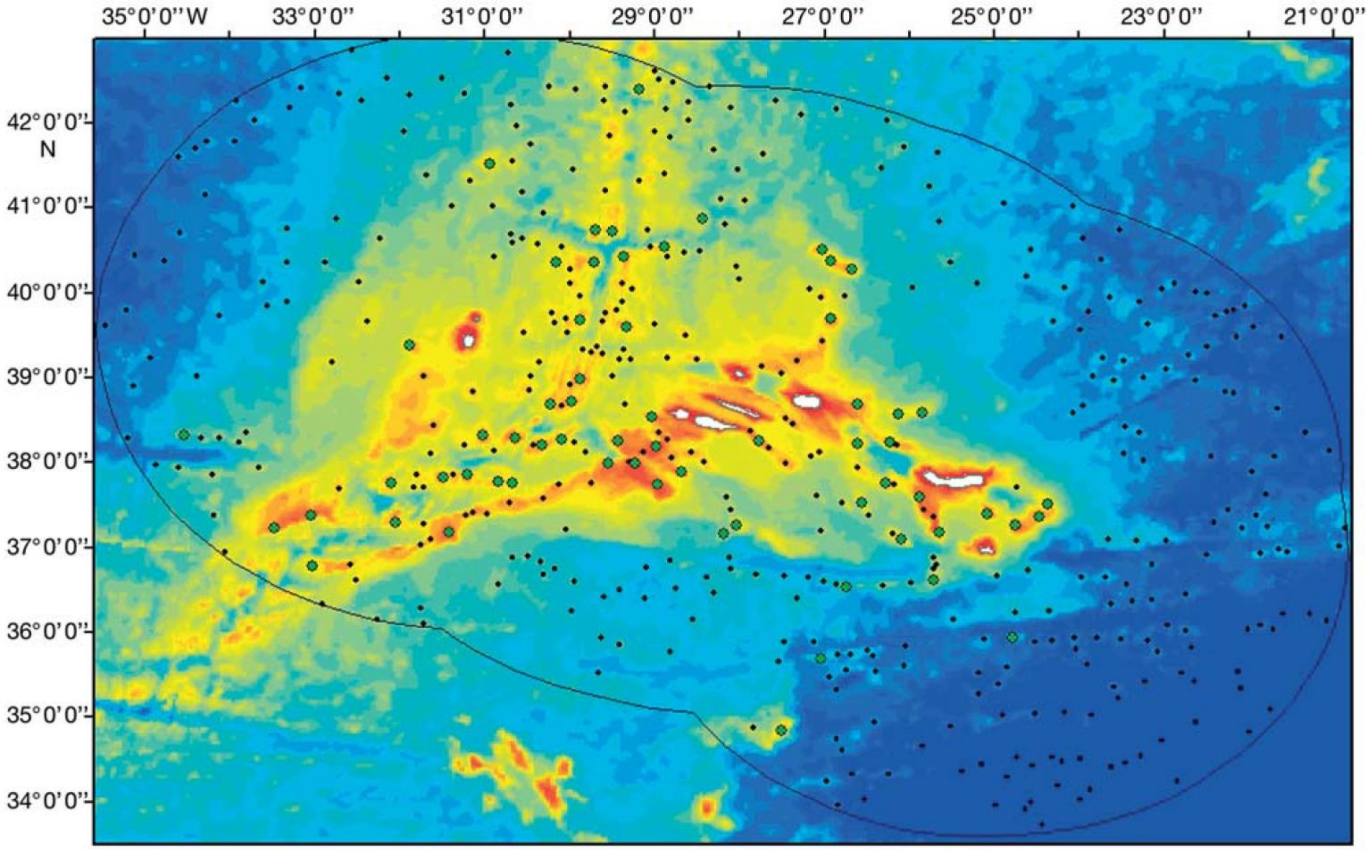
Environmental data:

Compile/collect environmental data

Identify meso- and small- scale water masses properties

Identify small-scale current patterns

In 2008, a total of **63 large and 398** small **seamount-like** features were mapped and described in the Azores EEZ



Vol. 357: 17–21, 2008
doi: 10.3354/meps07268

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

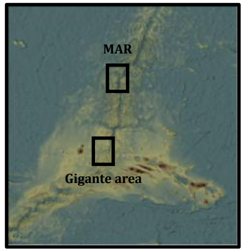
Published April 7

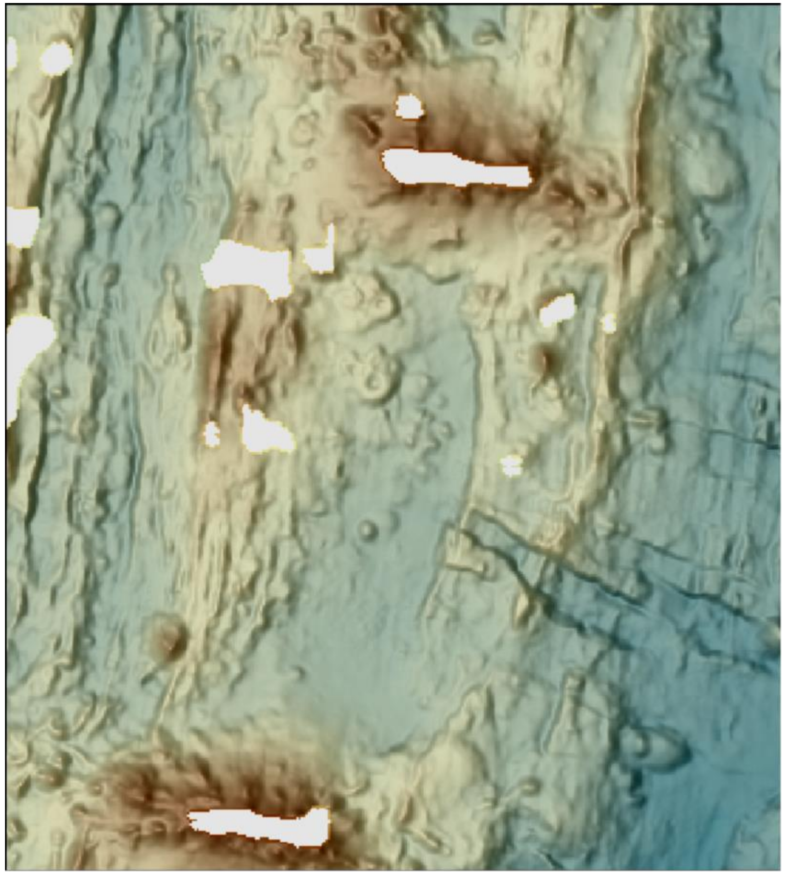
Abundance and distribution of seamounts in the Azores

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]

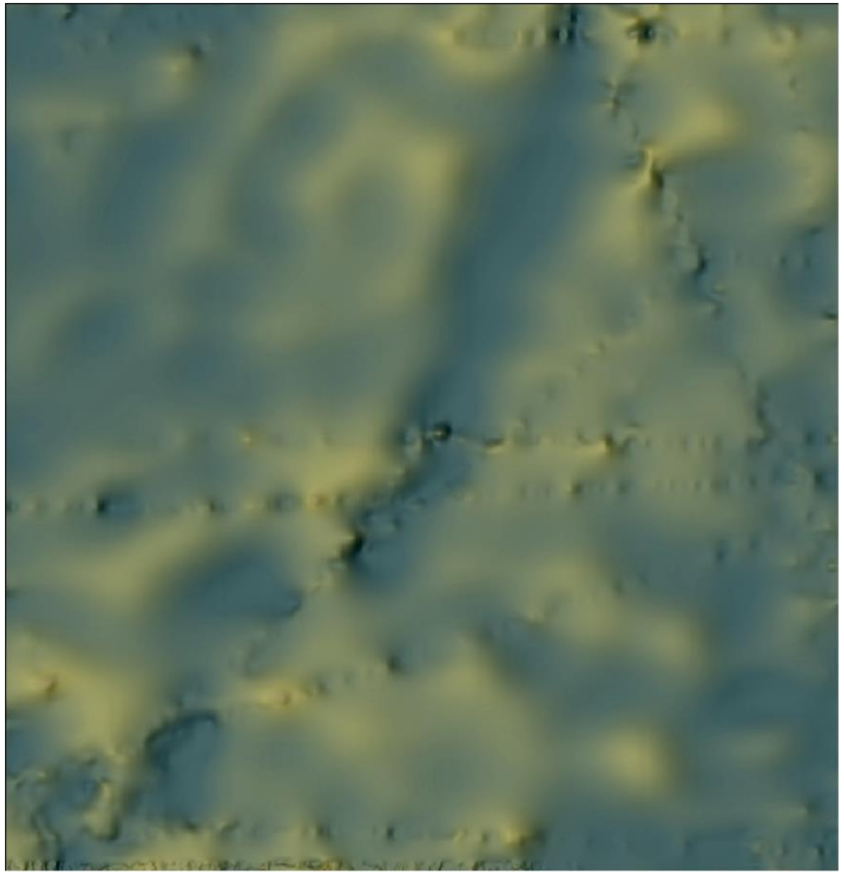
Now we know that some of these structures are **small ridges** and adopted the concept of **geomorphologic structures**, instead of seamounts

Good bathymetry is of paramount importance for understanding deep-sea biodiversity and inform management



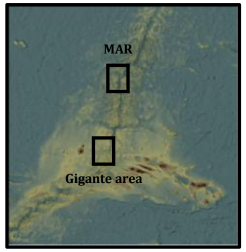


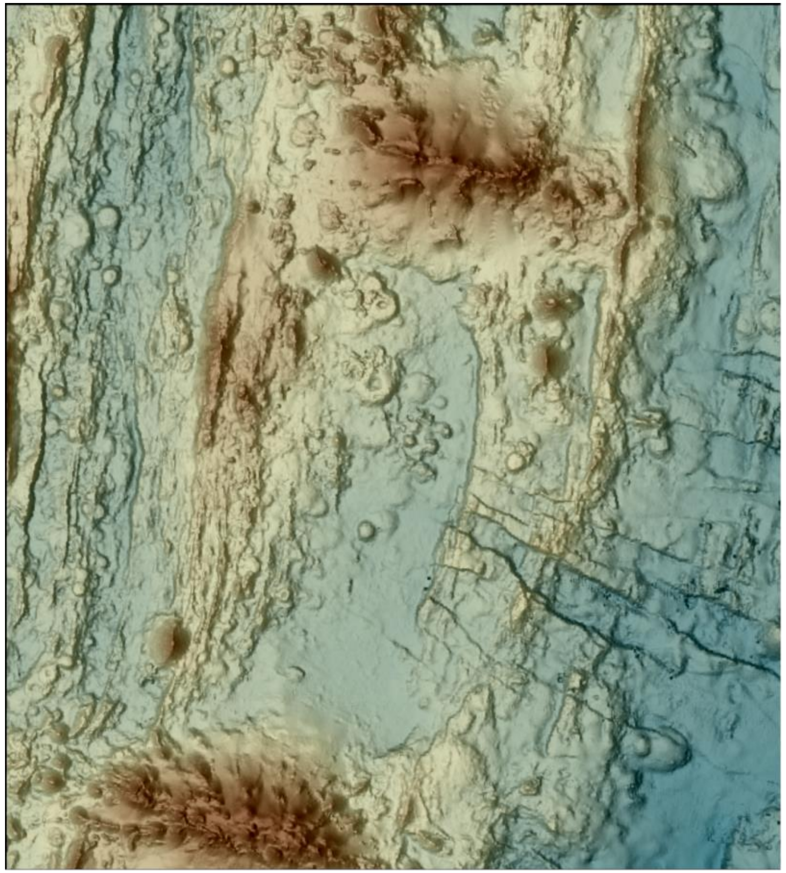
Gigante area



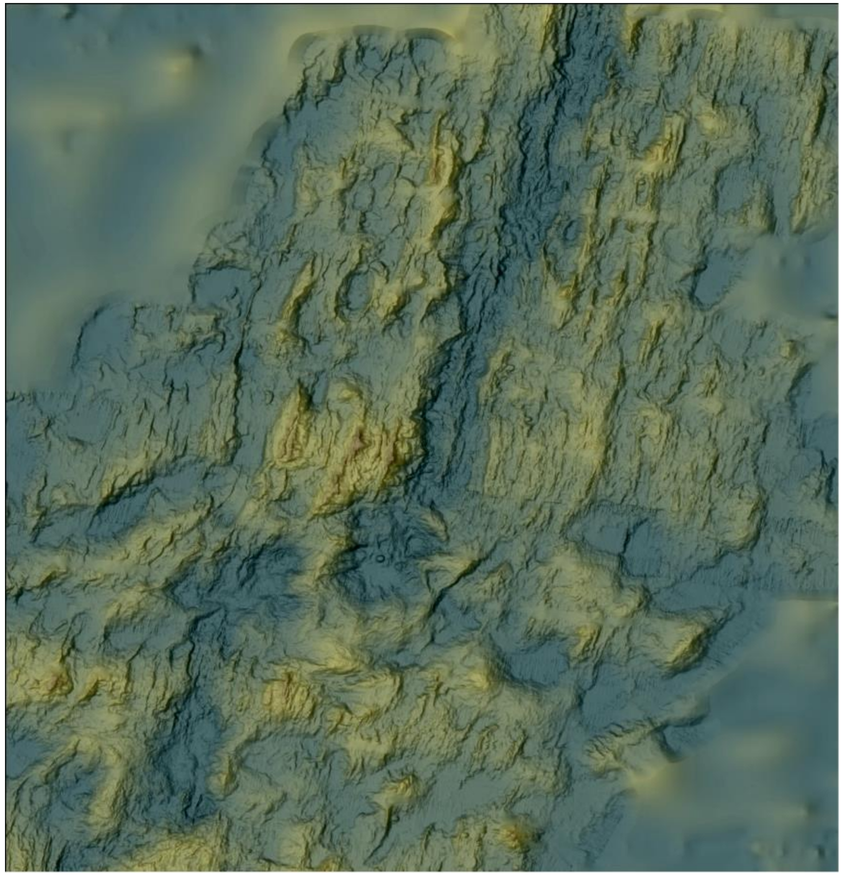
Mid Atlantic Ridge

Good bathymetry is of paramount importance for understanding deep-sea biodiversity and inform management





Gigante area



Mid Atlantic Ridge

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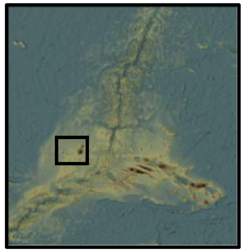
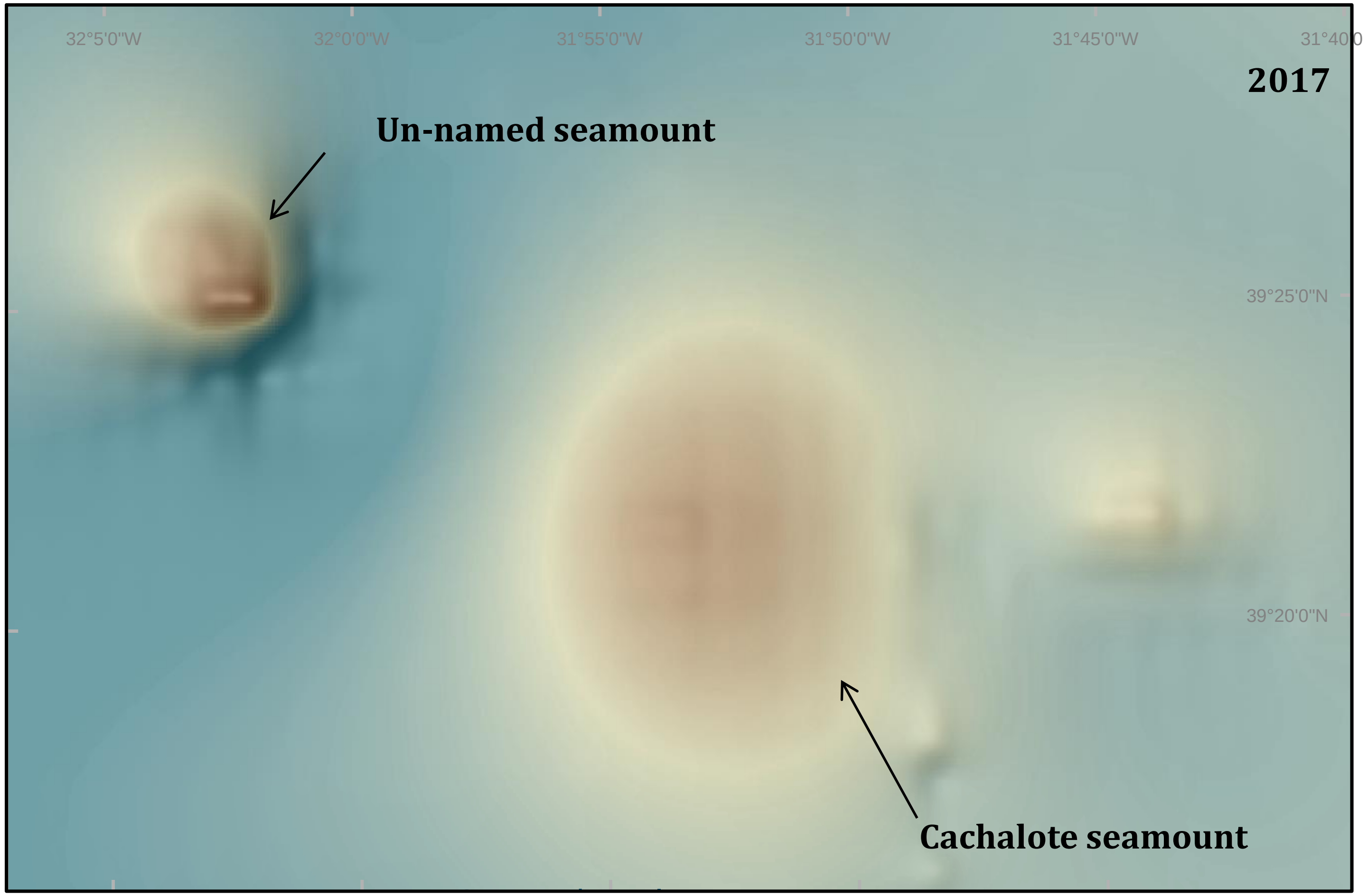
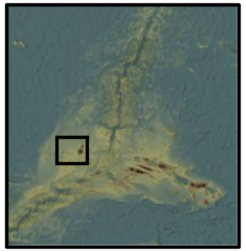


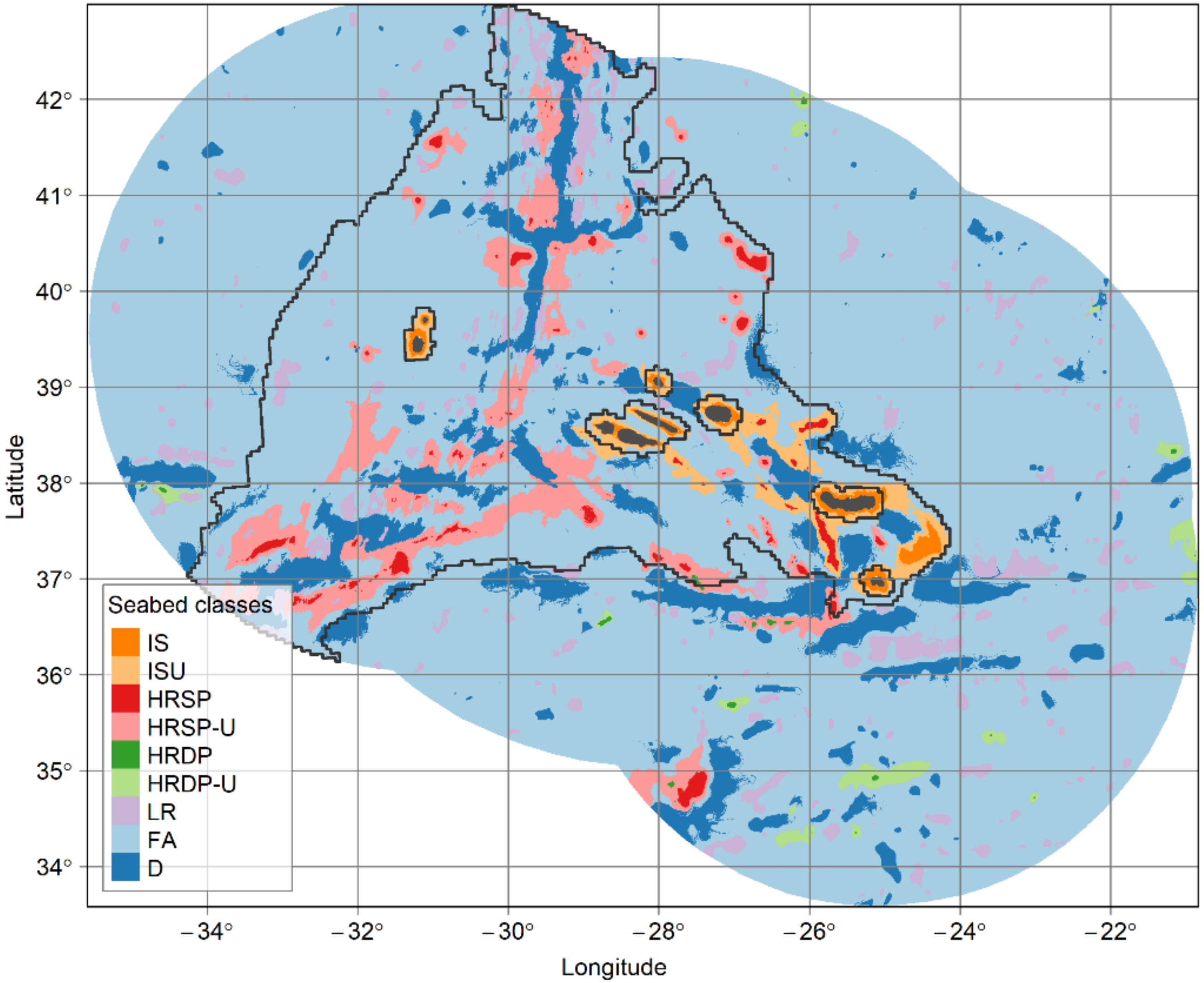


Good bathymetry is of paramount importance for understanding deep-sea biodiversity and inform management



Identify Geomorphology management units

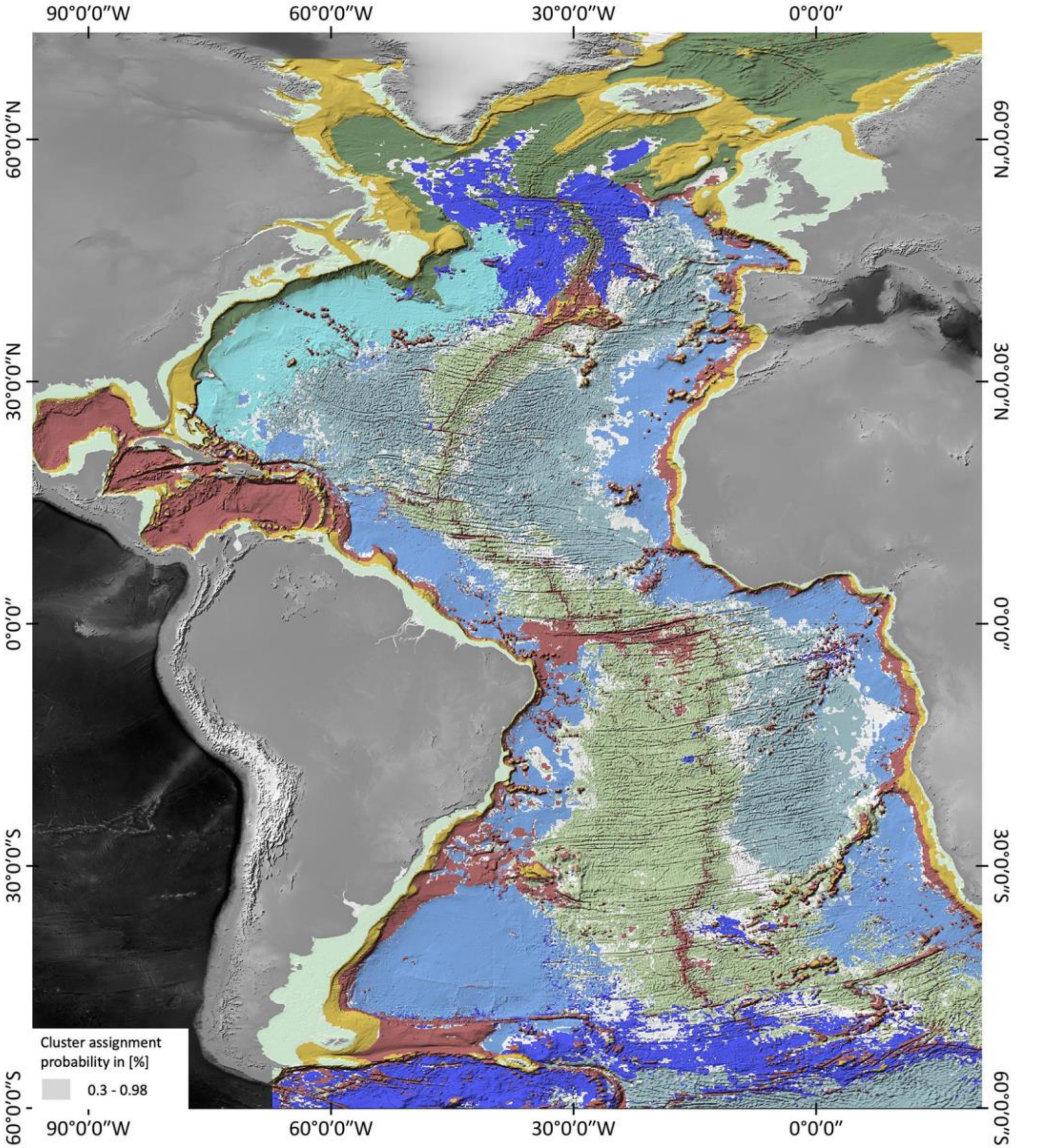
Representativity



An **automated cluster analysis** of the entire Atlantic seafloor environment, based on eight global datasets and their derivatives

The Atlantic Ocean landscape: A basin-wide cluster analysis of the Atlantic near seafloor environment

Mia Schumacher[1*], Veerle A. I. Huvenne[2], Colin W. Devey[1,3], Pedro Martínez Arbizu[4], Arne Biastoch[1,3] and Stefan Meinecke[5]



