# BIOS3300/4300 - Marine Biology

## **Primary Production (Plankton)**
## Long term observations

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# Outline

- Introduction to long term observation
  - Why ?
  - Where ?
- Some examples
  - Continuous Plankton Recorder
  - Hawaii
  - Bermuda
- Periodicity in plankton species occurrence
  - English Channel - Roscoff
  - Mediterranean Sea - Blanes
- Plankton species dynamics
  - *Synechococcus* in Woods Hole

# Reference material


- Bunse, C. & Pinhassi, J. 2017. Marine Bacterioplankton Seasonal Succession Dynamics. Trends in Microbiology. 25:494–505.
- Karl, D.M. & Church, M.J. 2014. Microbial oceanography and the Hawaii Ocean Time-series programme. Nature Reviews Microbiology. 12:699–713.
- Hunter-Cevera et al. 2016. Physiological and ecological drivers of early spring blooms of a coastal phytoplankter. Science 354:326–329.

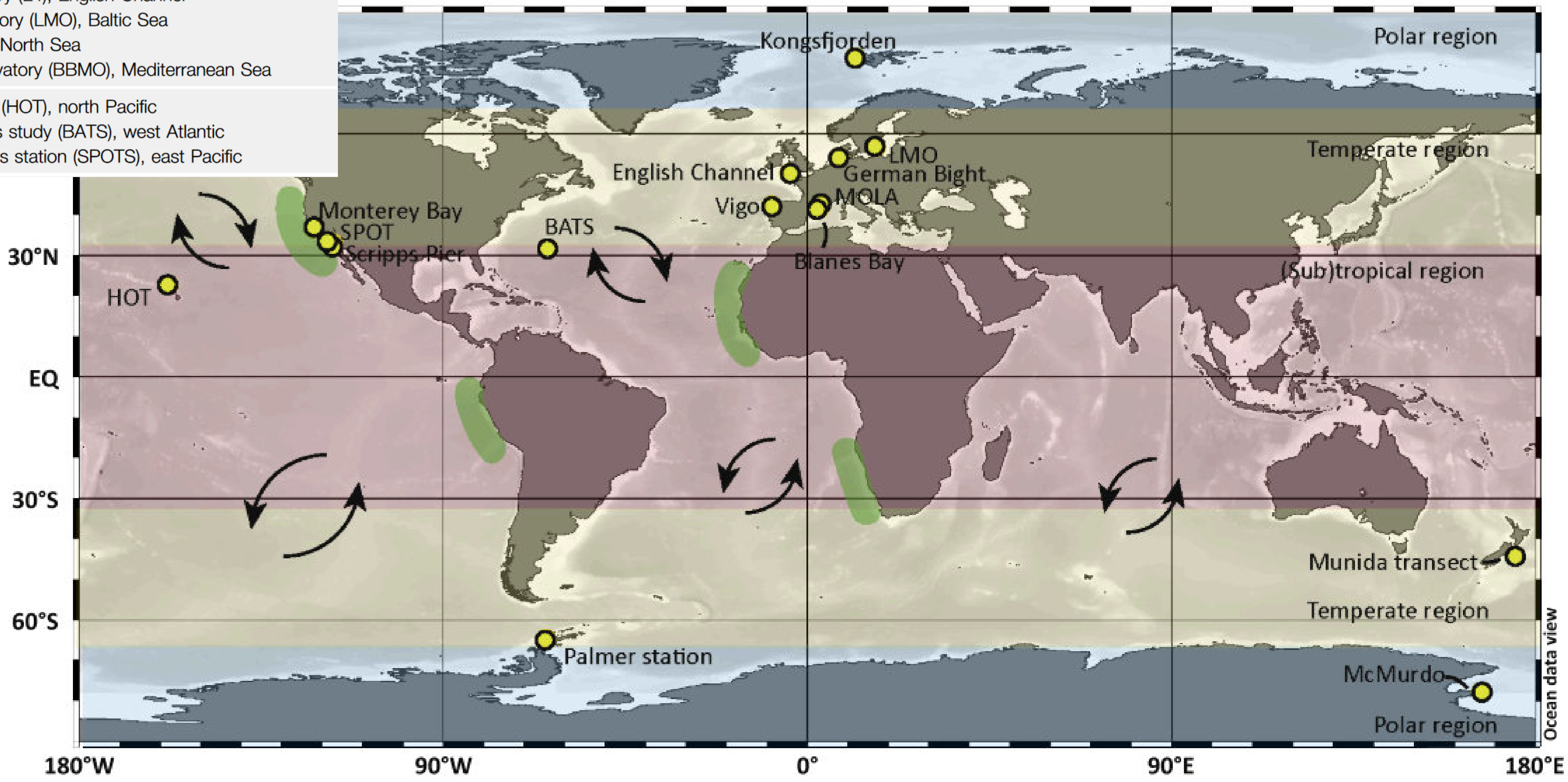

# Introduction to time series

# Questions to be solved by time series

- Monitoring the environment
  - changes in biomass & production
  - changes in species composition
- What are the key periodicities ?
  - annual (what about equator ?)
  - tides (monthly)
  - daily (light-dark cycle)
- Are species recurring from one year to the next ?
- What drives the year to year variability
- Long term climatic trends

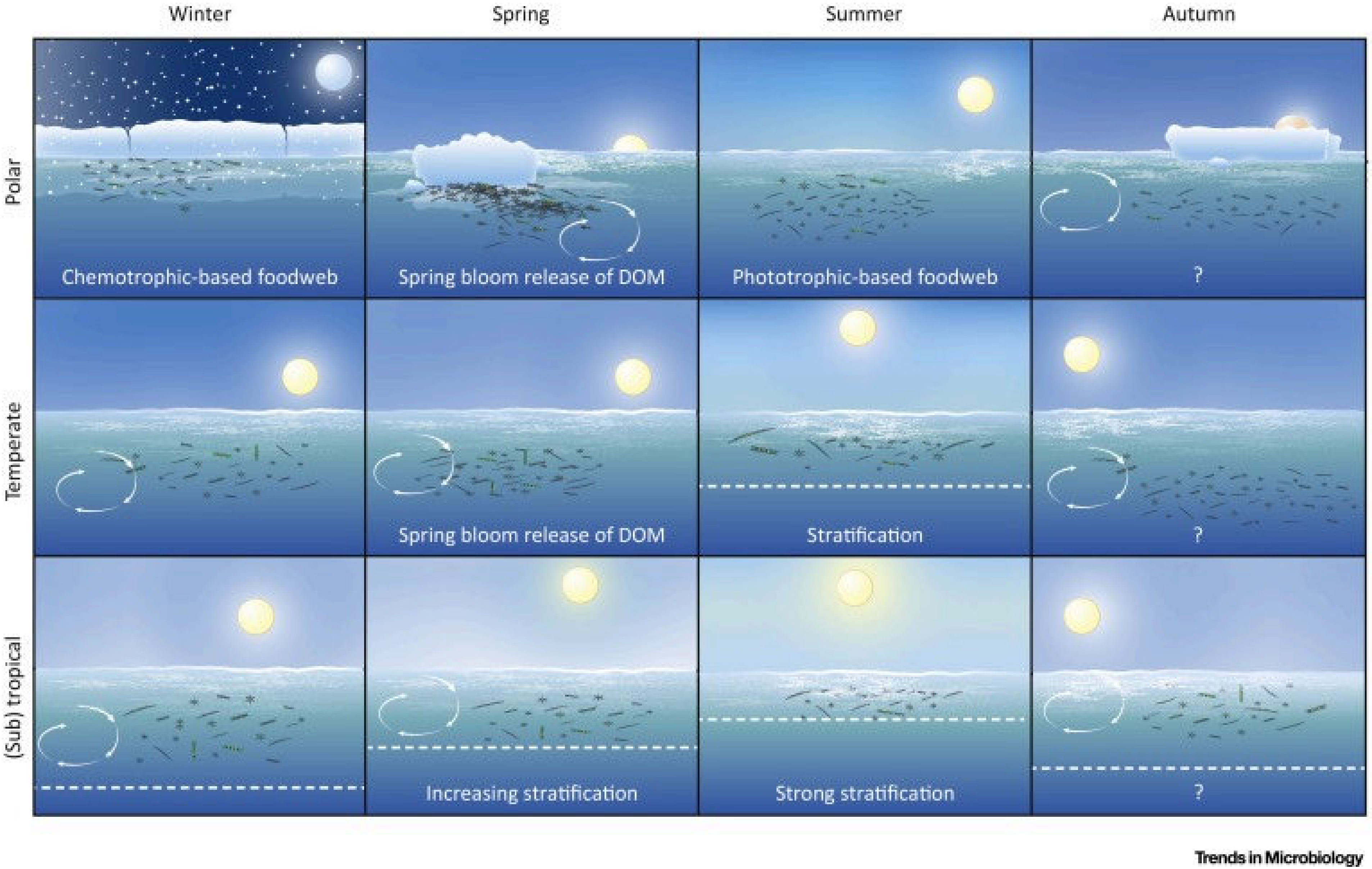
# Long term pelagic time series

| Region | Location |
|---|---|
| Polar | Antarctic Peninsula<br>Franklin Bay, Western Arctic |
| Temperate | RADIALES time-series project (E2), east Atlantic<br>Western Channel Observatory (L4), English Channel<br>Linnaeus Microbial Observatory (LMO), Baltic Sea<br>German Bight (Kabeltonne), North Sea<br>Blanes Bay Microbial Observatory (BBMO), Mediterranean Sea |
| (Sub)- Tropical | Hawaiian Ocean time-series (HOT), north Pacific<br>Bermuda Atlantic time-series study (BATS), west Atlantic<br>San Pedro Ocean time-series station (SPOTS), east Pacific |




Bunse C., Pinhassi J. 2017. Marine Bacterioplankton Seasonal Succession Dynamics. Trends in Microbiology 25:494–505.

# Long term pelagic time series




Bunse C., Pinhassi J. 2017. Marine Bacterioplankton Seasonal Succession Dynamics. Trends in Microbiology 25:494–505.

# Some examples

# Continuous Plankton Recorder (CPR)

# Continuous Plankton Recorder (CPR)

- conceived in 1920’s by Sir Alistair Hardy
- started in 1931
- North Atlantic
- 280 000 samples analyzed
- https://www.cprsurvey.org

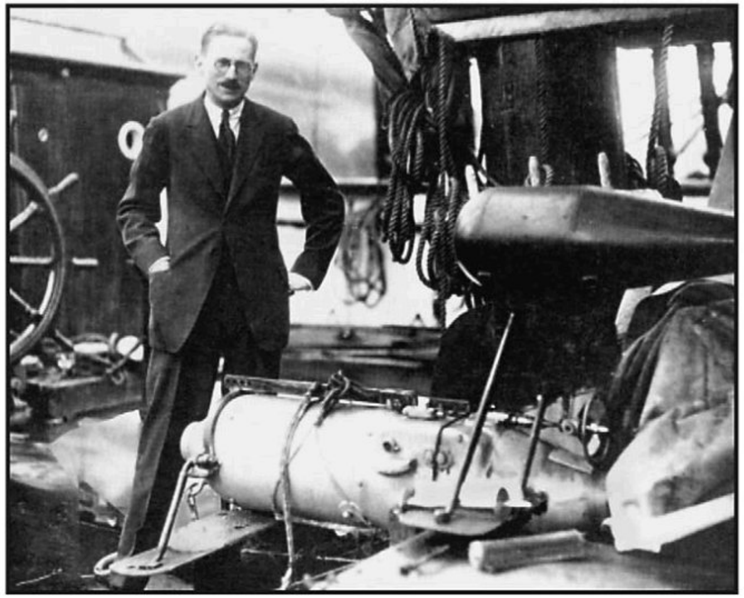


Fig. 2. Alister Hardy and CPR Type I on RRS *Discovery*.

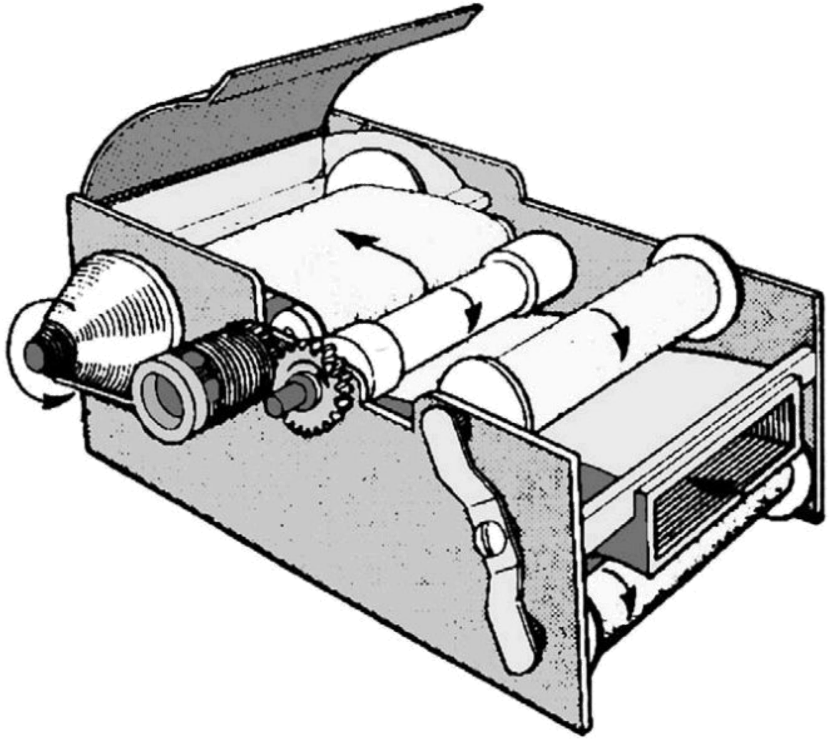


Fig. 5. Drawing of cassette plankton sampling mechanism (PSM) with arrows showing the movement of the silks from the filtering and covering reels to the storage tank. The lid of the tank is open. To the left, indicated by the circular arrow, the fusee mechanism with tightened wire, used to adjust the tension on the rolled up silks.

Reid et al. 2003. The Continuous Plankton Recorder: concepts and history, from Plankton Indicator to undulating recorders. Progress in Oceanography. 58:117–73.

# Instrumentation

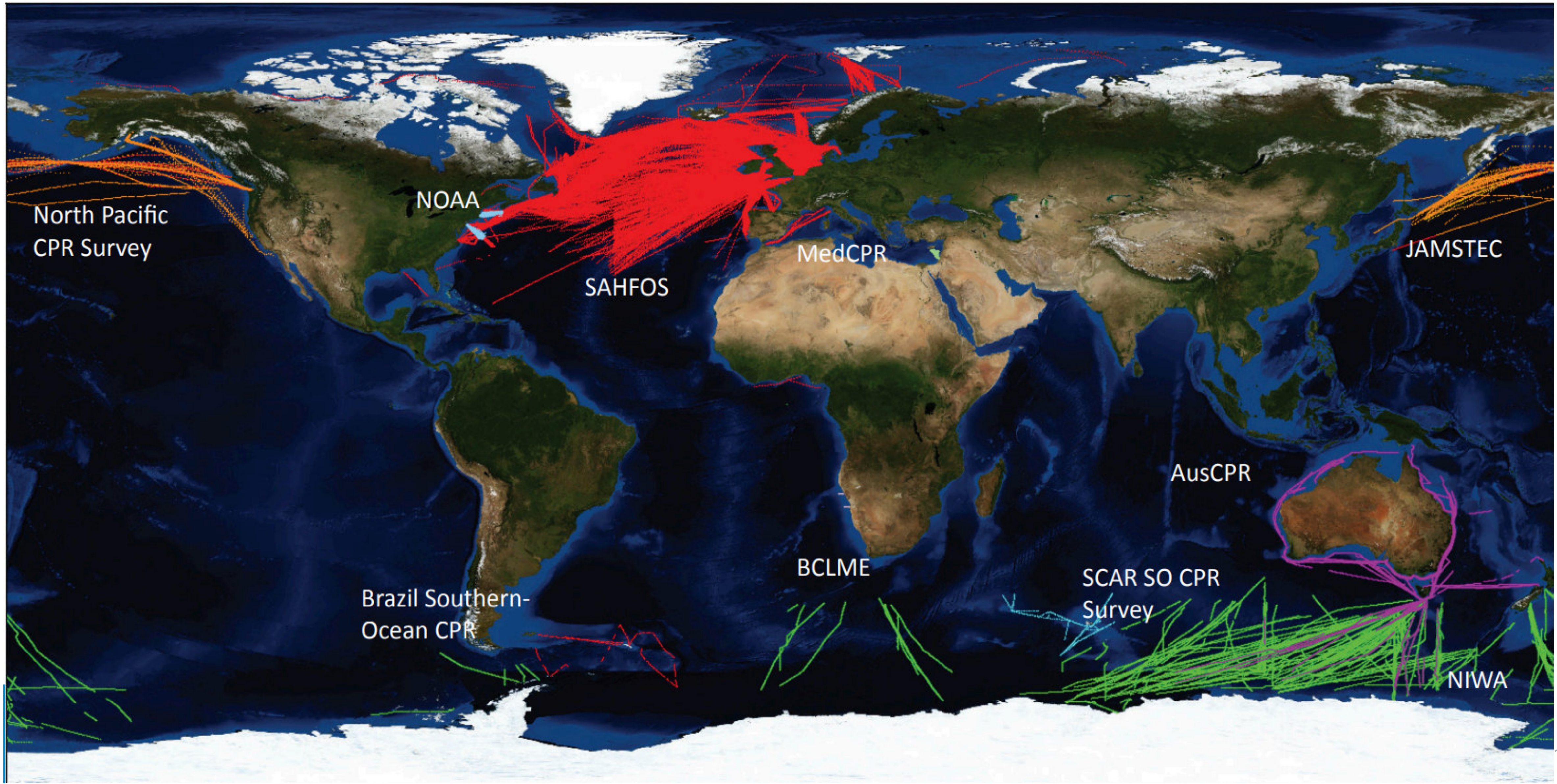
- Plankton collection

- Temperature
- Salinity
- Fluorescence


# Ship lines

LR & V- Eimskip: Lagarfoss
M- Sea Cargo: SC Express
DJ & DI Smyril Line: Norrona
IN P&O: Norbay
ST Bring: Norbjorn
IB, SA & SB MacAndrews : Encounter Vega Reederie: Vega Philipp
NI, MD & MC Eimskip: Skogafoss
North Atlantic
ST
NI
DJ
DI
A
M
V
Z
ZB
ZC
KC
C
LG
IN
LR
IB
HE
R
D
DA
PR
BA
SA
BB
BC
BD
SB
MC
MD
EB
EA
MB
A- SERCO Northlink Ferries: Hildasay
EA & EB D- & DA ACL: Atlantic Sea
PR Brittany Ferries: Armorique
C- DFDS: Petunia Seaways
HE DFDS: Hafnia Seaways
MB Container Line: Oleander
Z's Eimskip: Reykjafoss & Selfoss
B's MMD/ Geest Line: Benguela Stream
LG DFDS: Primula Seaways
R- DFDS: Anglia Seaways

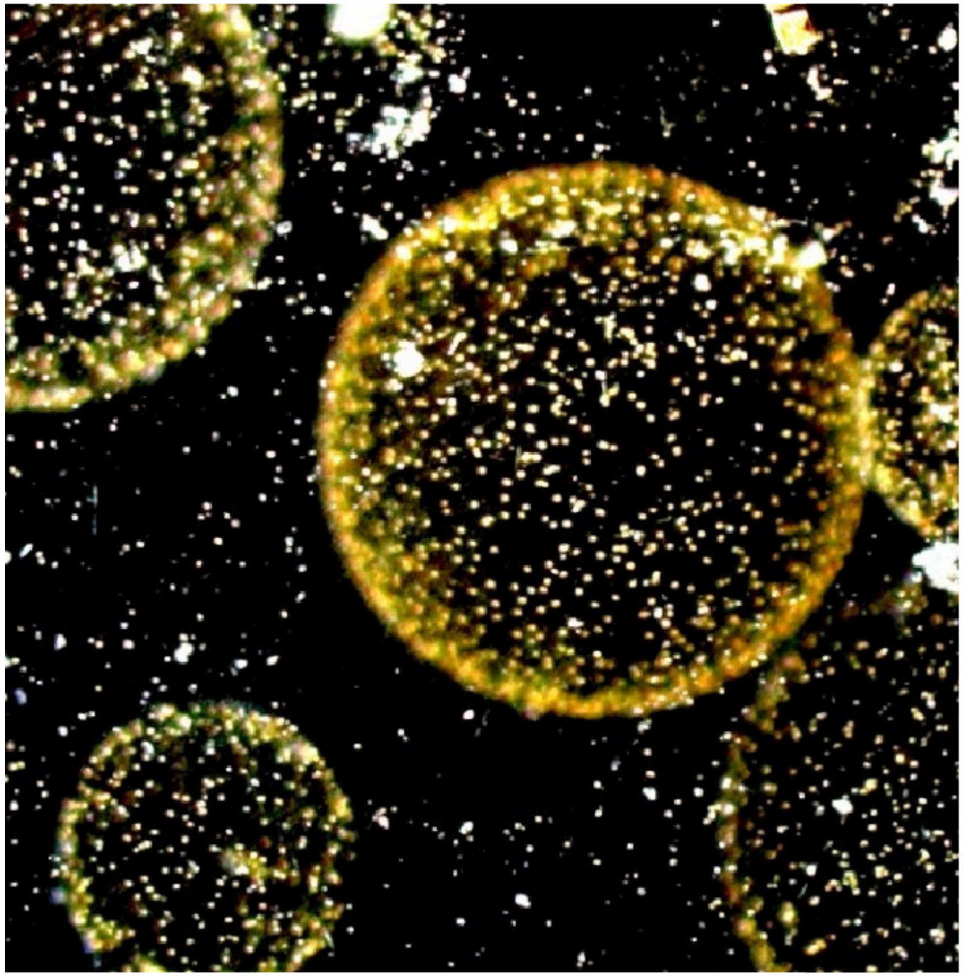
# Ship lines



North Pacific
CPR Survey
NOAA
SAHFOS
MedCPR
JAMSTEC
AusCPR
BCLME
Brazil Southern-
Ocean CPR
SCAR SO CPR
Survey
NIWA

# Annual variability in the 30's

- *Phaeocystis*



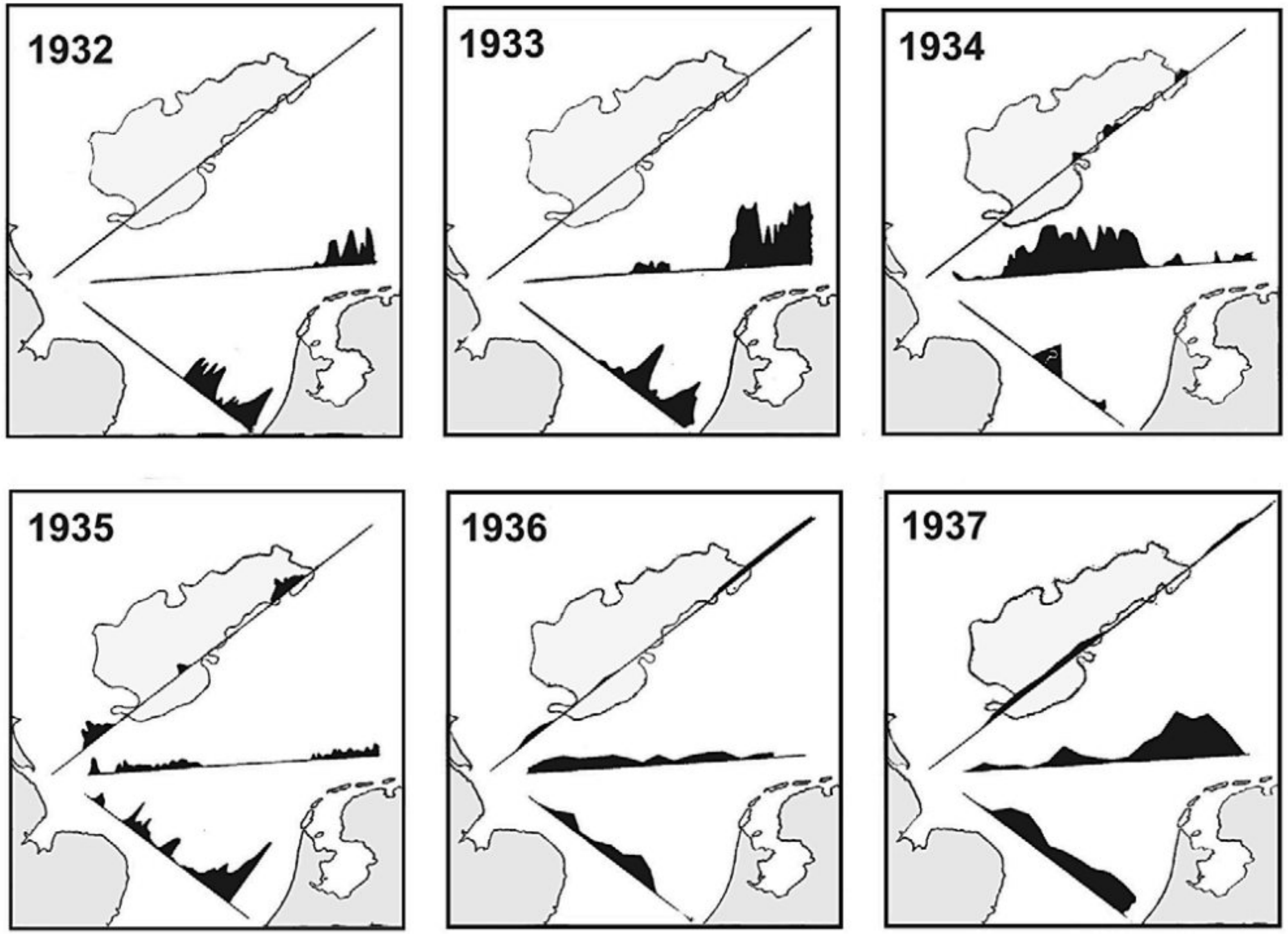
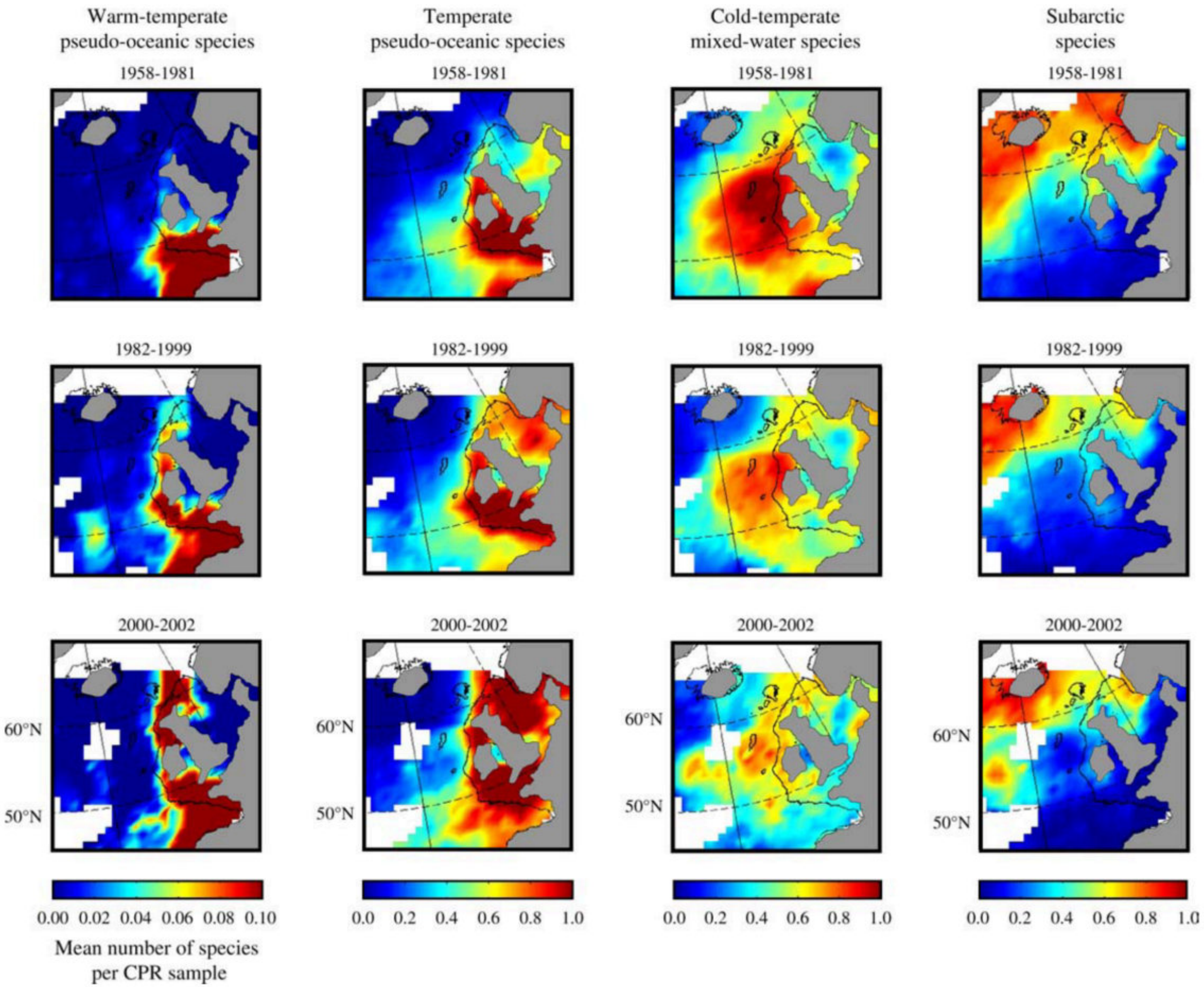



Fig. 7. Abundance of *Phaeocystis* along transects across the southern North Sea between 1932 and 1937 (Redrawn after Lucas, 1940). Dogger Bank outlined in light grey.

