S8: Get it from the image: In situ imaging and spatially detailed observations of zooplankton for ecosystem studies

Resolving the scales of plankton ecology with *in situ* imaging

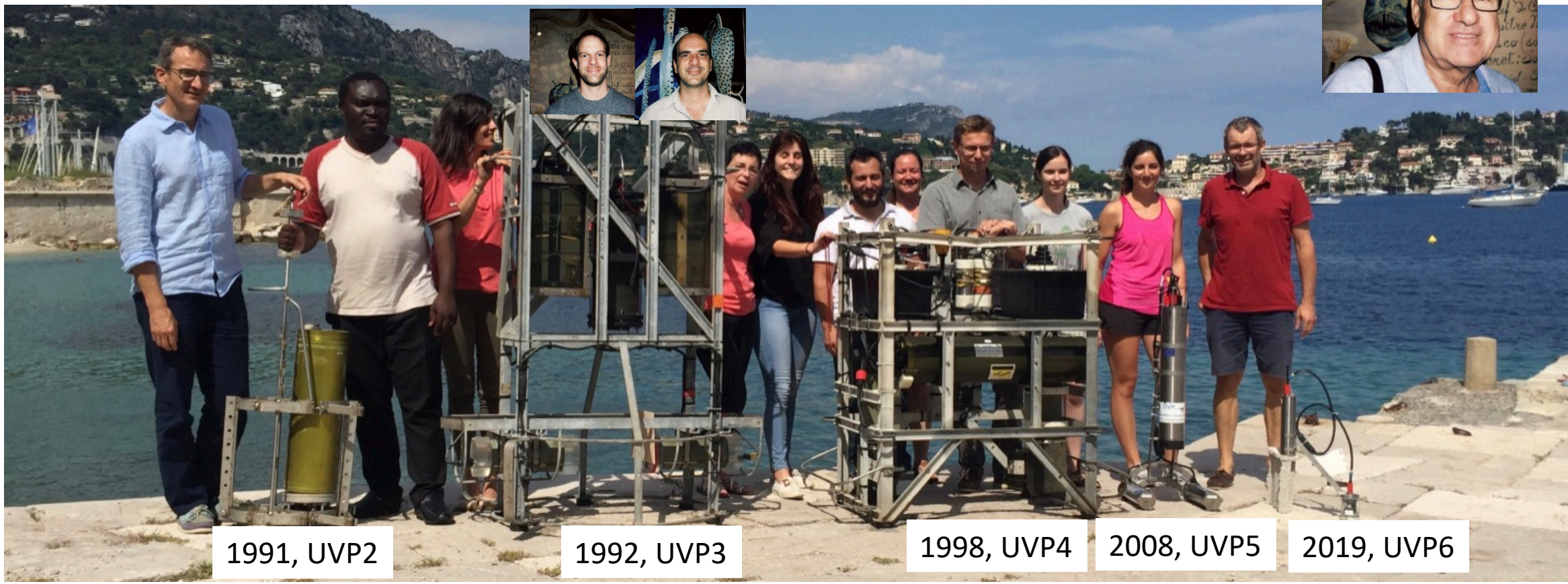
Lars Stemmann

Professor Sorbonne Université - Laboratoire d'Océanographie de Villefranche sur Mer

Thanks to :

Laetitia Drago, Thelma Panaïotis, Jean-Olivier Irisson, Marcel Babin, Tristan Biard, Fabien Lombard, Andrew M. P McDonnell, Dodji Soviadan, Jean-Baptiste Romagnan, Andreas Rogge, Anya M. Waite, Rainer Kiko, Rubens M. Lopes, Gaby Gorsky, Sakina Dorothée Ayata, Luis Felipe Artiga, Klas O. Möller, Helena Hause

The Villefranche team for Plankton Imaging



Gorsky et al., 1992

Gorsky et al., 2000

Gorsky et al., 2003

Picheral et al., 2008

Picheral et al., 2022

Resolving the scales of plankton ecology with *in situ* imaging

Content

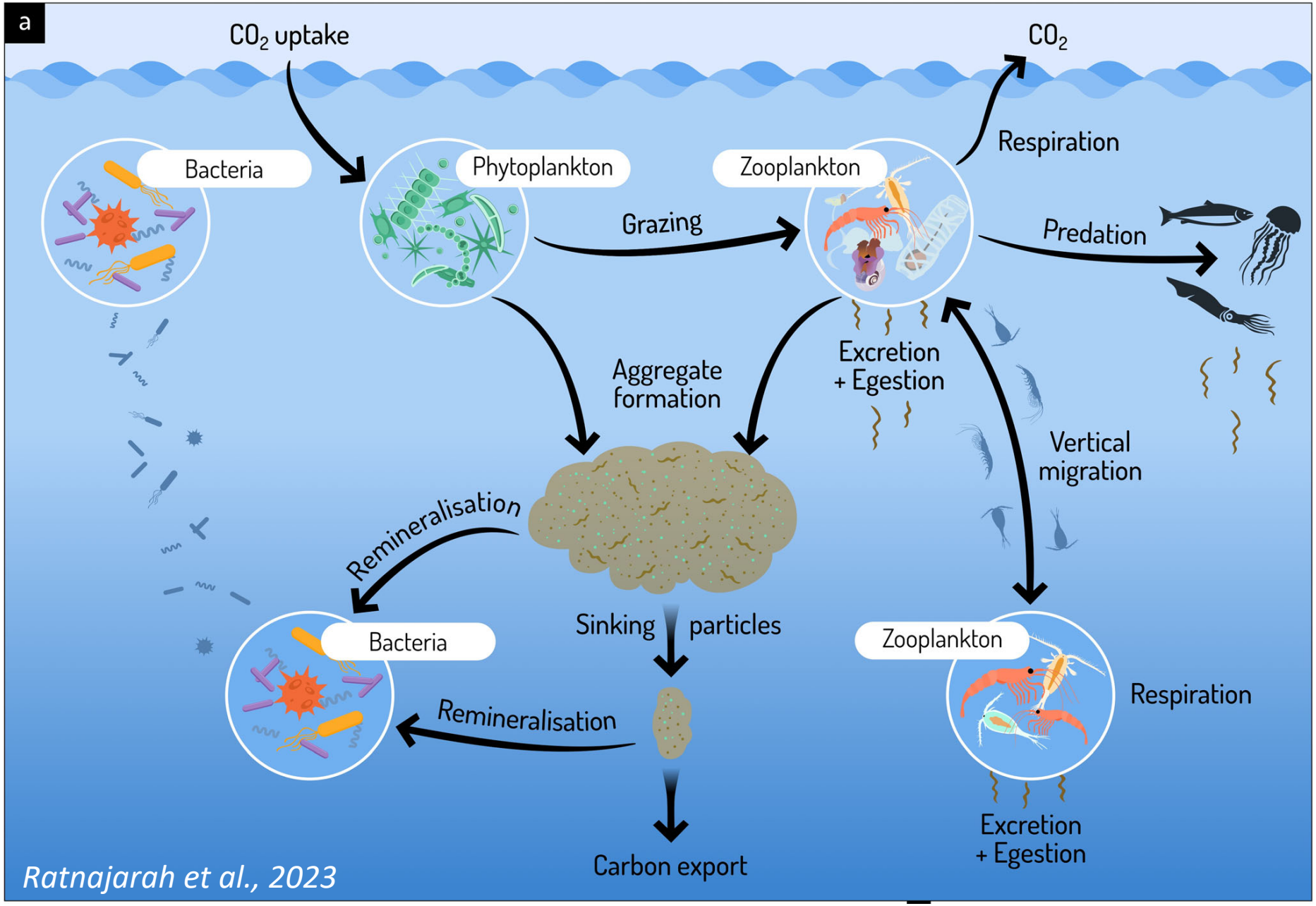
- Plankton: Who, Where, What, Why, How
- A portofolio of Scientific questions across scales
- The future data we need for research and monitoring
- The back Office
- The next steps

Players and processes in planktonic ecosystems

Basic questions

WHO ?
WHERE ?
WHAT ?

WHY ?



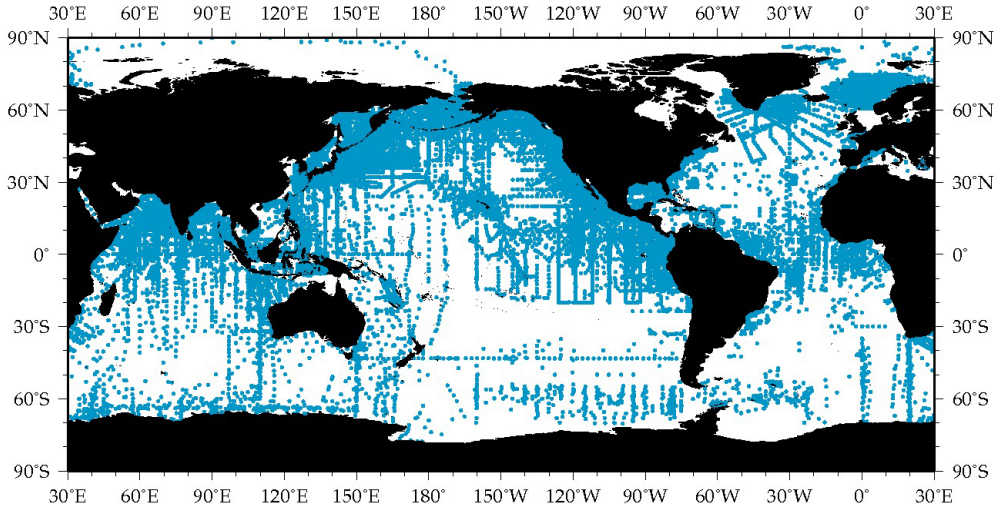
Traditional approaches

→ Collect organisms with different protocols (nets, bottles, CPR…)

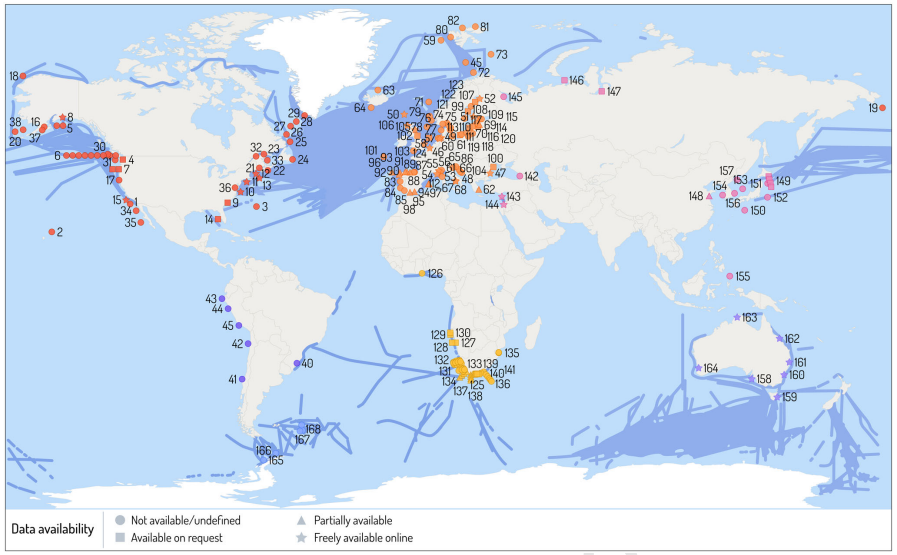
→ Count and Identify them with microscope

(also genomic)

Tara (2009-2013)



Moriarty and Obrien 2013



Ratnajarah et al., 2023

Traditional approaches

→ Collect organisms with different protocols (nets, bottles, CPR…)

→ Count and Identify them with microscope

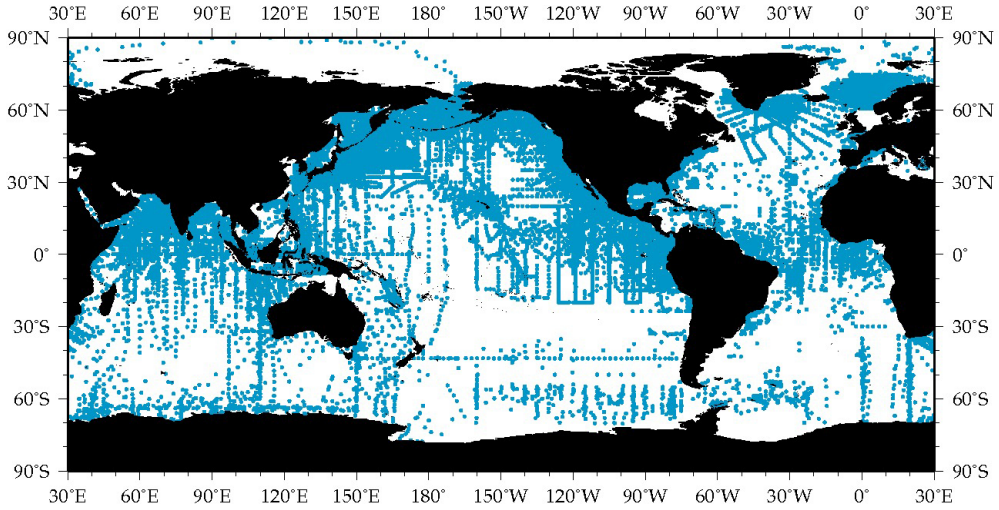
(also genomic)

→ difficult to homogenise results from multiple sampling and counting methods

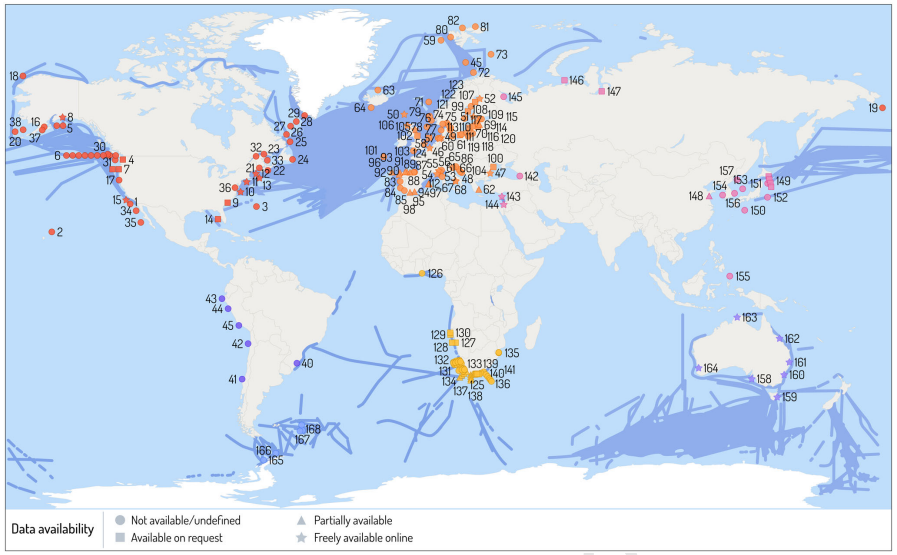
→ many datasets are not FAIR

→ difficult to use in biogeochemical models if the currency is not mass

Tara (2009-2013)

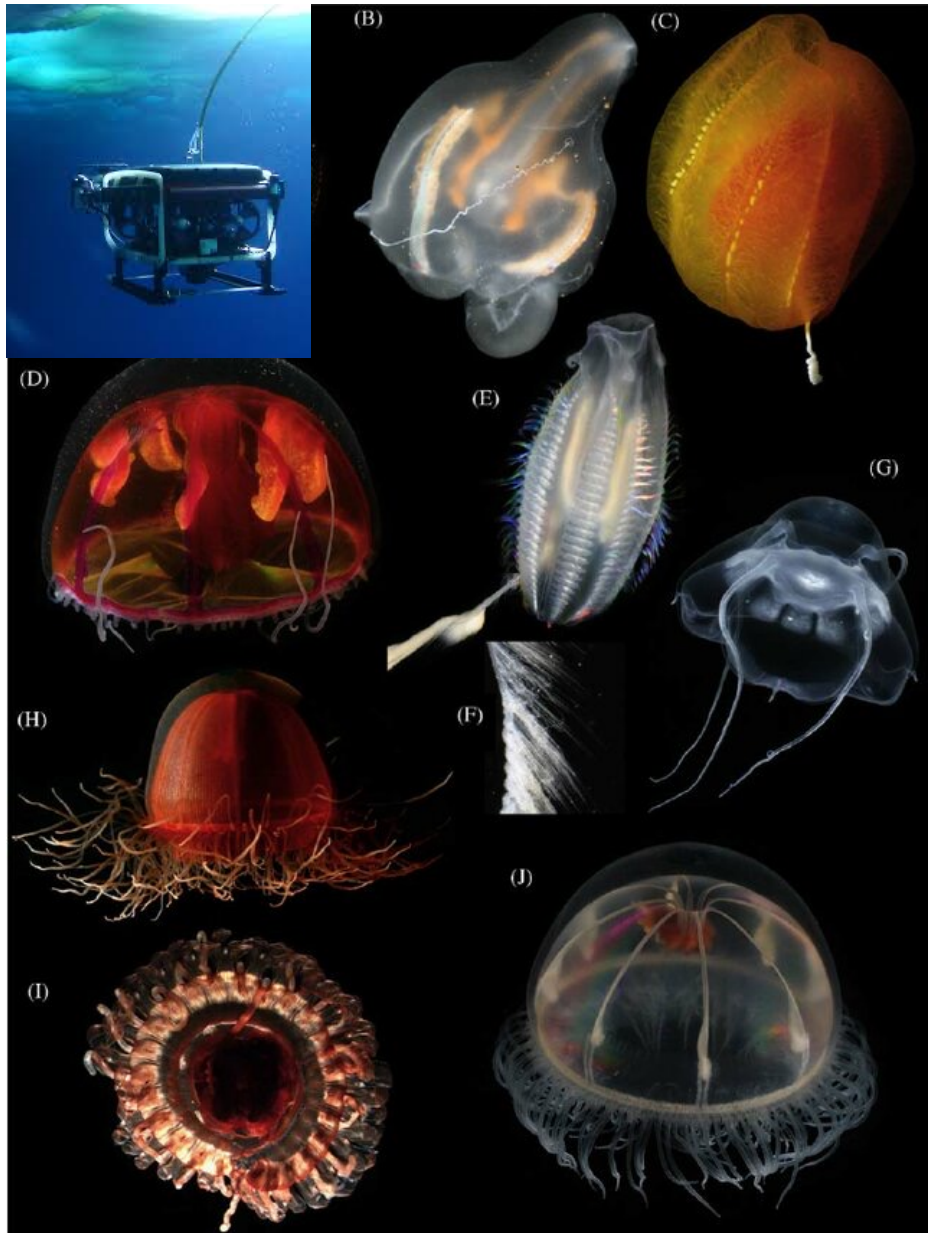


Moriarty and Obrien 2013



Ratnajarah et al., 2023

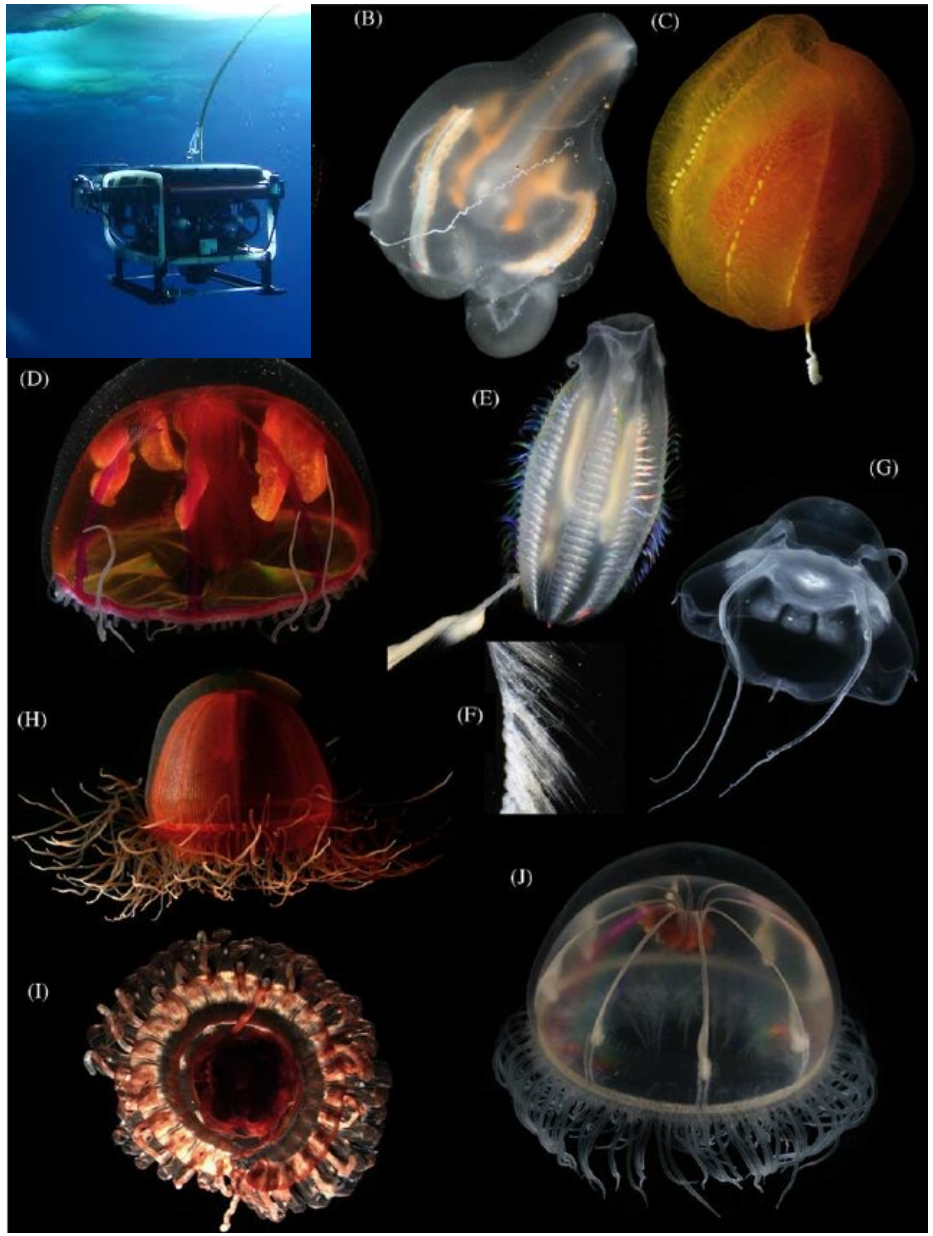
Plankton *qualitative* imaging



Raskoff et al., 2010

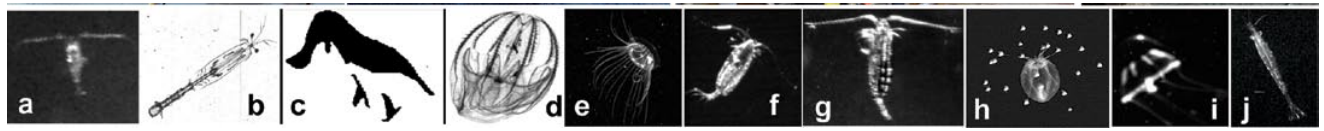
Plankton *quantitative* imaging

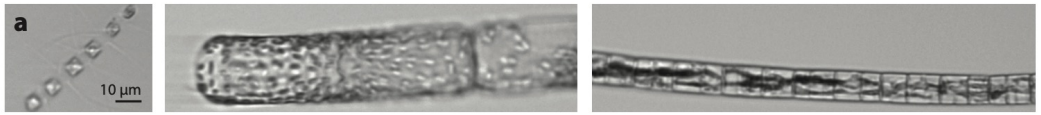
Plankton *qualitative* imaging

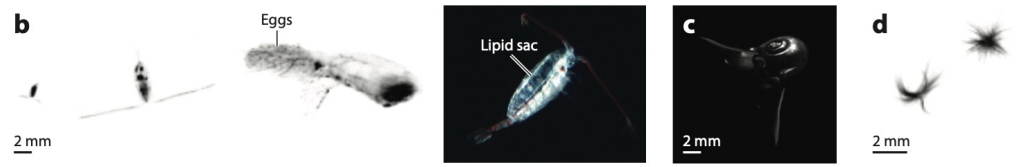


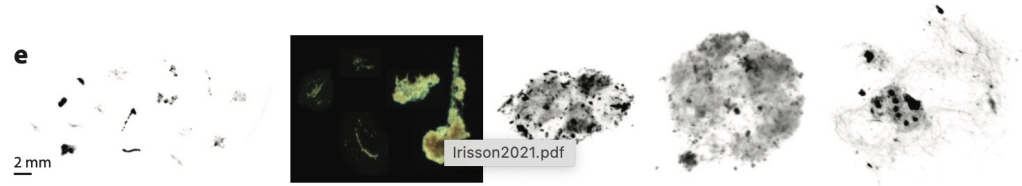
Raskoff et al., 2010

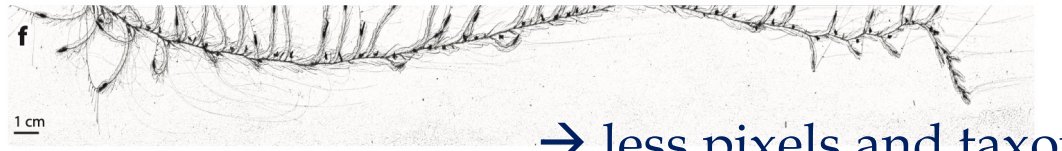
Plankton *quantitative* imaging

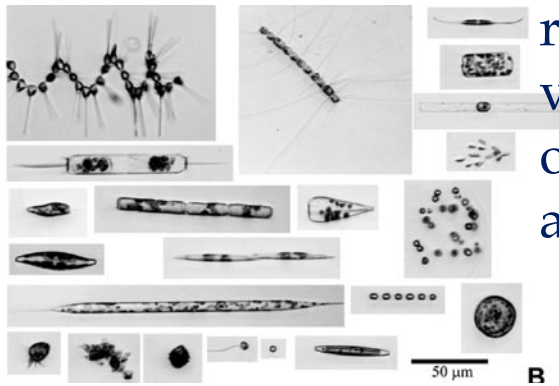












→ less pixels and taxonomic resolutions, smaller observed volume but traits and taxa obtained at individual models for a massive number of organisms

