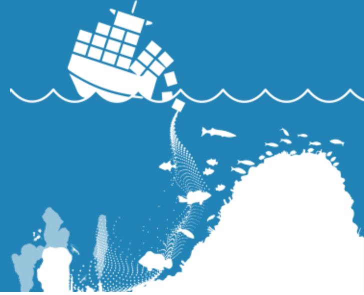
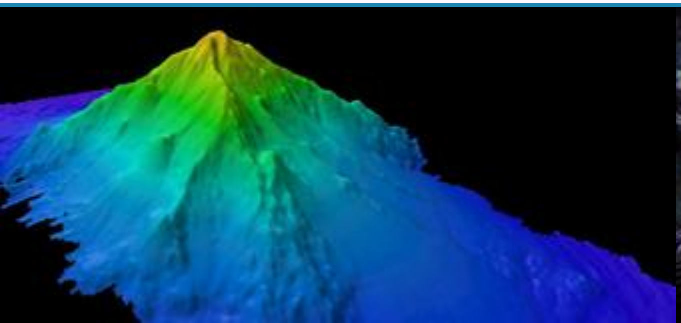
MSEAS
3-7 June 2024
Yokohama, Japan

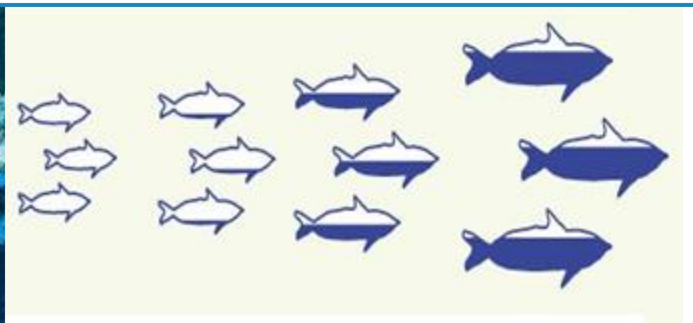


An integrated numerical framework for Environmental Risk Assessment in marine ecosystems affected by accidental spills

Irene Martins
imartins@ciimar.up.pt

CIIMAR- Interdisciplinary Centre of Marine and Environmental Research
Marine Ecosystem Modelling team (MEMO)
University of Porto, Portugal



Rationale

Hazardous and Noxious Substances (HNS)

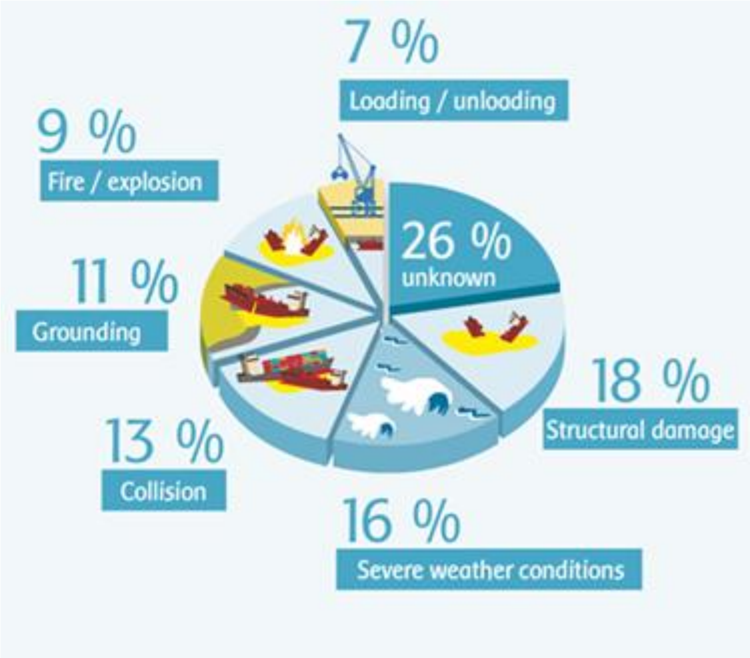
"Any substance other than oil which, if introduced into the marine environment,
is likely to create hazards to human health, to harm living resources and marine life"

Source: https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/HNS%20ConventionWebE.pdf

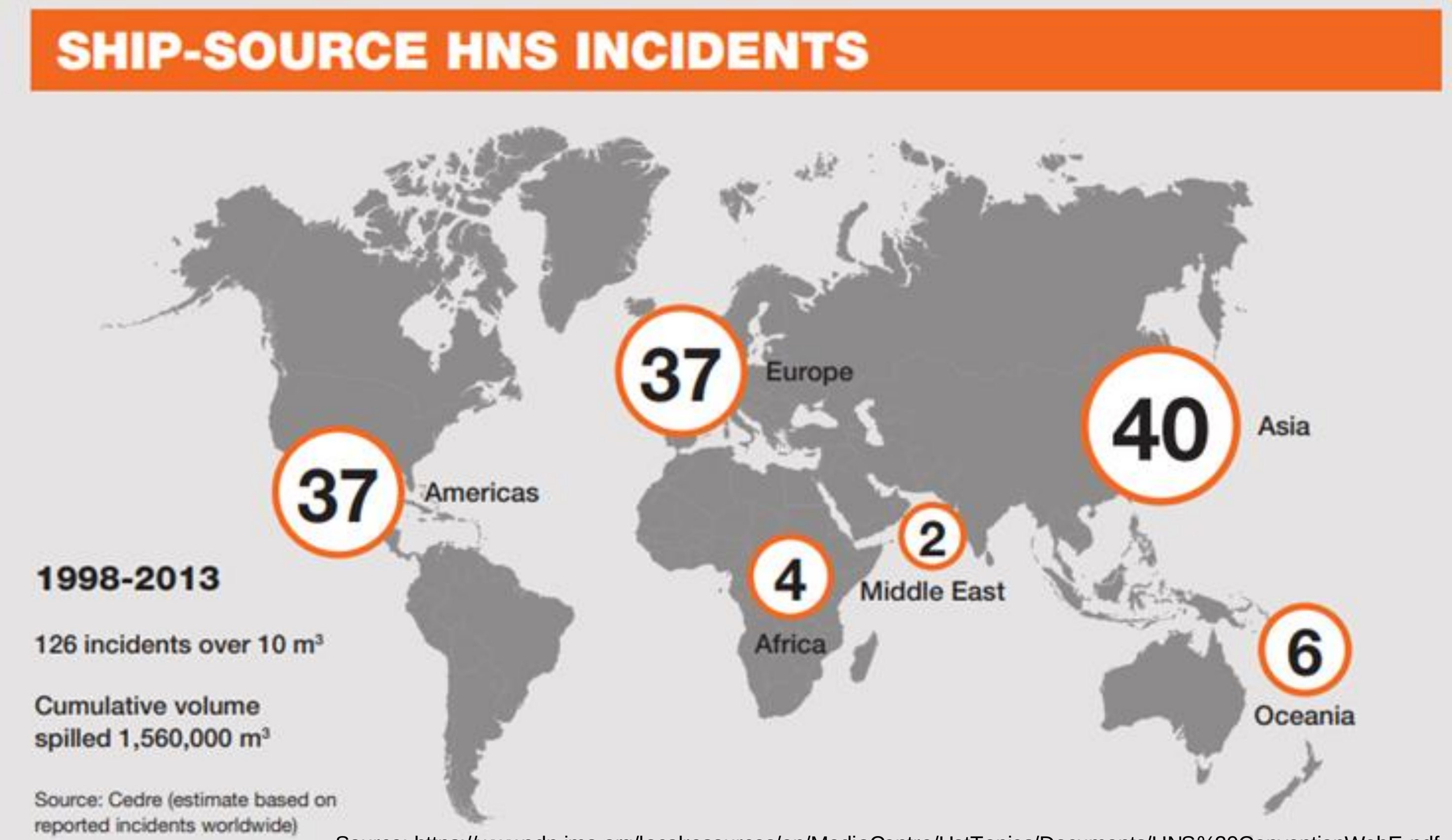
Rationale

Real risk of incidents and accidents involving HNS at Sea

Causes of ship-source accidents involving chemicals worldwide



Source: https://www.chemical-pollution.com/en/sources-pollution/accidental-pollution.php



Source: https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/HNS%20ConventionWebE.pdf