# Global change - Species

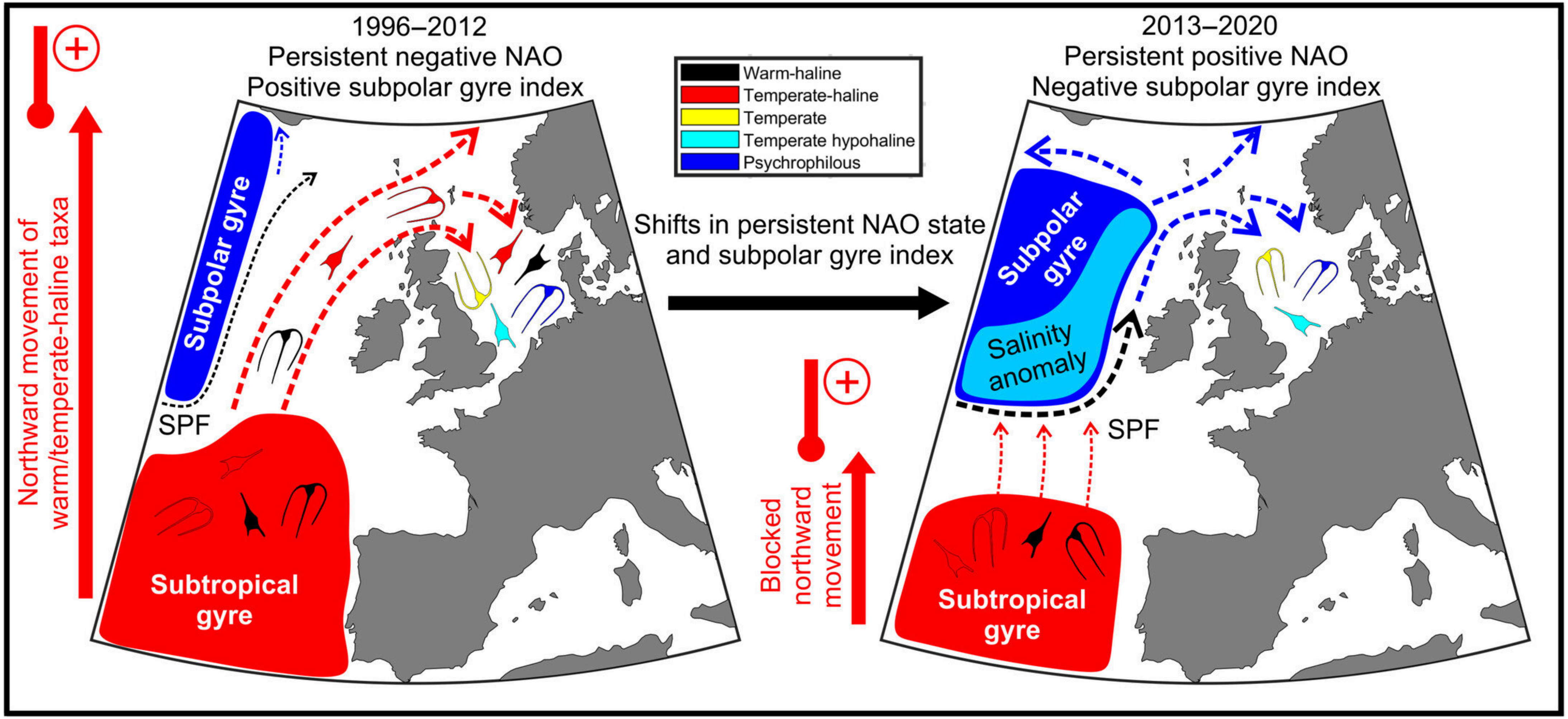
- Atlantification




Beaugrand, G. 2005. Monitoring pelagic ecosystems using plankton indicators. ICES Journal of Marine Science. 62:333–8.

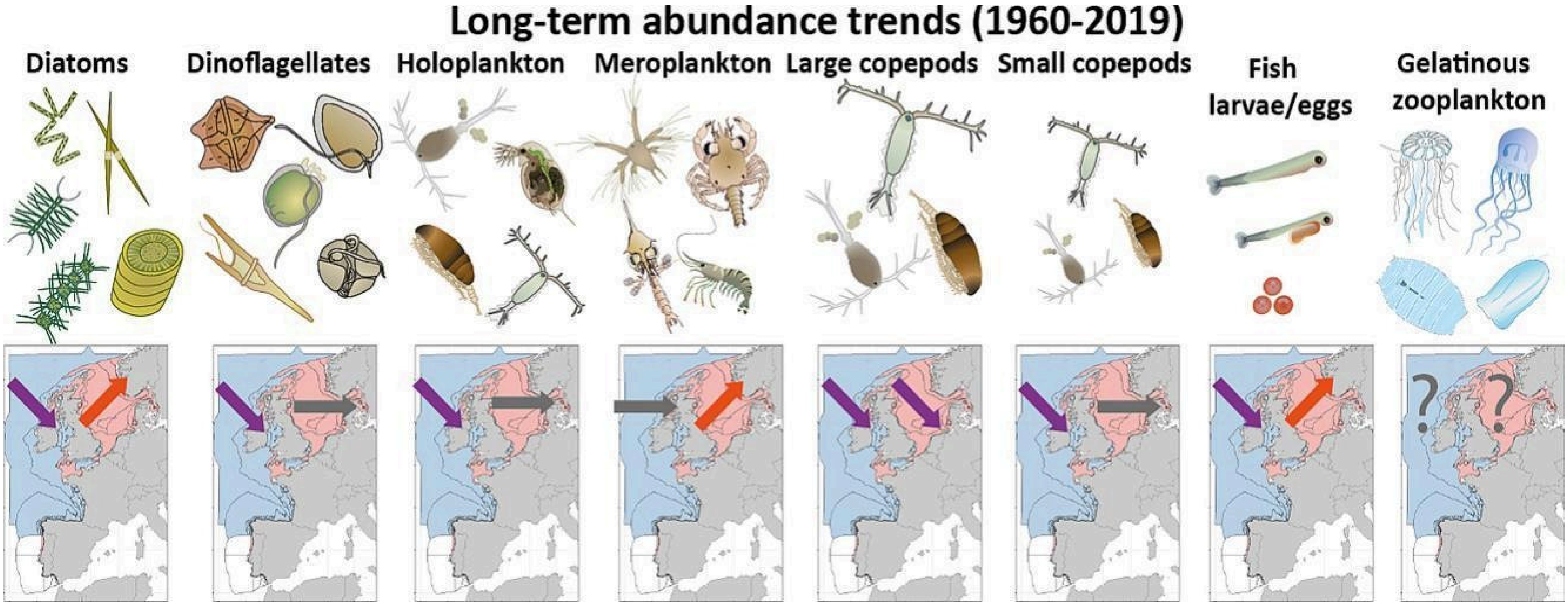
# Global change - Species

- Dinoflagellates



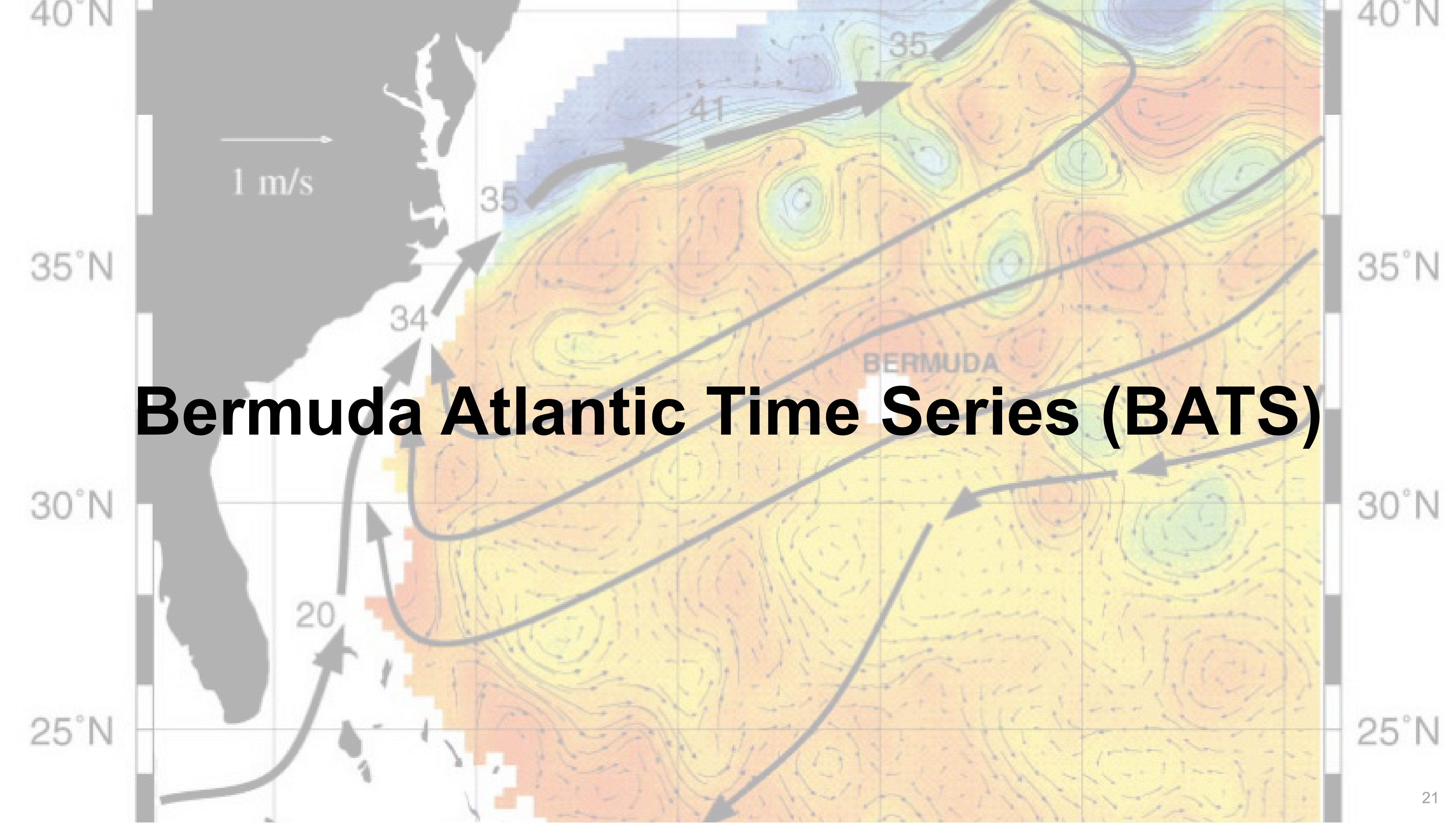

Kléparski et al. 2024. Ocean climate and hydrodynamics drive decadal shifts in Northeast Atlantic dinoflagellates. Global Change Biology.

# Global change - Biomass



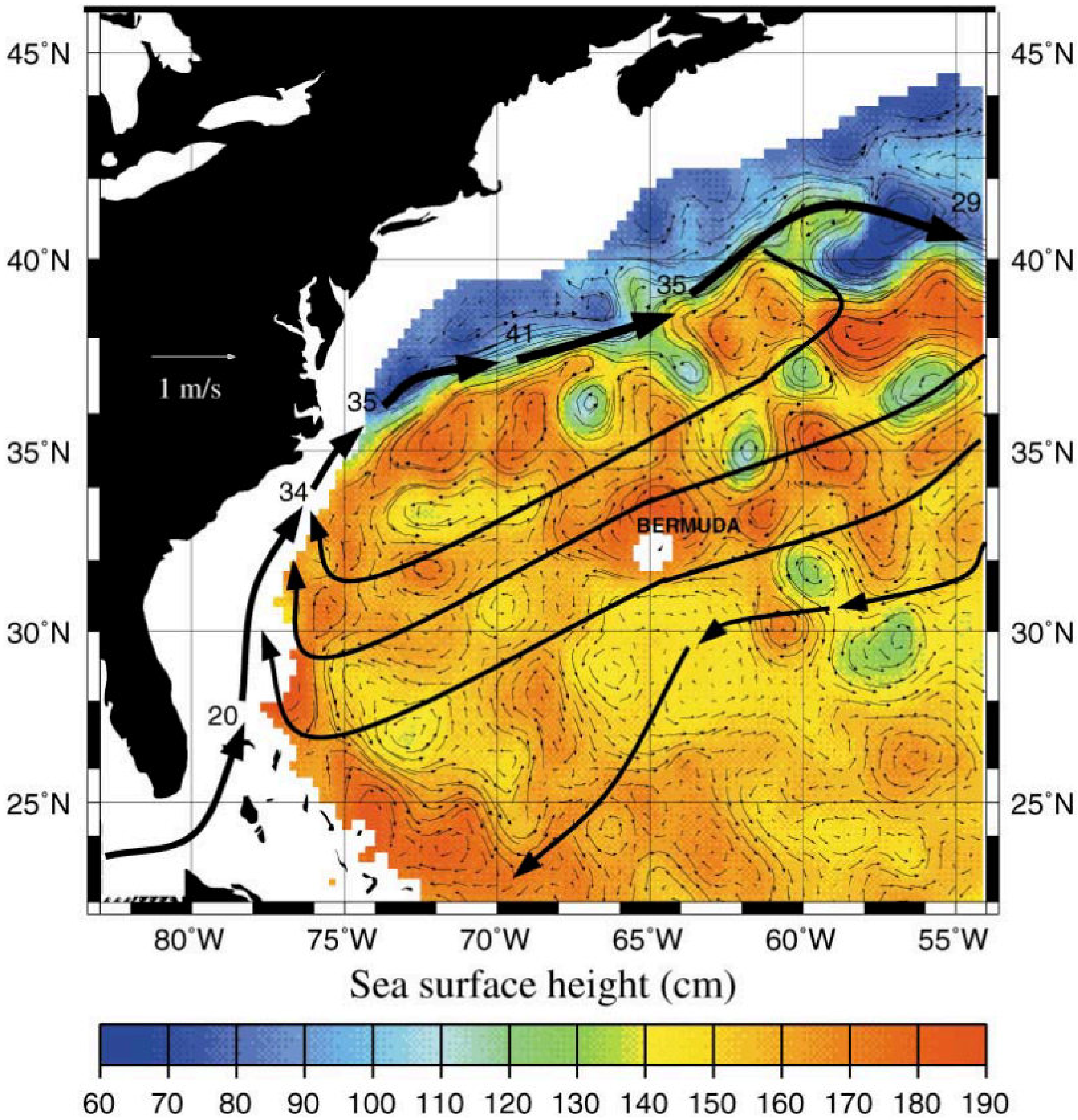

Holland et al. 2023. Major declines in NE Atlantic plankton contrast with more stable populations in the rapidly warming North Sea. Science of The Total Environment. 898:165505.

# Bermuda Atlantic Time Series (BATS)



# Bermuda Atlantic Time Series (BATS)

- located in Sargasso Sea
- started in 1989



# Measurements

| Parameter | Depth range (m) | Technique/instrument |
|---|---|---|
| *Continuous electronic measurements* | | |
| Temperature | 0–4200 | Thermistor on SeaBird SBE-911plus CTD |
| Salinity | 0–4200 | Conductivity sensor on SeaBird SBE-911plus CTD |
| Depth | 0–4200 | Digiquartz pressure sensor on SeaBird SBE-911plus CTD |
| Dissolved oxygen | 0–4200 | SeaBird Polarographic Oxygen Electrode |
| Beam attenuation[a] | 0–200 | SeaTech, 25 cm Transmissometer |
| Fluorescence | 0–500 | Chelsea Instruments Fluorometer |
| PAR[a] | 0–200 | Biospherical Scalar Irradiance Sensor, 400–700 nm |
| *Discrete measurements from Niskin bottles on CTD* | | |
| Salinity | 0–4200 | Conductivity on Guildline Autosal 8400A |
| Oxygen | 0–4200 | Winkler Titration, automated UV endpoint detection |
| Total $CO_2$ | 0–500 | Automated coulometric analysis |
| Alkalinity | 0–500 | High precision titration |
| Nitrate | 0–4200 | CFA colorometric with Technicon AA |
| Nitrite | 0–4200 | CFA colorometric with Technicon AA |
| Phosphate | 0–4200 | CFA colorometric with Technicon AA |
| Silicate | 0–4200 | CFA colorometric with Technicon AA |
| Dissolved organic carbon | 0–4200 | High-temperature combustion |
| Dissolved organic nitrogen | 0–4200 | UV oxidation |
| Particulate organic carbon | 0–4200 | High-temperature combustion, CHN analyzer |
| Particulate organic nitrogen | 0–4200 | High-temperature combustion, CHN analyzer |
| Particulate silica | 0–4200 | Chemical digestion, colorometric analysis |
| Fluorometric chlorophyll *a* | 0–250 | Acetone extraction, Turner fluorometer |
| Phytoplankton pigments | 0–250 | HPLC, resolves 19 pigments |
| Bacteria | 0–3000 | DAPI stained, fluorescence microscopy |
| *Rate measurements* | | |
| Primary production | 0–140 | Trace-metal clean, in situ incubation, $^{14}C$ uptake |
| Bacterial activity | 0–1000 | [$^{3}H$-methyl] thymidine incorporation |
| Particle fluxes | 150, 200, 300 | Free-drifting cylindrical trap (MultiPITs) |
| Mass flux | | Gravimetric analysis |
| Total carbon flux | | Manual swimmer removal, CHN analysis |
| Organic carbon flux | | Manual swimmer removal, acidification, CHN analysis |
| Organic nitrogen flux | | Manual swimmer removal, CHN analysis |

Steinberg et al. 2001. Overview of the US JGOFS Bermuda Atlantic Time-series Study (BATS): a decade-scale look at ocean biology and biogeochemistry. Deep Sea Research Part II. 48:1405–47.

# Temperature

- Deep winter mixing

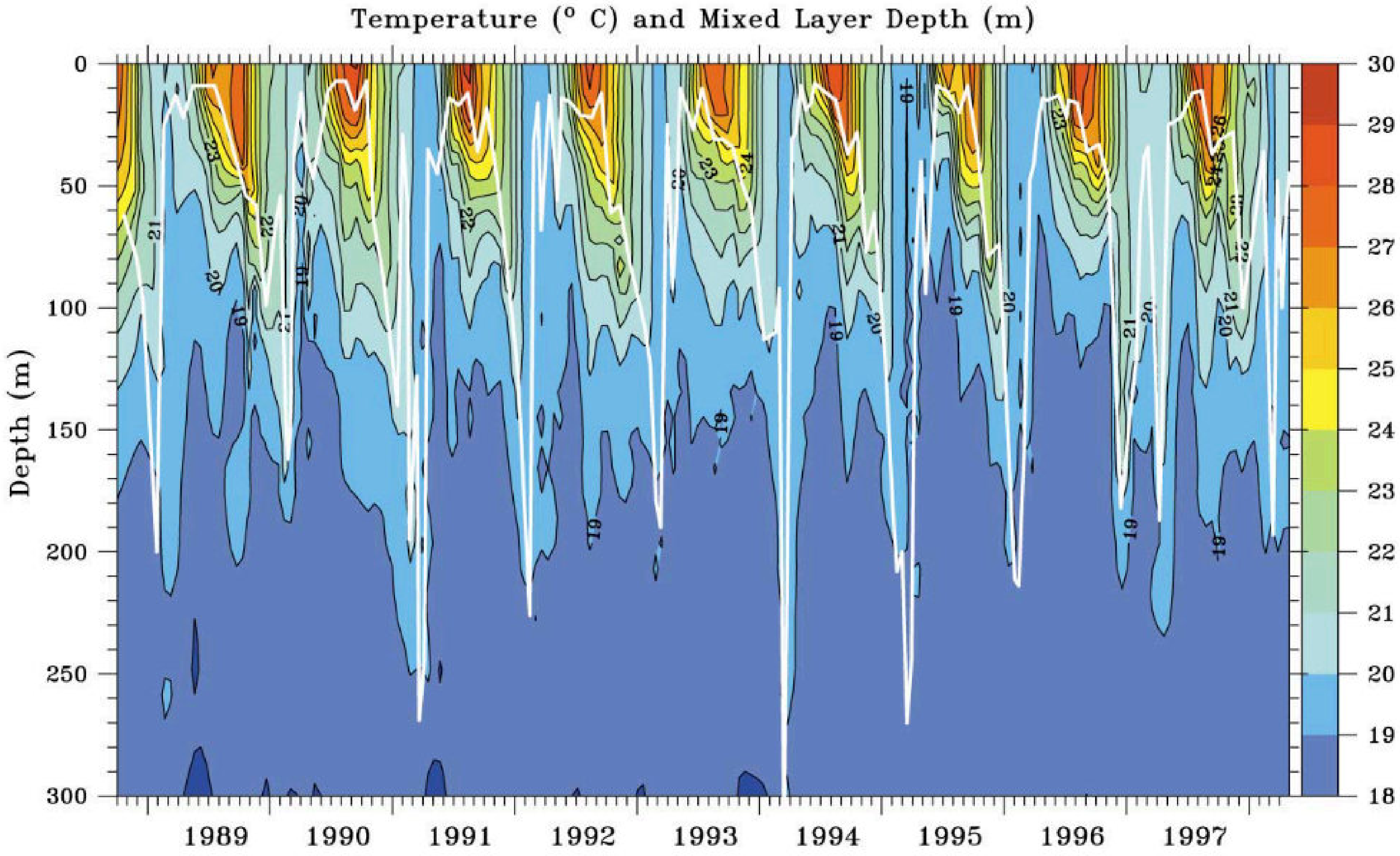



Fig. 3. Time-series contour plot of temperature with a 1°C contour interval. Mixed-layer depth is overlaid as a solid white line. Mixed-layer depth defined by using a variable sigma theta criteria (Sprintall and Tomczak, 1992) and assuming a 0.3°C diurnal temperature change.

Steinberg et al. 2001. Overview of the US JGOFS Bermuda Atlantic Time-series Study (BATS): a decade-scale look at ocean biology and biogeochemistry. Deep Sea Research Part II. 48:1405–47.

# Nutrients

- Effect of winter mixing

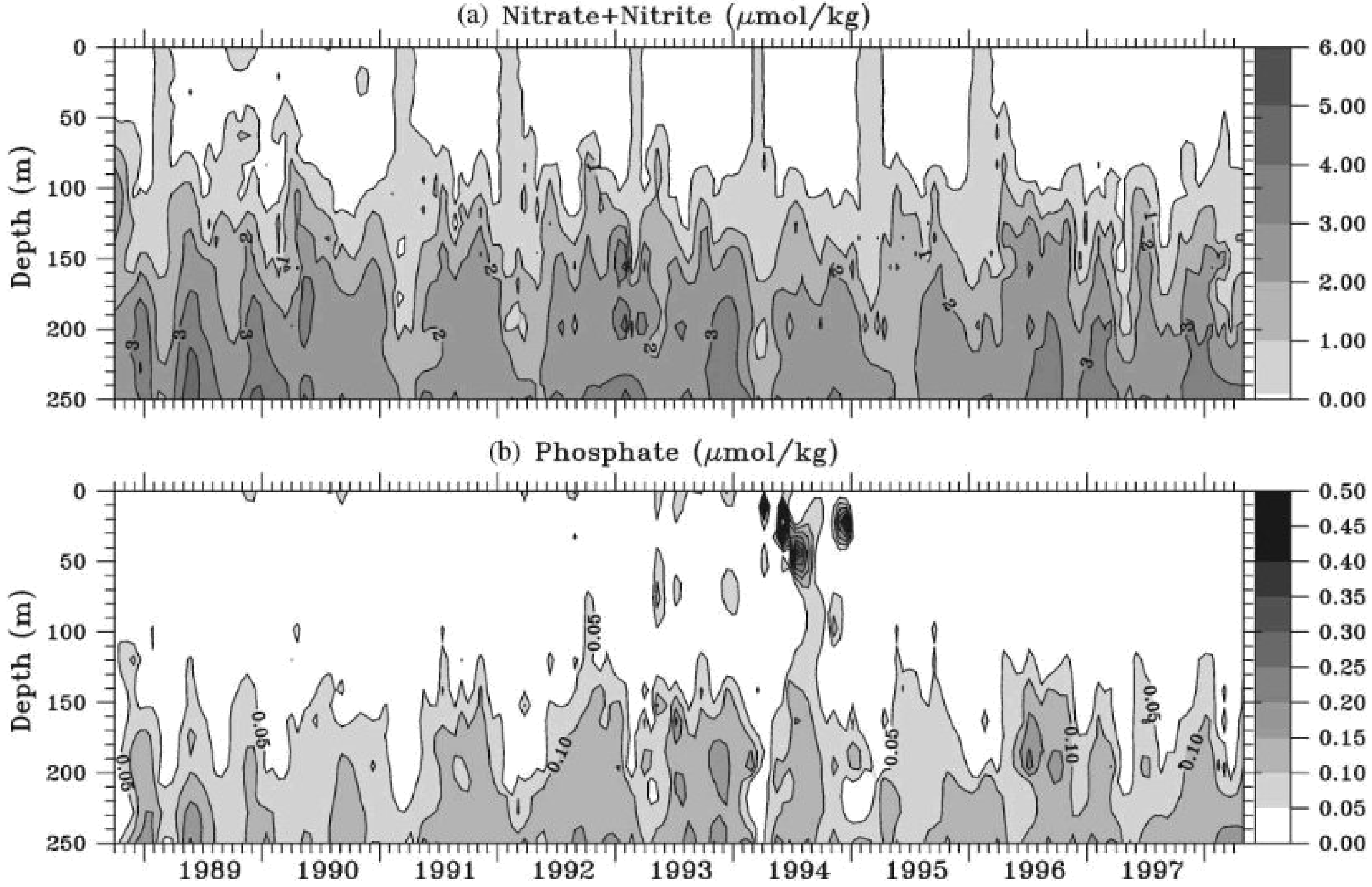



Fig. 6. Time-series contour plots of (a) nitrate + nitrite with a contour interval of 1 μmol kg$^{-1}$ (with exception of first interval of 0.1 μmol kg$^{-1}$), and (b) soluble reactive phosphate with a contour interval of 0.05 μmol kg$^{-1}$.

