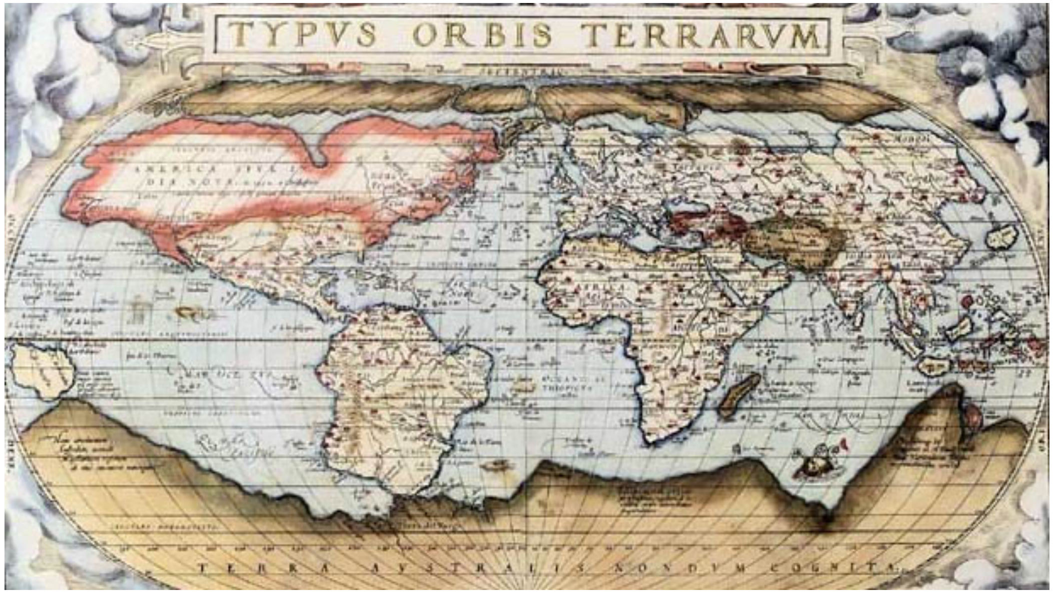
ANTON.VAN.DE.PUTTE@ULB.BE

THE SOUTHERN OCEAN

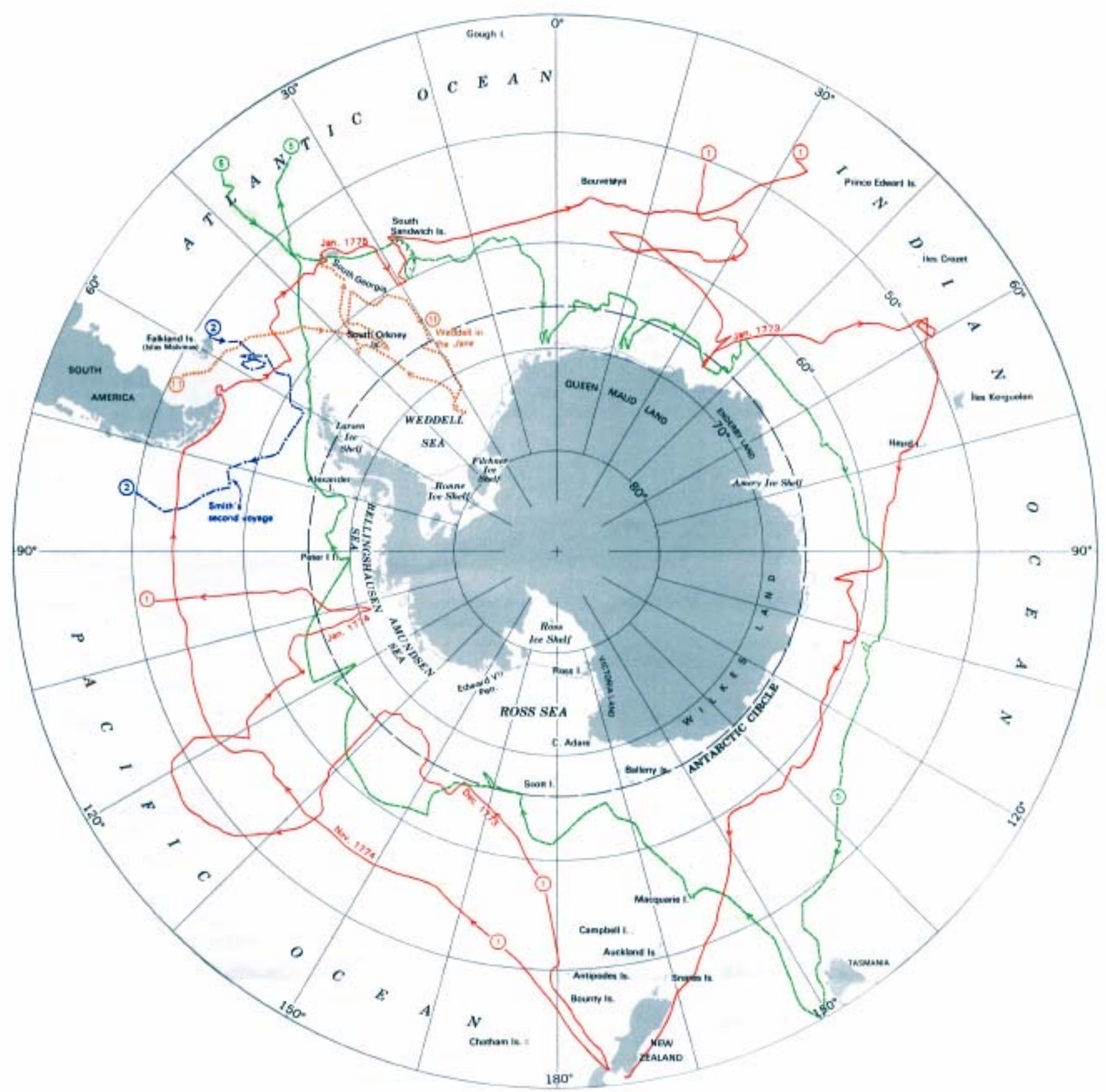


1570: WORLD MAP BY ORTELIU

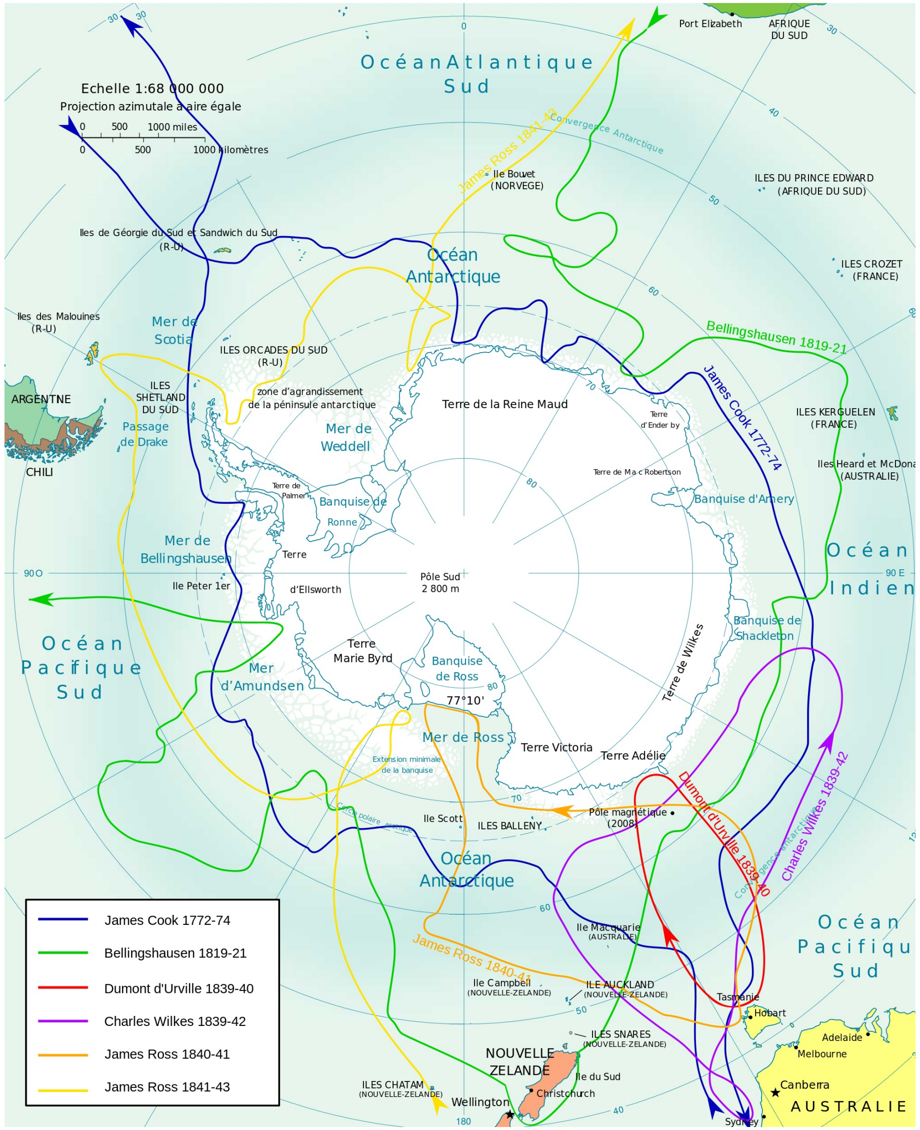
QUESTION: WHEN WAS THE FIRST BROADLY ACCURATE MAP OF ANTARCTICA MADE?

JAMES COOK'S SECOND VOYAGE (1772–75)

- First to enter the Antarctic Circle, Reports of great numbers of seals and whales
- Image Source: Antarctic Map Folio Series, 1975



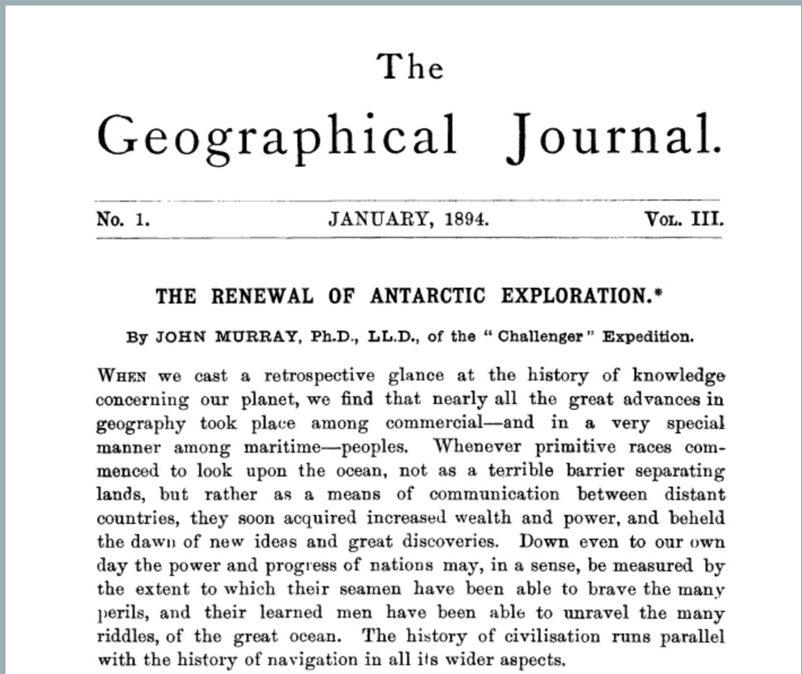
1819-1843



Echelle 1:68 000 000
Projection azimutale à aire égale
0 500 1000 miles
0 500 1000 kilomètres
Océan Atlantique Sud
Océan Antarctique
Océan Pacifique Sud
Océan Indien
Port Elizabeth
AFRIQUE DU SUD
Ile Bouvet (NORVEGE)
Convergence Antarctique
ILES DU PRINCE EDWARD (AFRIQUE DU SUD)
ILES CROZET (FRANCE)
ILES KERGUELEN (FRANCE)
Iles Heard et McDonald (AUSTRALIE)
Iles de Géorgie du Sud et Sandwich du Sud (R-U)
Iles des Malouines (R-U)
Mer de Scotia
ILES ORCADES DU SUD (R-U)
ILES SHETLAND DU SUD
zone d'agrandissement de la péninsule antarctique
ARGENTINE
CHILI
Passage de Drake
Mer de Weddell
Terre de la Reine Maud
Terre d'Ender by
Terre de Mac Robertson
Banquise d'Amery
Terre de Palmer
Banquise de Ronne
Mer de Bellingshausen
Ile Peter 1er
Terre d'Ellsworth
Pôle Sud 2 800 m
Terre Marie Byrd
Mer d'Amundsen
Banquise de Ross
77°10'
Mer de Ross
Terre Victoria
Terre Adélie
Terre de Wilkes
Banquise de Shackleton
Extension minimale de la banquise
Ile Scott
ILES BALLENY
Pôle magnétique (2008)
Ile Macquarie (AUSTRALIE)
Ile Campbell (NOUVELLE-ZELANDE)
ILE AUCKLAND (NOUVELLE-ZELANDE)
ILES SNARES (NOUVELLE-ZELANDE)
ILES CHATAM (NOUVELLE-ZELANDE)
NOUVELLE ZELANDE
Ile du Sud
Christchurch
Wellington
Tasmanie
Hobart
Adelaide
Melbourne
Canberra
Sydney
AUSTRALIE
Bellingshausen 1819-21
James Cook 1772-74
Dumont d'Urville 1839-40
Charles Wilkes 1839-42
James Ross 1840-41
James Ross 1841-43
James Cook 1772-74
Bellingshausen 1819-21
Dumont d'Urville 1839-40
Charles Wilkes 1839-42
James Ross 1840-41
James Ross 1841-43

HEROIC AGE 1897-1922

"The Renewal of Antarctic Exploration", given to the Royal geographical Society in London, November 27, 1893



The

Geographical Journal.

No. 1. JANUARY, 1894. Vol. III.

THE RENEWAL OF ANTARCTIC EXPLORATION.*

By JOHN MURRAY, Ph.D., LL.D., of the "Challenger" Expedition.

When we cast a retrospective glance at the history of knowledge concerning our planet, we find that nearly all the great advances in geography took place among commercial—and in a very special manner among maritime—peoples. Whenever primitive races commenced to look upon the ocean, not as a terrible barrier separating lands, but rather as a means of communication between distant countries, they soon acquired increased wealth and power, and beheld the dawn of new ideas and great discoveries. Down even to our own day the power and progress of nations may, in a sense, be measured by the extent to which their seamen have been able to brave the many perils, and their learned men have been able to unravel the many riddles, of the great ocean. The history of civilisation runs parallel with the history of navigation in all its wider aspects.

NAME SOME PEOPLE OF THE HEROIC AGE OF ANTARCTIC EXPLORATION

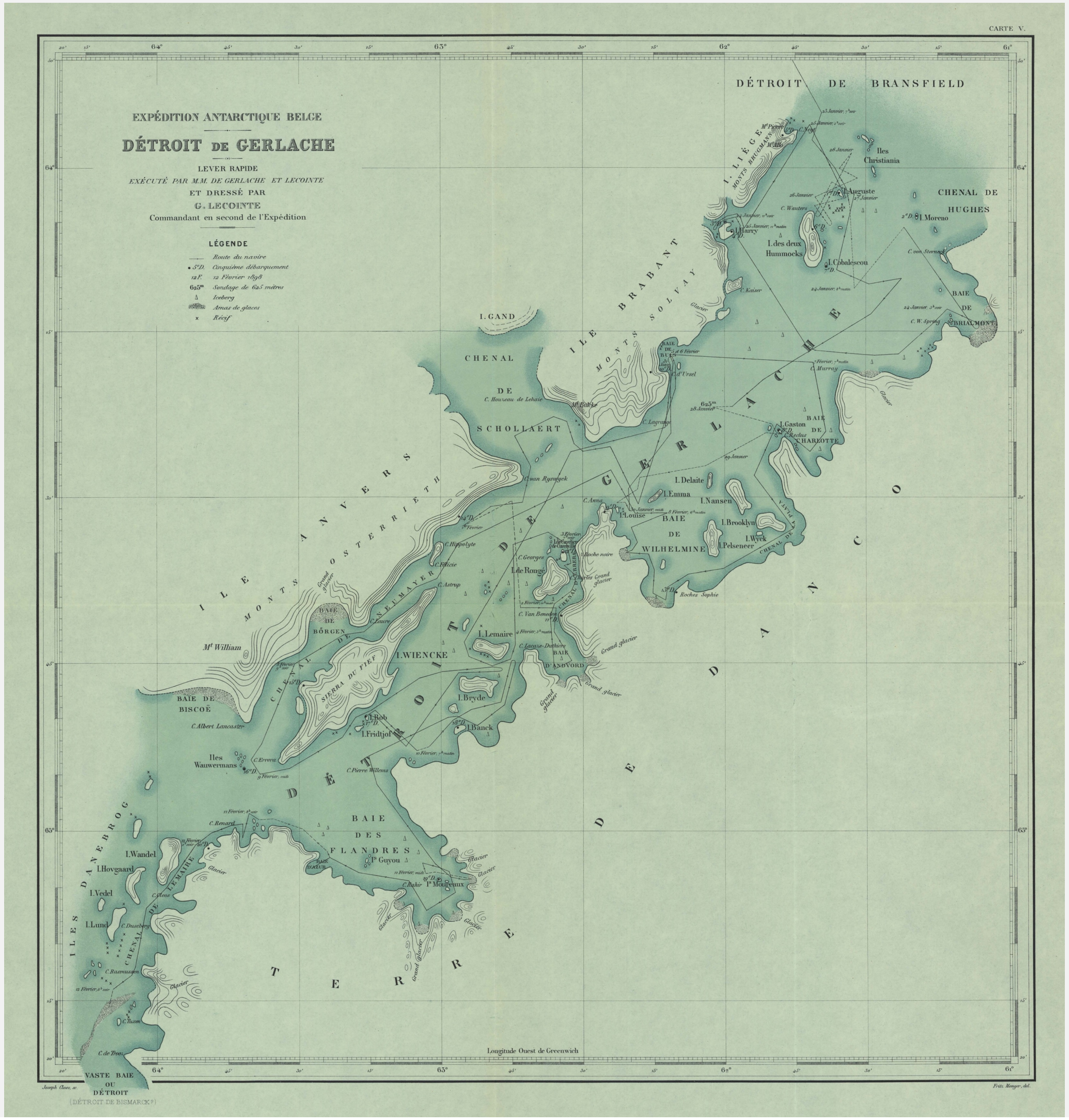
1897-1899 BELGIAN ANTARCTIC EXPEDITION

First international purely scientific expedition

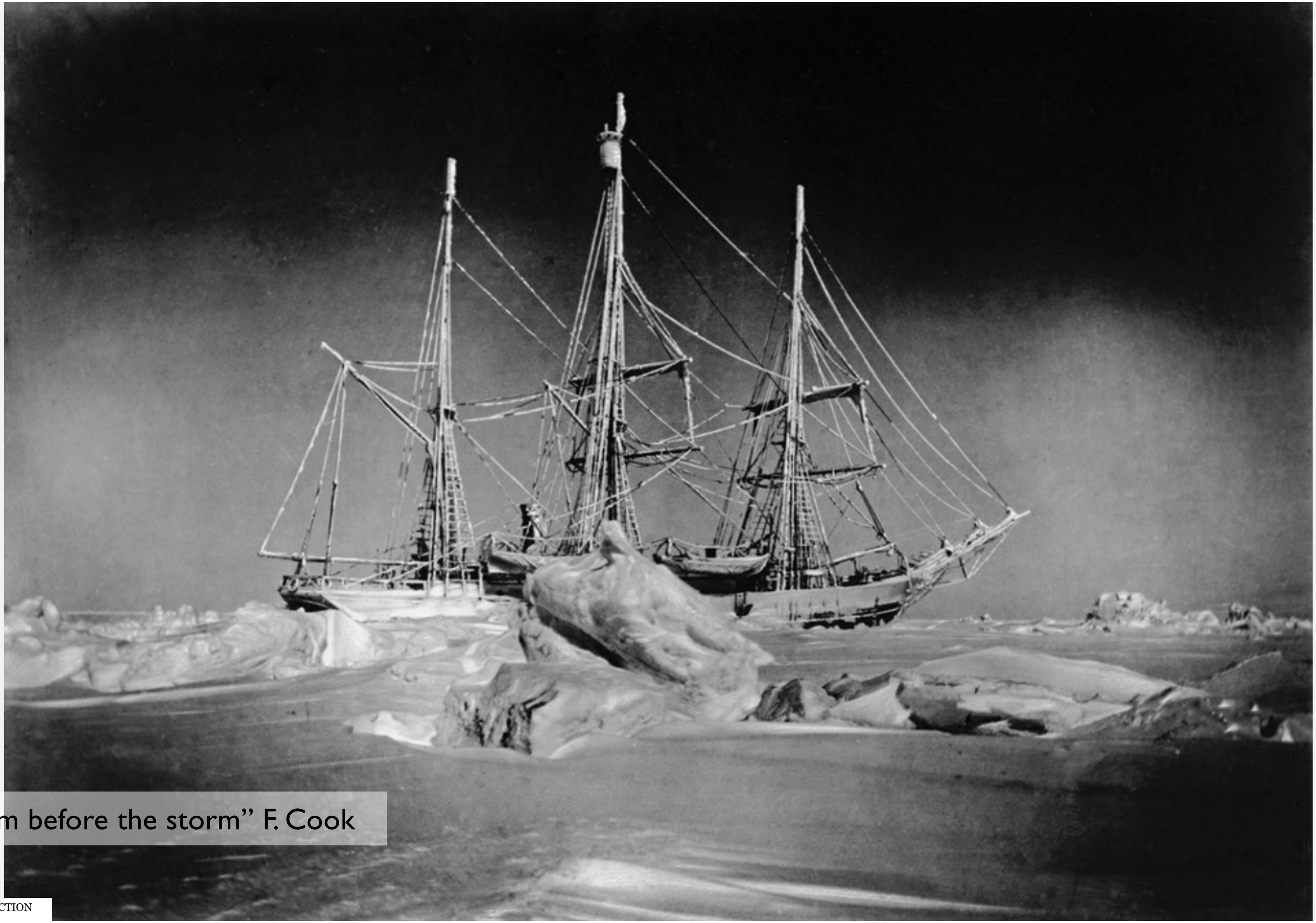
First expedition to winter within the Antarctic Circle

1 year of meteorological observations

- Detroite de Belgica

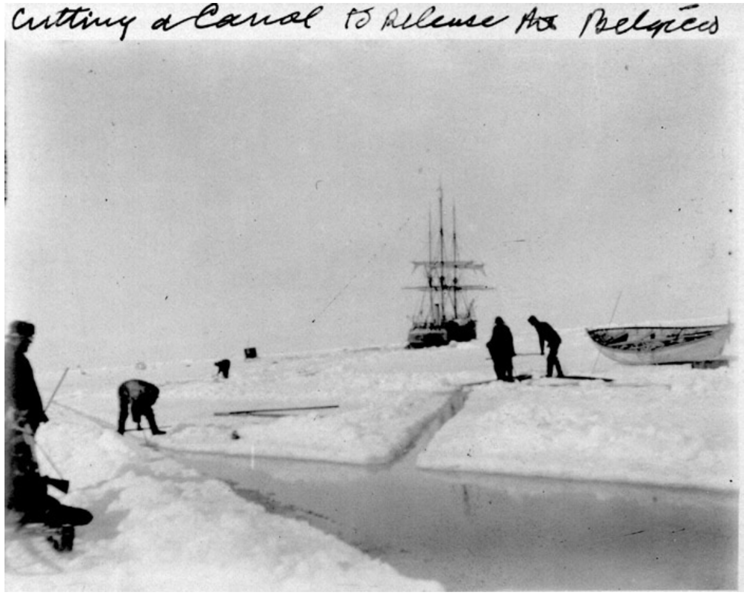


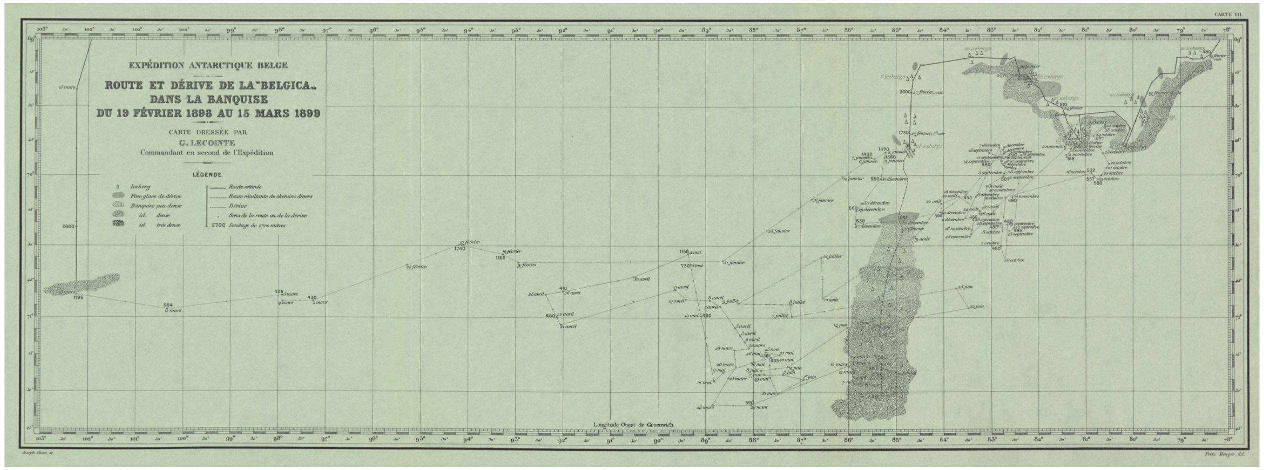
June
3th

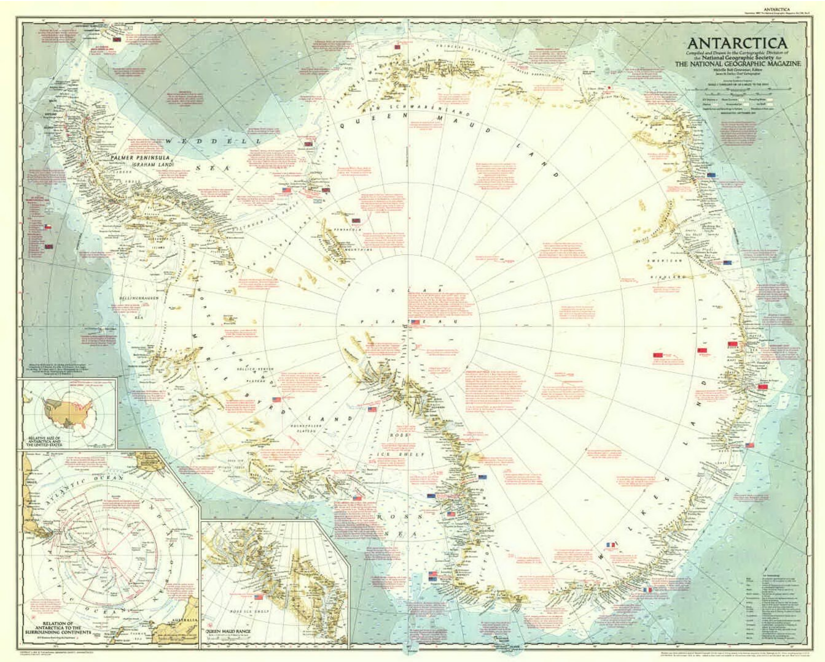


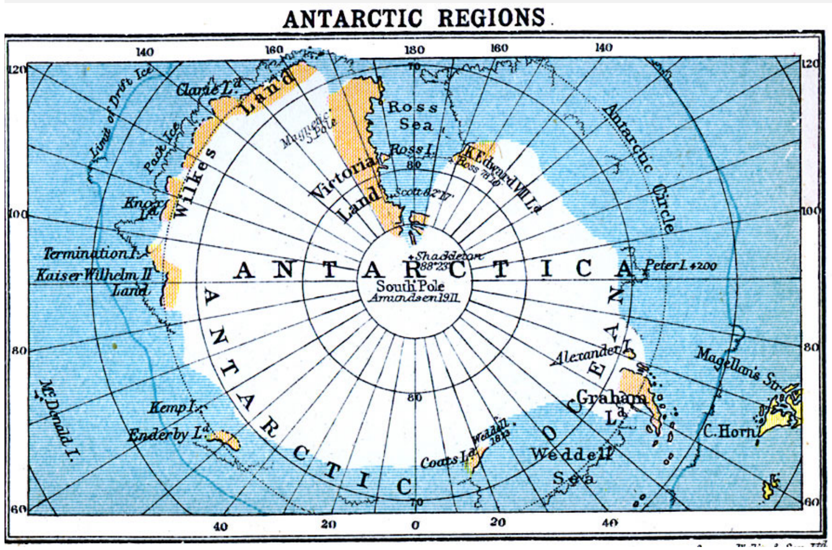
“The calm before the storm” F. Cook

Gerlache Family Collection


Cutting a Canal to Release the Belgica

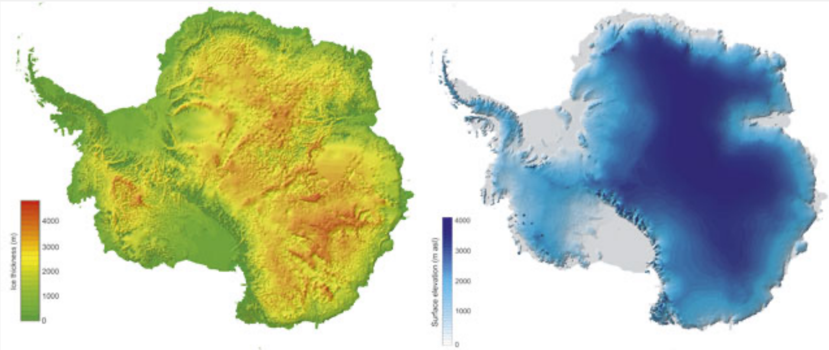

EXPÉDITION ANTARCTIQUE BELGE
ROUTE ET DÉRIVE DE LA "BELGICA" DANS LA BANQUISE DU 19 FÉVRIER 1898 AU 15 MARS 1899
CARTE DRESSÉE PAR
G. LECOINTE
Commandant en second de l'Expédition
LÉGENDE
Iceberg
Fine glace de dérive
Banquise peu dense
id. dense
id. très dense
Route estimée
Route résultante de chemins divers
Dérive
Sens de la route ou de la dérive
2700 Sondage de 2700 mètres
Longitude Ouest de Greenwich

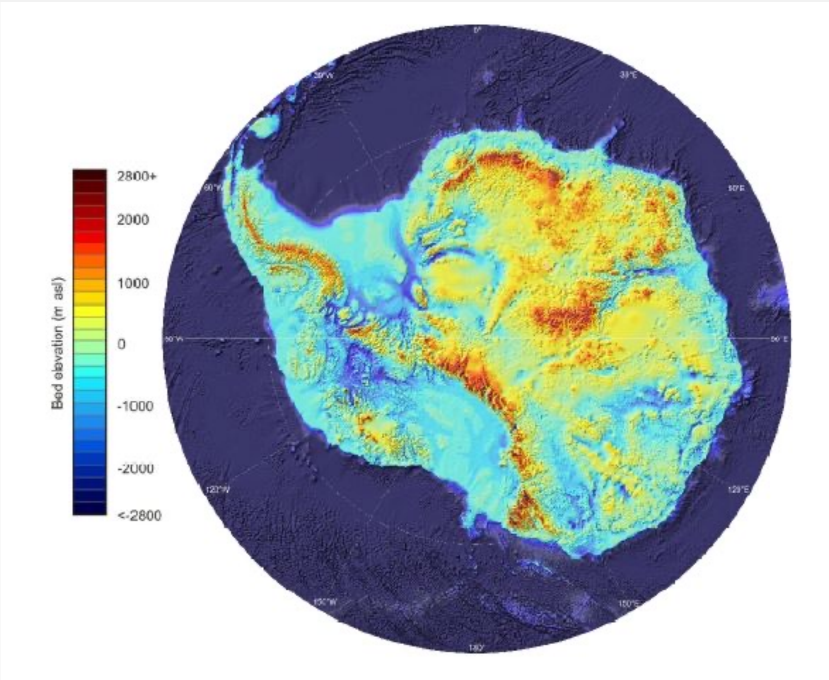




1920-1983

- 2nd International Polar Year
- International Geophysical Year of 1957-1958





Continent: 14 M km^2

Continental shelf deeper than usual (500-900m: 4x global ocean average)

Due to isostasic subsidence > ice mass on the continent (24.10^{15} T)

Narrower: 30-200 km (except Ross and Weddell Seas)

Basins usually deep (≥ 3000m)

Favours offshore and inshore water exchanges

Ocean encircles the continent: increases homogeneity

http://www.antarctica.ac.uk//bas_research/our_research/az/bedmap2/index.php

PHYSICO-CHEMICAL ENVIRONMENT

WATER MASSES AND CIRCULATION

- Coastal current:
  - East wind drift (anticlockwise)
- Offshore current:
  - West wind drift = Antarctic circumpolar current (ACC) (clockwise), main circulation system of Antarctic water masses

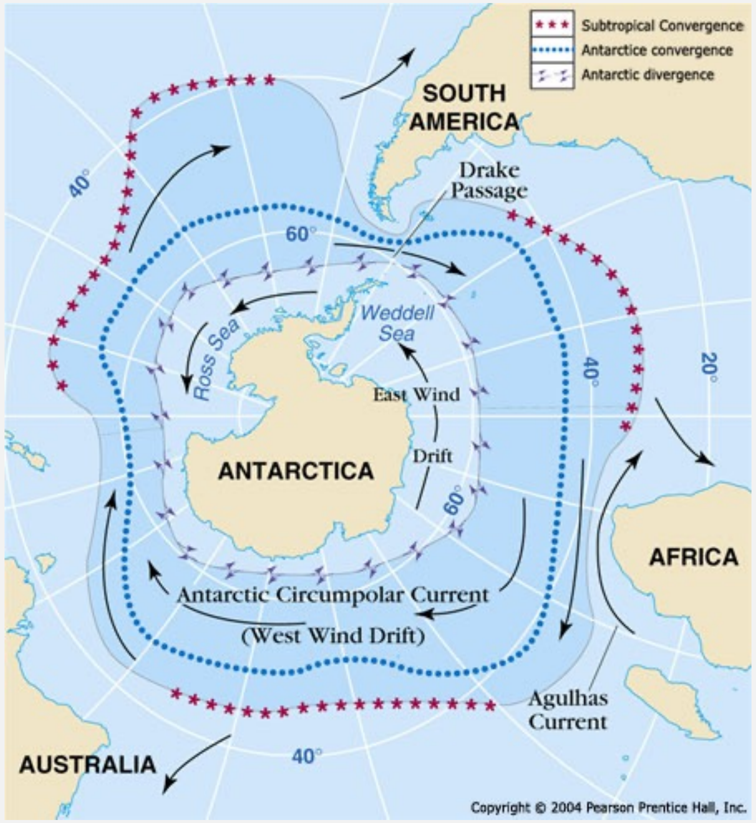
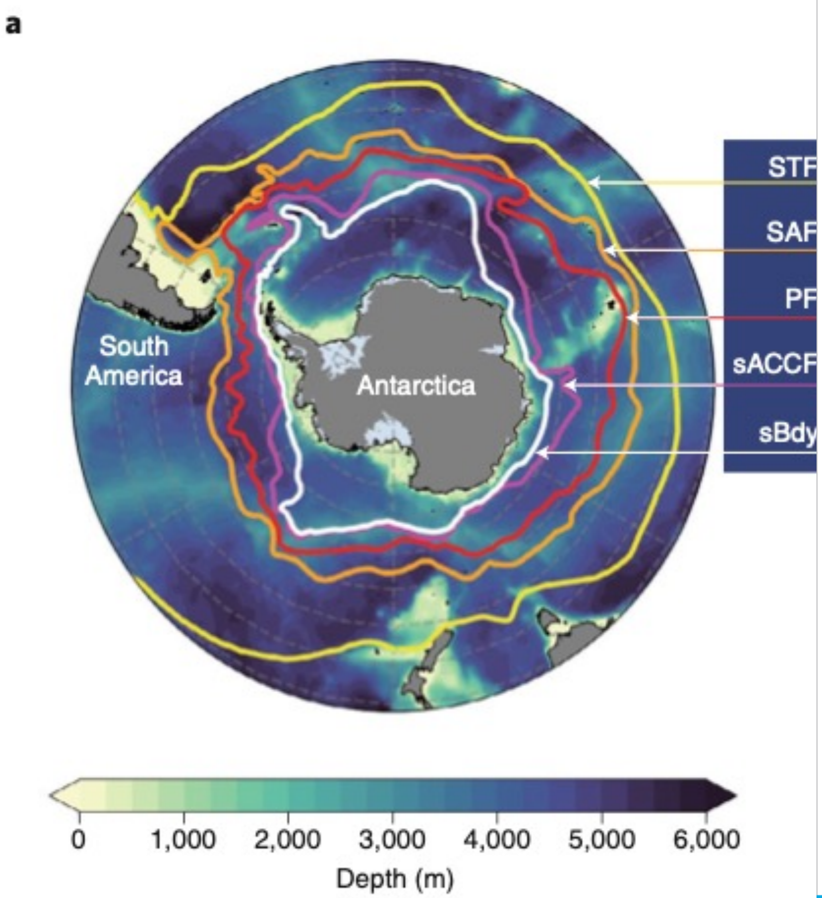
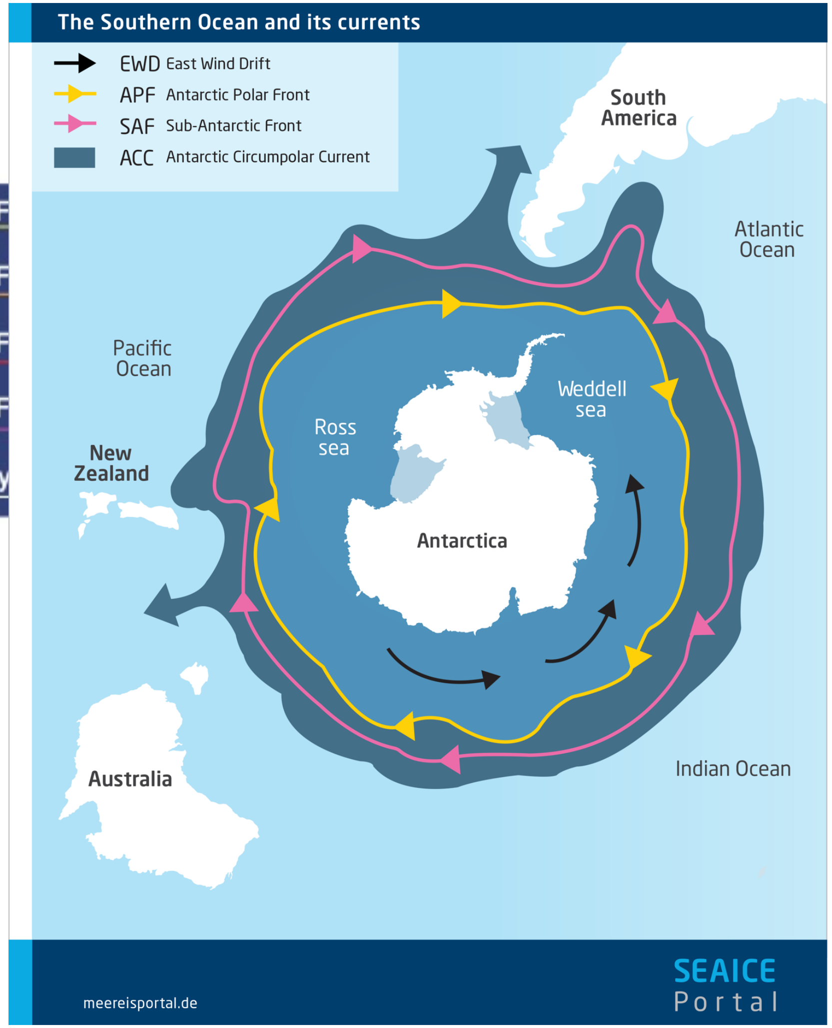


FIGURE 4. Circulation of the Southern Ocean, which is bounded by the Antarctic continent and the seafloor south of the Subtropical Convergence (Subantarctic Front Zone). The predominant clockwise trajectory of the West Wind Drift (Antarctic Circumpolar Current) extends south of the Antarctic Convergence (Antarctic Polar Front Zone), which is the northern boundary of the Antarctic marine ecosystem. South of the West Wind Drift is the counter-clockwise East Wind Drift and the Antarctic Divergence between them. (Modified from References 75, 93, and 214.)

