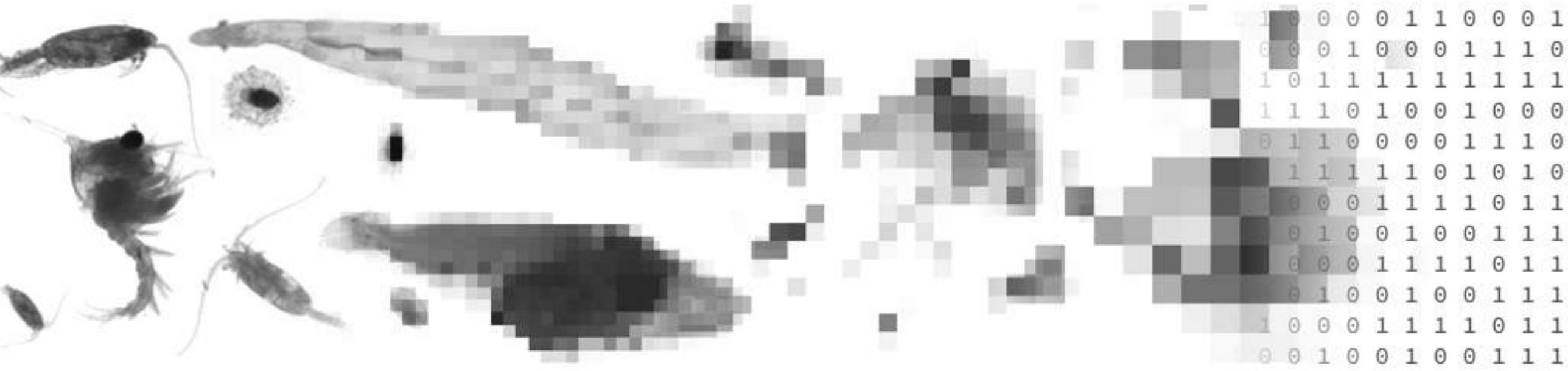
ML4Oceans, 2022-09-01
Jean-Olivier Irisson (with input from many colleagues!)

SCIENCES SORBONNE UNIVERSITÉ

Quantitative plankton imaging

From pictures to data



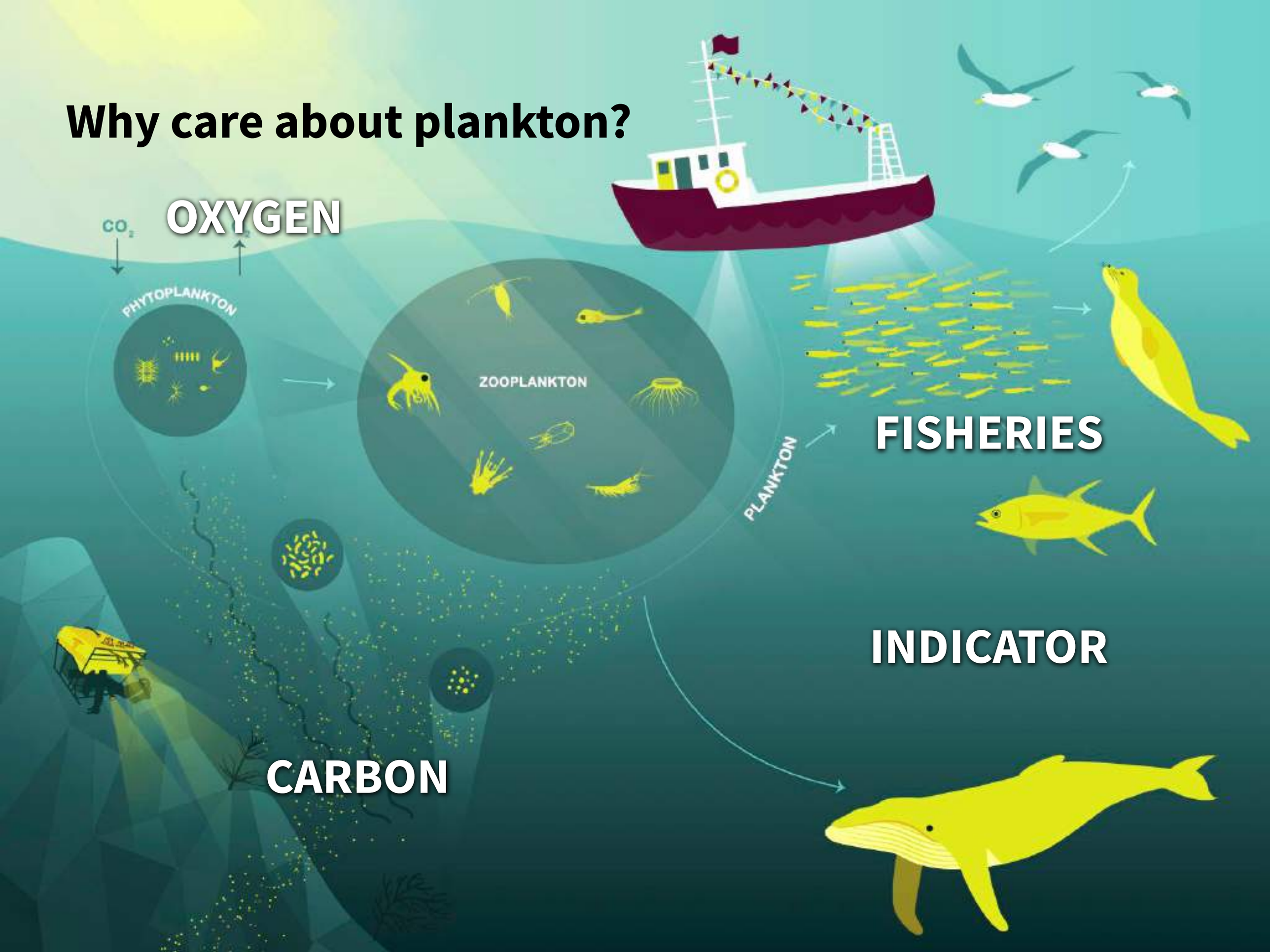
Why study plankton (with images)?

Beyond the nice pictures

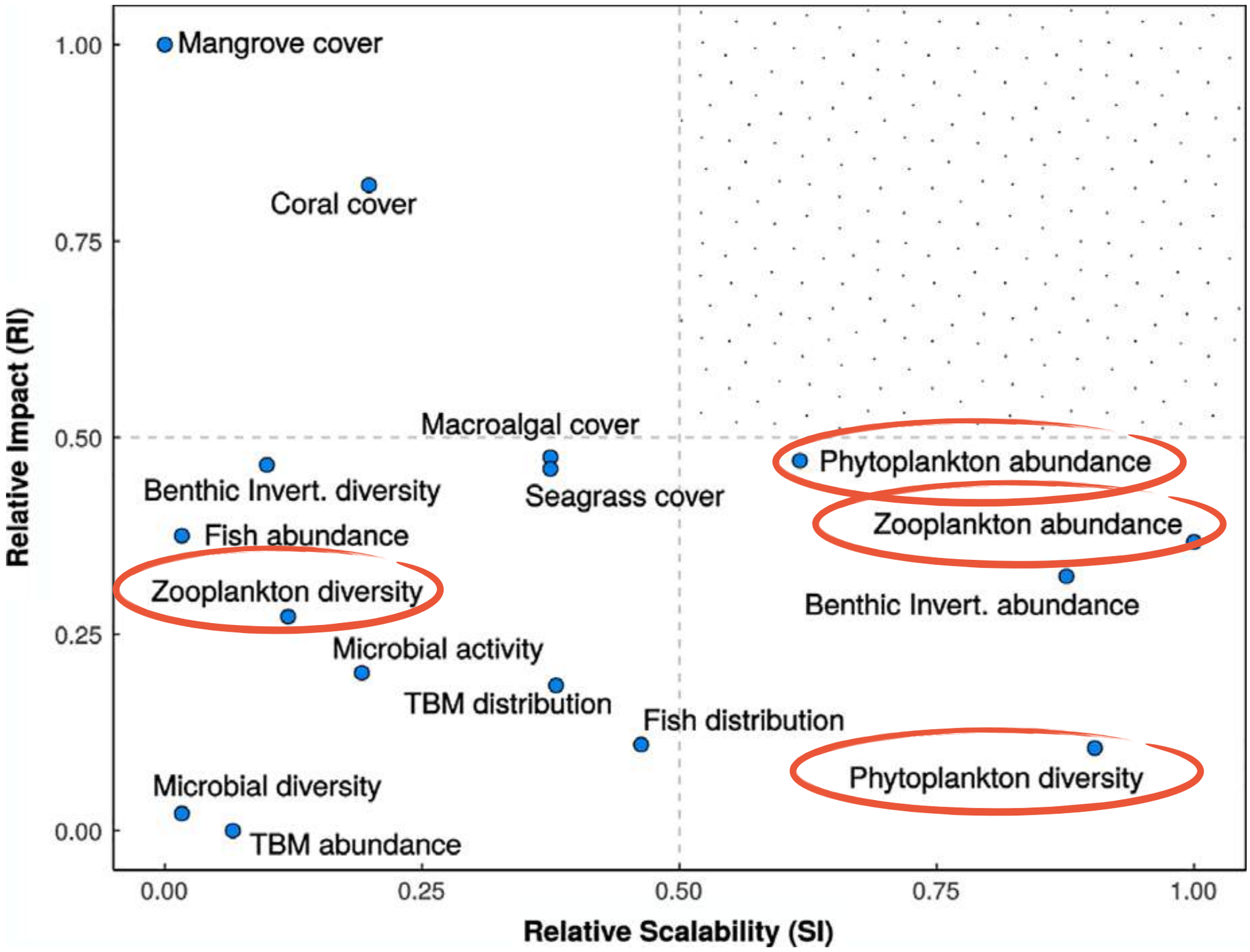
Most life in the ocean is small plankton

1L sea water
10,000,000 bacteria
100,000 unicellular
1000 multicellular

Why care about plankton?



Plankton monitoring has potential to scale well



Miloslavich et al 2018

Plankton monitoring has potential to scale well

frontiers in Marine Science

REVIEW
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Check for updates

Globally Consistent Quantitative Observations of Planktonic Ecosystems

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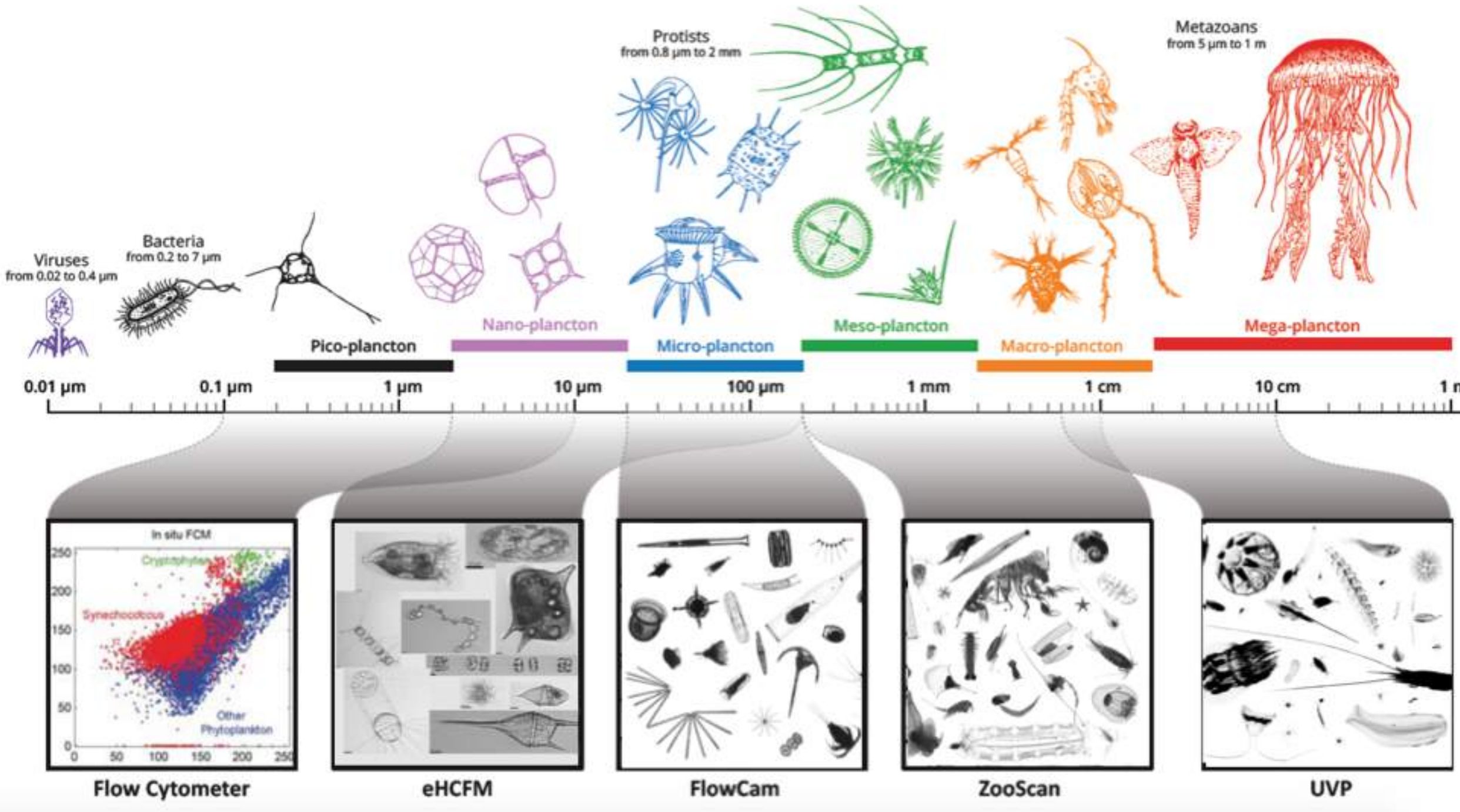
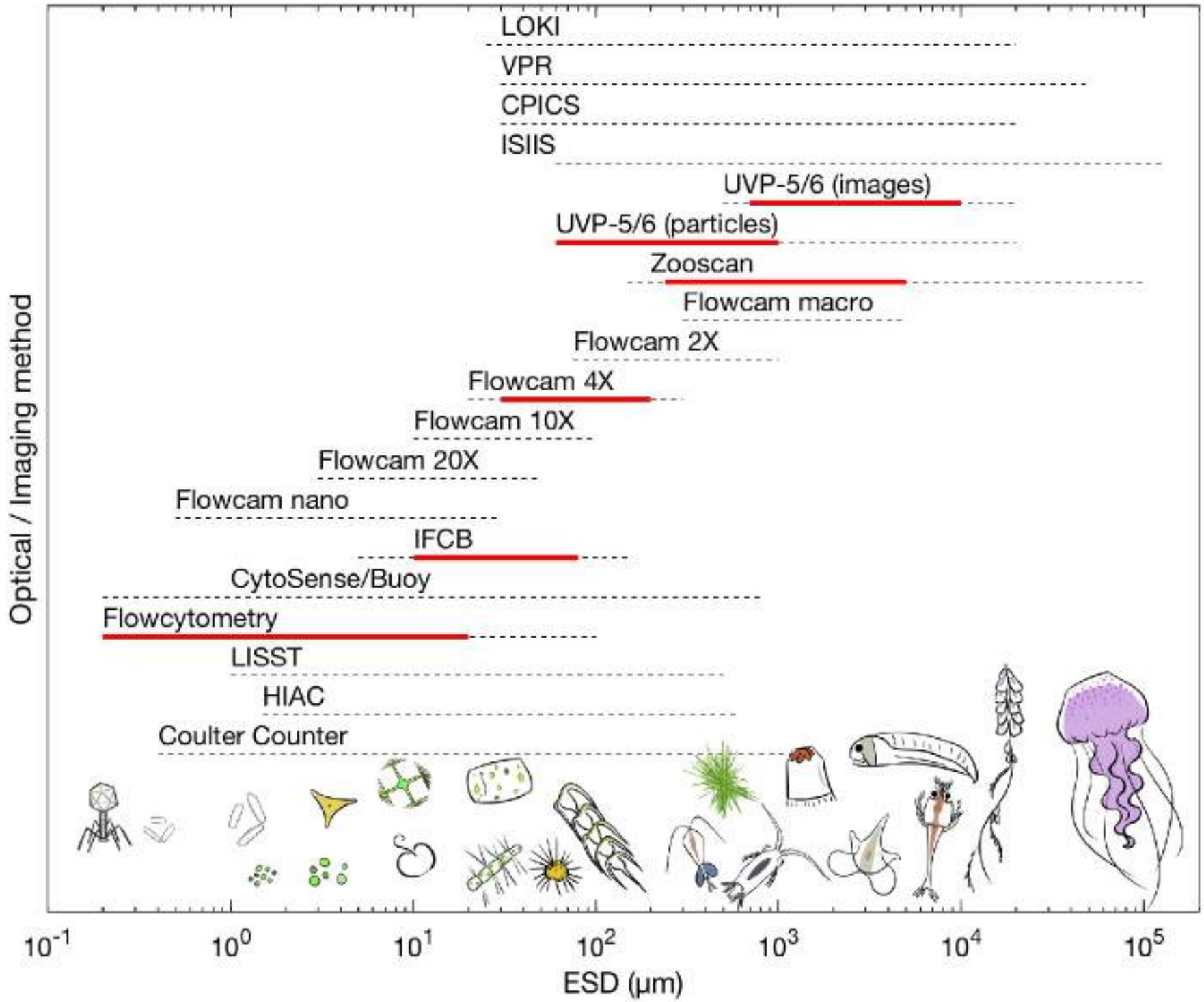
(Some) plankton imaging instruments

On ships, in labs, in your backyard

Several instruments to cover a wide size range



Several instruments to cover a wide size range



ZooScan

ZooScan

egg < oth… area [pixel] : 775
… area [pixel] : 778
…honaute area [pixel] : 782
trunk area [pixel] : 784
Coscinodiscus area [pixel] : 798
pluteus < Echinoidea area [pixel] : 844
Neoceratium area [pixel] : 845
cyphonaute area [pixel] : 867
Limacinidae area [pixel] : 877
nauplii < Cirripedia area [pixel] : 896
badfocus < artefact area [pixel] : 909
Evadne area [pixel] : 964

egg < Mollusca area [pixel] : 1003
Fritillariidae area [pixel] : 1006
Harpacticoida area [pixel] : 1025
Echinodermata area [pixel] : 1039
bubble area [pixel] : 1047
bubble area [pixel] : 1079
Oithonidae area [pixel] : 1104
Harosa area [pixel] : 1106
nauplii < Crustacea area [pixel] : 1118
Oithonidae area [pixel] : 1132
fiber < detritus area [pixel] : 1162

part < Annelida area [pixel] : 1192
Echinodermata area [pixel] : 1209
cypris area [pixel] : 1222
detritus area [pixel] : 1223
Harpacticoida area [pixel] : 1248
Calanoida area [pixel] : 1280
nauplii < Cirripedia area [pixel] : 1287
larvae < Annelida area [pixel] : 1295
Bivalvia < Mollusca area [pixel] : 1297
Acartiidae area [pixel] : 1308
Fritillariidae area [pixel] : 1316
fiber < detritus area [pixel] : 1317

Bivalvia < Mollusca area [pixel] : 1351
Noctiluca < Noctilucaceae area [pixel] : 1358
Temoridae area [pixel] : 1360
detritus area [pixel] : 1363
Foraminifera area [pixel] : 1376
badfocus < artefact area [pixel] : 1381
artefact area [pixel] : 1400
Creseidae area [pixel] : 1405
Limacinidae area [pixel] : 1467
bract < Diphyidae area [pixel] : 1472
Oncaeidae area [pixel] : 1477
Nemertea area [pixel] : 1485

actinula < Solmundella bitentaculata area [pixel] : 1501
Calanoida area [pixel] : 1504
Nemertea area [pixel] : 1518
Corycaeidae area [pixel] : 1535
Atlanta area [pixel] : 1580
nauplii < Crustacea area [pixel] : 1581
Coscinodiscus area [pixel] : 1595
Mollusca area [pixel] : 1614
juvenile < Cavolinia inflexa area [pixel] : 1617
Oncaeidae area [pixel] : 1635
Coscinodiscus area [pixel] : 1666
bubble area [pixel] : 1679