Atlantic Seabed Areas

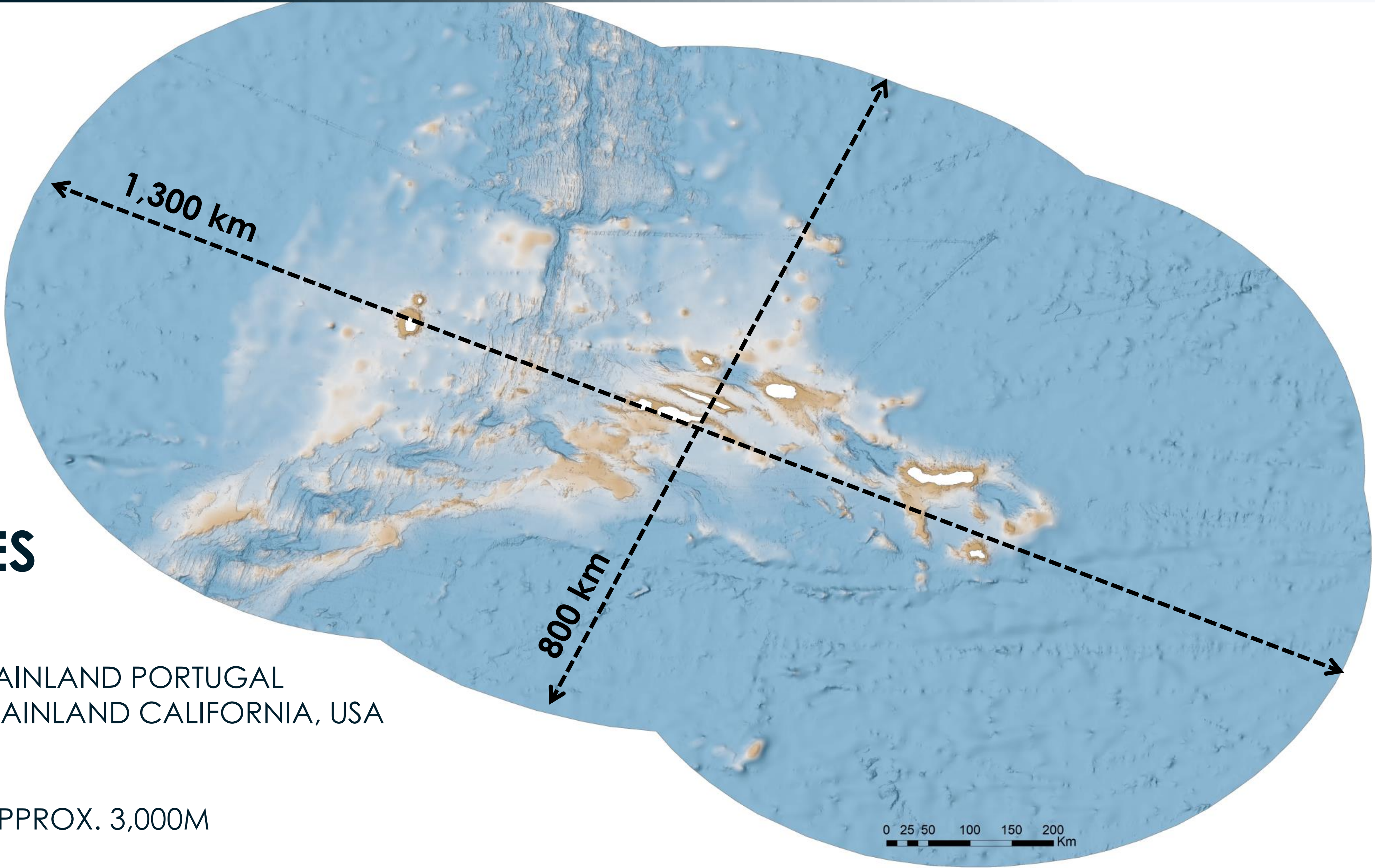
- SBA I: Oxic, mostly flat with regionally thick sediment cover sedimented, current influenced regions with low seasonal change
- SBA II: MAR spreading centre including abyssal ridges, trenches and continental slopes
- SBA III: Deep, cold, fresh & oxygen depleted abyssal plain with increased bottom current velocity
- SBA IV: Shallow, warm, nutrient-rich and saline deeper shelf zones with thick sediment cover, strong currents and strong local and seasonal changes
- SBA V: Small & regional, cold and fresh deep water influenced areas in North & South Atlantic at medium depth, with locally increased currents and current seasonal change
- SBA VI: Central deep Atlantic cool, nutrient-depleted area with very weak currents, covering some abyssal elevations and sinks
- SBA VII: Small & regional, deep, flat, sedimented oxic region with strong currents and high seasonal current change
- SBA VIII: Wider region around MAR covering new seafloor, faults and fracture zones, with extremely low sediment cover, no currents, very low oxygen and temperature
- SBA IX: Nutrient-rich, fresh, warm water continental shelf regions with thick sediment cover and strong seasonal fluctuations

Ref. Ellipsoid: WGS 84;

Lessons learned

Establish synergies and collaboration for bathymetry surveys and data sharing

DEEP-SEA BIODIVERSITY (New explorations)



THE AZORES

VAST

1 MILLION KM^2

10X TERRESTRIAL MAINLAND PORTUGAL

2.5X TERRESTRIAL MAINLAND CALIFORNIA, USA

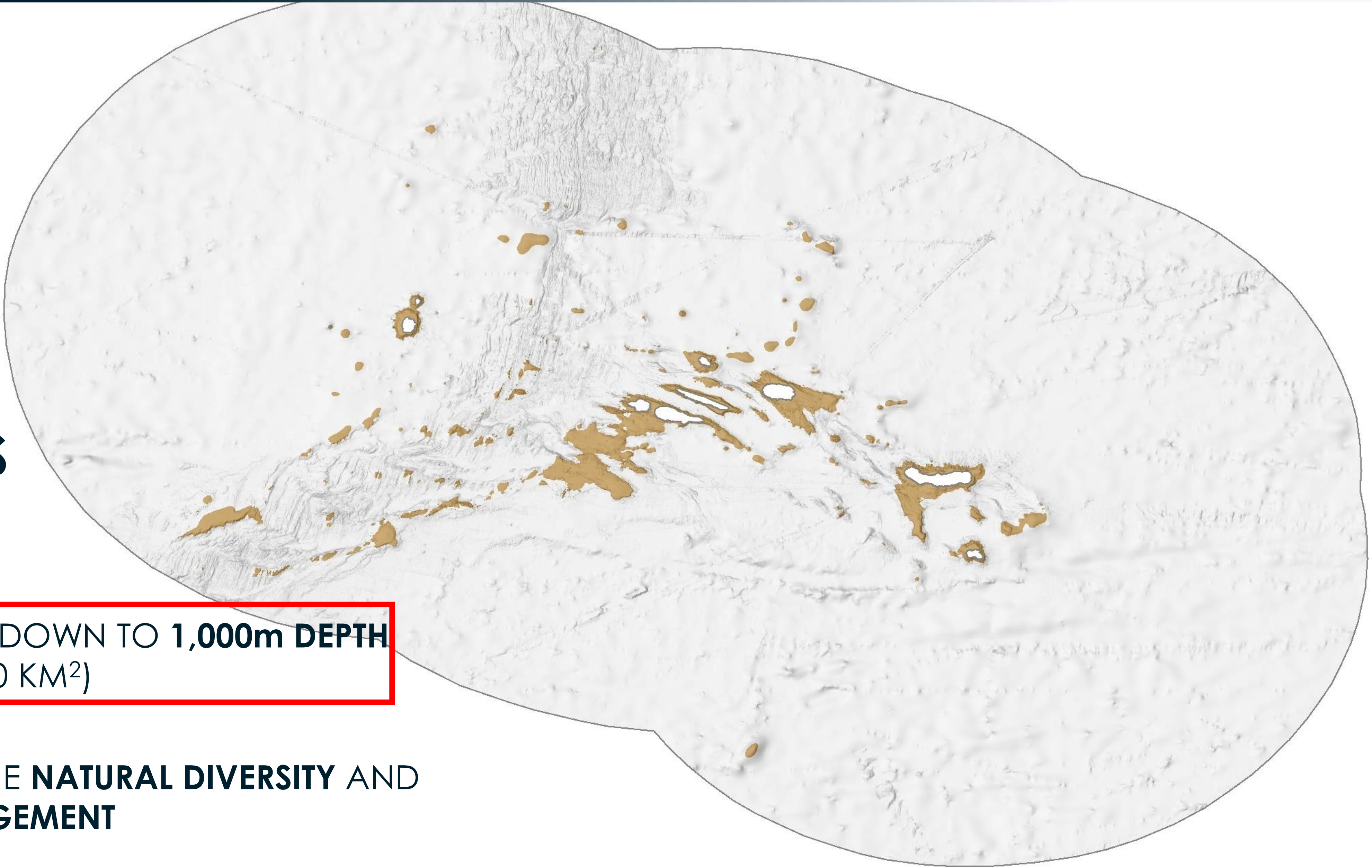
DEEP

AVERAGE DEPTH APPROX. 3,000M

IMPROVED DEEP-SEA BIODIVERSITY ASSESSMENTS

INFORM SUSTAINABLE MANAGEMENT CHALLENGE

AZORES DEEP-SEA RESEARCH



THE AZORES

CHALLENGE

- VISIT **ALL AREAS** DOWN TO **1,000m DEPTH** (APPROX. 16,000 KM^2)
- **160 AREAS**
- UNDERSTAND THE **NATURAL DIVERSITY** AND INFORM **MANAGEMENT**

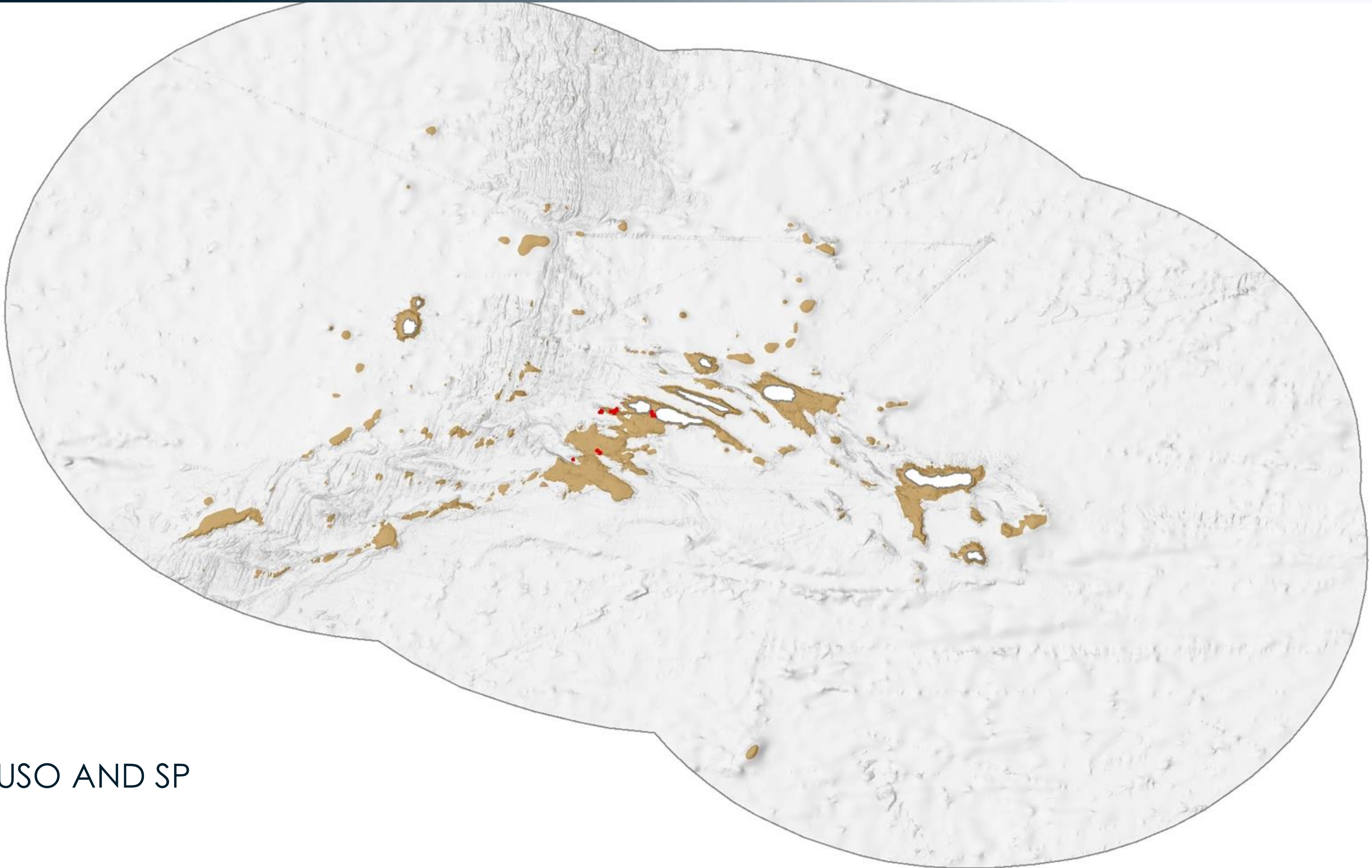
Lessons learned

Set a well-defined SMART target for deep-sea explorations

Specific, measurable, achievable, realistic and time-bounded

ROVs

<2015



FP7 **CORALFISH**
WORK WITH ROV LUSO AND SP

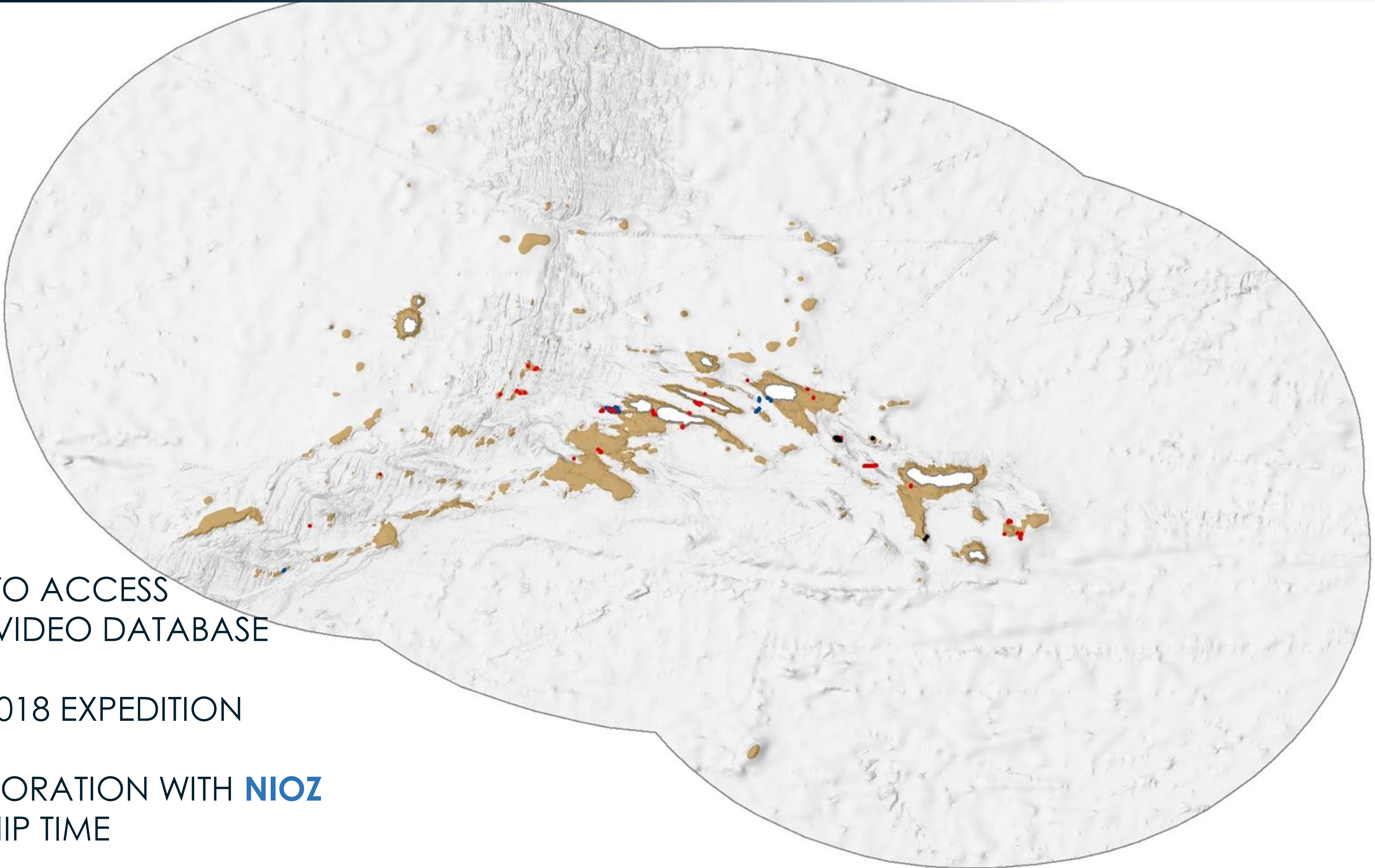
IMPROVED DEEP-SEA BIODIVERSITY ASSESSMENTS

INFORM SUSTAINABLE MANAGEMENT Telmo Morato: UNIVERSITY OF THE AZORES, PORTUGAL

AZORES DEEP-SEA RESEARCH

ROVs Tow cams

<2018



COLLABORATION TO ACCESS
EMEPC ROV LUSO VIDEO DATABASE

THE **BLUE AZORES** 2018 EXPEDITION

FIRST REAL COLLABORATION WITH **NIOZ**
FOR ACCESS TO SHIP TIME

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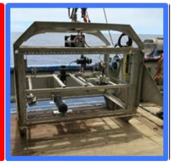
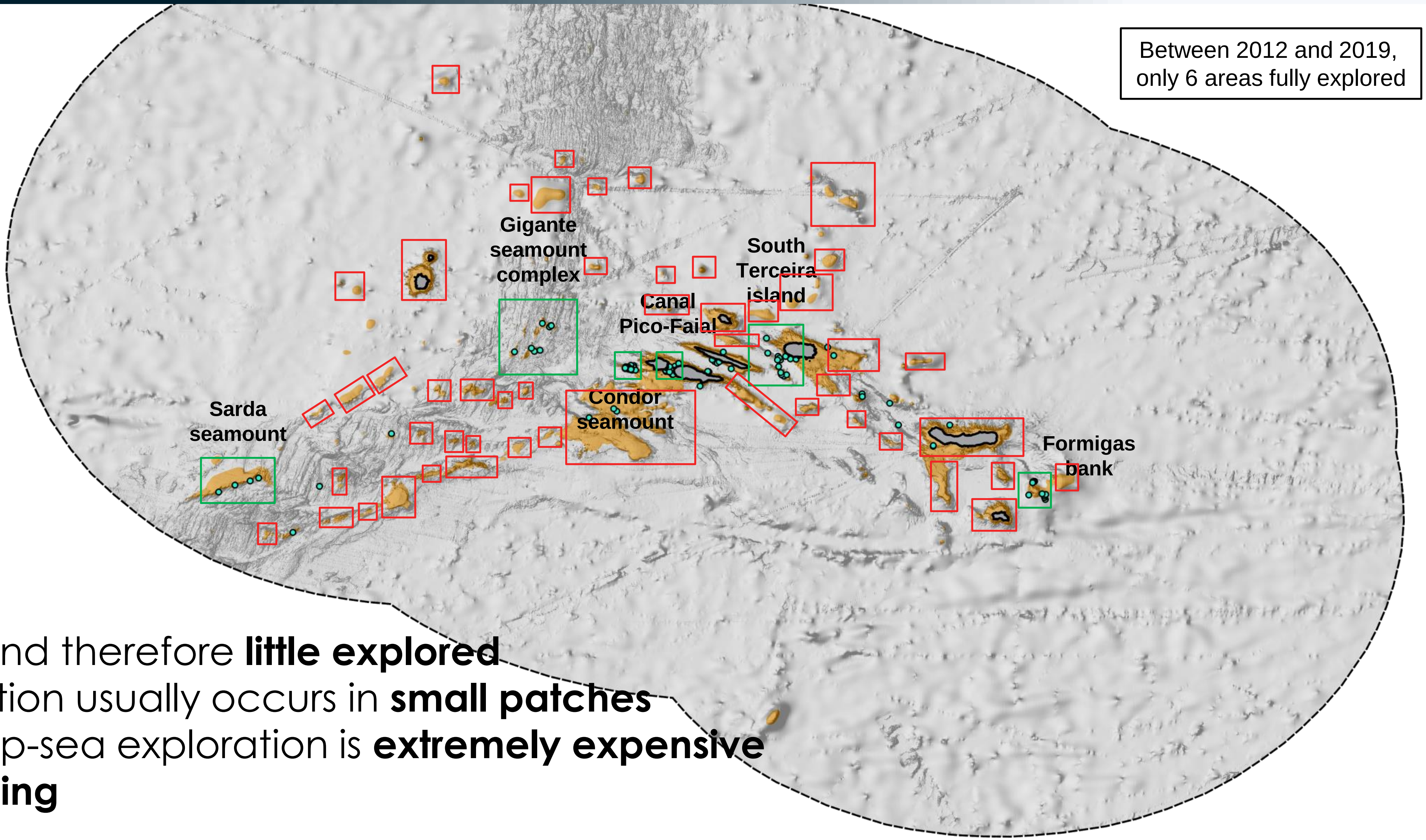
ROVs

Tow cams



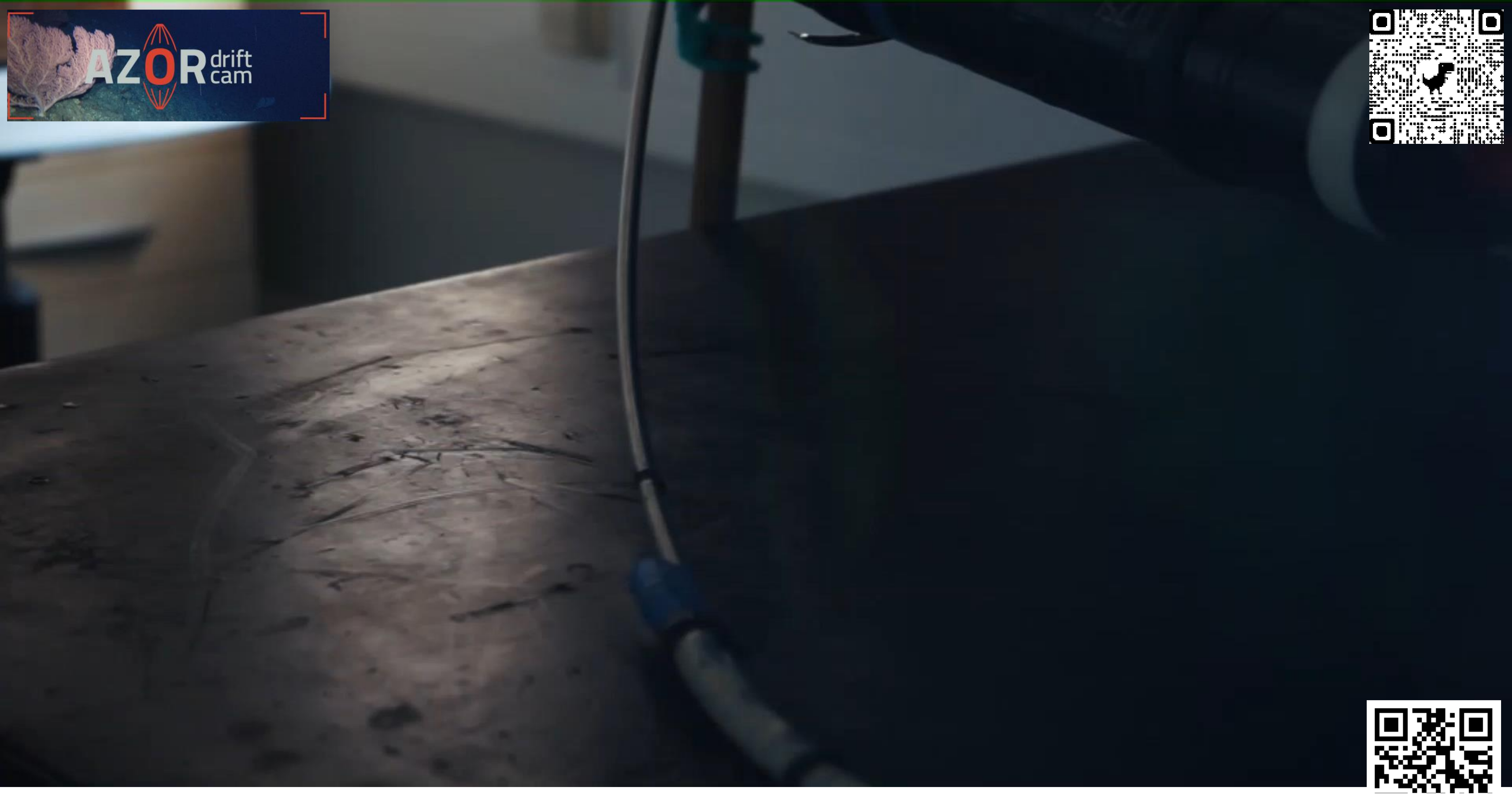
<2019

Between 2012 and 2019, only 6 areas fully explored



- Deep-sea is **vast** and therefore **little explored**
- Deep-sea exploration usually occurs in **small patches**
- Cutting-edge deep-sea exploration is **extremely expensive**
- Very **time-consuming**

Hence, only **few developed countries** have the technical/financial means to explore the deep sea



Guiding principles for the design of the Azor drift-cam

WORKSHOP 1 PICES ANNUAL MEETING 24-25 SEPTEMBER 2022, BUSAN, KOREA

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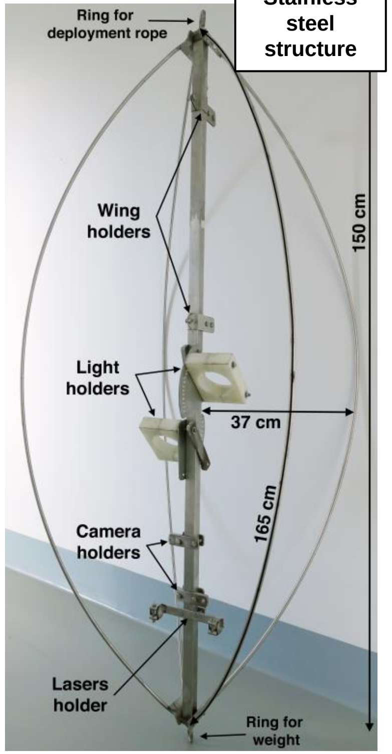
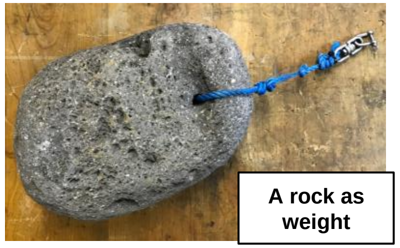
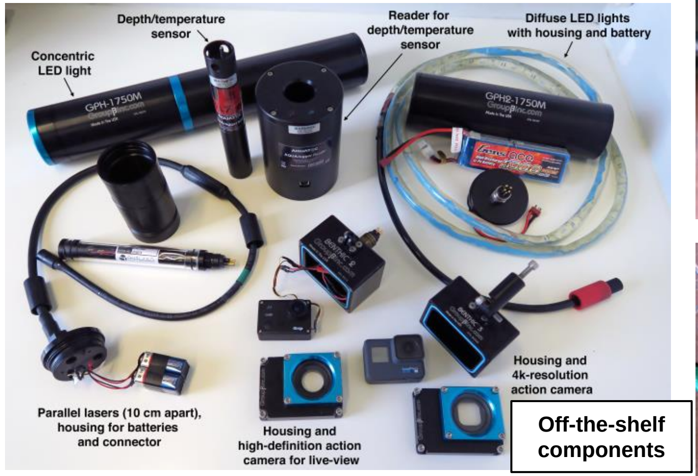
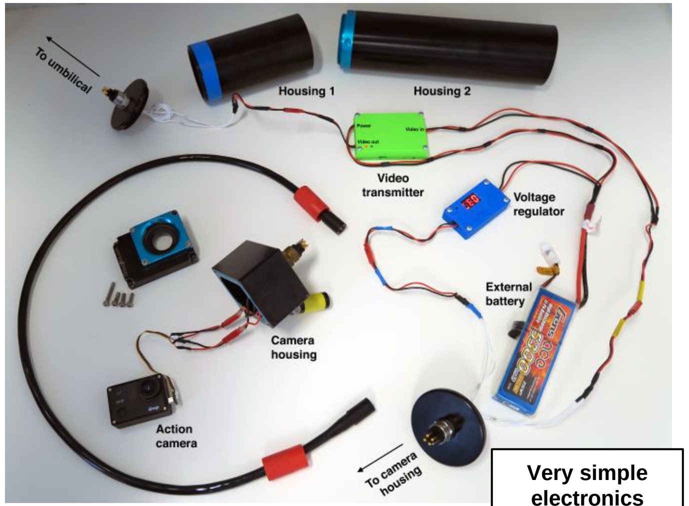
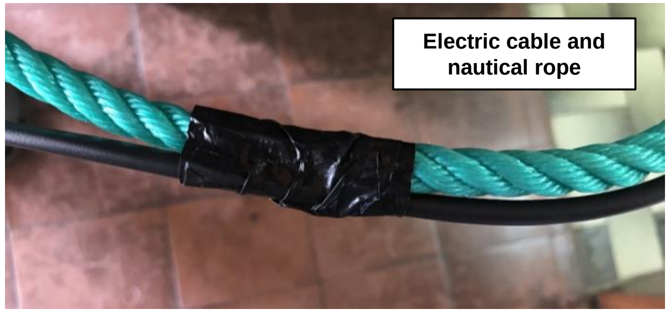
AZORES DEEP-SEA RESEARCH