# Primary production

- Effect of winter mixing

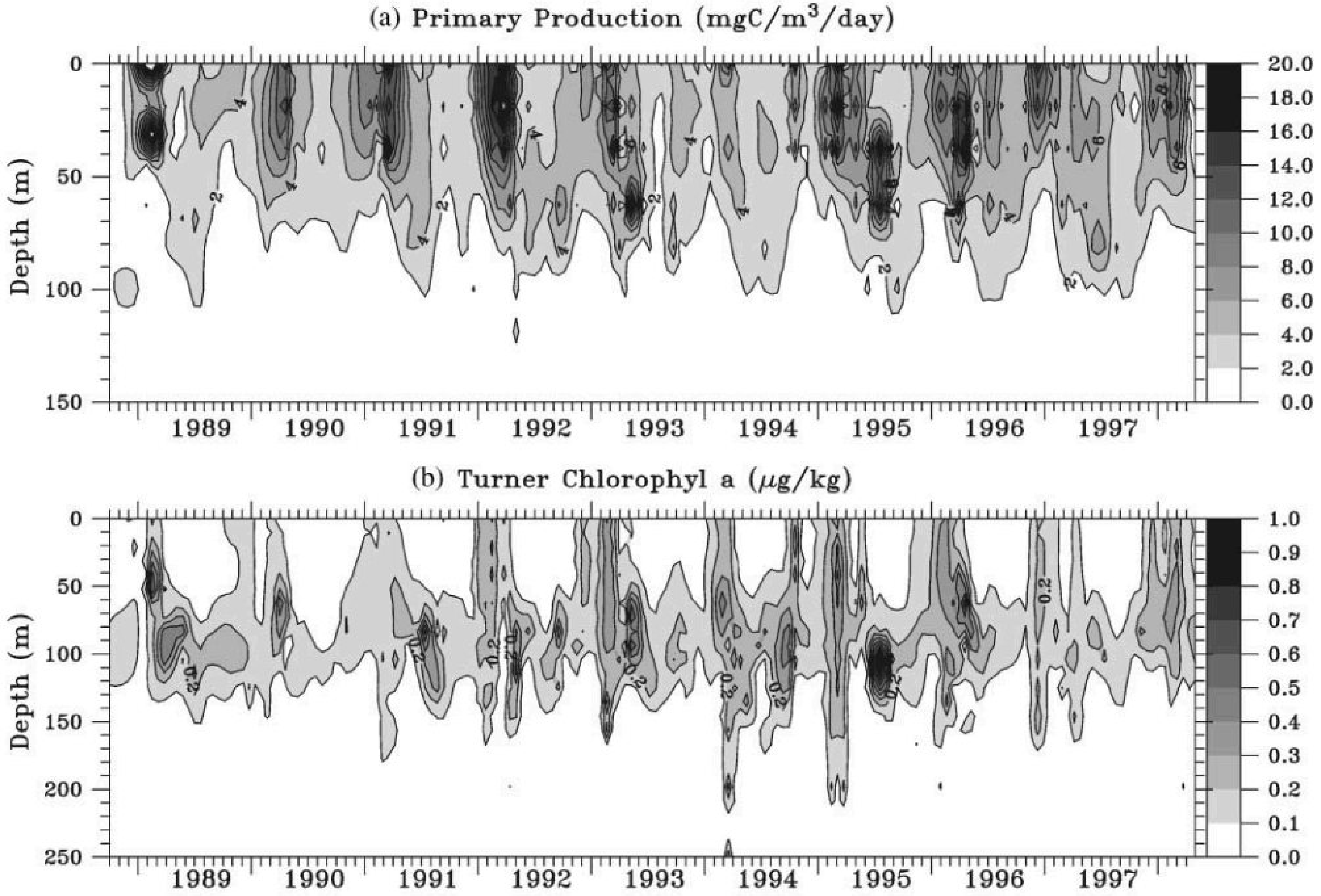
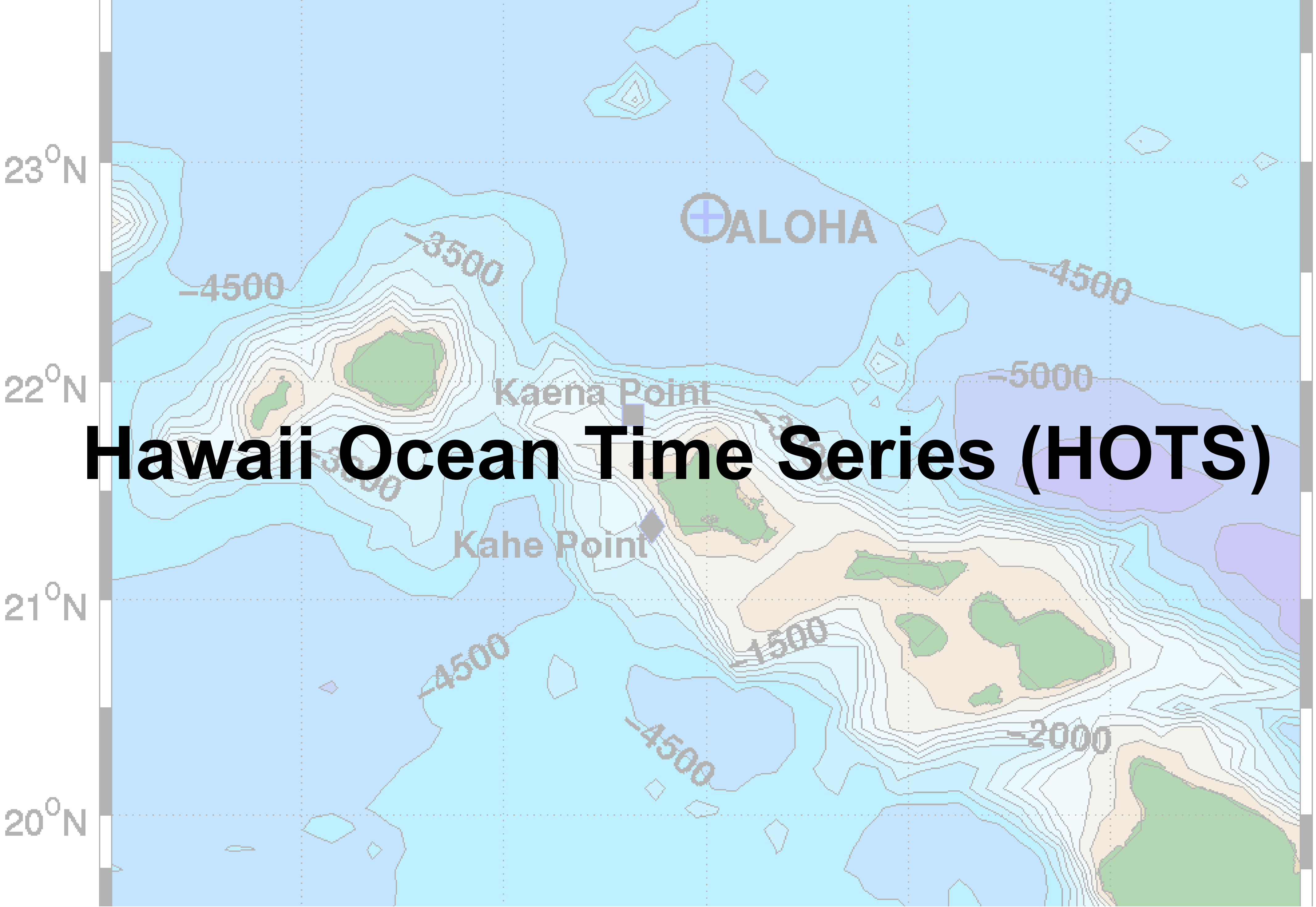


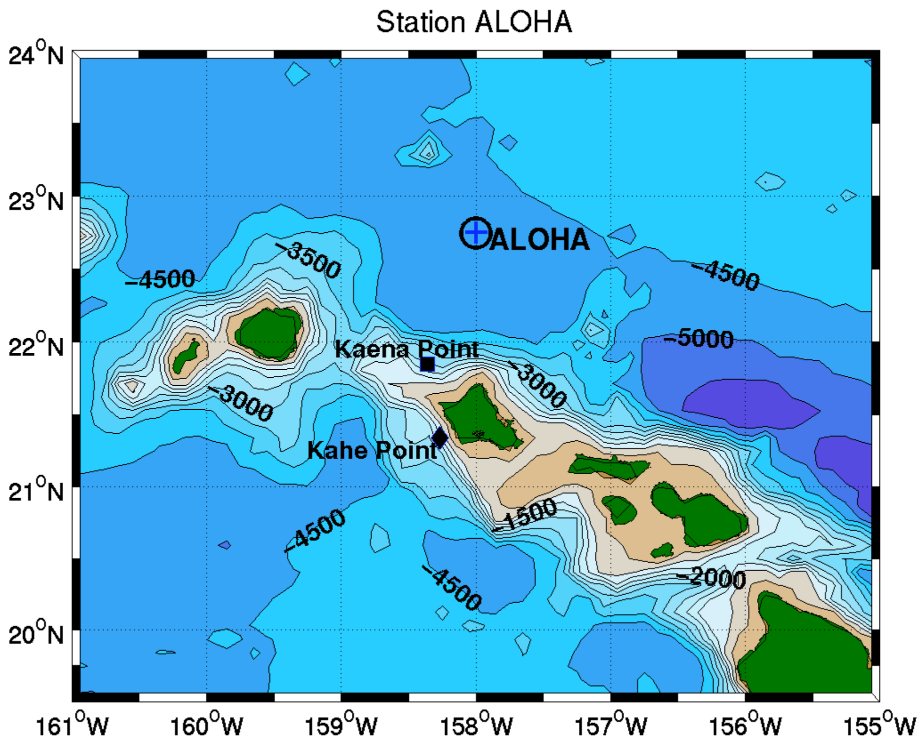

Fig. 7. Time-series contour plots of (a) primary production with a contour interval of $2\,mgC\,m^{-3}\,d^{-1}$, and (b) chlorophyll *a* with a contour interval of $0.1\,\mu g\,kg^{-1}$.

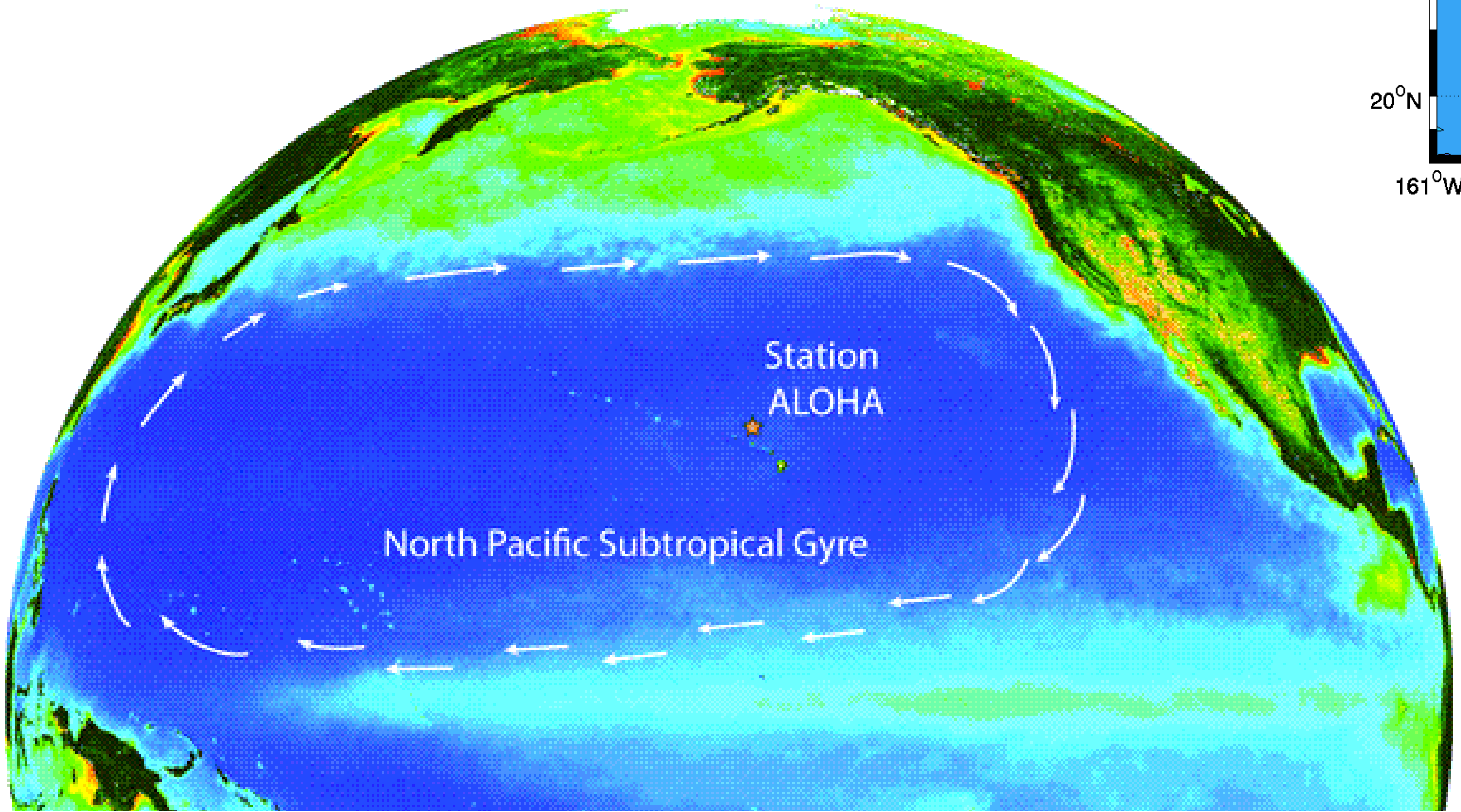
# Hawaii Ocean Time Series (HOTS)



# Hawaii Ocean Time Series (HOTS)

- Station ALOHA
- started in 1989
- located in oligotrophic area



# General characteristics

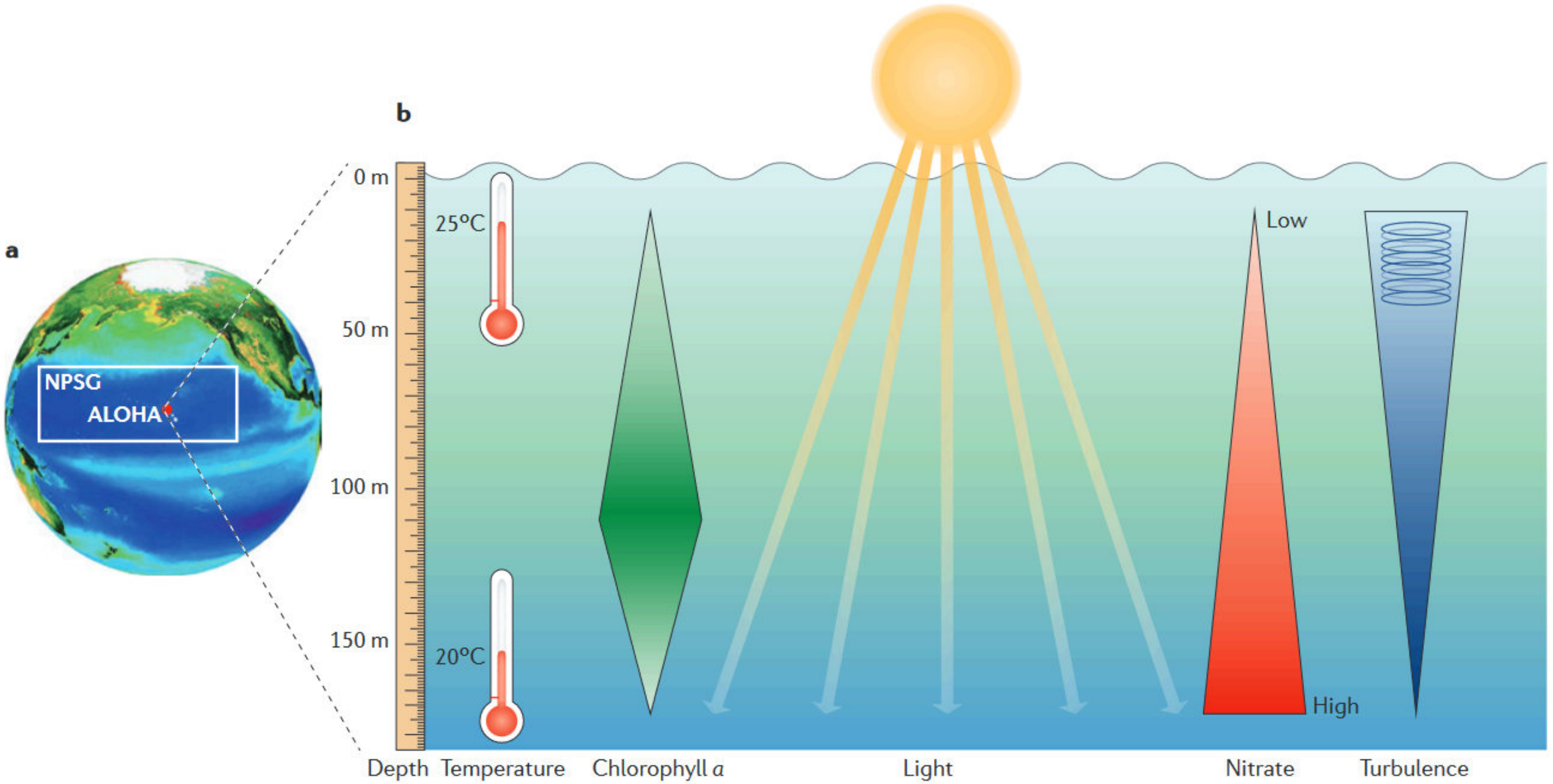
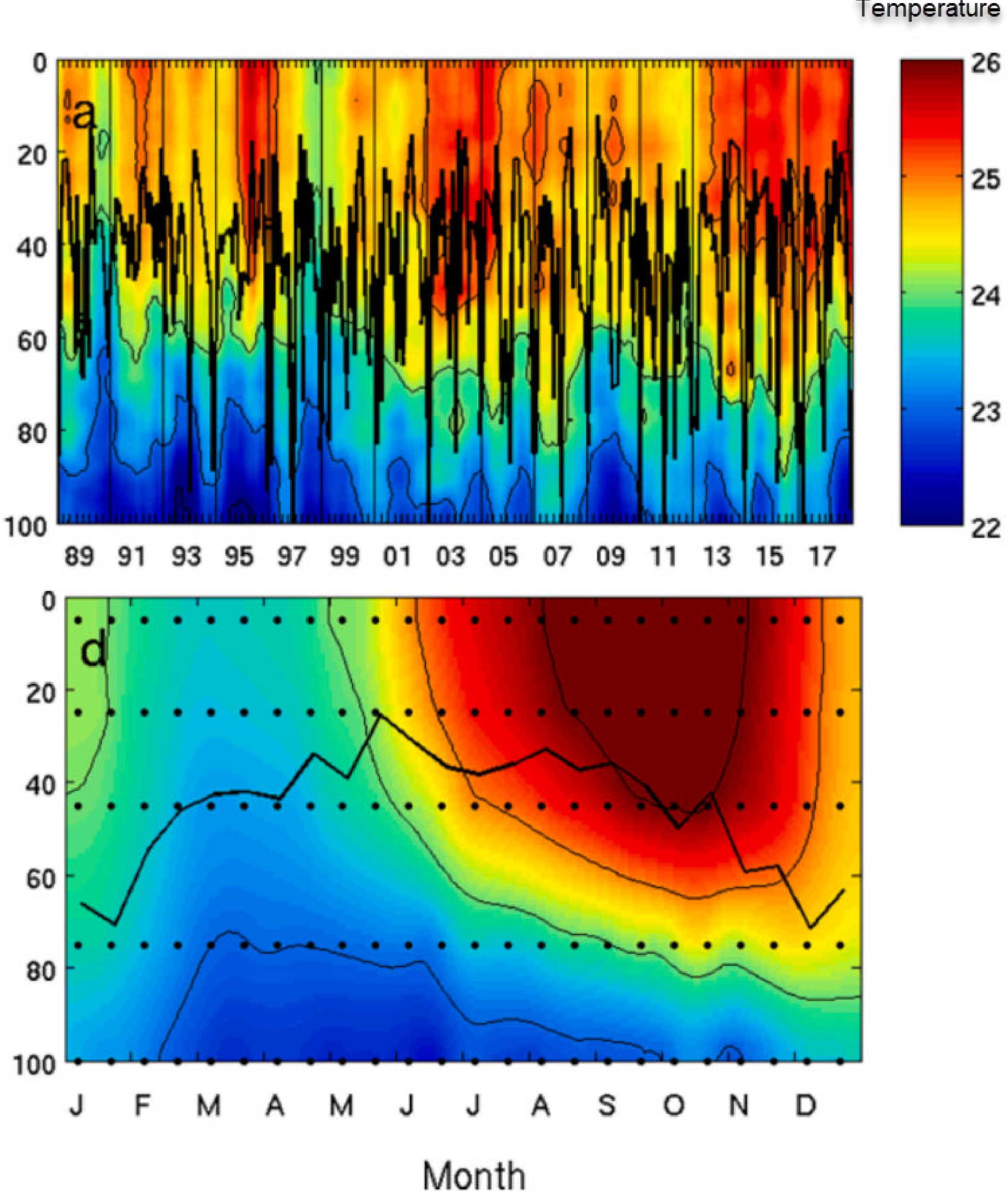



Figure 1 | **Station ALOHA habitat characteristics.** **a** | Location of Station ALOHA (A Long-term Oligotrophic Habitat Assessment) in the North Pacific Subtropical Gyre (NPSG) depicted on a Sea-viewing Wide Field-of-view Sensor (SeaWiFS) map of ocean colour (see Further information) showing the low concentrations of chlorophyll *a* (dark blue) that surround the site. **b** | The schematic shows the general habitat characteristics at Station ALOHA based on the 25 year climatology. This is an extremely oligotrophic environment that is characterized by low-standing stocks of chlorophyll (the subsurface chlorophyll peaks at ~105 m) and nitrate concentrations (note that primary production peaks where light is high but nutrients (such as nitrate) are nearly absent). Light that is sufficient for photosynthesis penetrates to at least 175 m. Temperature and the amount of turbulent mixing are also shown.

Karl, D.M. & Church, M.J. 2014. Microbial oceanography and the Hawaii Ocean Time-series programme. Nature Reviews Microbiology. 12:699–713.

# Temperature structure

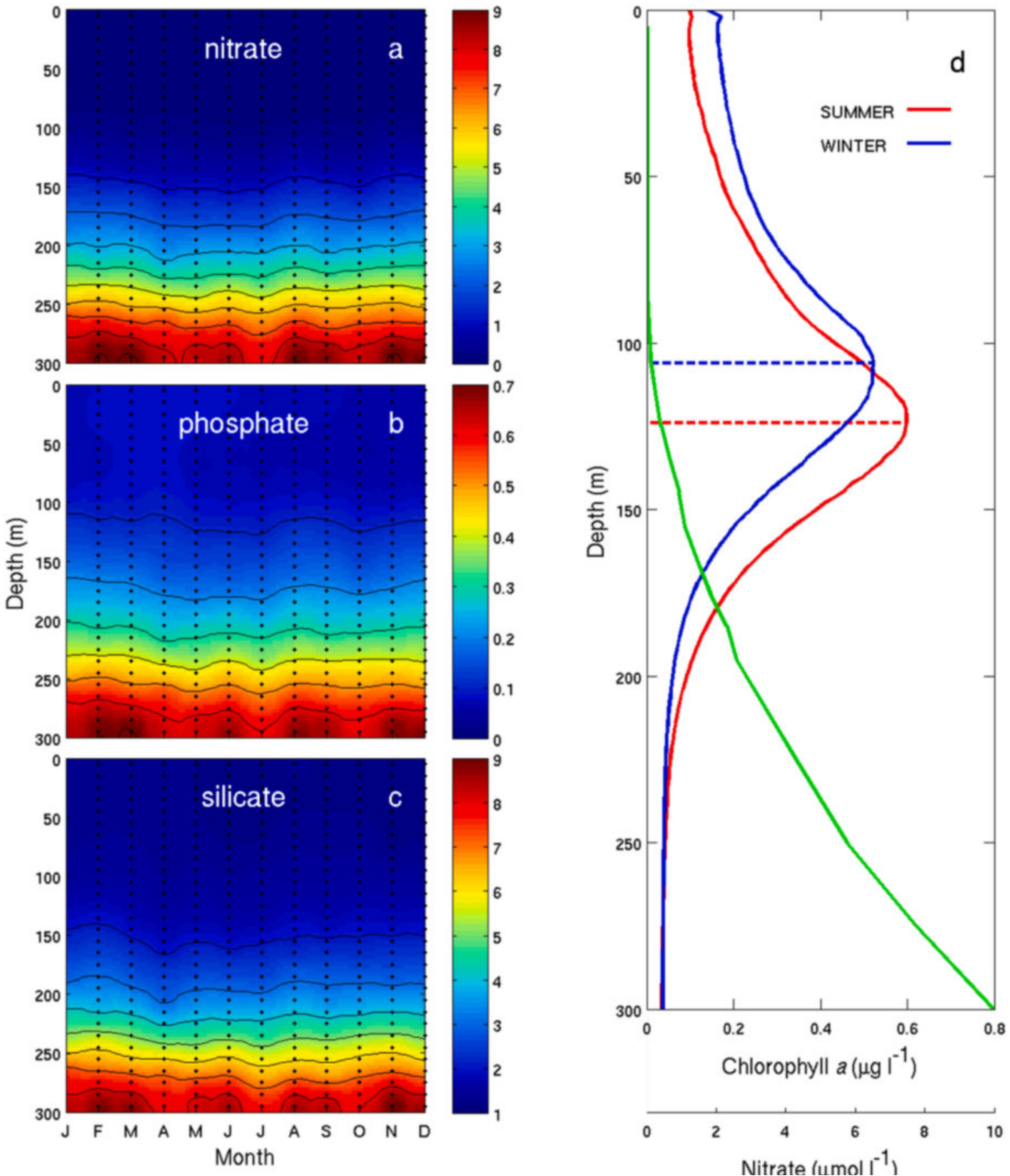
- Although tropical, temperature change




Karl et al. 2021. Seasonal-to-decadal scale variability in primary production and particulate matter export at Station ALOHA. Progress in Oceanography. 102563.