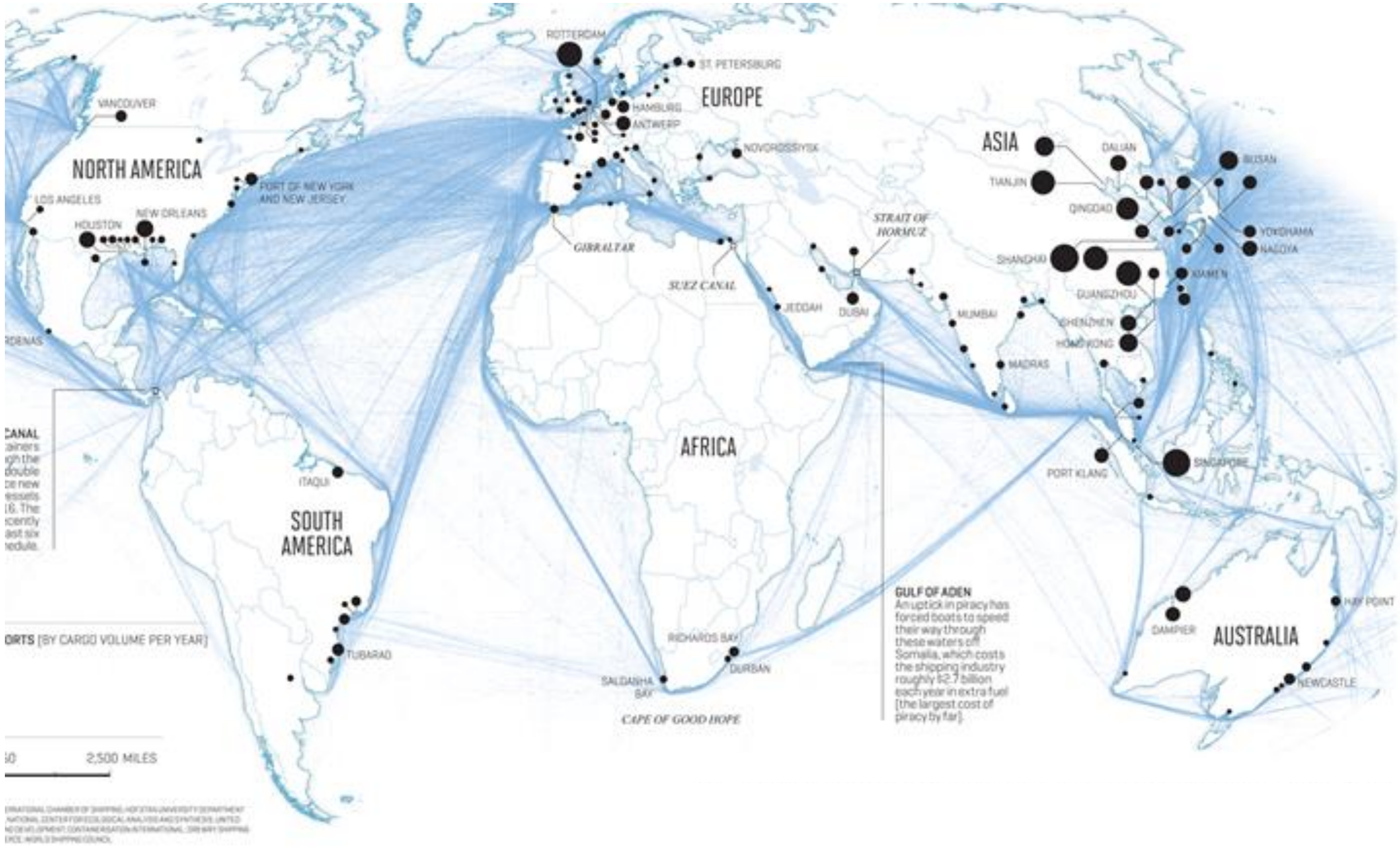
Rationale

A booming shipping network

Iconic deep-sea ecosystems located within maritime shipping routes that may be affected by HNS spills:

. Seamounts

. Hydrothermal vents



Source: https://nicolasrapp.com/studio/portfolio/the-shipping-news/

Rationale

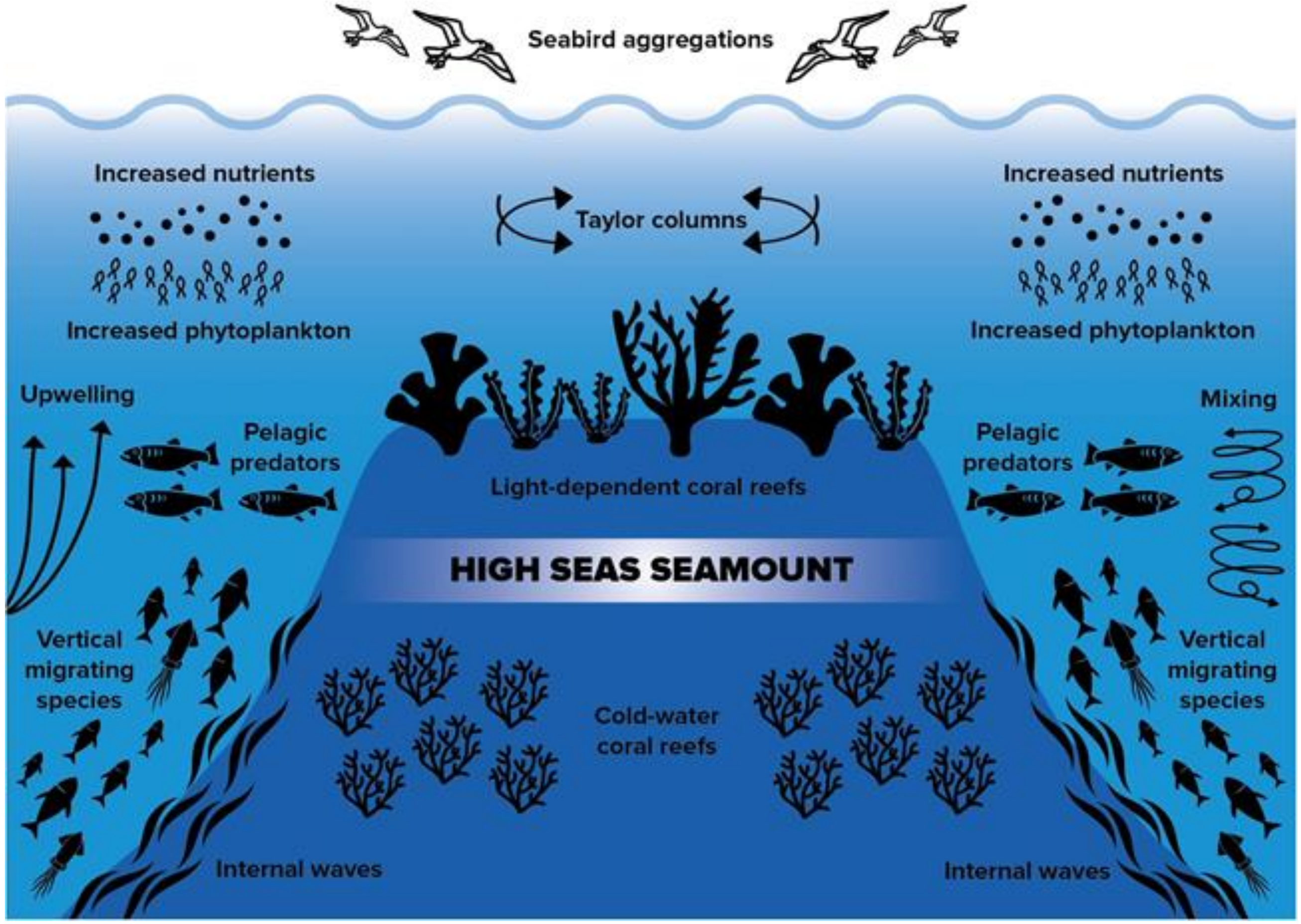
SEAMOUNTS: Hotspots of biodiversity

Seamounts

- Under water mountains
- Complex environment
- Important ecological biome

Source: https://flipboard.com/topic/coralreefs/deep-sea-coral-gardens-discovered-in-mysterious-canyons-the-weather-channel/a-cNMuLm8zRVCqz81L8cApmQ%3Aa%3A60286443-

Source: http://www.publicdomainfiles.com/show_file.php?id=13946949019945



Source: https://www.frontiersin.org/articles/10.3389/fmars.2020.567428/full

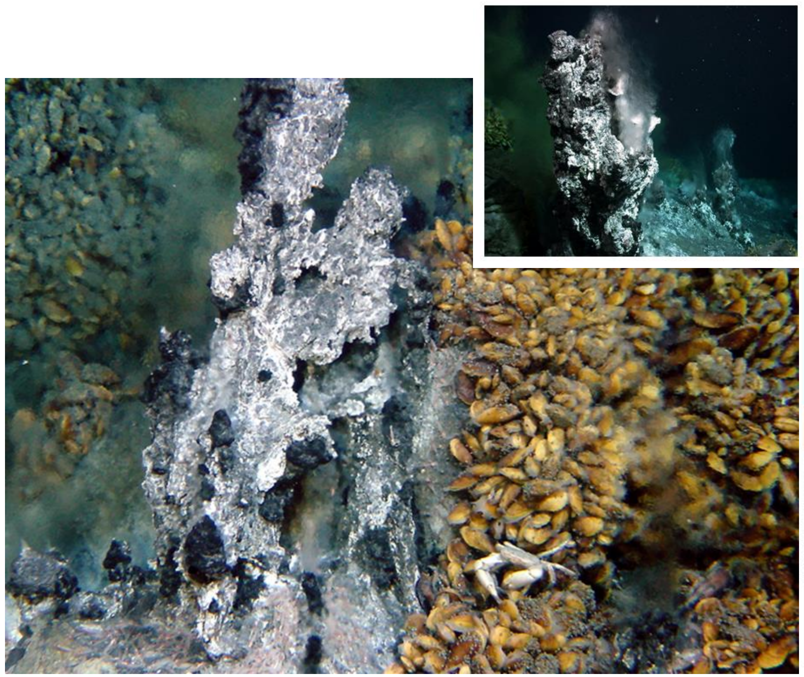
Rationale

HYDROTHERMAL VENTS: Deep-sea oases

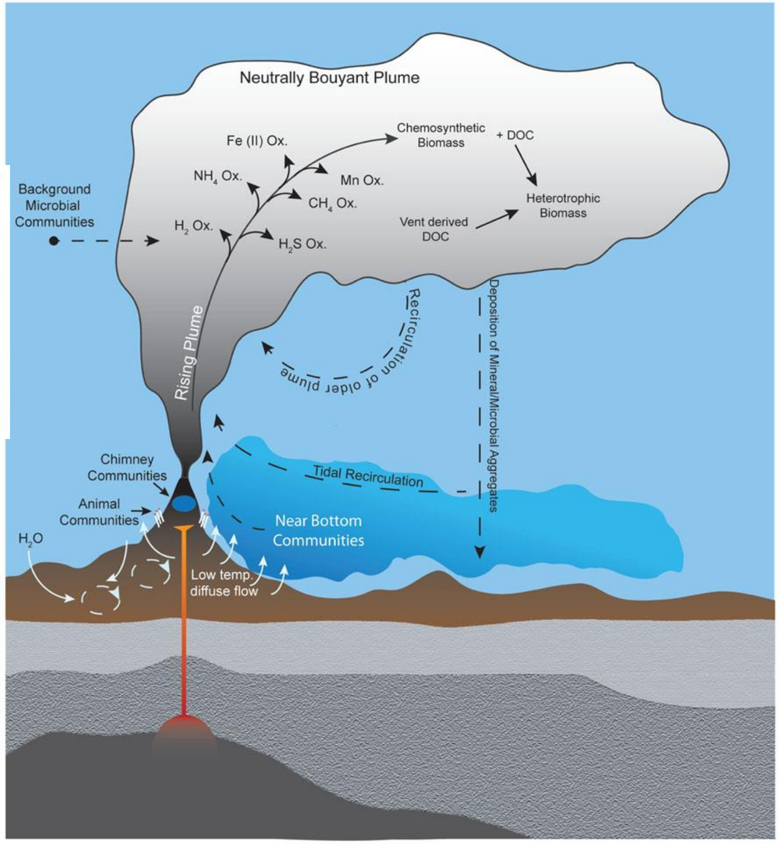
Deep sea hydrothermal vents

- Extreme environments with volcanic vents releasing hot mineral-rich fluids
- Found between <200 to ~5000 m
- Supported by chemosynthesis
- Support rare and endemic species