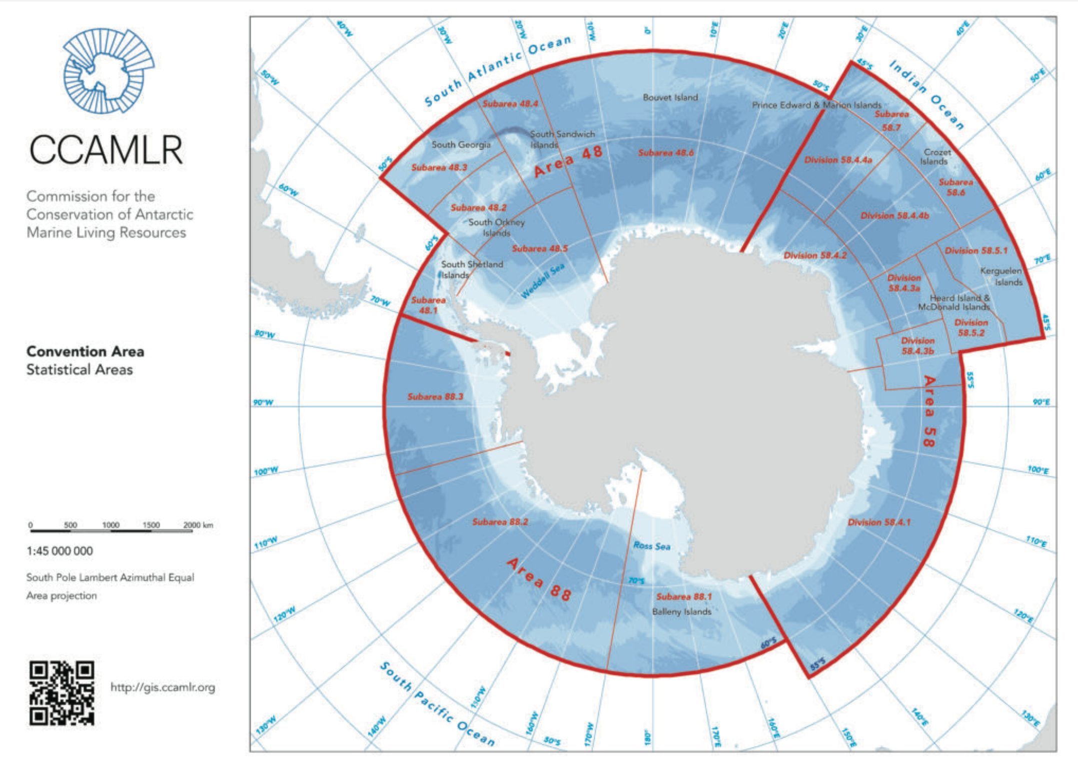
Sub Tropical Front	
Sub Antarctic Front	Antarctic Circumpolar Current
Polar Front	
Southern ACC Front	
Southern Boundary	
	Coastal Current/East Wind Drift

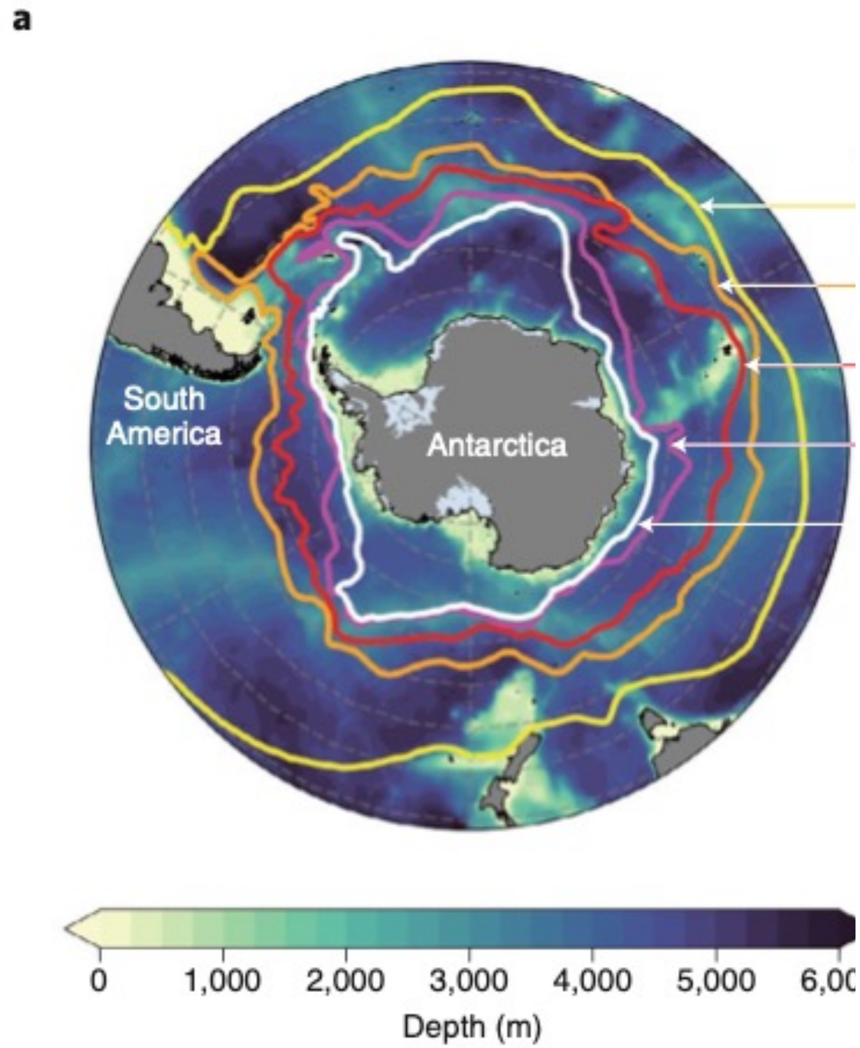




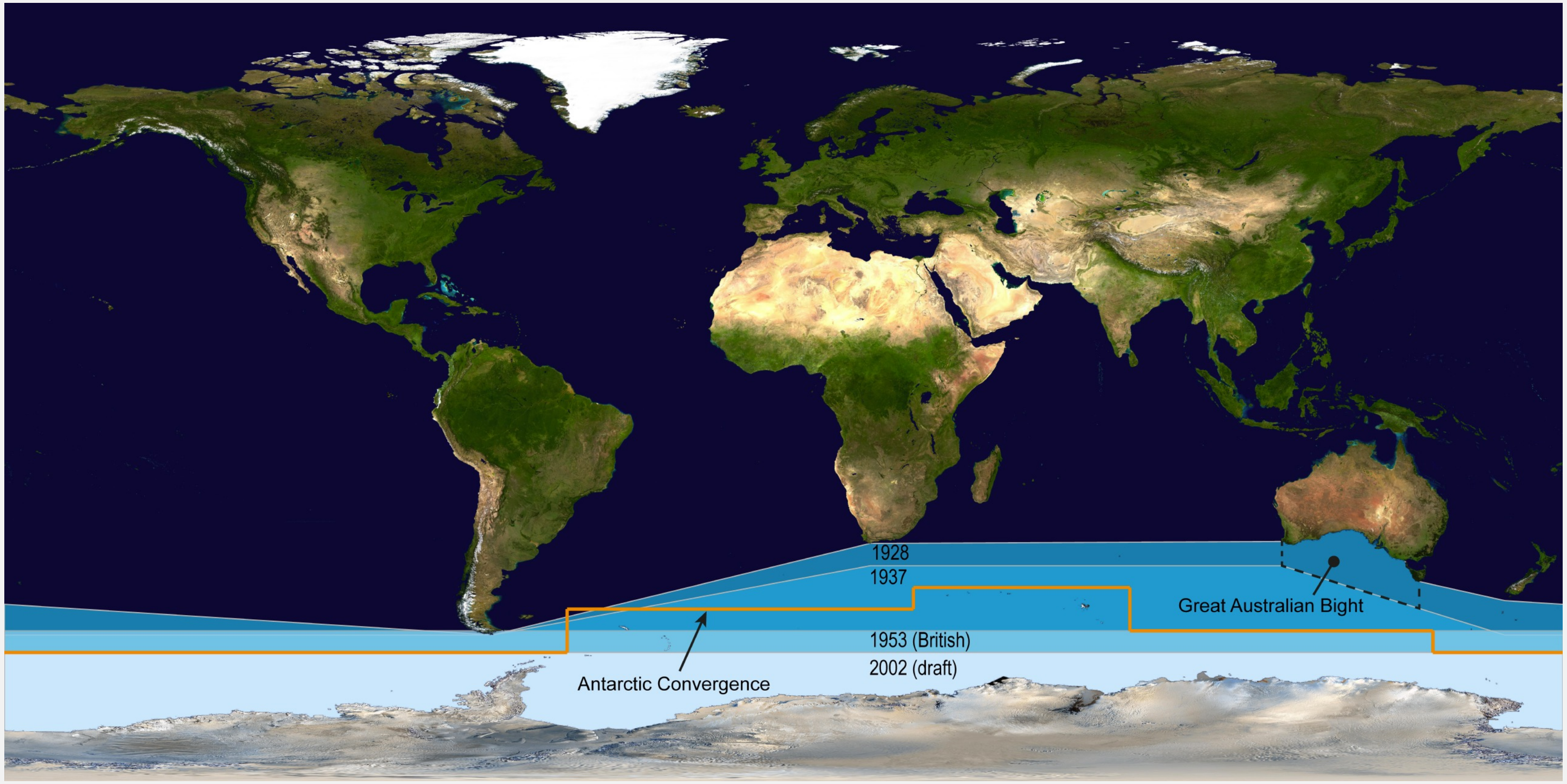
DIFFICULT TO DEFINE...

Antarctica is defined as all the land and ice shelves south of 60°S latitude


CCAMLR
Commission for the Conservation of Antarctic Marine Living Resources
Convention Area
Statistical Areas
1:45 000 000
South Pole Lambert Azimuthal Equal Area projection
http://gis.ccamlr.org
South Atlantic Ocean
Indian Ocean
South Pacific Ocean
Area 48
Area 58
Area 88
Subarea 48.1
Subarea 48.2
Subarea 48.3
Subarea 48.4
Subarea 48.5
Subarea 48.6
Subarea 58.6
Subarea 58.7
Division 58.4.1
Division 58.4.2
Division 58.4.3a
Division 58.4.3b
Division 58.4.4a
Division 58.4.4b
Division 58.5.1
Division 58.5.2
Subarea 88.1
Subarea 88.2
Subarea 88.3
South Georgia
South Sandwich Islands
South Orkney Islands
South Shetland Islands
Bouvet Island
Prince Edward & Marion Islands
Crozet Islands
Kerguelen Islands
Heard Island & McDonald Islands
Balleny Islands
Weddell Sea
Ross Sea


a
South America
Antarctica
0
1,000
2,000
3,000
4,000
5,000
Depth (m)

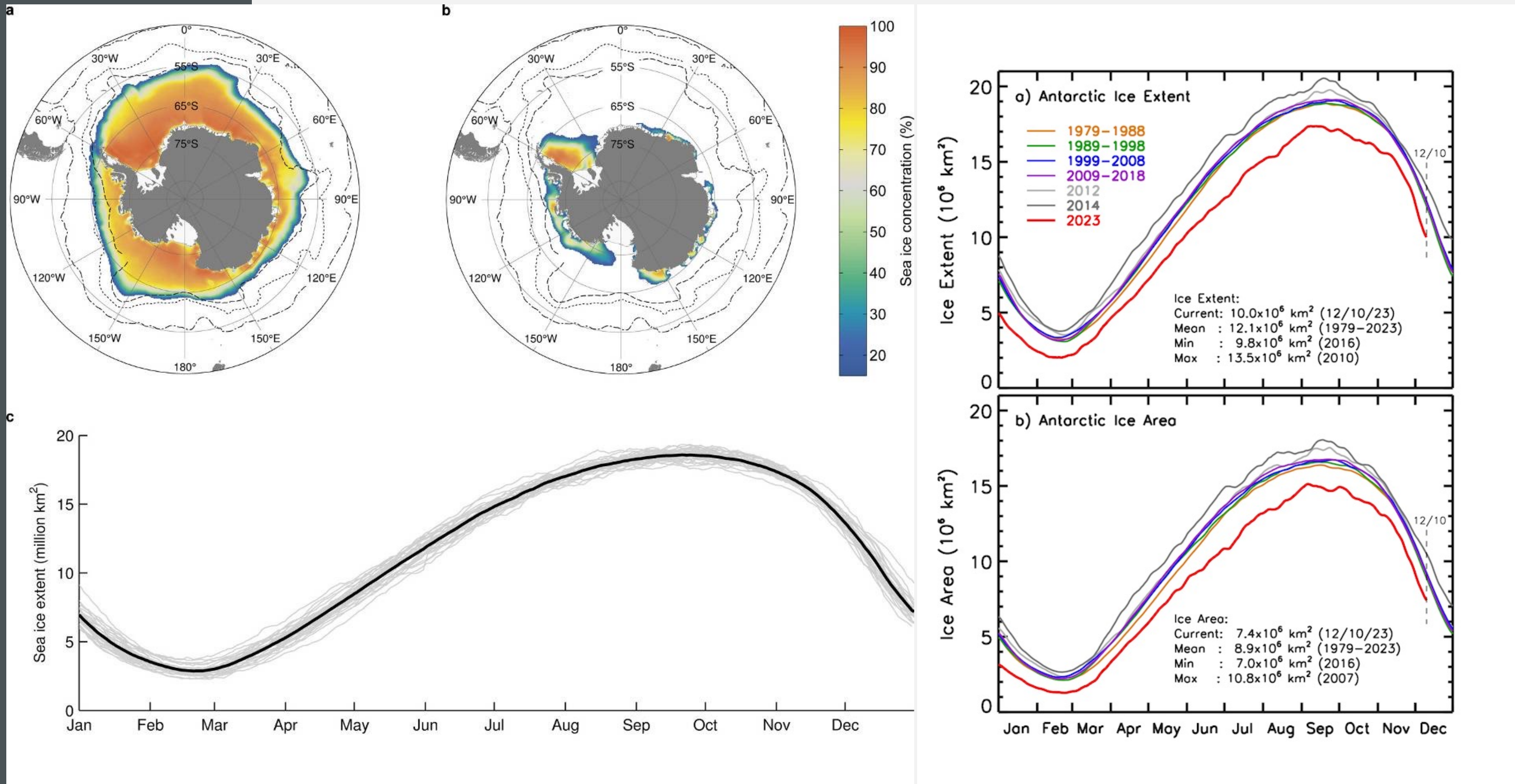
WORLD HYDROLOGICAL ORGANISATION



LIGHT

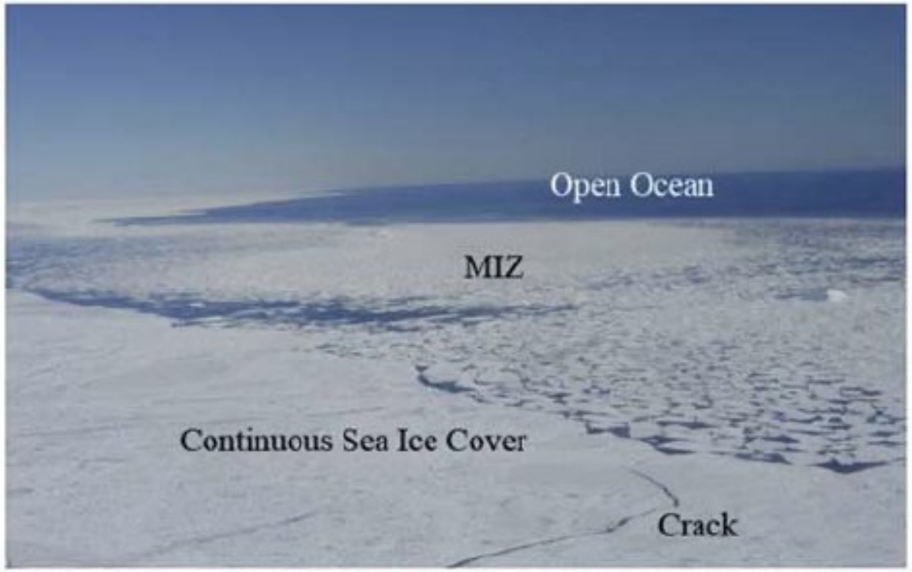
SEA ICE

- Sea Ice extent:
  - Max June - September
  - Min January – March
- Influence on light availability

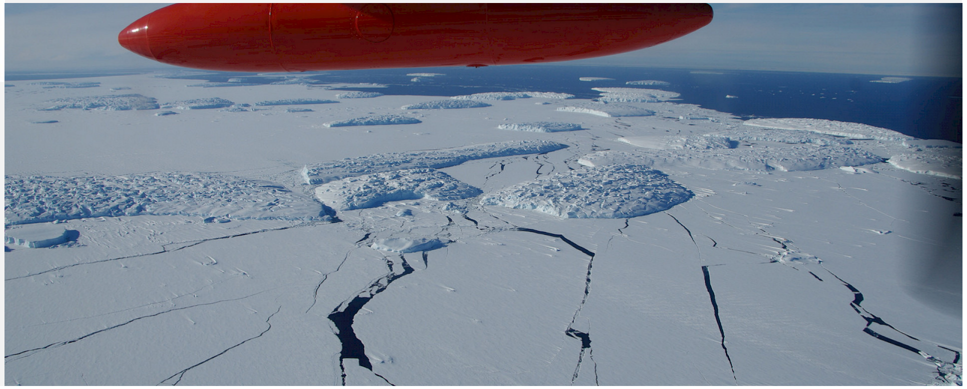


Post et al. 2014

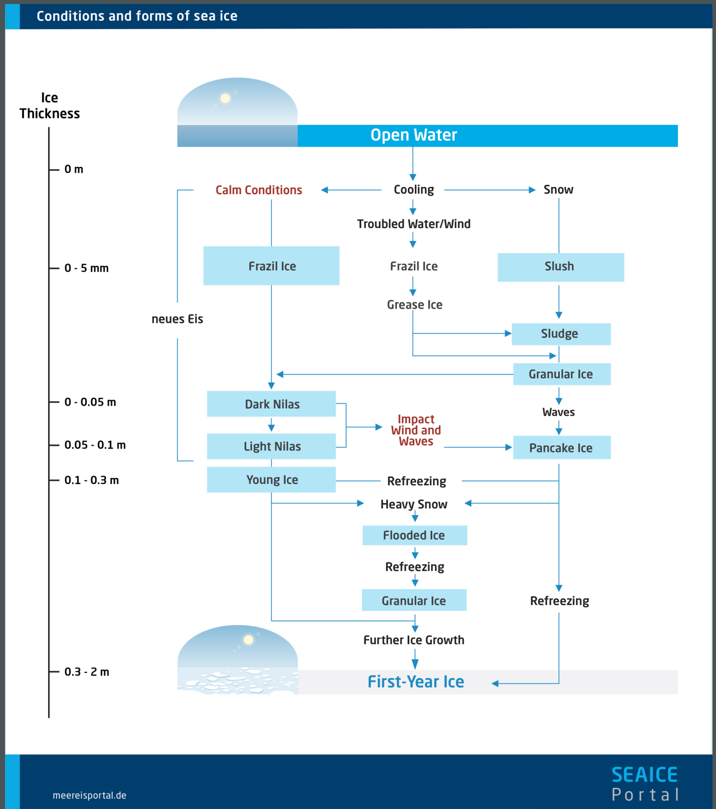
	Open Ocean	
Seasonal	Marginal Ice Zone	15-80% Ice cover
Perennial	Pack Ice Zone	smaller, free-floating pieces of sea ice.
	Shear Zone	highly deformed ice along the coast
	Fast Ice Zone	ice anchored to the shoreline

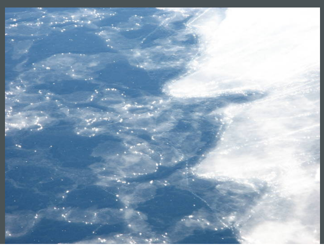


Fast ice (left) and pack ice (right). (Left: Peterfitzgerald (Own work) [CC BY-SA 3.0], via Wikimedia Commons; Right: Markus Trienke, https://www.flickr.com/photos/mtrienke/34281559366/in/photostream/ [CC BY-SA 2.0]).



TYPES OF ICE

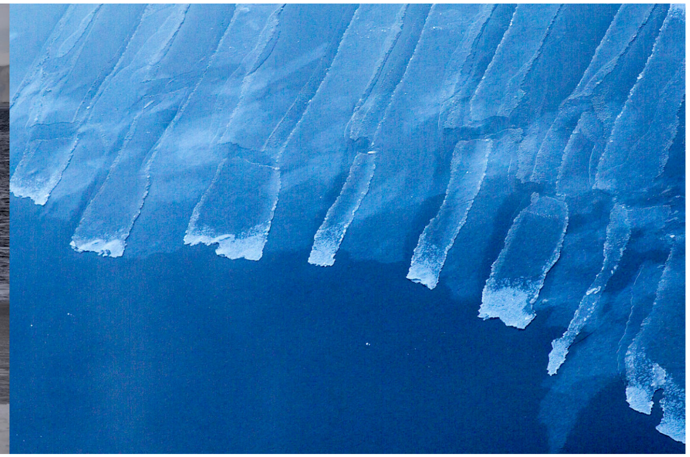




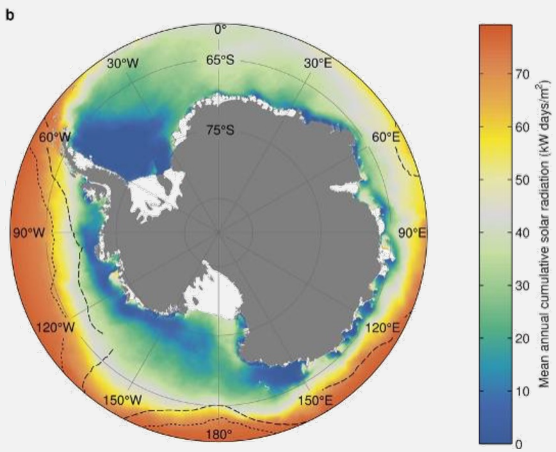
Frazil ice Photo: Frederique Olivier

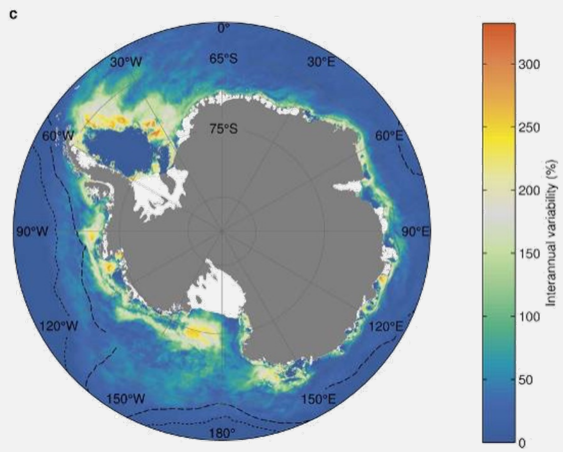
Pancake ice Photo: Sandra Zicus

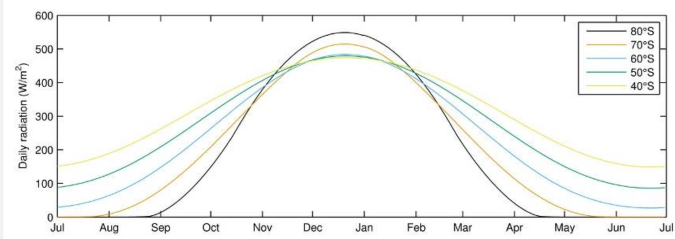
Grease ice: Photo: Jen Wressell

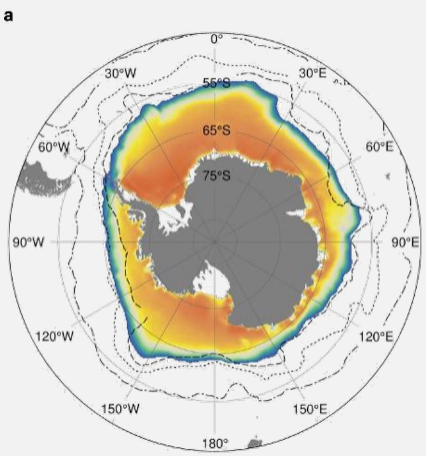


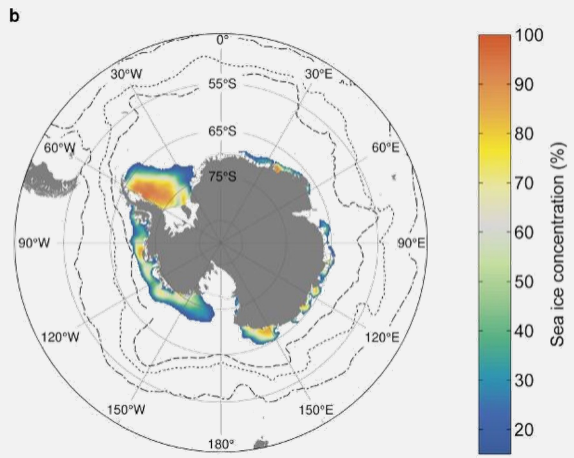
Nilas ice: Photo: Richard Youd

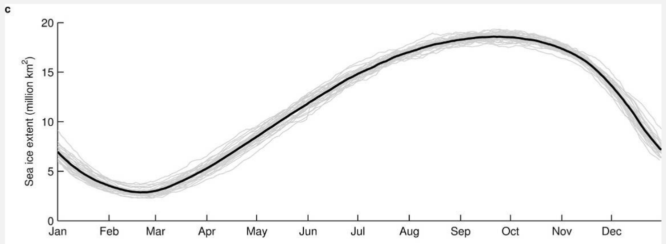








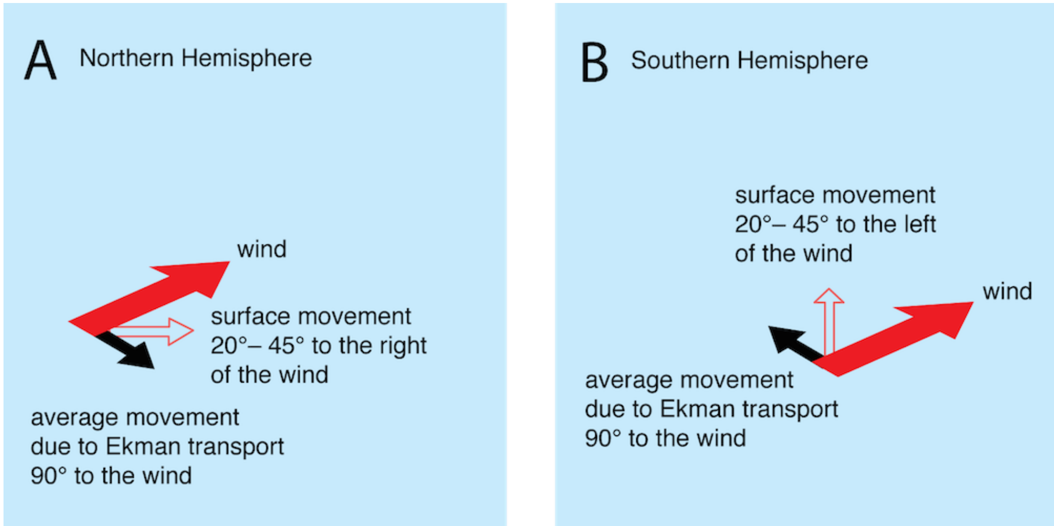


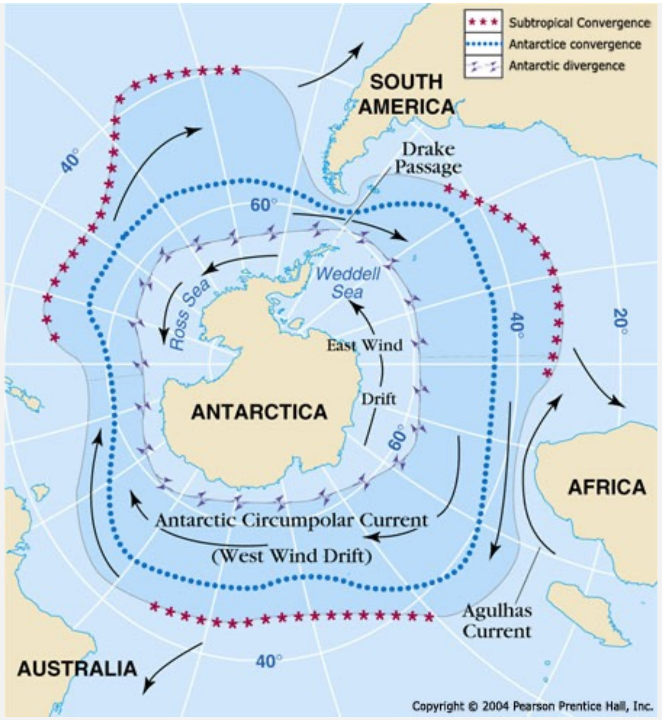


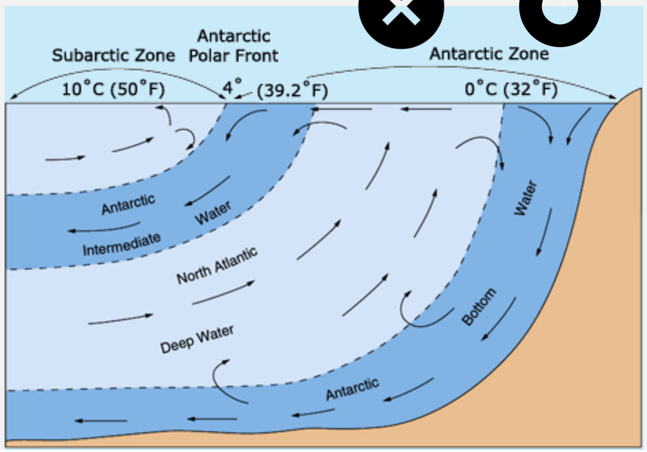
Post et al 2014

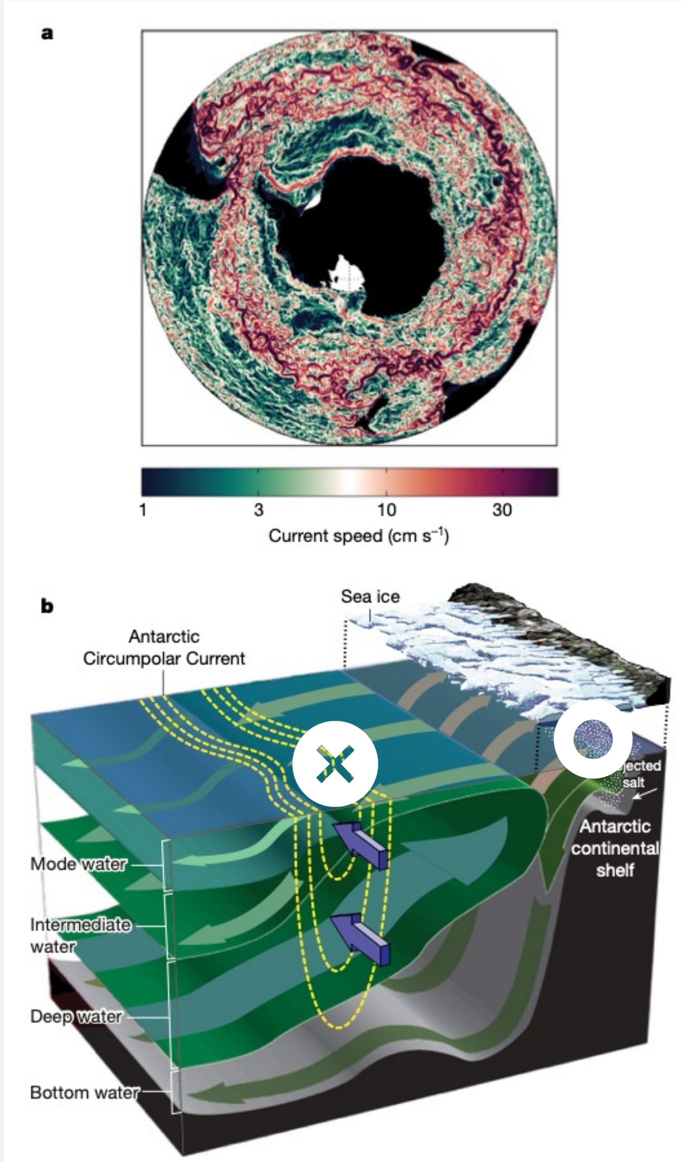
QUESTION WHICH DIRECTION IS THE CORIOLIS DEFECTION/EKMANN TRANSPORT IN THE SOUTHERN HEMISPHERE

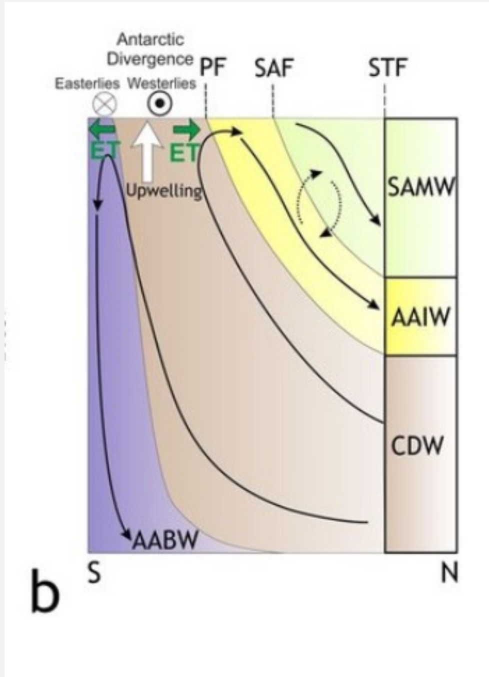
EKMAN TRANSPORT

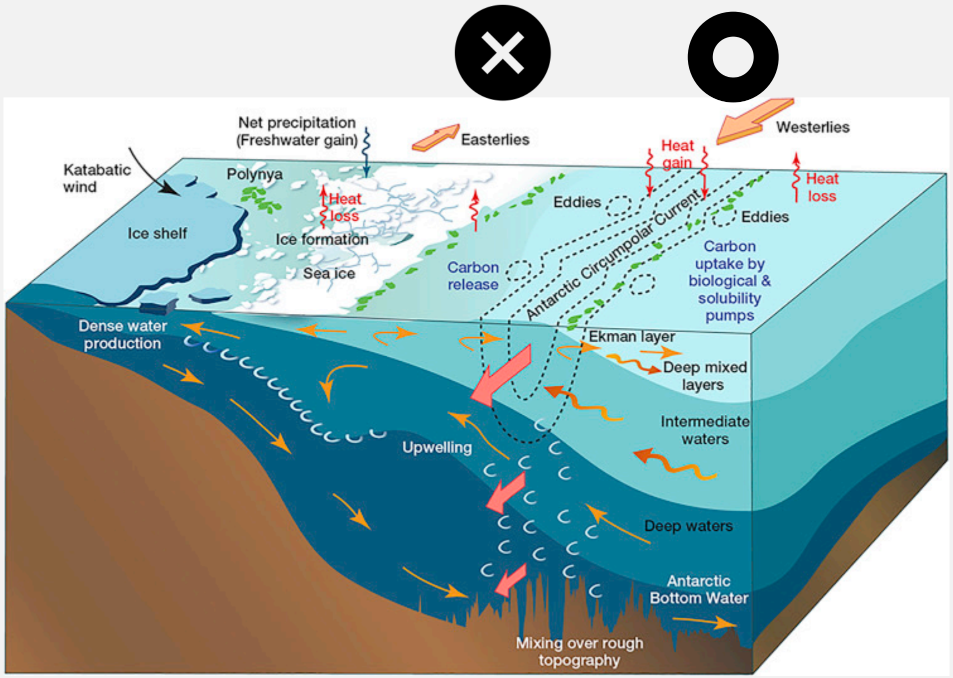



Subtropical Convergence
Antarctice convergence
Antarctic divergence
SOUTH AMERICA
Drake Passage
Weddell Sea
Ross Sea
East Wind
Drift
ANTARCTICA
AFRICA
Antarctic Circumpolar Current
(West Wind Drift)
Agulhas Current
AUSTRALIA
40°
60°
20°
Copyright © 2004 Pearson Prentice Hall, Inc.