ZooScan


nectophore < Abylopsis tetragona
area [pixel] : 7714

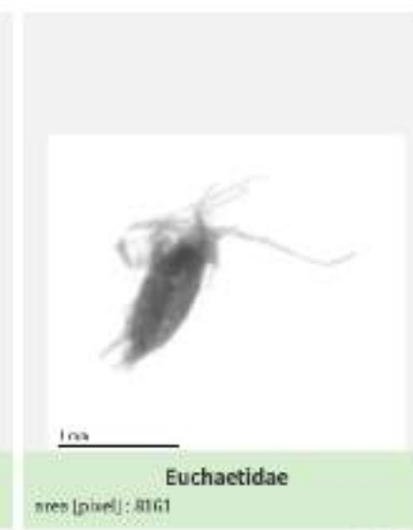

protozoea < Penaeidae
area [pixel] : 7852


head < Chaetognatha
area [pixel] : 7962


Cavolinia inflexa
area [pixel] : 7874

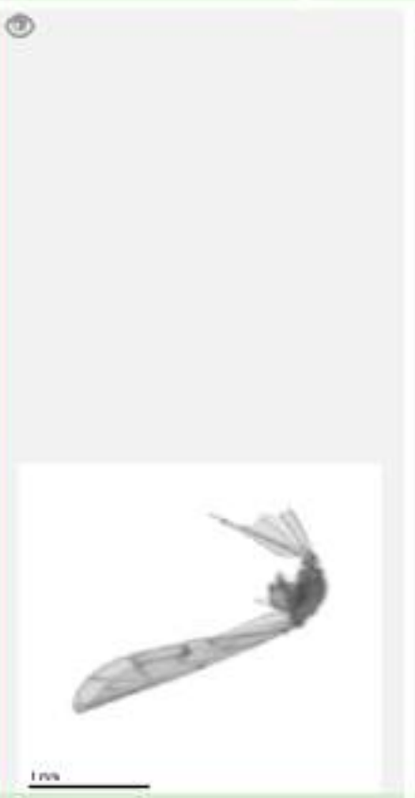

zoea < Brachyura
area [pixel] : 7886


cirrus
area [pixel] : 7973


Euchaetidae
area [pixel] : 8161

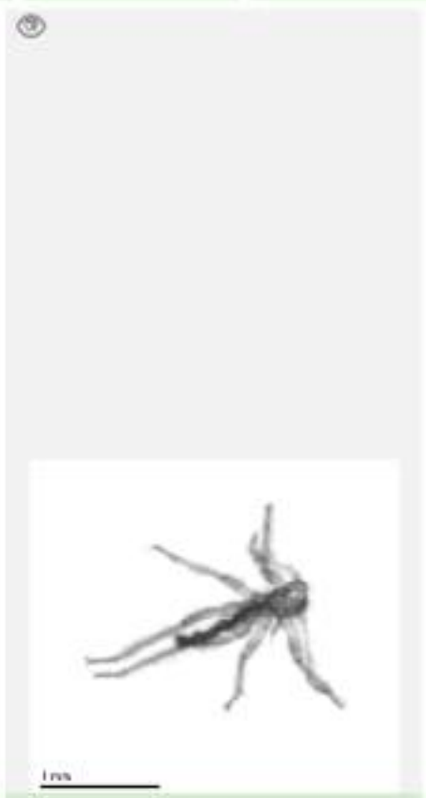

nectophore < Diphyidae
area [pixel] : 8331

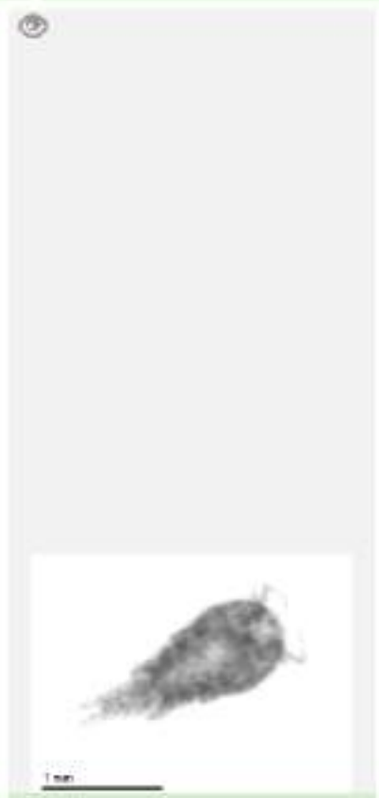

Metridinidae
area [pixel] : 8403

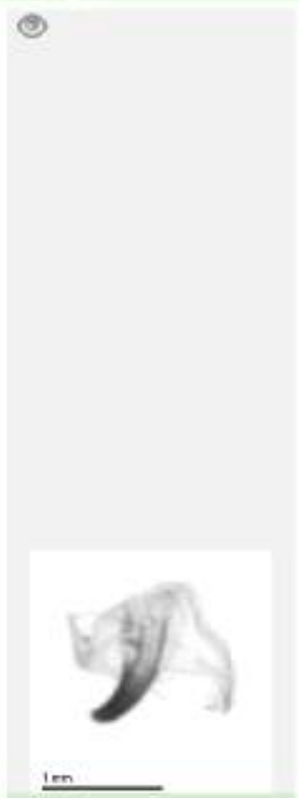

wing
area [pixel] : 8832


part < Crustacea
area [pixel] : 9021


Creseis acicula
area [pixel] : 9025


Insecta
area [pixel] : 9204

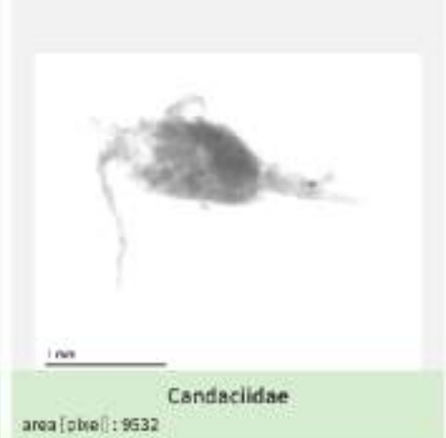

Sapphirinidae
area [pixel] : 9207

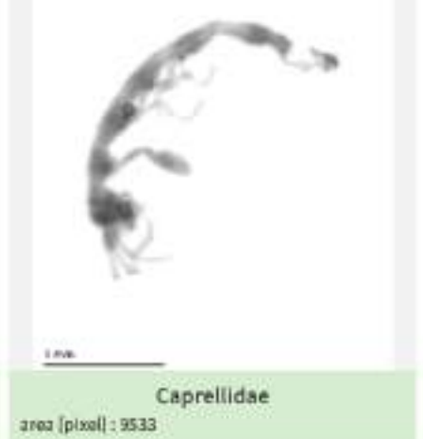

part < Mollusca
area [pixel] : 9226


nectophore < Physonectae
area [pixel] : 9232


Creseidae
area [pixel] : 9452

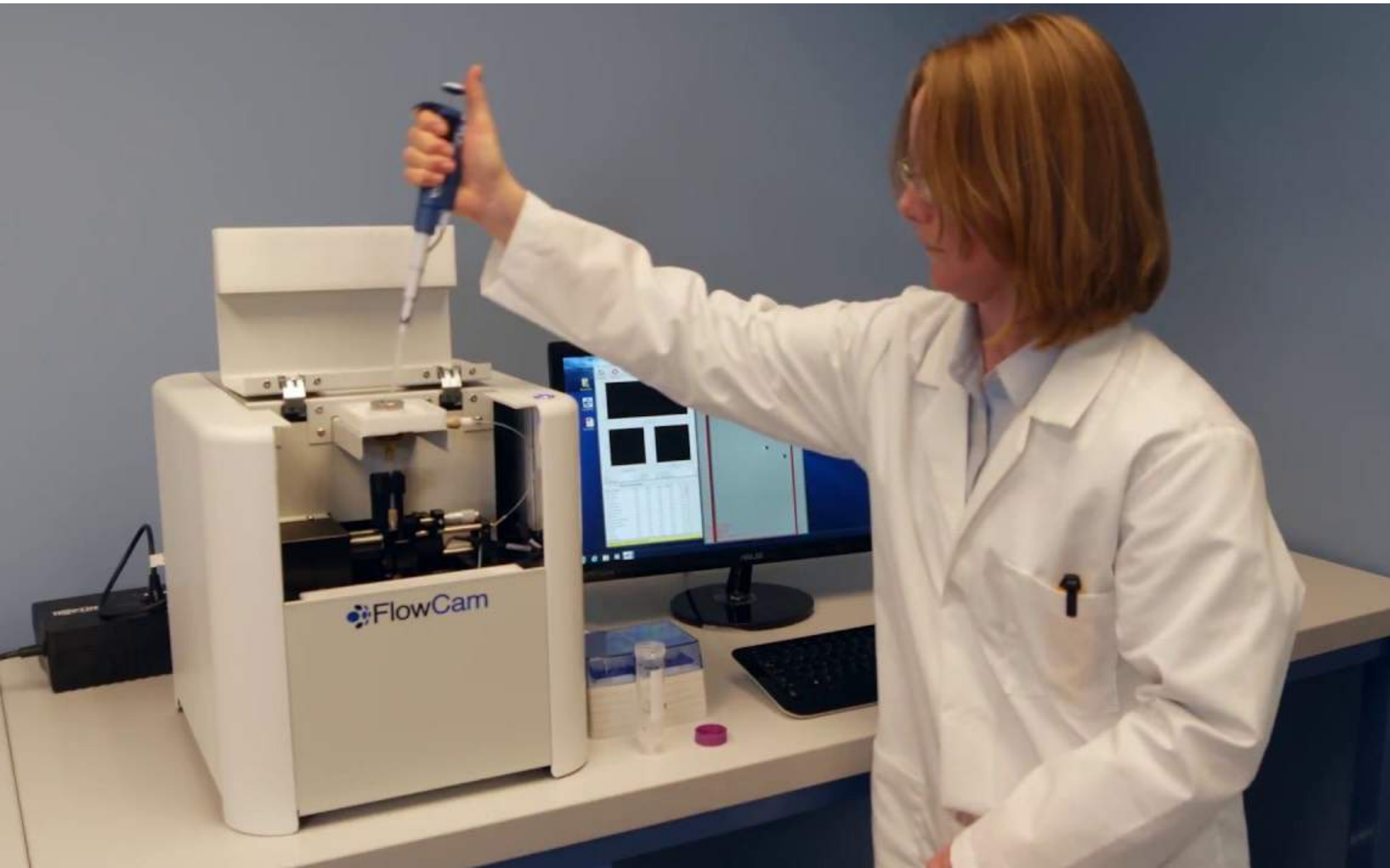

gonophore < Abylopsis tetragona
area [pixel] : 9471


Candaciidae
area [pixel] : 9532


Caprellidae
area [pixel] : 9533

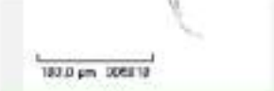

Chaetognatha
area [pixel] : 9569

Flowcam



Flowcam

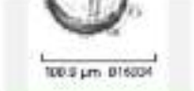

Corycaeidae


nauplii < Crustacea

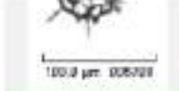

Climacodium


Diploconus


Gossleriella


crumple sphere


Foraminifera


Spumellaria


Salpingella
< Tintinnidiidae

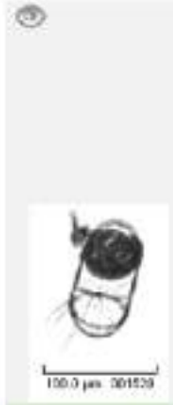

Protocystis


Nassellaria
< Polycystinea


Copepoda


Corethron

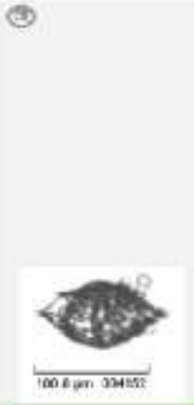

Codonella


Corethron

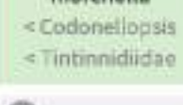

Gossleriella


Neoceratium 01


Ceratocorys

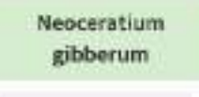

Podolampas bipes


Calanoida

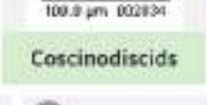

Codonellopsis morchella
< Codonellopsis
< Tintinnidiidae


Podolampas bipes

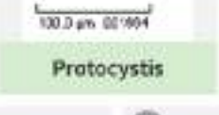

cyst < unicellular

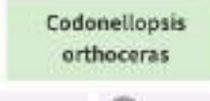

Neoceratium gibberum


Foraminifera


Coscinodiscids


Planktoniella sol


Protocystis


Codonellopsis orthoceras


Zoothamniidae


Zoothamniidae


Warnowia


Warnowia


Copepoda


Rhabdonella


nauplii < Crustacea

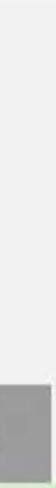

Xystonellopsis


Xystonellopsis

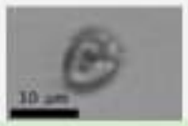

Pterosperma

IFCB

IFCB

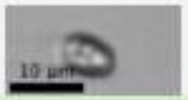


ving



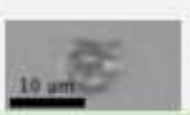
tempflagellates

other < living



other < living

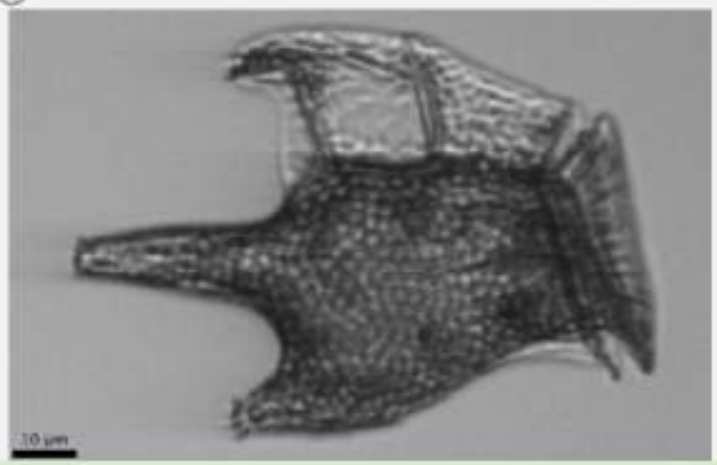
other < living



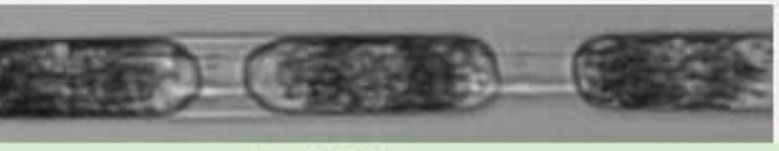
t014

t014

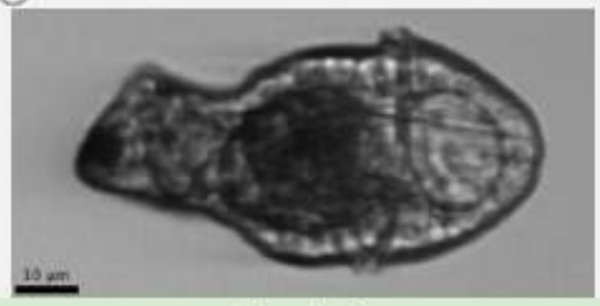
multiple < other



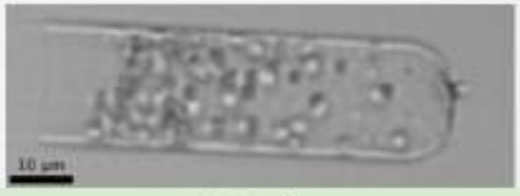
Dinophysis



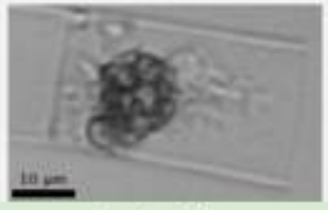
Hemiaulales



Dinophysis



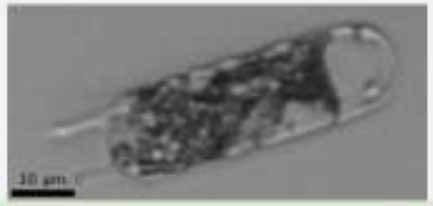
Guinardia



Hemiaulales

Guinardia

othertocheck



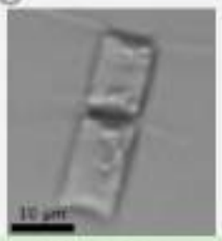
centric

Hemiaulales

Chaetoceros
< Mediophyceae

Hemiaulales

Hemiaulales

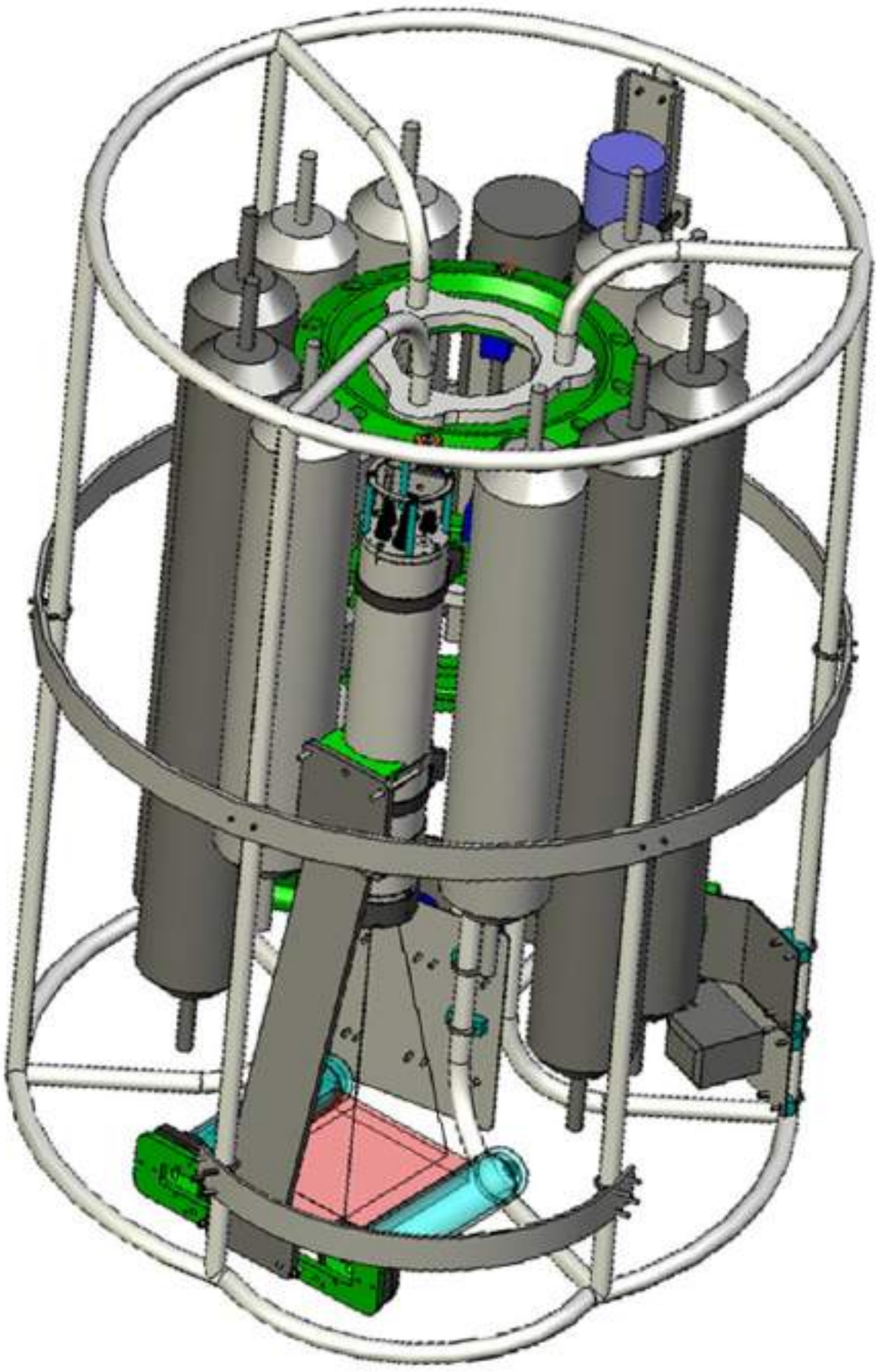


Chaetoceros
< Mediophyceae

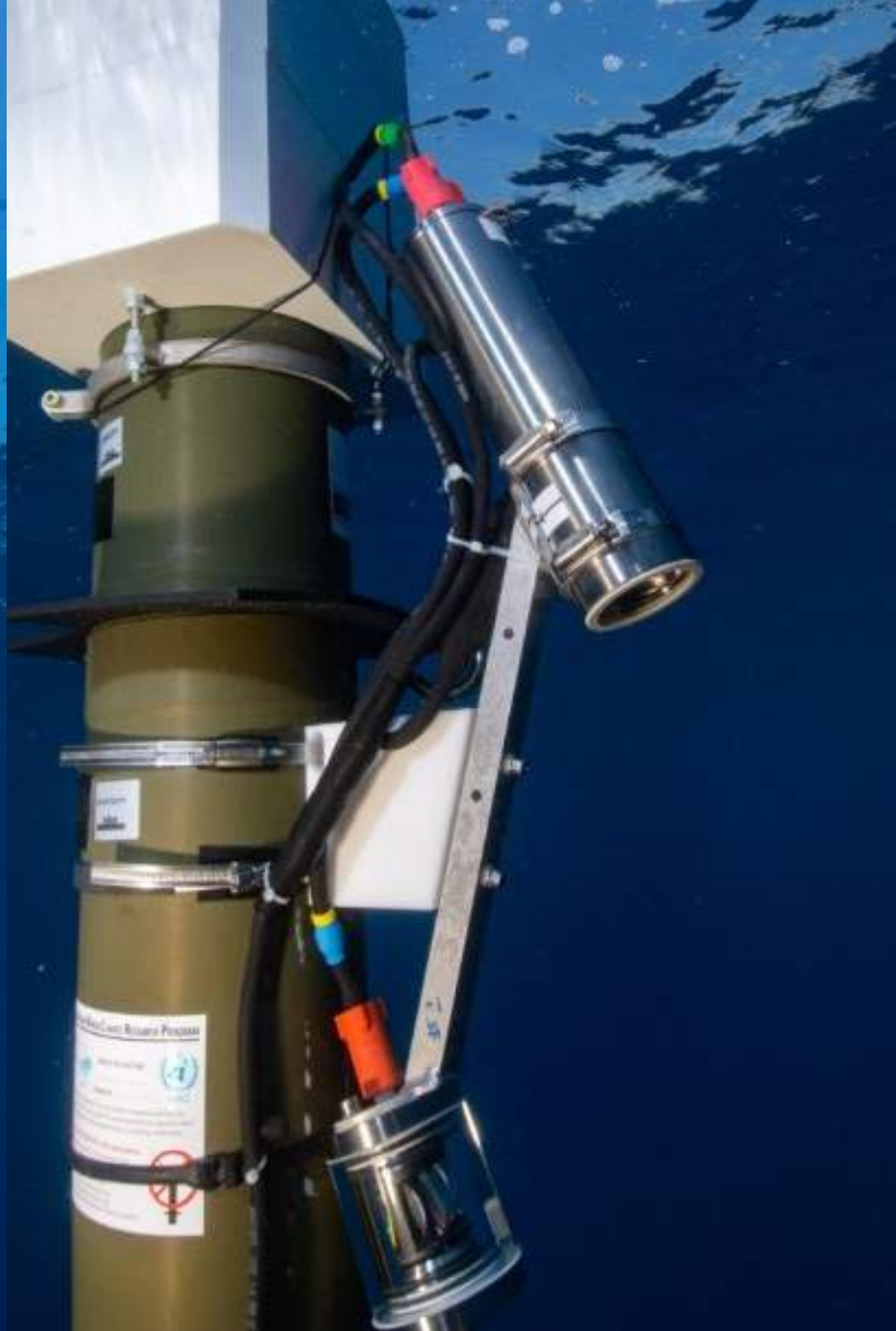
Hemiaulales

UVP


UVP



UVP



UVP

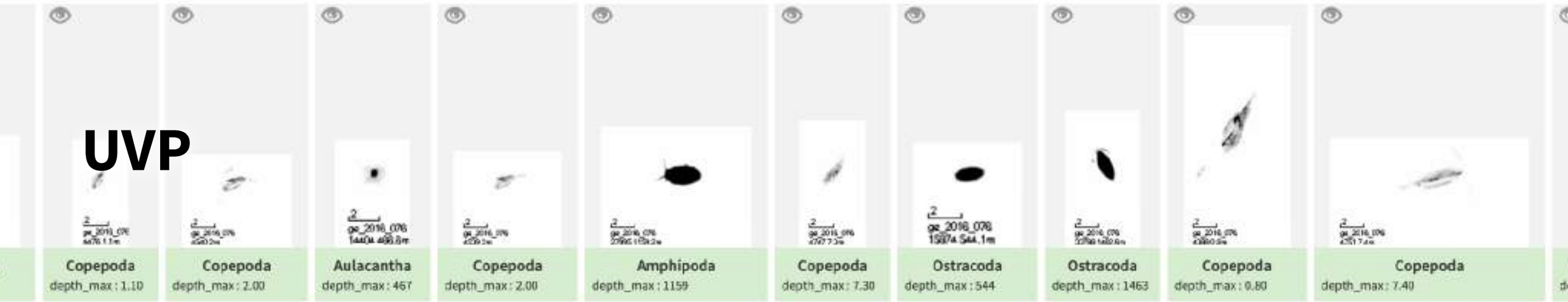
UVP

solitaryblack | Chaetognatha | solitaryblack | Medusettidae | Acantharea | Rhizaria | Rhizaria | Poeobius | Foraminifera | Phaeodaria | Aulacan

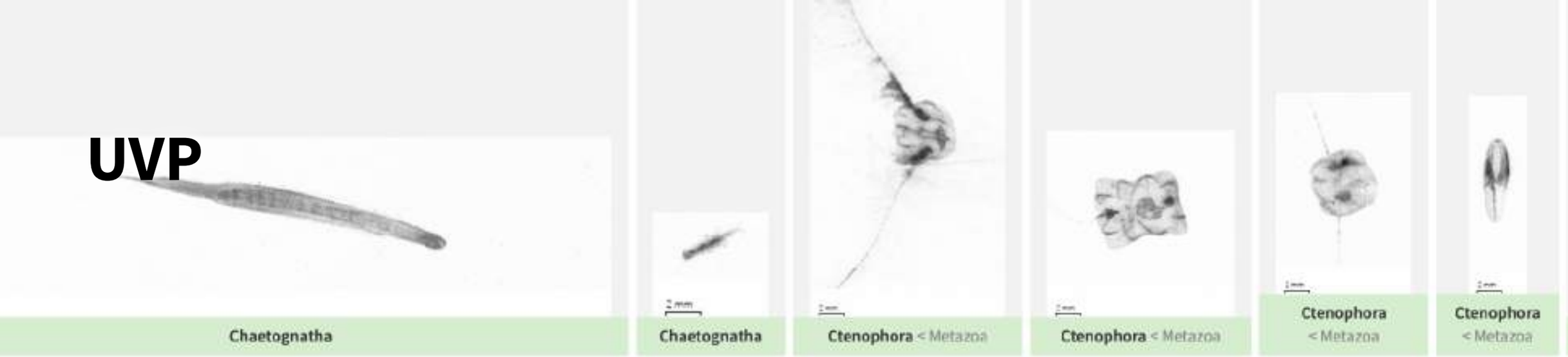
Ctenophora < Metazoa | Rhizaria | Crustacea | Rhizaria | Aulacanthidae | dark < fluffy | Coelodendrum | Rhizaria | Castanellidae | Narcomedusae

thidae | solitaryblack | leg < Phaeodaria | Aulacanthidae | Aulacanthidae | light < fluffy | colonial < Collodaria | colonial < Collodaria | detritus | Enteropneusta < Hemichordata XX | Forami

UVP


Copepoda
depth_max : 1.10
Copepoda
depth_max : 2.00
Aulacantha
depth_max : 467
Copepoda
depth_max : 2.00
Amphipoda
depth_max : 1159
Copepoda
depth_max : 7.30
Ostracoda
depth_max : 544
Ostracoda
depth_max : 1463
Copepoda
depth_max : 0.80
Copepoda
depth_max : 7.40
Copepoda
depth_max : 10.00
like < Copepoda
depth_max : 157
Copepoda
depth_max : 797
Cannosphaeri-dae
depth_max : 205
Copepoda
depth_max : 5.70
Copepoda
depth_max : 5.70
like < Copepoda
depth_max : 6.40
Eumalacostraca
depth_max : 1638
like < Copepoda
depth_max : 52.60
Coelographis
depth_max : 542
like < Copepoda
depth_max : 3.80
Copepoda
depth_max : 11.30
colonial < Aulosphaeridae
depth_max : 1266
like < Copepoda
depth_max : 2.00
Copepoda
depth_max : 148
Copepoda
depth_max : 1.00

UVP


Chaetognatha
Chaetognatha
Ctenophora < Metazoa
Ctenophora < Metazoa
Ctenophora < Metazoa
Ctenophora < Metazoa
Siphonoph
Calanoida
Calanoida
Swima
Swima
Swima
Swima
Calanoida
Calanoida
Calanoida
Calanoida
Calanoida
like < Copepoda
like < Copepoda
Calanoida
Calanoida
Calanoida
Calanoida
Calanoida
Calanoida
Calanoida
Calanoida
Chaetognatha
Calanoida
Phyllodocida
Calanoida
Ostracoda
Eukrohnia
Copepoda
Copepoda
Copepoda
Copepoda

