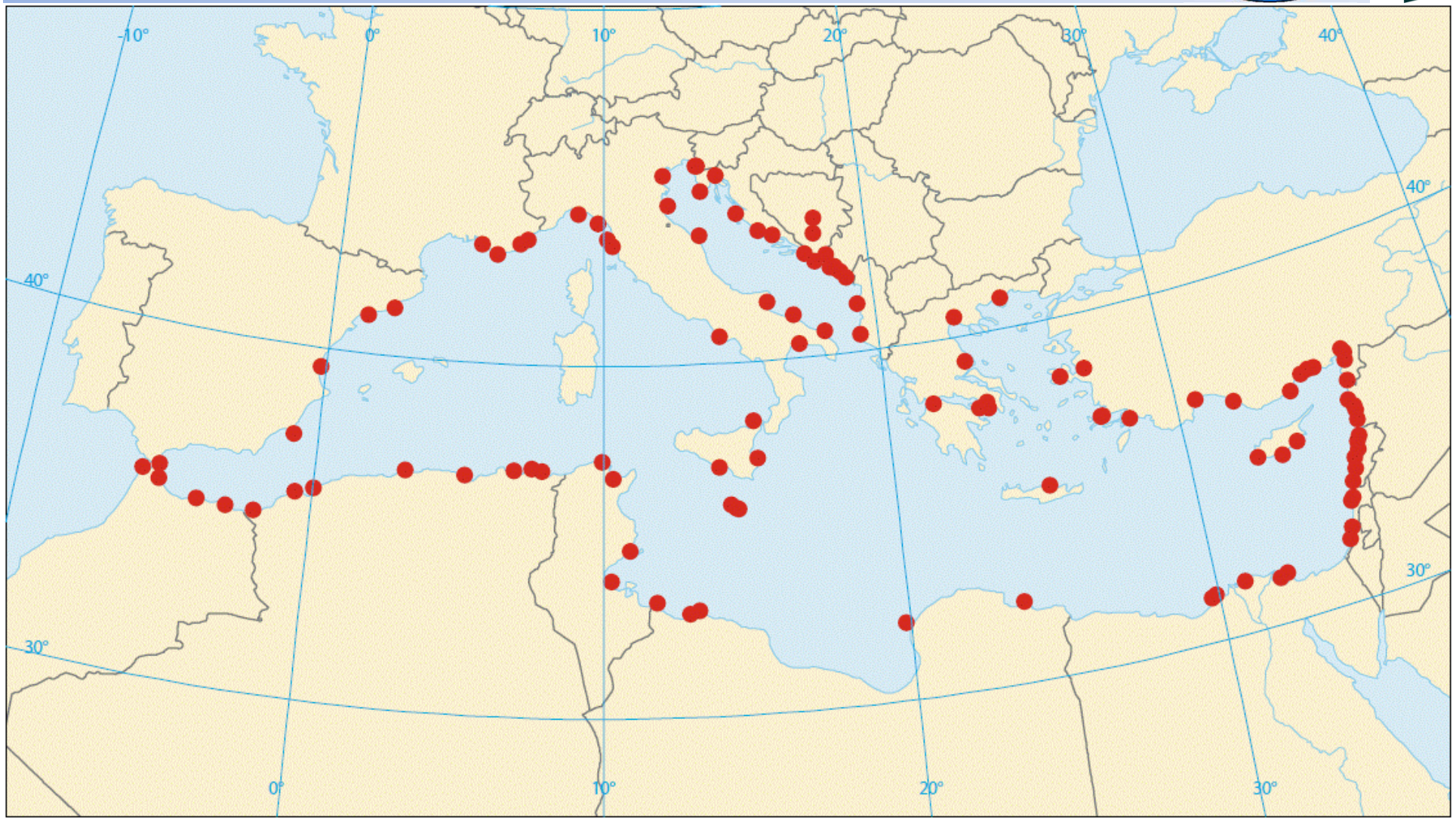
Liège, December the 12th

Coastal pollution of the Mediterranean and extension of its biomonitoring to trace elements of emerging concern

Dissertation presented by **Jonathan Richir**
for the fulfilment of the degree of PhD in Sciences

Coastal pollution of the Mediterranean

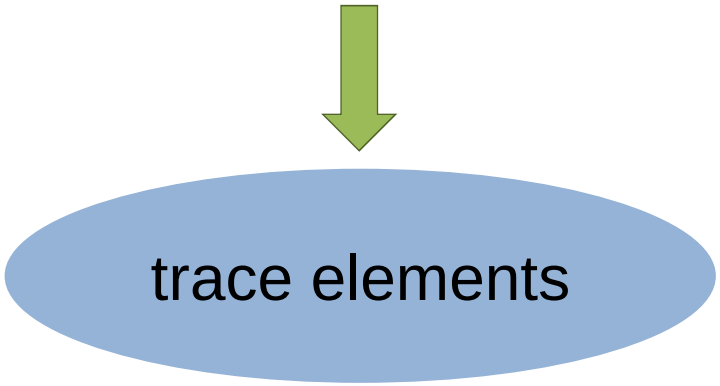


Pollution hot spots (full red circles) along the Mediterranean coasts (EEA 2006)

Trace elements

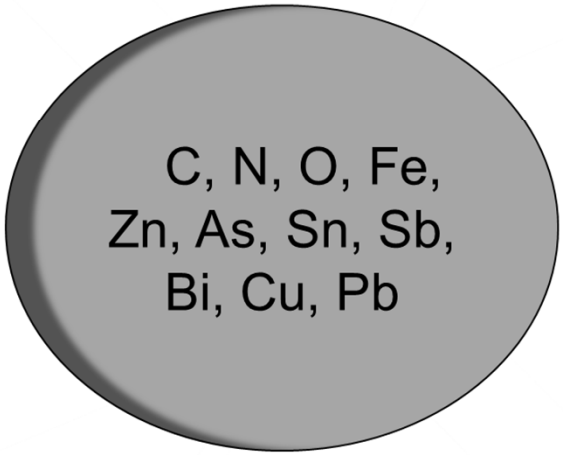
INTRODUCTION

pollution



Trace elements

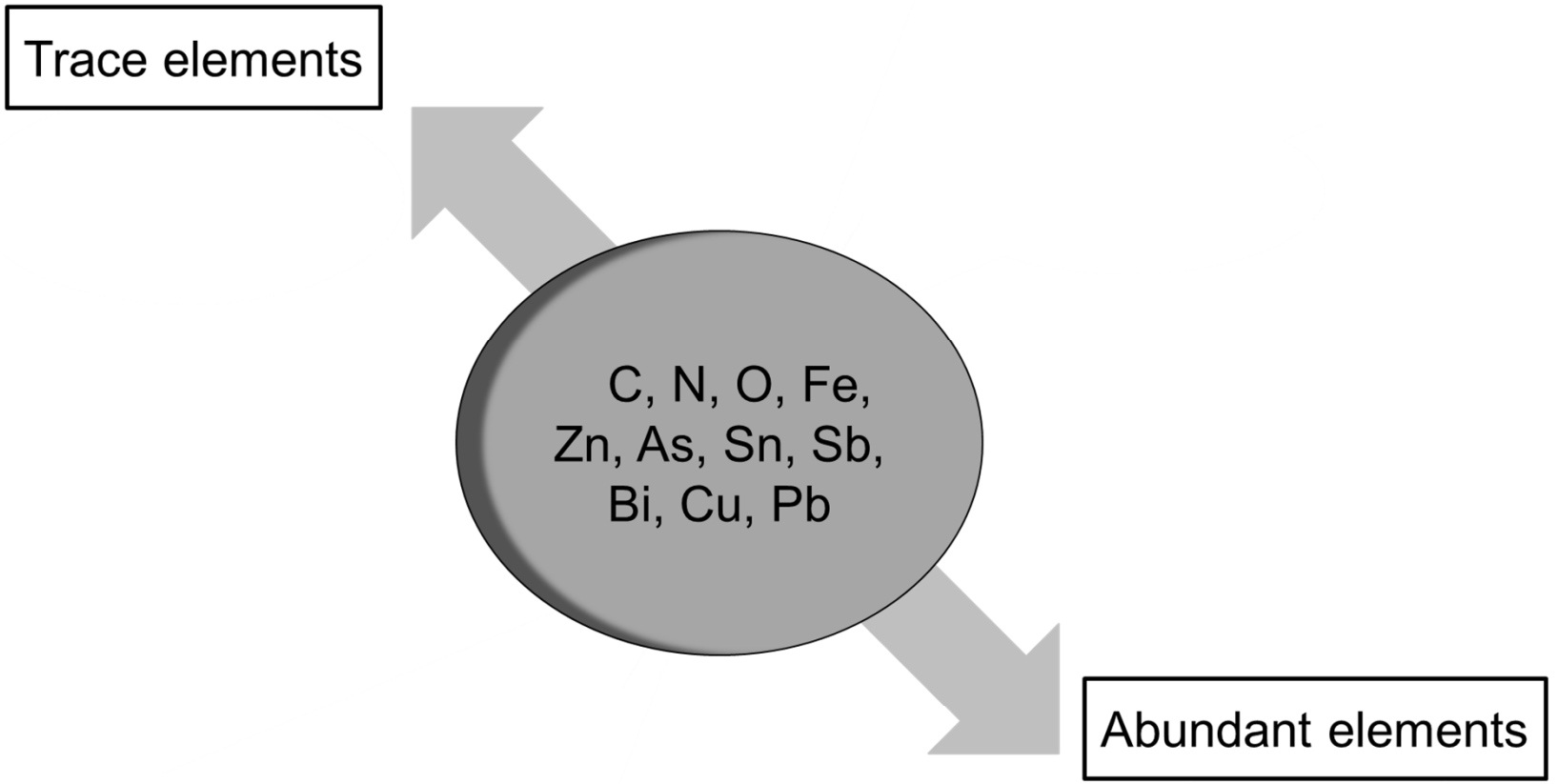
INTRODUCTION



(after Amiard 2011)