Subarctic Zone
Antarctic Polar Front
Antarctic Zone
10°C (50°F)
4° (39.2°F)
0°C (32°F)
Antarctic Intermediate Water
North Atlantic Deep Water
Antarctic Bottom Water


a
1
3
10
30
Current speed (cm s⁻¹)
b
Sea ice
Antarctic Circumpolar Current
Rejected salt
Antarctic continental shelf
Mode water
Intermediate water
Deep water
Bottom water

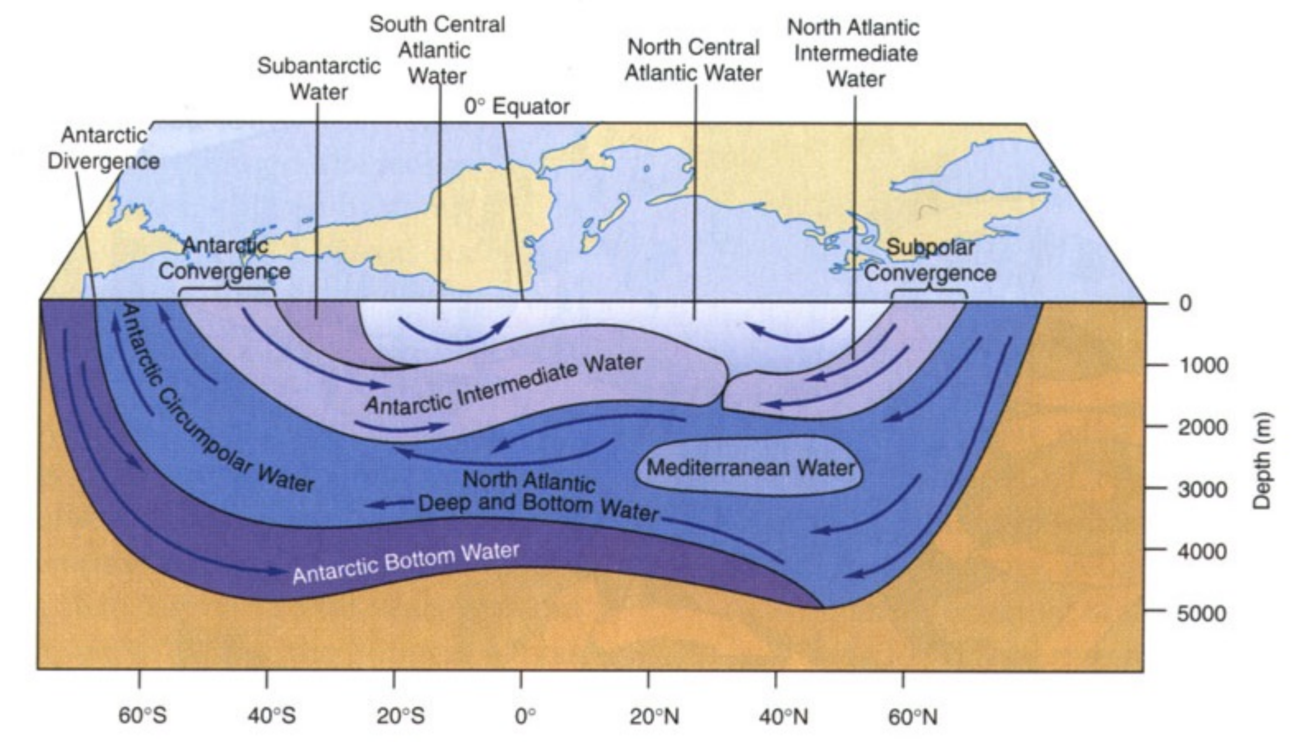




- Upwelling of Circumpolar Deep Water (> North Atlantic Deep Water)
- CDW mixes with cold Ice Shelf Water → sinks as Antarctic Bottom Water (→ up to 5°S)
- CDW also mixes with less salty Antarctic Superficial Water → Antarctic Intermediate Water
- AIW sinks below warmer Subantarctic water = Polar Front = Antarctic Convergence (downwelling)

http://hdrake.github.io/research.html

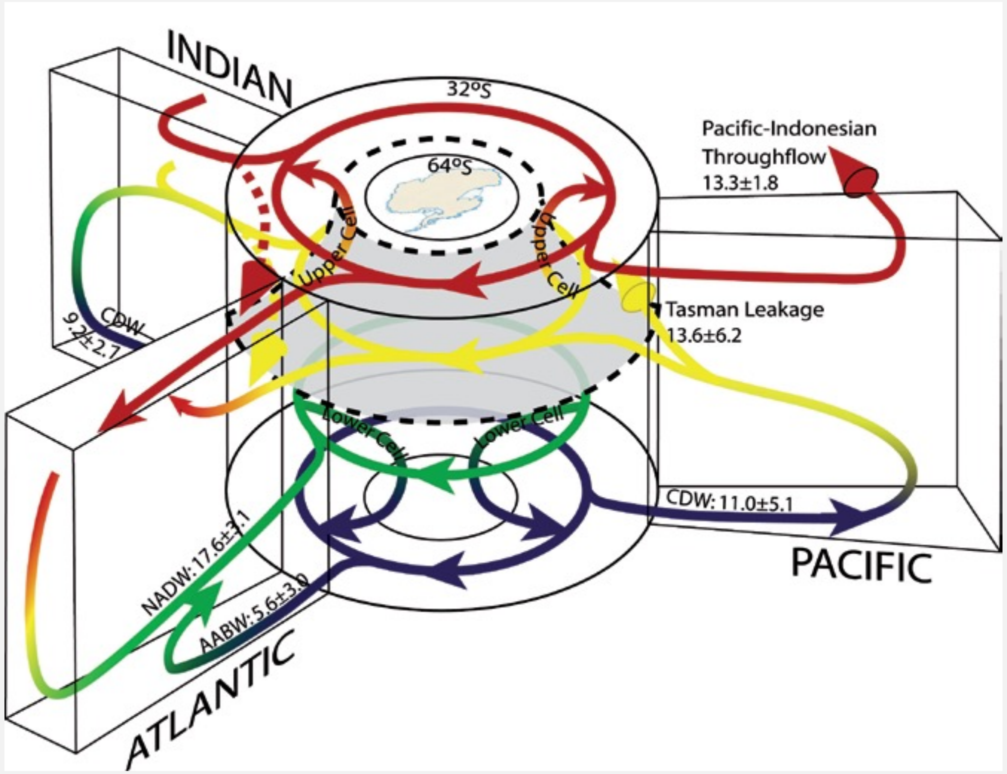
1. PHYSICO-CHEMICAL ENVIRONMENT
1.1. WATER MASSES AND CIRCULATION



Segar 1997

The Southern Ocean plays a key role in the general thermohaline circulation

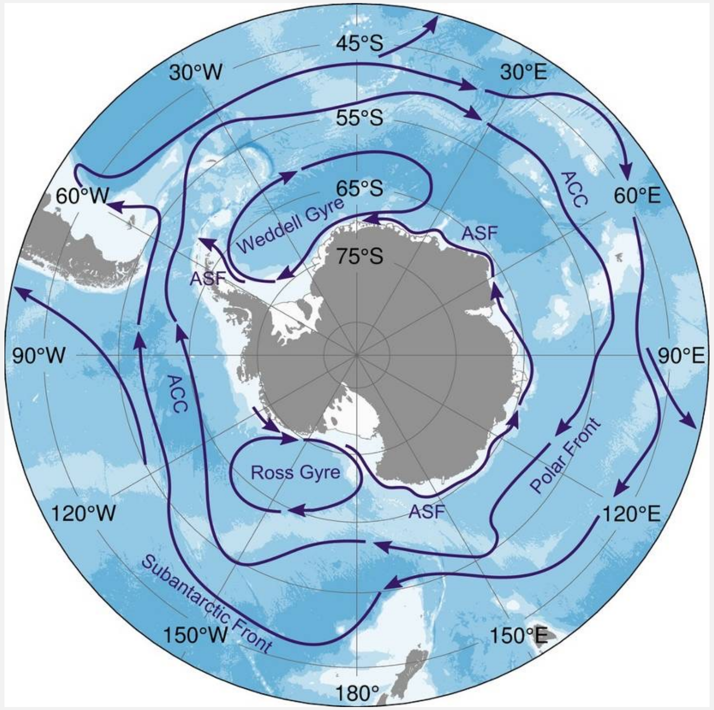
THERMOHALINE CIRCULATION



Lumpkin & Speer 2007

The Southern Ocean plays a key role in the general thermohaline circulation

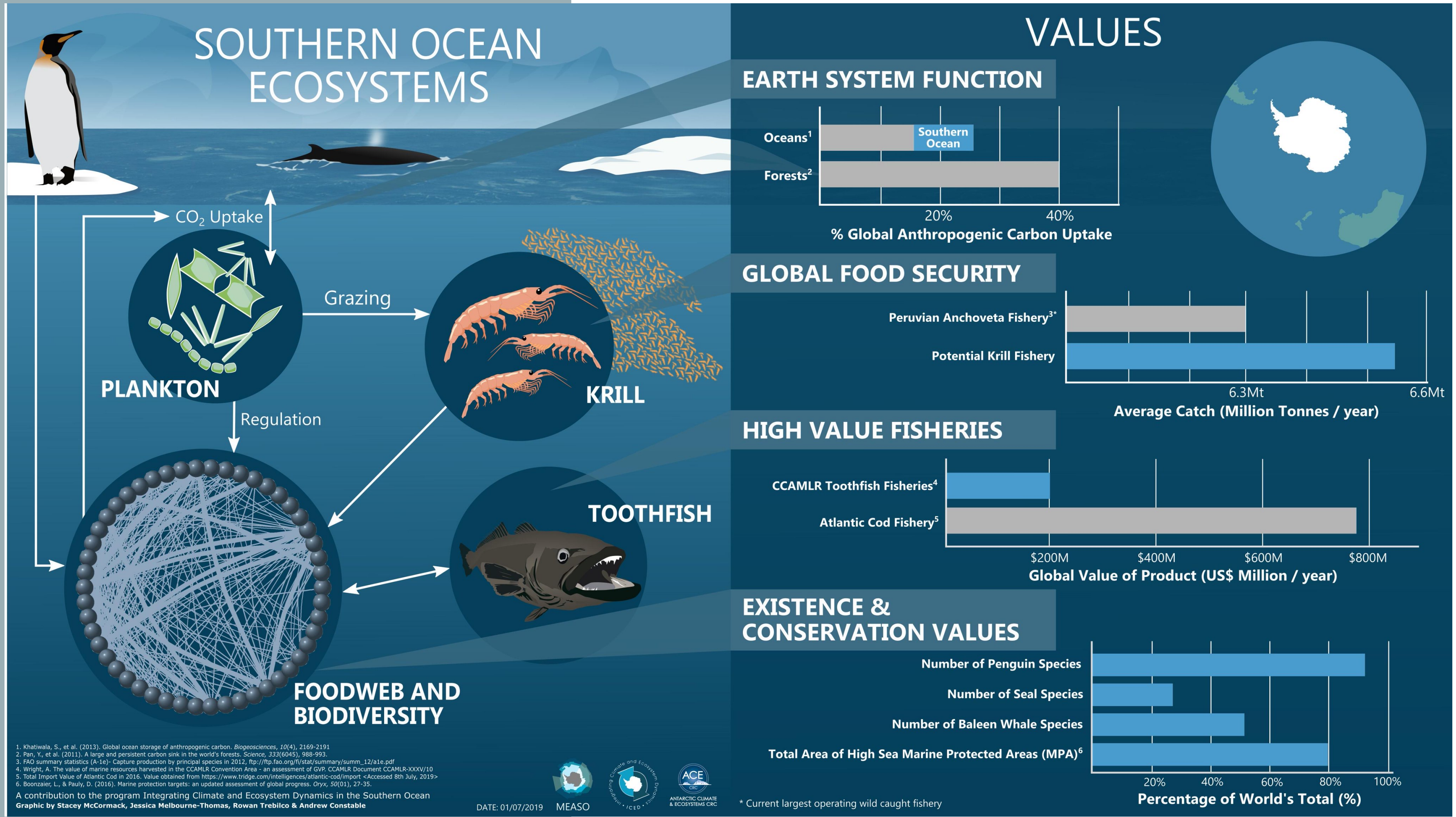
I. PHYSICO-CHEMICAL ENVIRONMENT
I.I. WATER MASSES AND CIRCULATION



- Antarctic convergence = north limit of Antarctic zone
- Between Antarctic and Subtropical convergences = Subantarctic zone
- Antarctic + Subantarctic zone= Southern Ocean
- Subantarctic zone 2-4°C warmer than Antarctic zone

➢ Antarctic convergence (Polar front)= strong biological border

WHAT ARE ECOSYSTEM SERVICE WE RECEIVE FROM THE SOUTHERN OCEAN

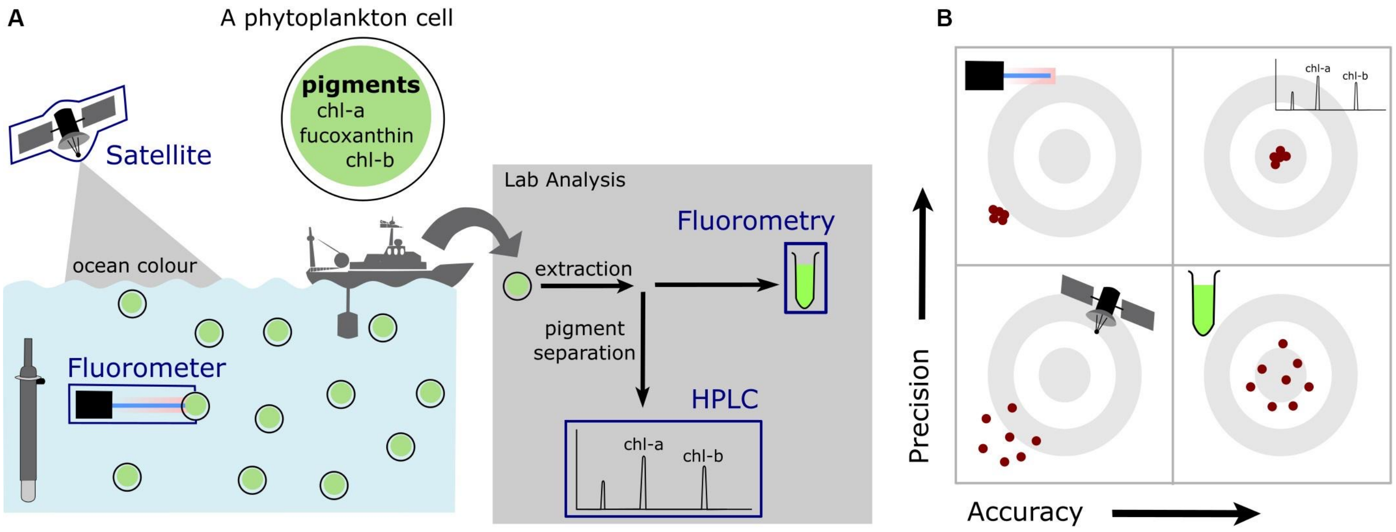

SOUTHERN OCEAN ECOSYSTEMS
CO_2 Uptake
Grazing
PLANKTON
Regulation
KRILL
TOOTHFISH
FOODWEB AND BIODIVERSITY
VALUES
EARTH SYSTEM FUNCTION
Oceans[1]
Southern Ocean
Forests[2]
20%
40%
% Global Anthropogenic Carbon Uptake
GLOBAL FOOD SECURITY
Peruvian Anchoveta Fishery[3*]
Potential Krill Fishery
6.3Mt
6.6Mt
Average Catch (Million Tonnes / year)
HIGH VALUE FISHERIES
CCAMLR Toothfish Fisheries[4]
Atlantic Cod Fishery[5]
$200M
$400M
$600M
$800M
Global Value of Product (US$ Million / year)
EXISTENCE & CONSERVATION VALUES
Number of Penguin Species
Number of Seal Species
Number of Baleen Whale Species
Total Area of High Sea Marine Protected Areas (MPA)[6]
20%
40%
60%
80%
100%
Percentage of World's Total (%)
* Current largest operating wild caught fishery
1. Khatiwala, S., et al. (2013). Global ocean storage of anthropogenic carbon. Biogeosciences, 10(4), 2169-2191
2. Pan, Y., et al. (2011). A large and persistent carbon sink in the world's forests. Science, 333(6045), 988-993.
3. FAO summary statistics (A-1e)- Capture production by principal species in 2012, ftp://ftp.fao.org/fi/stat/summary/summ_12/a1e.pdf
4. Wright, A. The value of marine resources harvested in the CCAMLR Convention Area - an assessment of GVP. CCAMLR Document CCAMLR-XXXV/10
5. Total Import Value of Atlantic Cod in 2016. Value obtained from https://www.tridge.com/intelligences/atlantic-cod/import <Accessed 8th July, 2019>
6. Boonzaier, L., & Pauly, D. (2016). Marine protection targets: an updated assessment of global progress. Oryx, 50(01), 27-35.
A contribution to the program Integrating Climate and Ecosystem Dynamics in the Southern Ocean
Graphic by Stacey McCormack, Jessica Melbourne-Thomas, Rowan Trebilco & Andrew Constable
DATE: 01/07/2019
MEASO
ACE
ANTARCTIC CLIMATE & ECOSYSTEMS CRC

ECOSYSTEM STRUCTURE

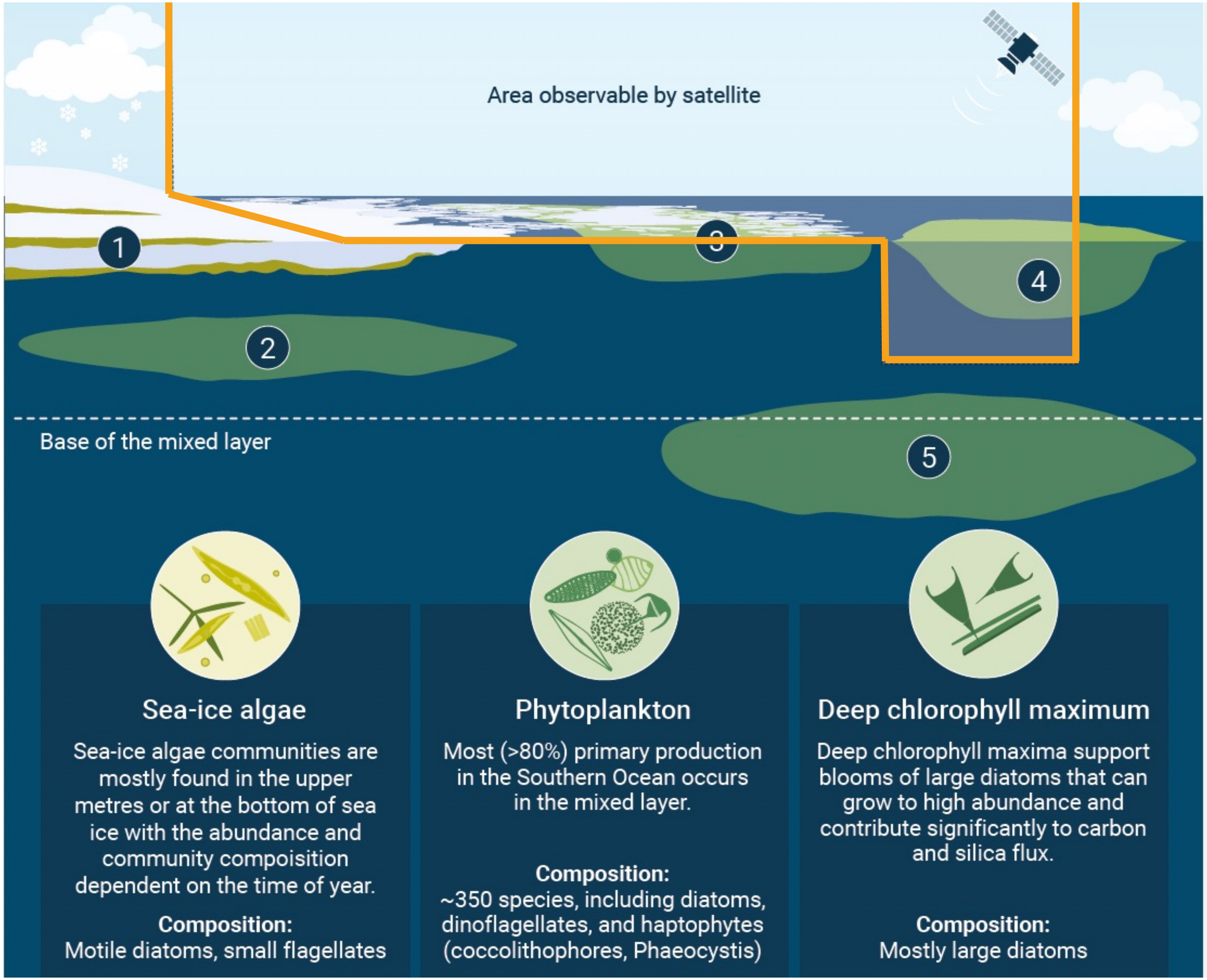
- Producers
- Consumers
- Top predators

- Sea ice
- (Meso)pelagic
- Bethic

MEASURING CHLOROPHYLL-*A*

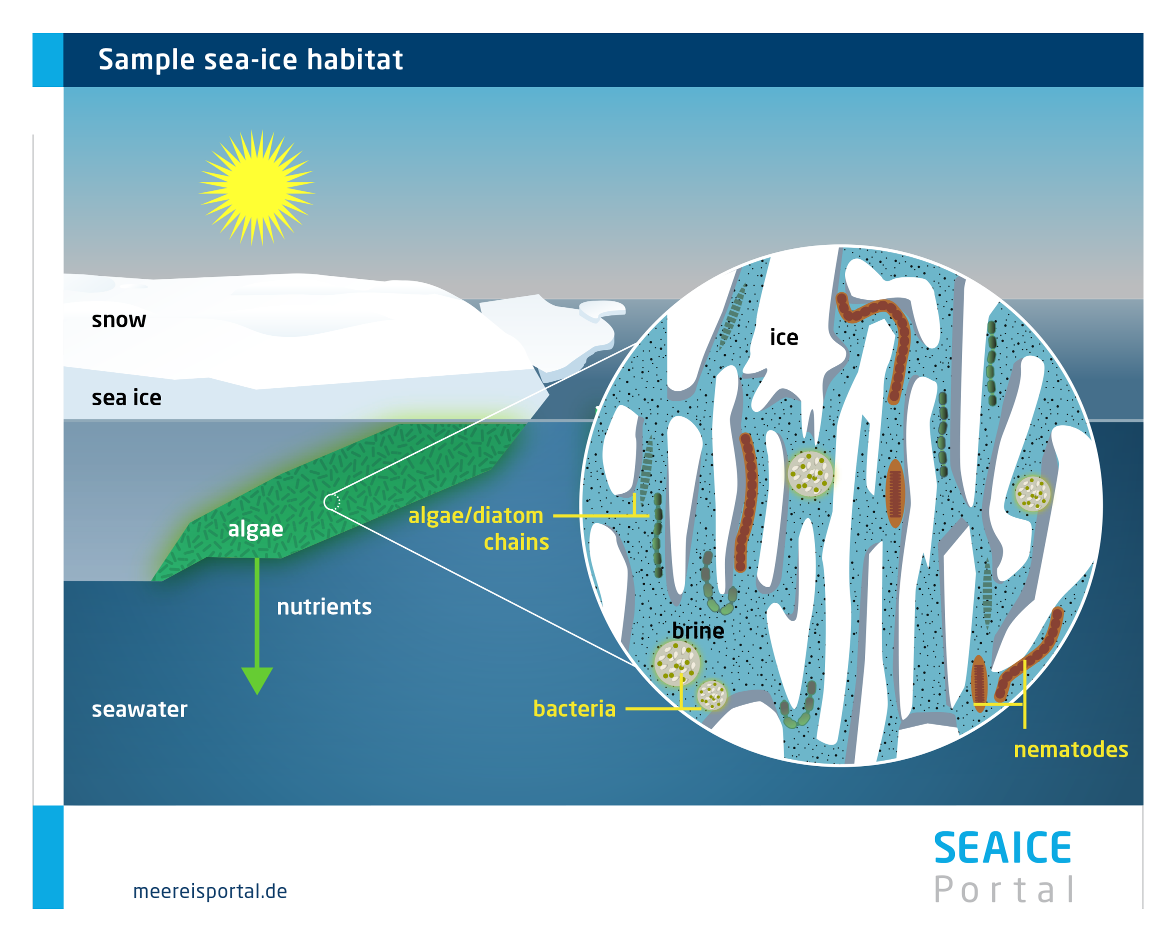


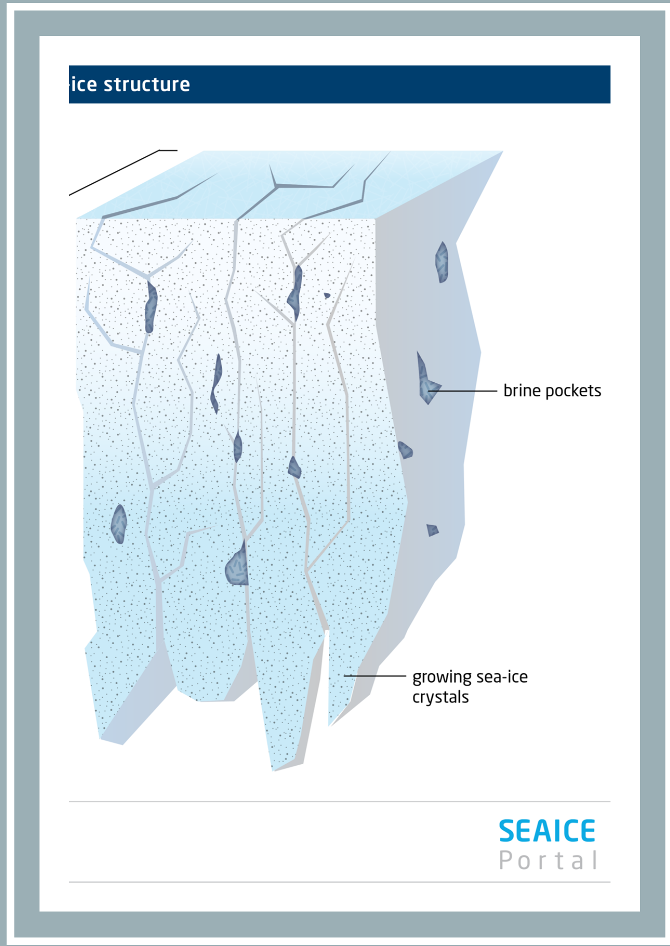
https://doi.org/10.3389/fmars.2020.00671



1. Sea Ice Algae
2. Phytoplankton beneath Sea ice
3. Ice edge phytoplankton bloom
4. Mixed Layer phytoplankton
5. Deep Chlorophyl maximum

SEA ICE


Sample sea-ice habitat
snow
sea ice
ice
algae
algae/diatom chains
nutrients
brine
seawater
bacteria
nematodes
SEAICE Portal
meereisportal.de


ice structure
brine pockets
growing sea-ice crystals
SEAICE Portal

SEA ICE ALGAE

- Temperature
- Salinity
- Light
- available food

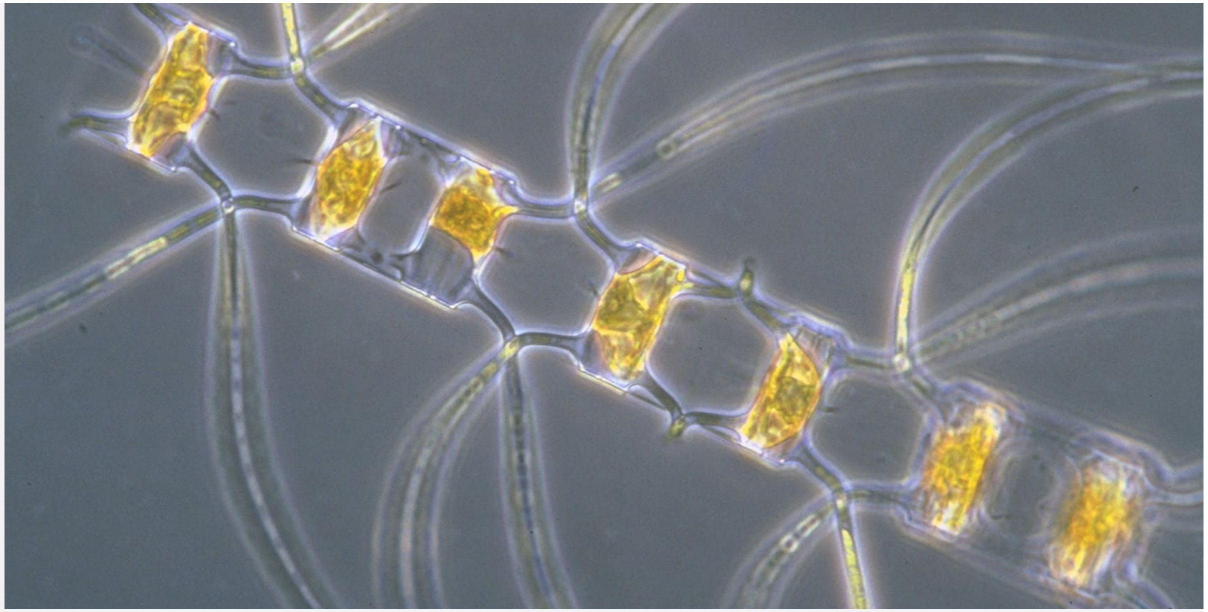
- 2-24 of total primary production
- Blooms
  - Spring
  - Occasionally in autumn
- Biomass rich layers
- Bioaccumulation
  - Macronutirients
  - Iron

SEA ICE ALGAE

- large species — *Amphiprora*, *Pinnularia*, *Pleurosigm*, *Synedra*, *Tropidoneis.*
- *Diatoms* — *Thalassiosira*, *Porosira*, ***Chaetoceros***

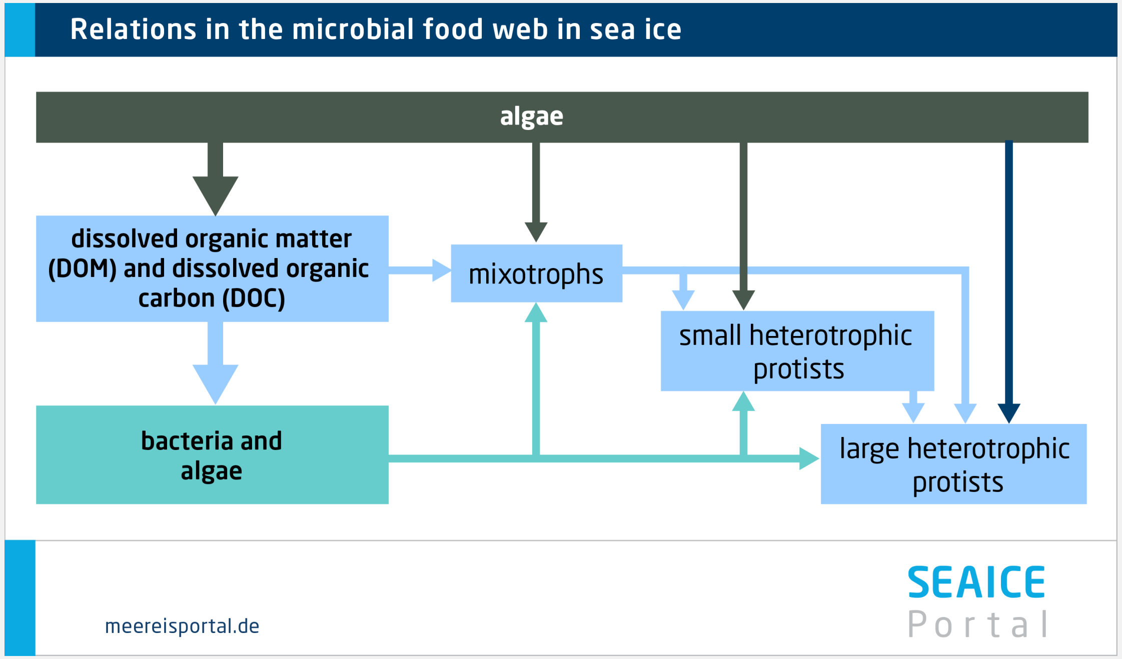
tend to dominate in the newly formed sea ice or platelet ice of the Antarctic.
Some diatom species form large structures : *Berkeleya* (filaments up to 15 cm)

- Flagellates — haptophytes, dinoflagellates, prasinophytes, chlorophytes (green algae), silicoflagellates, chrysophytes, cryptophytes

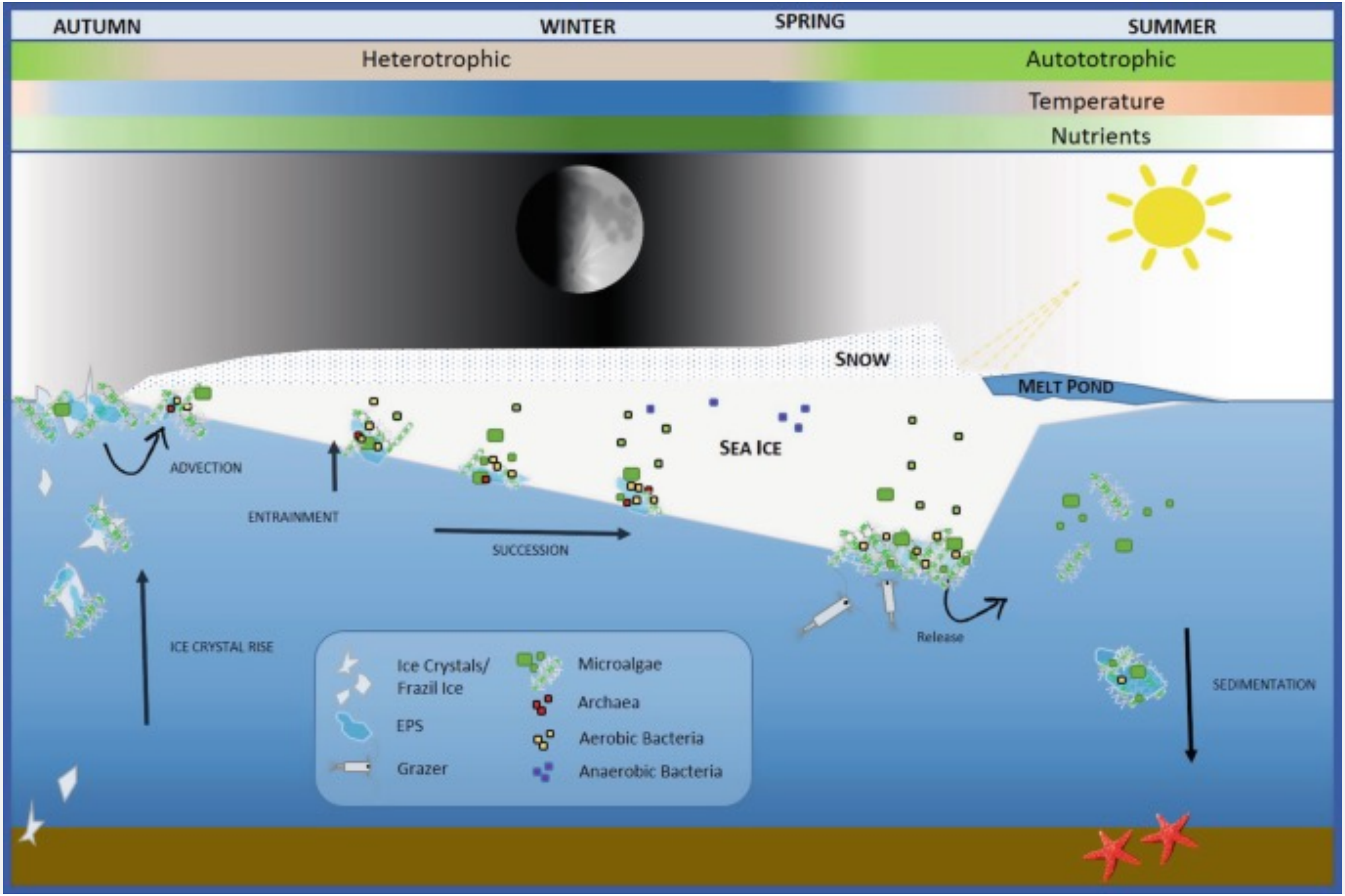


SEA ICE BACTERIA

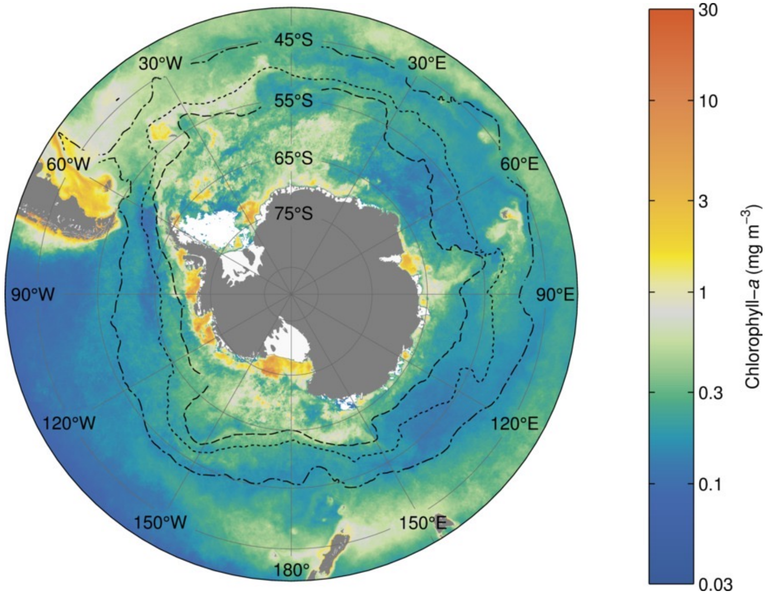
- bacterial density in sea ice >>> seawater bacterial enrichment factor
- Typically 5 - 10 times
- Can range from 2 to 54
- Remineralisation
- extracellular polymeric substances (EPS)



Bacteria form, together with ice algae, a reserve of organic material, which becomes encased in the ice in winter, offering both a food source for overwintering organisms and a 'kick-start' for the ecosystem in spring.



AUTUMN
WINTER
SPRING
SUMMER
Heterotrophic
Autototrophic
Temperature
Nutrients
SNOW
MELT POND
SEA ICE
ADVECTION
ENTRAINMENT
SUCCESSION
ICE CRYSTAL RISE
Release
SEDIMENTATION
Ice Crystals/
Frazil Ice
EPS
Grazer
Microalgae
Archaea
Aerobic Bacteria
Anaerobic Bacteria



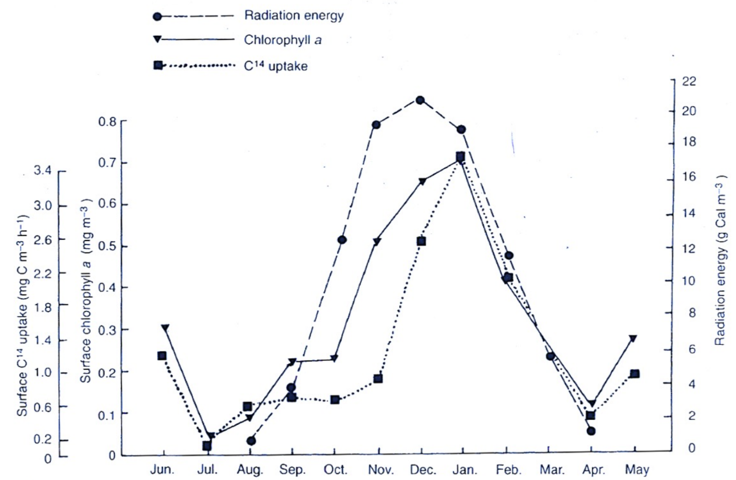


Fig. 2.13. Monthly variation of radiant energy (with average cloudiness) at Maudheim Station (71° 03′ S; 10° 56′ W) compared with monthly changes in surface chlorophyll *a* and C^{14} uptake in Antarctic waters. Redrawn from El-Sayed (1971a).

FACTORS: *LIGHT*

2.1. CONTROLLING FACTORS: *LIGHT ←→ ICE COVER*

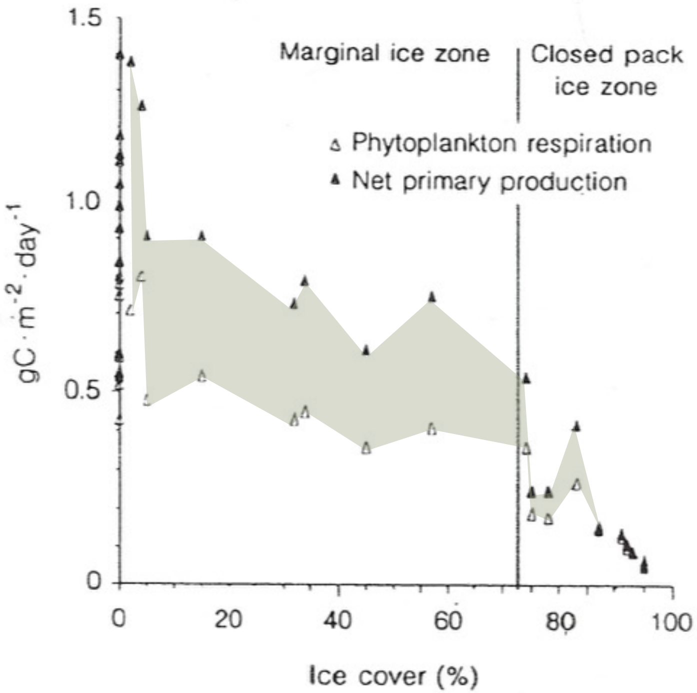


Fig. 7. Relationship between daily rate of net primary production (▲) and ice cover field in the sea ice associated areas (i.e. the marginal ice zone and the closed pack ice zone) of the northwestern Weddell Sea during spring 1988. Phytoplankton respiration (△) is also shown

Mathot et al 1992

- No bloom if ice cover > 20%
- => nanoplanktonic communities

WHAT IS SPECIAL ABOUT THE SOUTHERN OCEAN IN RELATION TO NUTRIENTS AND PRODUCTIVITY?