Source: https://www.marum.de/en/Discover/Deep-Sea.html



Source: https://oceanexplorer.noaa.gov/okeanos/



Source: https://doi.org/10.3389/fmicb.2013.00124

Goal

- Developing a numerical framework for Environmental Risk Assessment (ERA) of HNS spills at sea

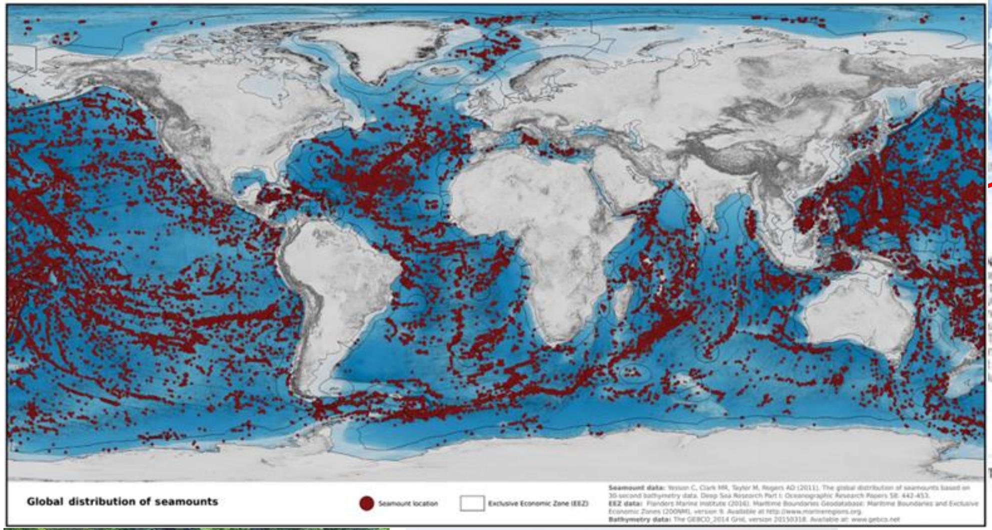
- Contribute to increased preparedness of responses to accidents involving spills at sea

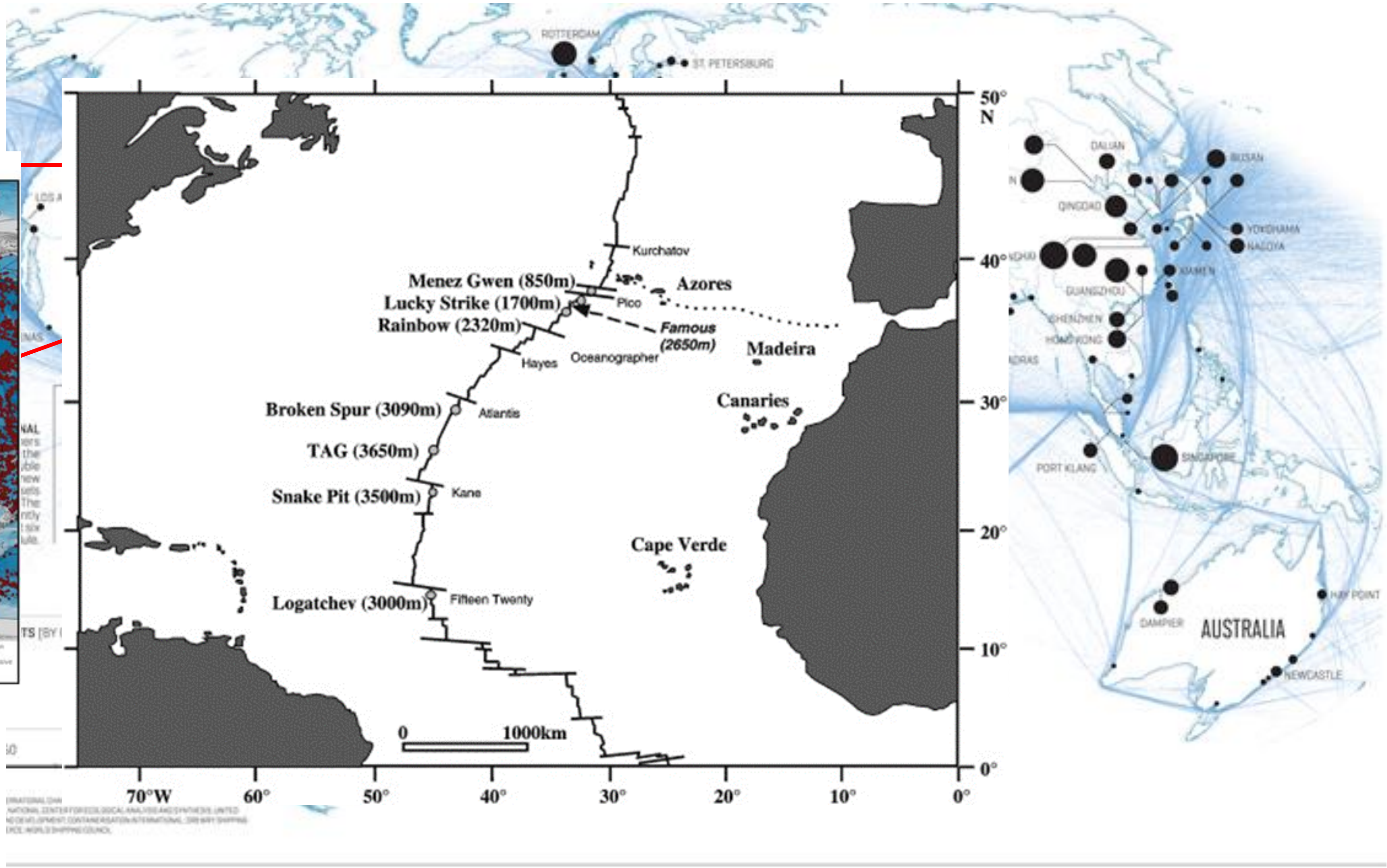
Study site

Mid-Atlantic Ridge (MAR) in the Azores area

. ~460 seamounts

. 7 large hydrothermal fields

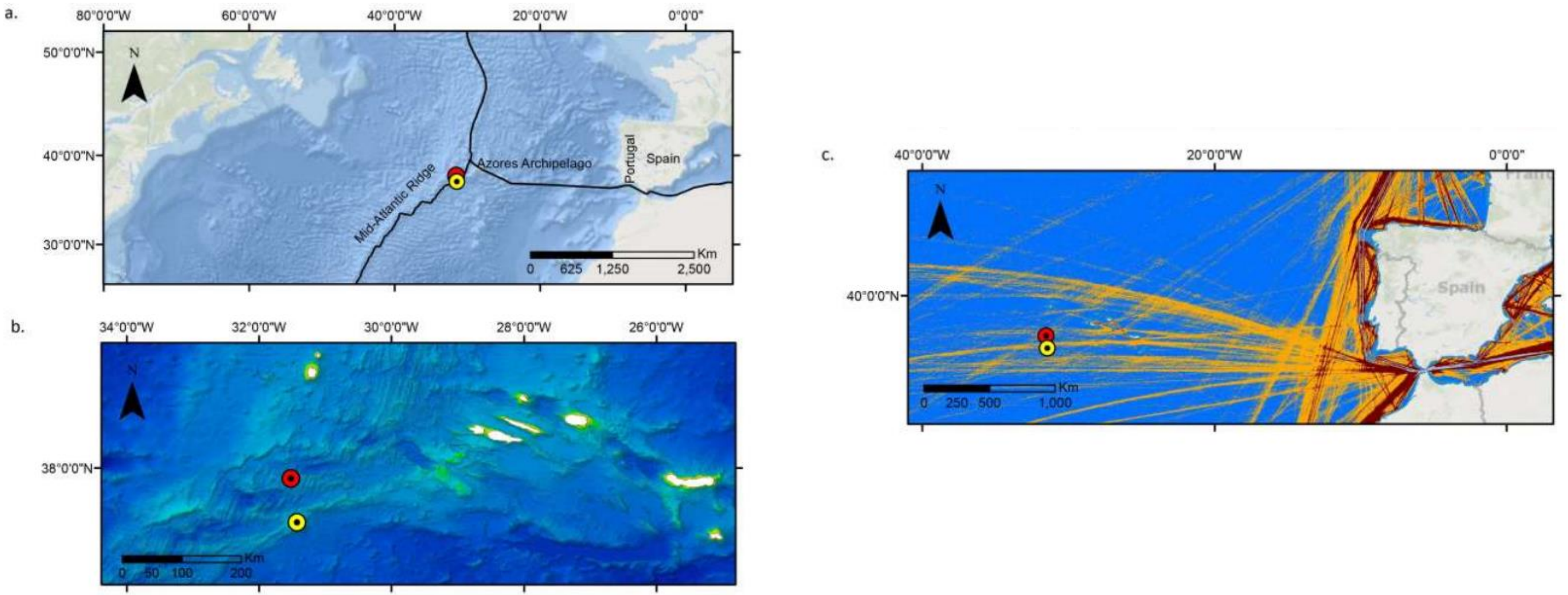




Study sites

Seamount 10 (summit at 400 m) and Menez Gwen vent field (850 m)