Trace elements

INTRODUCTION



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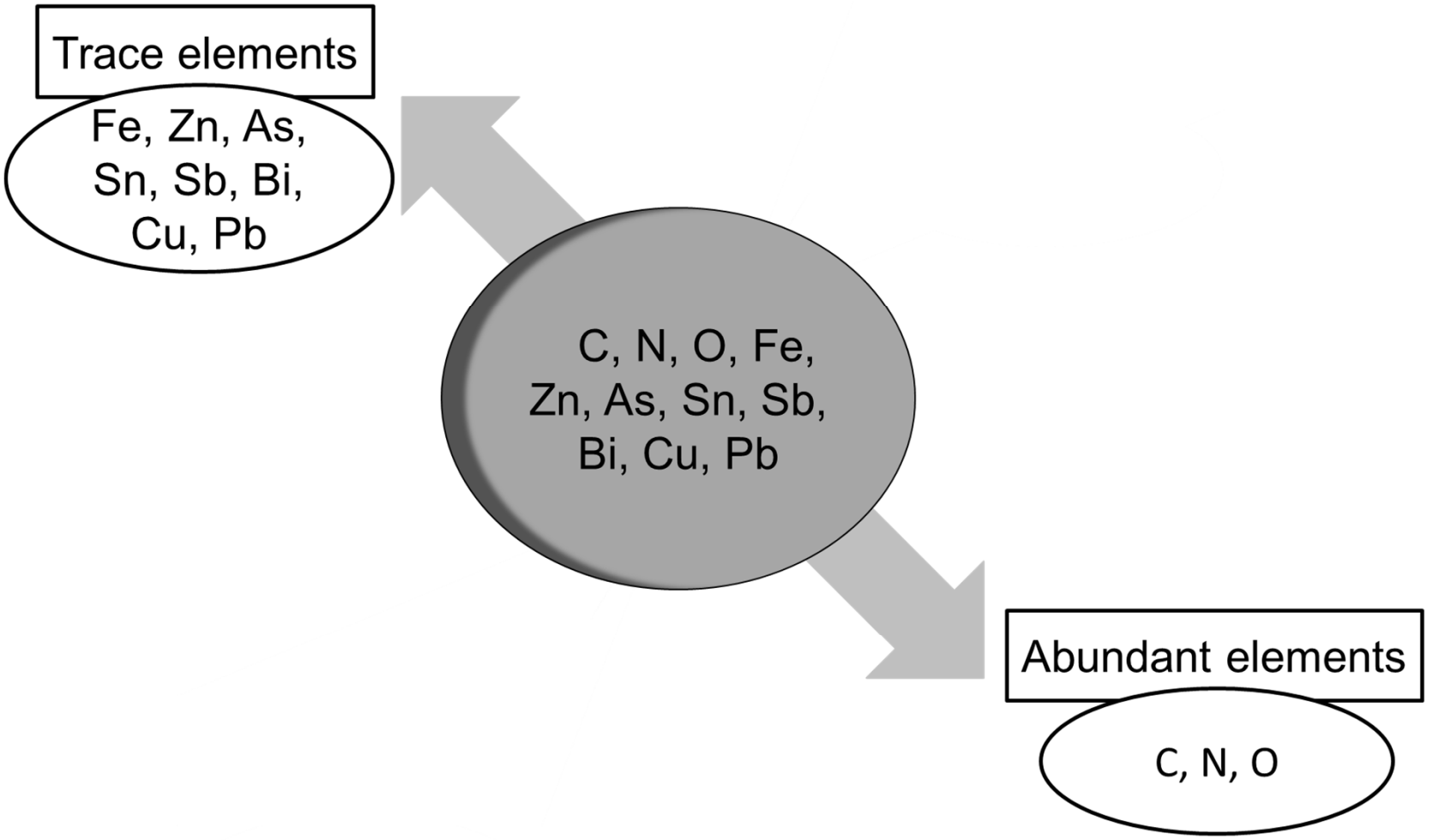

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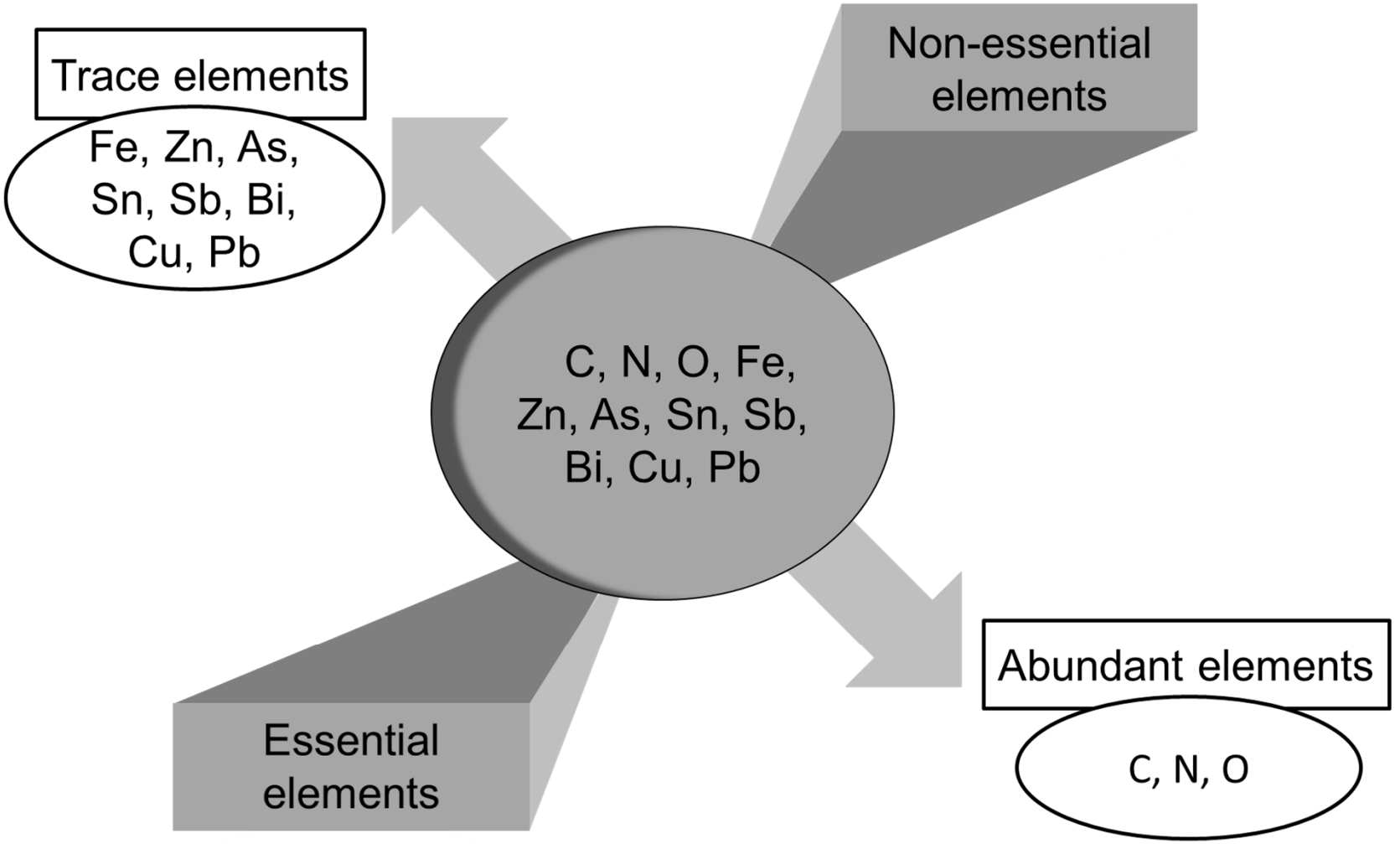

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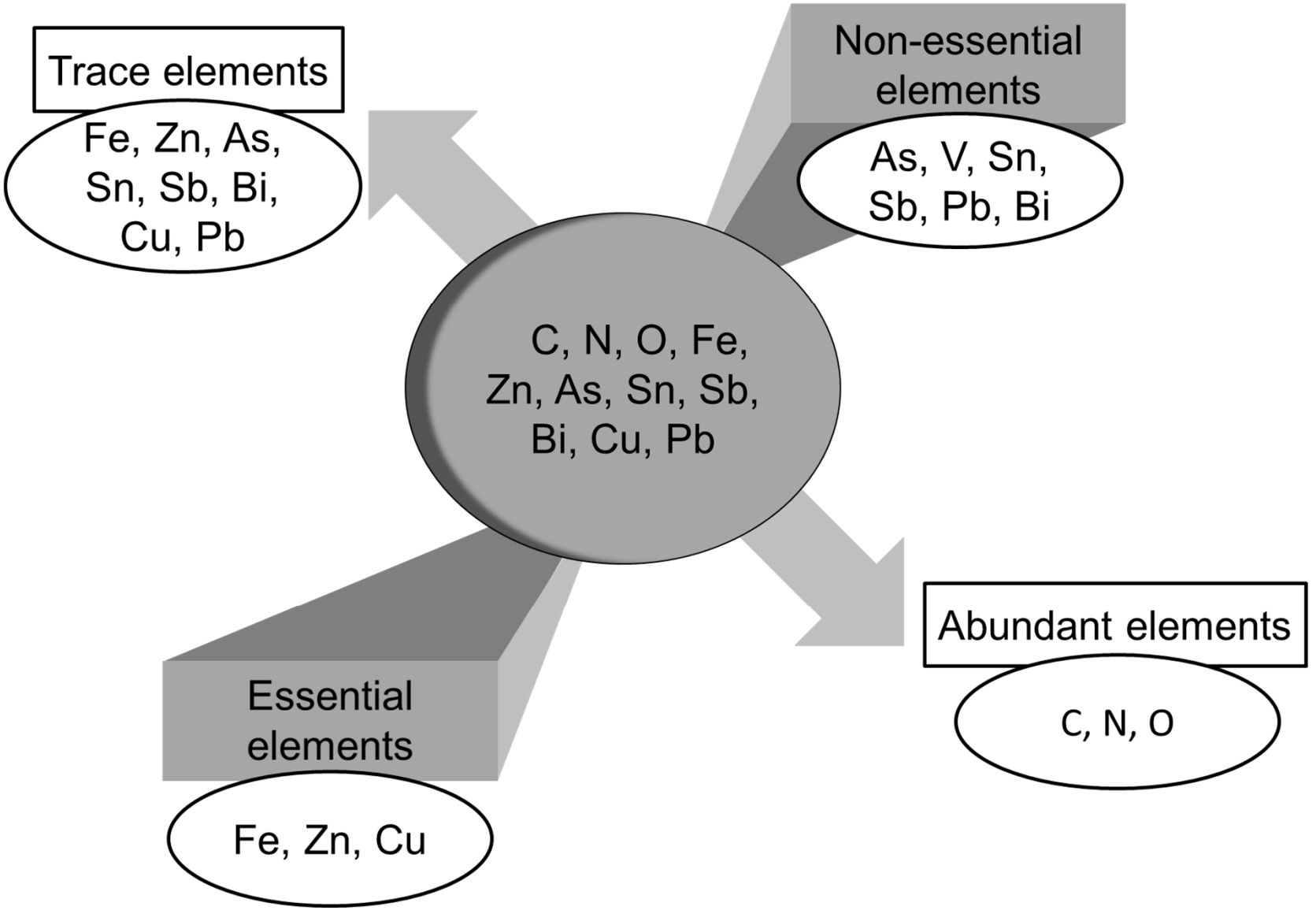