Benfield et al., 2007
Irisson et al., 2021

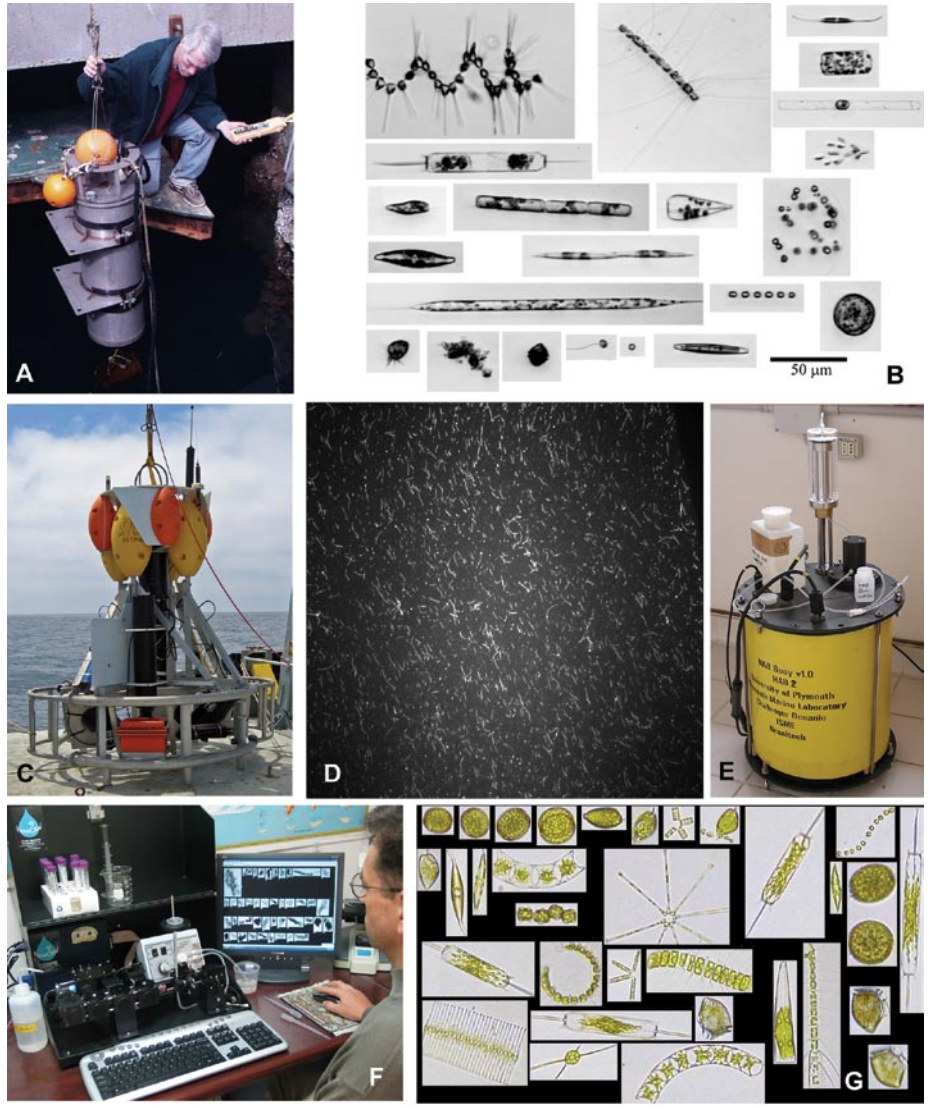
Early 2000's, Plankton imaging is promising

BREAKING WAVES

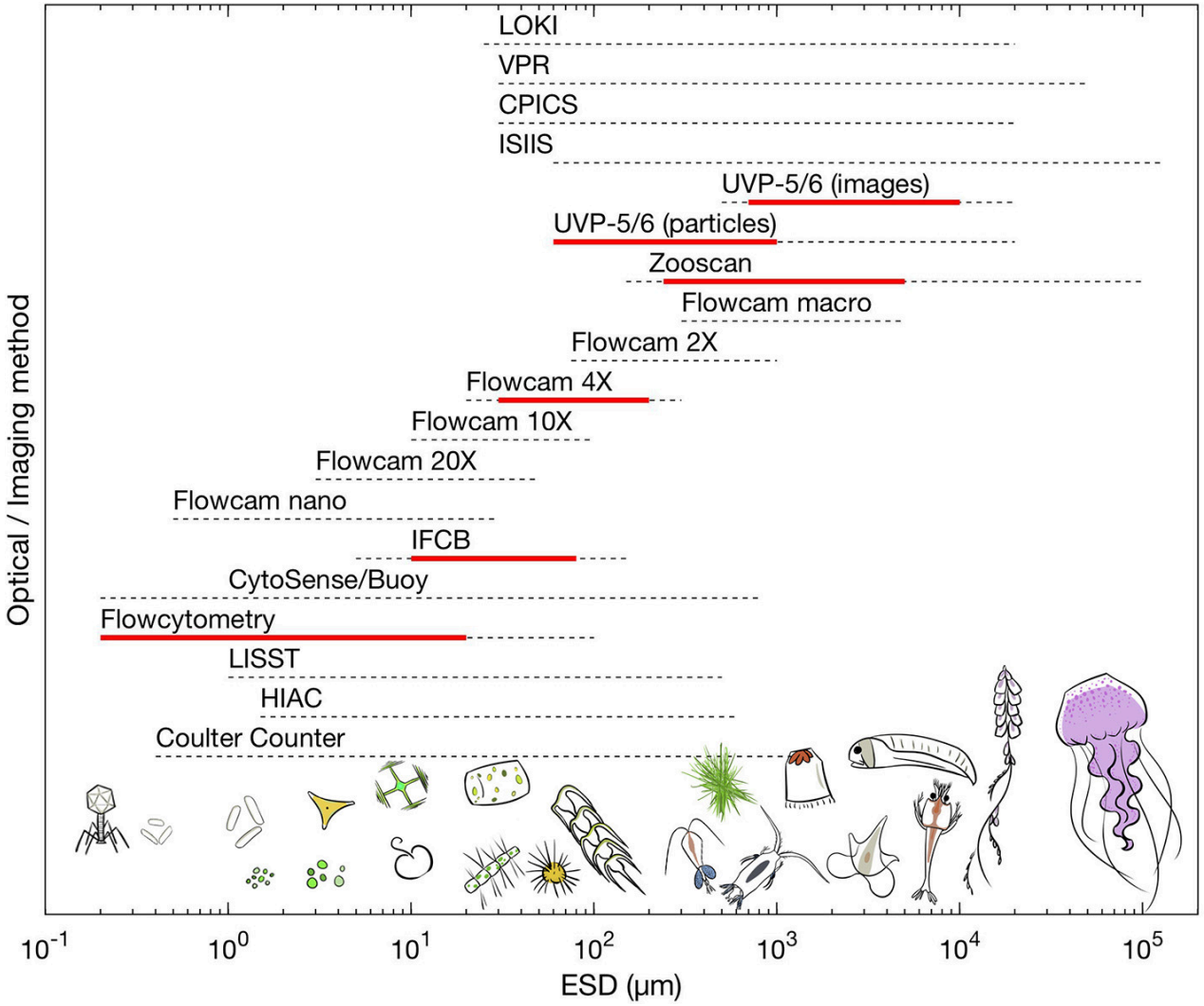
RAPID

Research on Automated Plankton Identification

Benfield et al., 2007

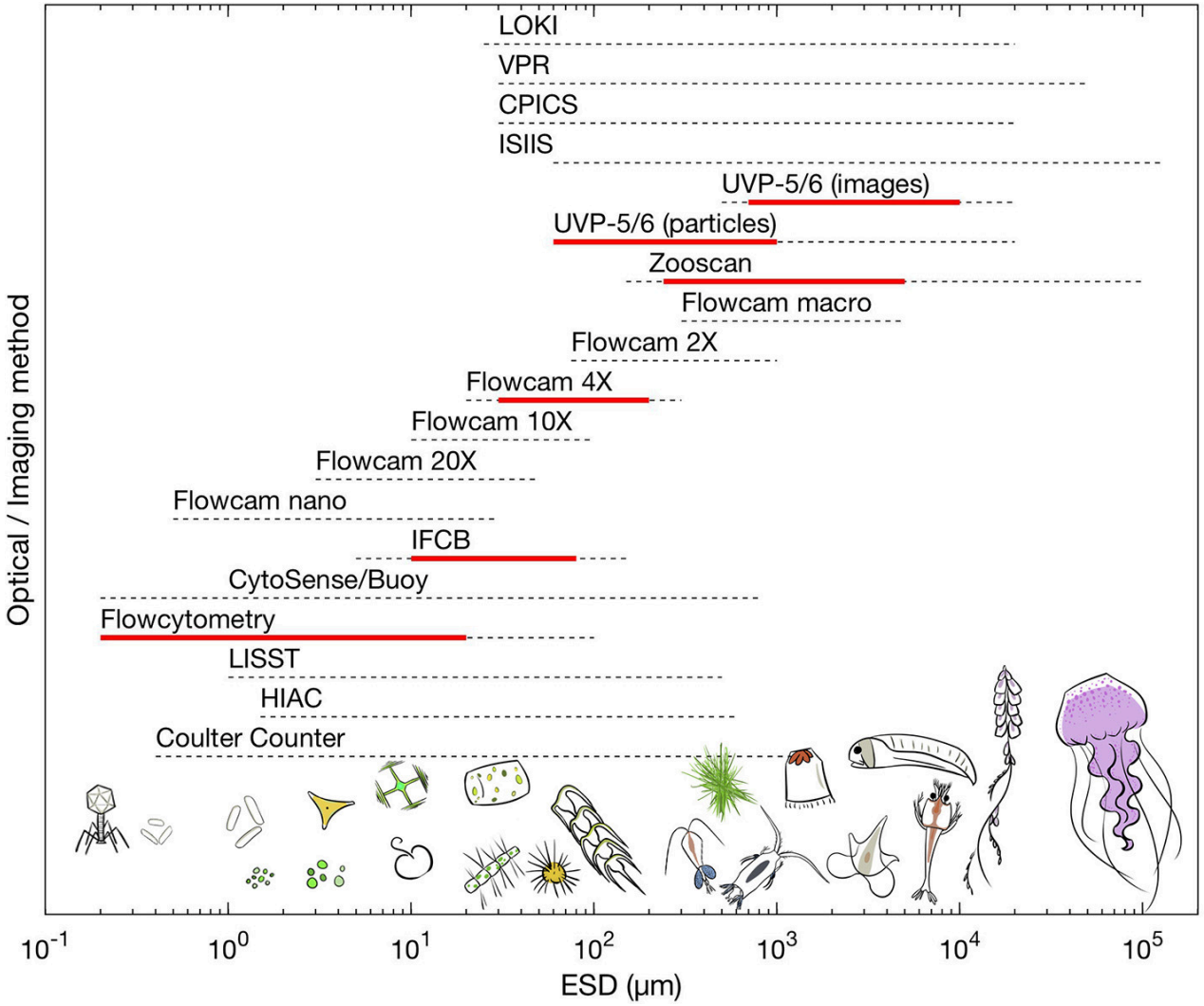


20 years later, many plankton imaging systems are available

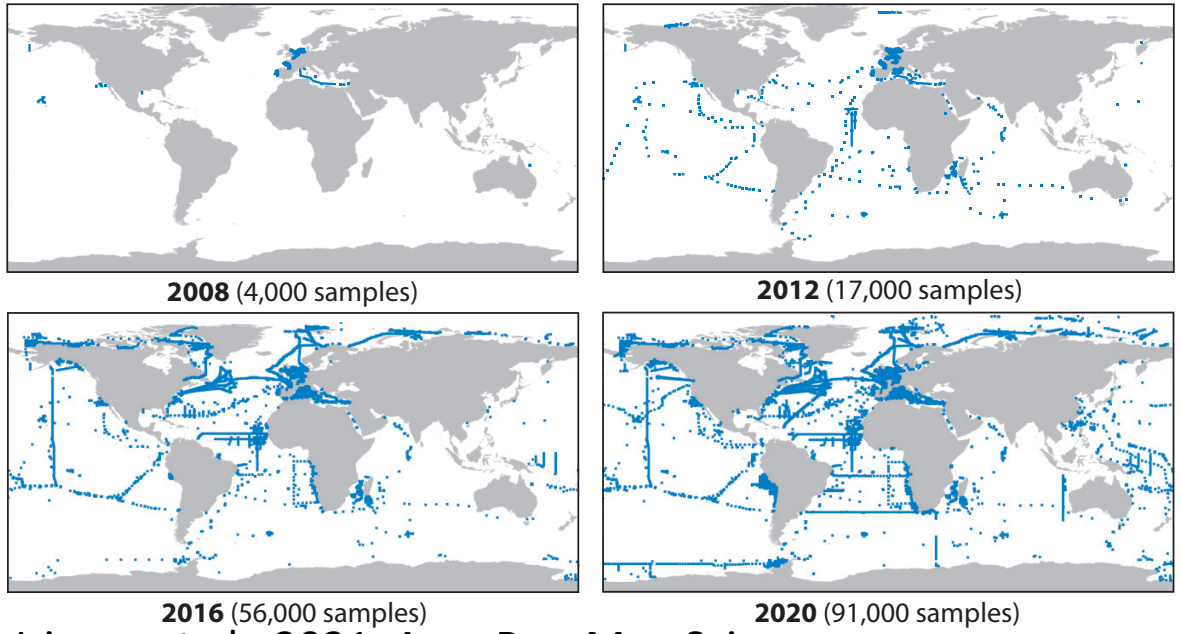


List of commercially available instruments in 2019
Lombard et al., (2019) Front. in Mar. Sci.

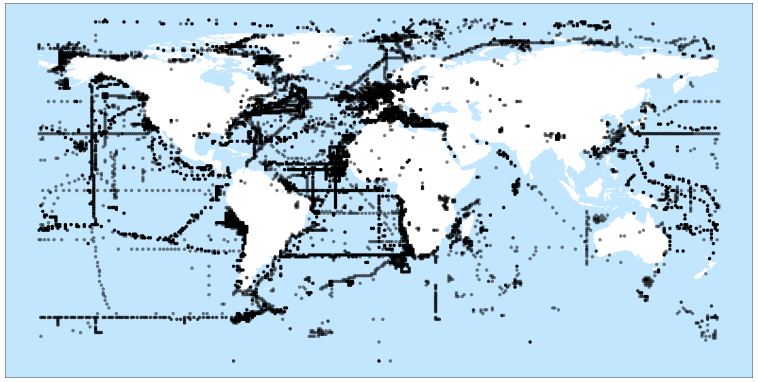
20 years later, many plankton imaging systems are available



List of commercially available instruments in 2019
Lombard et al., (2019) Front. in Mar. Sci.

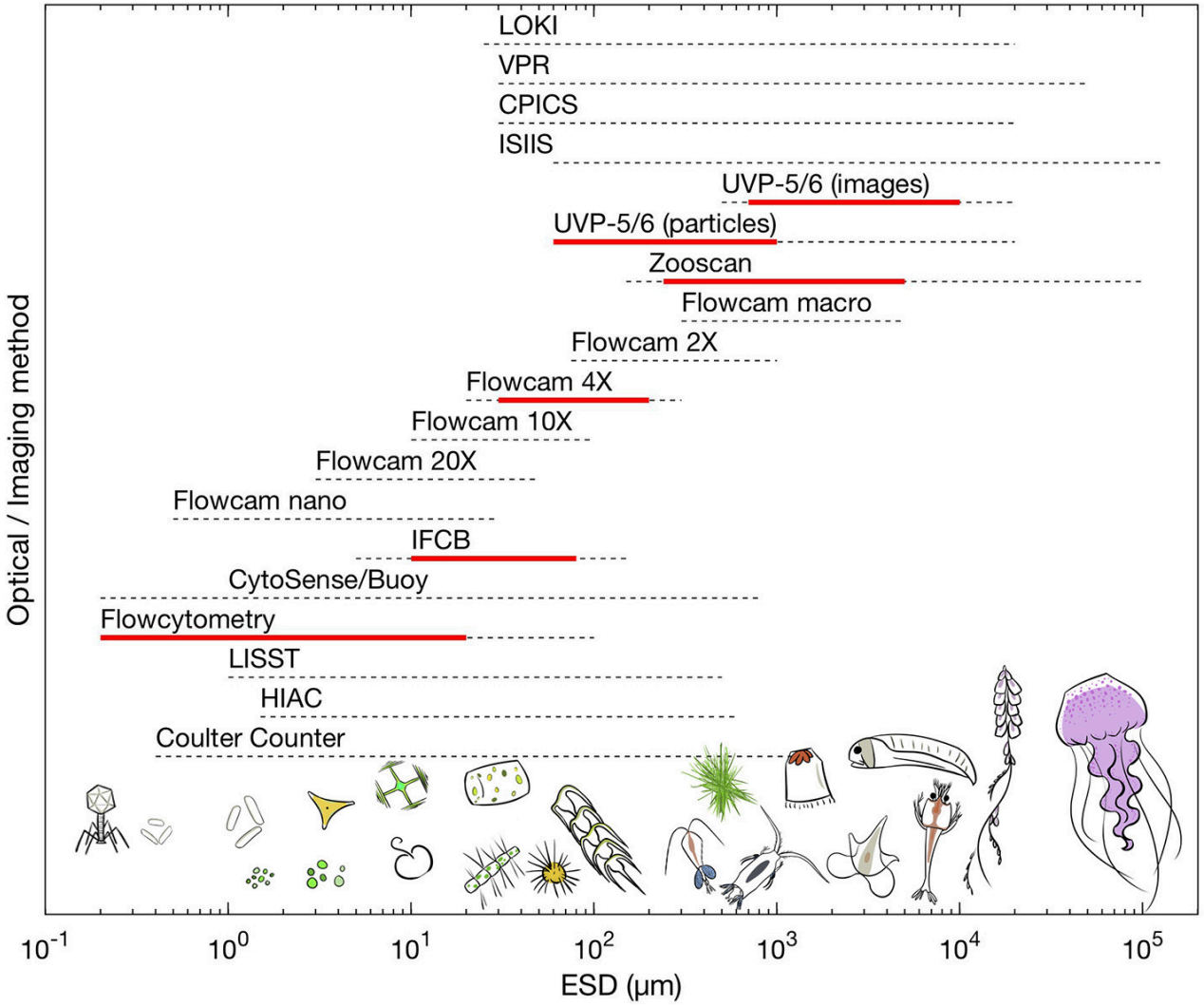


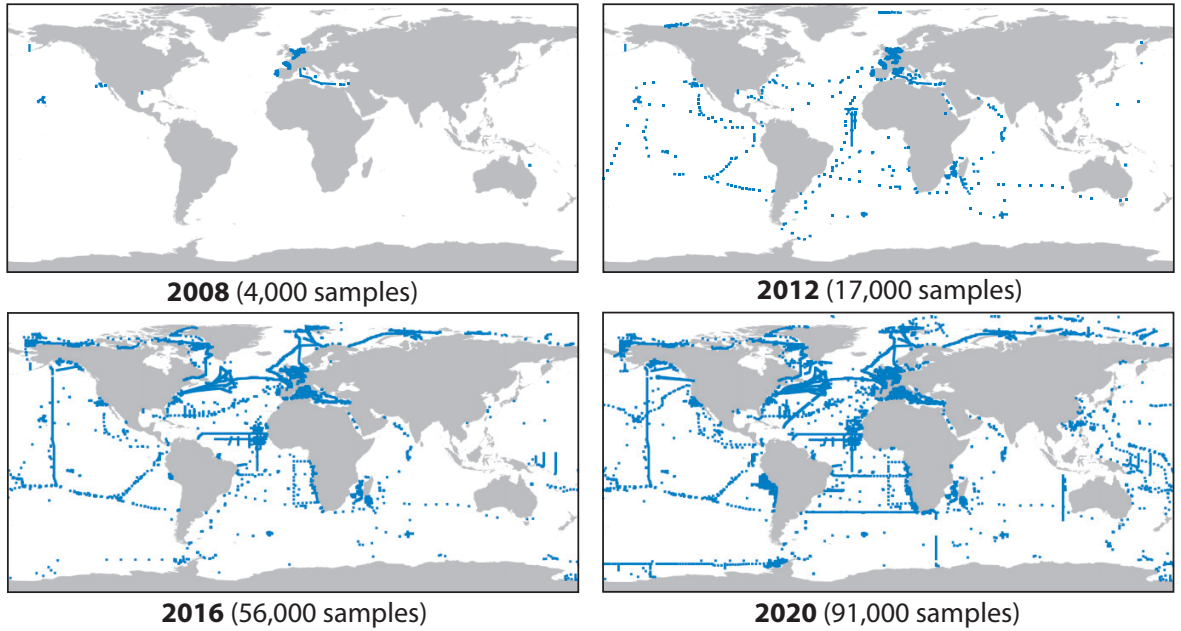
Irisson et al., 2021, Ann. Rev. Mar. Sci.



Today
120 000 sites, 400 000 000 images (40% validated), 2500 users

20 years later, many plankton imaging systems are available



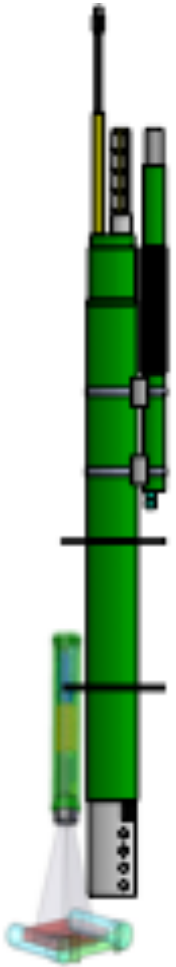


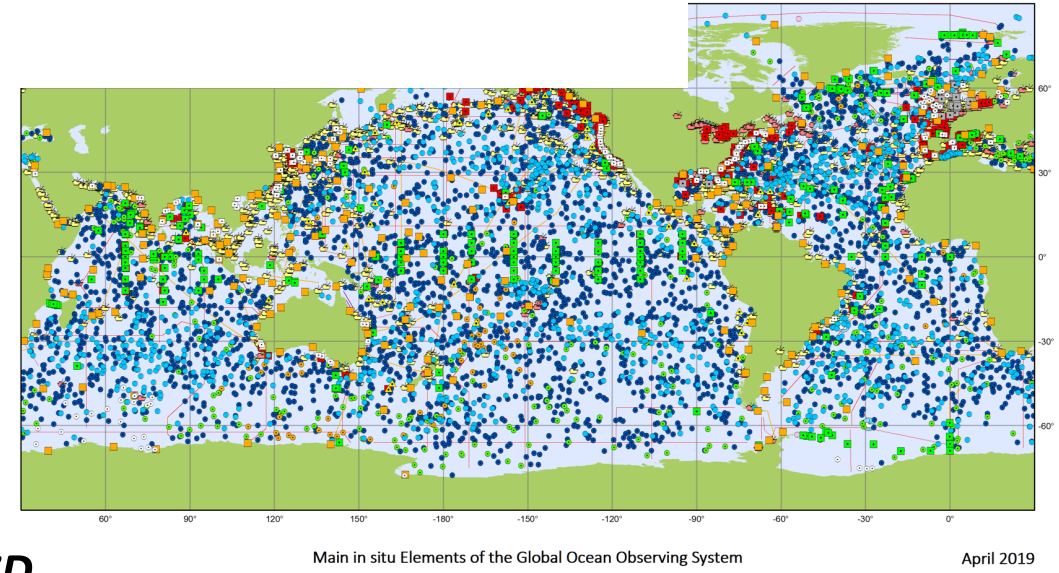
This session S8: more instruments
ISIIS-DPI, PlanktonScope, Zooglider, ImagePlanktonProbe, iCPR, PlanktonImager, Planktoscope, …

List of commercially available instruments in 2019
Lombard et al., (2019) Front. in Mar. Sci.

