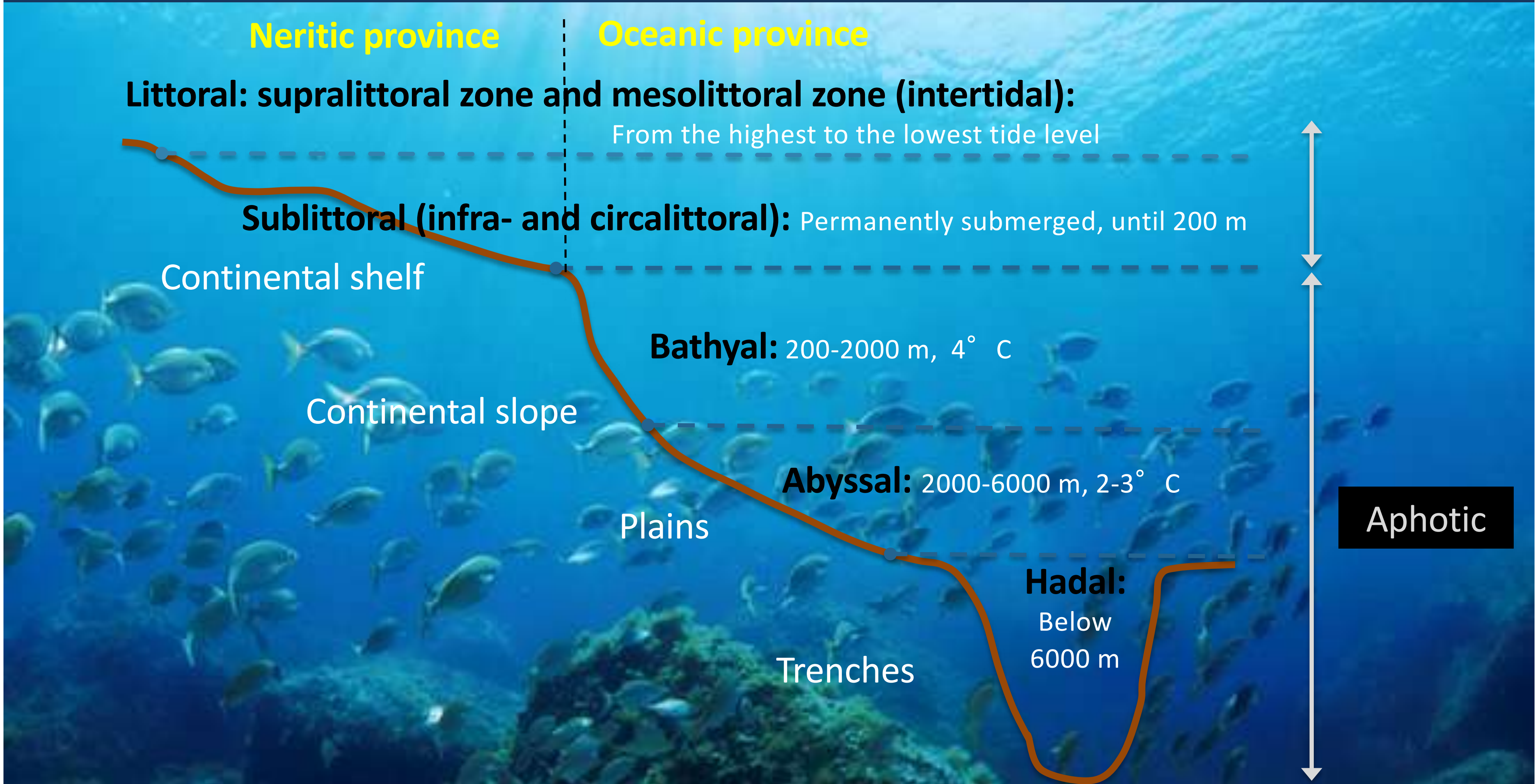
The deep sea



Waters and sea bottoms under 200 m are considered as deep sea environments
Average depth of oceans is 3850 m
> 50% of sea bottom is under 3000 m depth
> 84% of surface and 98% of volume are under 2000 m depth

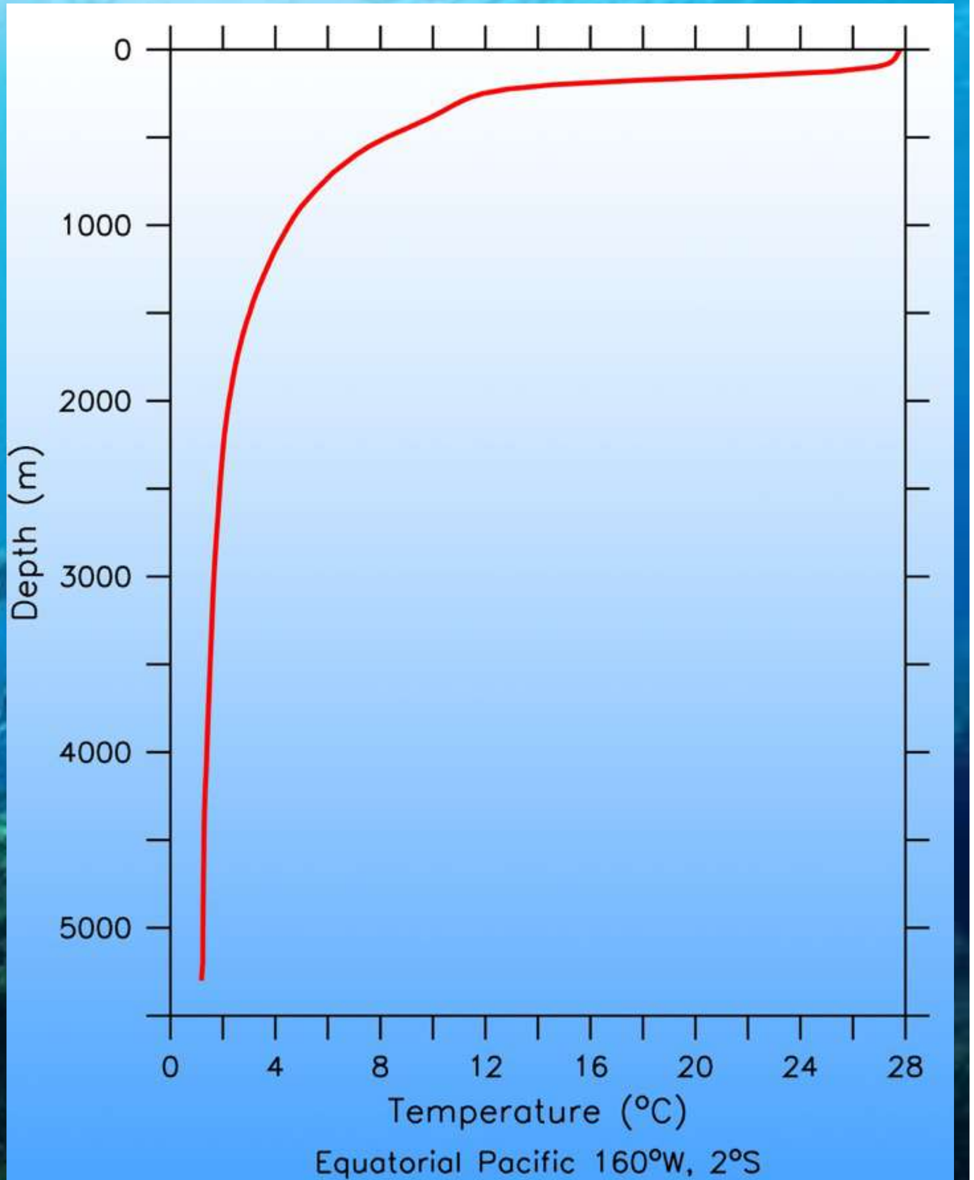
Main environmental features

Temperature < 4° C (-1.9° C)
Temperature > in the Mediterranean Sea (about 12° C)

Salinity: constant 34.8 (2000 m) 34.65 (> 6000 m)

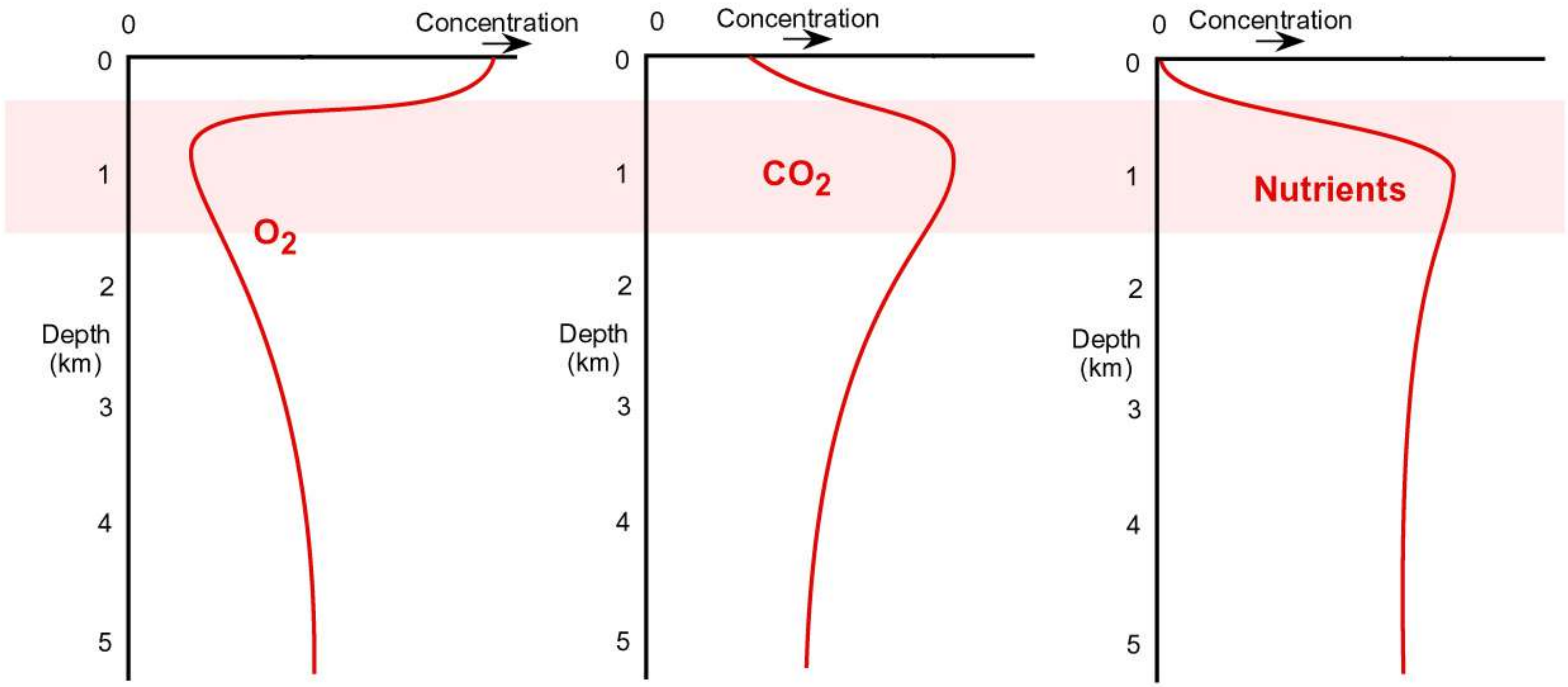
Hydrostatic pressure: very high, influence on metabolism (> 400 atm)

Substrate: hard bottoms uncommon, mostly incoherent



Main environmental features

In the photic zones oxygen is produced by macroalgae and plants, that consume carbon dioxide and nutrients. O_2 decreases with depth due to decline of photosynthetic activity and oxidation of organic matter, whereas CO_2 and nutrients increase due to respiration and increased solubility (high P and low T). Min of O_2 and max of CO_2 and nutrients is achieved at about 1000 m. Below this threshold, nutrients remain stable, O_2 slightly increases due to oxygenation from the surface through currents, and CO_2 slightly decreases due to reduced respiration rates (rarefaction of organisms)



Matter and energy

Falling animal carcasses

1. Marine mammals (e.g., whales)
2. Fish
3. Large invertebrates (e.g., cephalopods)

Falling detritus from plants

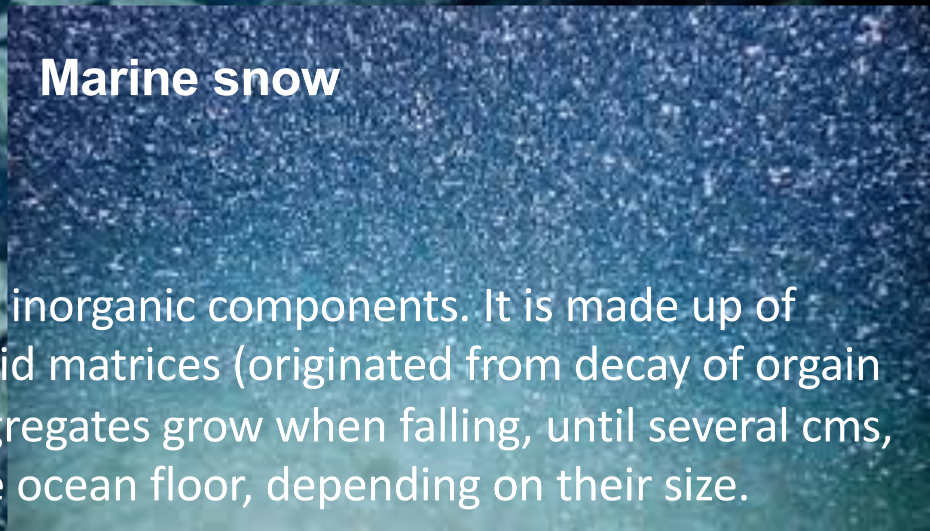
1. Macroalgae (e.g., *Sargassum*)
2. Marine plants
3. Terrestrial plants