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Monitoring of the pollution by trace elements

INTRODUCTION

pollution

trace elements

Group 1	Group 2	Group : 3	4	5	6	7	8	9	10	11	12	Group 13	Group 14	Group 15	Group 16
		d transition elements													
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11 0.93 Na 22.990	12 1.31 Mg 24.305											13 1.61 Al 26.98	14 1.90 Si 28.086	15 2.19 P 30.974	16 2.58 S 32.064
19 0.82 K 39.102	20 1.00 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.941	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.71	29 Cu 63.546	30 Zn 65.37	31 1.81 Ga 69.72	32 2.01 Ge 72.59	33 2.18 As 74.922	34 2.55 Se 78.96
37 0.82 Rb 85.47	38 0.95 Sr 87.62	39 Y 88.906	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.40	49 1.78 In 114.82	50 1.96 Sn 118.69	51 2.05 Sb 121.75	52 2.10 Te 127.60
55 0.79 Cs 132.91	56 0.89 Ba 137.34	57 La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.22	78 Pt 195.09	79 Au 196.97	80 Hg 200.59	81 2.04 Tl 204.37	82 2.32 Pb 207.19	83 2.02 Bi 208.98	84 Po (210)
87 Fr (223)	88 Ra 226.025	89 Ac 227.0	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Unb				

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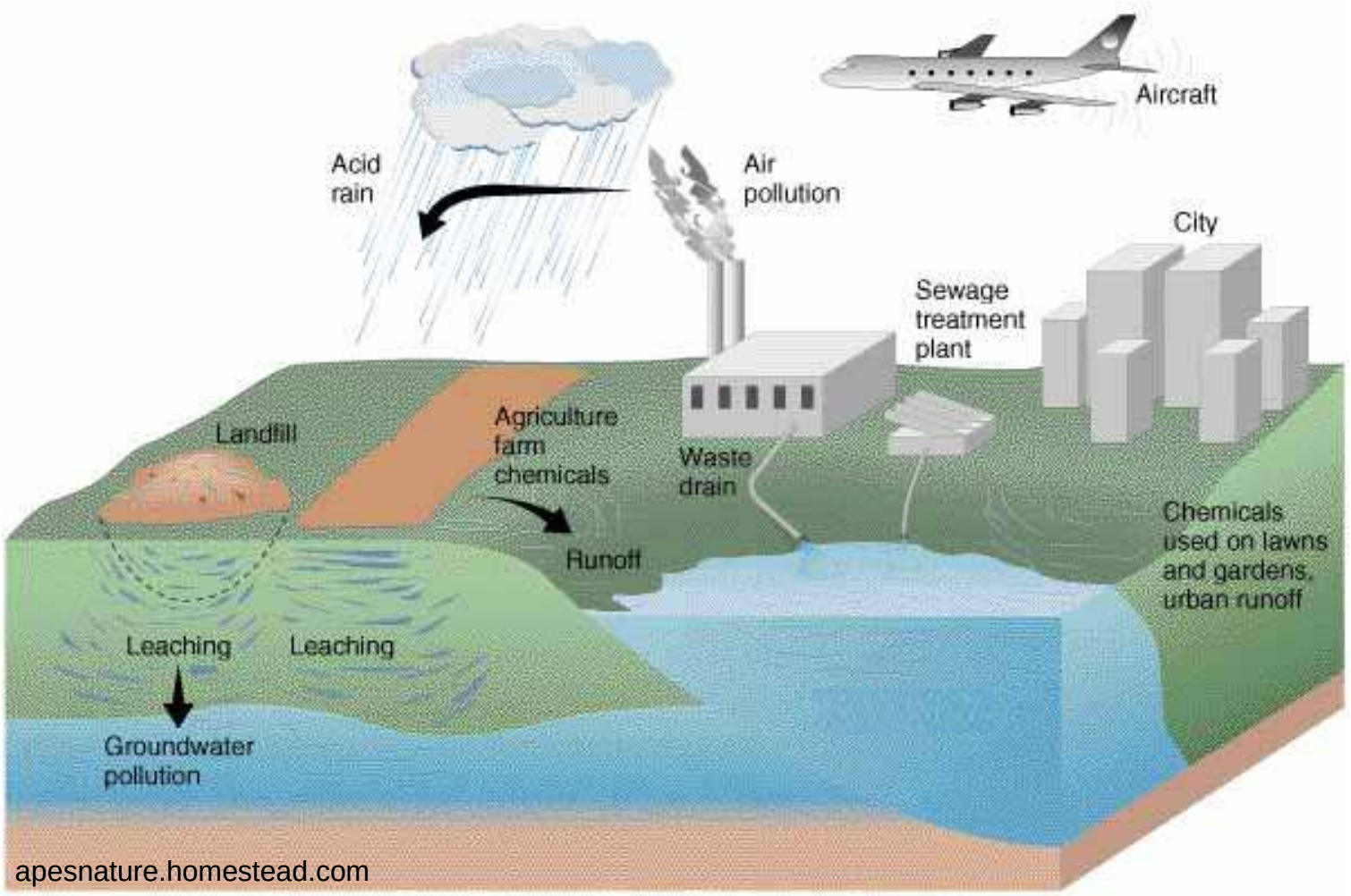
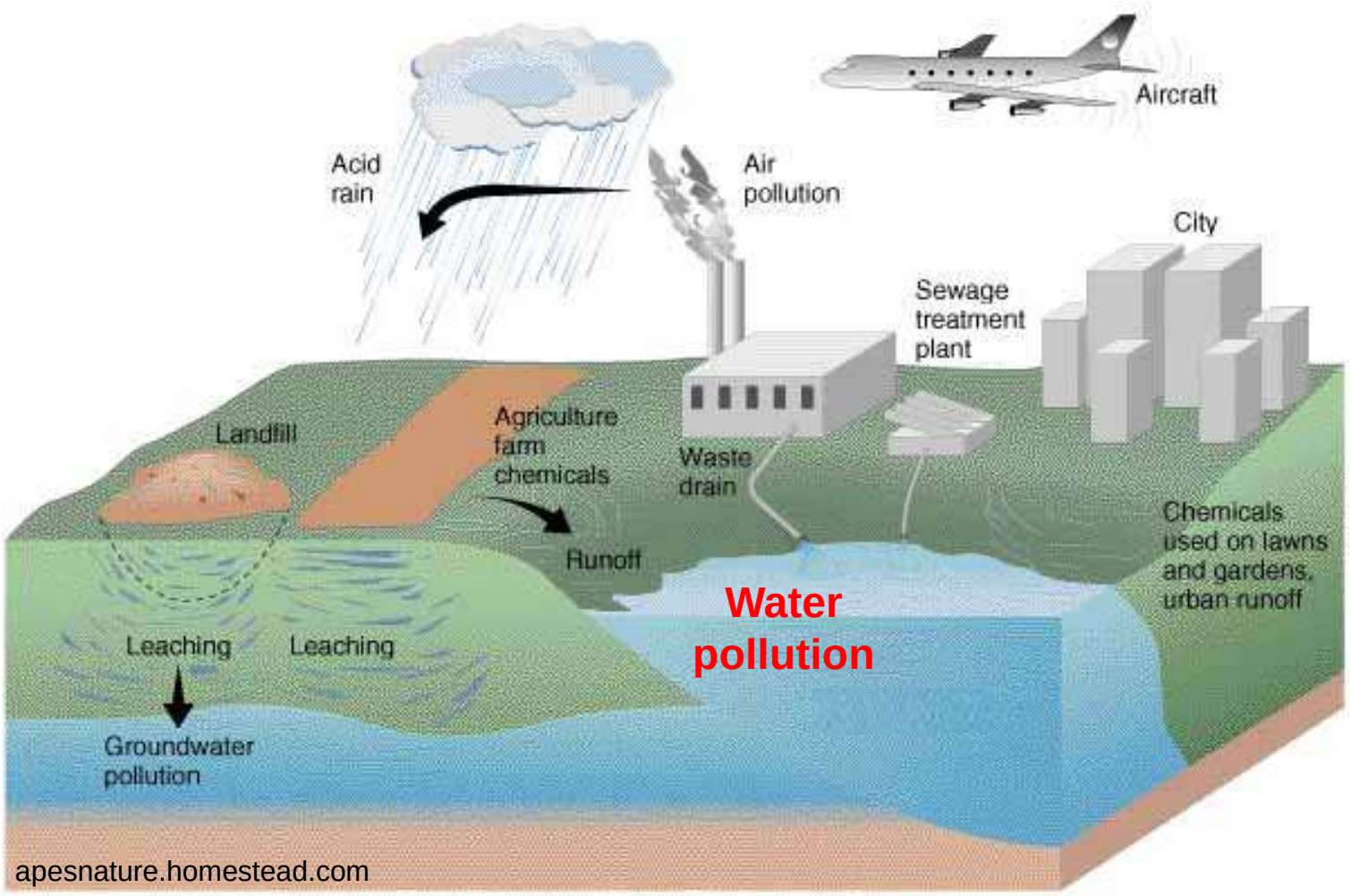
Water pollution