Today (or very soon), Global Plankton Imaging is possible

Imaging sensors from Autonomous platforms





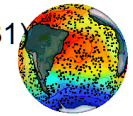
Profiling Floats (Argo)
- Core (3880)
- Deep (79)
- BioGeoChemical (352)

Data Buoys (DBCP)
- Surface Drifters (1444)
- Offshore Platforms (97)
- Ice Buoys (11)
- Moored Buoys (358)
- Tsunameters (38)

HF Radars (270)

Animal Borne Sensors (53)

Ocean Gliders (31)



Generated by www.jcommops.org, 14/05/2019

D_{PSD} ← **Particulate Organic Carbon**

Z_n ← **macro and mesoplankton (Taxa size spectra)**

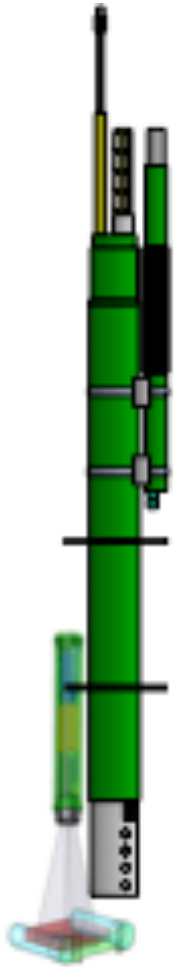
P_λ ← **Pico and microplankton (taxa, size spectra)**

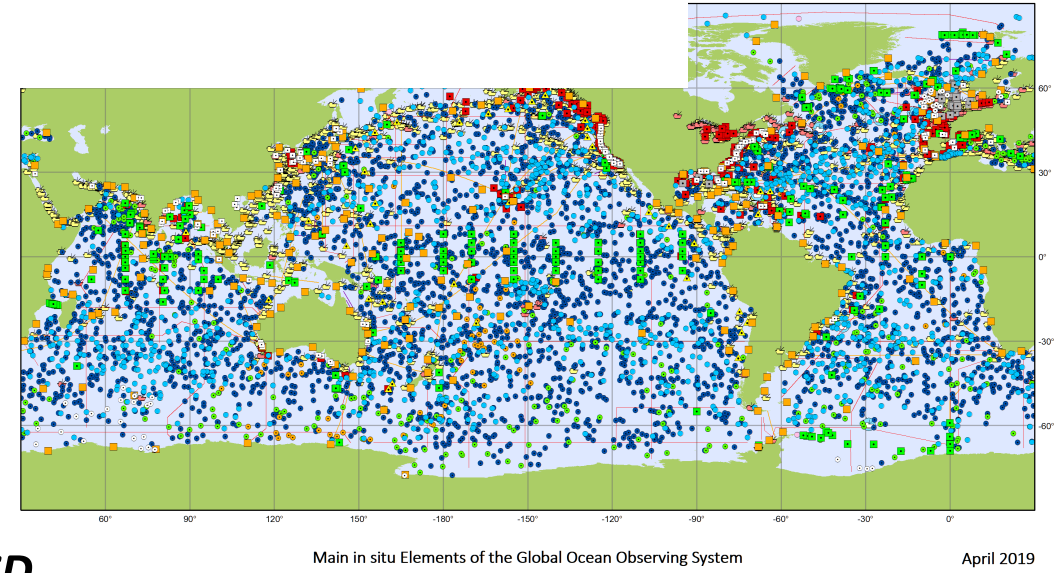
N ← **CTD and geochemical data**

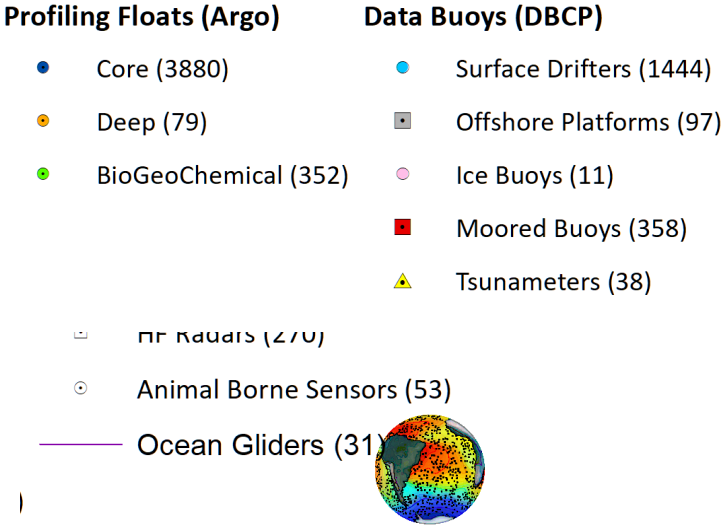
Stemmann et al., 2012

Today (or very soon), Global Plankton Imaging is possible

Imaging sensors from Autonomous platforms







D_{PSD} ← **Particulate Organic Carbon**

Z_n ← **macro and mesoplankton (Taxa size spectra)**

P_λ ← **Pico and microplankton (taxa, size spectra)**

N ← **CTD and geochemical data**

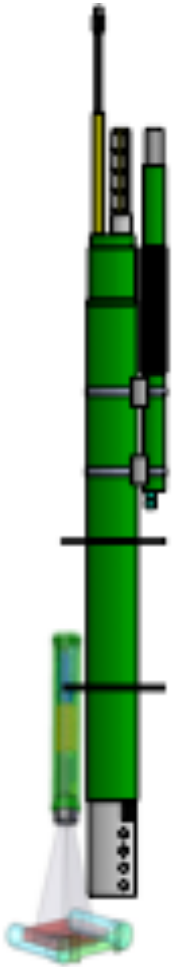
Stemmann et al., 2012

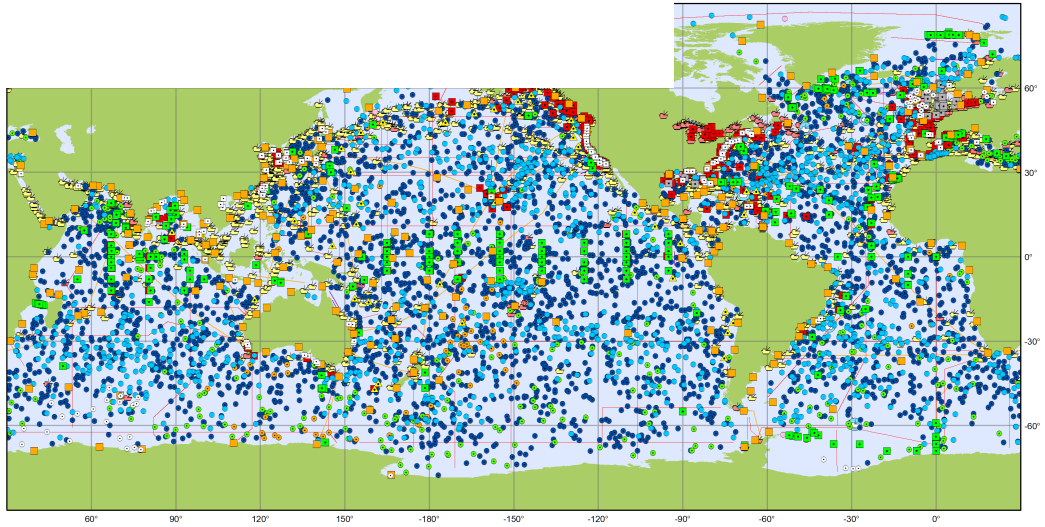
Are plankton nets a thing of the past?

Giering et al., (2022)

Today (or very soon), Global Plankton Imaging is possible

Imaging sensors from Autonomous platforms

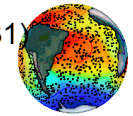




Main in situ Elements of the Global Ocean Observing System — April 2019

Profiling Floats (Argo)
- Core (3880)
- Deep (79)
- BioGeoChemical (352)

Data Buoys (DBCP)
- Surface Drifters (1444)
- Offshore Platforms (97)
- Ice Buoys (11)
- Moored Buoys (358)
- Tsunameters (38)
- HF Radars (270)
- Animal Borne Sensors (53)
- Ocean Gliders (31)



Generated by www.jcommops.org, 14/05/2019

Timeseries (OceanSITES)
- Interdisciplinary Moorings (351)

Repeated Hydrography (GO-SHIP)
- Research Vessel Lines (62)

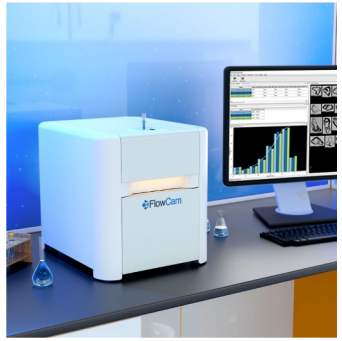
D_{PSD} ← **Particulate Organic Carbon**

Z_n ← **macro and mesoplankton (Taxa size spectra)**

P_λ ← **Pico and microplankton (taxa, size spectra)**

N ← **CTD and geochemical data**

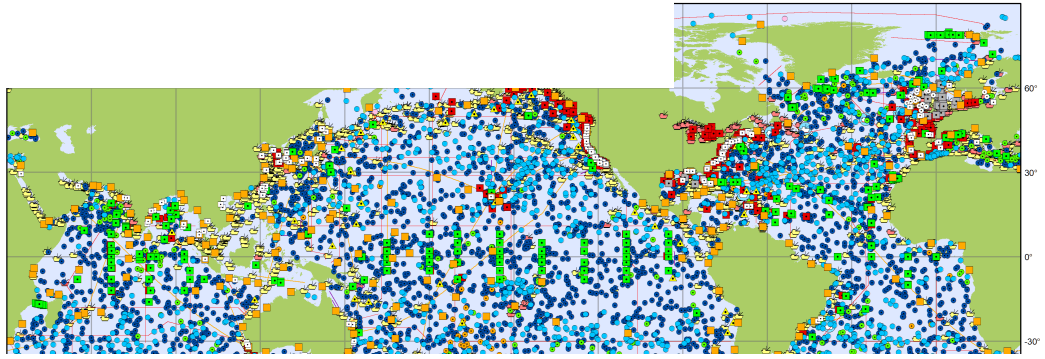
Imaging sensors on other platforms (*ex or in situ*)

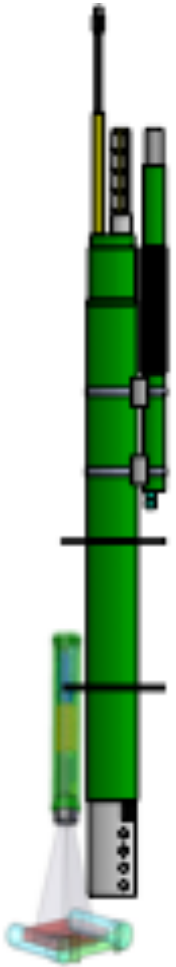


Stemmann et al., 2012 Lombard et al., 2019

Today (or very soon), Global Plankton Imaging is possible

Imaging sensors from Autonomous platforms





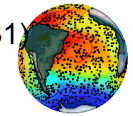
Profiling Floats (Argo)
- Core (3880)
- Deep (79)
- BioGeoChemical (352)

Data Buoys (DBCP)
- Surface Drifters (1444)
- Offshore Platforms (97)
- Ice Buoys (11)
- Moored Buoys (358)
- Tsunameters (38)

HF Radars (270)

Animal Borne Sensors (53)

Ocean Gliders (31)



Generated by www.jcommops.org, 14/05/2019

Timeseries (OceanSITES)
- Interdisciplinary Moorings (351)

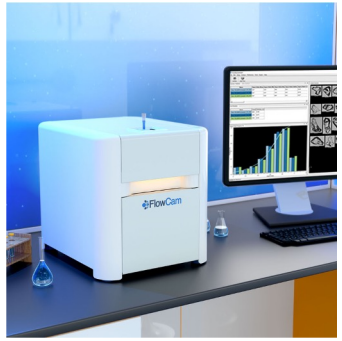
Repeated Hydrography (GO-SHIP)
- Research Vessel Lines (62)

Are data from lab and in situ gears comparable?

How can regionally scaled data feed global observation ?

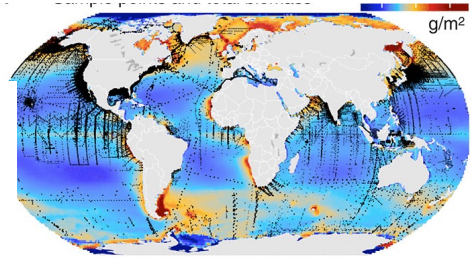
What are the conditions for a distributed observation ?

***Imaging sensors* on other platforms (*ex or in situ*)**

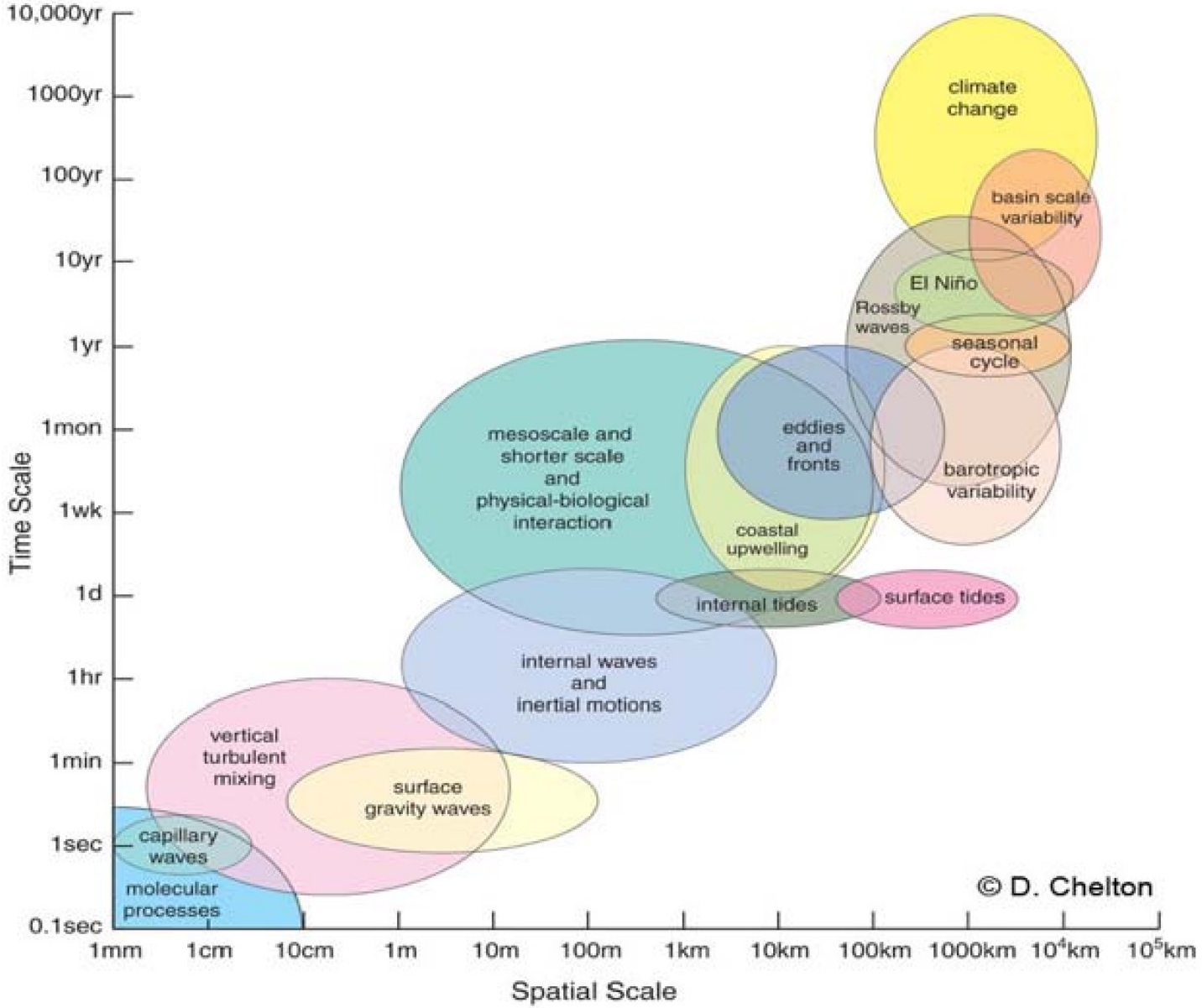


Stemmann et al., 2012 Lombard et al., 2019

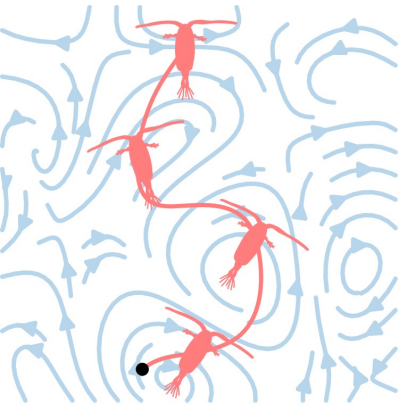
How to climb the ladder of scales ?



Hatton et al., 2021

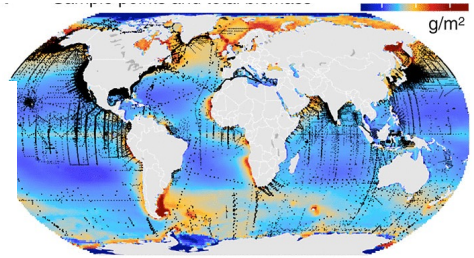


after Dickey (2001)

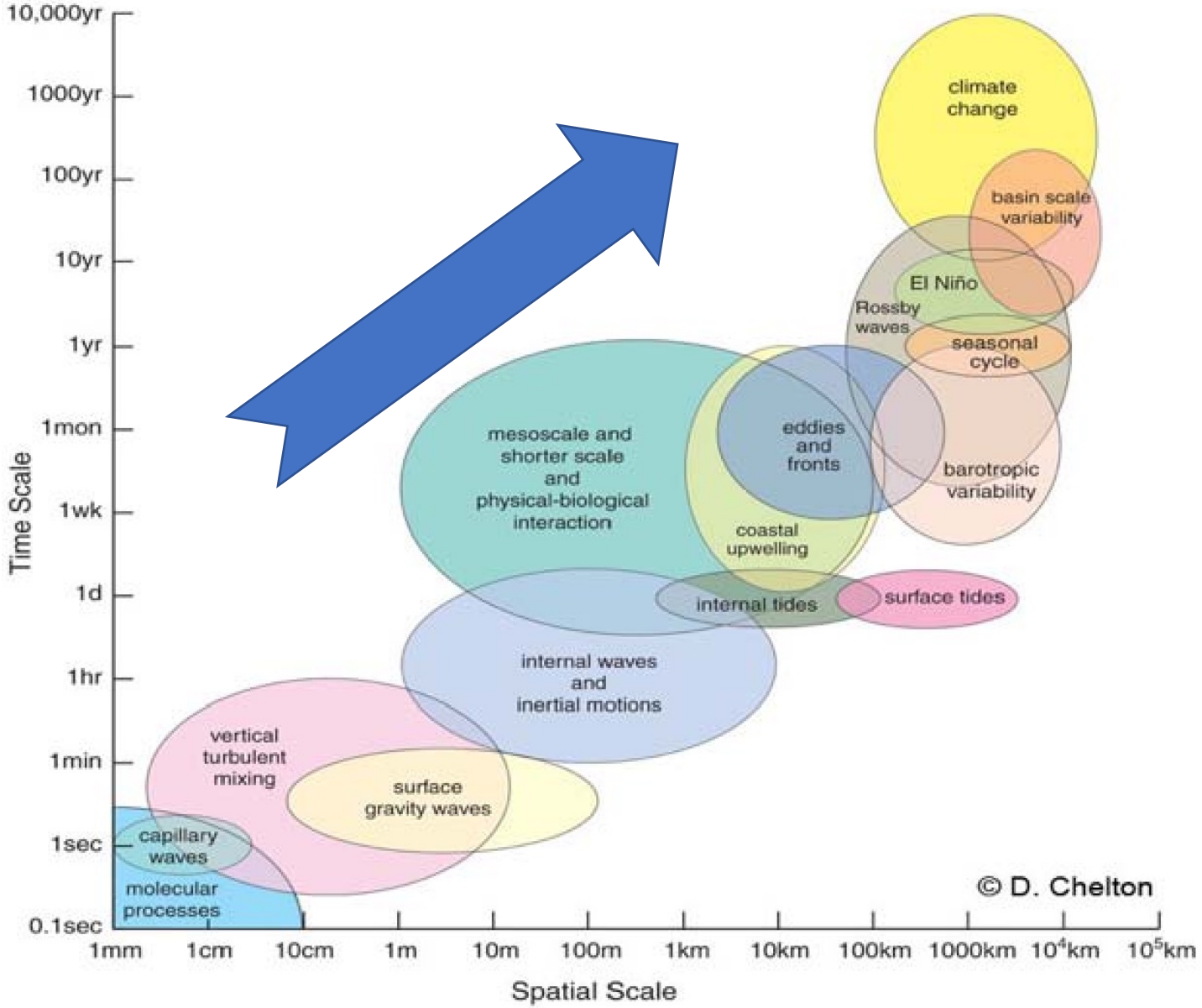


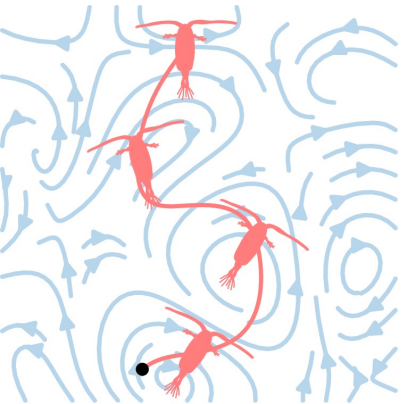
Monthiller *et al* (2022)

How to climb the ladder of scales ?



Hatton et al., 2021

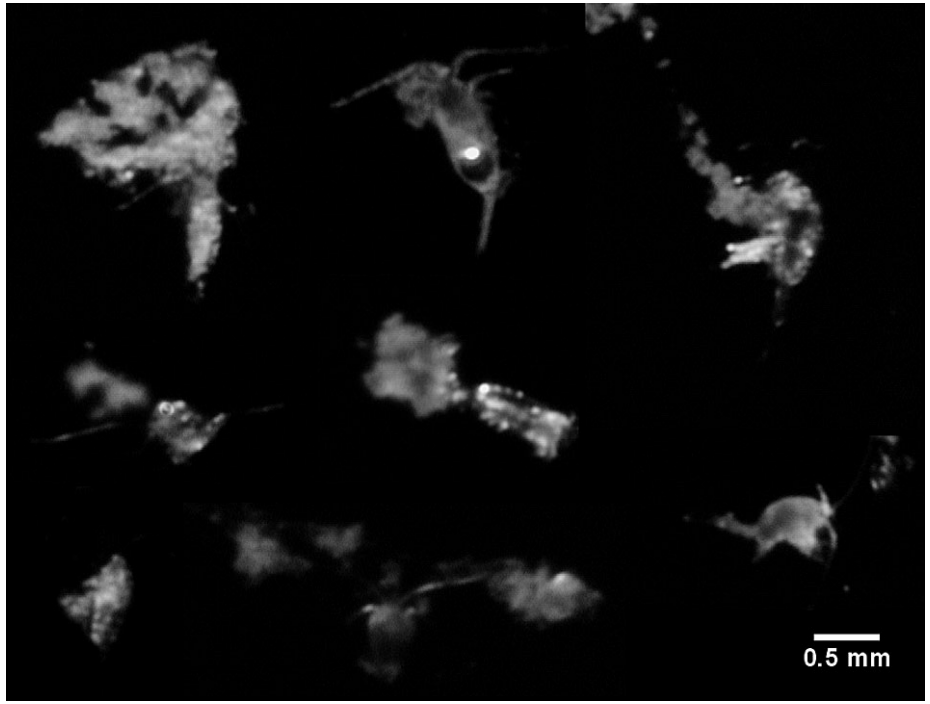




Monthiller *et al* (2022)

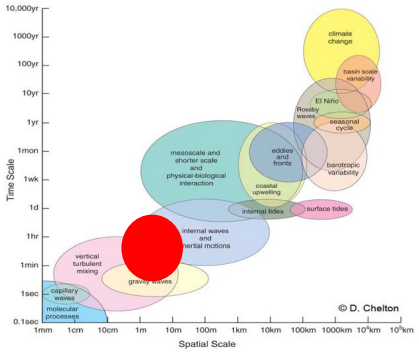
after Dickey (2001)

Plankton Ecology with imaging systems: small temporal changes



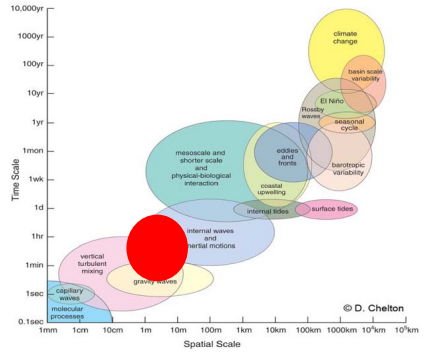
O. Möller et al., 2012, MEPS

< 1 day



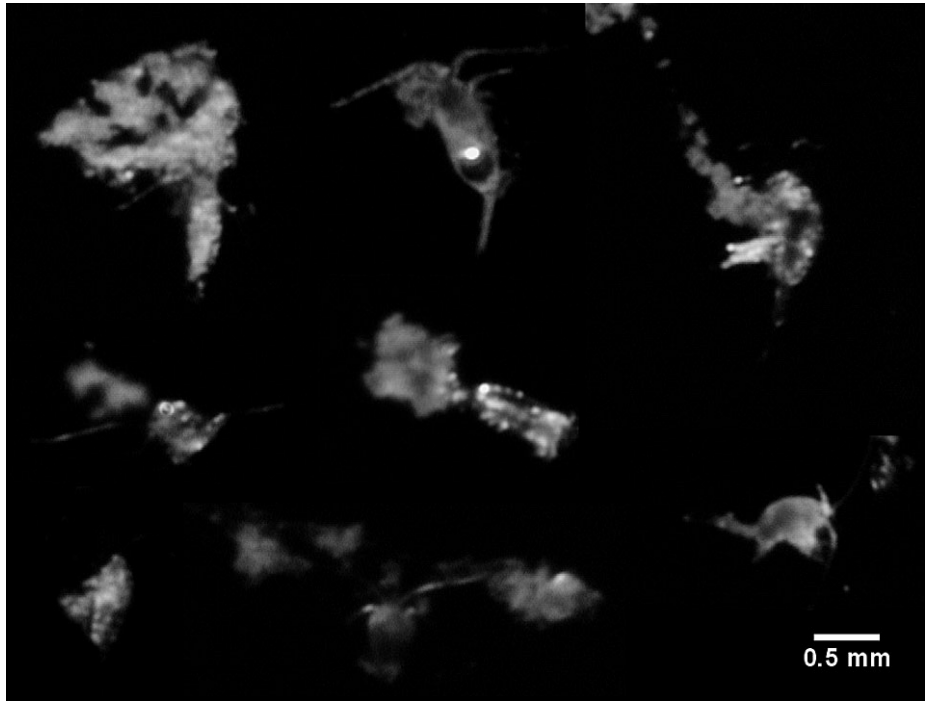
Can zooplankton benefit from thin layers of marine snow ?

