Long-term warming and human-induced plankton shifts at a coastal Eastern Mediterranean site

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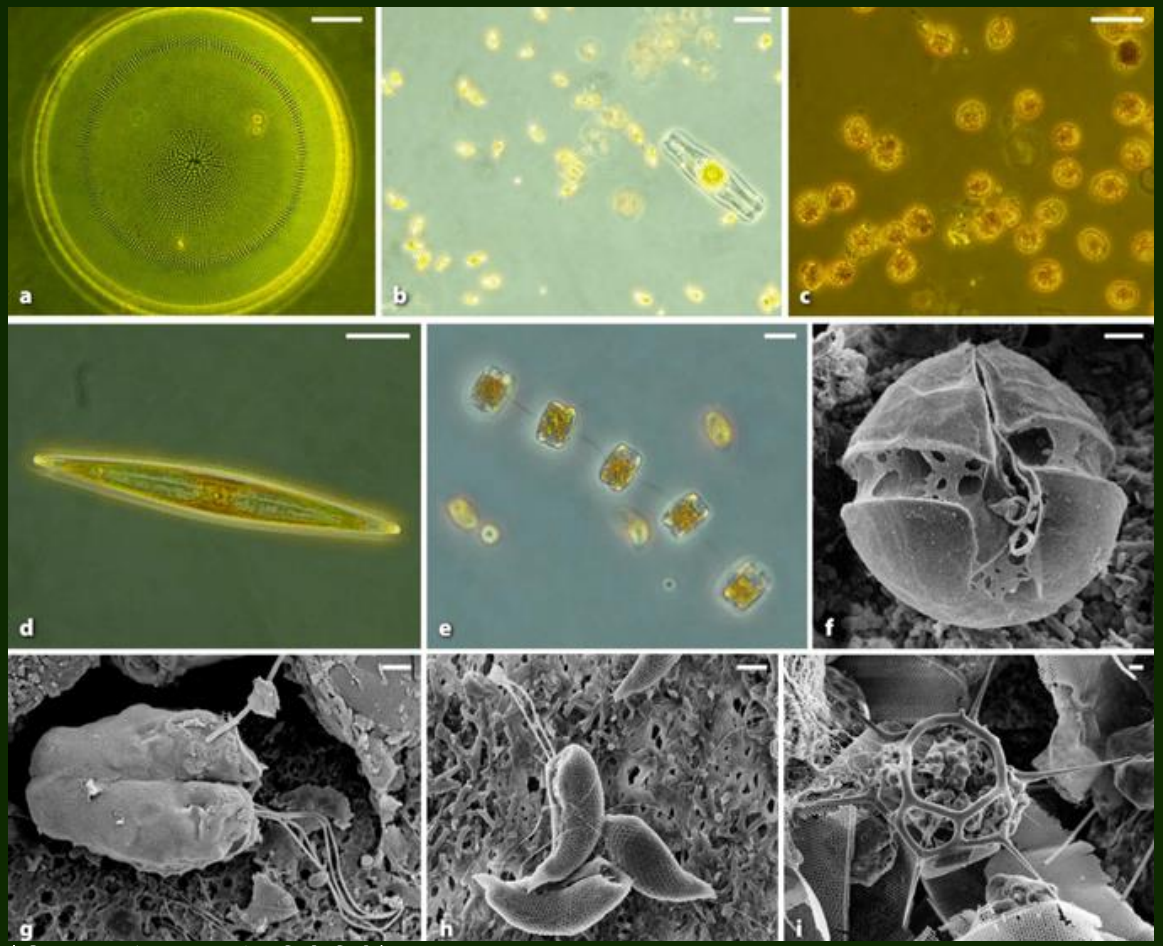
Introduction



(Cusick *et al.*, 2020)

(Bucklin *et al.*, 2021)

Phytoplankton are responsible for nearly half of the global net primary production.

Zooplankton are important for:

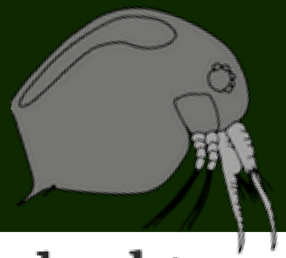
-Control on phytoplankton biomass

-Energy transfer through the marine food web

Phenology

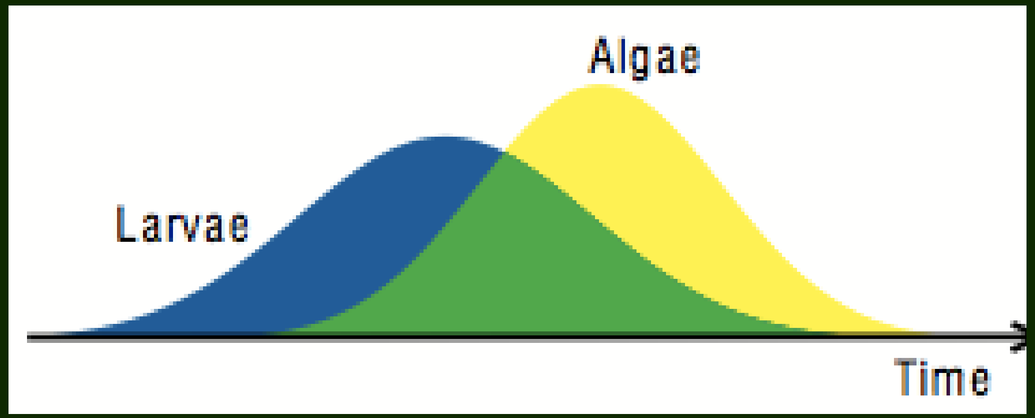
Phenology refers to the timing of annually recurring life cycle events.

Phenological indicators are particularly sensitive to climate change
(Edwards & Richardson, 2004; Hughes, 2000)

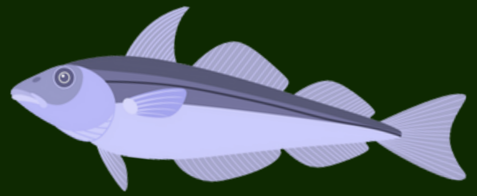


In hot water: zooplankton and climate change
Anthony J. Richardson
ICES Journal of Marine Science, Volume 65, Issue 3, April 2008, Pages 279–295,
https://doi.org/10.1093/icesjms/fsn028
Published: 11 March 2008 **Article history** ▾

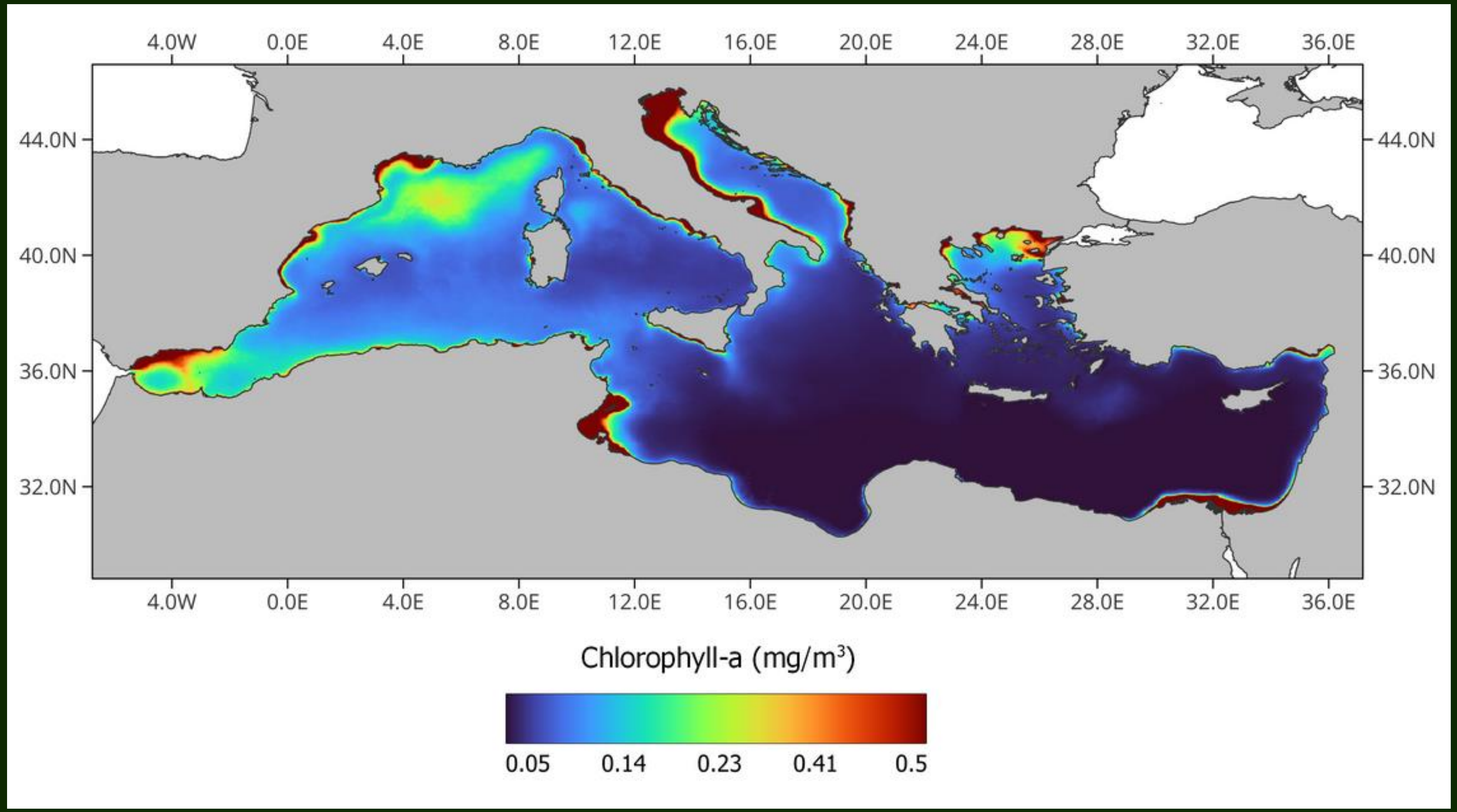
Brief Communication | Published: 22 May 2003
Marine ecology
Spring algal bloom and larval fish survival
Trevor Platt, Csar Fuentes-Yaco & Kenneth T. Frank
Nature **423**, 398–399 (2003) | Cite this article
4839 Accesses | **436** Citations | **25** Altmetric | Metrics

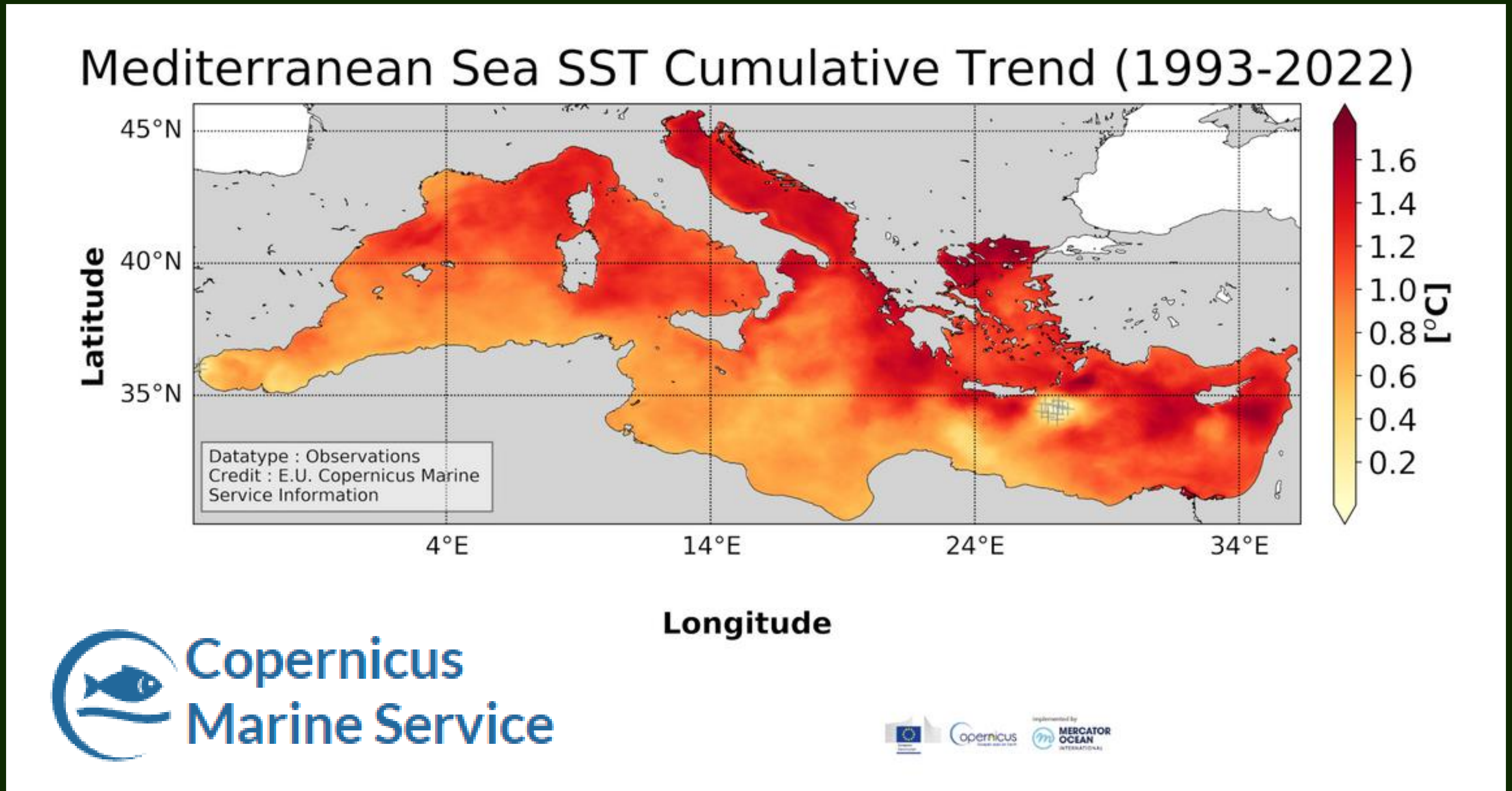


Platt *et al.* (2003)