ISIIS

ISIIS

ISIIS

Aulosphaeridae
area : 693

pluteus
< Ophiuroidea
area : 694

Ctenophora
< Metazoa
area : 705

streak
area : 709

part
< Ctenophora
area : 717

Ctenophora
< Metazoa
area : 730

Aulosphaeridae
area : 757

Cnidaria
< Metazoa
area : 760

Solmundella bitentaculata
area : 810

house
area : 821

Ctenophora
< Metazoa
area : 845

Solmundella bitentaculata
area : 864

Chaetognatha
area : 883

Rhopalonetidae
area : 890

actinula
< Solmundella bitentaculata
area : 917

solitaryblack
area : 939

pluteus
< Echinoidea
area : 1026

house
area : 1033

Appendicularia
area : 1087

t011
area : 1121

Cnidaria
< Metazoa
area : 1137

Crustacea
area : 1138

ephyra
< Scyphozoa
area : 1186

Trichodesmium
area : 1189

Doliolida
area : 1214

Siphonophorae
area : 1266

Aulosphaeridae
area : 1285

Eumalacostraca
area : 1497

Eumalacostraca
area : 1576

Chaetognatha
area : 1614

pluteus
< Echinoidea
area : 1706

Doliolida
area : 1773

part
< Ctenophora
area : 1832

Rhopalonematidae
area : 1851

Actinopterygii
area : 1861

multiple
< other
area : 1923

Trichodesmium
area : 1930

egg
< other
area : 2050

ephyra
< Scyphozoa
area : 2133

area : 2156

Eumalacostraca
area : 2233

Crustacea
area : 2376

Rhopalonematidae
area : 2456

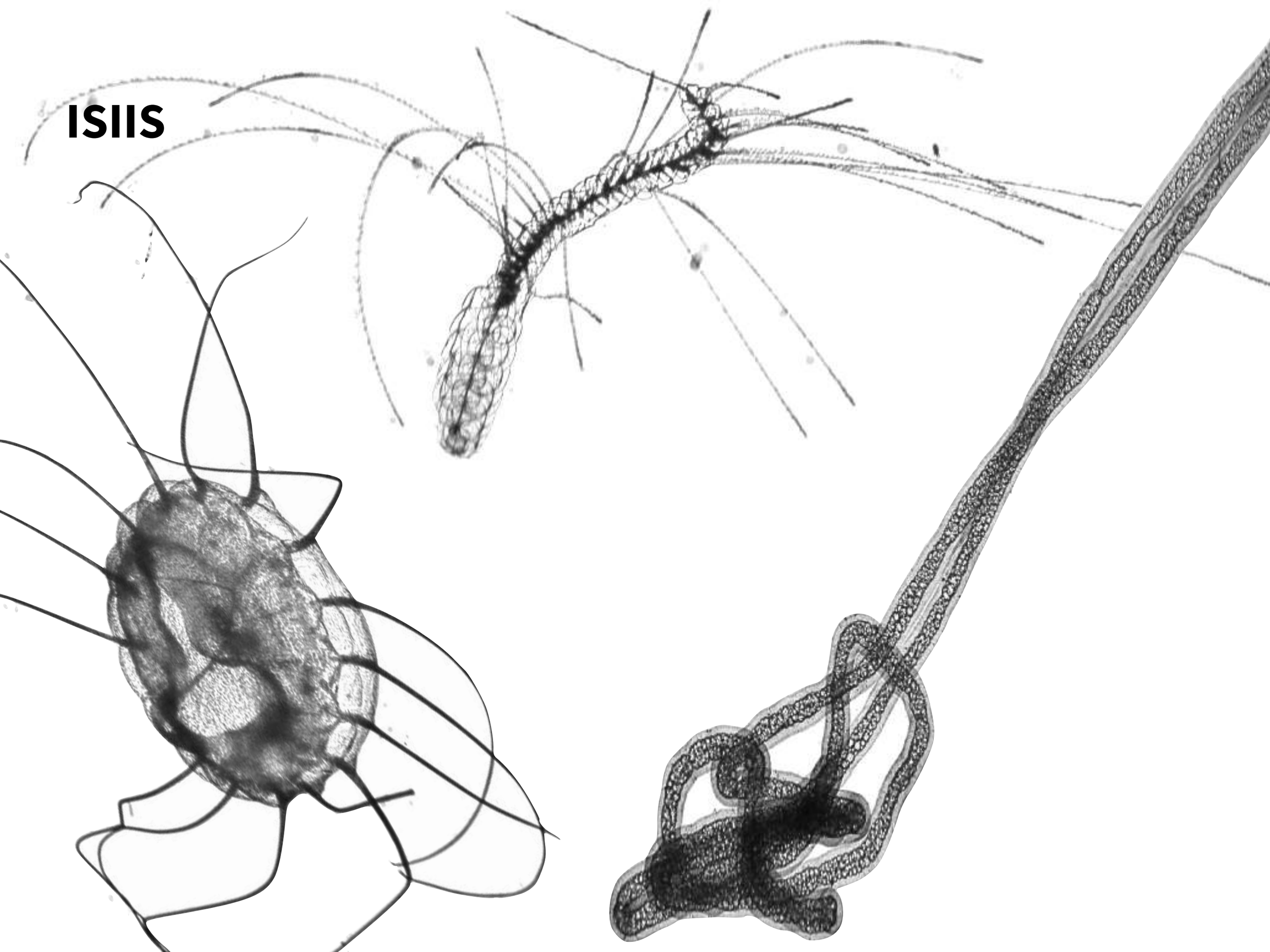
colonial
< Collodaria
area : 2781

Amphipoda
area : 3829

part
< Cnidaria
area : 4220

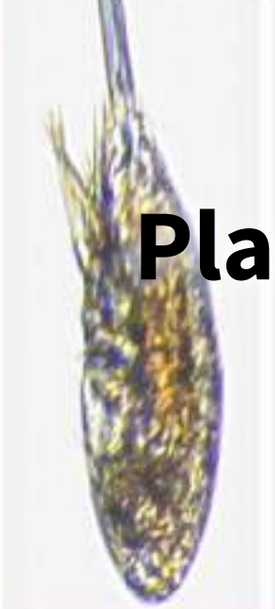
Amphipoda
area : 4250

ISIIS



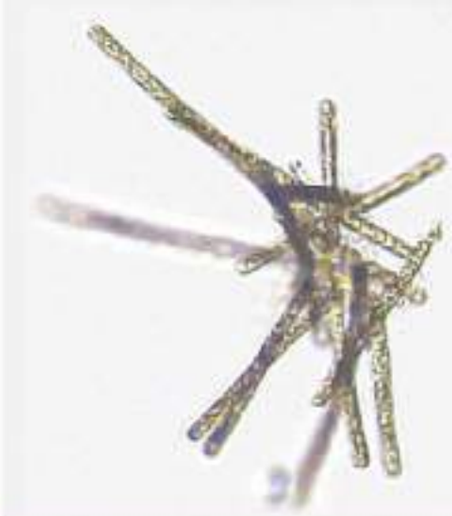
Planktoscope

Planktoscope


Microsetella

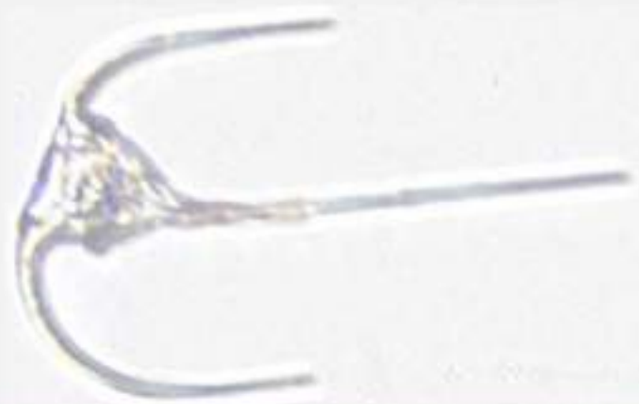
t009


multiple < other

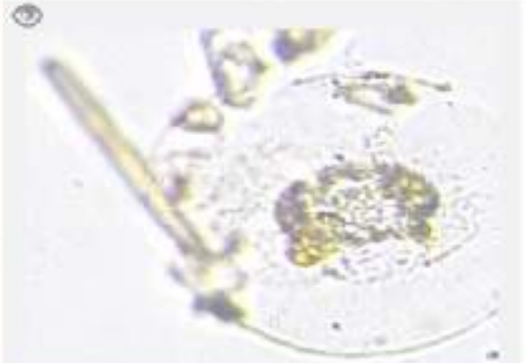

puff


Codonellidae


Striatella


Neoceratium karstenii


pa


Cystidium


dry


Codonellopsis
< Tintinnidiidae


Epiplocylis

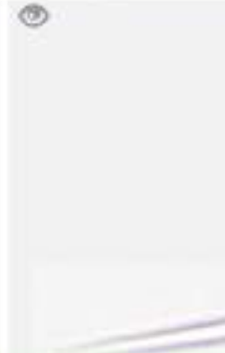

Rhabdonella


Lacrymaria
< Lacrymariidae


Epiplocylis

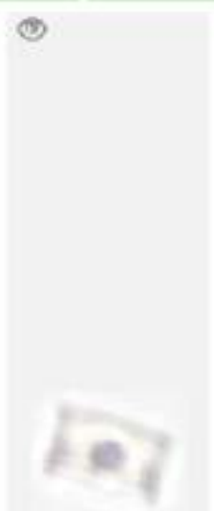

Codonellopsis
< Tintinnidiidae


Codonellopsis
< Tintinnidiidae

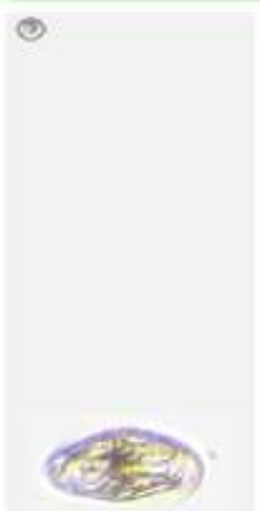

Salpingella <

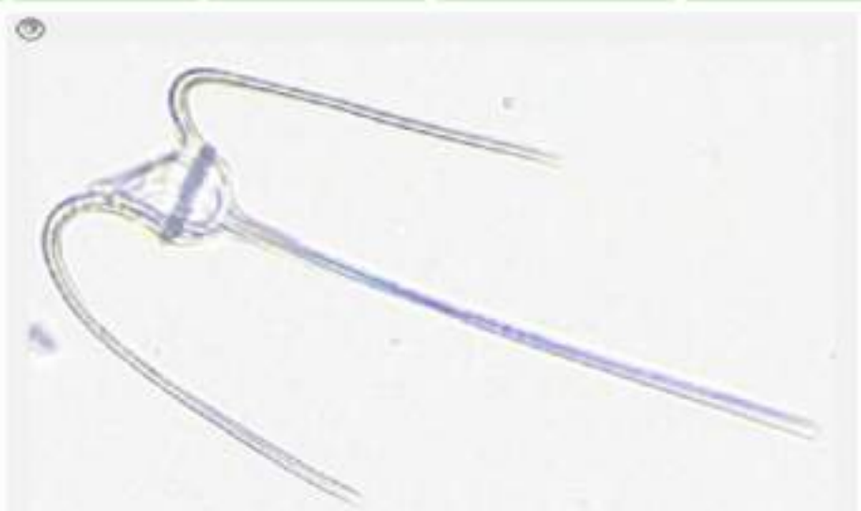

Foraminifera

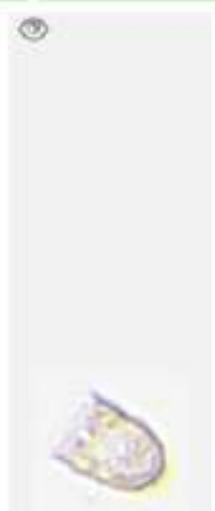

Dictyochophyceae


Striatella

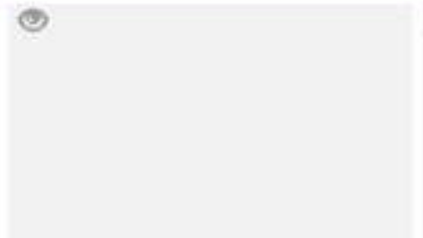

Neoceratium

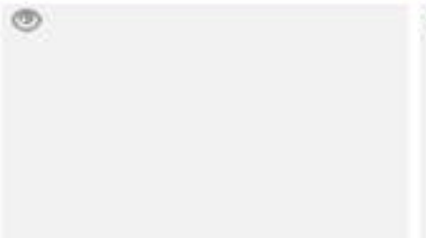

Pyrocystaceae

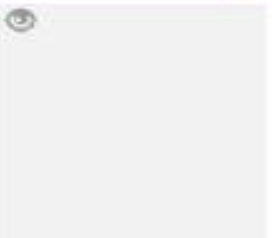

Neoceratium macroceros


Poroecus

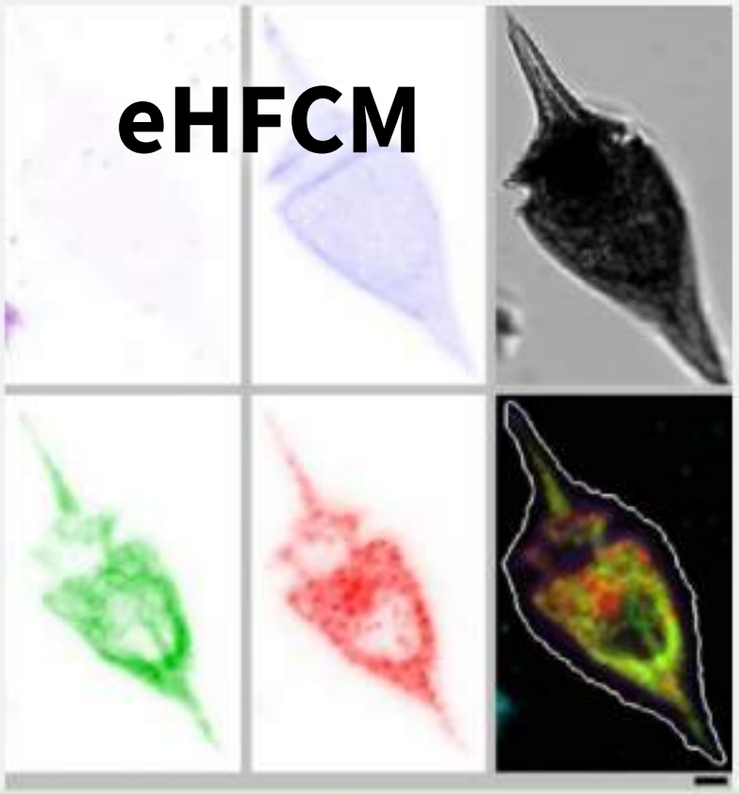

Rhabd



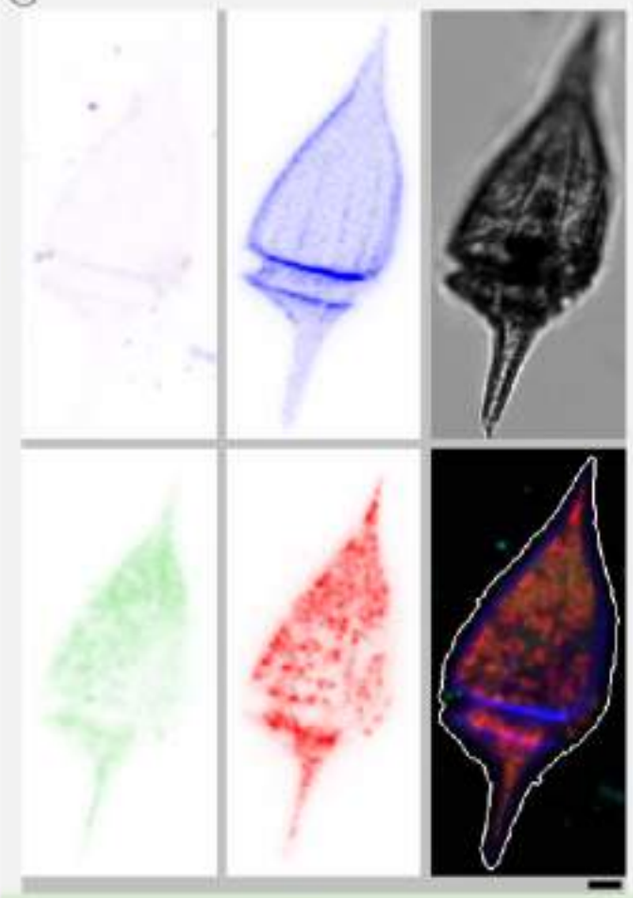




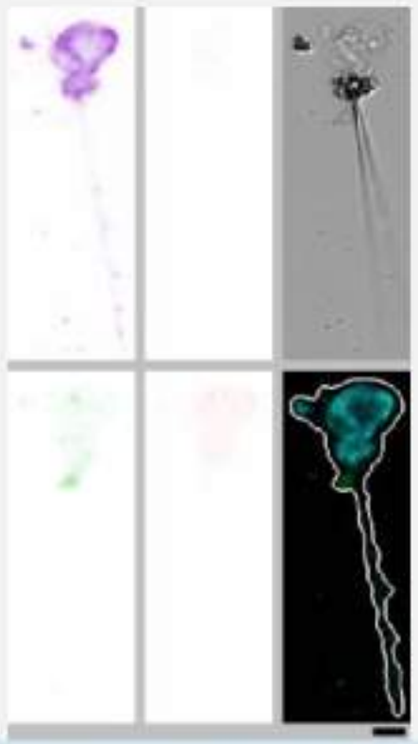
eHFCM



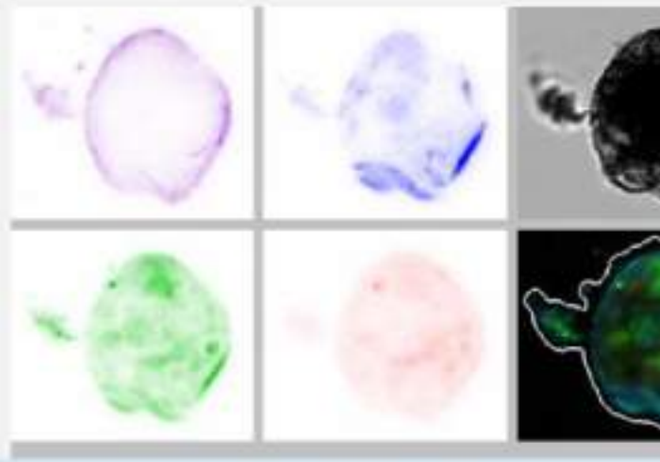
Oxytoxum milneri



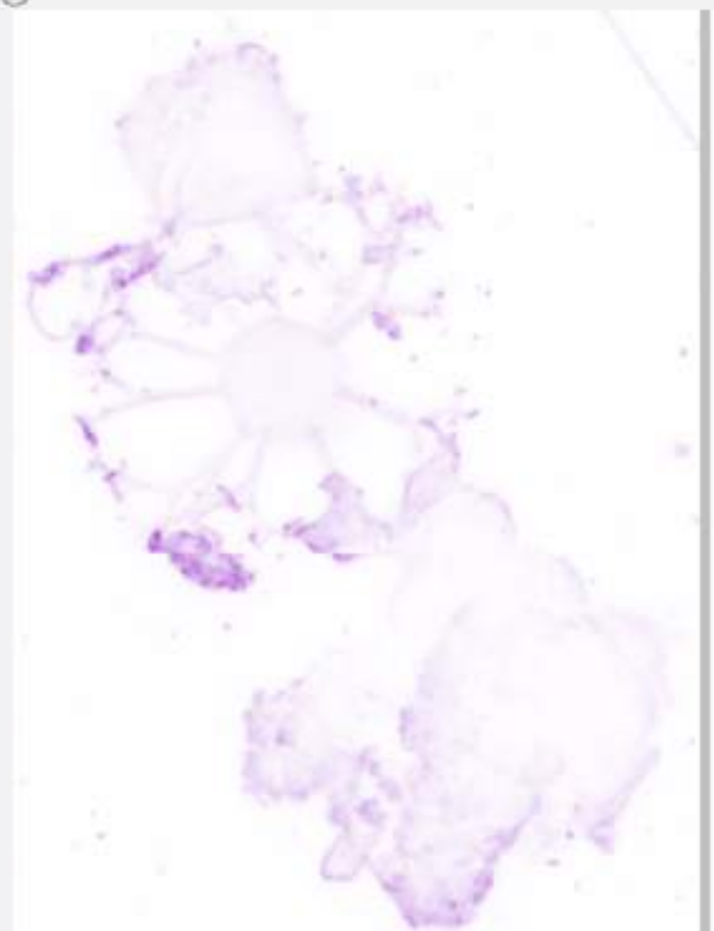
Oxytoxum milneri

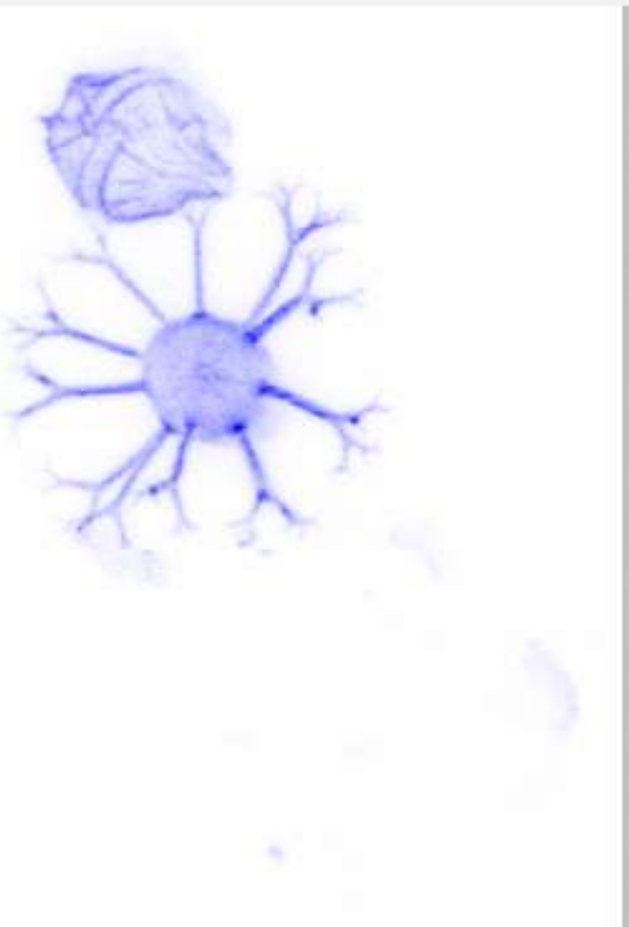


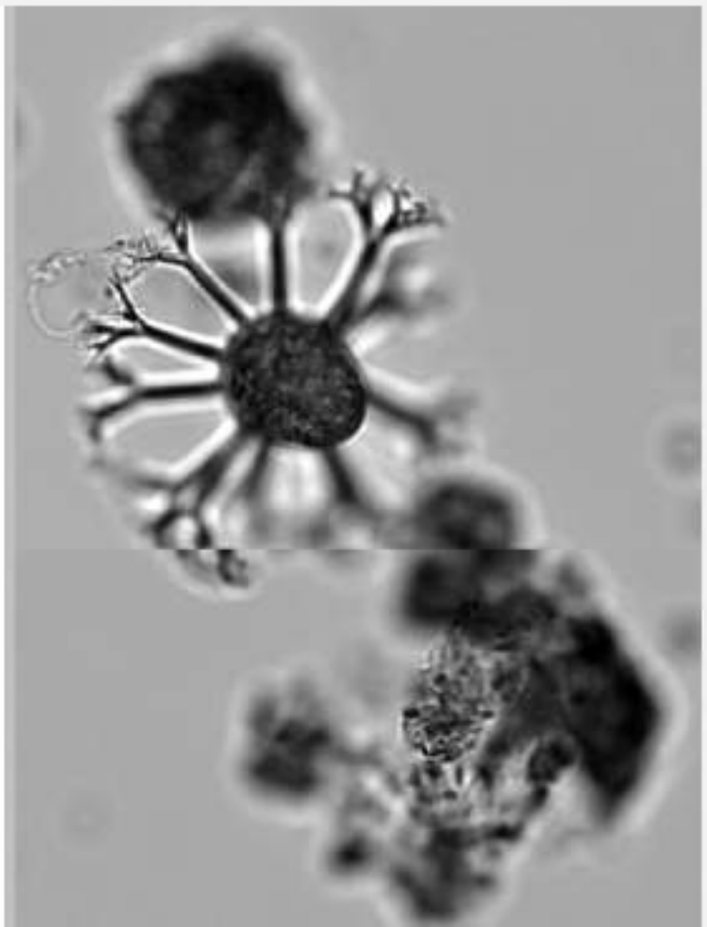
Chaetoceros = Chaetocerotales



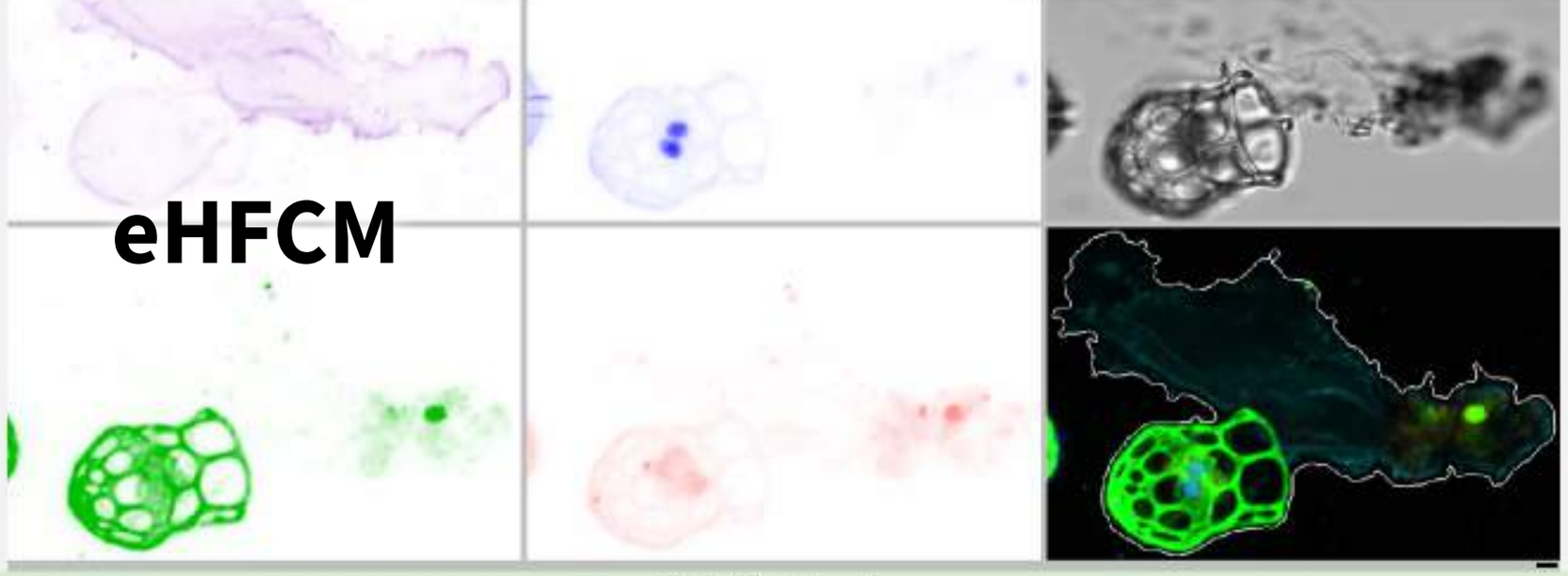
Corythodinium tesselatum



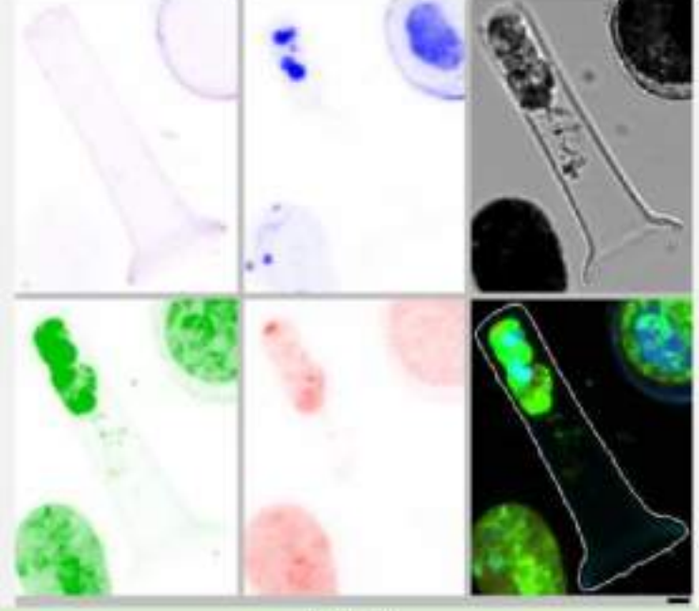




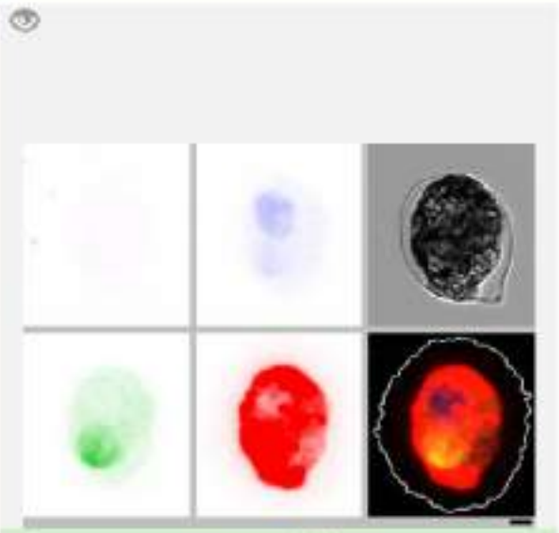
eHFCM



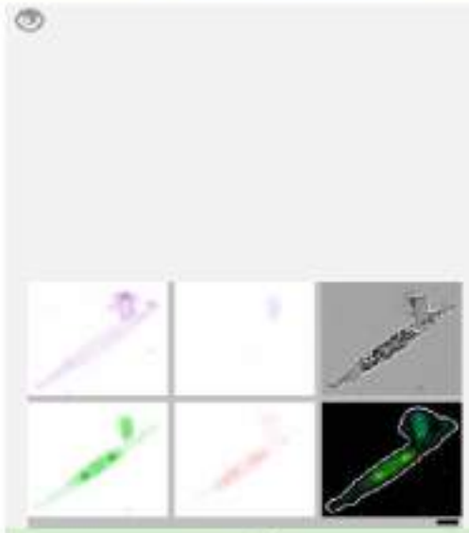
Nassellaria < Polycystinea



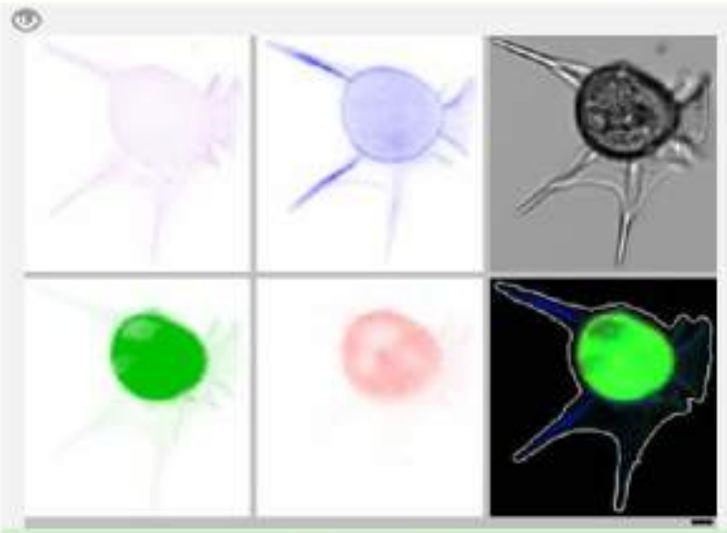
Tintinnida



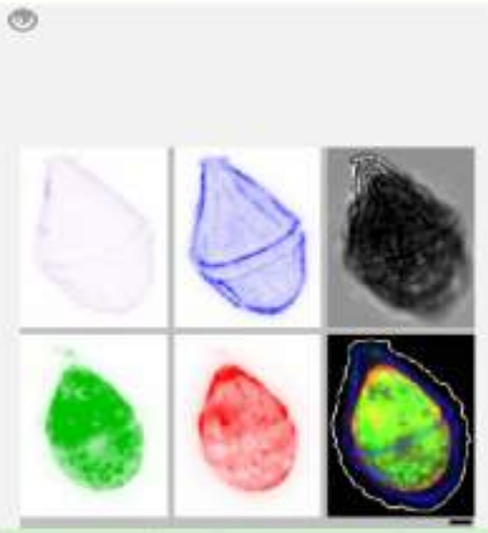
Gymnodiniales



Navicula

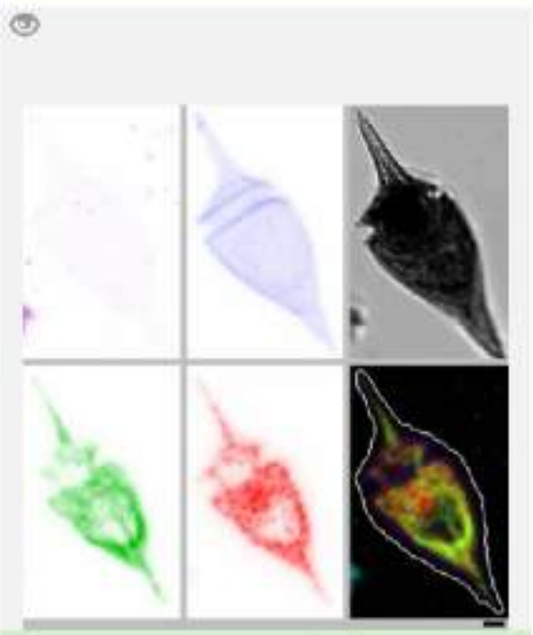


Ceratocorys

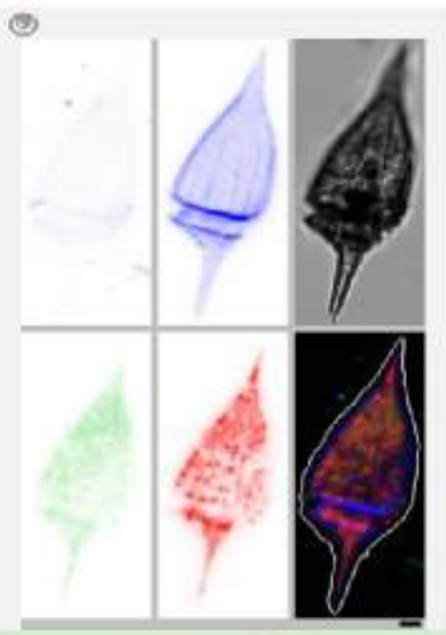


Gonyaulax polygramma < Gonyaulax

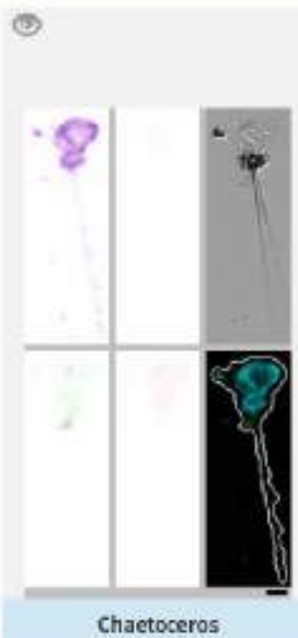
Protocerat



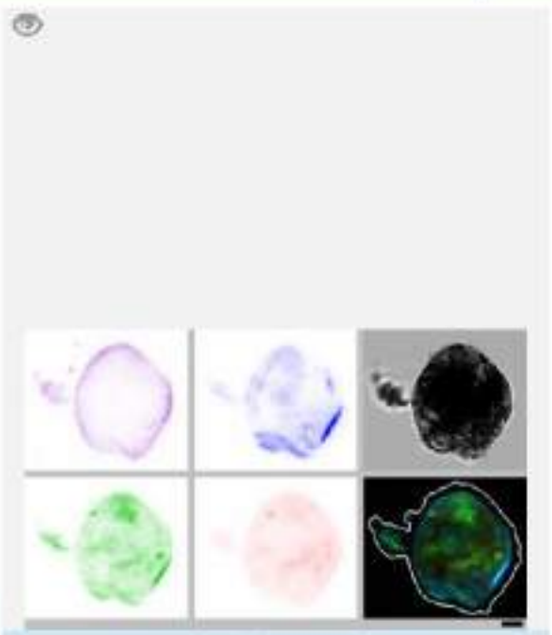
Oxytoxum milneri



Oxytoxum milneri



Chaetoceros
< Chaetocerotales



Corythodinium tesselatum

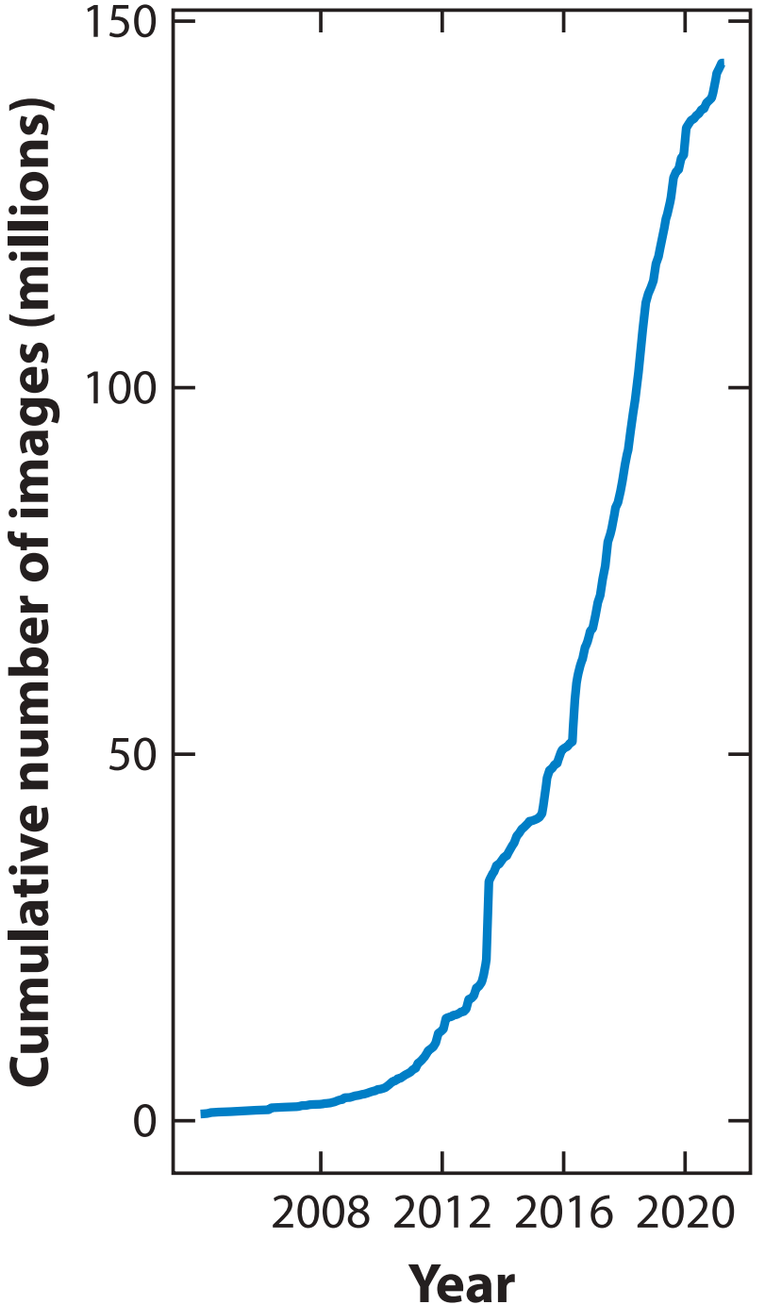
Processing plankton image data

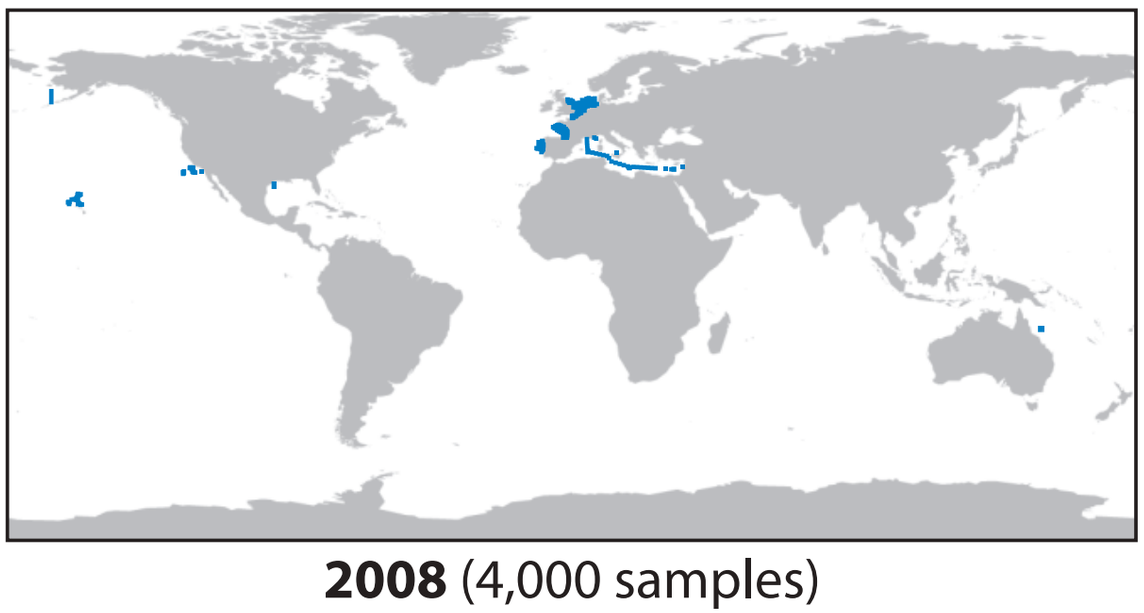
Surfing the data tsunami

A lot of data

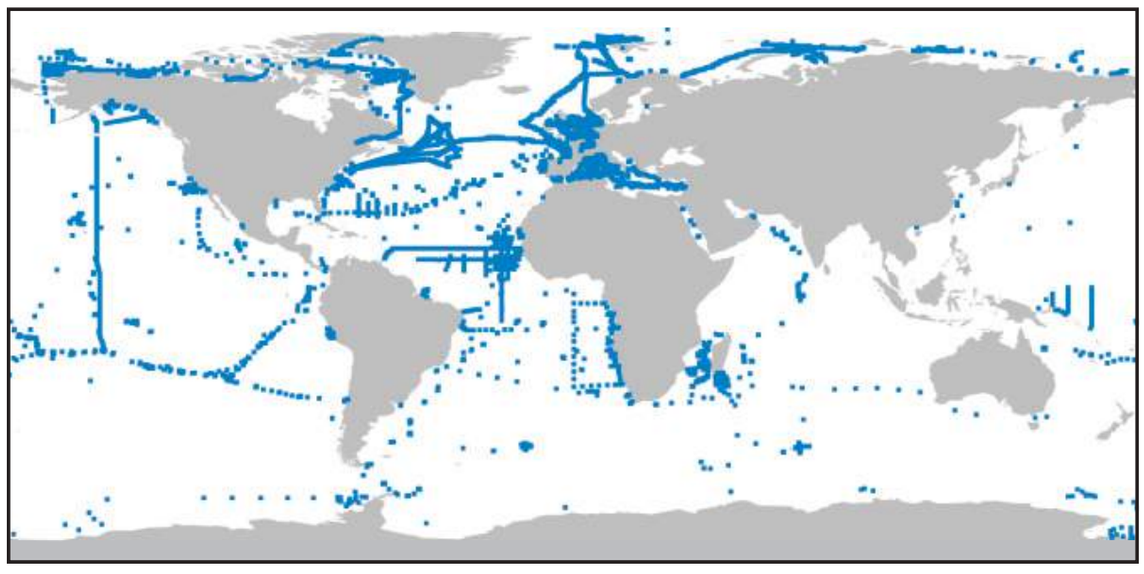
ZooScan = 1 Bpx/y, 1.5M objects/y
UVP = 8.6Bpx/y, ~10M objects/y
ISIIS = 25Tpx/y, 100M objects/y