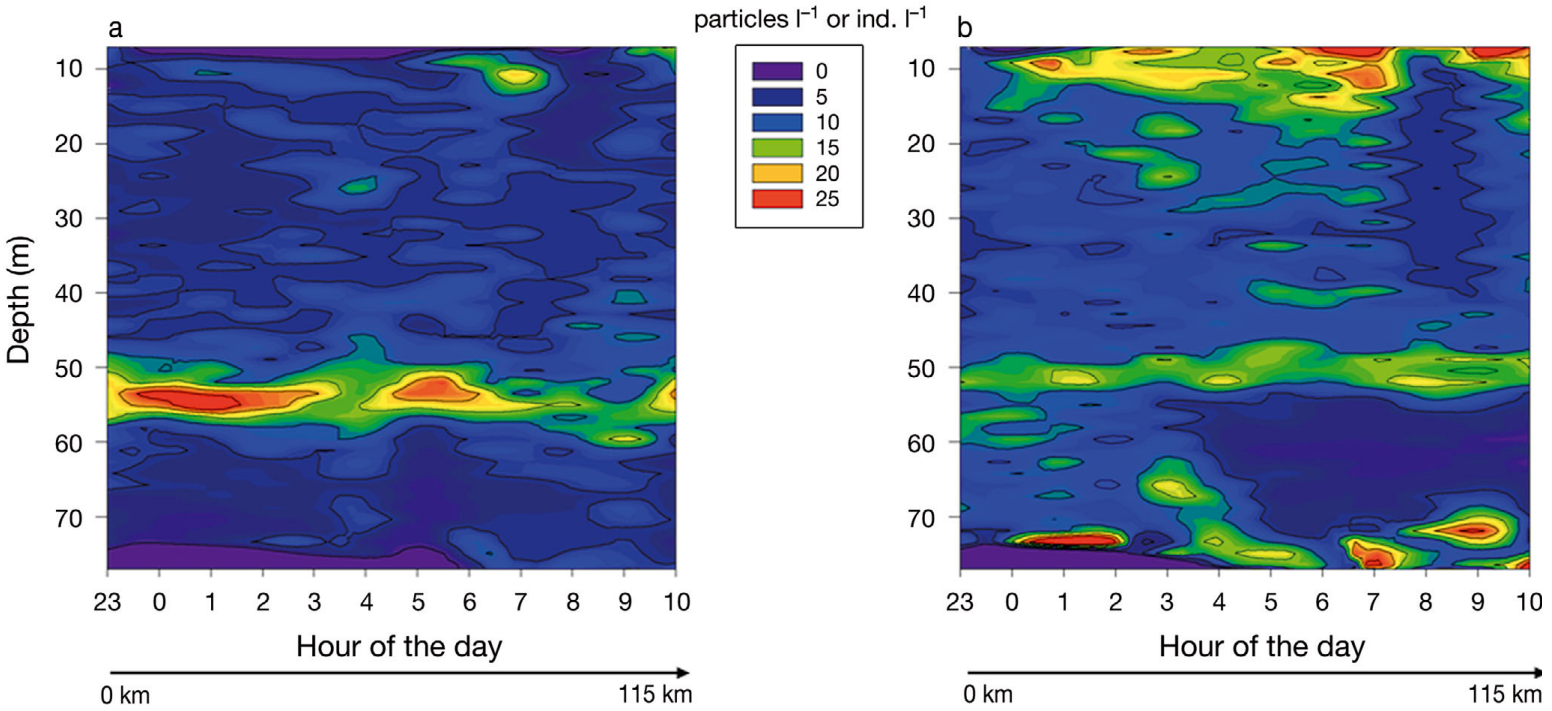
Plankton Ecology with imaging systems: small temporal changes



< 1 day

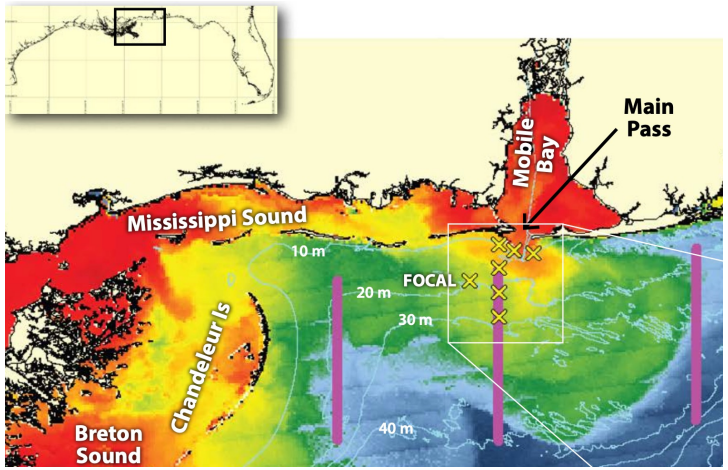
→ Marine snow, zooplankton and thin layers are spatially associated: indications of a trophic link ?



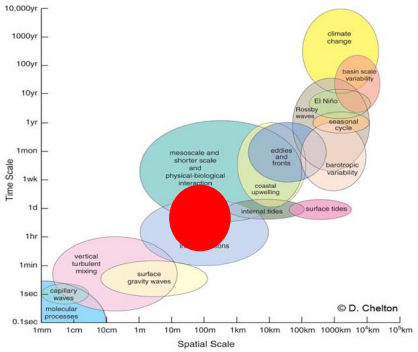


O. Möller et al., 2012, MEPS

Plankton Ecology with imaging systems: submeso-scale spatial variability



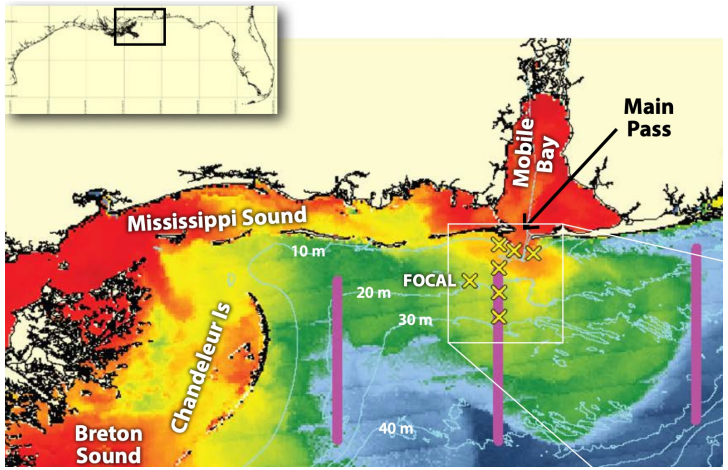
Greer et al., 2021, ICES-JMS

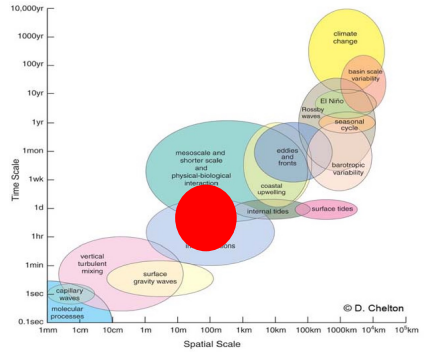


few km/few m

Are life cycles of doliolids separated in space in relation to the hydrology?

Plankton Ecology with imaging systems: submeso-scale spatial variability



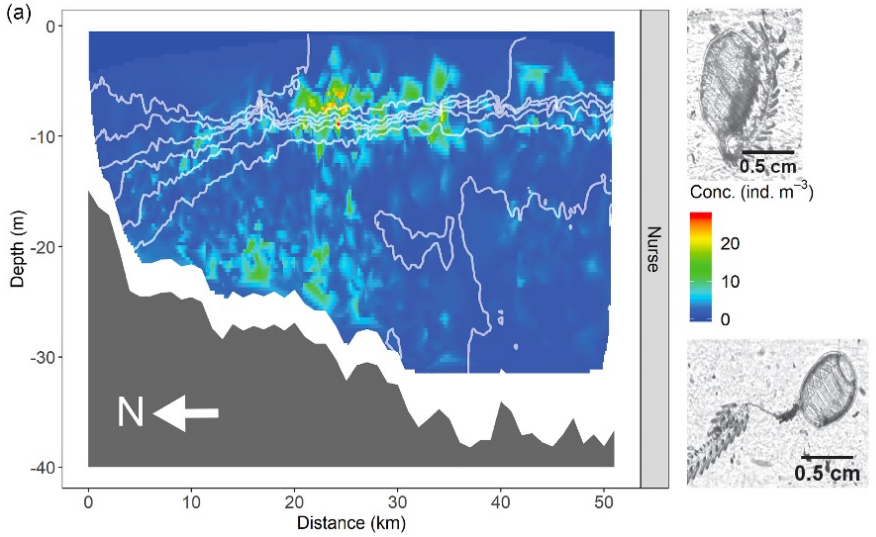


few km/few m

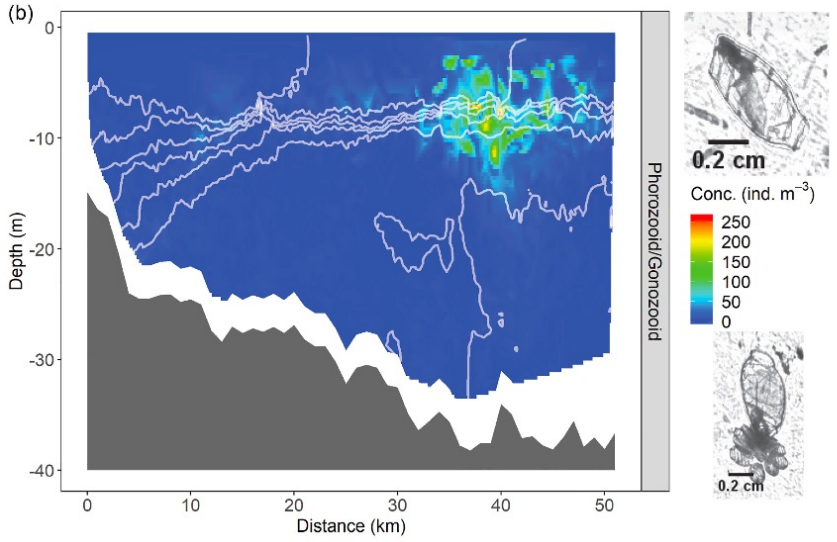
→ Life stage-specific distribution of doliolids in relation to isohalines

Greer et al., 2021, ICES-JMS

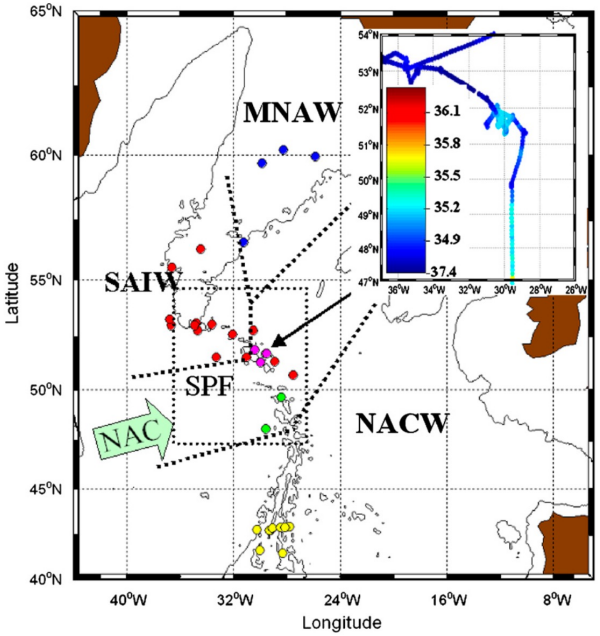
Nurse

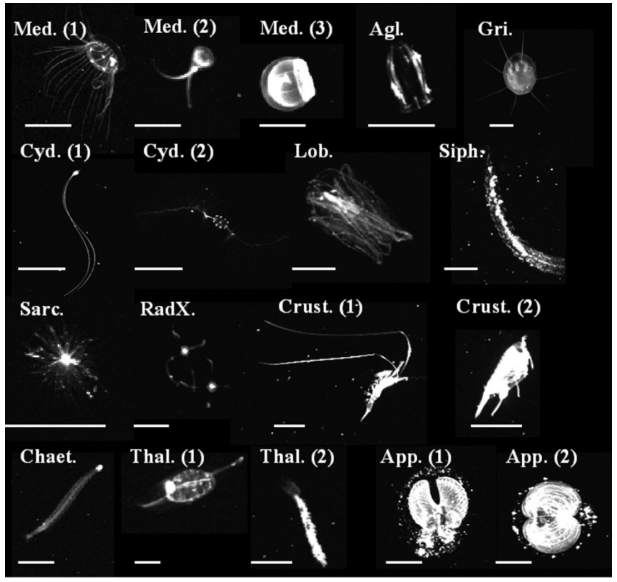


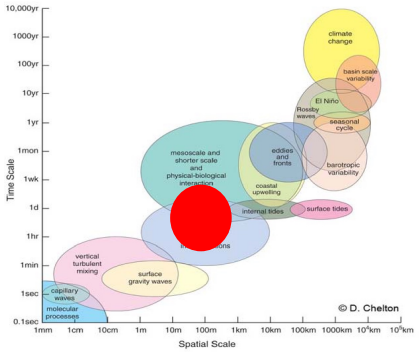
phorozooids/gonozooids



Plankton Ecology with imaging systems: meso-scale variability





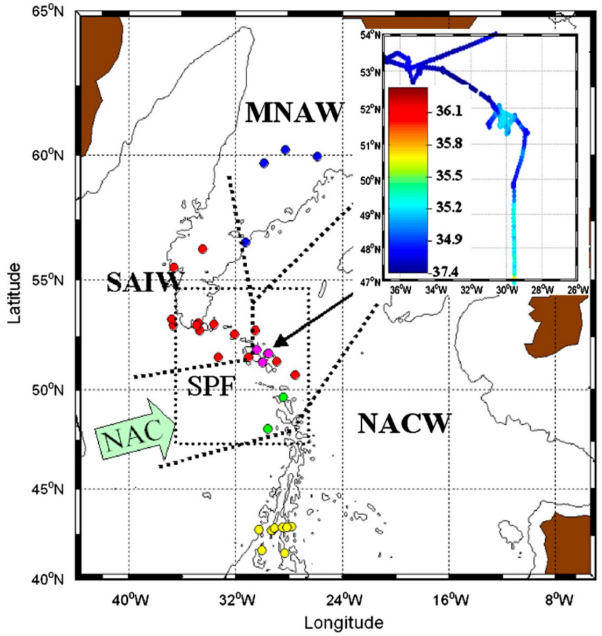


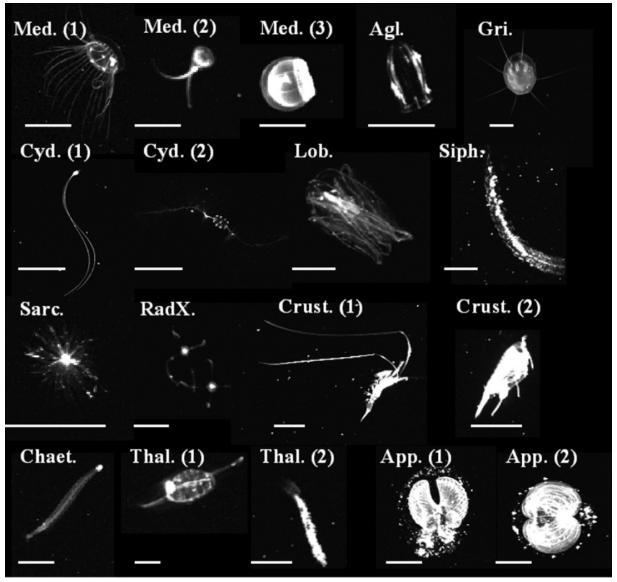
few km/few m

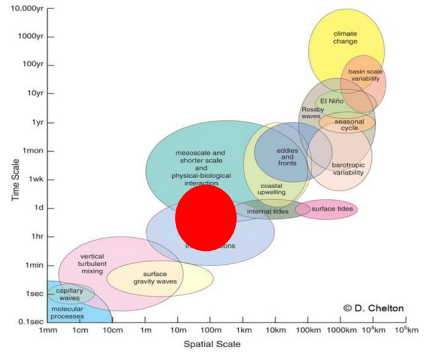
Do anticyclone eddies in the North Atlantic contain different macrozooplankton ?

Stemmann et al., 2008, **39 stations UVP4 in summer 2006, 20 taxa, >500 images**

Plankton Ecology with imaging systems: meso-scale variability

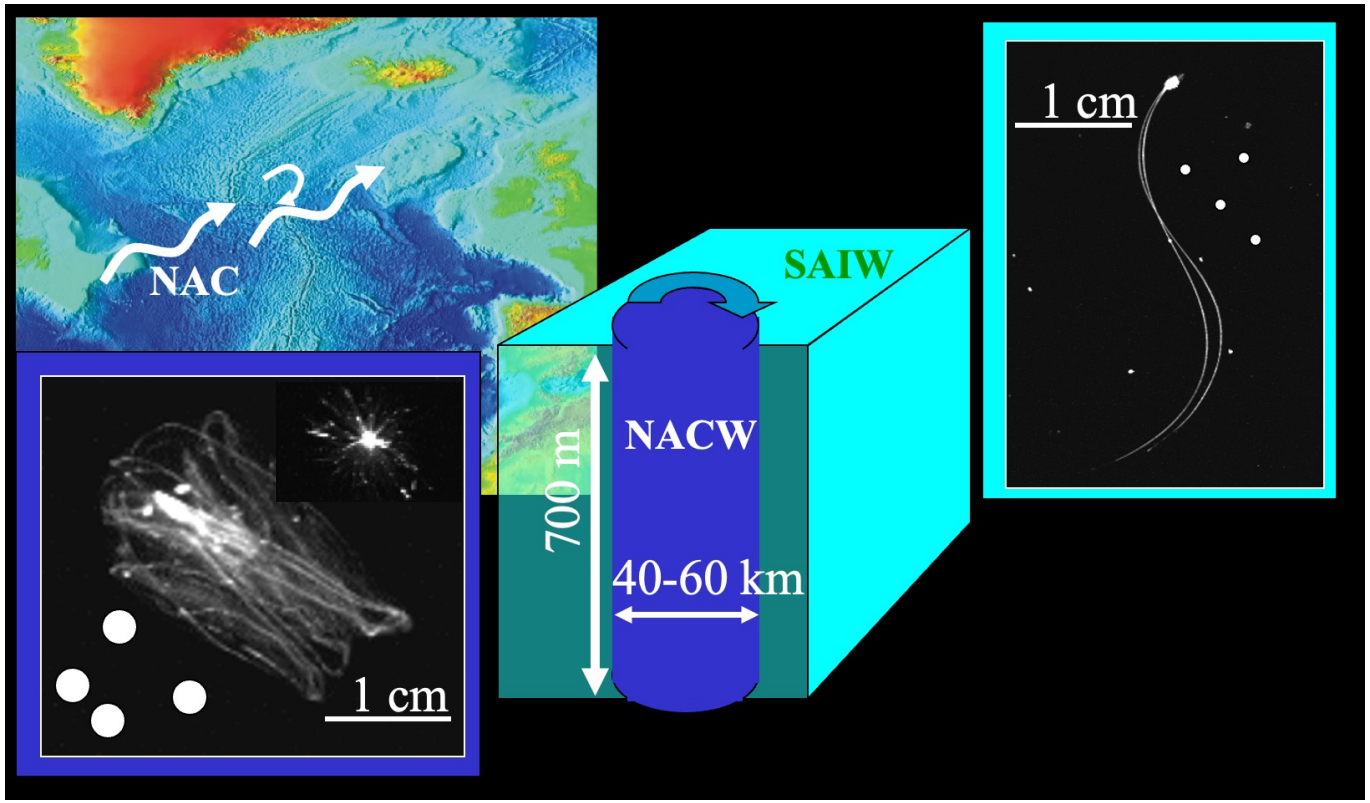






few km/few m

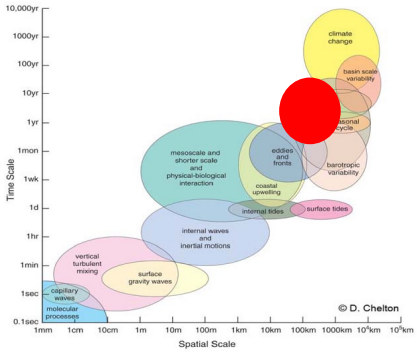
→ Yes not only macrozooplankton was different but also the particle distribution?

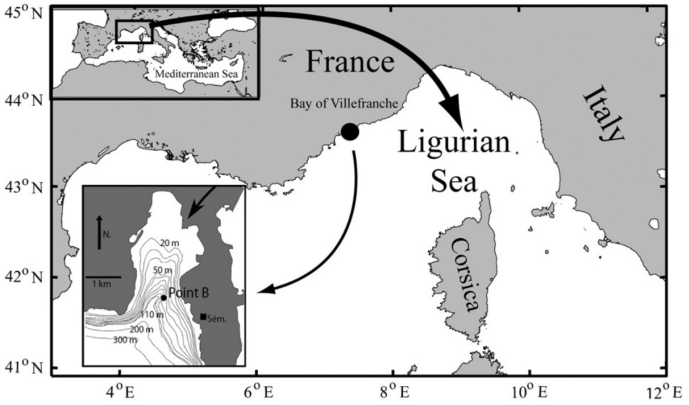


Stemmann et al., 2008, **39 stations UVP4 in summer 2006, 20 taxa, >500 images**

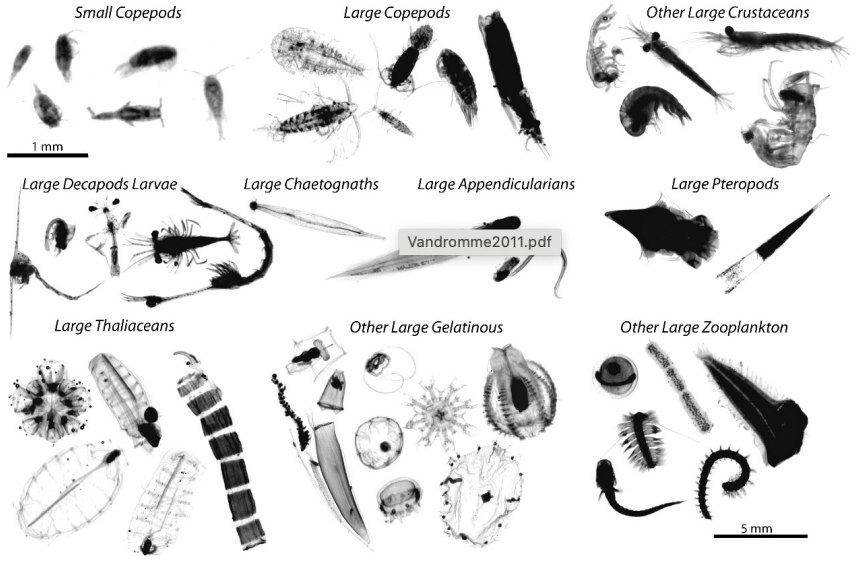
Plankton Ecology with imaging systems: long term temporal changes

> 20 years





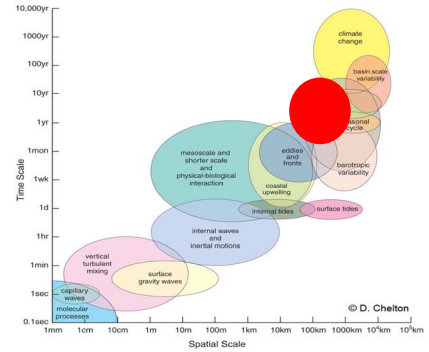
Is zooplankton observed community change in the NW Mediterranee associated to global warming?