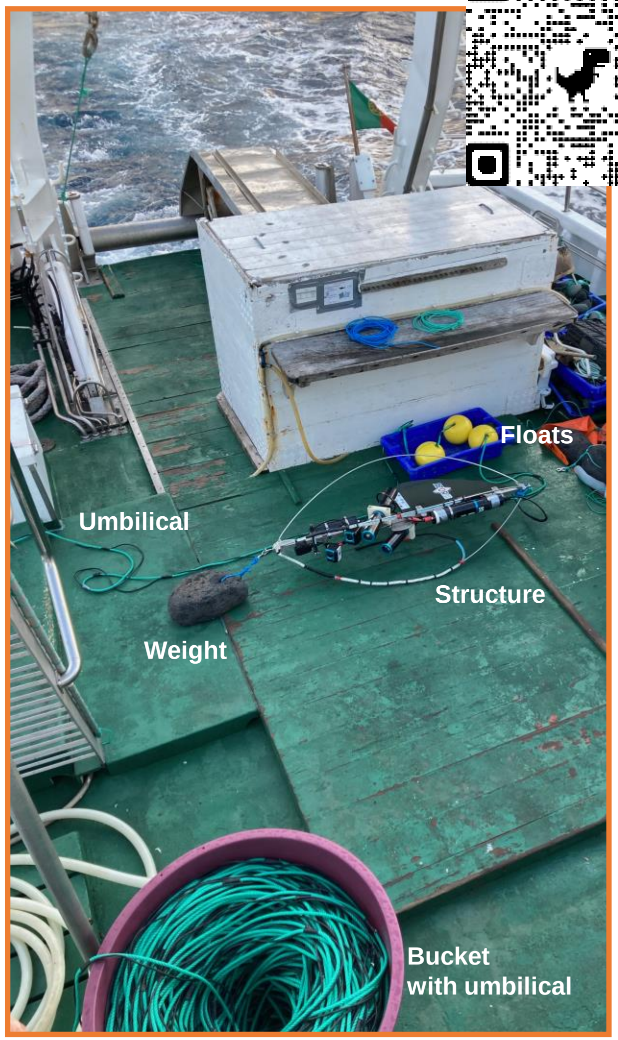












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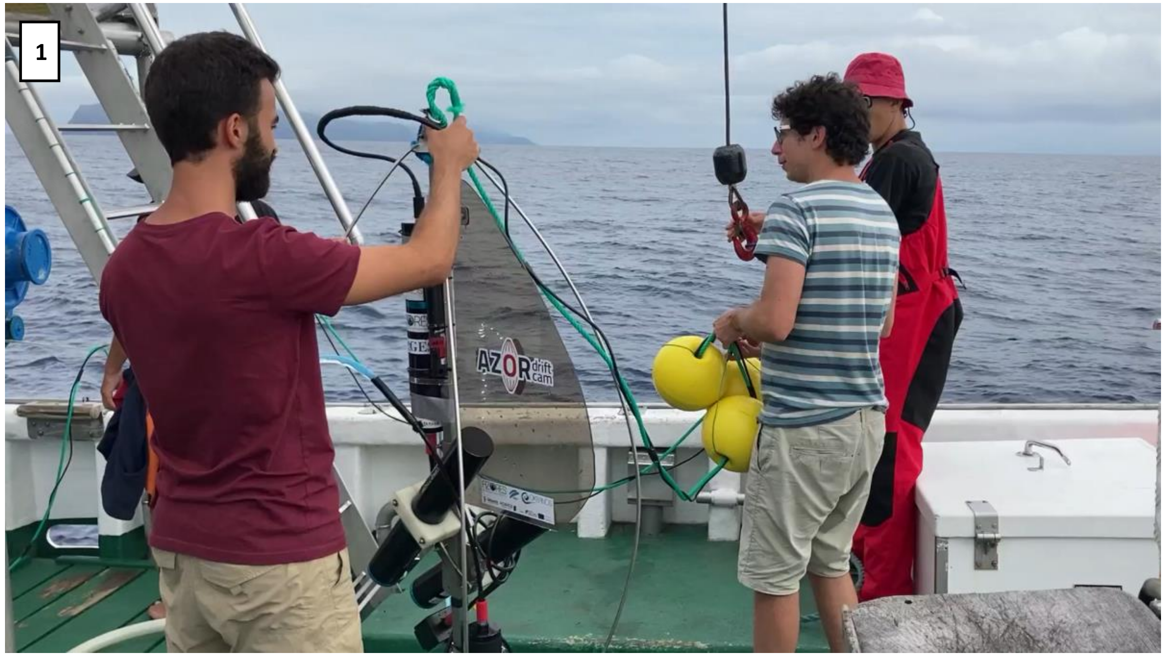
AZORES DEEP-SEA RESEARCH

1. The compact size ... also easy to deploy from the side of the vessel, either by hand or **using a crane**.

2. Once on the water, ... 0.4-0.5 m/s ...

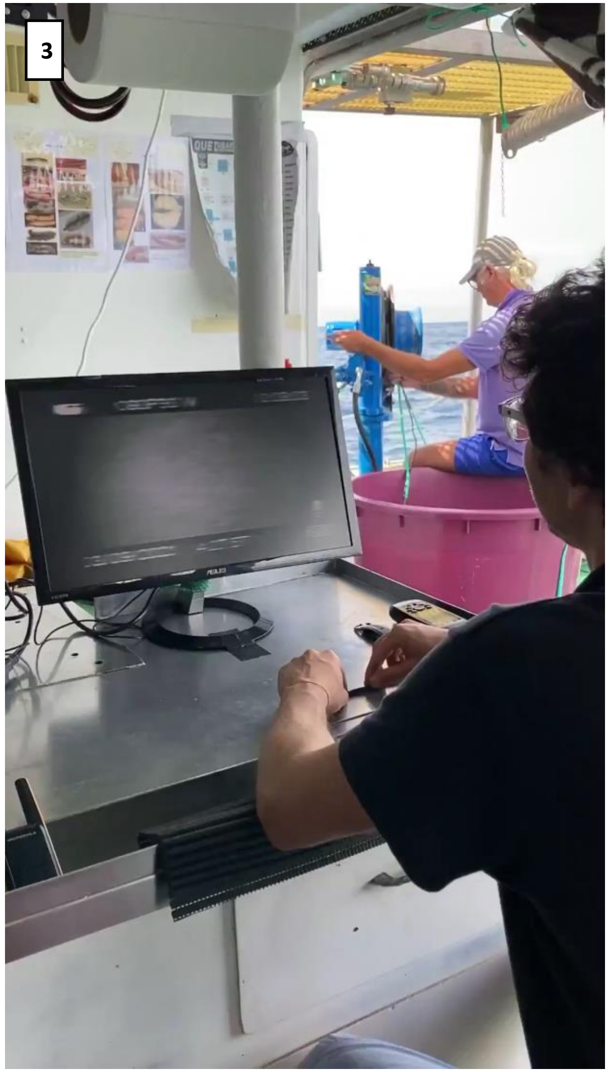
3. The camera ... following the vessel's drift with the distance kept between the system and the seafloor controlled with a **hydraulic winch**, giving or recovering umbilical as required. One observer provides indications to winch operators based on live-view images displayed on a TV screen.

1

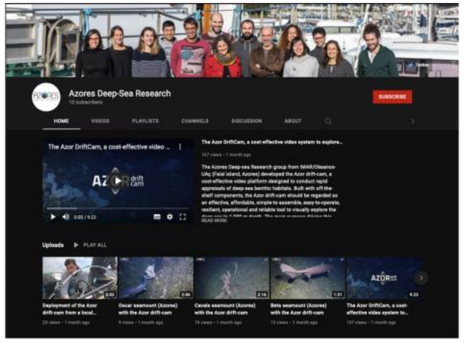


2

3



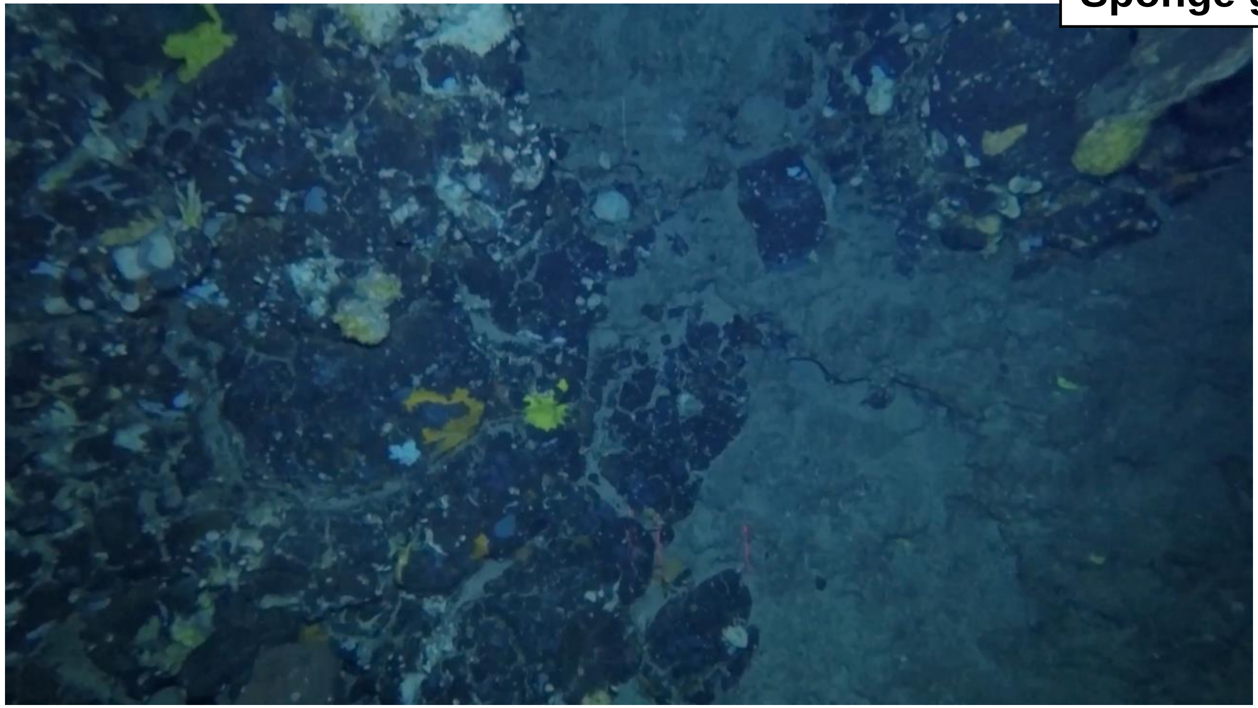
Coral gardens

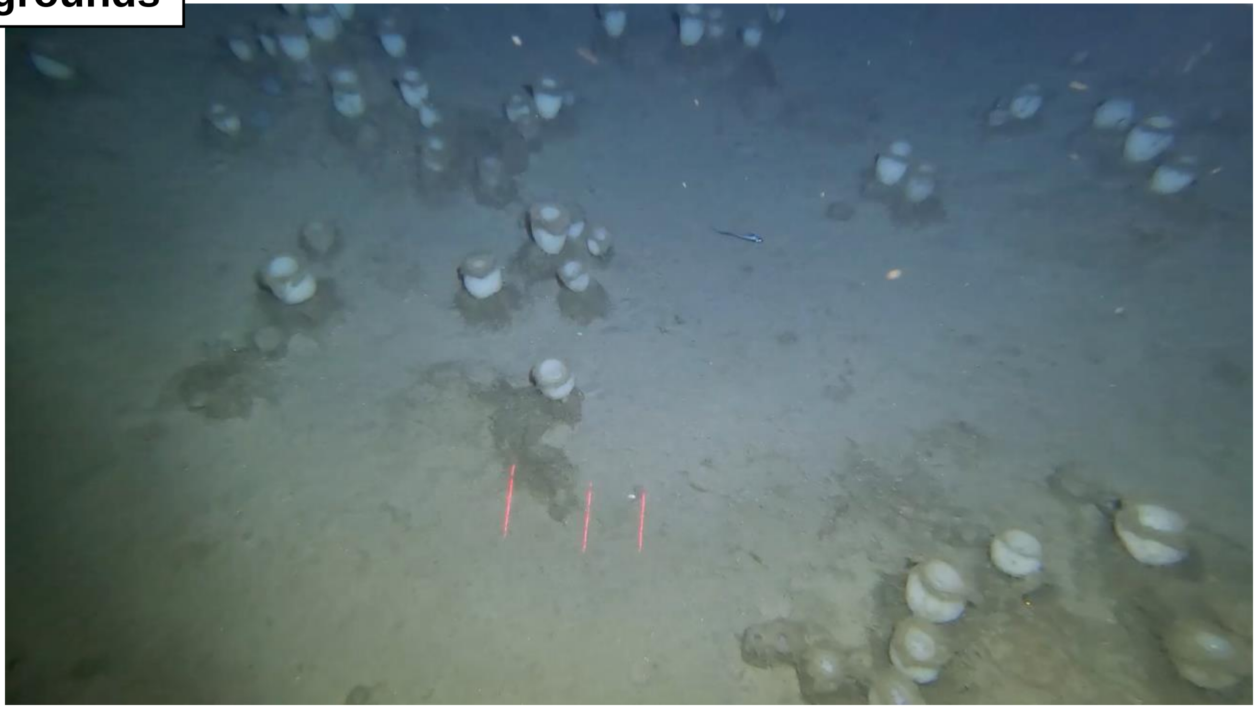


More clips from different seamounts surveyed with the Azor drift-cam can be watched in our group's Youtube channel

https://www.youtube.com/channel/UCrUCCk9866Ym8voq7ZwwZoQ

Sponge grounds





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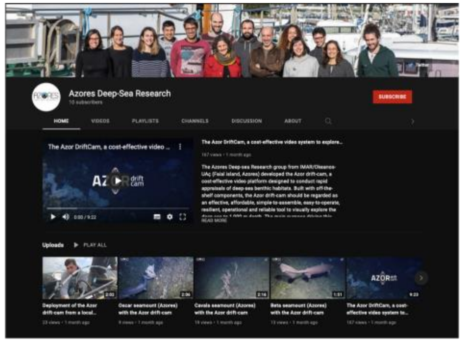

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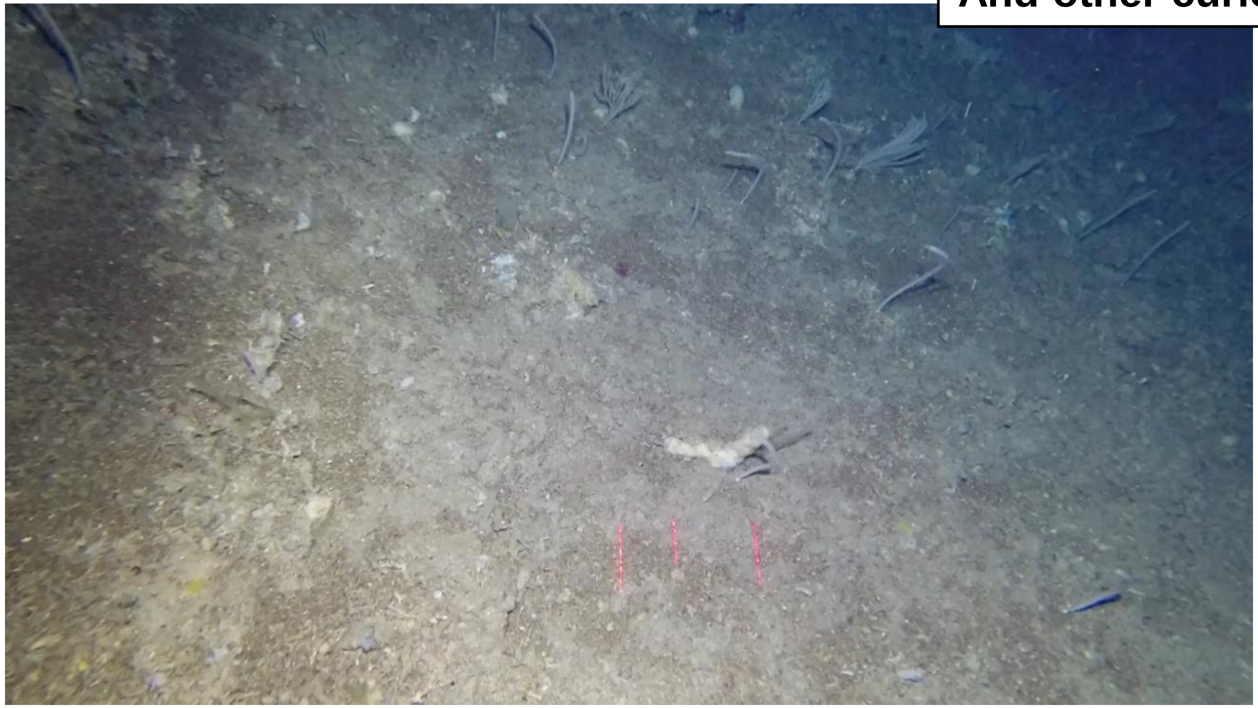
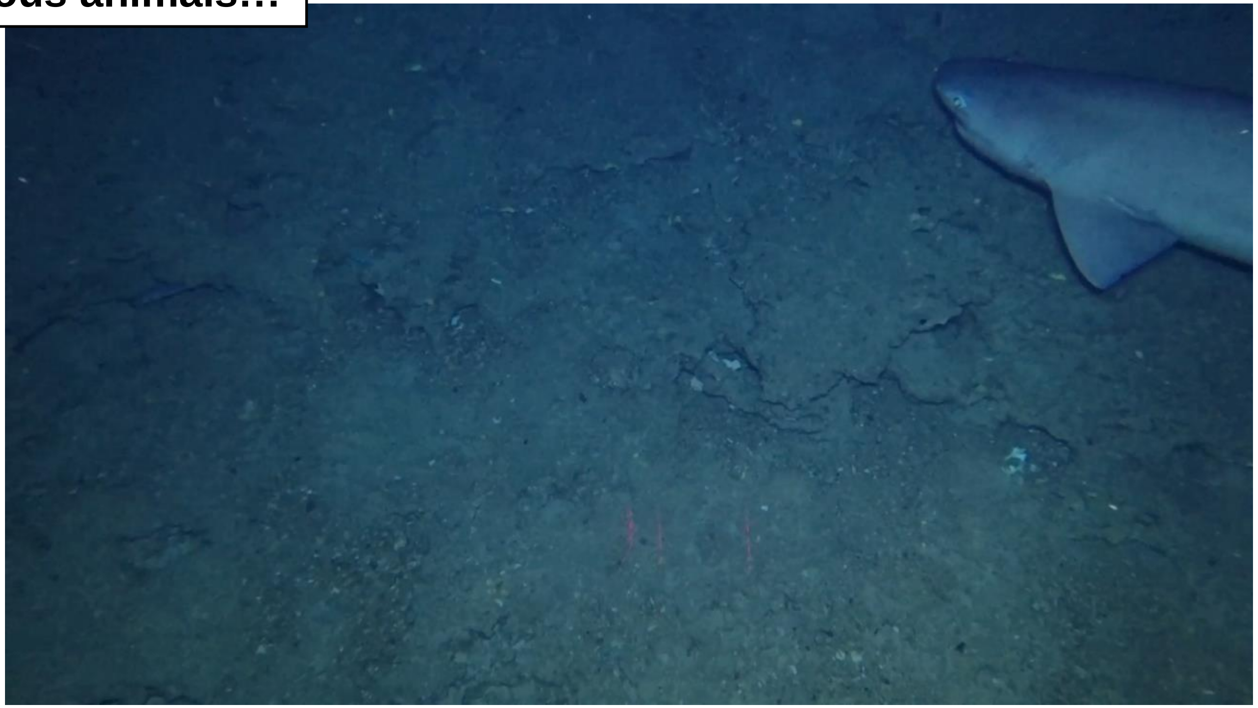
AZORES DEEP-SEA RESEARCH

And other curious animals…





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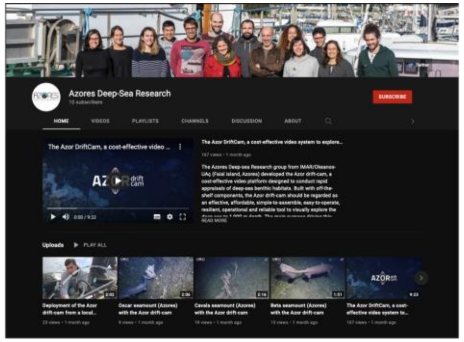

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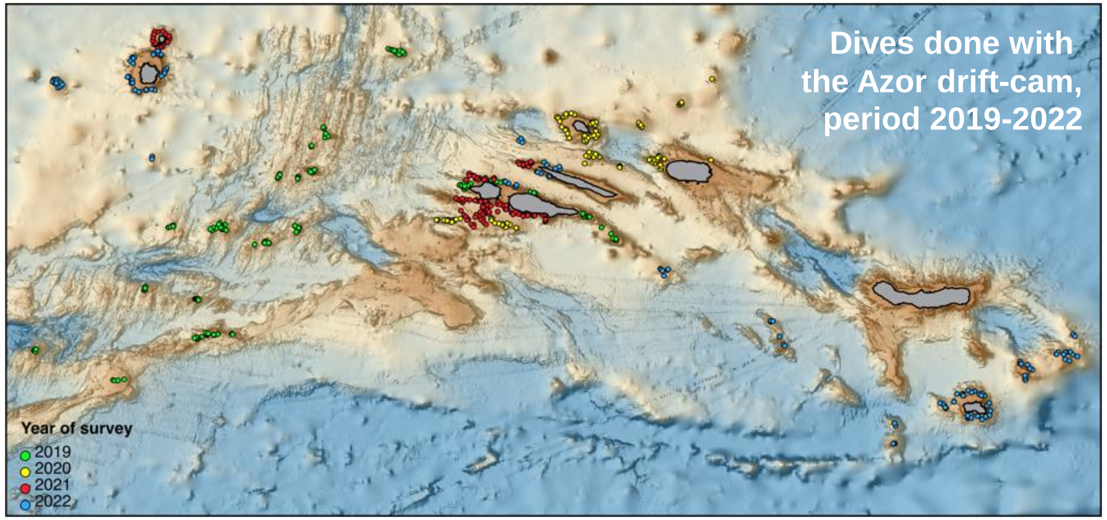


2019: 150 dives, 85 km of seafloor explored, 111 hours of new footage
2020: 103 dives, 53 km of seafloor explored, 74 hours of new footage
2021: 142 dives, 87 km of seafloor explored, 120 hours of new footage
2022: 134 dives, 71 km of seafloor explored, 130 hours of new footage

More than 500 dives in 4 years, with 430+ hours of new video footage

2 full surveys on board of fishing vessels in 2 different islands:

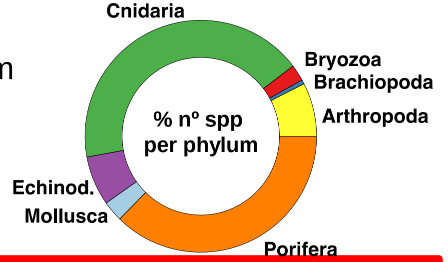
Graciosa island, 2020

Corvo island, 2021

Assessment of dives from MapGES 2019 survey with Azor drift-cam:

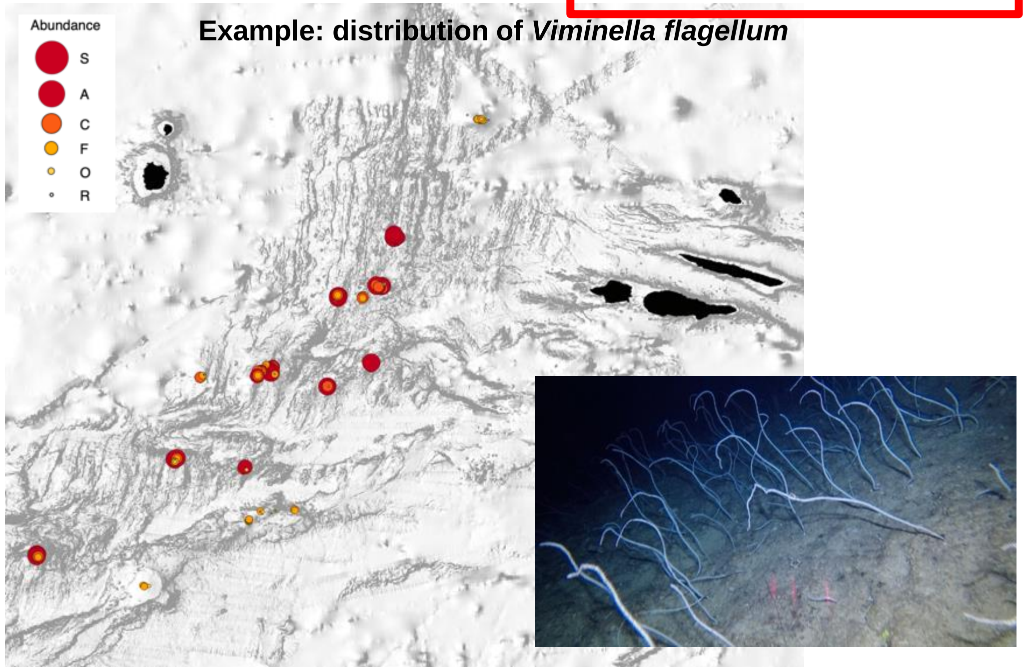
Number of dives analysed: 112
Distance covered over the seabed: 61 km
Depth range: 188-855 m
Area: Mid-Atlantic Ridge

Method of annotation:
- SACFOR at 100 m intervals
- Only benthic invertebrates



174 morphospecies
8690 new occurrence records

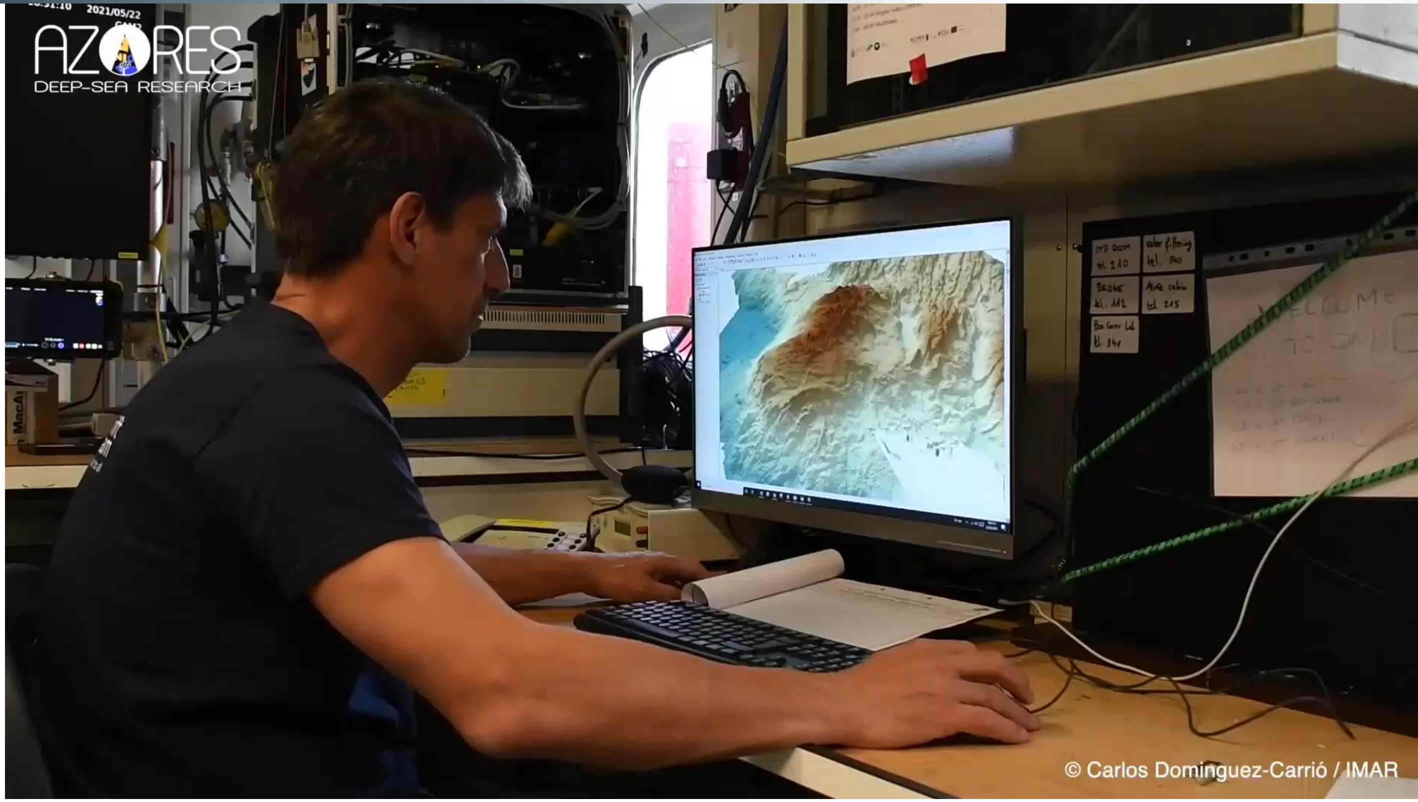
Example: distribution of *Viminella flagellum*



Lessons learned

Move to cost-effective deep-sea exploration and expand the spatial coverage of deep-sea data

HIGHLIGHTS OF RECENT DEEP-SEA EXPLORATION



HIGHLIGHTS OF RECENT DEEP-SEA EXPLORATION

Discovered several locations in the Azores **shallower than previously thought**

Two areas reach depths susceptible to be fished (<600 m), but since it has remained unknown it can be **considered intact**

Fundamental for understanding what **ecosystems looked like before they were impacted**

May be considered as **reference sites** and priority areas for conservation

HIGHLIGHTS OF RECENT DEEP-SEA EXPLORATION

The Azores is an **hotspot of cold-water coral** biodiversity in the whole Atlantic ocean

Mid-Atlantic Ridge supports more life and diversity than previous studies indicated.