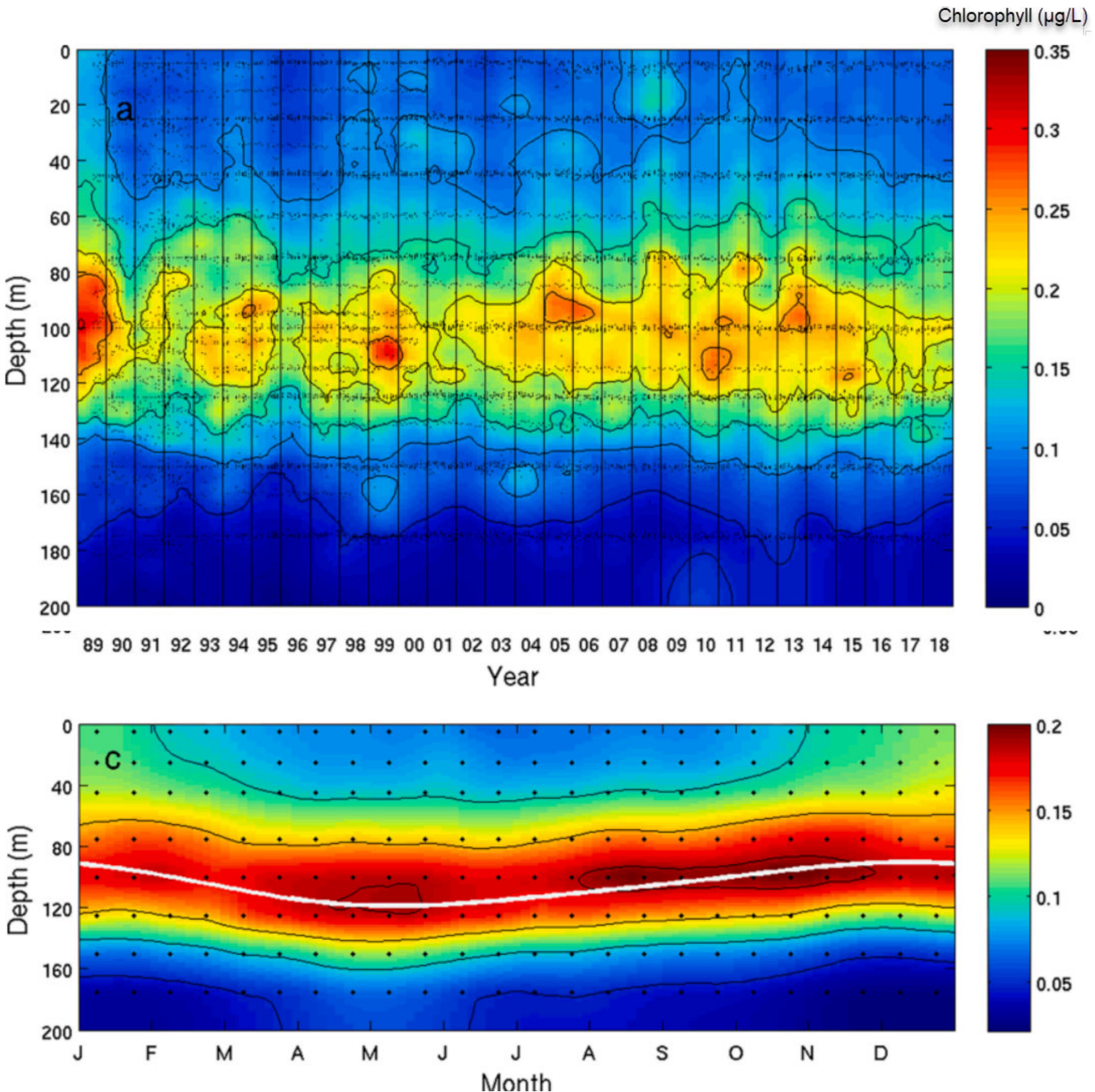
# Vertical structure

- Deeper in summer



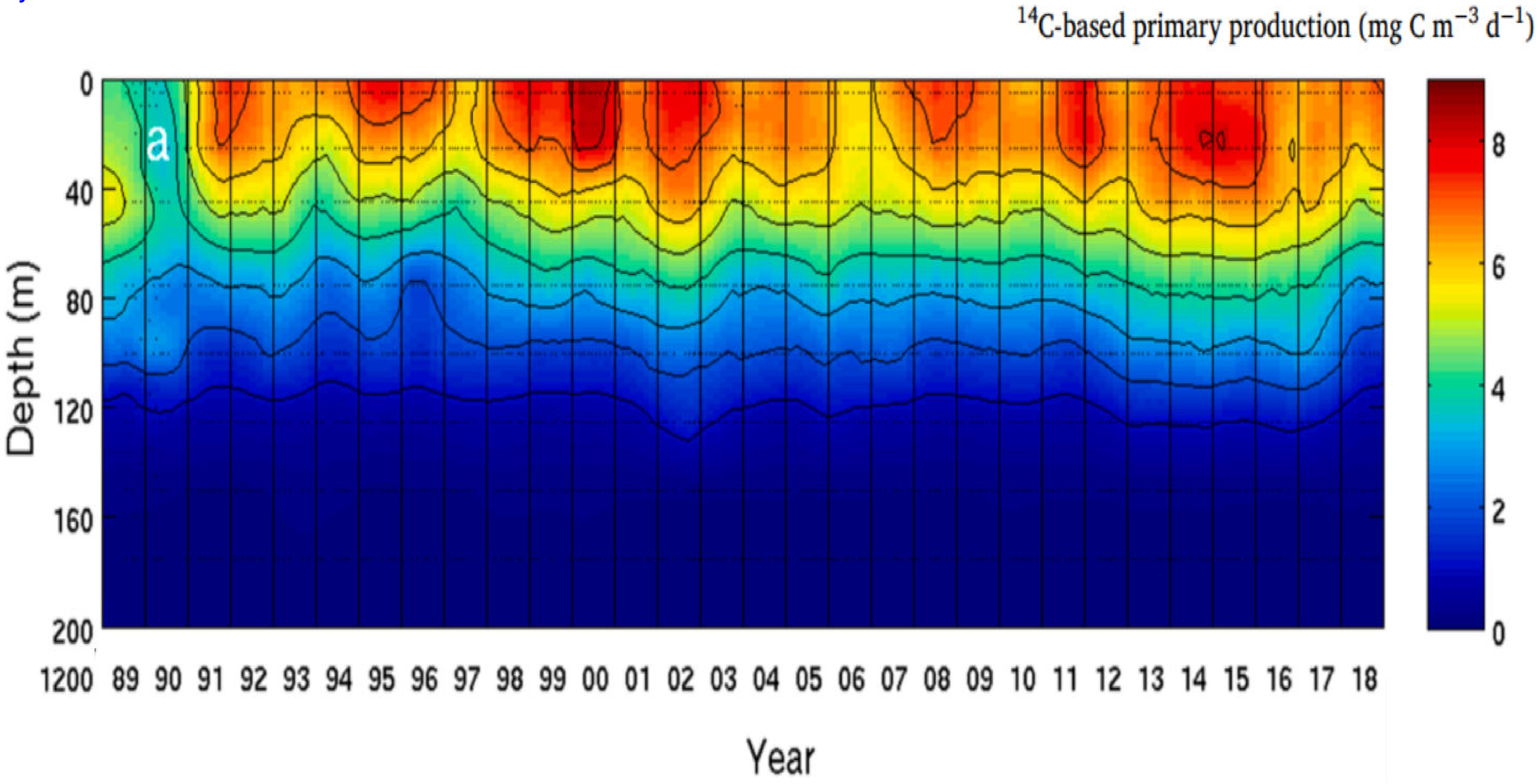
# Chlorophyll

- Deeper in summer



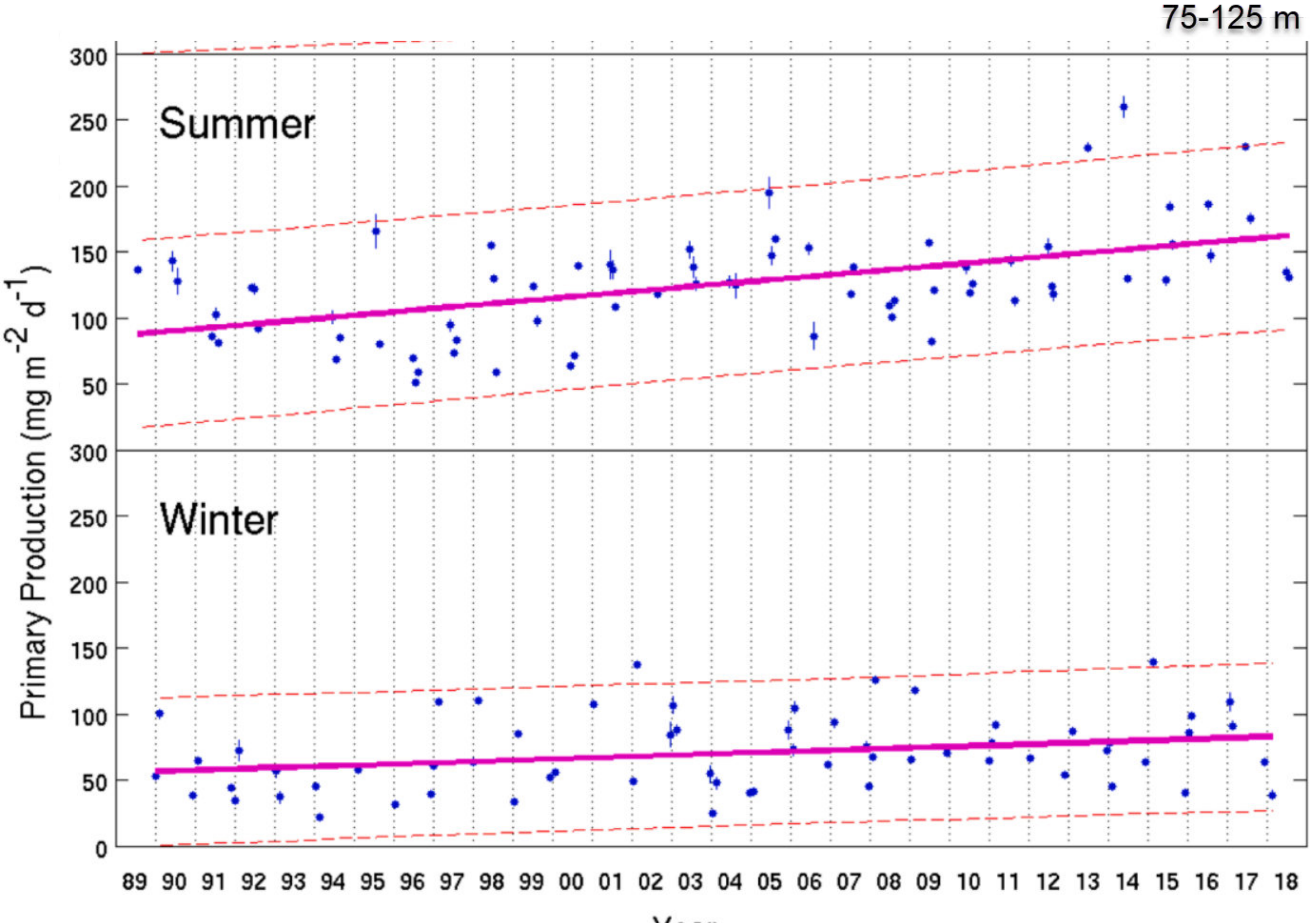
# Primary production

*What do you notice ?*



# Long term trends

- $CO_2$
- Chlorophyll
- Production

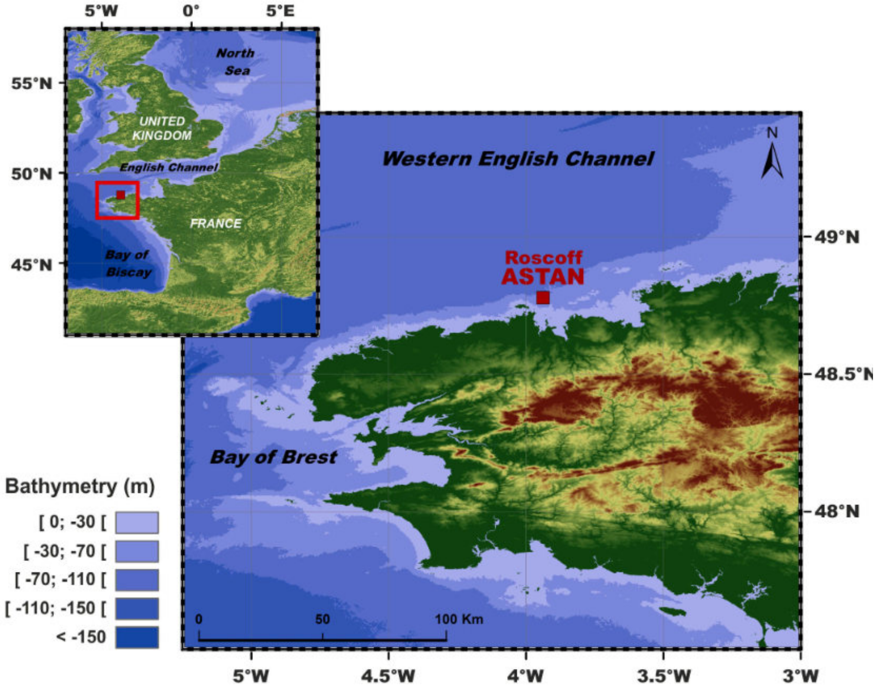


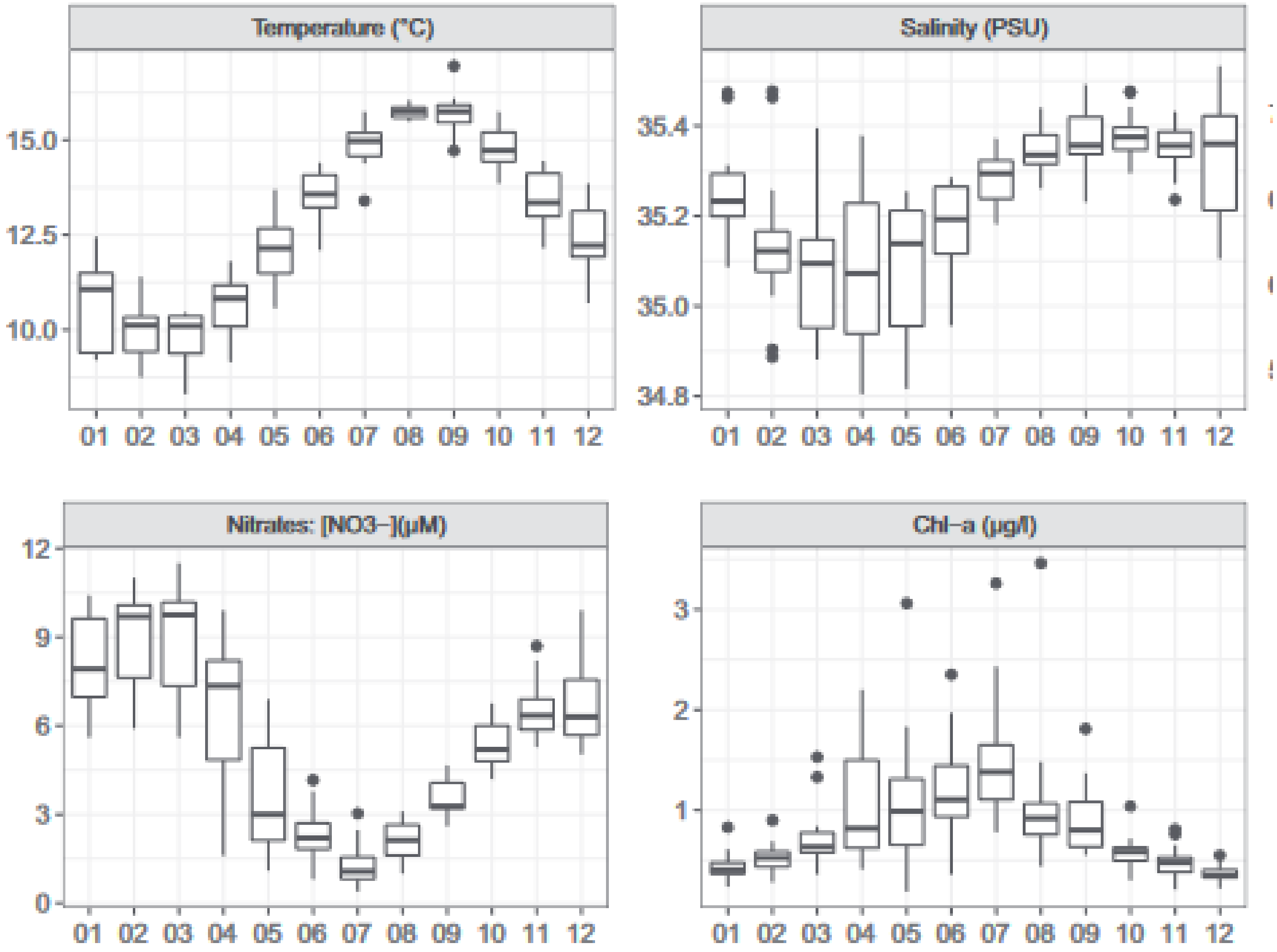
# Determining species periodicity

# English Channel

# English Channel

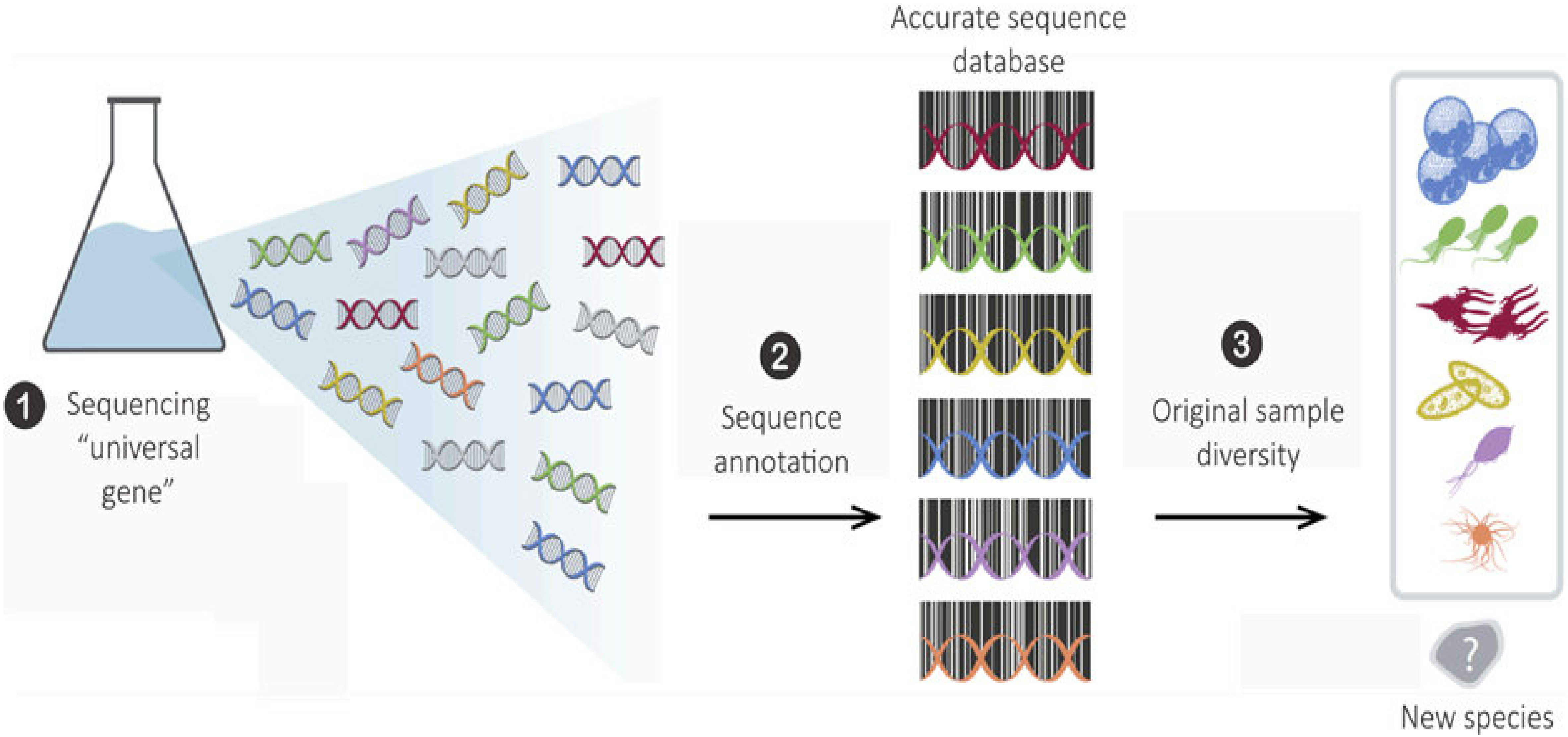
- Roscoff
- 2009-2016
- Very strong tide
- Always mixed



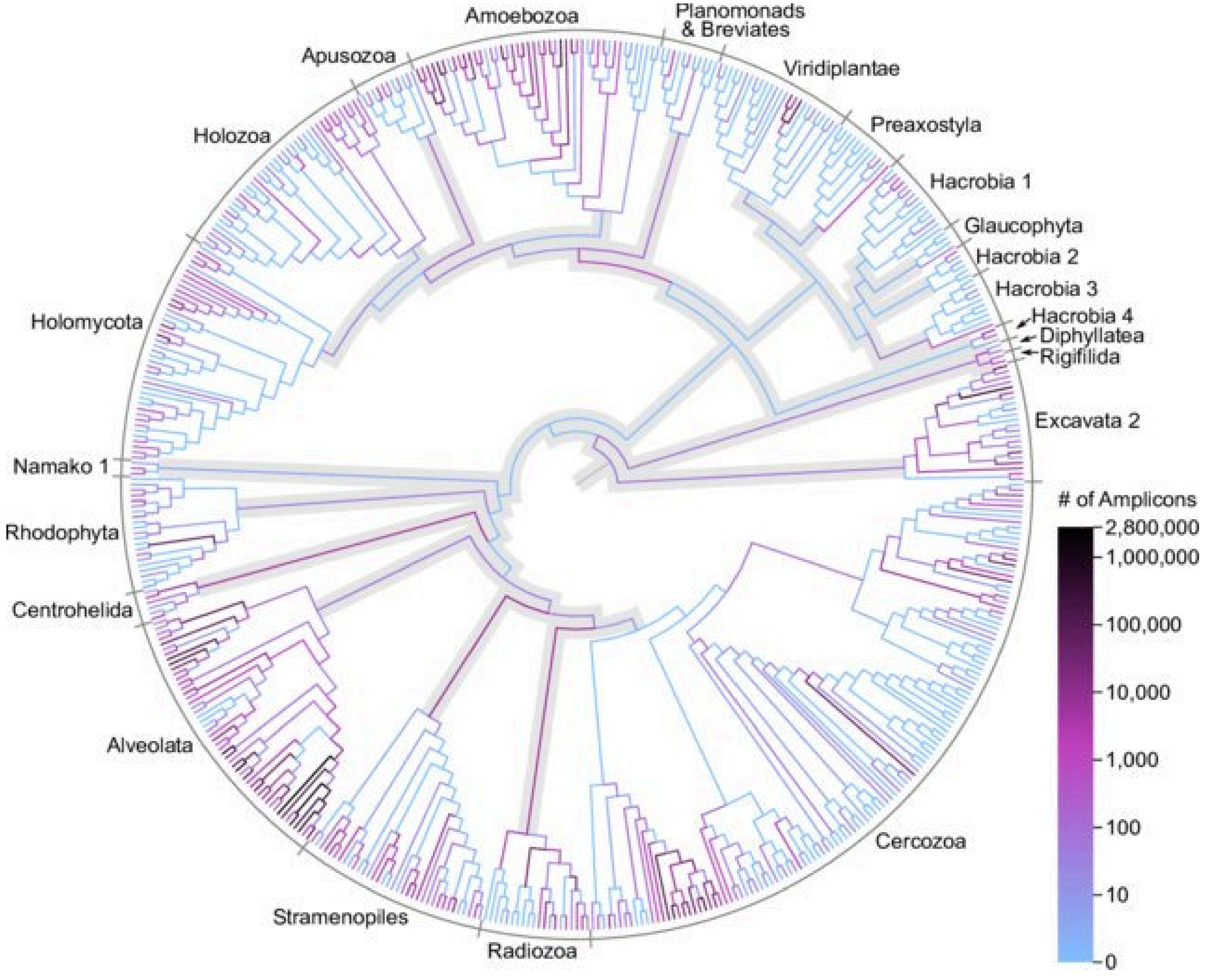

Caracciolo et al. 2022. Seasonal dynamics of marine protist communities in tidally mixed coastal waters. Molecular Ecology.

# Metabarcoding



# Metabarcoding

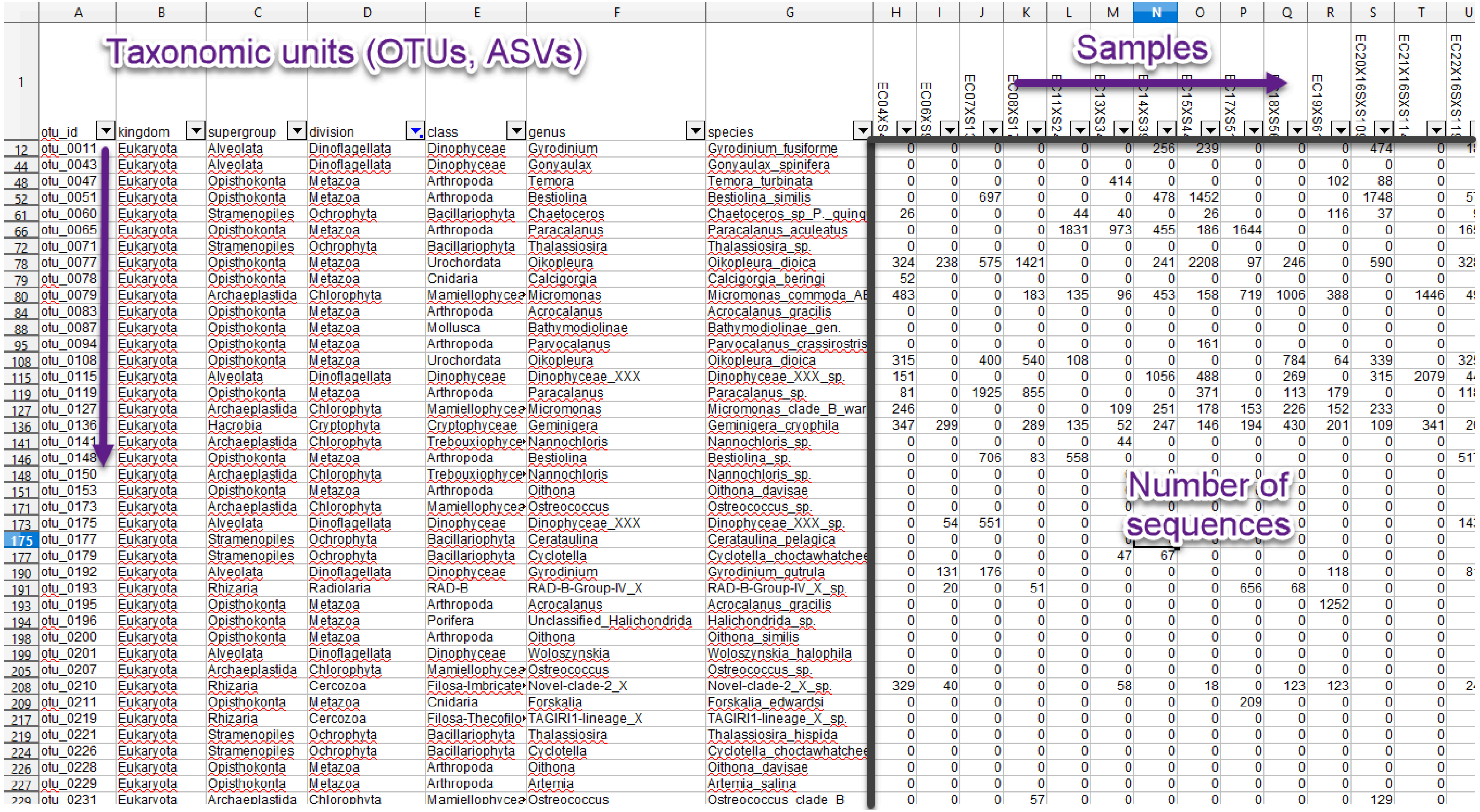
- Taxonomy of sequences




Mahé et al.. 2017. Parasites dominate hyperdiverse soil protist communities in Neotropical rainforests. Nature Ecology & Evolution 1:0091.