Currents

1. Particulate organic matter (POM)
2. Dissolved organic matter (DOM)

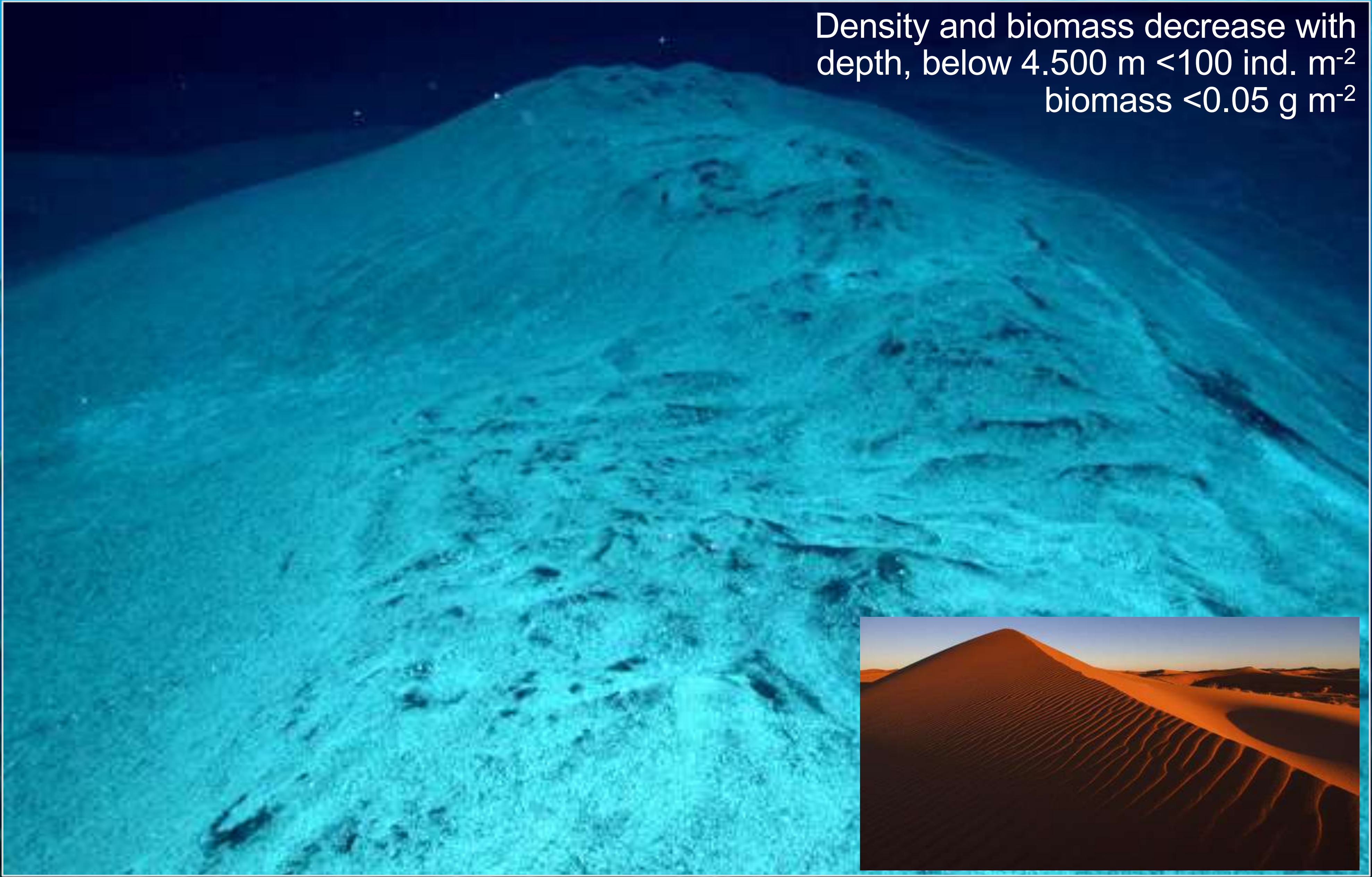
POM falling from the photic zone

1. Dead or dying small organisms
2. Fecal pellets
3. Moults (hard structures of zooplankton)



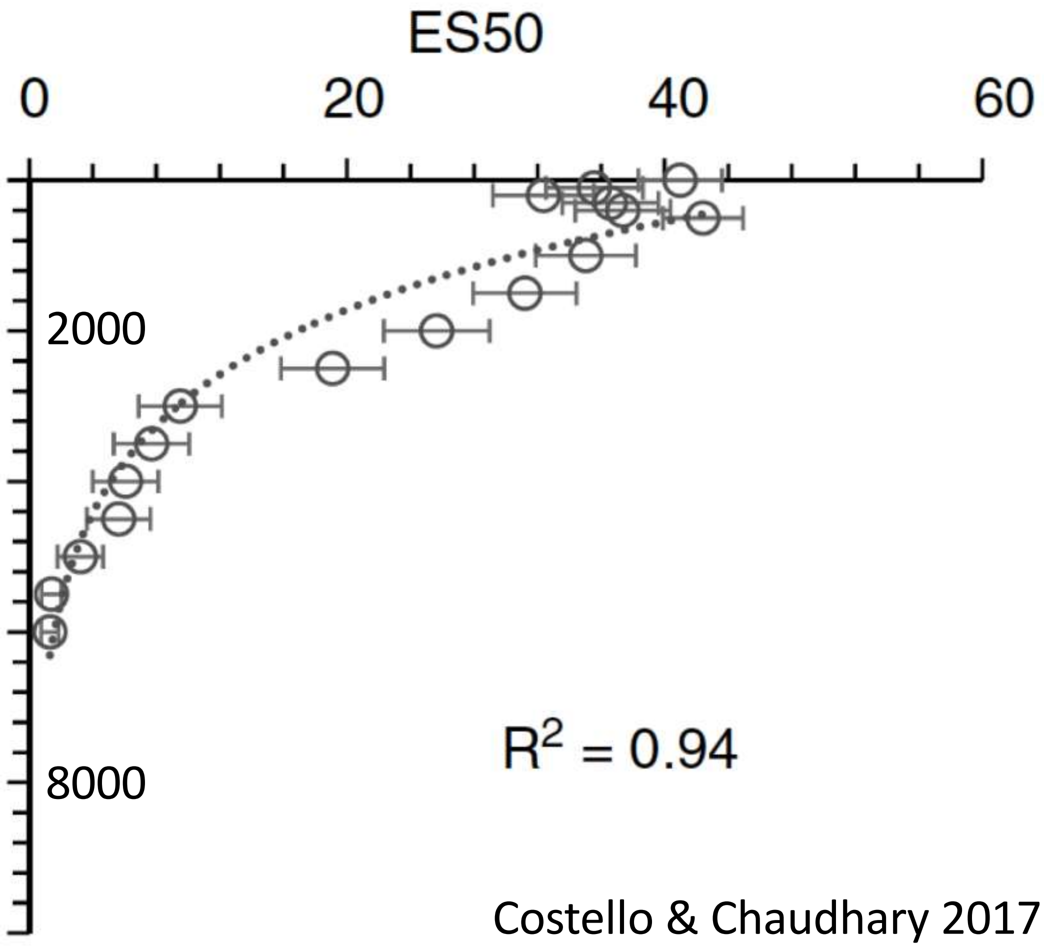
Marine snow is mostly organic matter, with some inorganic components. It is made up of aggregates of particles held together polysaccharid matrices (originated from decay of orgain matter and exudations of marine organisms). Aggregates grow when falling, until several cms, and could take days or weeks before reaching the ocean floor, depending on their size.

A desert?



Azoic theory of Forbes, half of 19th century

Stability-Time hypothesis



Costello & Chaudhary 2017

Sanders (1968) proposed a general model which he called the Stability-Time Hypothesis. This model says that physical instability in an environment prevents the establishment of diverse communities. However, if physically stable conditions persist for a long period of time, speciation and immigration will cause species diversity to increase gradually. Thus, high diversity in the deep sea is a result of the great long-term stability of that environment. Basic to his view is the idea that each species must occupy an increasingly narrow, specialized niche.

However…

1) Feeding behaviour are quite general: many are detritivorous, or filter-feeders, and some predator
2) In most cases species rely on different type of food
3) Low densities imply individuals to interact with many different species
4) Large areas and rarefaction decrease competition (Dayton and Hessler, 1972)

Heterogeneity

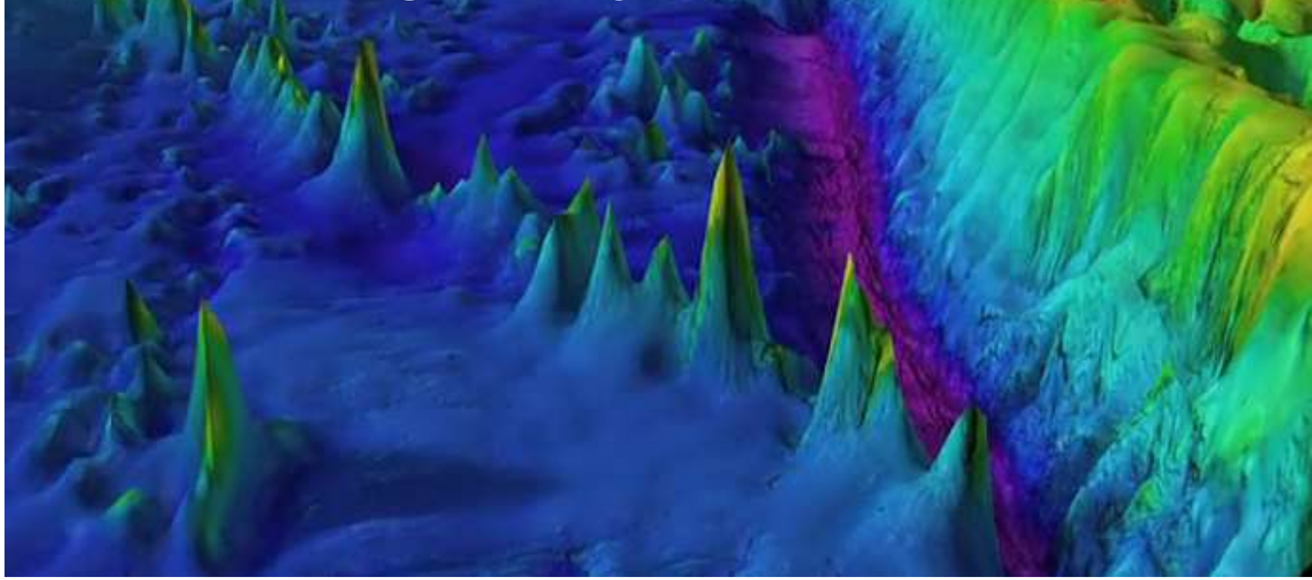
Habitat
mud flats, sea mounts, volcanos, trenches, canyons

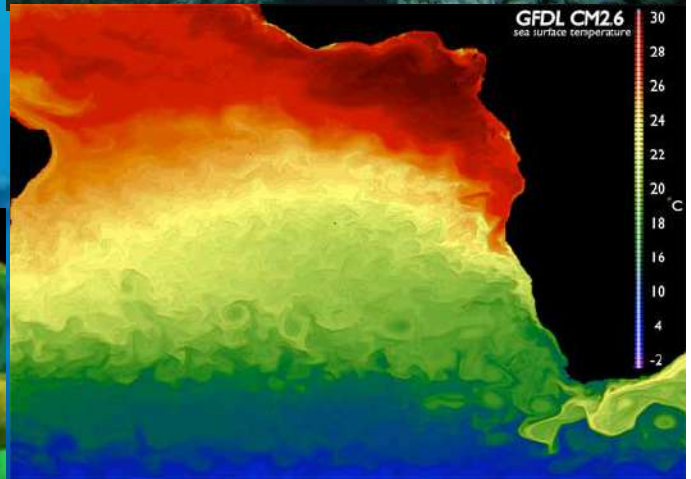
Hydrodynamism
Currents: there are areas of intense hydrodynamis
Eddies: cyclons 50-200 km with high energy flow

Variability:
interannual variations in conditions

Sea bottom perturbation:
resuspension of sediments in slope areas
bioturbation (microscale and small scale)

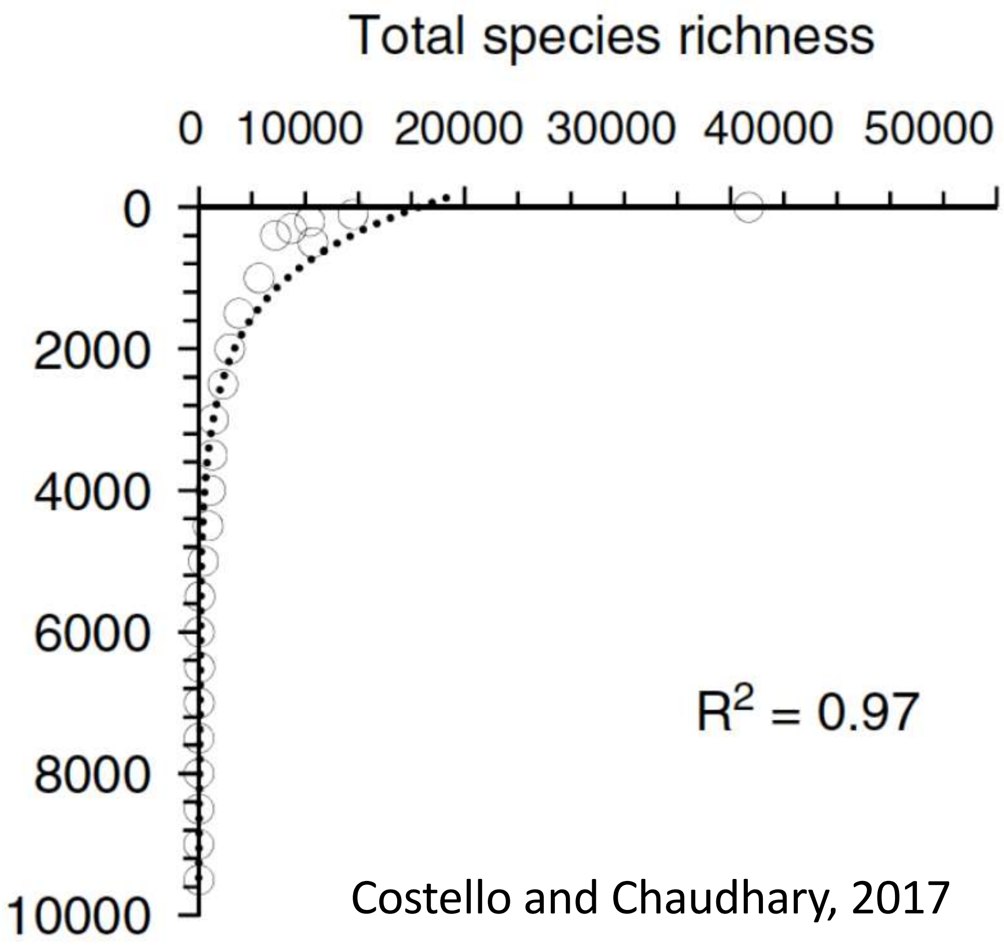
Resources:
food is heterogeneously distributed





Biodiversity

Biodiversity in the deep sea is lower than in shallower environments. However, we explored only the 1% of this system, and there could be many species still to be discovered.



Costello and Chaudhary, 2017

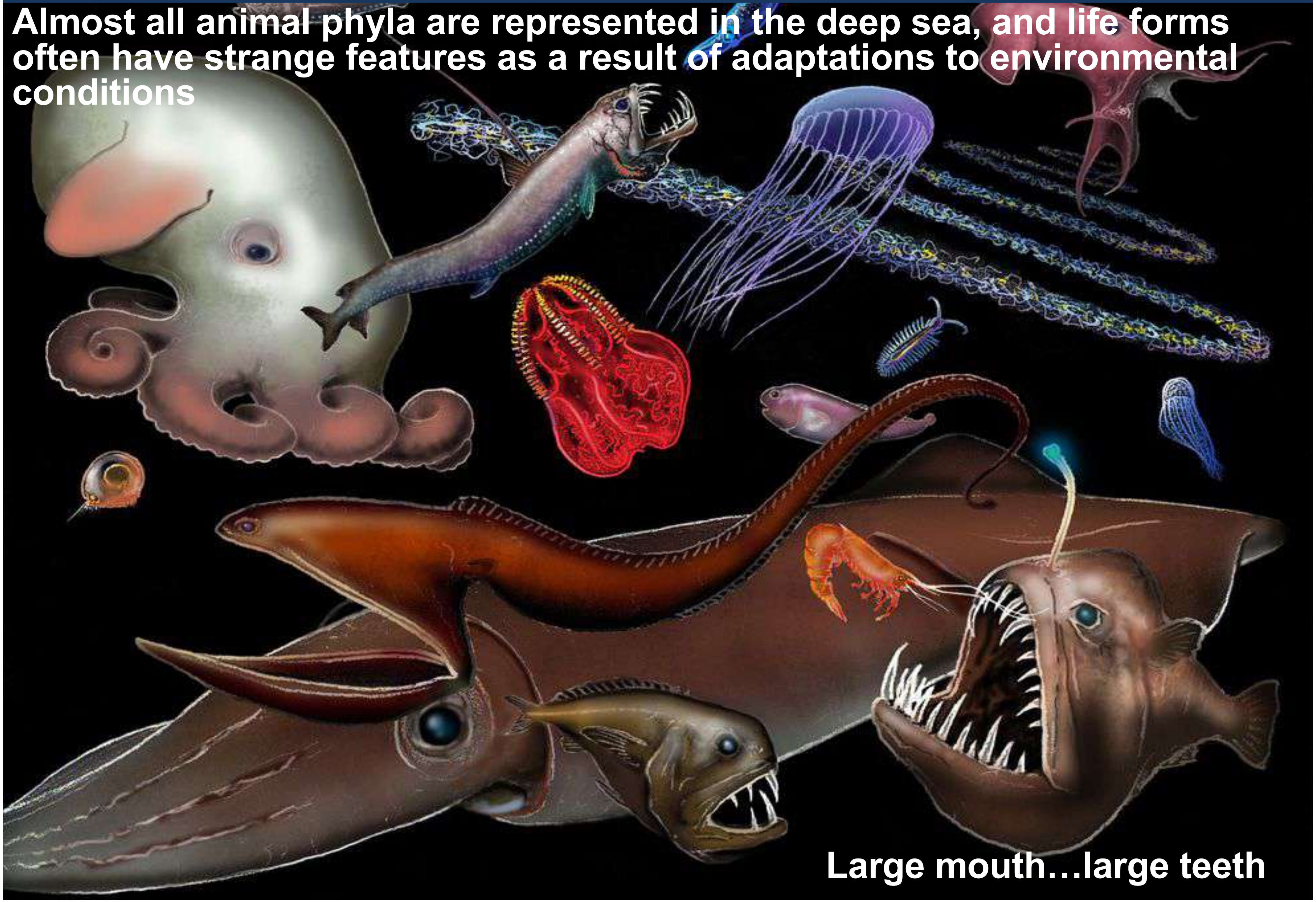
Species richness decline from the surface to the deeper areas. However, information is geographically restricted to some areas of the Atlantic, Pacific and Southern Ocean.
Very few studies in the Mediterranean

Dominant macrobenthic taxa:
polychaetes, cumaceans, tanaidacea, amphipods, isopods, gastropods, bivalves, scaphopods, oligochaetes, pogonophora, chitons, aplacophora