Steep growth in data acquisition

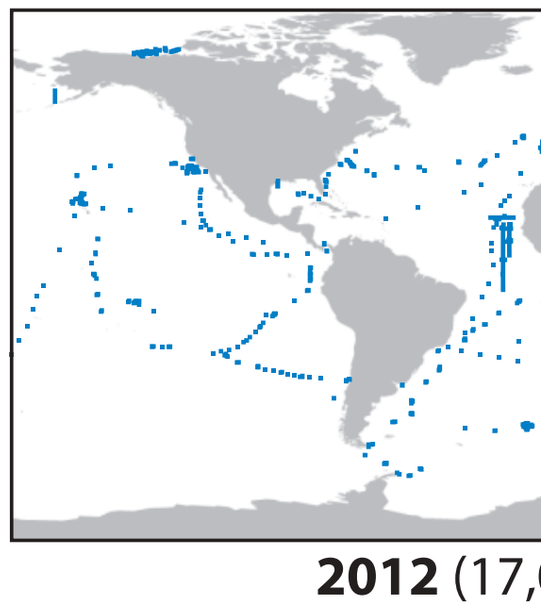




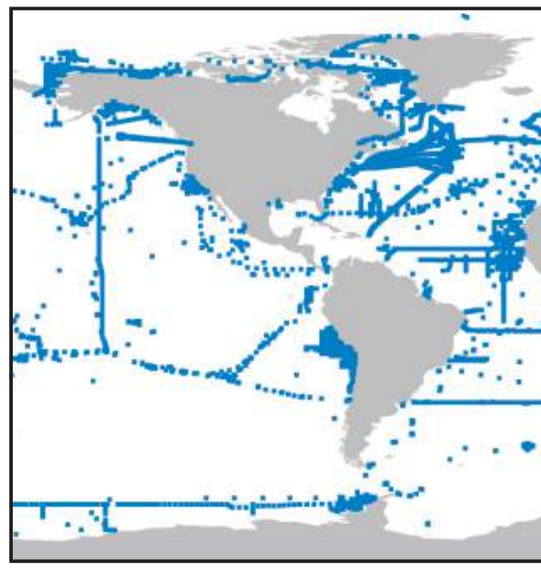
2008 (4,000 samples)



2016 (56,000 samples)

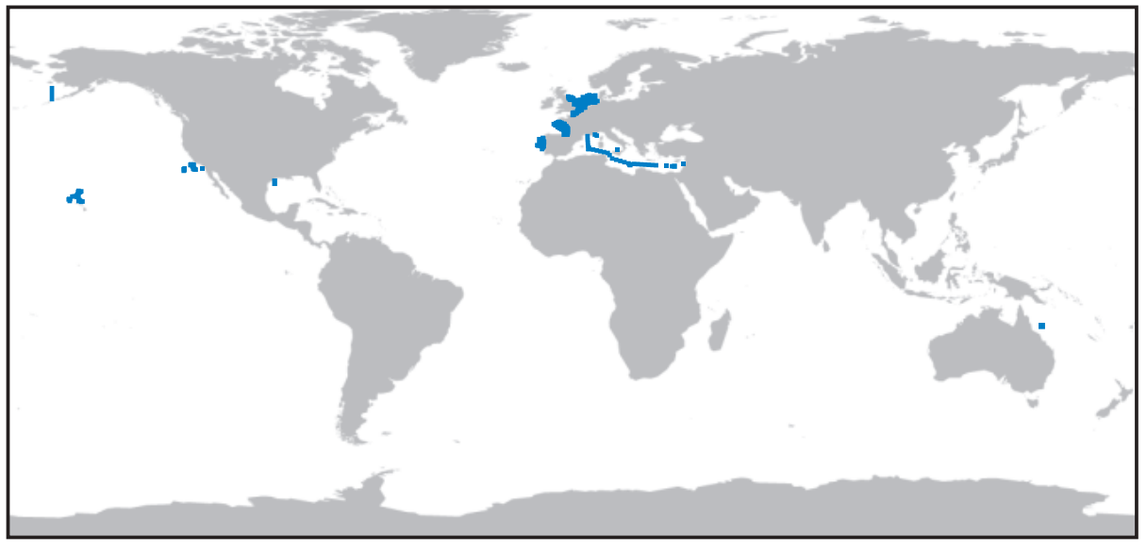


2012 (17,

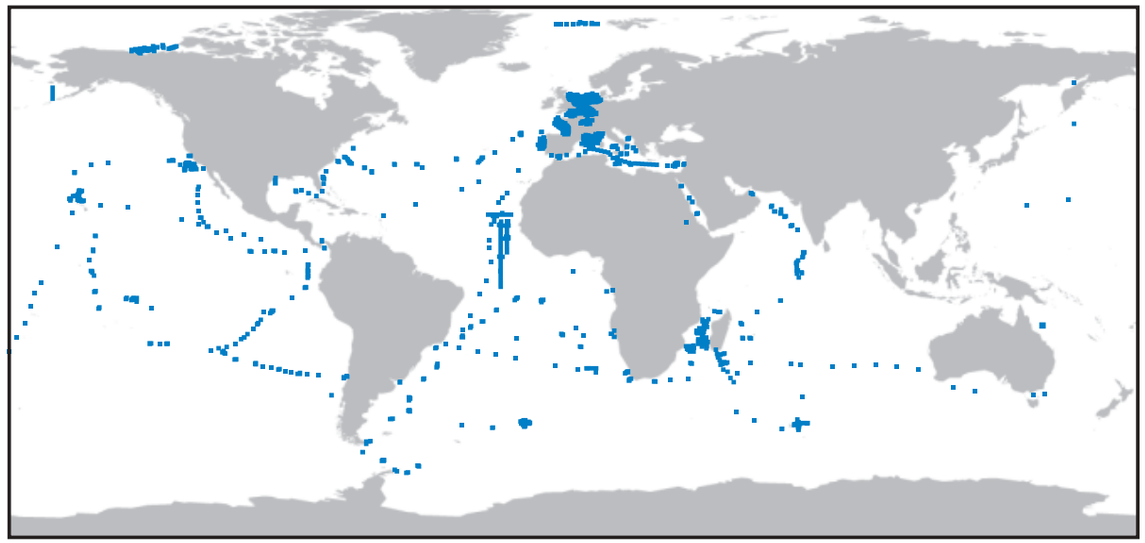


2020 (91,

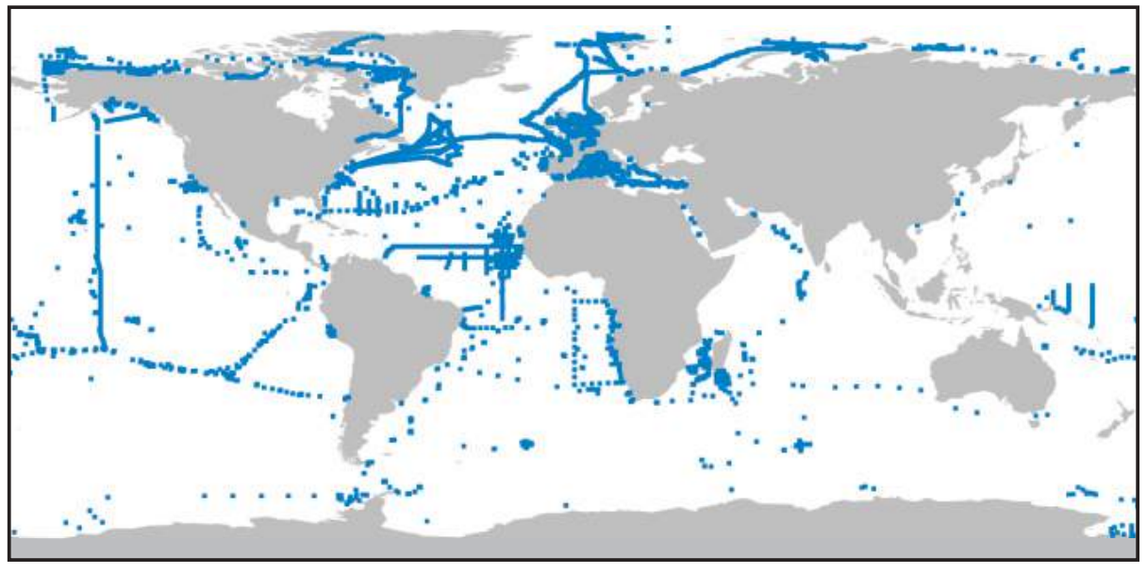
Steep growth in data acquisition



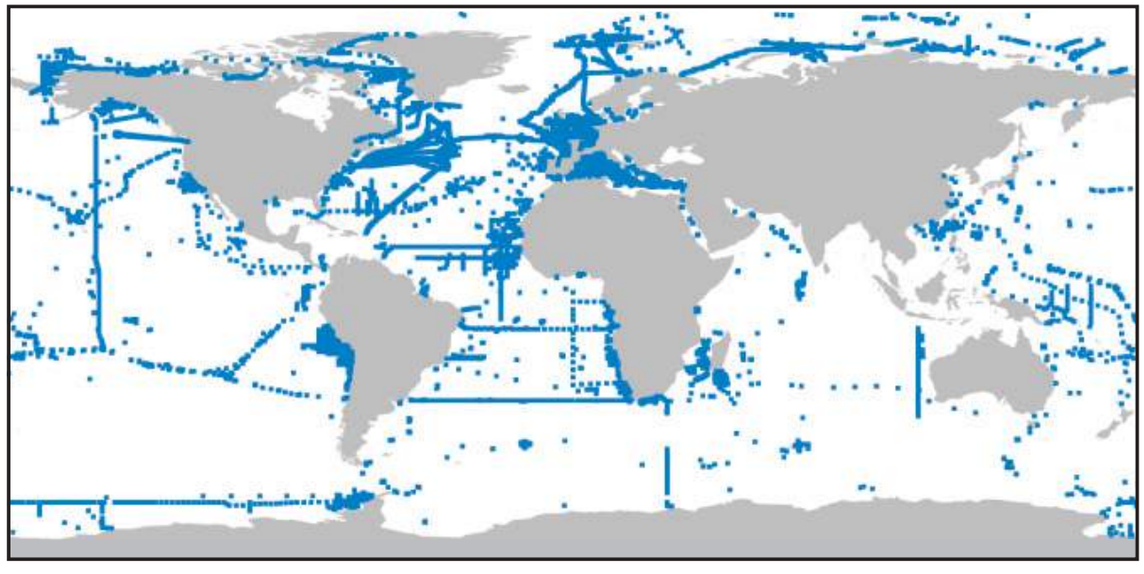
2008 (4,000 samples)



2012 (17,000 samples)

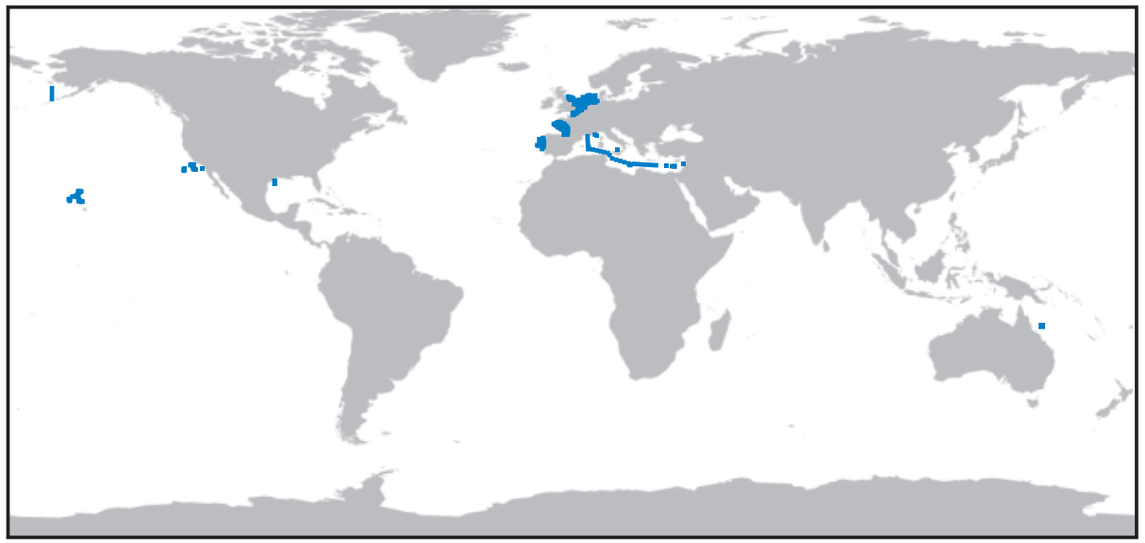


2016 (56,000 samples)

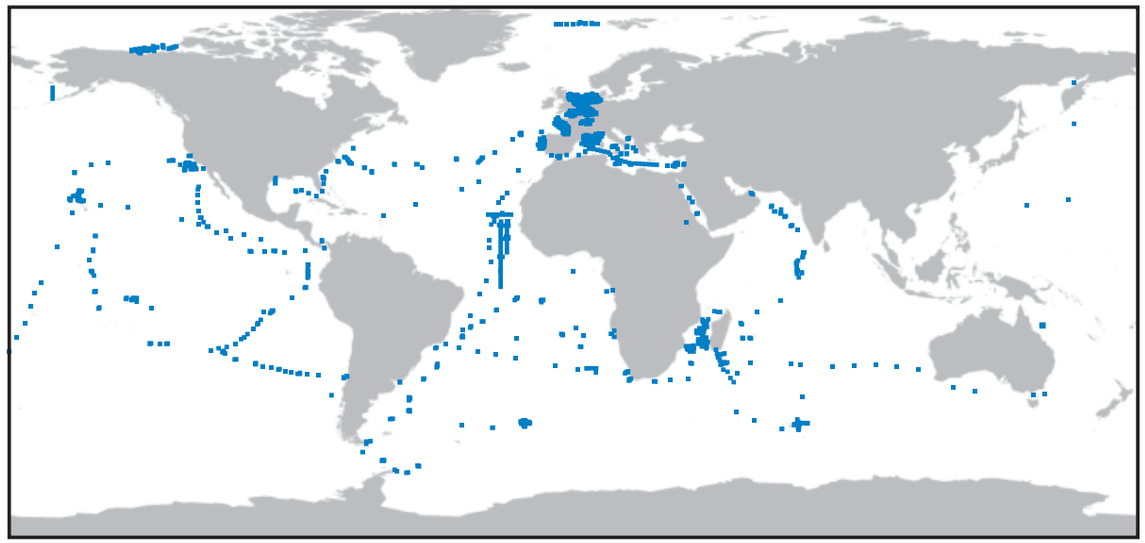


2020 (91,000 samples)

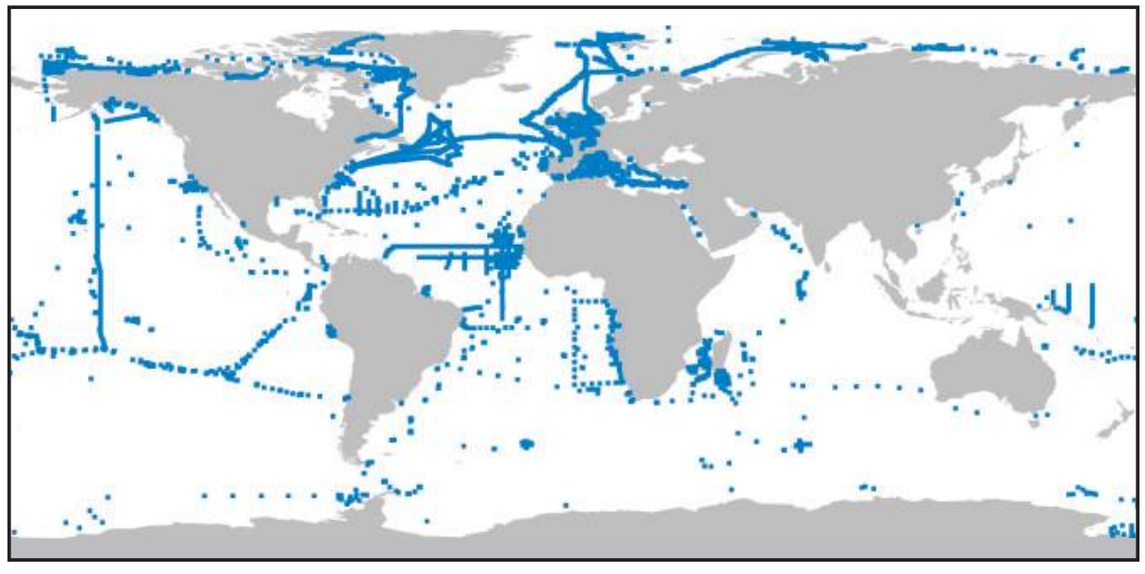
Steep growth in data acquisition



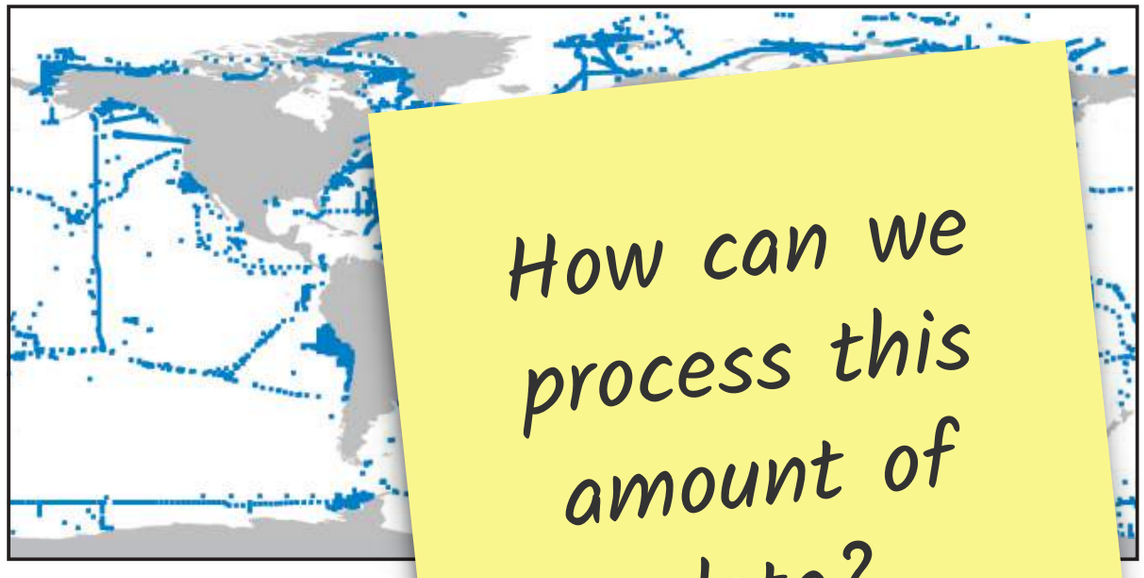
2008 (4,000 samples)



2012 (17,000 samples)



2016 (56,000 samples)

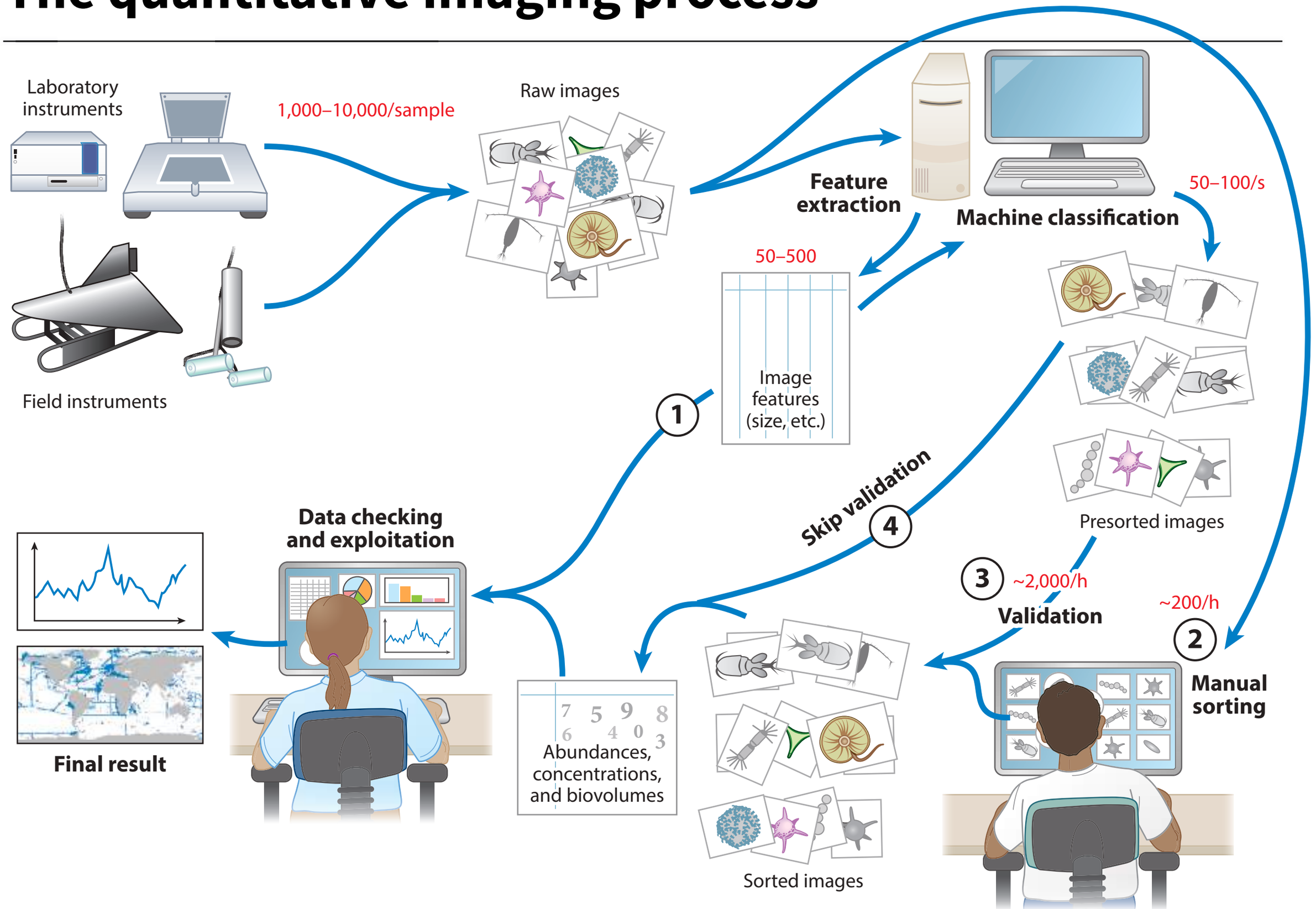


202

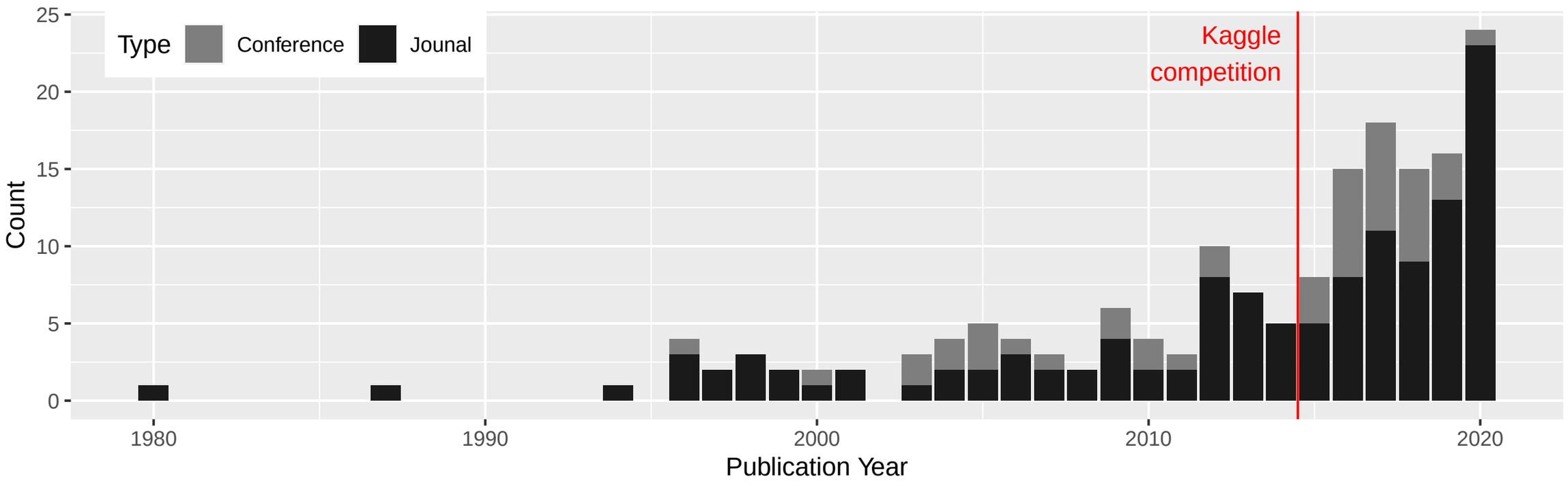
020

How can we process this amount of data?