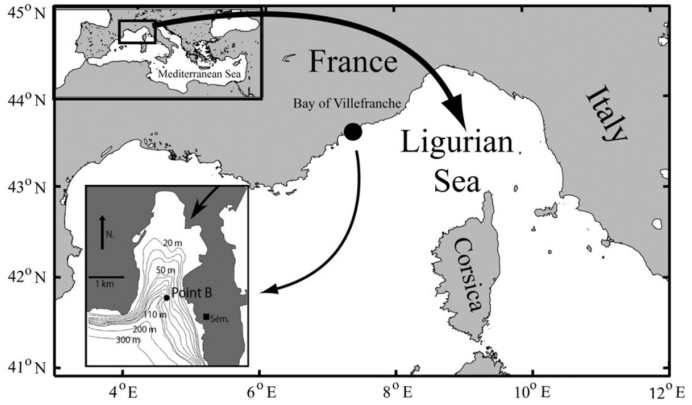


Garcia-Comas et al., 2011, JMS

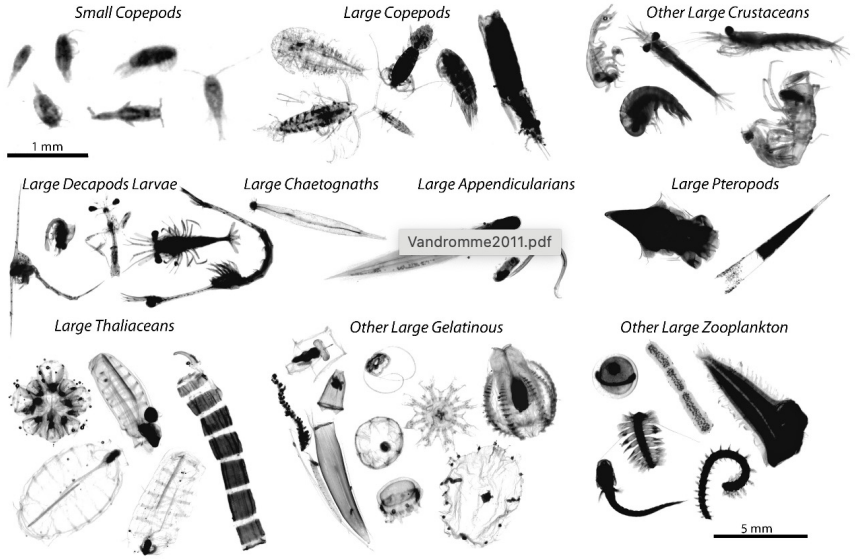
Plankton Ecology with imaging systems: long term temporal changes

> 30 years



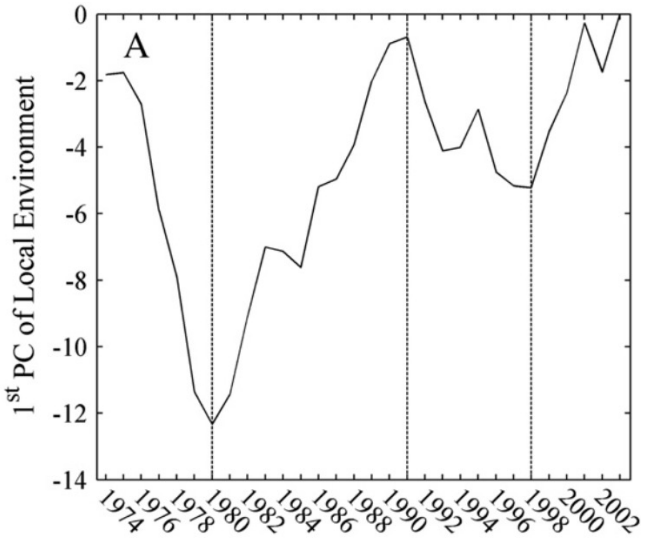


→ Decadal periodicity forced by winter hydrographic conditions related to large-scale atmospheric changes.

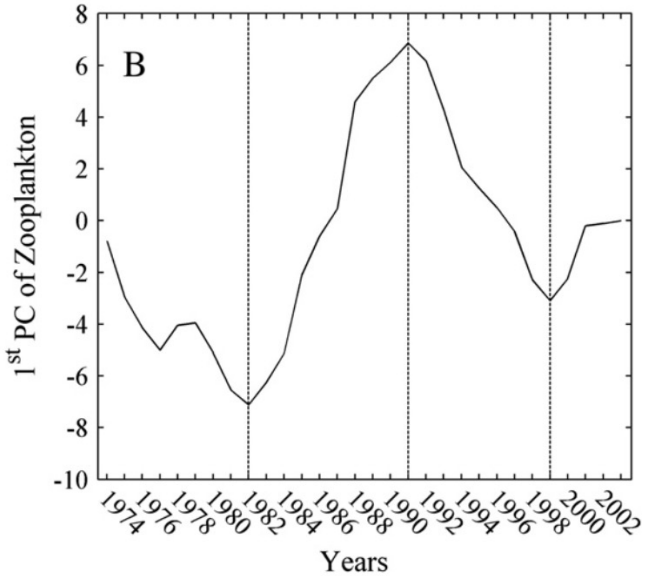


Garcia-Comas et al., 2011, JMS

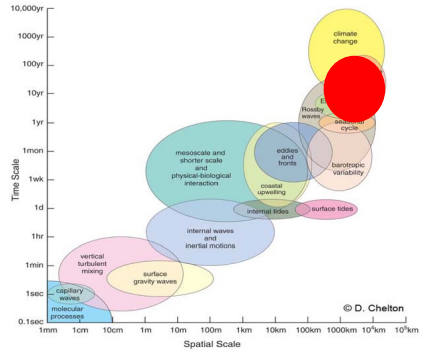
Climate/hydrology



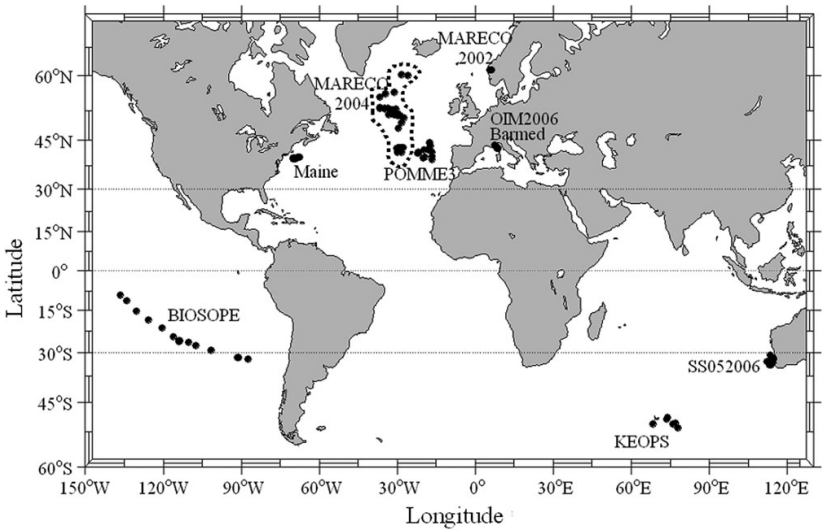
Zooplankton indicator

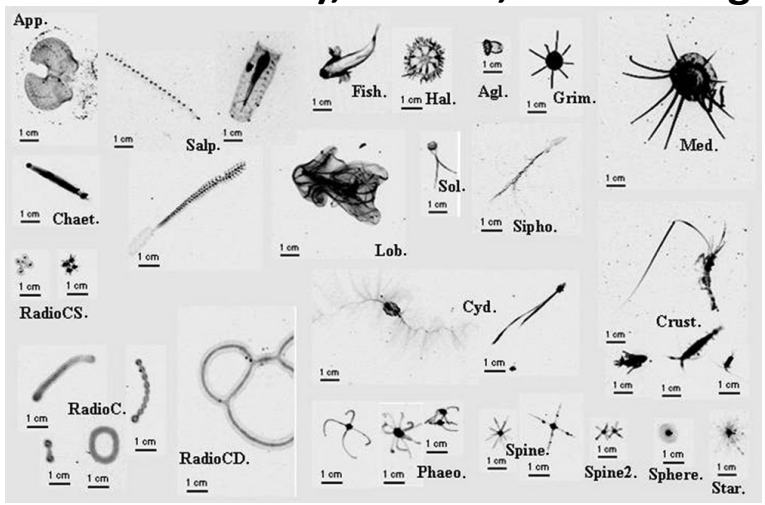


Plankton Ecology with imaging systems: global scale spatial variability



Stemmann et al., (2008), 296 stations UVP4 1996-2006), 20 taxa, >4000 images

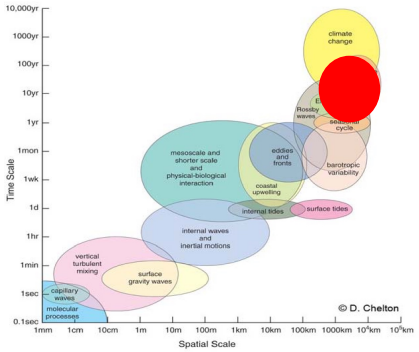




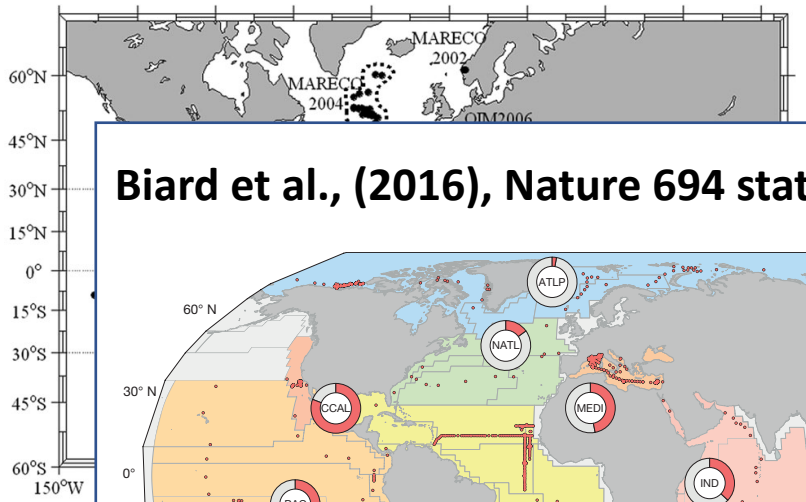
1312 crustacea
925 rhizarians
900 tunicates
…

Are mesopelagic zooplankton communities distributed according Longhurst patterns ?

Plankton Ecology with imaging systems: global scale spatial variability

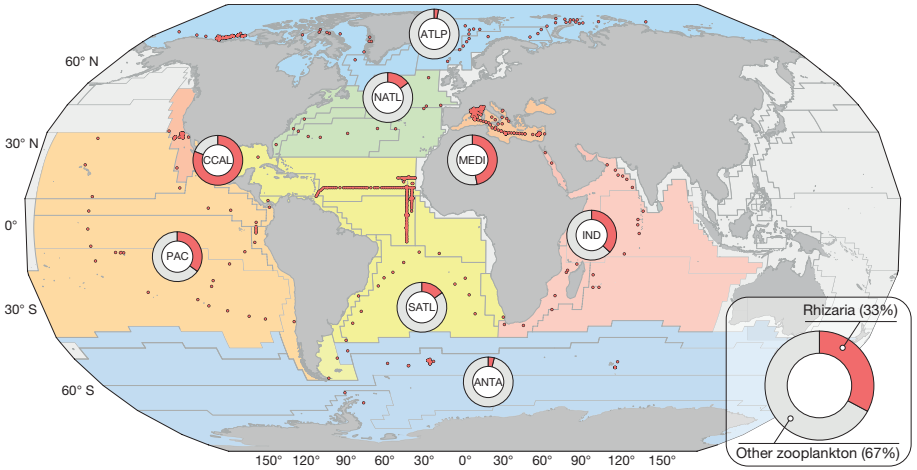


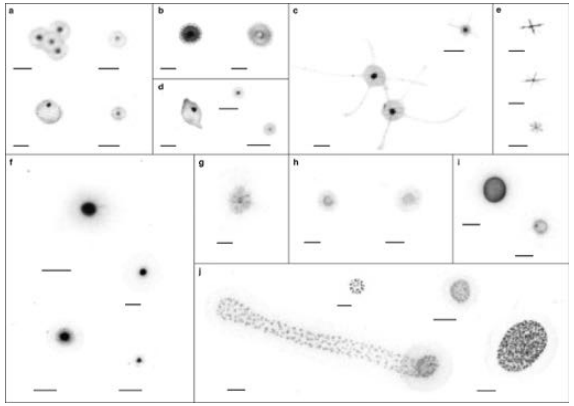
Stemmann et al., (2008) ICES, 296 stations UVP4 1996-2006), 20 taxa, >4000 images



1312 crustacea
925 rhizarians

Biard et al., (2016), Nature 694 stations (UVP5), 4 Taxa among Rhizaria, 36 000 images

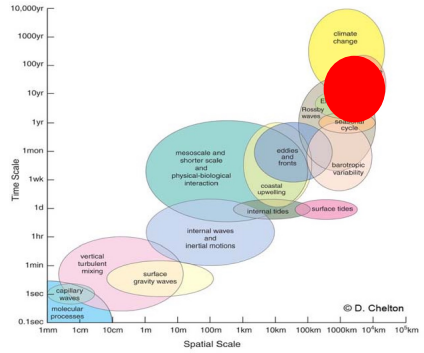




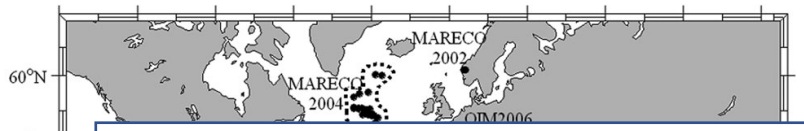
rhizarians in the top 200 m of world oceans represent a standing stock of 0.089 Pg carbon, equivalent to 5.2% of known biomass of zooplankton

Are Rhizarians major players in the ocean ?

Plankton Ecology with imaging systems: global scale spatial variability



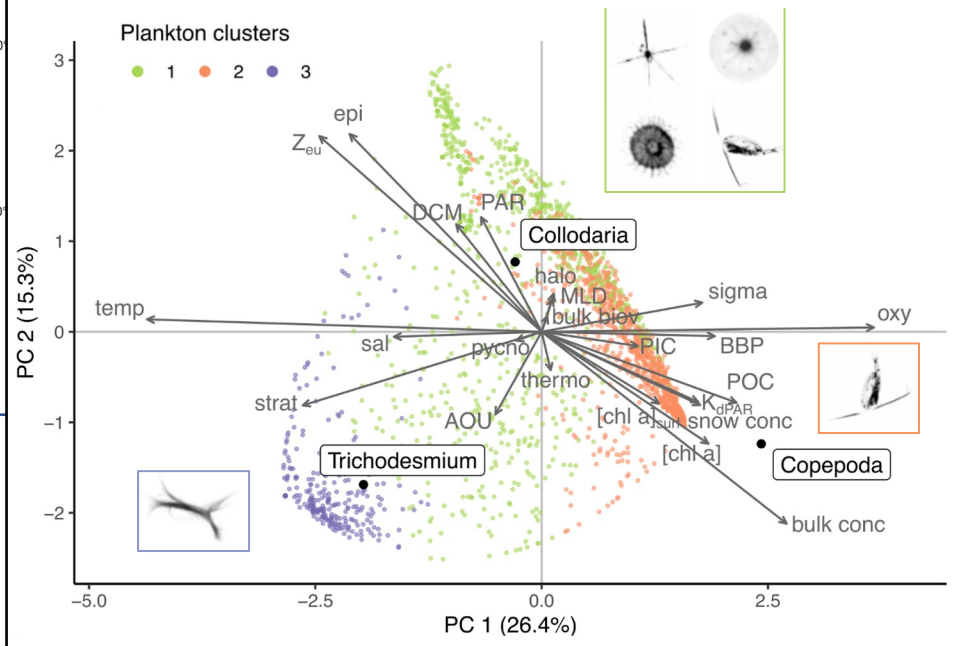
Stemmann et al., (2008) ICES, 296 stations UVP4 1996-2006), 20 taxa, >4000 images

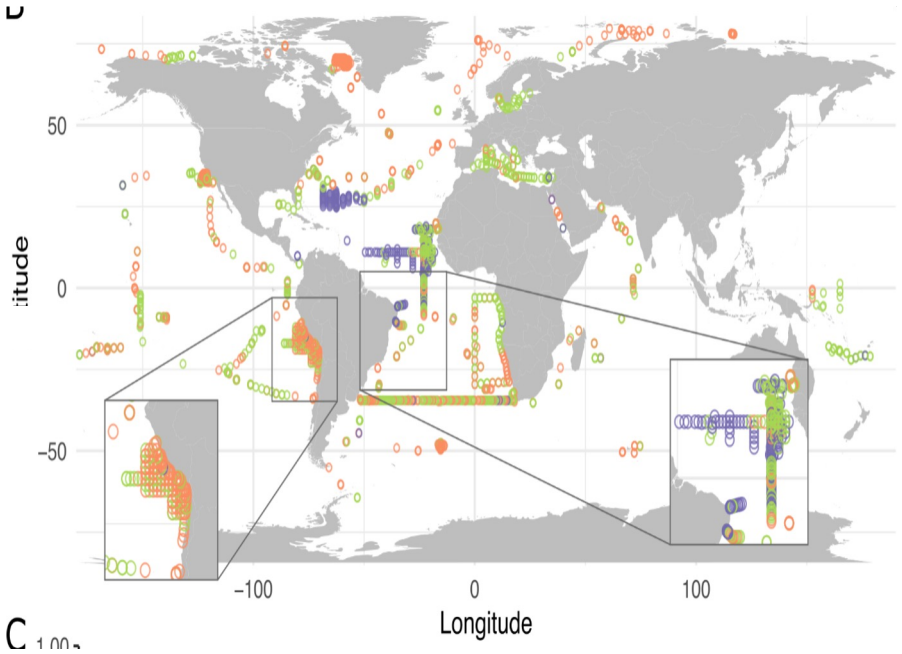


1312 crustacea
925 rhizarians

Biard et al., (2016), Nature 694 stations (UVP5), 4 Taxa among Rhizaria, 36 000 images

Panaiotis et al., (2022) Glob. Eco., 2500 stations, 28 taxa, 330 000 images

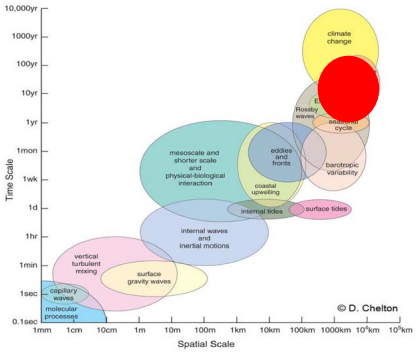




Relative contribution
1 - Trichodesmium
0.75 - Copepoda
0.25 - Rhizaria

What are the other major large players in the ocean ?

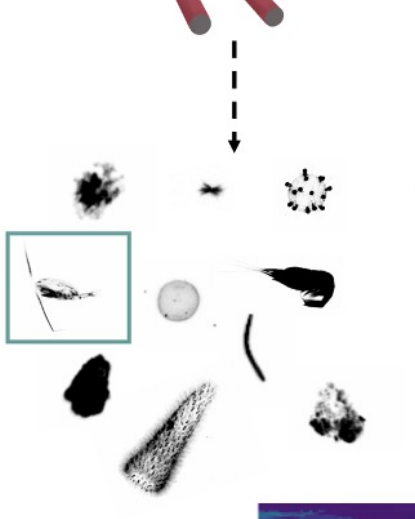
Plankton Ecology with imaging systems: with models



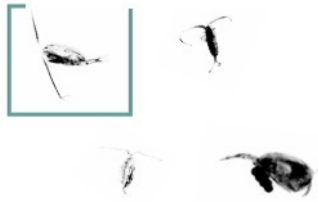
1

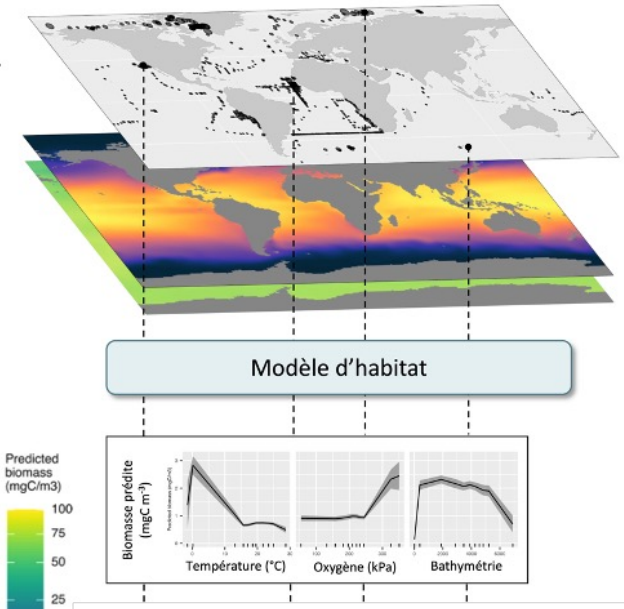
In situ observation

Drago et al., 2022,
2500 stations, 28 taxa, 330 000 images



2 Classification
Size

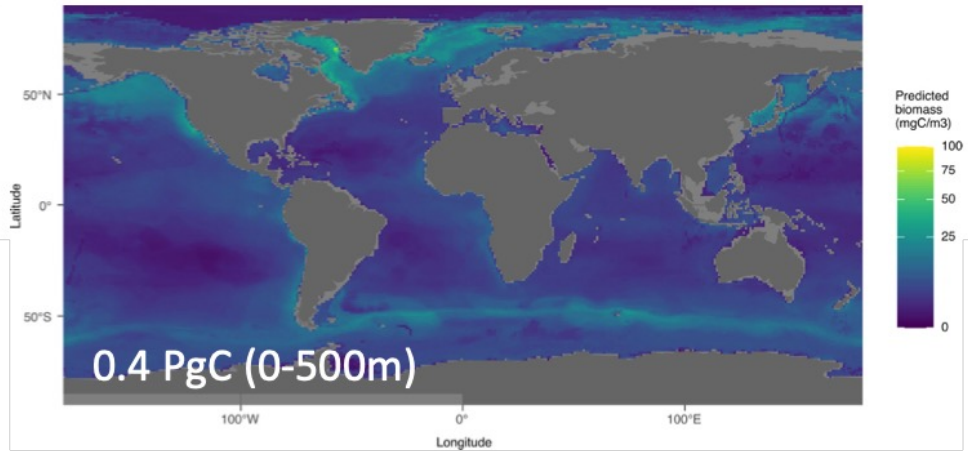




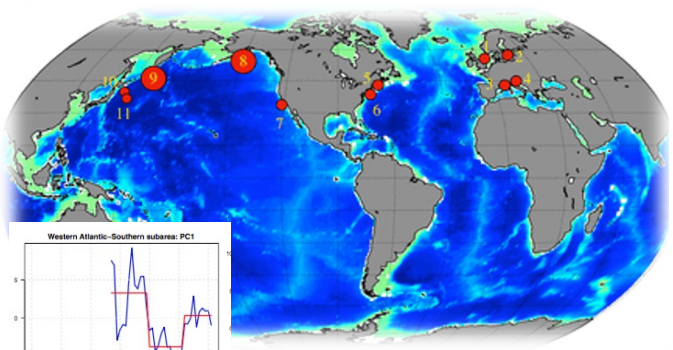
3 Observed biomass and taxa

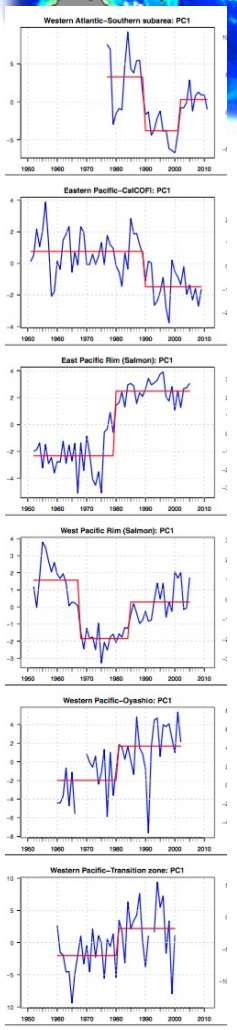
4 Environmental data

5 Habitat model (BRT)



Plankton Ecology with imaging systems: with models





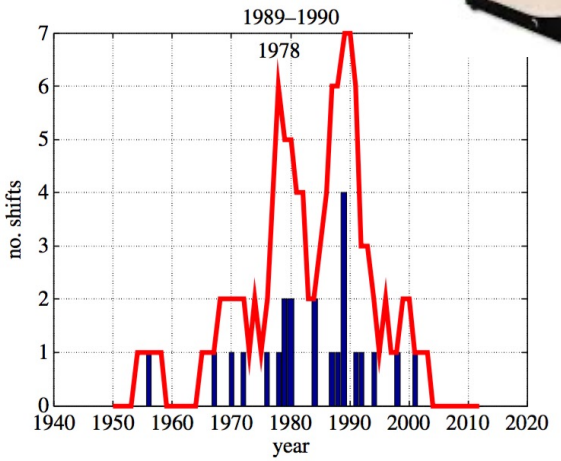
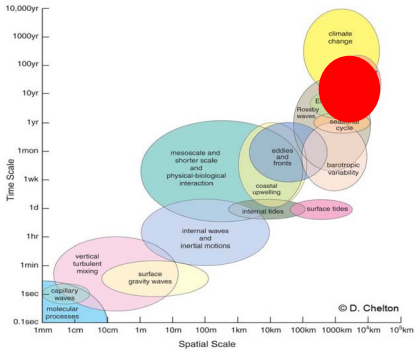


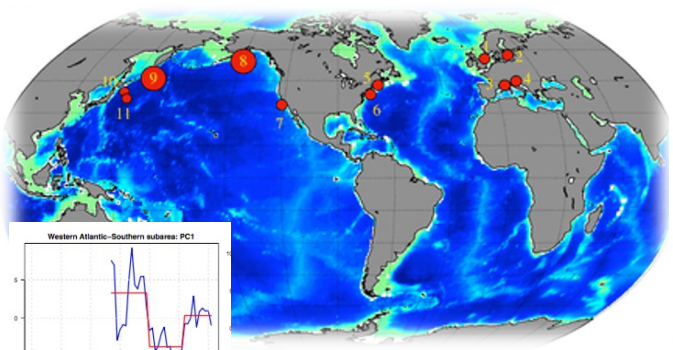
Figure 3. Summary of the results from change-point analysis performed on each of the first three principal components for each ecosystem (a total of 33 principal components). The number of significant shifts ($p < 0.05$) for each year is shown in the blue bar plot. The red curve above the bars indicates the number of shifts for a sliding 3-year period. For example, there were seven significant shifts centred around 1989–1990. (Online version in colour.)