Dominant meiofauna:
nematods, harpacticoid copepods, ostracods

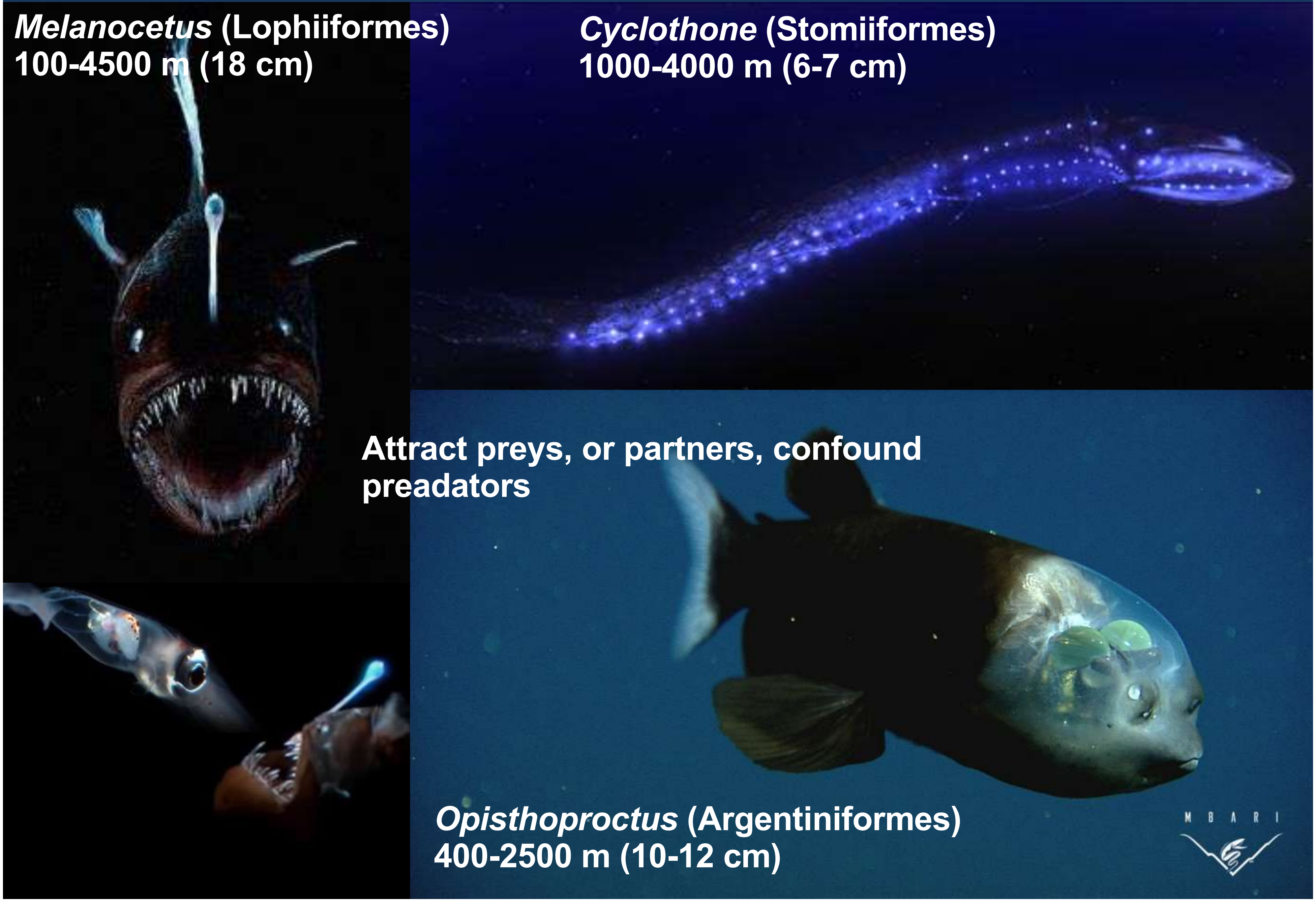
Strange guys

Almost all animal phyla are represented in the deep sea, and life forms often have strange features as a result of adaptations to environmental conditions



Large mouth…large teeth

Further adaptations

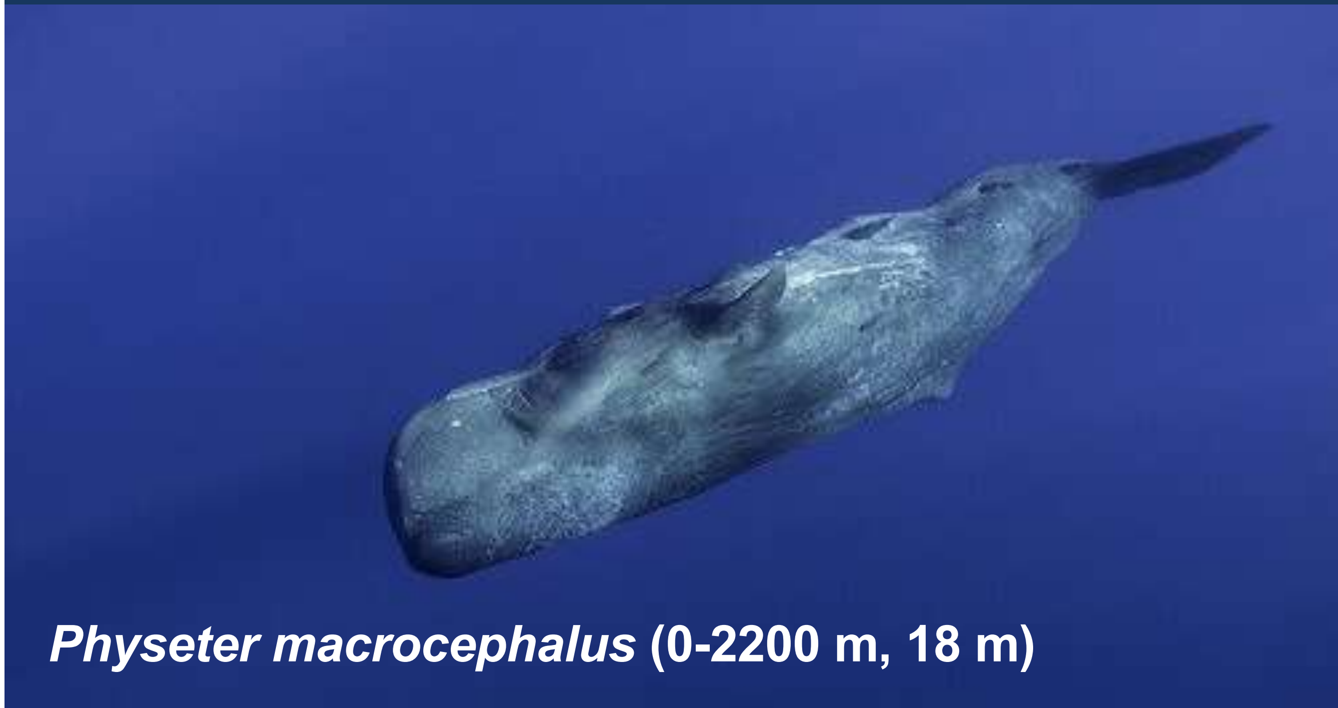


Living fossils

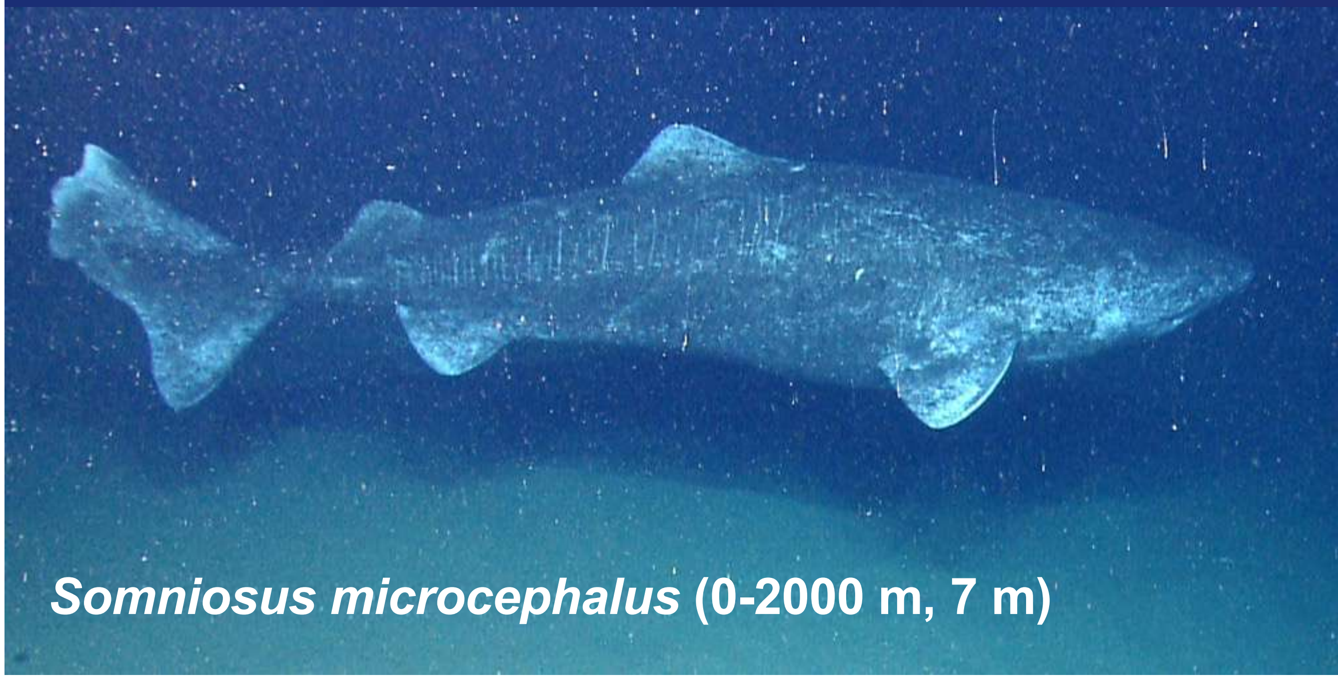
Latimeria chalumnae (Coelacanthiformes)
150-700m (140-165 cm)

Believed extinct since 65 millions years ago
(Madascar 1938)

Visitors from the surface



Physeter macrocephalus (0-2200 m, 18 m)



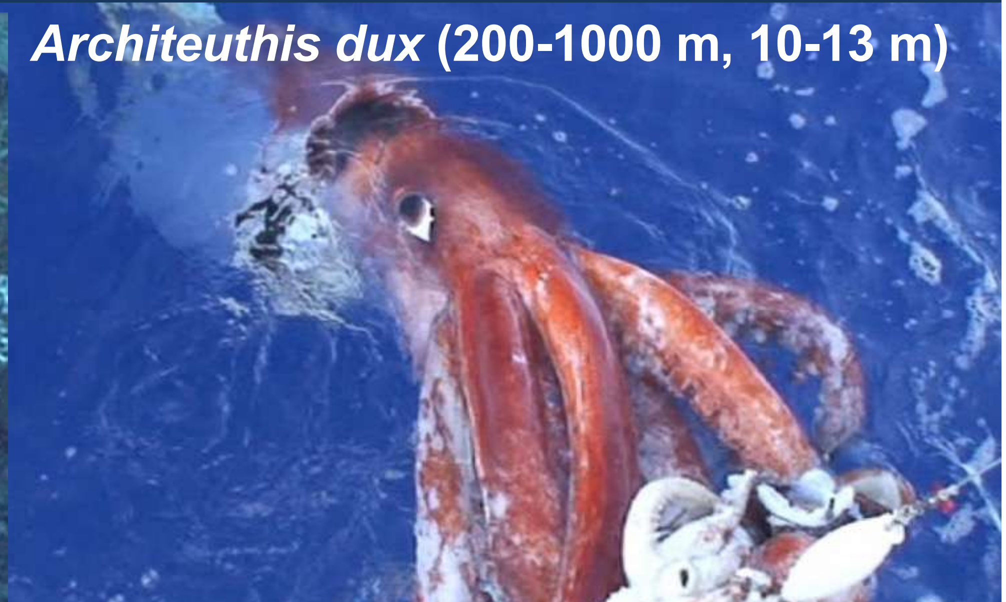
Somniosus microcephalus (0-2000 m, 7 m)

In some cases, animal living in shallow waters may visit deep sea for feeding

Others prefer conditions of deeper waters, but could occasionally frequent the surface or going more deeper

Big…strange guys

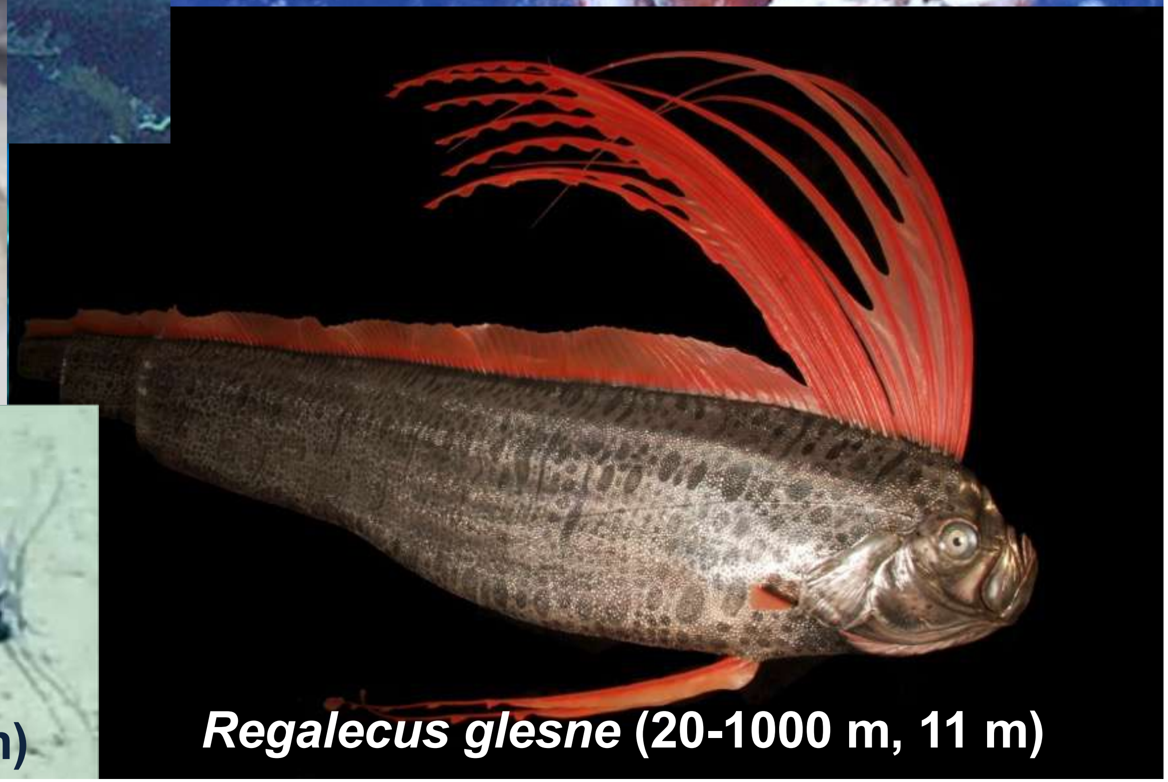
Xenophyophores (>6 km, 10 cm)



Architeuthis dux (200-1000 m, 10-13 m)

Macrocheira (150-300 m, 5 m)

Bathynomus (300-2500 m, 15 cm)

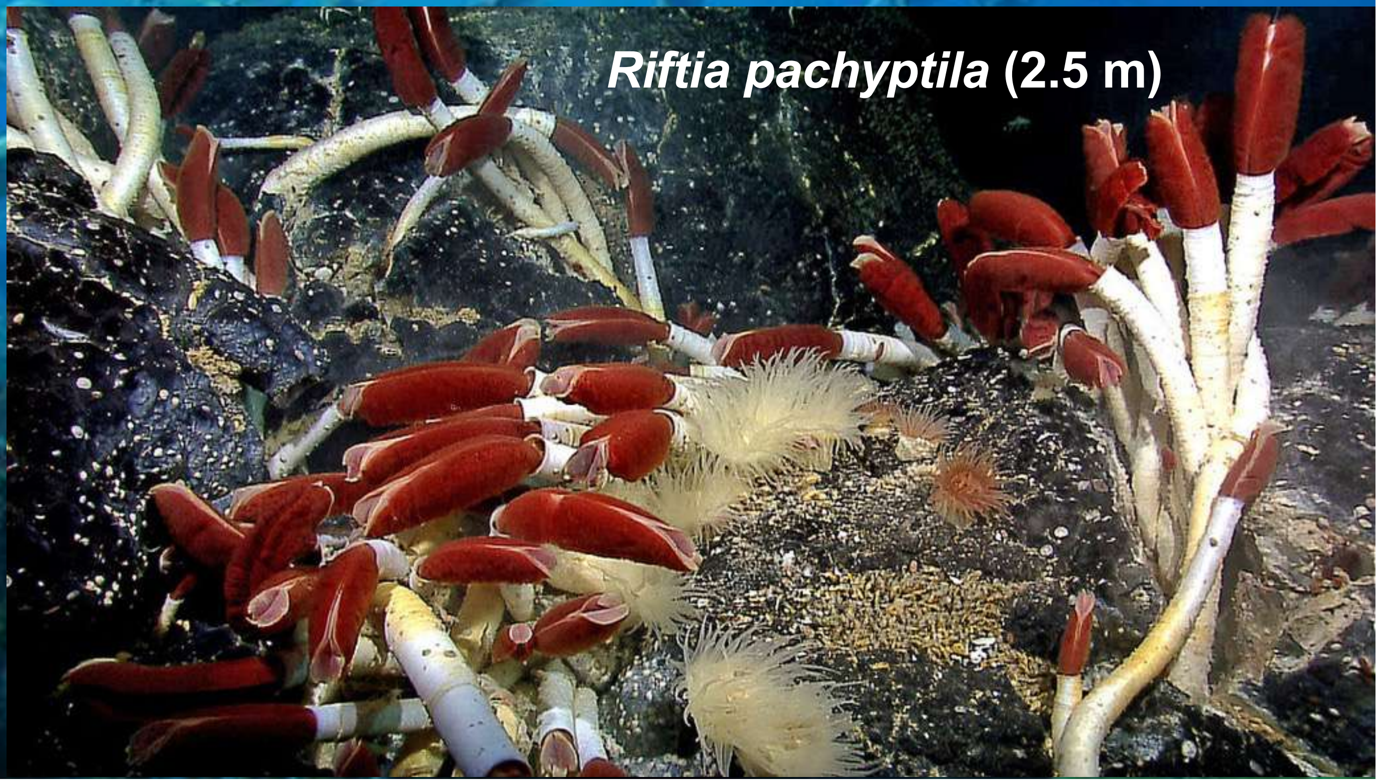


Regalecus glesne (20-1000 m, 11 m)

Abyssal gigantism

Late sexual development and continuous growth
Escaping predation through increasing size
Kleiber's rule: basal metabolism is proportional to body mass. Metabolism (and therefore energy consumption) slows down as body mass increase. So large organisms are more energetically efficient. This depends on heat dissipation, circulation, and proportion of structural and reserve mass.
Bergmann's rule: species of larger size are found in colder environments, and species of smaller size are found in warmer regions. This due to low surface area-to-volume ratio, which decrease heat dissipation.

