Fattori che influenzano lo stato trofico dell'Adriatico

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Focus su

- **Impatto degli apporti fluviali sulle concnetratzioni di nutrienti e sulla clorofilla**
- **Acidificazione**
- **Riscaldamento delle acque**
- **Contenuto di ossigeno nelle acque-eventi ipossici**

Riverine inputs into the North Adriatic

Po river discharge accounts for:

68% of all the riverine inputs in the Northern Adriatic Sea

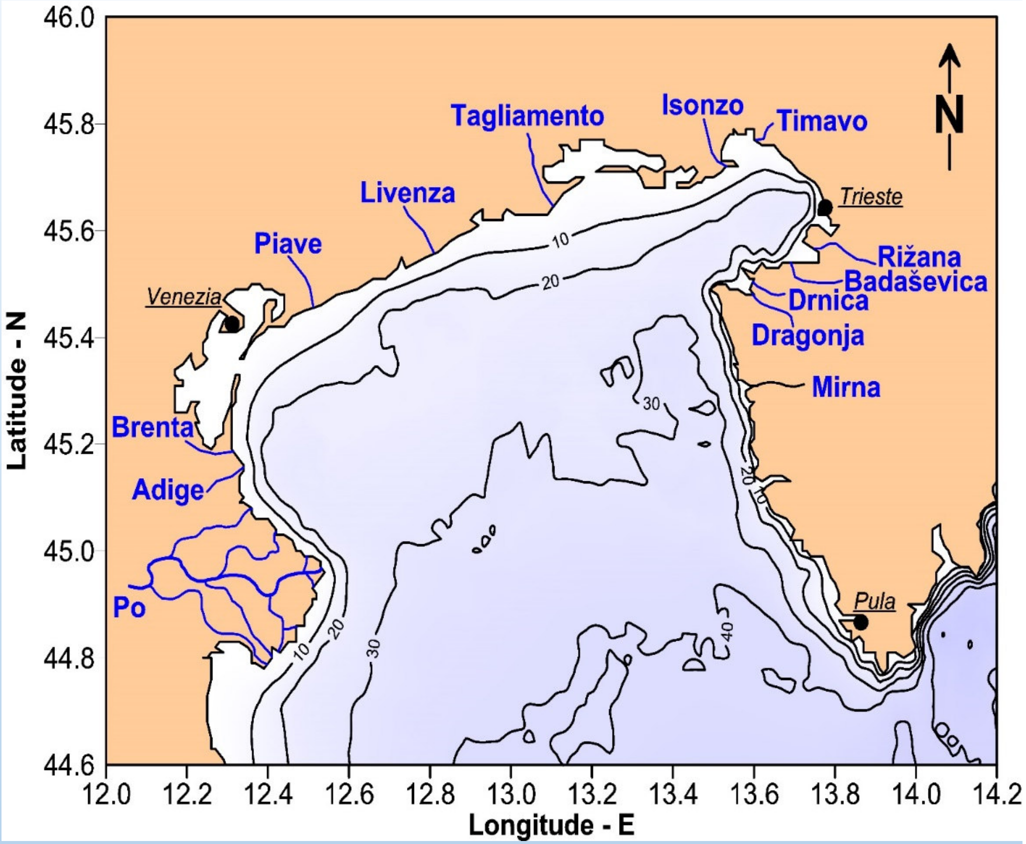
14% of the whole river discharge in the Mediterranean sea (312 km^3 y^{-1})

Drainage basin: 71 $*10^3$ km^2

Resident population: **$17*10^6$** inhabitants.

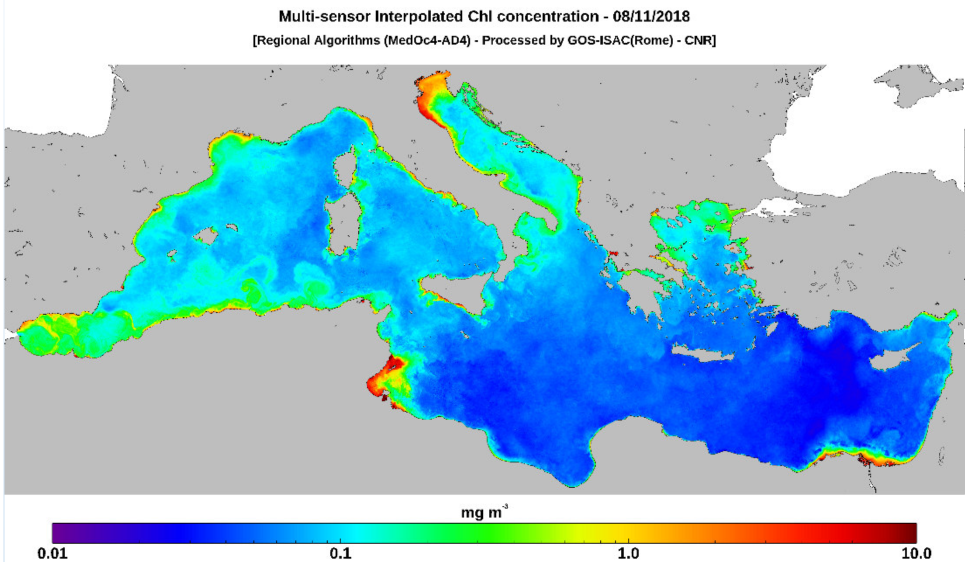
Animal population:

- **total 64 $*10^6$** Population Equivalent

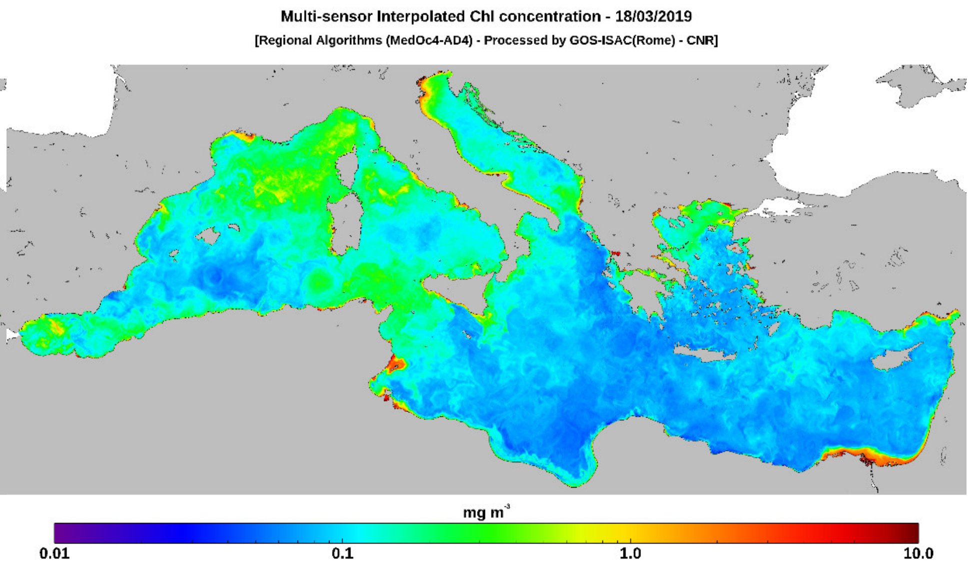


Seasonal variations of chlorophyll a concentrations from multisatellites

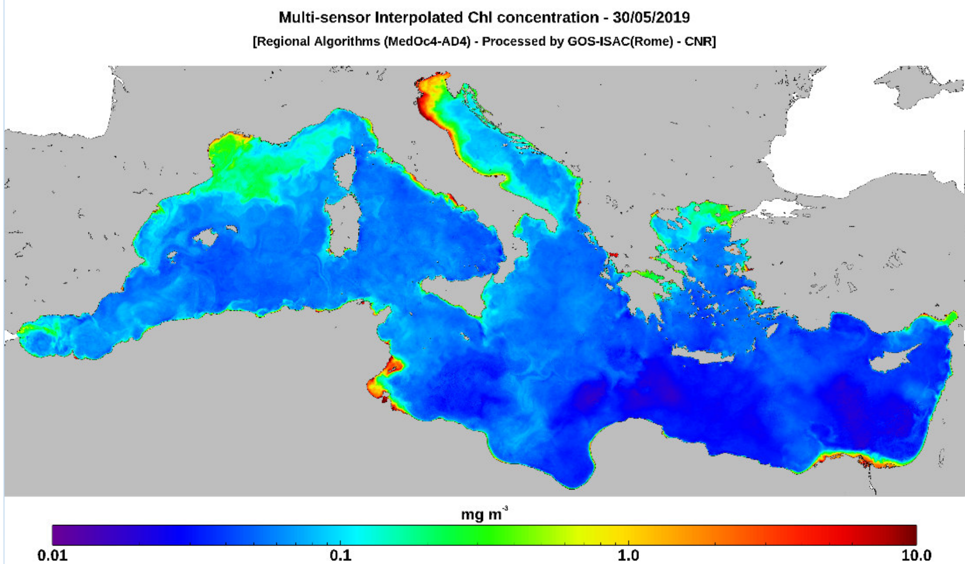
Autumn



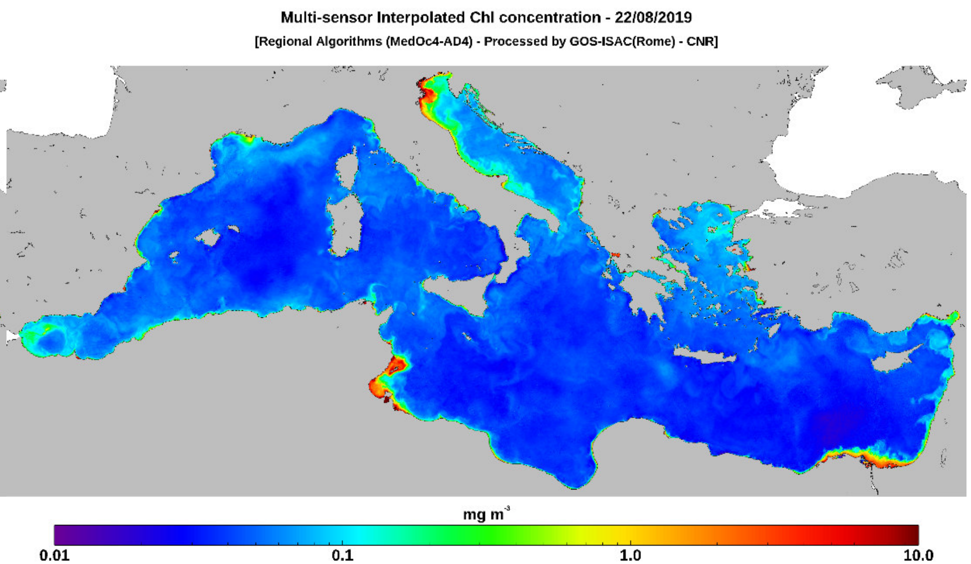
Winter



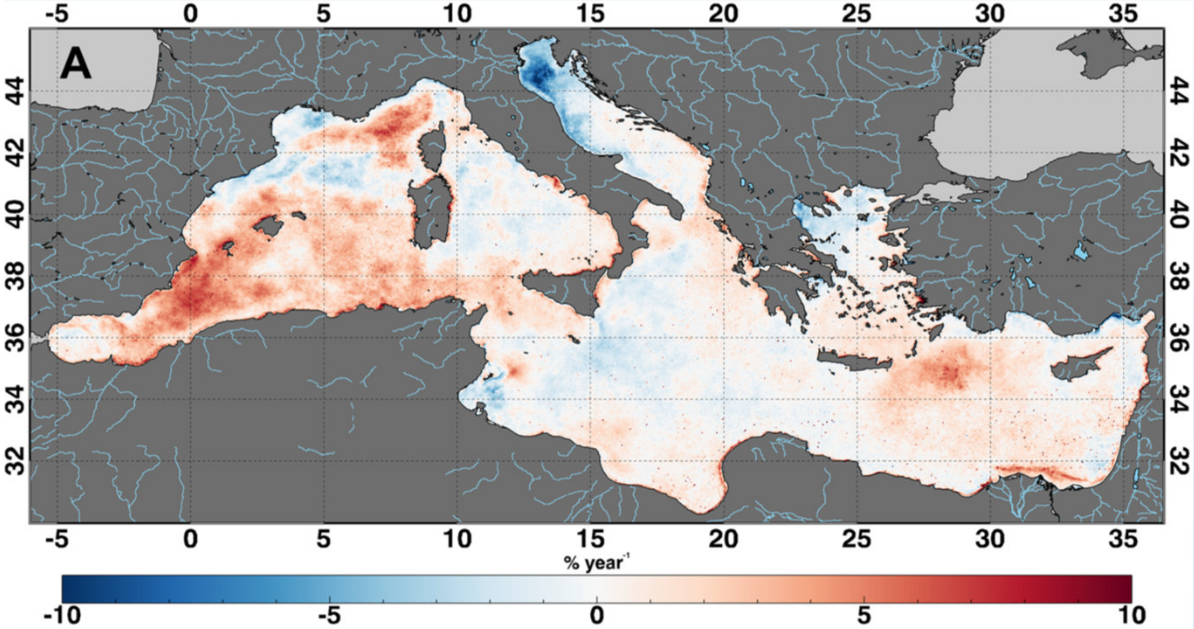
Spring



Summer



Chl a concentration trends from satellites

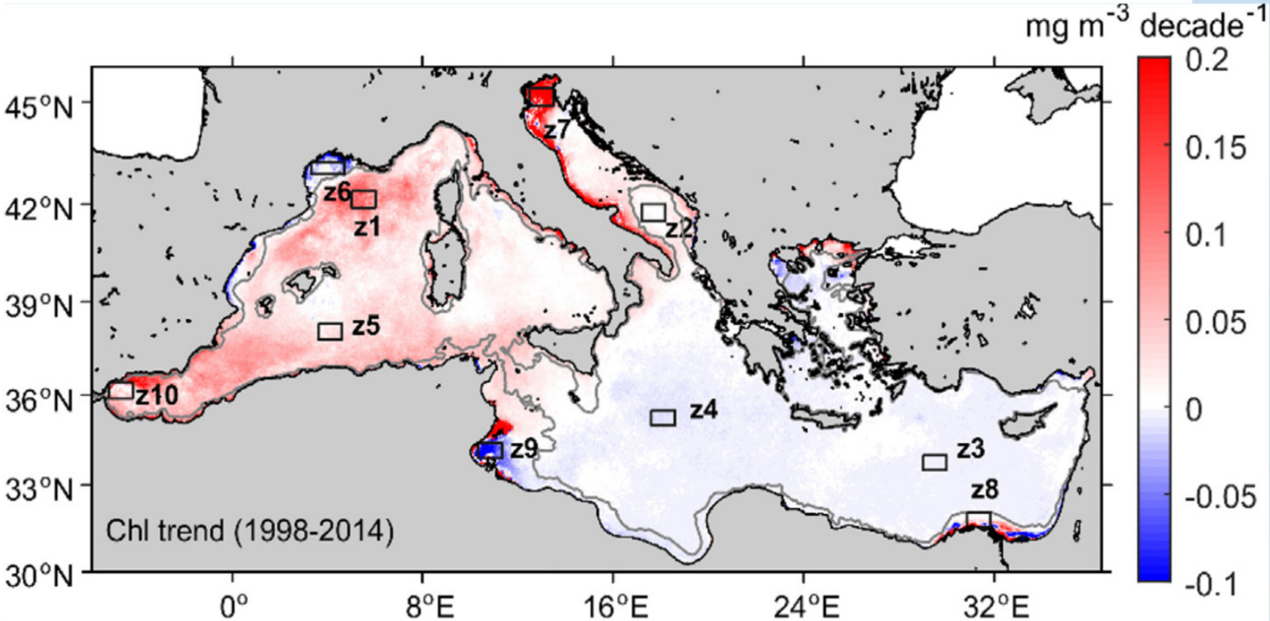


1998–2009

Color bar scale represents the relative changes (%) corresponding to the dimensional trend (mg m^{-3} y^{-1}) with respect to the climatological Chl concentration values.

North Adriatic: ~ -10% y^{-1}

From *Colella et al. 2016*



1998–2014

Scale units represent the changes in mg m^{-3} $decade^{-1}$. Only 95% significant Theil-Sen trends ($p < 0.05$) are shown.

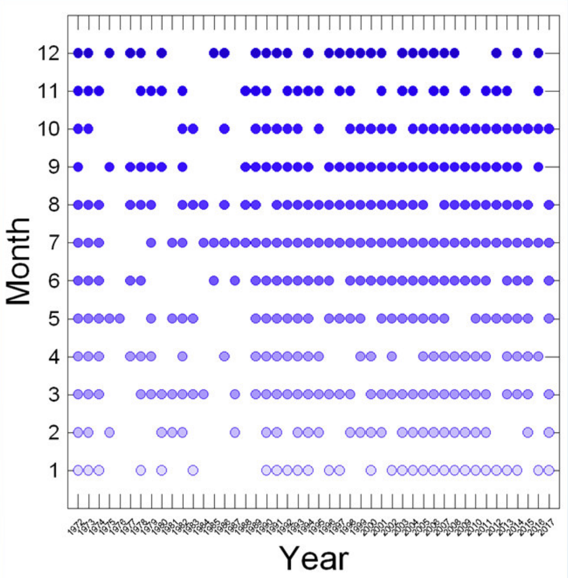
Large positive trends are found in the Adriatic Sea where the mean increase is

+0.047 ± 0.085 mg m^{-3} $decade^{-1}$, and maximum values are found along the north-western shore (+0.241 ± 0.022 mg m^{-3} $decade^{-1}$)

From *Salgado Hernanz et al. 2019*

Data sources and elaboration

Cruises in the NAd (1972-2017)



Data for the open NAd were collected by CRM-IRB Rovinj

Data on Po flow discharge at Pontelagoscuro/Polesella (closure section of the drainage basin) were obtained by ARPA Emilia Romagna.

The data of monthly river discharges for the period 1807-1916 were supplied by Zanchettin et al. (2008) who reconstructed the discharges from stage measurements.

Data on concentrations of nutrients in Po river at Pontelagoscuro/Polesella (1968-2016) were obtained from Autorità di Bacino del Fiume Po, ARPA Emilia Romagna, IRSA-CNR and from scientific publications.

Data on N and P fertilizer consumption for the period 1952-2016 were obtained by ISTAT (Annuari statistici agricoltura)

Annual integrated transport by river (**F**; expressed in tons of N, P and Si per year) was estimated for each nutrient using the equation based on discharge weighted means of daily transport:

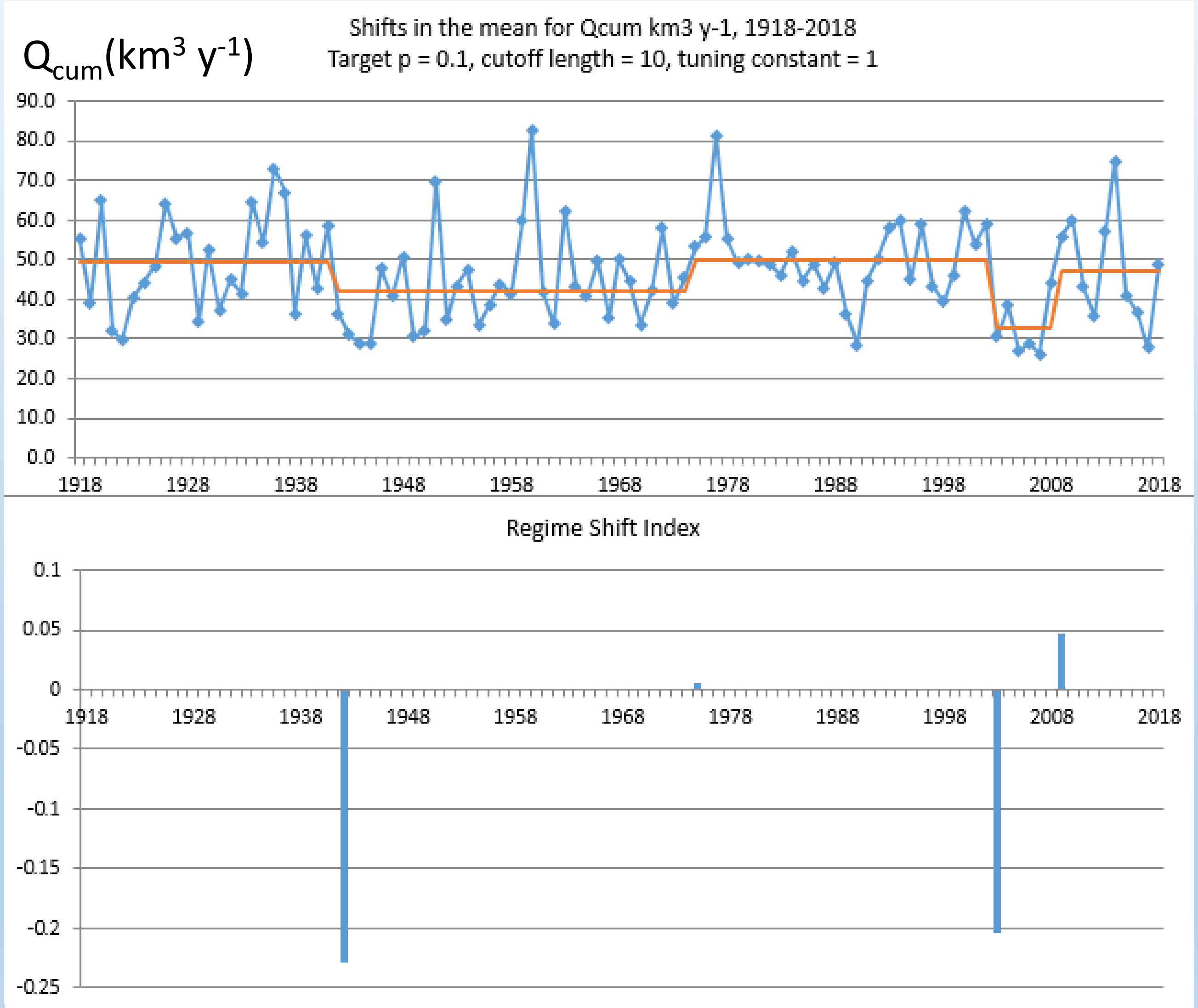
$$F = [\ \Sigma_i(C_i * Q_i) / \Sigma_i Q_i\ ]\ Q_Y * m_A * 10^{-6}$$

where:
C_i = nutrient concentration (mol m^{-3}) and Q_i = average flow rate ($m^3\ s^{-1}$) for each day of sampling,
Q_Y = annual runoff ($m^3\ y^{-1}$)
m_A = the atomic mass of the biogenic element.

Linear trends were estimated by **non-parametric Mann Kendall and Sen's Tests** (MAKESENS; Salmi et al. 2002).

Regime shifts in time series were detected by **a Sequential *T*-test Analysis of Regime Shifts** (Sequential Regime Shift Detector SRDS ver 5.2 software package (Rodionov, 2004). SRDS uses the *t*-statistic to estimate a threshold, or critical level, for the new regime to be detected.