INTRODUCTION



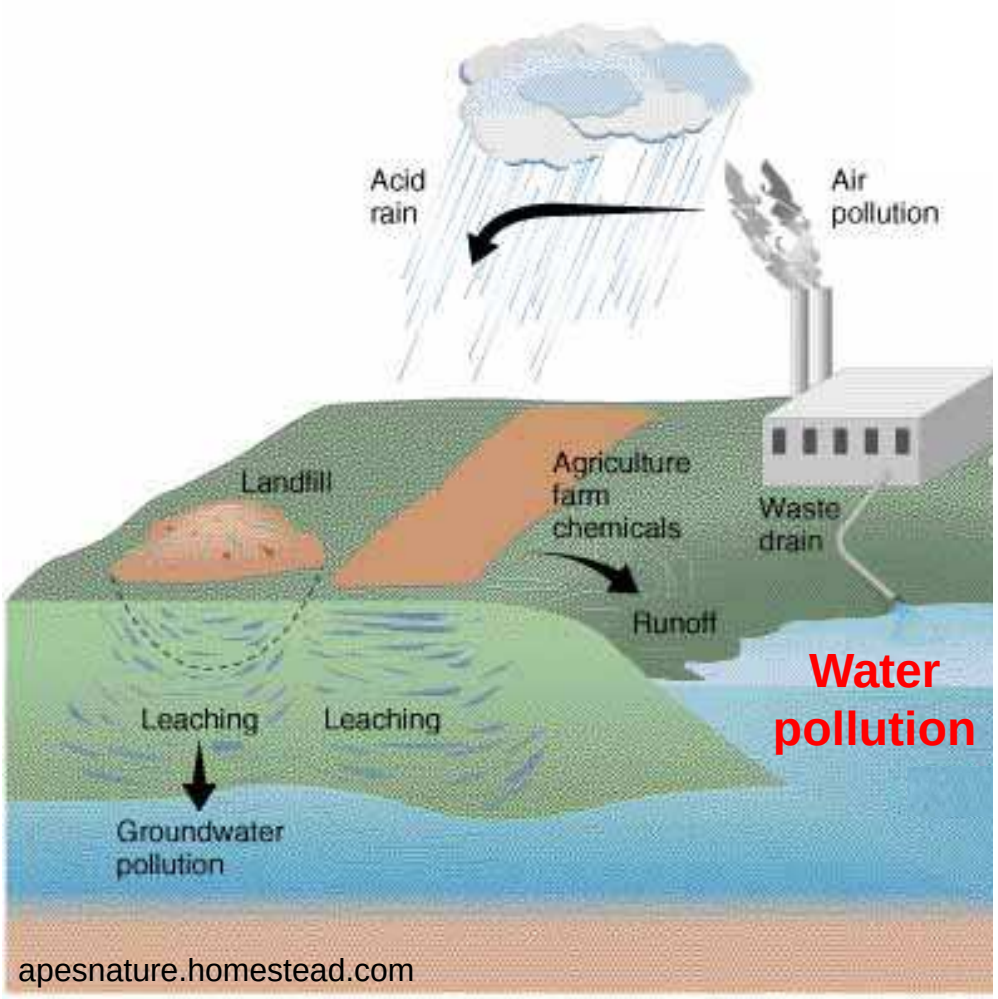
Water pollution

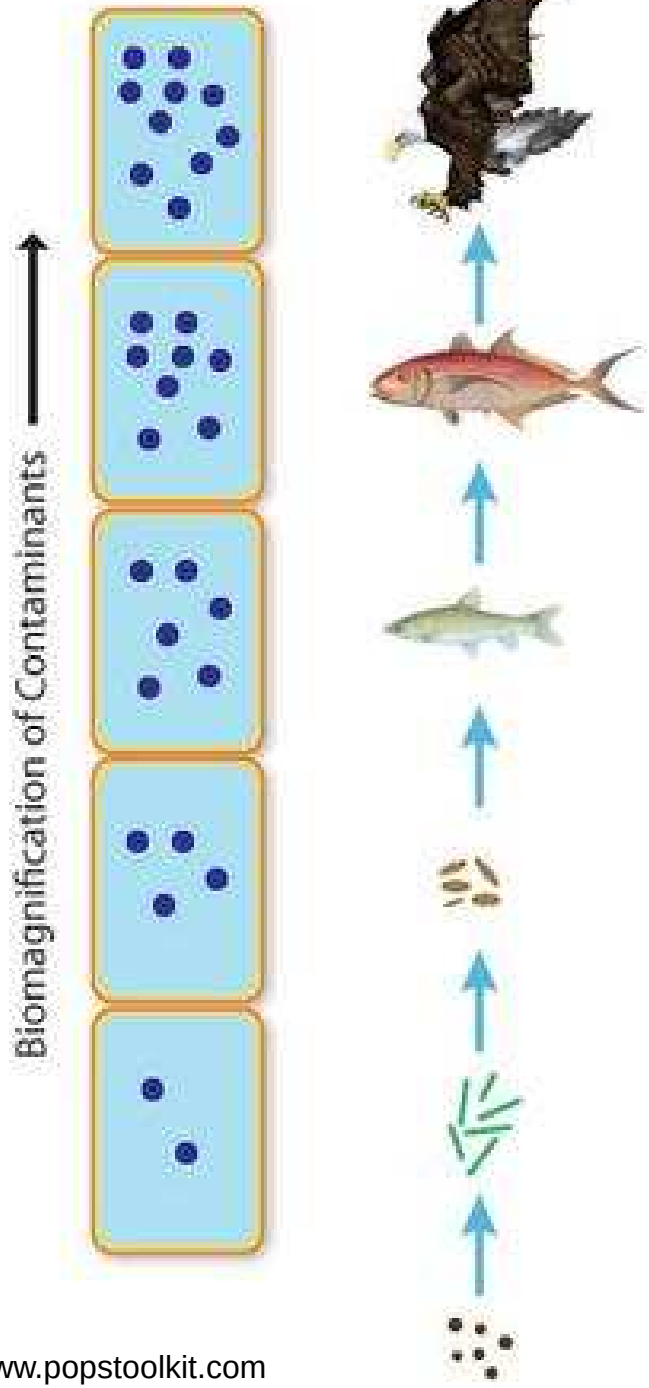
INTRODUCTION



INTRODUCTION

Water pollution



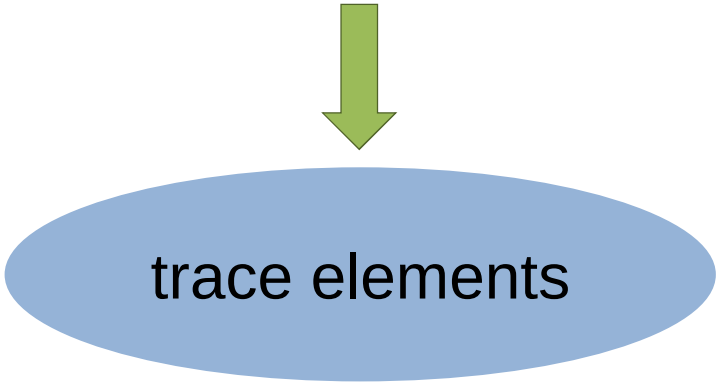


Public health

Biomonitoring

INTRODUCTION

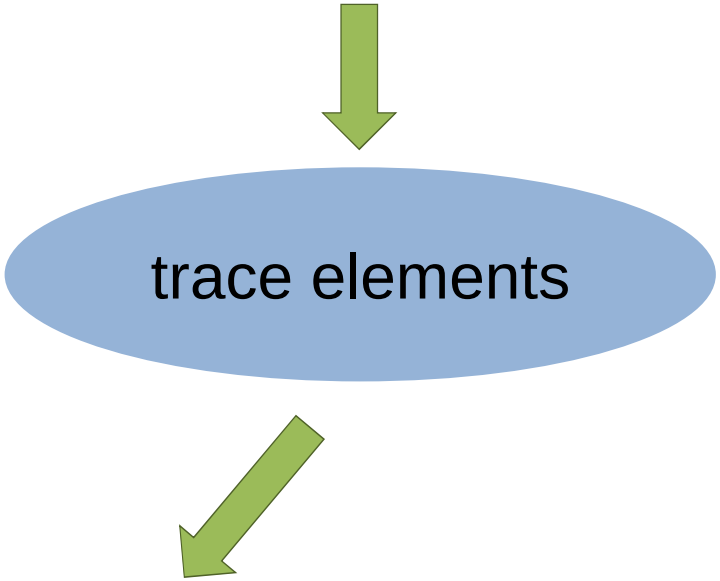
pollution



Biomonitoring

INTRODUCTION

pollution



direct measurements
in the environment

Biomonitoring

INTRODUCTION

pollution

trace elements

direct measurements in the environment

bioindicators = organisms accumulating pollutants to levels representative of their habitat pollution status.