HIGHLIGHTS OF RECENT DEEP-SEA EXPLORATION

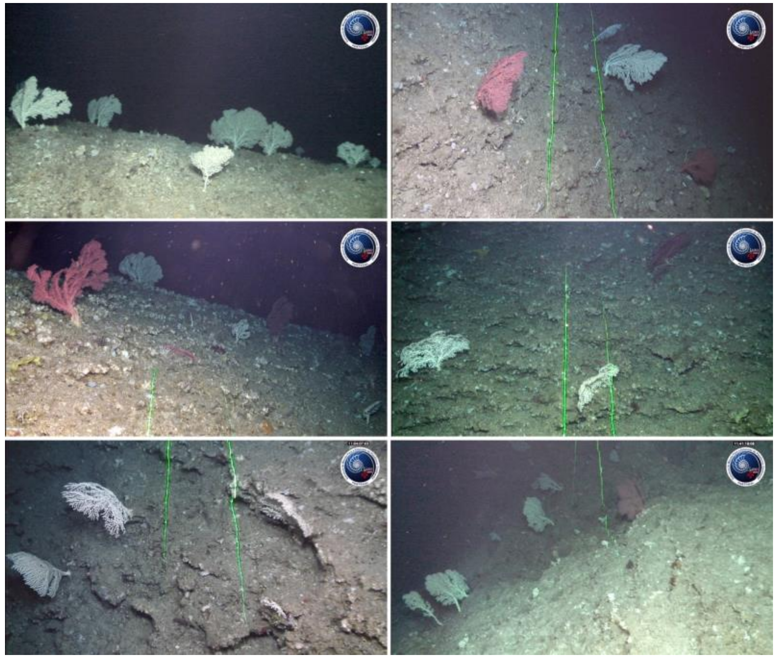
Discovered **new deep-sea species**; e.g. ***Epizoanthus martinsae*** lives in association with black corals

Also **new communities**, biotopes, and species associations

Endemic species with limited spatial distributions

HIGHLIGHTS OF RECENT DEEP-SEA EXPLORATION

Discovered the **densest garden of bubble-gum coral** (*Paragorgia johnsoni*)



NATURE NOTES

Ecology and Evolution WILEY

Dense cold-water coral garden of *Paragorgia johnsoni* suggests the importance of the Mid-Atlantic Ridge for deep-sea biodiversity

AZORES DEEP-SEA RESEARCH

HIGHLIGHTS OF RECENT DEEP-SEA EXPLORATION

Discovered the largest aggregation of **black corals** across the Atlantic

These corals can live for several **1,000 years**

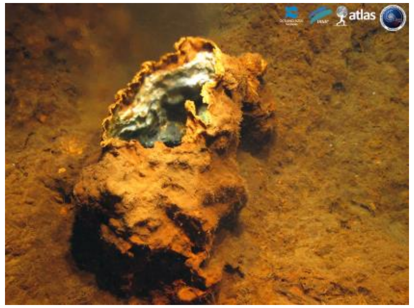
Equivalent to the **redwood forests** (some of the oldest trees) that still persist on the planet

HIGHLIGHTS OF RECENT DEEP-SEA EXPLORATION

Discovered the new low temperature **Luso hydrothermal vent**

Rich in **iron** and **hydrogen**

Play an important role in **fuelling local productivity**



HIGHLIGHTS OF RECENT DEEP-SEA EXPLORATION

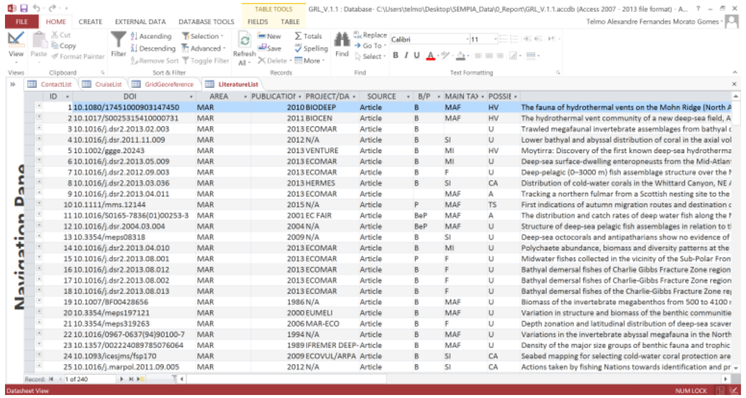
We also found aggregations of the **long-lived orange roughy** and cardinalfish

The **trawl ban** within the Azores (2005), has had positive effects for these species and the habitats they are associated with

Identified **essential fish habitats**

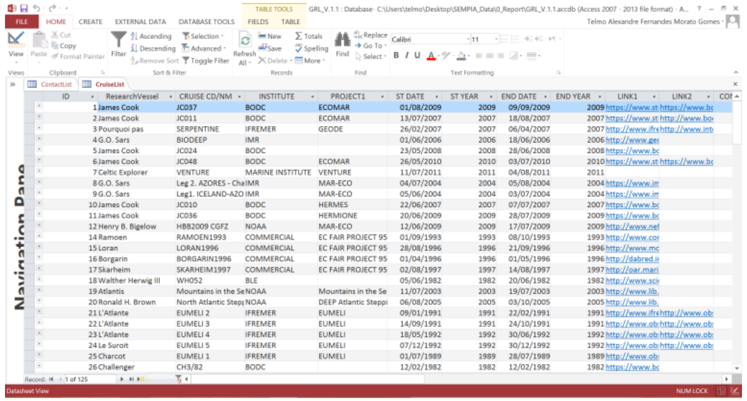
VULNERABLE MARINE ECOSSYSTEMS

Database on existing deep-sea biodiversity data in the N Atlantic



ID	DOI	AREA	PUBLICATIOI	PROJECT/DA	SOURCE	B/P	MAIN TAX	POSSIE	
1	10.1080/17451000903147450	MAR	2010	BIODEEP	Article	B	MAF	HV	The fauna of hydrothermal vents on the Mohn Ridge (North A
2	10.1017/S0025315410000731	MAR	2011	BIOCEN	Article	B	MAF	HV	The hydrothermal vent community of a new deep-sea field, A
3	10.1016/j.dsr2.2013.02.003	MAR	2013	ECOMAR	Article	B		U	Trawled megafaunal invertebrate assemblages from bathyal c
4	10.1016/j.dsr.2011.11.009	MAR	2012	N/A	Article	B	SI	U	Lower bathyal and abyssal distribution of coral in the axial vol
5	10.1002/ggge.20243	MAR	2013	VENTURE	Article	B	MI	HV	Moytirra: Discovery of the first known deep-sea hydrotherma
6	10.1016/j.dsr2.2013.05.009	MAR	2013	ECOMAR	Article	B	MI	U	Deep-sea surface-dwelling enteropneusts from the Mid-Atlan
7	10.1016/j.dsr2.2012.09.003	MAR	2013	ECOMAR	Article	B	F	U	Deep-pelagic (0–3000 m) fish assemblage structure over the N
8	10.1016/j.dsr2.2013.03.036	MAR	2013	HERMES	Article	B	SI	CA	Distribution of cold-water corals in the Whittard Canyon, NE A
9	10.1016/j.dsr2.2013.04.011	MAR	2013	ECOMAR	Article		MAF	A	Tracking a northern fulmar from a Scottish nesting site to the
10	10.1111/mms.12144	MAR	2015	N/A	Article	P	MAF	TS	First indications of autumn migration routes and destination c
11	10.1016/S0165-7836(01)00253-3	MAR	2001	EC FAIR	Article	BeP	MAF	A	The distribution and catch rates of deep water fish along the N
12	10.1016/j.dsr.2004.03.004	MAR	2004	N/A	Article	BeP	MAF	U	Structure of deep-sea pelagic fish assemblages in relation to t
13	10.3354/meps08318	MAR	2009	N/A	Article	B	SI	U	Deep-sea octocorals and antipatharians show no evidence of
14	10.1016/j.dsr2.2013.04.010	MAR	2013	ECOMAR	Article	B	MI	U	Polychaete abundance, biomass and diversity patterns at the
15	10.1016/j.dsr2.2013.08.001	MAR	2013	ECOMAR	Article	P	F	U	Midwater fishes collected in the vicinity of the Sub-Polar Fron
16	10.1016/j.dsr2.2013.08.012	MAR	2013	ECOMAR	Article	B	F	U	Bathyal demersal fishes of Charlie Gibbs Fracture Zone region
17	10.1016/j.dsr2.2013.08.002	MAR	2013	ECOMAR	Article	B	F	U	Bathyal demersal fishes of Charlie-Gibbs Fracture Zone region
18	10.1016/j.dsr2.2013.08.013	MAR	2013	ECOMAR	Article	B	F	U	Bathyal demersal fishes of the Charlie-Gibbs Fracture Zone re
19	10.1007/BF00428656	MAR	1986	N/A	Article	B	MAF	U	Biomass of the invertebrate megabenthos from 500 to 4100 r
20	10.3354/meps197121	MAR	2000	EUMELI	Article	B	MAF	U	Variation in structure and biomass of the benthic communitie
21	10.3354/meps319263	MAR	2006	MAR-ECO	Article	B	F	U	Depth zonation and latitudinal distribution of deep-sea scaver
22	10.1016/0967-0637(94)90100-7	MAR	1994	N/A	Article	B	MAF	U	Variations in the invertebrate abyssal megafauna in the North
23	10.1357/002224089785076064	MAR	1989	IFREMER DEEP-	Article	B	MAF	U	Density of the major size groups of benthic fauna and trophic
24	10.1093/icesjms/fsp170	MAR	2009	ECOVUL/ARPA	Article	B	SI	CA	Seabed mapping for selecting cold-water coral protection are
25	10.1016/j.marpol.2011.09.005	MAR	2012	N/A	Article	B	SI	CA	Actions taken by fishing Nations towards identification and pr

Record: 1 of 240



ID	ResearchVessel	CRUISE CD/NM	INSTITUTE	PROJECT1	ST DATE	ST YEAR	END DATE	END YEAR	LINK1	LINK2
1	James Cook	JC037	BODC	ECOMAR	01/08/2009	2009	09/09/2009	2009	https://www.st	https://www.bc
2	James Cook	JC011	BODC	ECOMAR	13/07/2007	2007	18/08/2007	2007	https://www.st	http://www.bo
3	Pourquoi pas	SERPENTINE	IFREMER	GEODE	26/02/2007	2007	06/04/2007	2007	http://www.ifre	http://www.int
4	G.O. Sars	BIODEEP	IMR		01/06/2006	2006	18/06/2006	2006	http://www.geo	
5	James Cook	JC024	BODC		23/05/2008	2008	28/06/2008	2008	https://www.bc	
6	James Cook	JC048	BODC	ECOMAR	26/05/2010	2010	03/07/2010	2010	https://www.st	https://www.bc
7	Celtic Explorer	VENTURE	MARINE INSTITUTE	VENTURE	11/07/2011	2011	04/08/2011	2011		
8	G.O. Sars	Leg 2. AZORES - Cha	IMR	MAR-ECO	04/07/2004	2004	05/08/2004	2004	https://www.im	
9	G.O. Sars	Leg1. ICELAND-AZO	IMR	MAR-ECO	05/06/2004	2004	03/07/2004	2004	https://www.im	
10	James Cook	JC010	BODC	HERMES	22/06/2007	2007	07/07/2007	2007	https://www.bc	
11	James Cook	JC036	BODC	HERMIONE	20/06/2009	2009	28/07/2009	2009	https://www.bc	
12	Henry B. Bigelow	HBB2009 CGFZ	NOAA	MAR-ECO	12/06/2009	2009	17/07/2009	2009	http://www.nef	
14	Ramoen	RAMOEN1993	COMMERCIAL	EC FAIR PROJECT 95	01/09/1993	1993	08/10/1993	1993	http://www.cor	
15	Loran	LORAN1996	COMMERCIAL	EC FAIR PROJECT 95	28/08/1996	1996	21/09/1996	1996	http://www.mc	
16	Borgarin	BORGARIN1996	COMMERCIAL	EC FAIR PROJECT 95	01/04/1996	1996	01/05/1996	1996	http://dabred.ir	
17	Skarheim	SKARHEIM1997	COMMERCIAL	EC FAIR PROJECT 95	02/08/1997	1997	14/08/1997	1997	http://oar.mari	
18	Walther Herwig III	WH052	BLE		05/06/1982	1982	20/06/1982	1982	http://www.sci	
19	Atlantis	Mountains in the Se	NOAA	Mountains in the Se	11/07/2003	2003	19/07/2003	2003	http://www.lib.	
20	Ronald H. Brown	North Atlantic Stepp	NOAA	DEEP Atlantic Steppi	06/08/2005	2005	03/10/2005	2005	http://www.lib.	
21	L'Atlante	EUMELI 2	IFREMER	EUMELI	09/01/1991	1991	22/02/1991	1991	http://www.ifre	http://www.ob
22	L'Atlante	EUMELI 3	IFREMER	EUMELI	14/09/1991	1991	24/10/1991	1991	http://www.ob	http://www.ob
23	L'Atlante	EUMELI 4	IFREMER	EUMELI	18/05/1992	1992	30/06/1992	1992	http://www.ob	http://www.ob
24	Le Suroit	EUMELI 5	IFREMER	EUMELI	07/12/1992	1992	30/12/1992	1992	http://www.ob	http://www.ob
25	Charcot	EUMELI 1	IFREMER	EUMELI	01/07/1989	1989	28/07/1989	1989	http://www.ob	
26	Challenger	CH3/82	BODC		12/02/1982	1982	12/02/1982	1982	https://www.bc	

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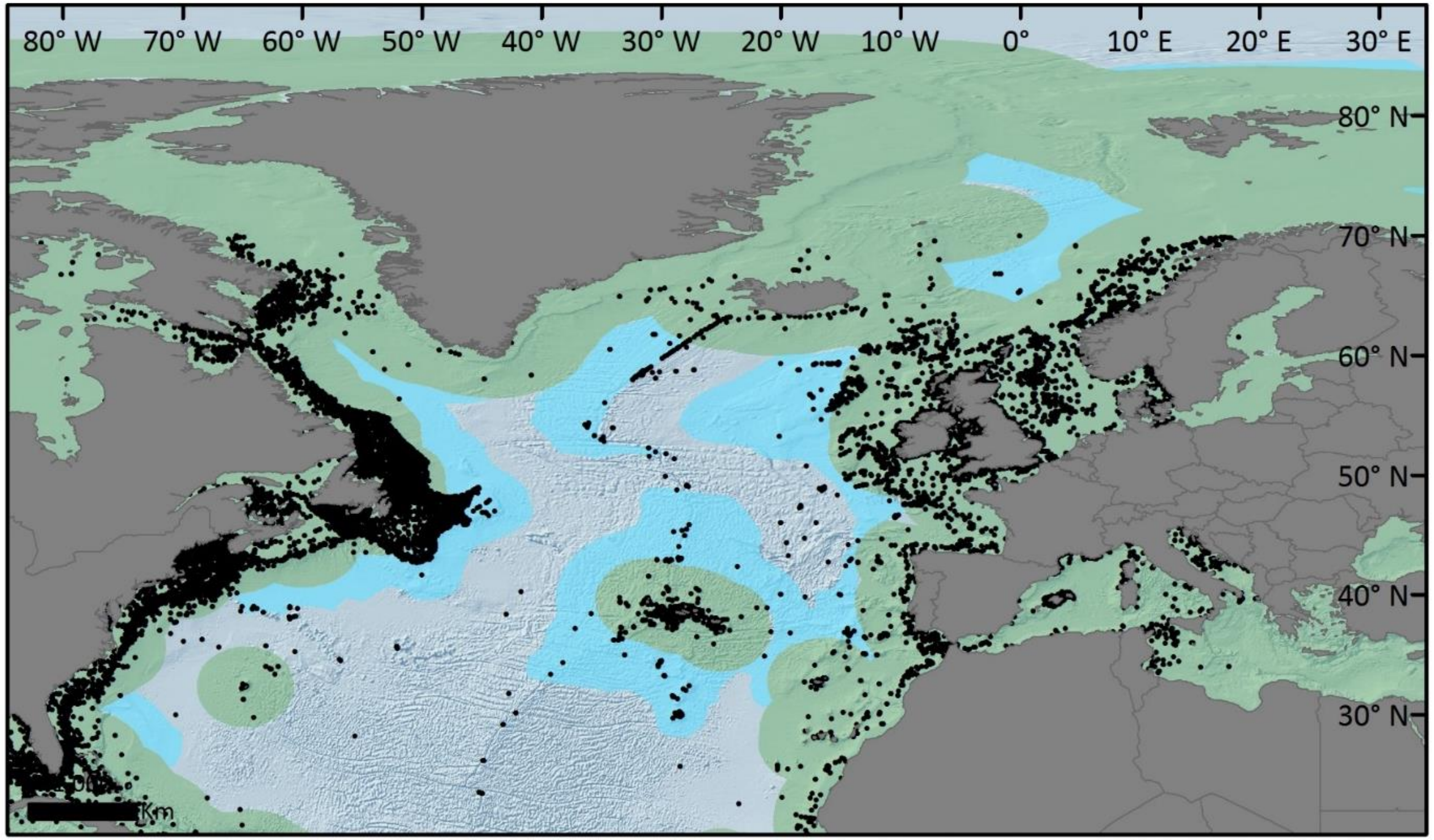


OBIS and published data for benthic VME indicator taxa (WGDEC, 2016)

ECS Submissions

World's EEZ

AZORES DEEP-SEA RESEARCH

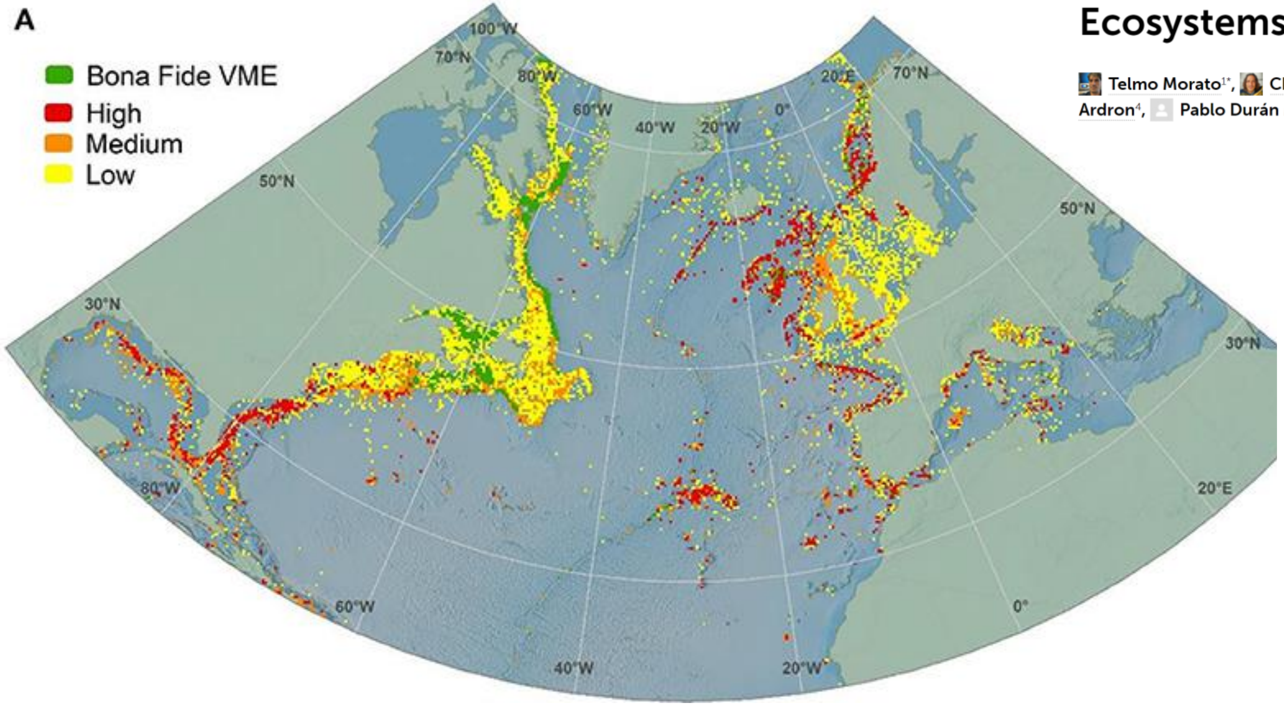
atlas

A multi-criteria assessment method for identifying VME

Taxa-dependent spatial method

VME indicator records → VME index

Data quality → confidence index



A Multi Criteria Assessment Method for Identifying Vulnerable Marine Ecosystems in the North-East Atlantic

Telmo Morato[1*], Christopher K. Pham[1], Carlos Pinto[2], Neil Golding[3], Jeff A. Ardron[4], Pablo Durán Muñoz[5] and Francis Neat[6]

North Atlantic Basin-Scale Multi-Criteria Assessment Database to Inform Effective Management and Protection of Vulnerable Marine Ecosystems

Telmo Morato[1,2*], Christopher K. Pham[1,2], Laurence Fauconnet[1,2], Gerald H. Taranto[1,2], Giovanni Chimienti[3,4], Erik Cordes[5], Carlos Dominguez-Carrió[1,2], Pablo Durán Muñoz[6], Hronn Egilsdottir[7], José-Manuel González-Irusta[1,2,8], Anthony Grehan[9], Dierk Hebbeln[10], Lea-Anne Henry[11], Georgios Kazanidis[11], Ellen Kenchington[12], Lenaick Menot[13], Tina N. Molodtsova[14], Covadonga Orejas[15], Berta Ramiro-Sánchez[11,16], Manuela Ramos[1,2], J. Murray Roberts[11], Luís Rodrigues[1,2], Steve W. Ross[17], José L. Rueda[18], Mar Sacau[6], David Stirling[19] and Marina Carreiro-Silva[1,2]

A multi-criteria assessment method for identifying VME

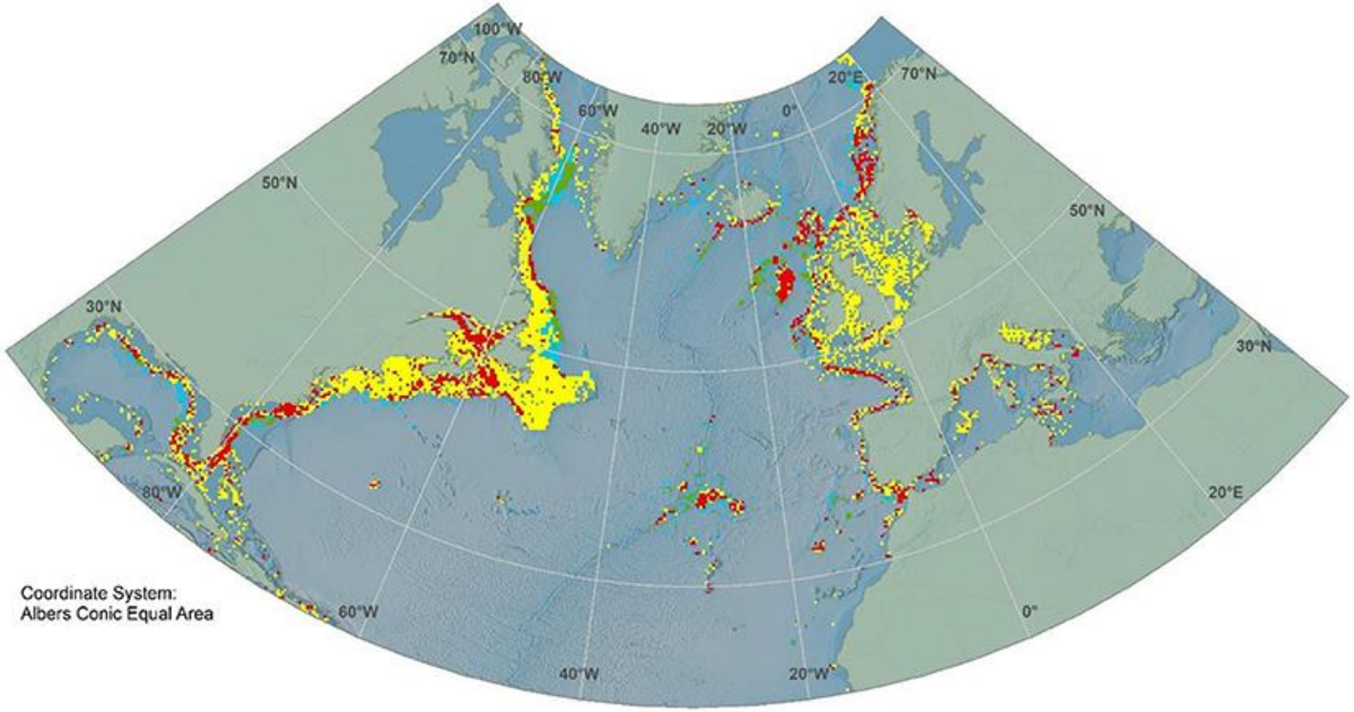
Taxa-dependent spatial method

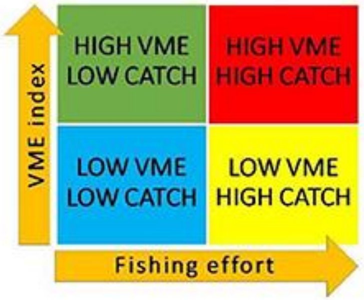
VME indicator records → VME index

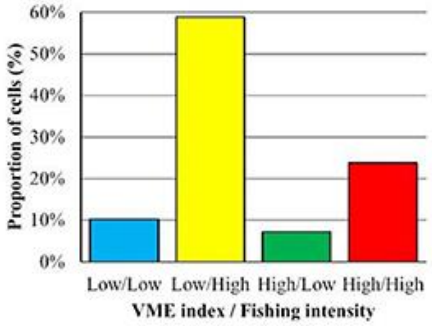
Data quality → confidence index

VME Indices + other data (fishing)

→ **Categorisation for conservation**







REGIONAL SCALE APPROACH

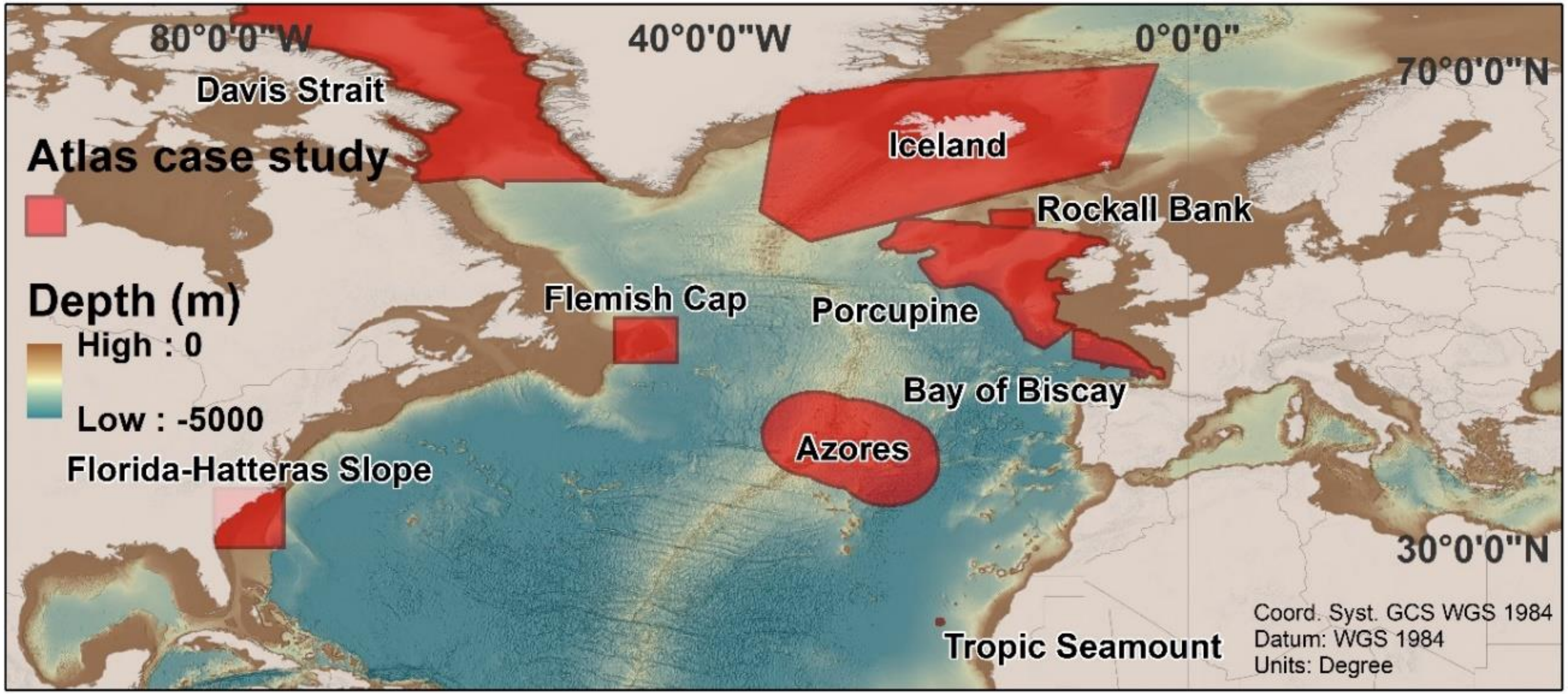
Vulnerable Marine Ecossystems

Unequivocal Vulnerable Marine Ecosystems were defined as **areas** that have been scientifically **explored**, **described** and that **meet the FAO criteria** (FAO, 2009) for defining VMEs.