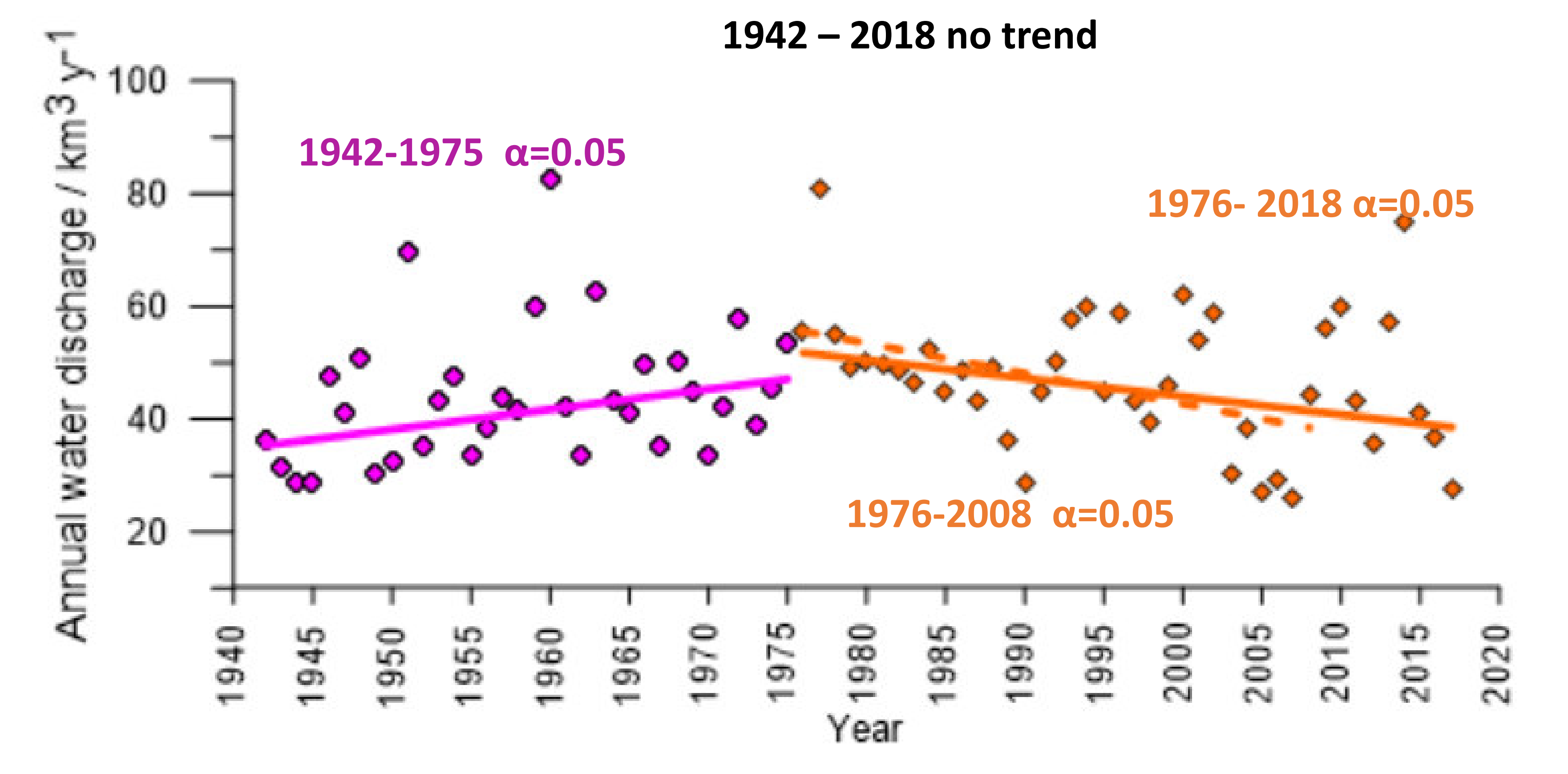
Po River annual freshwater discharge (1918-2018)



1483±384 m^3 s^{-1} (1918-2018)

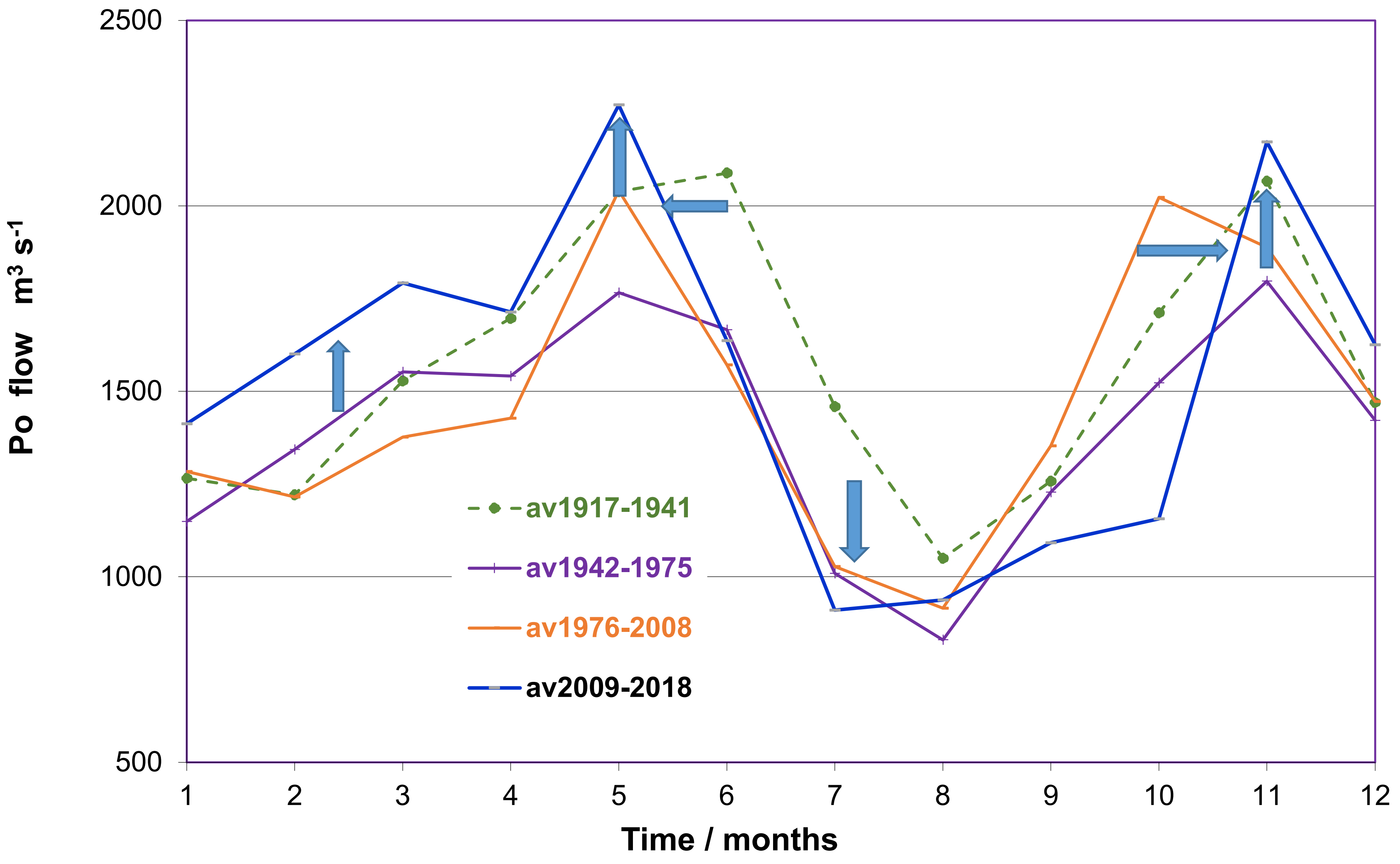
1527±446 m^3 s^{-1} (2009-2018)

Changes of the trend in Po River discharge in the period 1942-2018

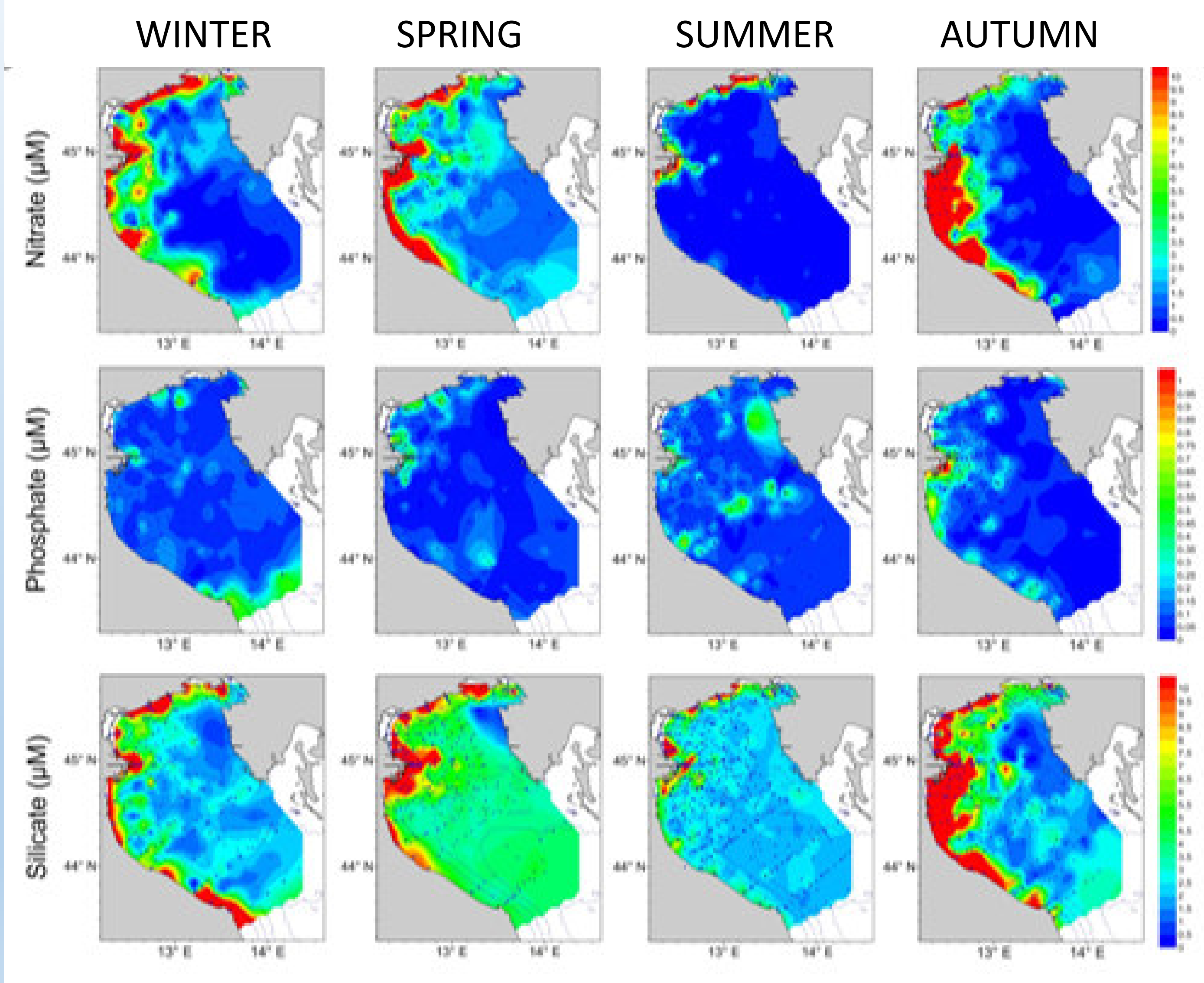


Non parametric Mann-Kendall test

Variations in seasonal discharge regime

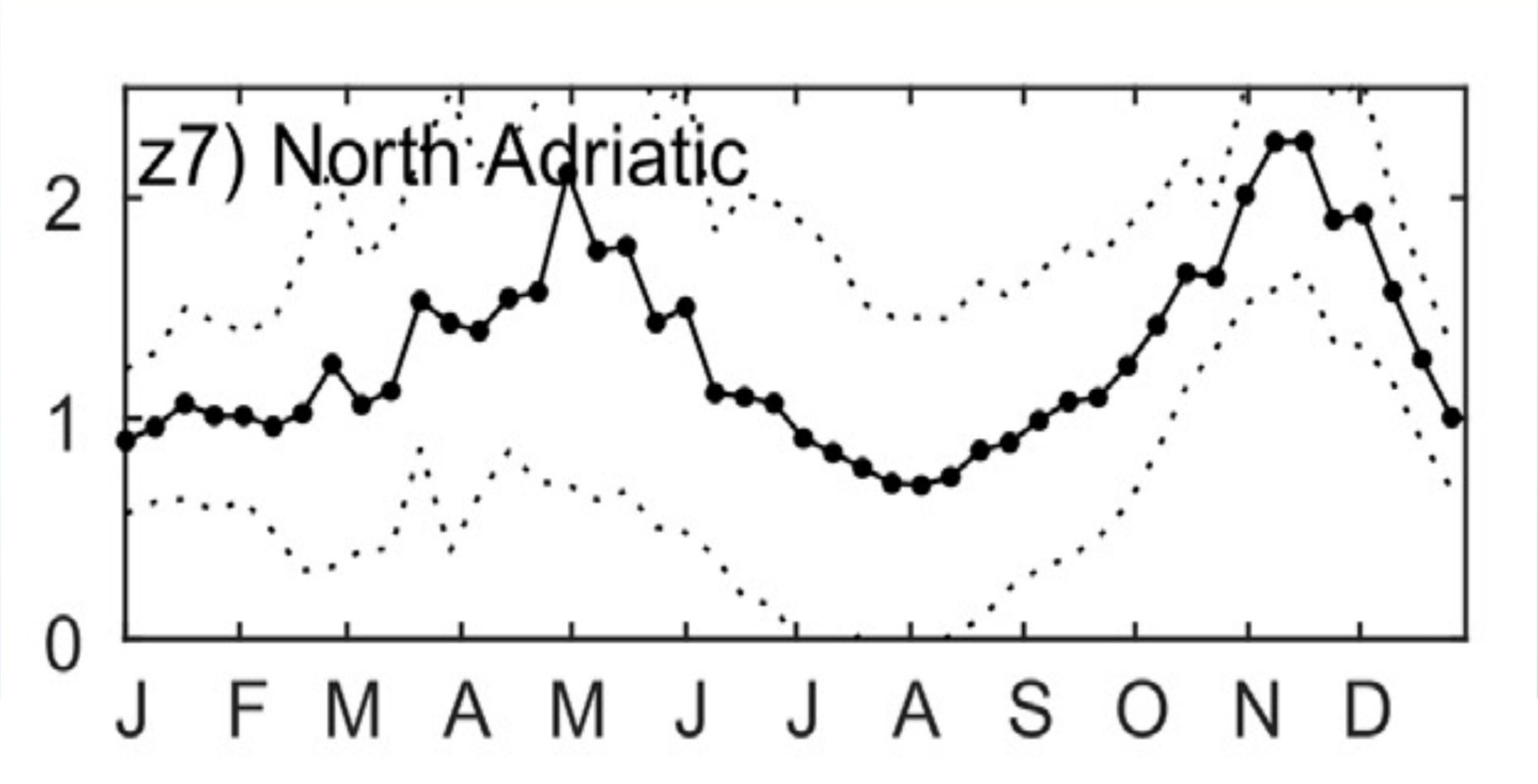


Seasonal variation of surface NO_3, PO_4 and SiO_2 concentrations



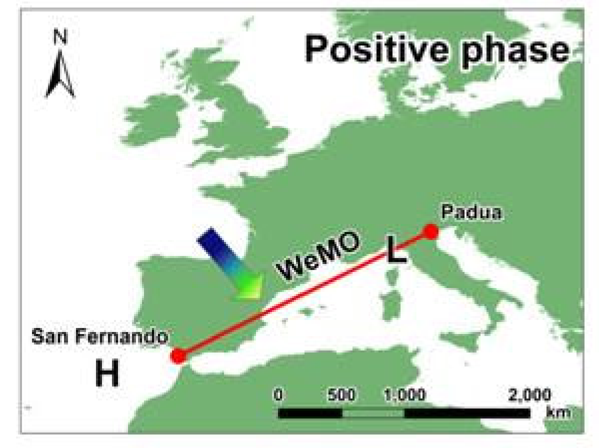
Grilli et al., SIBM 2018

Mean climatology of 8-day Chl a time series for a composite year, relative to the period 1998–2014

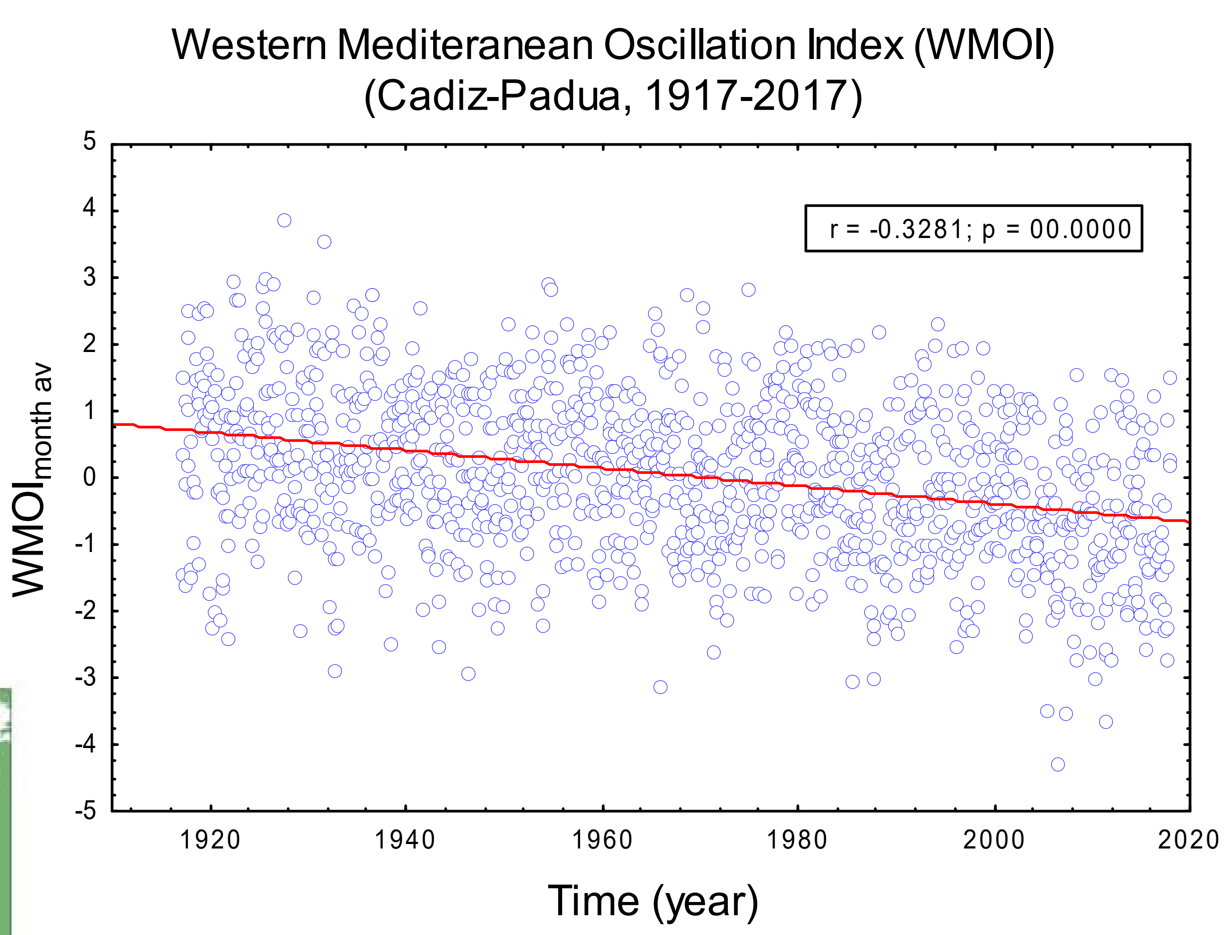


from Salgado-Hernanz et al., Remote Sensing Env. 2019

WMOI>0

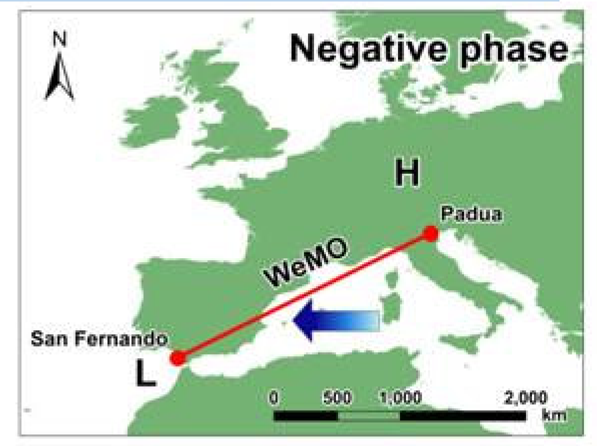


N
Positive phase
Padua
WeMO
L
San Fernando
H
0 500 1,000 2,000
km



Western Mediteranean Oscillation Index (WMOI)
(Cadiz-Padua, 1917-2017)
r = -0.3281; p = 00.0000
WMOImonth av
Time (year)
5
4
3
2
1
0
-1
-2
-3
-4
-5
1920
1940
1960
1980
2000
2020

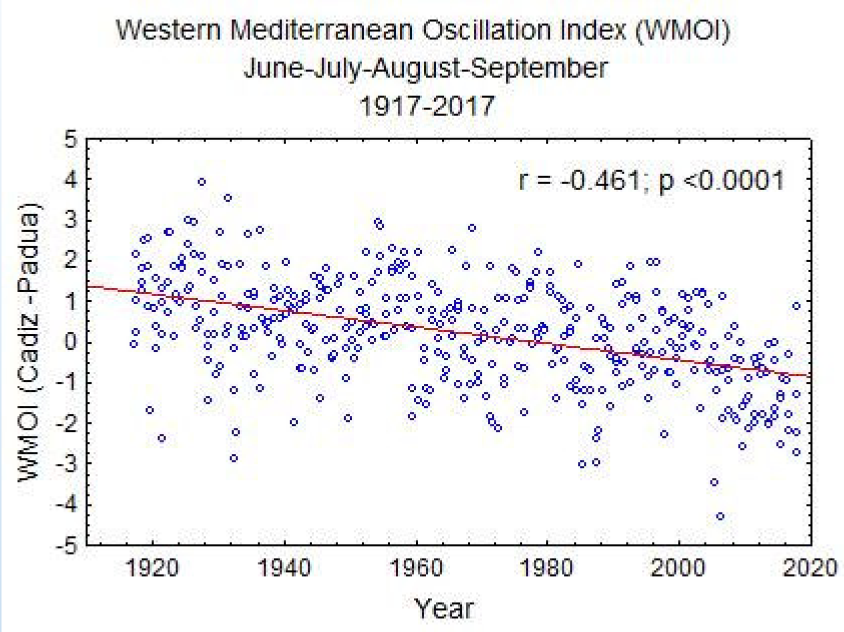
WMOI<0

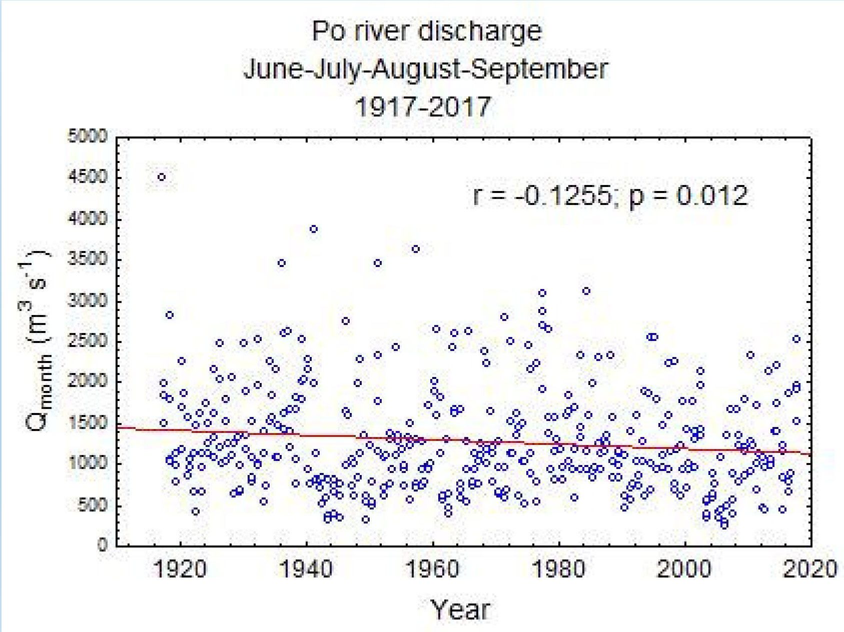


N
Negative phase
H
Padua
WeMO
San Fernando
L
0 500 1,000 2,000
km

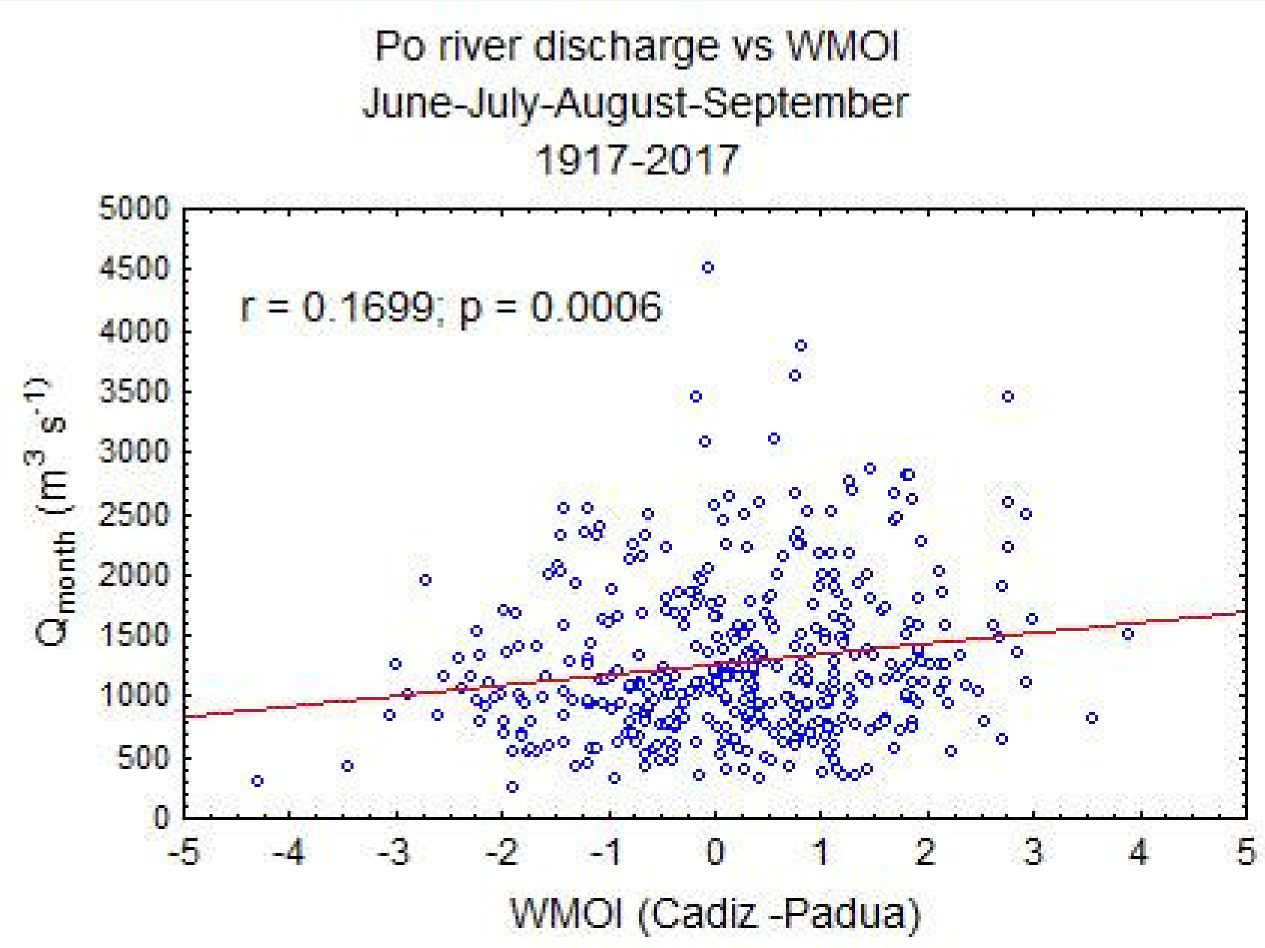
WMOI & Po discharges (Q) 1917-2017

Month	Q vs WMOI r	1917-2017 p
JAN	0.021	0.833
FEB	0.157	0.118
MAR	0.185	0.065
APR	0.281	0.004
MAY	0.070	0.490
JUN	0.295	0.003
JUL	0.239	0.016
AUG	0.236	0.018
SEP	0.259	0.009
OCT	0.012	0.903
NOV	0.150	0.135
DEC	0.495	0.625