Mediterranean Sea

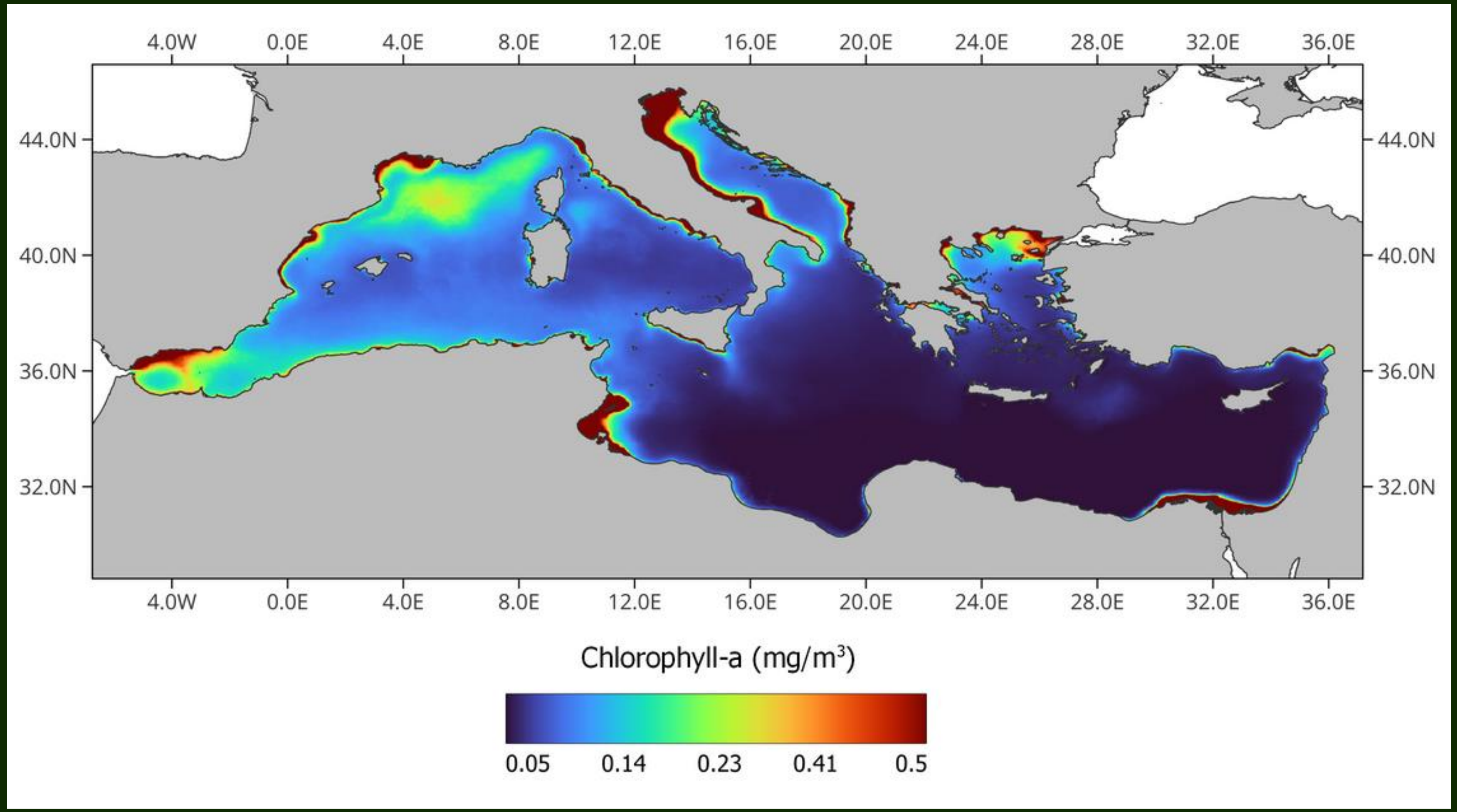




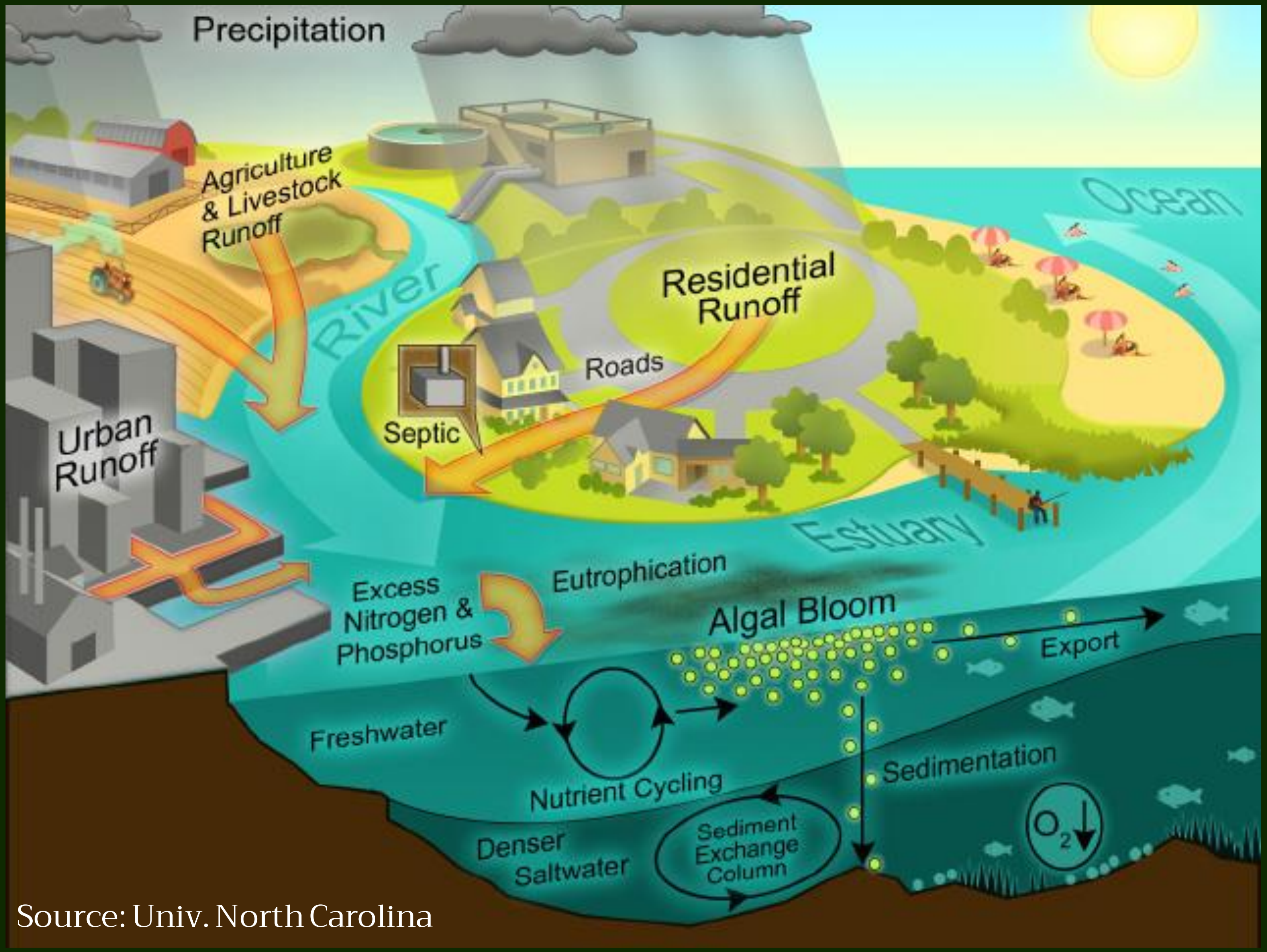
Chlorophyll-a averaged over the period September 1997 to December 2020, CMEMS

- Low Nutrient - Low Chlorophyll-a system
- Climate change hot-spot - Warming trend

Mediterranean Sea



Chlorophyll-a averaged over the period September 1997 to December 2020, CMEMS



- Low Nutrient - Low Chlorophyll-a system
- Climate change hot-spot - Warming trend
- Coastal marine ecosystems - elevated nutrient inputs

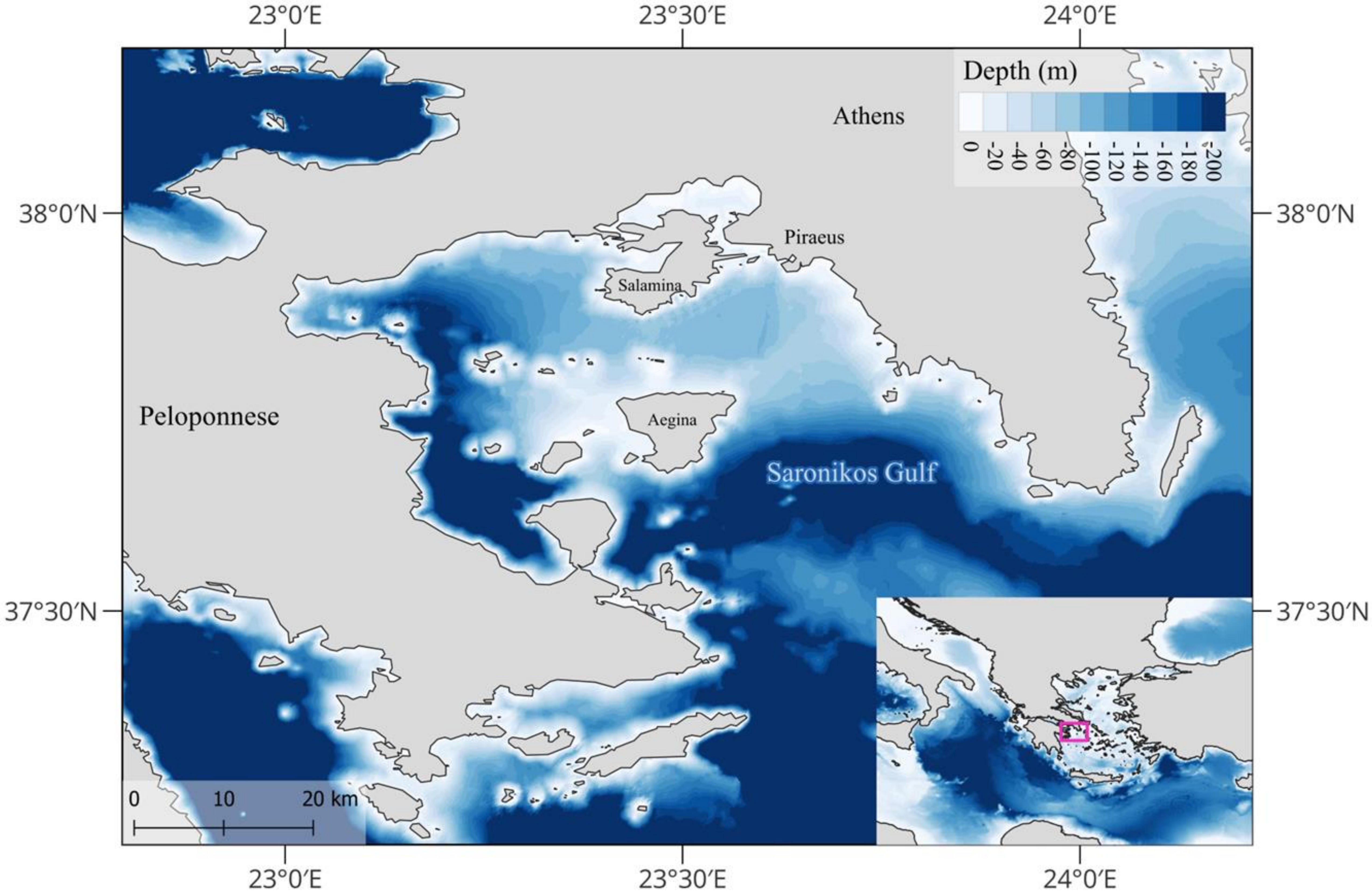
Study Area

Main pollution source of the Saronikos Gulf:

Wastewater discharge

~4 million inhabitants of Athens
~50% of Greece population

Untreated waste into surface waters



1994

Study Area

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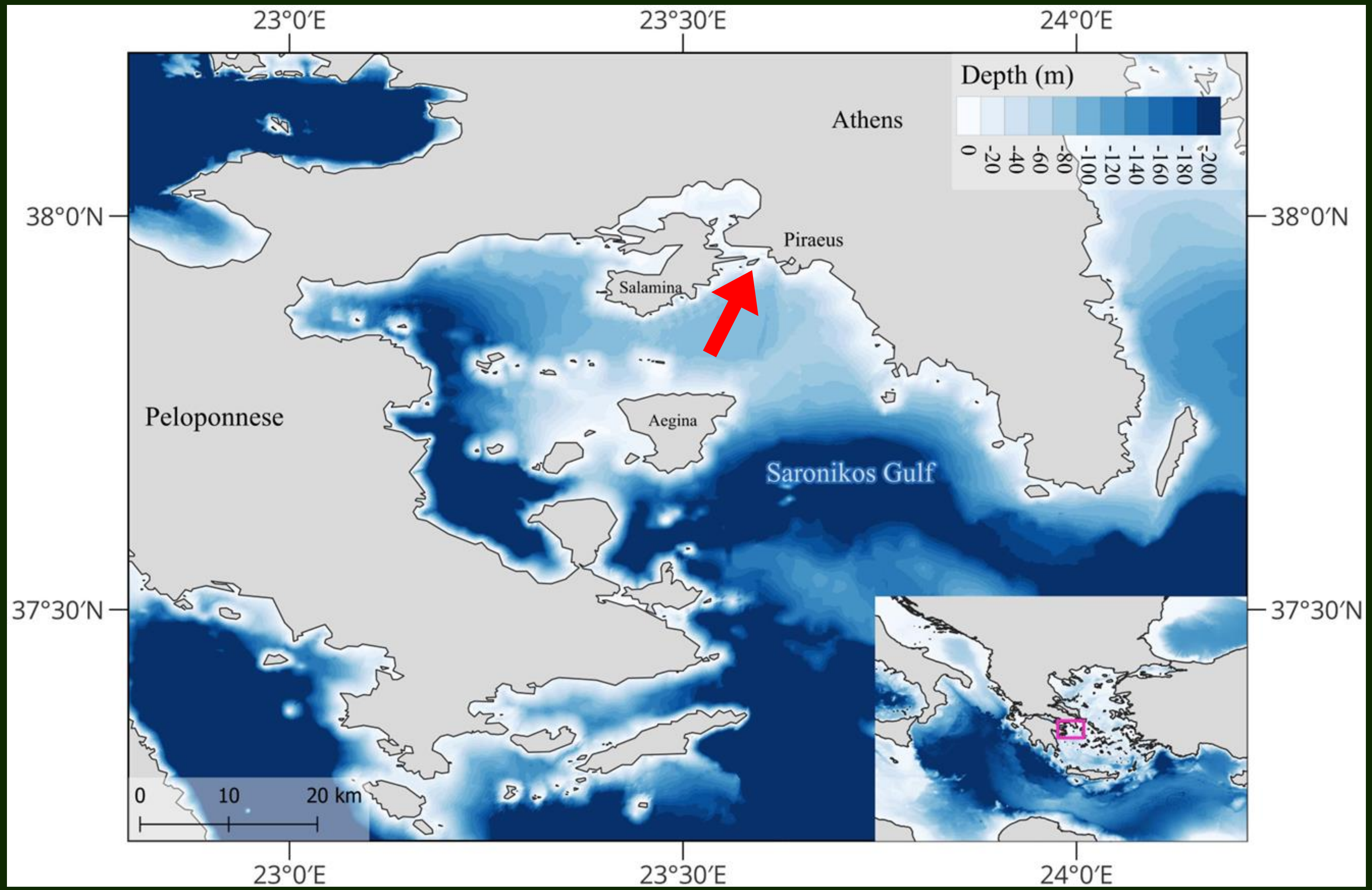

Primary stage

Discharge at 63 m
2 km from the coast

Untreated waste into surface waters

Psittalia Waste Water Treatment Plant

1994

2004

Study Area

Main pollution source of the Saronikos Gulf:

Wastewater discharge

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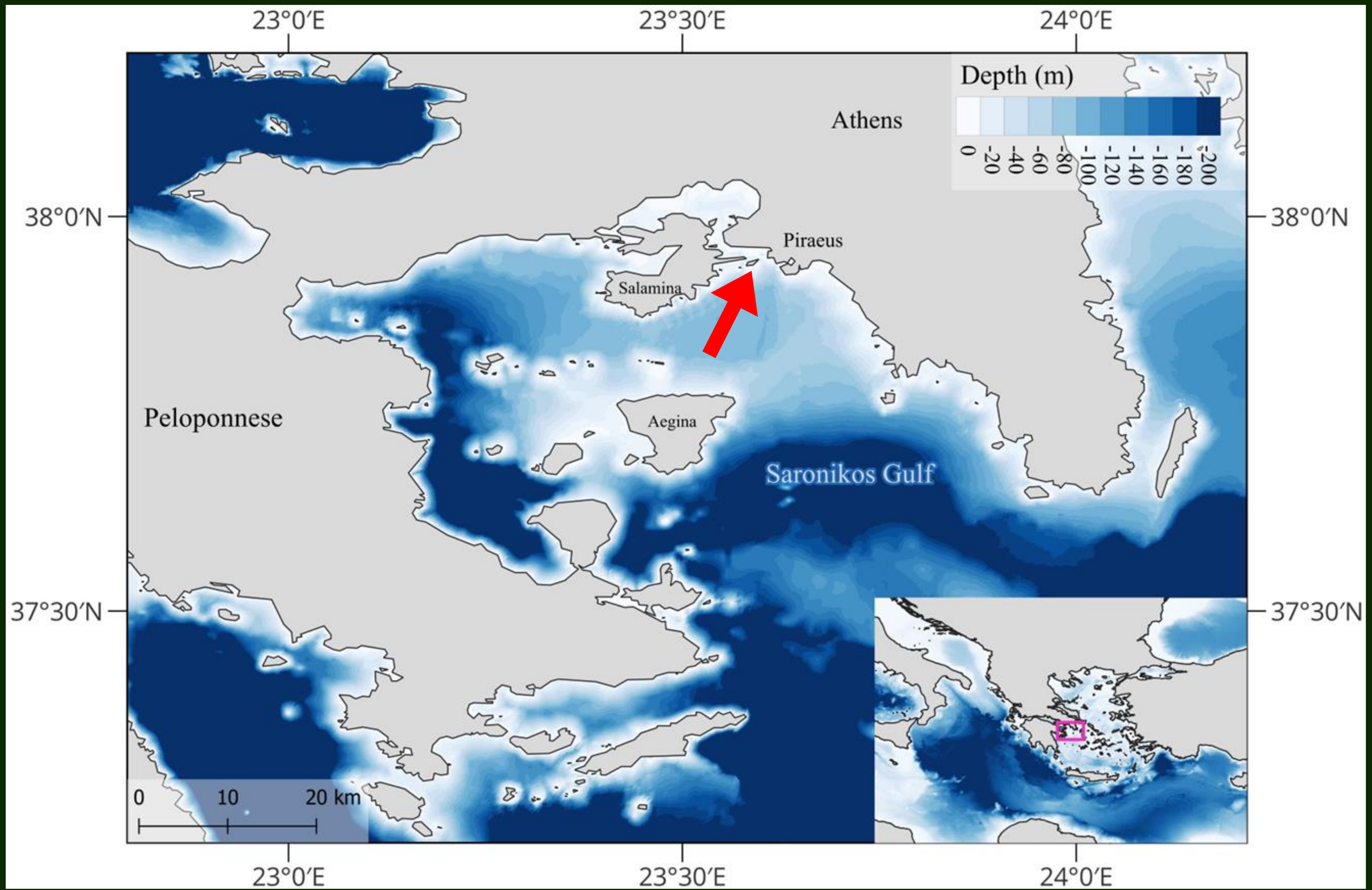