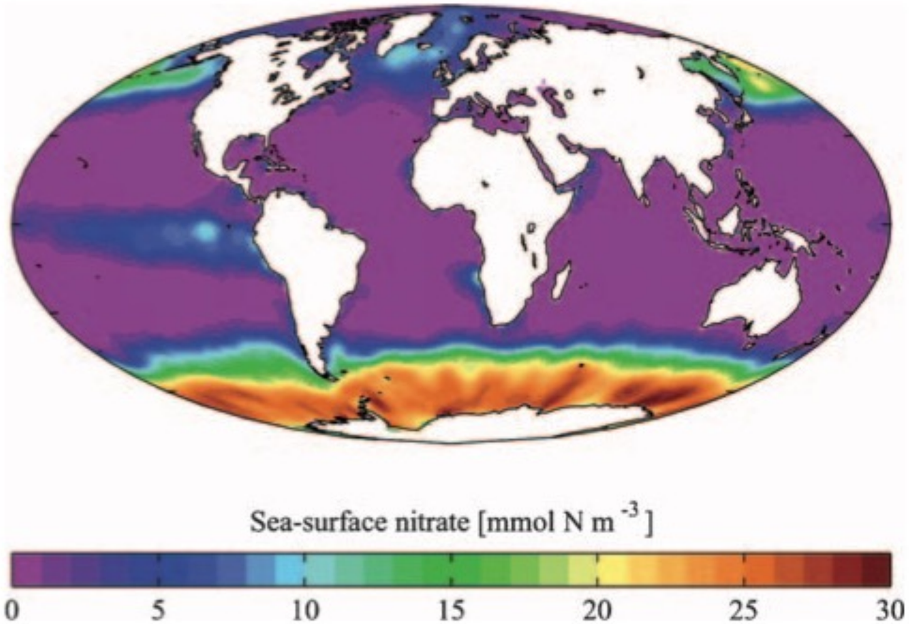


Fig. 17.3 Map of High Nutrient–Low Chlorophyll (HNLC) regions around the world. Measurement in map is of nitrate, with the *scale* as a gradient of color pictured on the bottom (http://www.atmosphere.mpg.de/media/archive/1058.gif)

Offshore upwelling → HNLC zone

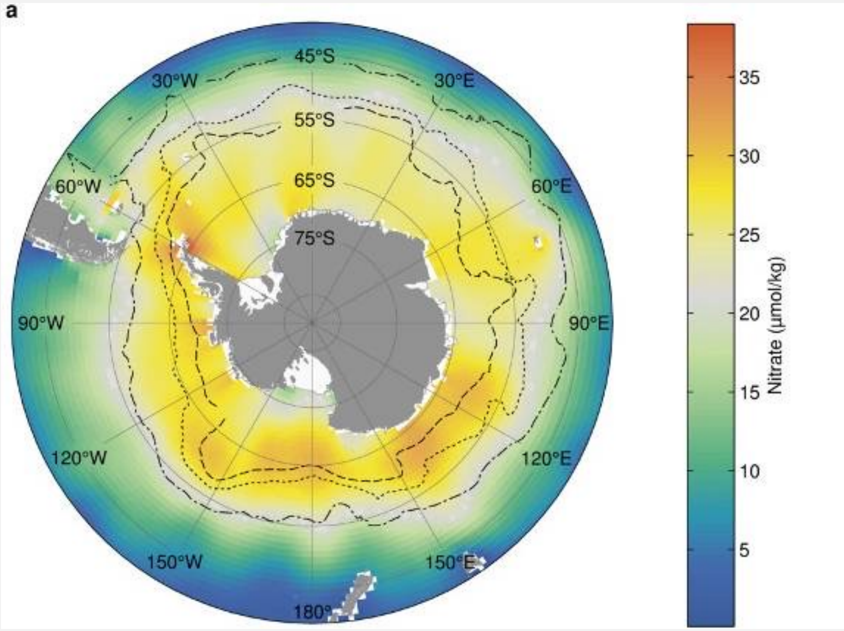
NO_3^-: 32.5μM

PO_4^{3-}: 2.5μM

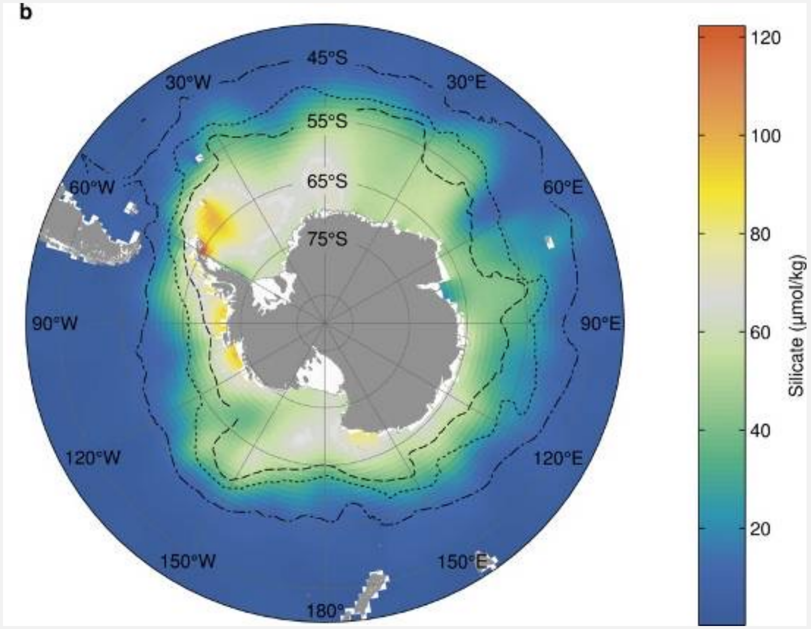
SiO_4^-: 100 μM

WINTER SURFACE

(A) NITRATE



(B) SILICATE



Mesocosm Fe enrichment experiment in the Antarctic Peninsula:

- Initially: nano- and picoplankton
- After 6d: shift towards diatoms

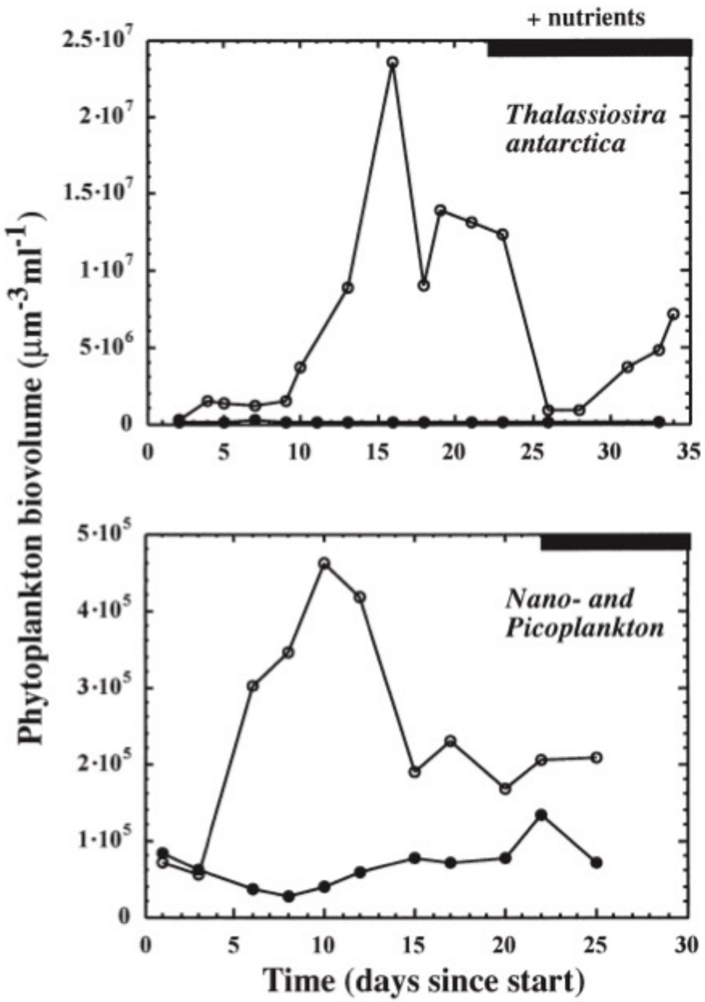
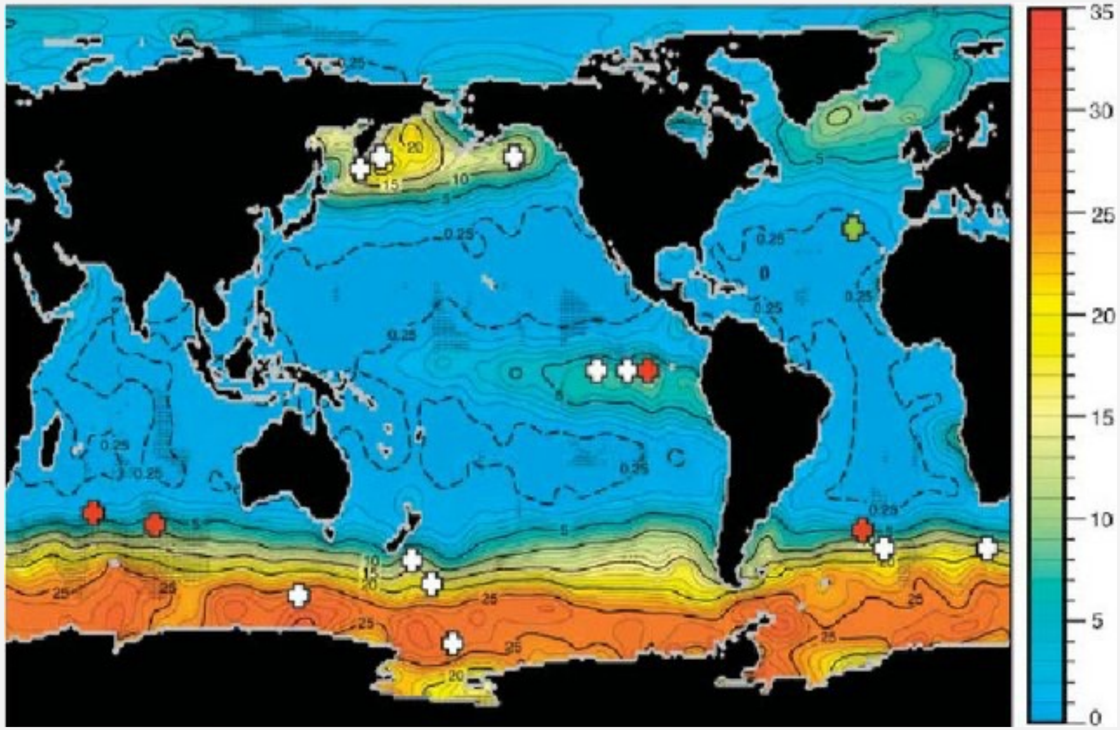


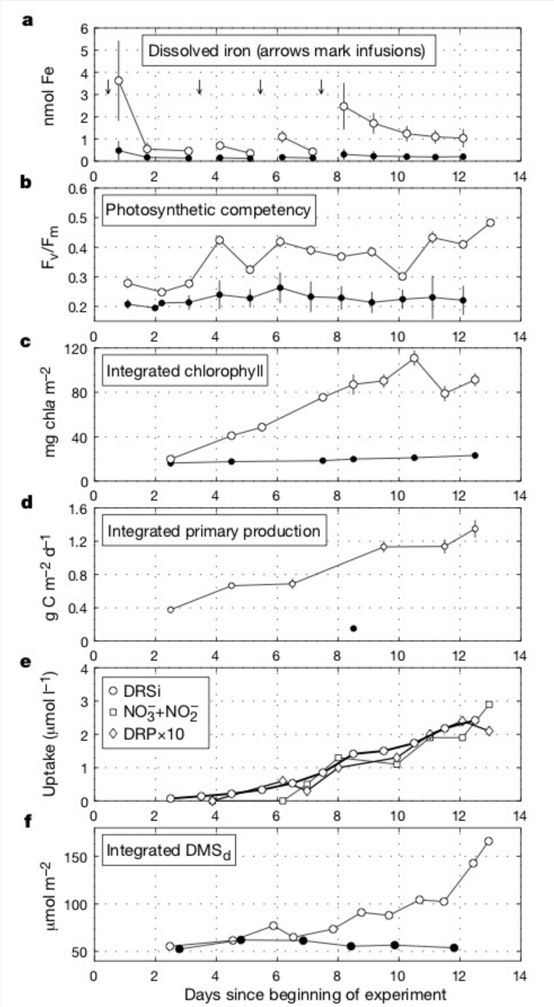
Fig. 8. Depth-integrated biovolume of diatoms and nano- and picophytoplankton in the mesocosm (○) and the ambient waters (●) during the experiment (January 19, 1999, to February 21, 1999)

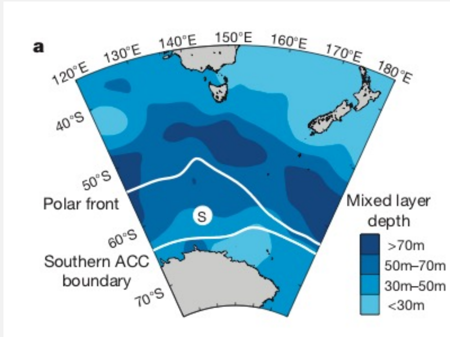
Agusti & Duarte 2000
MEPS 206: 73

- Distribution of nitrate in the surface ocean, showing elevated concentrations in the three HNLC regions of the Southern Ocean, Equatorial Pacific and Sub-Arctic Pacific.
- Location of twelve iron fertilization experiments (white crosses), natural iron fertilization experiments (red crosses), and excess surface nitrate concentrations (colors on map). Green cross is an iron plus phosphorus experiment [Boyd et al. , 2007]



P1: X3





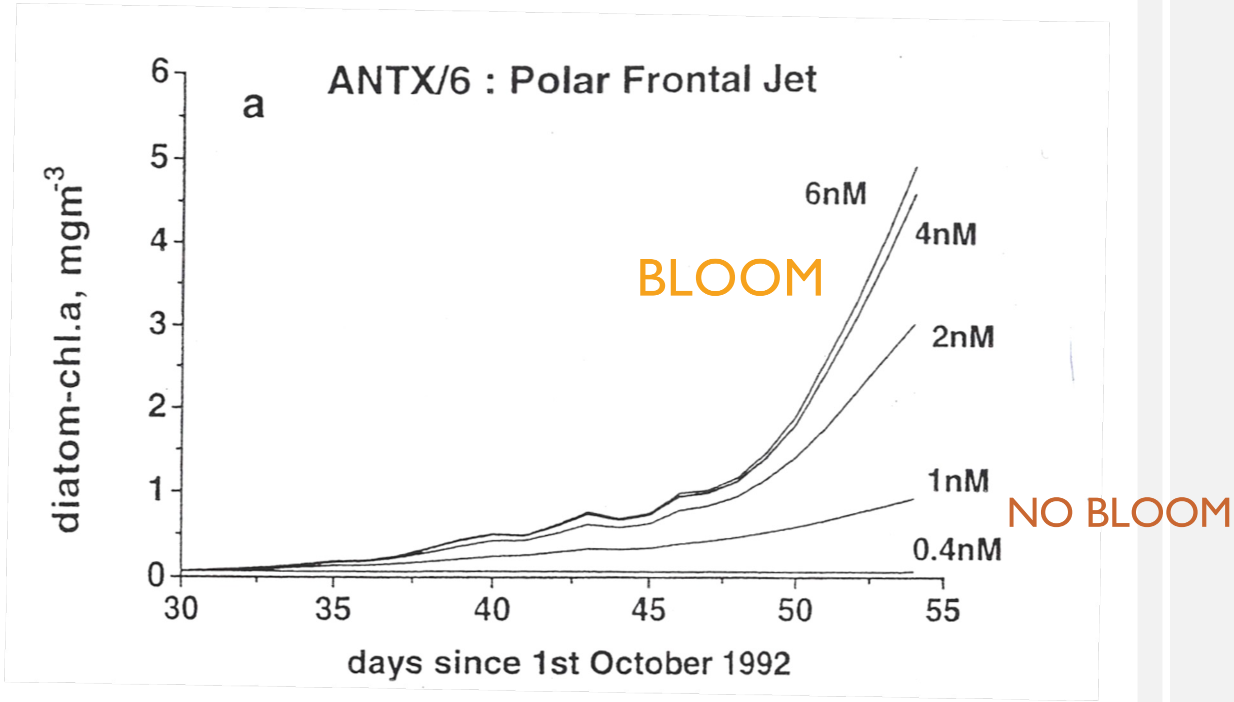
Field Fe enrichment experiment in the Pacific sector SOIREE with multiple enrichments

Figure 3 Time-series measurements made during SOIREE. Open and filled symbols show measurements made respectively inside and outside iron-fertilized waters. Underway data are expressed as the daily mean value for inside (defined as >50% of the peak SF_6 levels on that day) and outside the patch (defined as <10 fmol l^{-1}). Error estimates are expressed as ± 1 standard deviation of the mean for underway data (**a**, **b** and **e**) and ± 1 standard error of the mean for the discrete data (**c**, **d** and **f**). The range of sample sizes during SOIREE is provided in parentheses: **a**, underway sampling of dissolved iron levels (n = 5–17 (in); 9–29 (out)) in surface waters (~3 m) and the timing of the four iron infusions; **b**, underway sampling (~5 m) of community photosynthetic competency (F_v/F_m) (n = 8–40 (in); 6–84 (out)); **c**, column-integrated chlorophyll *a* (six depths, 0–65 m, n = 3 pseudo-replicates); **d**, column-integrated primary production (six depths, 0–65 m, n = 3 pseudo-replicates); **e**, macronutrient uptake (silicate: from ^{32}Si uptake[33], n = 2 pseudo-replicates, error always <10% of the mean), nitrate and phosphate depletion (underway sampling (~5 m), n = 12–18 (in); 14–34 (out), the greatest spatial variability was <15% of the standard deviation of the mean), DRSi is dissolved reactive silica, DRP is dissolved reactive phosphorus; **f**, column-integrated DMS (six depths, 0–65 m, n = 3 pseudo-replicates, errors are all smaller than the symbol size). Nitrate and phosphate depletion was obtained by subtraction of levels within the patch from levels in the surrounding waters (which exhibited no significant change in during SOIREE).

Boyd et al 2000
Nature 407: 695

No bloom if Fe < 2nM

Lancelot et al 1996



swamco predictions at latitude 47°S (ANTX/6 site, Polar Frontal Jet) : a) diatom development at different iron concentrations; b) wind mixed layer depth; c) dissolved iron

2. PRIMARY PRODUCTION
CONTROLLING FACTORS

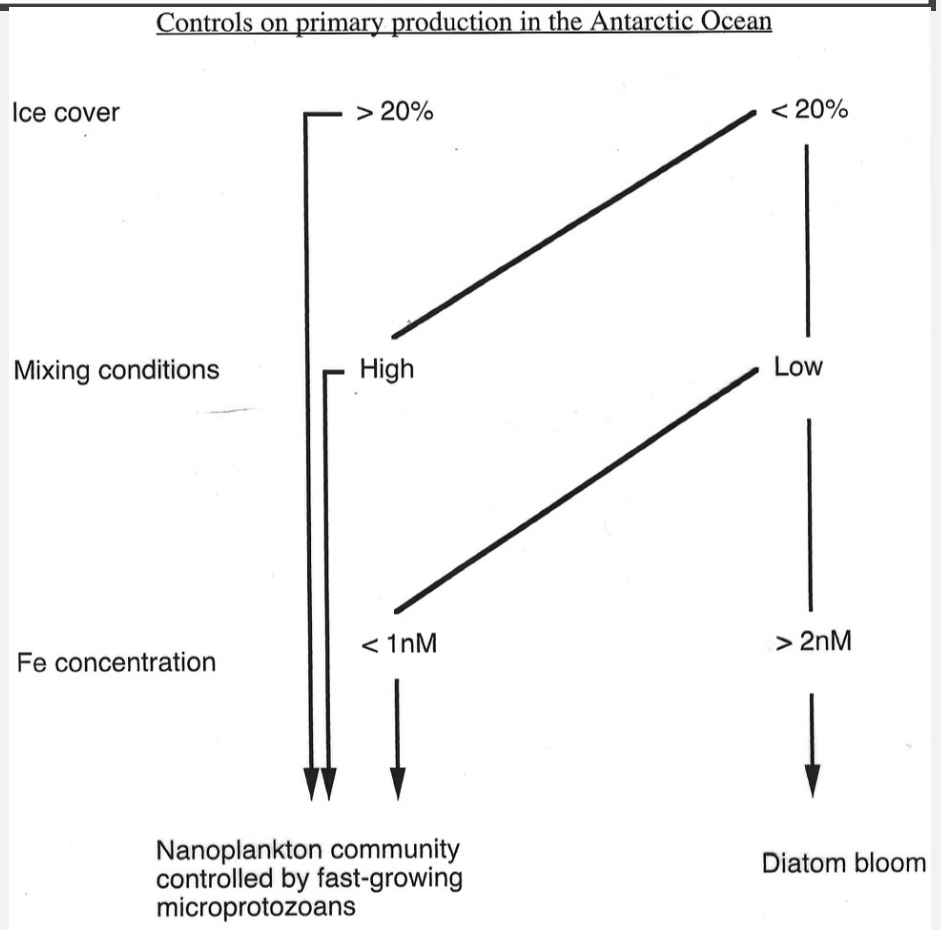


Table 5.I Iron distribution in the Southern Ocean

Site	dissolved iron, nM	Reference
Weddell/Scotia Sea	>1	Nolting et al., 1991
Drake passage		
inshore	5-7	Martin et al., 1990
offshore	0.1-0.9	
Ross Sea		
inshore	>1	Martin et al., 1990
offshore	<1	
Atlantic sector : 6°W		
ACC	<1	de Baar et al., 1996
Polar Front	>1	
Pacific sector : 89°W		de Jong et al., in prep.
subabtarctic	0.5	
Polar Front	0.6-1	
ACC	0.5	
cont. margin	0.6-1	

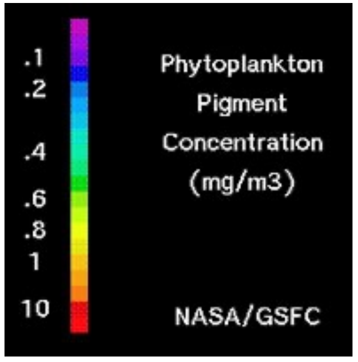
Lancelot et al

Dissolved Fe: usually <1nM except

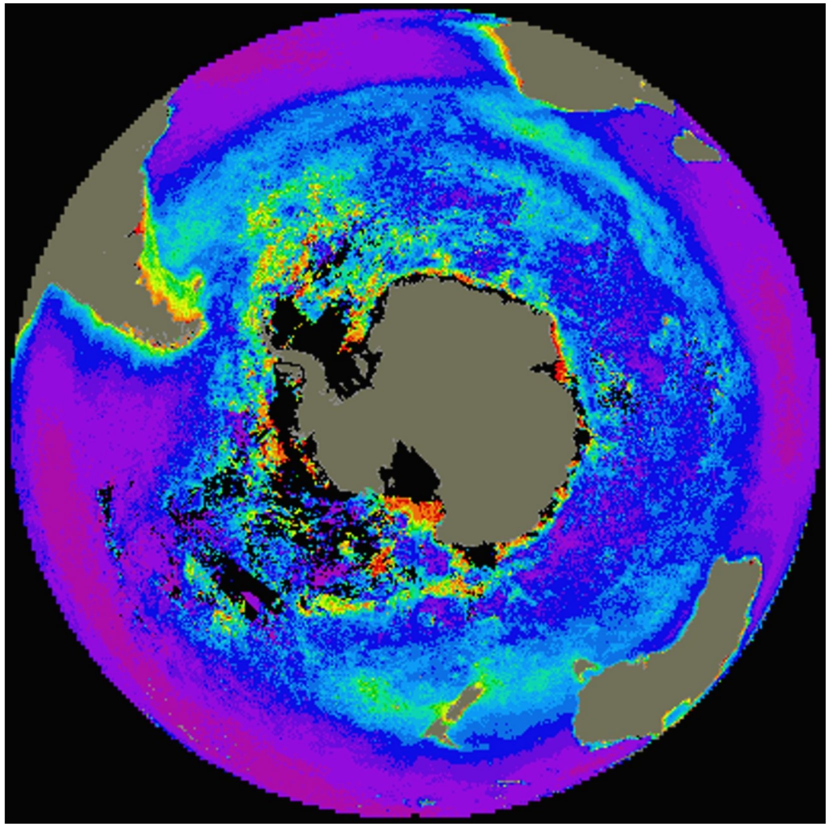
- Coastal zone and above continental plate (Weddell and Ross Seas)
- Downstream Drake passage
- Marginal ice zone

Marginal ice zone

- Sea ice concentrates
- airborne Fe during winter
- Remineralisation
- Psychrophilic algae seed the water column when ice melts



The map displays the composite of all Nimbus-7 Coastal Zone Color Scanner data acquired between Noverber 1978 and June 1986. Approximately 66,000 individual 2 minutes scenes were processed to produce this image

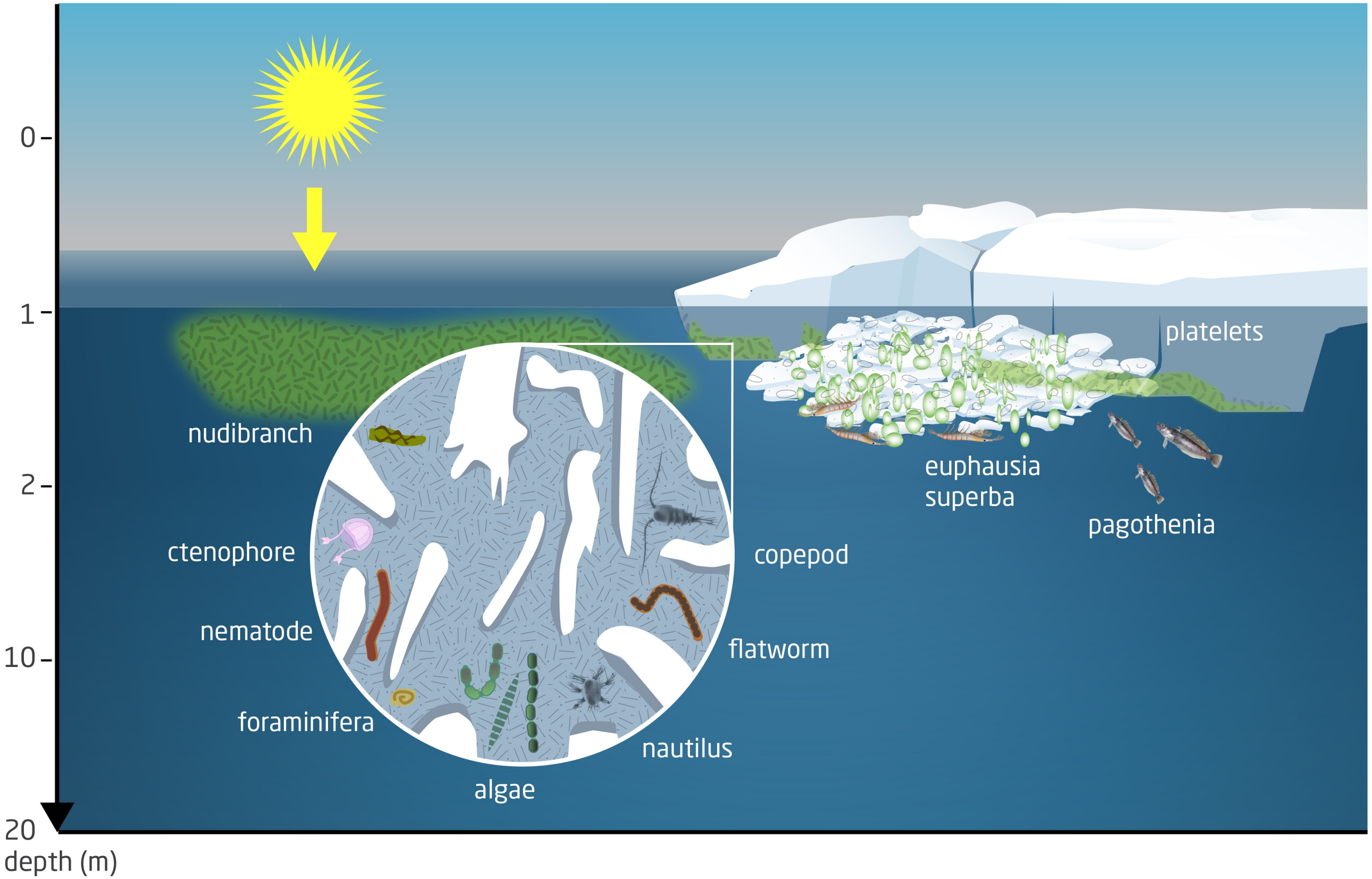


P1 parallels Fe distribution

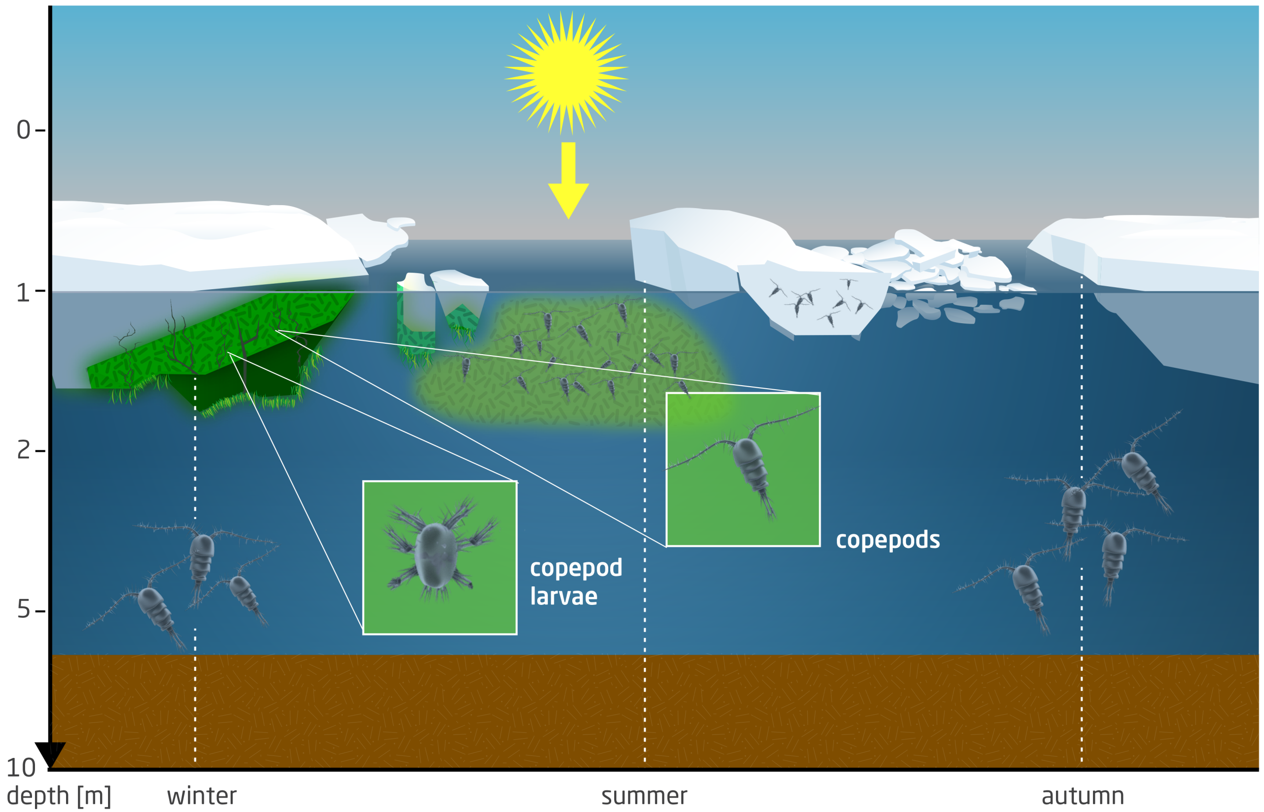
- Coastal zone and above continental plate (Weddell and Ross Seas)
- Downstream Drake passage
- Marginal ice zone

CONSUMERS

Habitats in the Antarctic ice (meiofauna and microfauna)



Ice fauna lifecycles (Antarctic)



meereisportal.de

SEAICE Portal

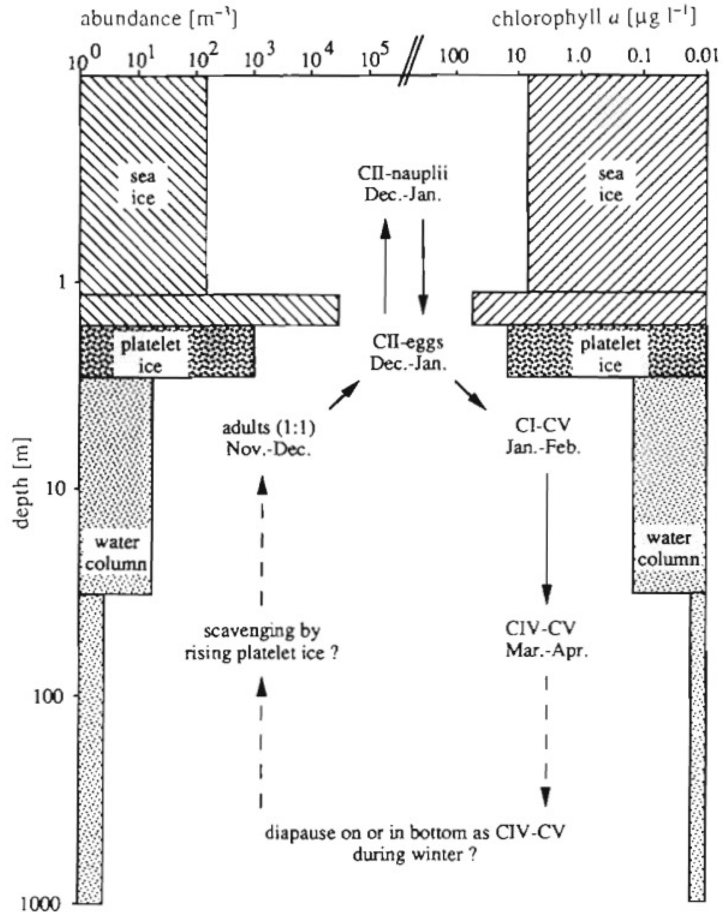
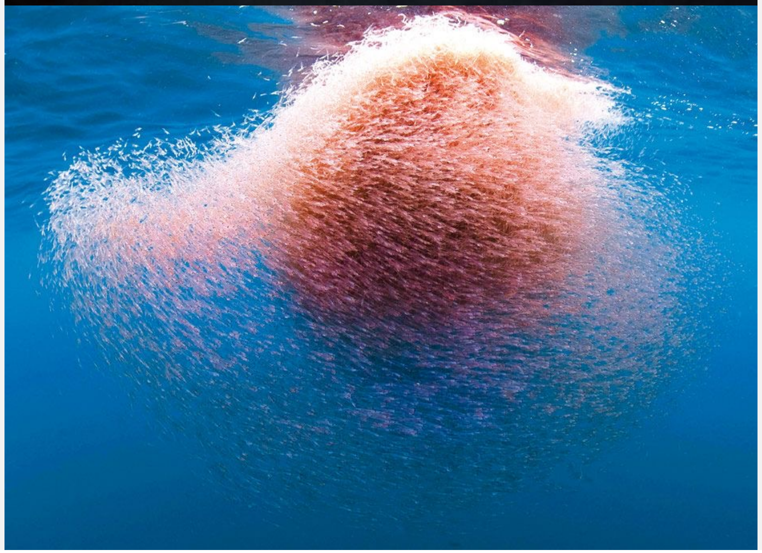


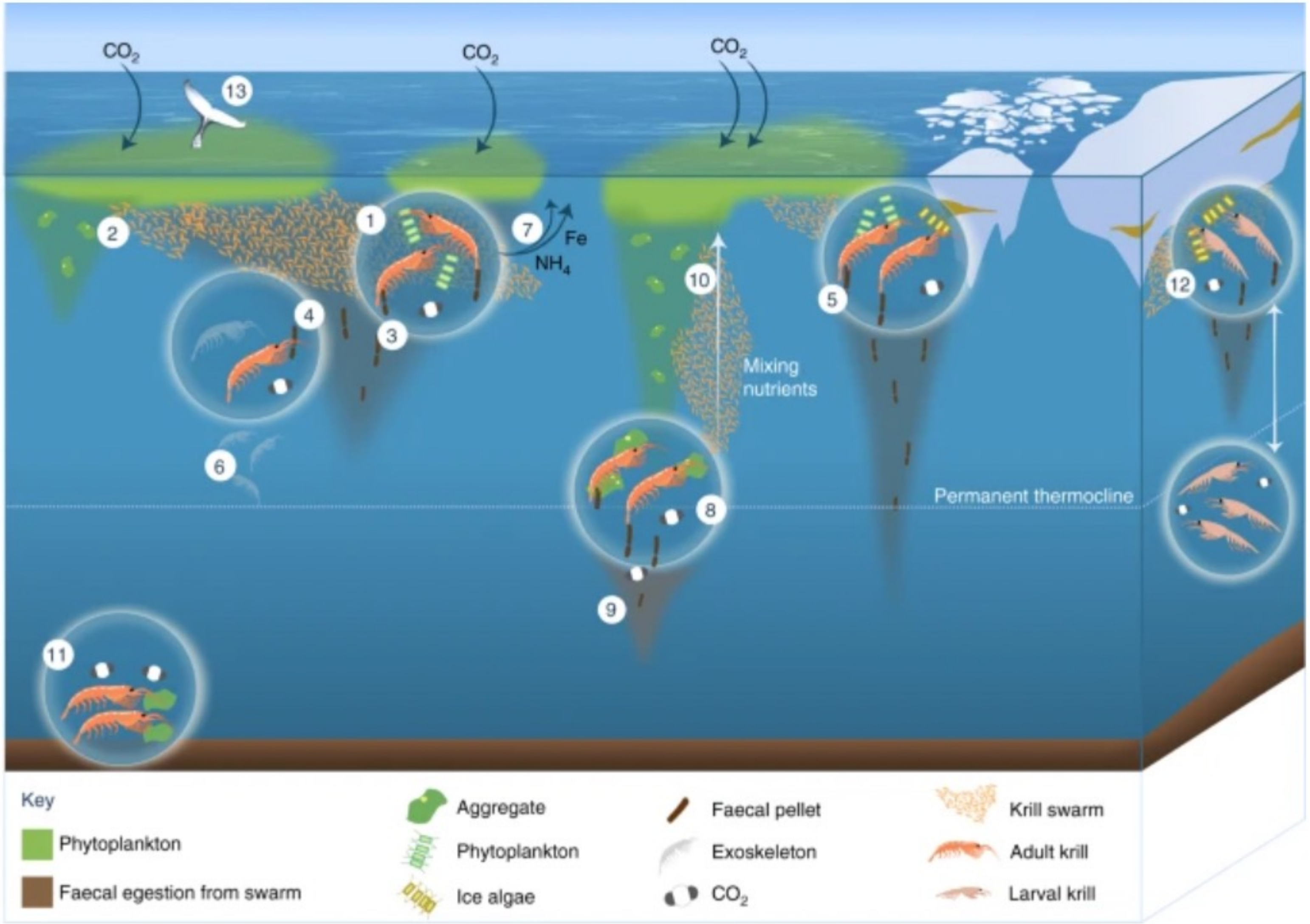
Fig. 9. Schematic representation of the abundance of different developmental stages of *Stephos longipes* and phytoplankton standing stock within and below the sea ice, and in the upper 1000 m of the water column

krill (*Euphausia superba*)



- Malacostracea, Eucarid
- Adult 6.5cm long, 1g FW, life span 4-7y
- Swimming speed: 1km/h → nekton!
- Make swarms of millions of T

en.mercopress.com



https://doi.org/10.1111/gcb.16009

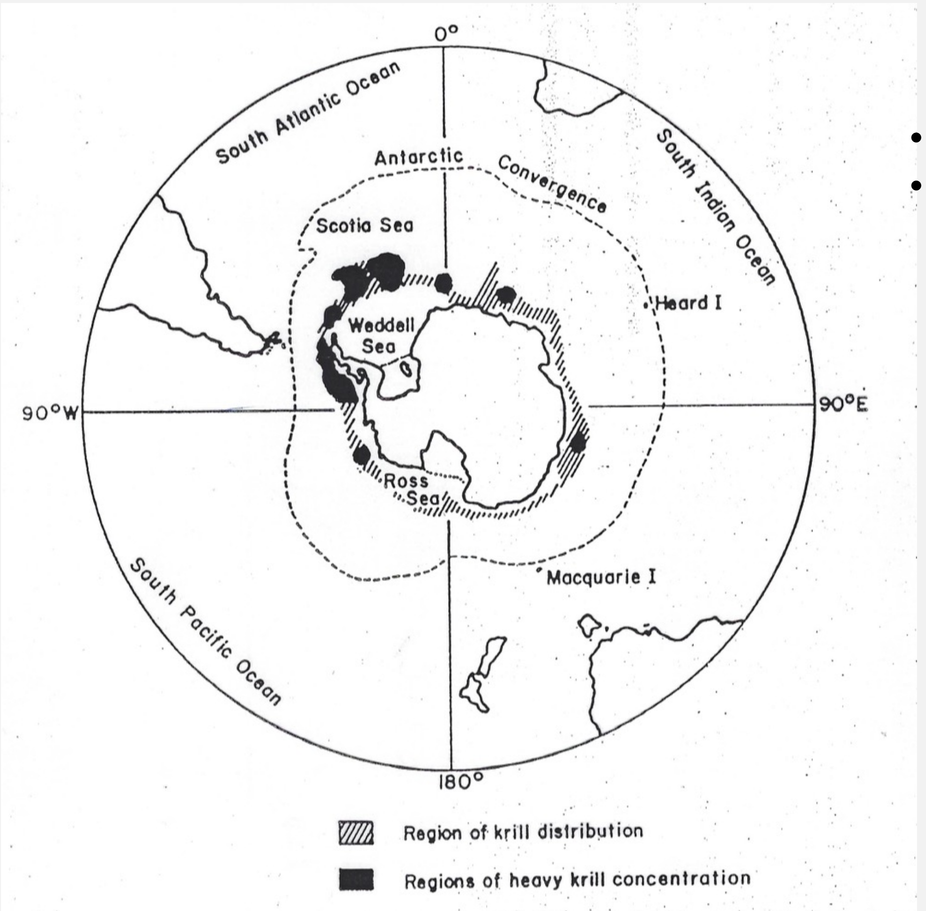
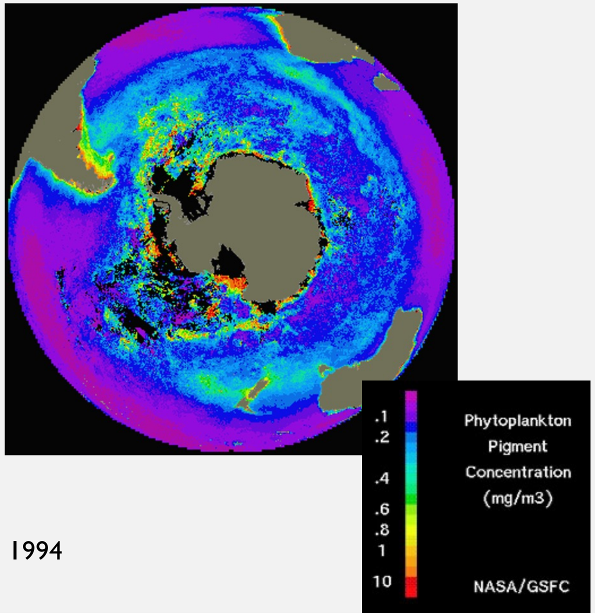
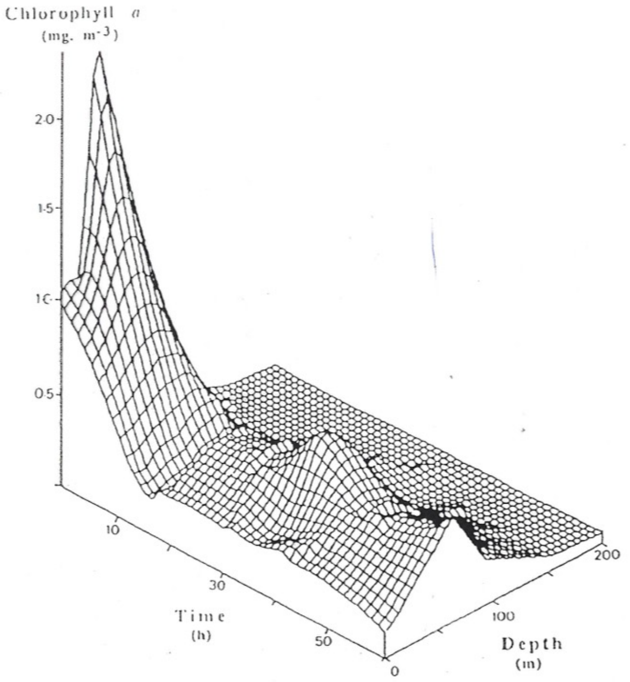


Fig. 3. The generalized distribution of Antarctic krill. Information compiled from a number of sources

- Make swarms of millions of T
- Aggregative distribution corresponding to zones of high P1



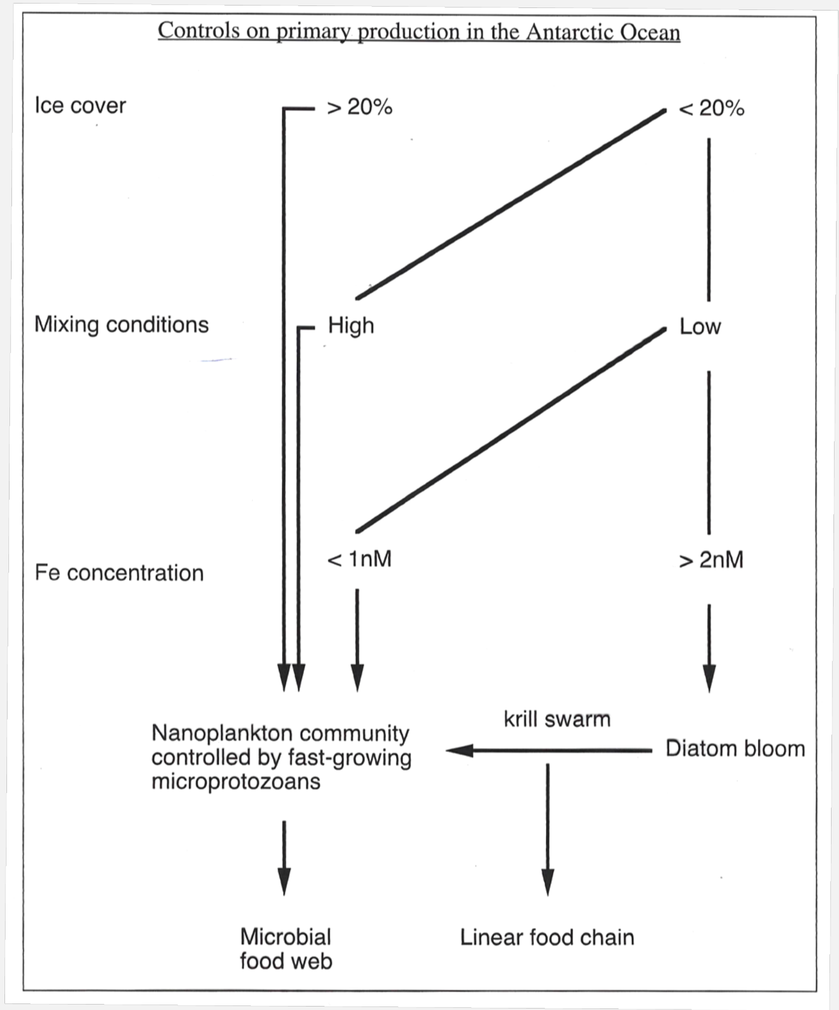
Nicol 1994



Three–dimensional evolution of a diatom bloom at station 157 in the Weddell Sea (5th December 1988). The diatom bloom vanished in less than 10 h, probably grazed down by a krill swarm, and the phytoplankton community toppled towards a flagellate–dominated system (from Jacques & Panouse, 1991).