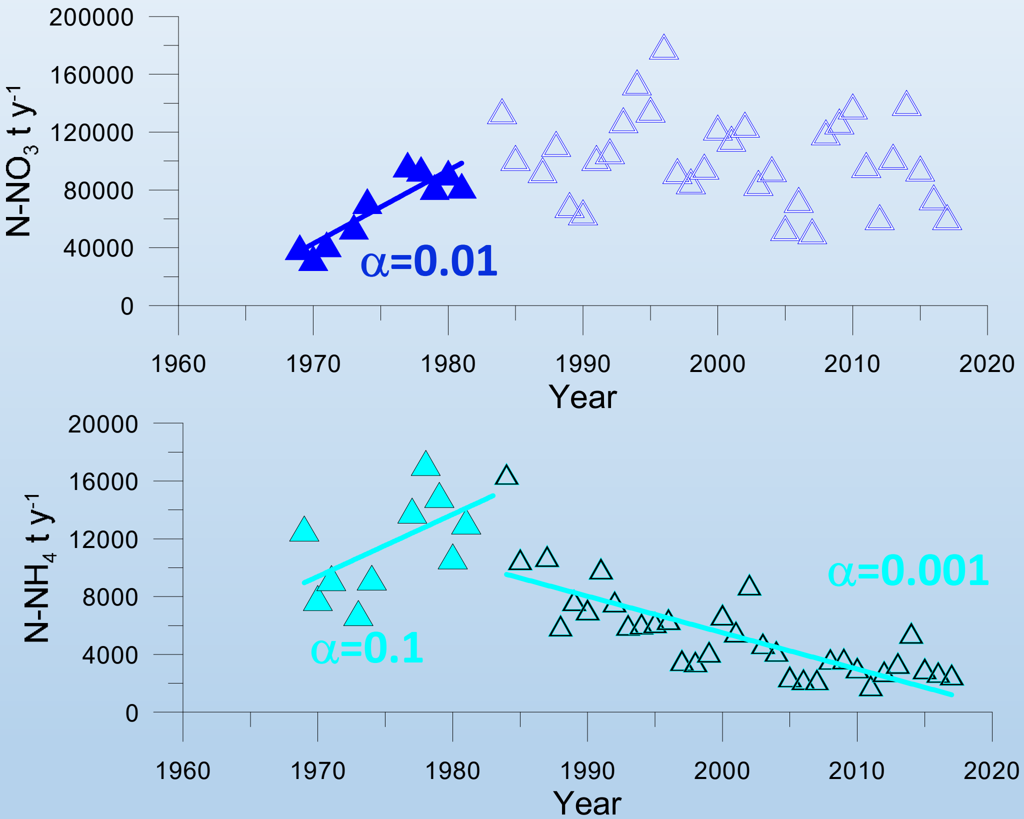




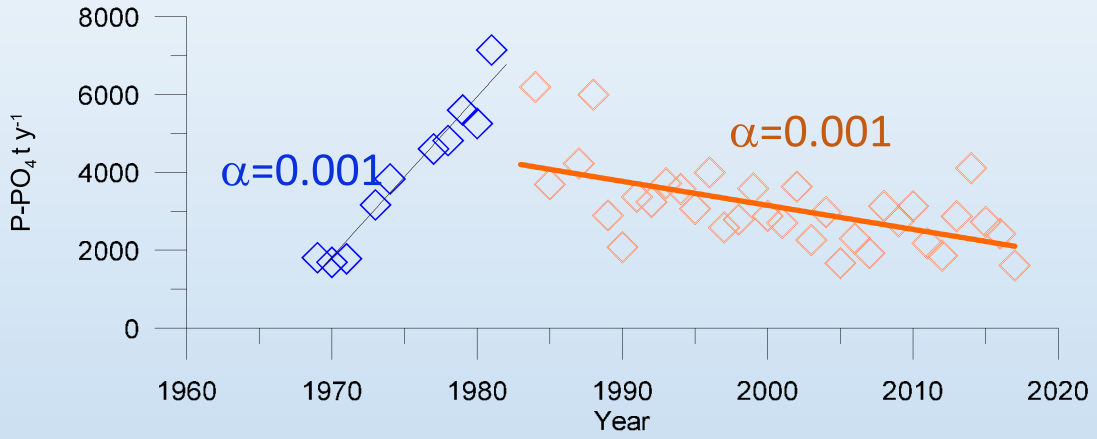
Po river discharge vs Western Mediterranean Oscillation Index 1917-2017

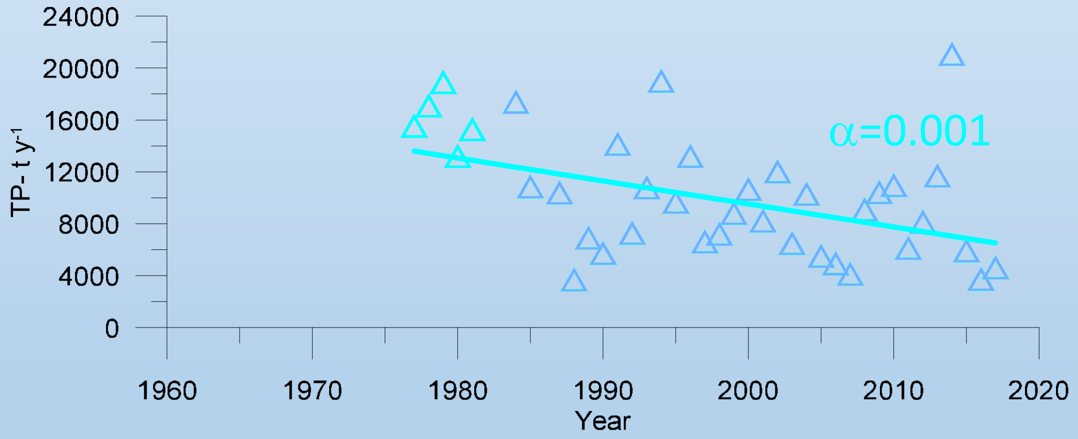


Trends of N loads in Po river 1969-2017

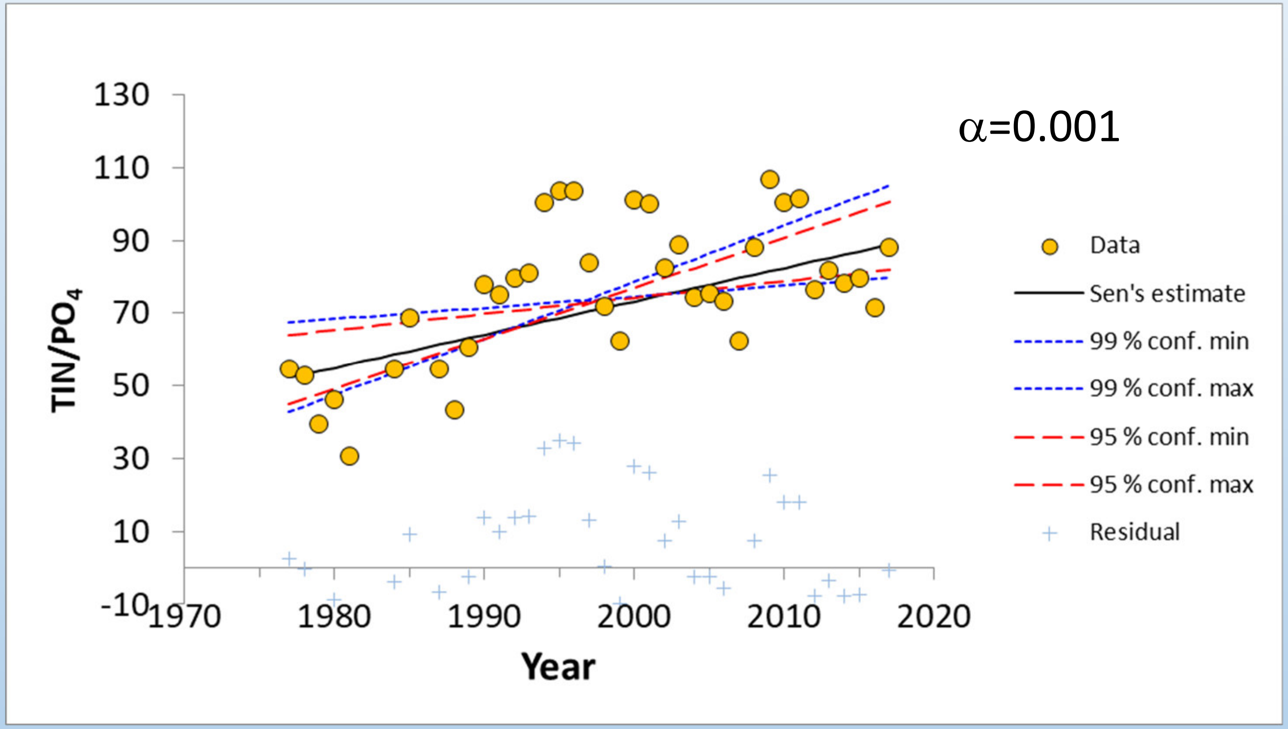


Trends of P loads in Po river

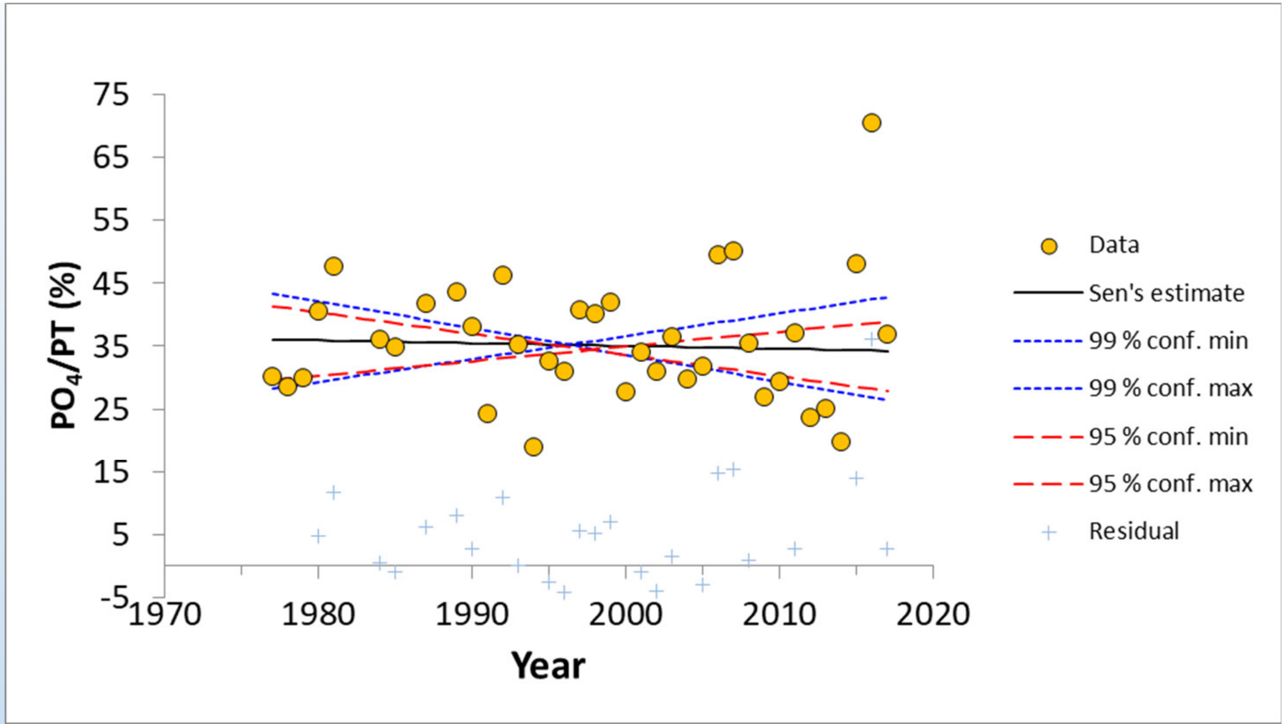




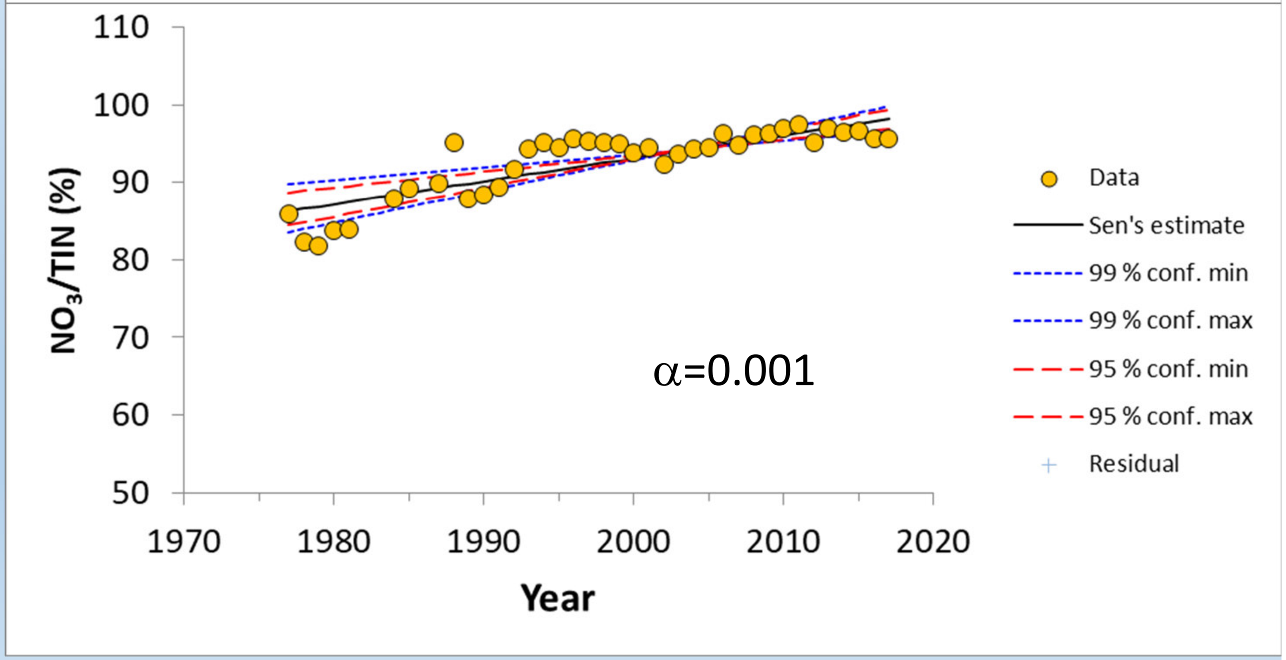
Trend of TIN/PO_4 molar ratio of Po river nutrients load 1977-2017



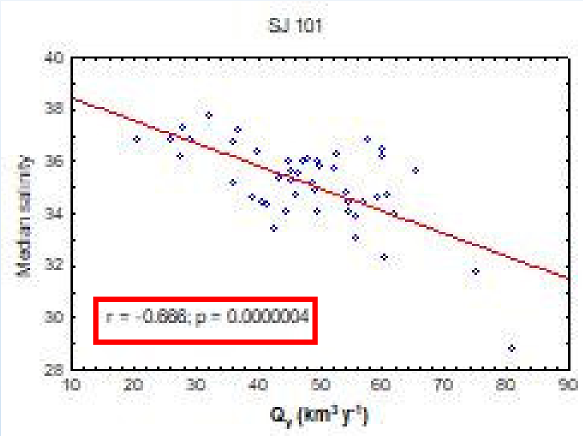
Relative incidence of PO_4 on total P

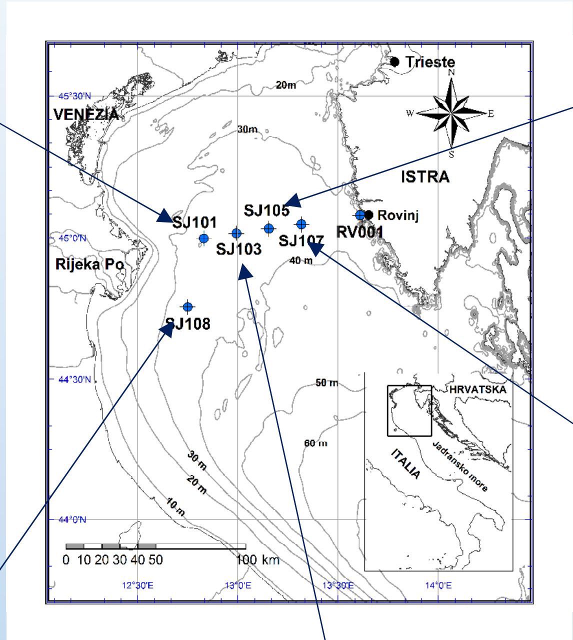


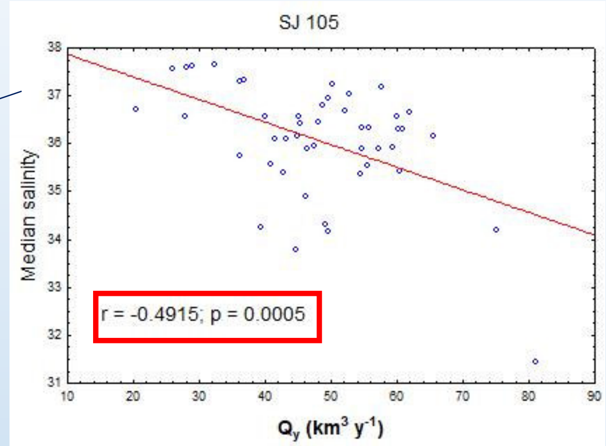
Relative incidence of NO_3 on dissolved inorganic N

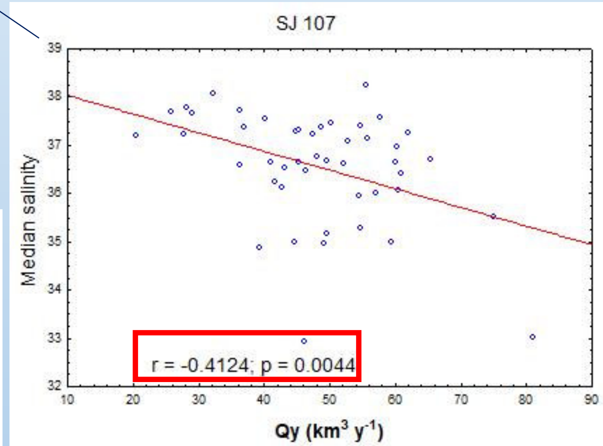


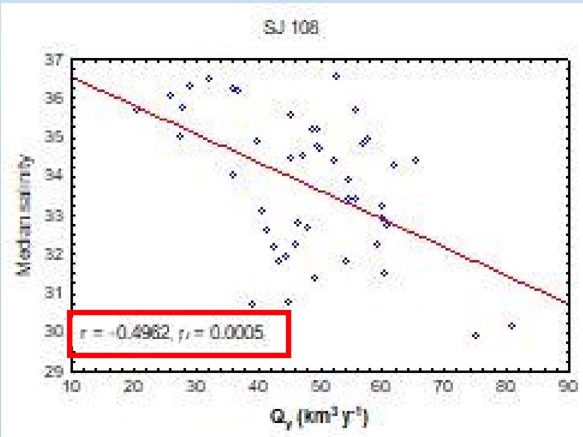
Median annual salinity vs Freshwaters annual discharge (1972-2017)