- Known hydrothermal vents
- Vulnerable benthic communities; cold-water coral gardens or sponge grounds

HABITAT SUITABILITY MODELS

Predicted spatial distribution of biodiversity in the North Atlantic

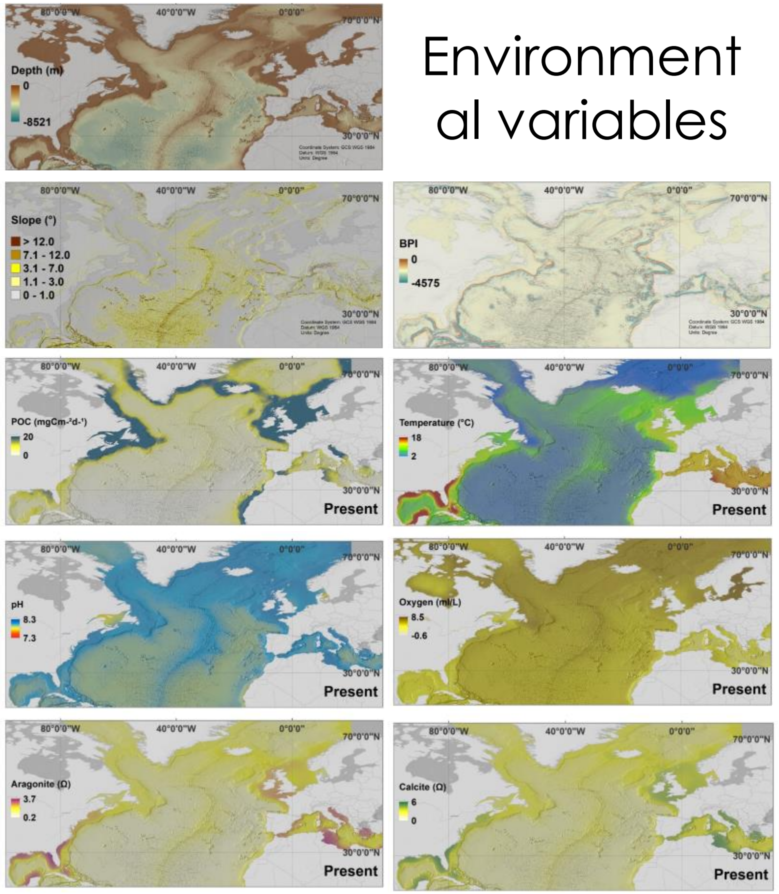


Habitat suitability models were developed at regional **case study** scales and at **ocean-basin**

Predicted spatial distribution of biodiversity in the North Atlantic

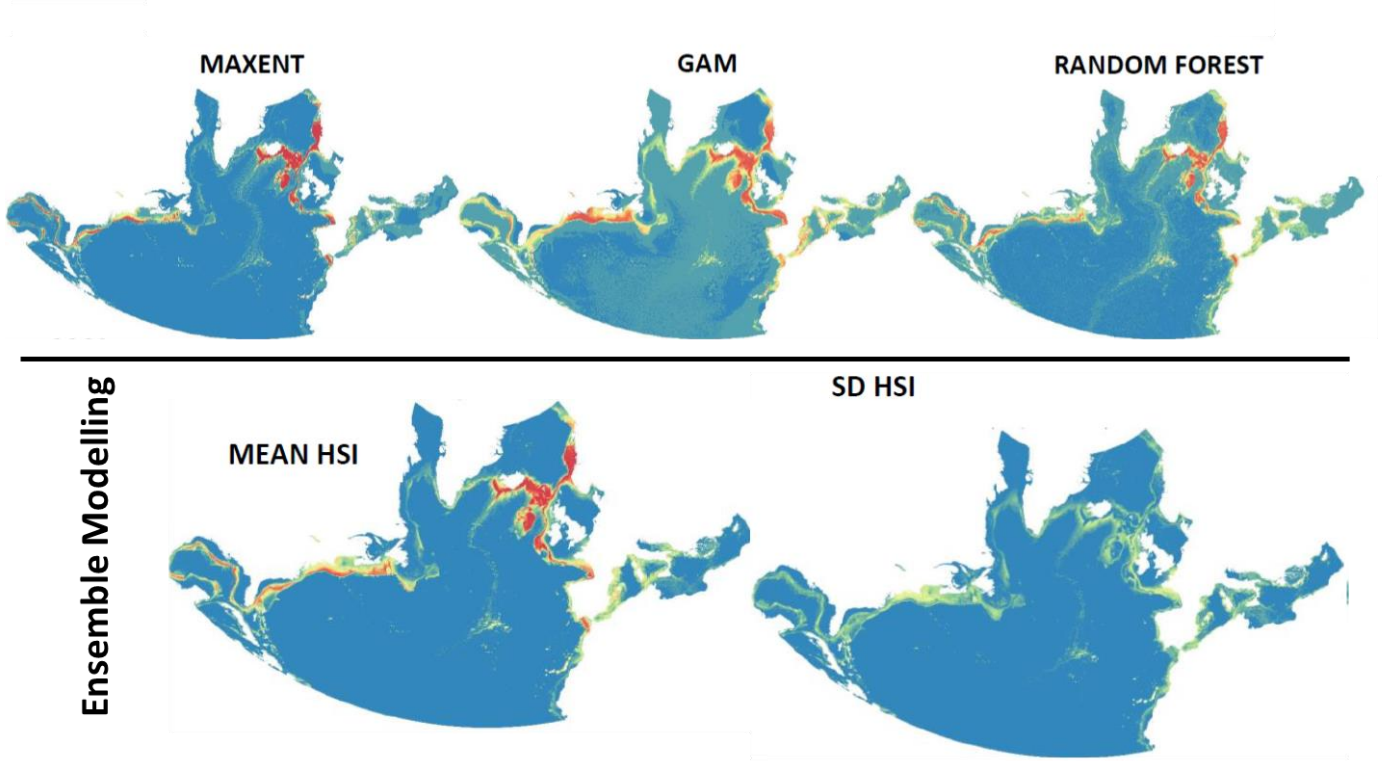
Ocean-basin scale

Environment al variables



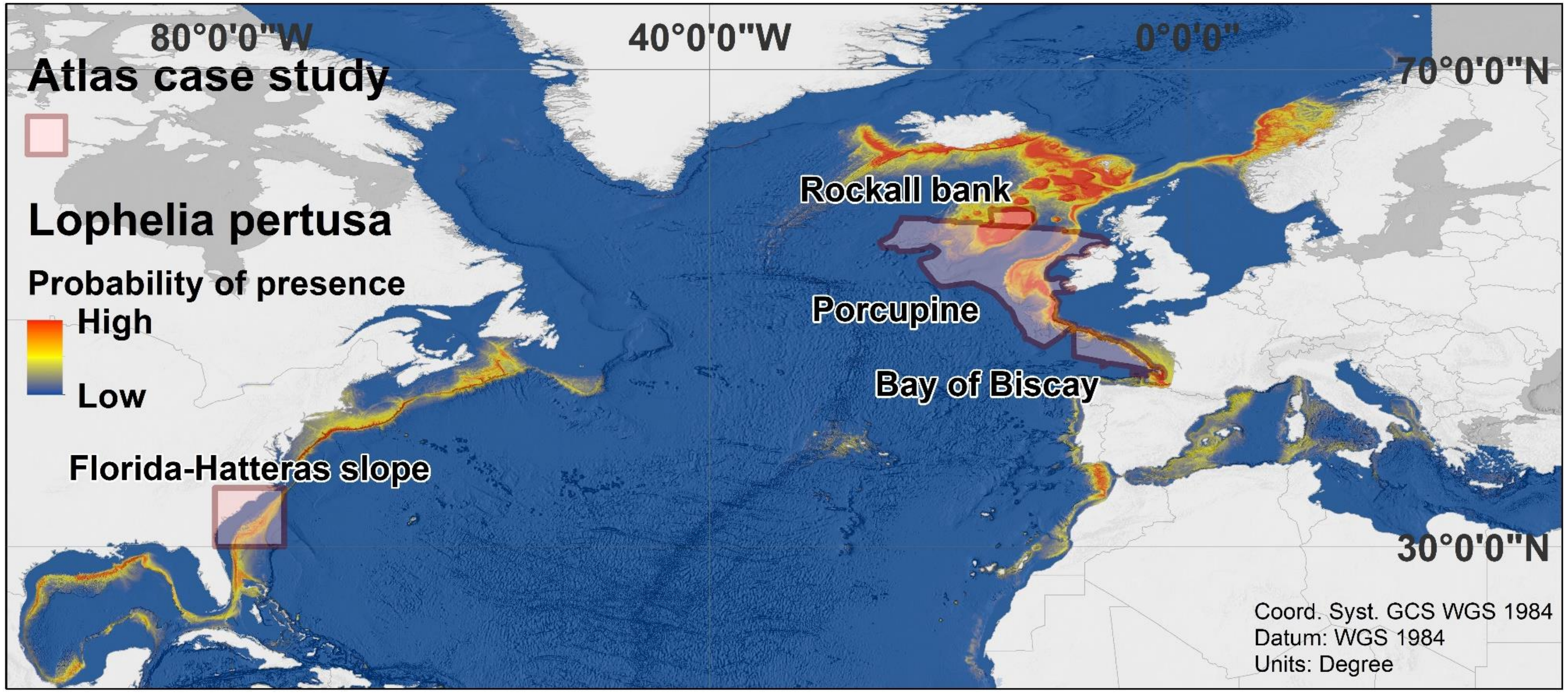
Species: six **cold-water corals** and six **deep-sea fish**

Modelling methods: Ensemble approach (GAM, RF, Maxent)



Predicted spatial distribution of biodiversity in the North Atlantic

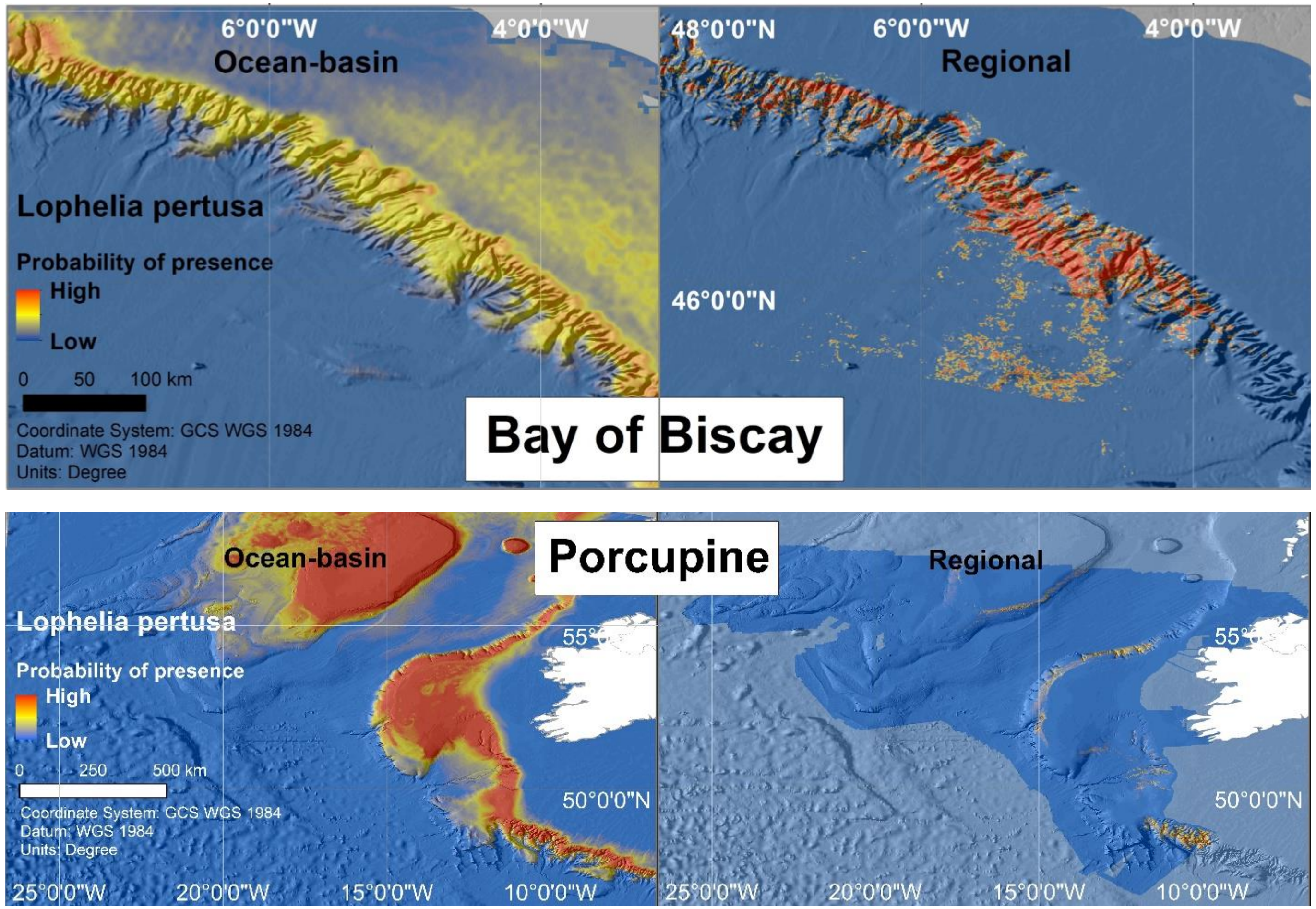
Ocean-basin scale



Ocean-basin scale HSM are valuable tools for evaluating the potential distribution of deep-sea benthic species at large scale, and to **identify broad areas of conservation** or **blue growth** importance

Predicted spatial distribution of biodiversity in the North Atlantic

Ocean-based scale

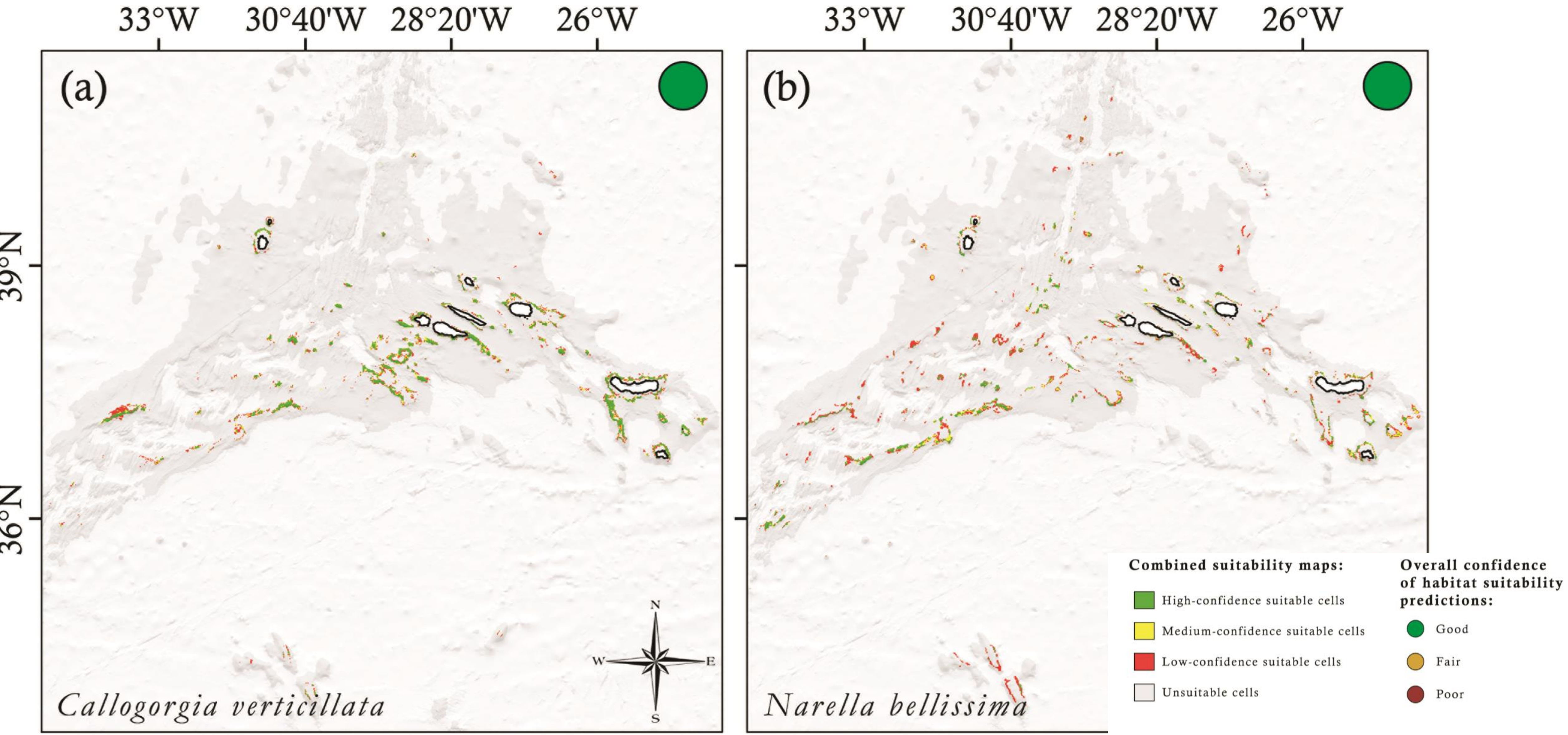


Regional scale

There are **obvious differences** between Ocean-base and Regional HSM outputs

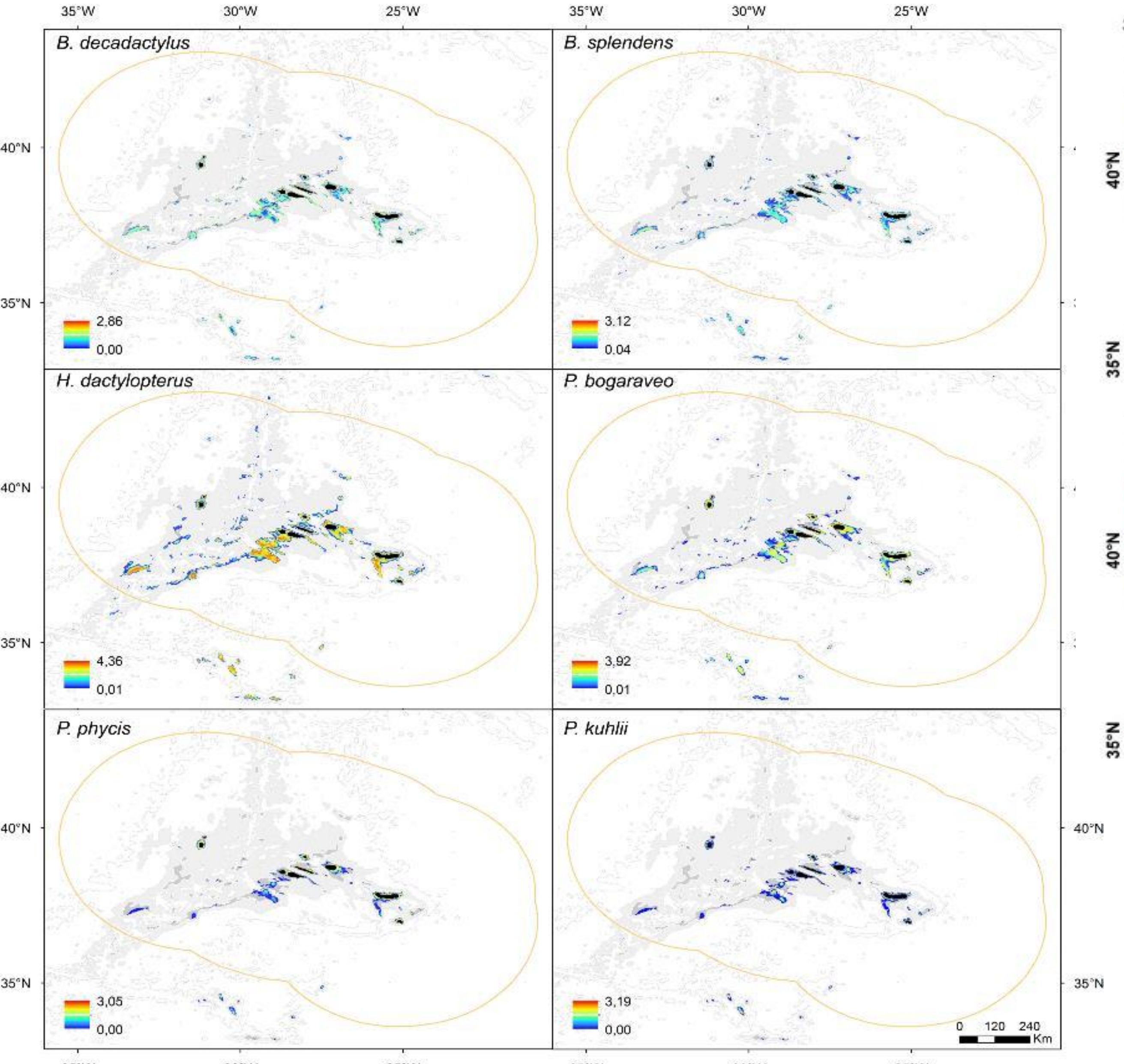
IMPROVED DEEP-SEA BIODIVERSITY ASSESSMENTS

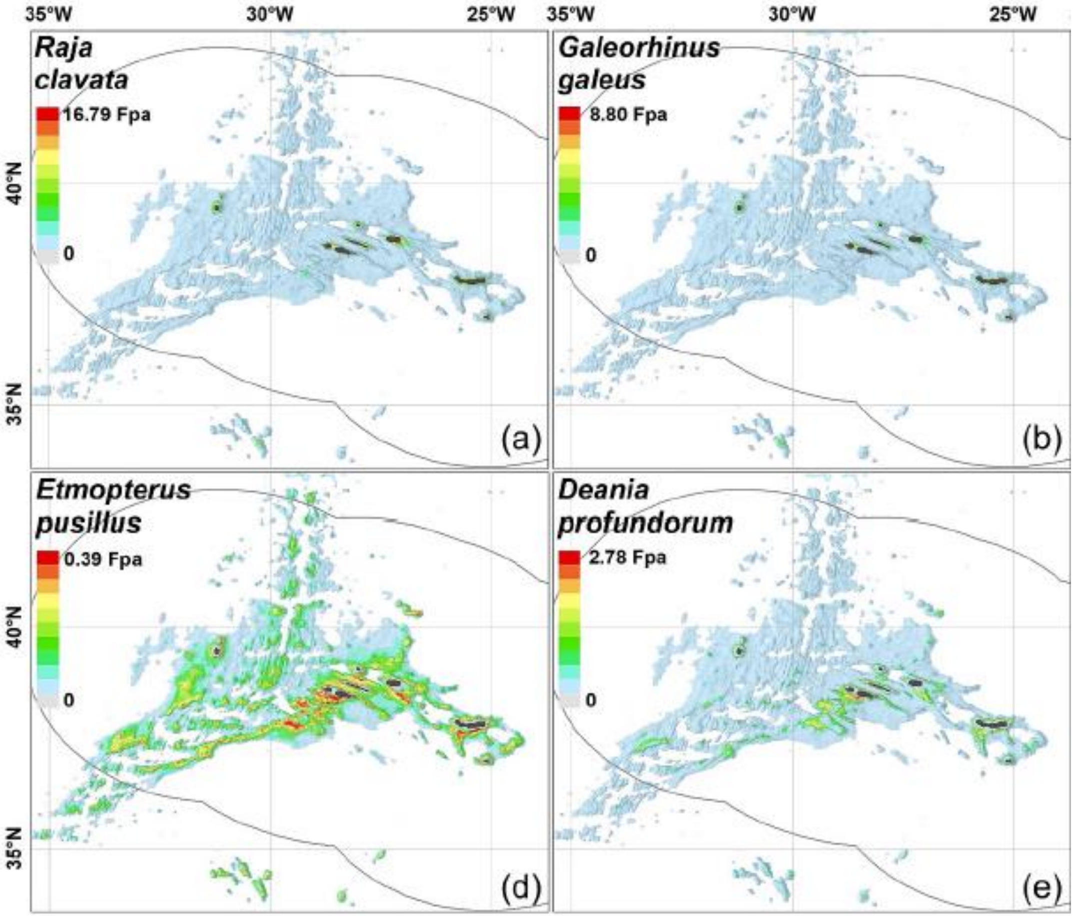
INFORM SUSTAINABLE MANAGEMENT Telmo Morato: UNIVERSITY OF THE AZORES, PORTUGAL