- Make swarms of millions of Tonnes
- Aggregative distribution corresponding to zones of high P1
- Consumers of microplankton
- Fast and massive consumption of diatom blooms

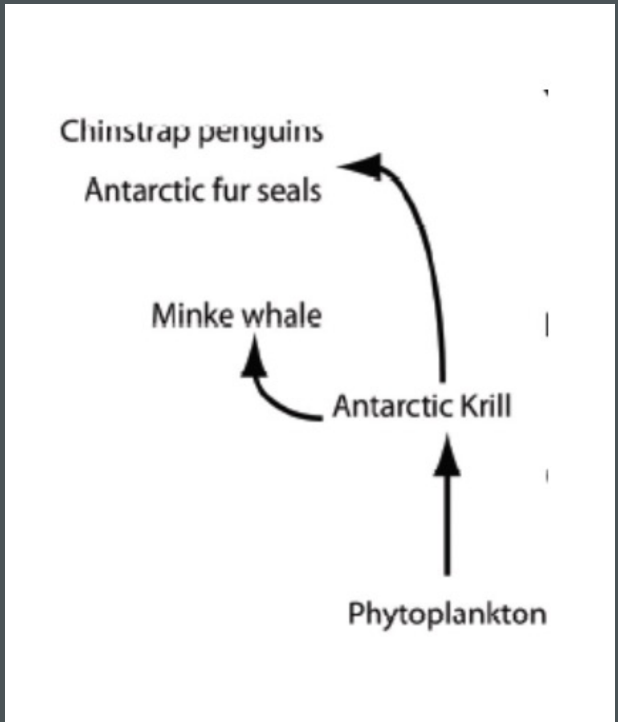
Primary production: Controlling factors



3. Consumers
3.2. Linear food chain: *Higher ranks*

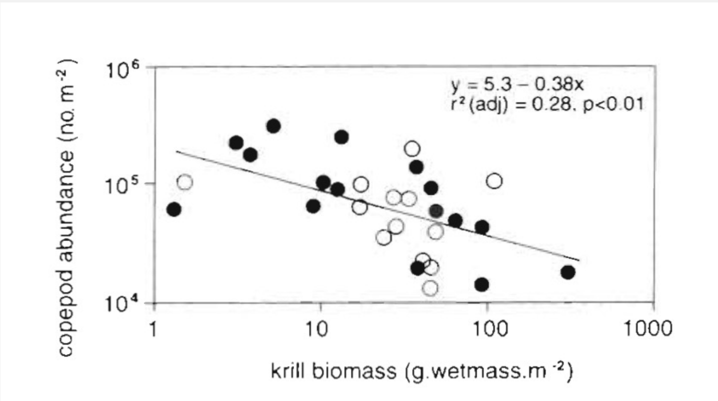
- Vertebrates and squids
- Most are krill eaters

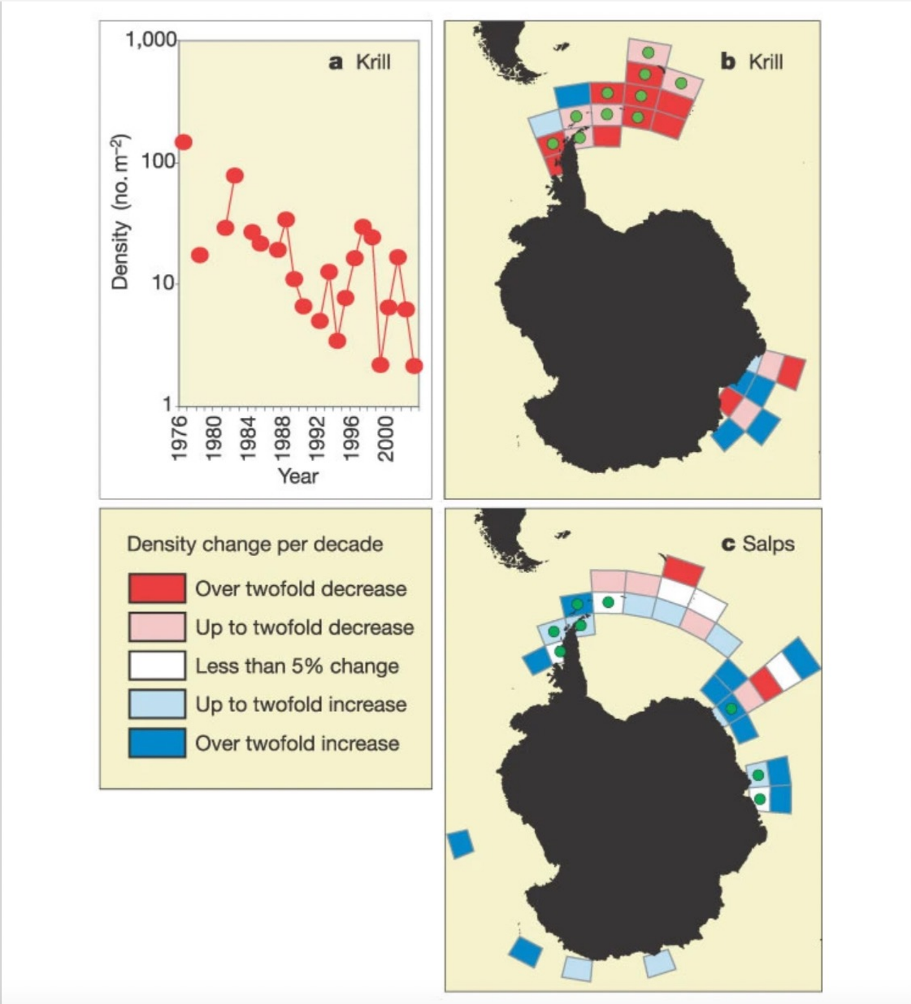
CLASSIC VIEW



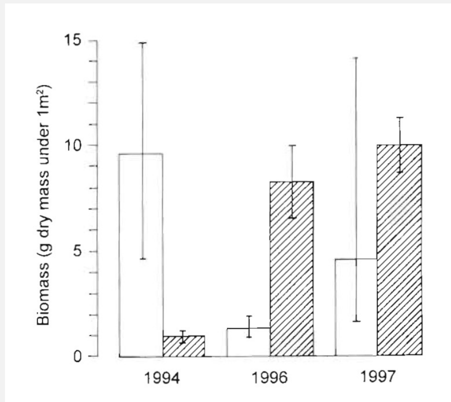
ADDITIONAL GRAZERS

- >Copepods



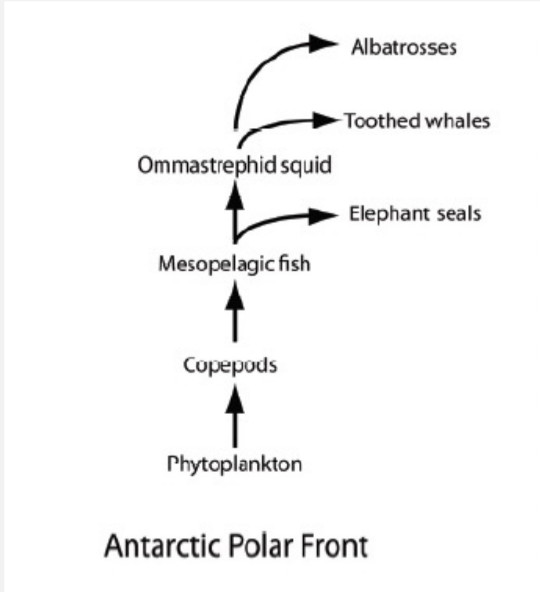


- Salp and krill habitats used to be spatially separated
- Warming leads to increasing overlap

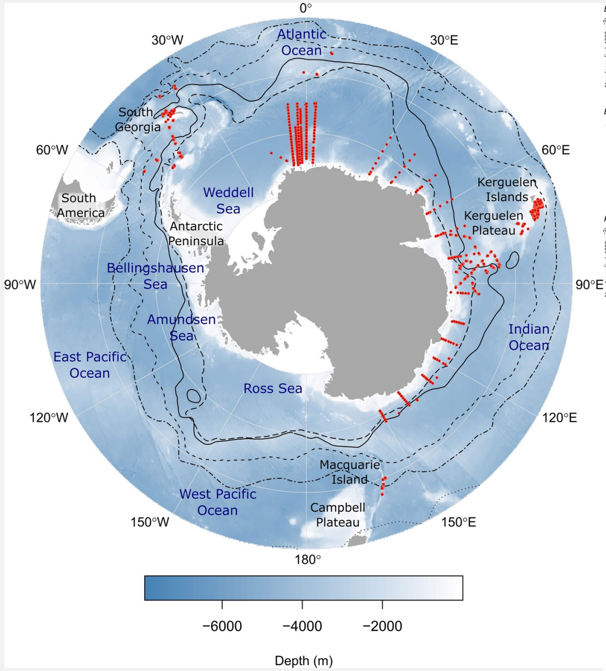


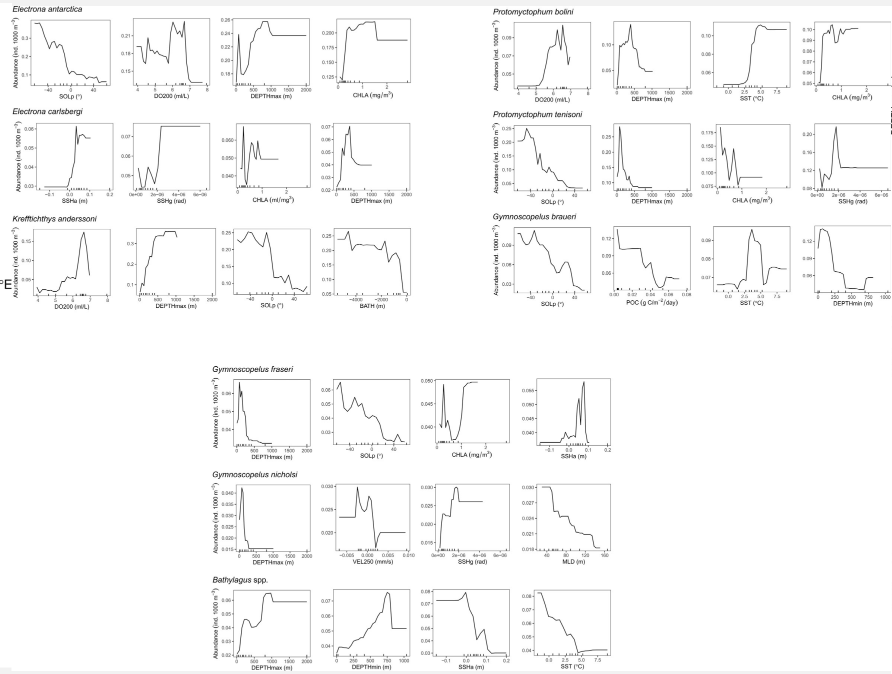
Atkinson et al 1999

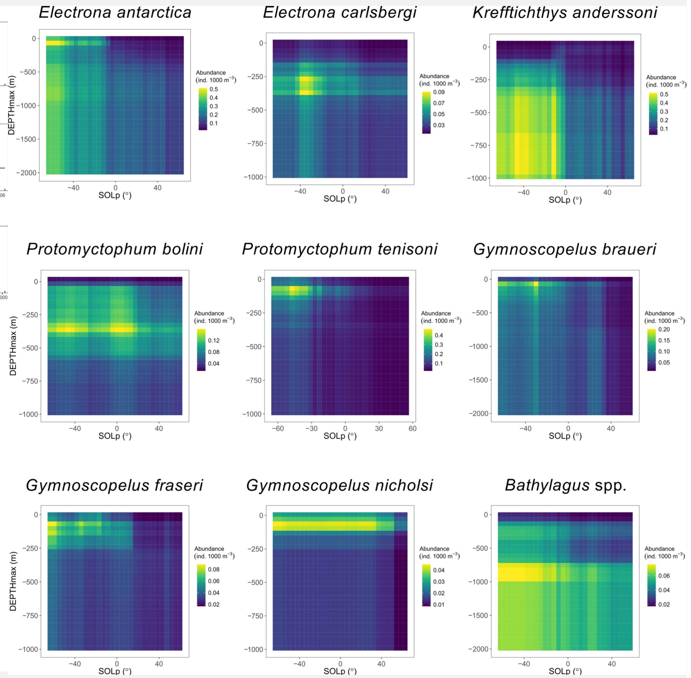
Atkinson, A., Siegel, V., Pakhomov, E. *et al.* Long-term decline in krill stock and increase in salps within the Southern Ocean. *Nature* **432**, 100–103 (2004). https://doi.org/10.1038/nature02996


Albatrosses
Toothed whales
Ommastrephid squid
Elephant seals
Mesopelagic fish
Copepods
Phytoplankton
Antarctic Polar Front

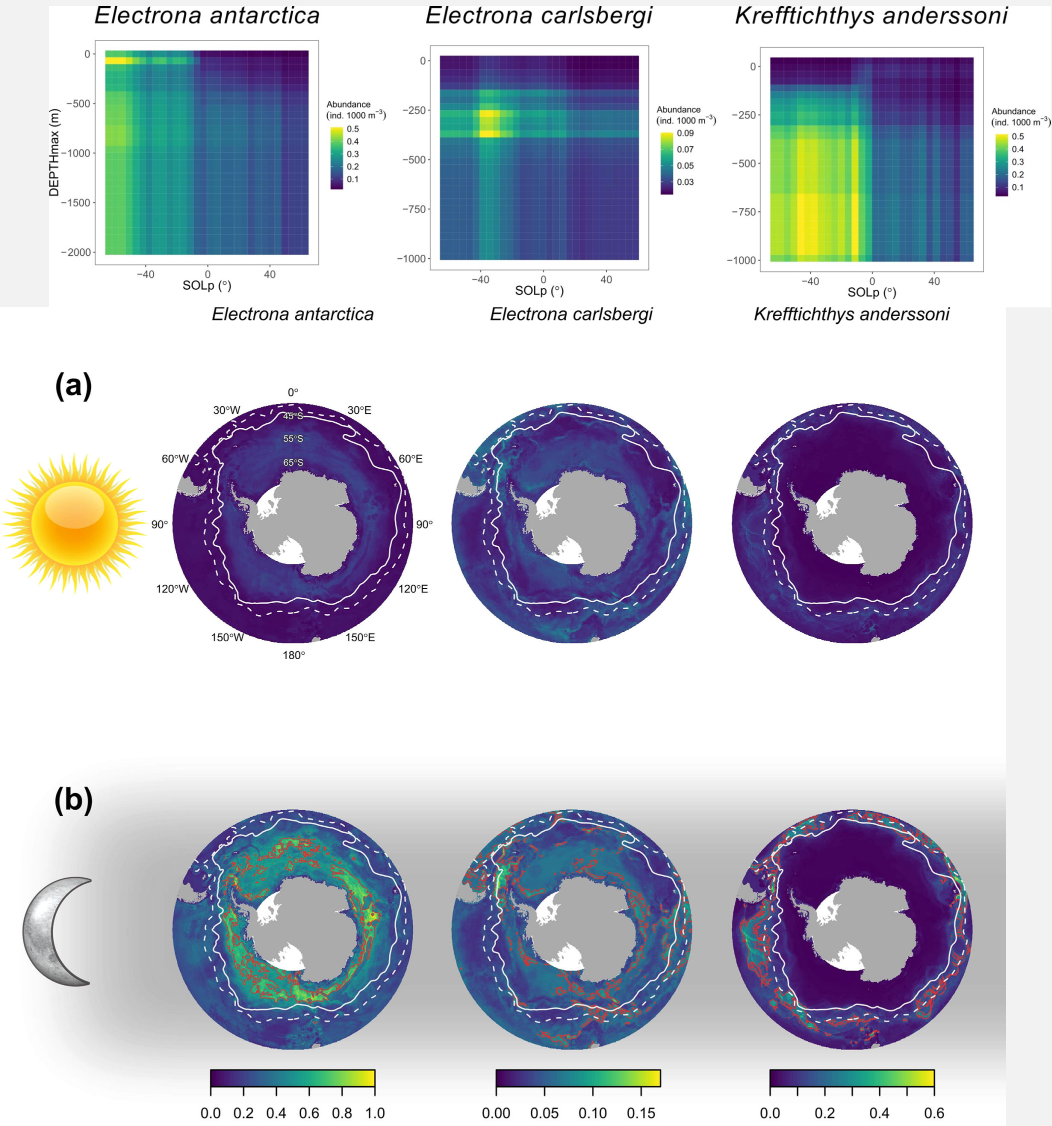
SPECIES DISTRIBUTION MODELS DESCRIBE SPATIAL VARIABILITY IN MESOPELAGIC FISH ABUNDANCE IN THE SOUTHERN OCEAN





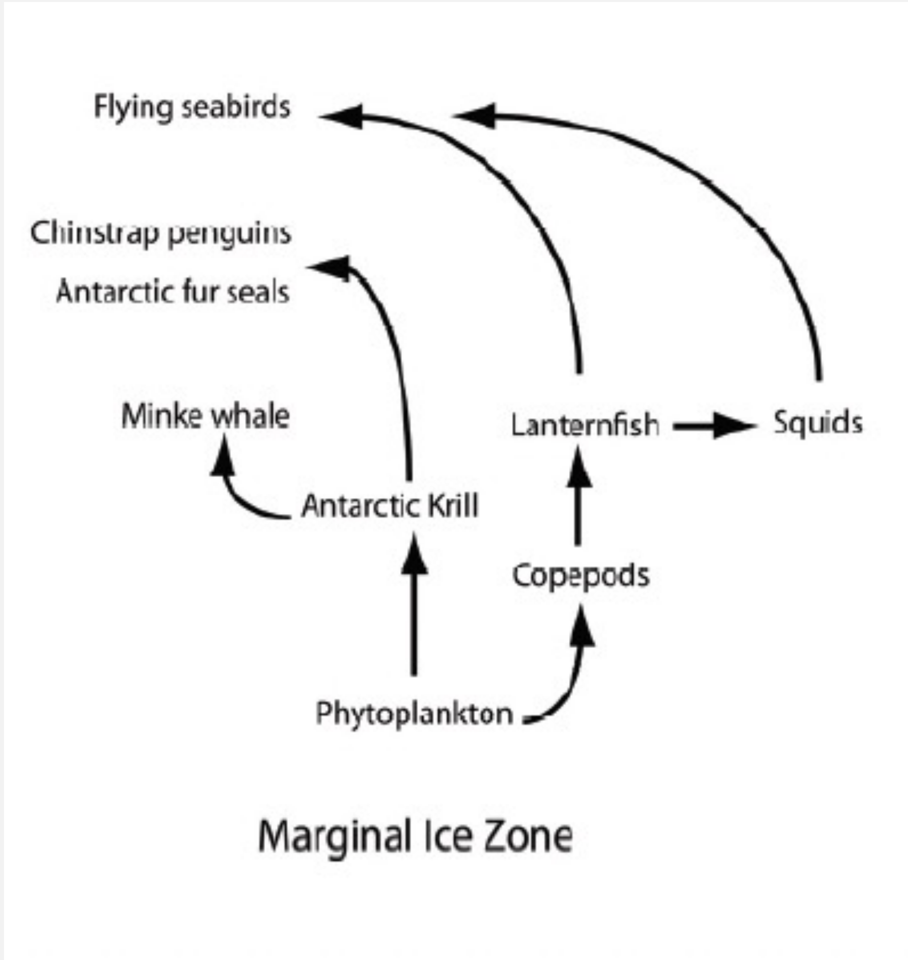


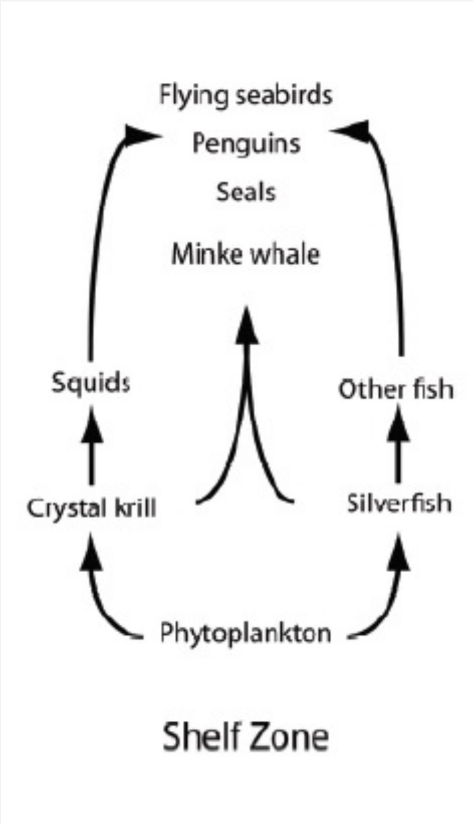
https://doi.org/10.3389/fmars.2022.981434

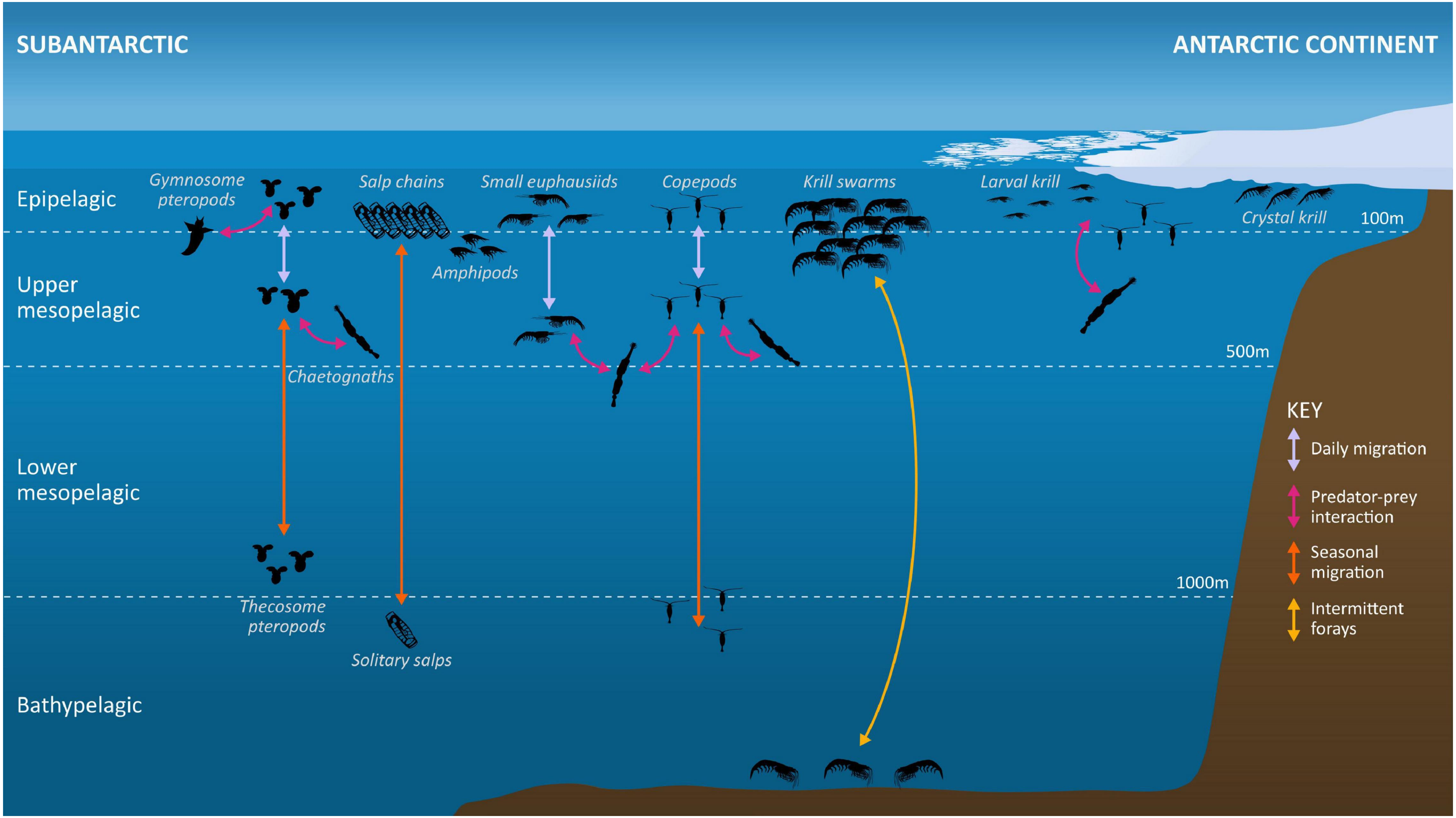


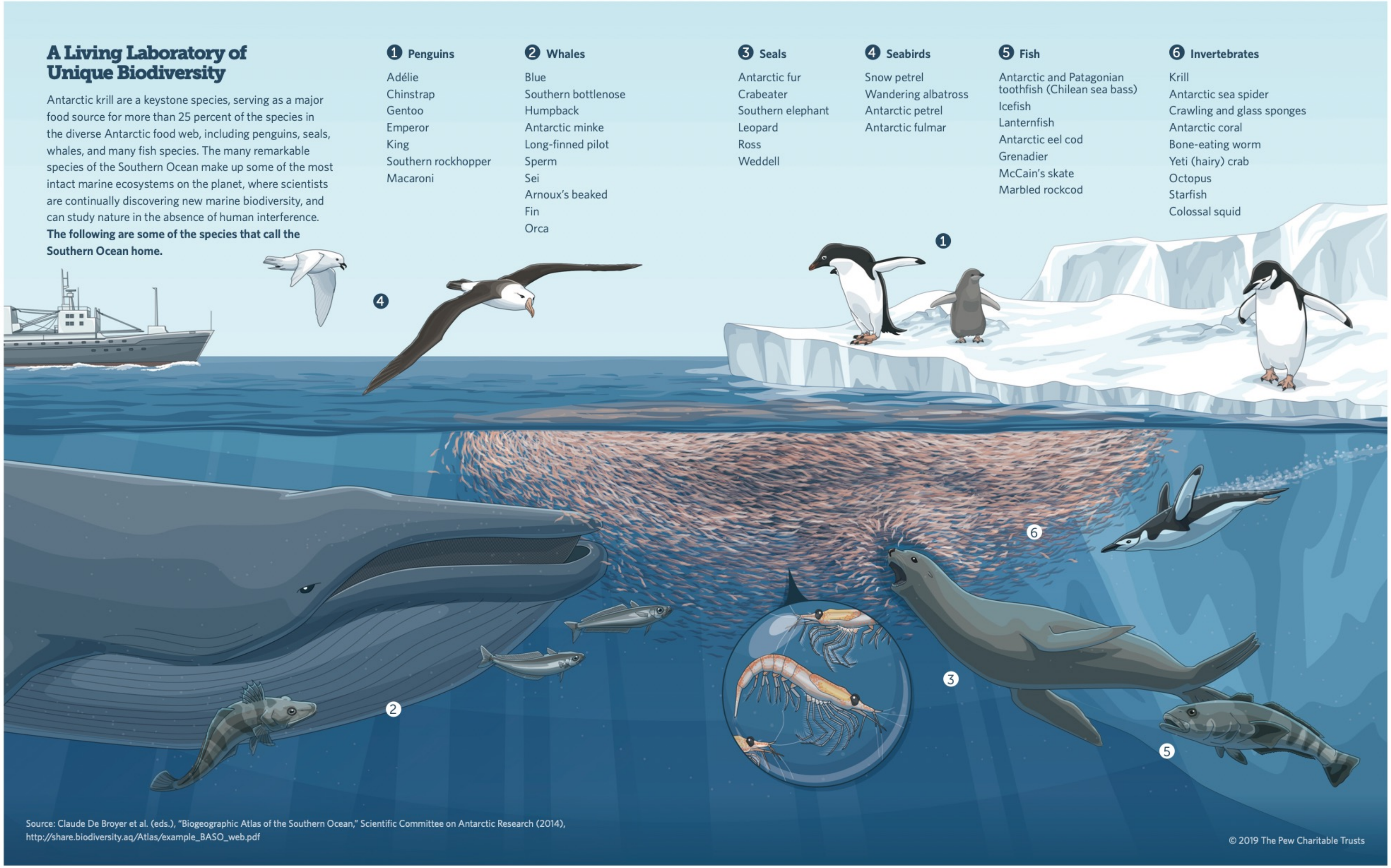
Electrona antarctica
Electrona carlsbergi
Krefftichthys anderssoni
DEPTHmax (m)
SOLp (°)
Abundance (ind. 1000 m⁻³)
Electrona antarctica
Electrona carlsbergi
Krefftichthys anderssoni
(a)
0°
30°W
30°E
45°S
55°S
65°S
60°W
60°E
90°
90°
120°W
120°E
150°W
150°E
180°
(b)
0.0 0.2 0.4 0.6 0.8 1.0
0.00 0.05 0.10 0.15
0.0 0.2 0.4 0.6

- Copopods lower standing biomass but higher productivity




Flying seabirds
Penguins
Seals
Minke whale
Squids
Other fish
Crystal krill
Silverfish
Phytoplankton
Shelf Zone

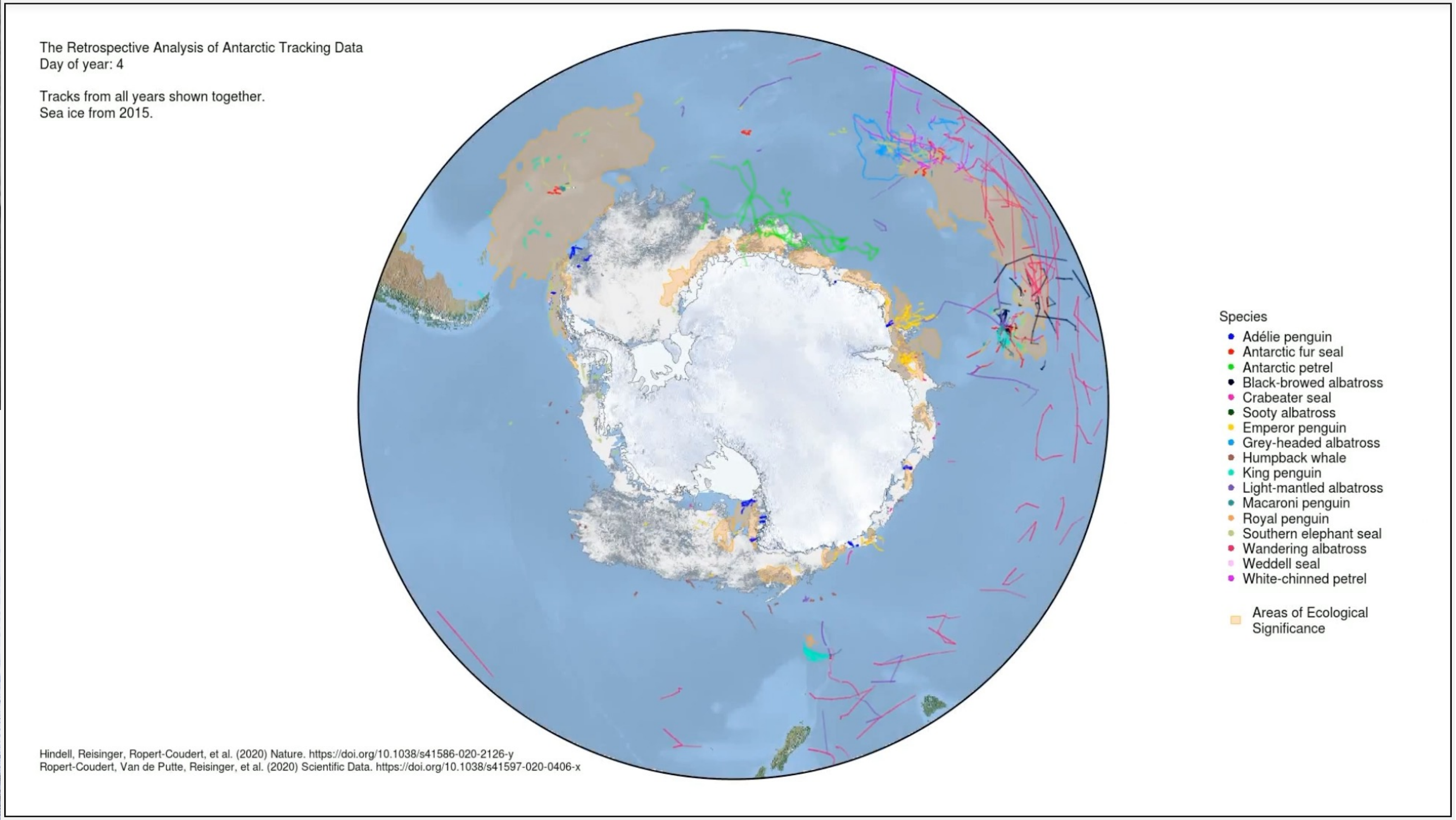

SUBANTARCTIC
ANTARCTIC CONTINENT
Epipelagic
Upper mesopelagic
Lower mesopelagic
Bathypelagic
Gymnosome pteropods
Salp chains
Small euphausiids
Copepods
Krill swarms
Larval krill
Crystal krill
Amphipods
Chaetognaths
Thecosome pteropods
Solitary salps
100m
500m
1000m
KEY
Daily migration
Predator-prey interaction
Seasonal migration
Intermittent forays



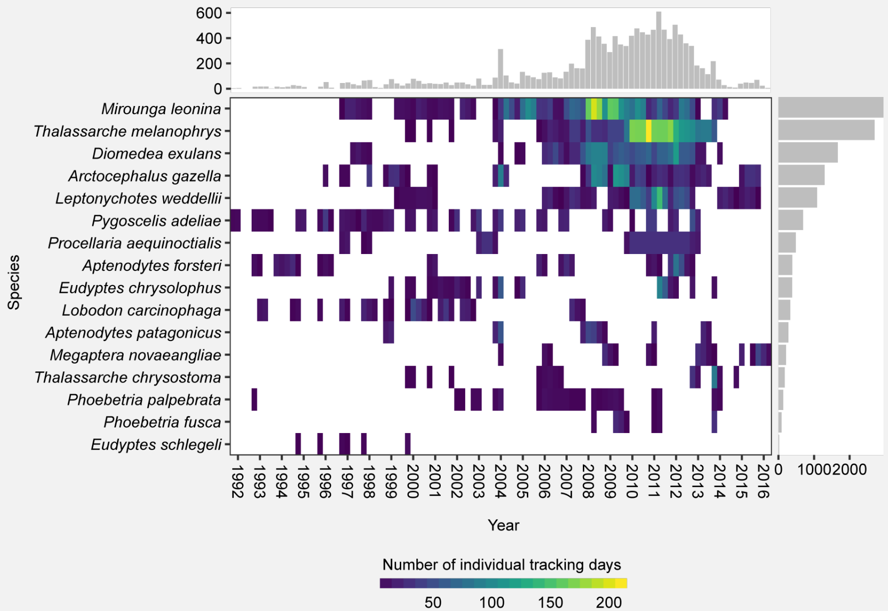
A Living Laboratory of Unique Biodiversity
Antarctic krill are a keystone species, serving as a major food source for more than 25 percent of the species in the diverse Antarctic food web, including penguins, seals, whales, and many fish species. The many remarkable species of the Southern Ocean make up some of the most intact marine ecosystems on the planet, where scientists are continually discovering new marine biodiversity, and can study nature in the absence of human interference. The following are some of the species that call the Southern Ocean home.
1 Penguins
Adélie
Chinstrap
Gentoo
Emperor
King
Southern rockhopper
Macaroni
2 Whales
Blue
Southern bottlenose
Humpback
Antarctic minke
Long-finned pilot
Sperm
Sei
Arnoux's beaked
Fin
Orca
3 Seals
Antarctic fur
Crabeater
Southern elephant
Leopard
Ross
Weddell
4 Seabirds
Snow petrel
Wandering albatross
Antarctic petrel
Antarctic fulmar
5 Fish
Antarctic and Patagonian toothfish (Chilean sea bass)
Icefish
Lanternfish
Antarctic eel cod
Grenadier
McCain's skate
Marbled rockcod
6 Invertebrates
Krill
Antarctic sea spider
Crawling and glass sponges
Antarctic coral
Bone-eating worm
Yeti (hairy) crab
Octopus
Starfish
Colossal squid
1
4
6
3
2
5
Source: Claude De Broyer et al. (eds.), "Biogeographic Atlas of the Southern Ocean," Scientific Committee on Antarctic Research (2014), http://share.biodiversity.aq/Atlas/example_BASO_web.pdf
© 2019 The Pew Charitable Trusts