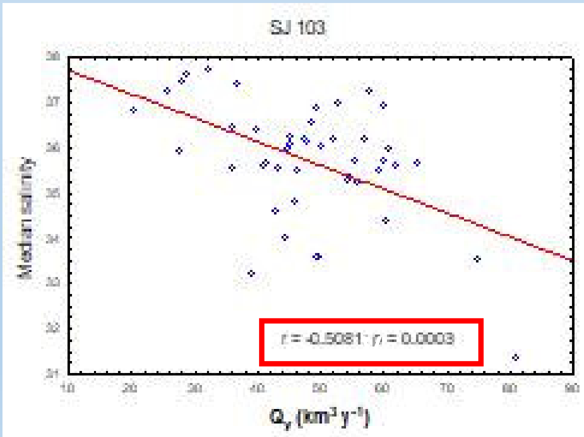






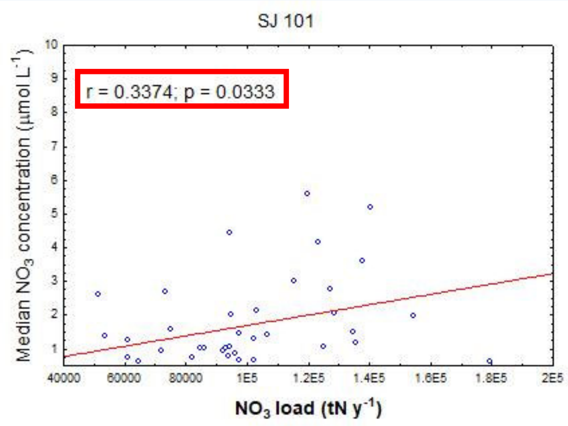


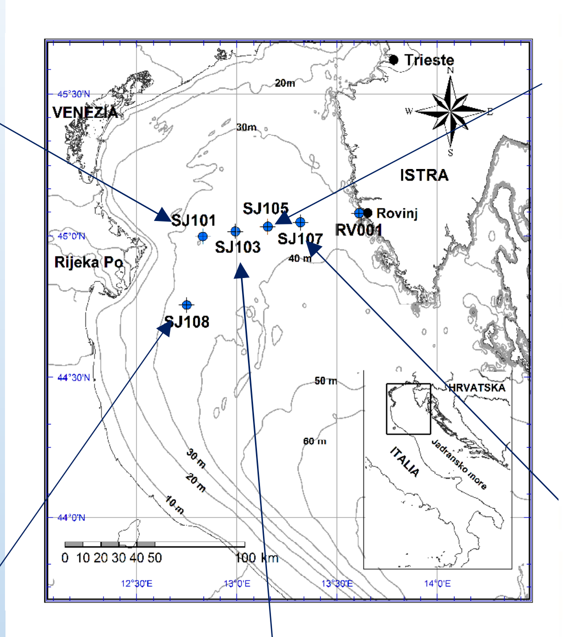


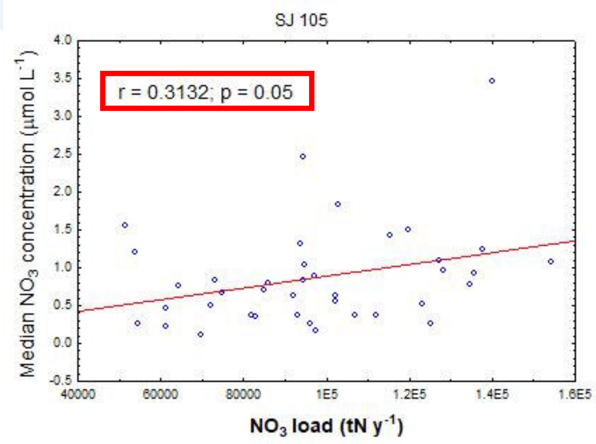


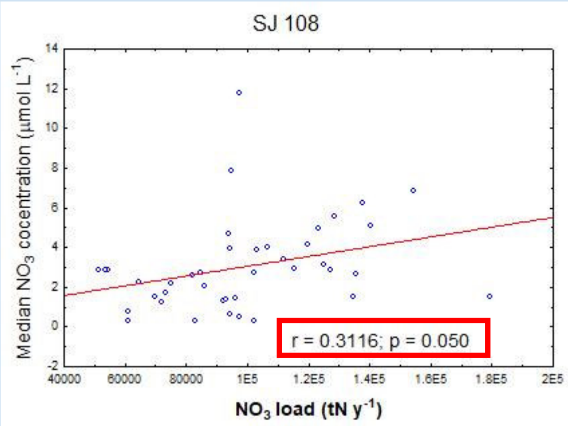
Significant linear correlations are marked in red

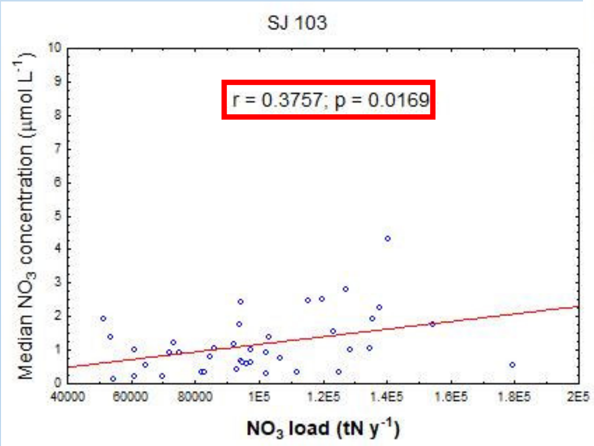
Median annual NO_3 concentrations vs NO_3 annual loads (1973-2017)

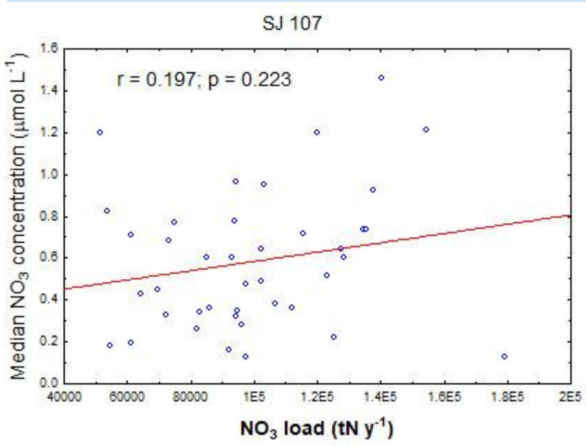






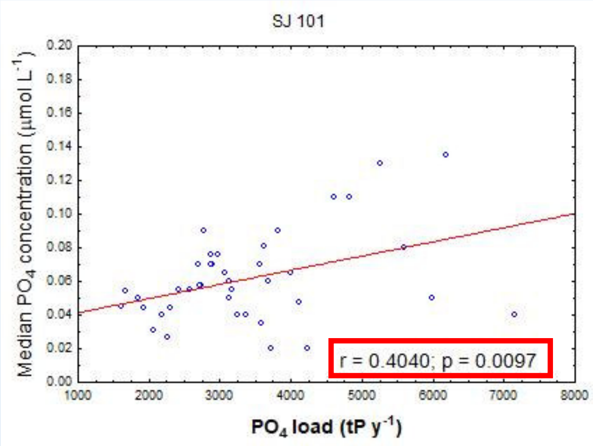


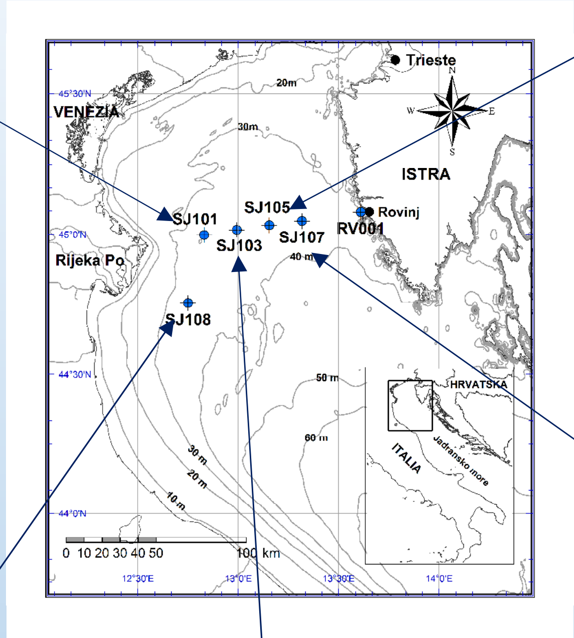


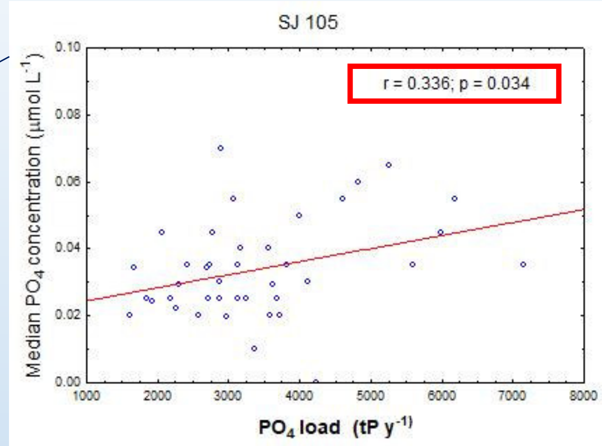


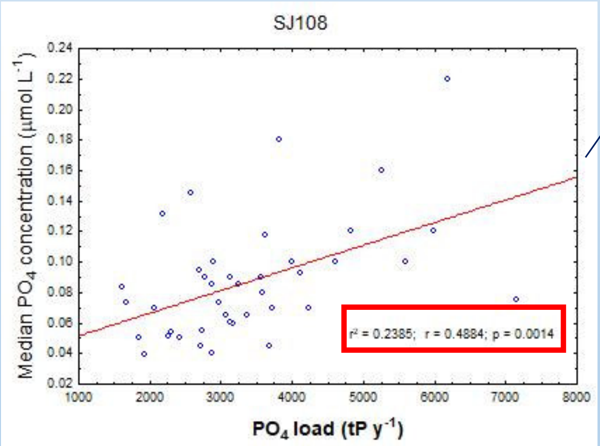
Significant linear correlations are marked in red

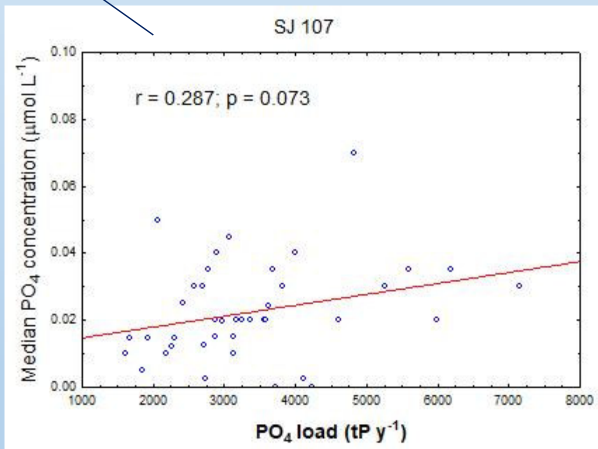
Median annual PO_4 concentrations vs PO_4 annual loads (1972-2017)

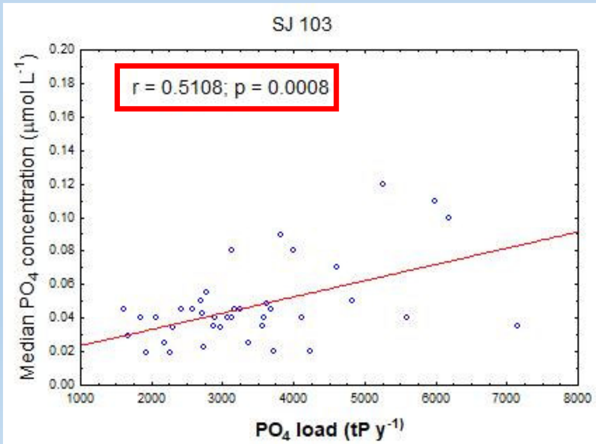






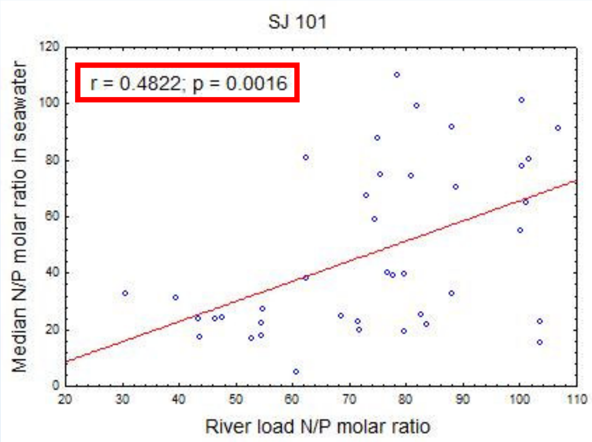


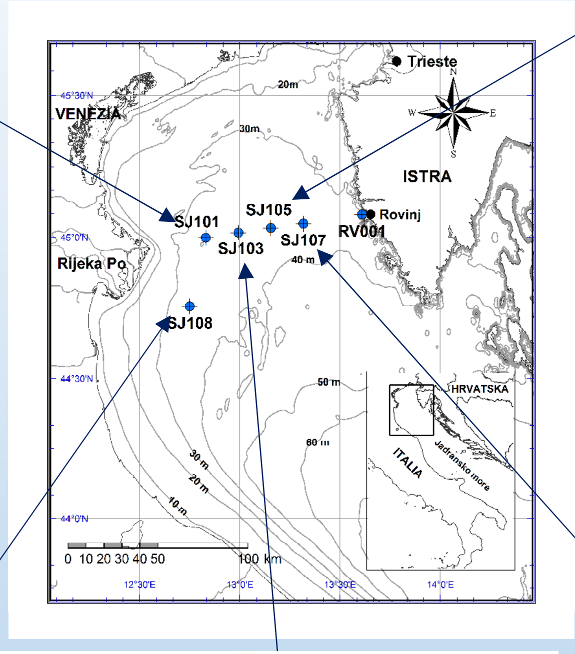


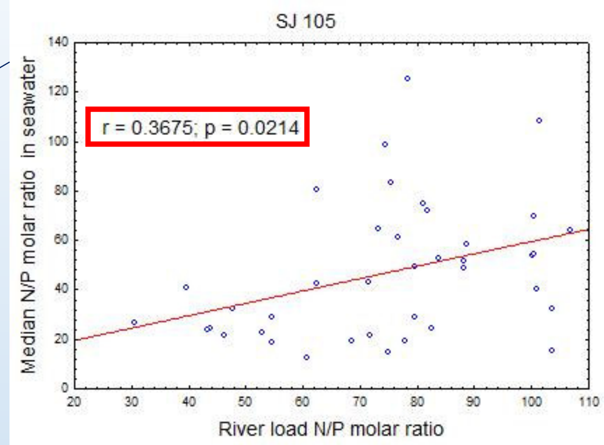


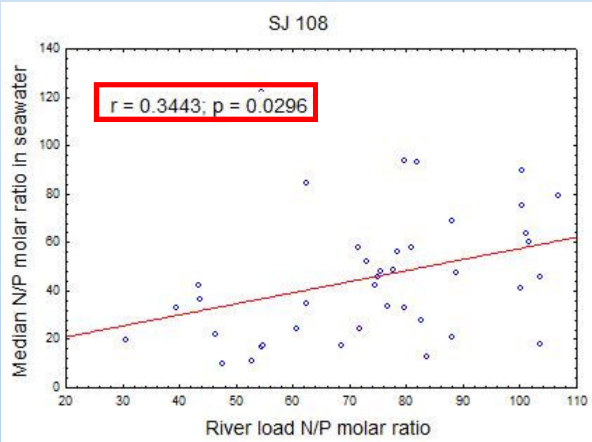
Significant linear correlations are marked in red

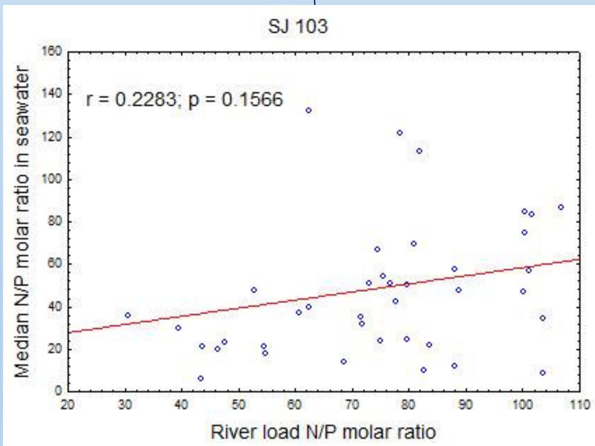
Median annual N/P ratio in seawater vs N/P annual load (1972-2017)

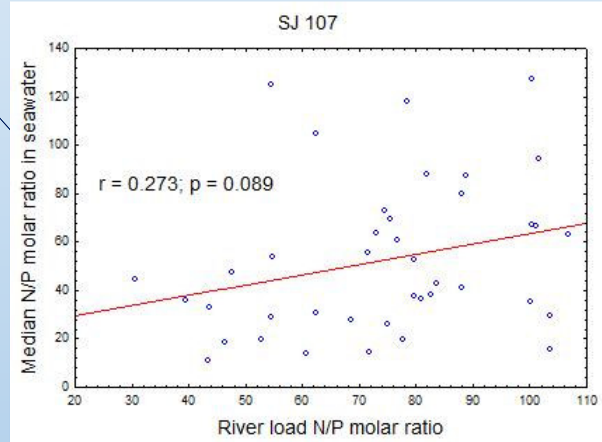








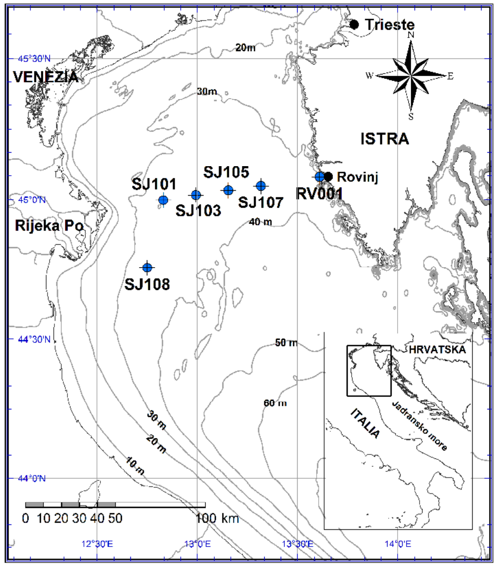




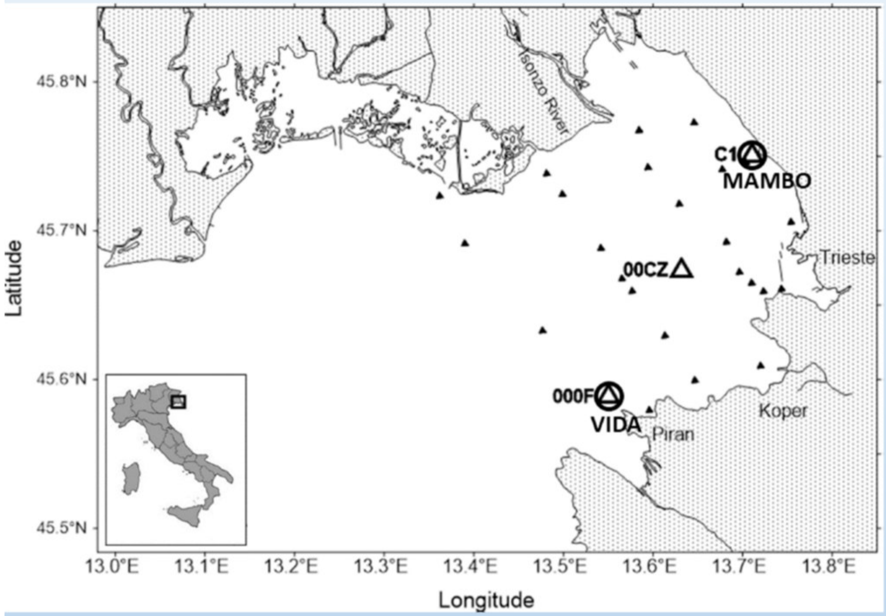
Significant linear correlations are marked in red

Temporal trends in the open surface waters of northern Adriatic sea 1972-2017

Stations (0-5m)		SJ108 r	SJ108 p	SJ101 r	SJ101 p	SJ103 r	SJ103 p	SJ105 r	SJ105 p	SJ107 r	SJ107 p
NO3	↑	0.1199	0.0006	0.1159	0.0012	0.1253	0.0006	0.0853	0.0179	0.1601	0.000002
PO4	↓	-0.0053	0.881	-0.1209	0.0008	-0.1503	0.00004	-0.1419	0.00008	-0.2135	0.0000
N/P	↑	0.1611	0.000005	0.1672	0.000004	0.1976	5E-08	0.1637	0.000006	0.1911	0.000000
Chl a	↓	-0.1263	0.0003	-0.0658	0.0613	-0.1038	0.0035	-0.0913	0.0096	-0.052	0.1087



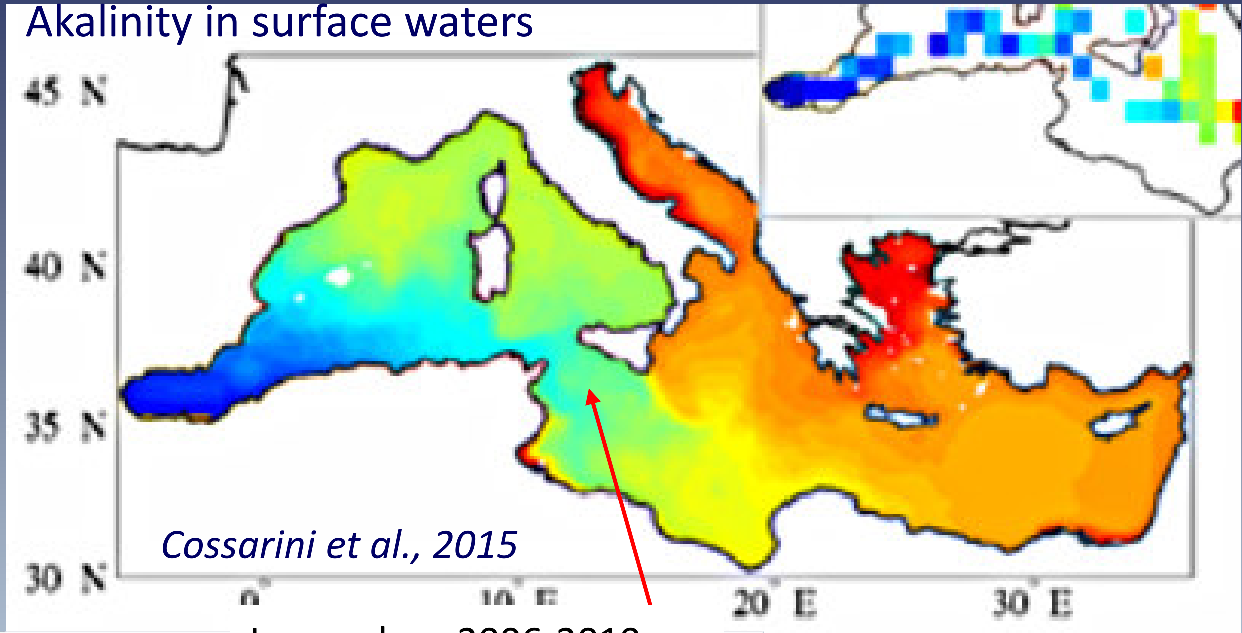
Chlorophyll a trends at three long term monitoring sites in the Gulf of Trieste (northern Adriatic Sea)