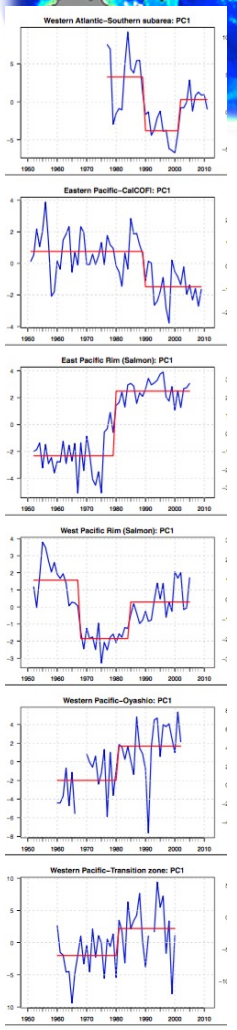
Beaugrand et al., (2015), PNAS



Do we see synchronicities in various plankton time series ?

Plankton Ecology with imaging systems: combining with models





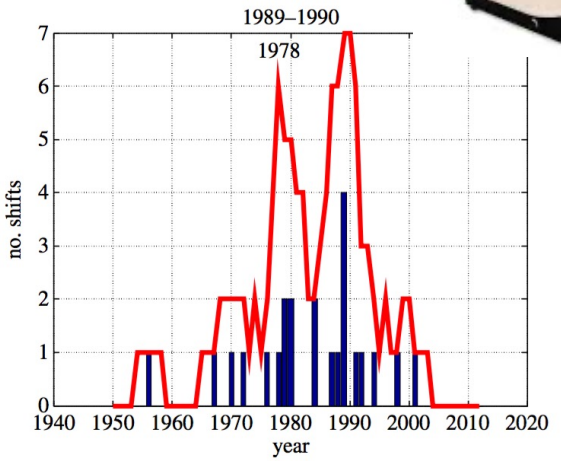
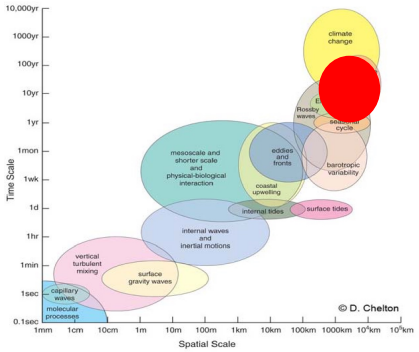
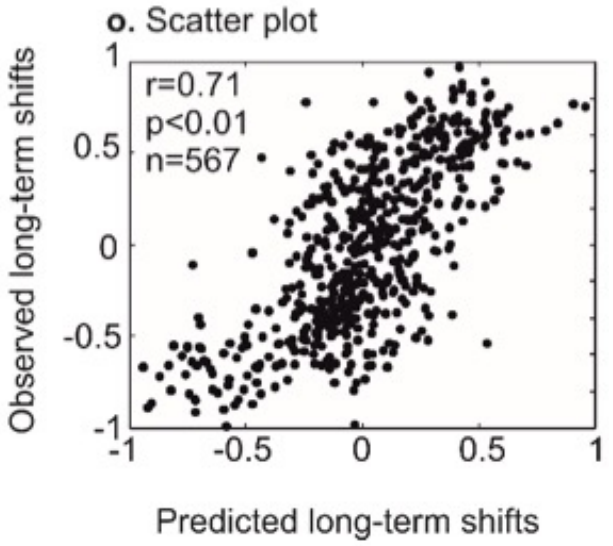


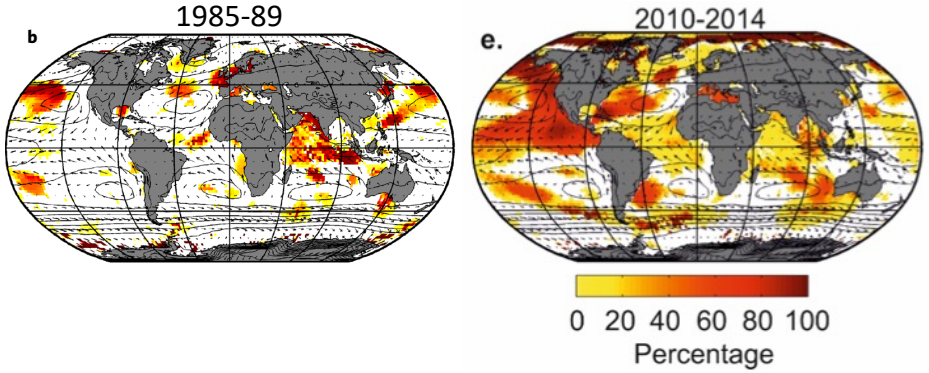
Figure 3. Summary of the results from change-point analysis performed on each of the first three principal components for each ecosystem (a total of 33 principal components). The number of significant shifts ($p < 0.05$) for each year is shown in the blue bar plot. The red curve above the bars indicates the number of shifts for a sliding 3-year period. For example, there were seven significant shifts centred around 1989–1990. (Online version in colour.)

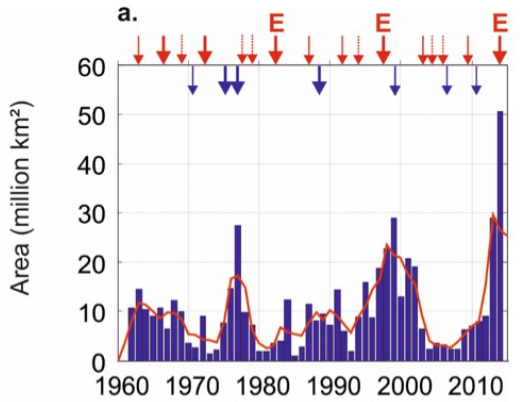
Beaugrand et al., (2015), PNAS



Yes and it can be modelled with habitat type model.



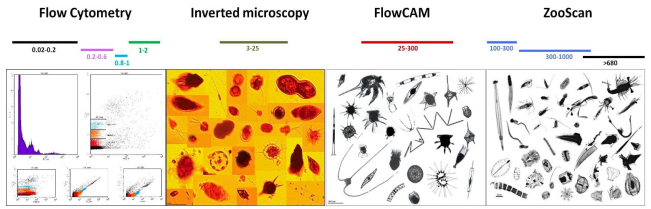


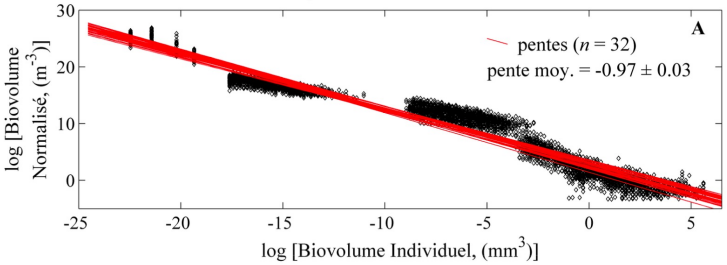


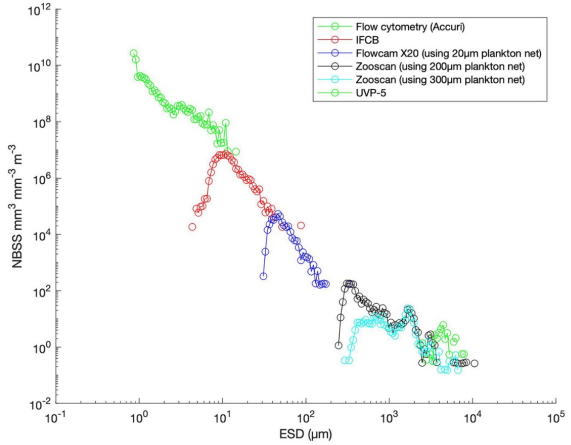
Beaugrand et al., (2019), Nature Climate Change

Coming research

Complete size range



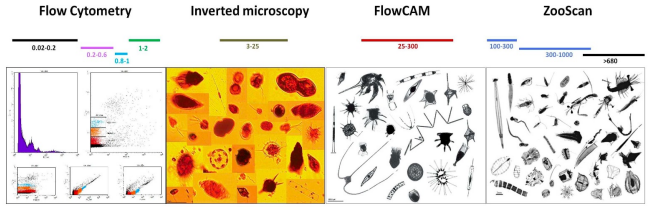


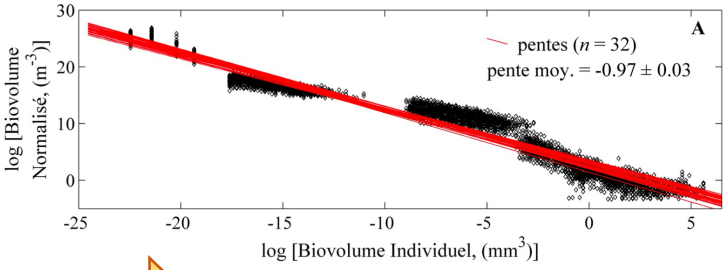


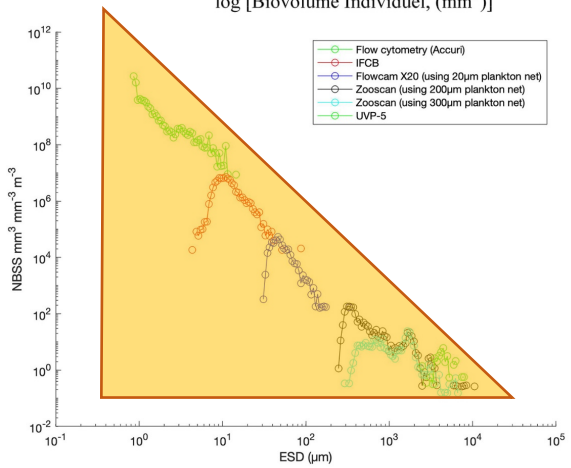
Romagnan et al., 2015
Lombard et al., 2019 + S4 this afternoon

Coming research

Complete size range

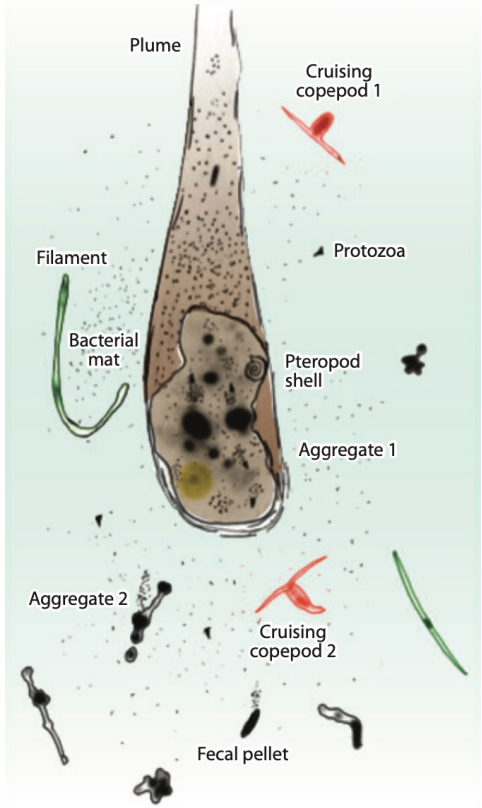






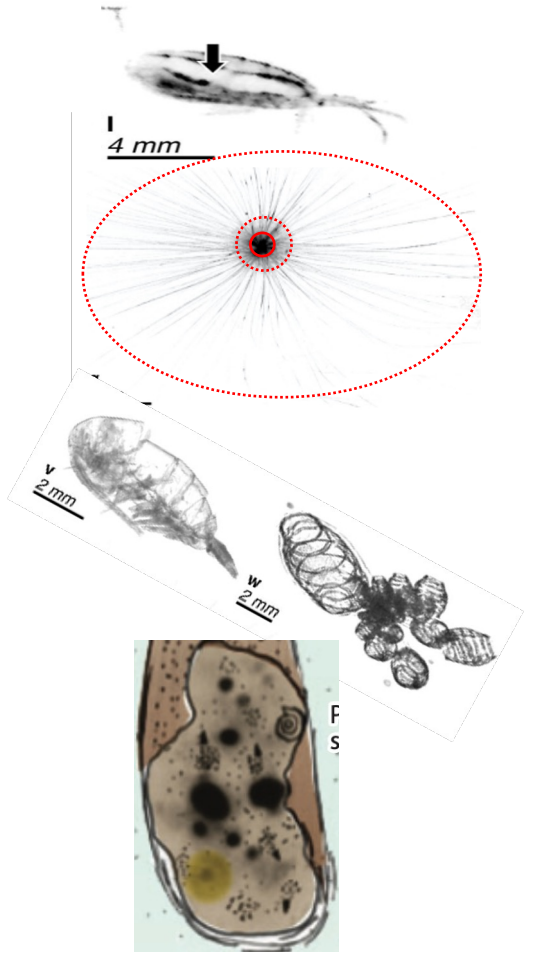
Romagnan et al., 2015
Lombard et al., 2019 + S4 this afternoon

The quasi-plankton (*living* marine snow)



Stemmann and Boss, 2012

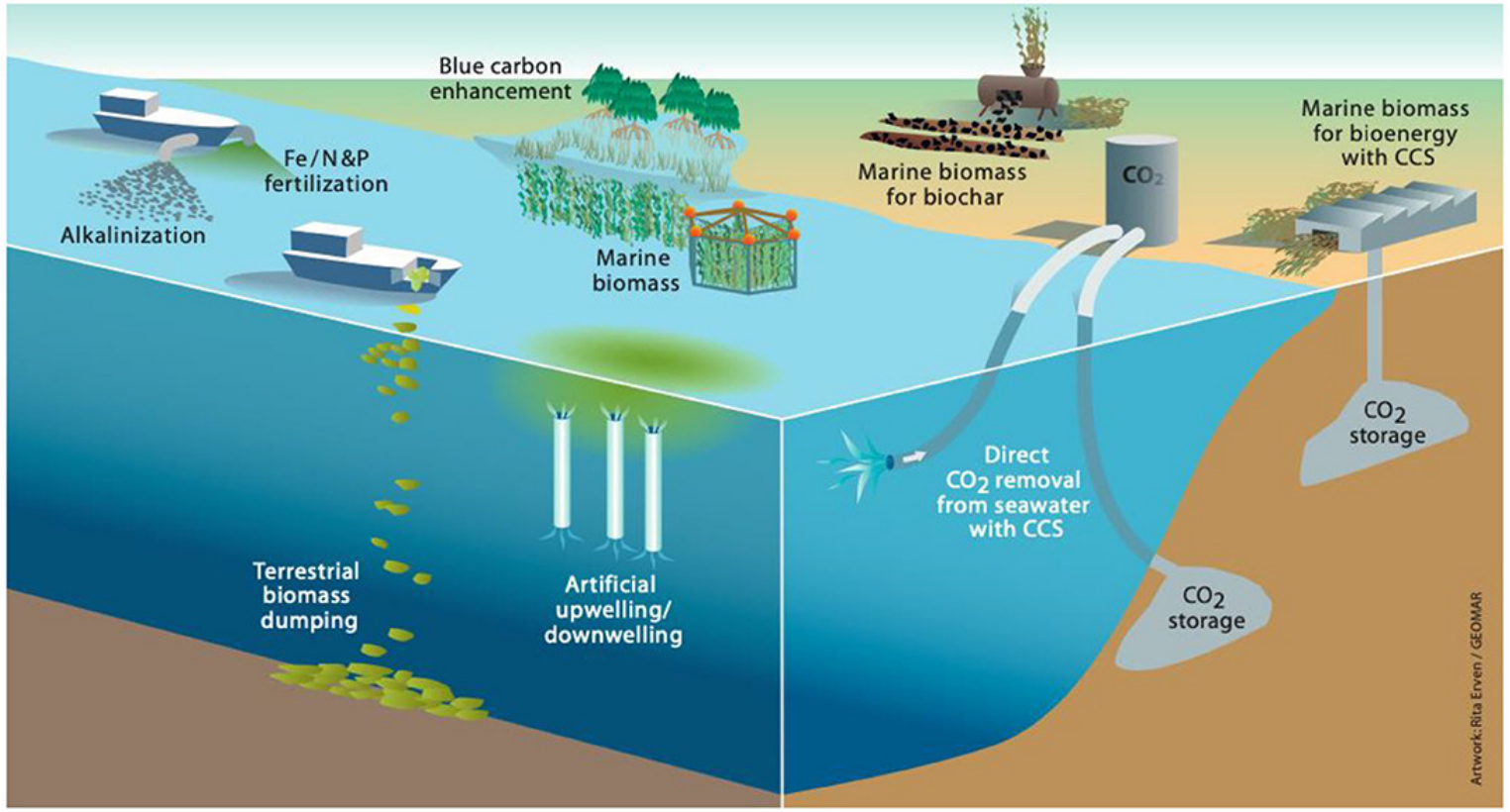
More than size→Traits



Irisson et al., 2022
Vilgrain et al., 2021

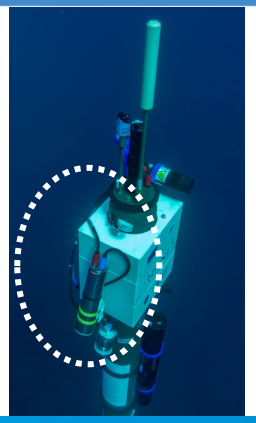
Coming monitoring the coming changes in plankton

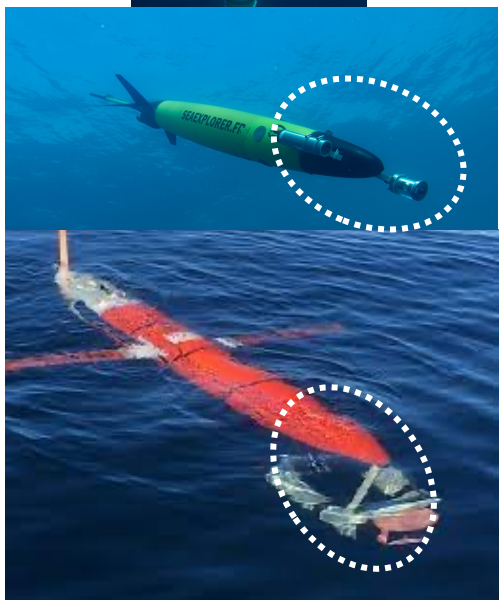
Monitoring Reporting Verification of human impact on plankton



Boettcher et al., 2021

Miniaturisation for autonomous sensors

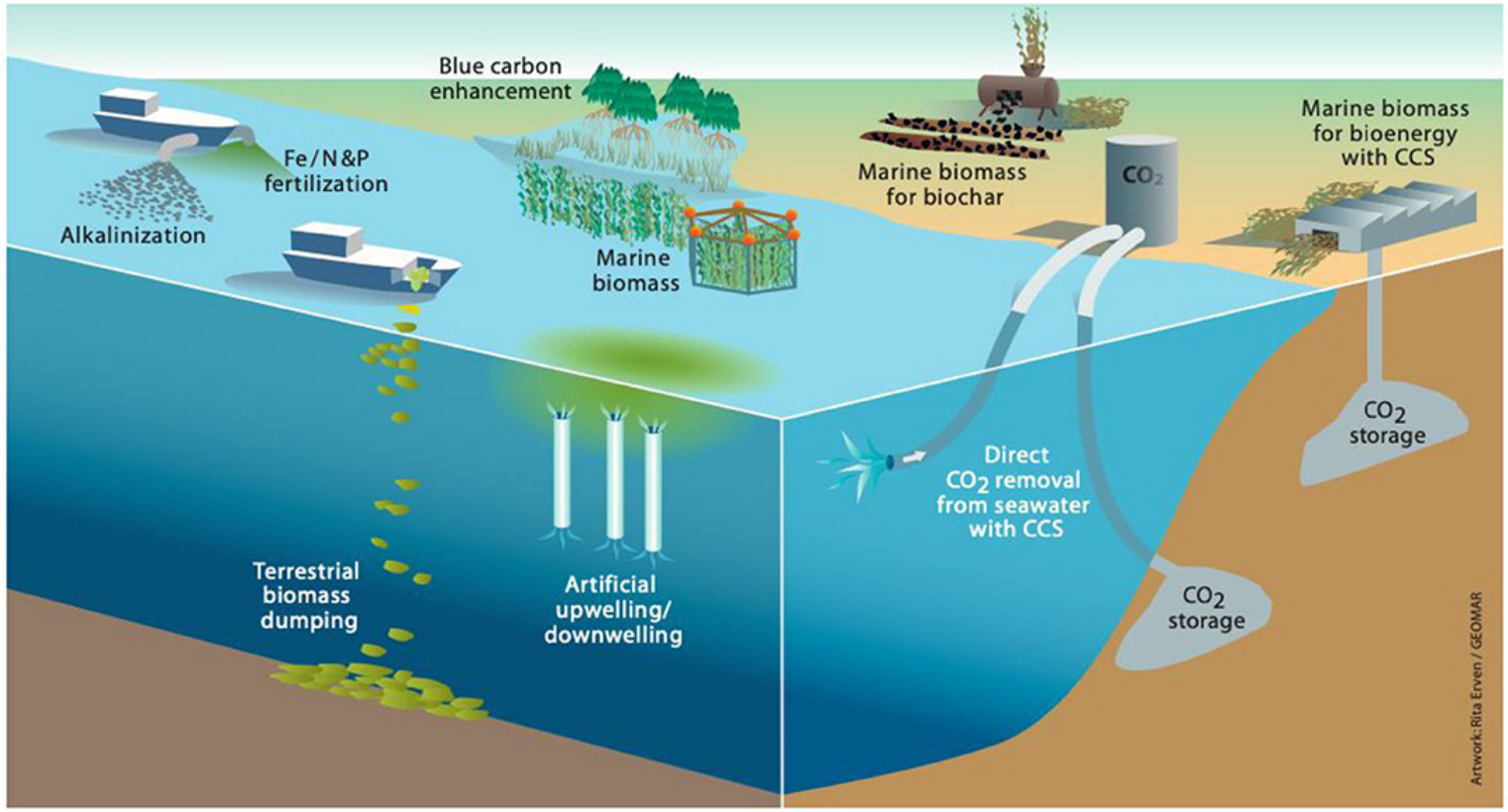




Picheral et al., 2022
Ohman et al., 2018

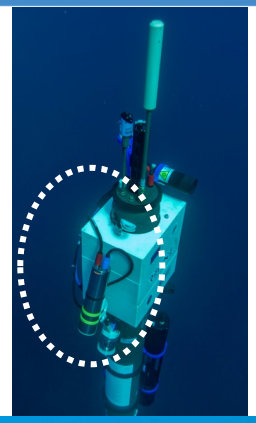
Monitoring the coming changes in plankton

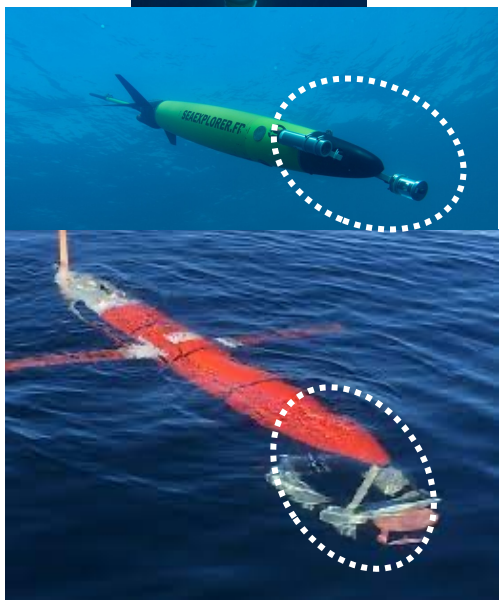
Monitoring Reporting Verification of human impact on plankton



Boettcher et a., 2021

Miniaturisation for autonomous sensors





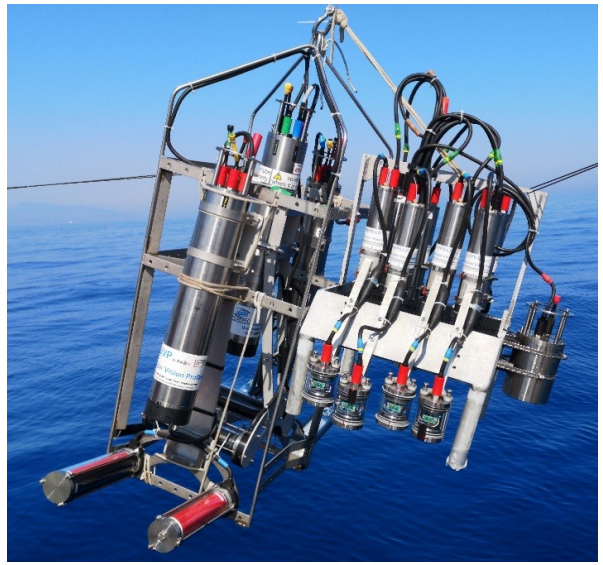
Picheral et al., 2022
Ohman et al., 2018

New sensors (low cost)