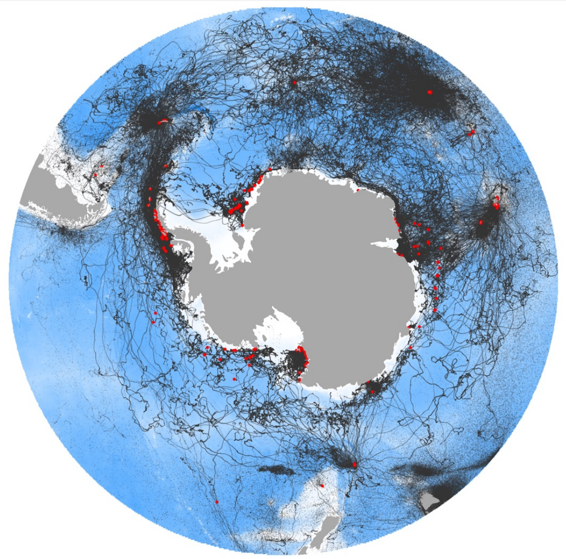

Judy Rebekah
ClarkeA


Clive R.
McMahon

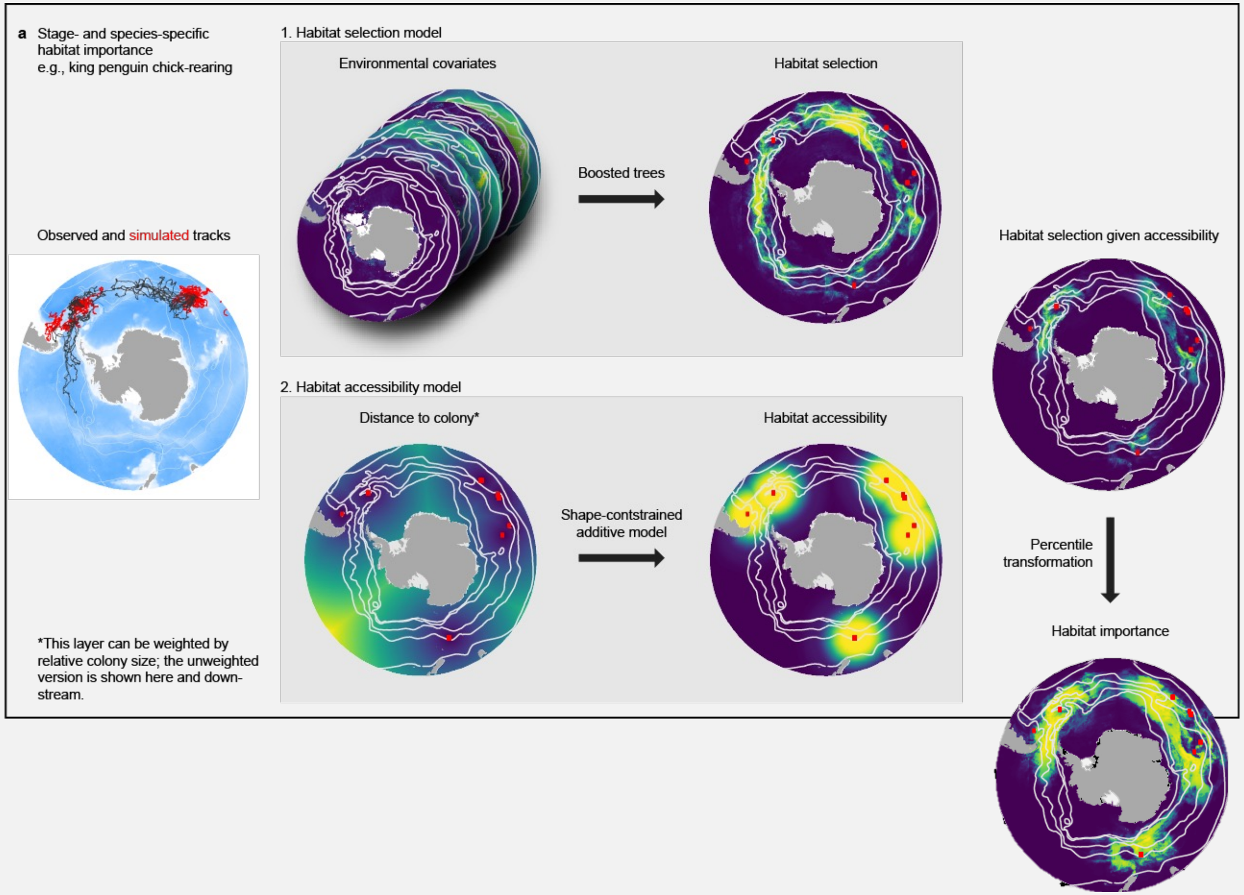

The Retrospective Analysis of Antarctic Tracking Data
Day of year: 4
Tracks from all years shown together.
Sea ice from 2015.
Species
Adélie penguin
Antarctic fur seal
Antarctic petrel
Black-browed albatross
Crabeater seal
Sooty albatross
Emperor penguin
Grey-headed albatross
Humpback whale
King penguin
Light-mantled albatross
Macaroni penguin
Royal penguin
Southern elephant seal
Wandering albatross
Weddell seal
White-chinned petrel
Areas of Ecological Significance
Hindell, Reisinger, Ropert-Coudert, et al. (2020) Nature. https://doi.org/10.1038/s41586-020-2126-y
Ropert-Coudert, Van de Putte, Reisinger, et al. (2020) Scientific Data. https://doi.org/10.1038/s41597-020-0406-x

4,060 tracks from
17 marine predator species

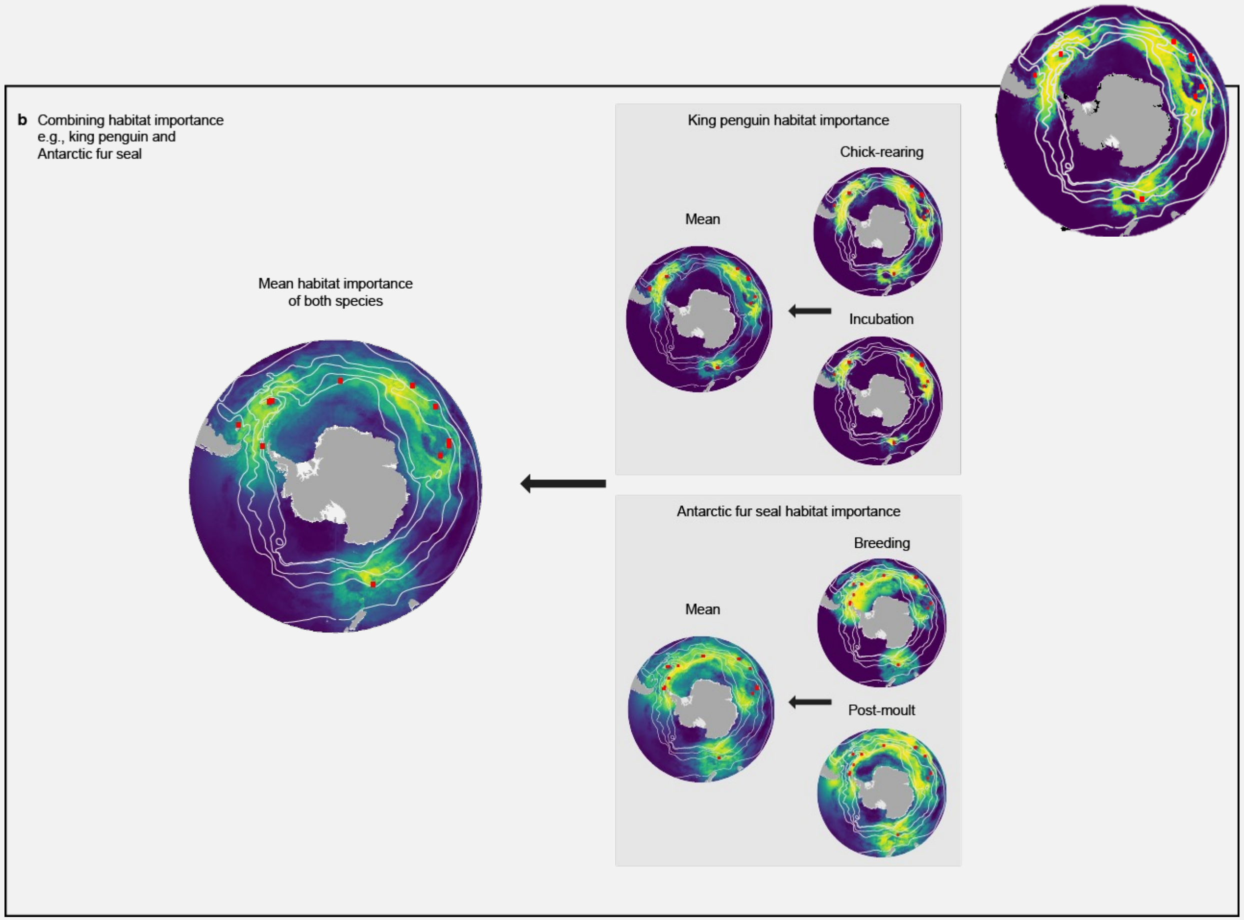




Hindell, Reisinger, Ropert-Coudert et al. in 2020
Ropert-Coudert, Van de Putte, Bornemann et al. 2020



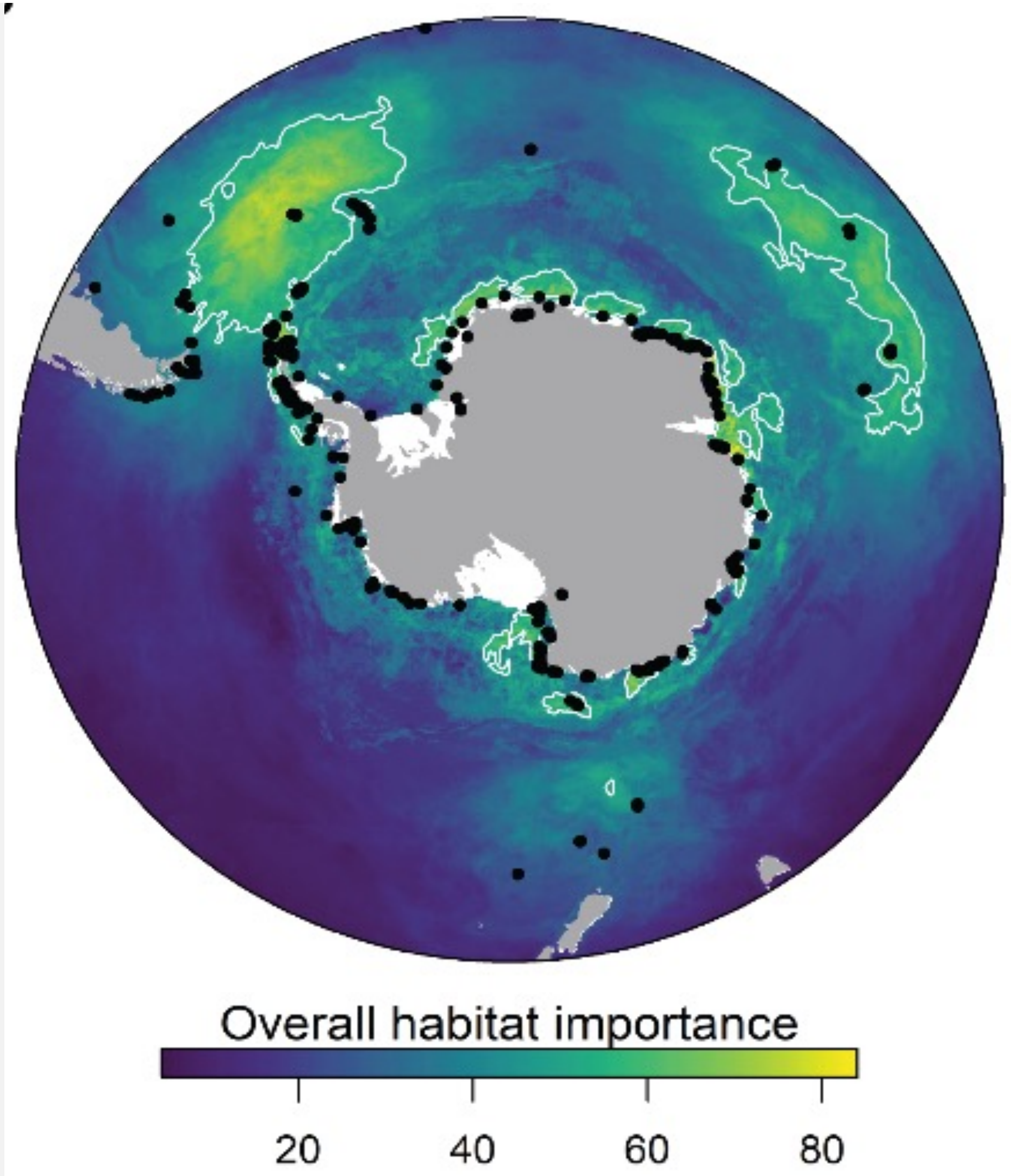
a Stage- and species-specific habitat importance
e.g., king penguin chick-rearing
Observed and simulated tracks
1. Habitat selection model
Environmental covariates
Boosted trees
Habitat selection
Habitat selection given accessibility
2. Habitat accessibility model
Distance to colony*
Shape-contstrained additive model
Habitat accessibility
Percentile transformation
Habitat importance
*This layer can be weighted by relative colony size; the unweighted version is shown here and down-stream.



b Combining habitat importance
e.g., king penguin and
Antarctic fur seal
King penguin habitat importance
Chick-rearing
Mean
Incubation
Mean habitat importance
of both species
Antarctic fur seal habitat importance
Breeding
Mean
Post-moult

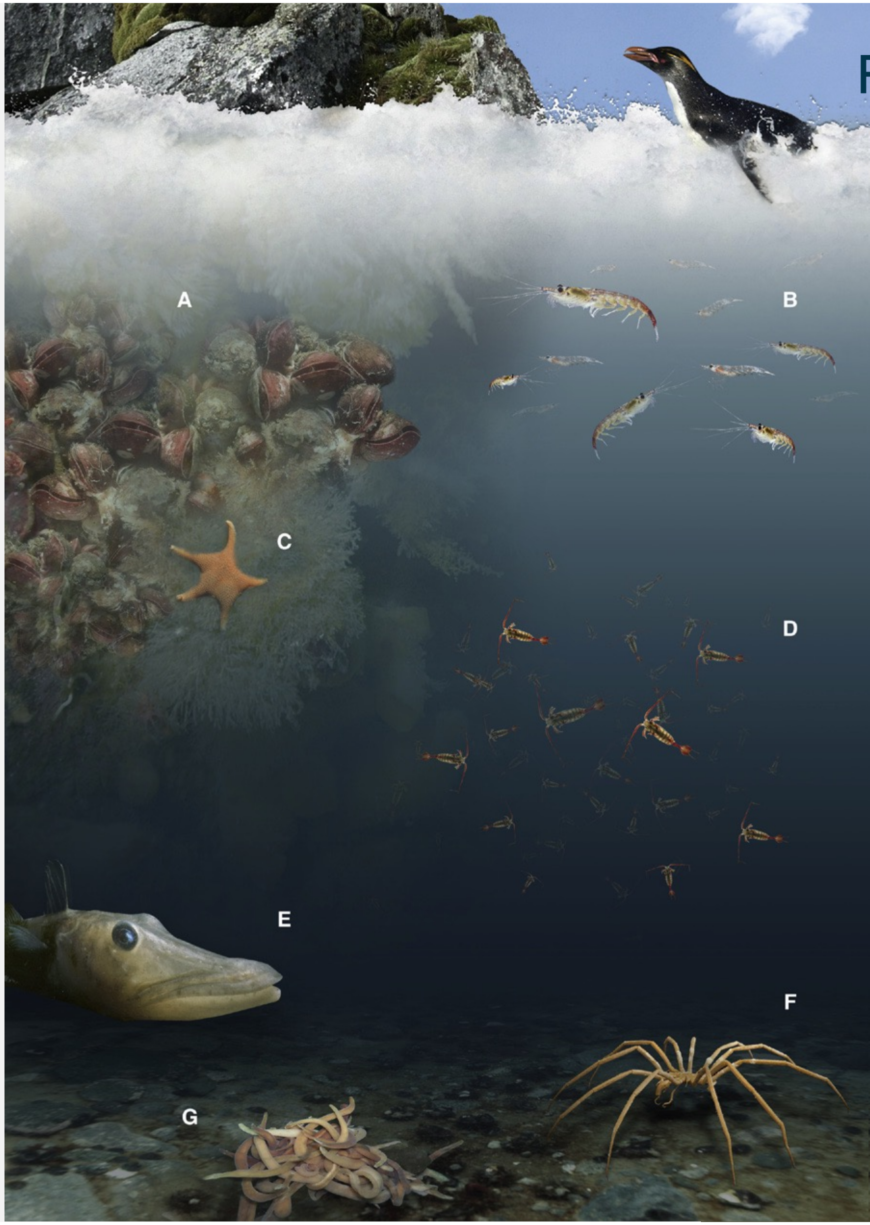
OVERALL HABITAT IMPORTANCE

Combination of species specific models of habitat importance.



BENTHIC

Penguin!



Estimated 20,000+ species

Penguin!

~90
species

~700
species

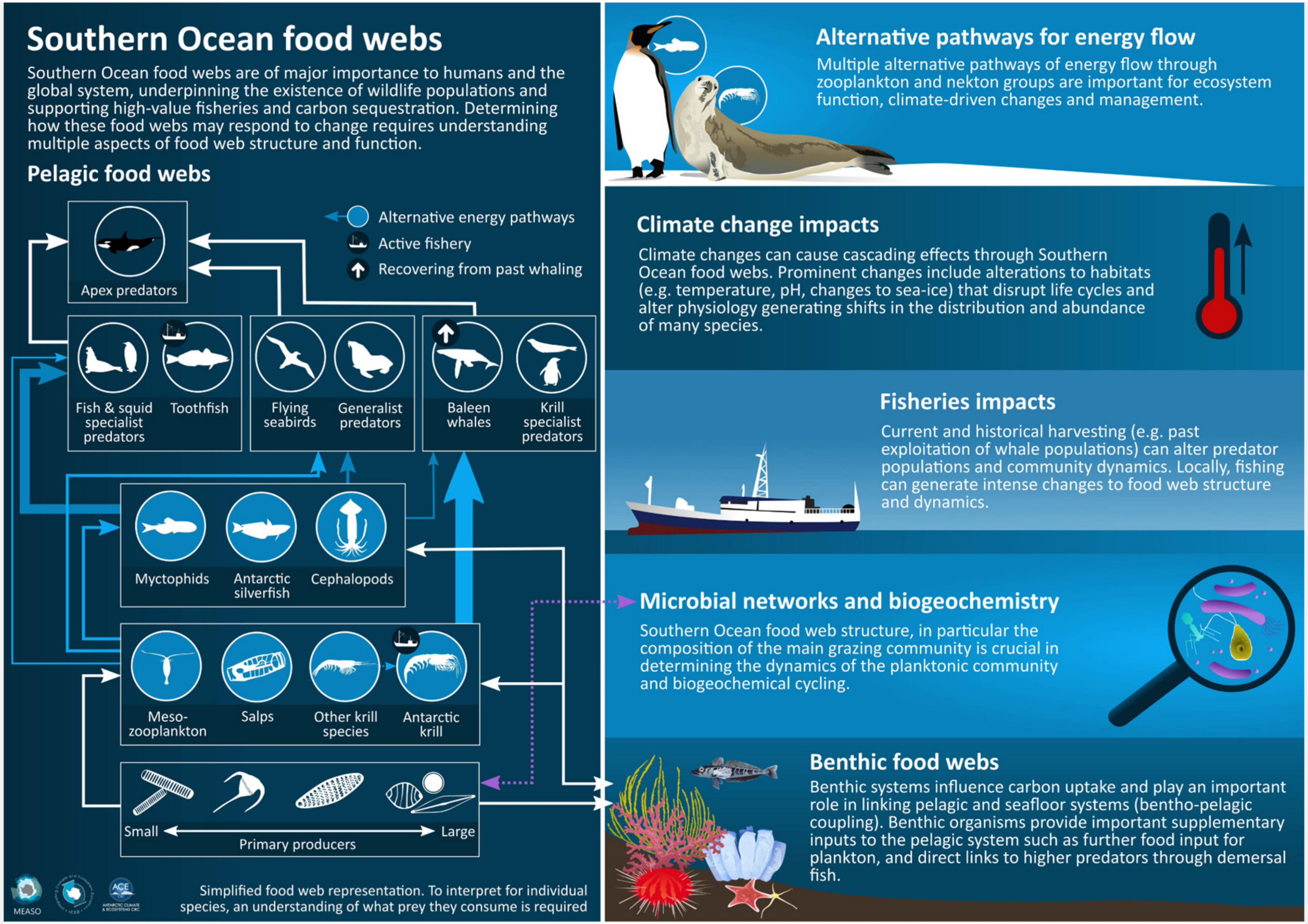
~19,000
species

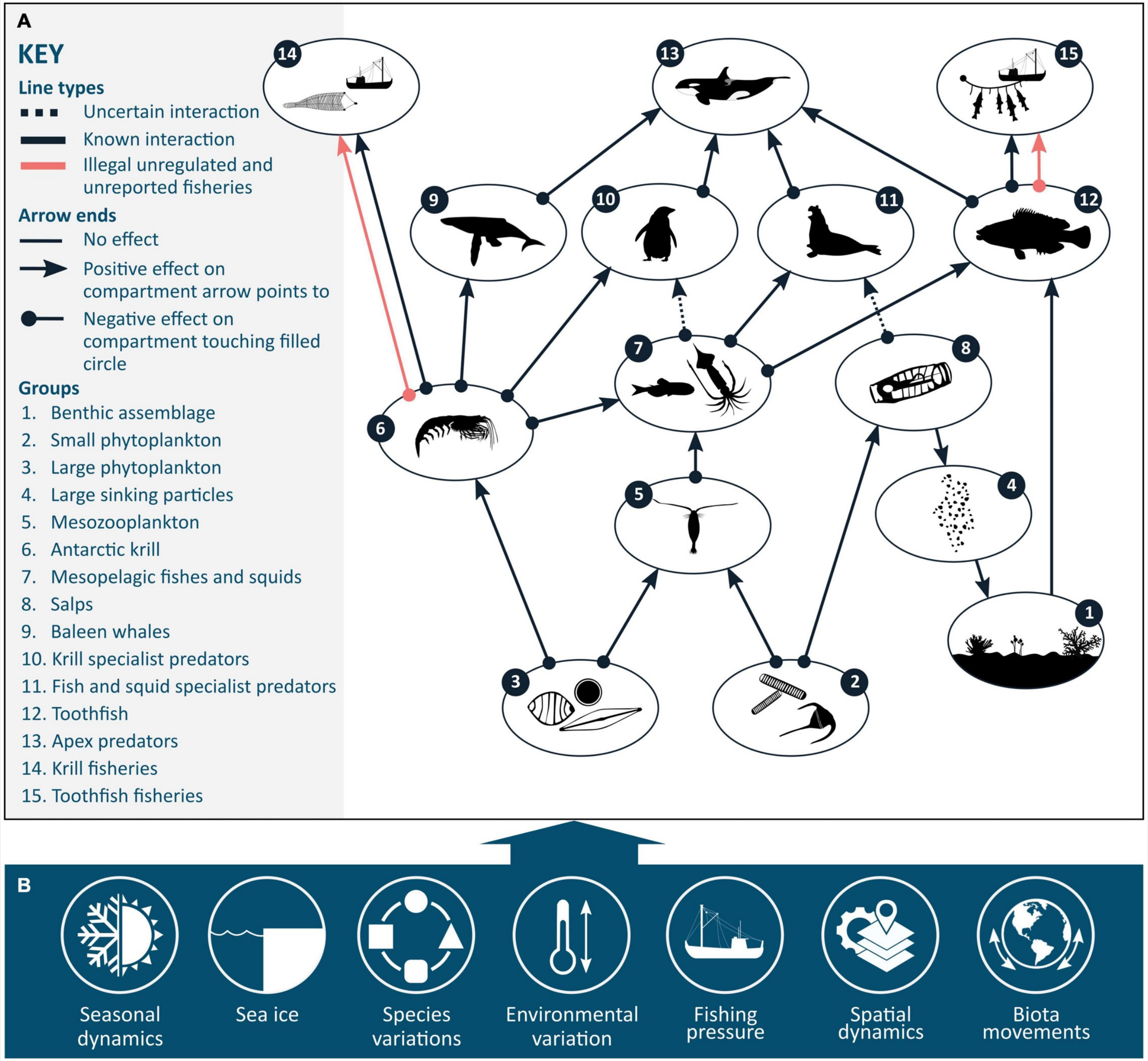
BIODIVERSITY

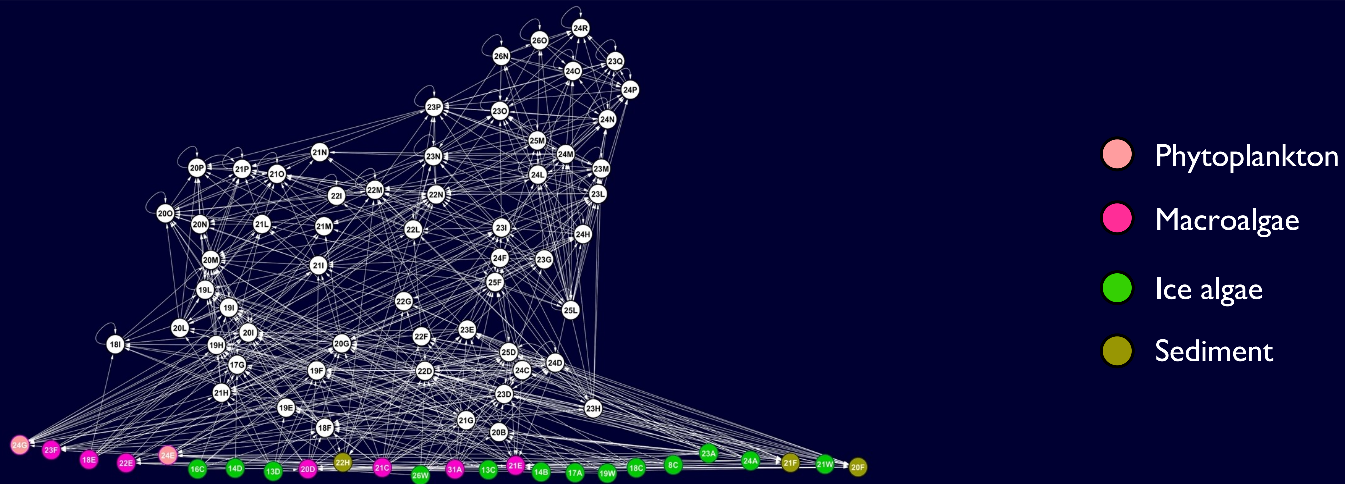
Higher predators


Plankton

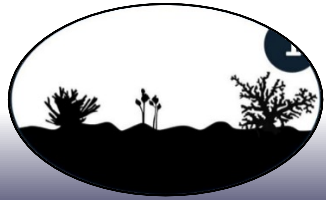

Benthos

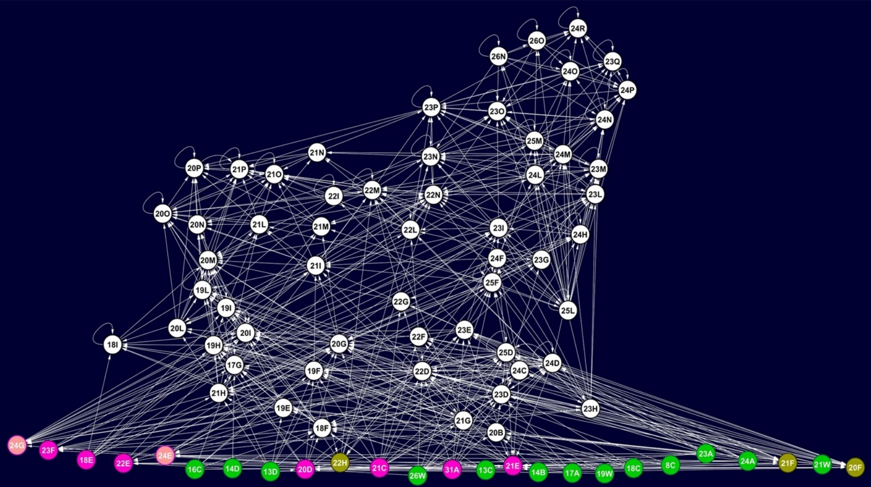

Southern Ocean food webs
Southern Ocean food webs are of major importance to humans and the global system, underpinning the existence of wildlife populations and supporting high-value fisheries and carbon sequestration. Determining how these food webs may respond to change requires understanding multiple aspects of food web structure and function.
Pelagic food webs
Alternative energy pathways
Active fishery
Recovering from past whaling
Apex predators
Fish & squid specialist predators
Toothfish
Flying seabirds
Generalist predators
Baleen whales
Krill specialist predators
Myctophids
Antarctic silverfish
Cephalopods
Meso-zooplankton
Salps
Other krill species
Antarctic krill
Small
Large
Primary producers
MEASO
Simplified food web representation. To interpret for individual species, an understanding of what prey they consume is required
Alternative pathways for energy flow
Multiple alternative pathways of energy flow through zooplankton and nekton groups are important for ecosystem function, climate-driven changes and management.
Climate change impacts
Climate changes can cause cascading effects through Southern Ocean food webs. Prominent changes include alterations to habitats (e.g. temperature, pH, changes to sea-ice) that disrupt life cycles and alter physiology generating shifts in the distribution and abundance of many species.
Fisheries impacts
Current and historical harvesting (e.g. past exploitation of whale populations) can alter predator populations and community dynamics. Locally, fishing can generate intense changes to food web structure and dynamics.
Microbial networks and biogeochemistry
Southern Ocean food web structure, in particular the composition of the main grazing community is crucial in determining the dynamics of the planktonic community and biogeochemical cycling.
Benthic food webs
Benthic systems influence carbon uptake and play an important role in linking pelagic and seafloor systems (bentho-pelagic coupling). Benthic organisms provide important supplementary inputs to the pelagic system such as further food input for plankton, and direct links to higher predators through demersal fish.


A
KEY
Line types
Uncertain interaction
Known interaction
Illegal unregulated and unreported fisheries
Arrow ends
No effect
Positive effect on compartment arrow points to
Negative effect on compartment touching filled circle
Groups
1. Benthic assemblage
2. Small phytoplankton
3. Large phytoplankton
4. Large sinking particles
5. Mesozooplankton
6. Antarctic krill
7. Mesopelagic fishes and squids
8. Salps
9. Baleen whales
10. Krill specialist predators
11. Fish and squid specialist predators
12. Toothfish
13. Apex predators
14. Krill fisheries
15. Toothfish fisheries
B
Seasonal dynamics
Sea ice
Species variations
Environmental variation
Fishing pressure
Spatial dynamics
Biota movements

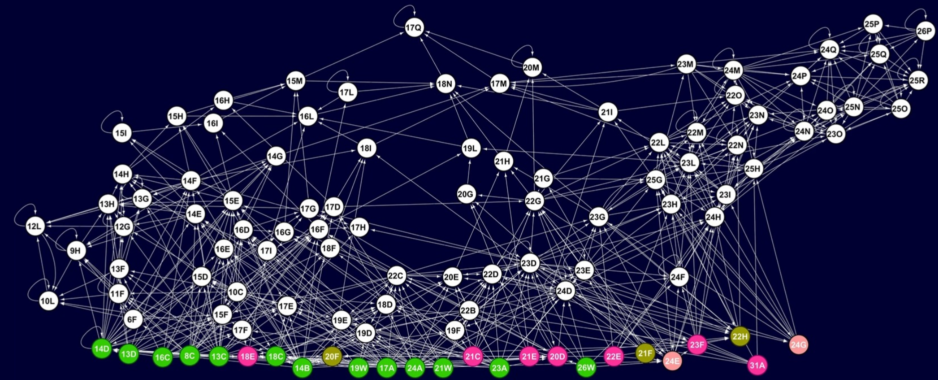


Rossi et al., 2019 - stable isotope analysis



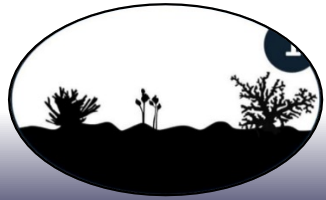


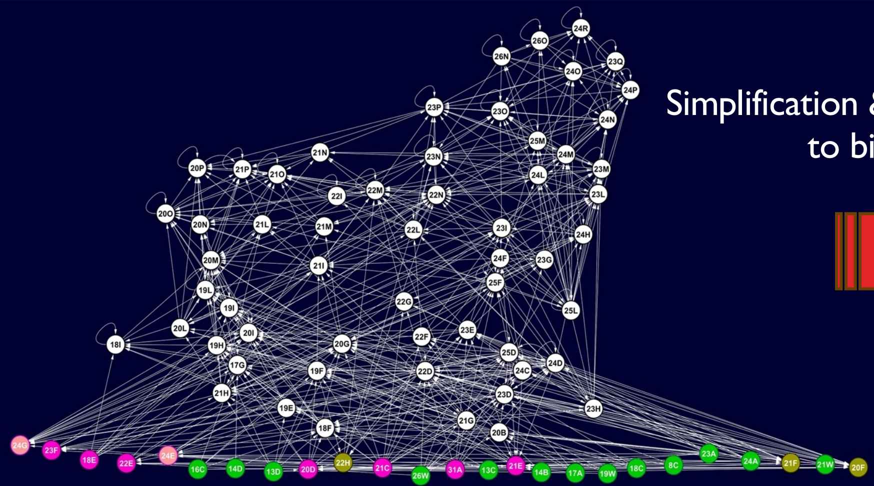
Before sea ice break up



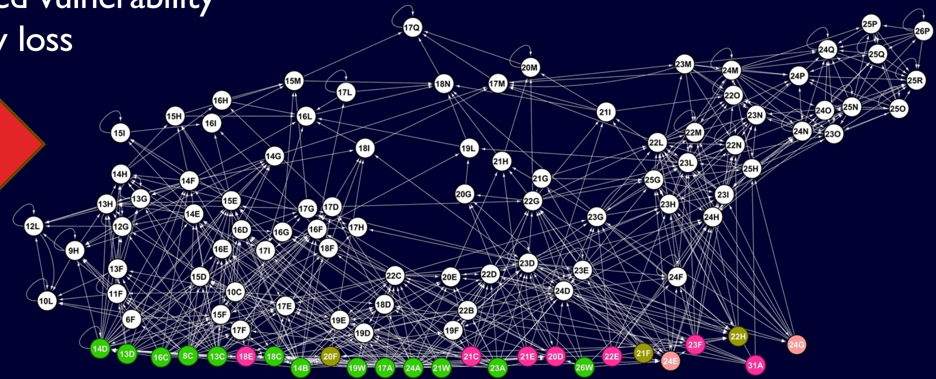
After sea ice break up

Rossi et al., 2019 - stable isotope analysis





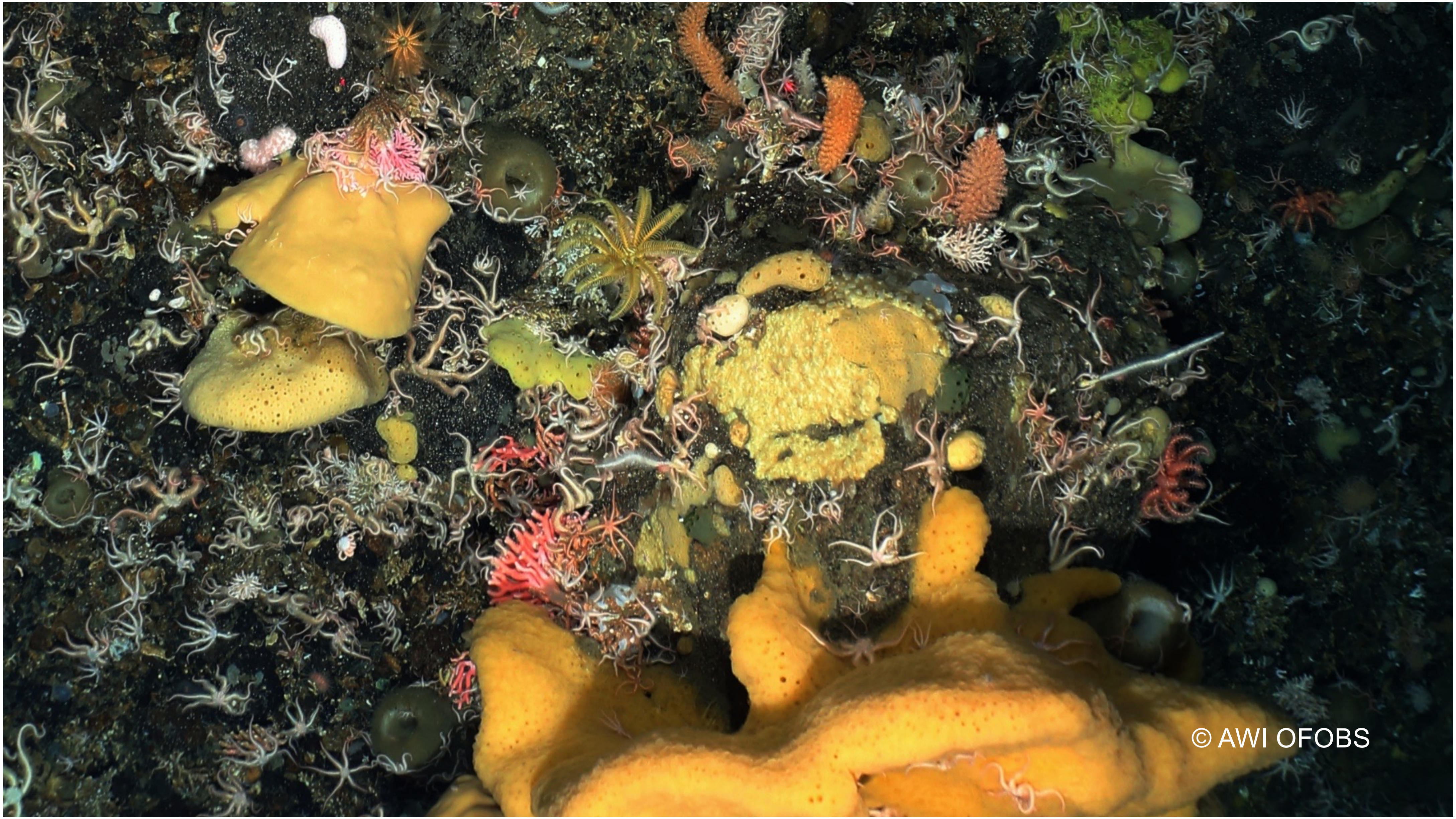
Simplification & increased vulnerability to biodiversity loss



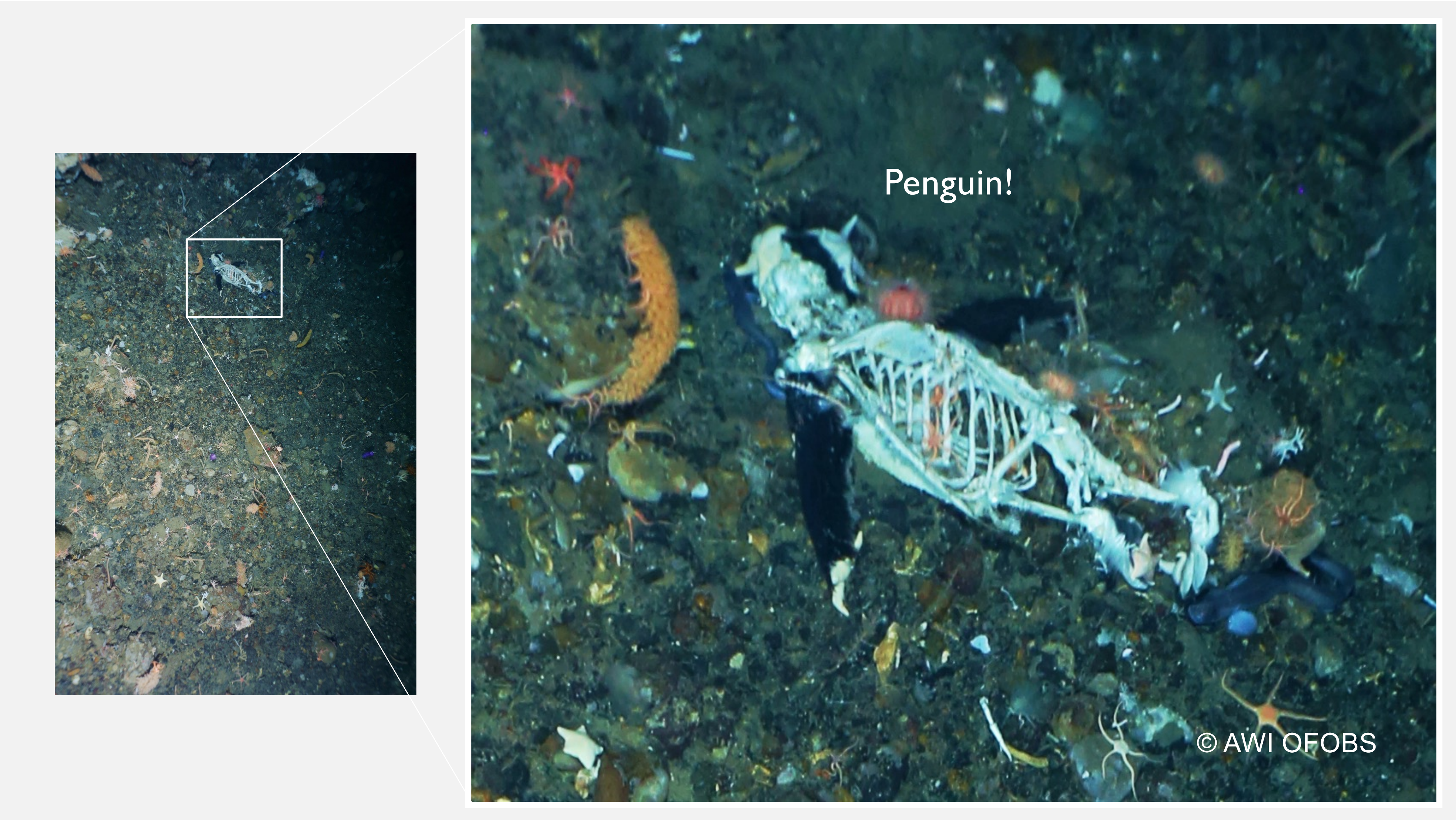
Before sea ice break up

After sea ice break up

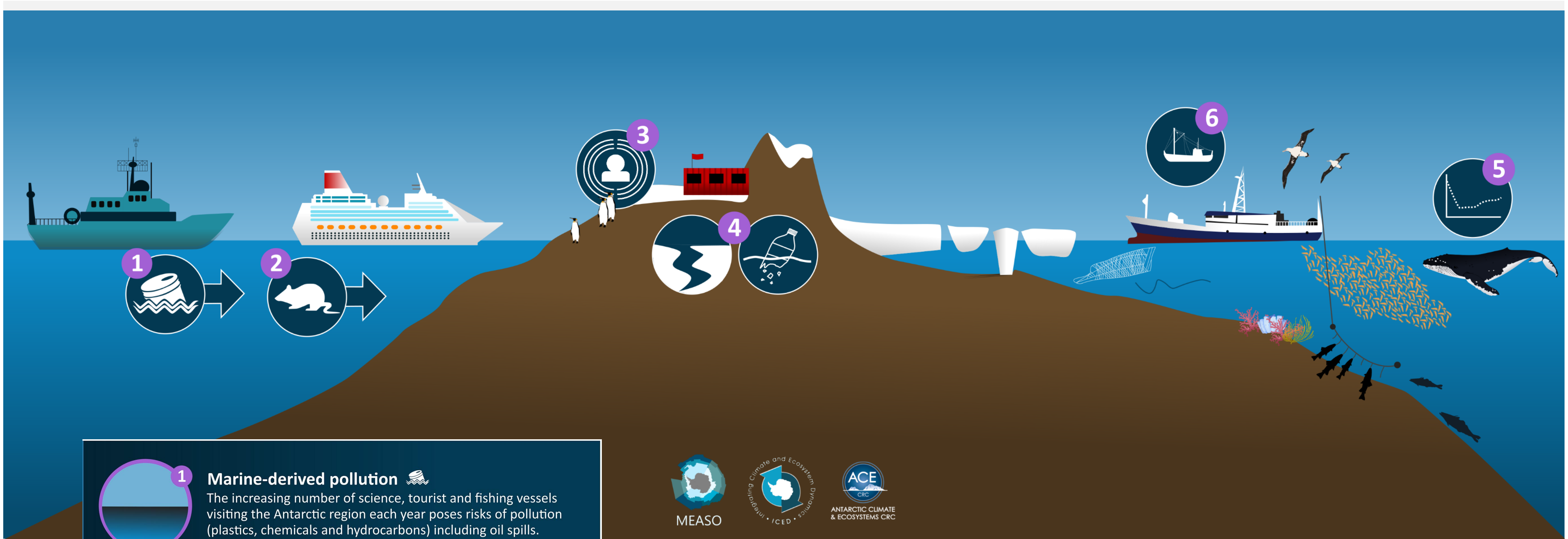
Rossi et al., 2019 - stable isotope analysis


© AWI OFOBS


© AWI OFOBS


Penguin!
© AWI OFOBS

LOCAL DRIVERS OF CHANGE



1 Marine-derived pollution
The increasing number of science, tourist and fishing vessels visiting the Antarctic region each year poses risks of pollution (plastics, chemicals and hydrocarbons) including oil spills.