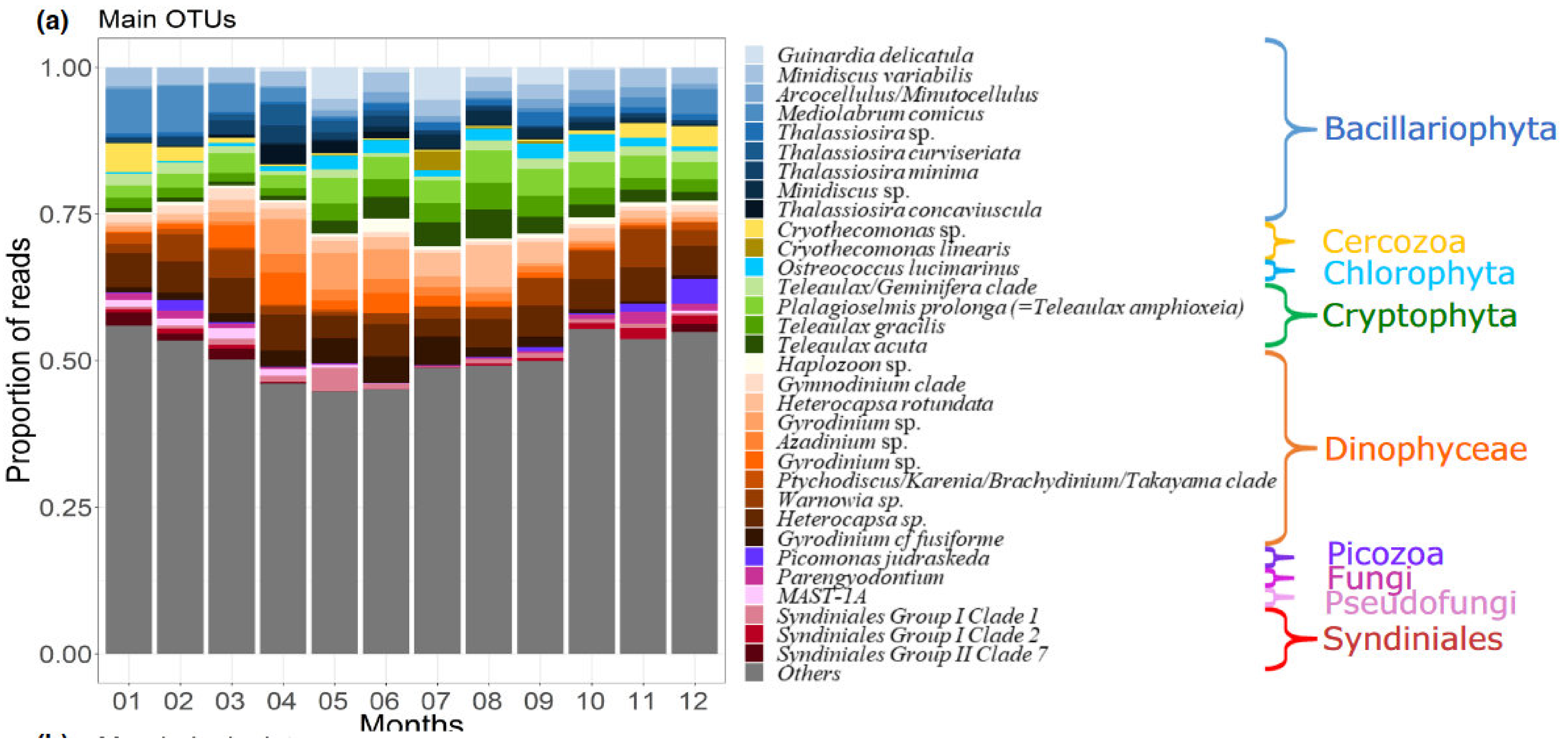
# Metabarcoding

- Output of metabarcoding




| | otu_id | kingdom | supergroup | division | class | genus | species | EC04XS | EC06XS | EC07XS1 | EC08XS1 | EC11XS2 | EC13XS3 | EC14XS3 | EC15XS4 | EC17XS5 | 18XS5 | EC19XS6 | EC20X16SXS10 | EC21X16SXS11 | EC22X16SXS11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | otu_0011 | Eukaryota | Alveolata | Dinoflagellata | Dinophyceae | Gyrodinium | Gyrodinium_fusiforme | 0 | 0 | 0 | 0 | 0 | 0 | 256 | 239 | 0 | 0 | 0 | 474 | 0 | 1 |
| 44 | otu_0043 | Eukaryota | Alveolata | Dinoflagellata | Dinophyceae | Gonyaulax | Gonyaulax_spinifera | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 48 | otu_0047 | Eukaryota | Opisthokonta | Metazoa | Arthropoda | Temora | Temora_turbinata | 0 | 0 | 0 | 0 | 0 | 414 | 0 | 0 | 0 | 0 | 102 | 88 | 0 | |
| 52 | otu_0051 | Eukaryota | Opisthokonta | Metazoa | Arthropoda | Bestiolina | Bestiolina_similis | 0 | 0 | 697 | 0 | 0 | 0 | 478 | 1452 | 0 | 0 | 0 | 1748 | 0 | 5 |
| 61 | otu_0060 | Eukaryota | Stramenopiles | Ochrophyta | Bacillariophyta | Chaetoceros | Chaetoceros_sp_P._quinq | 26 | 0 | 0 | 0 | 44 | 40 | 0 | 26 | 0 | 0 | 116 | 37 | 0 | [illegible] |
| 66 | otu_0065 | Eukaryota | Opisthokonta | Metazoa | Arthropoda | Paracalanus | Paracalanus_aculeatus | 0 | 0 | 0 | 0 | 1831 | 973 | 455 | 186 | 1644 | 0 | 0 | 0 | 0 | 16 |
| 72 | otu_0071 | Eukaryota | Stramenopiles | Ochrophyta | Bacillariophyta | Thalassiosira | Thalassiosira_sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 78 | otu_0077 | Eukaryota | Opisthokonta | Metazoa | Urochordata | Oikopleura | Oikopleura_dioica | 324 | 238 | 575 | 1421 | 0 | 0 | 241 | 2208 | 97 | 246 | 0 | 590 | 0 | 32 |
| 79 | otu_0078 | Eukaryota | Opisthokonta | Metazoa | Cnidaria | Calcigorgia | Calcigorgia_beringi | 52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 80 | otu_0079 | Eukaryota | Archaeplastida | Chlorophyta | Mamiellophycea | Micromonas | Micromonas_commoda_AB | 483 | 0 | 0 | 183 | 135 | 96 | 453 | 158 | 719 | 1006 | 388 | 0 | 1446 | 4 |
| 84 | otu_0083 | Eukaryota | Opisthokonta | Metazoa | Arthropoda | Acrocalanus | Acrocalanus_gracilis | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 88 | otu_0087 | Eukaryota | Opisthokonta | Metazoa | Mollusca | Bathymodiolinae | Bathymodiolinae_gen. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 95 | otu_0094 | Eukaryota | Opisthokonta | Metazoa | Arthropoda | Parvocalanus | Parvocalanus_crassirostris | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 161 | 0 | 0 | 0 | 0 | 0 | |
| 108 | otu_0108 | Eukaryota | Opisthokonta | Metazoa | Urochordata | Oikopleura | Oikopleura_dioica | 315 | 0 | 400 | 540 | 108 | 0 | 0 | 0 | 0 | 784 | 64 | 339 | 0 | 32 |
| 115 | otu_0115 | Eukaryota | Alveolata | Dinoflagellata | Dinophyceae | Dinophyceae_XXX | Dinophyceae_XXX_sp. | 151 | 0 | 0 | 0 | 0 | 0 | 1056 | 488 | 0 | 269 | 0 | 315 | 2079 | 4 |
| 119 | otu_0119 | Eukaryota | Opisthokonta | Metazoa | Arthropoda | Paracalanus | Paracalanus_sp. | 81 | 0 | 1925 | 855 | 0 | 0 | 0 | 371 | 0 | 113 | 179 | 0 | 0 | 11 |
| 127 | otu_0127 | Eukaryota | Archaeplastida | Chlorophyta | Mamiellophycea | Micromonas | Micromonas_clade_B_war | 246 | 0 | 0 | 0 | 0 | 109 | 251 | 178 | 153 | 226 | 152 | 233 | 0 | |
| 136 | otu_0136 | Eukaryota | Hacrobia | Cryptophyta | Cryptophyceae | Geminigera | Geminigera_cryophila | 347 | 299 | 0 | 289 | 135 | 52 | 247 | 146 | 194 | 430 | 201 | 109 | 341 | 2 |
| 141 | otu_0141 | Eukaryota | Archaeplastida | Chlorophyta | Trebouxiophyce | Nannochloris | Nannochloris_sp. | 0 | 0 | 0 | 0 | 0 | 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 146 | otu_0148 | Eukaryota | Opisthokonta | Metazoa | Arthropoda | Bestiolina | Bestiolina_sp. | 0 | 0 | 706 | 83 | 558 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 51 |
| 148 | otu_0150 | Eukaryota | Archaeplastida | Chlorophyta | Trebouxiophyce | Nannochloris | Nannochloris_sp. | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | 0 | 0 | |
| 151 | otu_0153 | Eukaryota | Opisthokonta | Metazoa | Arthropoda | Oithona | Oithona_davisae | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | 0 | 0 | |
| 171 | otu_0173 | Eukaryota | Archaeplastida | Chlorophyta | Mamiellophycea | Ostreococcus | Ostreococcus_sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 173 | otu_0175 | Eukaryota | Alveolata | Dinoflagellata | Dinophyceae | Dinophyceae_XXX | Dinophyceae_XXX_sp. | 0 | 54 | 551 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | 0 | 0 | 14 |
| 175 | otu_0177 | Eukaryota | Stramenopiles | Ochrophyta | Bacillariophyta | Cerataulina | Cerataulina_pelagica | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 0 | 0 | 0 | |
| 177 | otu_0179 | Eukaryota | Stramenopiles | Ochrophyta | Bacillariophyta | Cyclotella | Cyclotella_choctawhatchee | 0 | 0 | 0 | 0 | 0 | 47 | 67 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 190 | otu_0192 | Eukaryota | Alveolata | Dinoflagellata | Dinophyceae | Gyrodinium | Gyrodinium_gutrula | 0 | 131 | 176 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 118 | 0 | 0 | 8 |
| 191 | otu_0193 | Eukaryota | Rhizaria | Radiolaria | RAD-B | RAD-B-Group-IV_X | RAD-B-Group-IV_X_sp. | 0 | 20 | 0 | 51 | 0 | 0 | 0 | 0 | 656 | 68 | 0 | 0 | 0 | |
| 193 | otu_0195 | Eukaryota | Opisthokonta | Metazoa | Arthropoda | Acrocalanus | Acrocalanus_gracilis | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1252 | 0 | 0 | |
| 194 | otu_0196 | Eukaryota | Opisthokonta | Metazoa | Porifera | Unclassified_Halichondrida | Halichondrida_sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 198 | otu_0200 | Eukaryota | Opisthokonta | Metazoa | Arthropoda | Oithona | Oithona_similis | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 199 | otu_0201 | Eukaryota | Alveolata | Dinoflagellata | Dinophyceae | Woloszynskia | Woloszynskia_halophila | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 205 | otu_0207 | Eukaryota | Archaeplastida | Chlorophyta | Mamiellophycea | Ostreococcus | Ostreococcus_sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 208 | otu_0210 | Eukaryota | Rhizaria | Cercozoa | Filosa-Imbricate | Novel-clade-2_X | Novel-clade-2_X_sp. | 329 | 40 | 0 | 0 | 0 | 58 | 0 | 18 | 0 | 123 | 123 | 0 | 0 | 2 |
| 209 | otu_0211 | Eukaryota | Opisthokonta | Metazoa | Cnidaria | Forskalia | Forskalia_edwardsi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 209 | 0 | 0 | 0 | 0 | |
| 217 | otu_0219 | Eukaryota | Rhizaria | Cercozoa | Filosa-Thecofilo | TAGIRI1-lineage_X | TAGIRI1-lineage_X_sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 219 | otu_0221 | Eukaryota | Stramenopiles | Ochrophyta | Bacillariophyta | Thalassiosira | Thalassiosira_hispida | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 224 | otu_0226 | Eukaryota | Stramenopiles | Ochrophyta | Bacillariophyta | Cyclotella | Cyclotella_choctawhatchee | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 226 | otu_0228 | Eukaryota | Opisthokonta | Metazoa | Arthropoda | Oithona | Oithona_davisae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 227 | otu_0229 | Eukaryota | Opisthokonta | Metazoa | Arthropoda | Artemia | Artemia_salina | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 229 | otu_0231 | Eukaryota | Archaeplastida | Chlorophyta | Mamiellophycea | Ostreococcus | Ostreococcus_clade_B | 0 | 0 | 0 | 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 129 | 0 | |

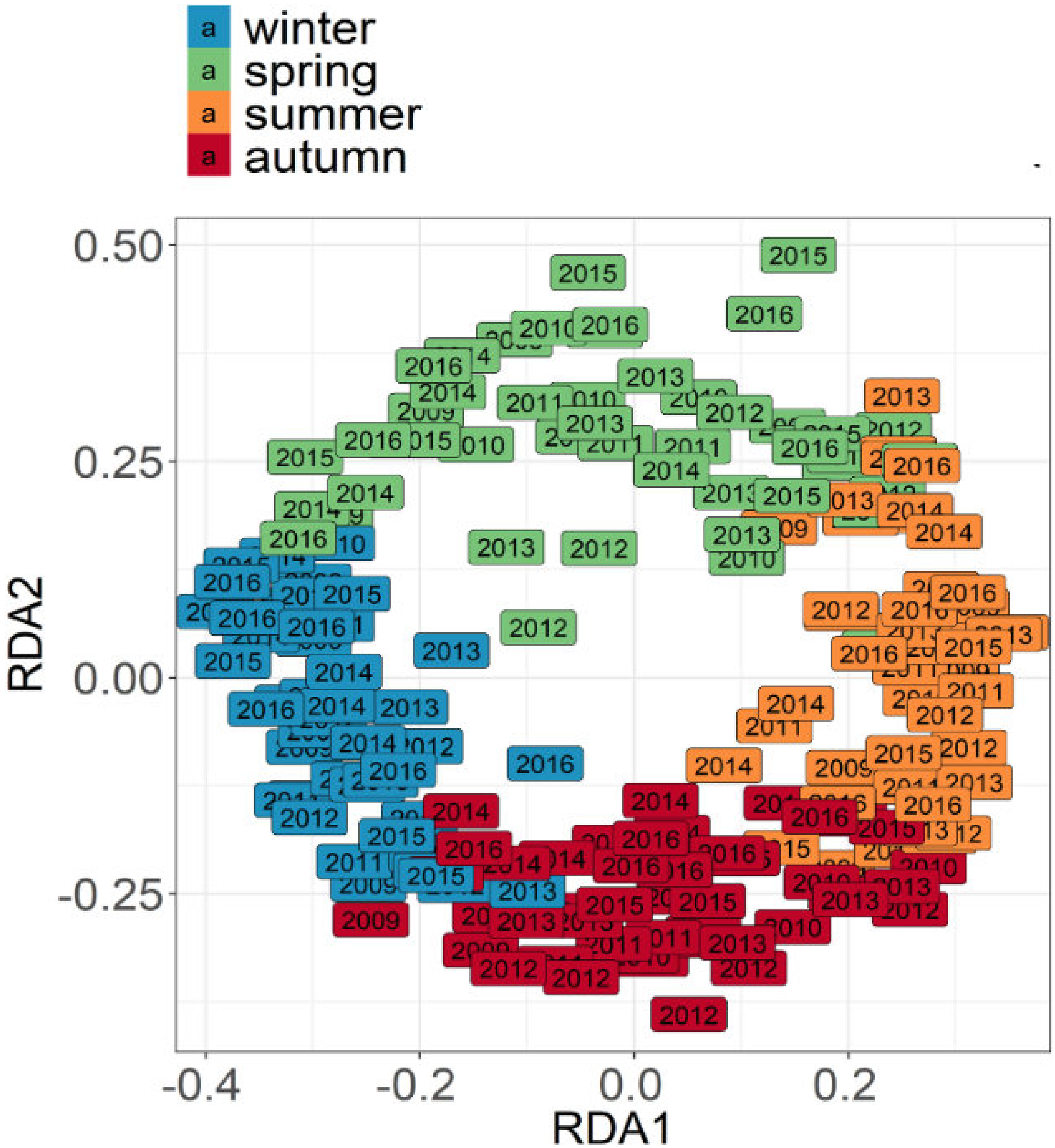
# Mean community composition




Caracciolo et al. 2022. Seasonal dynamics of marine protist communities in tidally mixed coastal waters. Molecular Ecology.

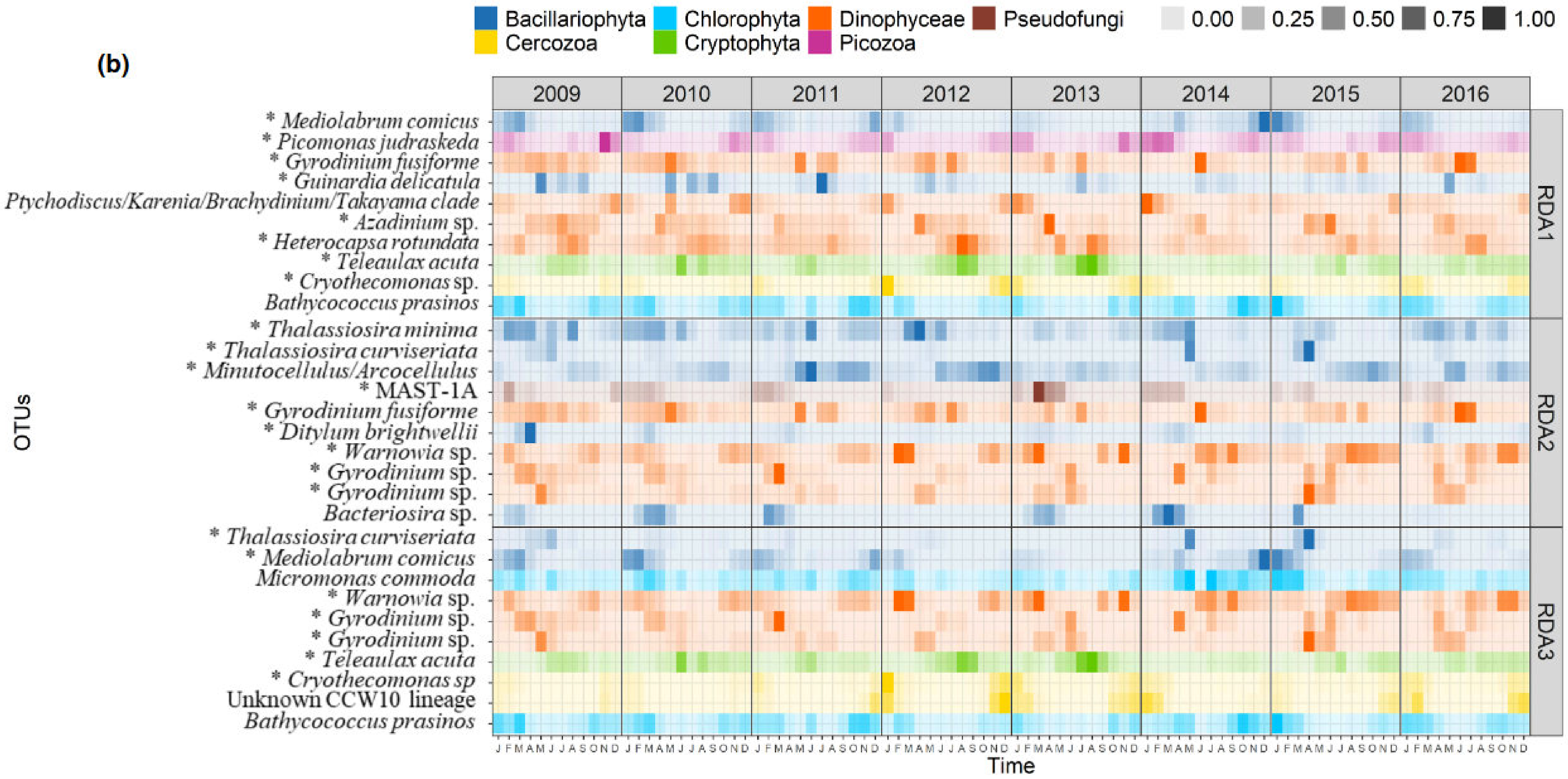
# Yearly cycle

- Redundancy analysis (RDA)

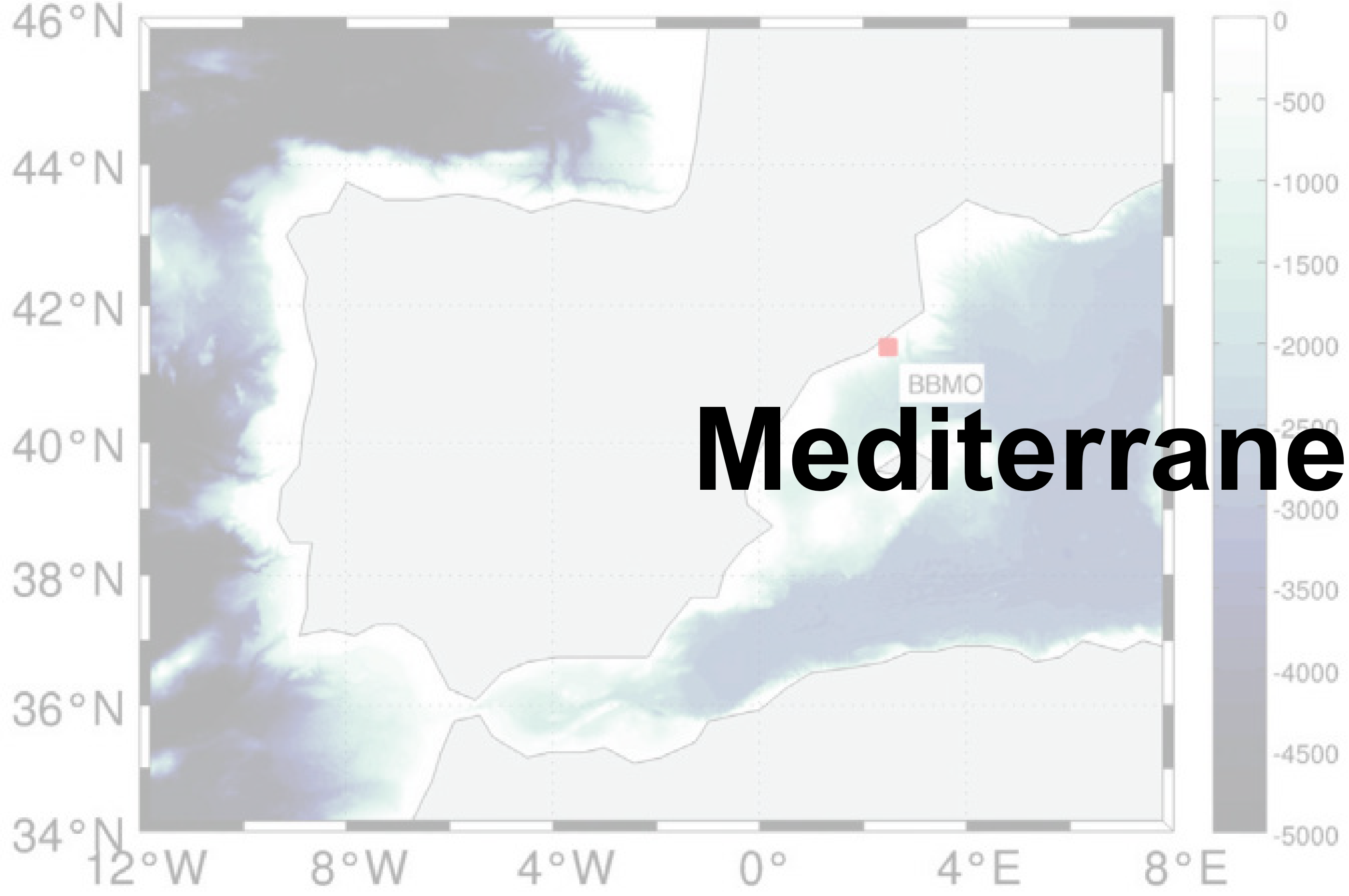


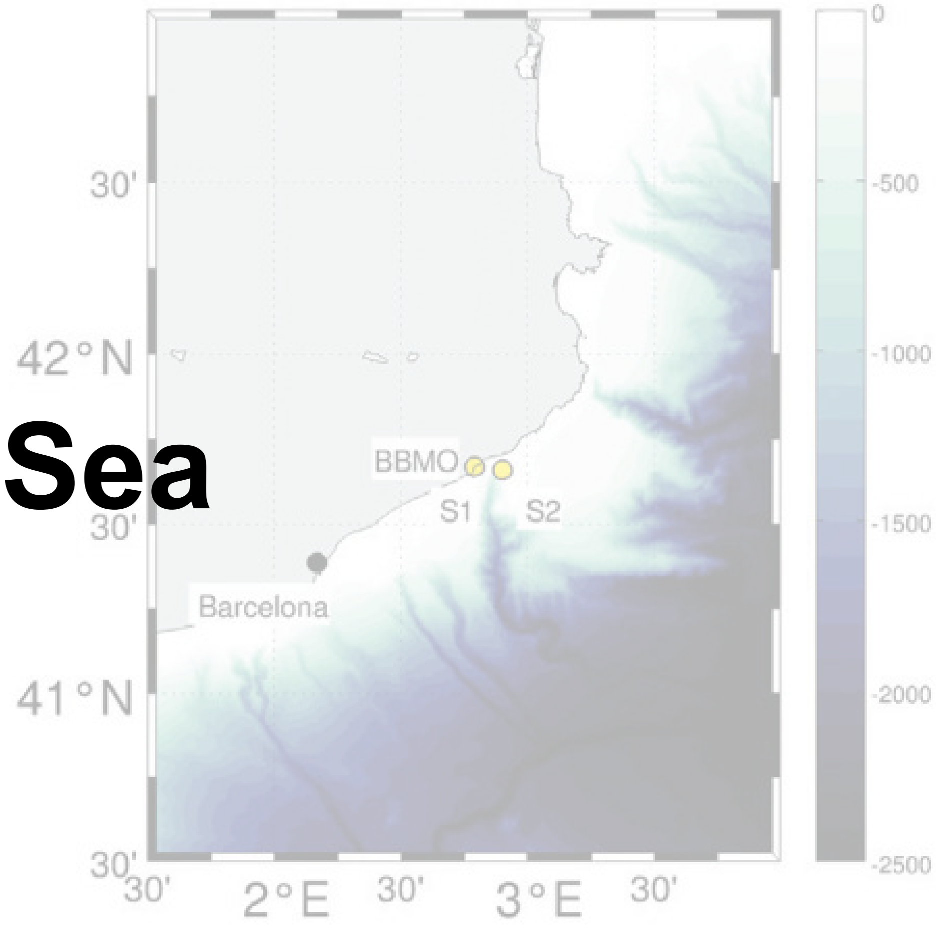
# Yearly cycle

- Redundancy analysis (RDA)



# Mediterranean Sea

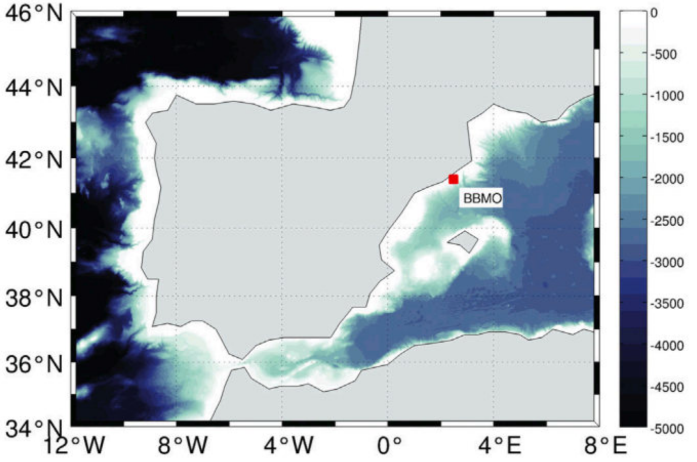


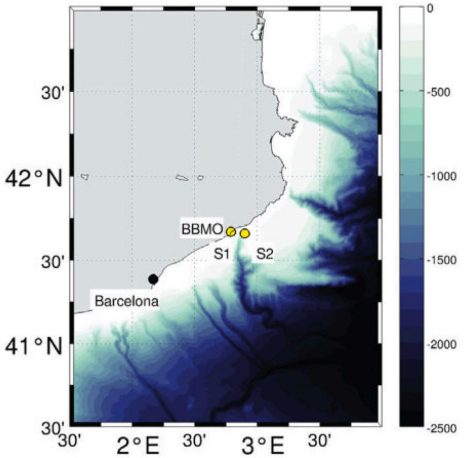



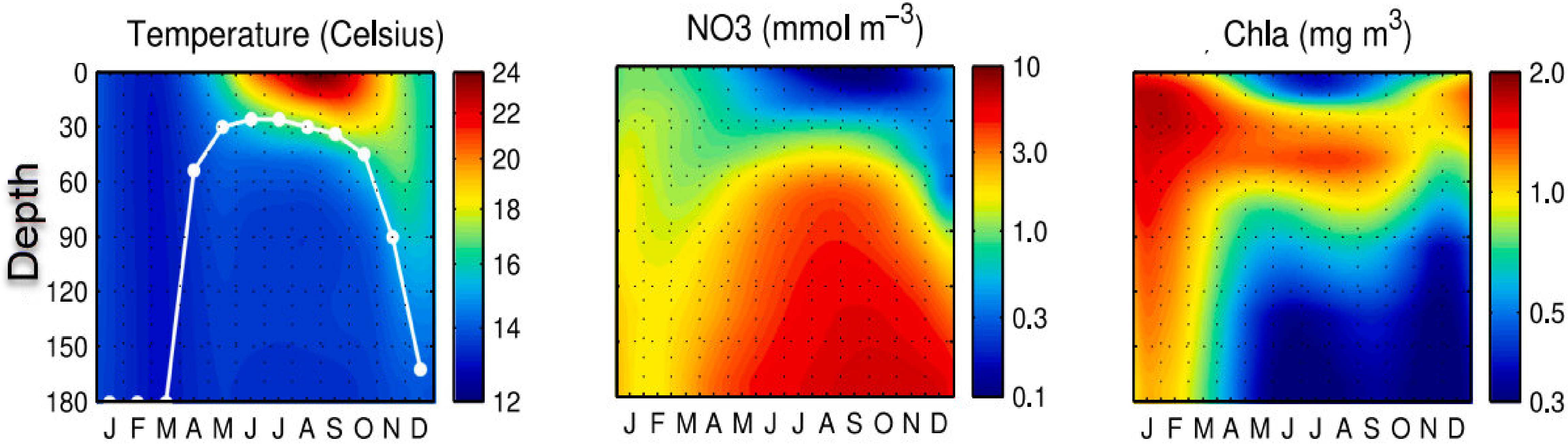
# Mediterranean Sea

- Blanes Bay (near Barcelona)
- 2004-2013
- Winter mixing
- January bloom

- Which groups/species exhibit periodic recurrence ?