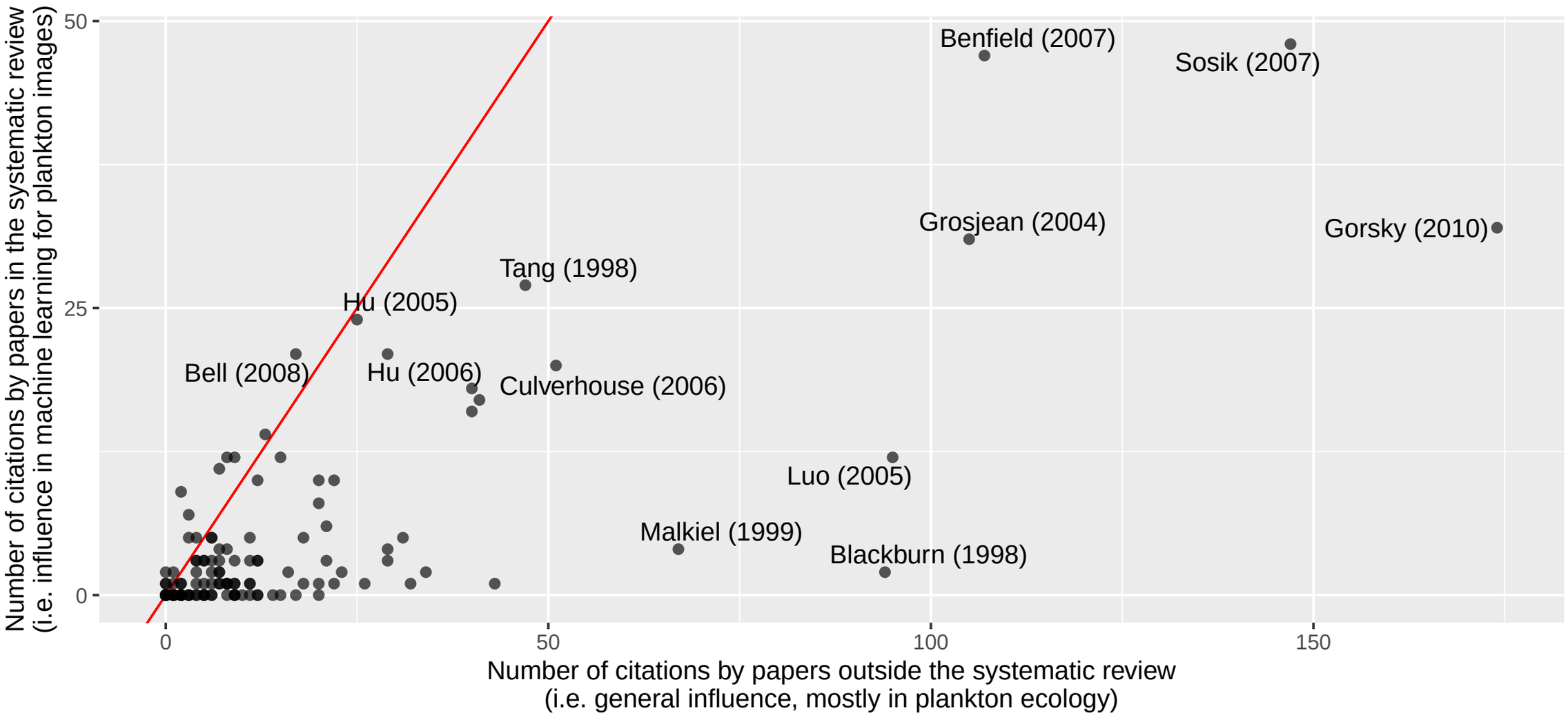
The quantitative imaging process



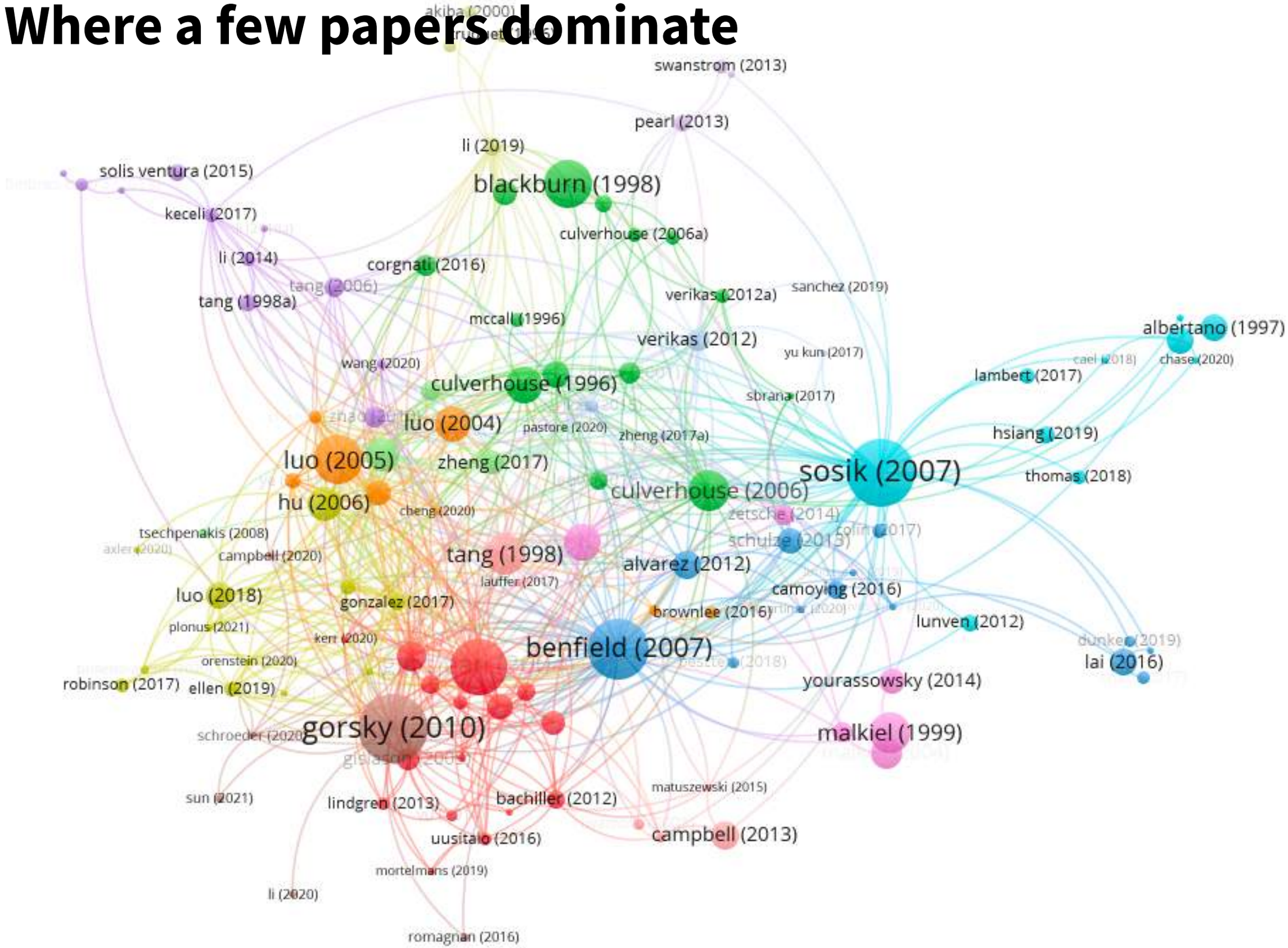
A challenging classification problem



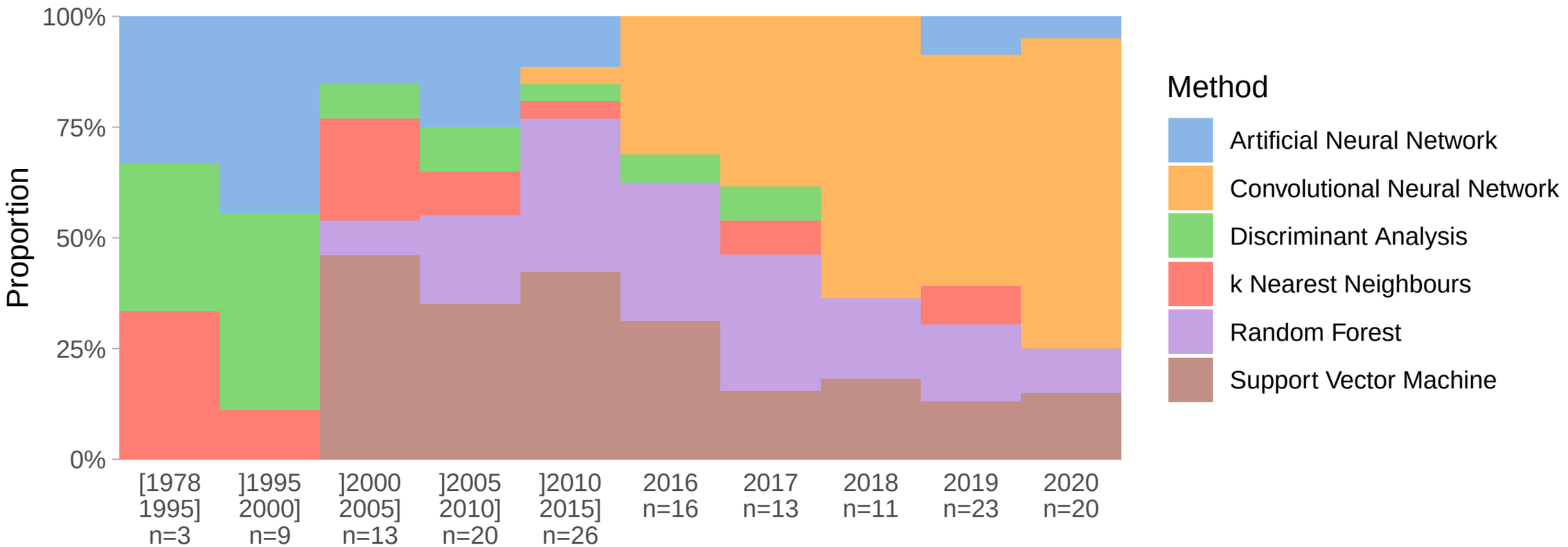
Where a few papers dominate



Where a few papers dominate



Shift in machine learning techniques



Measure + classify

Area (ESD)

Major/minor

Mean/SD of grey

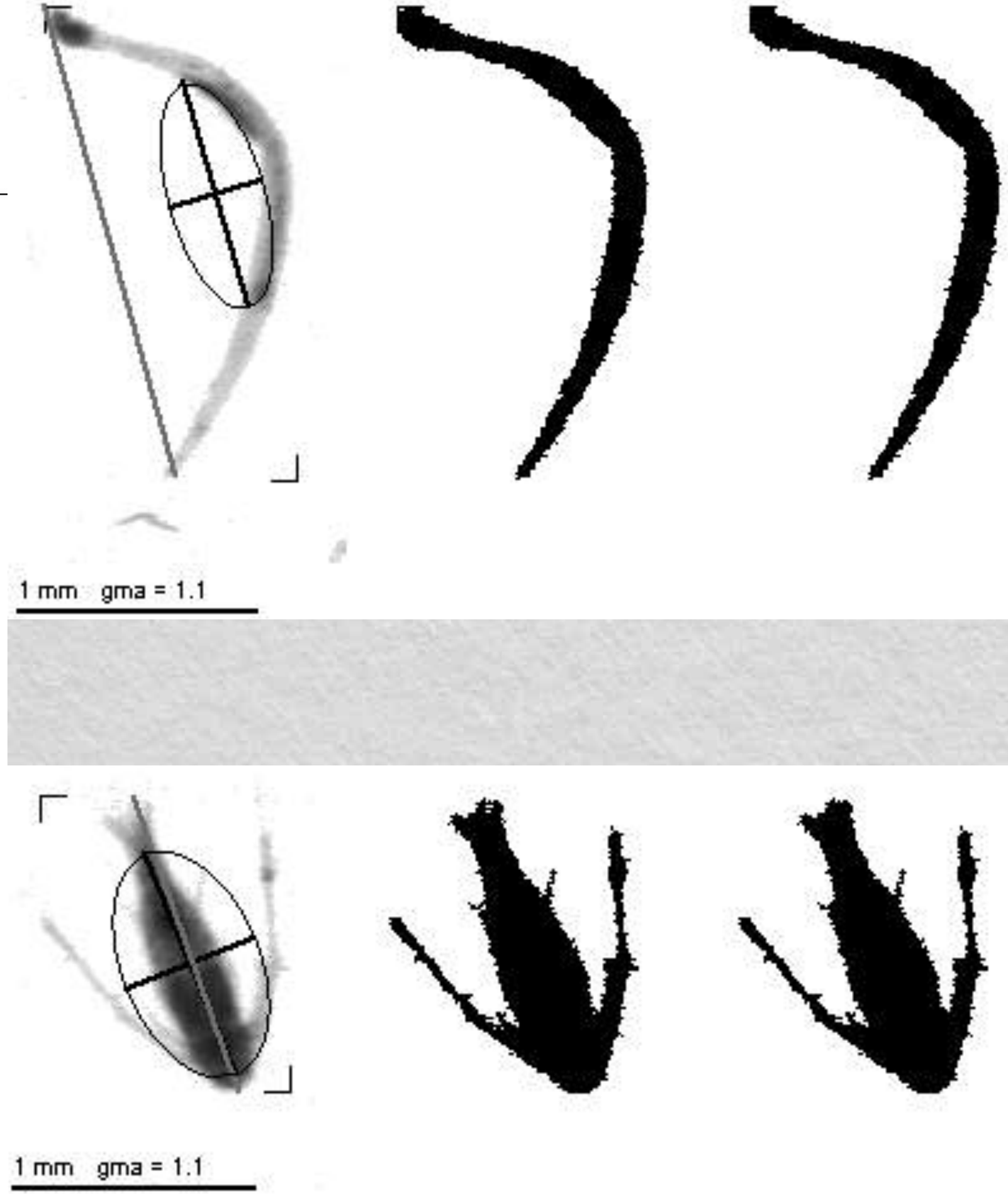
Angle of ellipse

Perimeter

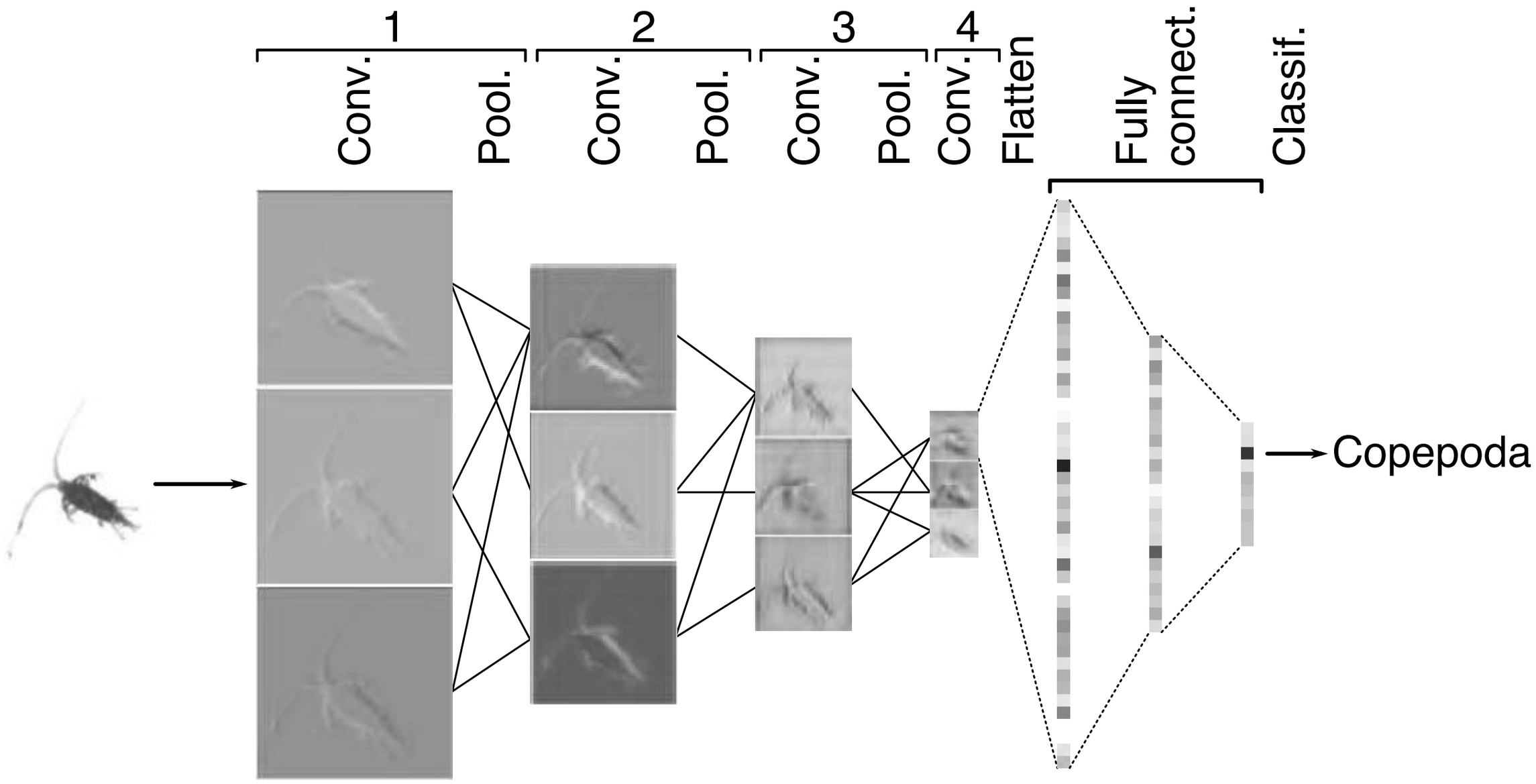
Fractal measurement

...

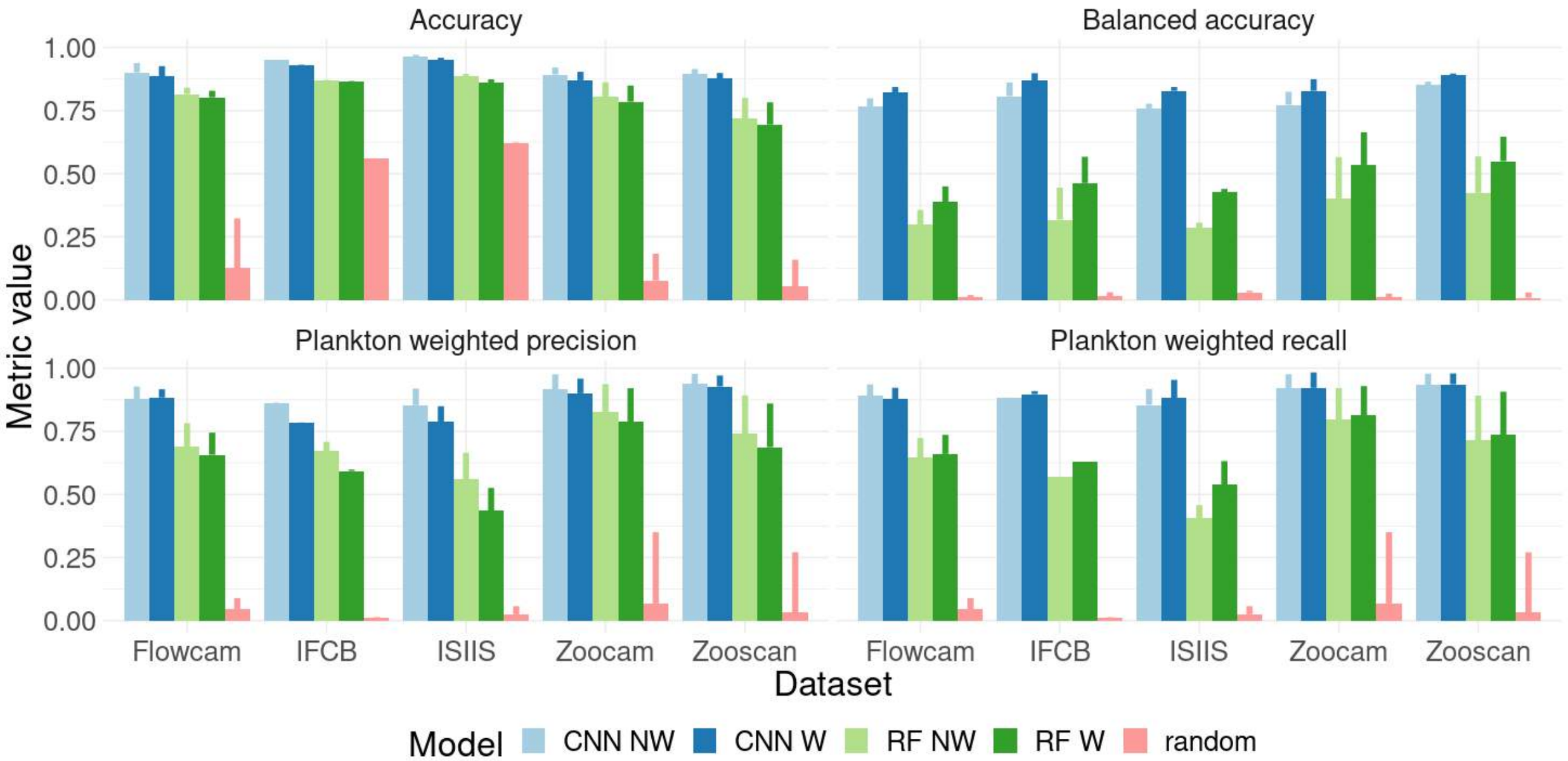
+ a **classifier**



Convolutional Neural Networks: all-in-one



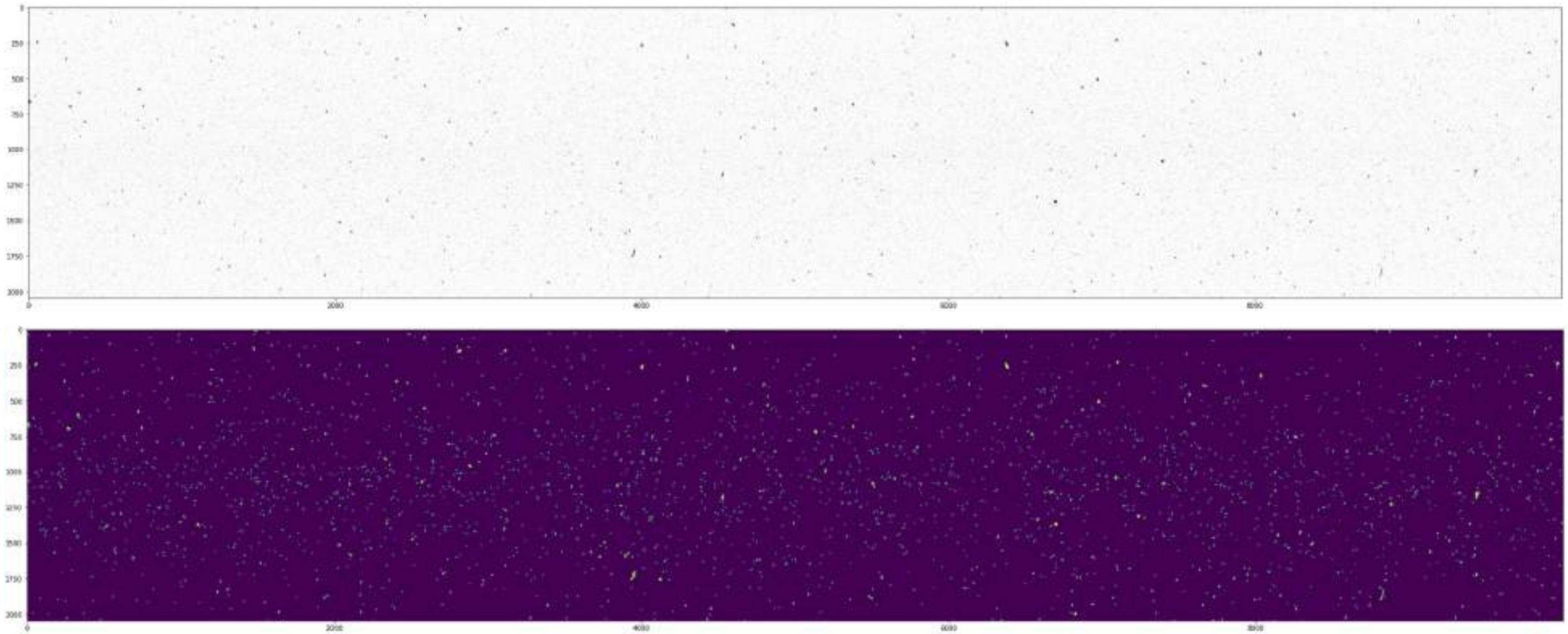
The old way *vs* the new way



And in real life

Metrics are hard to interpret!

Sometimes, classification is not enough



0.35s ~ 2500 objects

6h ~ 150 millions objects

on cruise ~ 1.5 billion objects, among which ~1% are plankton (~20-30 millions)

Semantic segmentation

Extract only certain objects from a scene

Detect or segment objects

Classify them a the same time

Detectron2

ecotaxa.obs-vlfr.fr/prj/859

EcoTaxa Demo Zooscan JO low taxo res

EcoTaxa 2.0 | Project | Filtered | Demo Zooscan JO low taxo res (0 , 0 , 0, 1397 / 1397) | Jean-Olivier Irisson (log out) | Action

Update view & apply filter | Select all | Display | Status All | 100 | % 70

Taxonomy filter | Other filters

Copepoda

- Appendicularia 0
- Copepoda 1
- detritus 0
  - fiber < detritus 0

Recalc. counts | Hide empty categories

ecotaxa.obs-vlfr.fr/prj/859

EcoTaxa Demo Zooscan JO low taxo res

EcoTaxa 2.0 | Project | Filtered | Demo Zooscan JO low taxo res (0 , 0 , 0, 1397 / 1397) | Jean-Olivier Irisson (log out) | Action

Update view & apply filter | Select all | Display | Status All | 100 | % 70 | 4 Selected

Taxonomy filter | Other filters

Copepoda

- Appendicularia 0
- Copepoda 1
- detritus 0
  - fiber < detritus 0

Recalc. counts | Hide empty categories

Taxonomy filter | Other filters

Copepoda

- Appendicularia 0
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ecotaxa.obs-vlfr.fr/prj/859

EcoTaxa Demo Zooscan JO low taxo res

EcoTaxa 2.0 | Project | Filtered

Demo Zooscan JO low taxo res (7, 1184, 0, 0 / 1191)

Filter: Taxo= Copepoda

Jean-Olivier Irisson (log out)

Action

Update view & apply filter | Select all | Score | Display | Status All | 100 | % 70

Taxonomy filter | Other filters

- Appendicularia 1
- Copepoda 7 1184
- Salpida 2 2
- Siphonophorae 4 5
- detritus 2 14
  - fiber < detritus 5 171

Recalc. counts | Hide empty categories

ecotaxa.obs-vlfr.fr/prj/859

EcoTaxa Demo Zooscan JO low taxo res

EcoTaxa 2.0 | Project | Filtered | Demo Zooscan JO low taxo res (7, 1184, 0, 0 / 1191) | Jean-Olivier Irisson (log out)

Filter: Taxo= Copepoda

Action

Update view & apply filter | Select all | Score | Display | Status All | 100 | % 70

Taxonomy filter | Other filters

- Appendicularia 1
- Copepoda 7 1184
- Salpida 2 2
- Siphonophorae 4 5
- detritus 2 14
  - fiber < detritus 5 171

Recalc. counts | Hide empty categories

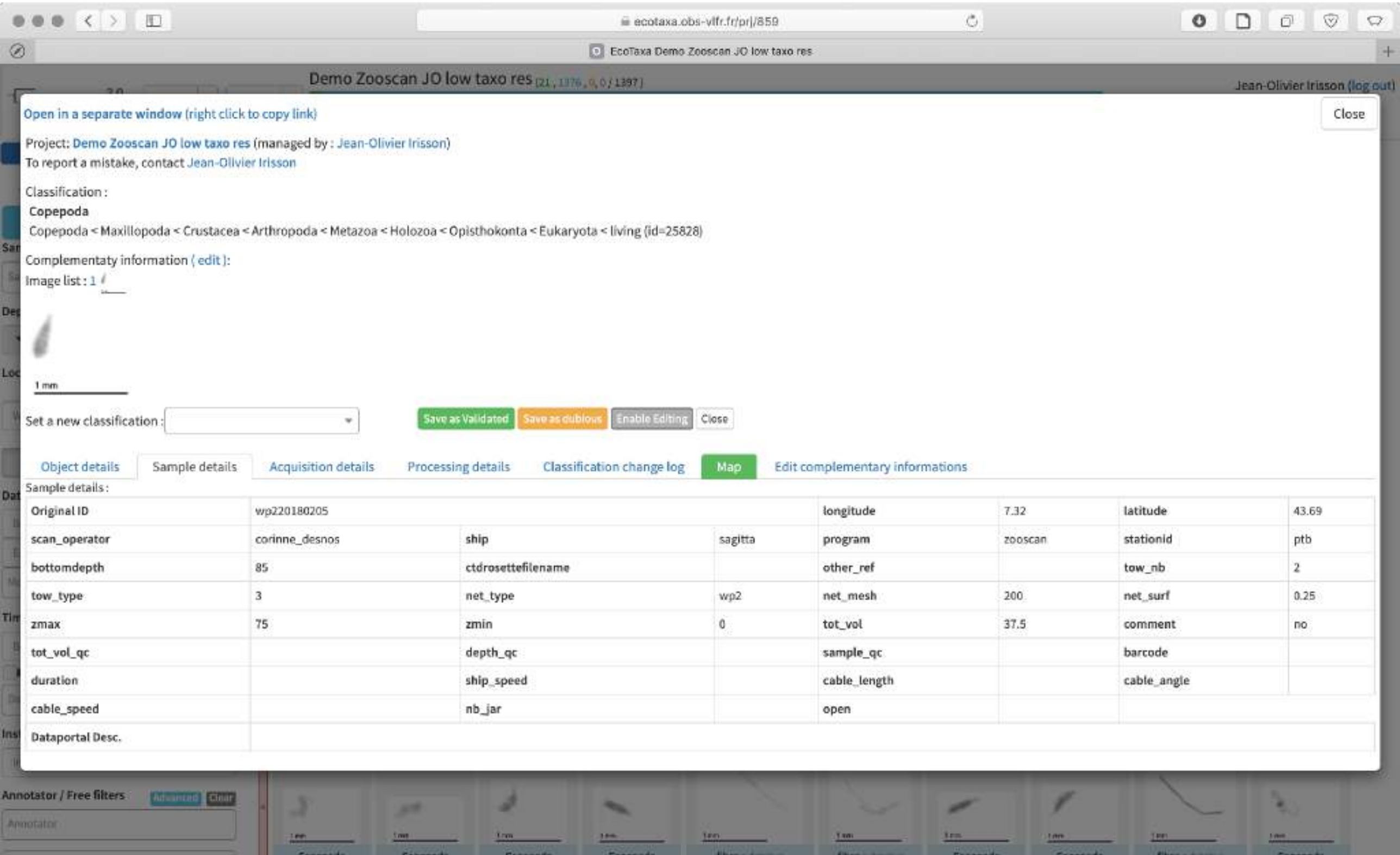
Copepoda Score : - | Copepoda Score : 0.86