2 Land-derived pollution
Human activities on land, both scientific and tourism-related, increase the risk of sewage runoff and point source pollution (plastics, chemicals and hydrocarbons).

3 Non-indigenous species
All vessels pose the risk of transporting non-indigenous species (including disease-causing species) to the Antarctic region in ballast water or on hull surfaces, as well as being taken ashore by visitors or in cargo.

4 Tourism and visitation
In addition to 1 and 3, visitor activities (both tourists and scientists) may cause disturbance to wildlife when visiting land-based colonies, or undertaking activities such as kayaking or diving.

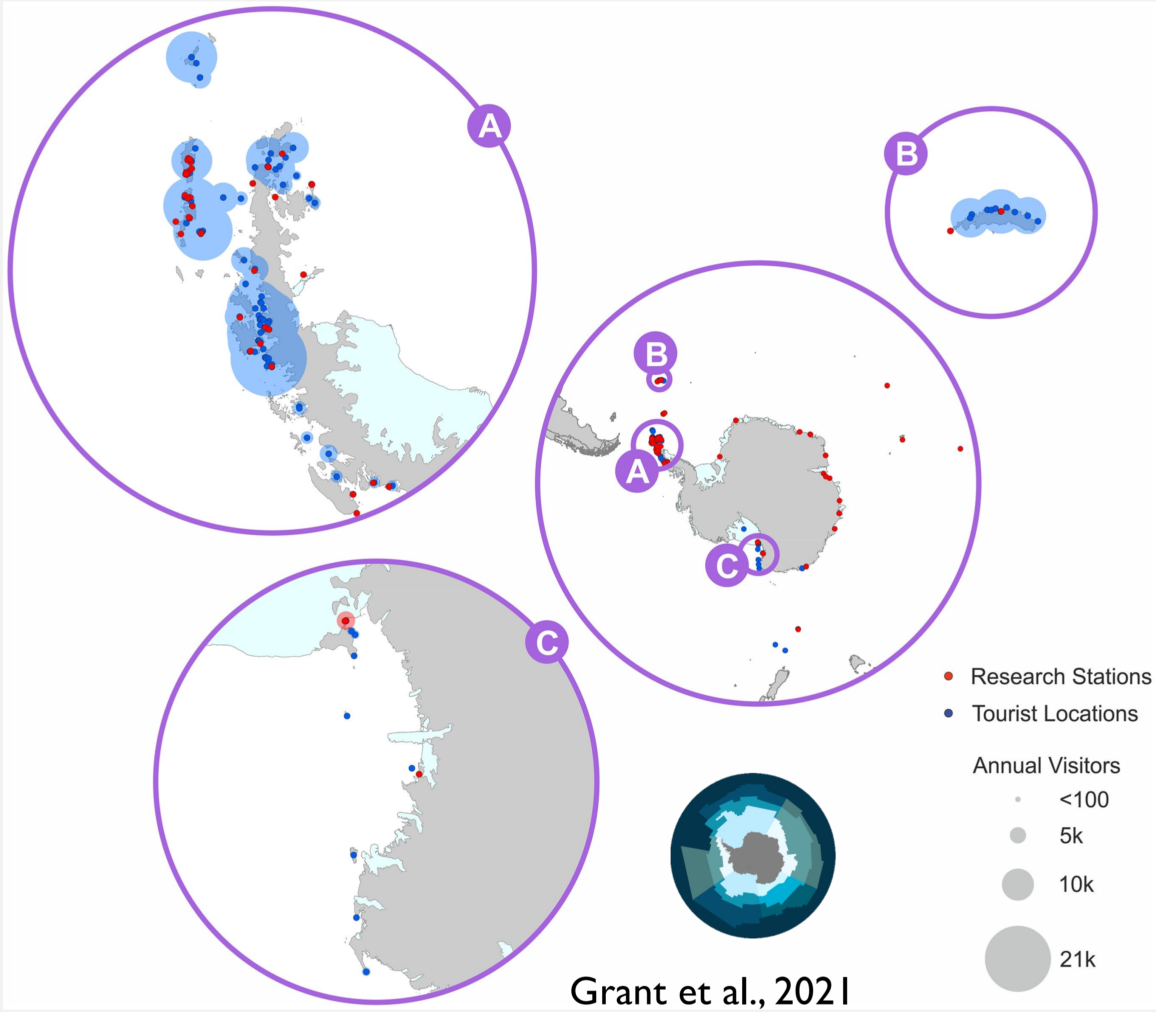
5 Marine mammal recovery
Many marine mammal species are recovering from past exploitation. Local population increases may influence krill swarms as well as oceanic nutrient enrichment and mixing.

6 Fishing
In addition to 1 and 3, fishing activities including long-lining and pelagic trawling pose local risks such as depletion of fish/krill stocks, incidental mortality, entanglement, bycatch of non-target species, and physical damage to vulnerable marine ecosystems such as benthic habitats.

7 Coastal change
Ice loss from coastal glacier retreat and ice shelf collapses may cause increased scouring and impacts on local benthic biodiversity.

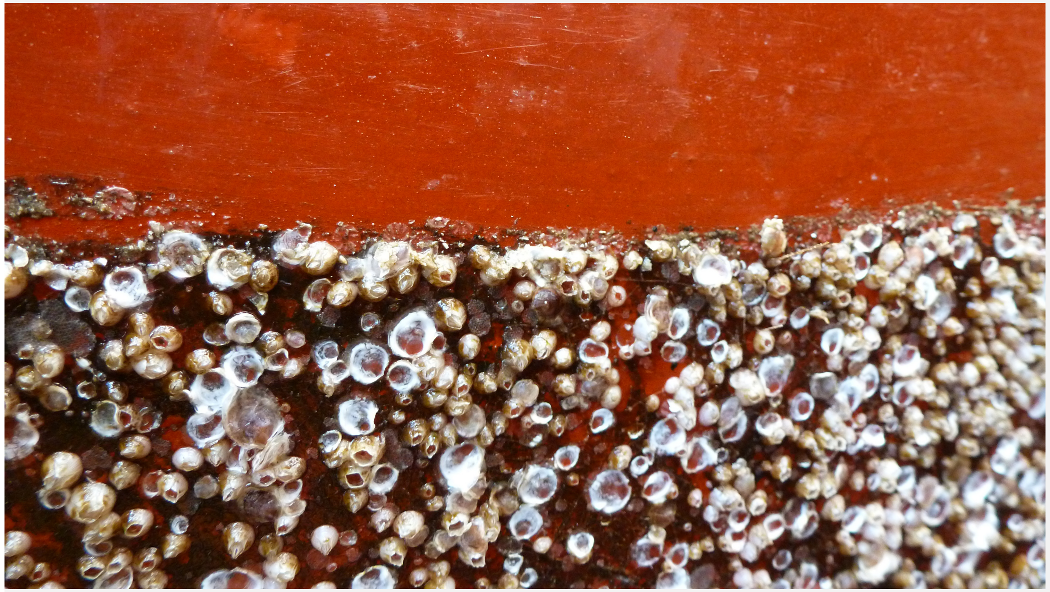
TOURISM AND VISITATION

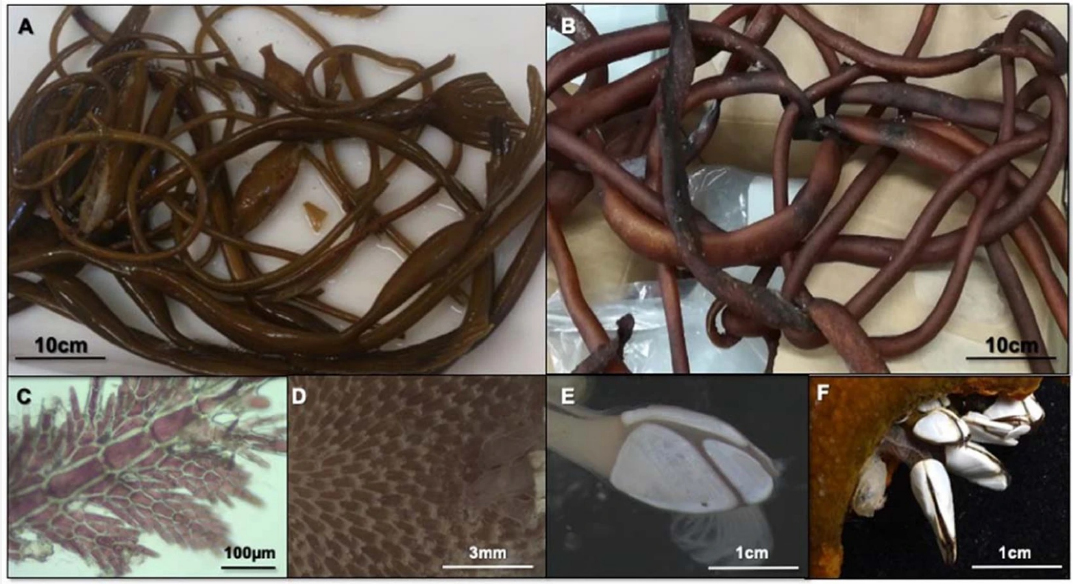
Rothera Research Station



Grant et al., 2021

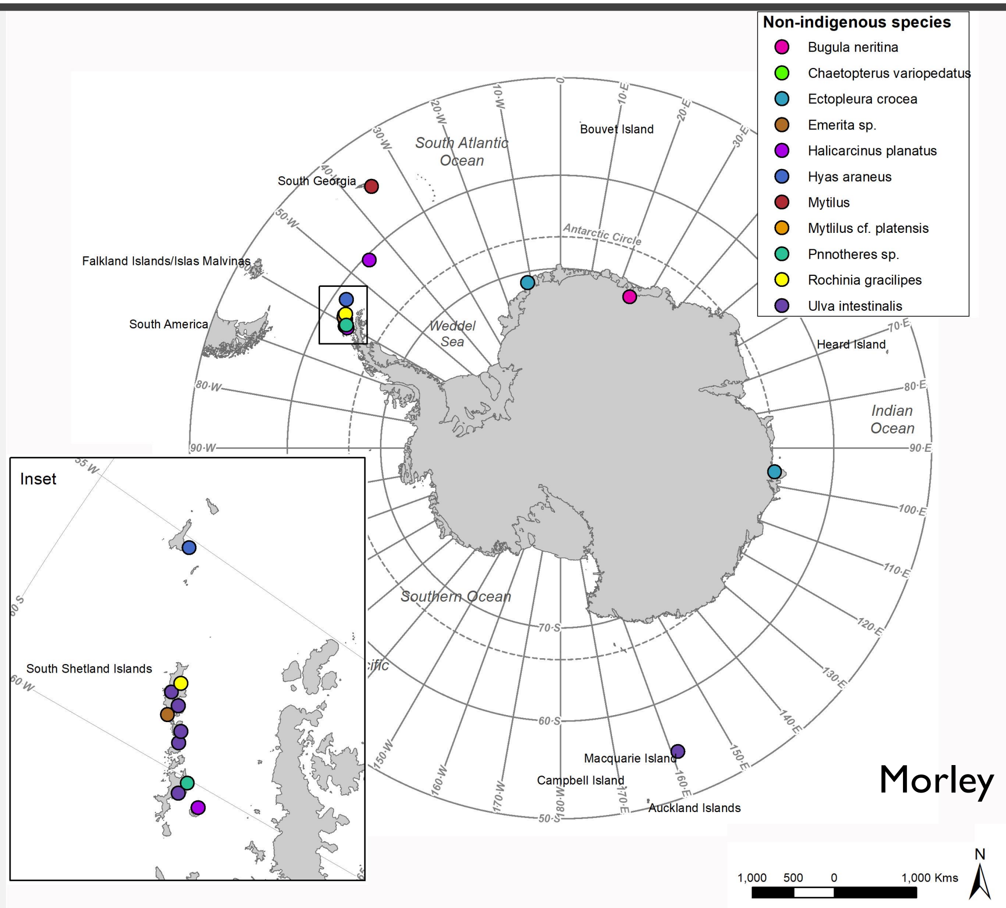
NON INDIGENOUS SPECIES





Avila et al., 2020

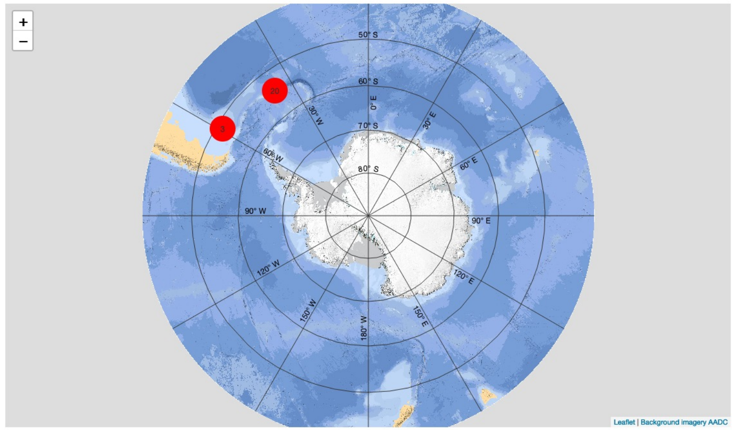
NON INDIGENOUS SPECIES

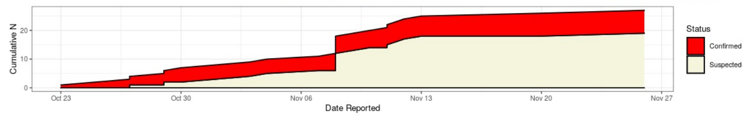


Morley et al., 2020

AVIAN INFLUENZA

Cases | About this app





Total cases

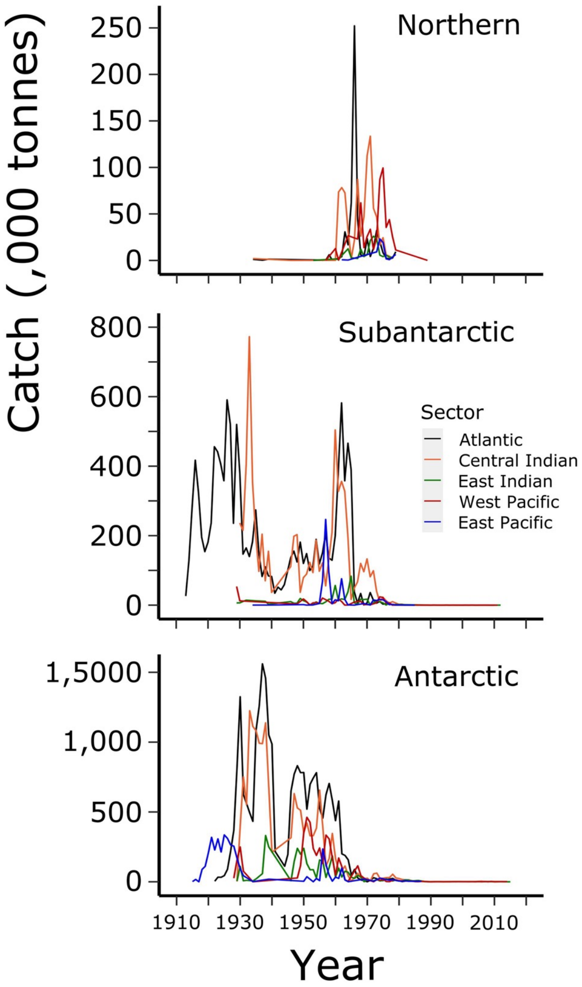
Suspected: 19

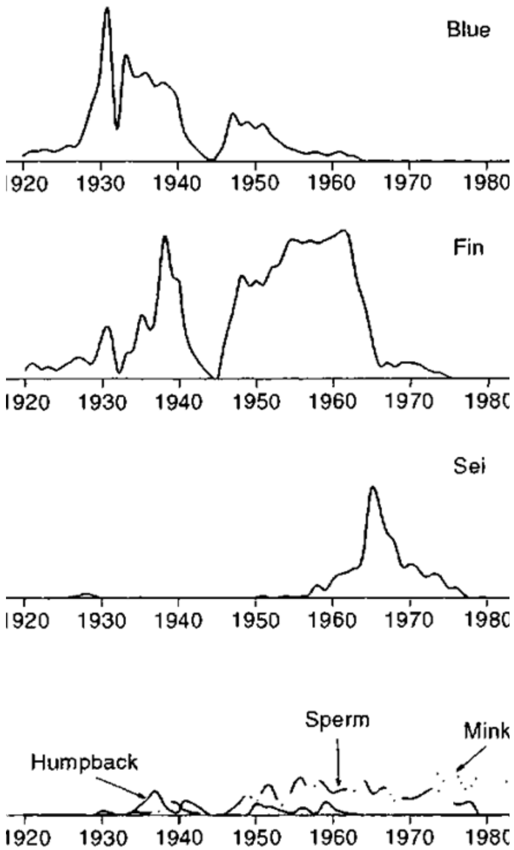
Confirmed: 8

Date Reported	Site	Species Affected	Status
All	All	All	All
2023-10-23	Bird Island	Brown Skuas	Confirmed
2023-10-25	Hound Bay	Brown Skuas, Kelp Gulls	Confirmed
2023-10-27	Royal Bay (Moltke)	Brown Skuas, Kelp Gulls	Confirmed
2023-10-27	Royal Bay (Moltke)	Elephant Seals, Giant Petrel	Suspected
2023-10-29	Harpon	Brown Skuas	Confirmed
2023-10-29	Harpon	Giant Petrel	Suspected
2023-11-03	Gold Harbour	Elephant seal, Kelp Gulls, Brown Skua	Suspected
2023-11-03	Cooper Bay	Elephant seal mortality*	Suspected
2023-10-30	Stanley	One Southern Fulmar	Confirmed
2023-11-07	Elsehul	Elephant seal	Suspected

Show 10 entries

MARINE MAMMAL RECOVERY



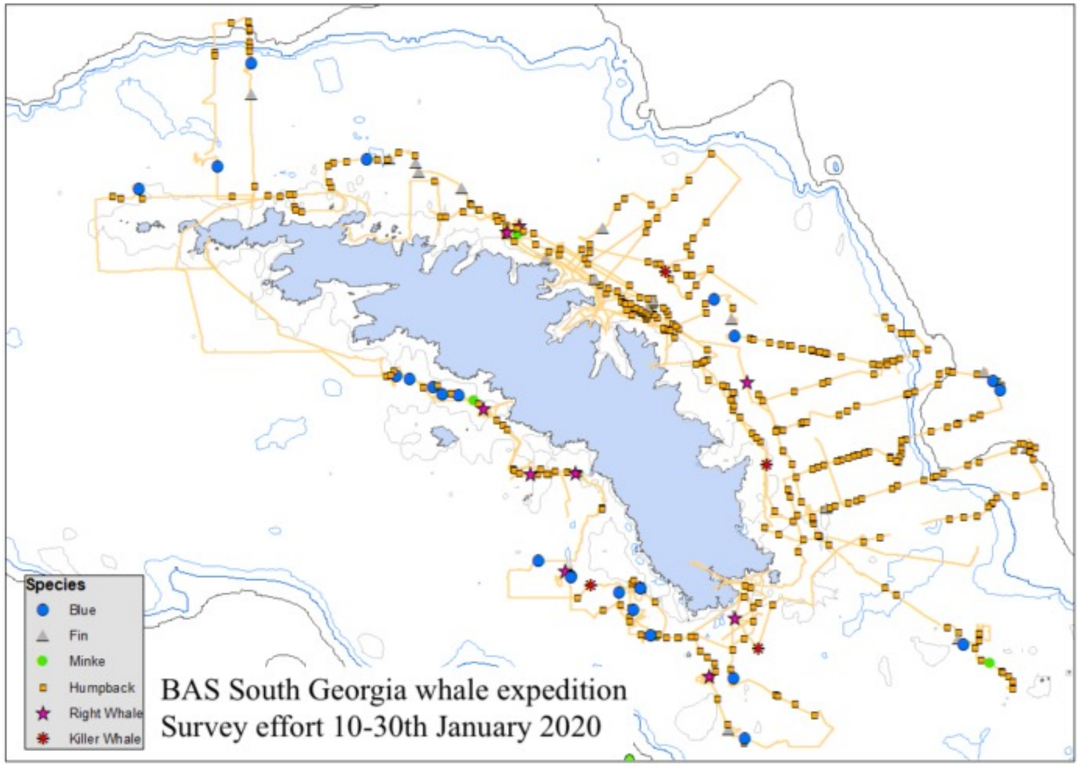


- • exploratory sealing
- • late 18th early 19th century
- • preindustrial sealing and whaling
- • 19th century
- • industrial whaling
- • 20th Century

	Lower estimate	Higher estimate
	Krill production (10^6 T/year)	
	400	1385
Present		
Taxa	Krill consumption (10^6 T/year)	
Cetaceans (baleen whales)	34	43
Seals (crabeater seal Lobodon carcinophagus)	64	129
Cephalopods (principally squids of the order Oegopsidea)	30	50
Birds (penguins accounting for 90% of the biomass of and 86% of the food consumed by Antarctic birds)	25	50
Fishes (Champsocephalus gunnari Notothenia rossii)	10 ?	20 ?
Total	163	292
% of krill production	163/1385= 12%	292/400= 73%
Before whale hunting		
Baleen whales		190

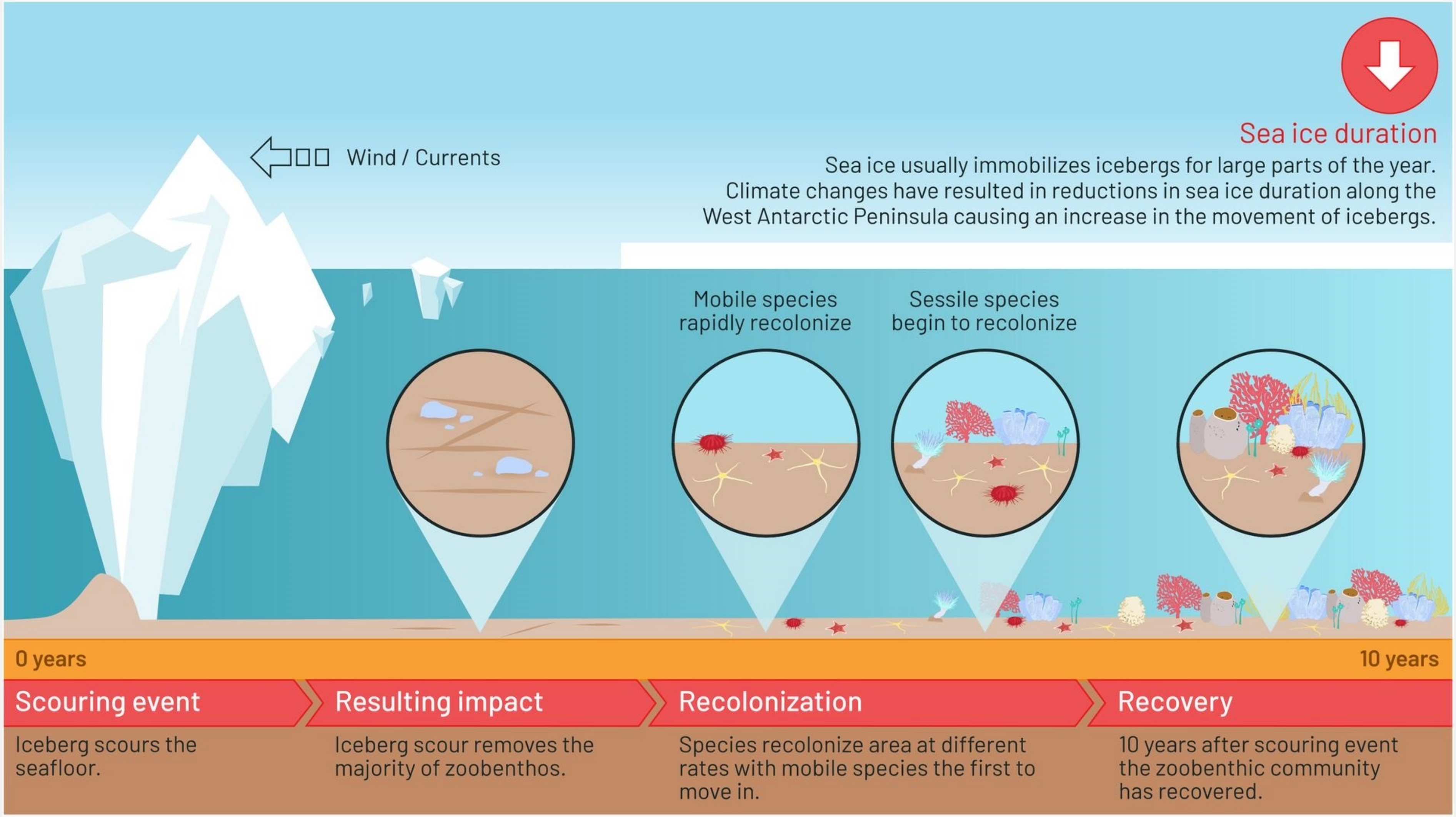
- Krill eaters consume a significant part of krill production
- Before whale hunting, most of krill production was probably consumed

➢ Bottom-up control

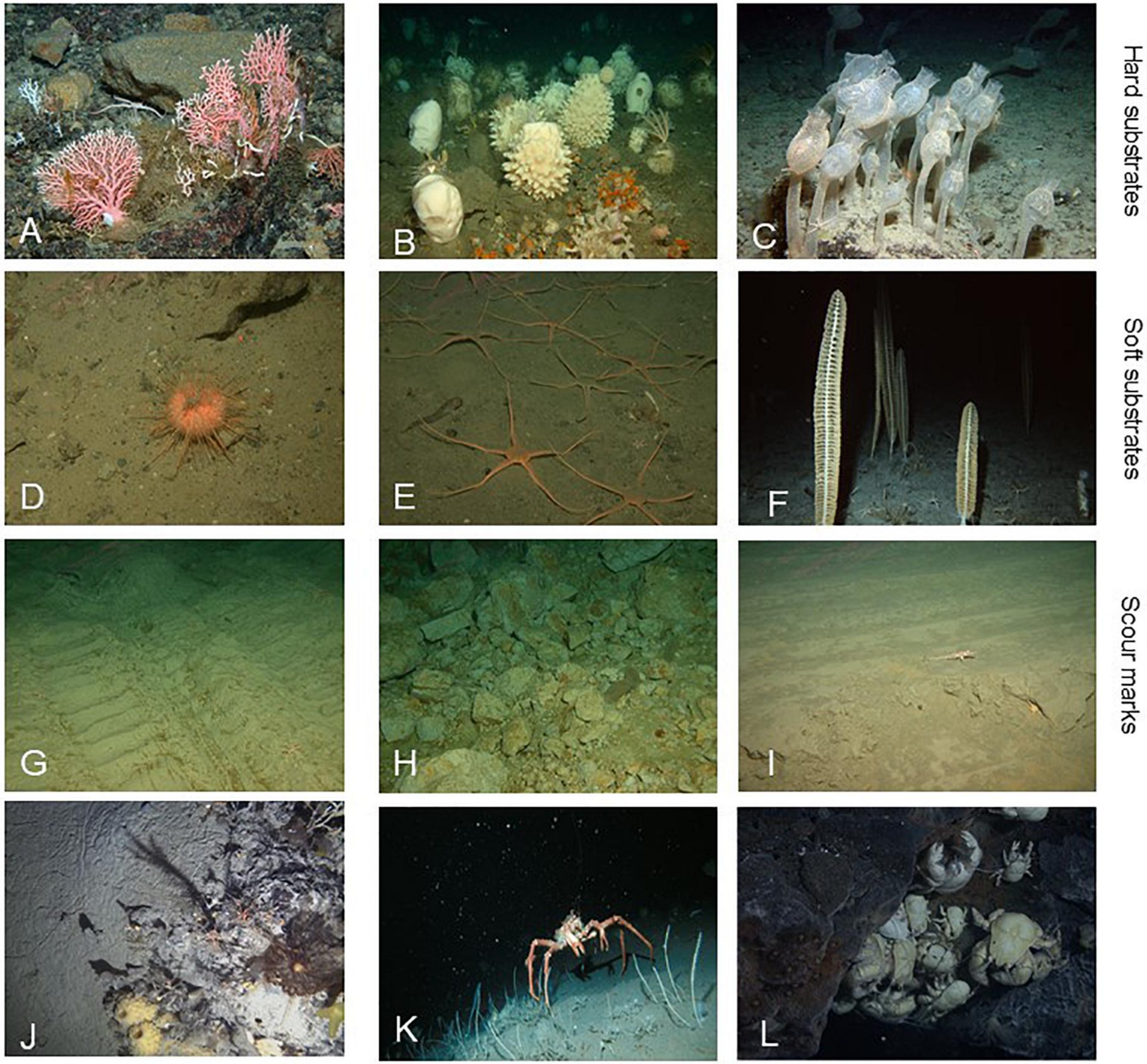

Species
Blue
Fin
Minke
Humpback
Right Whale
Killer Whale
BAS South Georgia whale expedition
Survey effort 10-30th January 2020


South Georgia blue whale. Photo: Martin Collins

COASTAL CHANGE

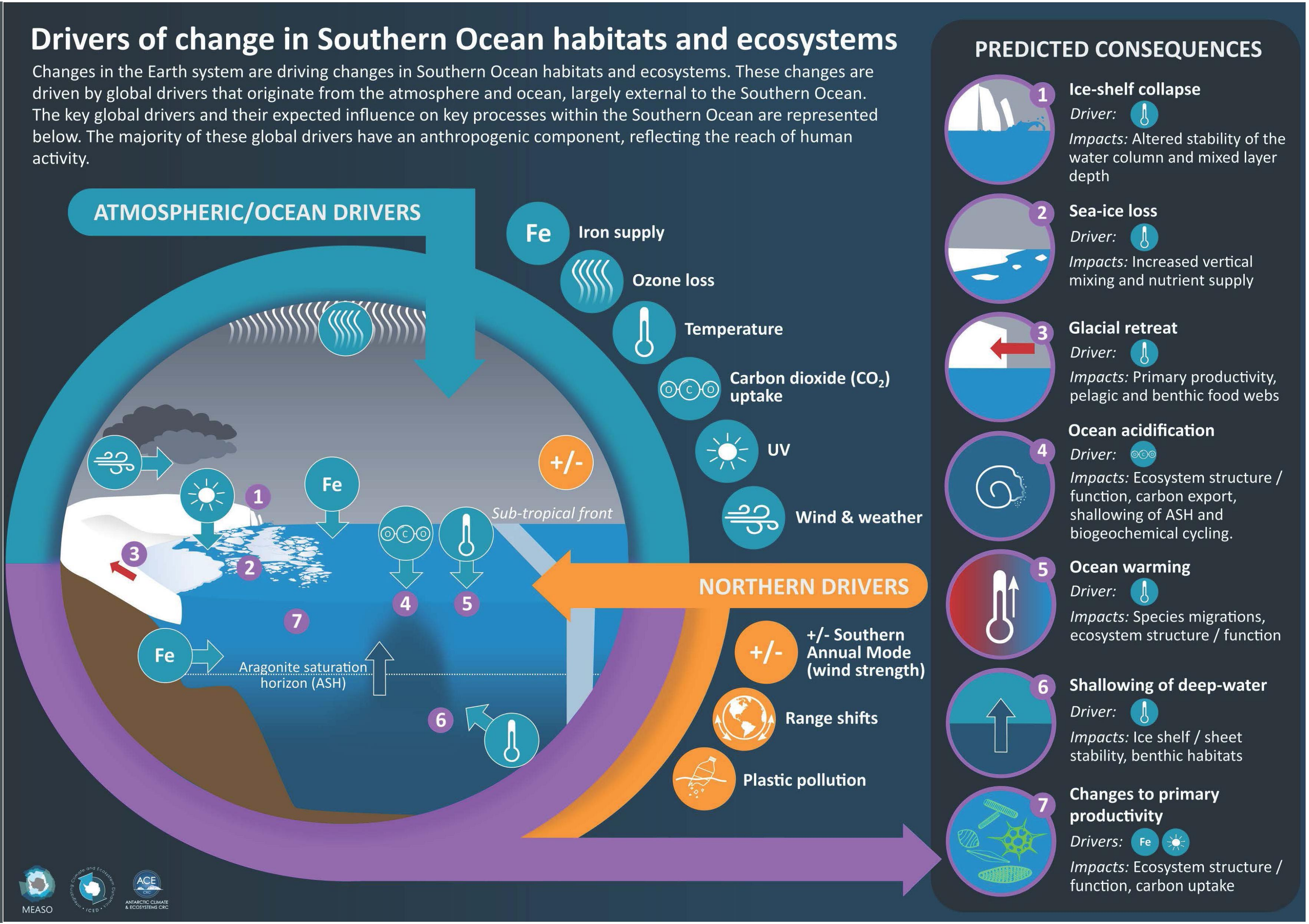


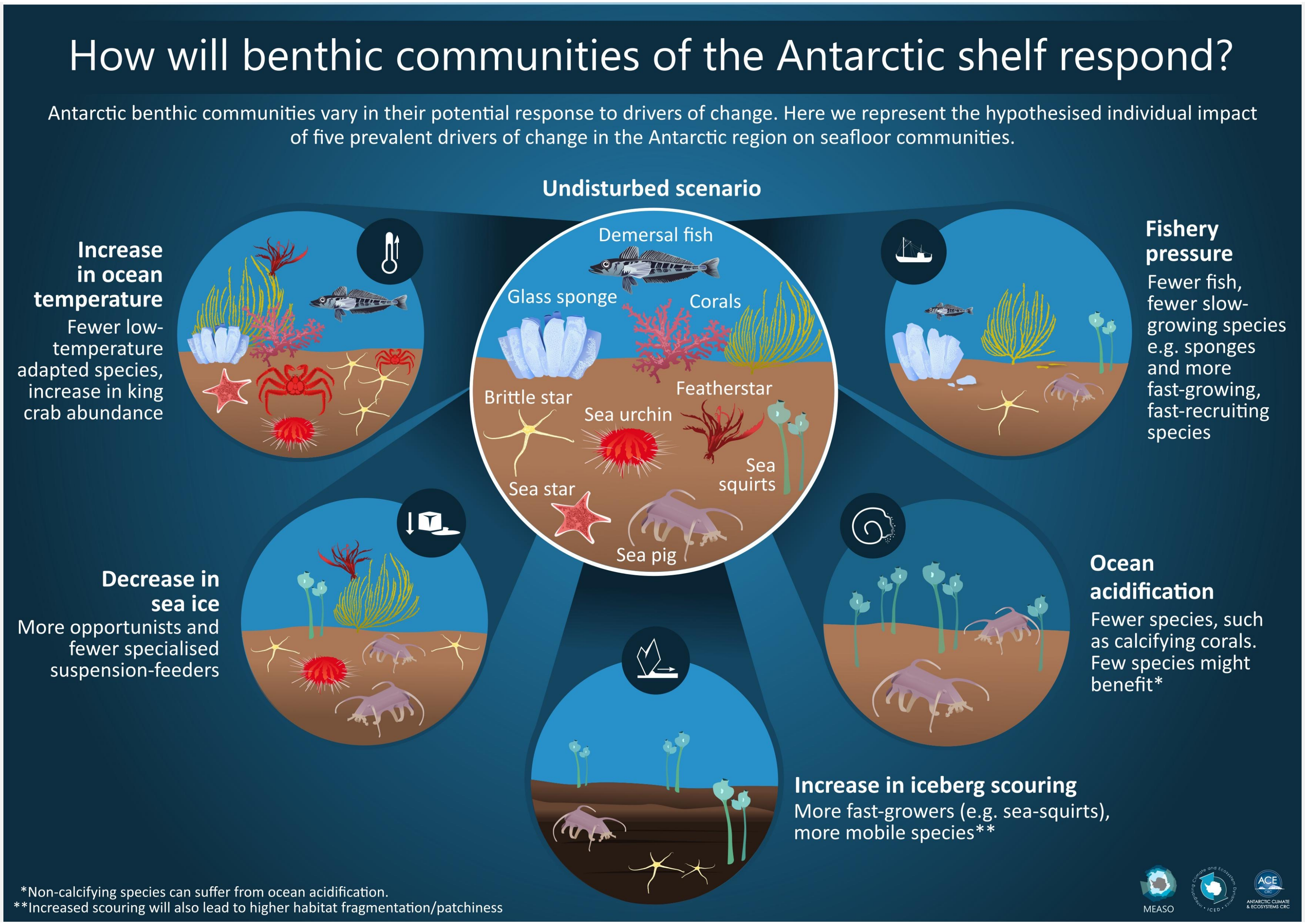
Zwerschke et al., 2021


A
B
C
Hard substrates
D
E
F
Soft substrates
G
H
I
Scour marks
J
K
L

GLOBAL DRIVERS OF CHANGE

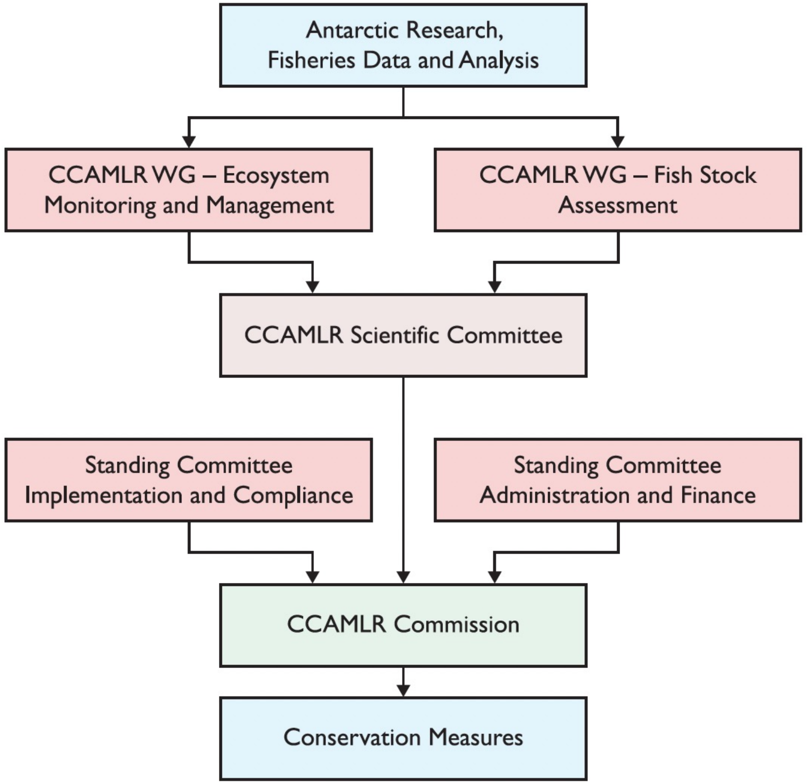
- Front. Mar. Sci., 15 December 2020
- Sec. Global Change and the Future Ocean
- https://doi.org/10.3389/fmars.2020.547188