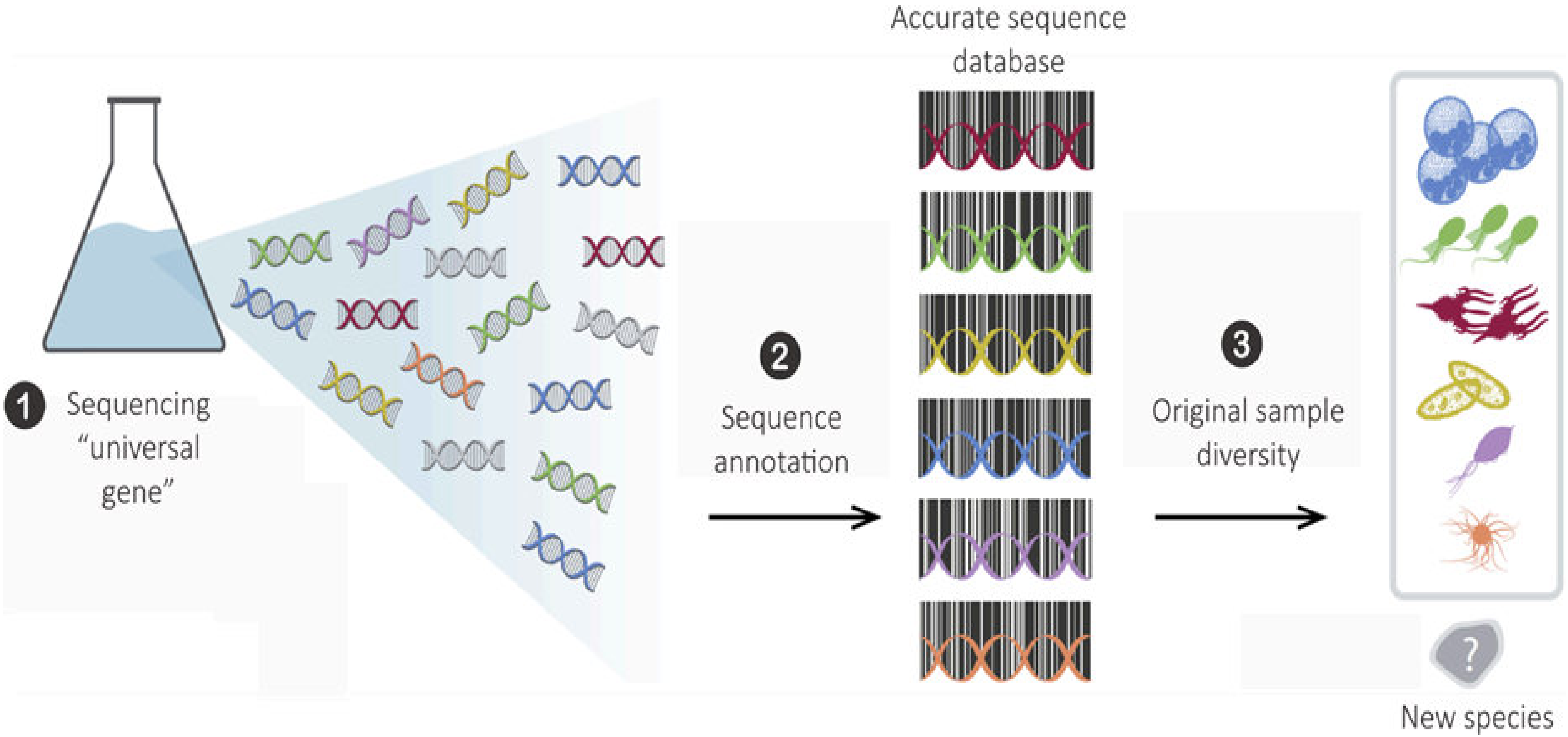


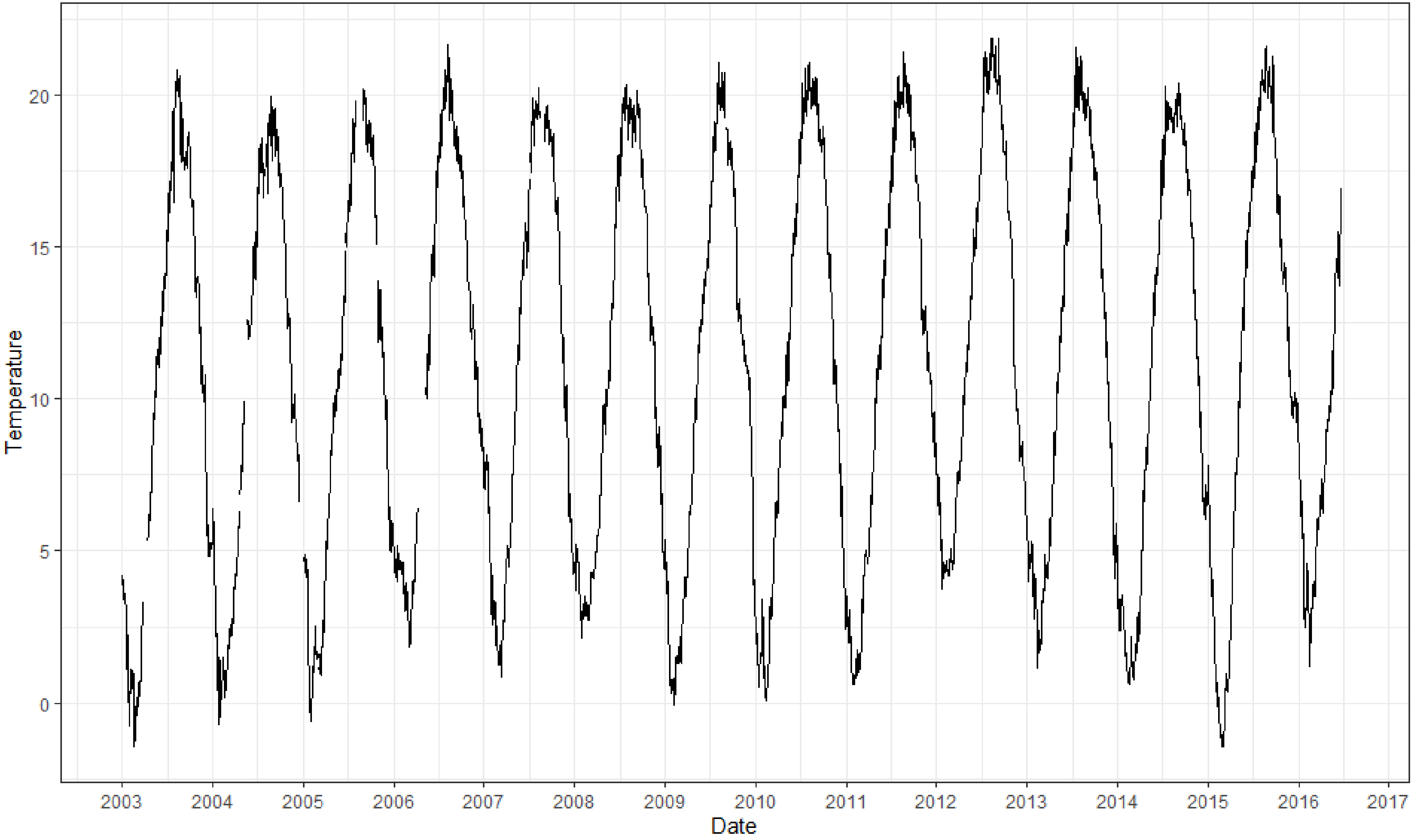




Vallina et al. 2023. Seasonal dynamics of phytoplankton community assembly at the Blanes Bay Microbial Observatory (BBMO), NW Mediterranean Sea. Progress in Oceanography. 219:103125.

# Metabarcoding

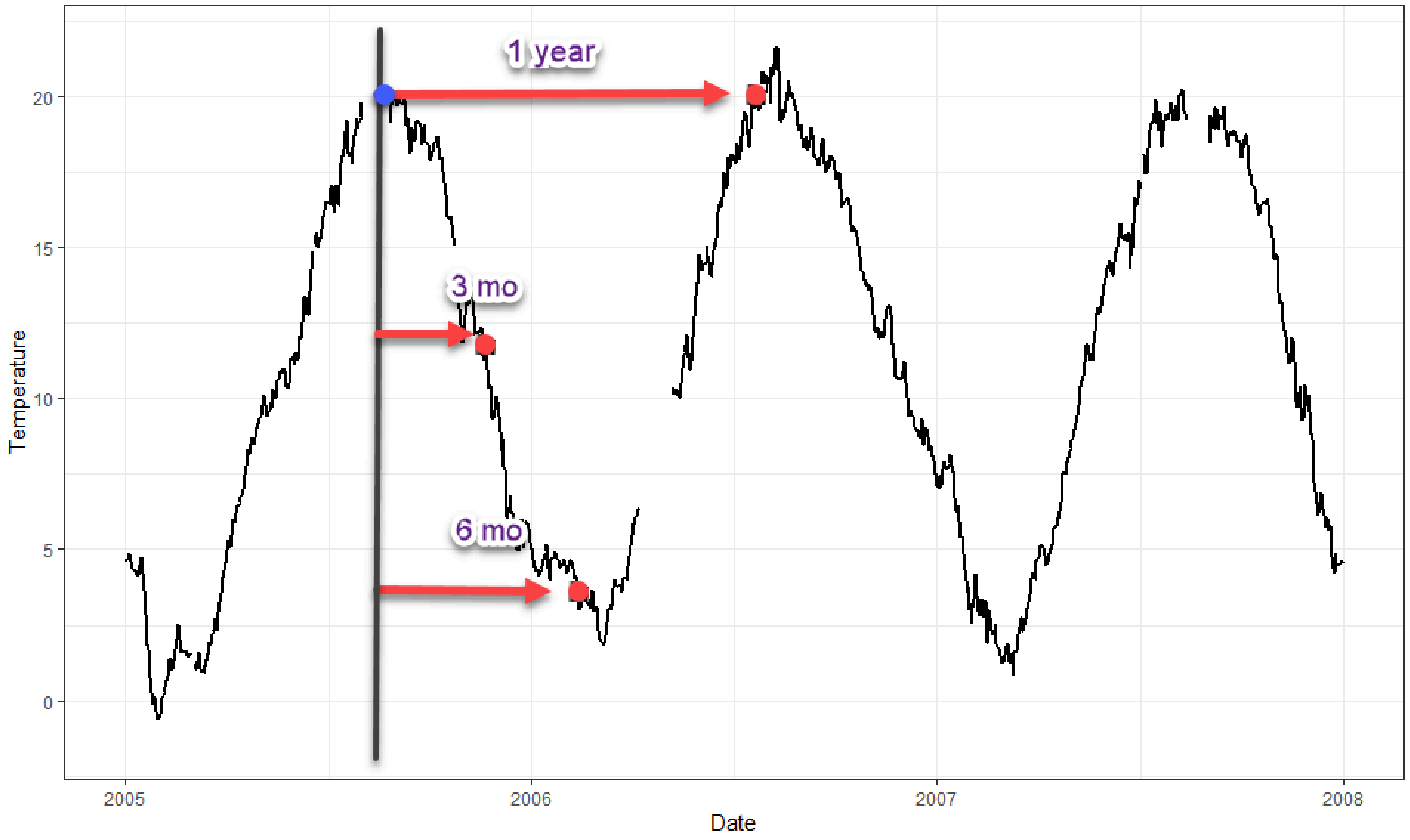


# How to determine periodicity ?



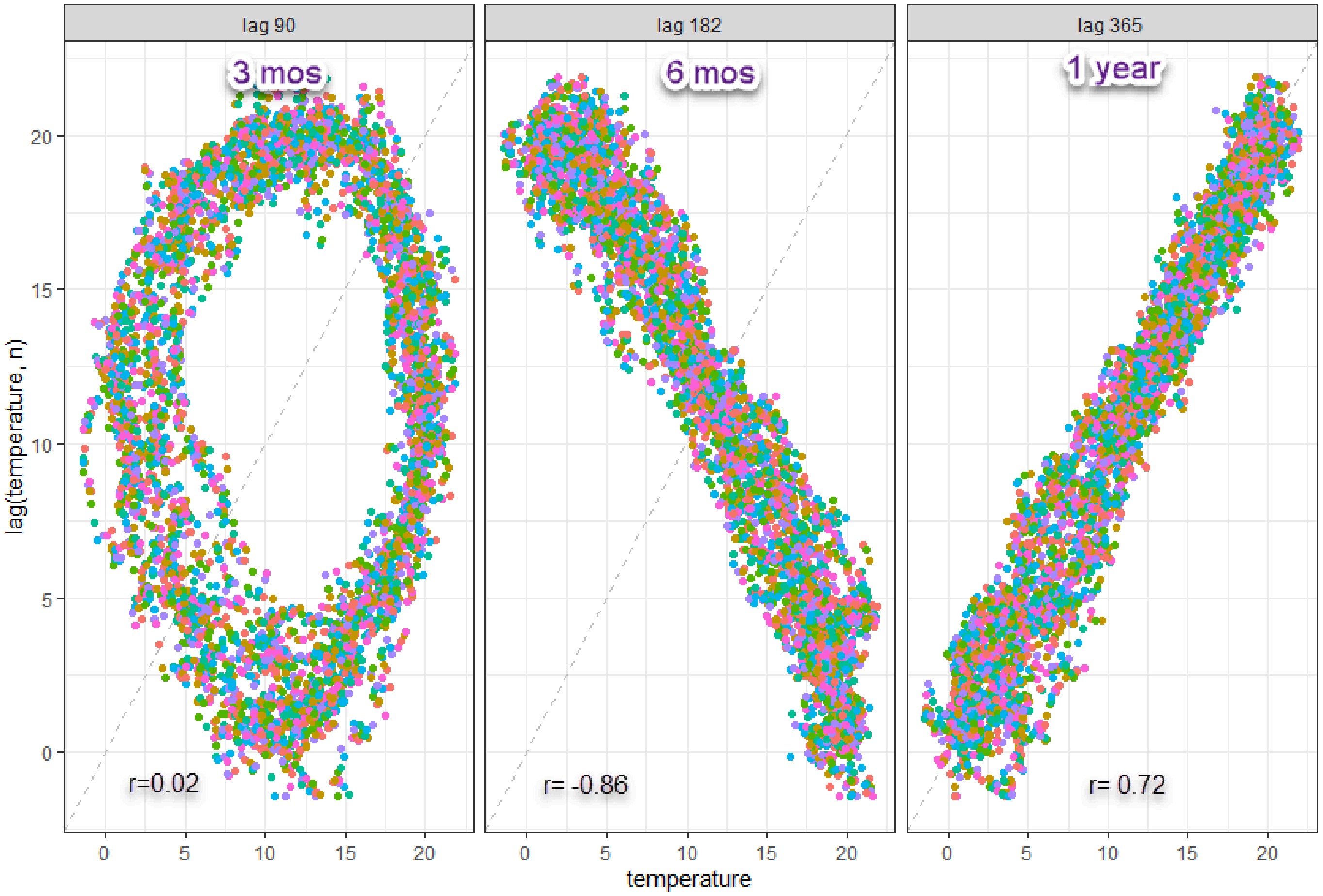
# How to determine periodicity ?

- Autocorrelation



# How to determine periodicity ?

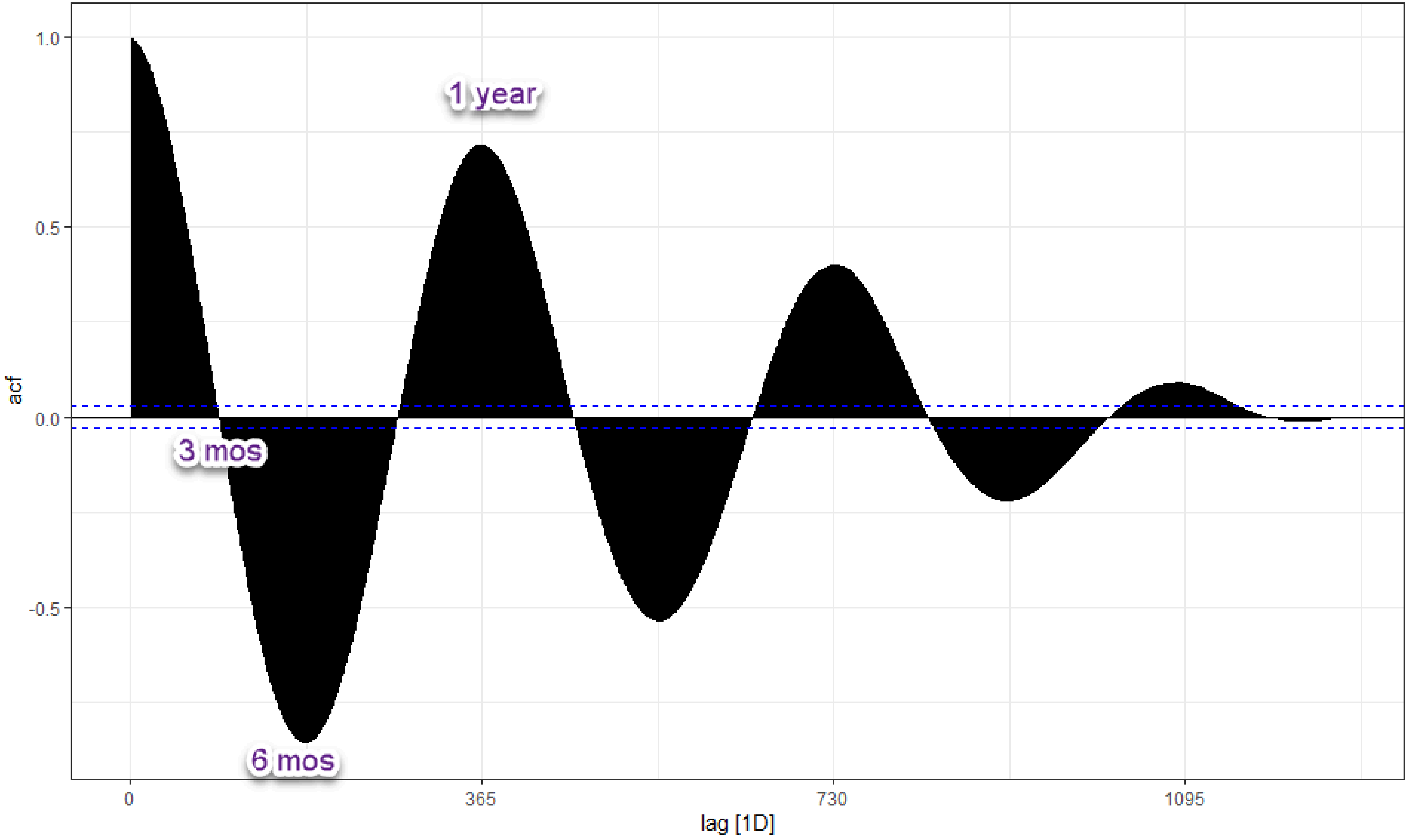
- Autocorrelation




$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

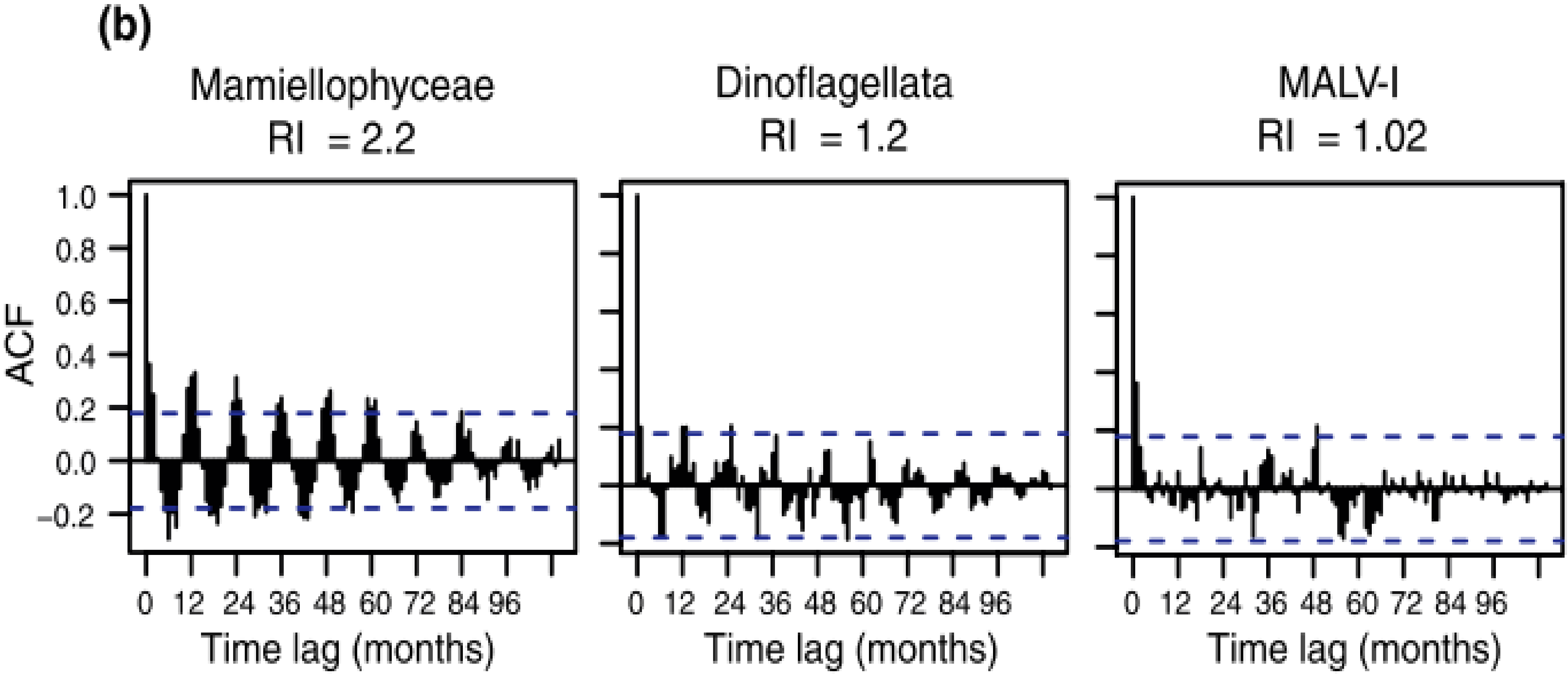
# How to determine periodicity ?

- Autocorrelation



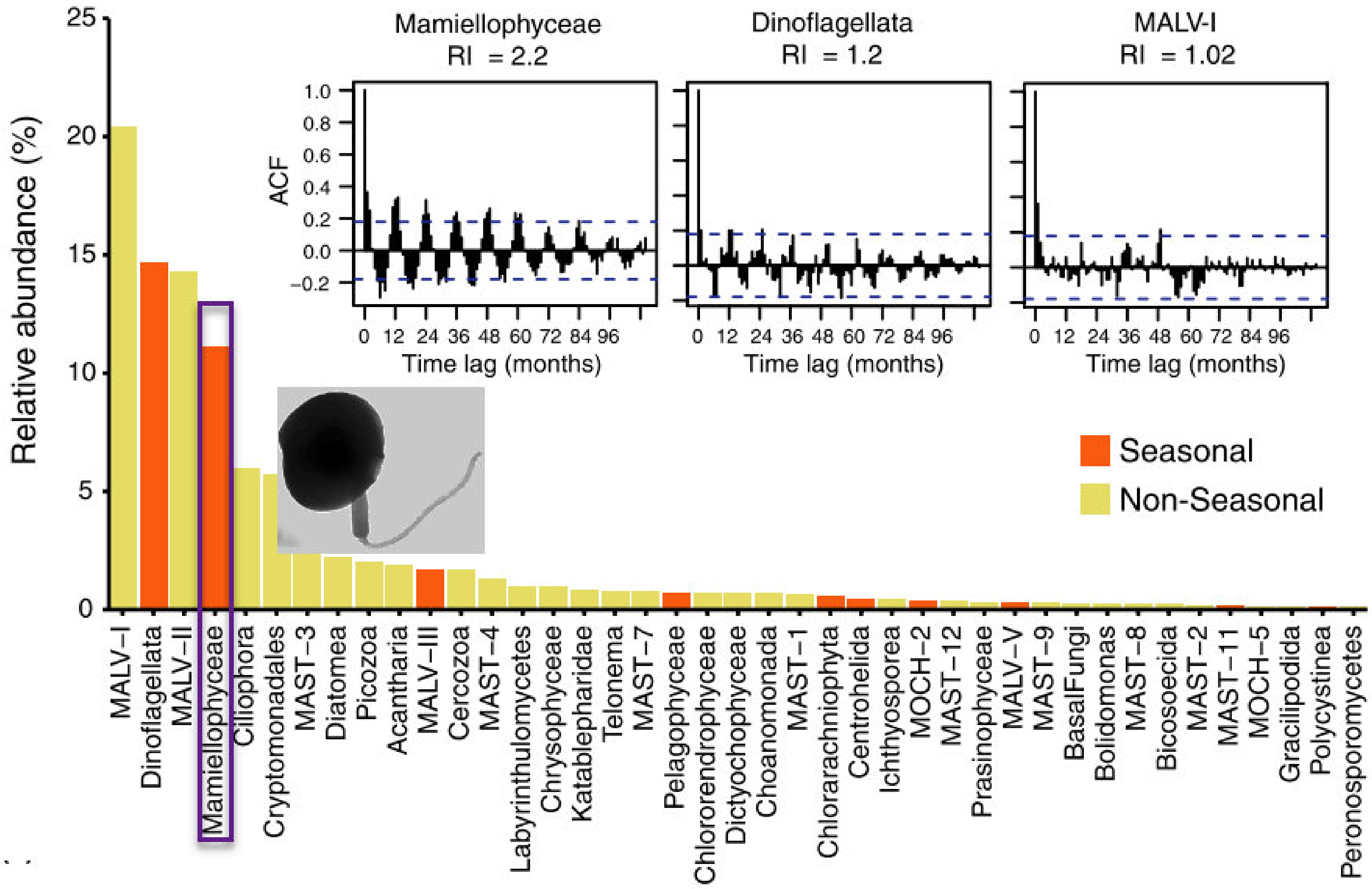
# Class periodicity

- Autocorrelation function

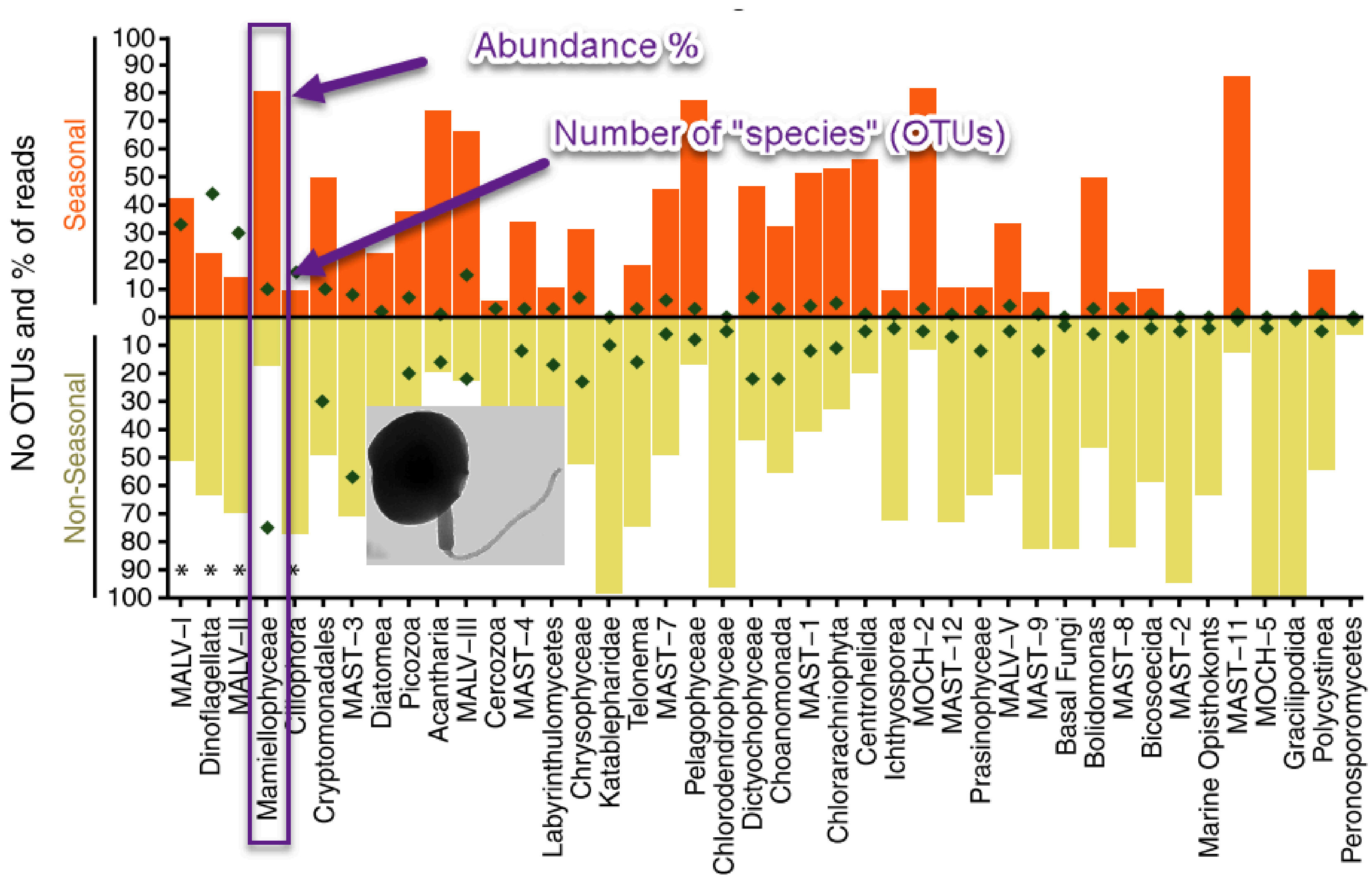



Giner et al. 2019. Quantifying long-term recurrence in planktonic microbial eukaryotes. 28:923-935. Molecular Ecology