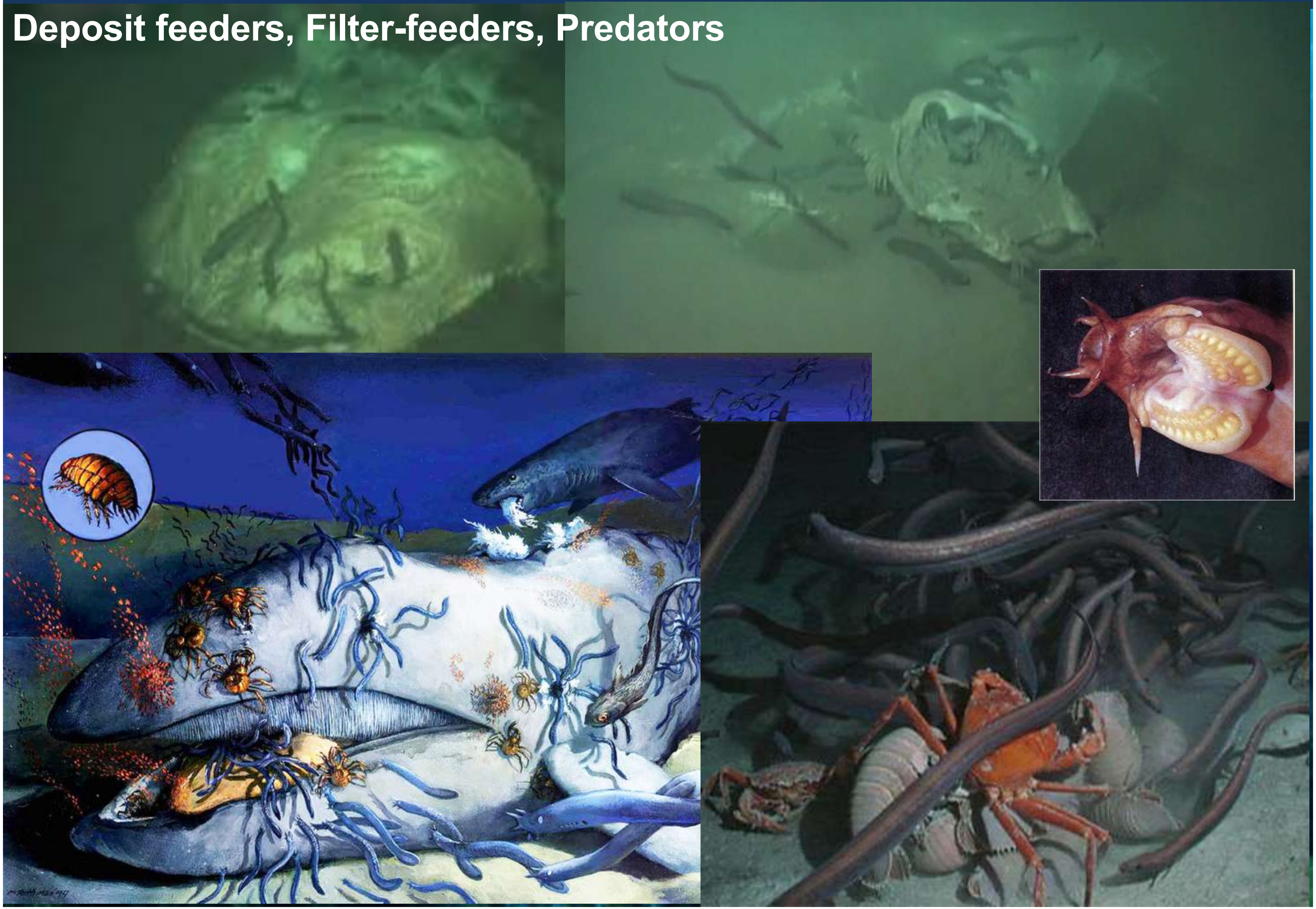
Trophic reasons (optimal foraging, higher productivity of endosymbionts)



Riftia pachyptila (2.5 m)

Scavengers

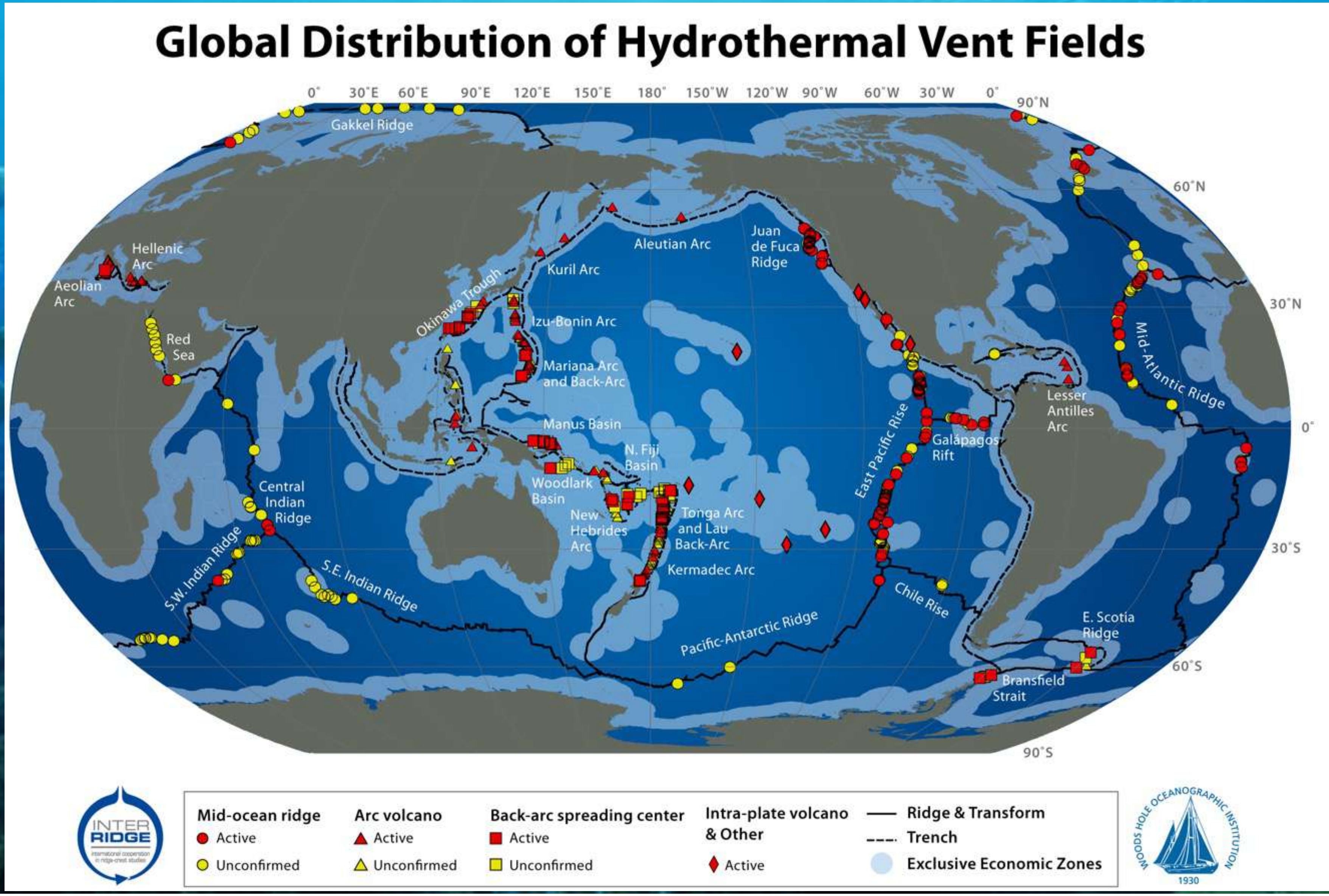
Deposit feeders, Filter-feeders, Predators



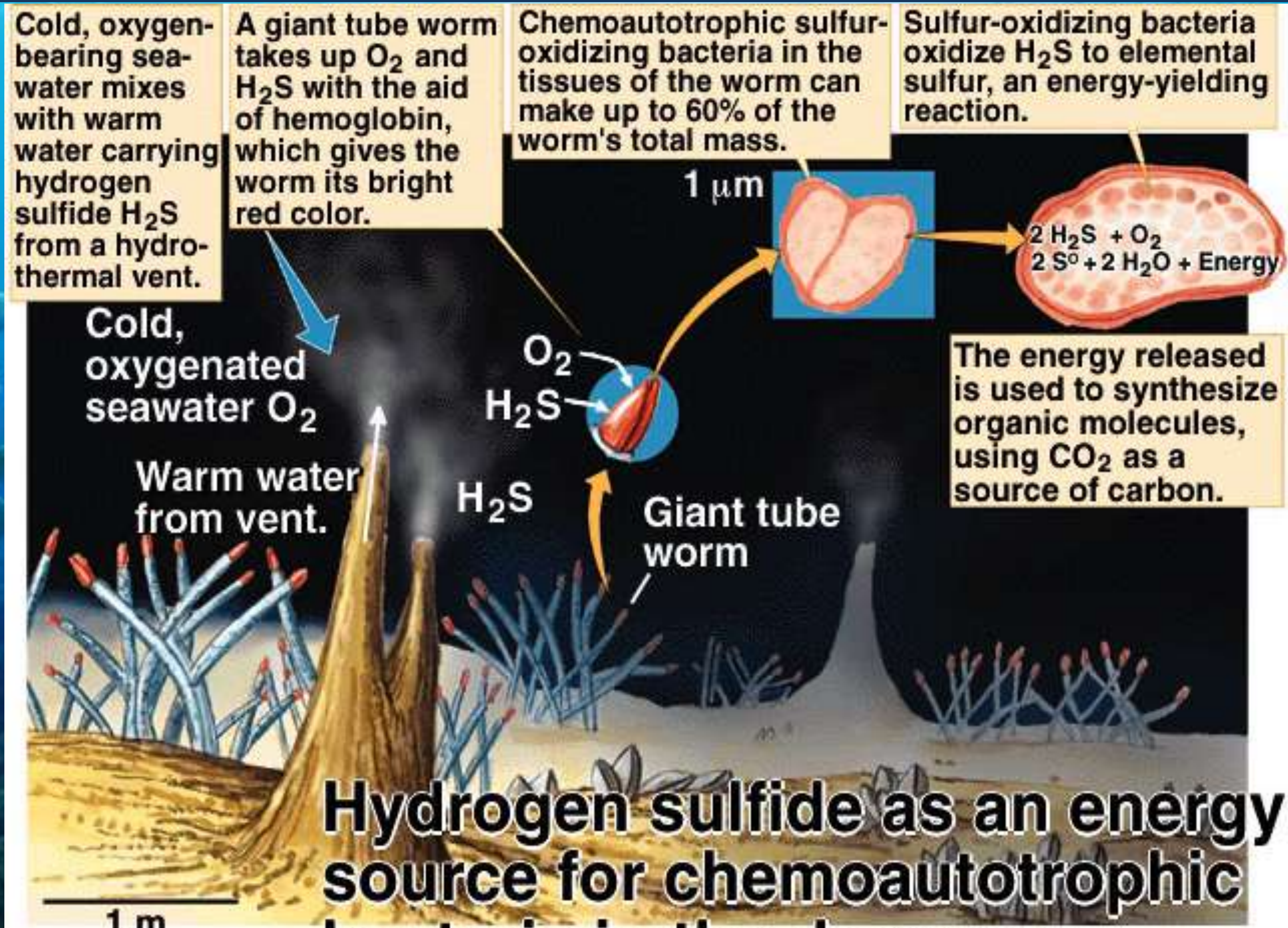
Hydrothermal vents

First discovered at Galapagos in 1977

Typical of areas of intense tectonic activity. High temperature (100-350° C), often at 2500 m depth



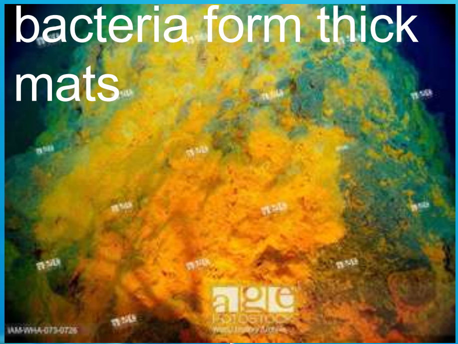
How they work



Hydrogen sulfide as an energy source for chemoautotrophic bacteria in the deep sea.

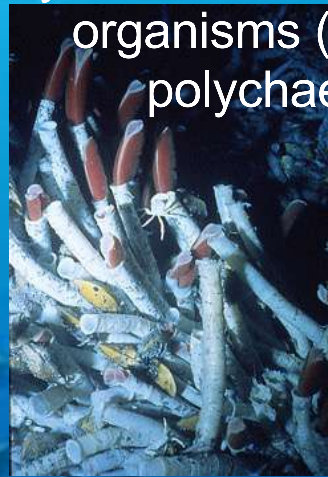
Mesocosm ecosystems

Chemosynthetic bacteria form thick mats



Snails, crabs, fish, cephalopods prey on vent organisms

Chemosynthetic bacteria are also symbionts of many organisms (e.g., polychaetes)



Grazers feed on these mats (e.g., amphipods, copepods)

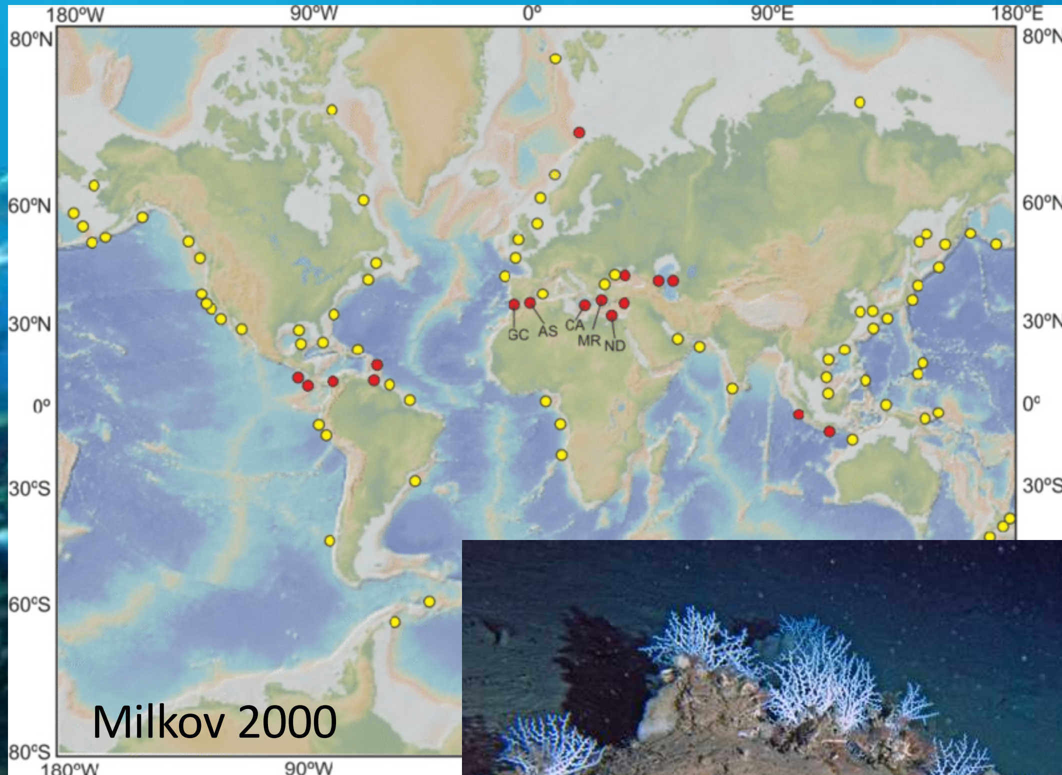
Filter-feeders exploit plankton and POM (some have also symbionts)

Hotspots of biodiversity, with population densities >>> higher than neighbouring areas, high primary productivity from chemosynthesis and secondary productivity from associated fauna

Cold seeps

They are places where hydrocarbons – mostly methane but also ethane, propane, or even oil – seep from the sediment. From few to 1000s m, often near continental margins. In contrast to vents, fluids are not at a high temperature (so "cold"). Methanotrophic bacteria oxidise CH_4 and sulphate-reducing bacteria produce H_2S. A community could develop. Also, H_2S sustain chemosynthetic bacteria and further increase colonization of seeps.