Copepoda Score : 0.83 | Copepoda Score : 0.82

Copepoda Score : 0.81 | Copepoda Score : 0.80

Combination of deep features and classic classifiers

Handle metadata in addition to images



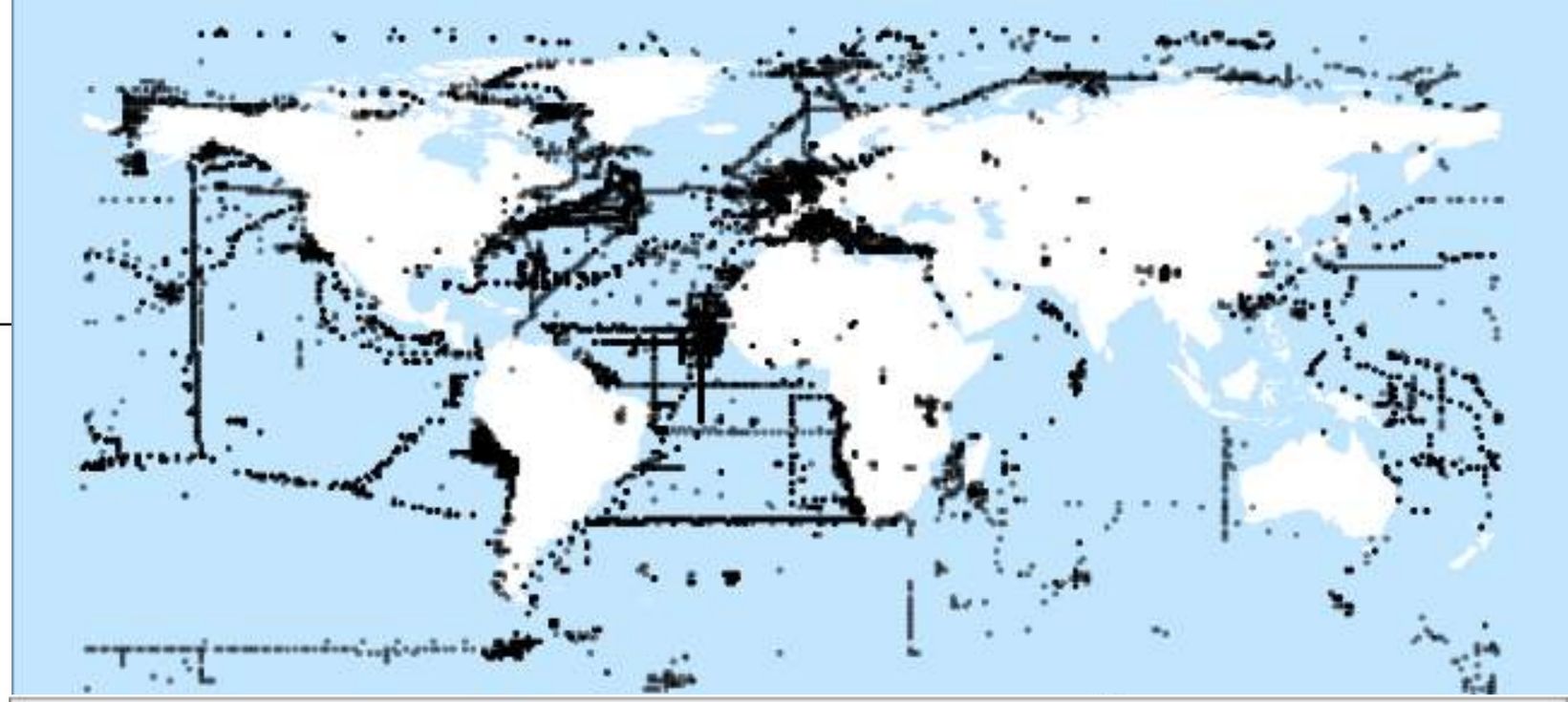
Eco**Taxa today**

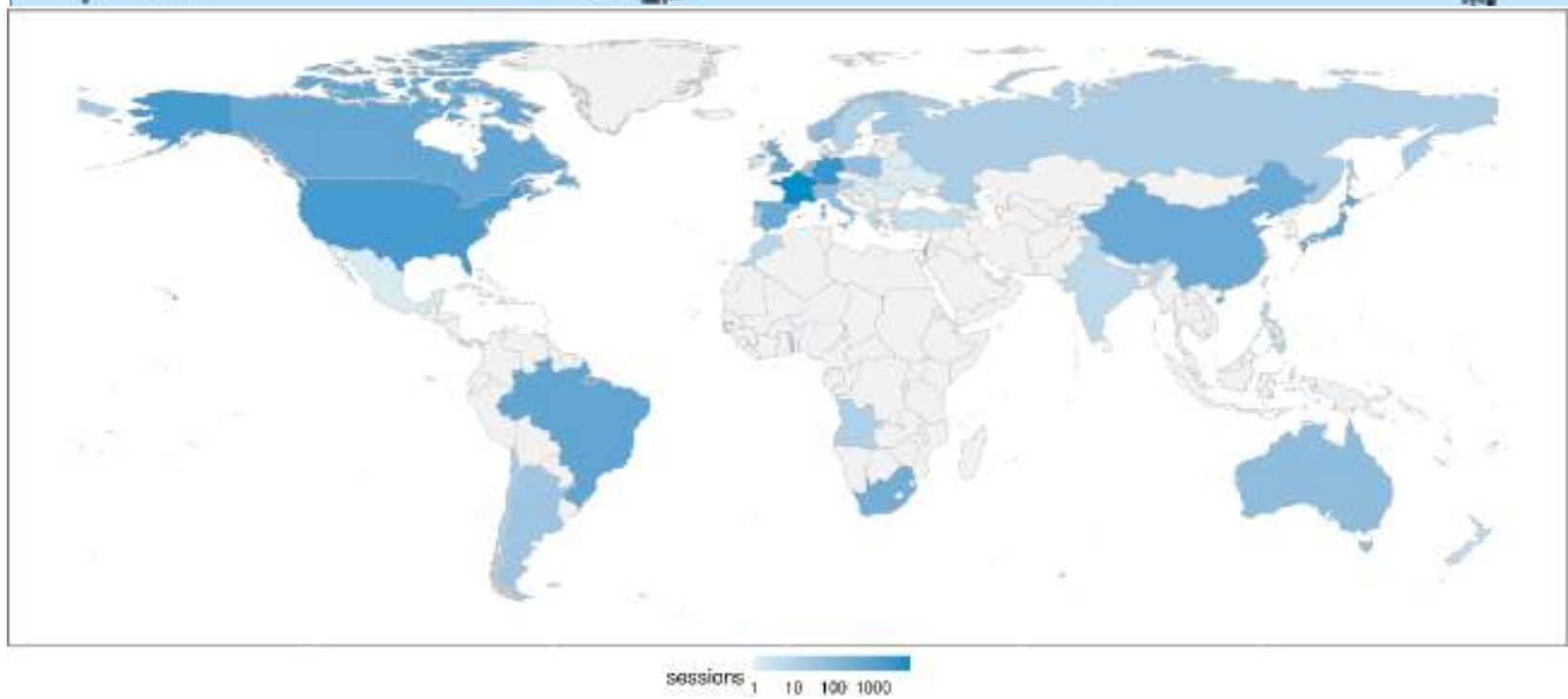
225M objects, 94M human-validated (41%)

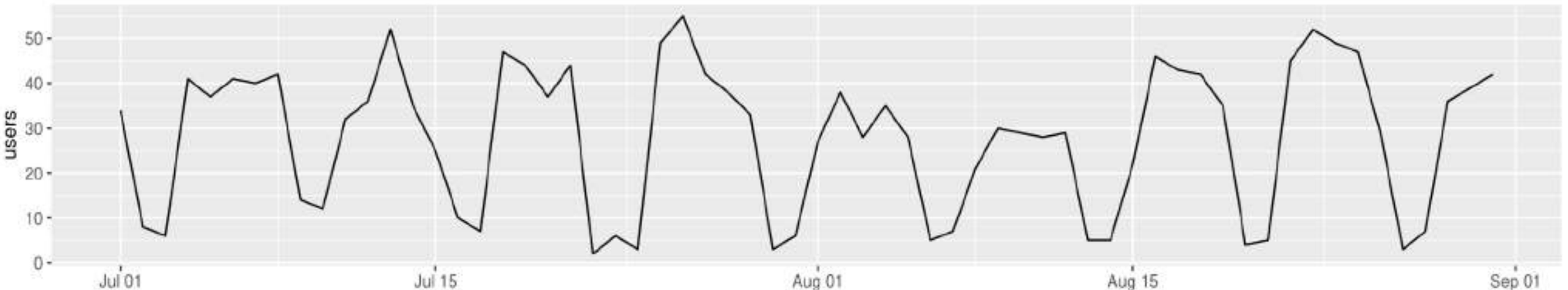
>100k locations in the world's oceans

1600 users, **500 organisations**, from various countries

40 concurrent users at all times





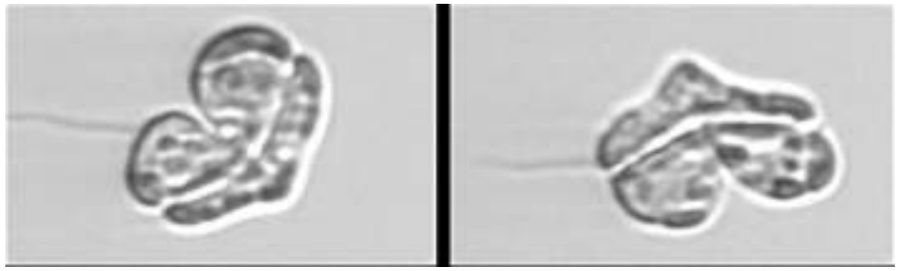


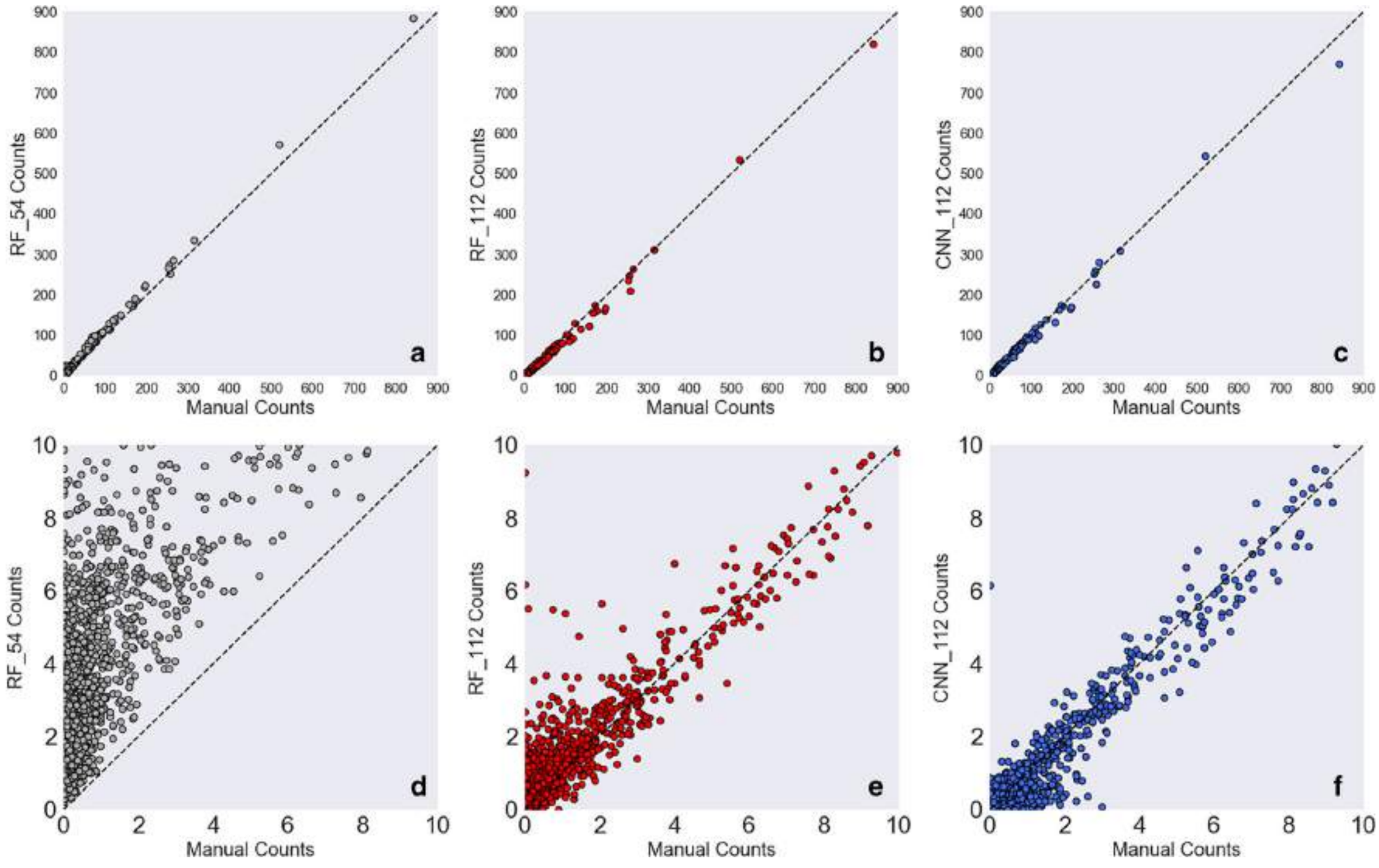
Ecology with plankton images

From small to large scales

Temporal patterns

Harmful algal bloom detection

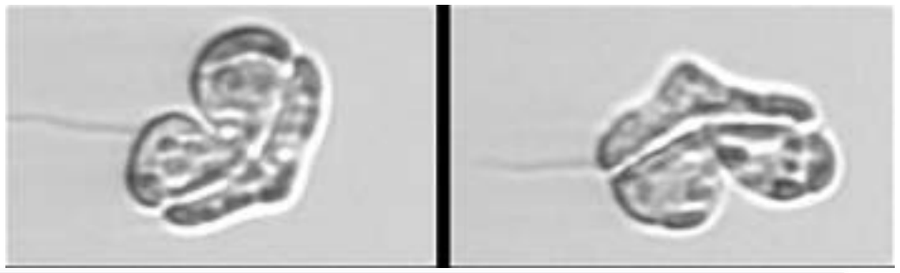


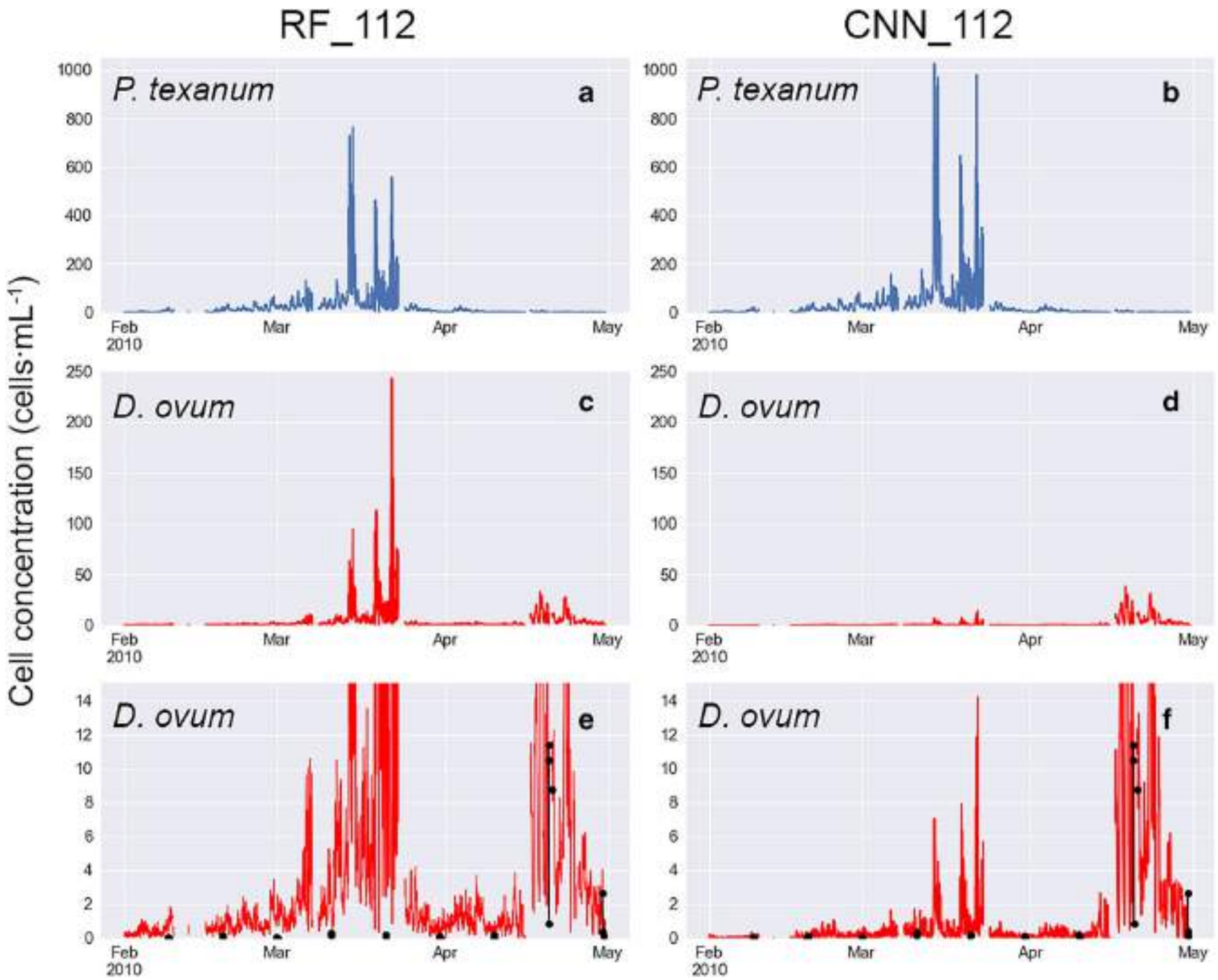


Henrichs DW, Anglès S, Gaonkar CC, Campbell L (2021) Application of a convolutional neural network to improve automated early warning of harmful algal blooms. Environ Sci Pollut Res.

Temporal patterns

Harmful algal bloom detection

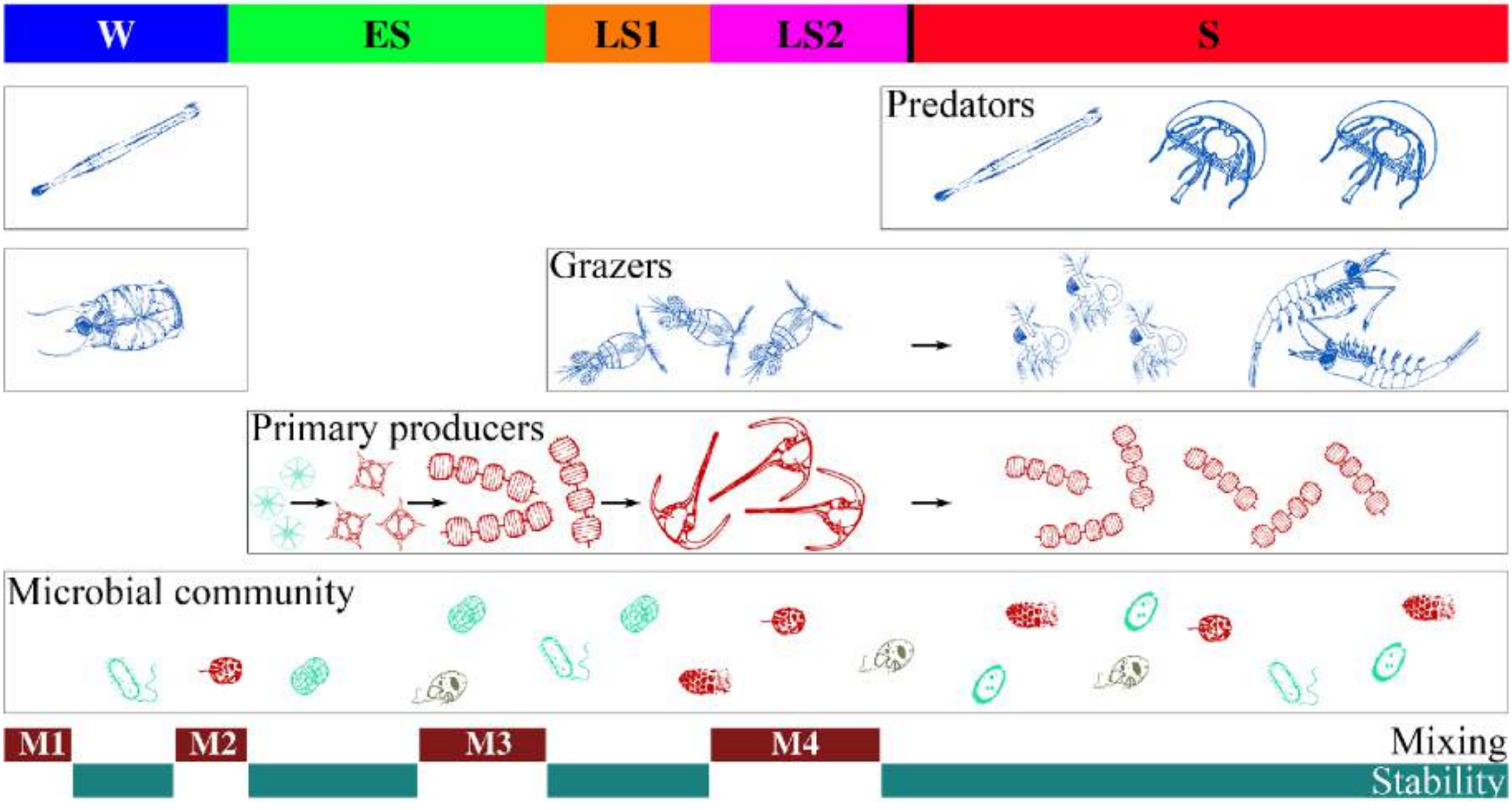




Henrichs DW, Anglès S, Gaonkar CC, Campbell L (2021) Application of a convolutional neural network to improve automated early warning of harmful algal blooms. Environ Sci Pollut Res.

Temporal patterns

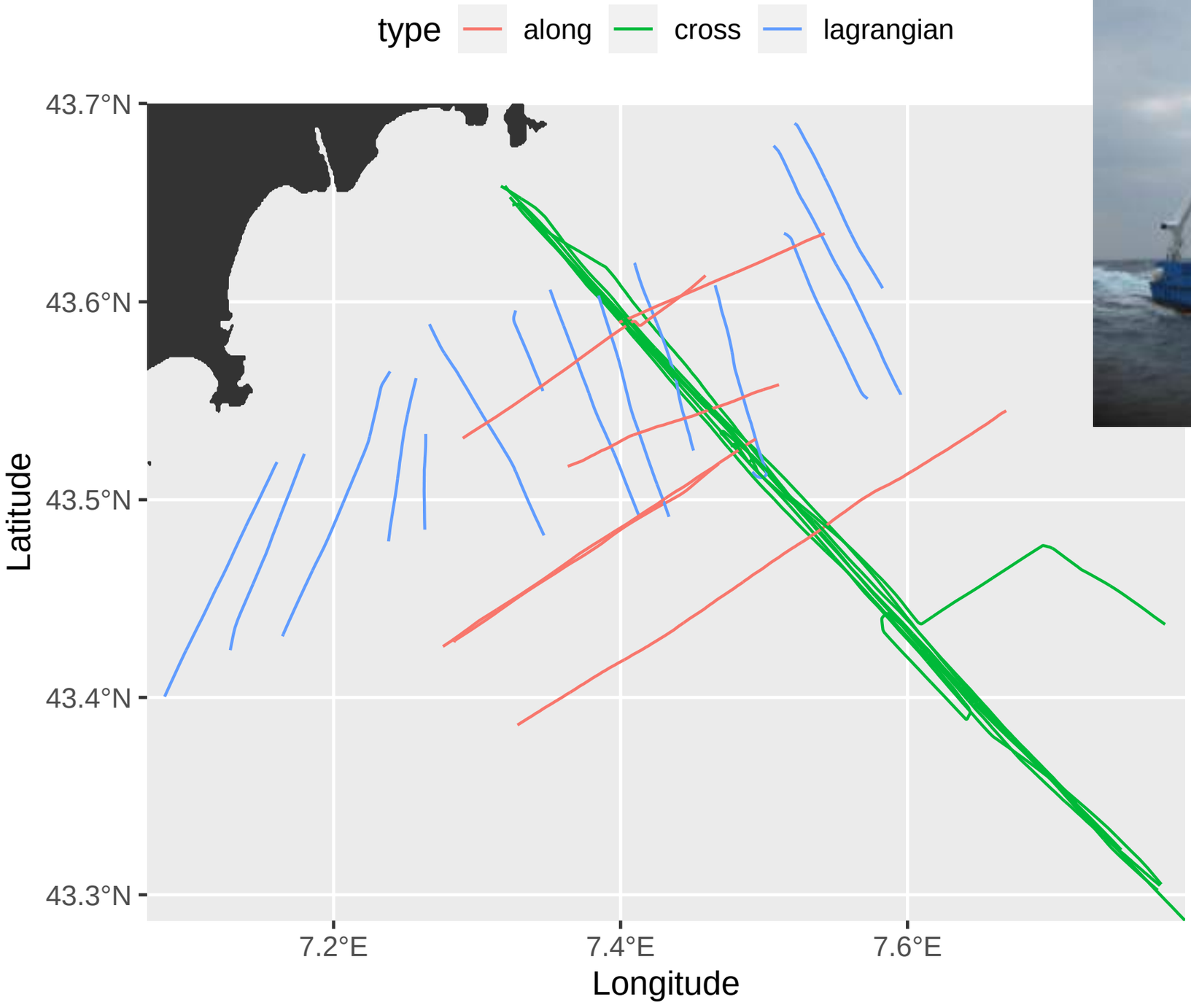
Ecological “stacking” rather than succession



Romagnan J-B, Legendre L, Guidi L, Jamet J-L, Jamet D, Mousseau L, Pedrotti M-L, Picheral M, Gorsky G, Sardet C, Stemmann L (2015) Comprehensive Model of Annual Plankton Succession Based on the Whole-Plankton Time Series Approach. PLOS ONE 10:e0119219.

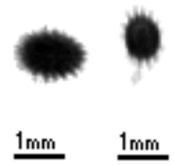
Spatial patterns

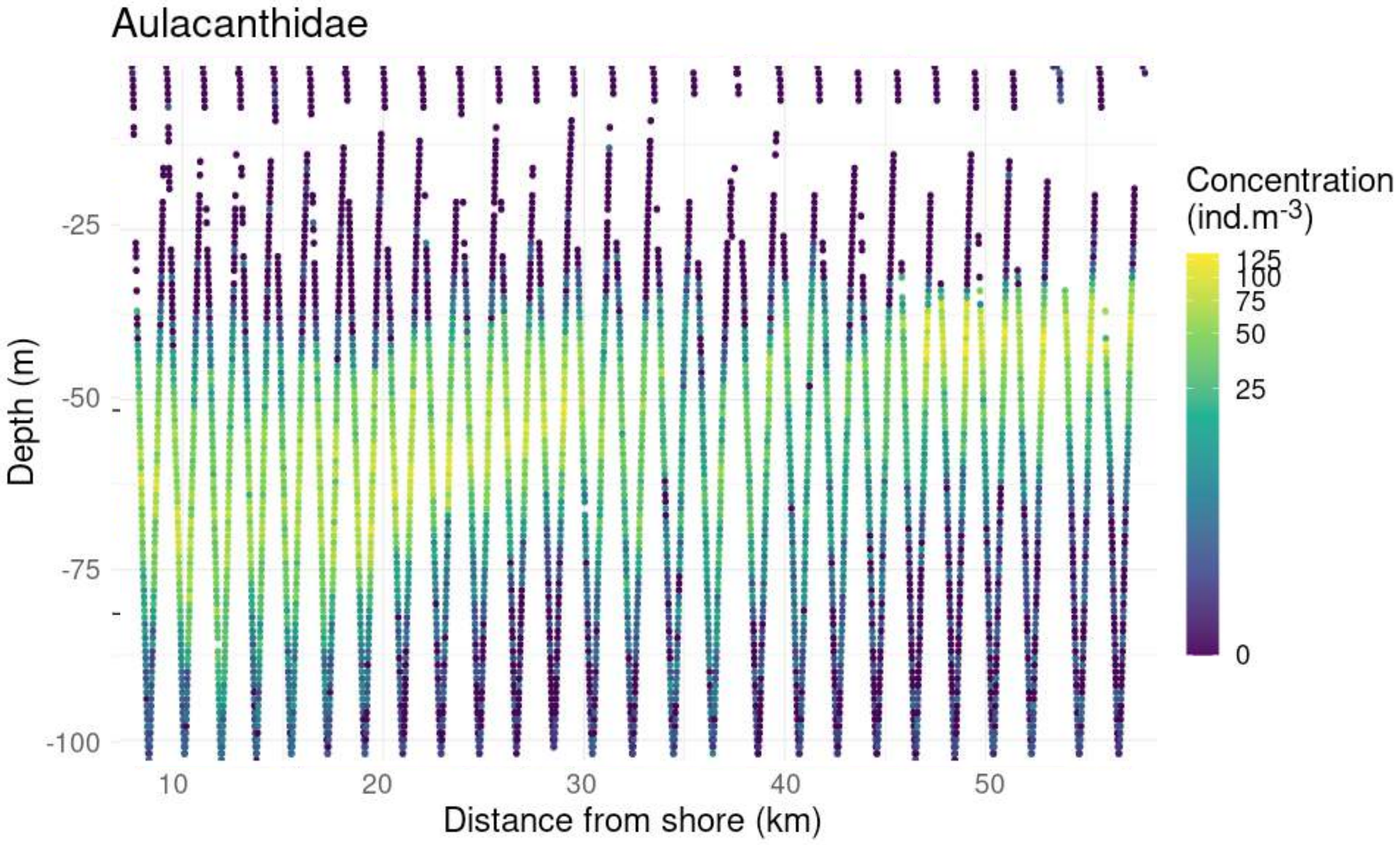
Mesoscale features drive fine scale distribution



Spatial patterns

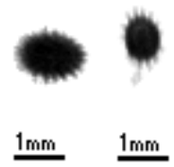
Mesoscale features drive fine scale distribution