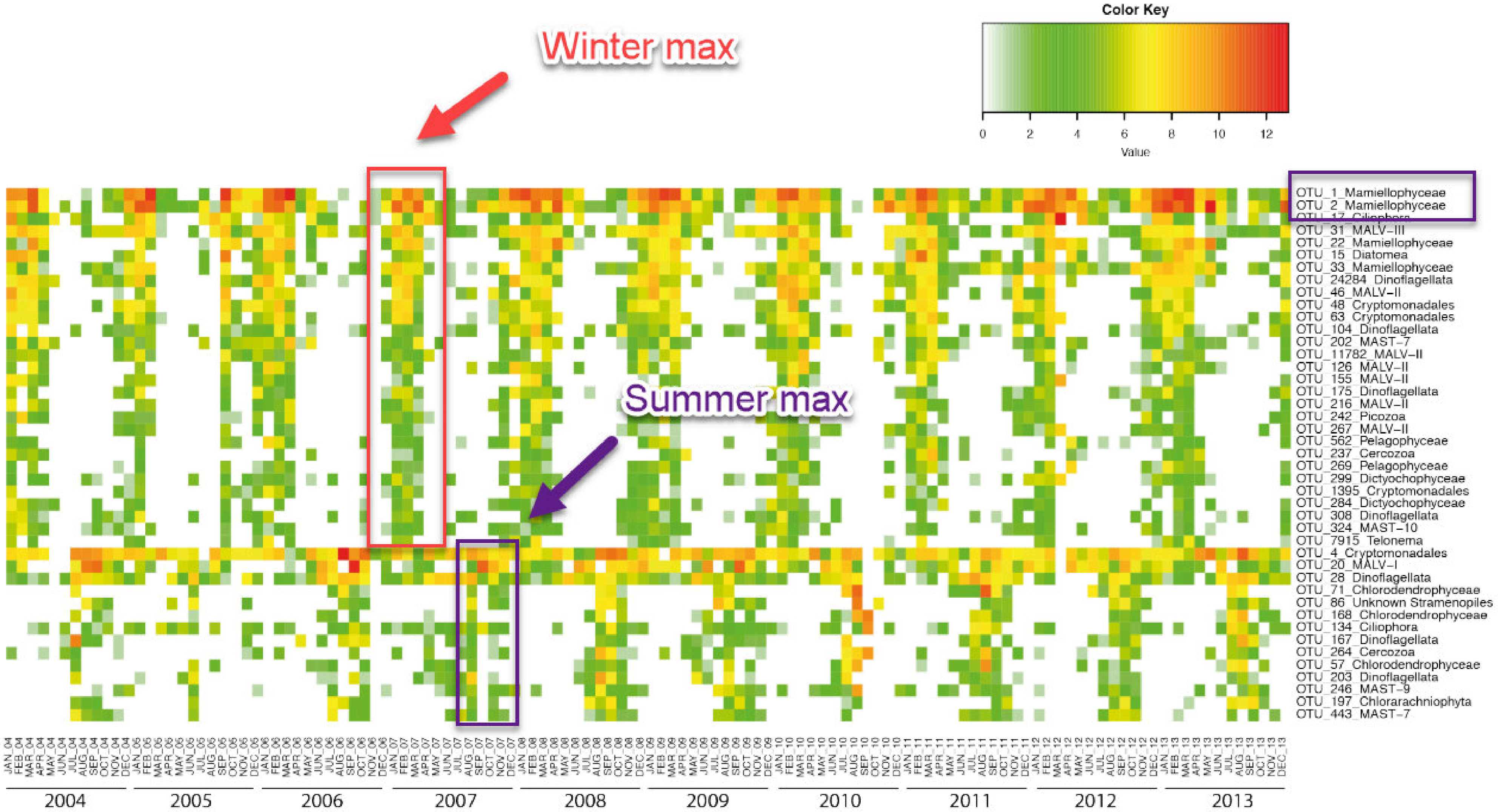
# Class periodicity



# Species periodicity



# Species periodicity

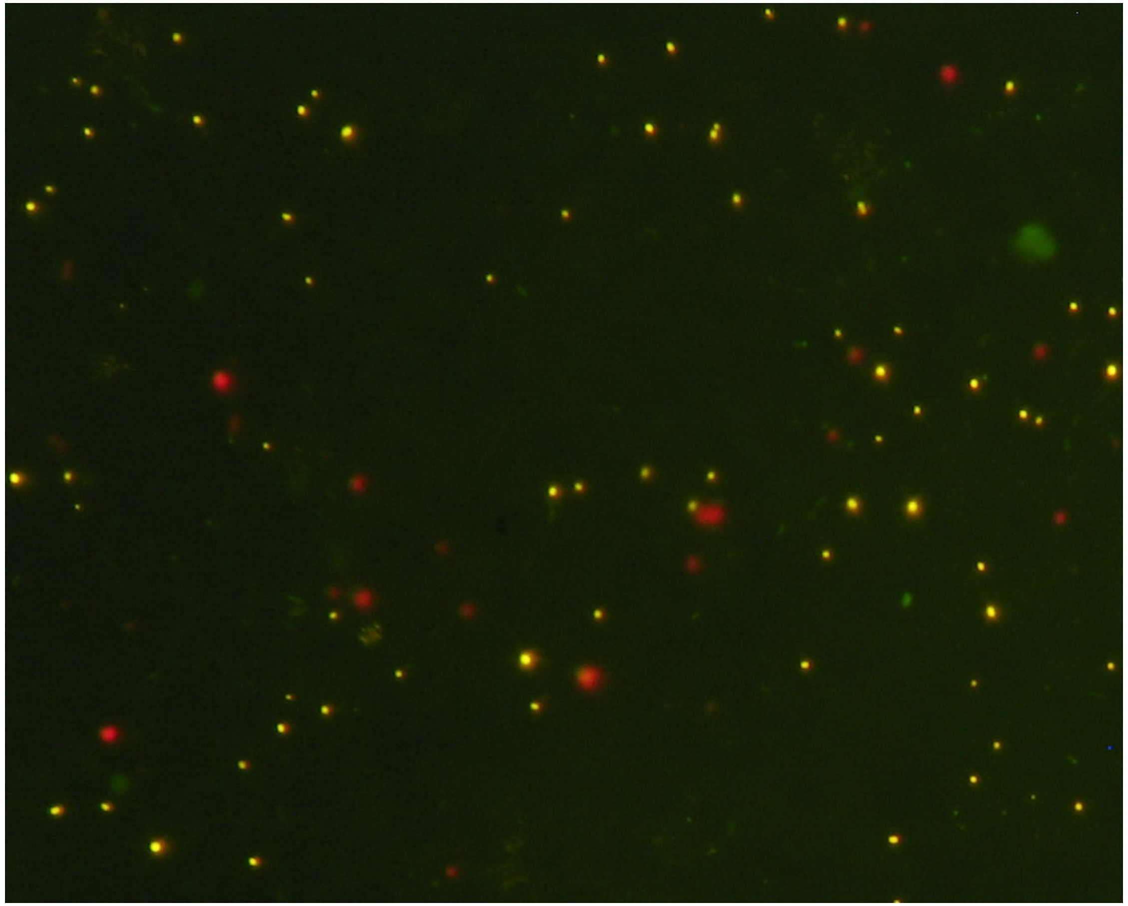


# Species dynamics

# What drives the *Synechoccus* bloom

# *Synechococcus*

- Discovered in 1979 by John Waterbury
- Epifluorescence microscopy



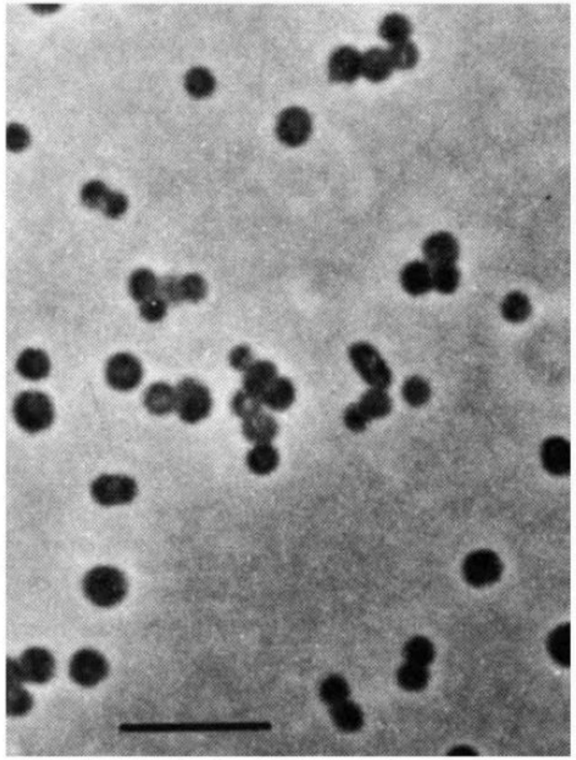
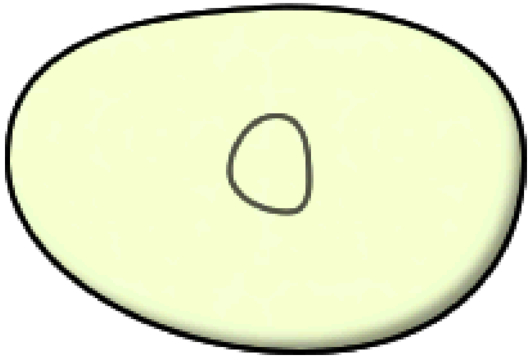


**Fig. 1** Phase contrast photomicrograph of *Synechococcus* sp. (strain Syn-48) illustrating general cell morphology (scale bar, 5.0 μm).

Waterbury, J.B., Watson, S.W., Guillard, R.R.L. & Brand, L.E. 1979. Nature. 277:293–4.

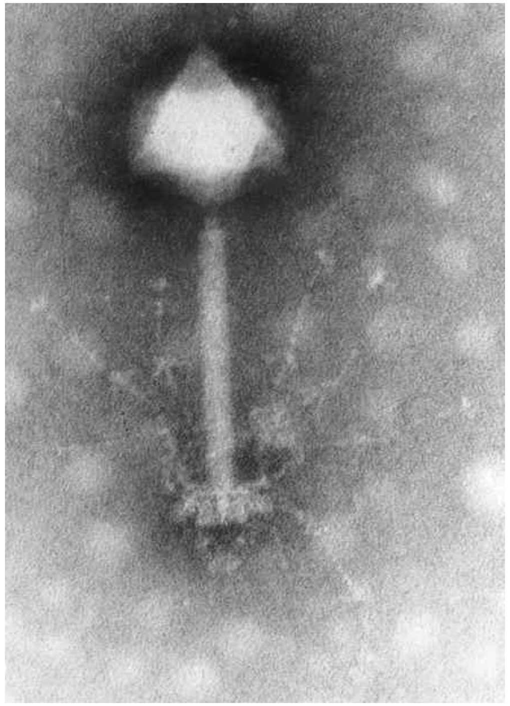
# Cell multiplication

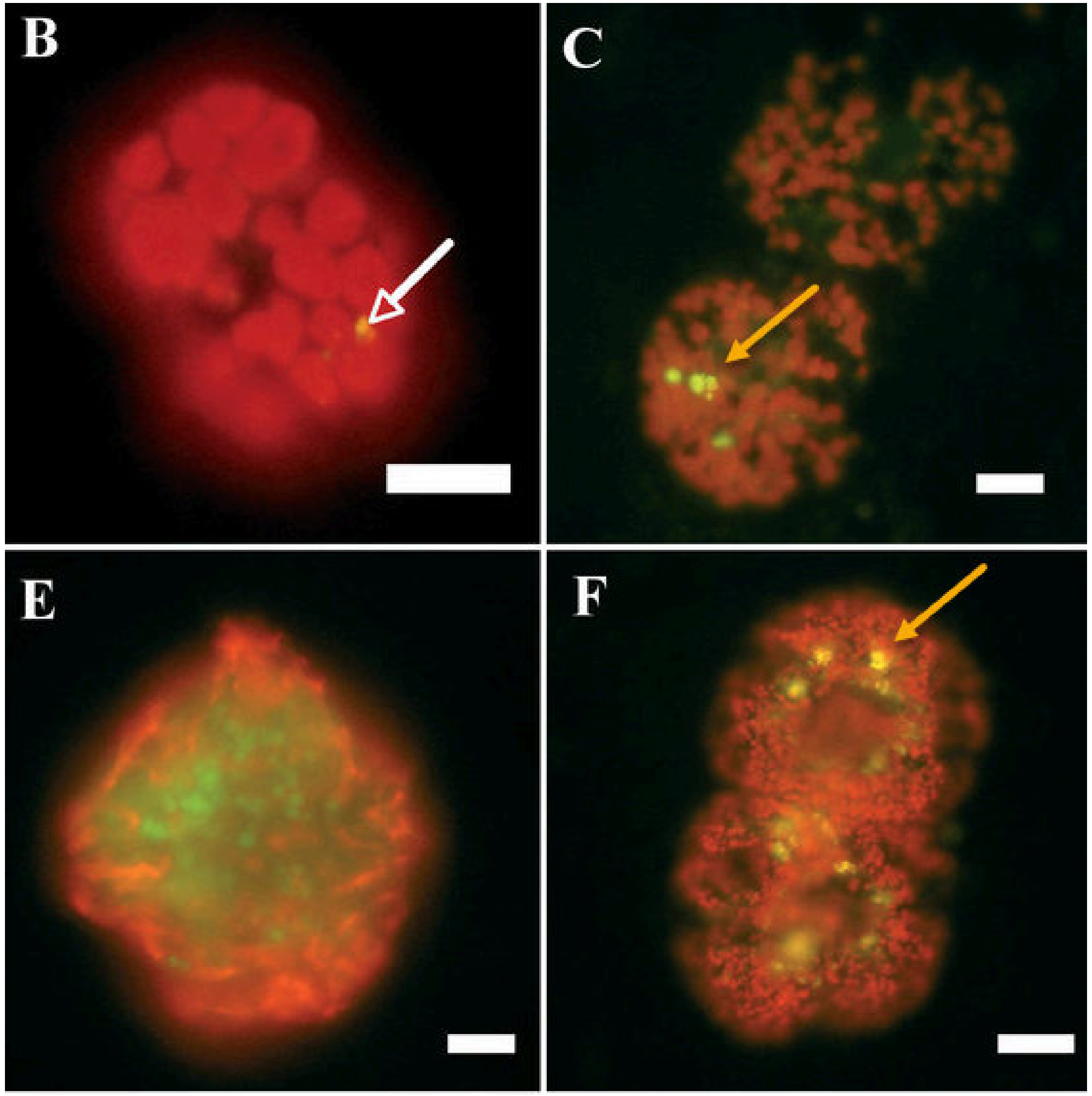
- Binary fission
- Typically once every day



# Cell disappearance

- Virus
- Predation
- Cell death (UV, nutrient deprivation)





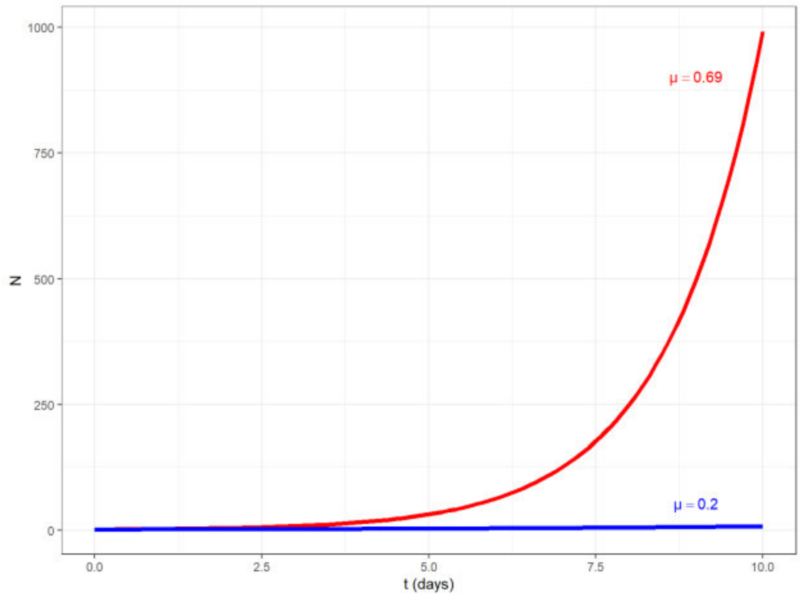
# Growth rate vs Loss rate

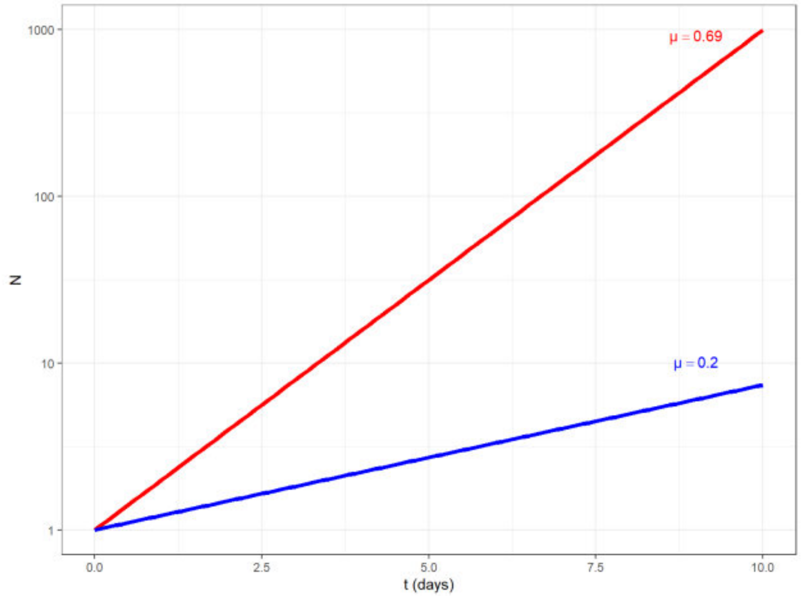
$$\frac{dN}{dt} = \mu_{net} * N$$

$$N = N_0 \exp^{\mu_{net} * t}$$

$$\mu_{net} = \mu_{growth} - \mu_{loss}$$

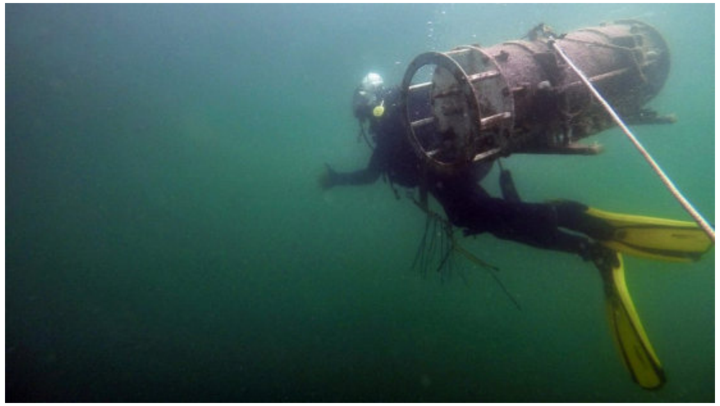
- Growth rate = division
- Loss rate = cell death, predation, viruses

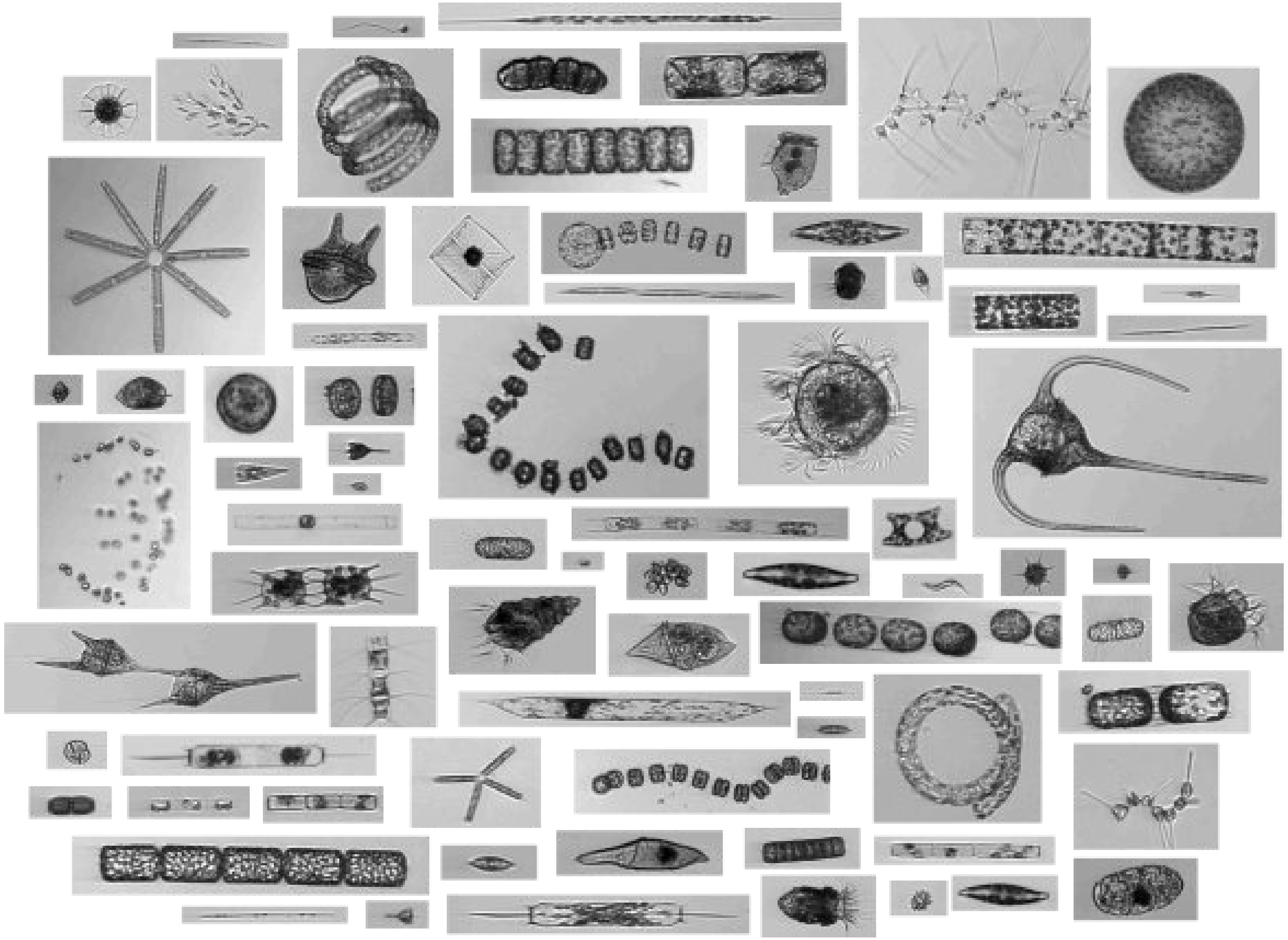


# Flow Cytobot

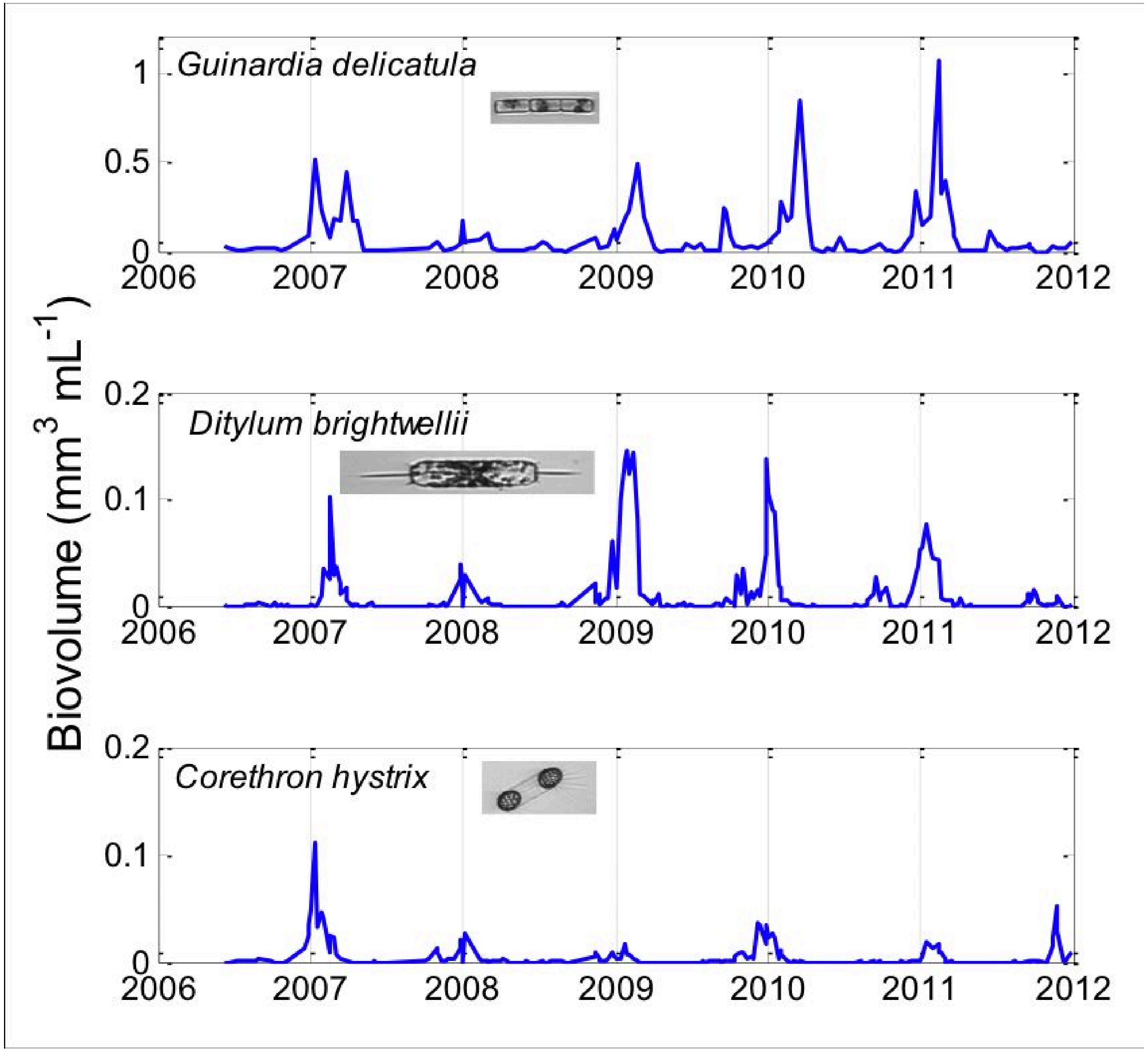
- Imaging and flow cytometry





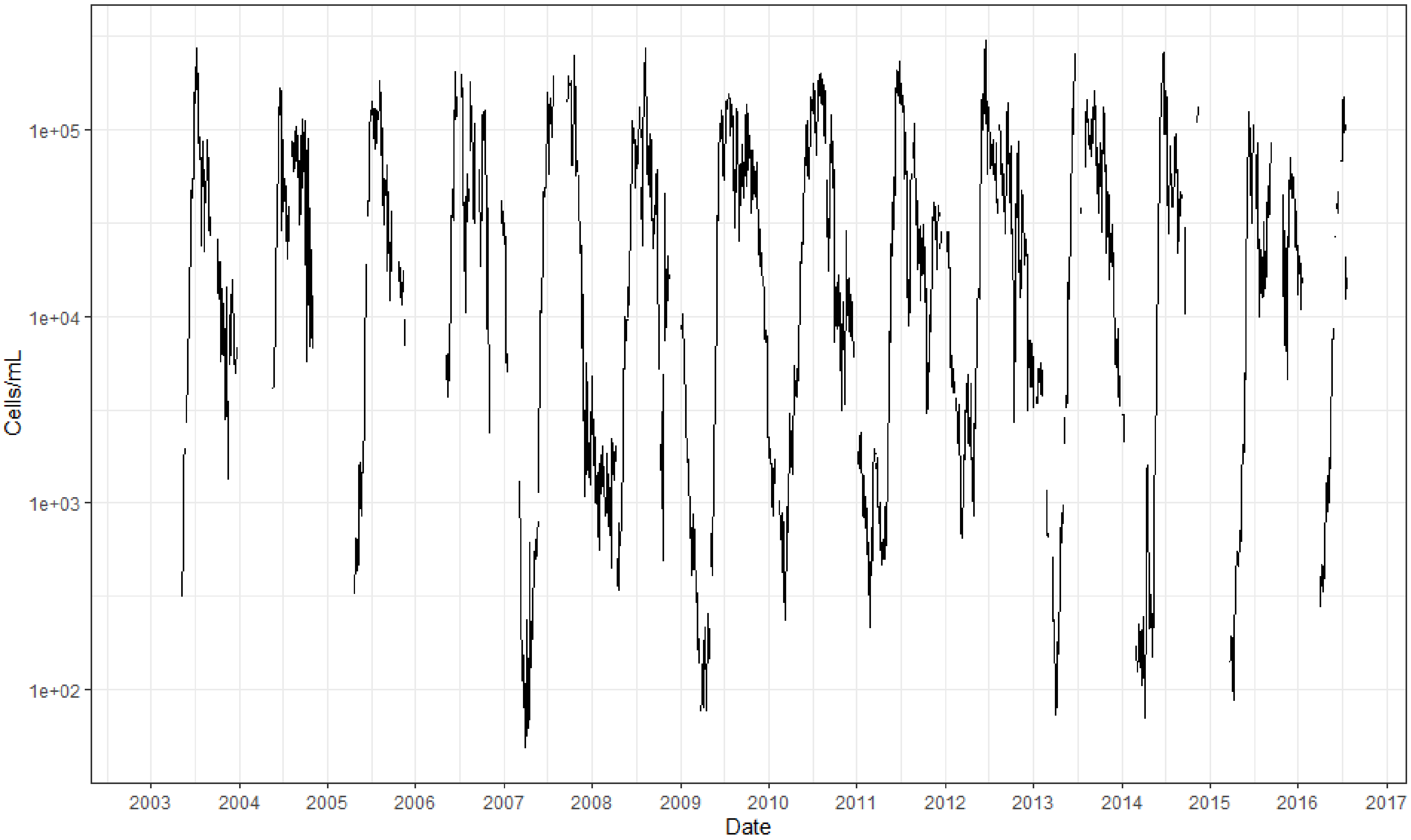
# Flow Cytobot

- Diatoms



# *Synechococcus* abundance

- Annual periodicity




Hunter-Cevera et al. 2016. Physiological and ecological drivers of early spring blooms of a coastal phytoplankter. Science 354:326–329.