Biomonitoring

M. galloprovincialis

pollution

trace elements

P. oceanica

direct measurements in the environment

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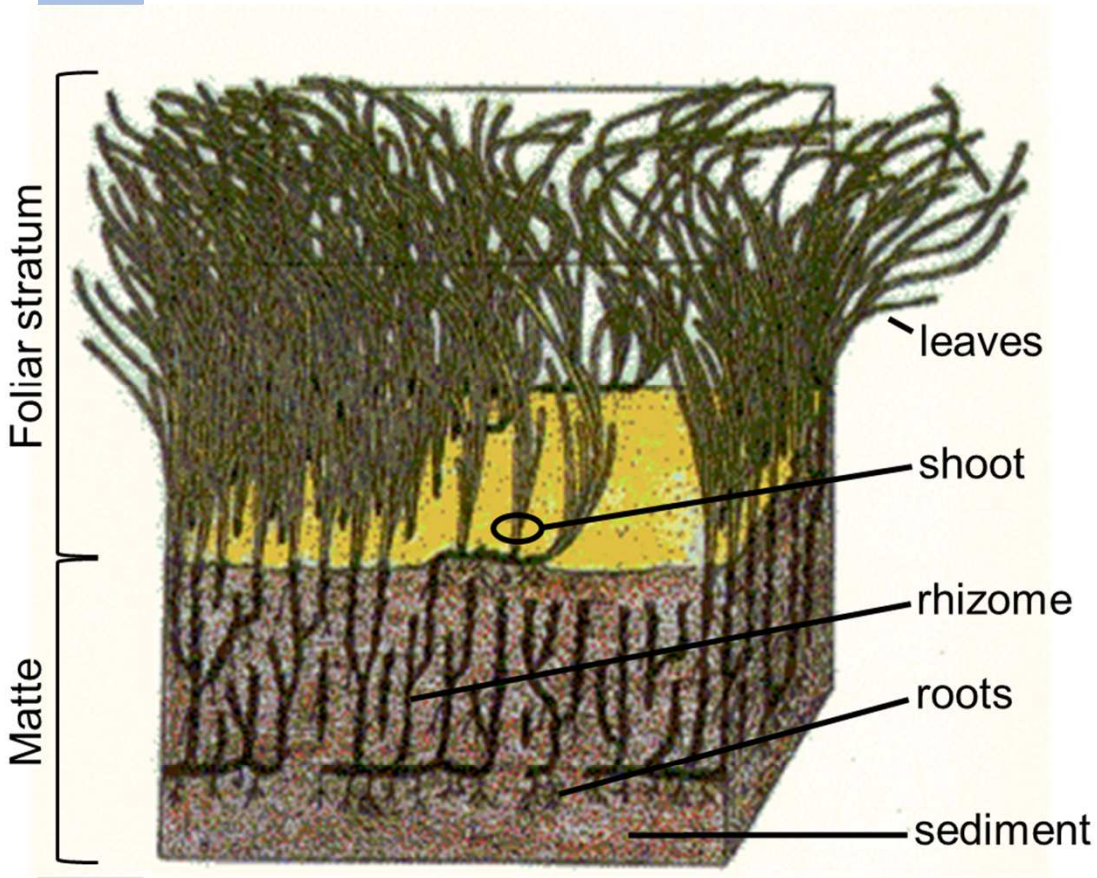
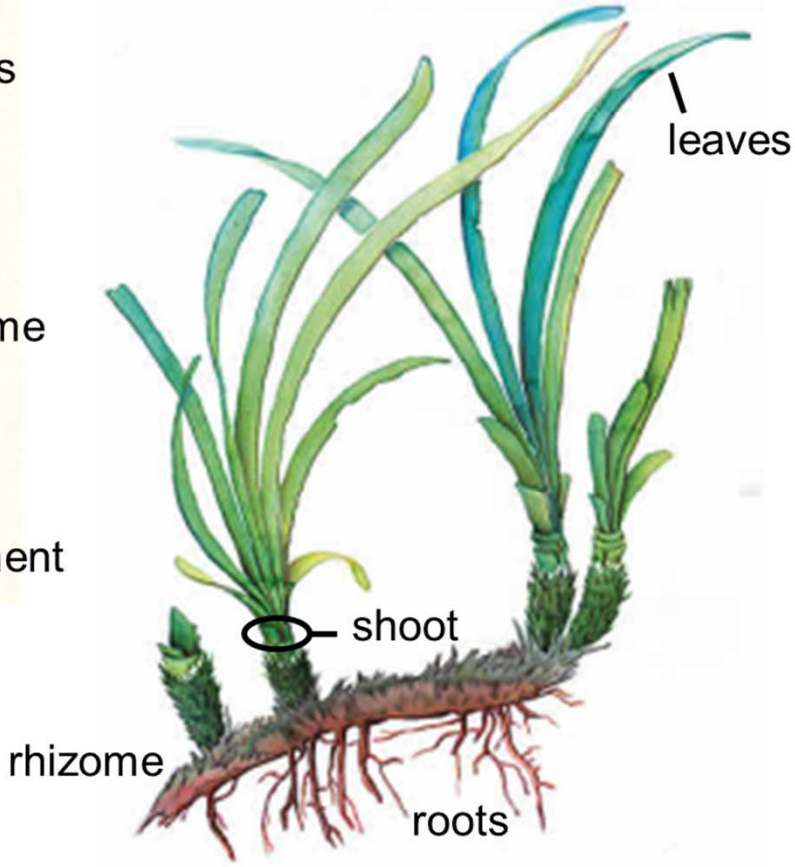
Posidonia oceanica

INTRODUCTION

Posidonia oceanica

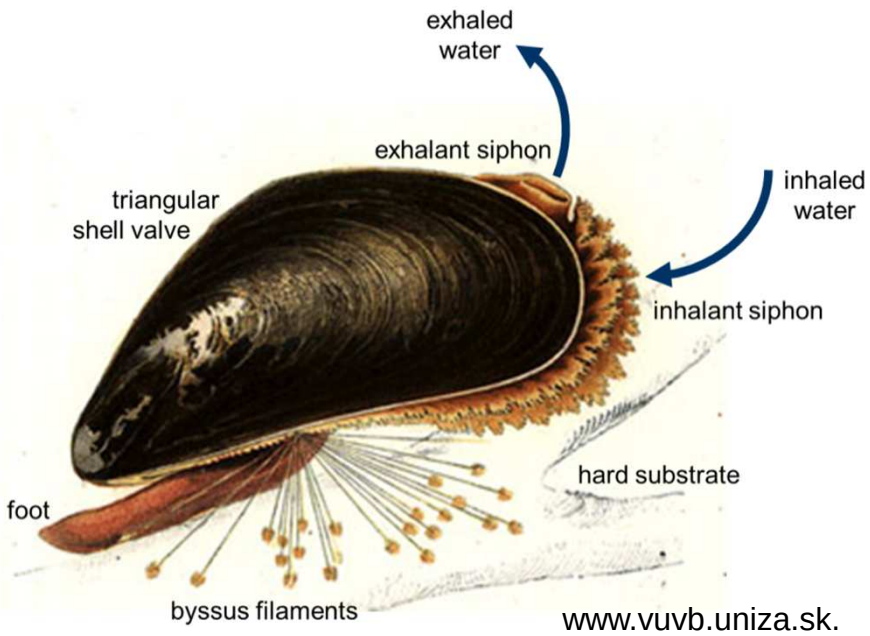


(after Boudouresque and Meinesz 1982)



Mytilus galloprovincialis

INTRODUCTION



www.vuvb.uniza.sk.

Main objectives

INTRODUCTION

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INTRODUCTION

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INTRODUCTION

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INTRODUCTION

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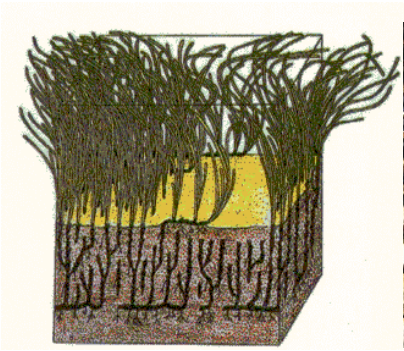
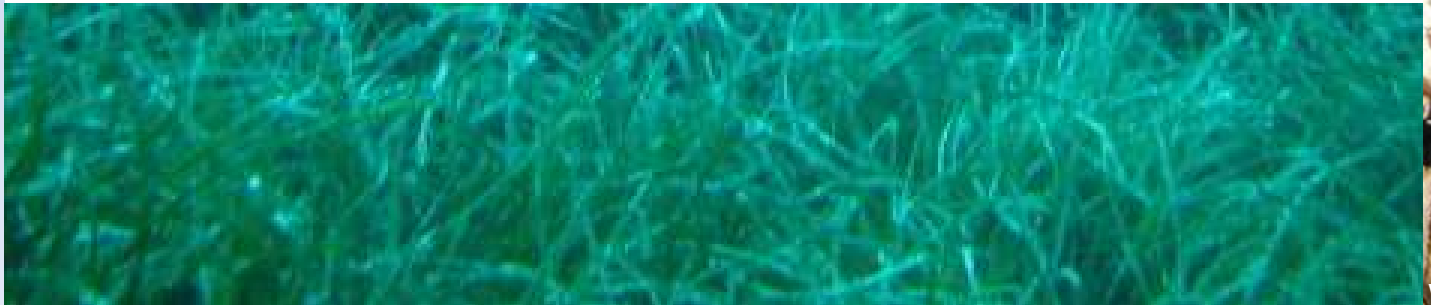
❖ to investigate the potential use of *P. oceanica* and *M. galloprovincialis* to biomonitor trace elements of environmental "emerging concern";

❖ to study the mechanisms determining trace element accumulation in both species, under reference conditions or when exposed to environmental changes of pollutant loads.