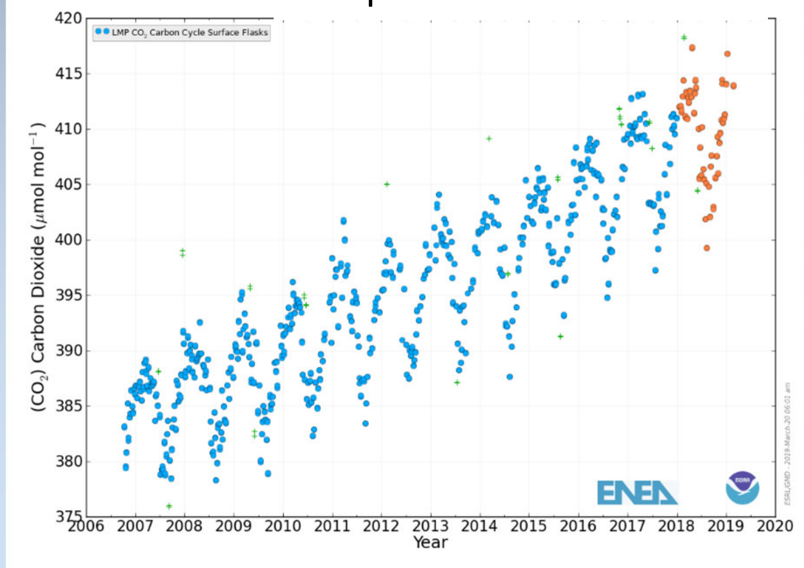
Station	Depth (m)	p	r	Slope (µg L^{-1} y^{-1})	Period (years)
00CZ	<20	0.000	-0.227	-0.026	1989-2016
00CZ	<=5	0.001	-0.26	-0.026	1989-2016
00CZ	>=24	0.711	-0.042	-0.006	1989-2016
000F	<20	0.004	-0.16	-0.014	1983-2016
000F	<=5	0.004	-0.207	-0.015	1983-2016
000F	>=21	0.045	-0.206	-0.018	1983-2016
C1	<=15	0.000	-0.289	-0.027	1986-90/1999-2016
C1	<=15	0.612	-0.035	-0.005	1999-2016
C1	<=5	0.000	-0.338	-0.024	1986-90/1999-2016
C1	<=5	0.272	-0.107	-0.011	1999-2016

from Kralj et al. Deep Sea Res. 2019

Acidification in the Mediterranean Sea

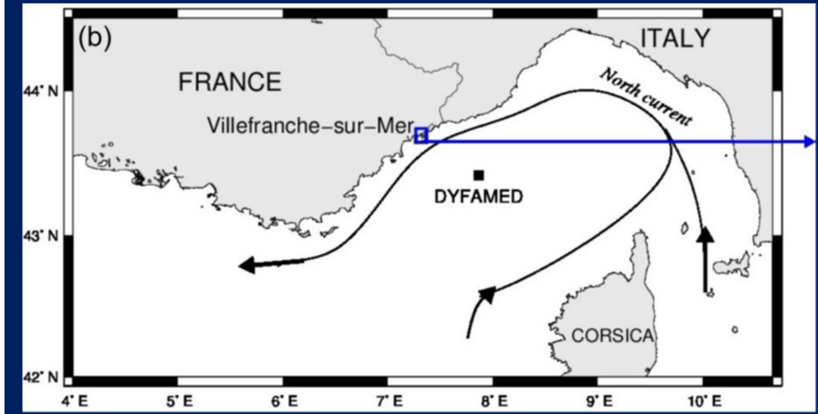


Lampedusa 2006-2019



Area	Salinity	sd	TA µmol kg^{-1}	sd	TCO_2 µmol kg^{-1}	sd	pH_T (25°C)	sd	Ω aragonite	sd
E Mediterranean										
surface	39.1	*0.13*	2612	*10*	2277	*15*	8.01	*0.02*	3.6	*0.1*
deep	38.8	*0.02*	2613	*2*	2306	*3*	7.97	*0.00*	2.7	*0.2*
Atlantic										
surface	36.8	*0.89*	2423	*83*	2166	*83*	7.93	*0.04*	2.7	*0.2*
deep	36.10	0.25	2390	16	2201	6	7.80	0.03	1.9	0.1

from Alvarez et al., Ocean Sci. 2014

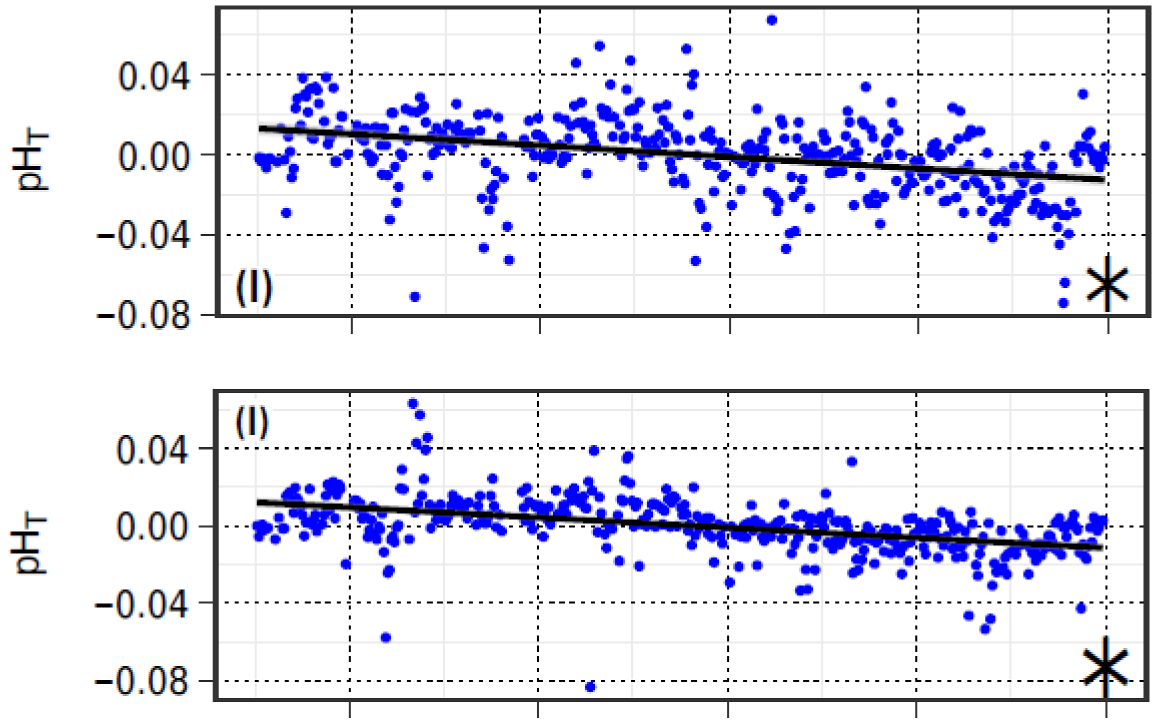


The acidification trend in Mediterranean Sea

pH trend

Point B Villefranche –sur Mer (France)

.



1 m

$\Delta pH_T\ yr^{-1}$: -0.0028 ±0.0003

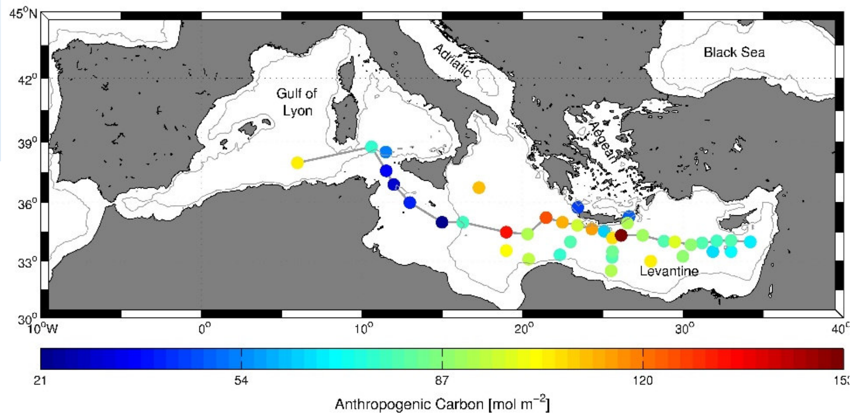
50 m

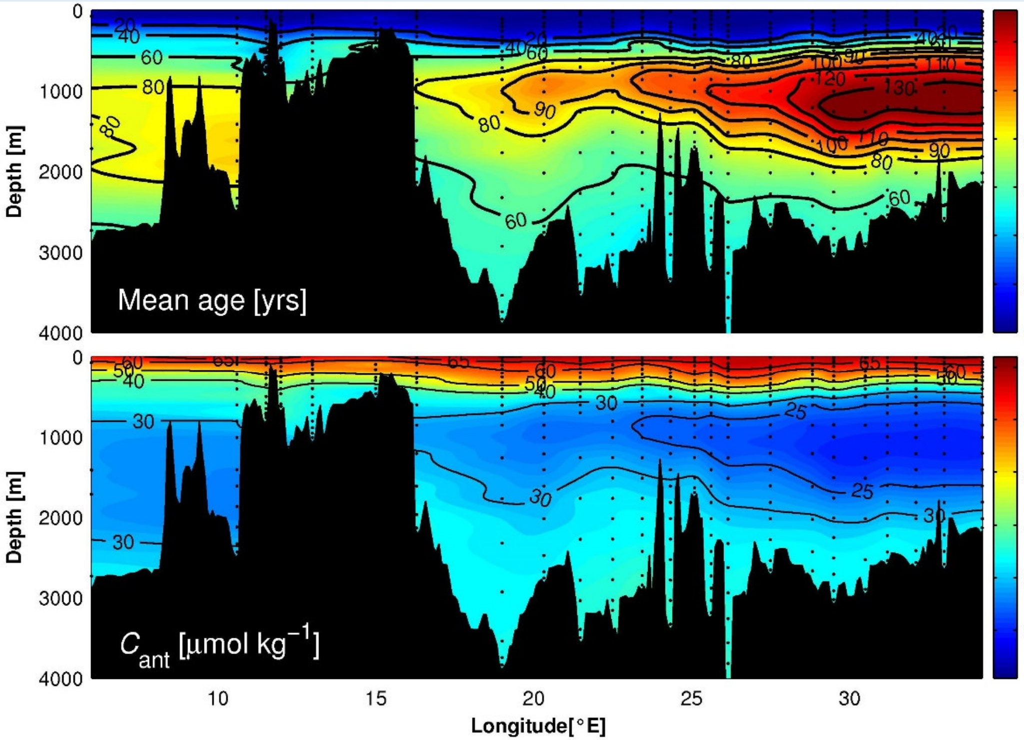
$\Delta\ pH_T\ yr^{-1}$: -0.0026 ±0.0002

2008 2010 2012 2014 2016

da Kapsenberg et al., Ocean Science, 2017

Anthropogenic carbon in the Mediterranean Sea

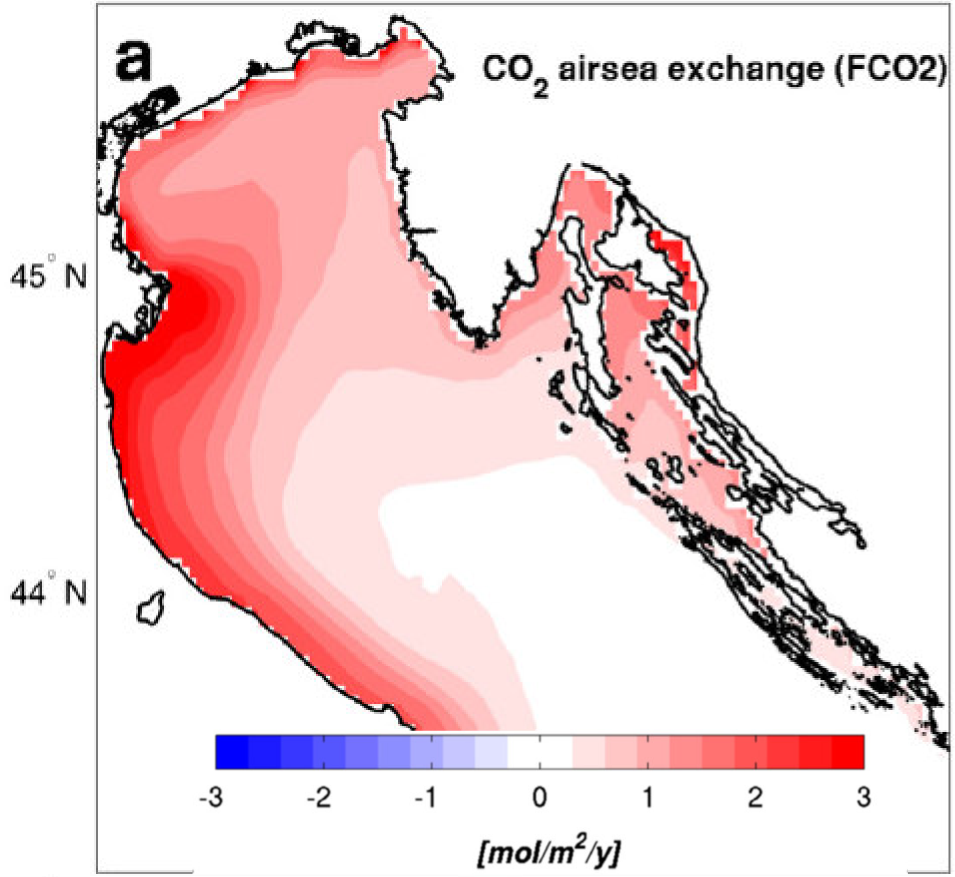


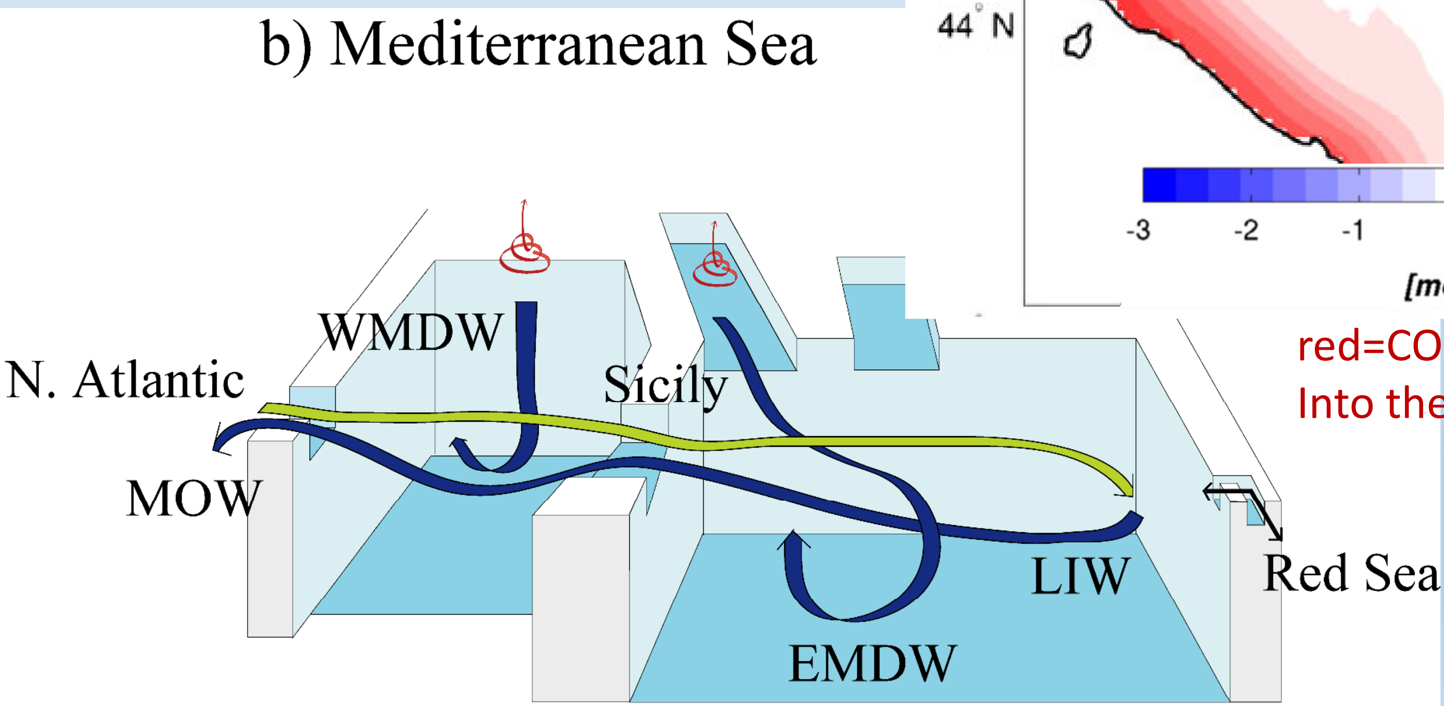


- C_{ant} invaded the whole water column with high quantity: 1.7 PgC
- 0.3% of global volume
- 1.7% of the global C_{ant} quantity

Schneider et al., 2010

Average annual CO_2 flux between air and sea in the north Adriatic

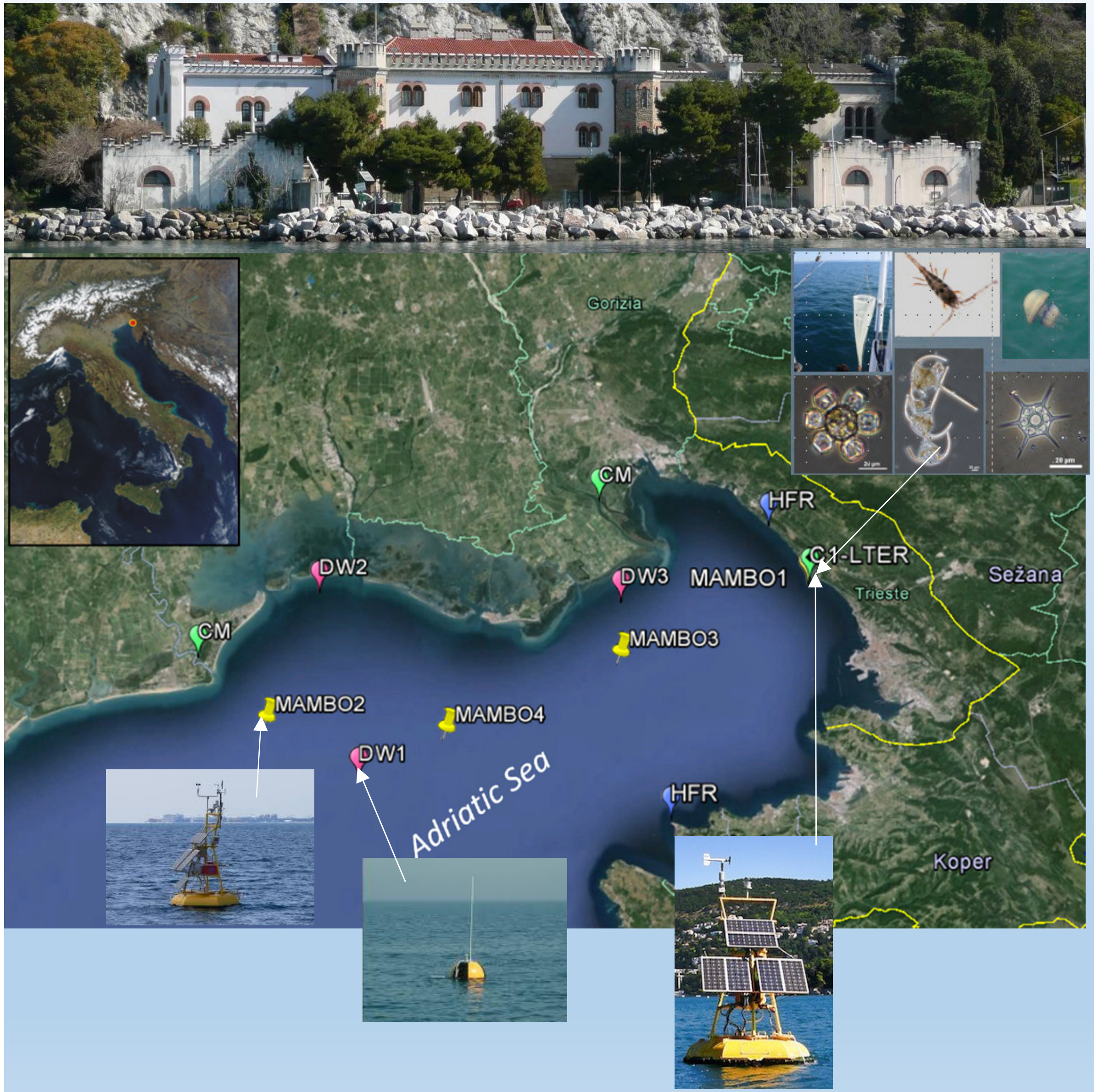




red=CO_2 absorbtion
Into the sea

from Cossarini et al, 2015

Sistema osservativo marino del Golfo di Trieste



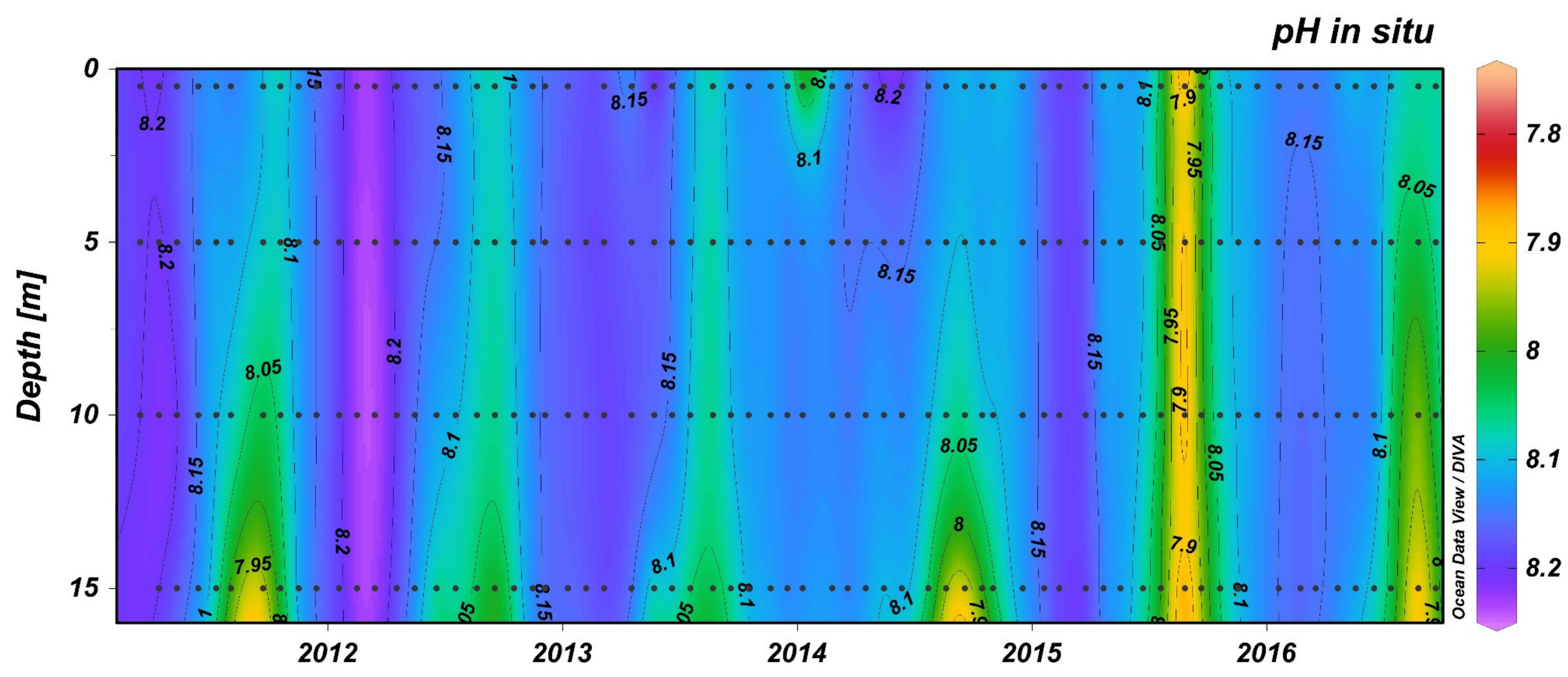
Acqua

Temperatura, salinità (dal 1986)
O2 disciolto (dal 1986)
Nutrienti (dal 1996)
C, N, P organici (dal 1998)
pH , alcalinità (dal 2011)
Clorofilla (dal 1986)
Picoplancton (dal 1993)
Nanoplancton (dal 1998)
Microfitoplancton (dal 1986)
Microzooplancton (dal 1986)
Mesozooplancton (dal 1986)
Prod. Primaria (dal 1998)
Prod. Secondaria (dal 1998)
Attività esoenzimatiche (dal 1998)

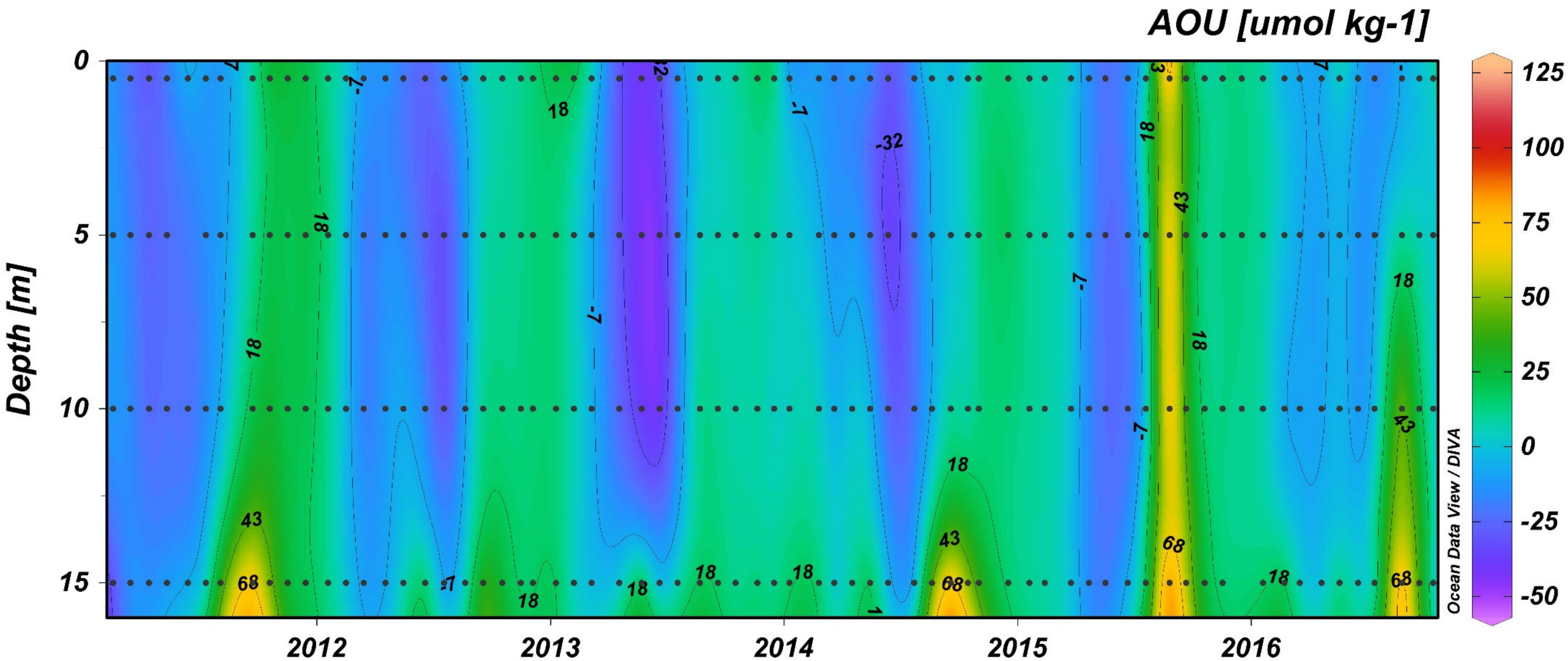
Sedimento

Microfitobenthos (dal 2002)
Meiobenthos (dal 2002)
Macrozoobenthos (dal 2002)
Prod. Primaria (dal 2002)
Respirazione (dal 2010)
Prod. secondaria (dal 2010)
Attività esoenzimatiche (dal 2010)