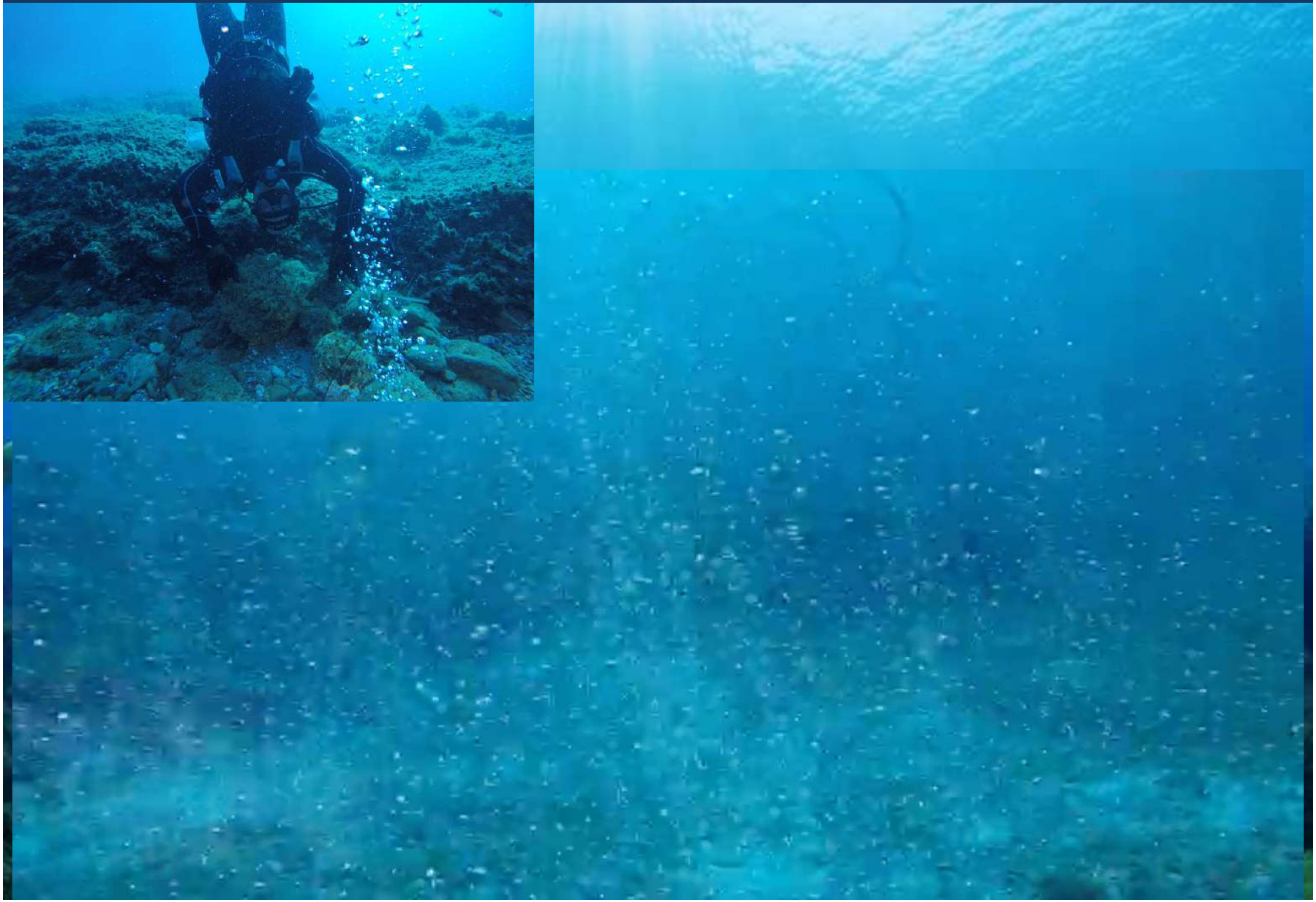
Brine pools



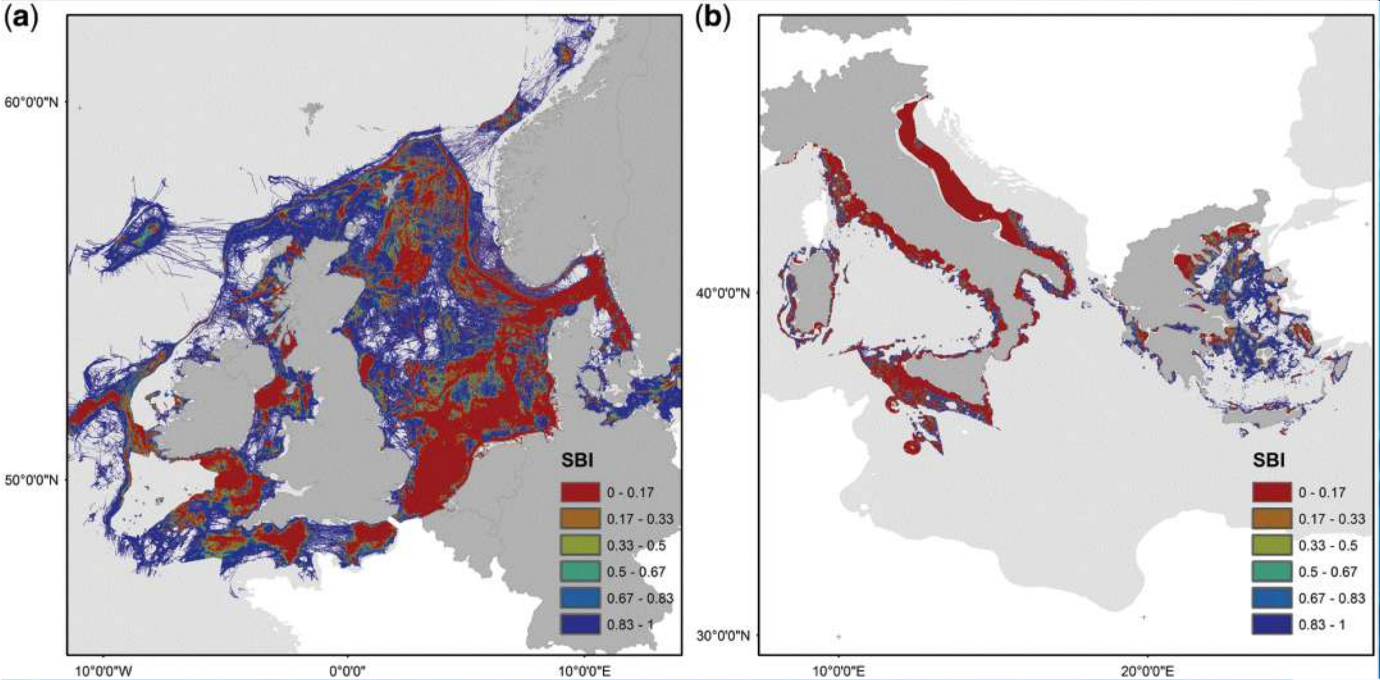
Milkov 2000

Carbonate deposition forms hard substrate for sessile organisms (worms and corals)

CO_2 seeps



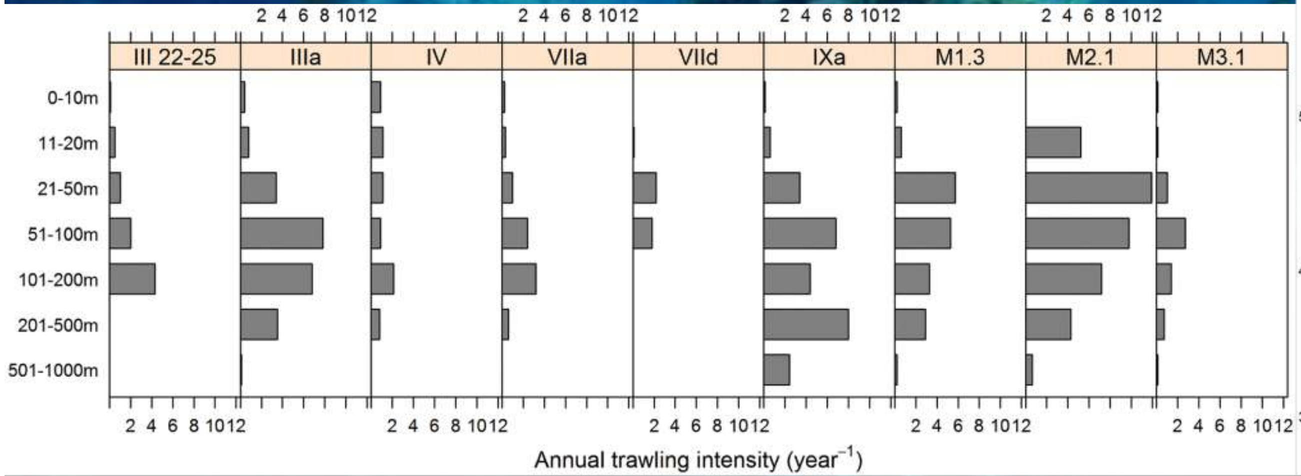
Trawling

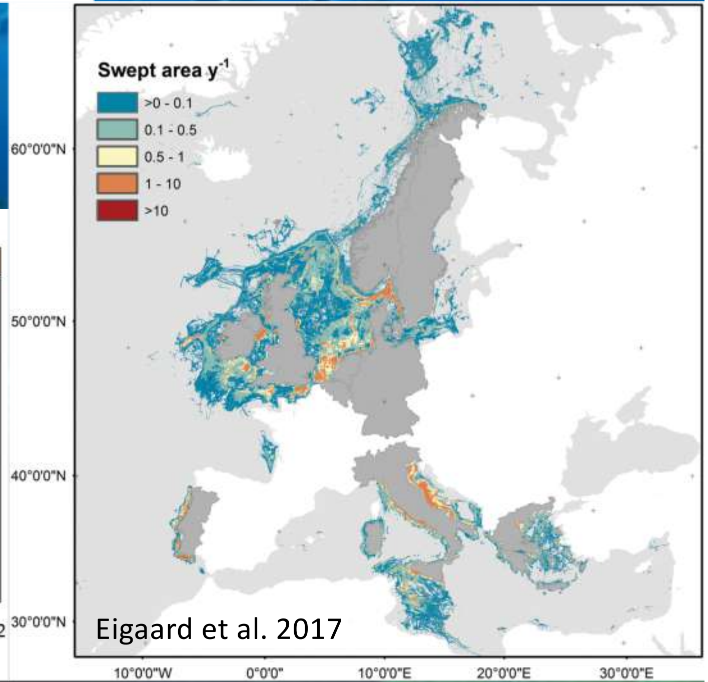


SBI values corresponding to the subsurface trawling intensities (sediment abrasion ≥ 2 cm). SBI (sea bed integrity index), 0 = all taxa affected – 1 = no taxa affected

Mean annual trawling intensity in the period 2010–2012 at the subsurface level (sediment abrasion ≥ 2 cm).

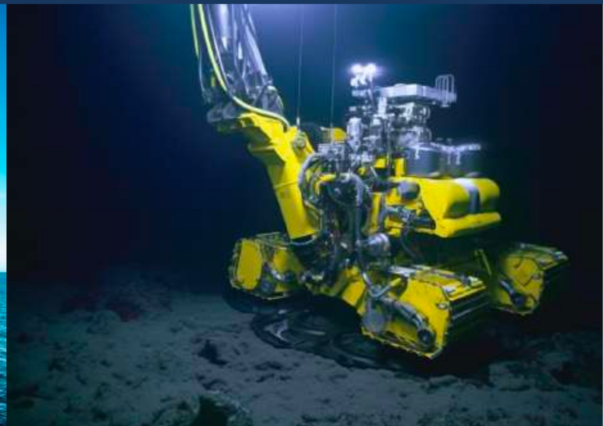
Trawling intensity by depth zone for the nine management area with the highest trawling pressure: III (W Baltic), IIIa (Skagerrak-Kattegat), IV (North Sea), VIIa (Irish Sea), (VIId Channel), IXa (Iberian-Portuguese), M1.3 (Tyrrhenian), M2.1 (Adriatic), M3.1 (Aegean)