Untreated waste into surface waters

1994

Primary stage

Discharge at 63 m
2 km from the coast

Psittalia Waste Water Treatment Plant

2004

Secondary stage

Significant decrease in nutrient concentrations & organic load

Improvement of ecological quality status

Pavlidou *et al.*, 2014

Aims

Investigate:

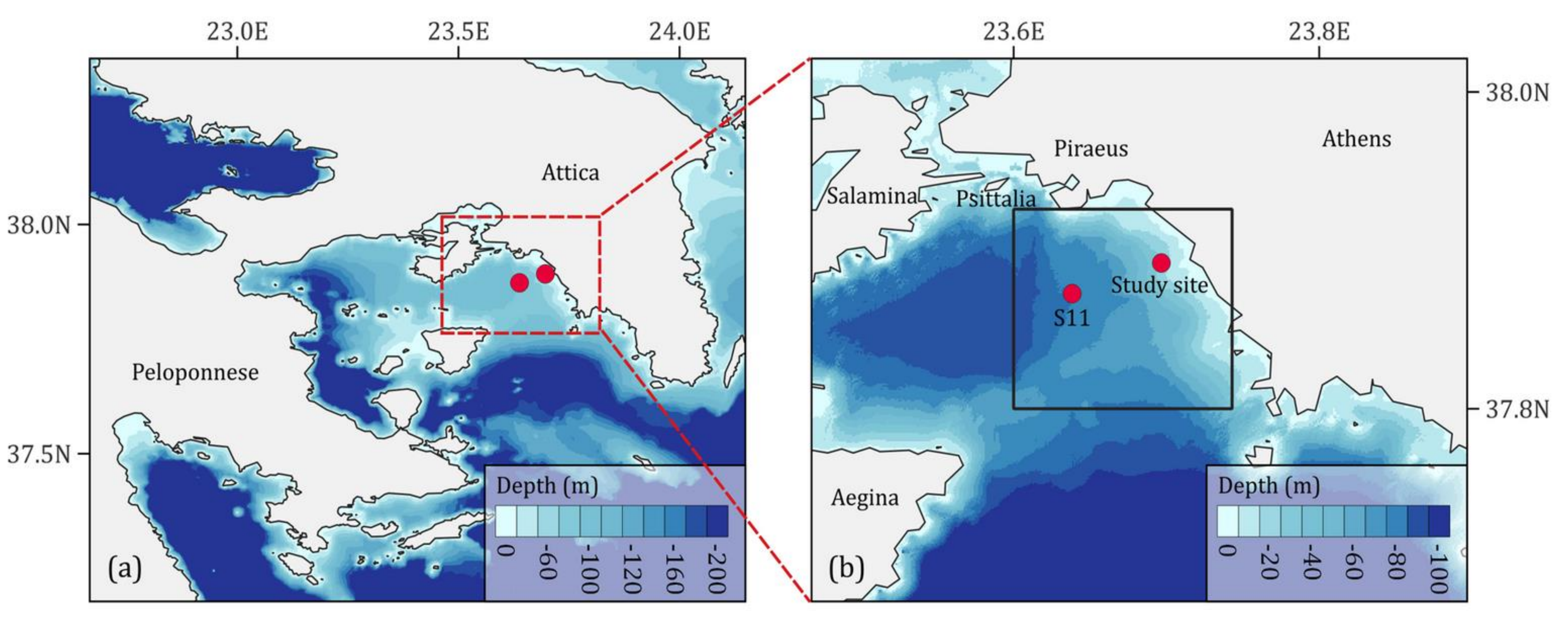
- The interannual variability of chlorophyll-a and mesozooplankton biomass (since 1988)
- Shifts in phenology
- Changes in copepod and cladoceran abundances

within a warmer, anthropogenically-impacted coastal region of the Saronikos Gulf.

in situ data

26 years of biweekly *in situ* measurements

Location	Period	Time interval	Parameters	Method
● **Study site** Depth: 12 m	from **Nov-1988** to **Apr-2015**	**~14 days** 631 samples in total	**Mesozooplankton Biomass**	200 μm WP-2 net
				Dry-weight method (Omori & Ikeda, 1984)
			Chlorophyll-a Concentration	Sampling depths: 1m, 5m and 10m
				GF/F filters (0.7μm)
				Fluorometric determination of acetone extracts (Yentsch and Menzel, 1963)



in situ data

26 years of biweekly *in situ* measurements

Location

Study site
Depth: 12 m

Period

from **Nov-1988** to **Apr-2015**

Time interval

~14 days
631 samples in total

Parameters

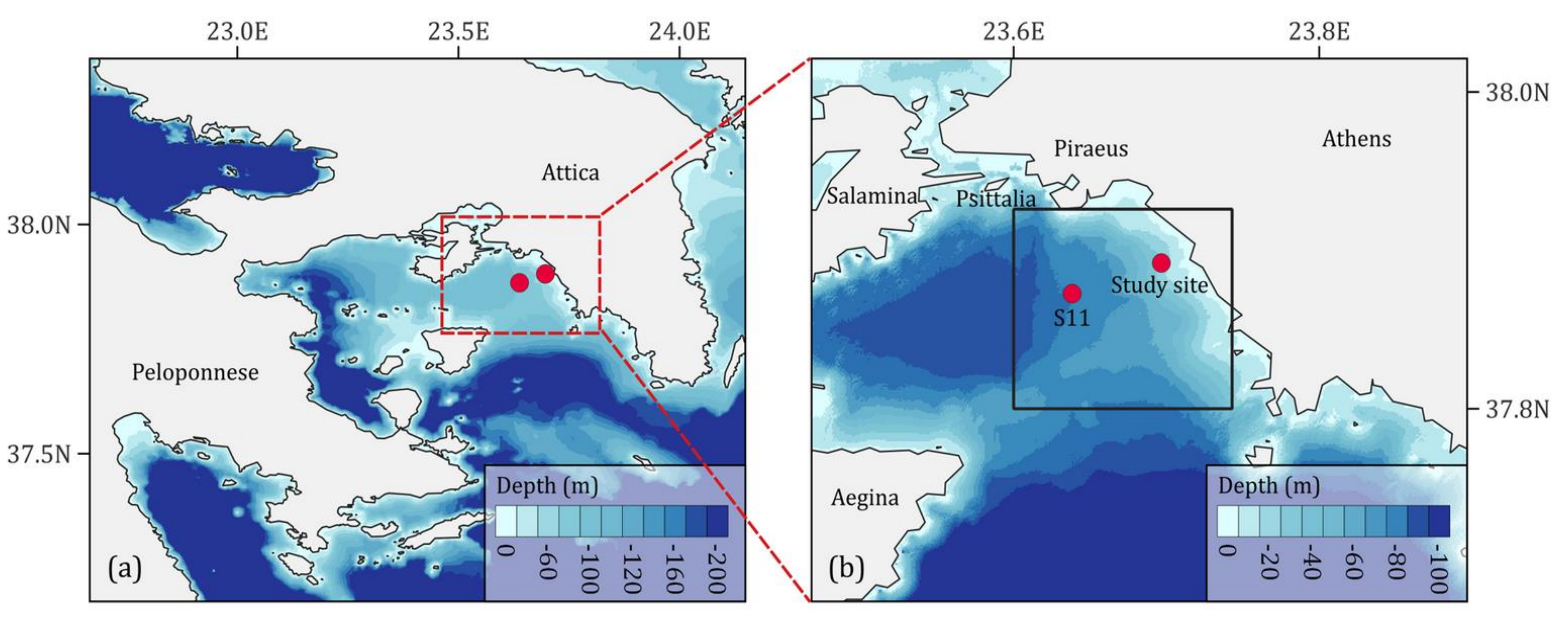
Mesozooplankton Biomass

Chlorophyll-a Concentration

Data Processing

Two study periods: before & after secondary wastewater treatment

P1: 1988-2004
P2: 2005-2015



in situ data

Location

Station S11
Depth: 78 m
5 km offshore

Period

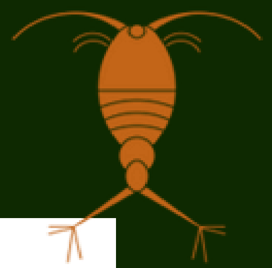
from **Feb-1987** to **Aug-2009**

Method

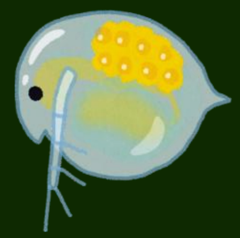
200 μm WP-2 net

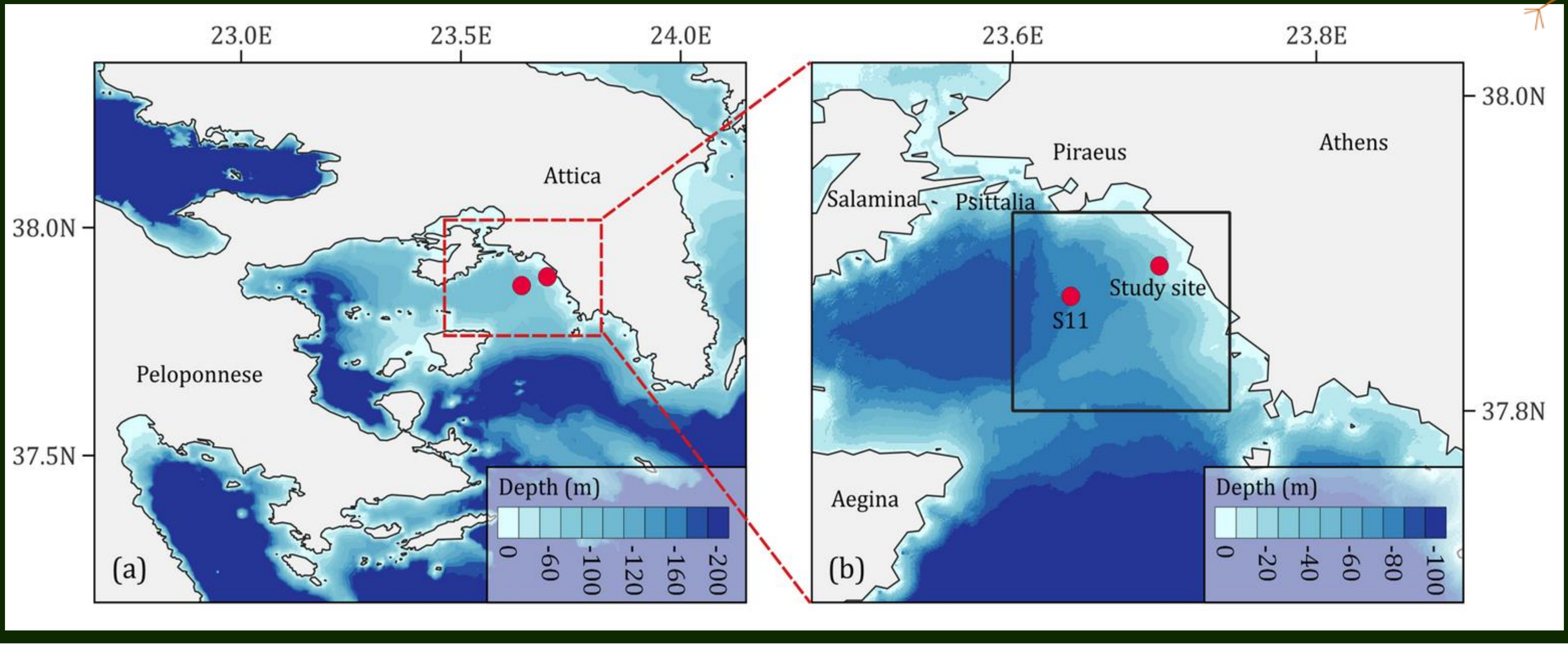
Parameters

Total Copepod & Cladoceran Abundance



85 mesozooplankton samples in total





satellite-derived data

Copernicus Marine Service

SST_MED_SST_L4_REP_OBSERVATIONS_010_021

EU Copernicus Marine Environment Monitoring Service (CMEMS)

Reprocessing of collated level-3 climate data from ESA Climate Change Initiative (CCI), the Copernicus Climate Change Service (C3S) & the AVHRR Pathfinder dataset version 5.3

Level 4, interpolated, **gap-free**

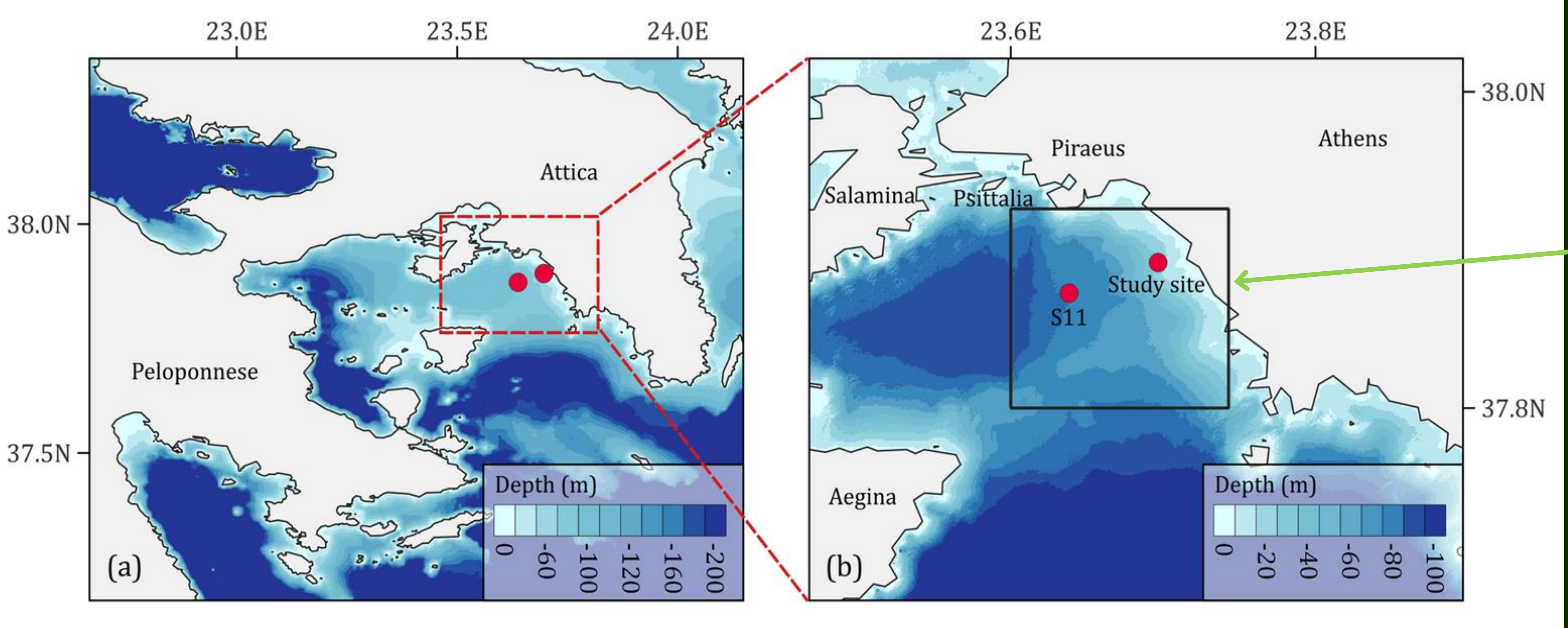
Temporal Resolution **1-day**

Spatial resolution ~ **5.5 km**

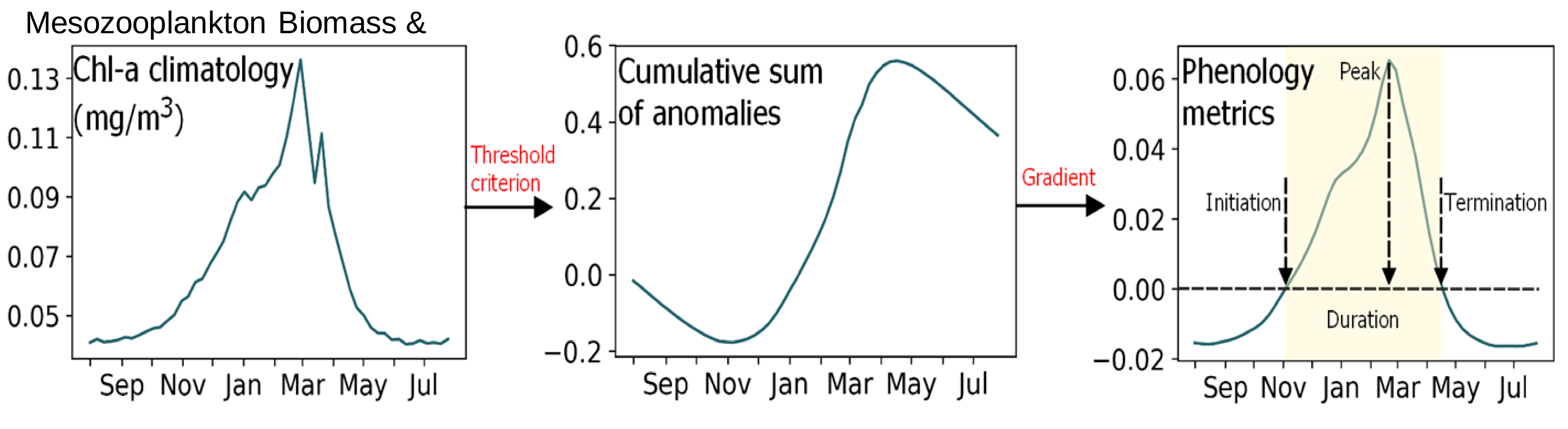
Available from 1982-present

Averaged over an Inner Saronikos Gulf region (37.8, 37.92N, 23.60, 23.74E)