Variazioni interannuali del pH nell' AMP di Miramare 2011-2016

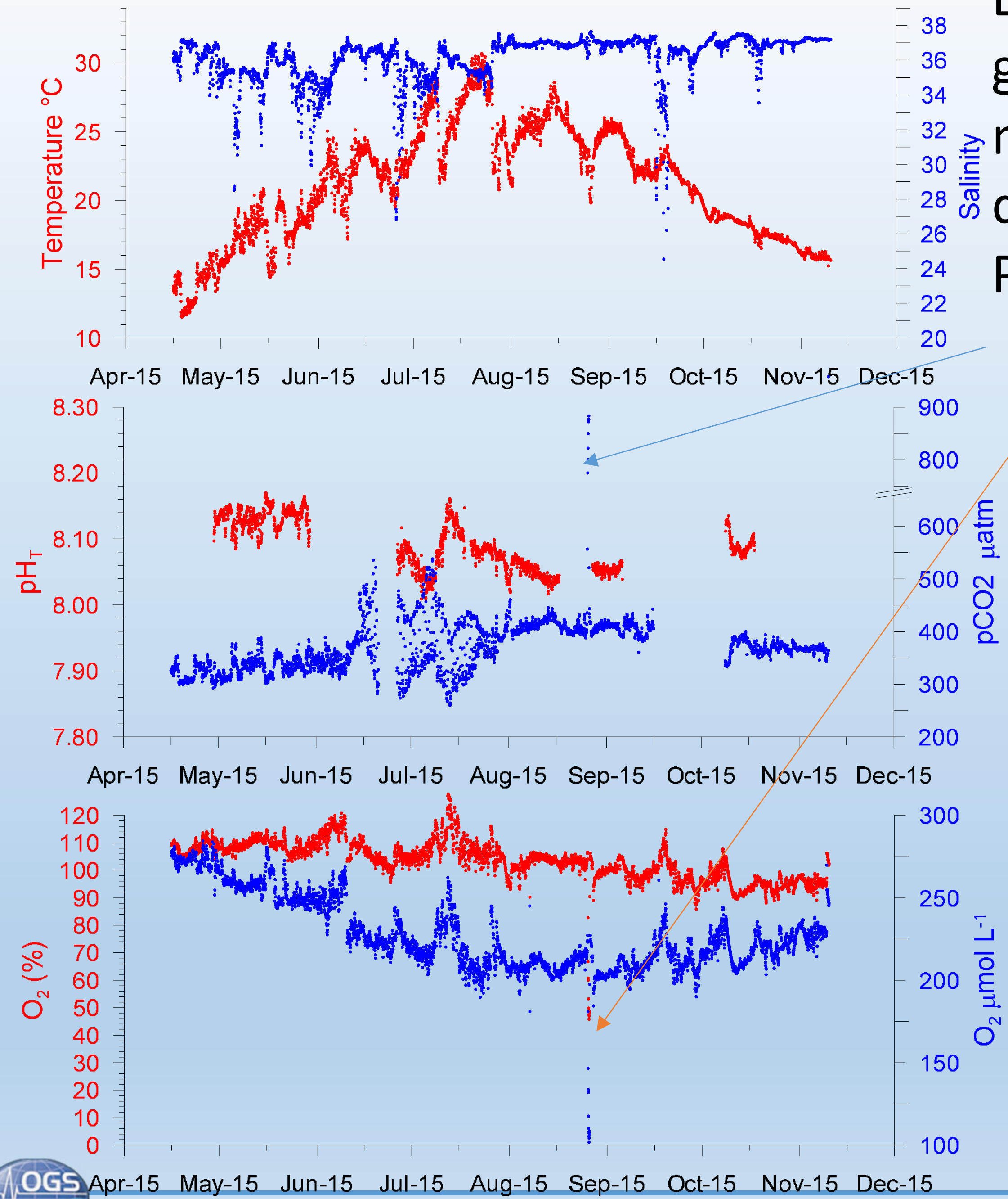


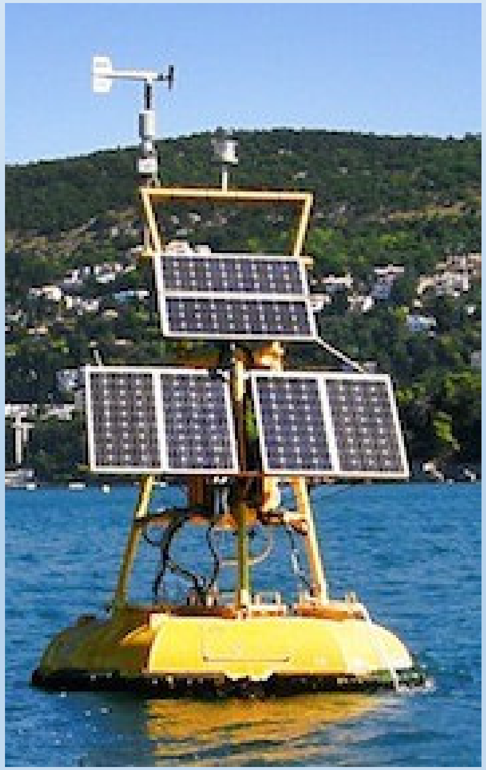
Variazioni interannuali del consumo apparente di ossigeno nell' AMP di Miramare -C1



Evento di ipossia nel golfo di Trieste nell'estate 2015 rilevato dai sensori Posti sulla boa MAMBO

aumento CO_2
e diminuzione O_2

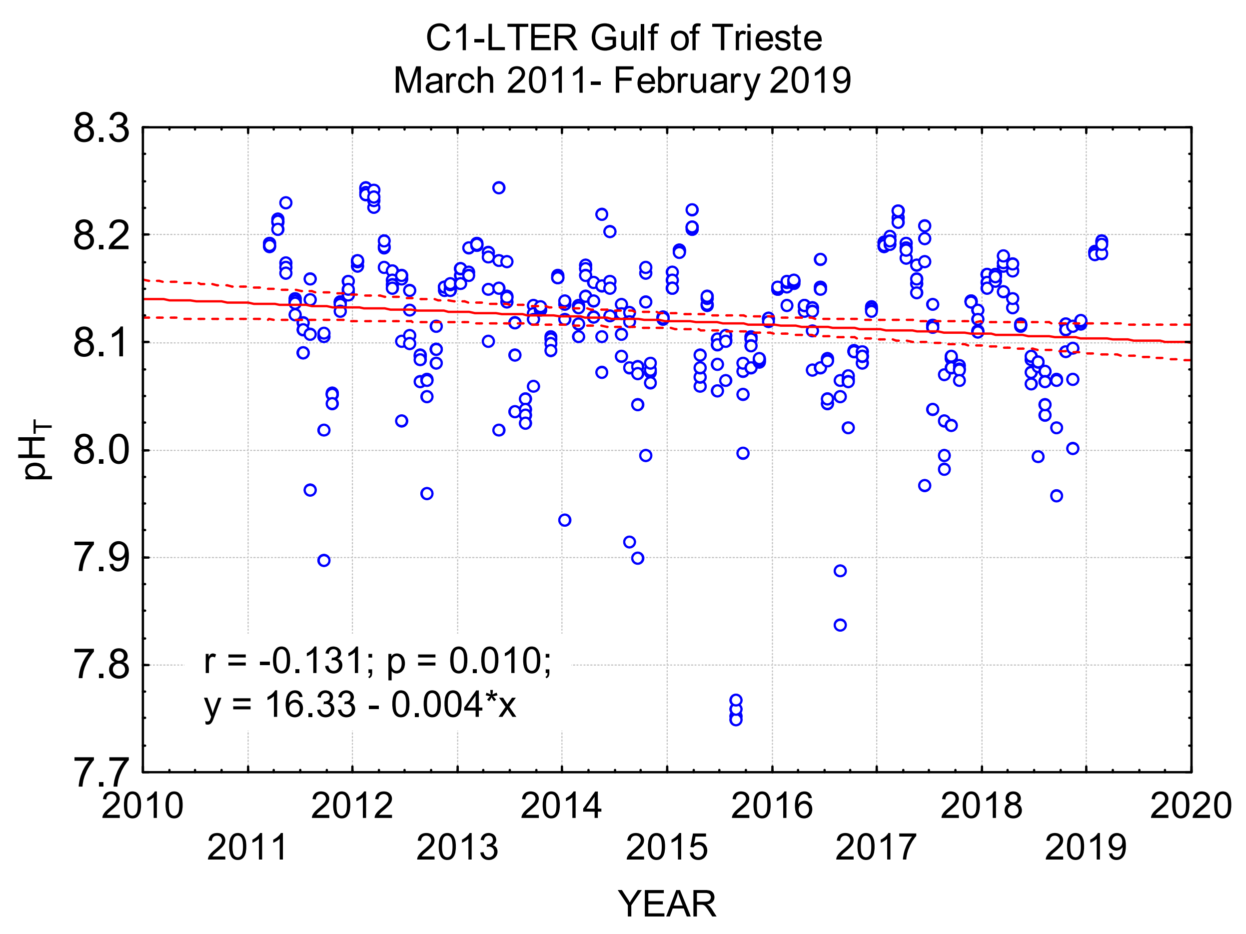




Trends nel pH

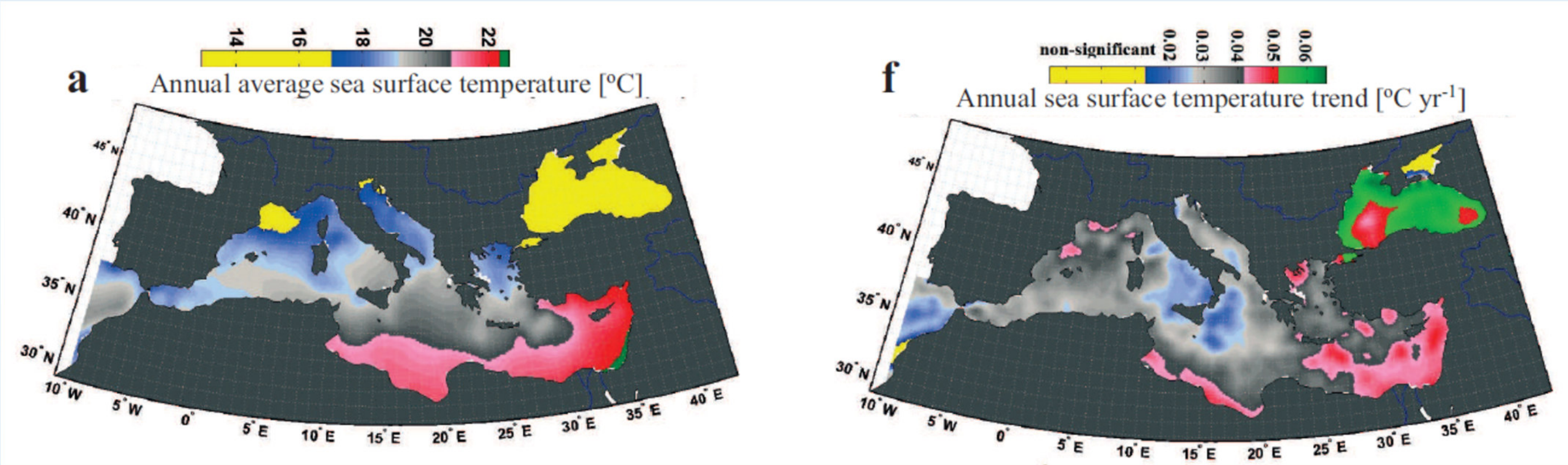
2011-2019

AMP Miramare - C1



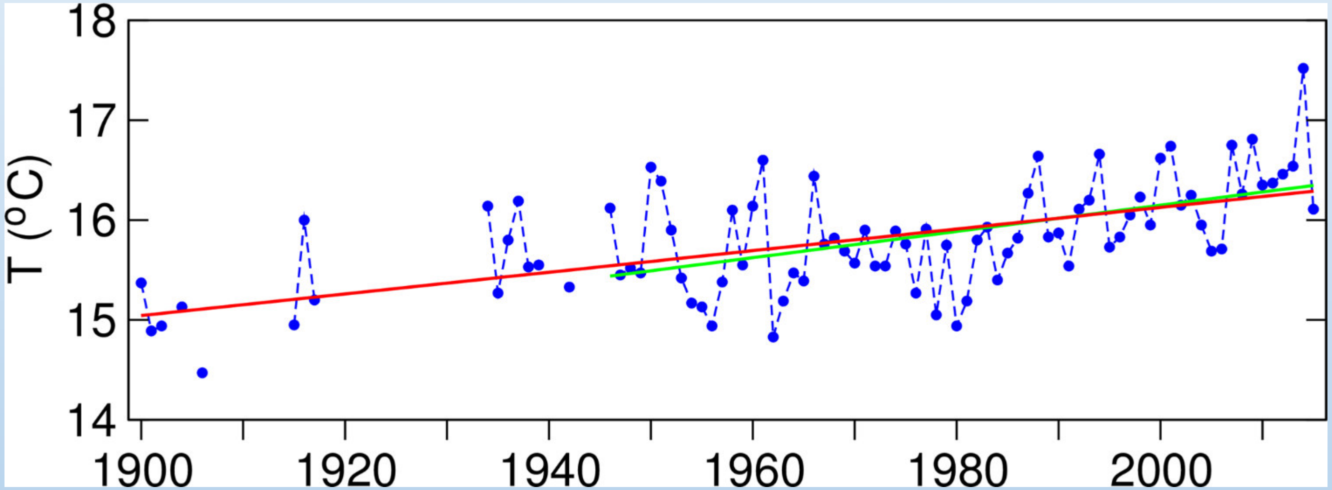
Riscaldamento delle acque superficiali

Il Mediterraneo si sta riscaldando di 0.35°C per decade (1982-2012),
con un trend nella variabilità stagionale che risulta massimo in primavera



Shaltout & Omstedt, 2014

Annual mean sea temperature at 2 m depth for 1899 to 2015 (blue dots and dashed curve) and linear trend for 1899 to 2015 (red line) and for 1946-2015 (green line).
Gulf of Trieste



1.3±0.5◦C/100yr

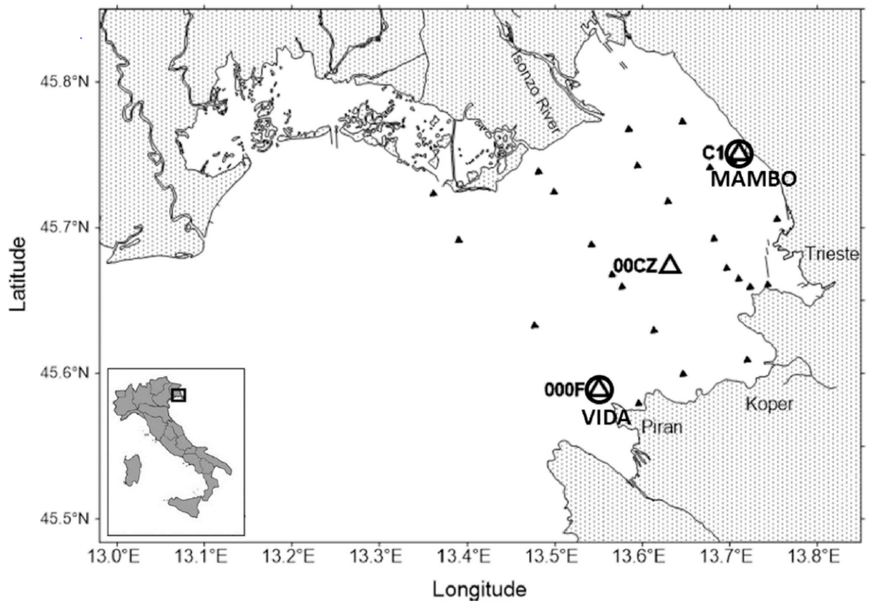
1.1±0.3◦C/100 yr

From Raicich & Colucci, Earth Syst. Sci Data, 2019

Seawater warming in the water column in the Trieste gulf

Linear regression between Temperature, Dissolved Oxygen (DO), Apparent Oxygen Utilization (AOU), Salinity, Chlorophyll a, and Period during August-September-October. Values in bold are considered as statistically significant.

Parameter (unit)	Station	Depth (m)	p	r	Slope (unit y^{-1})	Period (years)
Temperature (°C) *	00CZ	< 20	0.050	0.103	0.032	1989-2016
	00CZ	< =5	0.105	0.111	0.034	1989-2016
	00CZ	> =24	0.061	0.183	0.039	1989-2016
	000F	< 20	0.001	0.145	0.038	1983-2016
	000F	< =5	0.040	0.126	0.033	1983-2016
	000F	> =21	0.009	0.201	0.031	1983-2016
	C1	< =15	0.000	0.084	0.023	1986-2016
	C1	< =5	0.034	0.052	0.016	1986-2016



From Kralj et al. Deep Sea Res, 2019

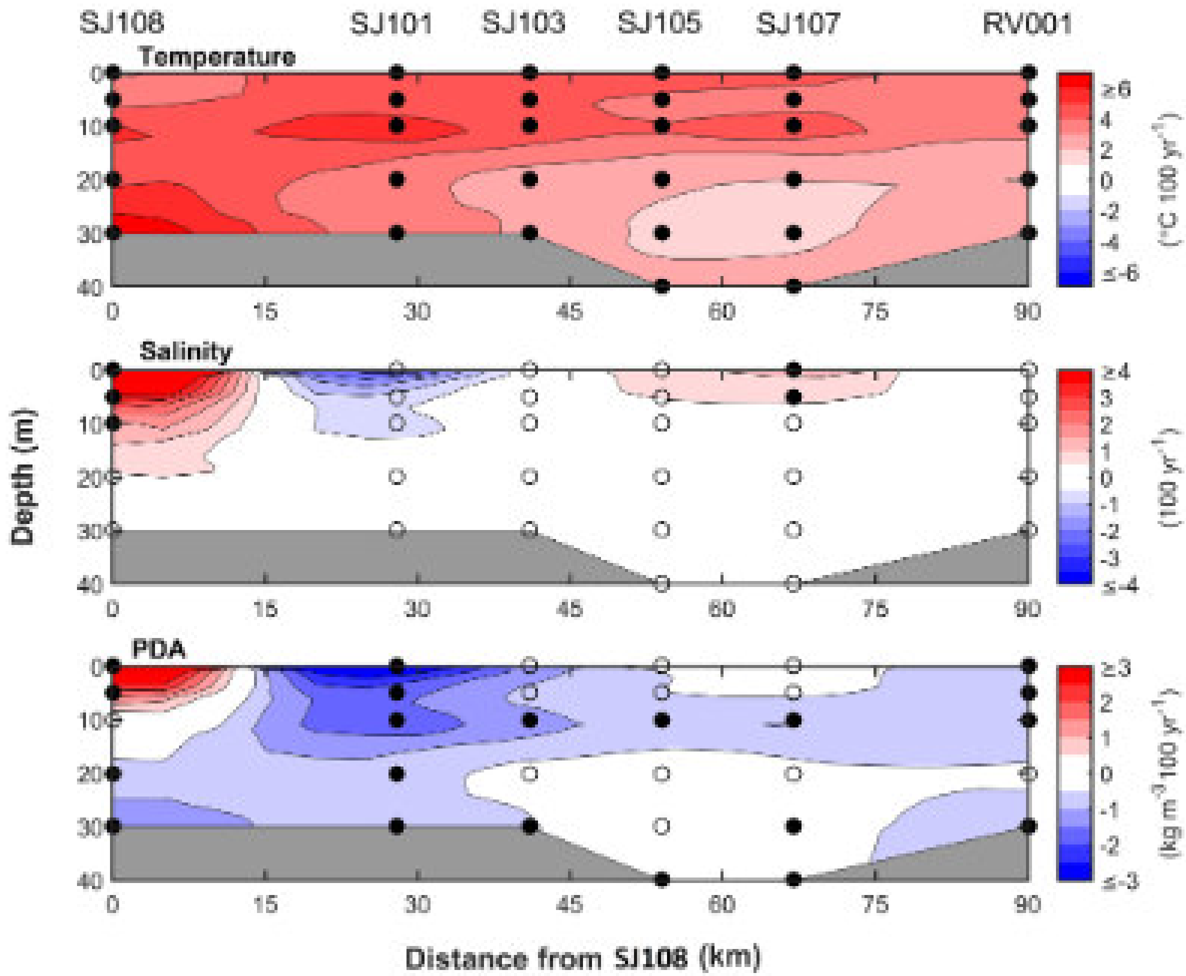
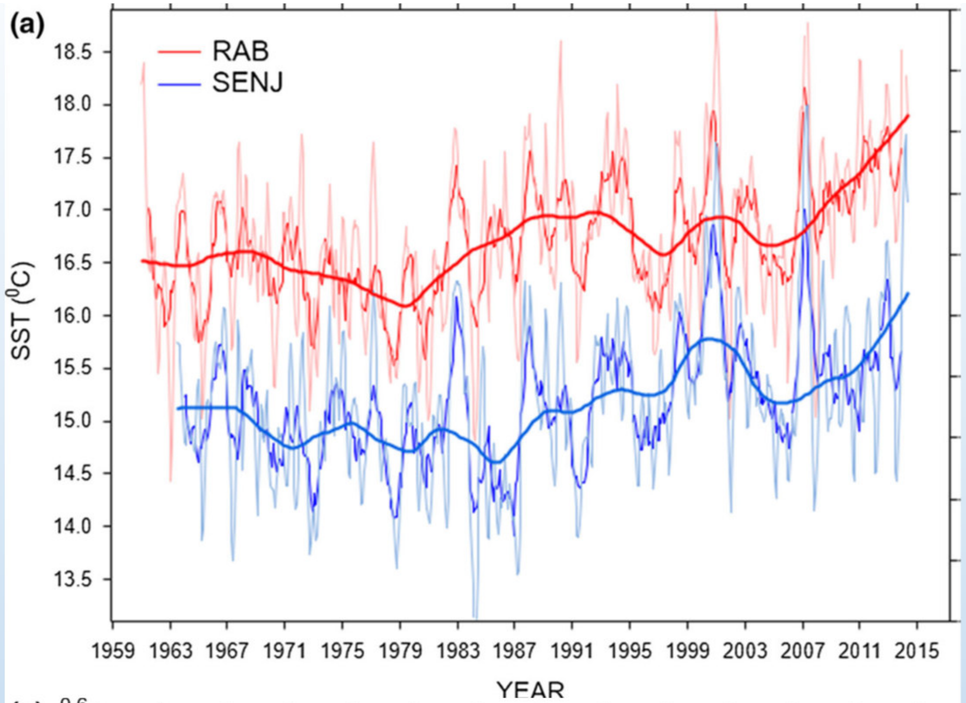
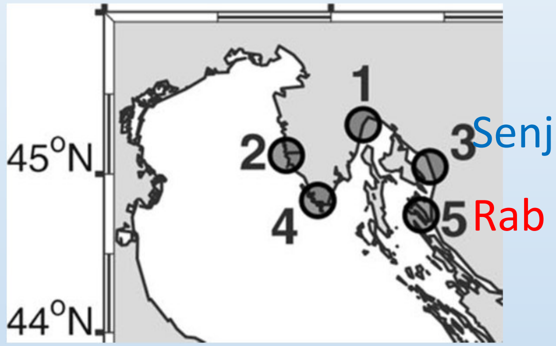


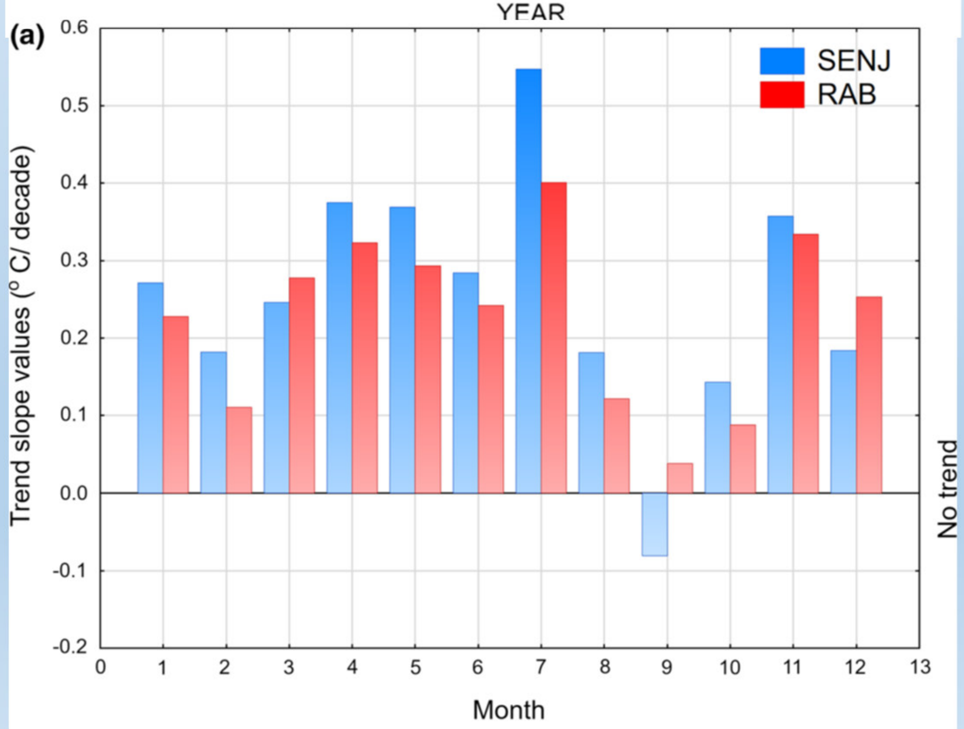
Figure 8. Annual trends in residual temperature, salinity and PDA. Filled circles denote trends with a significance level of 95 %.