S10 | MG

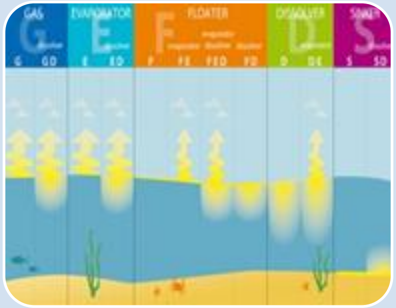


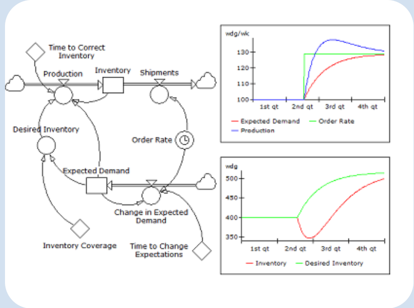
Menez Gwen vent field

Seamount 10

Methods - workflow

Overview





1. Select HNS (different behaviours)

- 4-nonylphenol (F)
- Aniline (FD)
- Nitrobenzene (SD)
-Tetrachloroethylene (S)

2. Ocean circulation & Lagrangian dispersion model

- ROMS
- OceanDrift from OpenDrift
- Seasonal simulations (summer/winter)

3. Ecosystem models

-Seamount model (AQUATOX- EPA)
-Hydrothermal vent model (EwE)
- Ecotoxicity of HNS (LC50)

4. Scenarios simulations

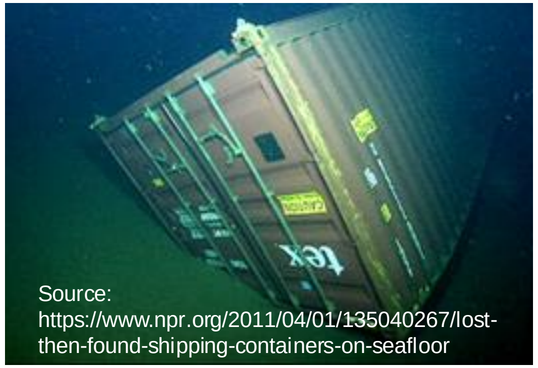
- HNS hypothetical incident
- Inputs to numerical models
- Medium-term simulations

Simulated HNS spills

For each selected HNS- hypothetical incident conditions*:

- 100 containers (volume of 76 m^3 each) sank to the bottom and reached the summit of S10 (~400 m) and MG (~800 m)
- A total volume of 7600 m^3 leaked for 5 days until all containers were empty; simulations ran for 5 days more
- Simulations accounted for winter and summer conditions

Source: https://maritimecyprus.com/2022/10/24/maritime-loss-prevention-400-increase-of-containers-lost-at-sea-in-2020-2021/



Source: https://www.npr.org/2011/04/01/135040267/lost-then-found-shipping-containers-on-seafloor

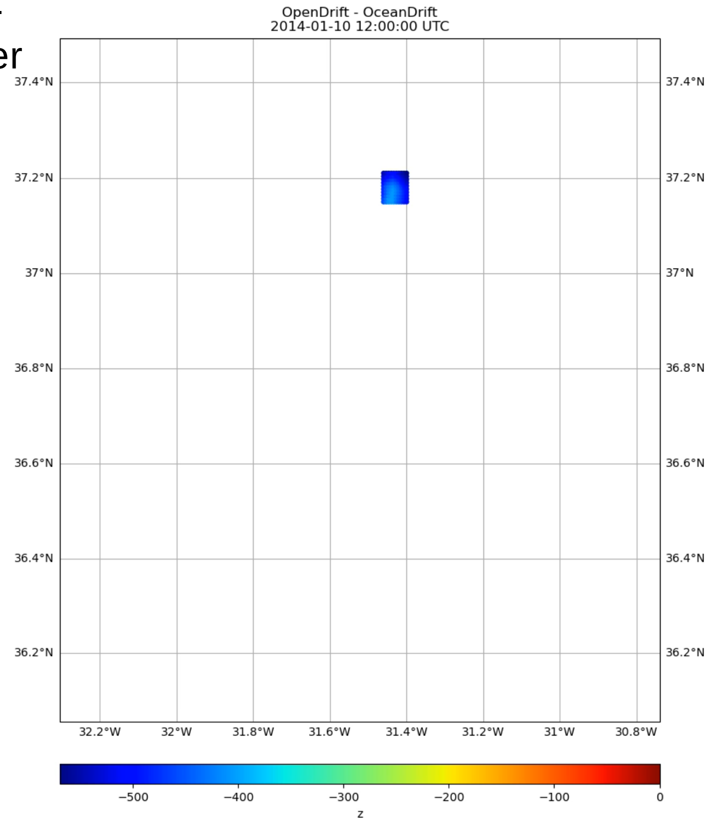
* Based on Galierikova et al. 2021

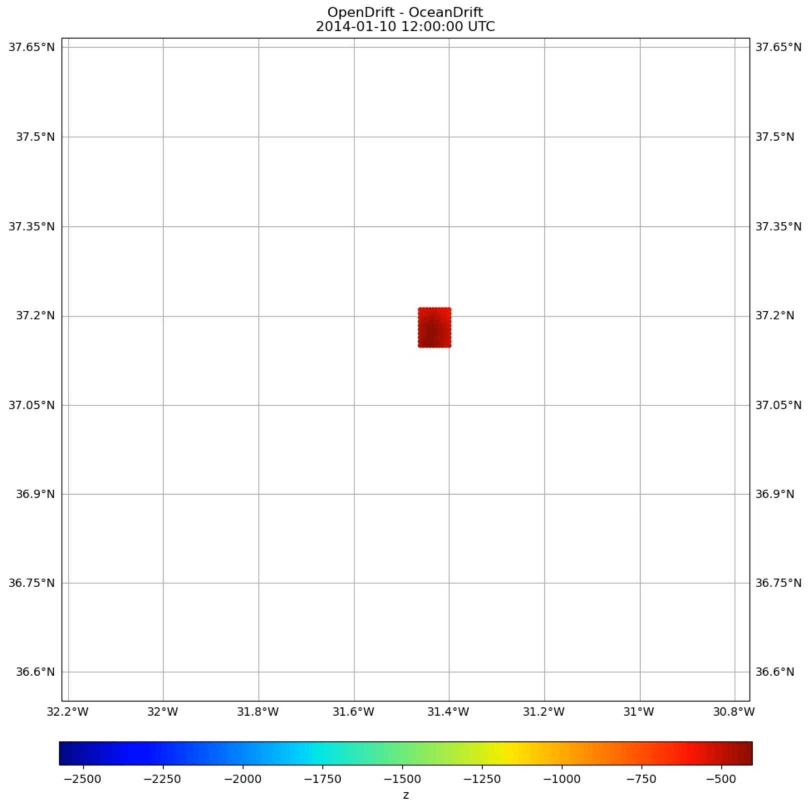
Results

HNS concentrations at the seamount S10 (Winter conditions)

Task 2

4-Nonylphenol –
Persistent Floater





Tetrachloroethylene
Sinker

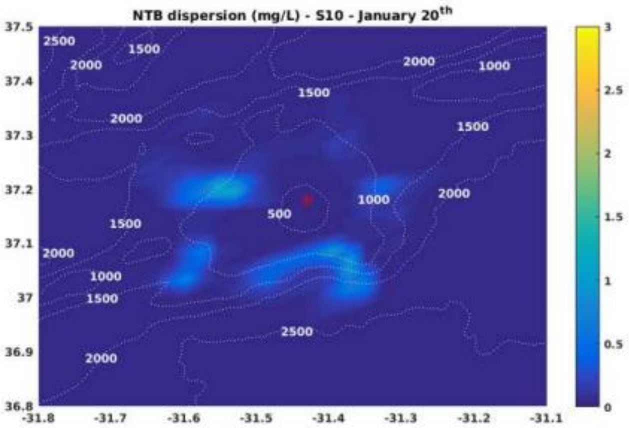
Results

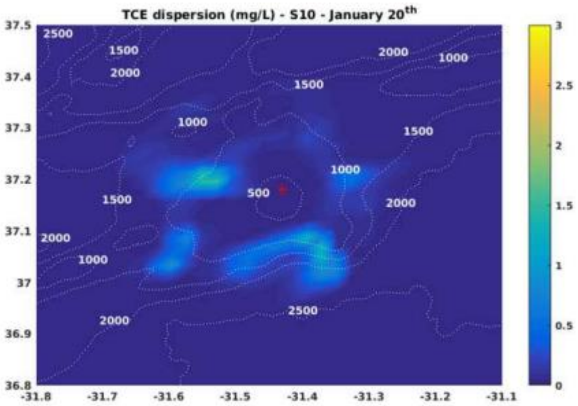
HNS concentrations at the seamount S10

Task 2

Nitrobenzene
Sinker/Dissolver

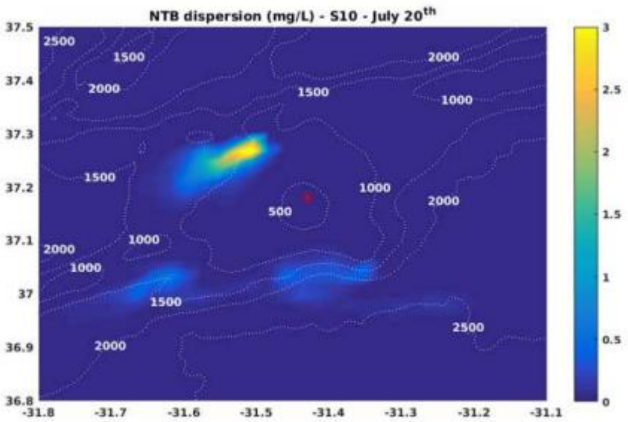
Winter

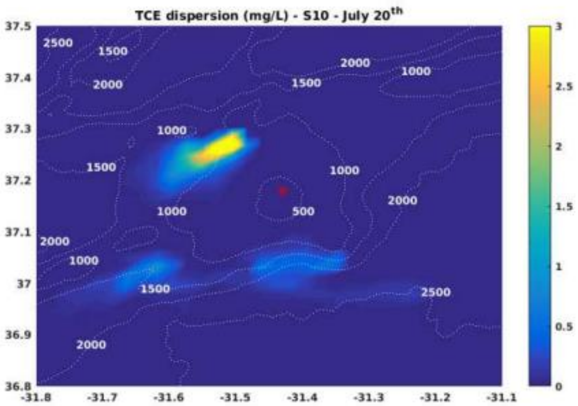




Tetrachloroethylene
Sinker

Summer





● Seamount 10

Results

Seamount S10 model – AQUATOX (US- EPA)