Covering the period: **1988-2015**



Phenology Metrics



Kournopoulou *et al.*, 2024

Phenology algorithm
Racault *et al.*, 2012, 2014, 2015

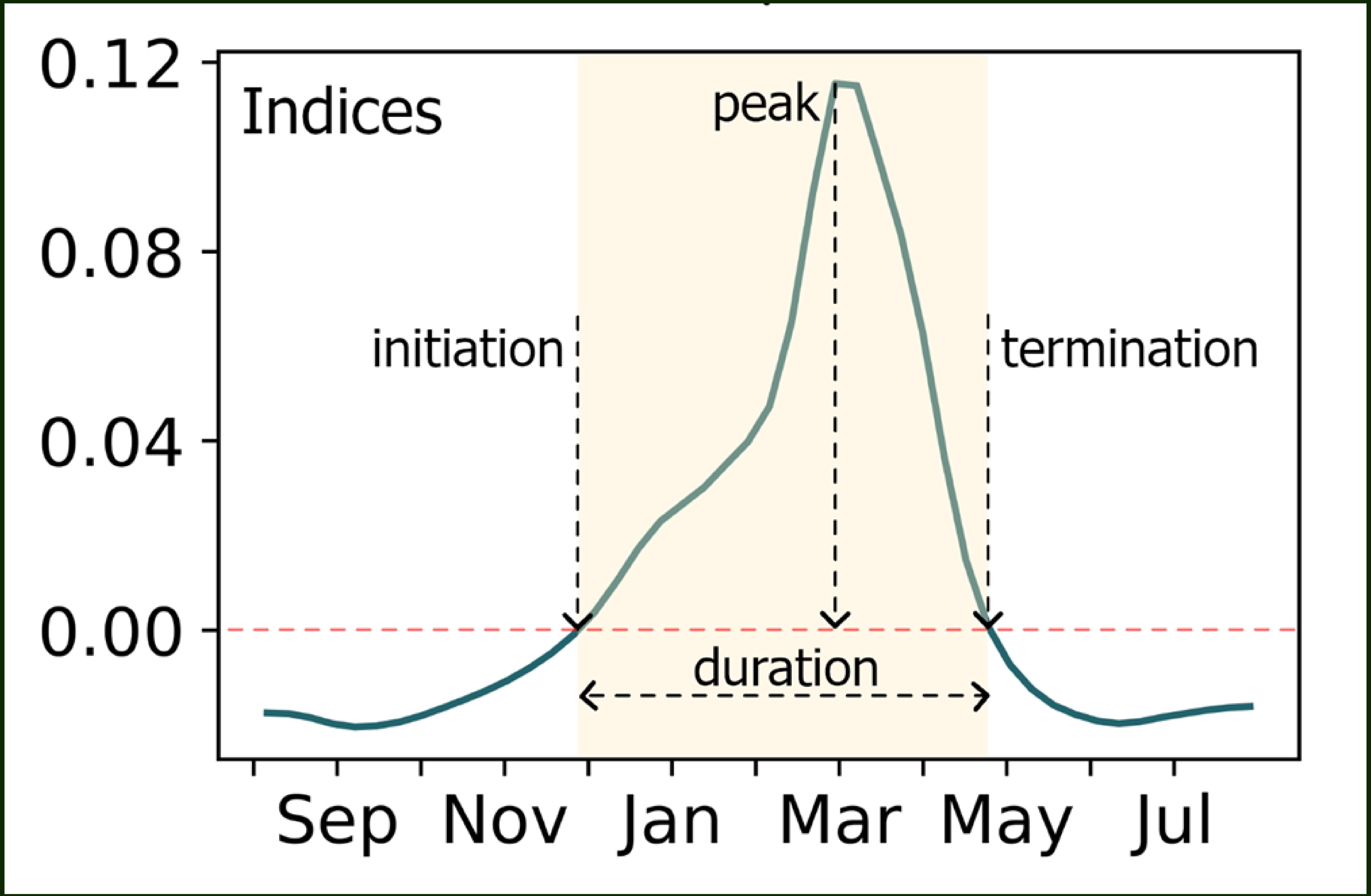
Climatology
Biweekly

Long-term threshold criterion
Median + 5%

Anomalies
Climatology - threshold

Cumulative sum of anomalies

Phenology Metrics



Kournopoulou *et al.*, 2024

Phenology algorithm
Racault *et al.*, 2012, 2014, 2015

Climatology
Biweekly

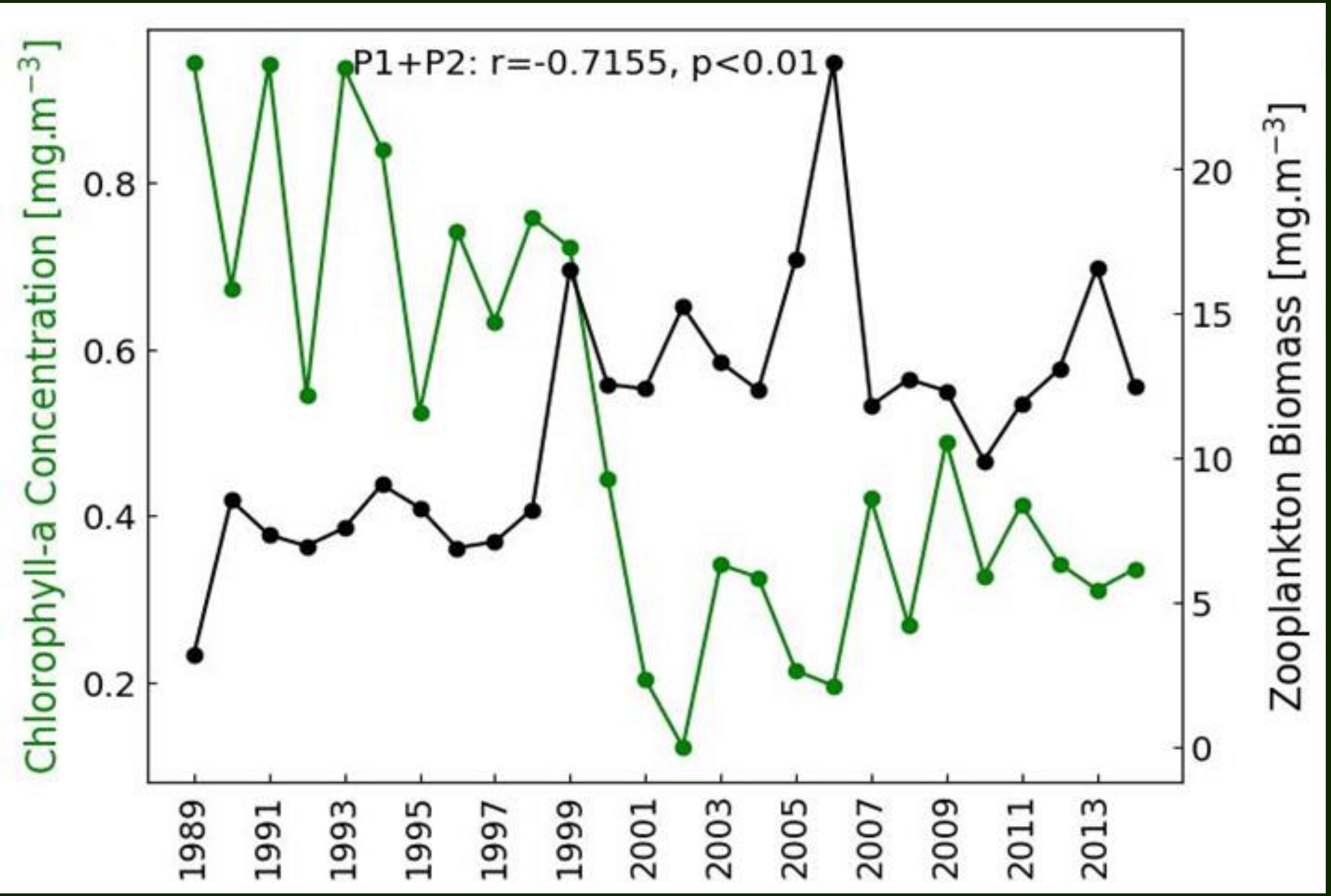
Long-term threshold criterion
Median + 5%

Anomalies
Climatology - threshold

Gradient of the cumulative sums

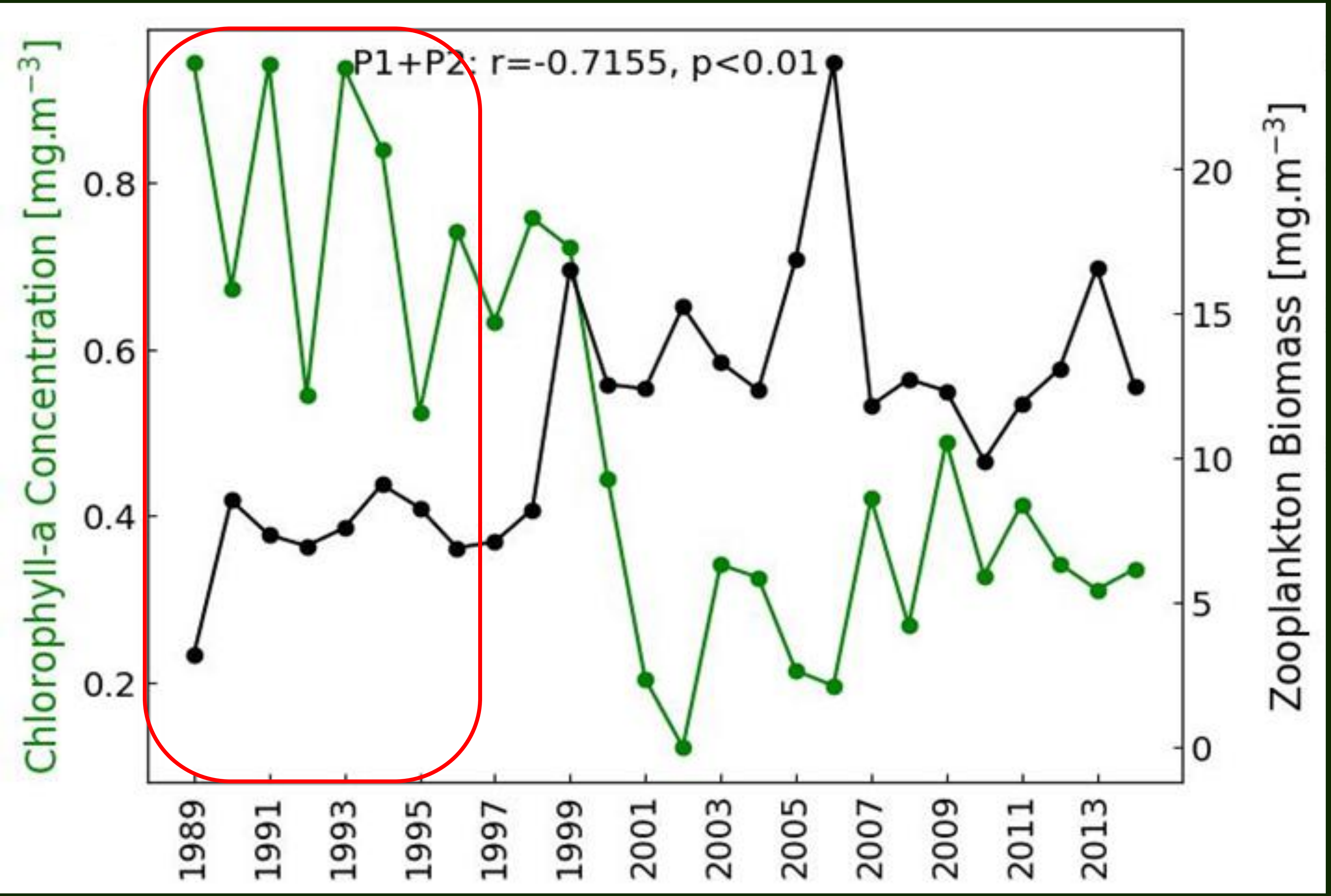
Interannual Variability

Chl-a vs. Zooplankton biomass Annual timeseries



Interannual Variability

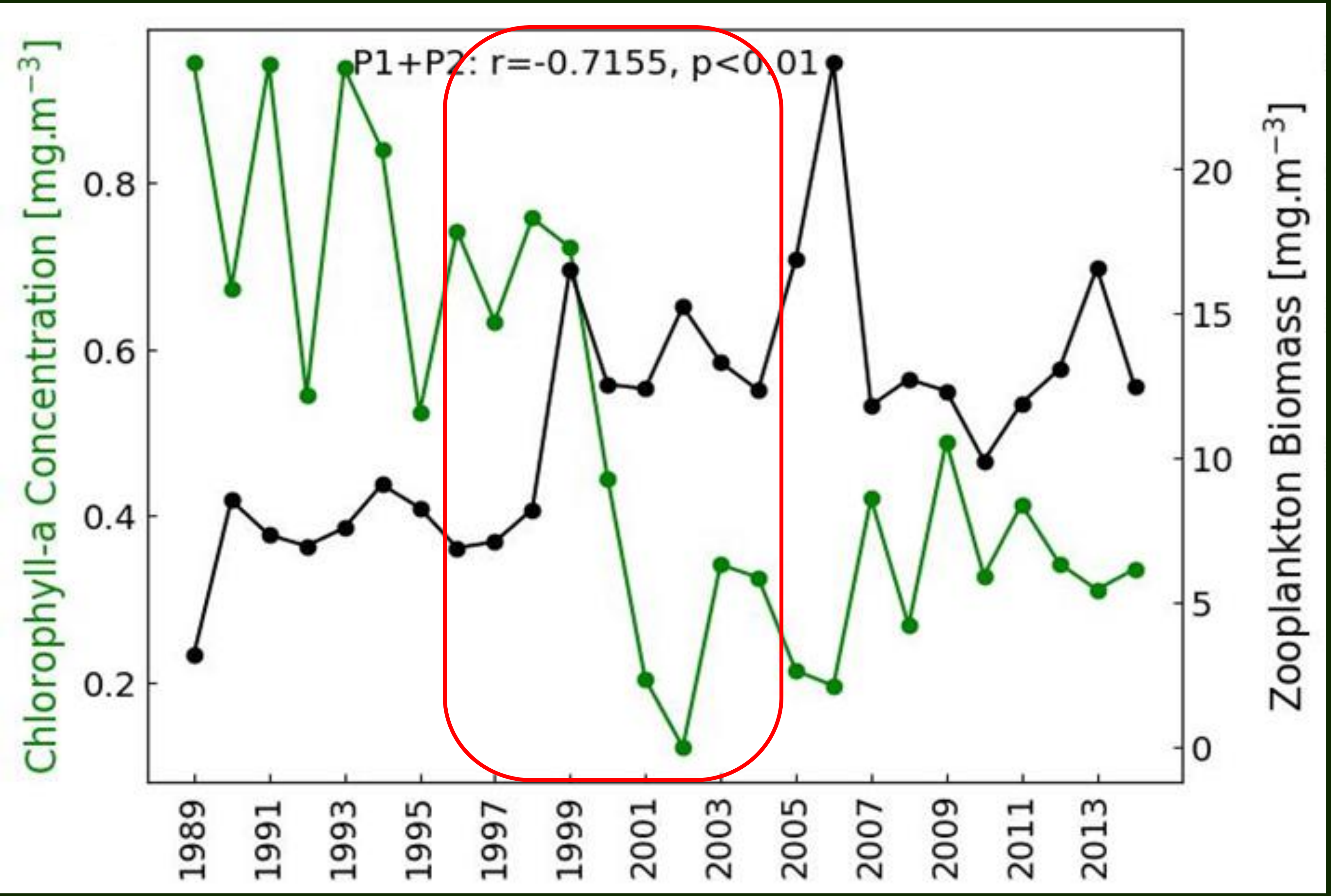
Chl-a vs. Zooplankton biomass Annual timeseries