IMPROVED DEEP-SEA BIODIVERSITY ASSESSMENTS

INFORM SUSTAINABLE MANAGEMENT Telmo Morato: UNIVERSITY OF THE AZORES, PORTUGAL





Lessons learned

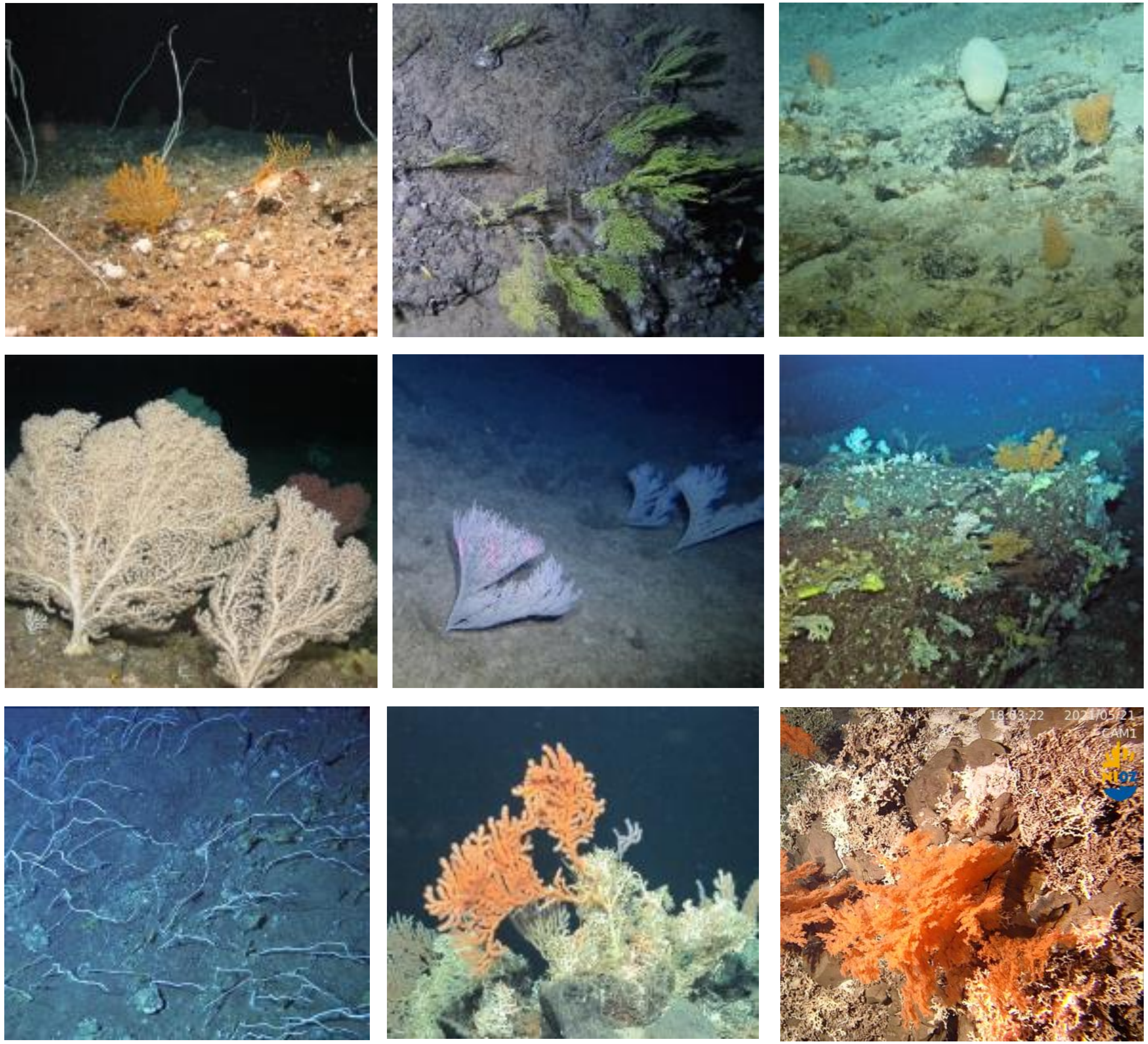
Ocean-basin scale HSM to identify broad areas of conservation interest

Regional HSM help the implementation of area-based management tools at a finer scale

CLIMATE PROJECTIONS

The **deep sea** plays a critical role in global **climate regulation** through uptake and storage of heat and carbon dioxide

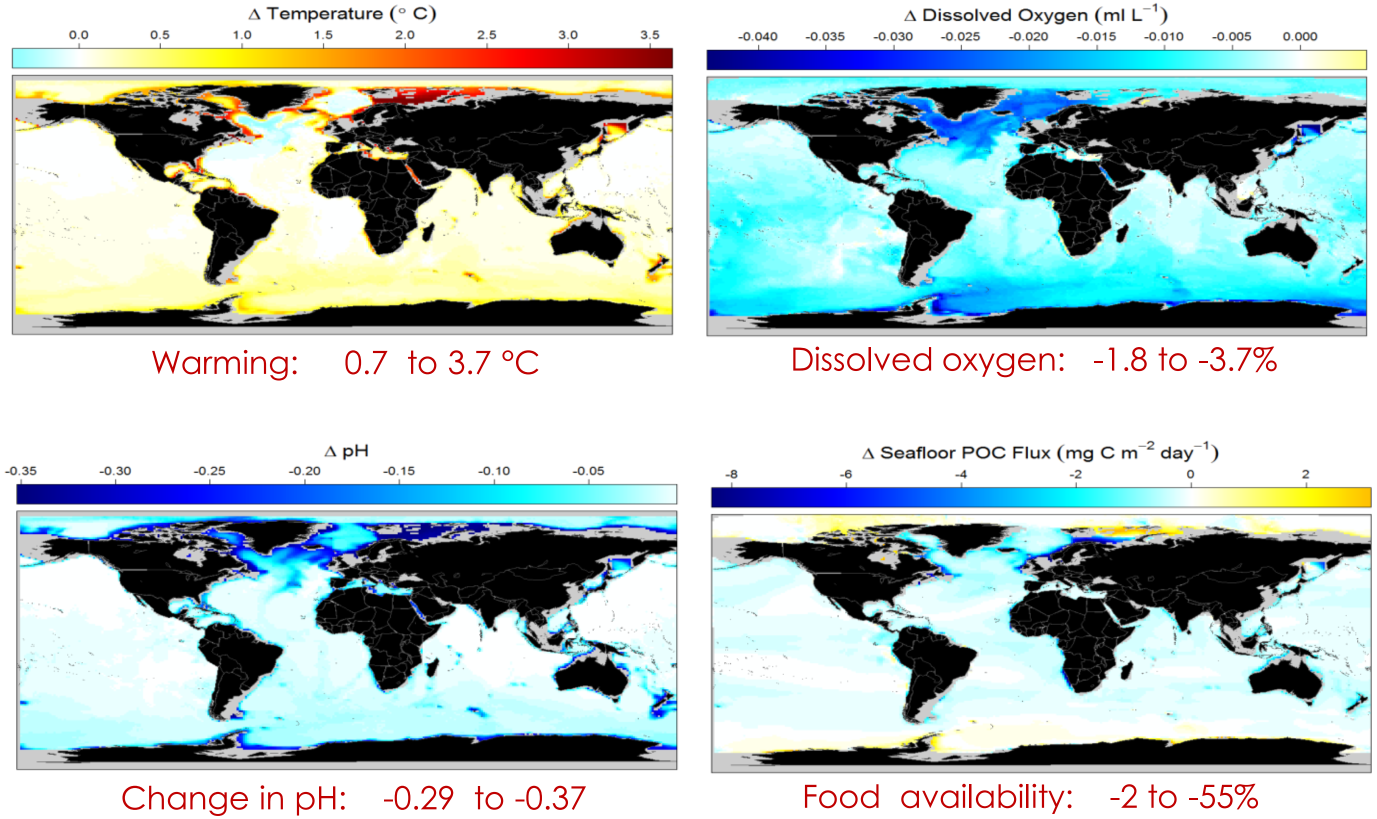
"**warming**, **acidification** and **deoxygenation** of deep waters"



Background

However, this regulating service causes **warming**, **acidification** and **deoxygenation** of deep waters, leading to **decreased food** availability at the seafloor

Projected changes in environmental conditions at seafloor by 2100



Sweetman *et al.* (2017)

Background

Understanding how climate change can lead to **shifts in deep-sea species distributions** is critically important in developing management measures

Global Change Biology

OPINION | Open Access

Climate change considerations are fundamental to management of deep-sea resource extraction

Lisa A. Levin, Chih-Lin Wei, Daniel C. Dunn, Diva J. Amon, Oliver S. Ashford, William W. L. Cheung, Ana

Published: 24 June 2015

Options for managing impacts of climate change on a deep-sea community

Ronald E. Thresher, John M. Guinotte, Richard J. Matear & Alistair J. Hobday

Nature Climate Change **5**, 635–639 (2015) | Cite this article

ELSEVIER

Marine Policy

Volume 87, January 2018, Pages 111-122

Climate change is likely to severely limit the effectiveness of deep-sea ABMTs in the North Atlantic

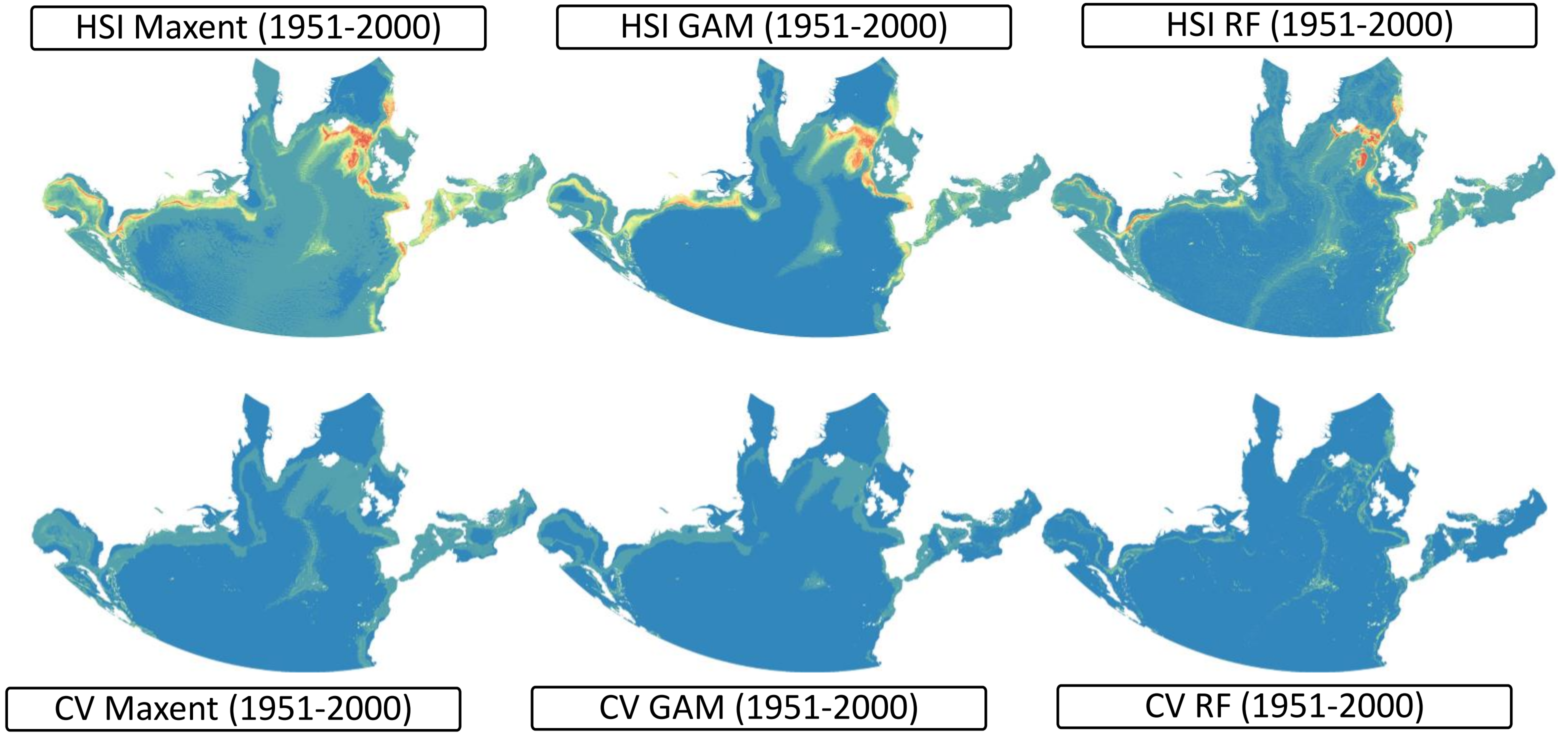
David Johnson [a], Maria Adelaide Ferreira [a], Ellen Kenchington [b]

The Approach

e.g. Lophelia pertusa

Modelled the habitat suitability under current (1951–2000) climate conditions

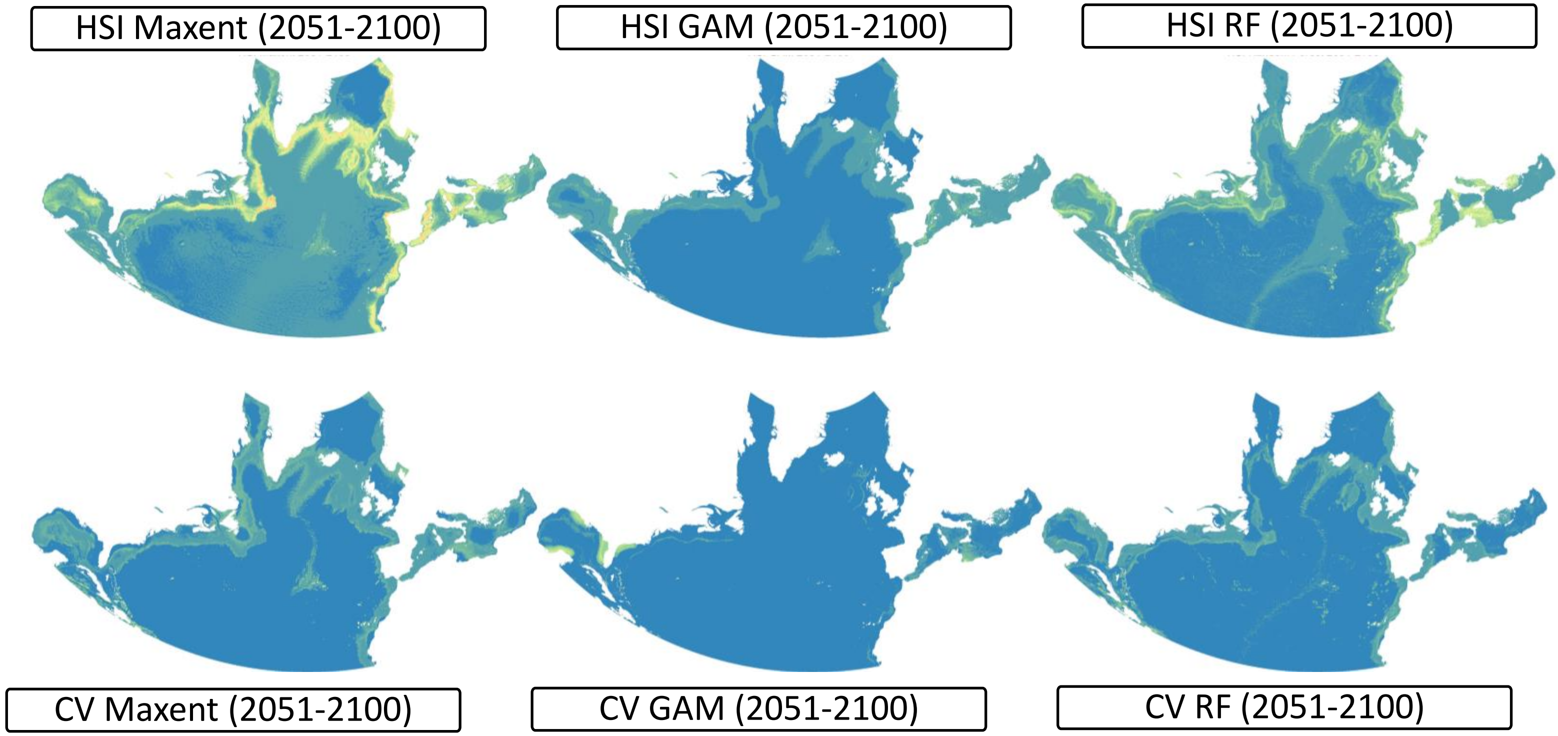
Ensemble modeling approach (Maxent, GAMs, Random Forest)



The Approach

e.g. Lophelia pertusa

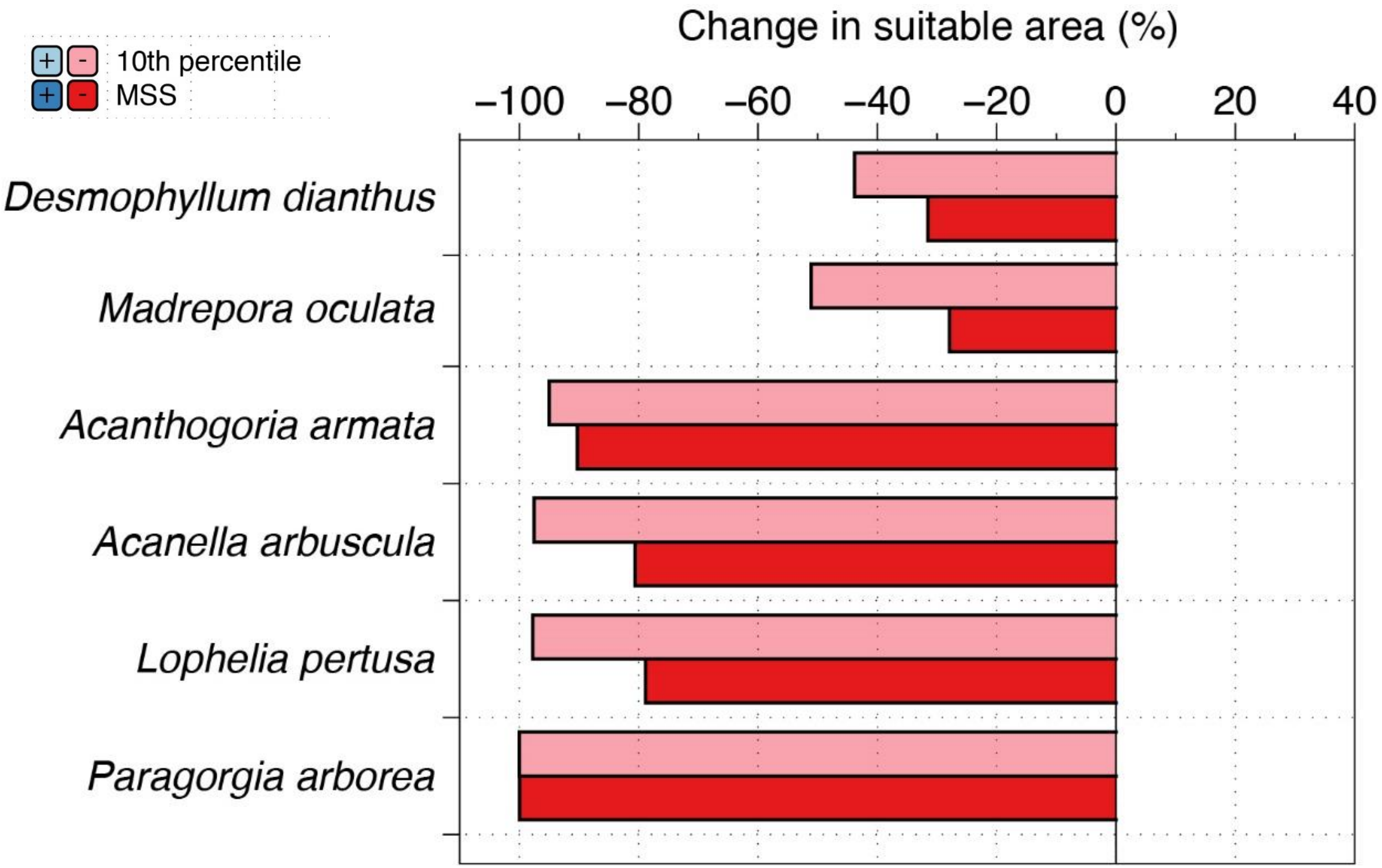
Projected distribution under **future climate** scenarios (RCP8.5 or BAU) for the whole North Atlantic



iAtlantic
INTEGRATED ASSESSMENT OF ATLANTIC MARINE ECOSYSTEMS IN SPACE AND TIME

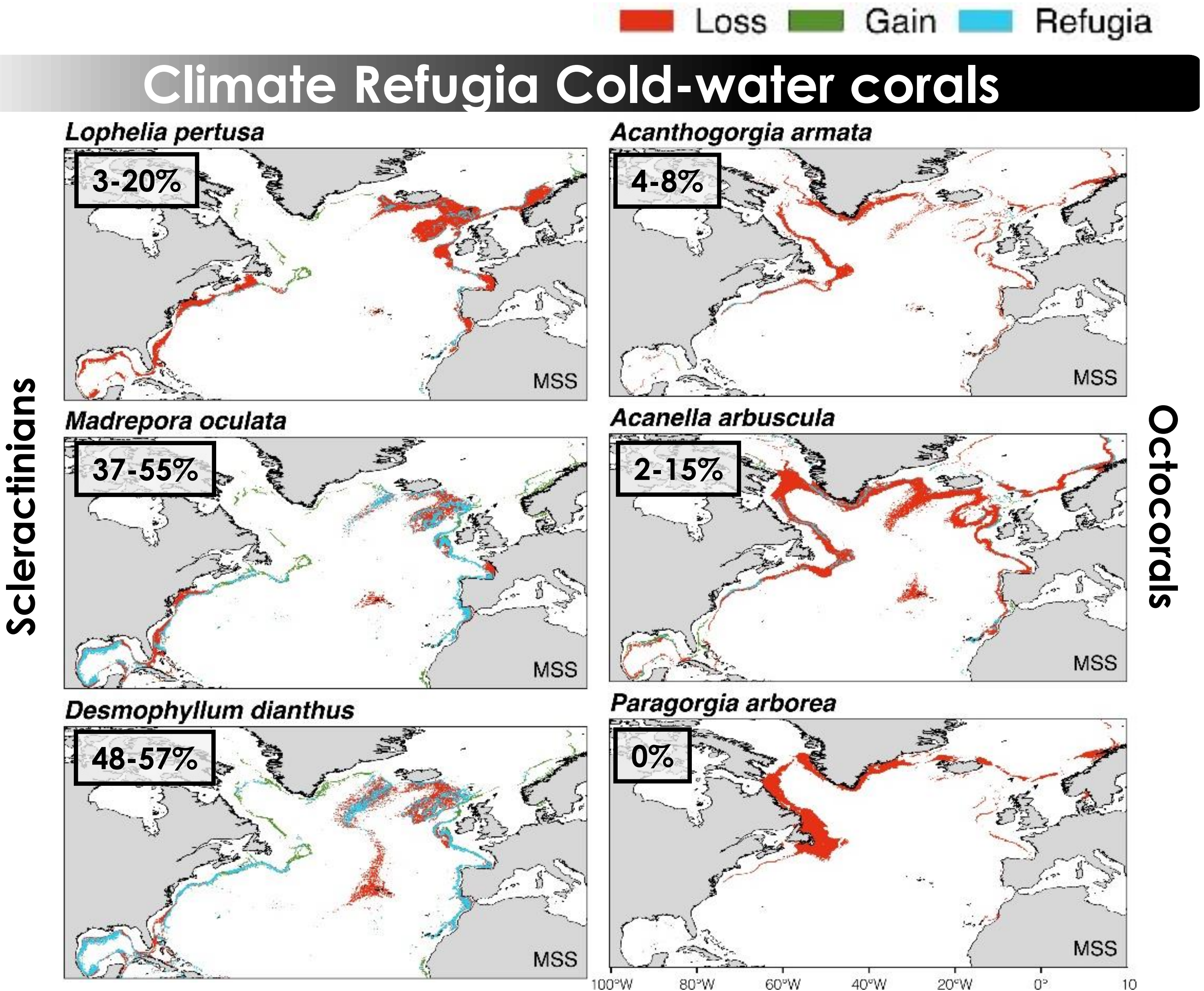
Cold-water corals

Projected a **decrease of 28%–100%** in suitable habitat for cold-water corals (RCP8.5)



Projected **limited climate refugia** locations in the North Atlantic by 2100

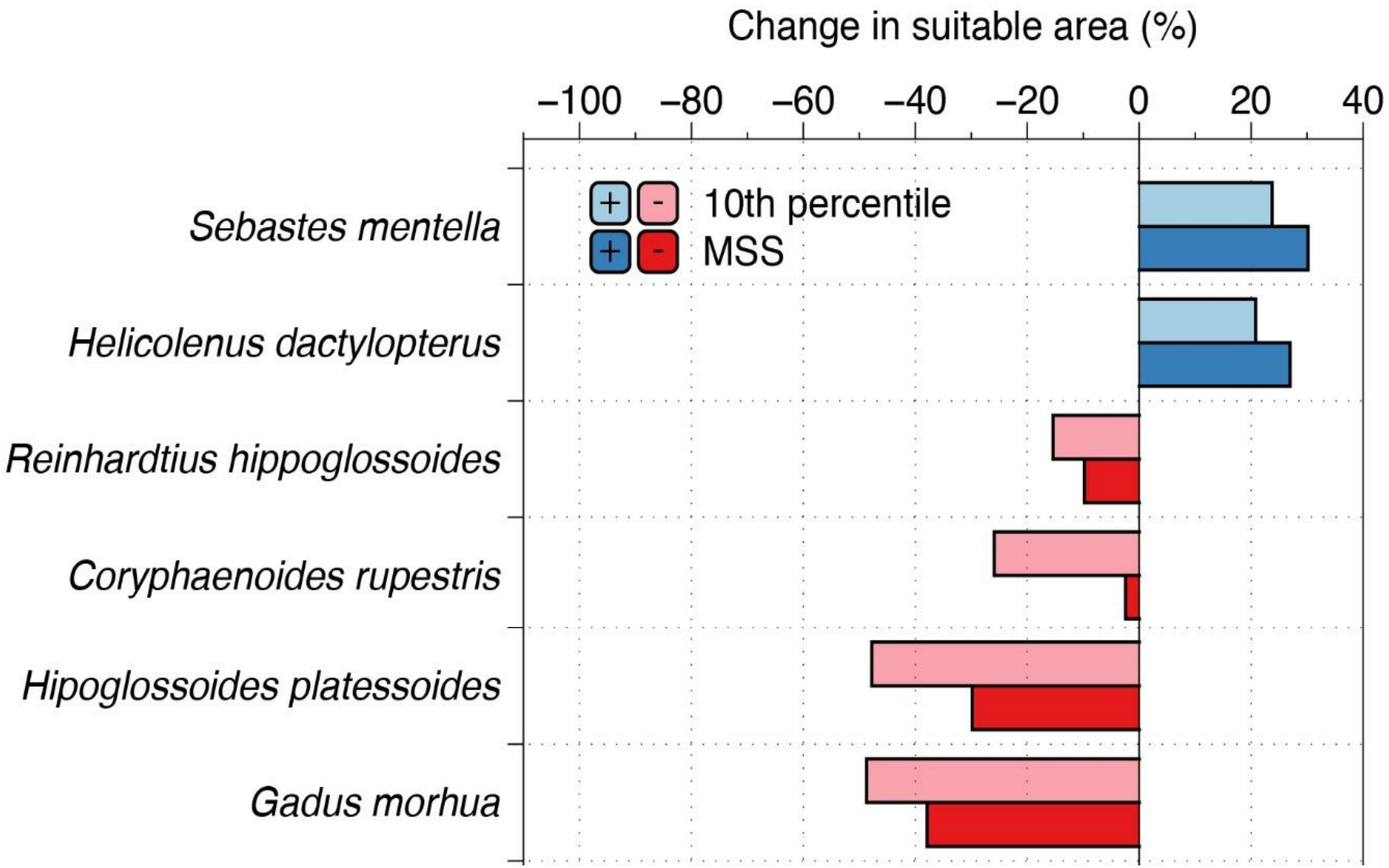
Should these areas be considered **priority areas for conservation**?