Task 3

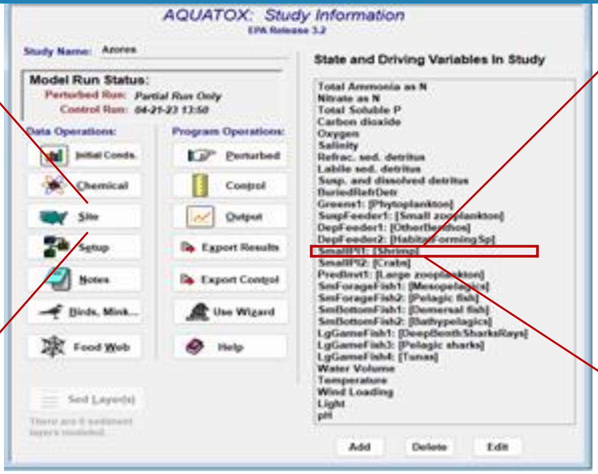
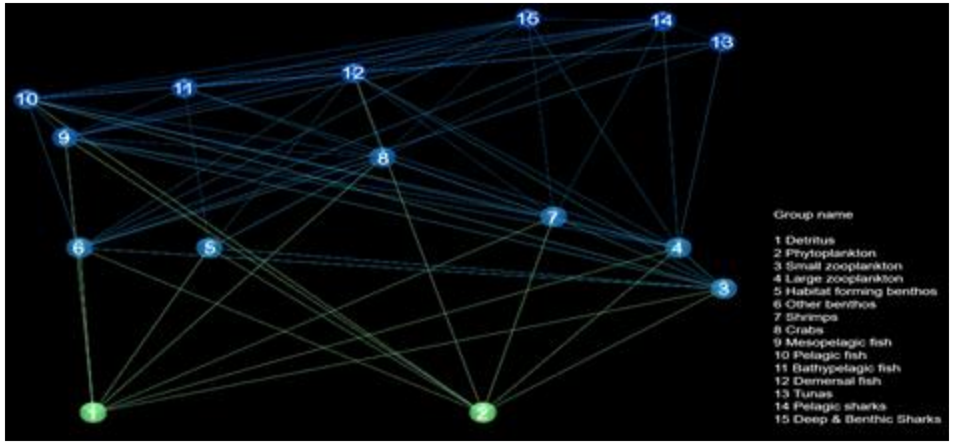
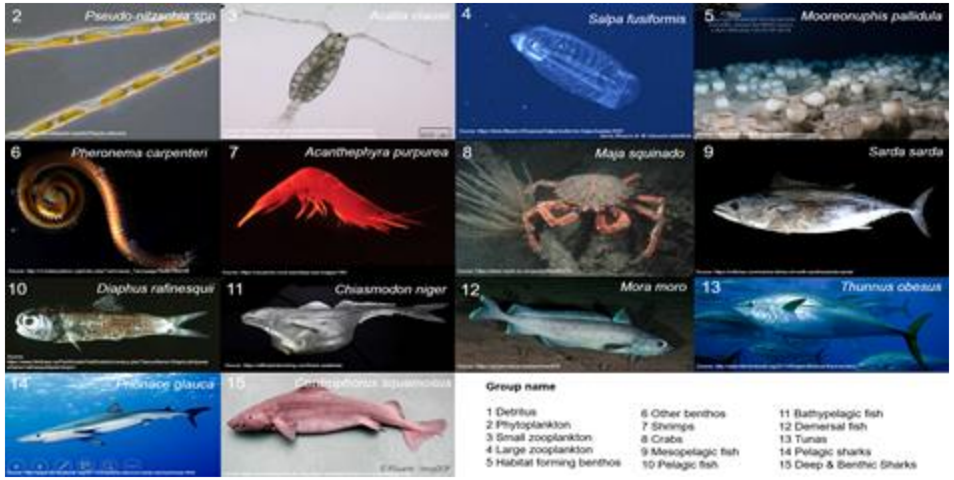


Table 4. Biotic groups, representative species of each group (endemic and commercially important) and biomass considered in the seamount food web model

Group	Group name	Representative species	Biomass (g m^{-2})
Phytoplankton	Phytoplankton	*Pseudo-nitzchia spp.*	0.580
Zooplankton	Small zooplankton	*Acatia clausii*	0.904
Zooplankton	Large zooplankton	*Salpa fusiformis*	0.767
Benthic invertebrate	Other benthos	*Mooreonuphis pallidula*	0.448
Benthic invertebrate	Habitat forming benthos	*Pheronema carpenteri*	0.442
Benthic invertebrate	Shrimp	*Acanthephyra purpurea*	0.459
Benthic invertebrate	Crabs	*Maja squinado*	0.406
Fish	Pelagic fish	*Sarda sarda*	0.128
Fish	Mesopelagic fish	*Diaphus rafinesquii*	0.196
Fish	Bathypelagic fish	*Chiasmodon niger*	0.135
Fish	Demersal fish	*Mora moro*	0.238
Fish	DeepWaterAndBenthic Sharks and Rays	*Centrophorus squamosus*	0.002
Fish	Pelagic sharks	*Prionace glauca*	0.010
Fish	Tunas	*Thunnus obesus*	0.018



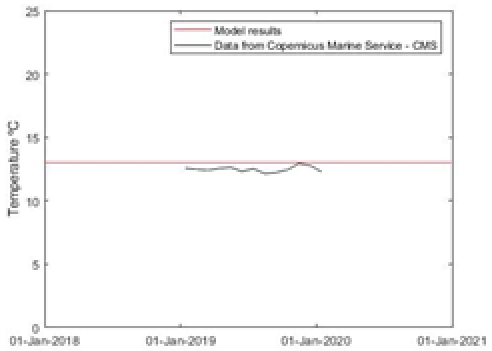


Results

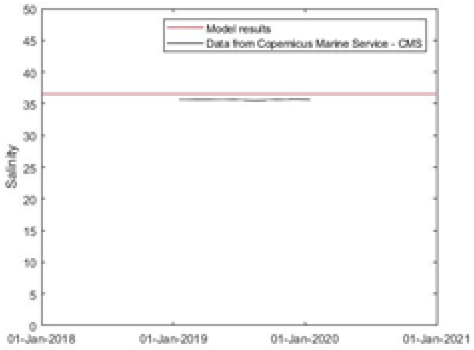
Seamount S10 model – AQUATOX (US- EPA)

Task 3

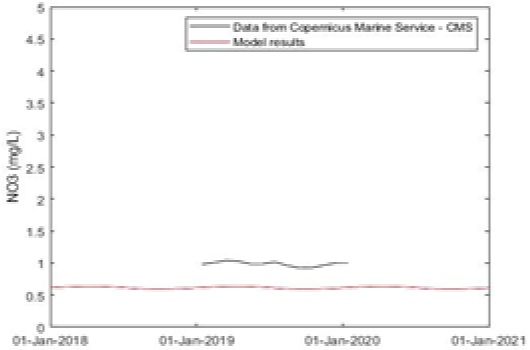
Abiotic parameters - Compared with data from Copernicus Marine Service (ocean data)



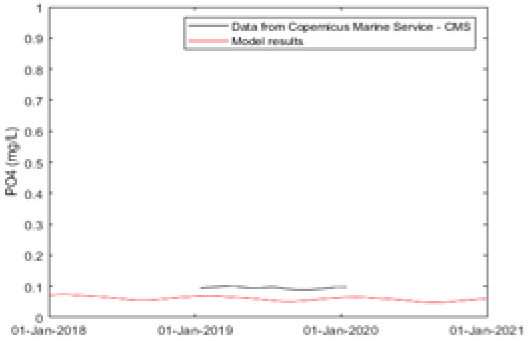
Absolute error (%) = 4.1%



Absolute error (%) = 2.4%



Absolute error (%) = 37.6%



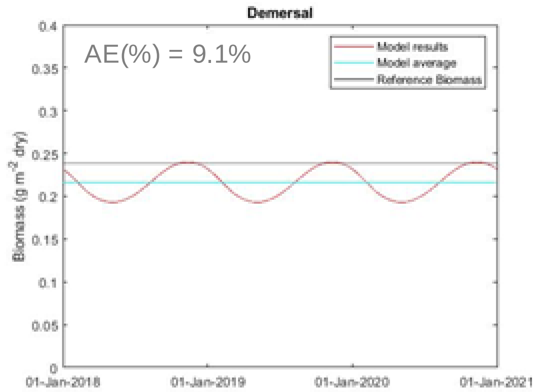
Absolute error (%) = 36.3%

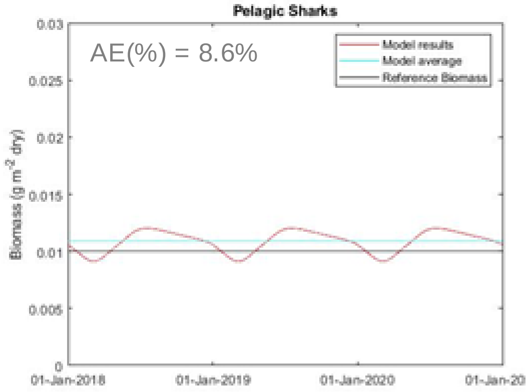
Results

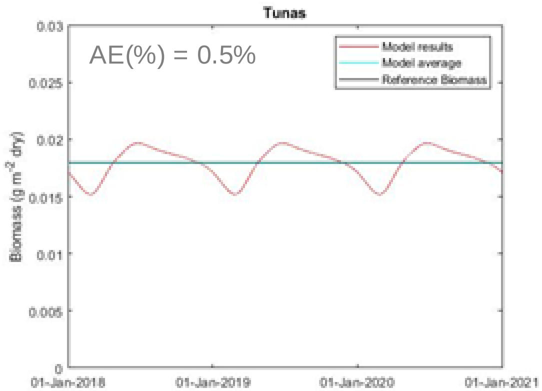
Seamount S10 model – AQUATOX (US- EPA)