Weak grazing control

Interannual Variability

Chl-a vs. Zooplankton biomass Annual timeseries

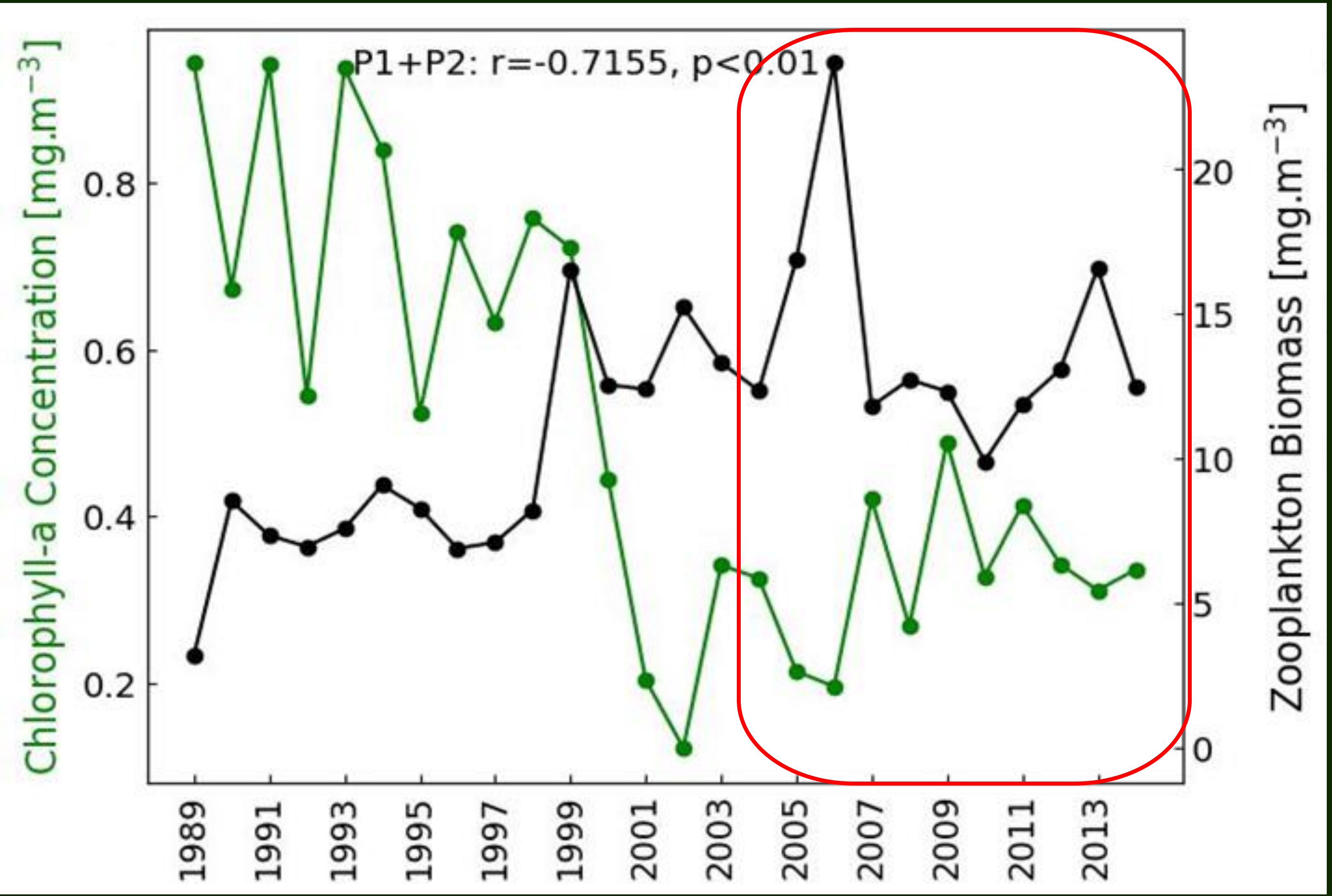


Lower surface nutrient concentrations (Siokou-Frangou *et al.*, 2009)

Chl-a decrease | Mesozooplankton biomass increase

Interannual Variability

Chl-a vs. Zooplankton biomass Annual timeseries

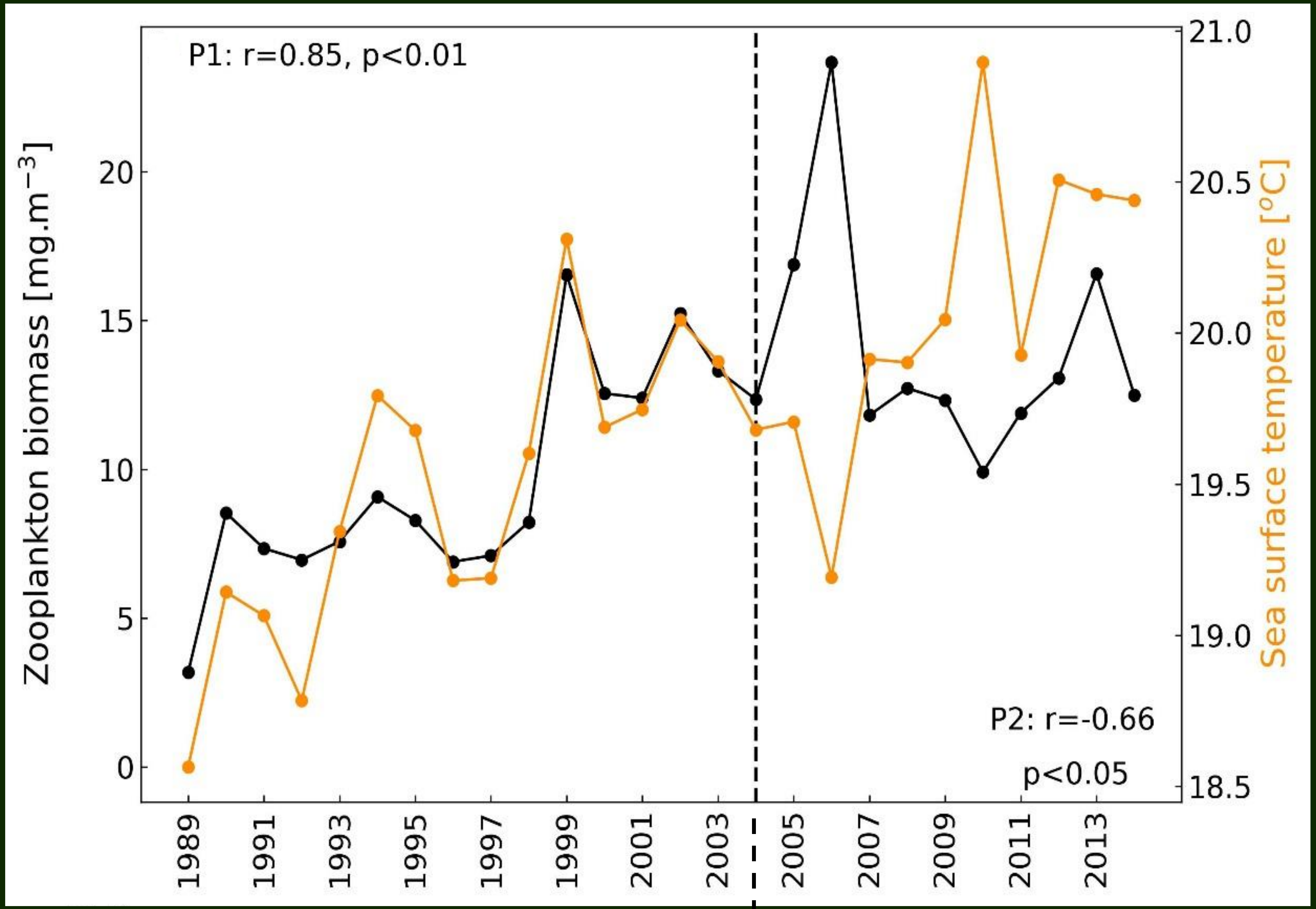


P2: Improved grazing control

→

Interannual Variability

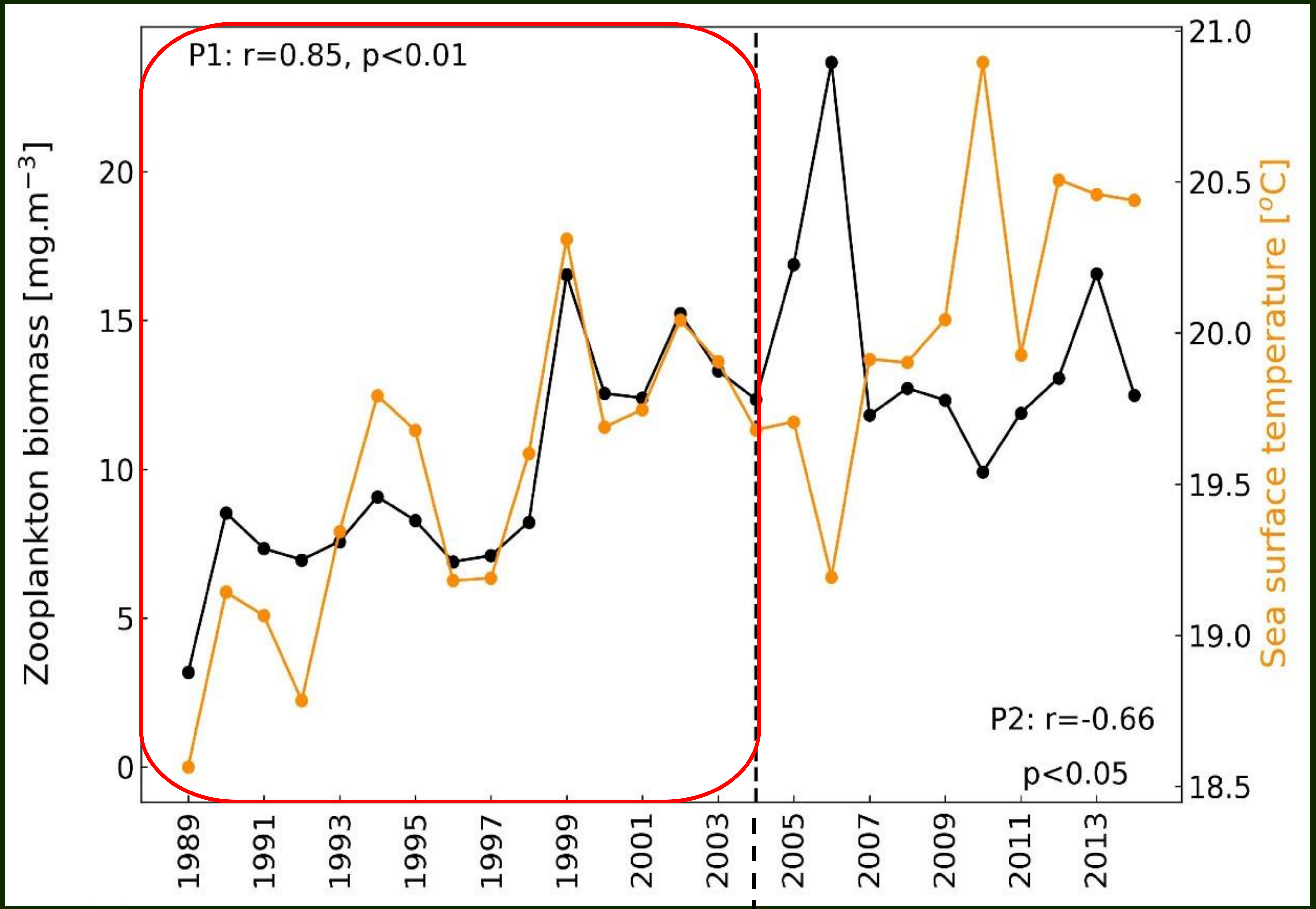
Zooplankton biomass vs. SST Annual timeseries