From Vilibic et al., Ocean Sci., 2019



Mean monthly sea surface temperature for northern stations Rab and Senj



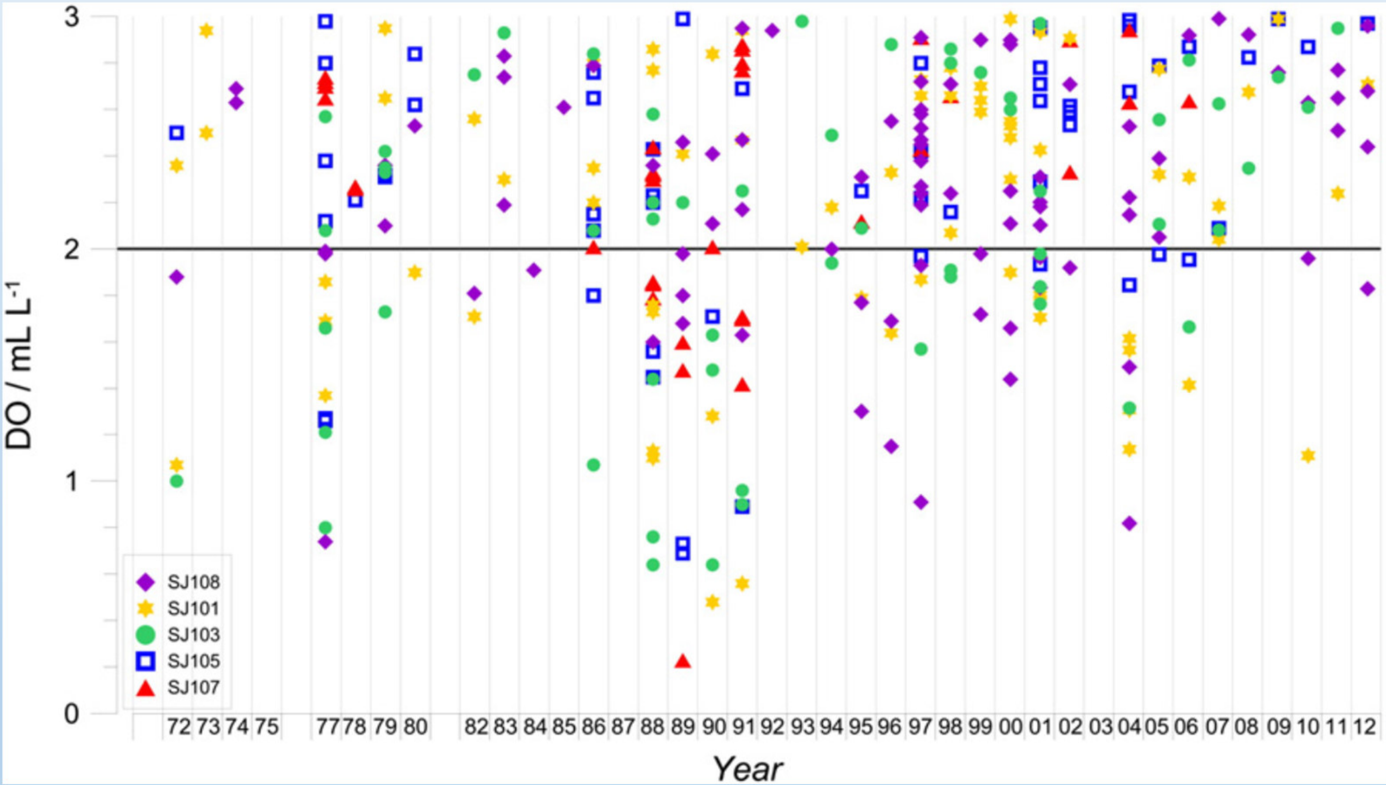


Monthly linear SST trends
for the warming period 1979–2015 at:

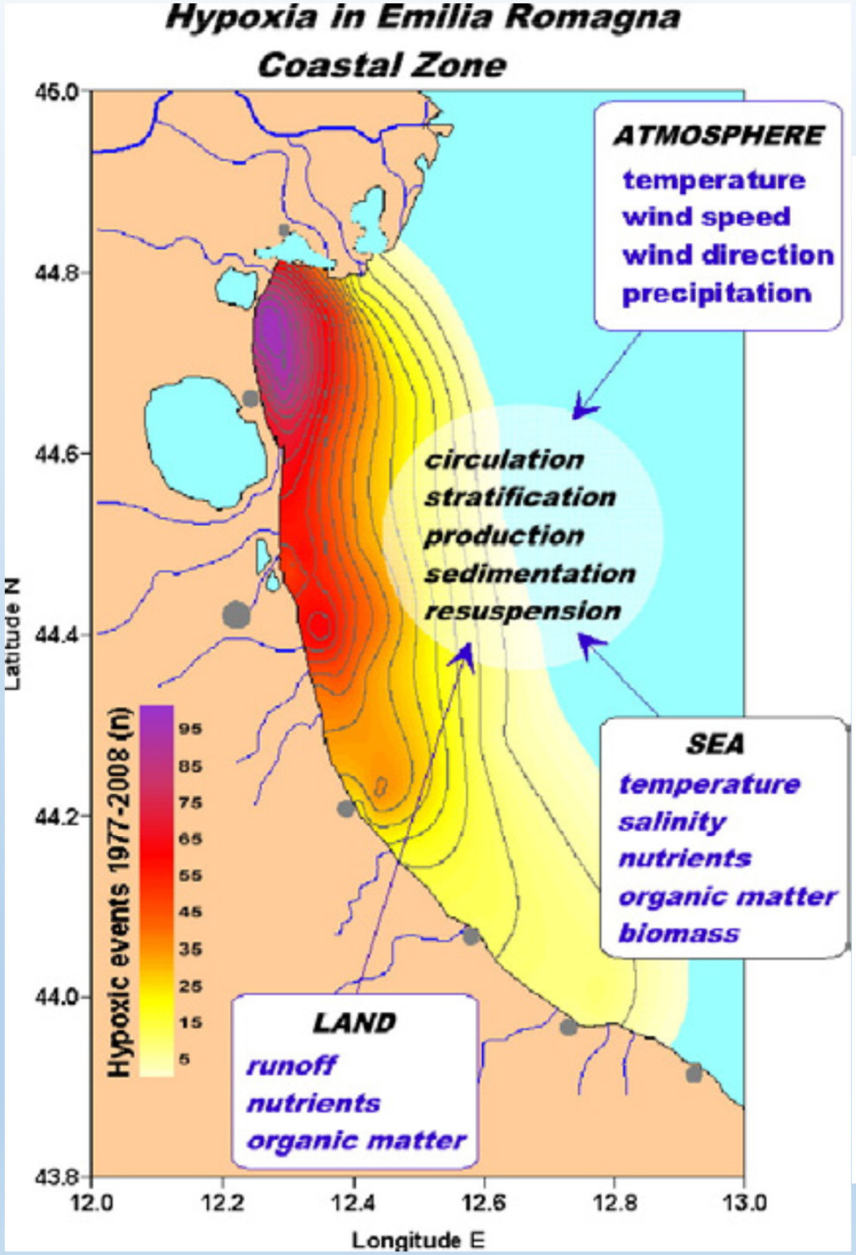
Senj (+0.293 °C/10 yr)
and
Rab (+0.226 °C/10 yr)

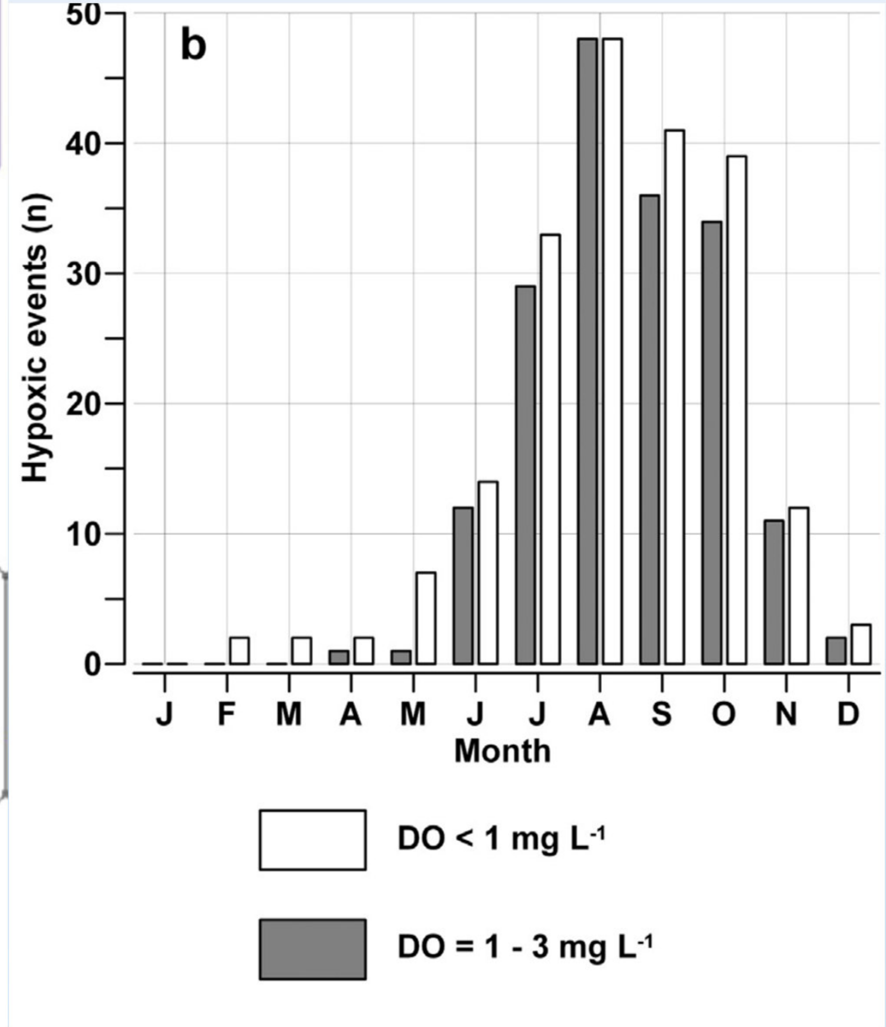
From Grbec et al., Pure Appl. Geophys., 2018

Hypoxia in bottom waters of the Northern Adriatic Sea



From Djakovac et al. J. Mar. Sys 2015





Alvisi & Cozzi, Sci. Tot. Environ., 2016

Quale futuro ?

- E' molto difficile prevedere i trend negli apporti di acque dolci
- C'e' un surplus di N che dovrebbe essere ridotto (lo sbilanciamento N/P è in aumento)
- Sembra che la P limitazione continui a mantenere un trend di diminuzione della clorofilla
- Il riscaldamento nel NAd è significativo non solo nelle acque superficiali ma fino a più di 20 m e ciò avrà effetti sulle attività metaboliche degli organismi, sulle abbondanze delle specie plantoniche, sui periodi di fioritura
- Increasing stratification? Effects on overturning of bottom waters?
- Trend di diminuzione degli eventi ipossici nelle acque aperte
- Deossigenazione dovuta all'aumento delle temperature
- Acidificazione dovuta alla dissoluzione delle CO_2 dall'atmosfera
- Specie invasive che possono avere impatti rilevanti su alcuni livelli della rete trofica (ad es Mnemiopsis leiidyi)

Considerazioni finali

Il Nord Adriatico ed il golfo di Trieste sono soggetti a molteplici effetti dei cambiamenti climatici e di crescenti pressioni antropiche.

Sebbene i trends di alcune variabili e di alcune pressioni siano prevedibili (T, S, CO2,..) altre non lo sono (ad es.: sviluppo di specie non indigene, incremento delle specie algali potenzialmente tossiche, prolungati periodi di siccità, eventi meteorologici estremi,…).

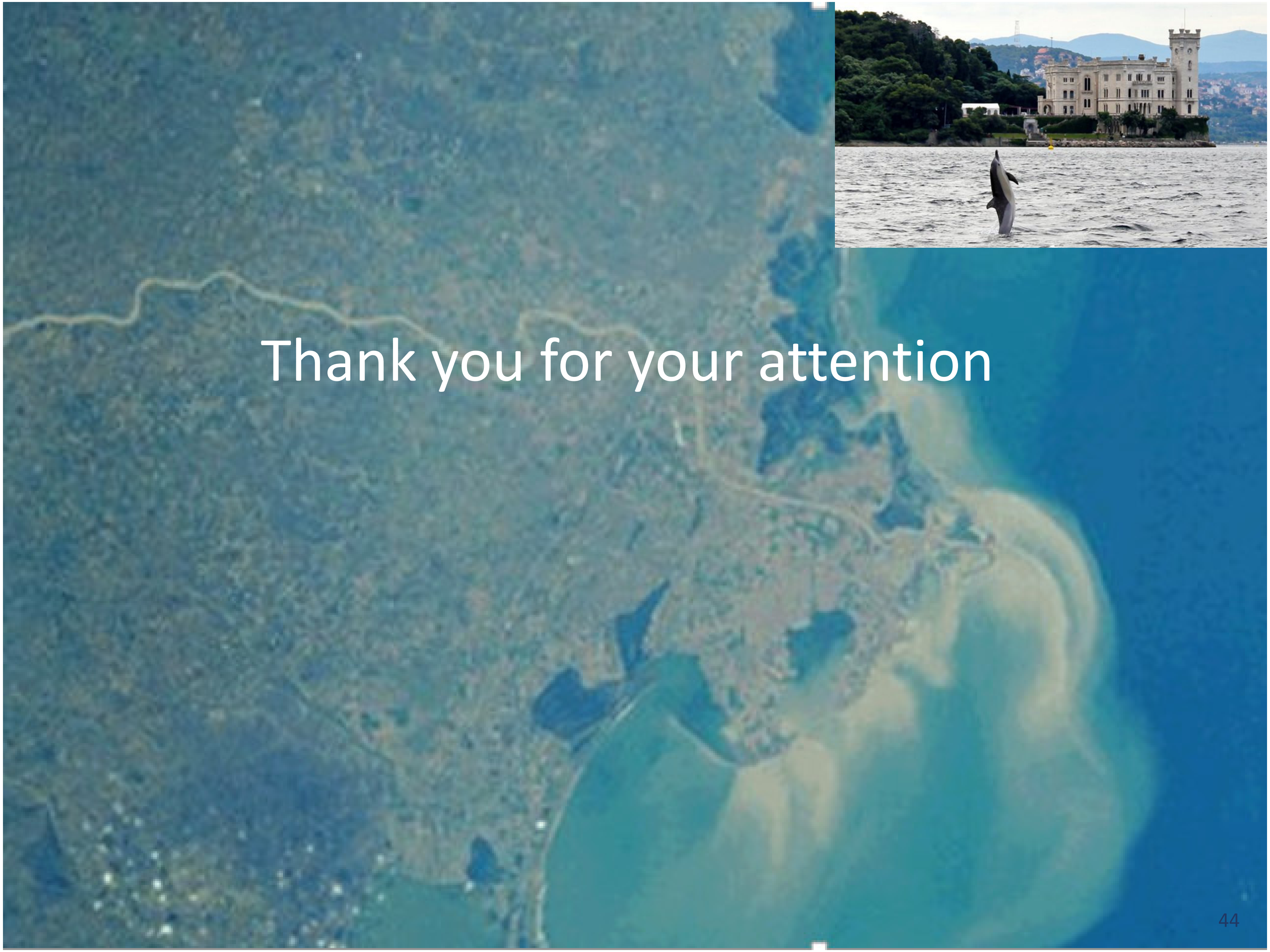
L’interazione tra i diversi fattori fisici, chimici e biologici, viene integrata in modelli ecologici sempre più complessi, ma non si può prescindere da un sistema osservativo (complesso ed integrato) che fornisca risultati utili per comprendere sempre meglio, sulle appropriate scale spazio-temporali, i processi che governano gli ecosistemi marini.
Prevedere l’evoluzione dello stato trofico del Nord Adriatico considerata la sua complessità e variabilità e molto ambizione e richiede grandi sforzi coordinati e multidisciplinari protratti sul lungo periodo.

Ringraziamenti

- **Ministry of Science, Education and Sport of the Republic of Croatia projects 0982705-2731 and 0982705-2707.**
- **EC INTERREG III projects,**
- **Joint Italian–Croatia–Slovenian Commission for the Protection of the Adriatic**

Sea (ASCOP Project),

- **Alpe Adria project on mucilages,**
- **MAT(Mucilages in the Adriatic and Tyrrhenian seas) project, financed by**
- **the Italian Ministry of the Environment**
- **Croatian–USA collaboration (granted by NSF and Smithsonian Institute).**
- **PERSEUS FP7 project**
- **ARPA Emilia Romagna**
- **Autorità di bacino del Fiume Po**
- **ISTAT**
- **GOS ISAC CNR Rome & ISMAR-CNR Ancona**
- **Crews of Vila Velebita**



Thank you for your attention

Conclusions

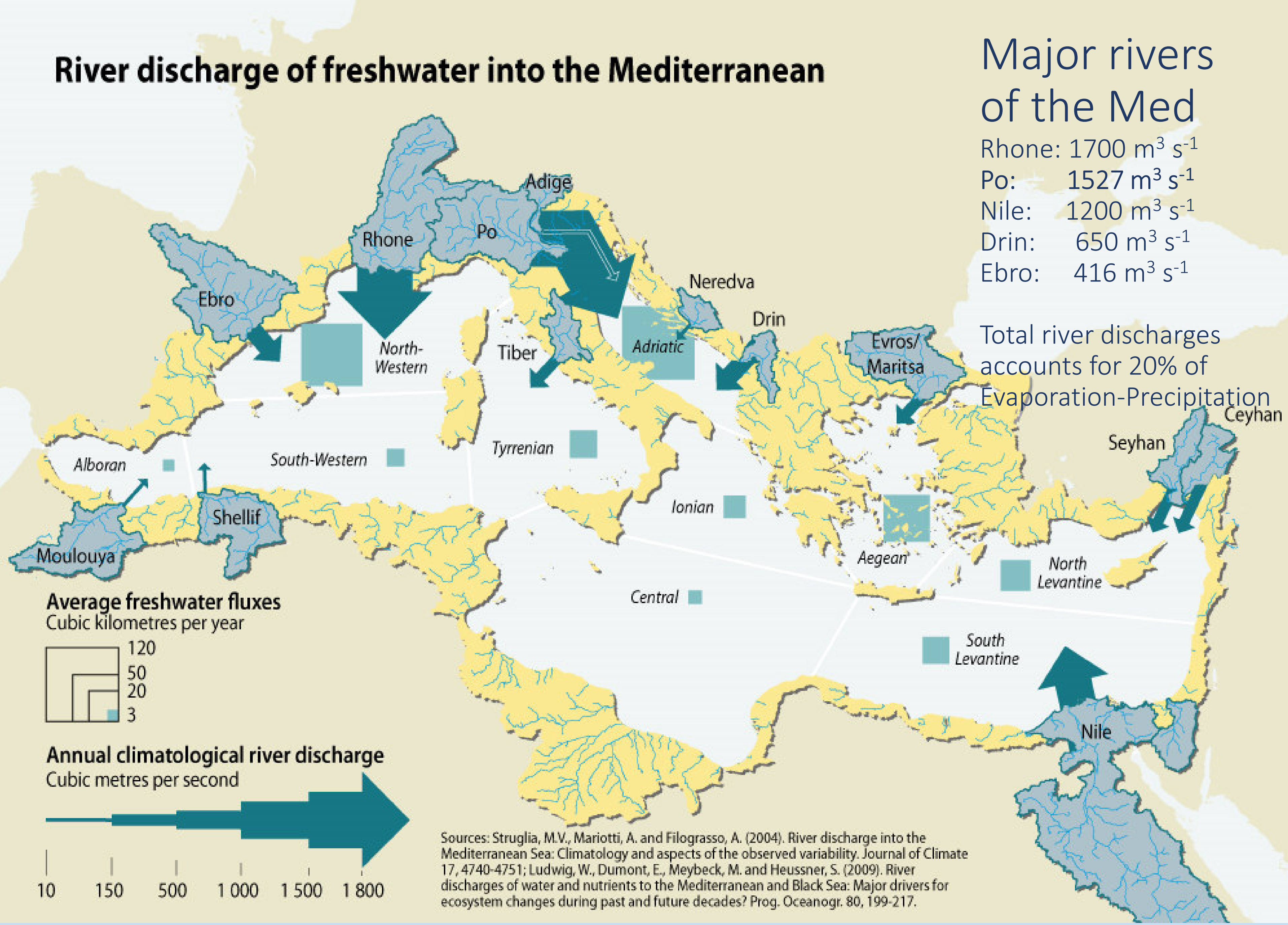
- Po river discharge show **strong multidecadal variations**: in the last 40y there was a slight decreasing trend (not significant on a longer time scale)
- Po river frewshwater discharges show **variations in the seasonal regime** with lower discharge in the summer, anticipation of spring peak, and more intense freshets in spring and autumn
- The lower summer discharges are strongly related to the negative phase of WMOI (High pressure over Italy)
- Strong changes in the freshwater and nutrients discharges occurred in the last 4 decades:

Po nutrients loads **P** ⇩ **NO_3 =** **NH_4**⇩ **N/P**⇧

The reduction of P consumption in agricolture seems to be one of the causes together with P ban in detergents, of the decrease of PO_4 load in Po river