Deep-sea fishes

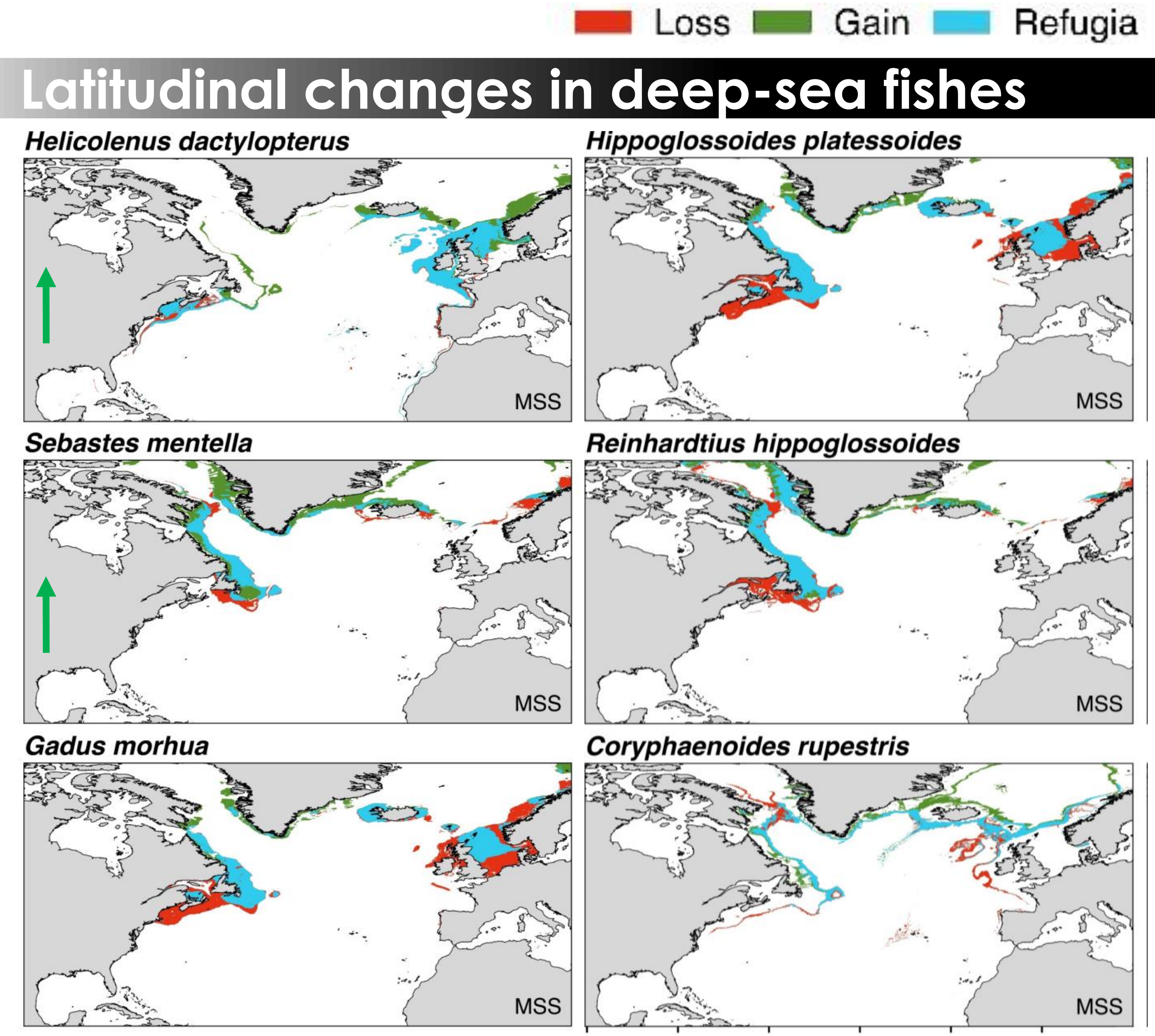
Projected a **decrease** in suitable habitat for 4 fish species (RCP8.5)

An expansion for *Helicolenus dactylopterus* and *Sebastes mentella* (20%–30%)



A **shift** in suitable habitat for deep-sea fishes of 2.0°–9.9° **towards higher latitudes**

Latitudinal changes in deep-sea fishes



Lessons learned

Despite all the caveats, HSM can produce potentially useful projections of changes in the distribution of deep-water fish and invertebrate species

AZORES DEEP-SEA RESEARCH

SPATIAL MANAGEMENT & CONSERVATION PLANNING

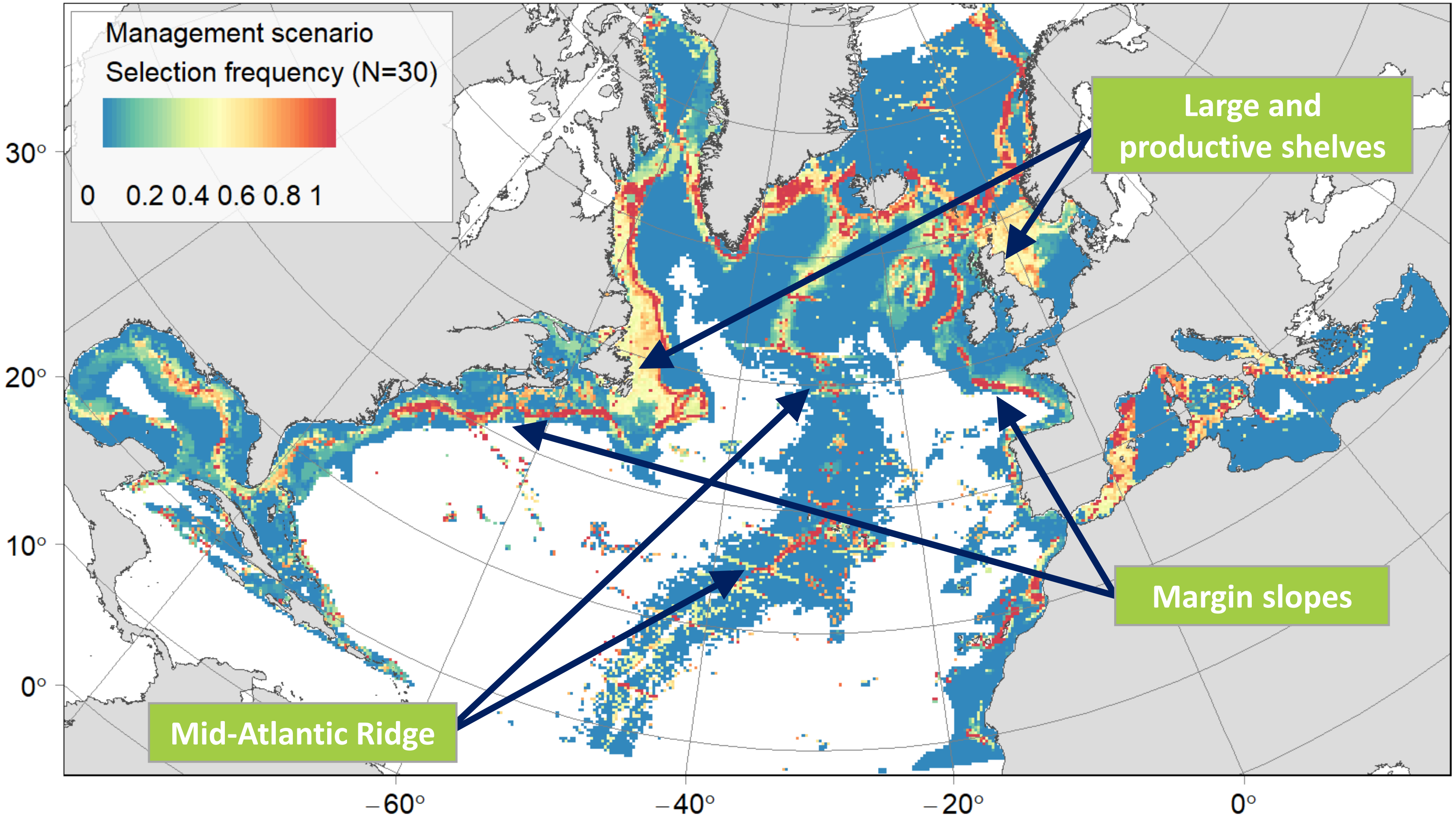
INFORM SPATIAL PLANNING AND DECISION MAKING

Integrate available data into a comprehensive **Systematic Conservation Planning** approach at **Ocean Basin** and **regional scales**, for identifying priority areas in the deep-sea to:

Protect natural diversity, ecosystem structure, function, connectivity and resilience of deep-sea communities in a changing planet, while allowing the environmentally sustainable use of natural resources for current and future generations

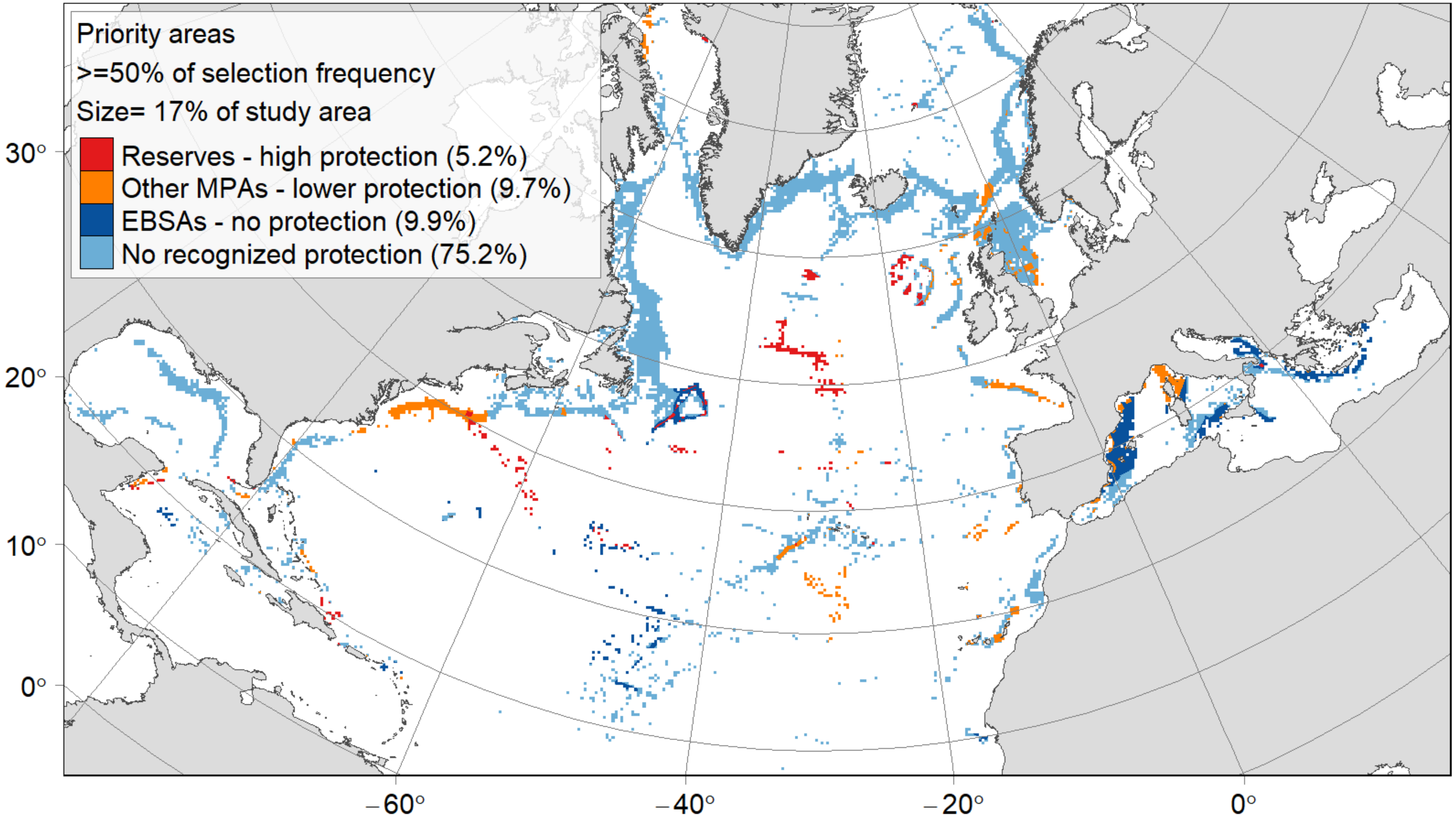
INFORM SPATIAL PLANNING AND DECISION MAKING

Identification of **areas of management importance** –
MARXAN approach



INFORM SPATIAL PLANNING AND DECISION MAKING

Identification of **areas of management importance** – MARXAN approach



Identify overarching statement, Principles, Goals, Objectives

OKEANOS imar MapGES atlas OCEANO AZUL fundação AÇORES 2020 PROGRAMA OPERACIONAL FEDER FSE GOVERNO DOS AÇORES PORTUGAL 2020 UNIÃO EUROPEIA Fundo Europeu de Desenvolvimento Regional

Identify overarching statement, Principles, Goals, Objectives

Overarching statement

Protect **ecosystem structure**, **function**, **natural diversity**, **connectivity** and **resilience** of deep-sea communities in the Azores in a **changing planet**, while allowing a socially equitable and **environmentally sustainable use** of natural resources for current and future generations

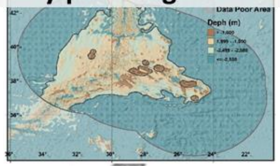
Overarch. Goal	Ecological Goals	Objectives
Ecosystem structure	Ensure protection of intact and restoration of degraded Vulnerable Marine Ecosystems	• Ensure full protection (100%) of bona fide Vulnerable Marine Ecosystems by 2023 • Protect at least 30% of known records of endemic, extremely long-lived, and reef engineers Vulnerable Marine Ecosystems indicators by 2023 • Protect at least 15% of inferred Vulnerable Marine Ecosystems by 2023
	Maintain food-web structure and networks of trophic relationships	• ***No SMART objectives defined due to data gap***
Ecosystem function	Ensure protection of intact and restoration of essential deep habitats	• Protect a minimum of 75% of the known essential deep-sea habitats by 2023
	Ensure protection of intact and restoration of keystone and foundation species	• Ensure the identification of keystone and foundation species by 2025 • Protect a minimum of 30% of the known keystone and foundation species distribution by 2028
	Ensure the long-term maintenance of biologically mediated processes	• ***No SMART objectives defined due to data gap***
	Maintain functional diversity of deep-sea ecosystems	• ***No SMART objectives defined due to data gap***

IMPROVED DEEP-SEA BIODIVERSITY ASSESSMENTS

INFORM SUSTAINABLE MANAGEMENT Telmo Morato: UNIVERSITY OF THE AZORES, PORTUGAL

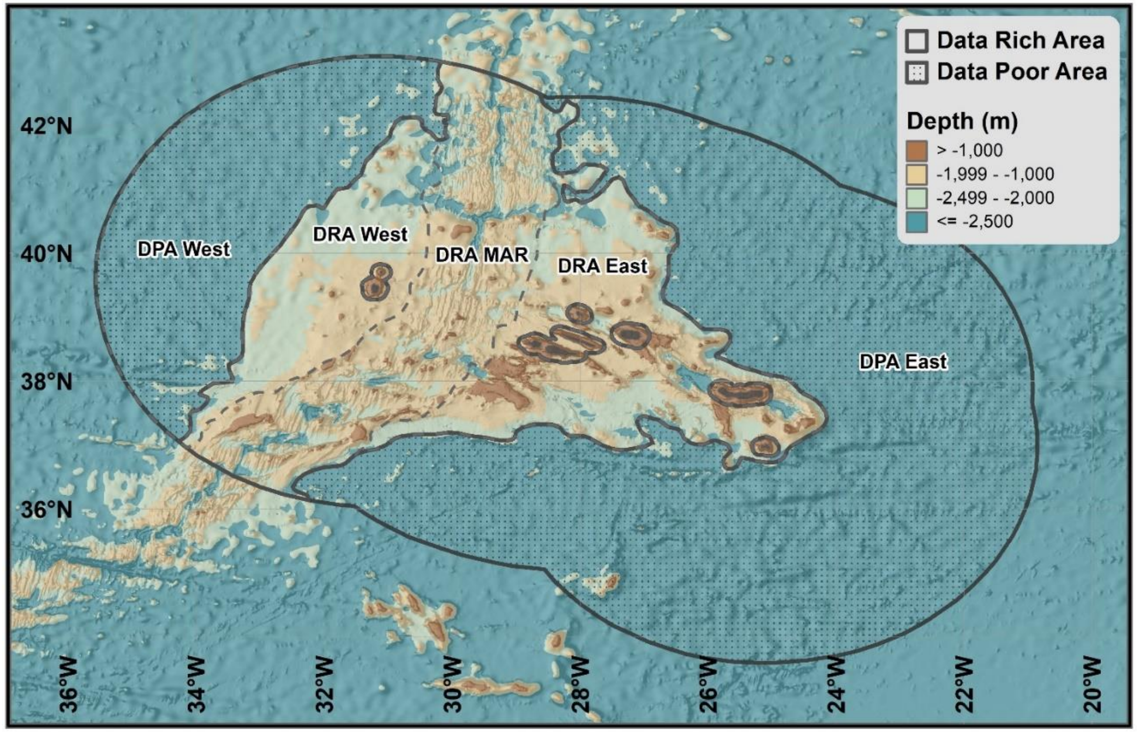
Identify overarching statement, Principles, Goals, Objectives

Identify planning area and units



Spatial planning boundaries

Based on the “science-based principle” the spatial planning area was divided in: a “**data-rich** planning area” (<2,500m) and a “**data-poor abyssal** planning area”.

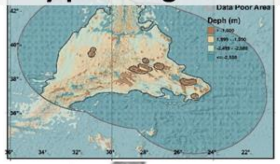


Based on the “ecosystem-based approach” principle and the representativity and replication criteria the planning areas were subdivided into 5 sub-areas

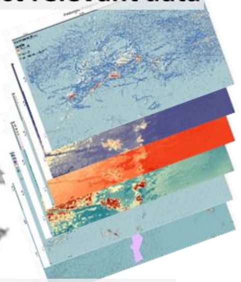
AZORES DEEP-SEA RESEARCH

Identify overarching statement, Principles, Goals, Objectives

Identify planning area and units

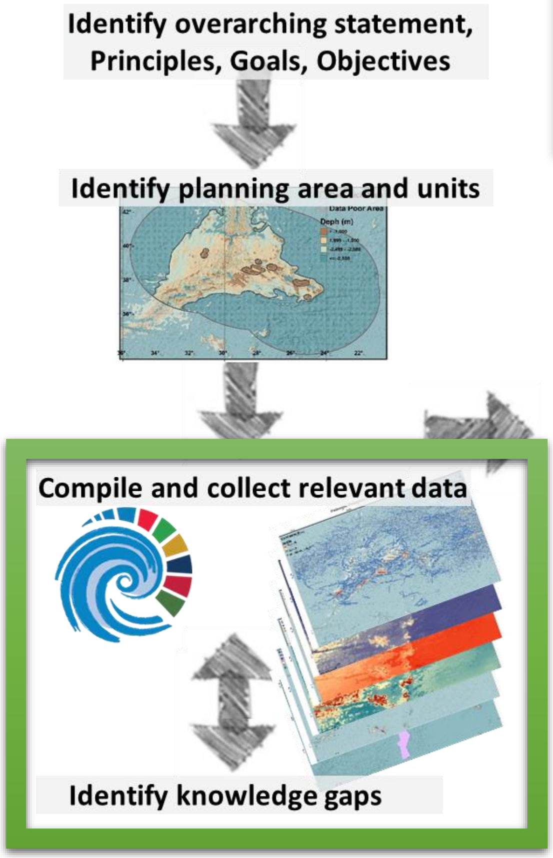


Compile and collect relevant data



Identify knowledge gaps

continue



Data-driven approach

Scientific information used to address management goals and objectives

Objectives	
• Ensure full protection (100%) of bona fide Vulnerable Marine Ecosystems by 2023	● (yellow)
• Protect at least 30% of known records of endemic, extremely long-lived, and reef engineers considered Vulnerable Marine Ecosystems indicators by 2023	● (light green)
• Protect at least 15% of inferred Vulnerable Marine Ecosystems by 2023	● (purple) ● (black) ● (brown)
• (food-web structure objectives)	Data gap
• Protect a minimum of 75% of the known essential deep-sea habitats by 2023	Data gap
• Ensure the identification of keystone and foundation species by 2025	Data gap
• Protect a minimum of 30% of the known distribution of keystone and foundation species by 2028	Data gap
• (objectives for long-term maintenance of biologically mediated processes)	Data gap
• (objectives for maintaining functional diversity of deep-sea ecosystems)	Data gap
• Ensure no further loss of deep-sea biodiversity at ecologically relevant scales by 2030	● (red) ● (yellow) ● (light green) ● (green) ● (light blue) ● (blue) ● (pink) ● (purple) ● (grey) ● (black) ● (brown)
• Halt significant adverse impacts on vulnerable, endangered, or critically endangered species or habitats by 2030	● (red) ● (yellow) ● (light green) ● (light blue) ● (purple) ● (grey) ● (black) ● (brown)
• Protect a minimum of 75% of the known hotspots of biodiversity of deep-sea ecosystems by 2023	● (green)
• Protect 100% of the near-natural habitats within current fishing depths by 2023	● (light blue)
• Ensure at least 15% of all deep-sea benthic habitats and associated ecosystems are protected by 2023	● (blue) ● (brown)
• Ensure that the connectivity patterns, maximum larval dispersal distances and average annual movements of deep-sea foundation, keystone, vulnerable, and economically important deep-sea species are revealed by 2030	Data gap
• Ensure that maximum distances between the network units smaller than the 75th percentile of the median larval dispersal distances and average annual movements of mobile fauna by 2033	○
• (Resilience)	Data gap
• Ensure the identification of areas with least climate hazards and climate-refugia for deep-sea biological diversity and commercially important deep-sea benthic fishes by 2025	Data gap

Supporting scientific information

- ● (red) Known essential fish habitats (Santos et al., 2010; Menezes et al., 2012; Melo and Menezes, 2002)
- ● (yellow) Known Vulnerable Marine Ecosystems (Morato, Carreiro-Silva, Dominguez-Carrió et al., unpublished data; Beaulieu & Szafranski, 2019)
- ● (light green) Known occurrence records of selected Vulnerable Marine Ecosystems indicator taxa (endemic, extremely long-lived, and reef engineers) (COLETA database; multiple other sources)
- ● (green) Known shallow (<250m) and deep (>1500m) seamounts (Morato et al., 2008; 2013; Rodrigues et al., unpub. data)
- ● (light blue) Known near natural areas in the range of current deep-sea benthic fishing activities (< 1200m) (Morato et al., unpublished data)
- ● (blue) Geomorphic Management Units derived from the best-compiled bathymetry dataset (Gerald Taranto, unpublished data)
- ● (pink) Habitat suitability and abundance models of commercially important deep-sea benthic fish (Parra et al., 2017)
- ● (purple) Habitat suitability models of habitat-forming and vulnerable cold-water corals (Taranto et al., unpublished data)
- ● (grey) Habitat suitability models of endangered or critically endangered deep-water sharks and rays (Das et al., unpublished data)
- ● (black) Inferred Vulnerable Marine Ecosystems index (Morato et al., 2018)
- ● (brown) Existing area-based management tools (e.g. MPAs)
- ○ Other published sources

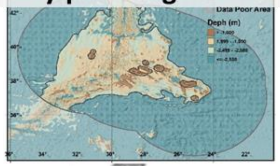
continue

IMPROVED DEEP-SEA BIODIVERSITY ASSESSMENTS INFORM SUSTAINABLE MANAGEMENT

Telmo Morato: UNIVERSITY OF THE AZORES, PORTUGAL

Identify overarching statement, Principles, Goals, Objectives

Identify planning area and units



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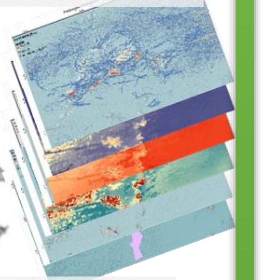
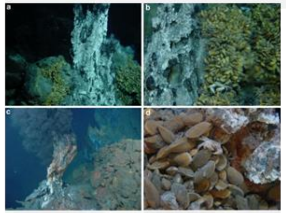


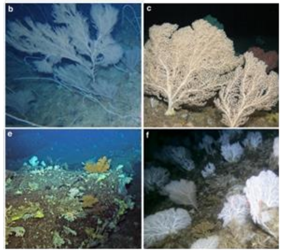
Identify knowledge gaps

Important Areas approach

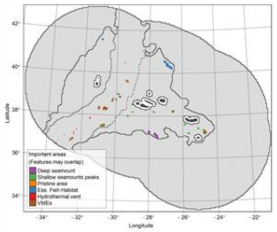
Known Hydrothermal Vents



Known VMEs



Known Essential Fish Habitats, Near-natural areas, shallow and very deep seamounts



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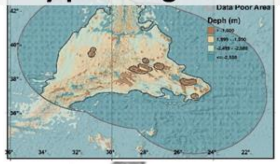

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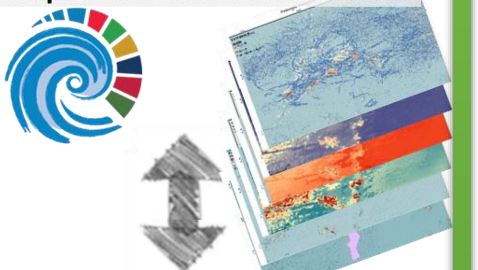

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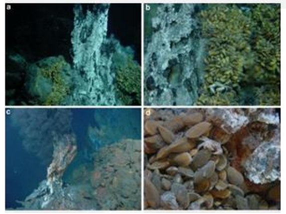

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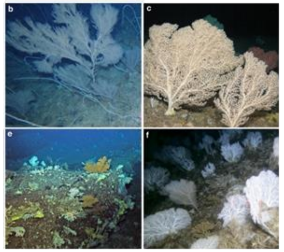