Secondary wastewater treatment stage

Interannual Variability

Zooplankton biomass vs. SST Annual timeseries

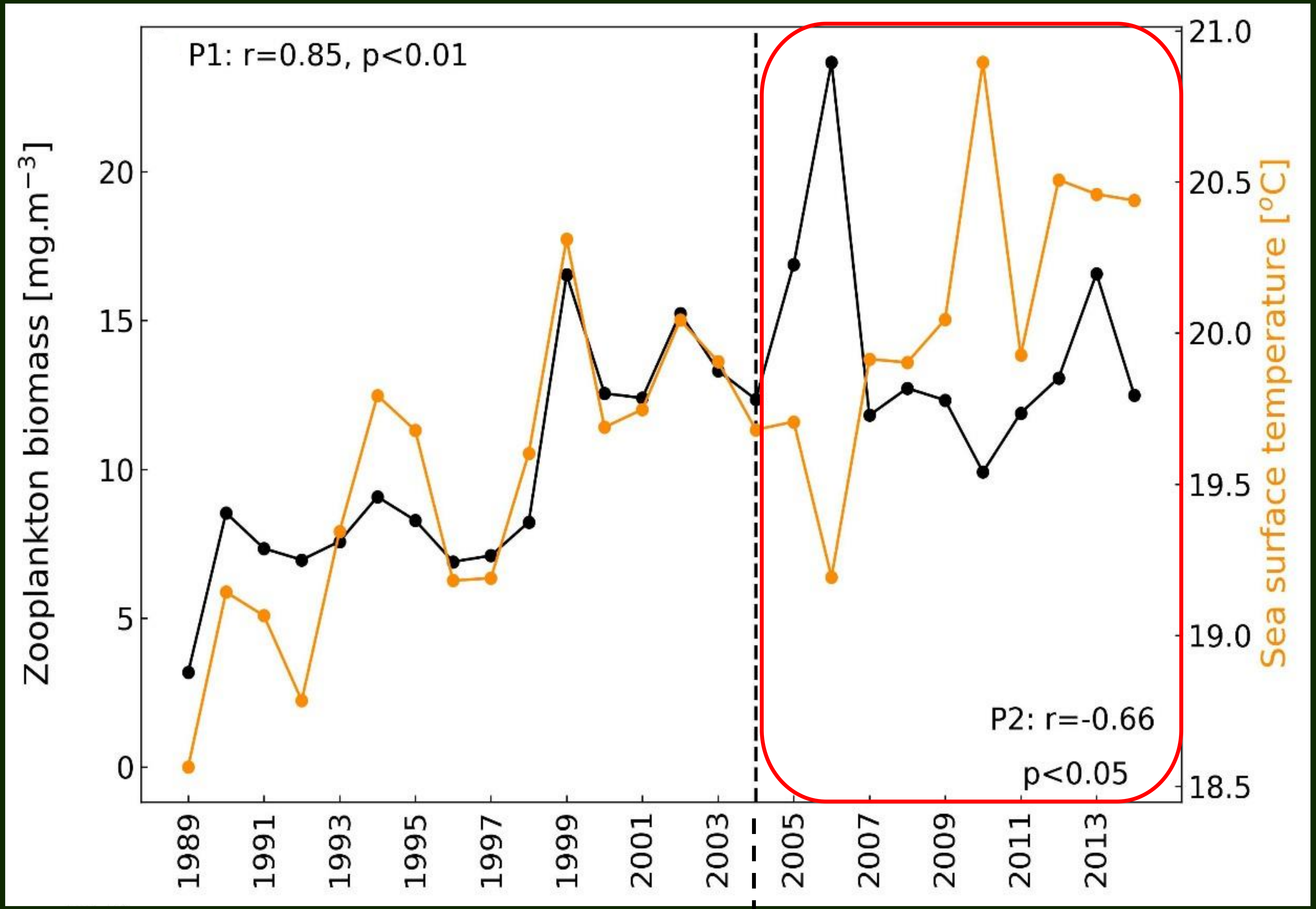


P1: Mesozooplankton biomass increases with warming

Secondary wastewater treatment stage

Interannual Variability

Zooplankton biomass vs. SST Annual timeseries



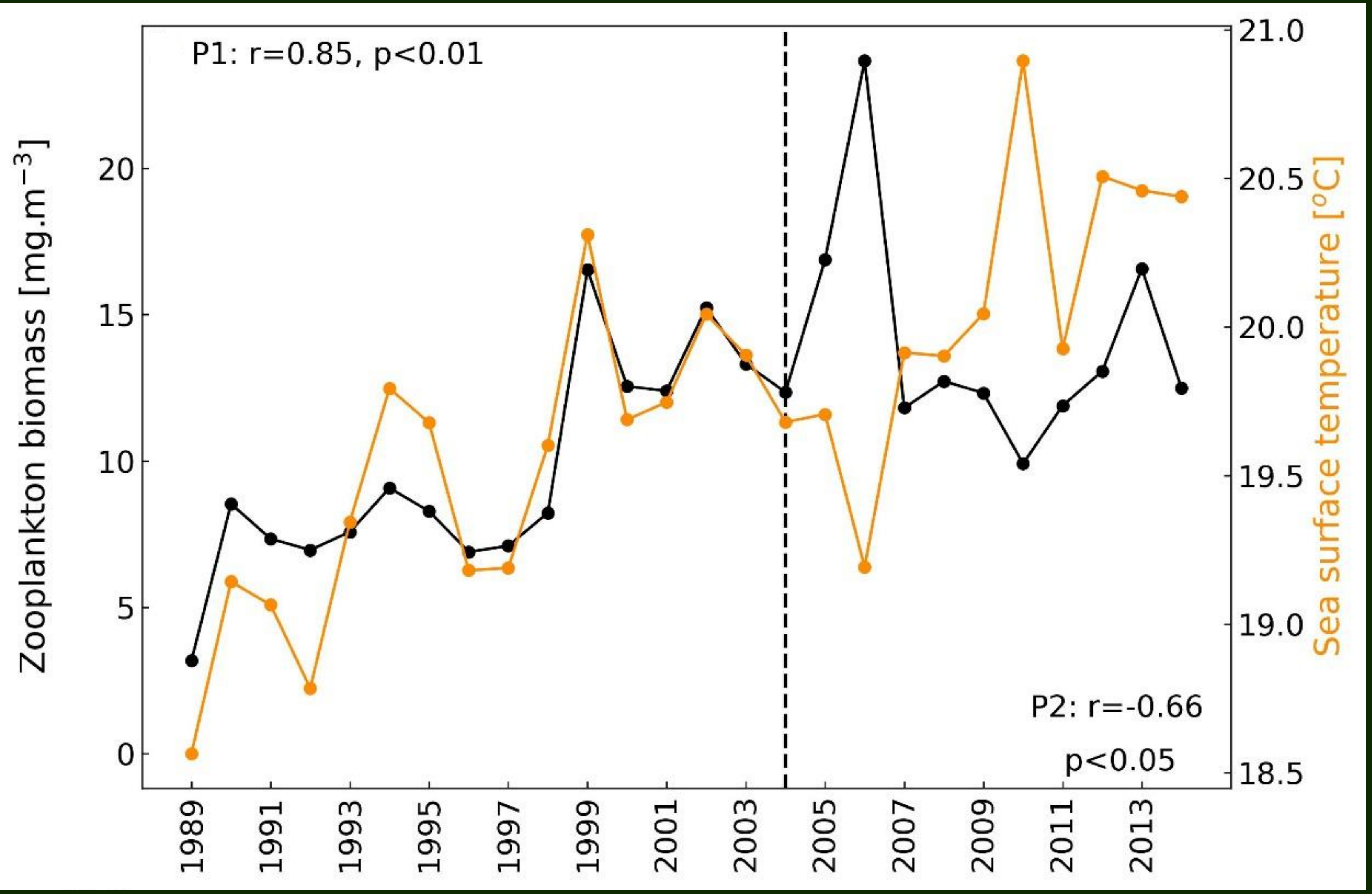
P2:
Abrupt reversal in the interannual relationship between mesozooplankton biomass and SST after 2004

Secondary wastewater treatment stage

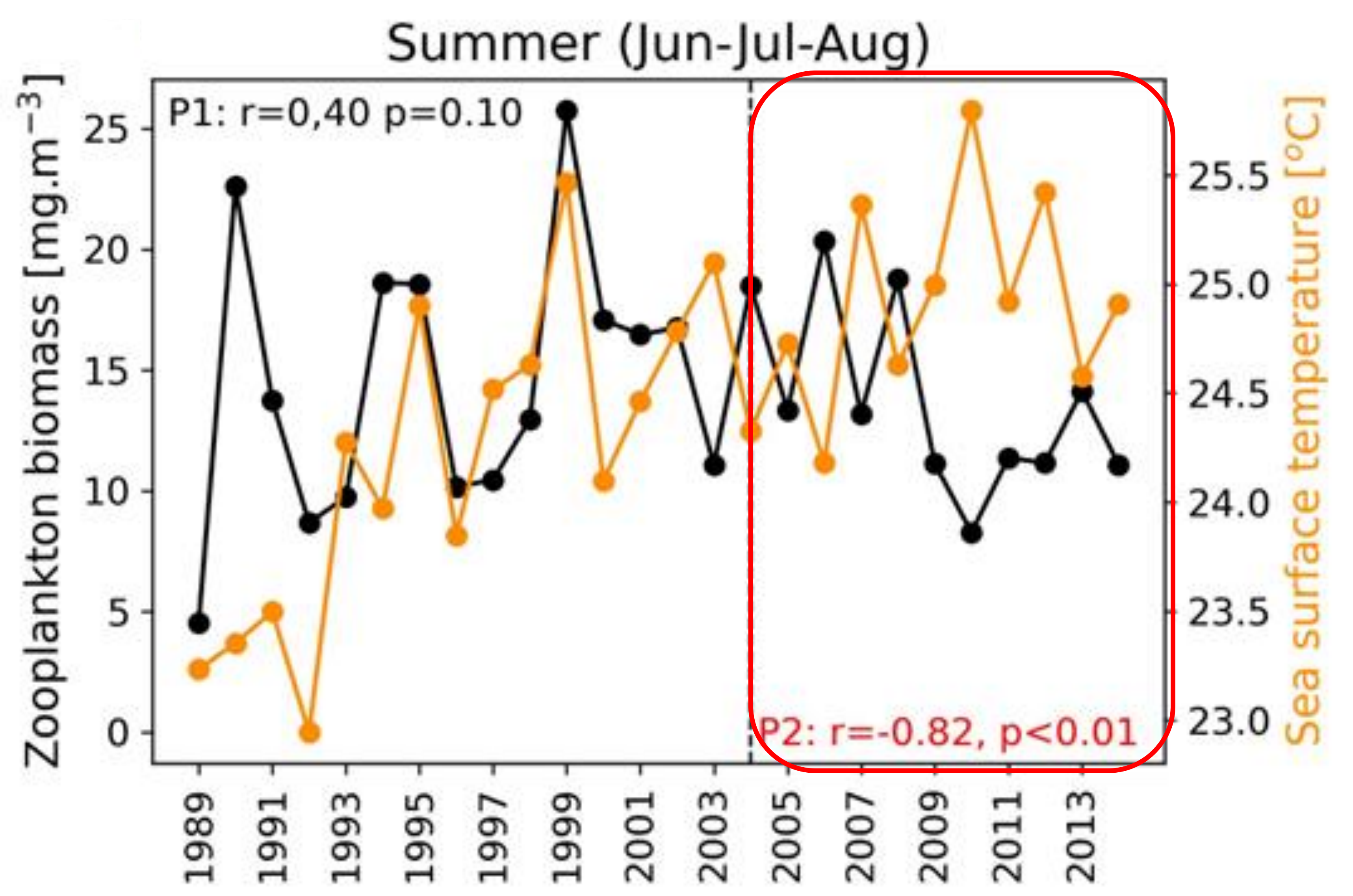
Interannual Variability

Abrupt reversal in the interannual relationship between mesozooplankton biomass and SST after 2004

Zooplankton biomass vs. SST



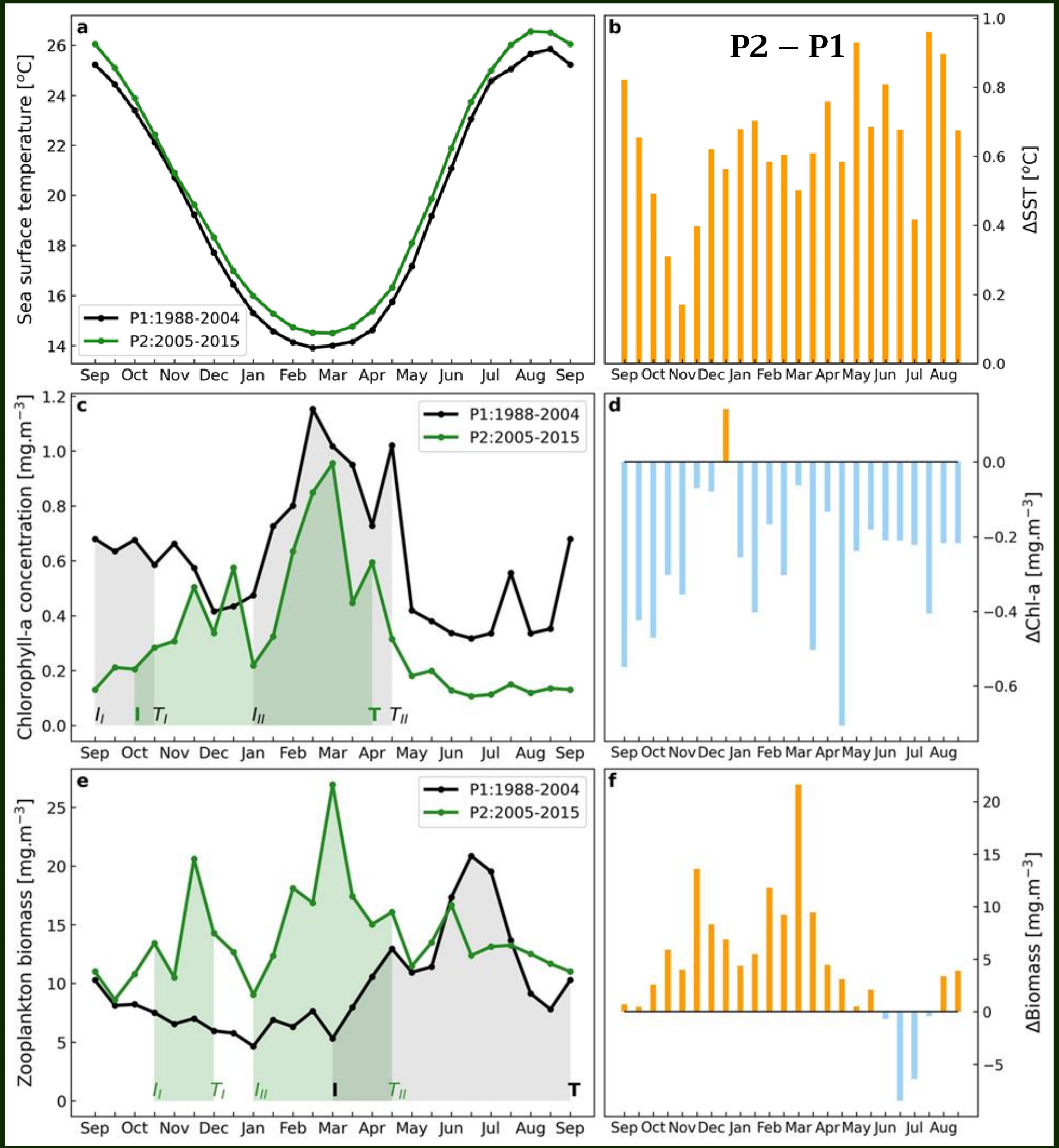
-Annual timeseries

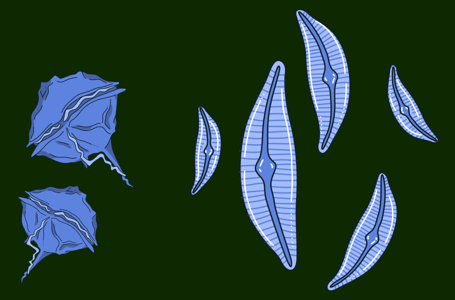


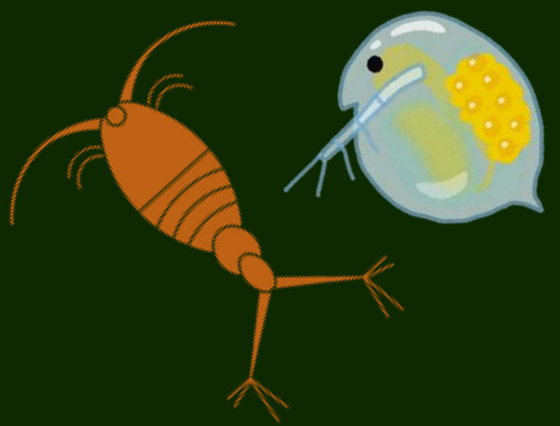
-Summer timeseries

Seasonal cycles & Phenological shifts

Biweekly climatologies

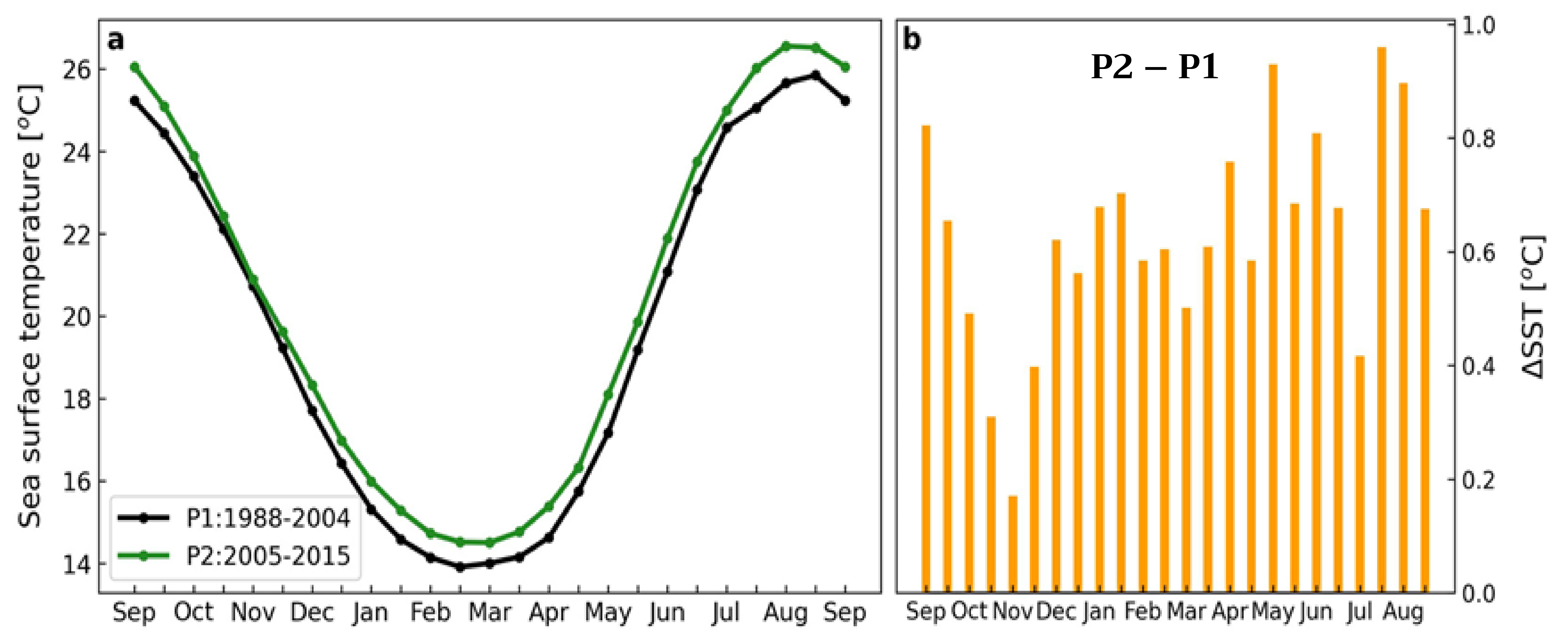






Seasonal cycles & Phenological shifts

Biweekly climatologies

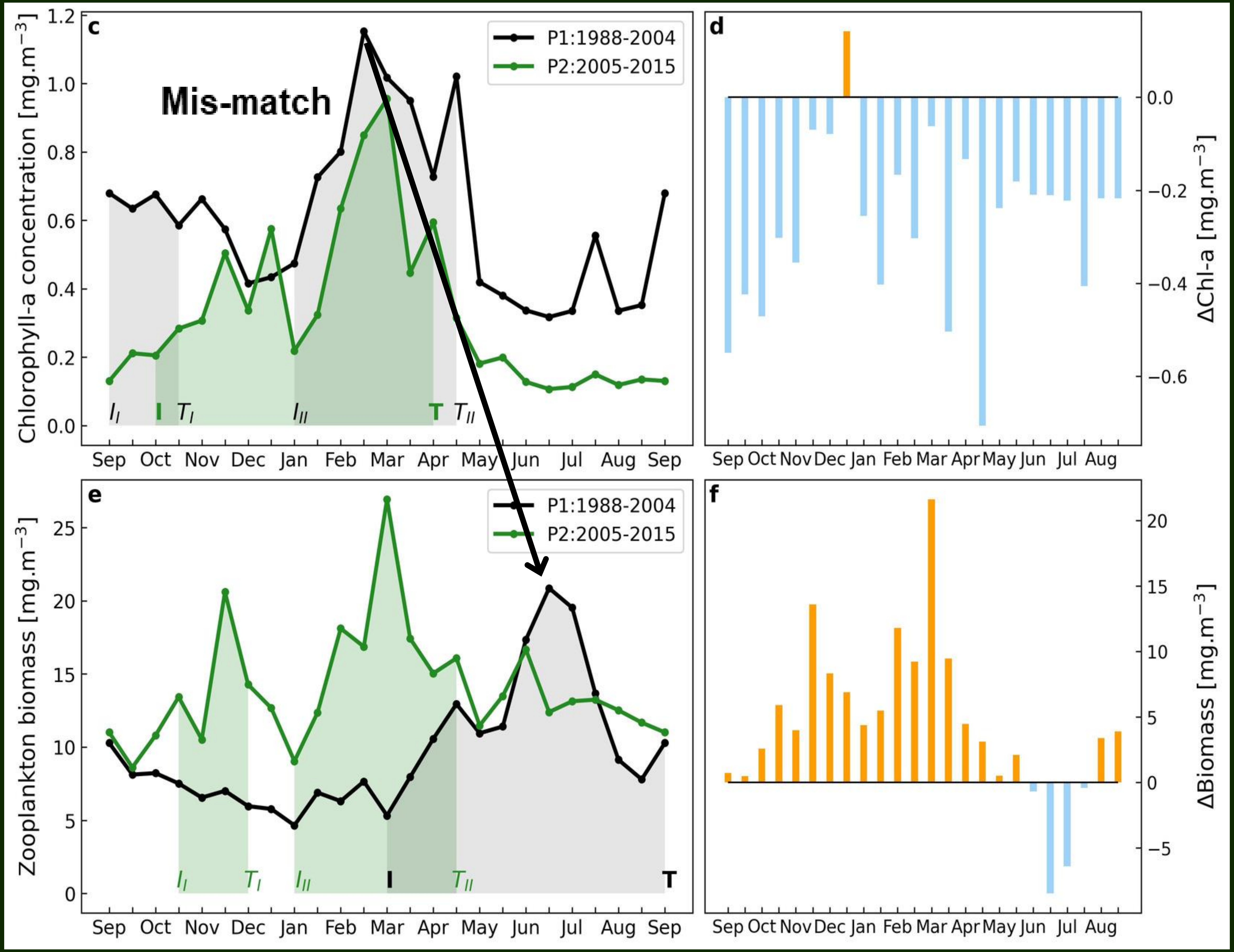


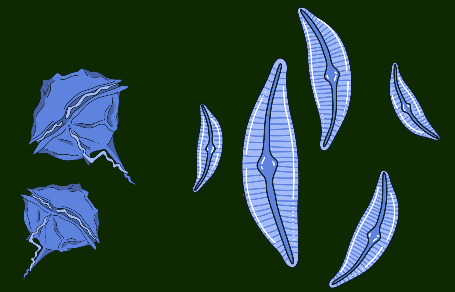
Mean SST increase in P2:
- February – March: ~0.5 °C
- April – September: ~0.8 °C