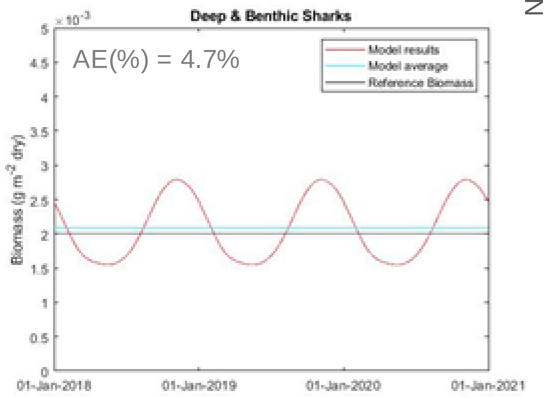
S10 model

Biotic groups' biomass

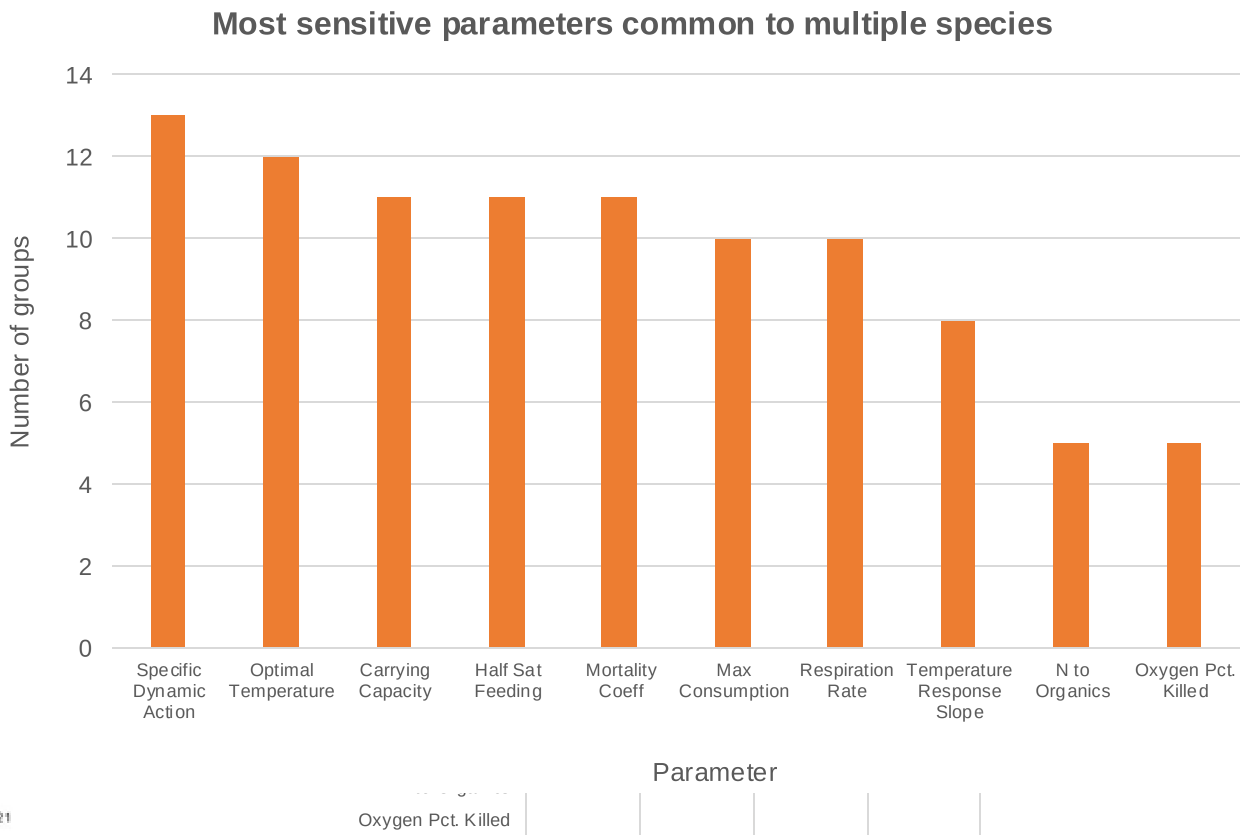








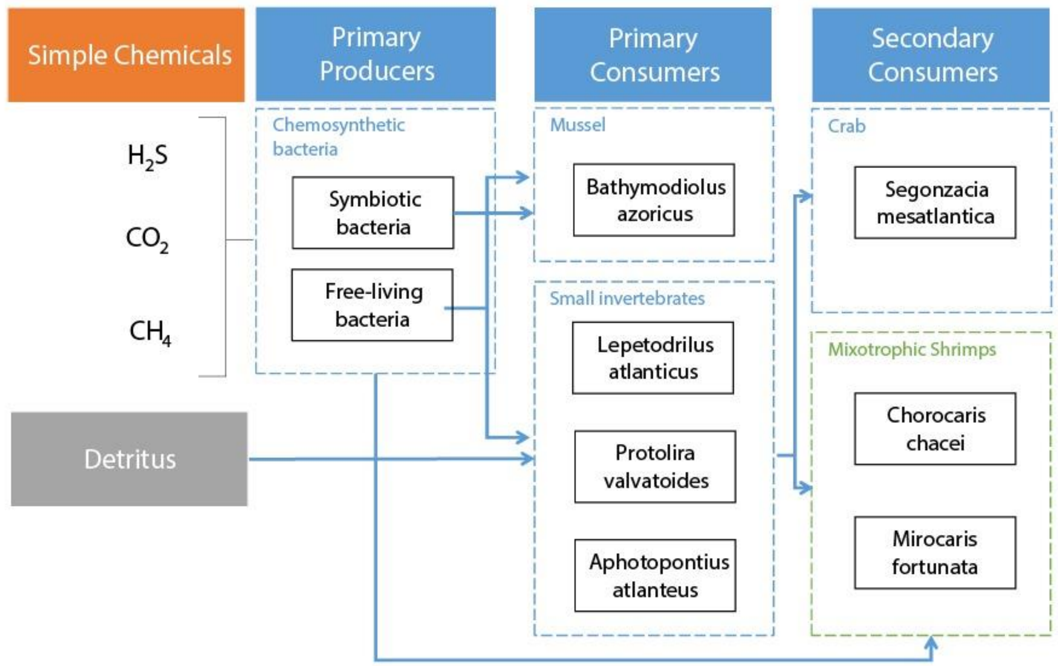
Sensitivity analysis



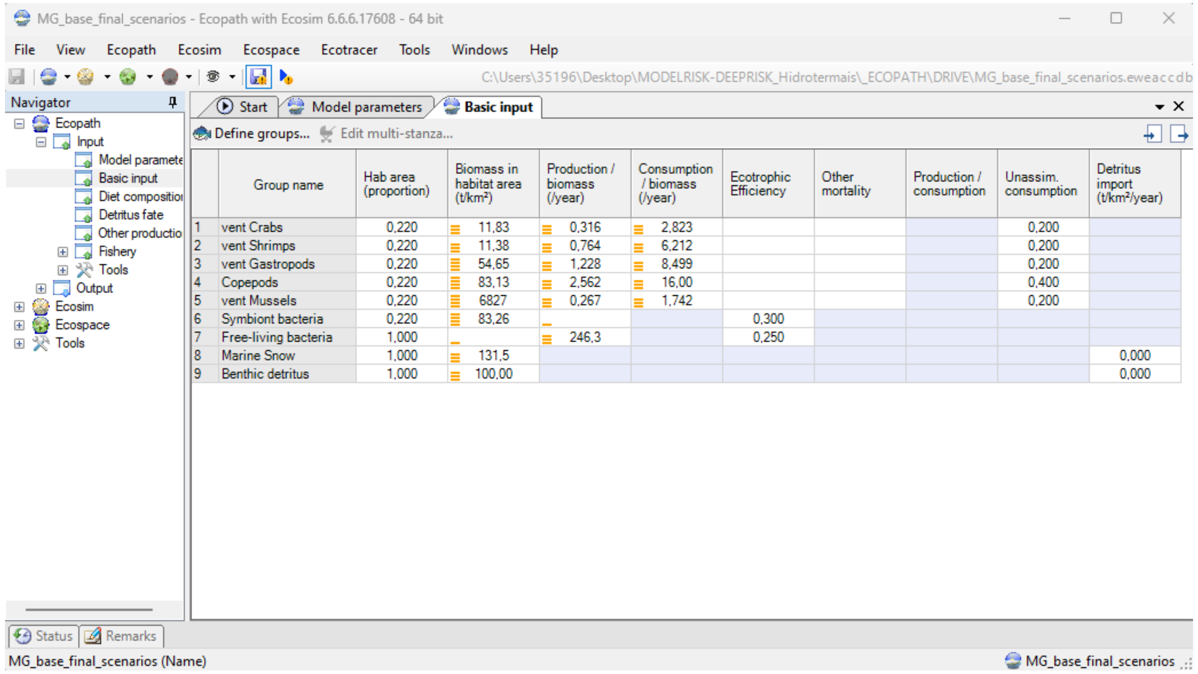
Results

Menez Gwen vent field– Ecopath with Ecosim (EwE)