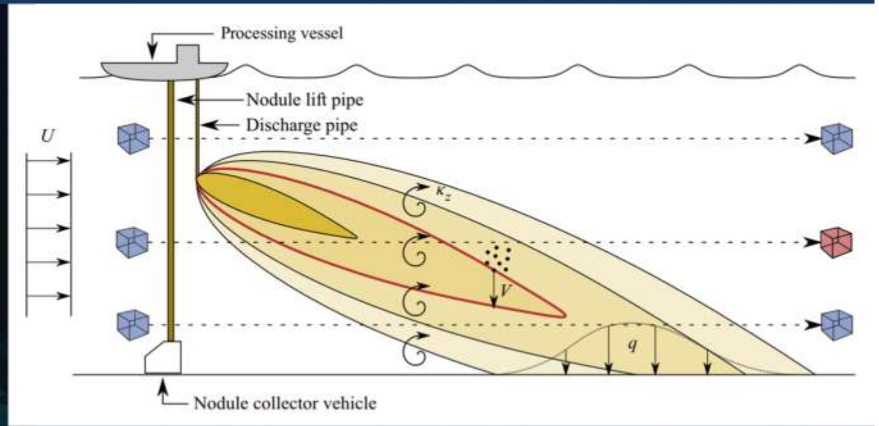




Eigaard et al. 2017

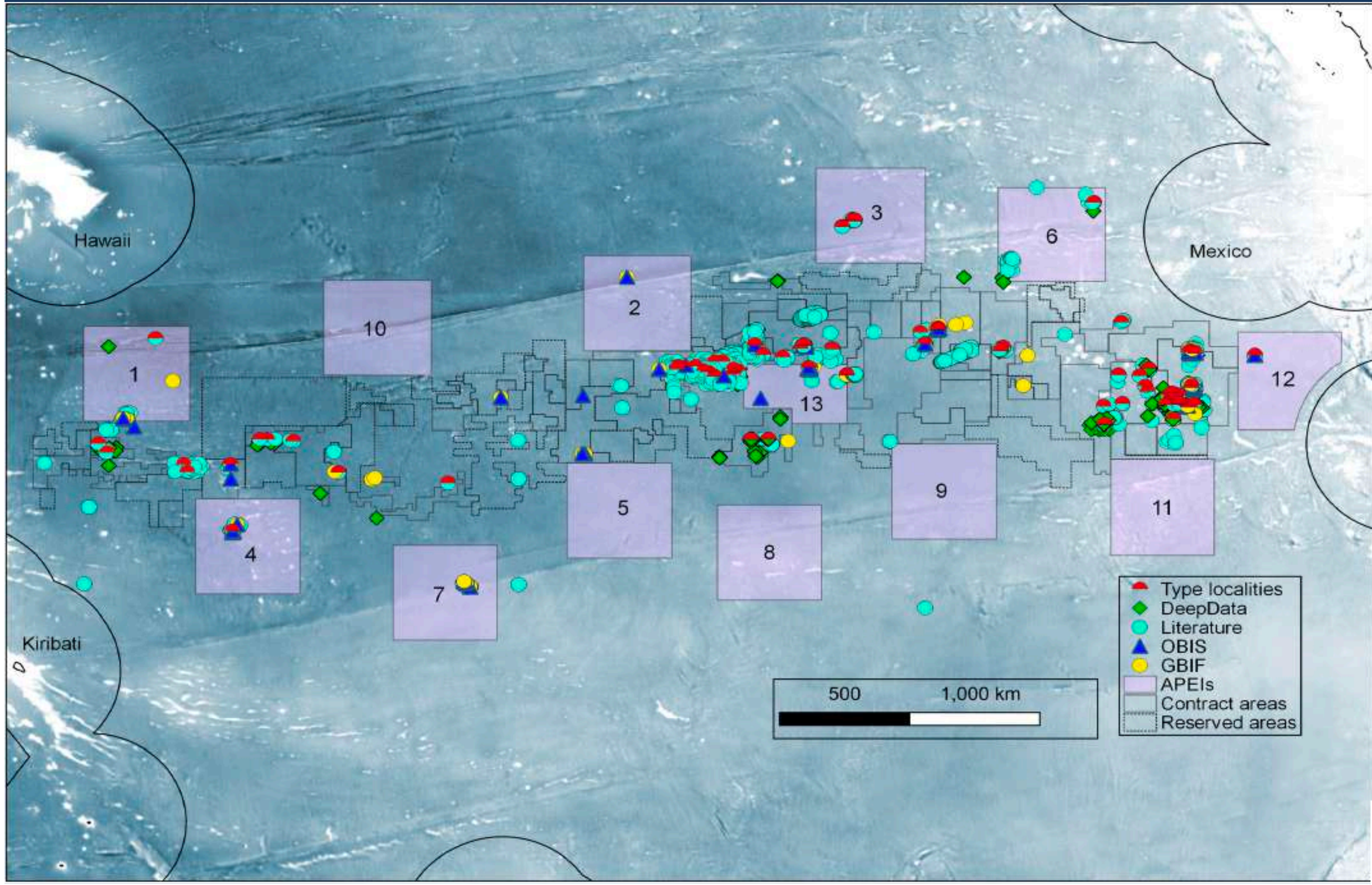
Sea bed mining

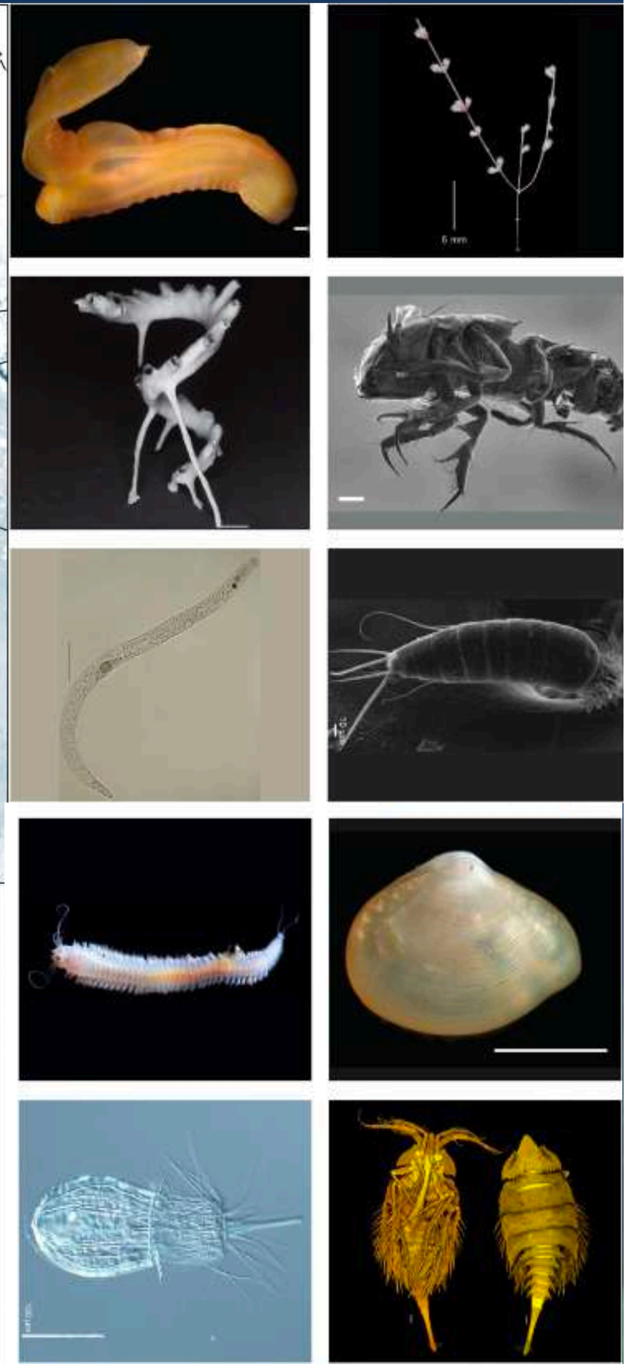




Direct displacement, injuries, killing
Burying/smothering
Hampering respiration/behaviour
Long-term species and ecosystem disruption

Sea bed mining



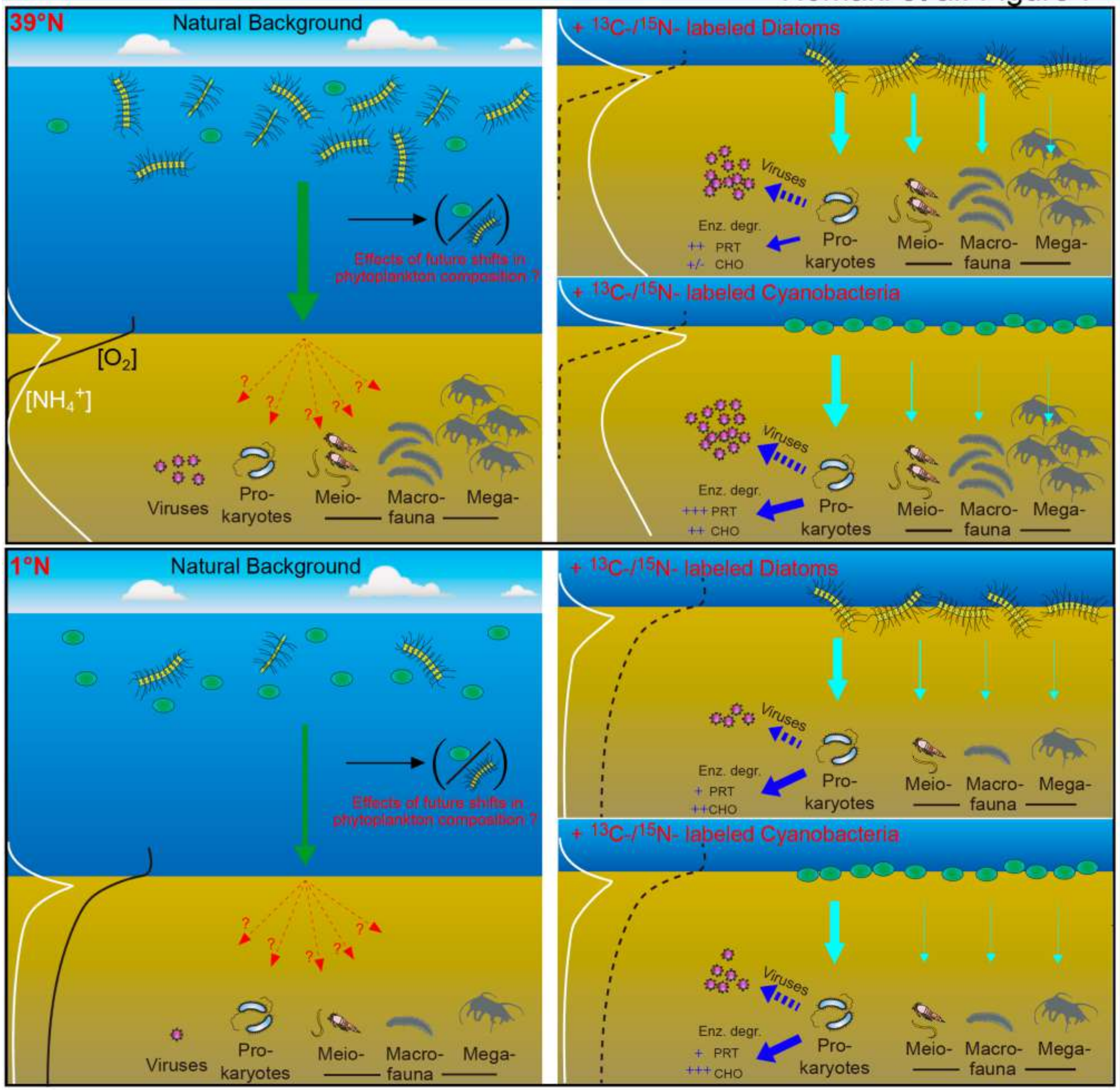


CCZ Taxonomic knowledge		CCZ Checklist		CCZ Biodiversity Estimators	
New species:	185	Phyla:	27	Unnamed species:	5,142
New genera:	31	Classes:	49	Total species:[a]	5,578
New families:	3	Orders:	163	Chao1 species richness:	6,233 (+/ −82 SE)

Rabone et al. 2023

Potential effect of CC on deep sea

Increasing sea water temperature could lead to oligotrophic conditions at high latitudes due stratification. This could increase the primary production of picophytoplankton against diatoms



2 stations (NWP, 1 near the equator, oligotrophic; 1 off the coast of Japan – 4-5000 m)

Shift in supply of organic matter from cyanobacteria instead of diatoms will increase viral and bacterial production against eukaryotes especially at high latitudes, with profound change in the carbon fluxes and biodiversity

Nomaky et al. 2021

GLOBAL CHANGE ECOLOGY AND SUSTAINABILITY
a.a. 2023-2024

Conservation and Management of Marine Ecosystems
Prof. Stanislao Bevilacqua (sbevilacqua@units.it)

Polar systems

Scienze per l’Ambiente Marino e Costiero

a.a. 2023-2024

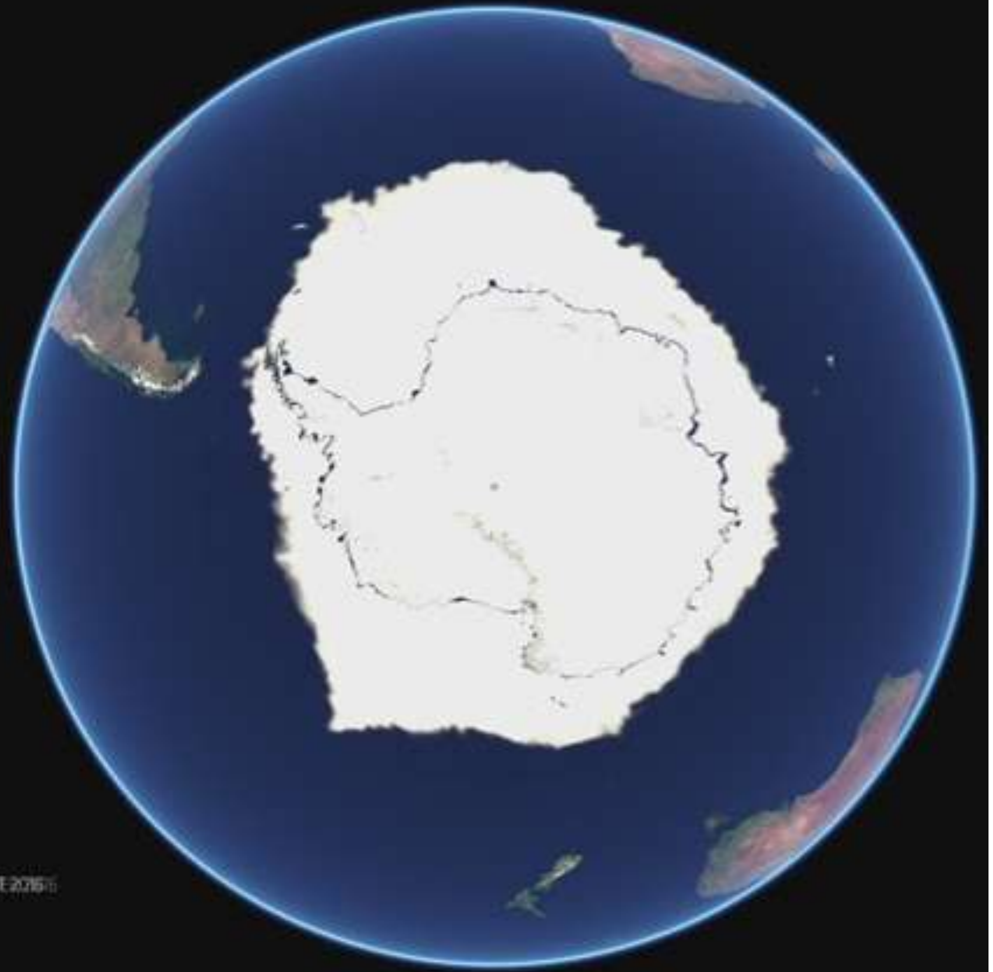
GESTIONE E CONSERVAZIONE ECOSISTEMI MARINI - IMPATTI ANTROPICI E CONSERVAZIONE DELLA FAUNA MARINA

Prof. Stanislao Bevilacqua (sbevilacqua@units.it)

Polar systems

Poles apart

Polar regions are those beyond the 66°33'39” parallel, N and S



Arctic

Include the Arctic Ocean and portion of land in Eurasia, North America, and Greenland. Open waters and continental shelves almost covered by ice or floating ice, with perennial cap on Greenland. Averaged depth around 1000 m (>5000 m). Avg T winter about -35° C (-50), summer 3-12° C. Winds 40-50 km (>90 km). Low solar irradiation

Antarctic

Include the Antarctica, other islands, and the surrounding portion of the Southern Ocean. Open waters covered by ice or floating ice, mainland covered by perennial ice cap (avg 1600 m). Max depth >7000 m (avg >3000). Avg T -10 to -60° C (-90). Wind 100 km (200 km). Low solar irradiation

Biodiversity

Biodiversity is low compared with warmer areas. Almost all phyla are represented, however.

Benthic communites are well developed, except for the deep Arctic Ocean, due to the low supply of organic matter. Antarctic continental shelf and some regions in the Arctic (e.g., Bering, Chukchi, and Barents) have high benthic and planktonic production, supporting large populations of fish, marine mammals, and sea birds.

Antarctic

Taxon	Number of valid species	Number in MarBIN	Percentage with location	Number of records
Annelida	487	45	9.24	445
Arthropoda	2,309	1,014	43.92	132,585
Brachiopoda	68	10	14.71	17
Chaetognatha	5	4	80.00	1,588
Chordata	718	395	55.01	359,968
Cnidaria	372	65	17.47	1,112
Echinodermata	550	434	78.91	5,314
Mollusca	684	633	92.54	13,121
Nematoda	1,909	301	15.77	702
Nemertina	77	74	96.10	2
Porifera	268	12	4.48	39

doi:10.1371/journal.pone.0011683.t002

Griffiths, 2010

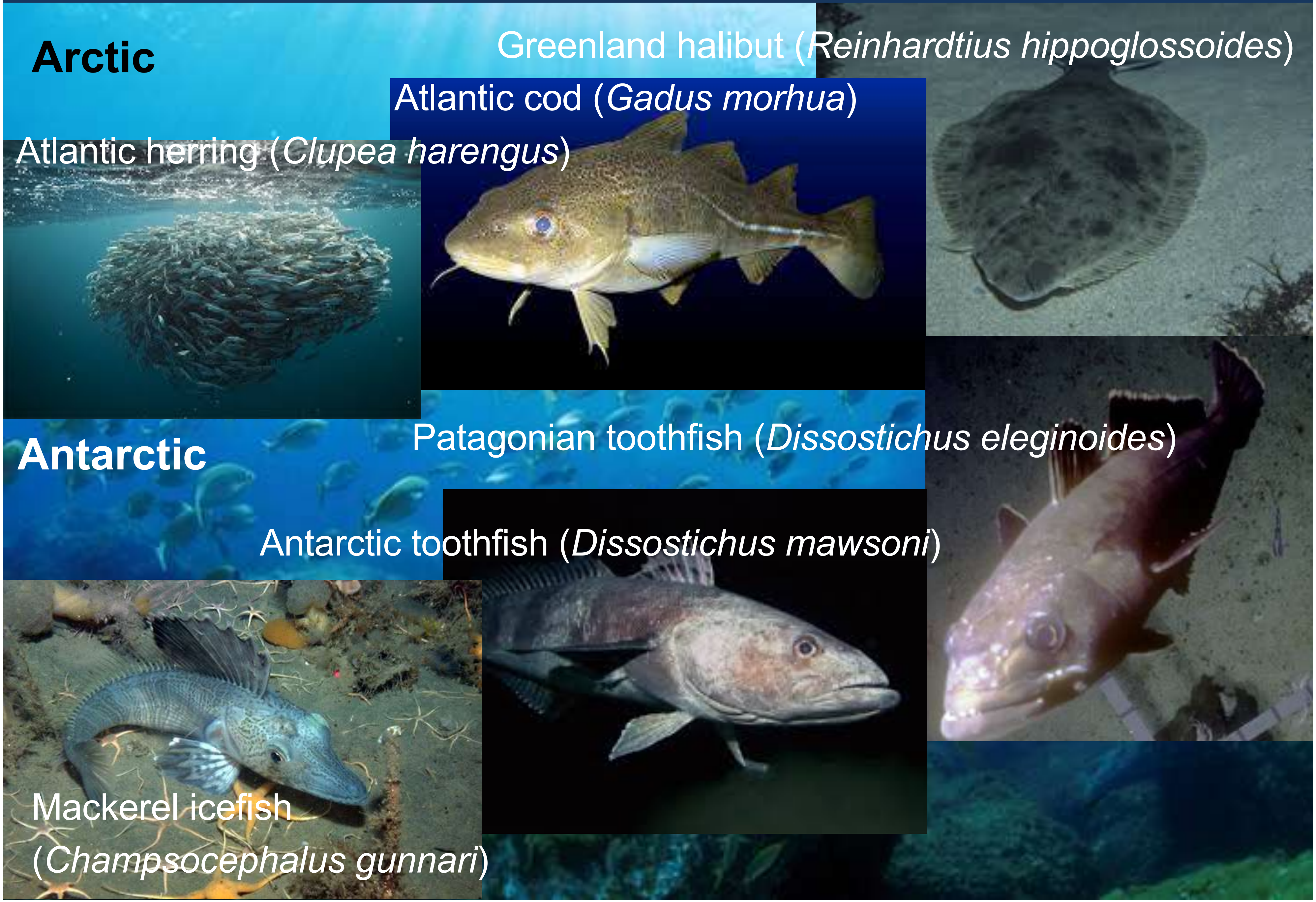
About 8100 animal species (De Broyer et al. 2014)