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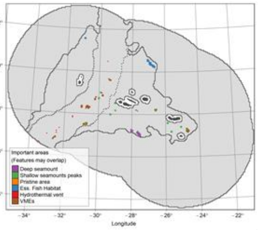
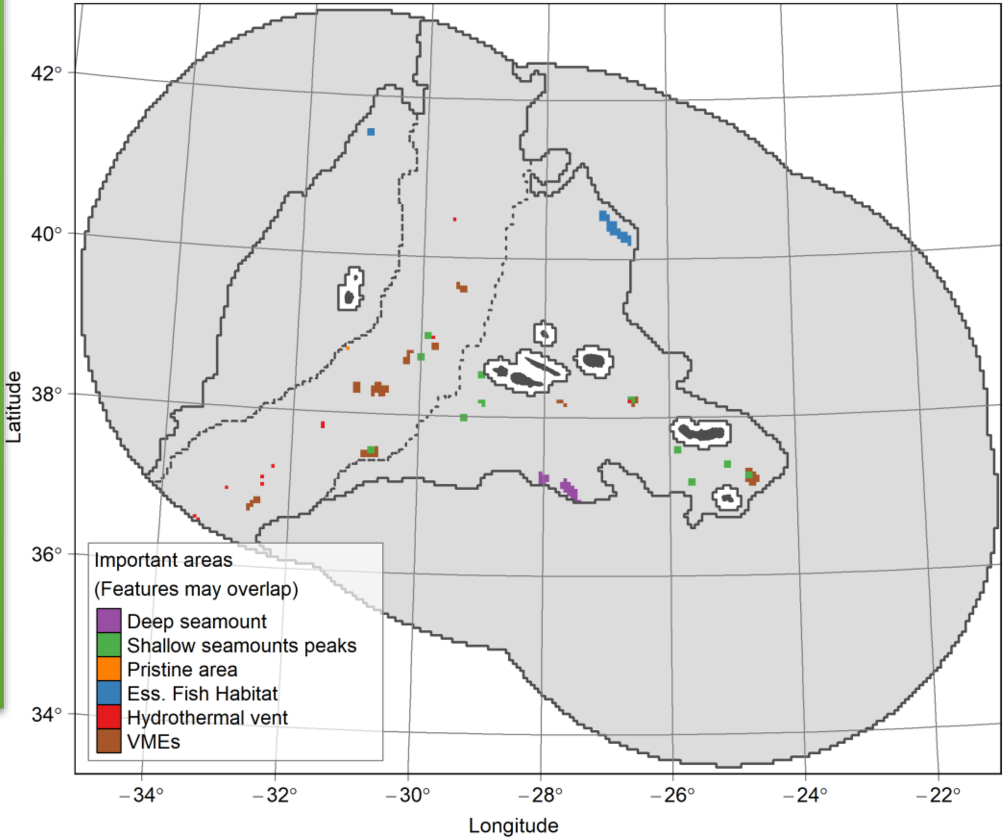


Important Areas planning boundaries

Features that based on the best available knowledge are of ecologically or biologically importance. Placement of closures should fully capture these areas



Important areas	N of areas
Known VMEs	12
Hydrothermal vents	10
Essential Fish Habitats	2
Shallow-water seamounts peaks	11
Deep seamounts in the data-rich area	2
Near natural areas	1
Total	30*

IMPROVED DEEP-SEA BIODIVERSITY ASSESSMENTS

INFORM SUSTAINABLE MANAGEMENT

Telmo Morato: UNIVERSITY OF THE AZORES, PORTUGAL

AZORES DEEP-SEA RESEARCH

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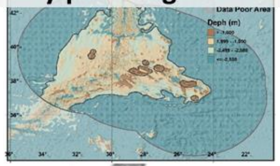

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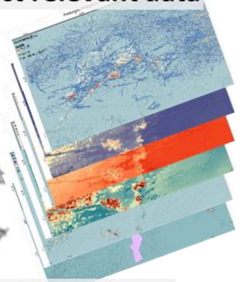

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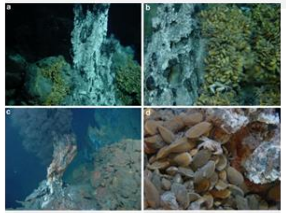

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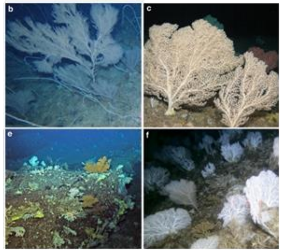

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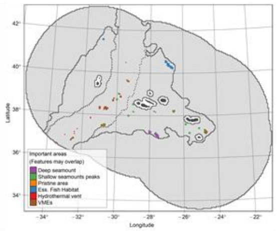
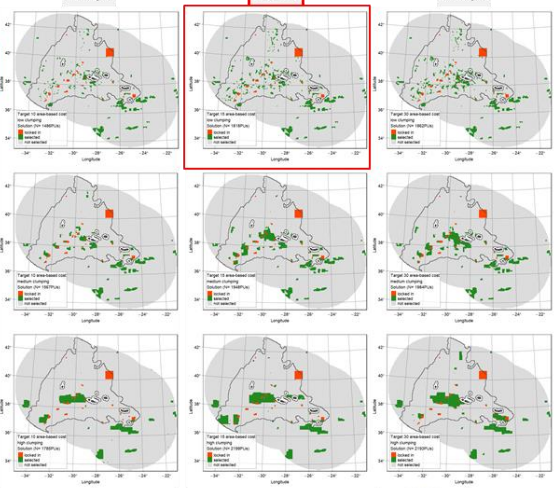


Prioritization approach



MARXAN conservation solutions

"minimum set" objective function: Finds the set of PUs that minimizes the cost of the solution whilst ensuring that all targets and other constraints are met

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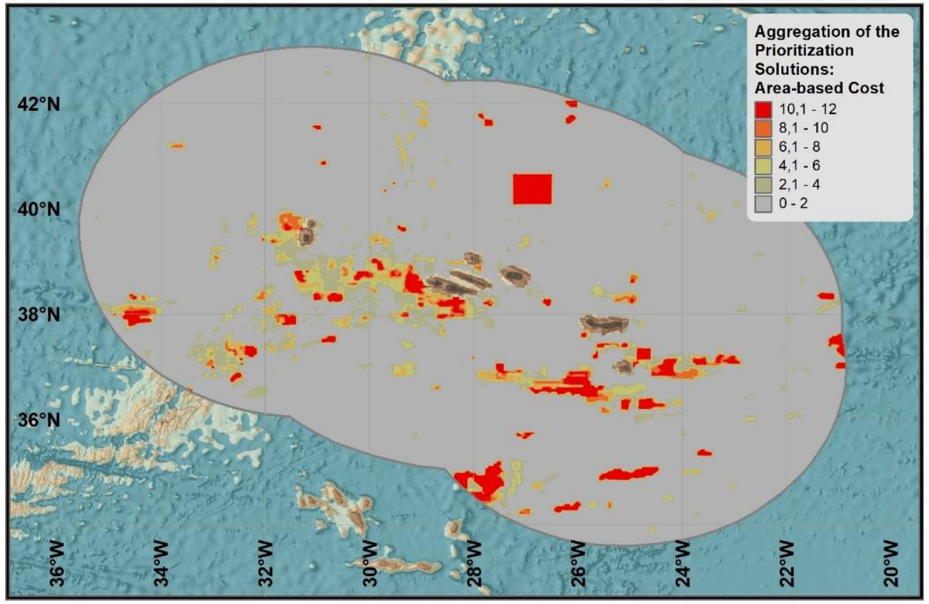

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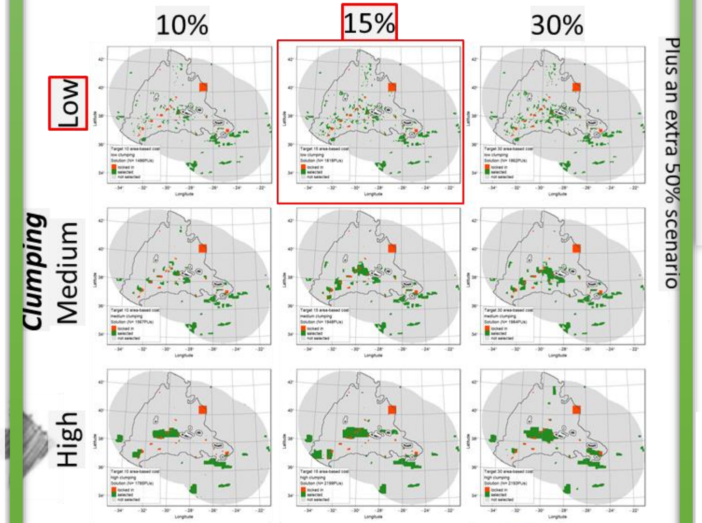


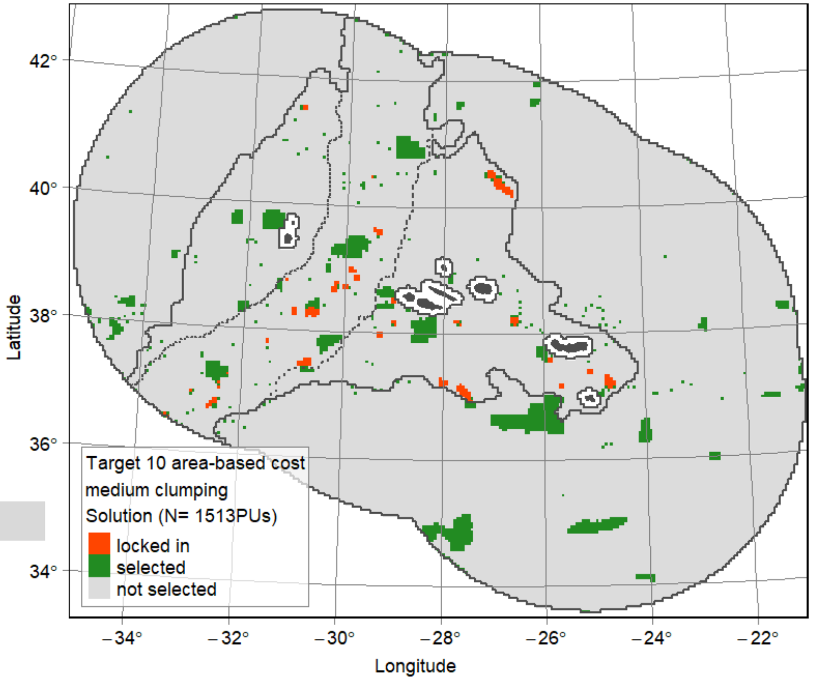
MARXAN conservation solutions

"minimum set" objective function: Finds the set of PUs that minimizes the cost of the solution whilst ensuring that all targets and other constraints are met

Spatial prioritization tool

Complement the network with Important Resources necessary to achieve the prioritization targets

24 Scenarios were produced



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IMPROVED DEEP-SEA BIODIVERSITY ASSESSMENTS INFORM SUSTAINABLE MANAGEMENT

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AZORES DEEP-SEA RESEARCH

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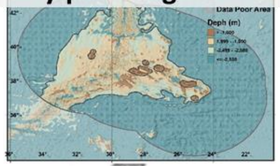

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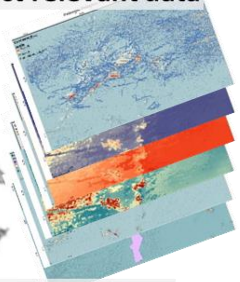

Identify knowledge gaps

Important Areas approach

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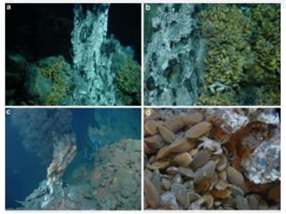

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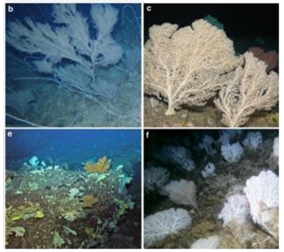

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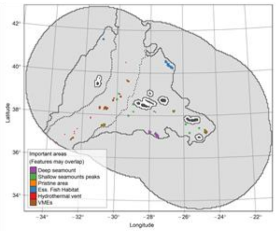

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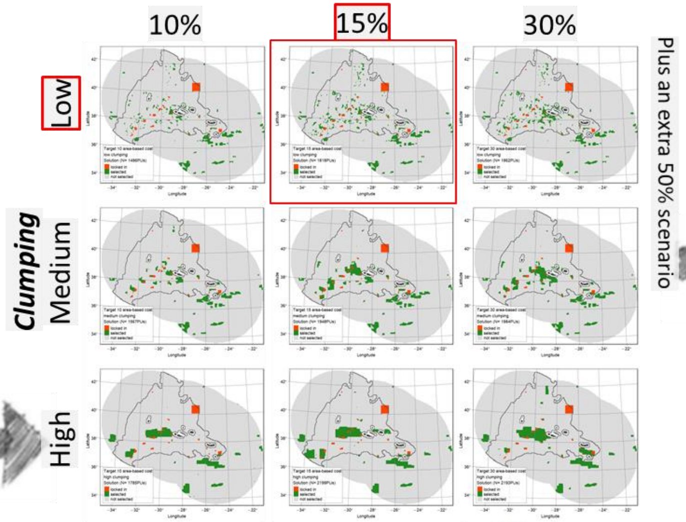
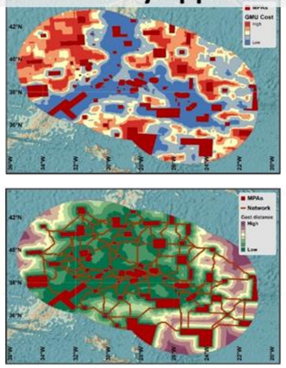


MARXAN conservation solutions

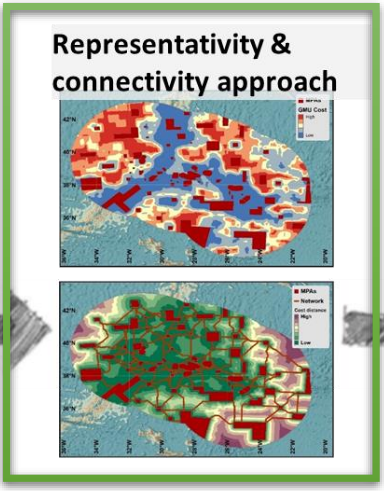
"minimum set" objective function: Finds the set of PUs that minimizes the cost of the solution whilst ensuring that all targets and other constraints are met

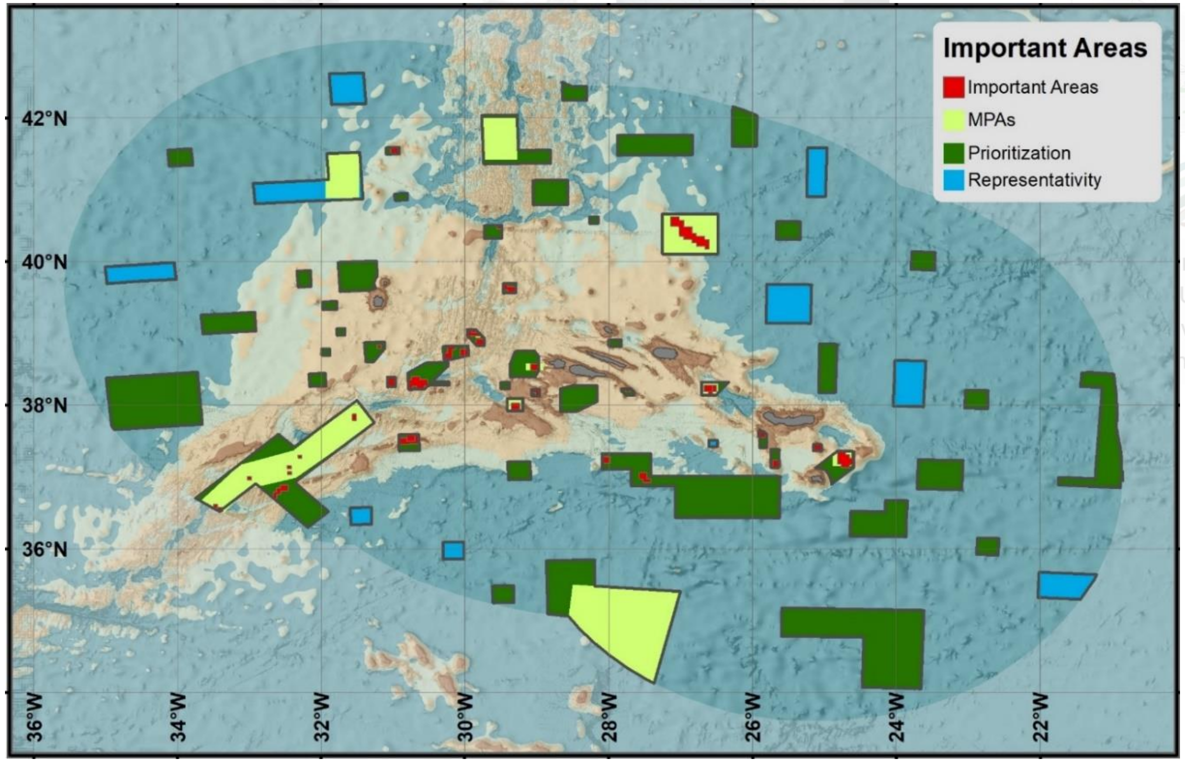
Representativity & connectivity approach



Complementing the network with a representativity and connectivity approach

To achieve the prioritization targets (spatial planning closure and feature's representation targets) in the "data-poor abyssal" area and to ensure connectivity across the entire spatial planning area





1. Topological cost connectivity framework to define the optimum network of least-cost paths (commonly used by social network's experts to assess the centrality of a given community)
2. Network centrality metrics to identify the importance of the different elements in the network
3. Simplification of the systematic conservation planning scenarios

AZORES DEEP-SEA RESEARCH

Performance assessment of the solutions against the design criteria

1) Viability & Adequacy, 2) Replication, 3) Connectivity, 4) Representativity, 5) Important resources, 6) Important Areas, 7) Resilience to climate change and other stressors

Performance assessment

Protect								
Single			Bands			Multi		
15	30	50	15	30	50	15	30	50
1	1	1	6	4	5	6	5	4
101	115	130	25	66	102	71	91	116
62	105	157	45	85	133	81	150	216
	0	55	81	131	175	19	60	138
0	11	21	9	21	50			4
47	132	188	46	104	211	42	105	185
7	32	67	4	20	56	1	8	48

Design criteria	Indicator
Viability and adequacy	Size of the network (1,000 km²)
	Proportion of the spatial planning area in the solution
	Proportion of the spatial planning closure targeted area achieved
	Proportion of priority areas in the "data-poor abyssal" area
	Average size of priority areas
	Proportion of the network that is already protected
	Proportion of the fishing footprint in the network
	Proportion of the total fishing effort in the network
Replication	Number of priority areas
	Number of priority areas larger than 100km²
Connectivity	Average distance to closest neighbour (km)
	Maximum distance to closest neighbour (km)
	Proportion of isolated priority areas (dist. >100km)
	Proportion of total network area that is isolated
	Proportion of highly connected priority areas (≥10 neighbours, ≤ 100km)
	Proportion of total network area that is highly connected
Representativity	Proportion of depth class in the solution
	Proportion of each seabed class in the solution
	Number of GMUs that achieved the spatial planning target
	Proportion of shallow (0-800m), medium (800-1500m) and deep (>1500m) seamounts in the solution

continue

Spatial planning area targets	15%						30%					
Cost	Area-based			Fishing-based			Area-based			Fishing-based		
Clumping	Low	Med.	High	Low	Med.	High	Low	Med.	High	Low	Med.	High
Viability and adequacy												
Size of the network (x1000 km²)	51.2	51.1	57.0	49.7	52.3	56.2	57.5	57.6	62.9	57.4	58.2	62.3
% Spatial planning area	5.4	5.4	6.0	5.3	5.5	6.0	6.1	6.1	6.7	6.1	6.2	6.6
% "Data-rich" area	9.3	9.0	10.3	8.8	9.3	10.0	10.7	10.4	11.6	10.7	10.5	11.4
% "Data-poor abyssal" area	3.5	3.6	3.9	3.5	3.6	3.9	3.8	3.9	4.1	3.7	3.9	4.1
% Spatial closure target achieved	36.2	36.1	40.3	35.1	36.9	39.7	20.3	20.3	22.2	20.3	20.6	22.0
% "Data-rich" spatial target achieved	61.8	59.9	68.5	58.6	61.9	66.8	35.6	34.8	38.7	35.6	35.1	38.1
% "Data-poor abyssal" target achieved	23.1	23.9	25.8	23.1	24.2	25.9	12.5	12.9	13.8	12.4	13.1	13.8
% Priority areas in "data-poor abyssal"	42.2	43.9	42.4	43.5	43.4	43.1	40.8	42.1	41.1	40.6	42.2	41.4
Average size of priority areas (km²)	280	367	750	213	201	677	217	400	983	284	207	889
% Network already protected	3.0	3.7	3.2	3.4	3.4	3.3	3.4	3.5	3.1	2.7	3.4	3.1
% Fishing footprint in the network	22.5	21.9	24.9	13.4	16.8	19.6	31.3	34.7	35.0	17.5	22.0	26.4
% Fishing effort in the network	27.7	27.2	31.0	20.7	22.2	24.0	41.9	44.6	44.2	25.5	27.9	30.2
Replication												
N priority areas	183	139	76	233	260	83	265	144	64	202	281	70
N priority areas larger than 100km²	91	78	45	103	67	46	96	87	46	99	82	46
Connectivity												
Ave distance to closest neighbour (km)	16.8	20.9	33.3	15.3	13.1	29.5	12.8	21.2	38.9	15.8	12.3	34.1
Max distance to closest neighbour (km)	152.6	233.1	204.1	152.6	179.0	209.4	156.2	148.1	240.0	152.6	181.2	240.0
% Isolated priority areas (dist. >100km)	2.2	1.4	2.6	2.2	1.2	2.4	1.5	2.1	4.7	2.0	1.1	4.3
% Network area that is isolated	0.8	1.0	7.8	0.9	0.9	8.5	0.7	7.4	9.5	0.7	0.5	8.9
% Highly connected areas*	54.1	48.9	26.3	71.7	84.6	25.3	66.8	56.9	3.1	62.4	86.8	5.7
% Network area that is highly connected	65.2	47.3	28.4	70.6	73.6	23.4	68.1	54.3	22.6	70.7	71.3	13.2

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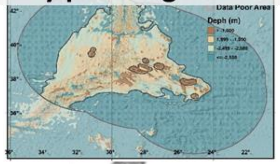

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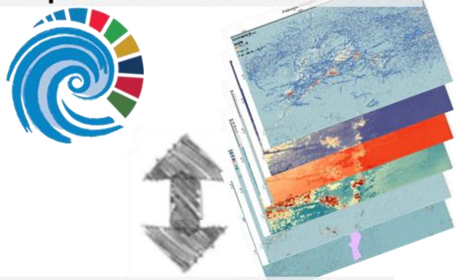

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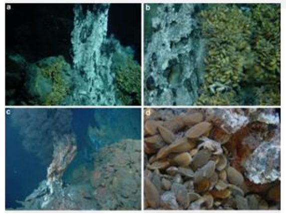

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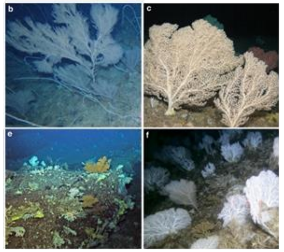

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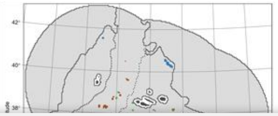

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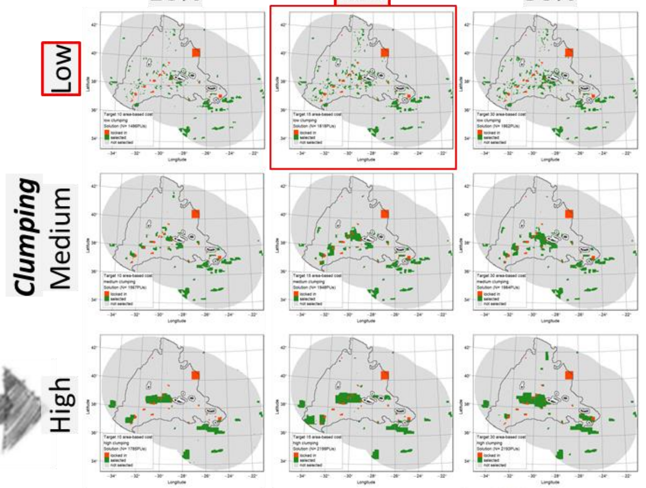

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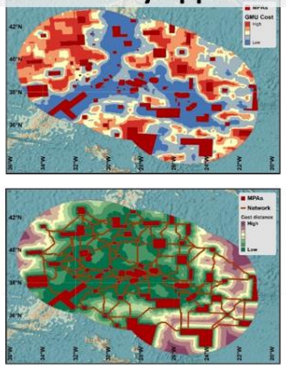

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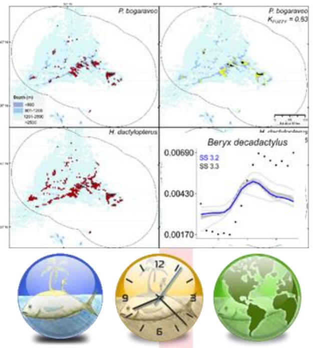
Spatial ecosystem projections



Forecasting ecosystem-level outcomes: The outputs of the SCP approach were transferred into the spatially-oriented ecosystem model (EwE) to forecast the effects of such management measures in the whole ecosystem

continue

AZORES DEEP-SEA RESEARCH

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INFORM SPATIAL PLANNING AND DECISION MAKING

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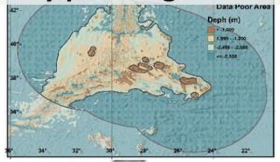

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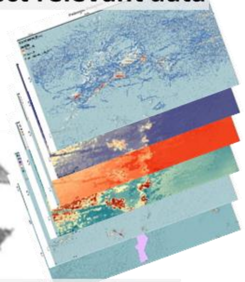

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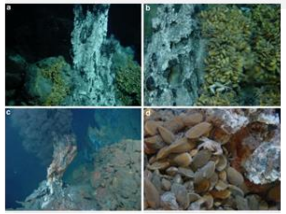

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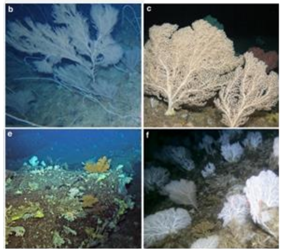

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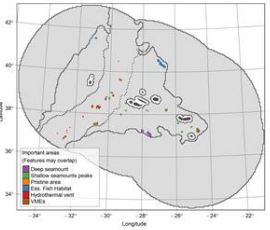
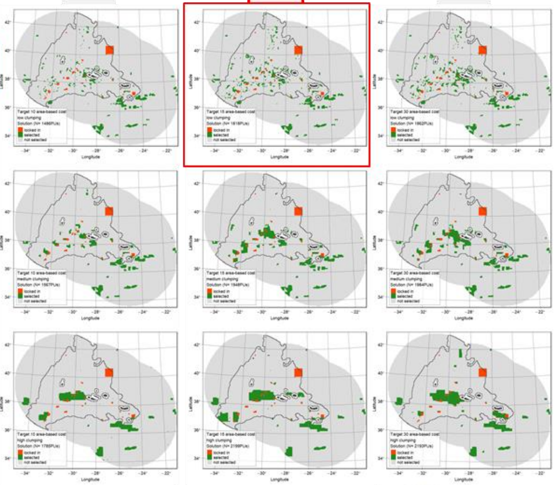


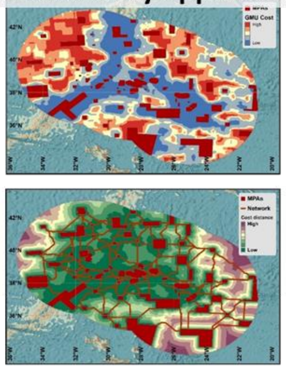
Prioritization approach



MARXAN conservation solutions

"minimum set" objective function: Finds the set of PUs that minimizes the cost of the solution whilst ensuring that all targets and other constraints are met

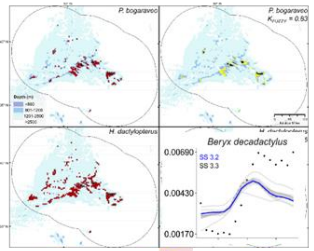
Representativity & connectivity approach



Performance assessment

Protect								
Single			Bands			Multi		
15	30	50	15	30	50	15	30	50
1	1	1	6	4	5	6	5	4
101	115	130	25	66	102	71	91	116
62	105	157	45	85	133	81	150	216
	0	55	81	131	175	19	60	138
0	11	21	9	21	50			4
47	132	188	46	104	211	42	105	185
7	32	67	4	20	56	1	8	48

Spatial ecosystem projections



Lessons learned

Ocean-basin scale SCP to identify broad areas of conservation interest

Regional SCP help the implementation of area-based management tools at a finer scale

OBRIGADO