# *Synechococcus* characteristics

- Annual periodicity

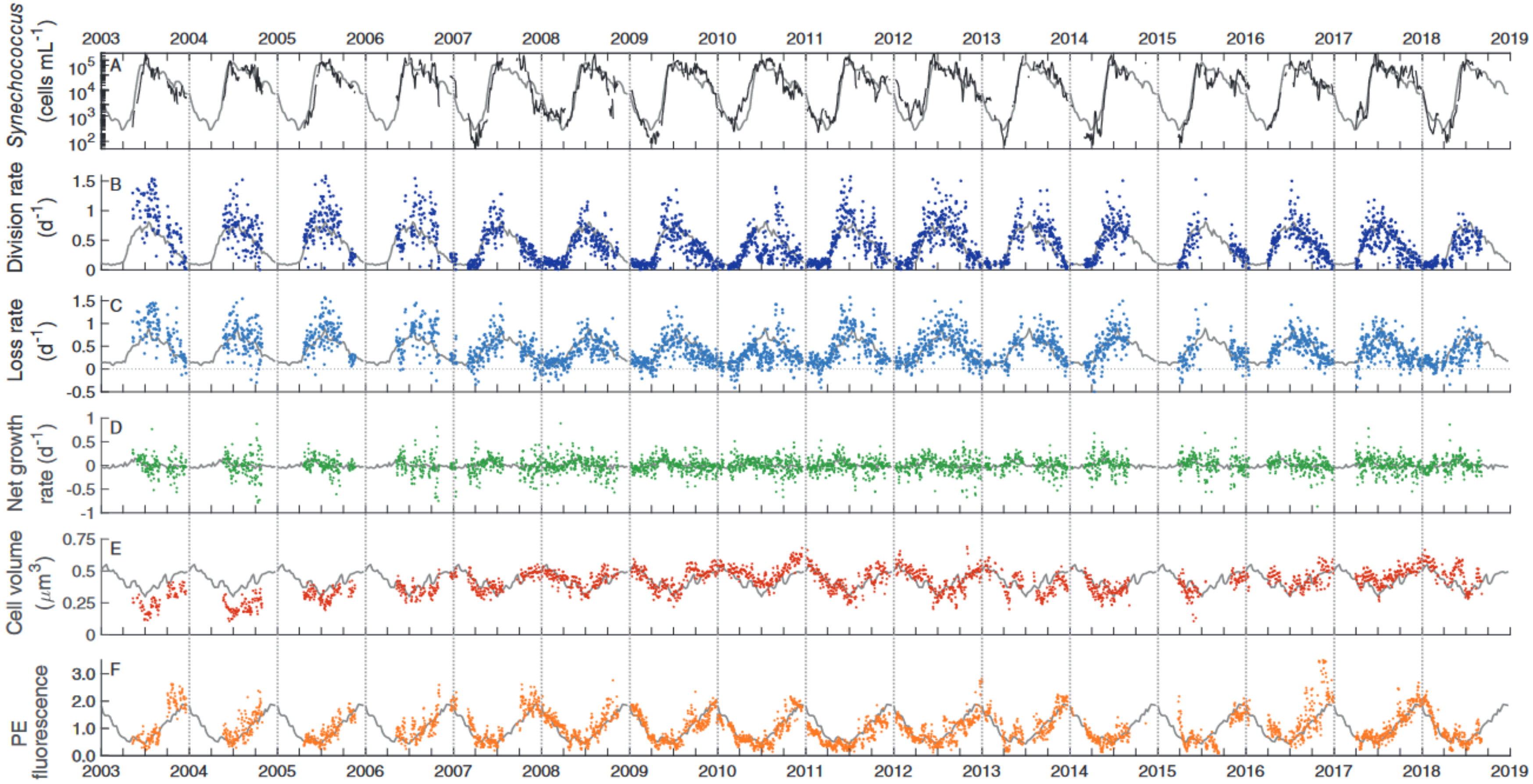



**Fig. 4.** Daily time series of *Synechococcus* properties for (**A**) cell concentration, log scale, (**B**) daily division rate, (**C**) calculated daily loss rate, (**D**) net growth rate, (**E**) cell volume, and (**F**) cellular PE fluorescence. Gray lines in each panel are annual patterns (weekly median climatology) for reference.

Hunter-Cevera et al. 2020. Seasons of Syn. Limnology and Oceanography. 65:1085–102.

# *Synechococcus* annual cycle

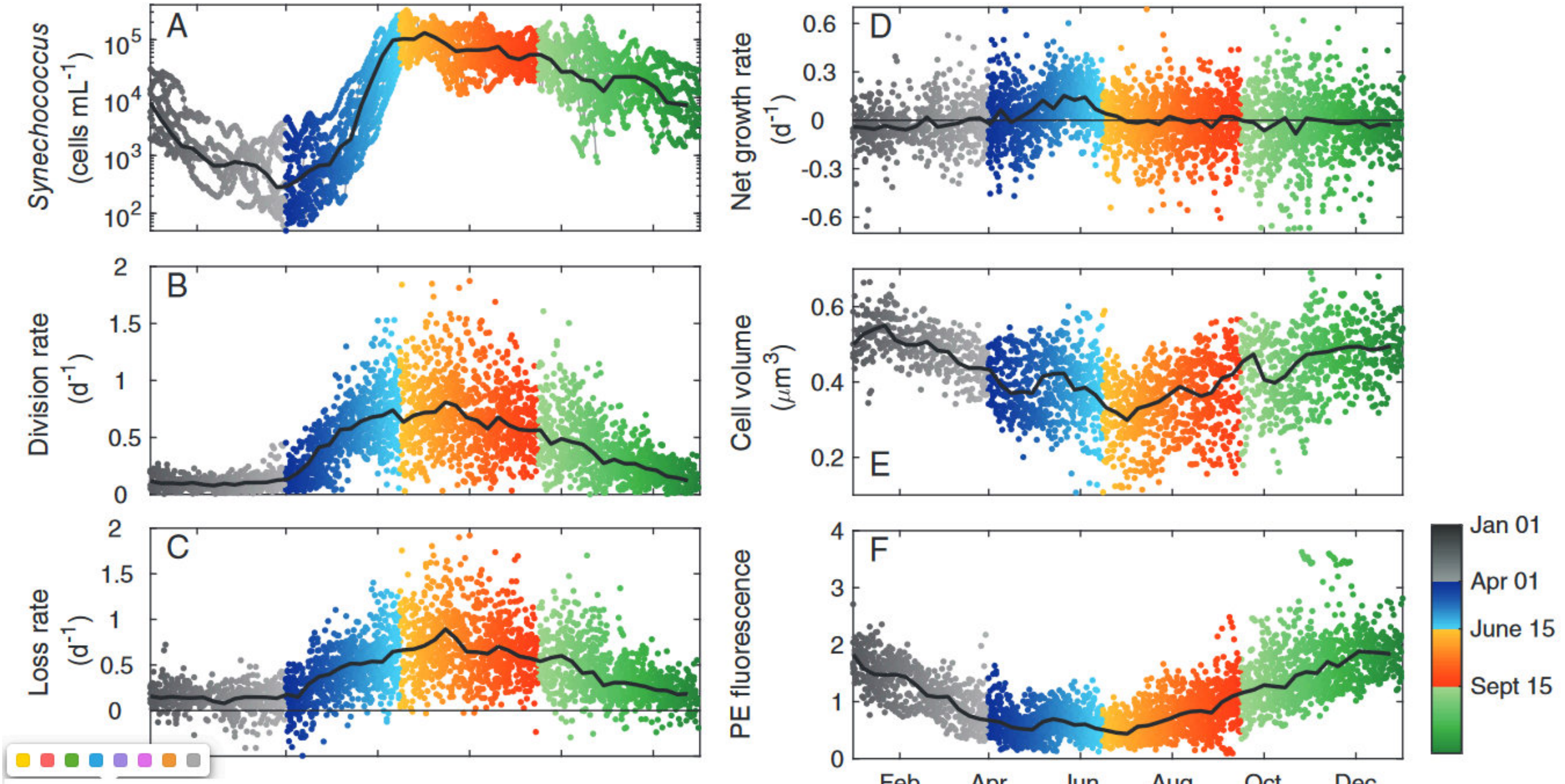
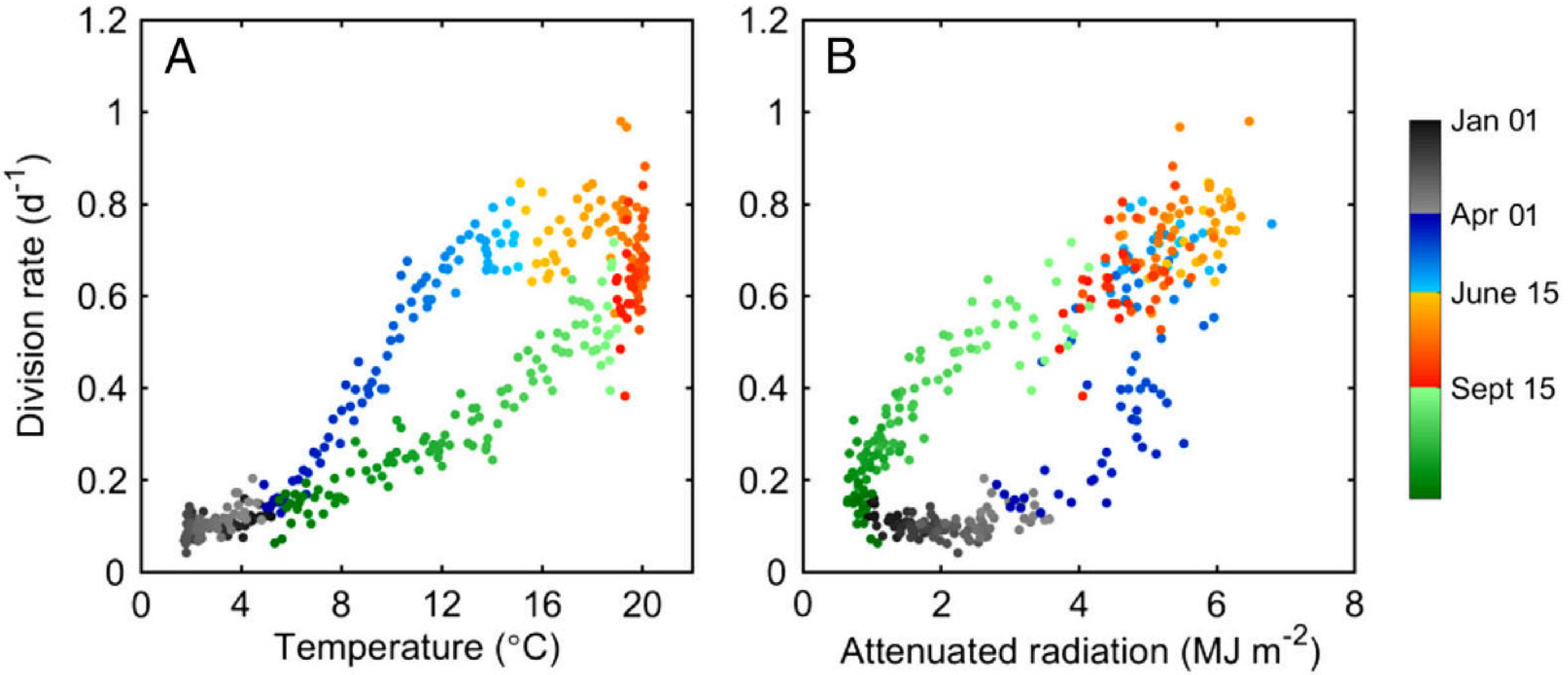



**Fig. 5.** Scatter plots of (**A**) *Synechococcus* concentration, (**B**) division rate, (**C**) loss rate, (**D**) net growth rate, (**E**) cell volume, and (**F**) cellular PE fluorescence by year day for data from 2003 to 2018. Black line in each panel is weekly median climatology. Color indicates season and year day.

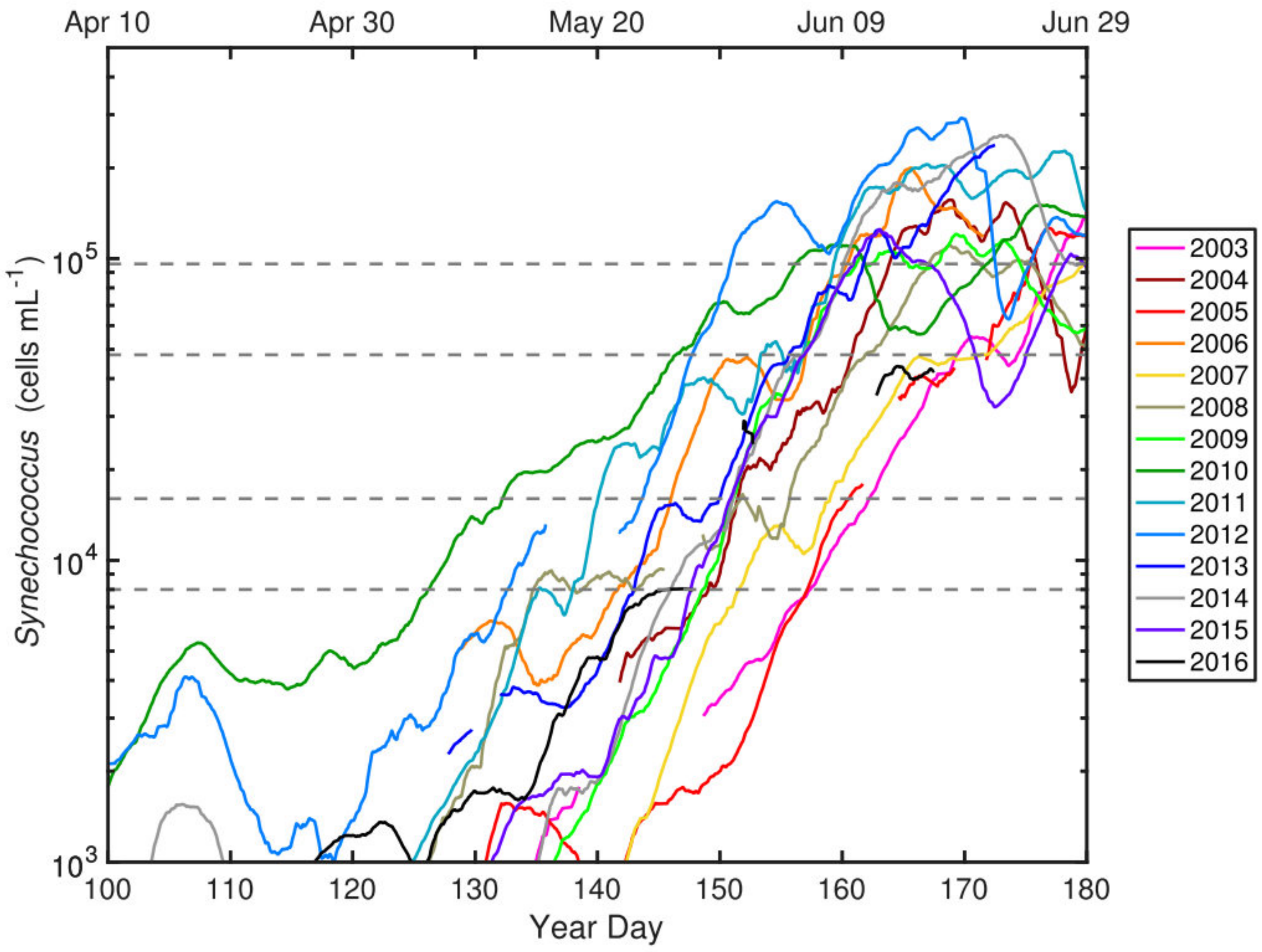
# *Synechococcus* annual cycle

- Division rate
  - Temperature
  - Radiation
- Hysteresis



# *Synechococcus* abundance

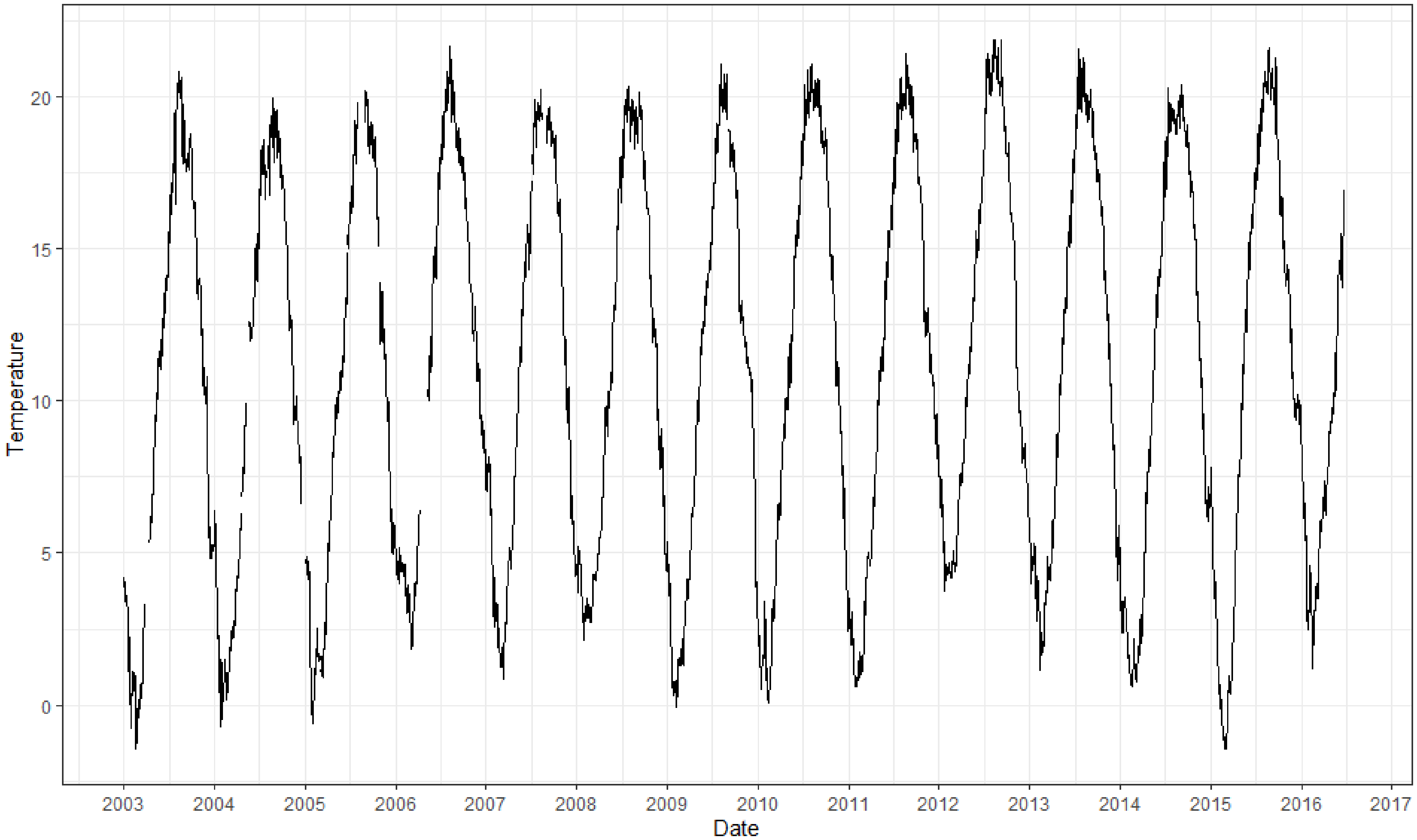
- Varies from one year to next




Hunter-Cevera et al. 2016. Physiological and ecological drivers of early spring blooms of a coastal phytoplankter. Science 354:326–329.

# Temperature

- Can temperature explain ?



# Temperature anomaly

- Some years are warmer than others

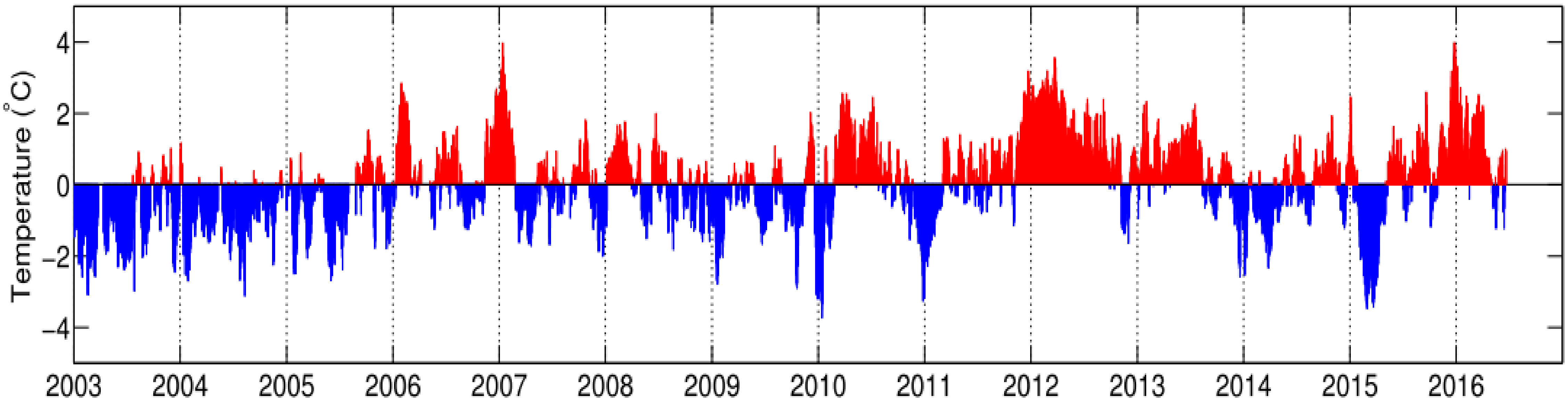



**Figure S3**. Daily temperature anomalies (ºC) from daily climatological average for 2003 to available 2016. Red values indicate positive anomalies, while blue indicates negative anomalies.

# *Synechococcus* vs. Temperature

- Day when temperature > threshold
- Matches Syn concentration > threshold

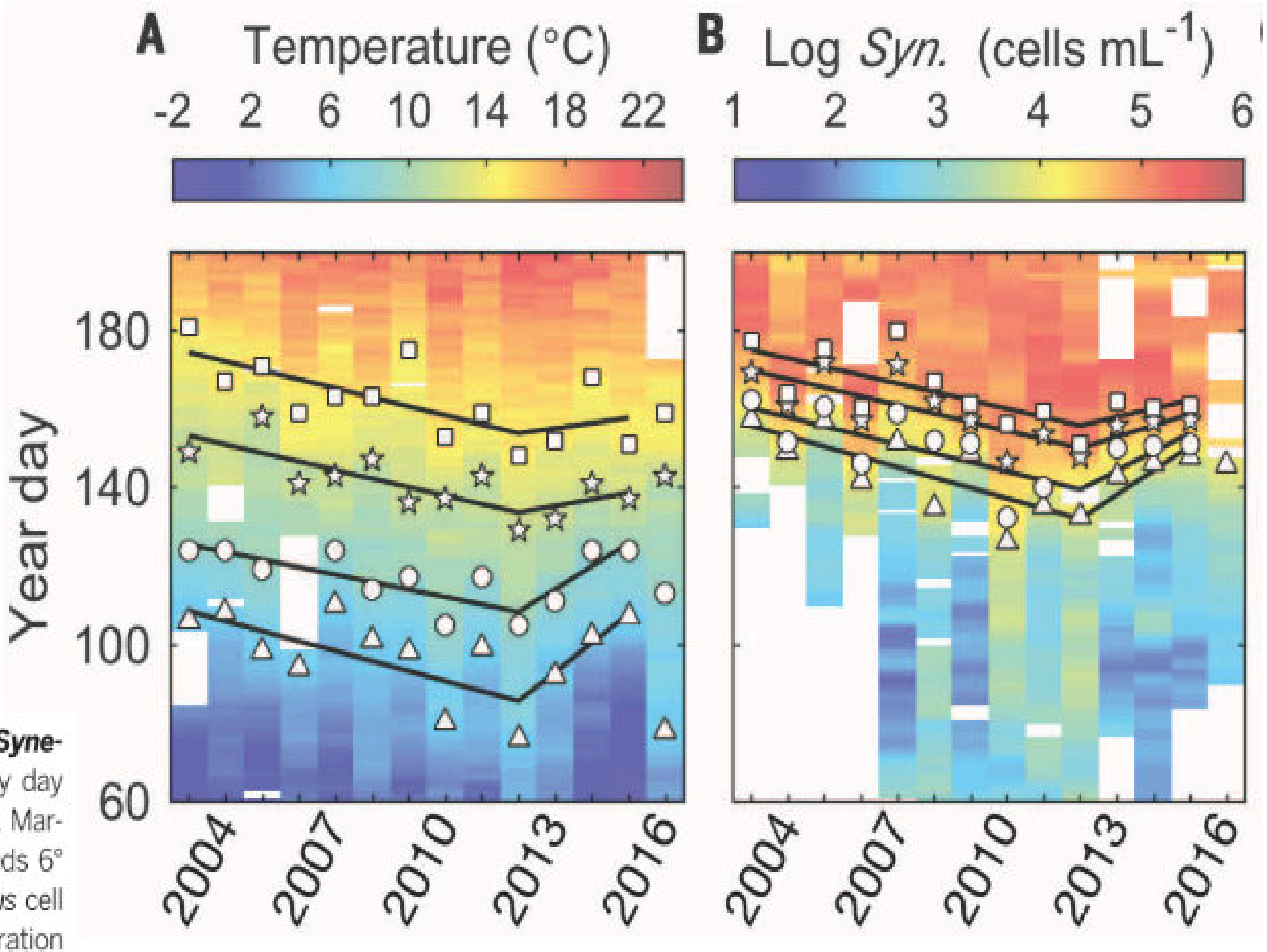



**Fig. 2. Multiyear trends showing spring temperature changes and *Synechococcus* bloom shifts from 2003 to 2016.** The data are shown by day of the year (vertical axis), with values denoted by color. (**A**) Temperature. Markers indicate the day in each year when water temperature first exceeds 6° (triangles), 9° (circles), 12° (stars), or 15°C (squares). (**B**) *Synechococcus* cell concentration. Markers indicate the day in each year when cell concentration exceeds $8 \times 10^3$ (triangles), $1.6 \times 10^4$ (circles), $4.8 \times 10^4$ (stars), or $9.6 \times 10^4$ (squares) cells $ml^{-1}$. (**C**) Integrated division rate (cumulative summed division

# Take home messages

- Long term observation is key to understand:
  - what changes?
  - what drives the change?
- Some examples
  - CPR allowed to detect “Atlantification”
  - Hawaii long term change in Pacific
- More basic research questions
  - Which species re-occur from one year to the next?
  - What causes year-to-year variability for one given species?

# Questions ?