Taxon/realm	Number of species/taxa	Species endemic to the Arctic	Abundant and/or widespread species	Key reference(s)
Single-celled eukaryotes in phytoplankton and sea ice	2,106 (1,027 sympagic, 1,875 pelagic)	Diatoms *Melosira arctica* and *Nitzschia frigida*	Diatoms *Nitzschia frigida, Melosira arctica, Chaetoceros furcillatus, Thalassioria nordenskioeldii, Fragilariopsis oceanica, F. cylindrus,* and *Cylongrotheca closterium,* Dinoflagellate *Protoperidinium pellucidum*	Poulin et al., 2011
Sea ice fauna	At least 50	Hydroid *Sympagohydra tuuli*; nematodes *Theristus melnikovii, Cryonema tenue,* and *C. crissum*; amphipods *Gammarus wilkitzkii, Apherusa glacialis, Onisimus nanseni,* and *O. glacialis*	Unidentified Acoela; copepod nauplii; amphipods *Gammarus wilkitzkii, Apherusa glacialis, Onisimus nanseni,* and *O. glacialis*	Bluhm et al., 2010a
Zooplankton	354	Copepods *Spinocalanus elongatus, S. horridus, Paraeuchaeta polaris, Scaphocalanus polaris,* and *Lucicutia pseudopolaris*; Cnidarians *Rhabdoon reesi* and *Rudjakovia plicata*; larvacean *Fritillaria polaris*	Copepods *Calanus hyperboreus, C. glacialis, Metridia longa, Oithona similis, Oncaea borealis,* and *Paraeuchaeta glacialis*; chaetognaths *Parasagitta elegans, Eukrohnia hamata,* and *Homoeonema platygonon*; amphipod *Themisto libellula*	Kosobokova et al., 2011
Seaweeds	~ 160	*Platysiphon verticillatus, Jonssonia pulvinata, Chukchia pedicellata, C. endophytica, Kallymenia schmitzii,* and *Leptophytum arcticum*	*Agarum clathratum, Desmarestia aculeate, Ectocarpus siliculosus, Saccharina latissima, Polyshiphonia arctica, Odonthalia dentate,* and *Ulva intestinalis*	Wilce, 1990, 2009, and recent work; Mathieson et al., 2010
Zoobenthos	~ 4,600	Amphipod *Onisimus caricus,* bryozoan *Alcyonidium disciforme*; holothuroids *Elpidia belyaevi, E. heckeri, E. glacialis,* and *Kolga hyalina*	Brittle star *Ophiocten sericeum*; amphipods *Ampelisca eschrichti* and *Anony nugax*; bivalve *Macoma calcarea*; polychaetes *Eteone longa, Aglaophamus malmgreni,* and *Lumbrineris fragilis*	Sirenko, 2001; Piepenburg et al., 2011; Rogacheva, 2007, 2011
Fish	243	*Artediellus scaber, Arctogadus glacialis, Paraliparis bathybius, Rhodichtys regina, Lycodes frigidus,* and *L. adolfi*	*Boreogadus saida, Arctogadus glacialia, Gymnocanthus tricuspis, Myoxocephalus scorpius, M. quadricornis,* and *Lycodes polaris*	Mecklenburg et al., 2011, and *pers. comm.,* February 16, 2011
Seabirds	64	Ivory gull, thick-billed murre, Dovekie, Kittlitz's murrelet, horned puffin, Heuglin's Gull, and various seabird subspecies	Glaucous and Iceland gull; Arctic tern; parasitic and long-tailed jaeger	Huettmann et al., 2011
Marine mammals	16	Polar bear; narwhal, beluga, and bowhead whales; walrus; ringed seal; bearded seal	Ringed seal; bearded seal	Huntington and Moore, 2008; Kovacs et al., 2011

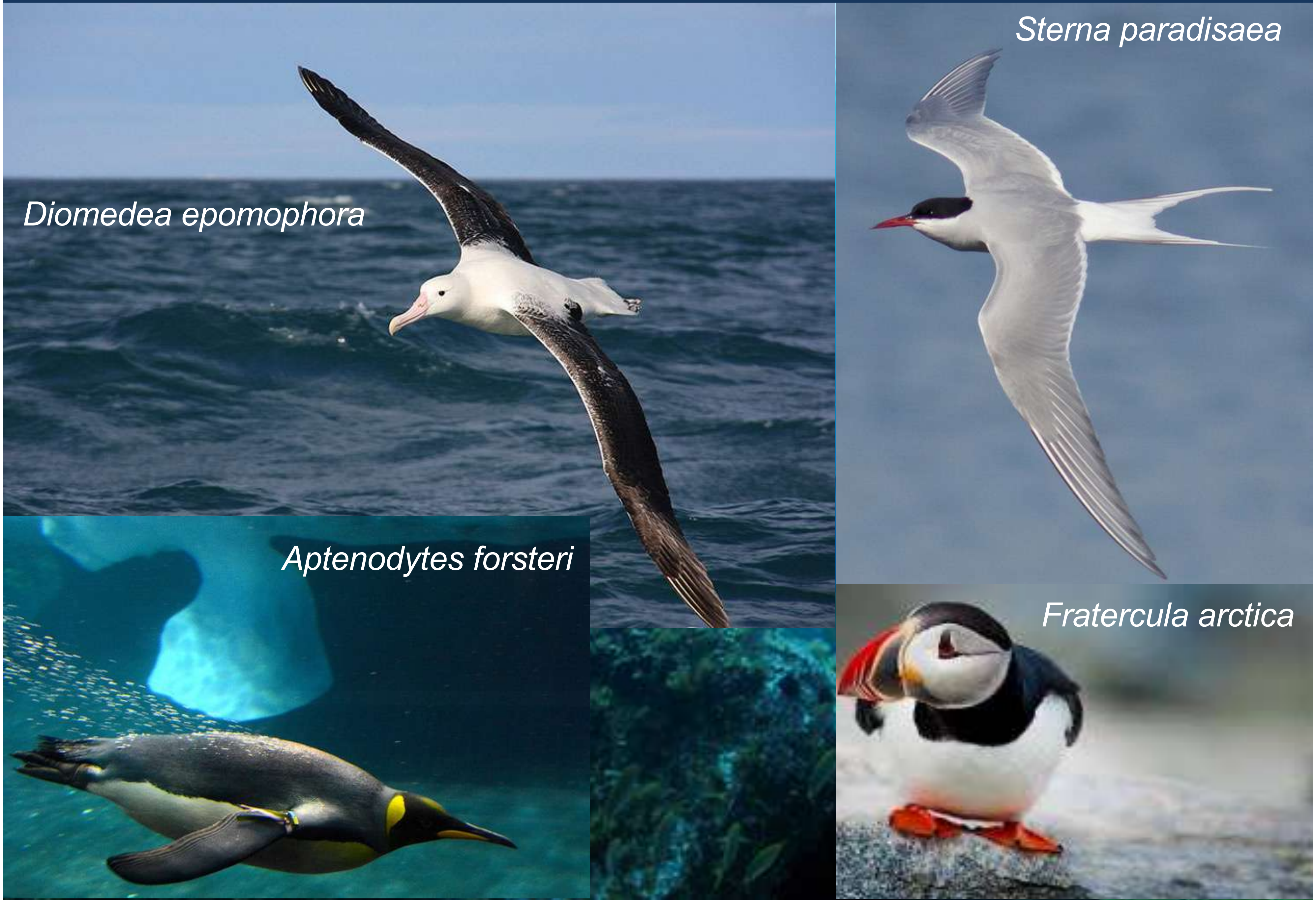
Bluhm et al., 2011

Arctic
About 7600 species

Fish


Arctic
Greenland halibut (*Reinhardtius hippoglossoides*)
Atlantic cod (*Gadus morhua*)
Atlantic herring (*Clupea harengus*)
Antarctic
Patagonian toothfish (*Dissostichus eleginoides*)
Antarctic toothfish (*Dissostichus mawsoni*)
Mackerel icefish
(*Champsocephalus gunnari*)

Marine birds



Mammals

Odobenus rosmarus

Pagophilus groenlandicus

Hydrurga leptonyx

Leptonychotes weddellii

Mirounga leonina

Ursus maritimus

Monodon monoceros

Balaenoptera musculus

Balaenoptera acutorostrata
(*B. bonaerensis*)

Orcinus orca

Adaptations

Polar marine organisms tend to **grow slower and live longer** than their temperate and tropical counterparts (slow basal metabolisms, as many deep sea organisms)

Many species have **conservative reproductive strategies** (e.g., late sexual maturity, few eggs, parental care for a long time, as many sea birds, polar bears and whales). Opposite strategy for high variable habitats, such as sea ice.

Many resident polar animals **store large quantities of lipids** in their bodies as reserve, others overwinter in a dormant form (e.g., polar bears).

Ice algae secret **osmolytes** (DMSP) to maintain osmotic equilibrium in salty waters, secrete **special protein** to protect membranes from ice crystals, and have **high levels of xantophyll** to avoid damage from excessive UV exposure during summer.

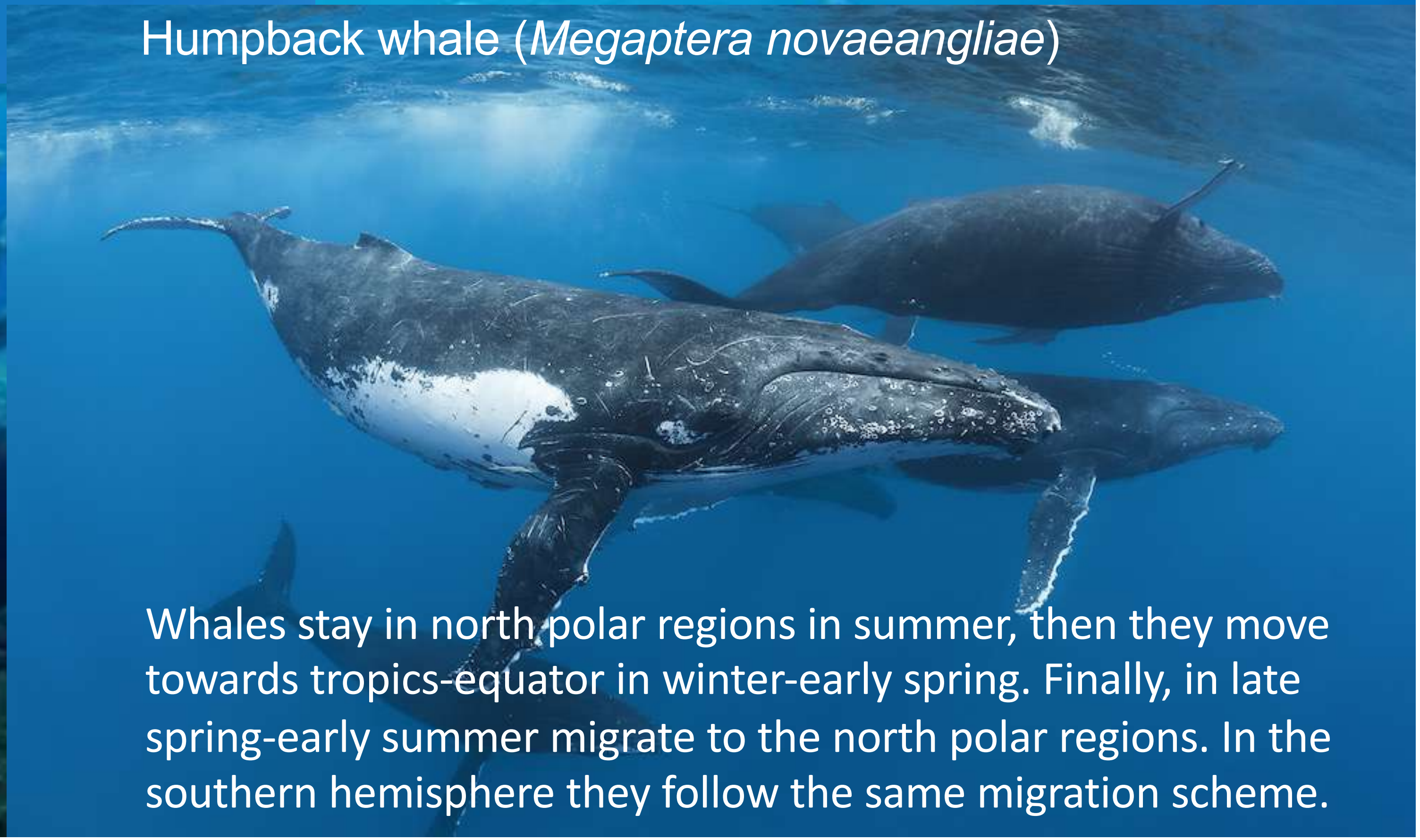
Icefish also have **anti-freezing proteins** in their blood. No hemoglobin, due to high oxygenation of waters. This allows saving energy facilitating body circulation.

Some species, such as many whales and seabirds, **migrate** into Arctic marine areas during the productive summers and overwinter in warmer areas.

Migrations

The Arctic Tern migrate for breeding to north polar areas in summer, and to southern polar areas in winter. This birds fly for about 40.000 km in few months

Arctic Tern (*Sterna paradisaea*)

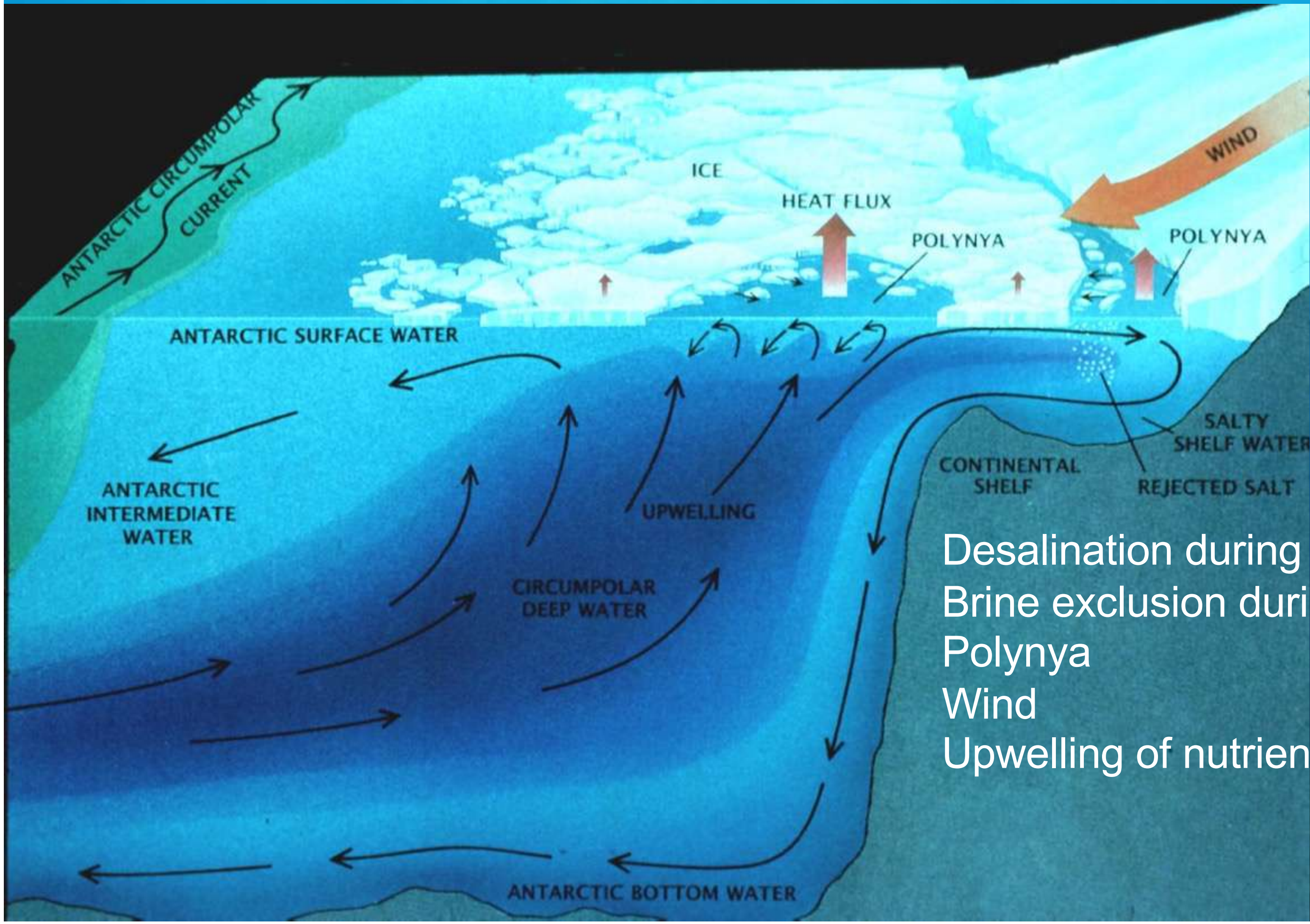


Humpback whale (*Megaptera novaeangliae*)

Whales stay in north polar regions in summer, then they move towards tropics-equator in winter-early spring. Finally, in late spring-early summer migrate to the north polar regions. In the southern hemisphere they follow the same migration scheme.