Specific objectives

INTRODUCTION



www.wwfsassi.co.za/

Specific objectives

INTRODUCTION

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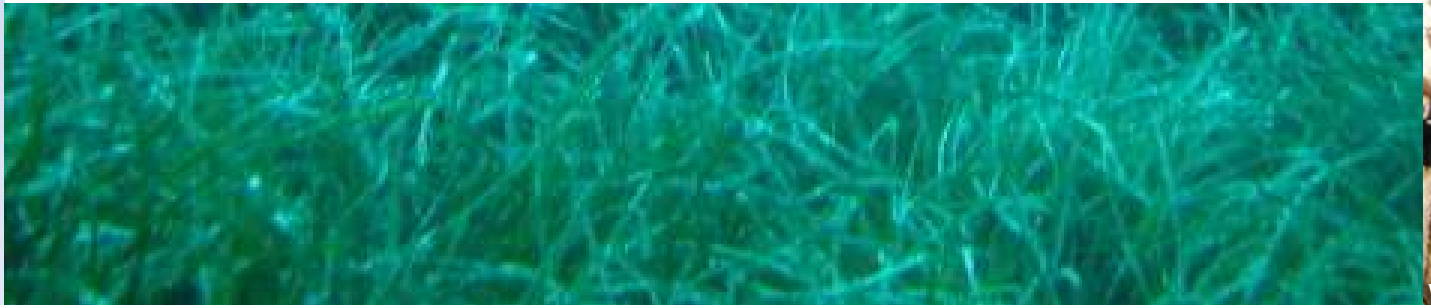

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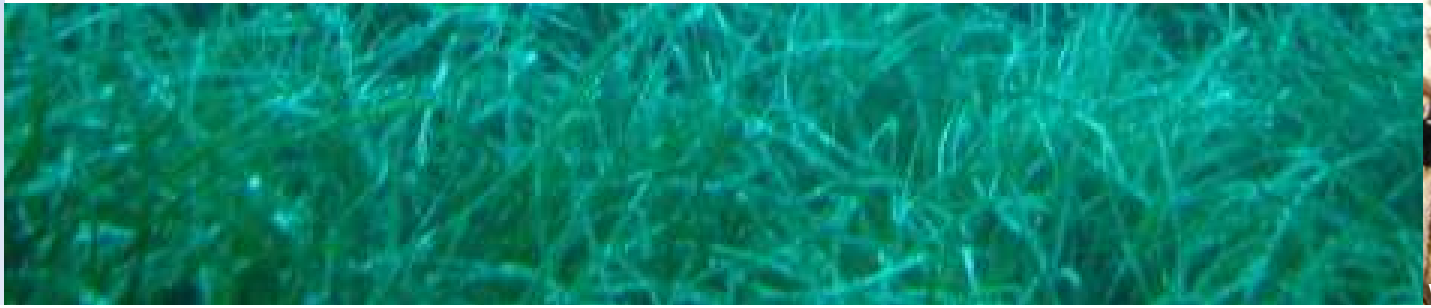

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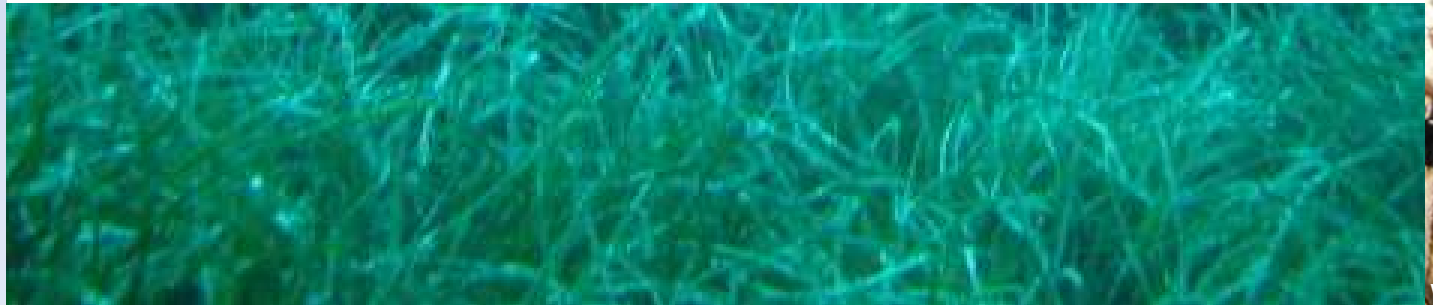

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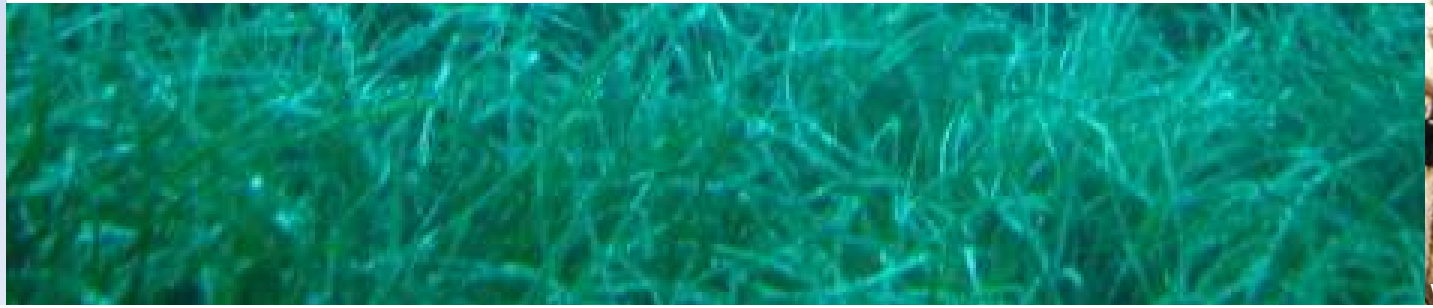
4. trace element uptake and loss kinetics by both species.



Specific objectives

SPATIAL VARIATION

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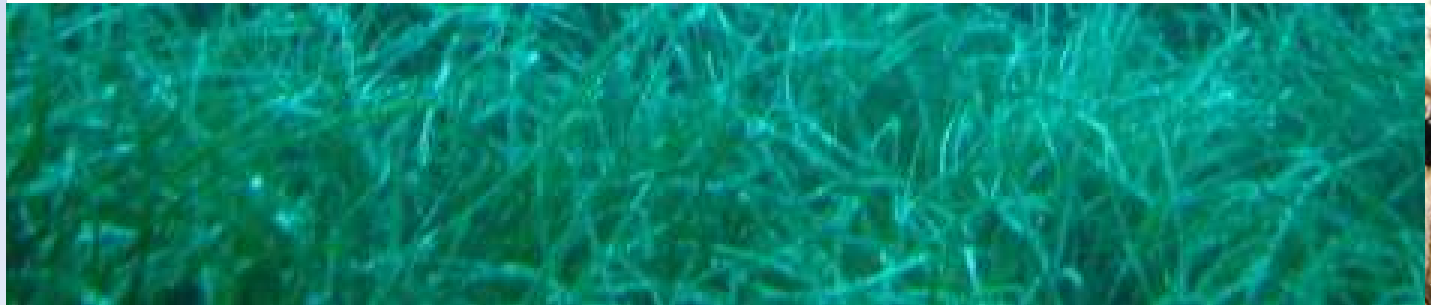