These variations were quite well correlated with the variations in seawater

NAd concentrations **PO_4** ⇩ **NO_3**⇧ **N/P**⇧

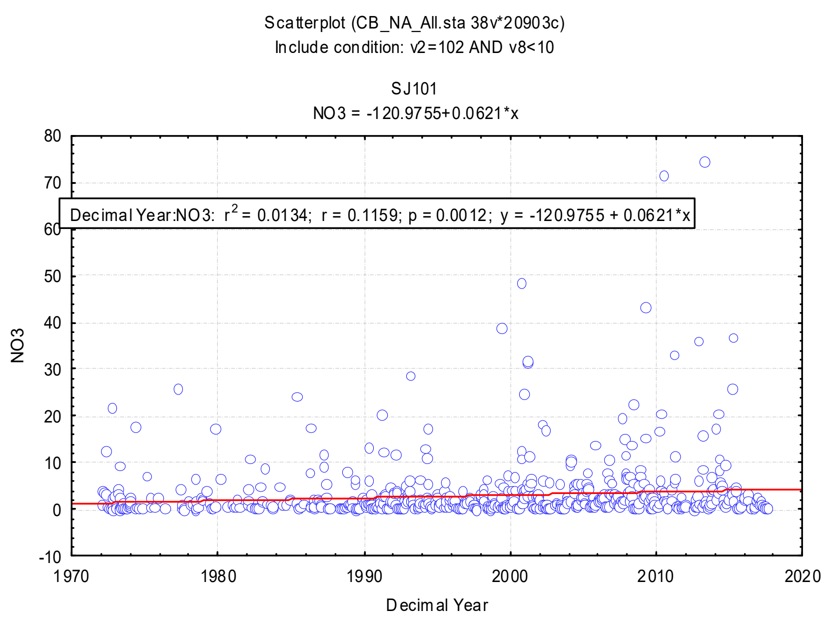


Major rivers of the Med

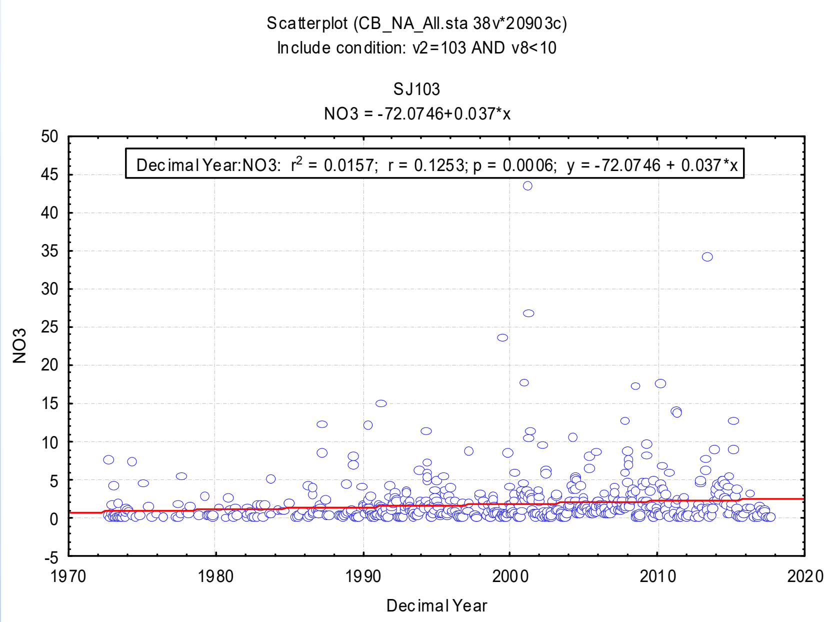
Rhone: 1700 $m^3\ s^{-1}$
Po: 1527 $m^3\ s^{-1}$
Nile: 1200 $m^3\ s^{-1}$
Drin: 650 $m^3\ s^{-1}$
Ebro: 416 $m^3\ s^{-1}$

Total river discharges accounts for 20% of Evaporation-Precipitation

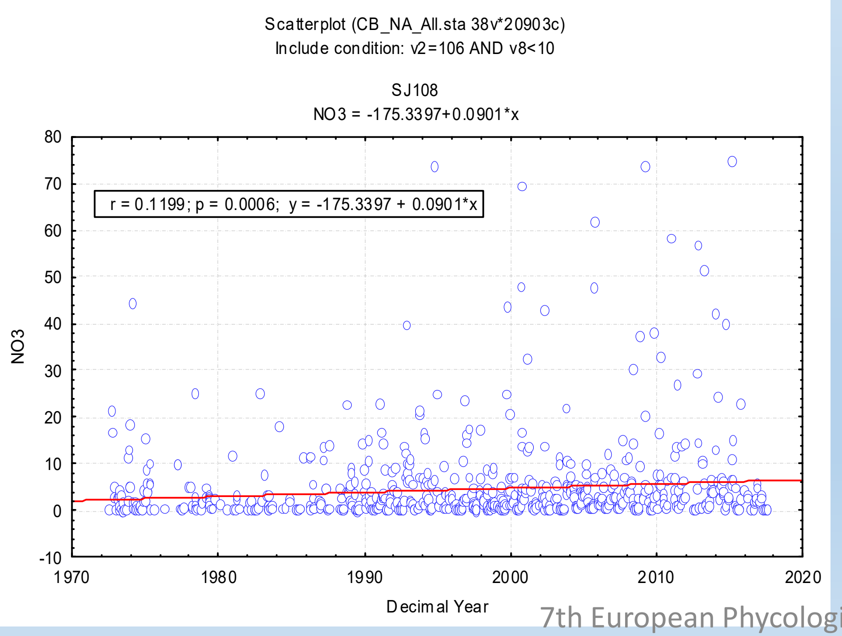
Credit: UNEP 2012



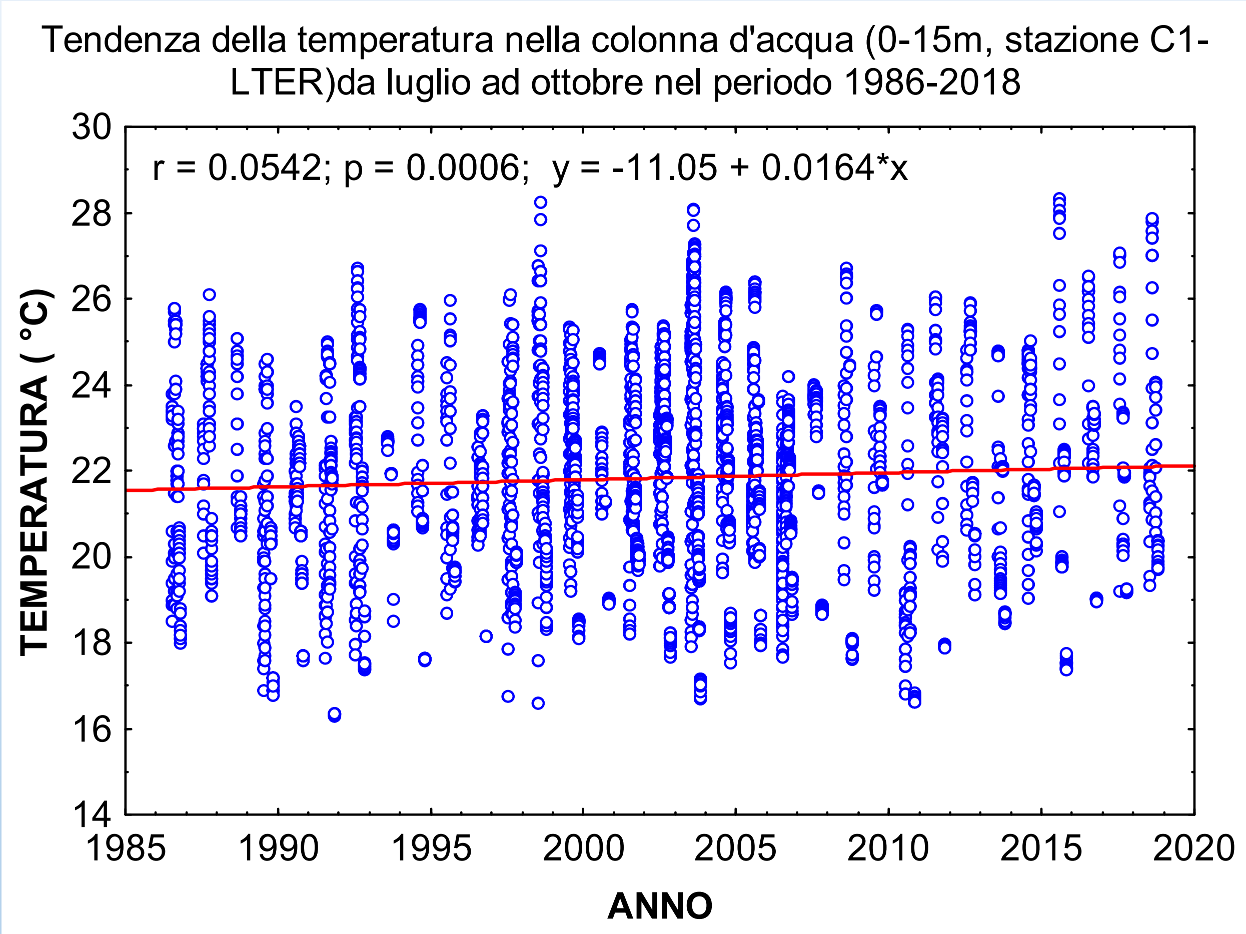
Scatterplot (CB_NA_All.sta 38v*20903c)
Include condition: v2=102 AND v8<10
SJ101
NO3 = -120.9755+0.0621*x
Decimal Year:NO3: r2 = 0.0134; r = 0.1159; p = 0.0012; y = -120.9755 + 0.0621*x
NO3
Decimal Year

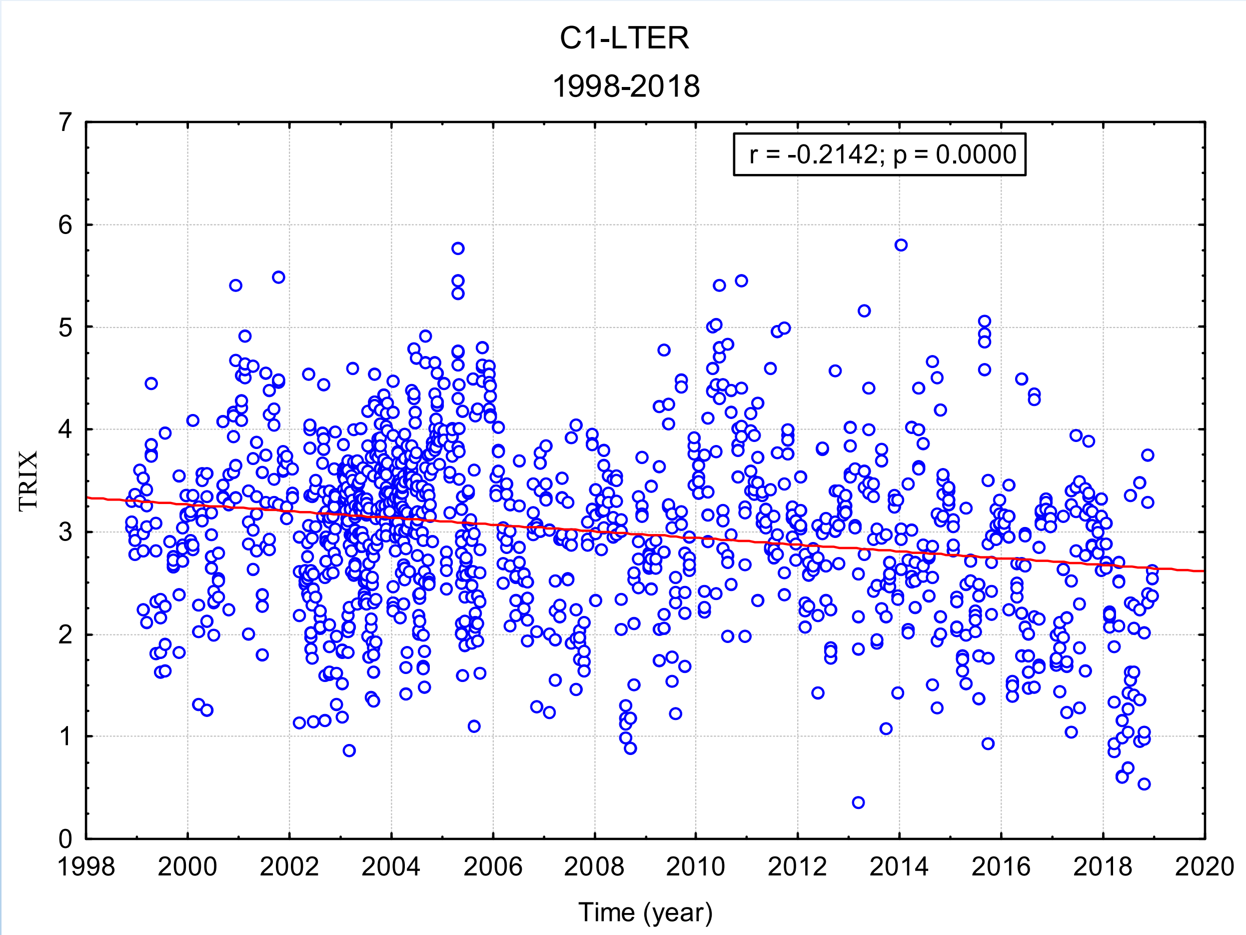


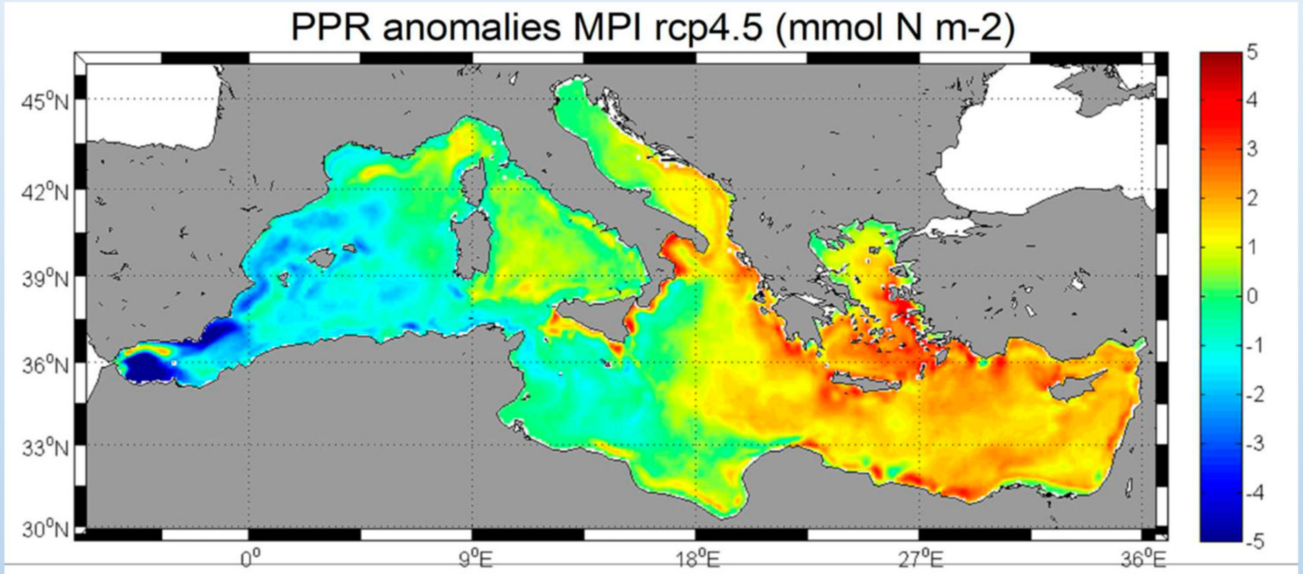
Scatterplot (CB_NA_All.sta 38v*20903c)
Include condition: v2=103 AND v8<10
SJ103
NO3 = -72.0746+0.037*x
Decimal Year:NO3: r2 = 0.0157; r = 0.1253; p = 0.0006; y = -72.0746 + 0.037*x
NO3
Decimal Year



Scatterplot (CB_NA_All.sta 38v*20903c)
Include condition: v2=106 AND v8<10
SJ108
NO3 = -175.3397+0.0901*x
r = 0.1199; p = 0.0006; y = -175.3397 + 0.0901*x
NO3
Decimal Year


Tendenza della temperatura nella colonna d'acqua (0-15m, stazione C1-LTER)da luglio ad ottobre nel periodo 1986-2018
r = 0.0542; p = 0.0006; y = -11.05 + 0.0164*x
TEMPERATURA (°C)
30
28
26
24
22
20
18
16
14
1985
1990
1995
2000
2005
2010
2015
2020
ANNO

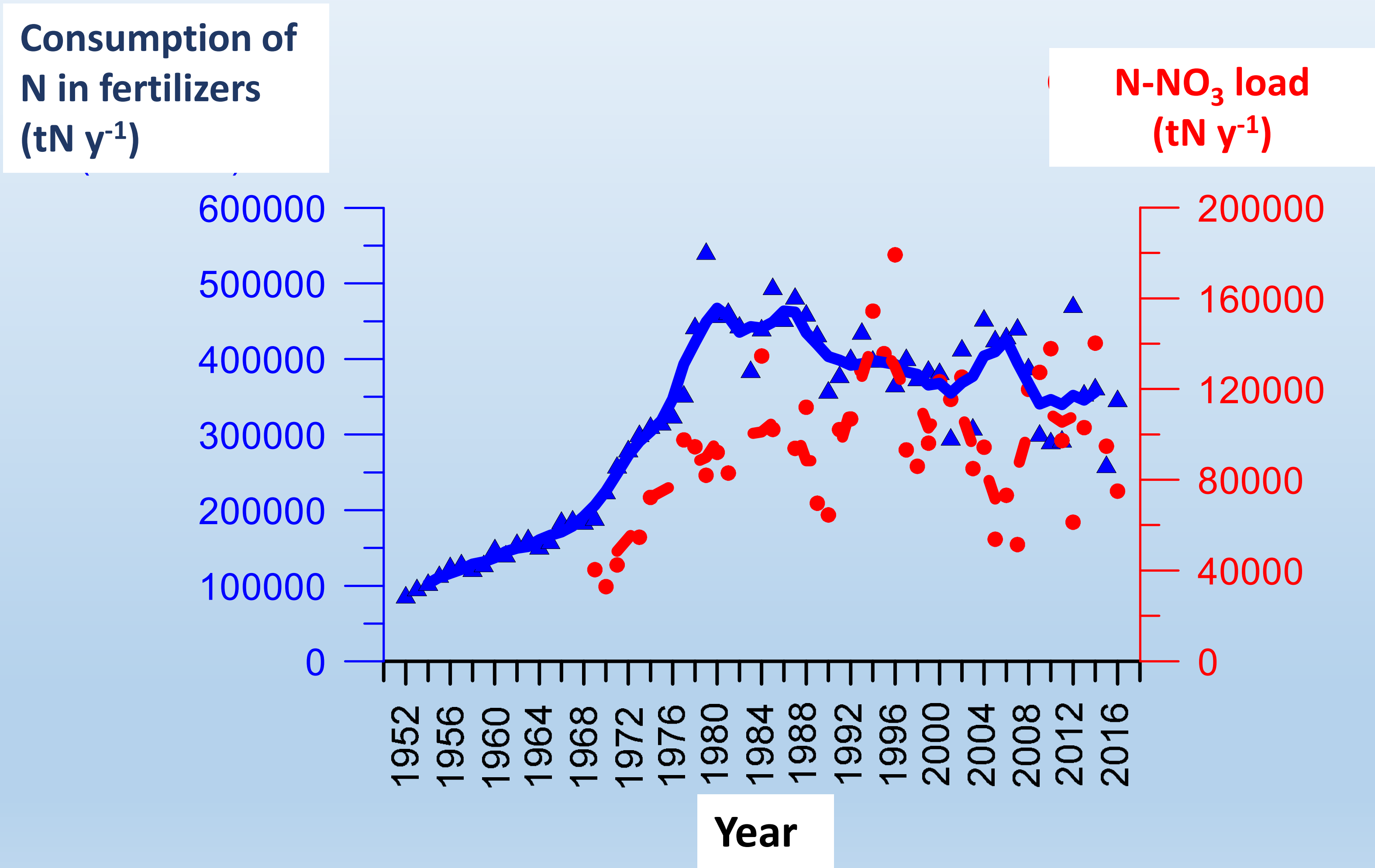

C1-LTER
1998-2018
r = -0.2142; p = 0.0000
TRIX
Time (year)
0
1
2
3
4
5
6
7
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020



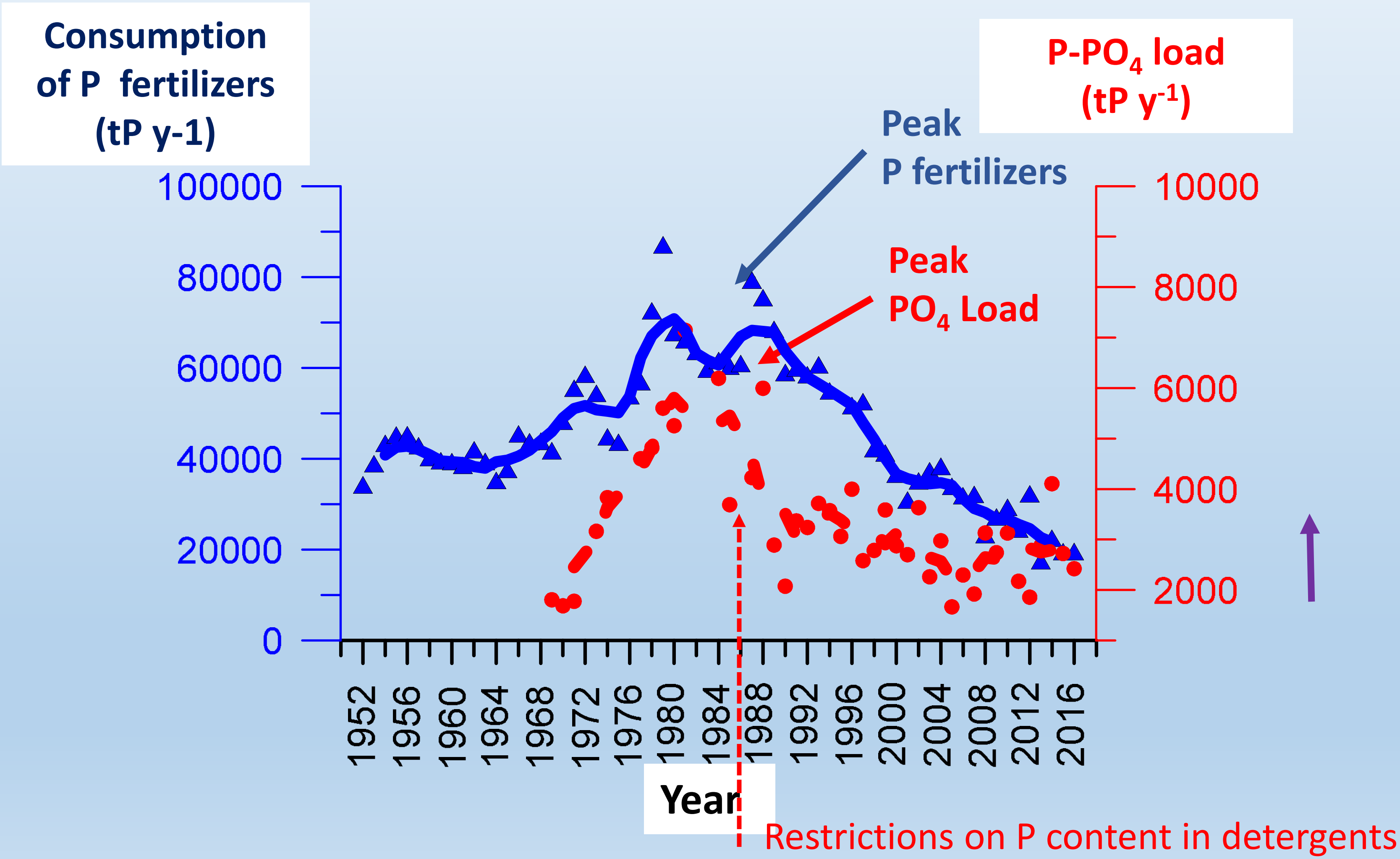
Spatial maps of Primary Productivity Rates, PPR, anomalies (mean from 2095 to 2099 minus 2015-2019) for the scenario runs.(A)
MPI, rcp45.5

From Macias et al. 2015

Consumption of N fertilizers (blue line) in the Po River watershed and NO_3 load (red dots) transported by Po River



Consumption of P fertilizers (blue line) in the Po river watershed and P-PO_4 load (red dots) transported by Po river



P-PO_4 load from Po Rivers vs P in fertilizers consumed in Po valley