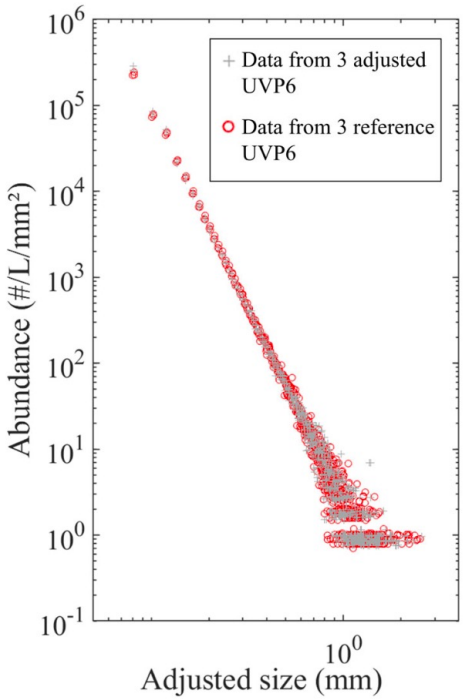
Observing capacities (global south)

Poster session
S:08 P3
S:08 P5
S08 P8

The back office in plankton imaging: calibrate, inter-calibrate, inter-compare

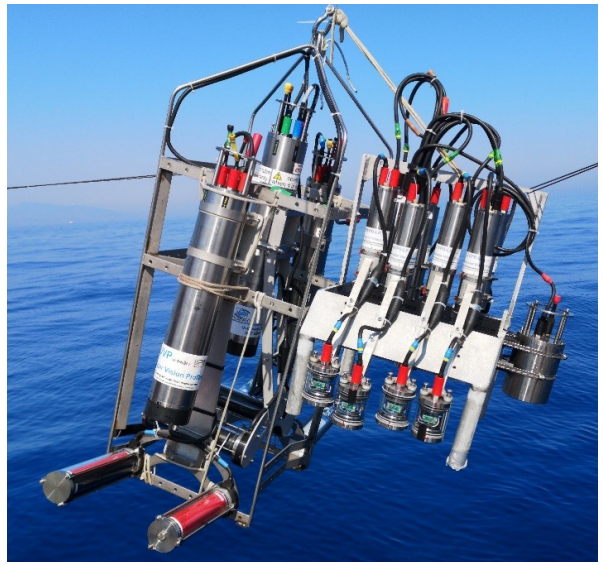


Picheral et al., 2022, L&O

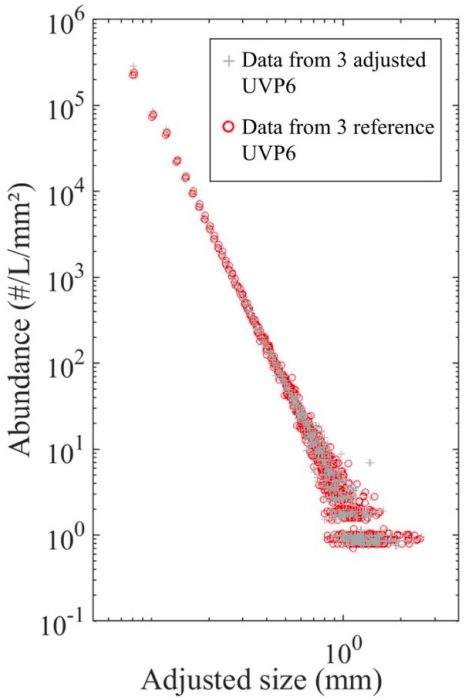


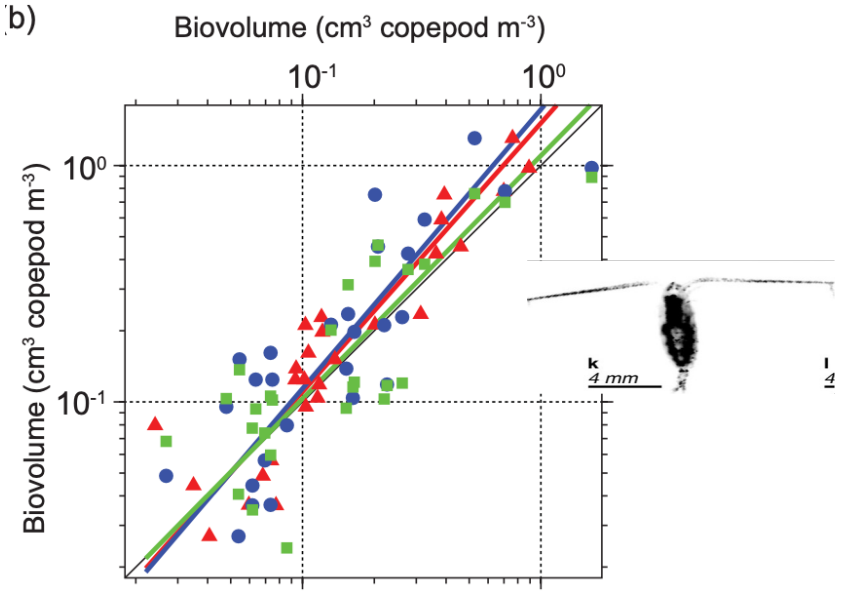
Calibration and inter-calibration

The back office in plankton imaging: calibrate, inter-calibrate, inter-compare



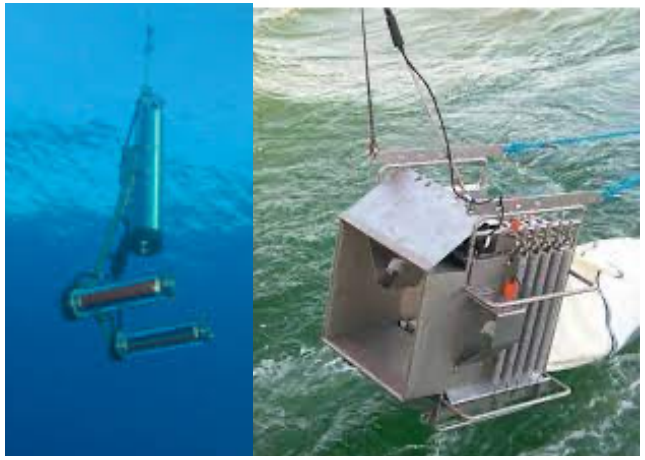
Picheral et al., 2022, L&O





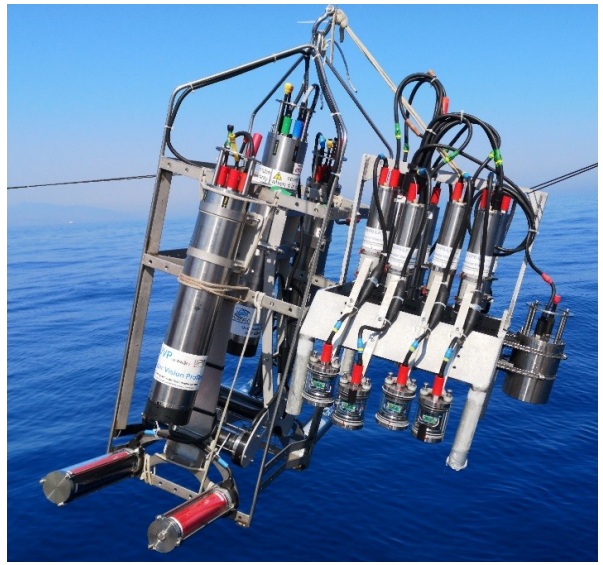
(Forest et al., 2009)

Calibration and inter-calibration

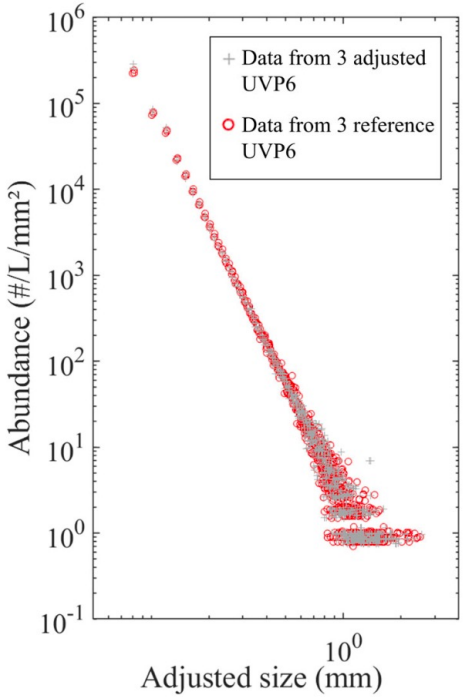


Intercomparisons

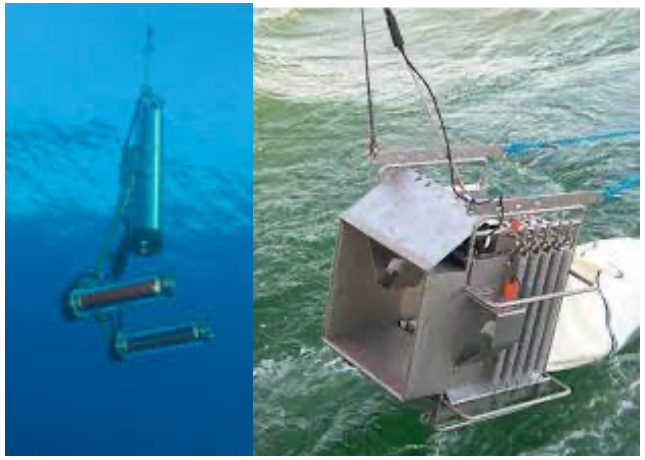
The back office in plankton imaging: calibrate, inter-calibrate, inter-compare



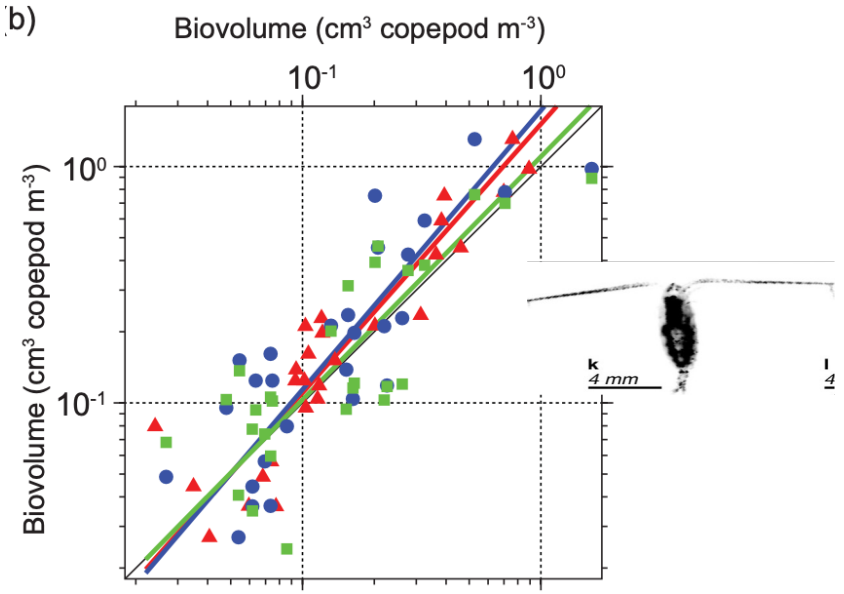
Picheral et al., 2022, L&O

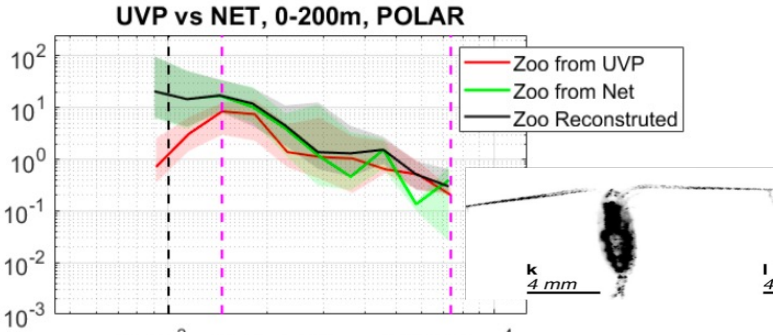


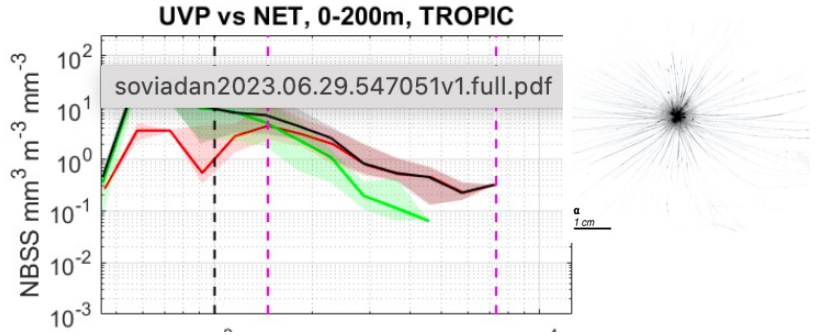
Calibration and inter-calibration



Intercomparisons

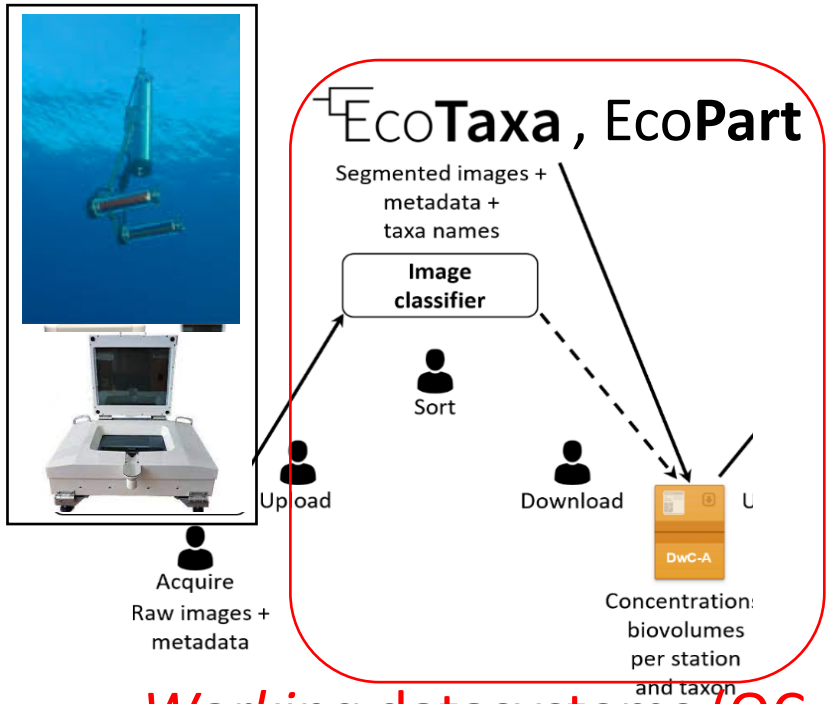






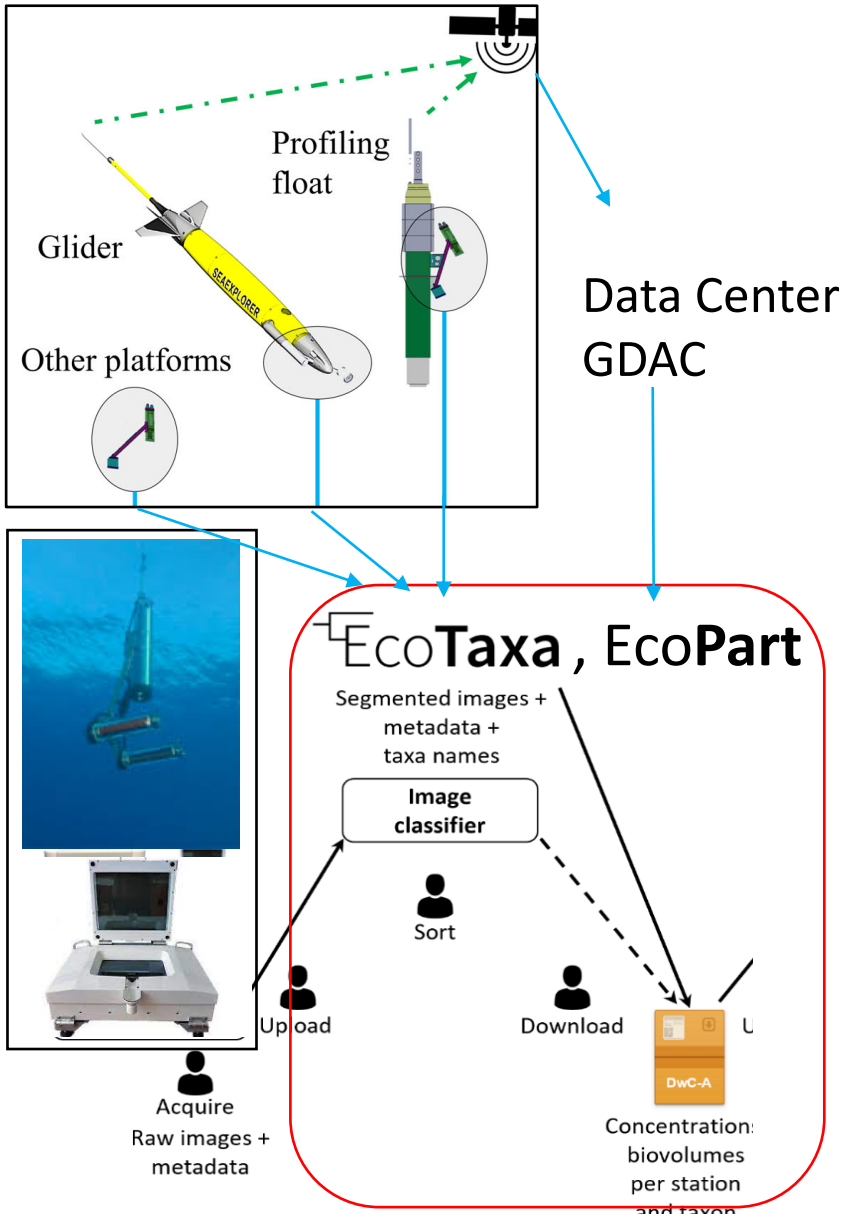
Soviadan et al., in review

The back office in plankton imaging: inter-operability of different systems



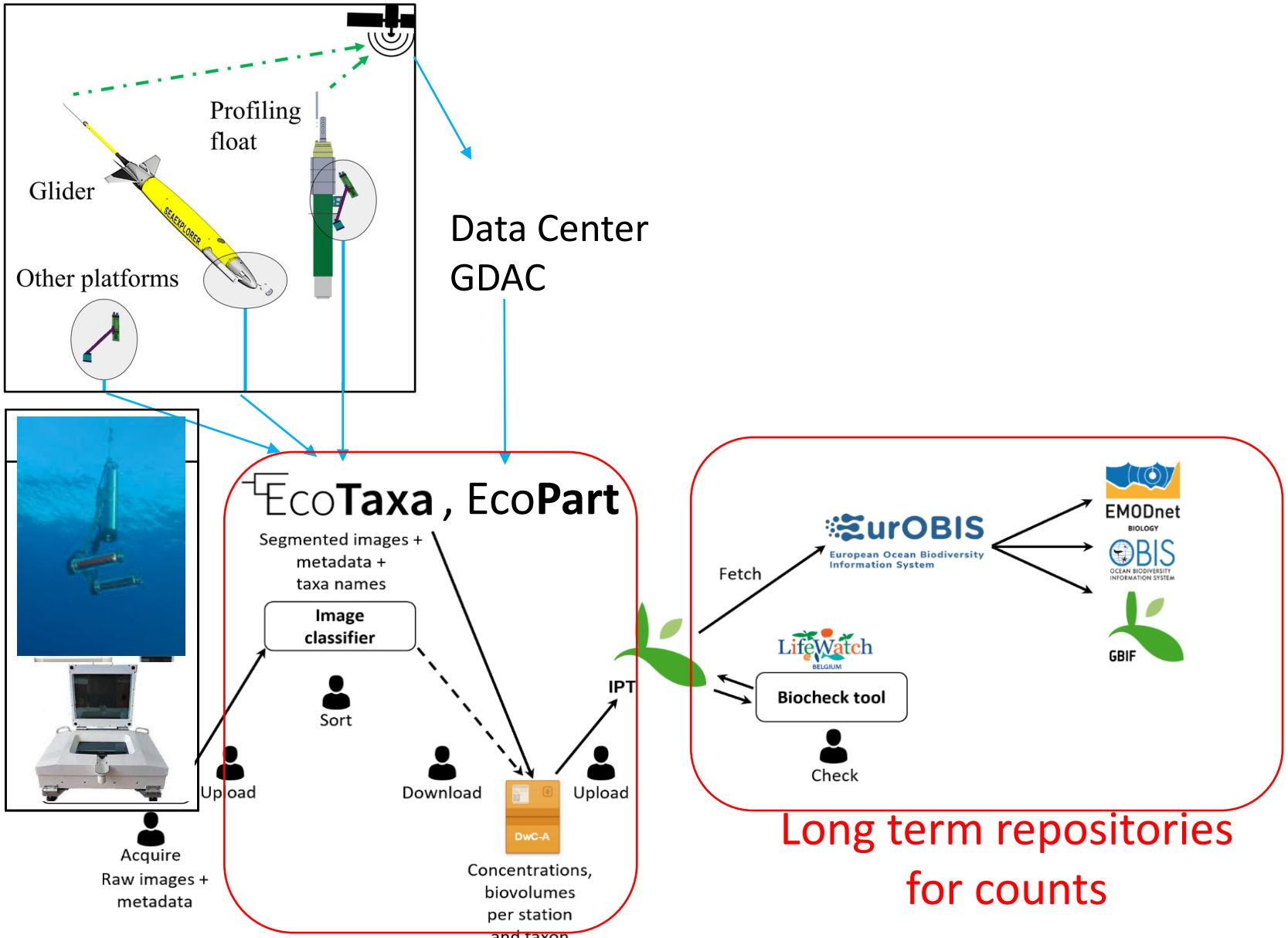
Working datasystems (QC, IA, network)

The back office in plankton imaging: inter-operability of different systems



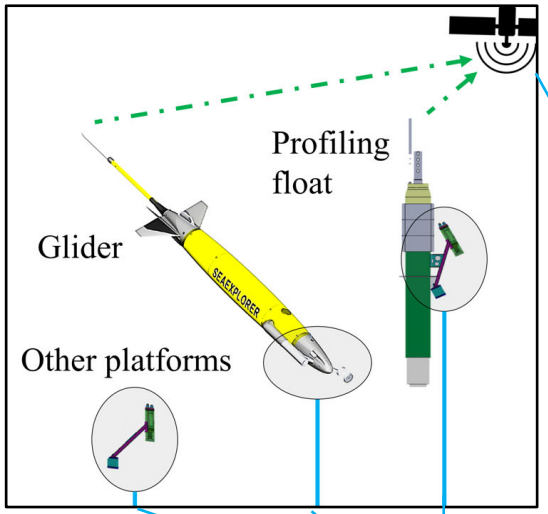
Working datasystems (QC, IA, network)

The back office in plankton imaging: inter-operability of different systems

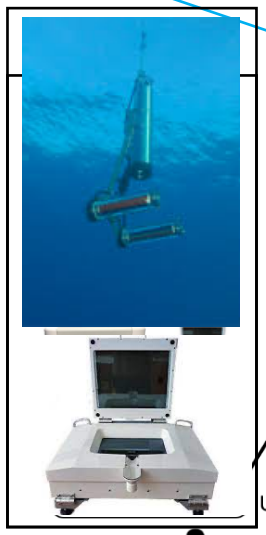


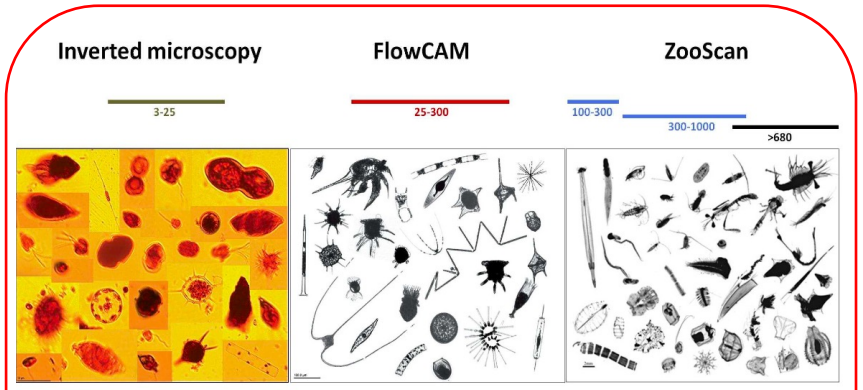
Working datasystems (QC, IA, network)

The back office in plankton imaging: inter-operability of different systems



Data Center
GDAC





But not adapted to images

EcoTaxa , EcoPart

Segmented images +
metadata +
taxa names

Image
classifier

Sort

Upload

Download

Upload

IPT

DwC-A

Concentrations,
biovolumes
per station
and taxon

Acquire
Raw images +
metadata

Fetch

EurOBIS
European Ocean Biodiversity Information System

EMODnet
BIOLOGY

OBIS
OCEAN BIODIVERSITY INFORMATION SYSTEM

GBIF

LifeWatch
BELGIUM

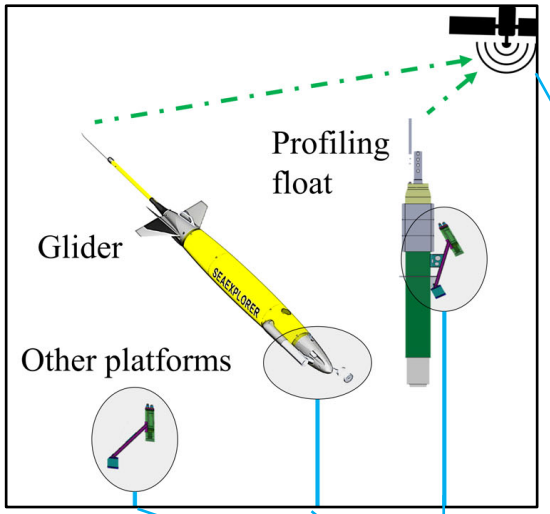
Biocheck tool

Check

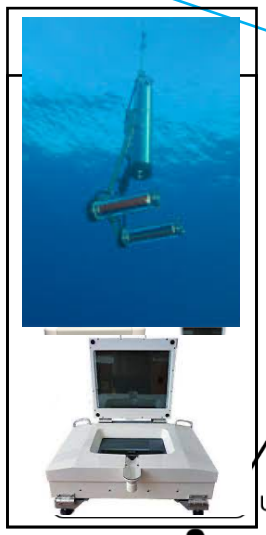
Long term repositories
for counts

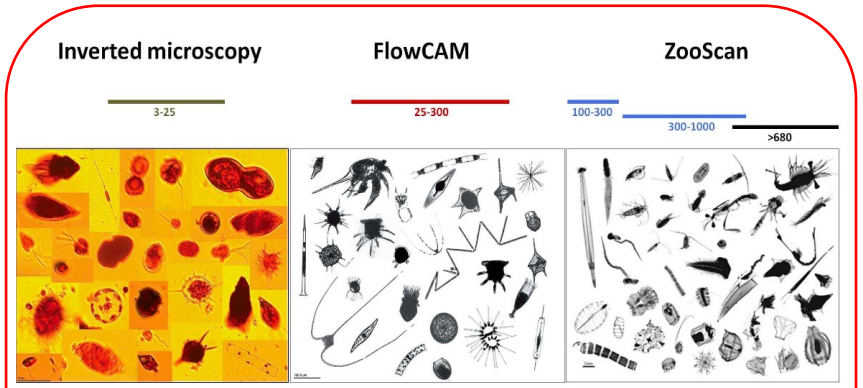
Working datasystems (QC, IA, network)

The back office in plankton imaging: inter-operability of different systems



Data Center
GDAC





But not adapted to images

What about the other systems ?