Ice and life

Despite harsh environmental conditions, polar marine ecosystems are among the most productive ones. This is particularly true for the Southern Ocean. The Arctic Ocean, in general, are not especially productive, but some subpolar areas (Bering, Barents, Iceland Sea) include some of the most productive basins in the northern hemisphere.



Desalination during ice formation
Brine exclusion during ice melting
Polynya
Wind
Upwelling of nutrient-rich deep waters

Primary productivity

This high availability of nutrients triggers phytoplanktoni blooms cyanobacteria, dinoflagellates, and especially diatoms are responsible for most primary production in polar marine systems. Ice algae live on the ice surface or melting ponds, within the ice in creek, pores, brine channels, and under the sea ice where they can form thick mats.

Melosira arctica

Fragilariopsis cylindrus

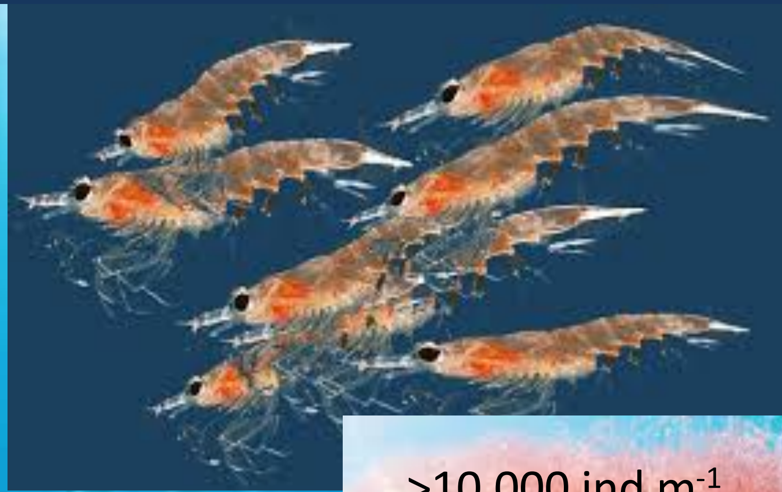
Macroalgae are less common, because of ice scouring, strong seasonality of solar radiation, being constrained to sea bottom and subpolar regions, where could be locally abundant.

Ascophyllum nodosum

Desmarestia menziesii

Krill

Krill (Euphausiacea) are shrimp-like crustaceans that are extremely abundant in polar waters. In the Arctic they are abundant in waters on the Atlantic portion and in the Bering Sea. Krill can constitute up to 45% of zooplankton catches but krill are, more prominent in the Sourthern Ocean.



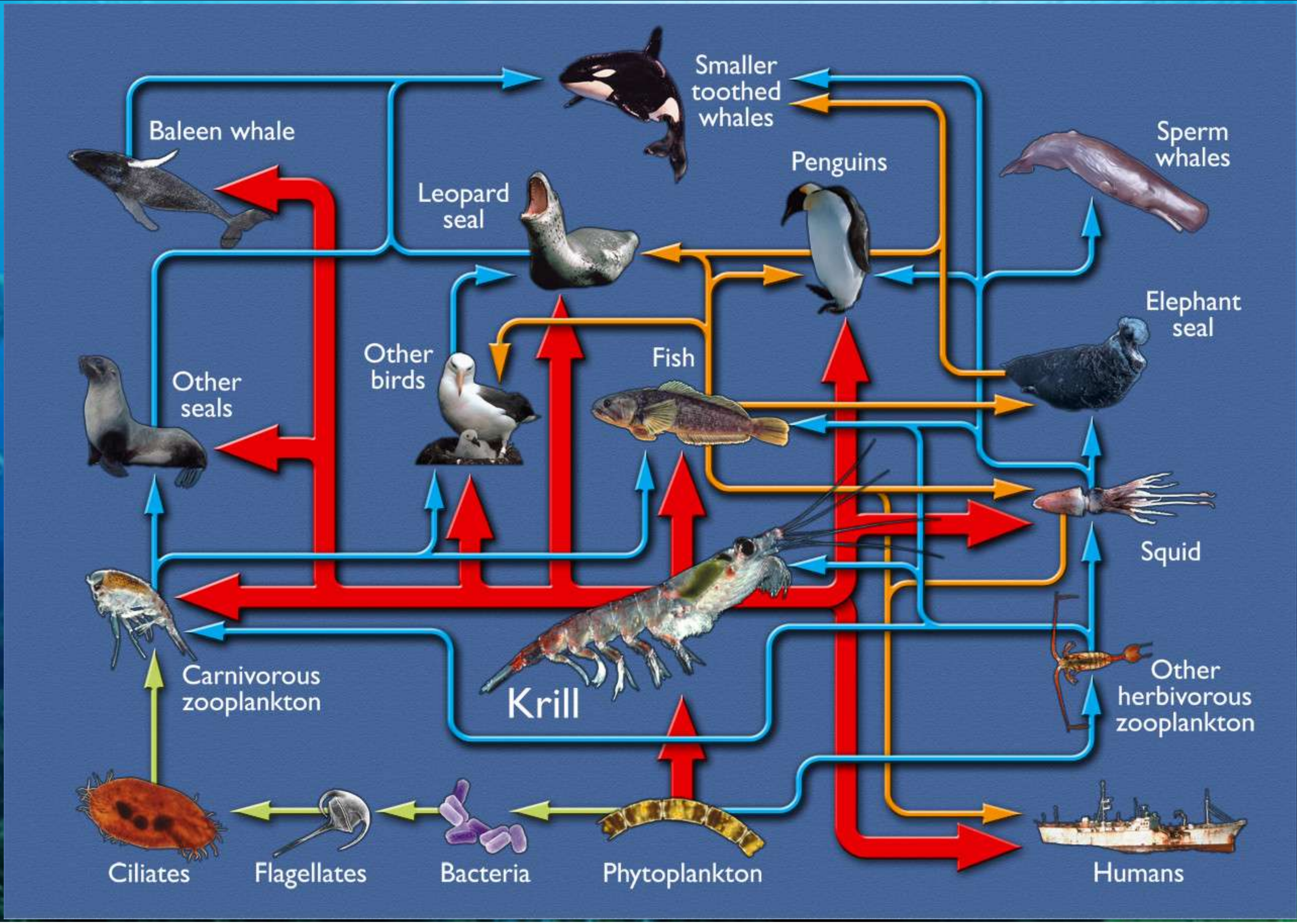
>10.000 ind m^{-1}
(William et al., 1983)

Antarctic krill *Euphausia superba* often dominates the zooplankton community in numbers and biomass. Antarctic krill has adapted to almost the entire range of marine habitats in the Southern Ocean, including the abyssal plains and the underside of pack-ice. Its potential distribution covers large parts of the Southern Ocean. Krill are highly influential organisms, capable of grazing as much as 55% of the net primary production and sustaining the functioning of the whole marine ecosystem in the Antarctic (Flores et al., 2012). Many polar organisms, from zooplankton to whales rely on krill as a primary food resource. Its estimated biomass Reach >400 million tons (Flores et al., 2012).

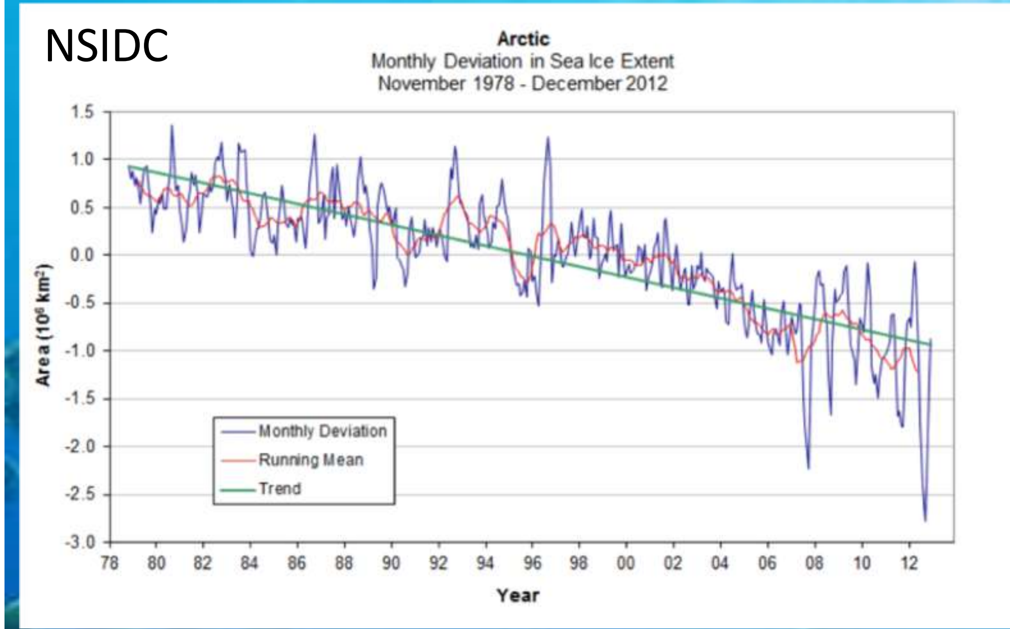
Crab-eater seal

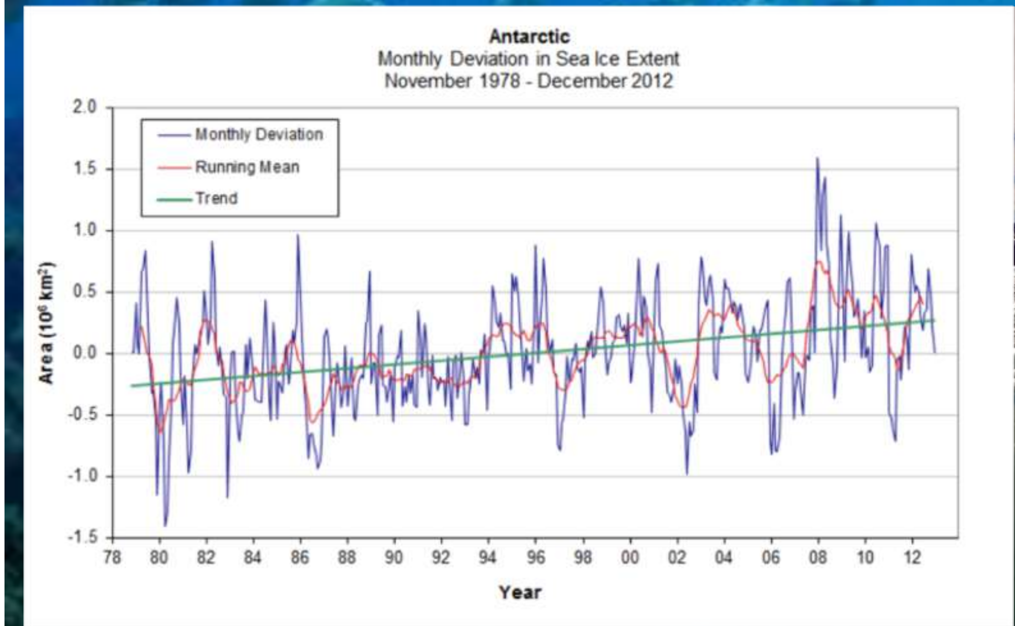
(*Lobodon carcinophaga*)

Trophic nets



Major threats to polar ecosystems





Global warming

Global warming is causing a fast reduction in ice cover especially in northern polar region. Antarctic ice seems more stable, or slighly increasing. However, some areas in the southern ocean are experiencing a decreasing trend.

Habitat destruction for seals and bears with consequent loss of feeding grounds and refuge

Decrease in primary productivity and risk of cascading effects

Earlier spring sea ice retreat and later fall sea ice formation

Shifts in species composition and northward faunal range expansions

Grebmeier 2012

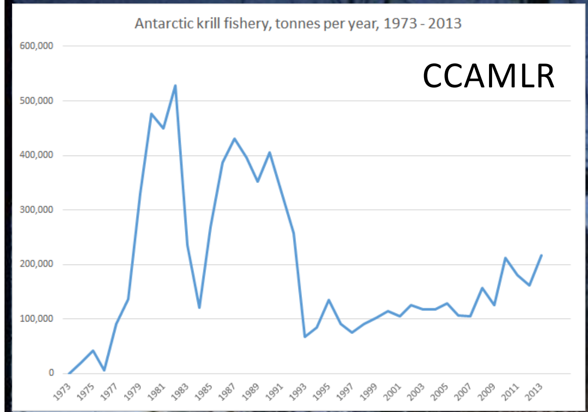
Major threats to polar ecosystems

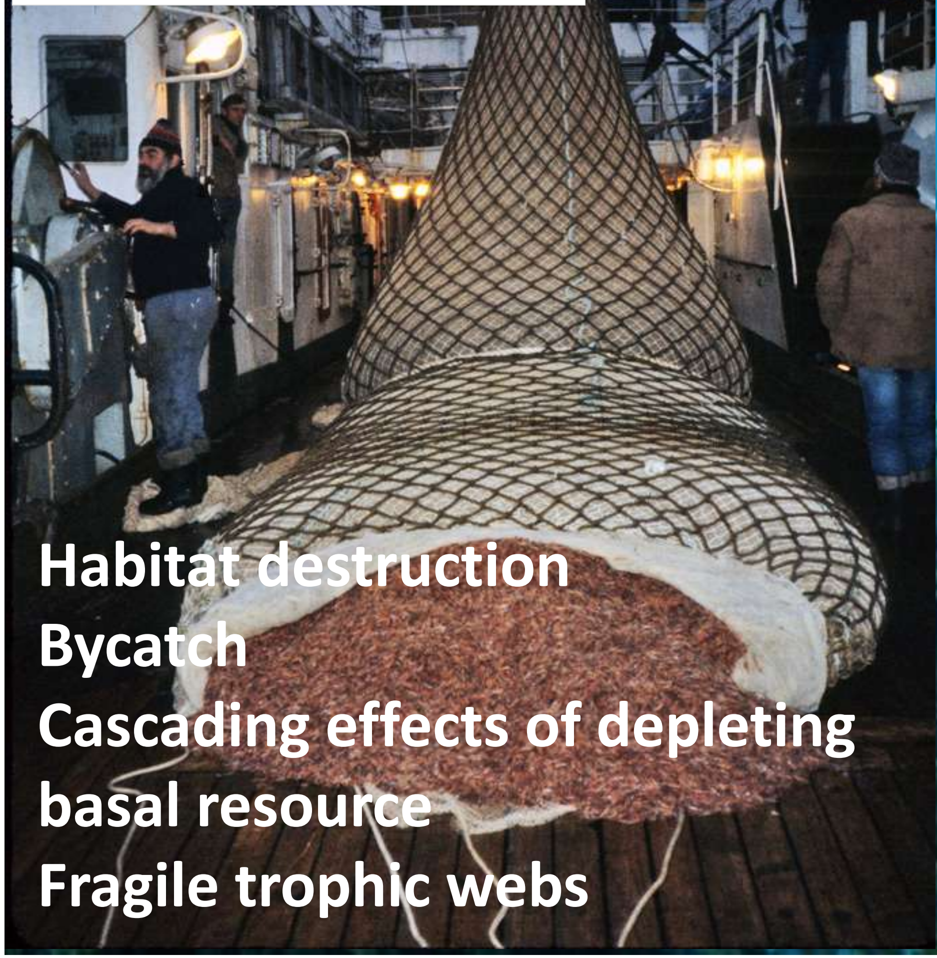
Pollution

Oil spills
Radioactive substances
PCBs, organochlorine
organochlorine pesticides
Heavy metals such as mercury, lead, cadmium
Plastic debris
(Muir et al 1992, Khalturin et al. 2005; Còzar et al., 2017)

Decrease primary production
Accumulation through trophic webs
Effects on reproduction and physiology
Injuries and dead

Major threats to polar ecosystems





Melting ice in the Far North open opportunities to extend fishing grounds.

Arctic (crabs, scallops, cod, halibut and many other)

Antarctic cod (toothfish)/ Icefish – now regulated

Habitat destruction
Bycatch
Cascading effects of depleting basal resource
Fragile trophic webs

Protection

International agreements to stop commercial fisheries for 16 years in the Arctic (2017). National regulations (e.g., Canada) to restric fishing areas. CAFF areas of management/use or park/reserve.
In 2016, OSPAR proposal of huge MPA, but some countries say not

There are currently 67 Antarctic Specially Protected Areas (ASPAs) and 7 Antarctic Specially Managed Areas (ASMAs) under international agreements, of which 6 are dedicated marine ASPAs, while 11 ASPAs and 4 ASMAs contain both marine and terrestrial habitat. (Griffiths 2010)