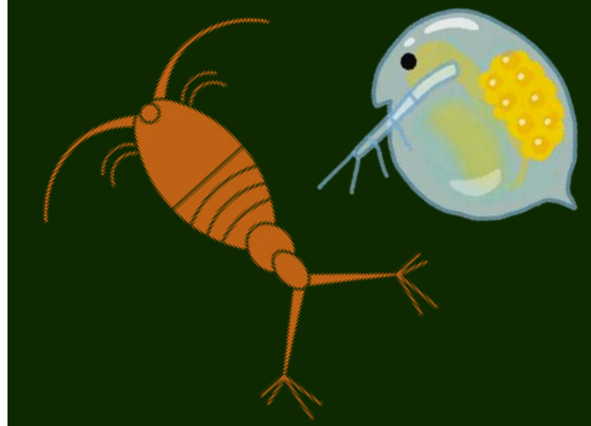
Results

Seasonal cycles & Phenological shifts

Biweekly climatologies



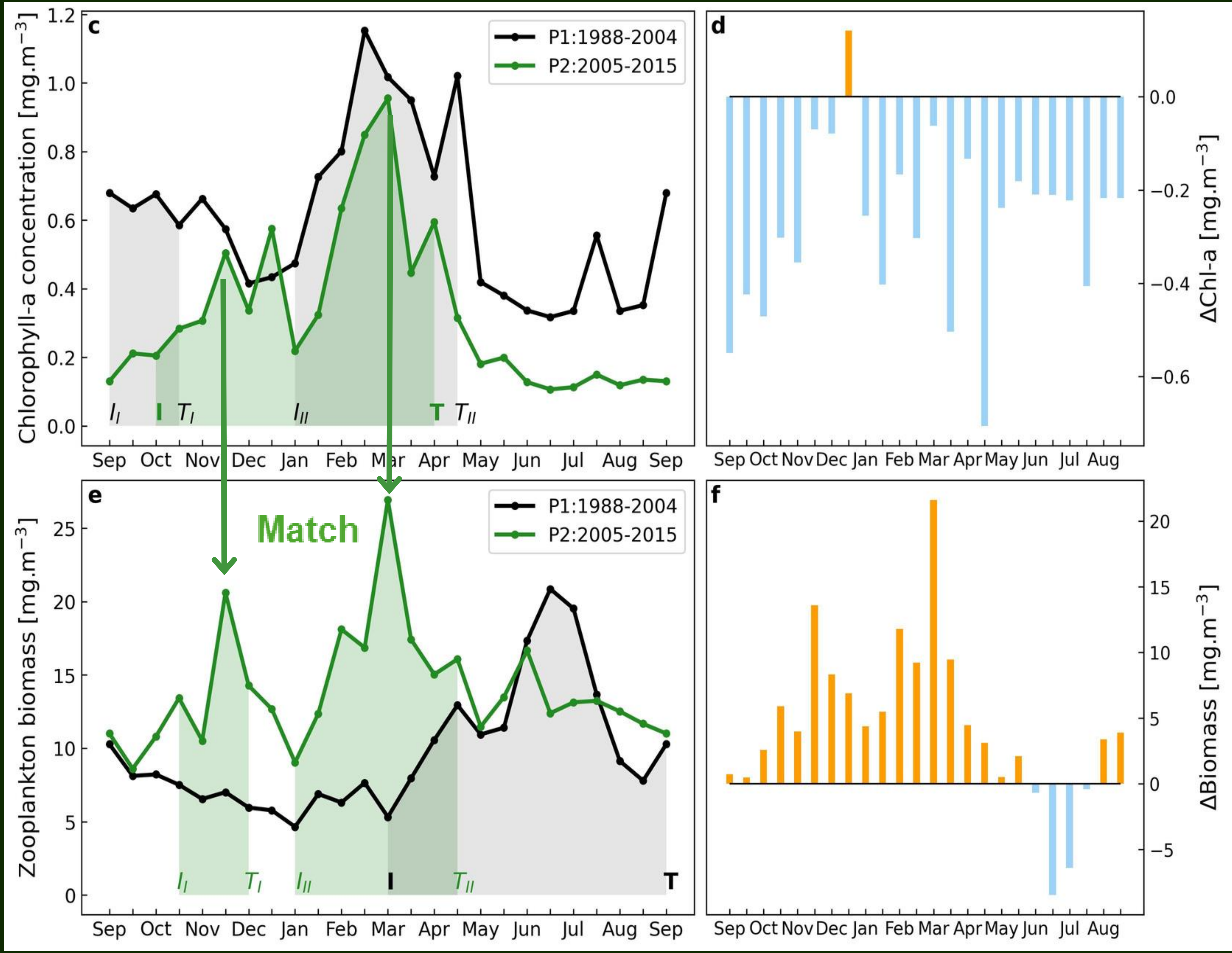


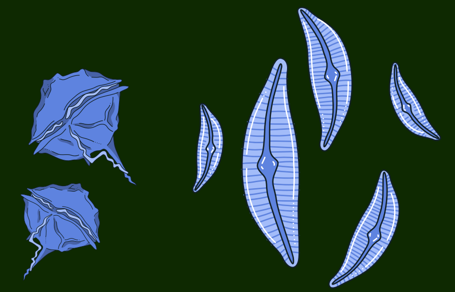


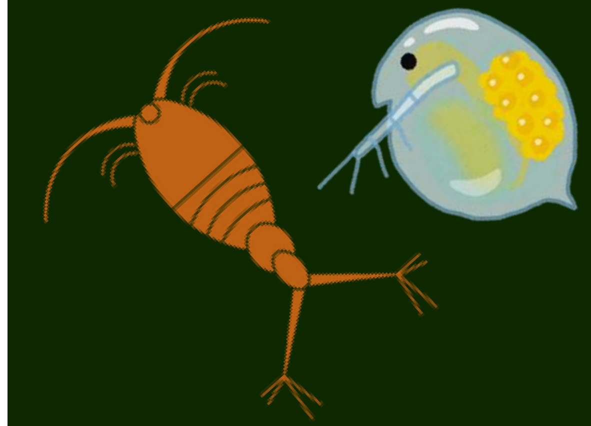
Results

Seasonal cycles & Phenological shifts

Biweekly climatologies







Shifts in plankton phenology:

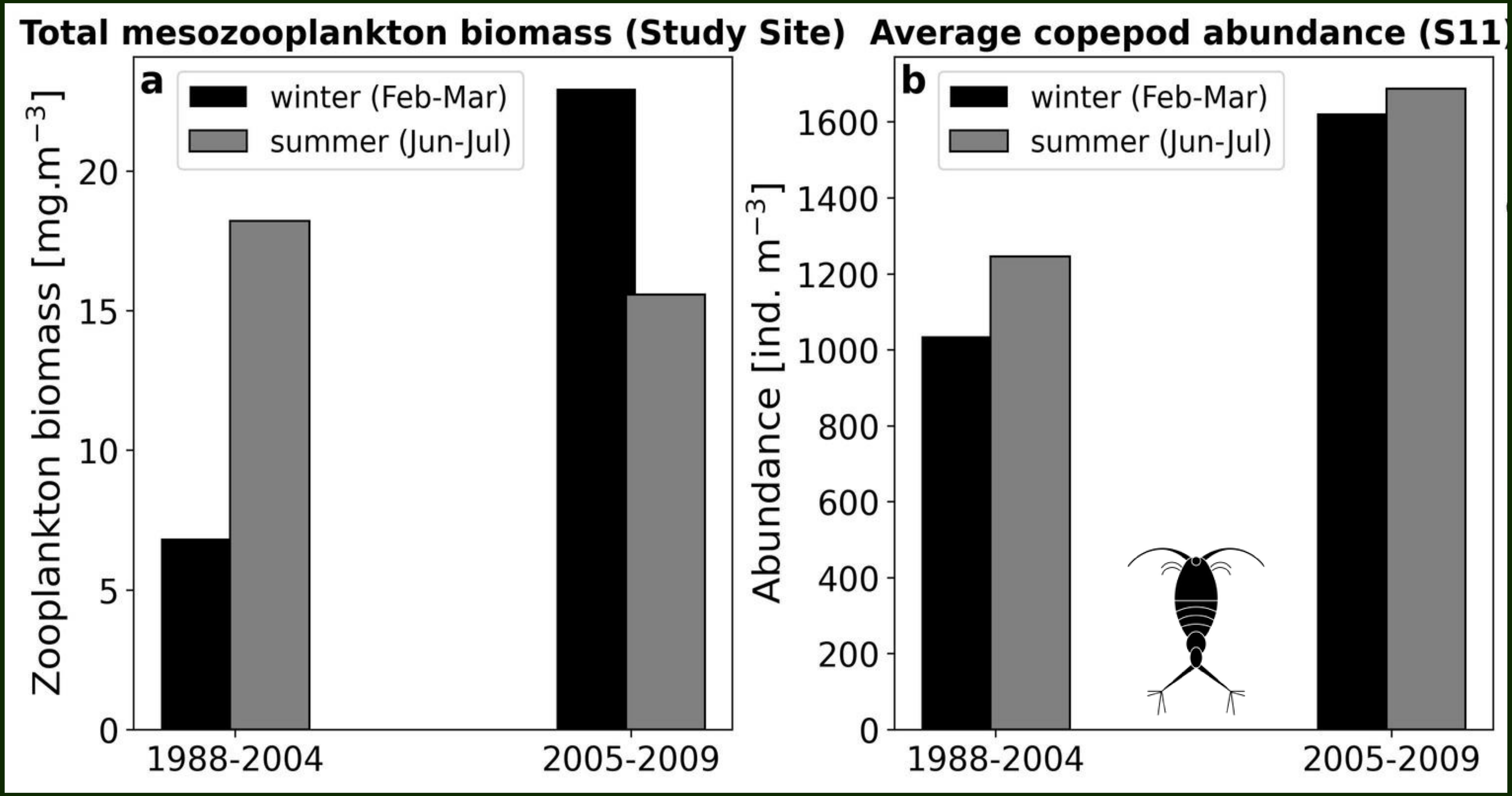
An interplay of warming and improved water quality in the region

Mesozooplankton biomass *vs.* S11 copepod & cladoceran abundance

Data Processing

Annual basis

Separation between:
-**1988-2004** (P1)
-**2005-2009**
&
-**winter** (as average of February & March)
-**summer** (as average of June & July)



Mesozooplankton biomass *vs.* S11 copepod & cladoceran abundance

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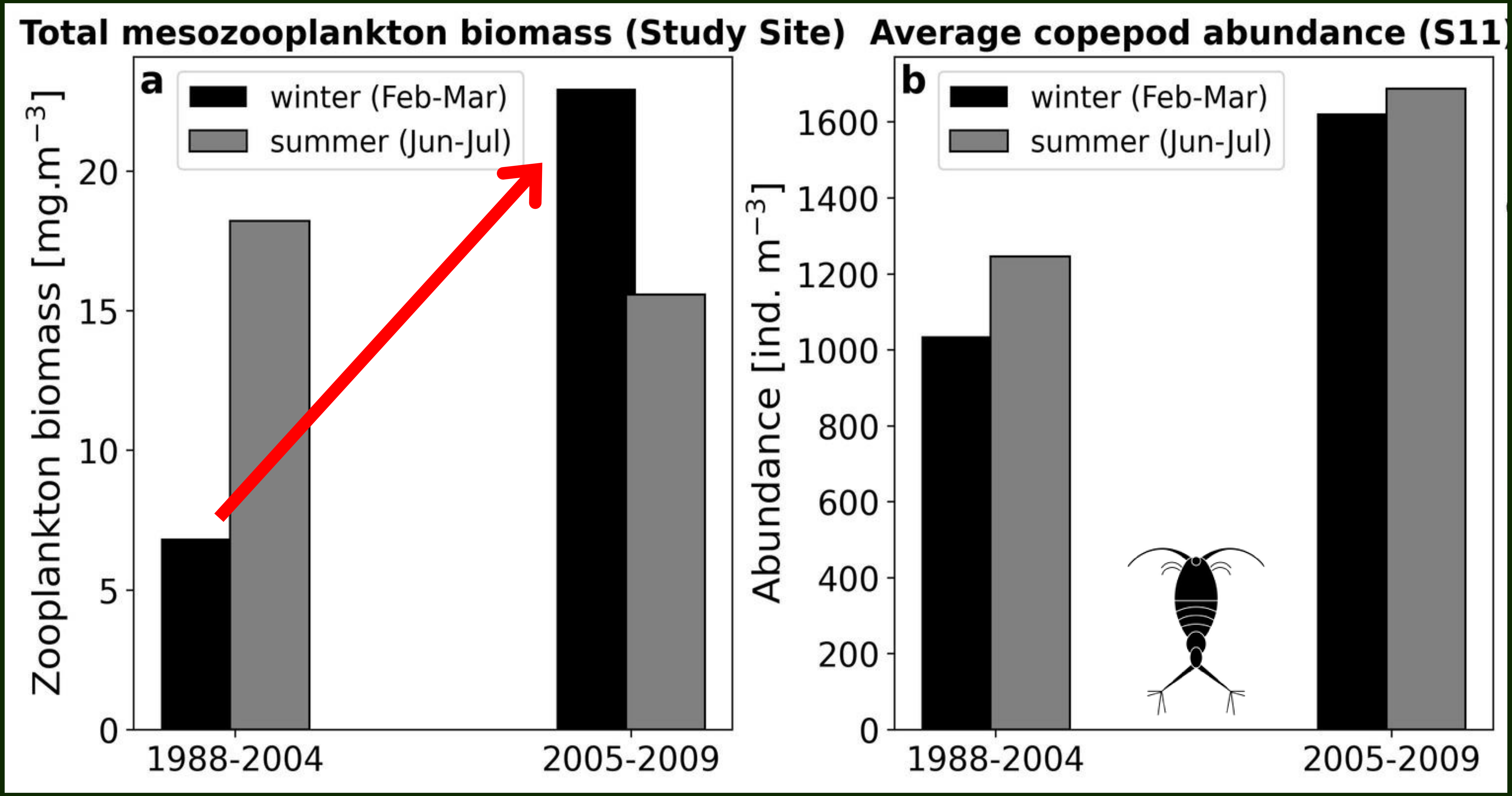
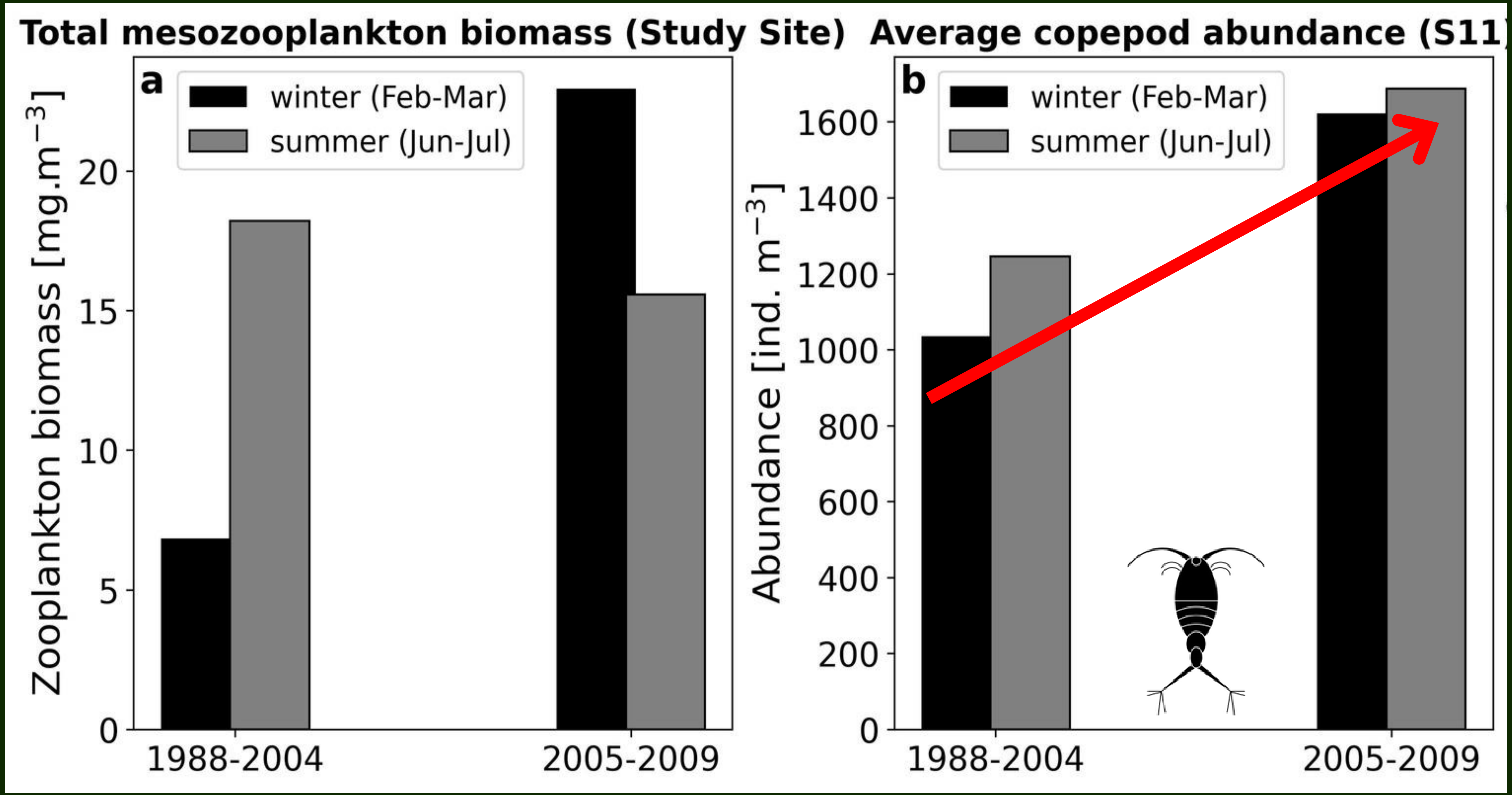