Menez Gwen food web



EwE– set up



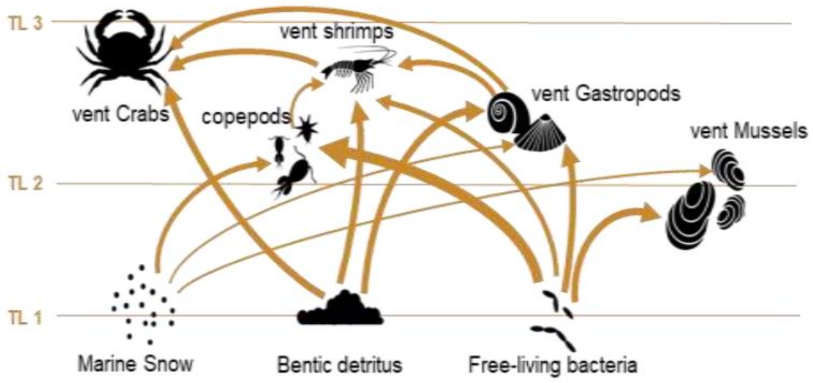
	Group name	Hab area (proportion)	Biomass in habitat area (t/km²)	Production / biomass (/year)	Consumption / biomass (/year)	Ecotrophic Efficiency	Other mortality	Production / consumption	Unassim. consumption	Detritus import (t/km²/year)
1	vent Crabs	0,220	11,83	0,316	2,823				0,200	
2	vent Shrimps	0,220	11,38	0,764	6,212				0,200	
3	vent Gastropods	0,220	54,65	1,228	8,499				0,200	
4	Copepods	0,220	83,13	2,562	16,00				0,400	
5	vent Mussels	0,220	6827	0,267	1,742				0,200	
6	Symbiont bacteria	0,220	83,26			0,300				
7	Free-living bacteria	1,000		246,3		0,250				
8	Marine Snow	1,000	131,5							0,000
9	Benthic detritus	1,000	100,00							0,000

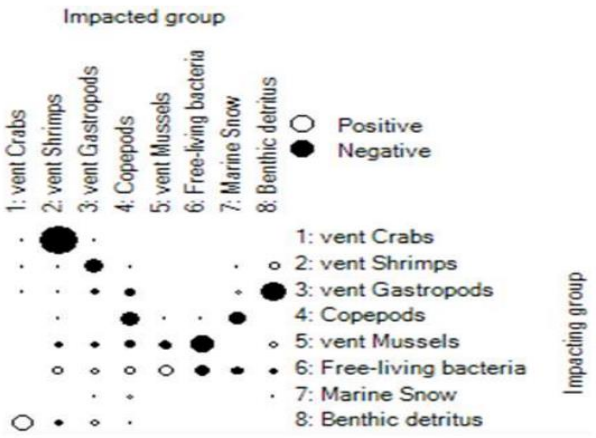
Results

Menez Gwen vent field– Ecopath with Ecosim (EwE)

MG model

Trophic levels





Mixed Trophic Impact matrix (MTI)

Ecosystem metrics and network analysis

Parameter	Value	units
Sum of all consumption	1 837.96	t.km^{-2}.y^{-1}
Sum of all exports	3 016.17	t.km^{-2}.y^{-1}
Sum of all respiratory flows	997.26	t.km^{-2}.y^{-1}
Sum of all flows into detritus	3 733.53	t.km^{-2}.y^{-1}
Total system throughput (TST)	9 584.91	t.km^{-2}.y^{-1}
Sum of all production	3 661.95	t.km^{-2}.y^{-1}
Calculated total net primary production	3 225.19	t.km^{-2}.y^{-1}

Parameter	Value	units
Total primary production/total respiration (TPP/TR)	3.23	t.km^{-2}.y^{-1}
Net system production	2 227.93	t.km^{-2}.y^{-1}
Total primary production/total biomass (TPP/TB)	2.05	t.km^{-2}.y^{-1}
Total biomass/total throughput (TB/TST)	0.16	t.km^{-2}.y^{-1}
Total biomass (excluding detritus)	1 572.79	t.km^{-2}
Connectance Index (CI)	0.44	
System Omnivory Index (SOI)	0.11	
Ascendency (A)	46	%
Overhead (O)	54	%
Finn's cycling index (FCI)	0.22	% of TST
Ecopath pedigree	0.455	
Shannon diversity index	0.19	t.km^{-2}.y^{-1}
Development Capacity (C)	29 471.00	flow bits
Transfer efficiencies (TE)	1.66	%

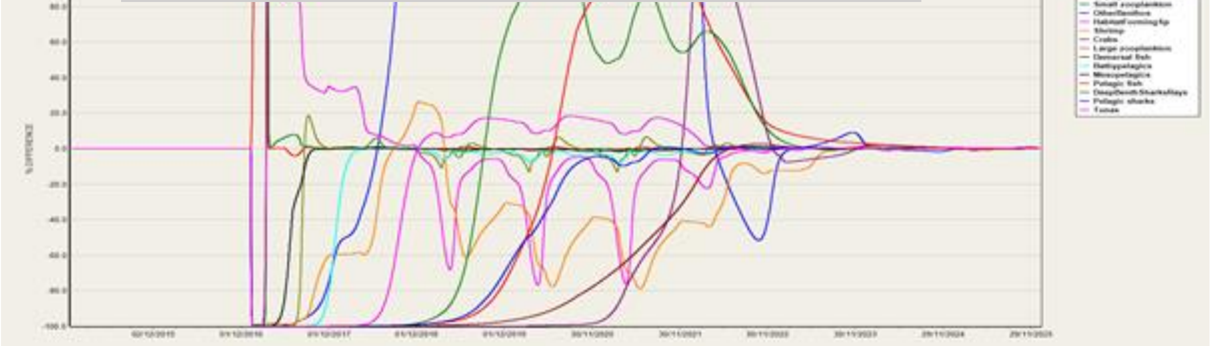
Results

Impacts of HNS spills on the seamount ecosystem

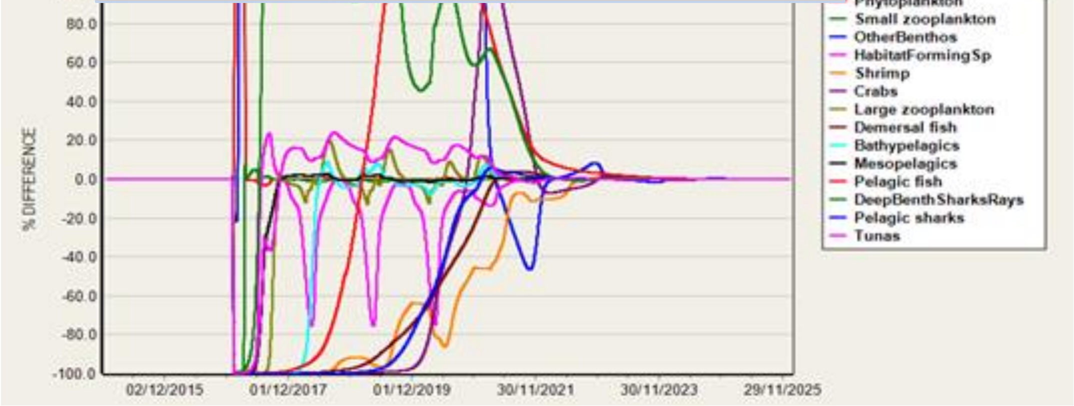
% of difference relative to the control run