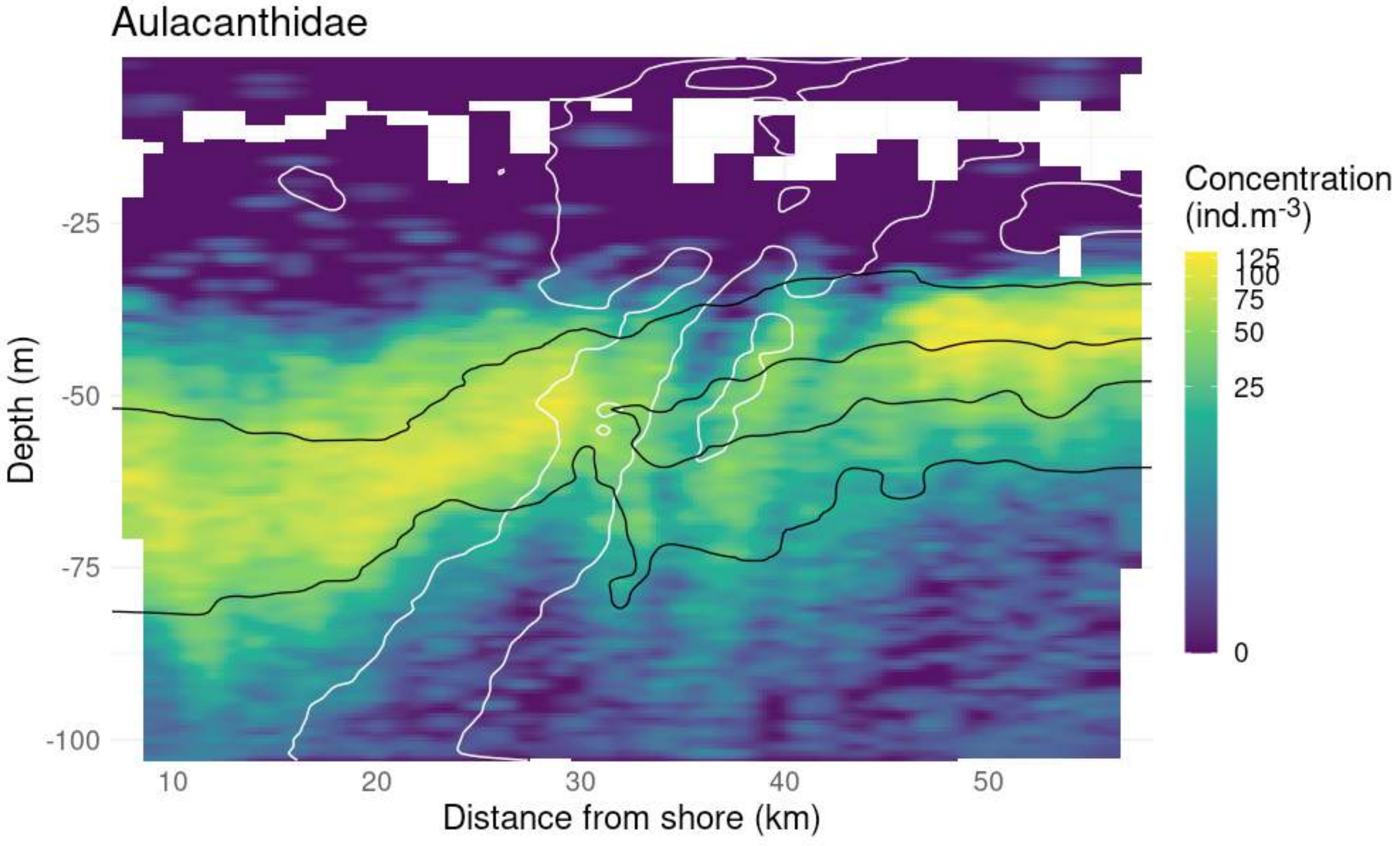




Spatial patterns

Mesoscale features drive fine scale distribution





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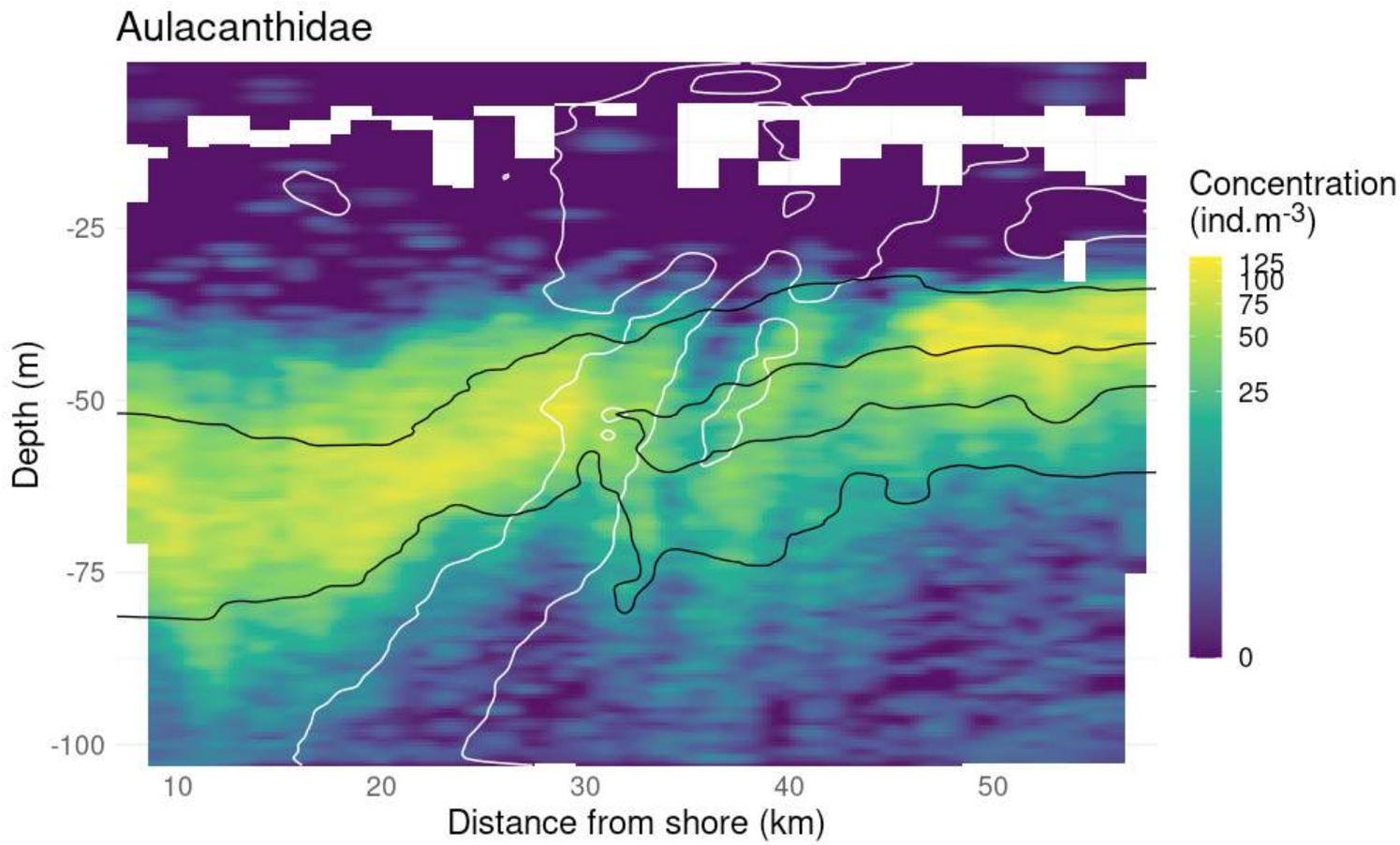
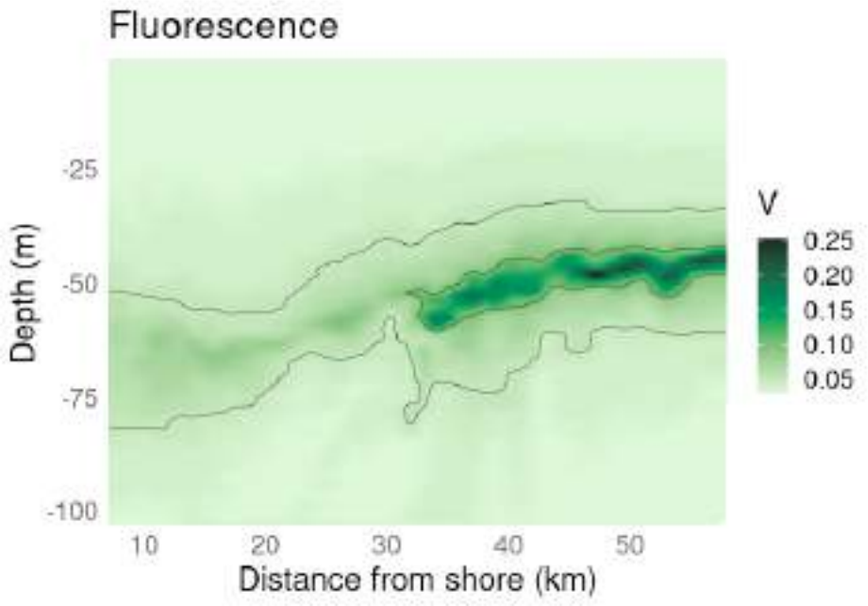
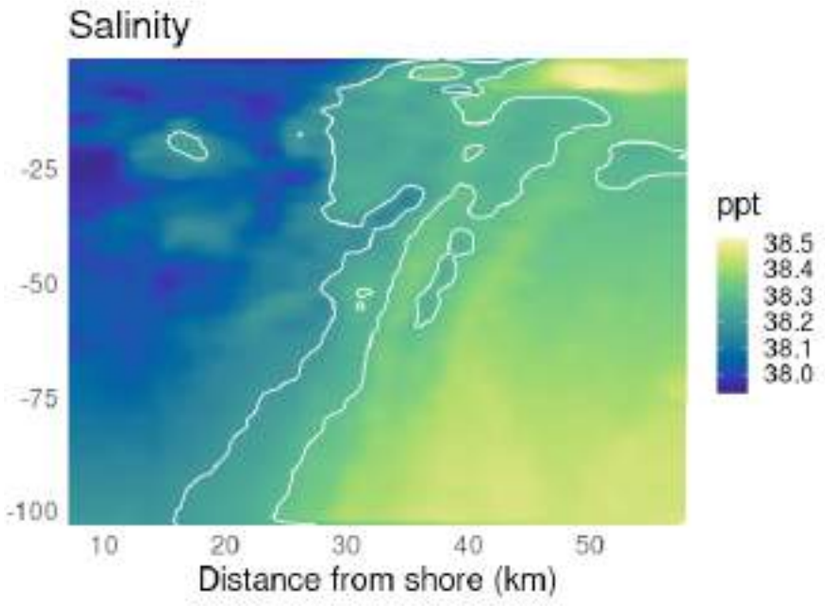
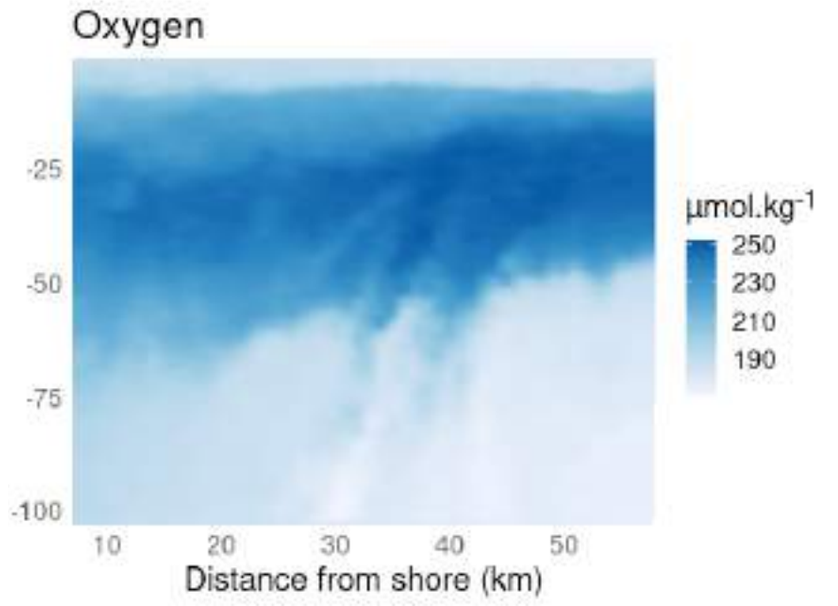
Mesoscale features drive fine scale distribution



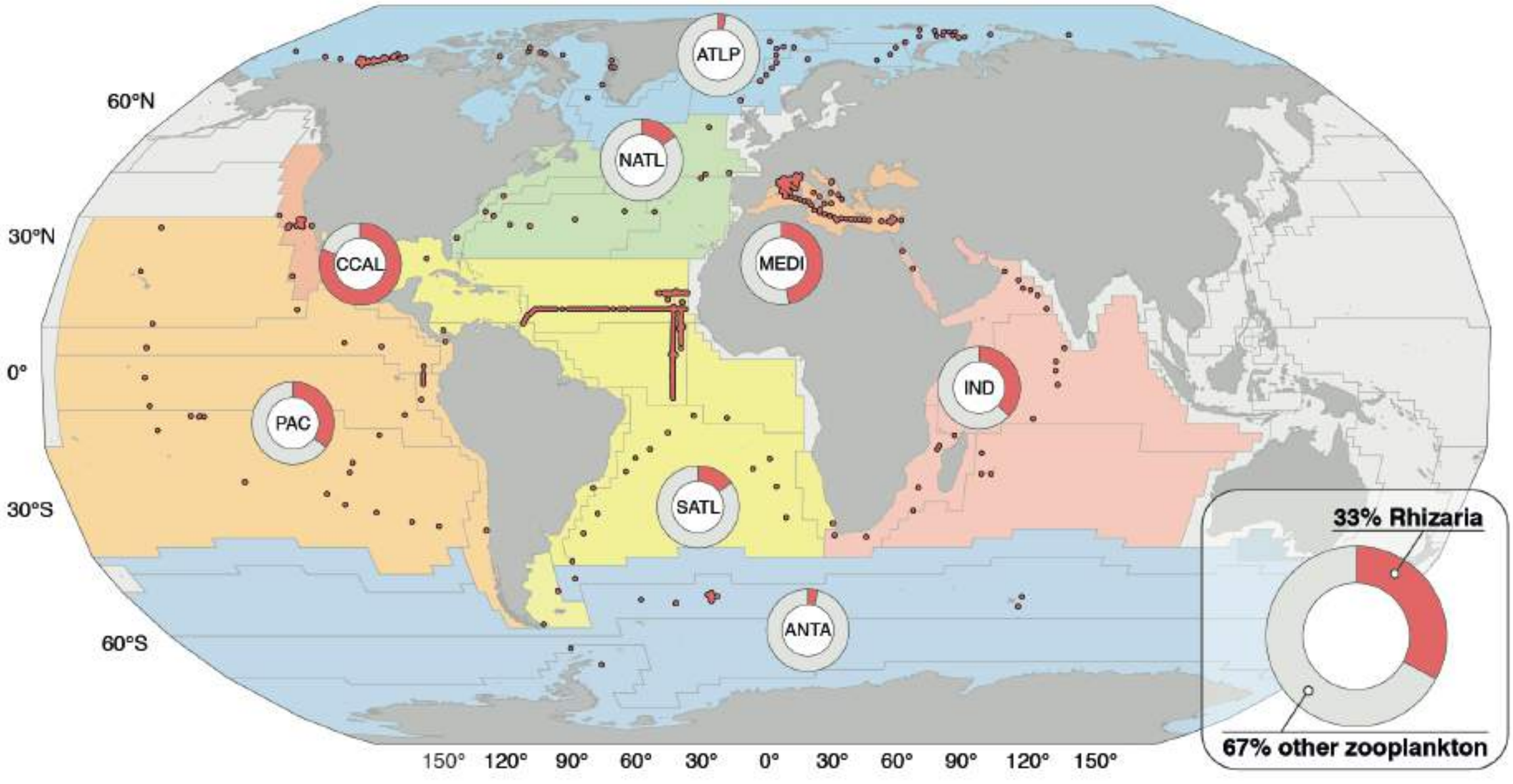






Spatial patterns

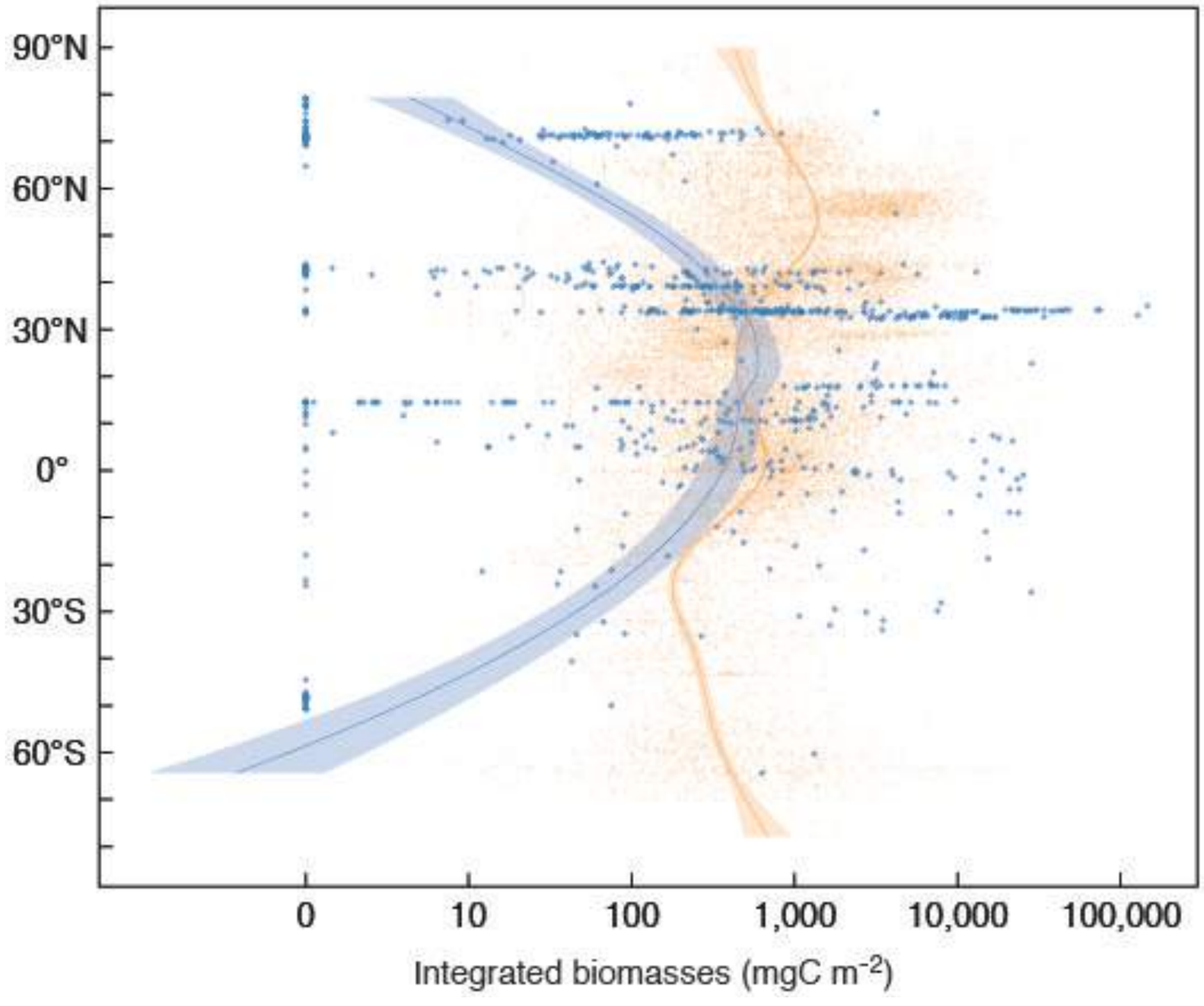
Biomass of fragile plankton



Biard T, Stemmann L, Picheral M, Mayot N, Vandromme P, Hauss H, Gorsky G, Guidi L, Kiko R, Not F (2016) In situ imaging reveals the biomass of giant protists in the global ocean. Nature 532:504.

Spatial patterns

Biomass of fragile plankton



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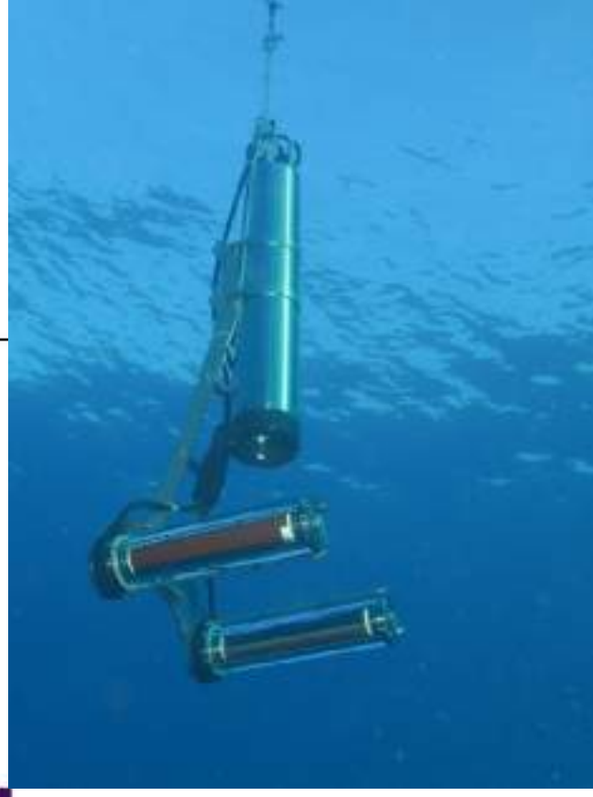
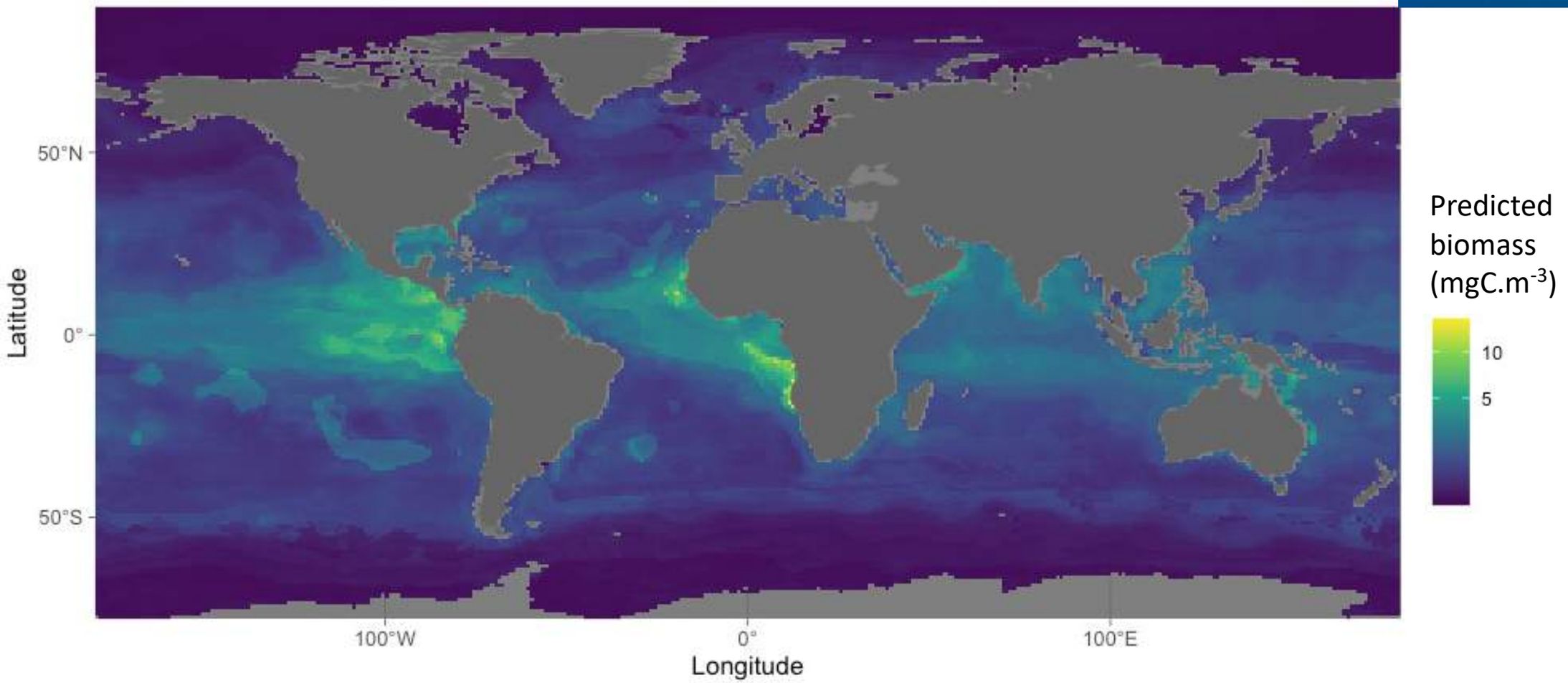


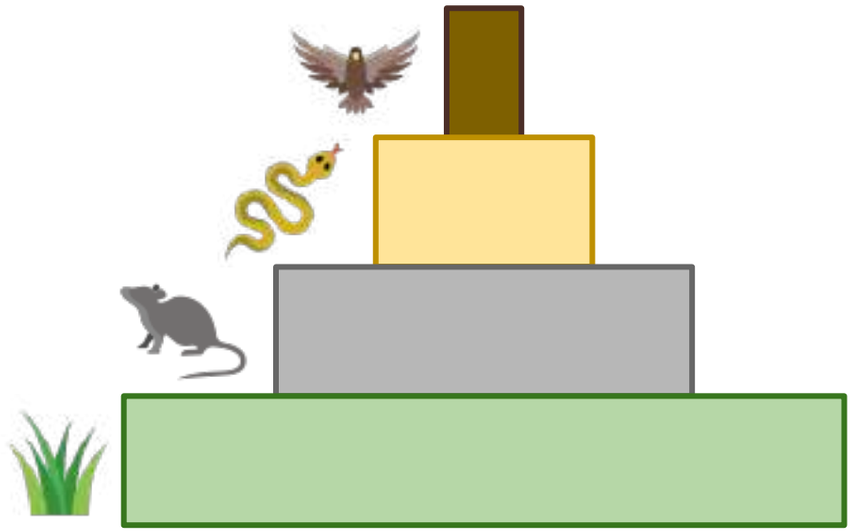
2mm

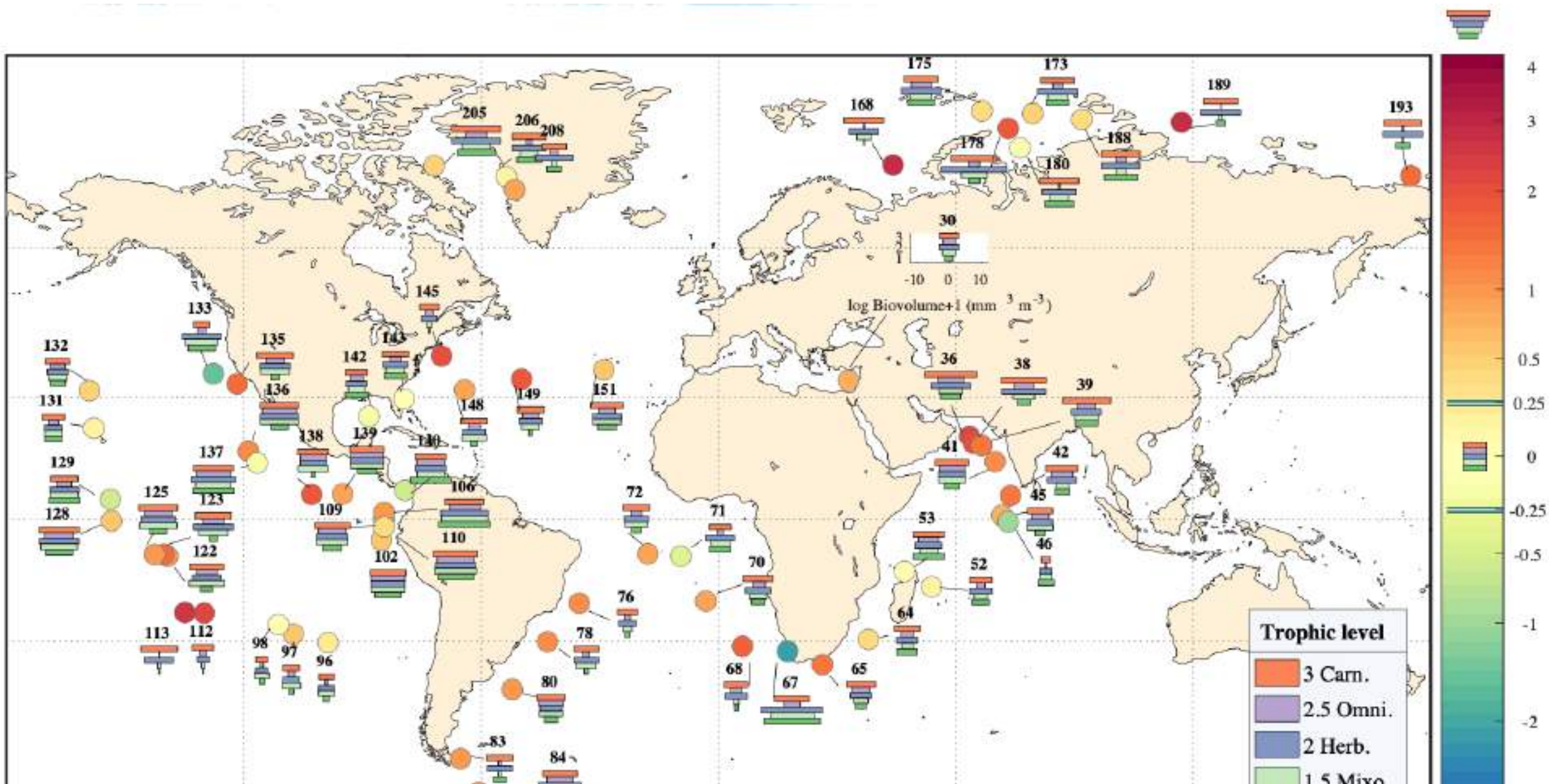


Drago L, Panaïotis T, Irisson J-O, Babin M, Biard T, Carlotti F, Coppola L, Guidi L, [...], Picheral M, Rogge A, Waite AM, Stemmann L, Kiko R (2022) Global Distribution of Zooplankton Biomass Estimated by In Situ Imaging and Machine Learning. Frontiers in Marine Science 9.