Mesozooplankton biomass ***vs.*** S11 copepod & cladoceran abundance

Copepods were favored by the ecological conditions that prevailed after 2004.

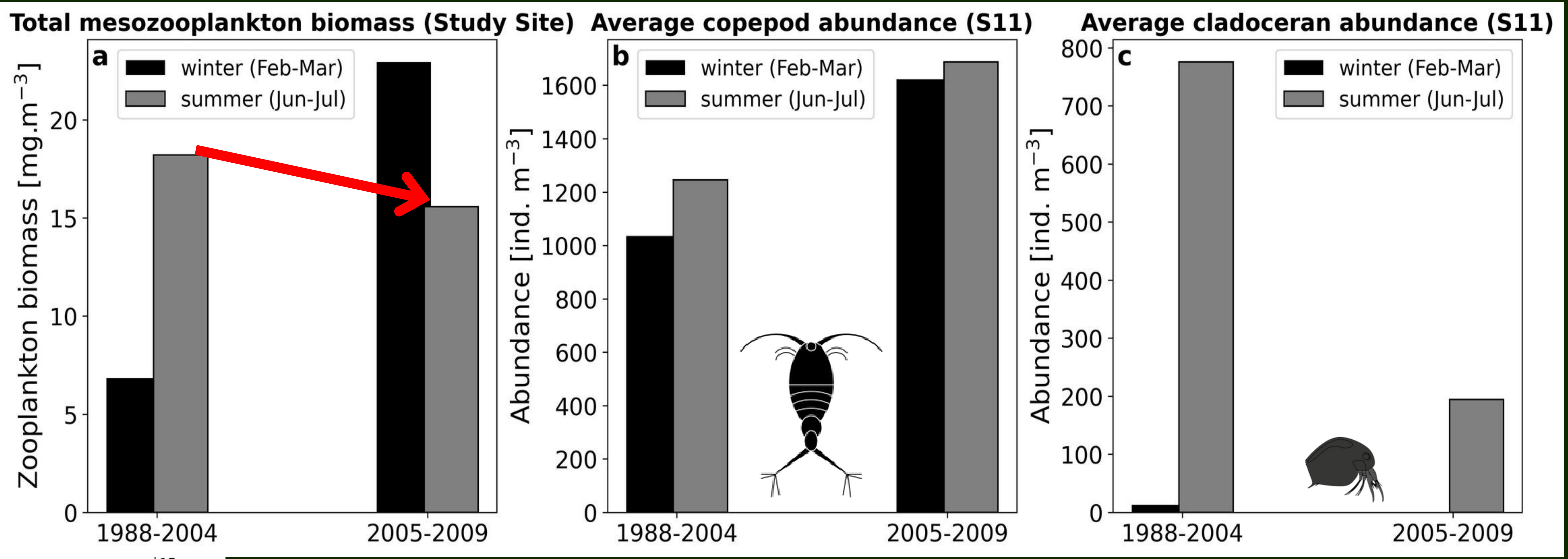


Winter: 56% increase

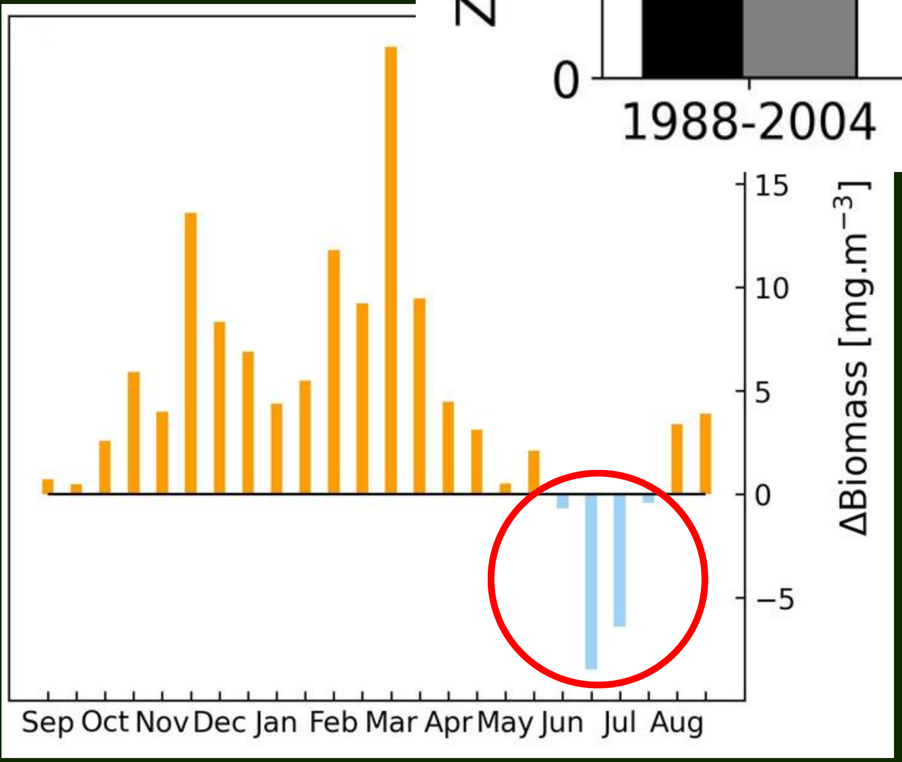
Summer: 35% increase

Results

Mesozooplankton biomass *vs.* S11 copepod & cladoceran abundance

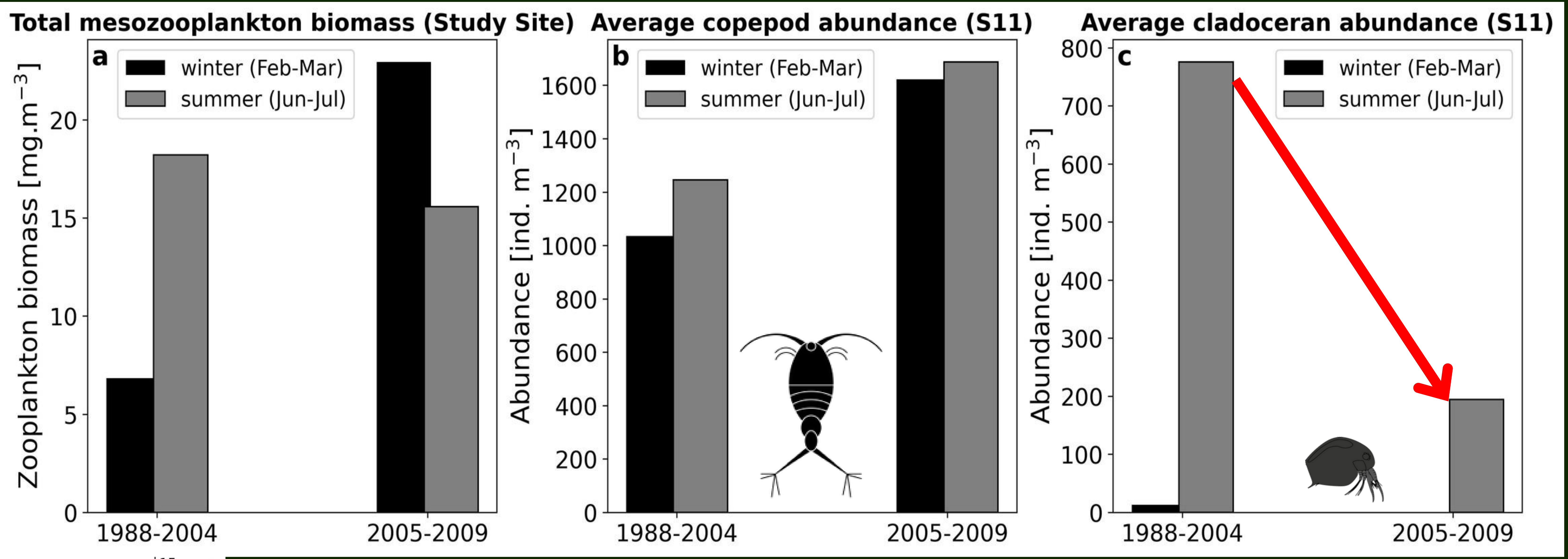


Climatological difference (P2-P1)

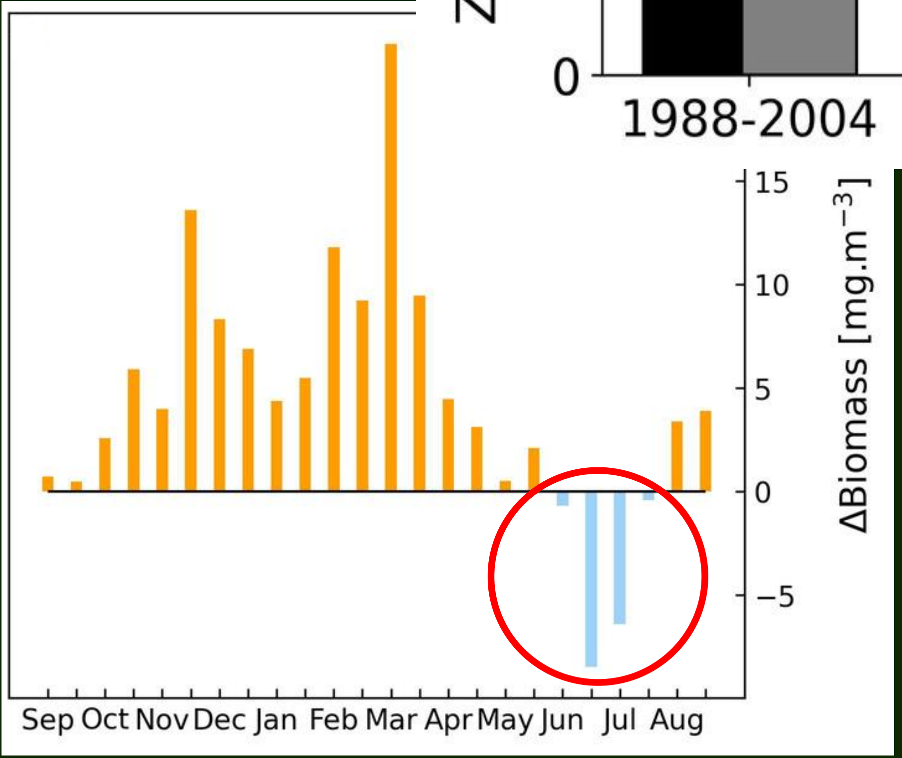


Decreased summer mesozooplankton biomass after 2004

Mesozooplankton biomass *vs.* S11 copepod & cladoceran abundance



Climatological difference (P2-P1)



Decreased summer mesozooplankton biomass after 2004

Transition to less mesotrophic and warmer conditions in P2 (2005-2015)

Winter: near zero

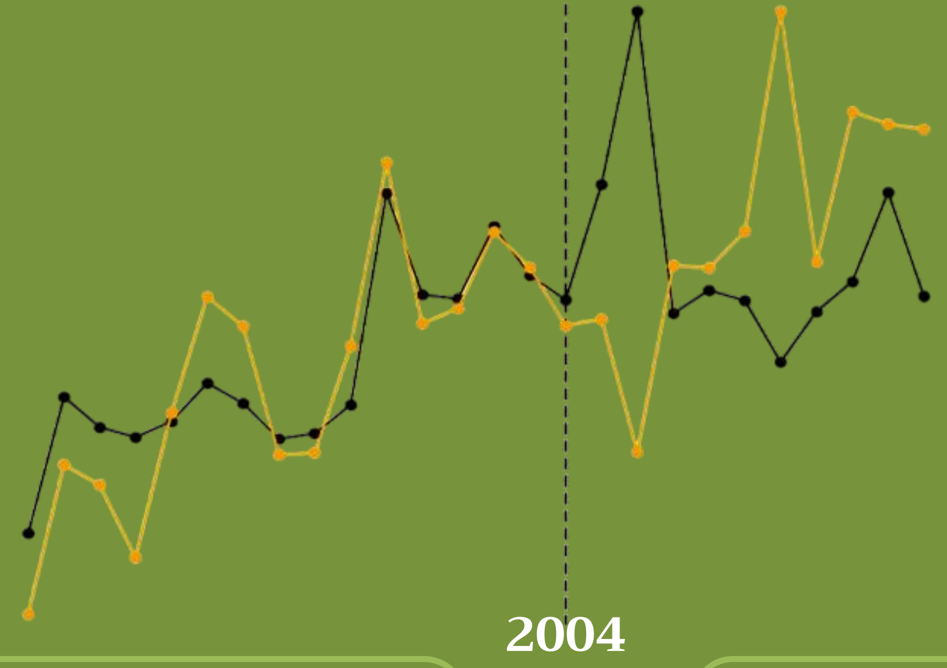
Summer: 75% decrease

Concluding Remarks

An **interplay** of long-term human-induced pressures (warming and wastewater discharge) led to shifts in plankton biomass and phenology in Saronikos Gulf.

Interestingly, once the Gulf showed signs of recovery (2004), the signal of oceanic warming in plankton ecological indicators became apparent.

Concluding Remarks



An interplay of long-term human-induced pressures (warming and wastewater discharge) led to shifts in plankton biomass and phenology in Saronikos Gulf.

Interestingly, once the Gulf showed signs of recovery (2004), the signal of oceanic warming in plankton ecological indicators became apparent.

Future plans

- **Revisit the historical samples and reanalyze them to estimate plankton community structure**
- **Assess potential links with fisheries datasets.**

Thank you for your attention!

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