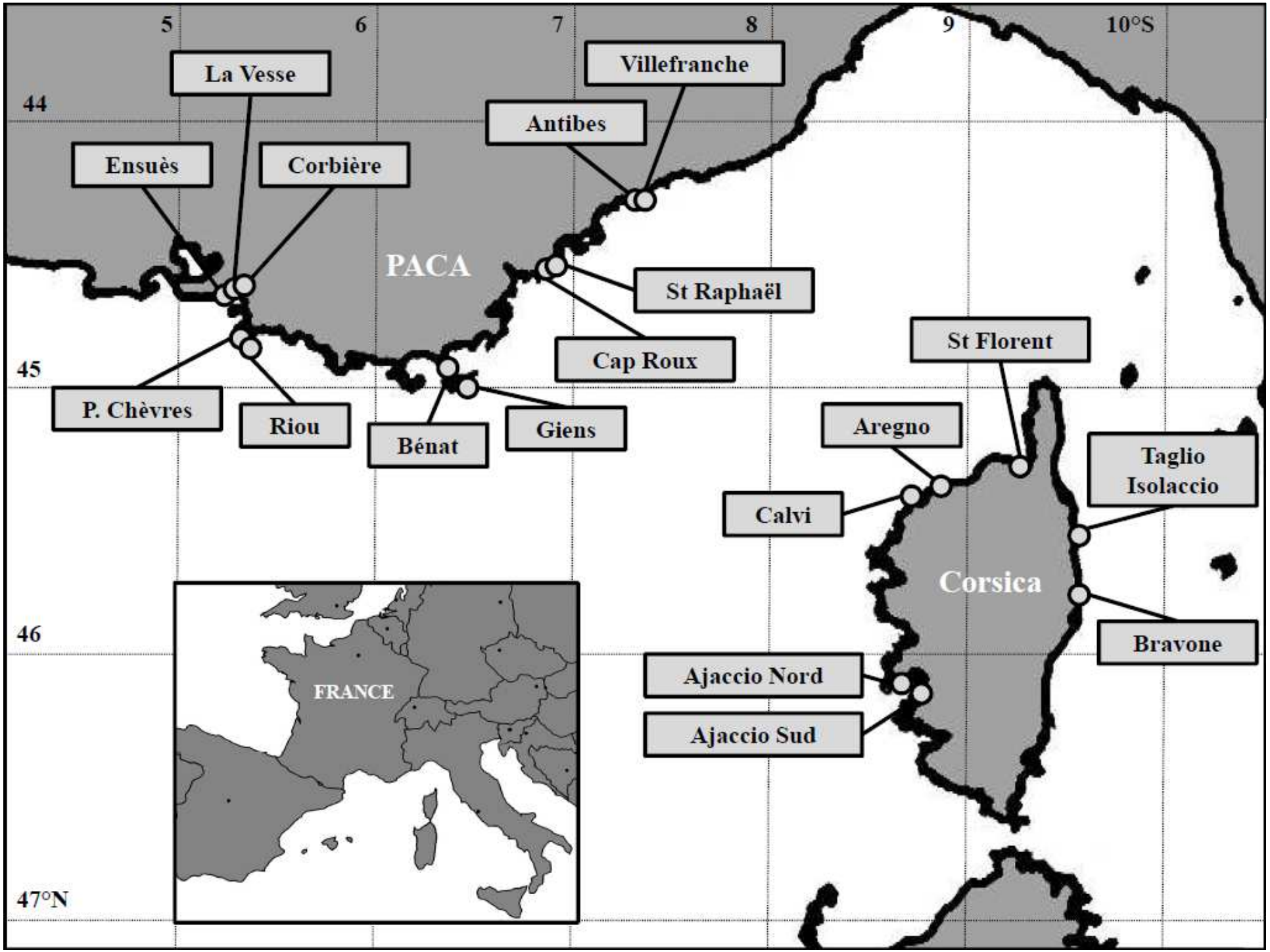
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47°N
La Vesse
Villefranche
Antibes
Ensuès
Corbière
PACA
St Raphaël
Cap Roux
St Florent
P. Chèvres
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Giens
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Taglio Isolaccio
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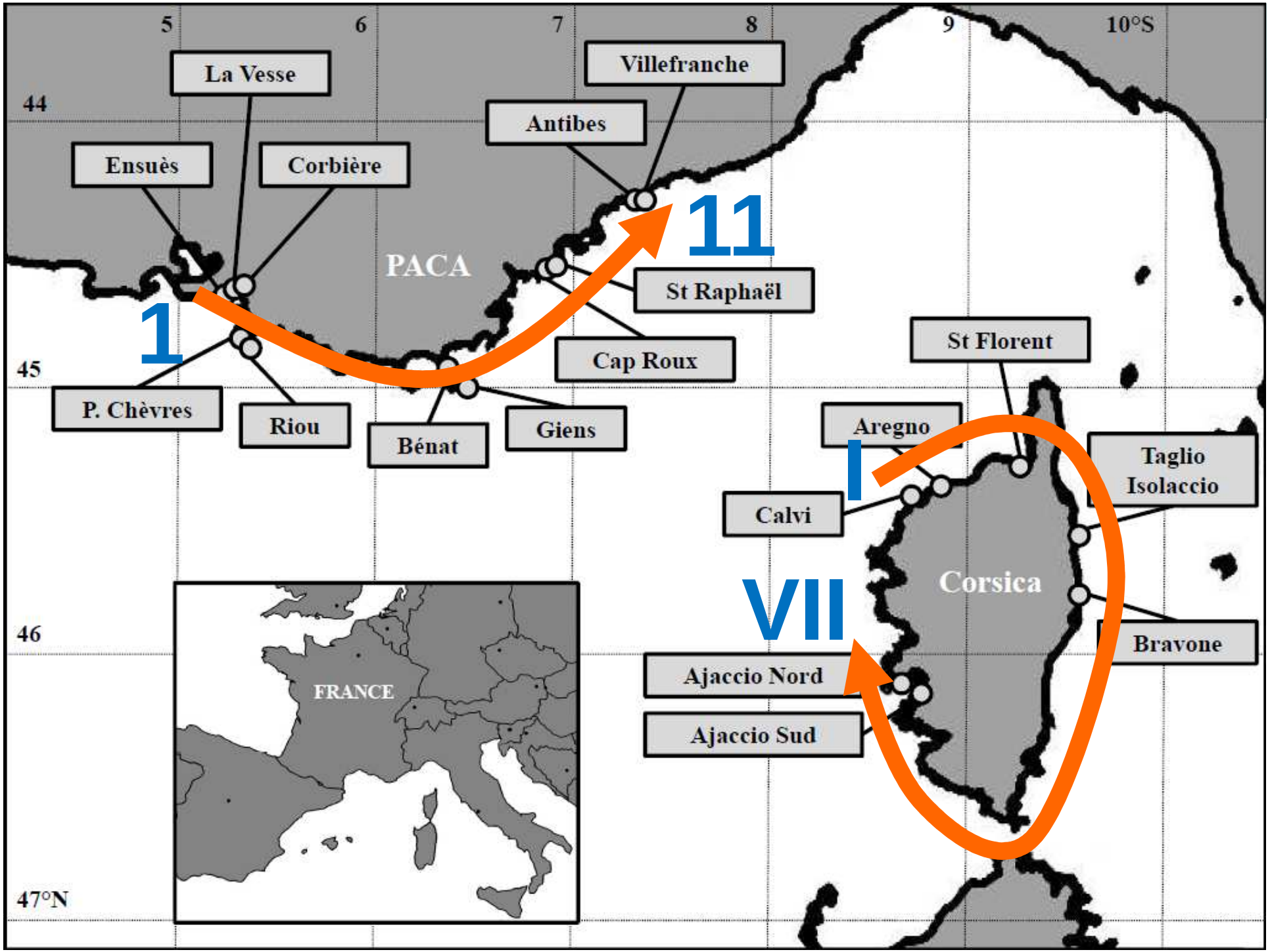
Bravone
Ajaccio Nord
Ajaccio Sud
FRANCE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Bravone
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FRANCE

1 - petroleum products (V)

SPATIAL VARIATION

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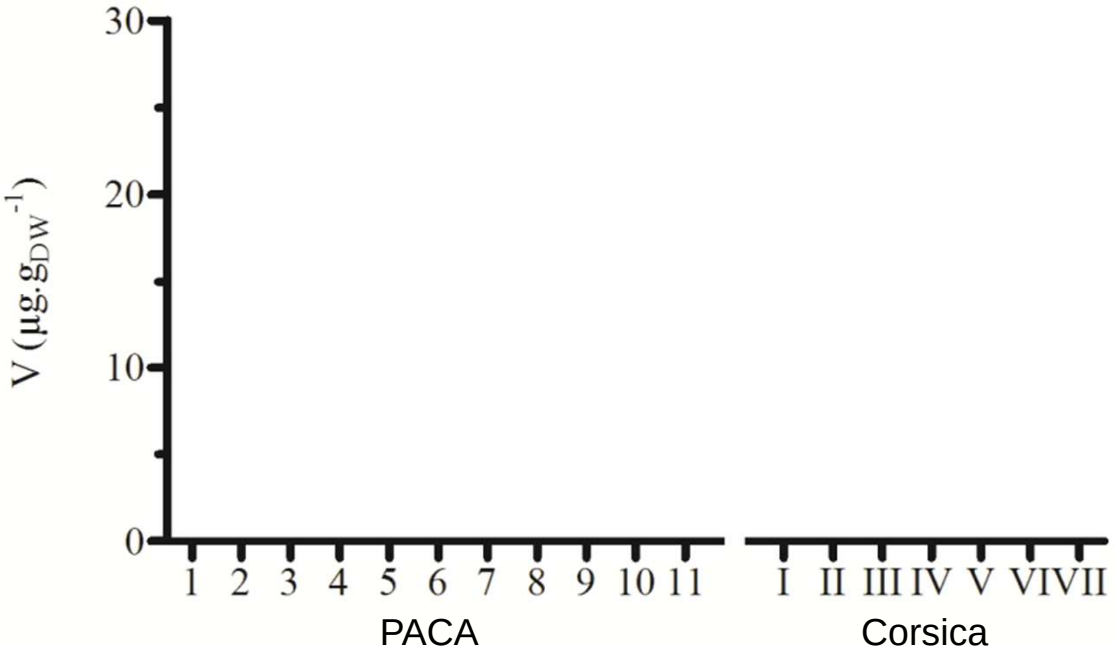
SPATIAL VARIATION



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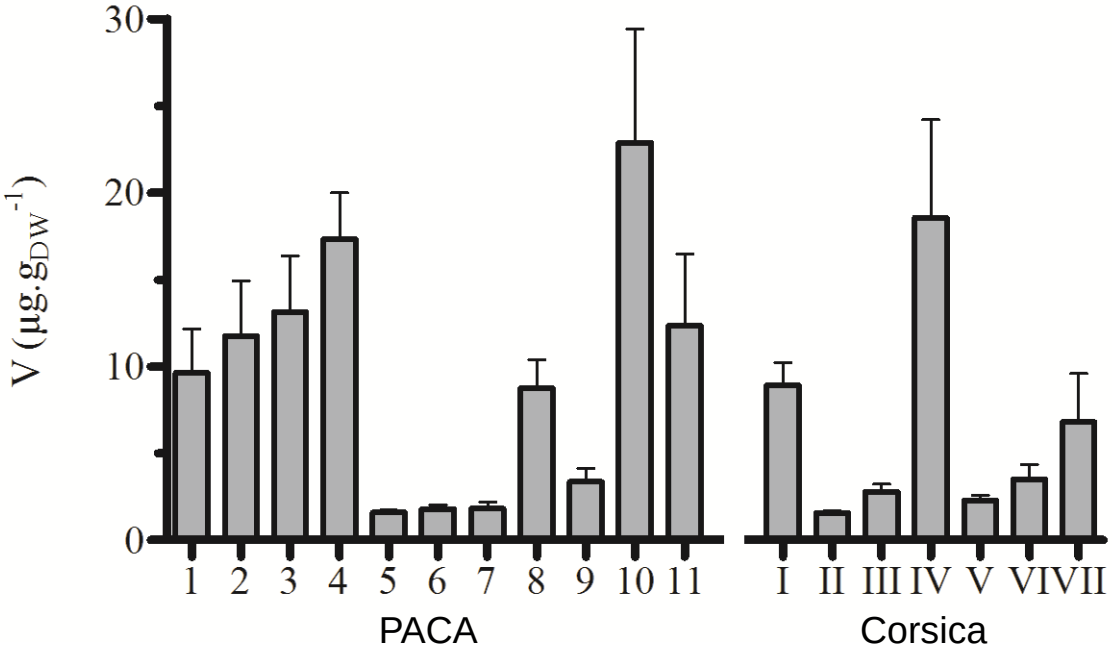