Functional patterns

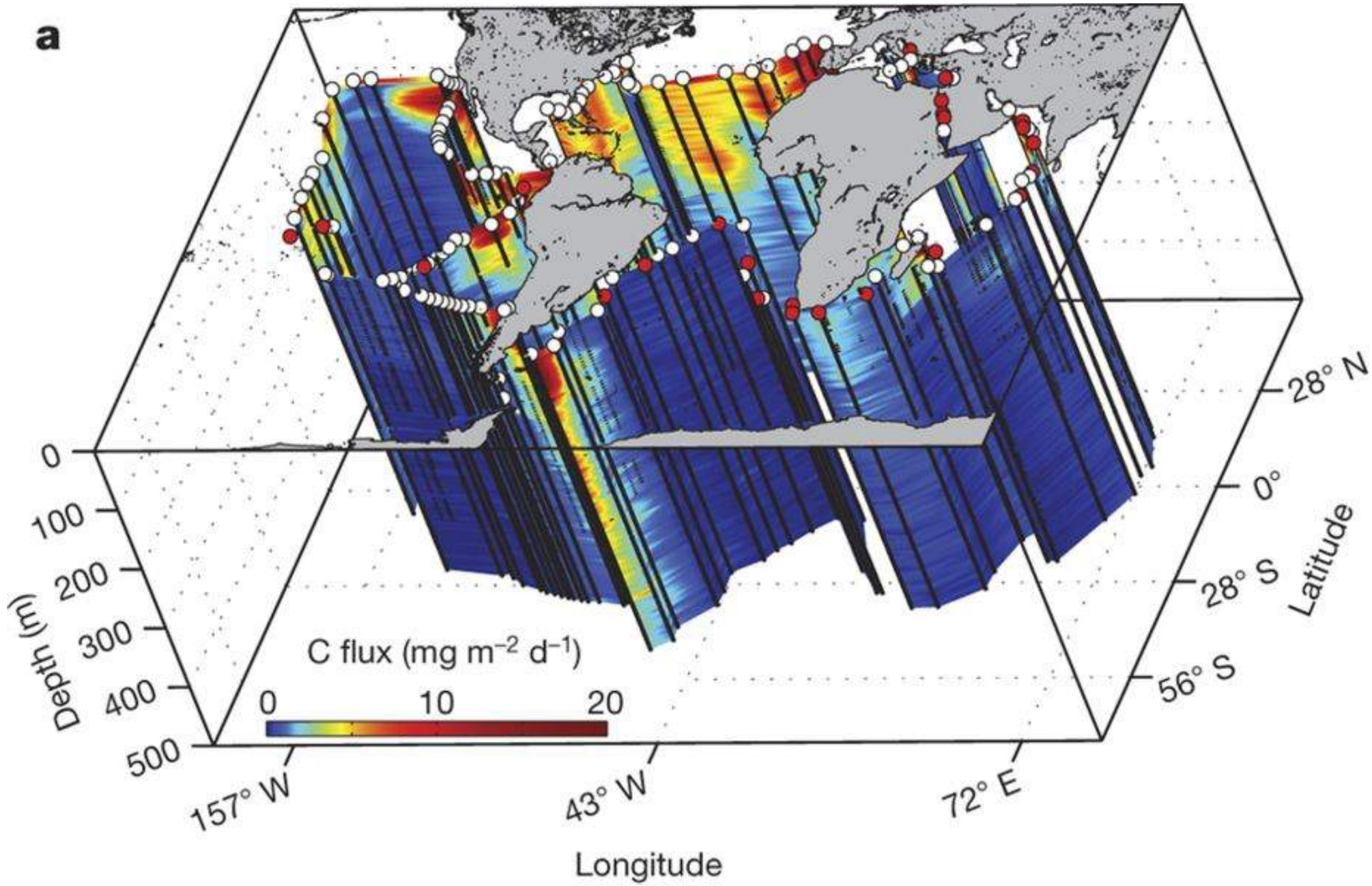
Trophic pyramids





Carbon export

Flux from images, players from genomics



Guidi L, Chaffron S, Bittner L, Eveillard D, Larhlimi A, Roux S, Darzi Y, Audic S, Berline L, [...], Gorsky G (2016) Plankton networks driving carbon export in the oligotrophic ocean. Nature 532:465–470.

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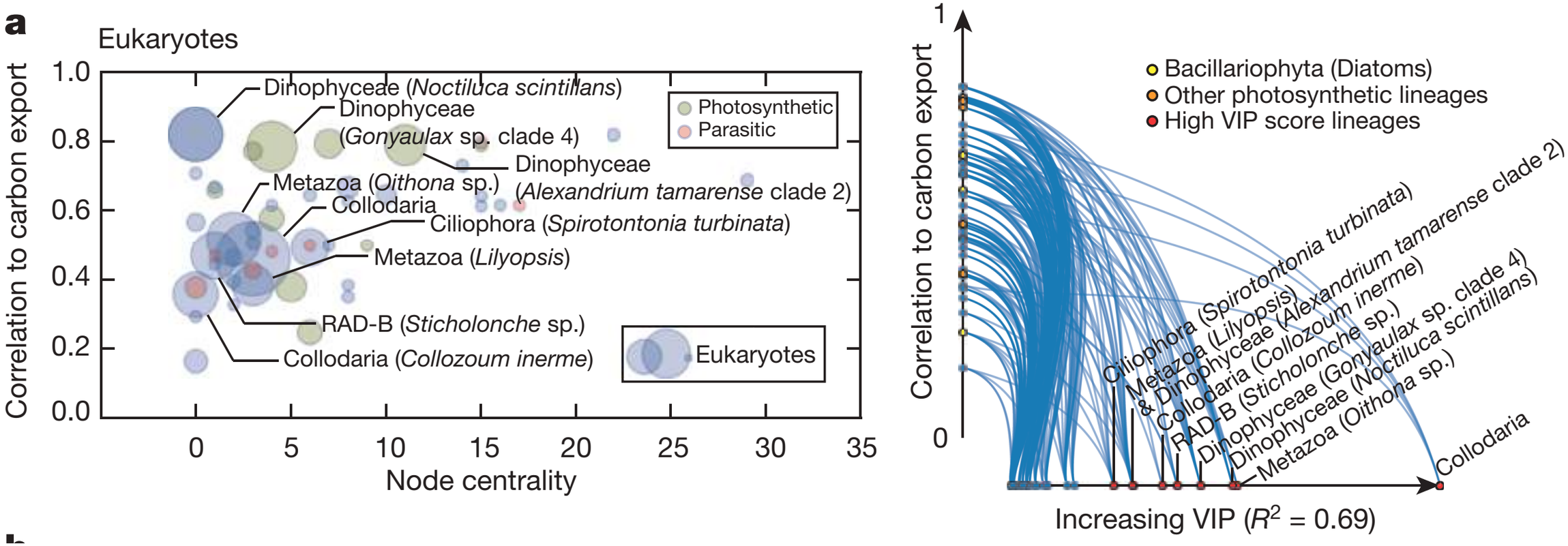

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Ecological traits

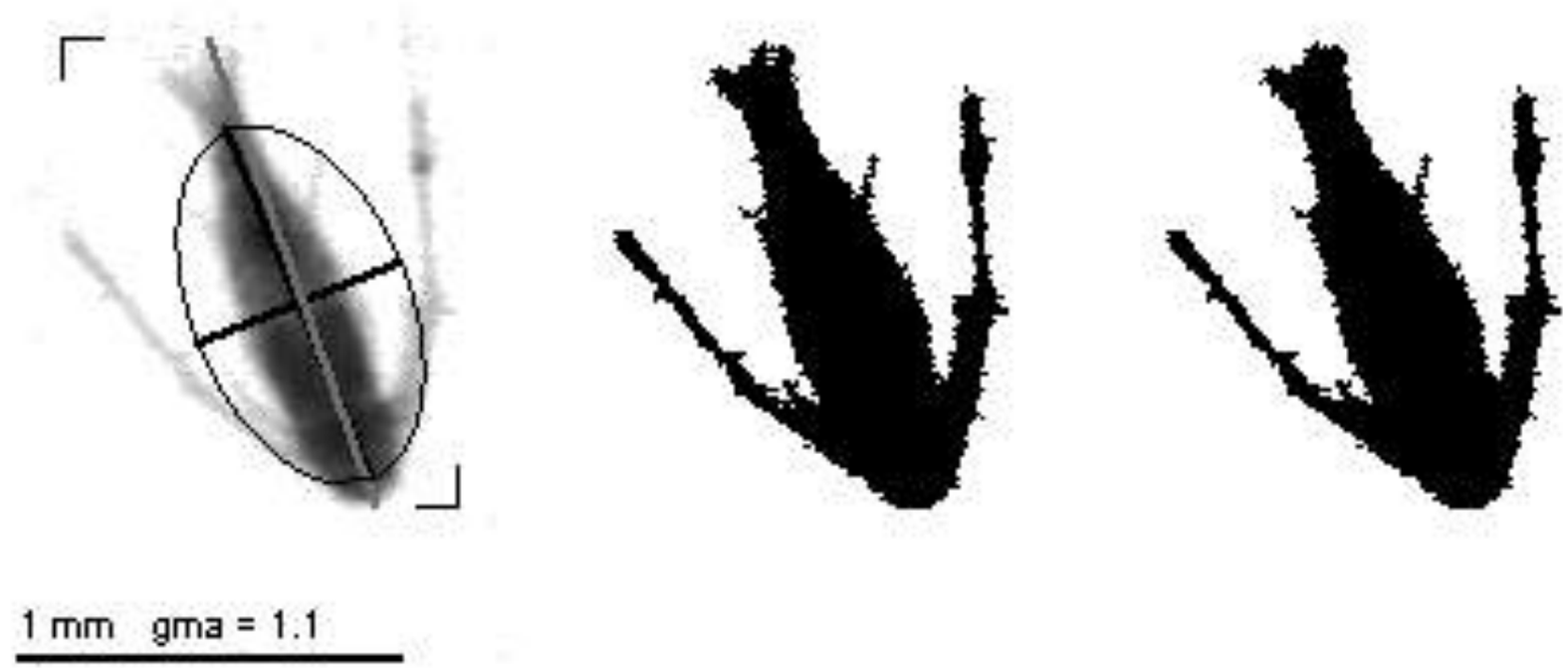
Images provide individual traits measurements

Area (ESD)
Major/minor
⇒ Size

Mean/SD of grey
⇒ Opacity

Angle of ellipse
⇒ Orientation

Perimeter
Fractal measurement
⇒ Appendages



Ecological traits

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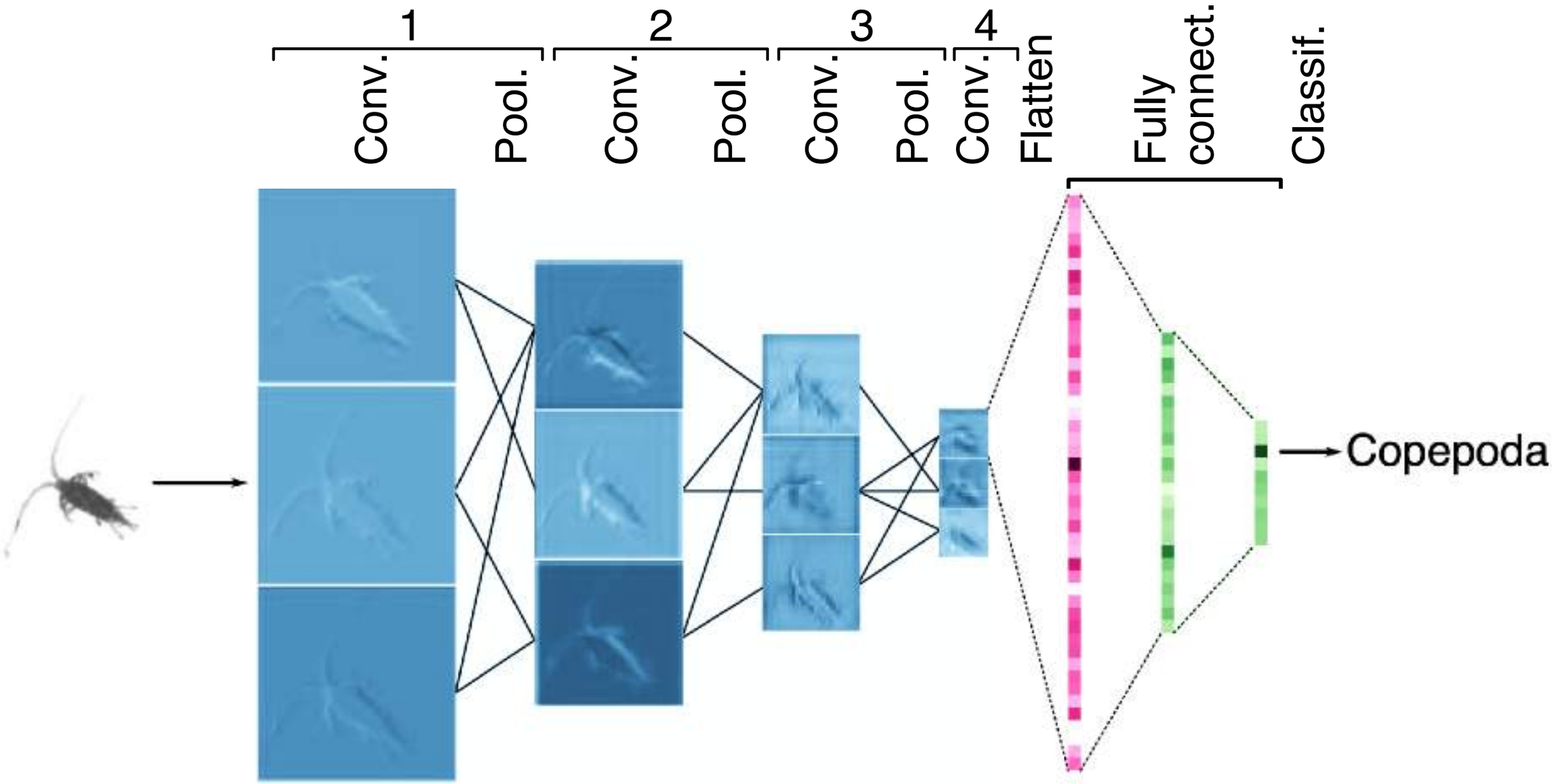
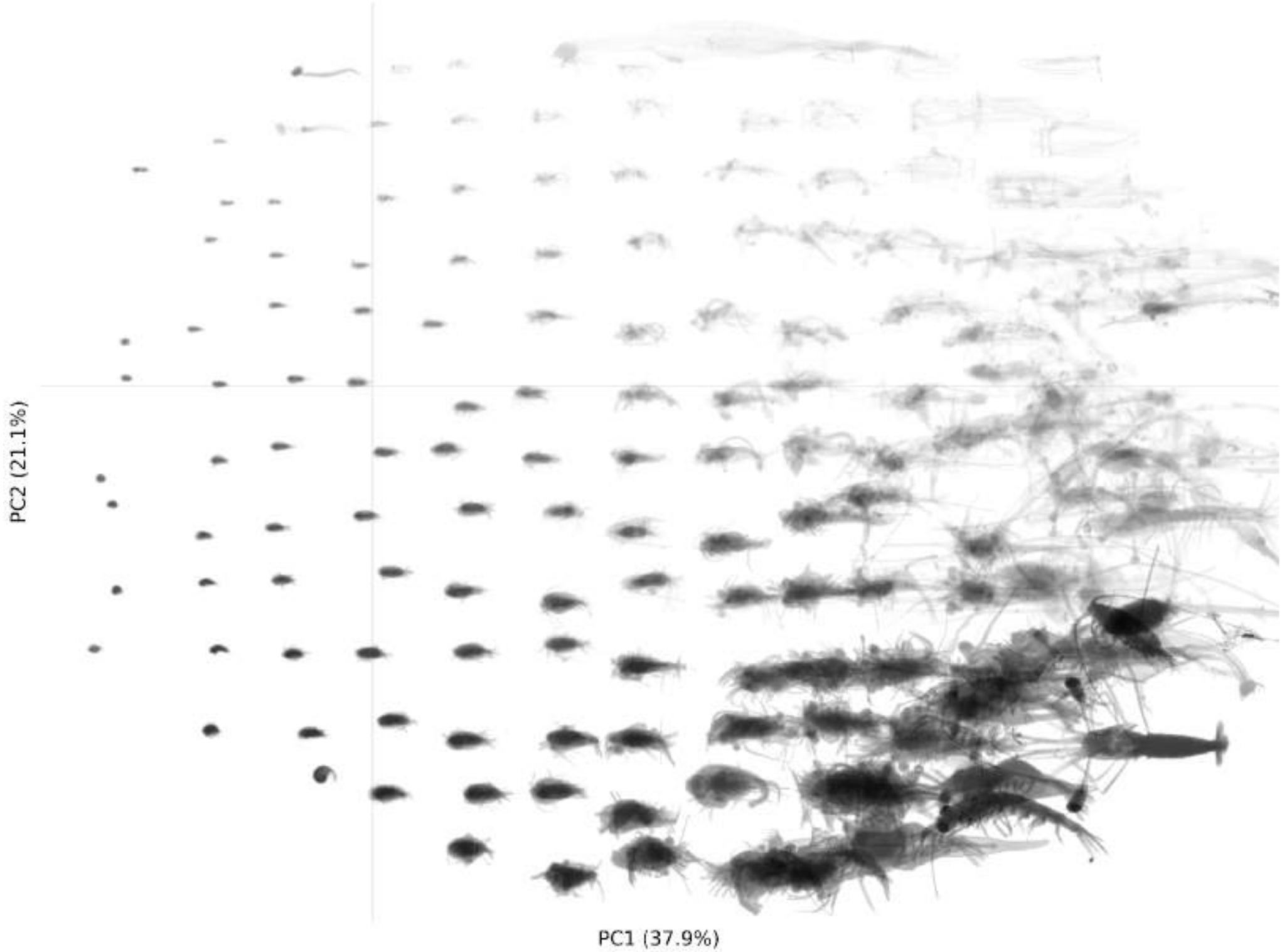


Ecological traits

Diversity of zooplankton morphology



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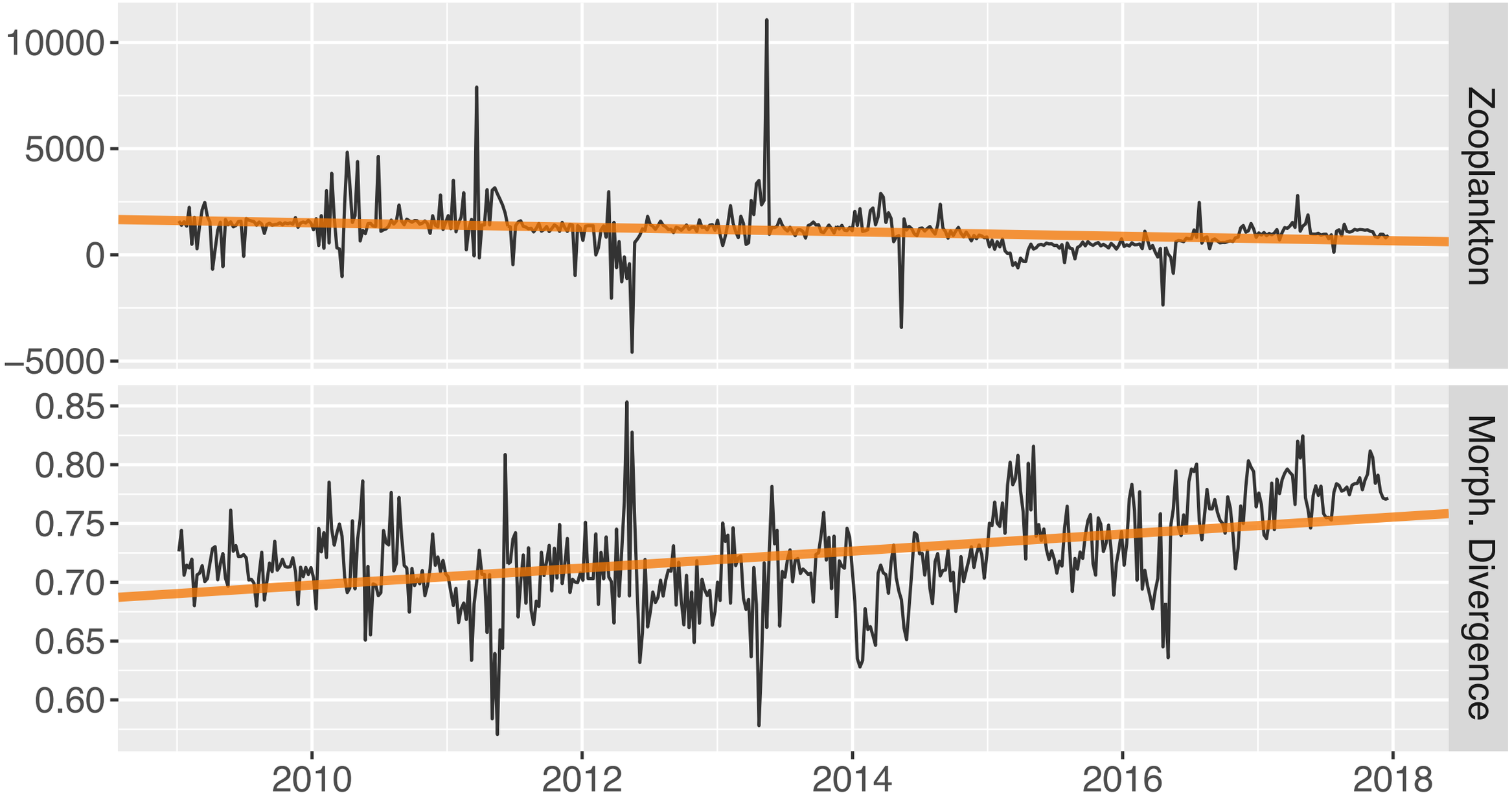
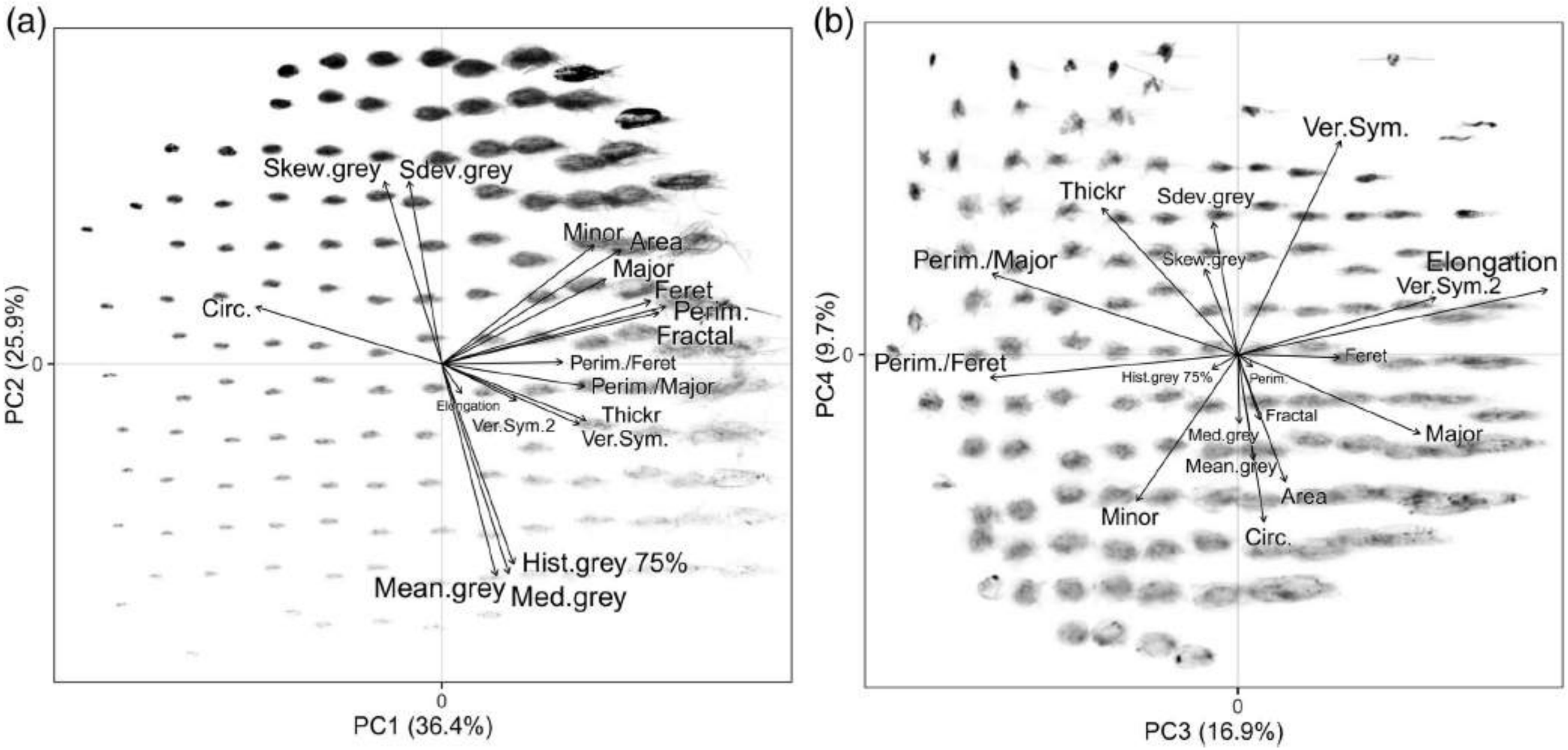


Ecological traits

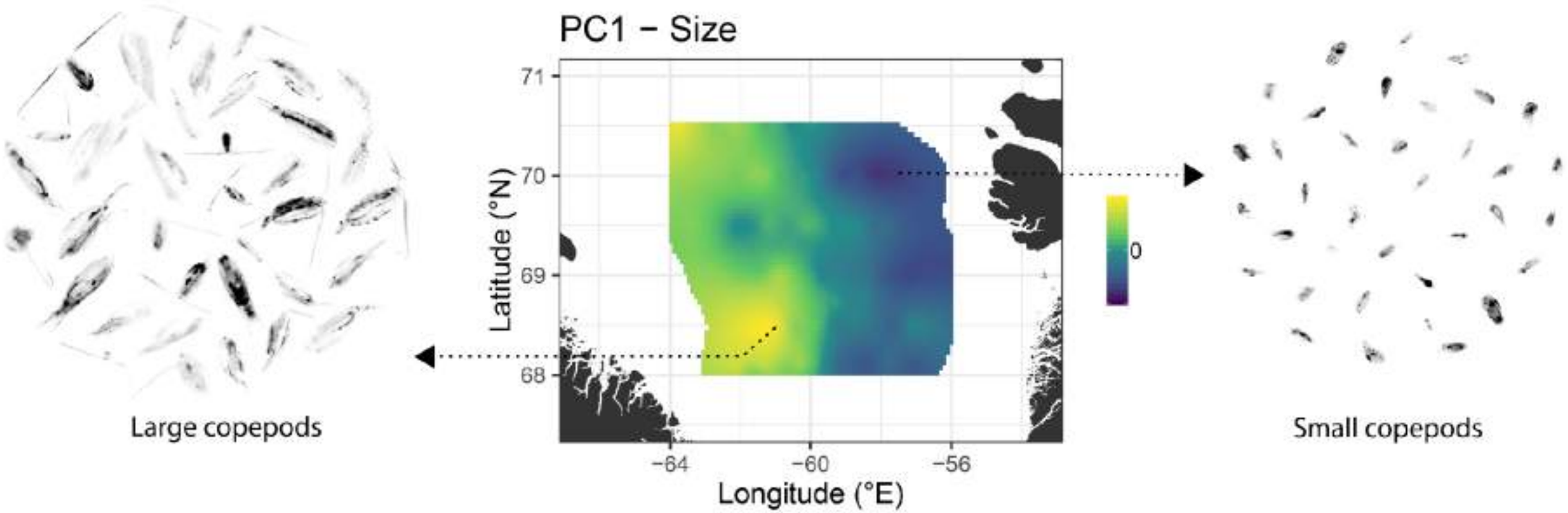
In situ behaviour of organisms



Vilgrain L, Maps F, Picheral M, Babin M, Aubry C, Irisson J-O, Ayata S-D (2021) Trait-based approach using in situ copepod images reveals contrasting ecological patterns across an Arctic ice melt zone. Limnology and Oceanography 66:1155–1167.

Ecological traits

In situ behaviour of organisms



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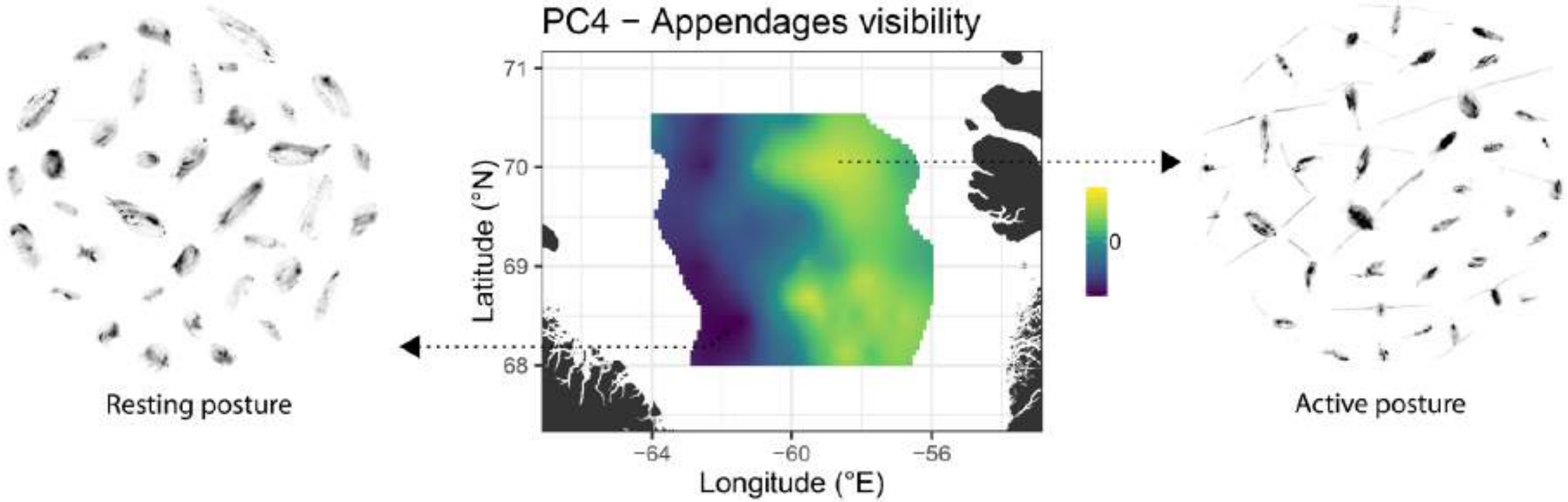

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Merci