Other image data systems and flow

ISIIS-XX, PlanktonScope, Zooglider, IPP, iCPR, PI, ..

EcoTaxa , EcoPart

Segmented images + metadata + taxa names

Image classifier

Sort

Upload

Download

Upload

IPT

DwC-A

Concentrations, biovolumes per station and taxon

Acquire Raw images + metadata

Fetch

EurOBIS
European Ocean Biodiversity Information System

EMODnet BIOLOGY

OBIS OCEAN BIODIVERSITY INFORMATION SYSTEM

GBIF

LifeWatch BELGIUM

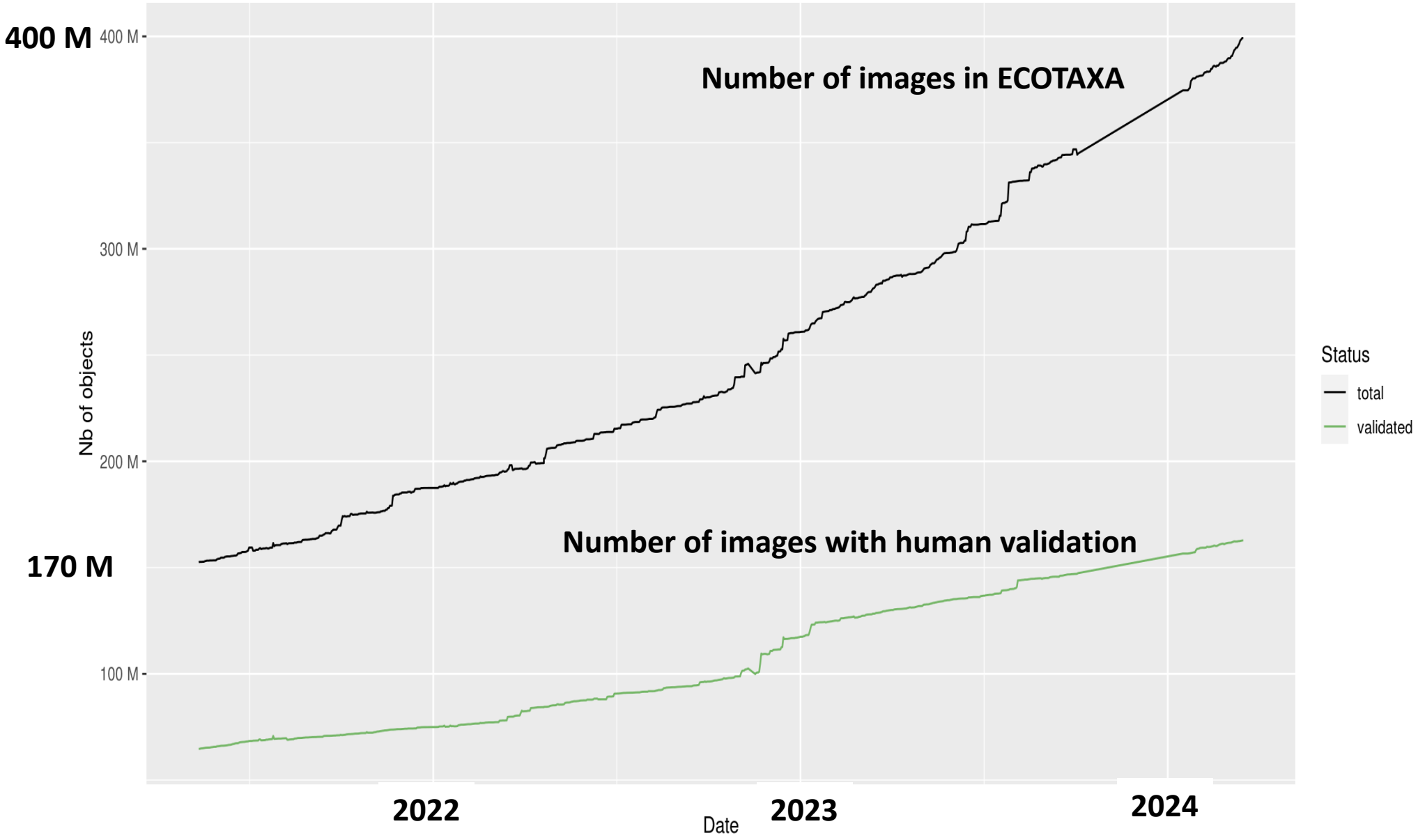
Biocheck tool

Check

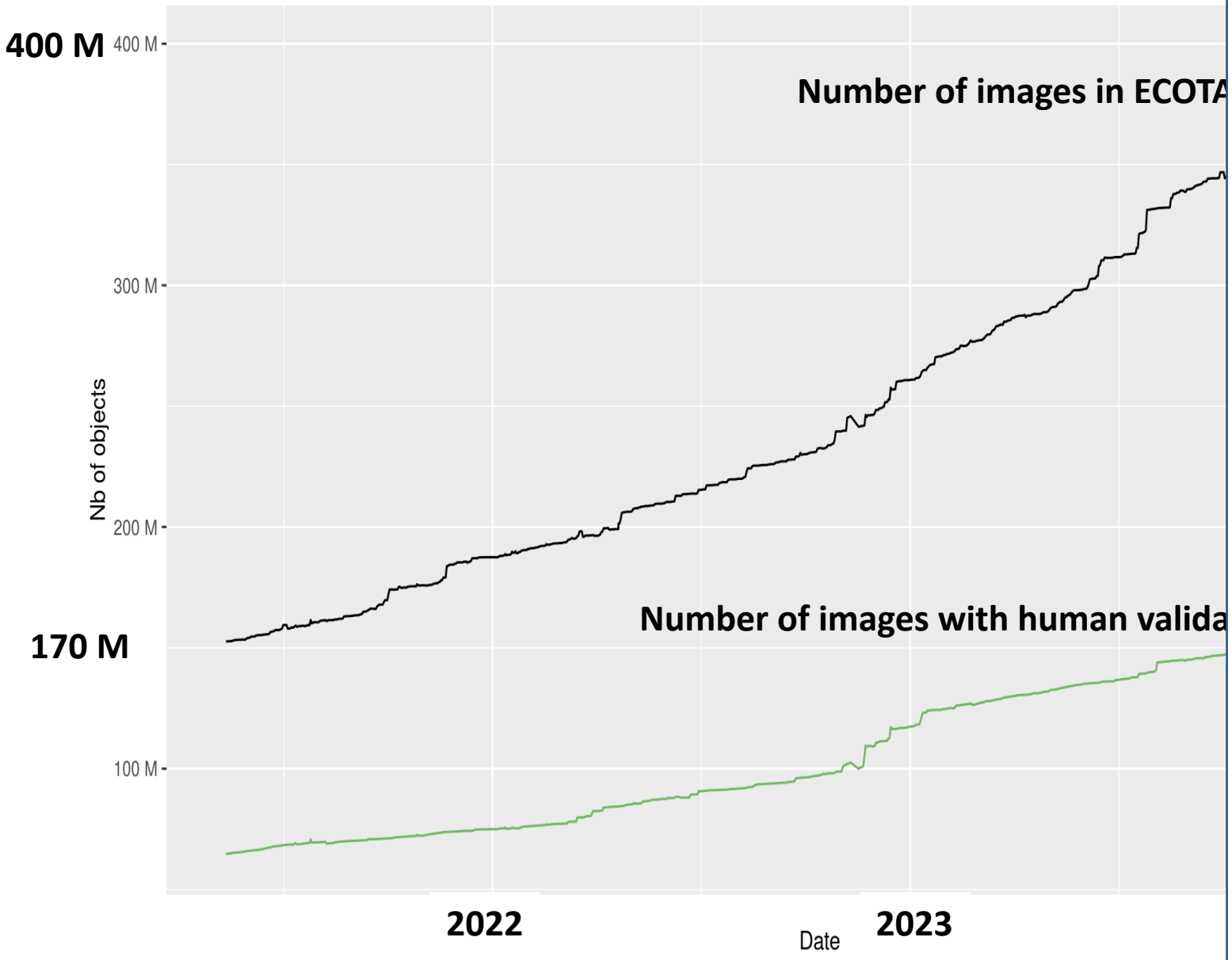
Long term repositories

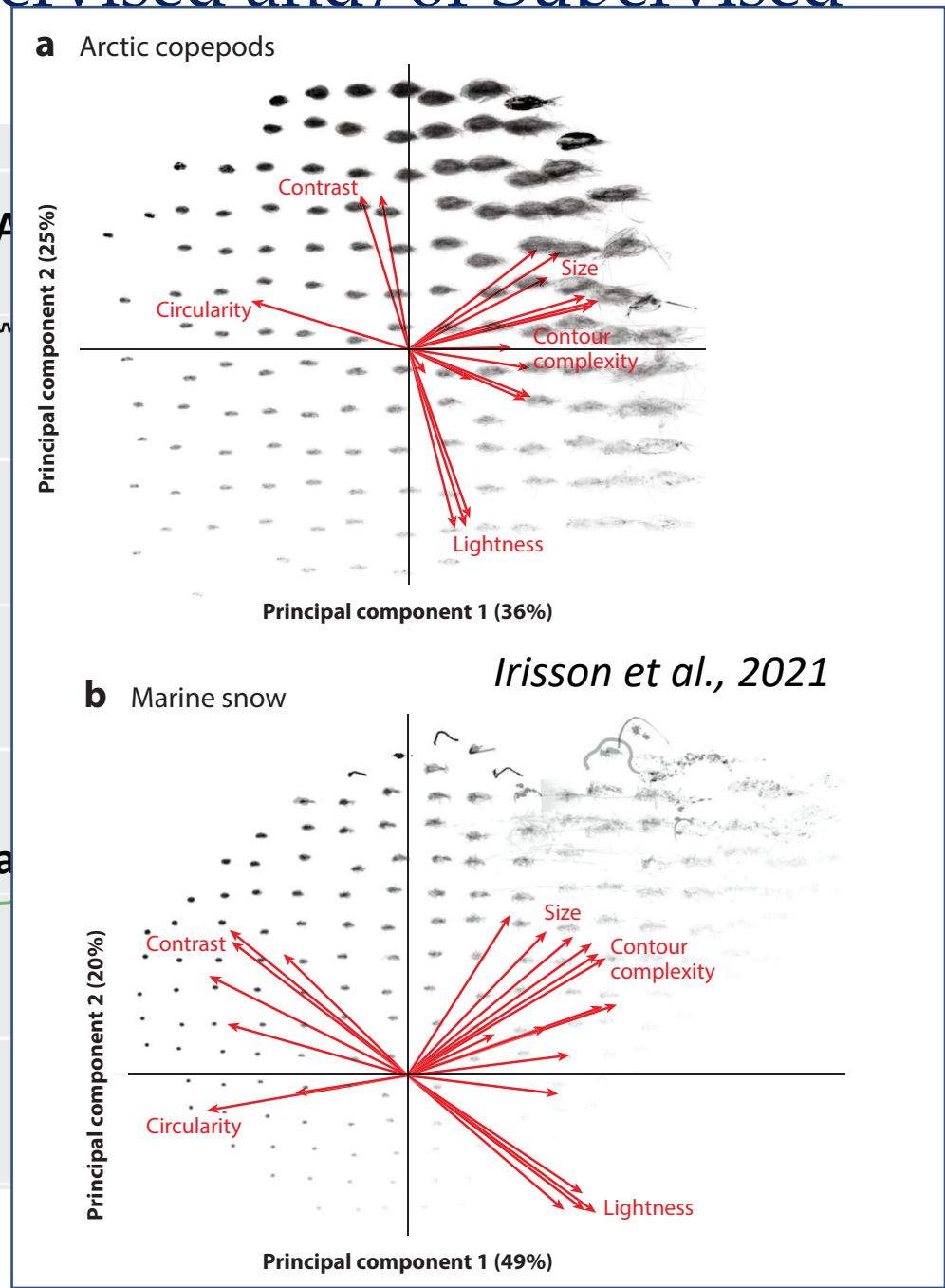
Working datasystems (QC, IA, network)

The back office in plankton imaging : Unsupervised and/or Supervised Automatic recognition ?



The back office in plankton imaging : Unsupervised and/or Supervised
Automatic recognition or trait based approach





Irisson et al., 2021

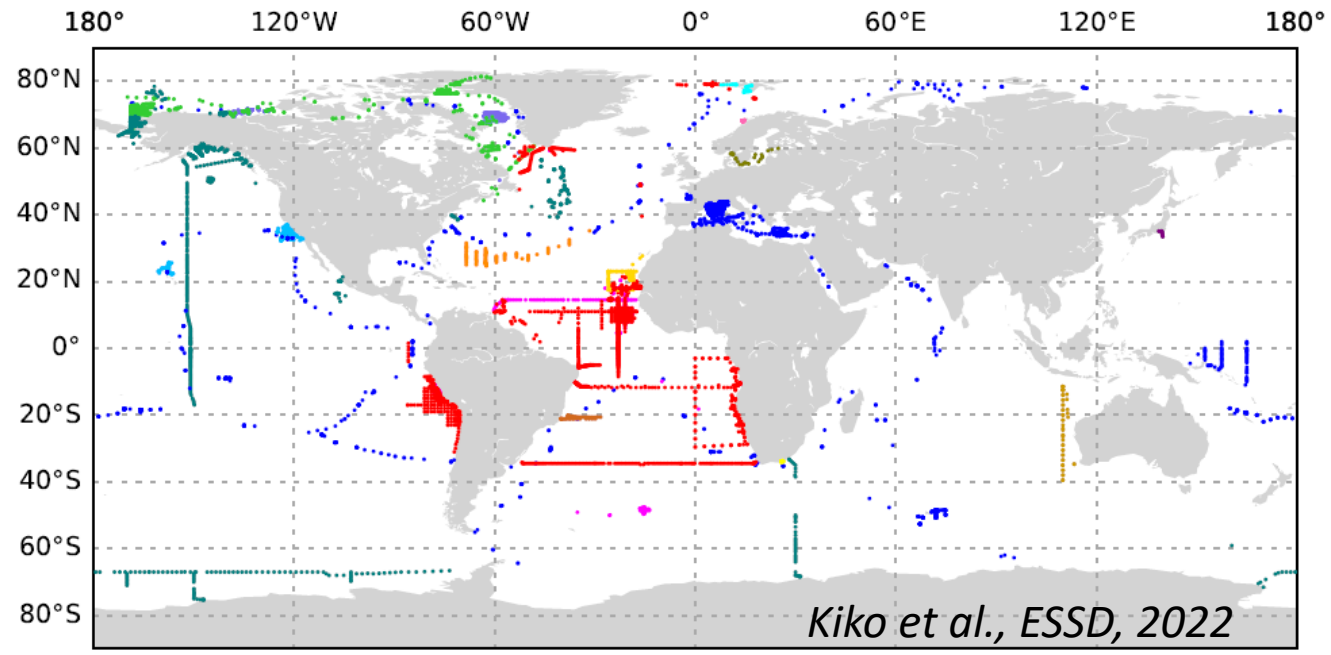
The back office in plankton imaging : Data sharing with all (gridded products)

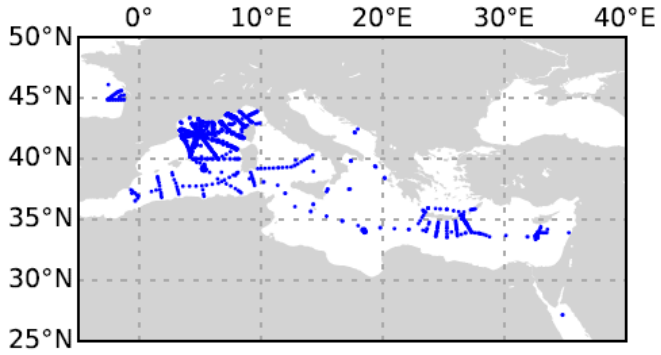
Data description paper

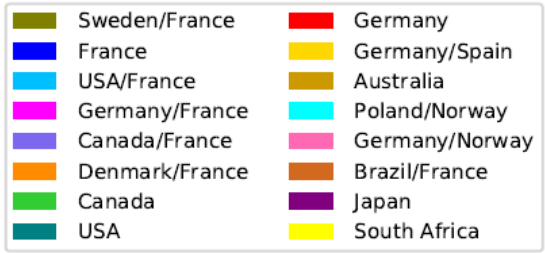
Earth System Science Data

22 Sep 2022

A global marine particle size distribution dataset obtained with the Underwater Vision Profiler 5







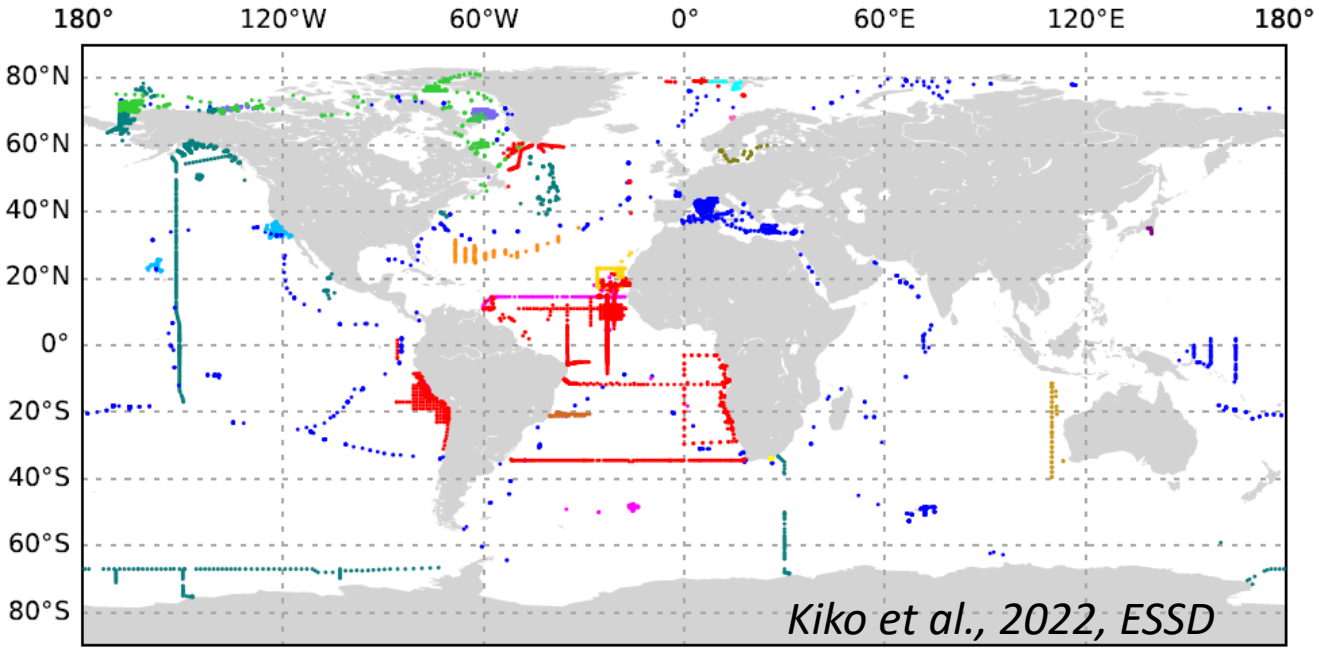
The back office in plankton imaging : Data sharing with all (gridded products)

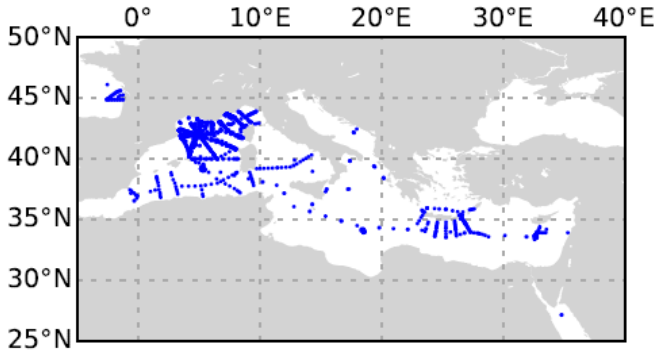
Data description paper

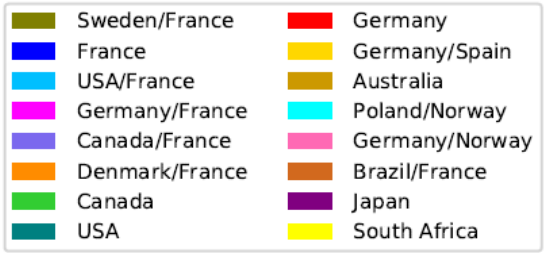
Earth System Science Data

22 Sep 2022

A global marine particle size distribution dataset obtained with the Underwater Vision Profiler 5







June 2, 2023

Dataset | Open Access

A Pelagic Size Structure database (PSSdb) to support biogeochemical modeling: first release

Dugenne, Mathilde; Corrales-Ugalde, Marco; O'Brien, Todd; Lombard, Fabien; Irisson, Jean-Olivier; Stemmann, Lars; Stock, Charles; Kiko, Rainer; Luo, Jessica Y.

A Pelagic Size Structure database (PSSdb) to support biogeochemical modeling: first release

Mathilde Dugenne*[1], Marco Corrales-Ugalde*[2], Todd O'Brien[3], Fabien Lombard[1], Jean-Olivier Irisson[1], Lars Stemmann[1], Charles Stock[4], Rainer Kiko[5] and Jessica Y. Luo[4].

[1] Sorbonne Université, CNRS, Laboratoire d'Océanographie de Villefranche, 06230 Villefranche-sur-mer, France

[2] Atmospheric and Oceanic Sciences, Princeton University, Princeton, NJ, USA.

[3] NOAA Fisheries - Office of Science & Technology - Marine Ecosystems Division, Silver Spring, Maryland, USA

[4] NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA.

[5] Department Ocean Ecosystems Biology, GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany

Dugenne et al., 2023, ESSD

Datasets

Project webpage

Preprint

Take Home messages

Distributed Global Observation of plankton and particle is needed and possible

Ocean and Coastal Research

COLLECTIVE POSITIONING

http://doi.org/10.1590/2675-2824071.23109rk

ISSN 2675-2824

Towards a distributed and operational pelagic imaging network

Rainer Kiko [1] *, Rubens M. Lopes [2], Y. Dodji Soviadan [3,4] and Lars Stemmann [3]

*We provide **recommendations** how it can be attained via the **voluntary activities** of the pelagic imaging community and **strategic support** from funding agencies and other stakeholders*

BUILDING AN ALL ATLANTIC OCEAN COMMUNITY
Implementing the Belém Statement

I/ITAPINA: Imagine/**I**maging **T**he **A**tlantic – A **P**elagic **I**maging **N**etwork **A**pproach

Current post doc opportunities with us

https://emploi.cnrs.fr/Offres/CDD/UMR7093-MADWAL-014/Default.aspx?lang=EN

"The true journey of discovery lies not in seeking new landscapes, but in seeing with new eyes."

Marcel Proust
A la recherche du temps perdu
In Search of Lost Time

OCEANOMICS

BRIDGES
BRINGING TOGETHER RESEARCH AND INDUSTRY FOR THE DEVELOPMENT OF GLIDER ENVIRONMENTAL SERVICES

TRIATLAS

JERICO RI
SCIENCE - SERVICES - SUSTAINABILITY

bpifrance

JERICO-S3
Temporary logo - 02.2020

BELMONT FORUM

MERCI / THANKS