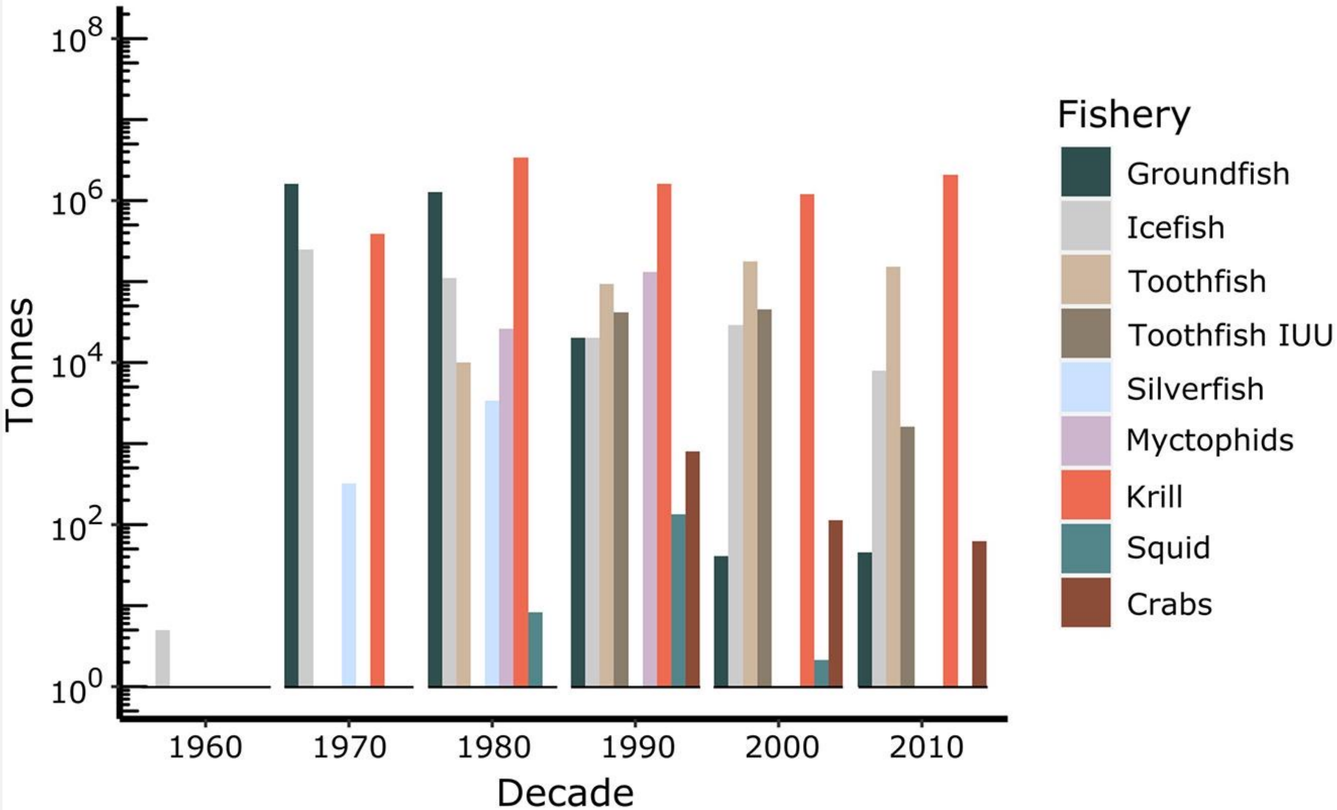

How will benthic communities of the Antarctic shelf respond?
Antarctic benthic communities vary in their potential response to drivers of change. Here we represent the hypothesised individual impact of five prevalent drivers of change in the Antarctic region on seafloor communities.
Undisturbed scenario
Demersal fish
Glass sponge
Corals
Brittle star
Featherstar
Sea urchin
Sea squirts
Sea star
Sea pig
Increase in ocean temperature
Fewer low-temperature adapted species, increase in king crab abundance
Fishery pressure
Fewer fish, fewer slow-growing species e.g. sponges and more fast-growing, fast-recruiting species
Decrease in sea ice
More opportunists and fewer specialised suspension-feeders
Ocean acidification
Fewer species, such as calcifying corals. Few species might benefit*
Increase in iceberg scouring
More fast-growers (e.g. sea-squirts), more mobile species**
*Non-calcifying species can suffer from ocean acidification.
**Increased scouring will also lead to higher habitat fragmentation/patchiness
MEASO

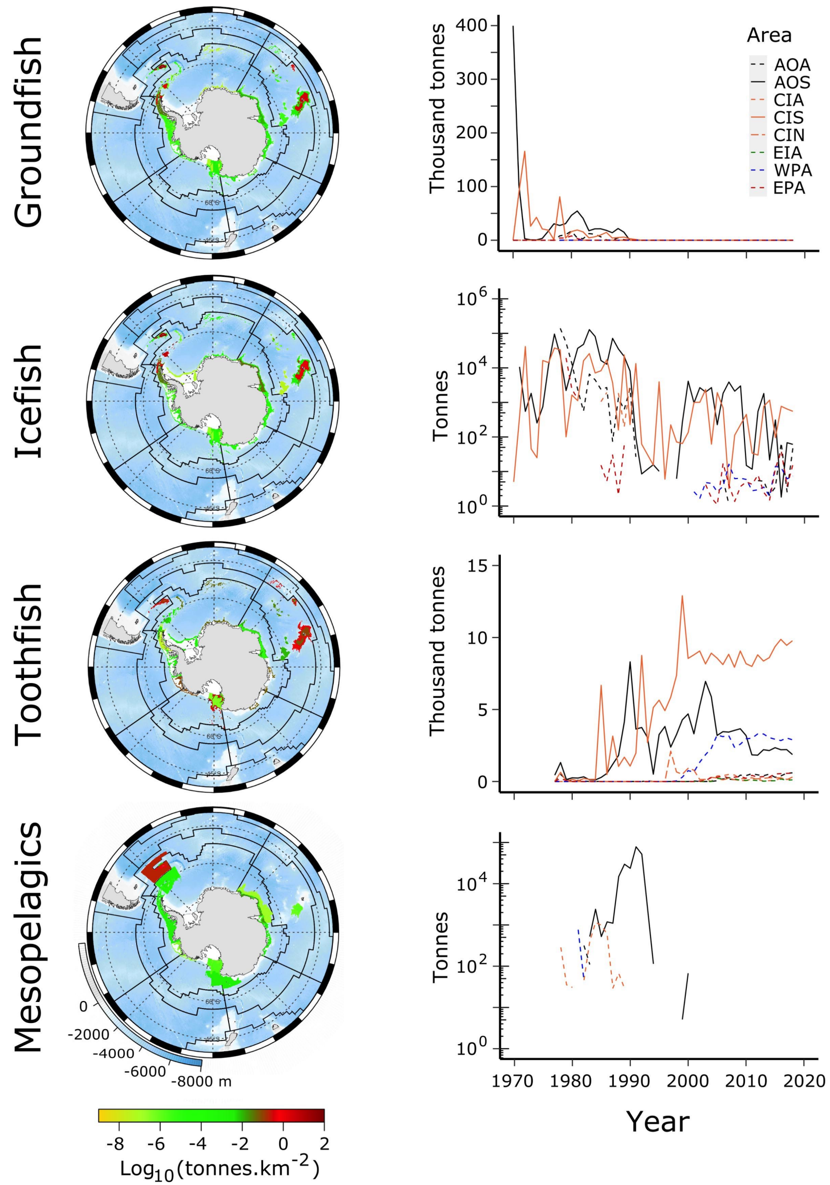
MANAGING THE SOUTHERN OCEAN

CCAMLR

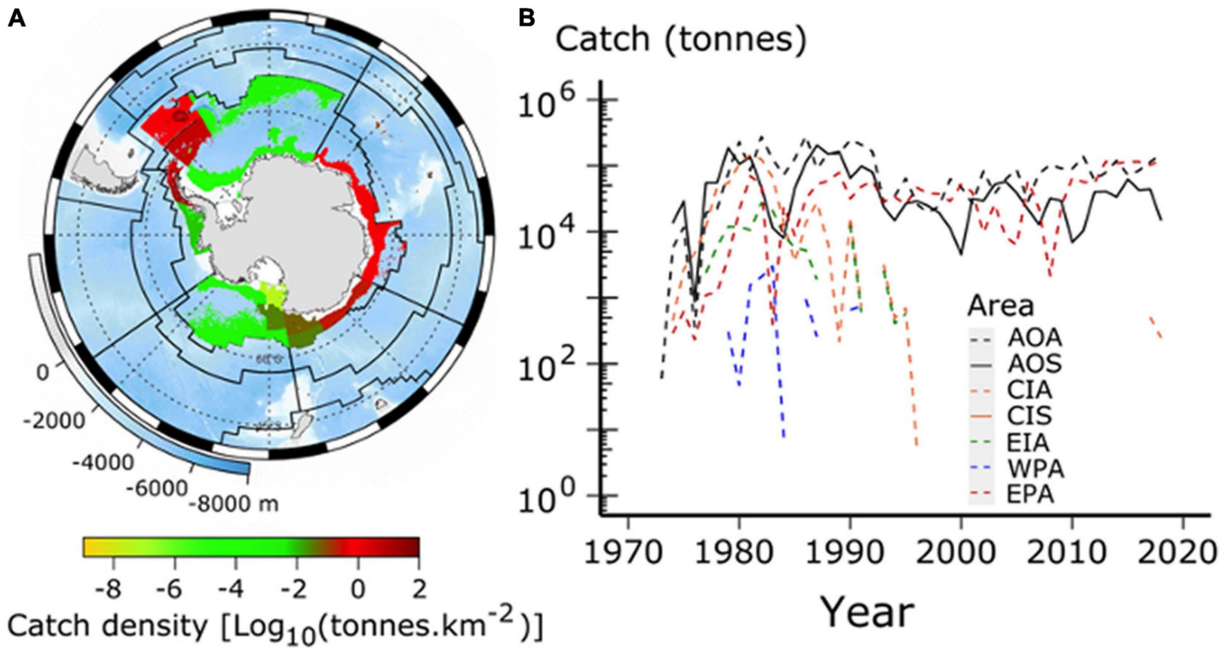

Antarctic Research,
Fisheries Data and Analysis
CCAMLR WG – Ecosystem
Monitoring and Management
CCAMLR WG – Fish Stock
Assessment
CCAMLR Scientific Committee
Standing Committee
Implementation and Compliance
Standing Committee
Administration and Finance
CCAMLR Commission
Conservation Measures

FISHERIES BIOMASS





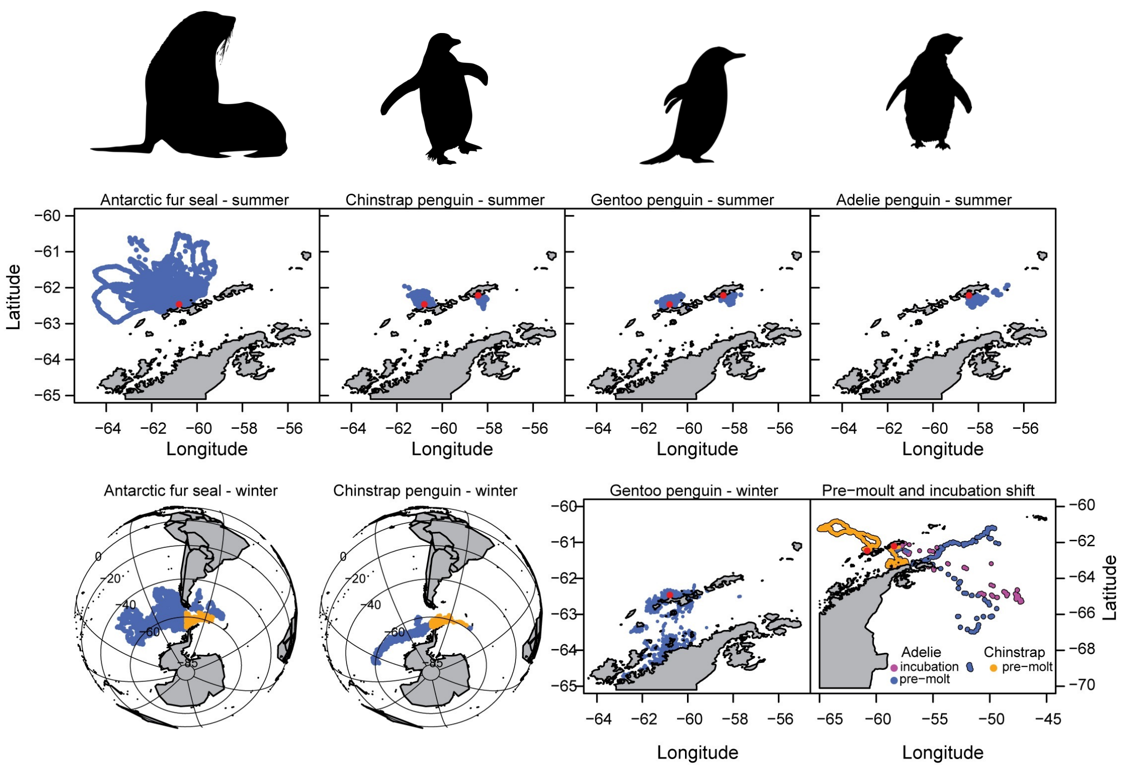
CATCHES
OF
GROUNDFISH
TOOTHFISH
ICEFISH
MESOPELAGIC FISH
1970 TO 2018

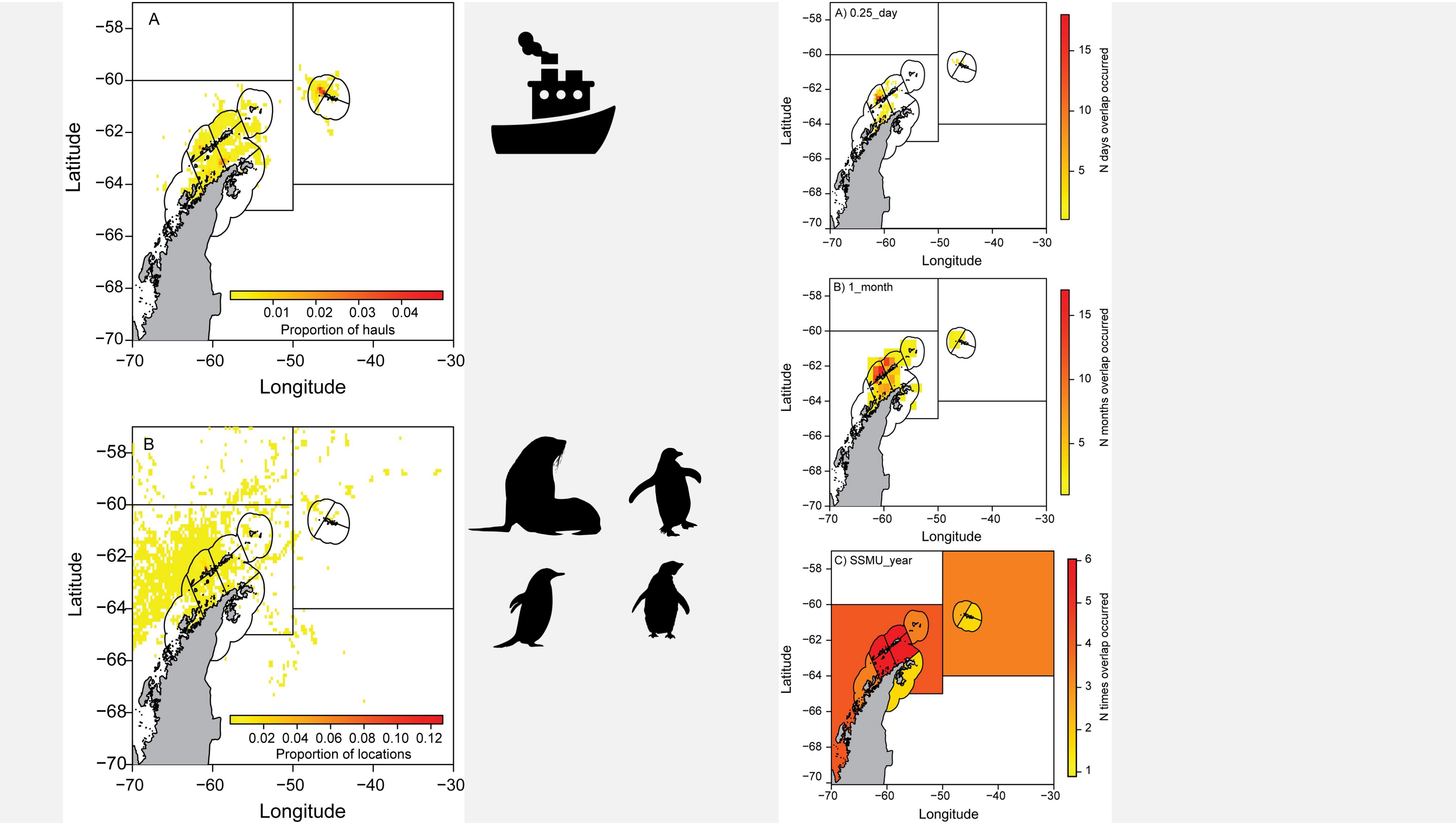


Sectors are Atlantic (AO), Central Indian (CI), East Indian (EI), West Pacific (WP), and East Pacific (EA). Zones are Antarctic (A), Subantarctic (S), and Northern (N).

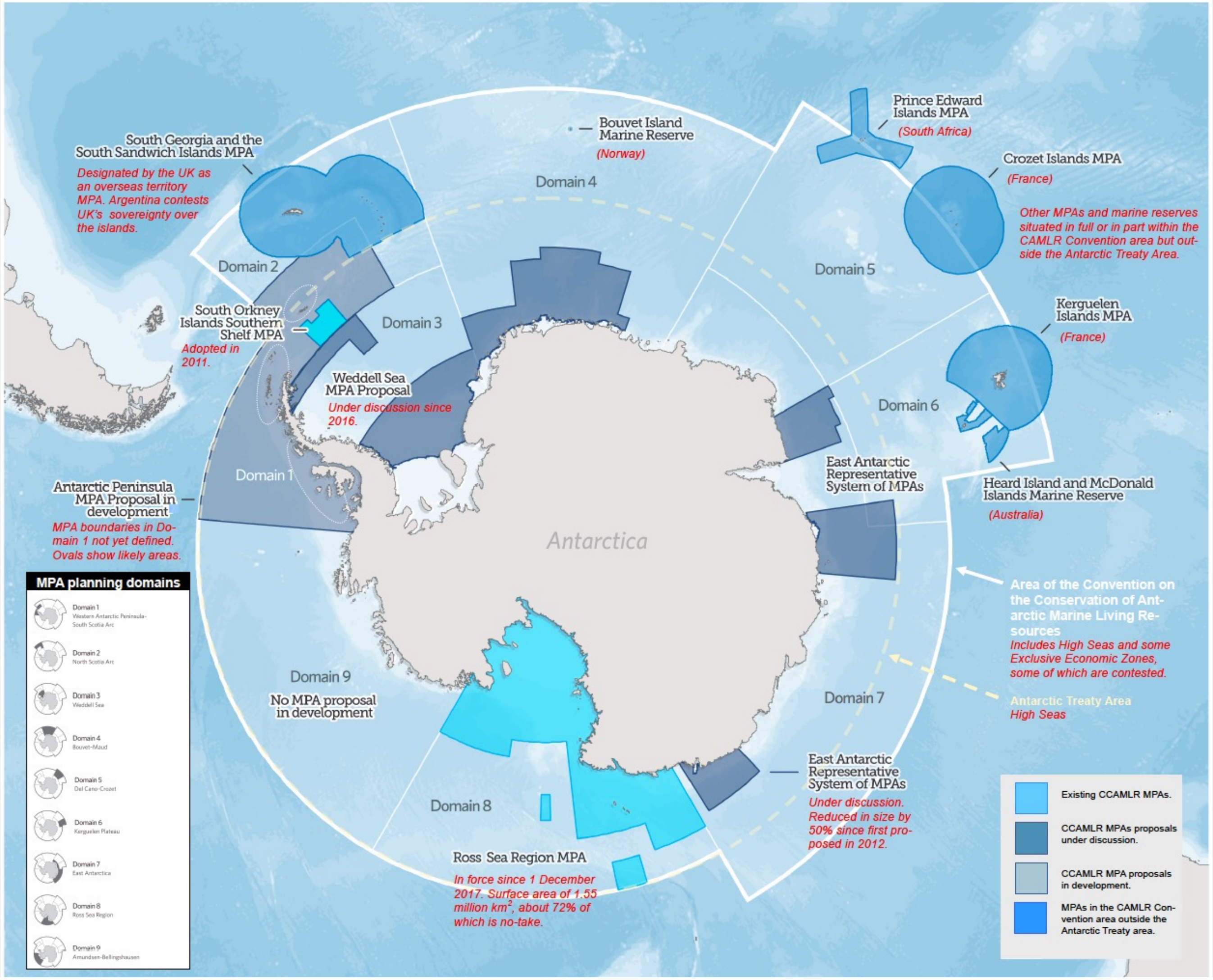
CATCHES OF
ANTARCTIC KRILL
EUPHAUSIA SUPERBA
1970 TO 2018

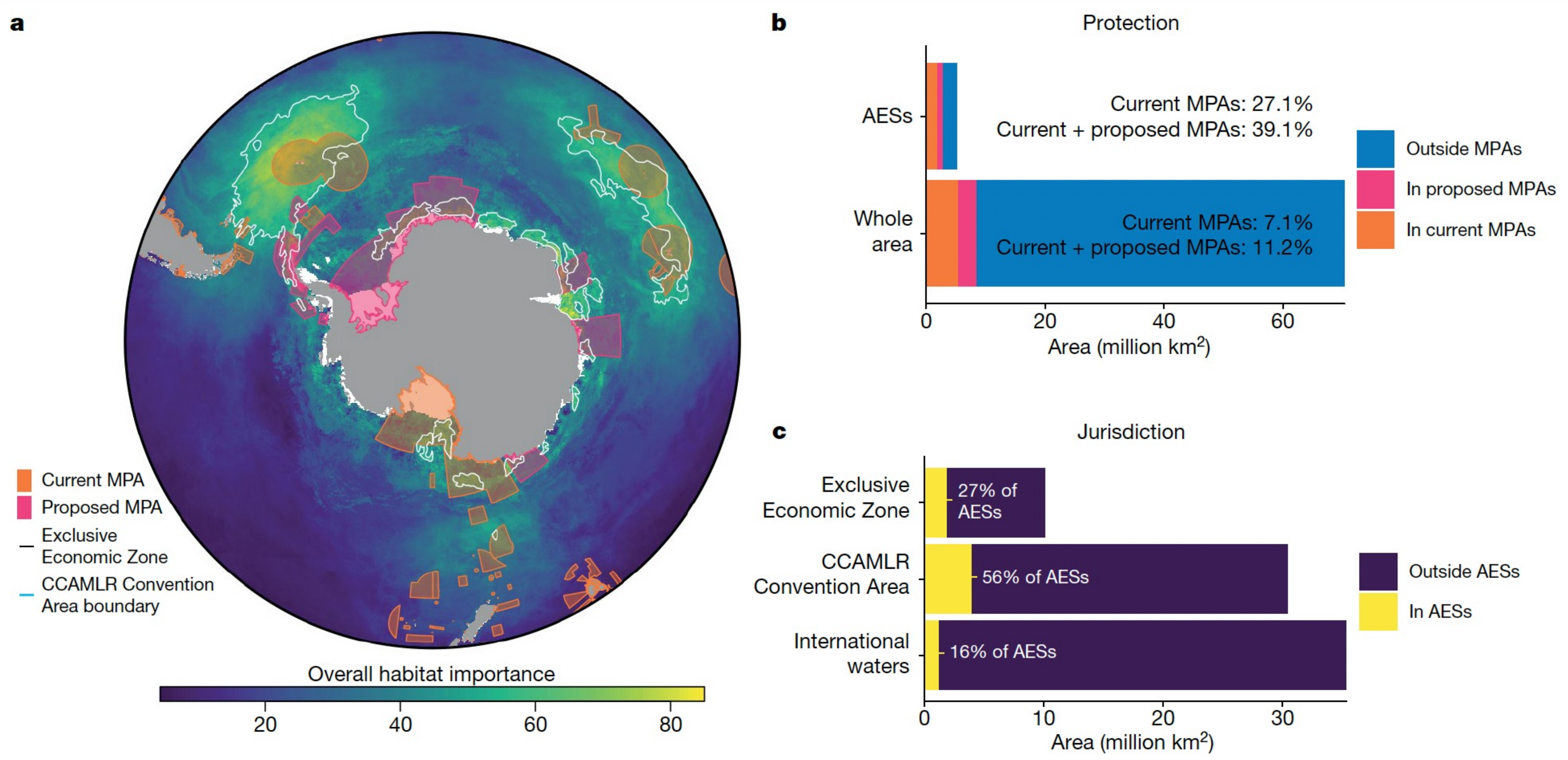
TRACKING TOP PREDATORS



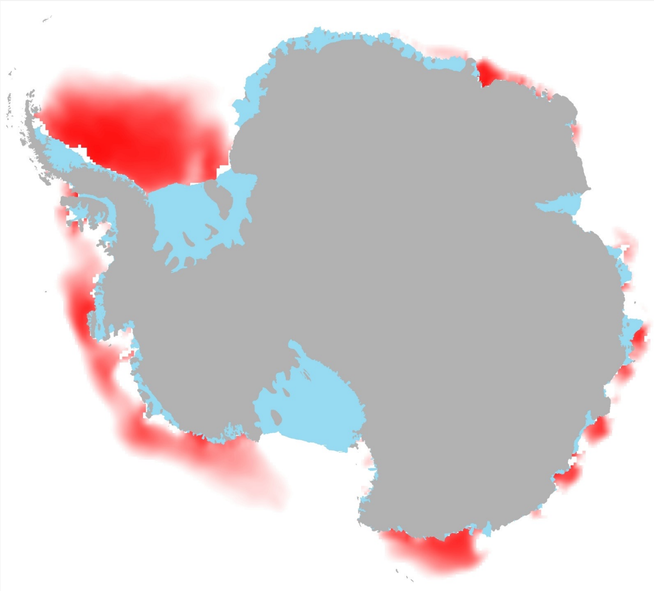

A
Proportion of hauls
0.01 0.02 0.03 0.04
B
Proportion of locations
0.02 0.04 0.06 0.08 0.10 0.12
Latitude
Longitude
−58 −60 −62 −64 −66 −68 −70
−70 −60 −50 −40 −30
A) 0.25_day
N days overlap occurred
5 10 15
B) 1_month
N months overlap occurred
5 10 15
C) SSMU_year
N times overlap occurred
1 2 3 4 5 6

Marine Protected Areas in the Southern Ocean (Dec. 2017)

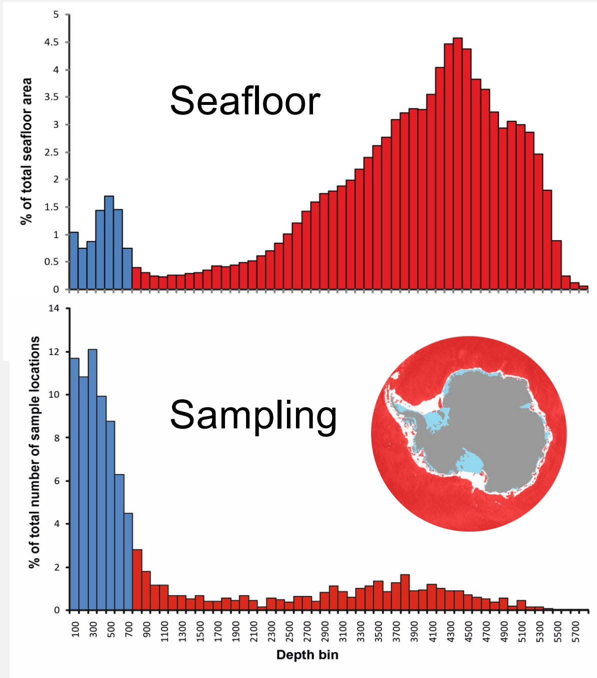



a
Current MPA
Proposed MPA
Exclusive Economic Zone
CCAMLR Convention Area boundary
Overall habitat importance
20
40
60
80
b
Protection
AESs
Whole area
Current MPAs: 27.1%
Current + proposed MPAs: 39.1%
Current MPAs: 7.1%
Current + proposed MPAs: 11.2%
Outside MPAs
In proposed MPAs
In current MPAs
0
20
40
60
Area (million km²)
c
Jurisdiction
Exclusive Economic Zone
CCAMLR Convention Area
International waters
27% of AESs
56% of AESs
16% of AESs
Outside AESs
In AESs
0
10
20
30
Area (million km²)

FUTURE PERSPECTIVES: **GEOGRAPHIC GAPS**



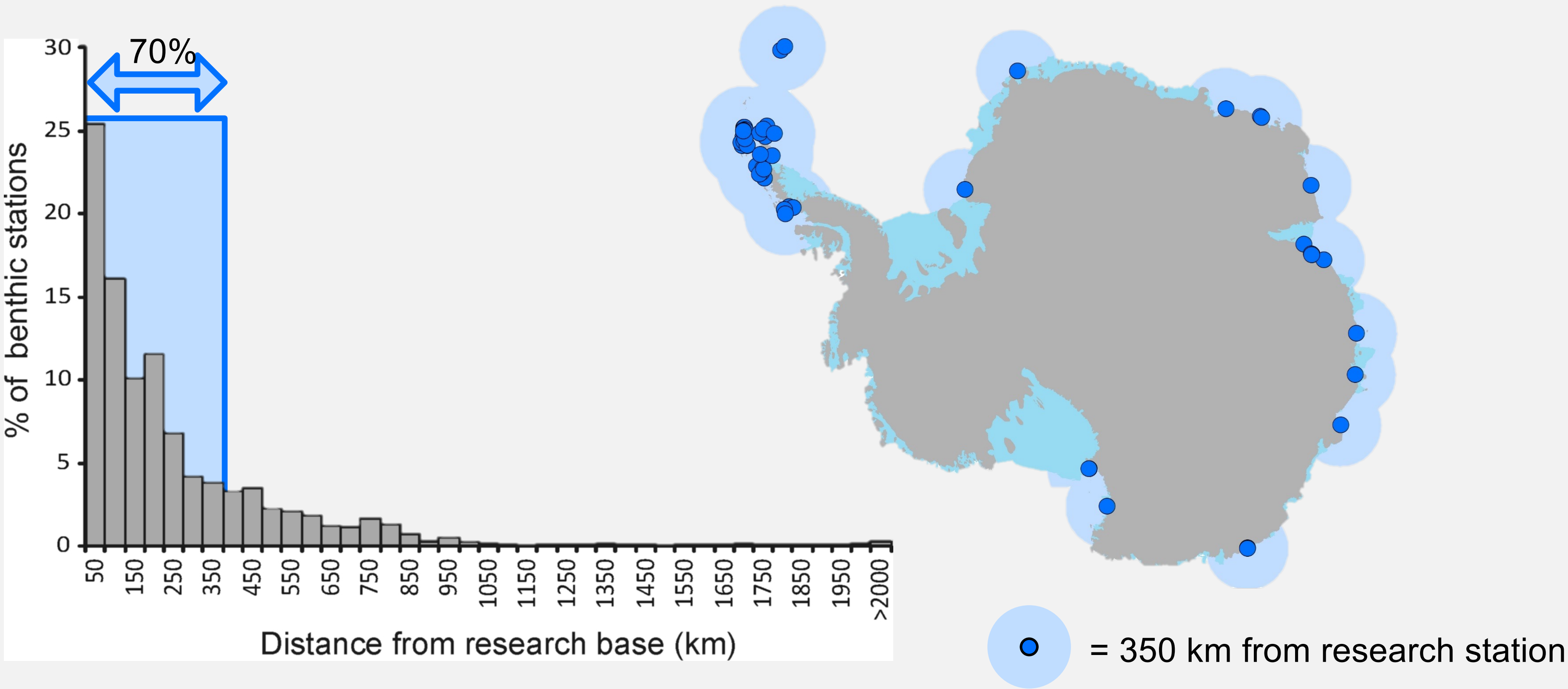
Summer Sea Ice



Depth

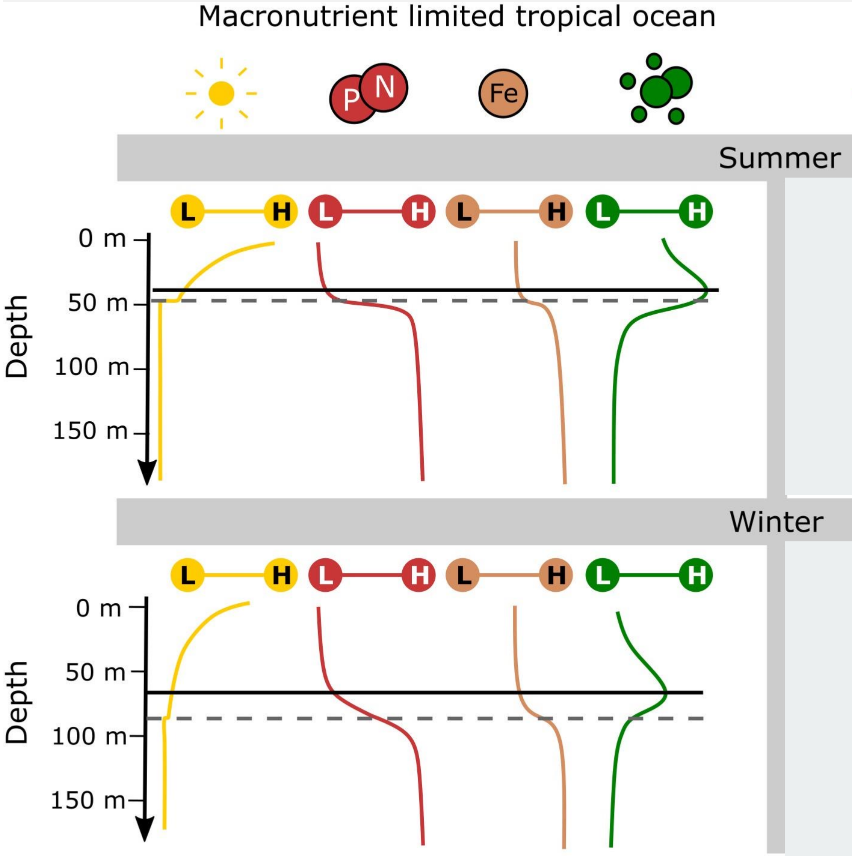
Ice Shelves

FUTURE PERSPECTIVES: **GEOGRAPHIC GAPS**



END

Deep Chlorophyl maximum



downward irradiance

macronutrients

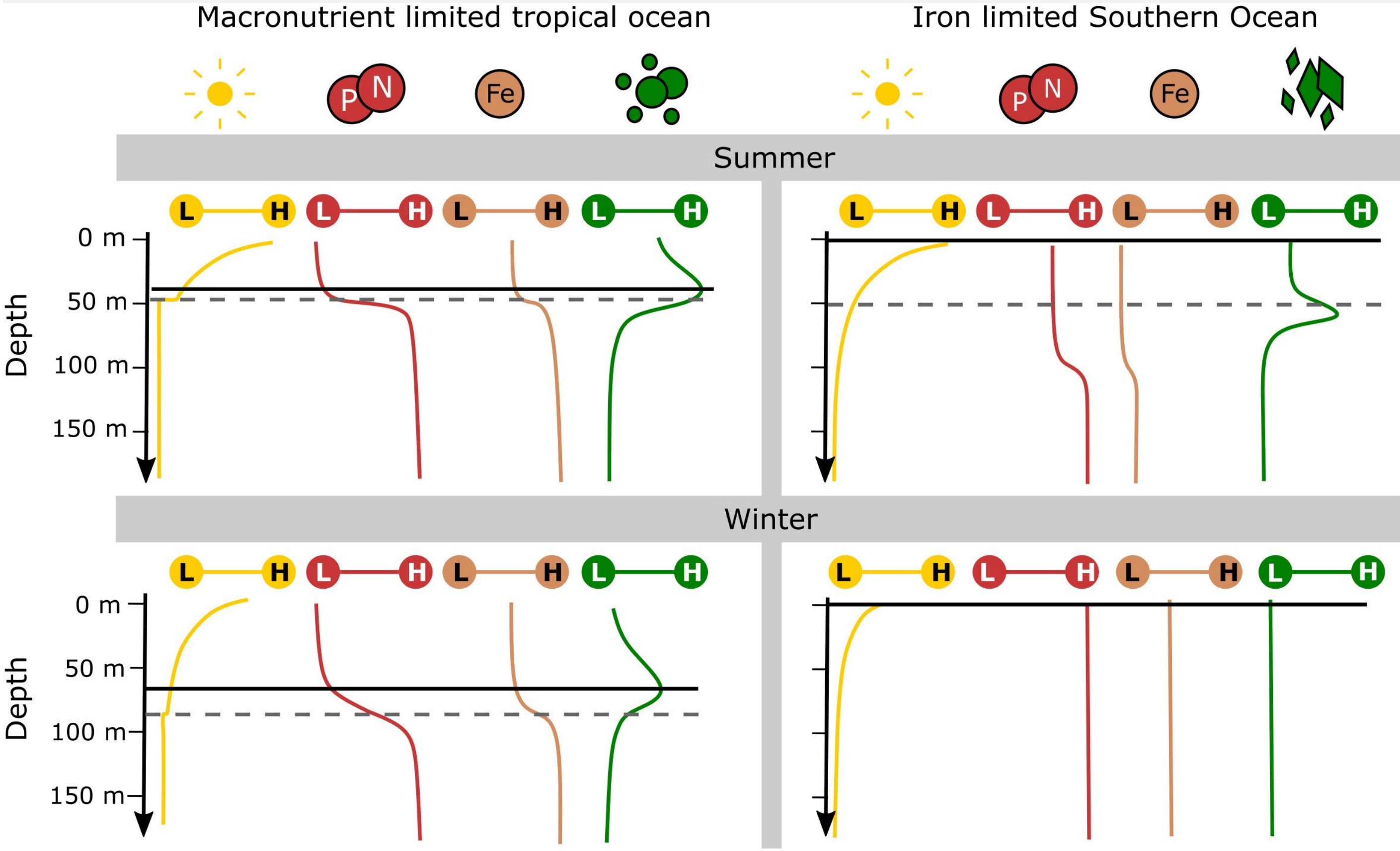
Iron

- - - - mixed layer depths

____ optimum depth of phytoplankton growth

● ● picophytoplankton community

◆ ◆ high silicate community



downward irradiance

macronutrients

Iron

____ mixed layer depths

- - - - optimum depth of phytoplankton growth

● ● picophytoplankton community

◆ ◆ high silicate community

https://doi.org/10.3389/fmars.2020.00671