4-NP: Full-recovery after ~3 years

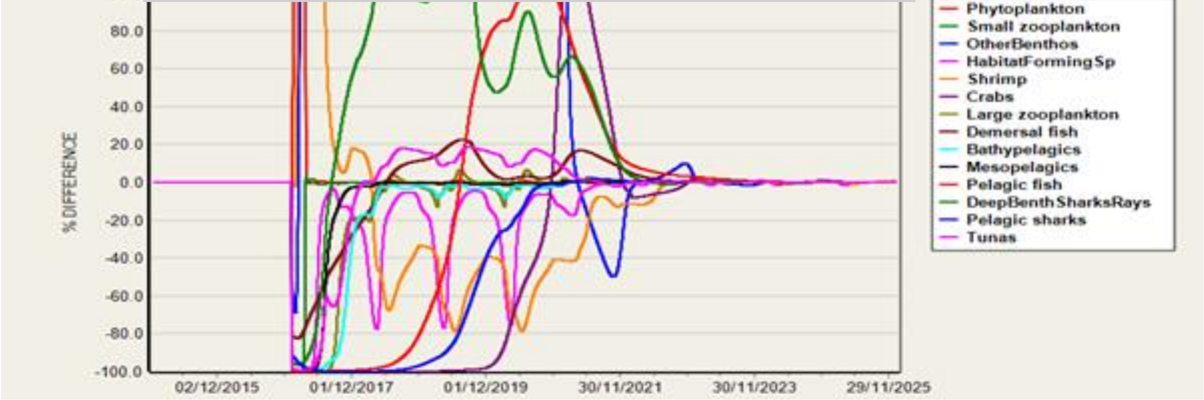
Aniline: Full-recovery after ~7 years



NTB: Full-recovery after ~5 years



TCE: Full-recovery after ~5 years



Results

Impacts of HNS spills on the Menez Gwen ecosystem

Relative biomass variation

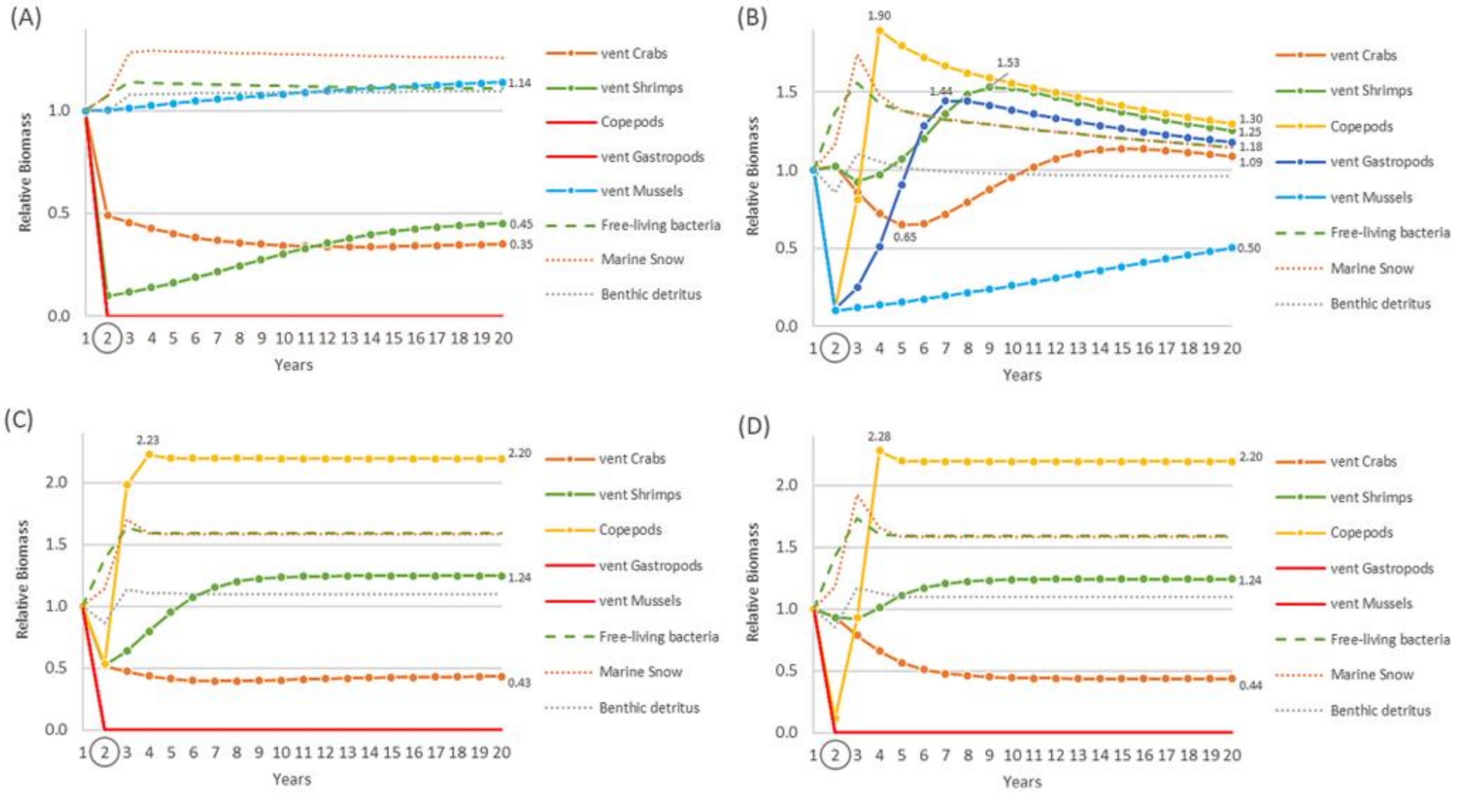
MG

4- NP

Aniline

NTB

TCE



Main findings- Seamount 10

- ✓ The variation of water temperature and salinity showed a good fitting with observed data. However, nutrients, especially nitrate, were underestimated possibly because **the model does not account for the upwelling of deeper, nutrient-enriched waters**.
- ✓ Despite the sinking behaviour of TCE and NTB, **aniline induced the longest recovery period (~7 years)** (possibly related with modelling constraints).
- ✓ Significant **trophic cascade effects** drive the overall variation in the seamount ecosystem.
- ✓ AQUATOX predicts a **decrease in oxygen concentration promoted by the degradation of the four HNS,** which in turn leads to the mortality of biotic groups that are strongly limited by dissolved oxygen concentrations, particularly, at higher depths. Although these results require validation**, the indirect effect of pollutants degradation on oxygen depletion with depth cannot be ruled out in case of HNS spills at sea**.

Main findings- MG vent field

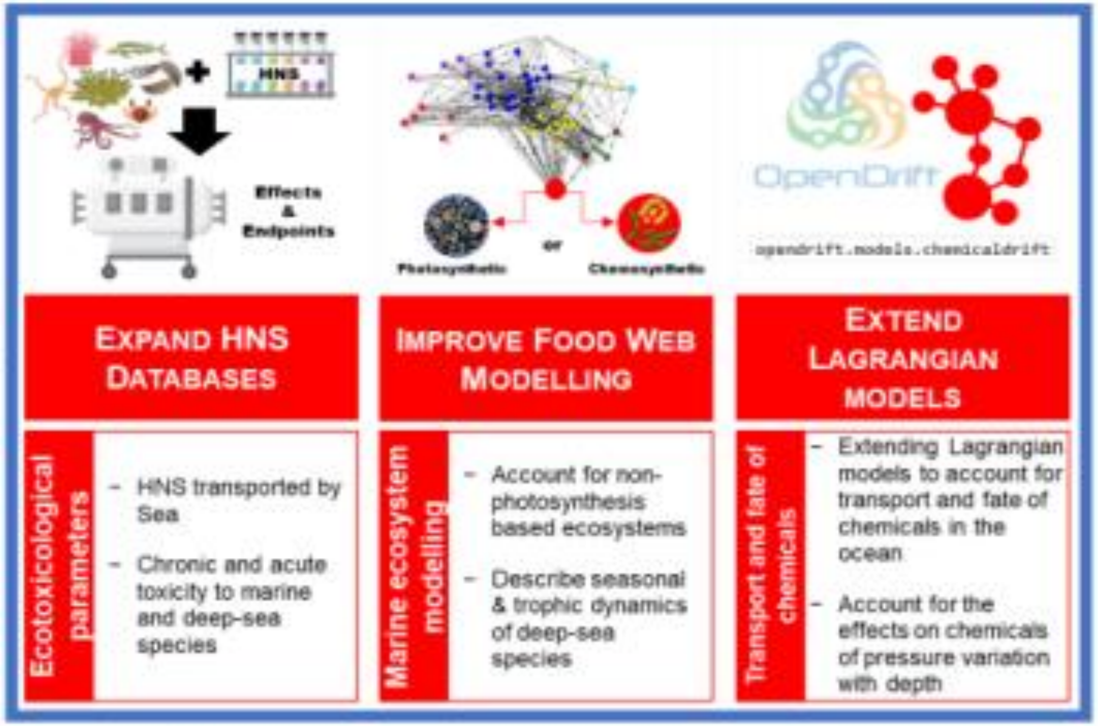
- ✓ The simulated concentrations of the four HNS at MG **have potential to harm the vent biota** either directly or indirectly through trophic cascade effects along the hydrothermal vent food web. Still, TCE and NTB cause more adverse effects.
- ✓ The food web of the MG hydrothermal field is quite **simple**, with only three trophic levels and low predation. **Free-living bacteria and vent mussels** are key in shaping the ecosystem.
- ✓ Network analysis suggests a **system under development that has not yet reached full maturity**.

Main findings: Data limitations

- ✓ At this point, our results regarding the effects of the four HNS on the studied deep-sea ecosystems **should be regarded cautiously.**
- ✓ If a protection factor of 10000 would be used to set the LC50 as frequently recommended in case of data gaps (Soares et al., 2020), the effects of the studied HNS on both ecosystems **would be much stronger**, potentially, leading to the extinction of deep-sea communities.
- ✓ On the other hand, some of these organisms **are adapted to extreme environmental conditions**, including metal-enriched environments as is the case of the Atlantic deep-sea mussel (*Bathymodiolus* sp), and have developed mechanisms to cope with such extreme conditions (e.g., metallothioneins) (Company et al., 2007).
- ✓ We do not know if these adaptions would confer them some kind of protection against other type of pollutants.

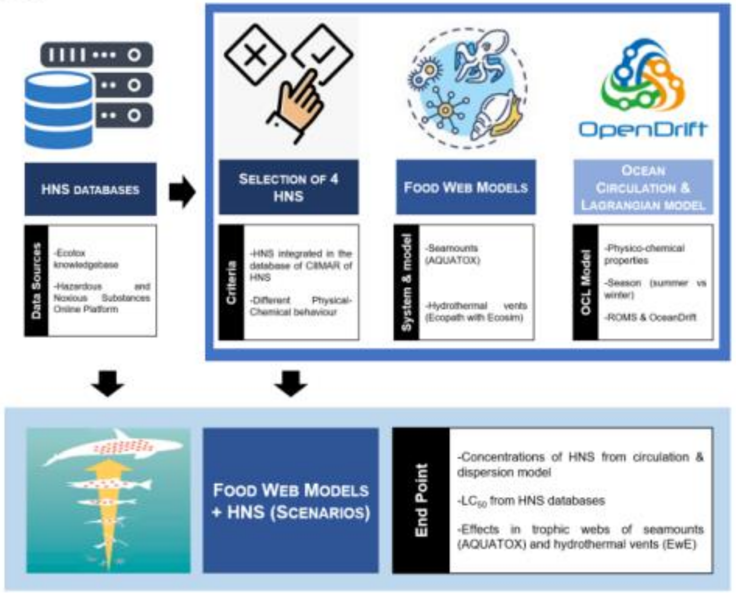
Final remarks

- There is a **strong knowledge gap** regarding chronic and acute **toxicity** of most HNS on marine and deep sea species;
- Available ecosystem models are **not appropriate to simulate chemosynthetic ecosystems;**
- Available knowledge regarding the **ecology and physiology** of many marine species and most deep-sea species is rather limited.
- The **complexity of behaviors of HNS** must be accounted for in models (*the first version of a model that describes pollutants fate in the water has just recently been released- ChemicalDrift by OpenDrift - Aghito et al., 2023*);



Future directions

The modelling framework presented here can be applied to other ecosystems, namely coastal areas. This will depend on available data to parametrize, calibrate, and validate the models.



MODELRISK team

Irene Martins | Ana Costa Azevedo | Alexandra Guerra
(MEMO team- CIIMAR)



Fabíola Amorim| Isabel Iglesias
(COD team- CIIMAR)


Miguel Santos | Teresa Neuparth |Joana Soares
(EDEC team- CIIMAR)



Ana Colaço (Okeanos, Univ. Azores)

Thank you!

Irene Martins
imartins@ciimar.up.pt

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