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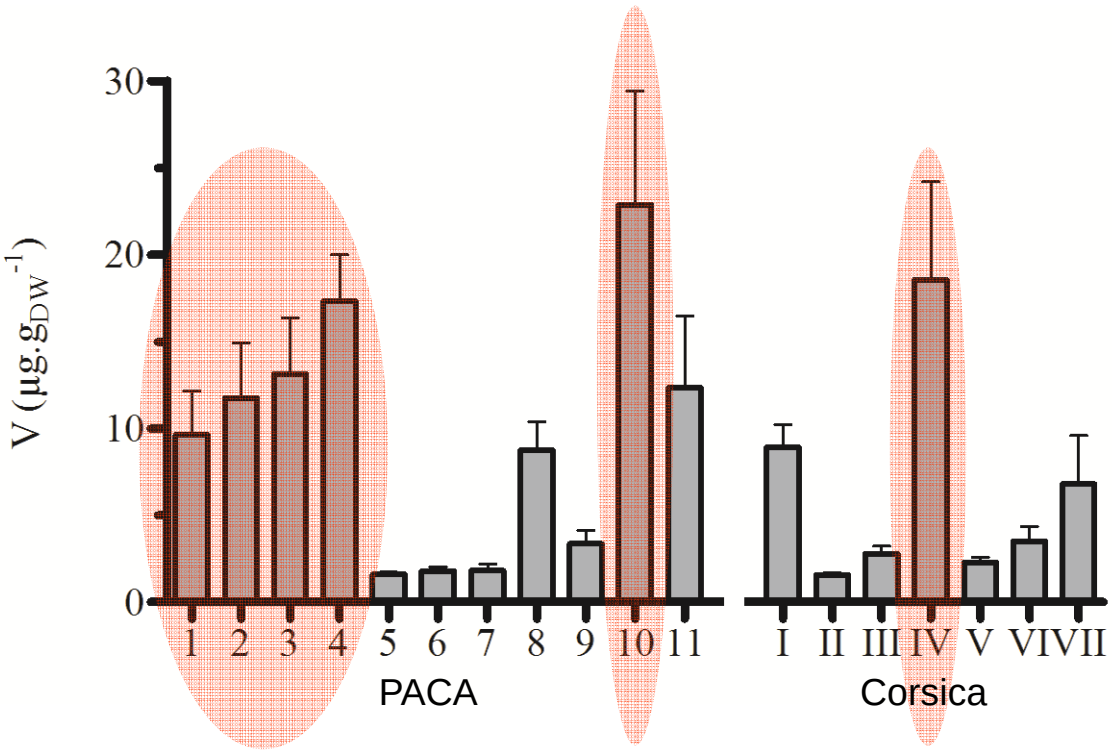

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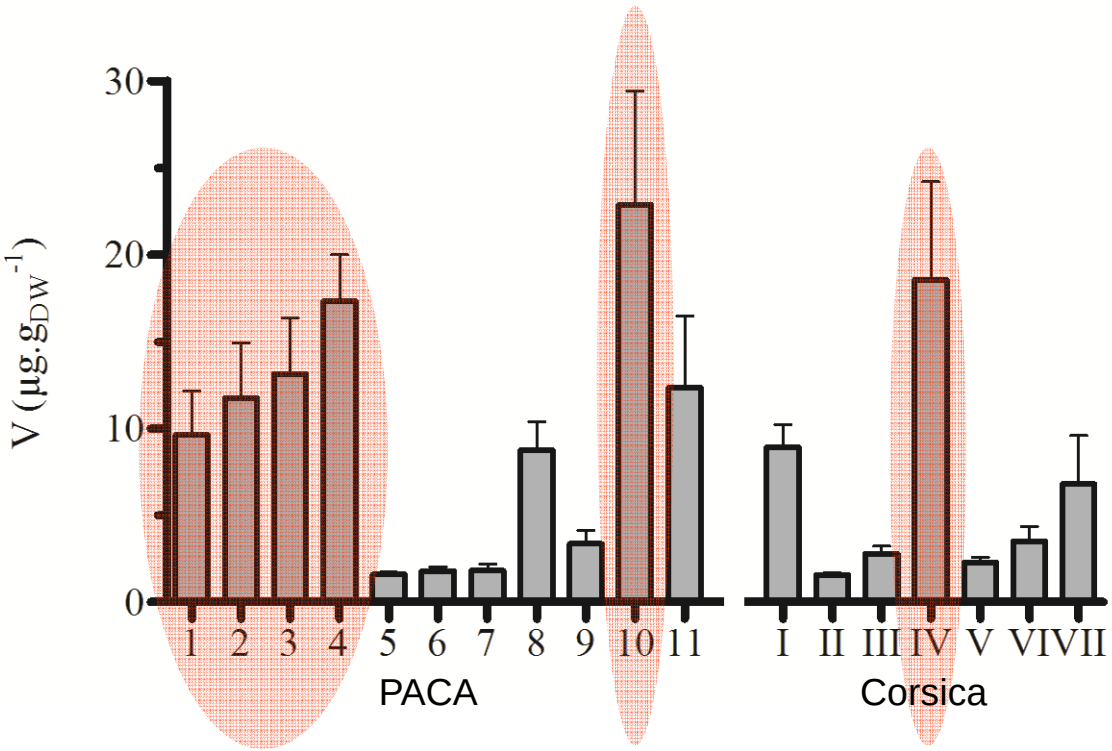
SPATIAL VARIATION



Marseille oil refinery

Antibes oil-exporting harbour

Taglio-Isolaccio petroleum depot

2 - mining (Sb, Zn) activities

SPATIAL VARIATION

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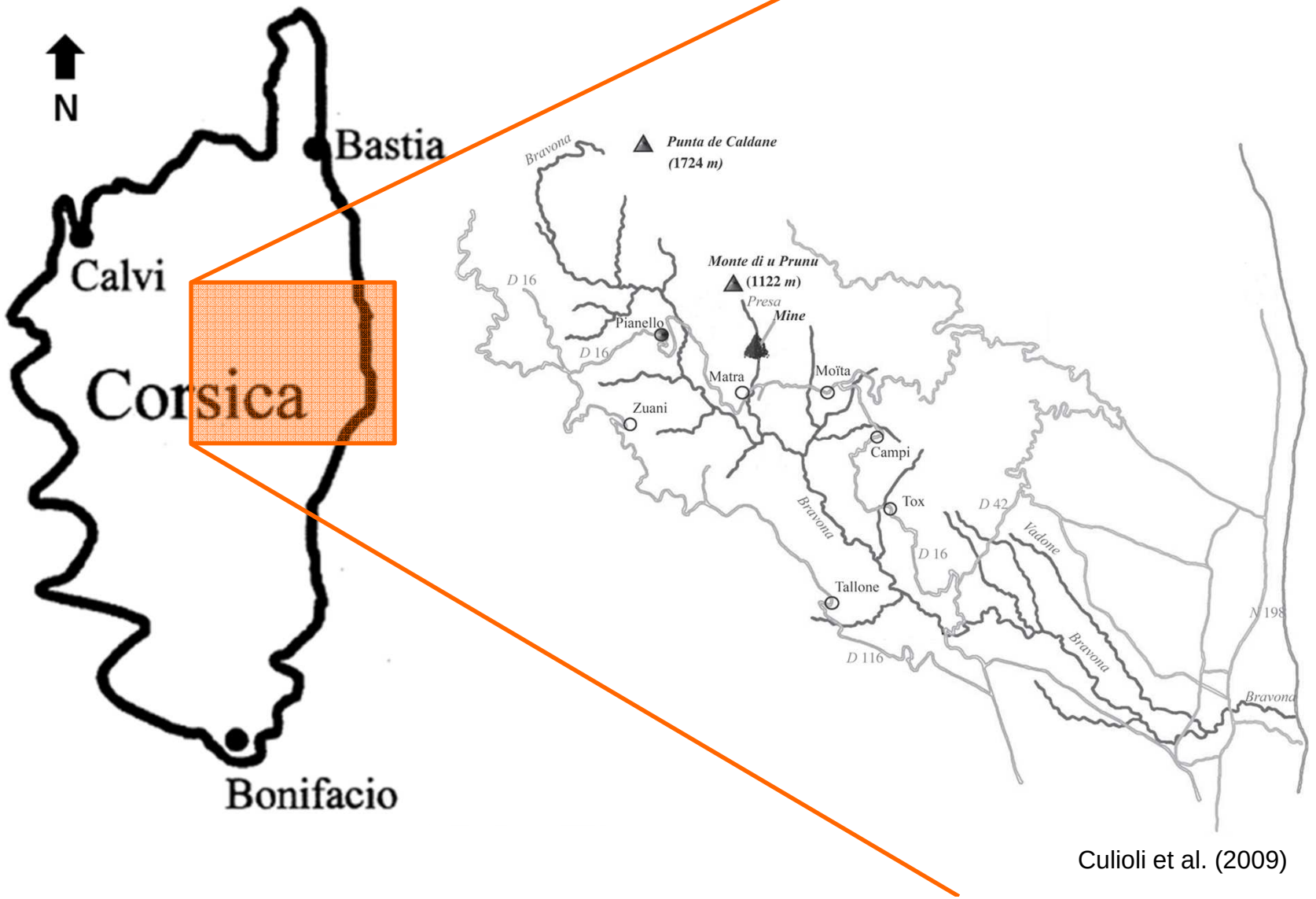

Culioli et al. (2009)

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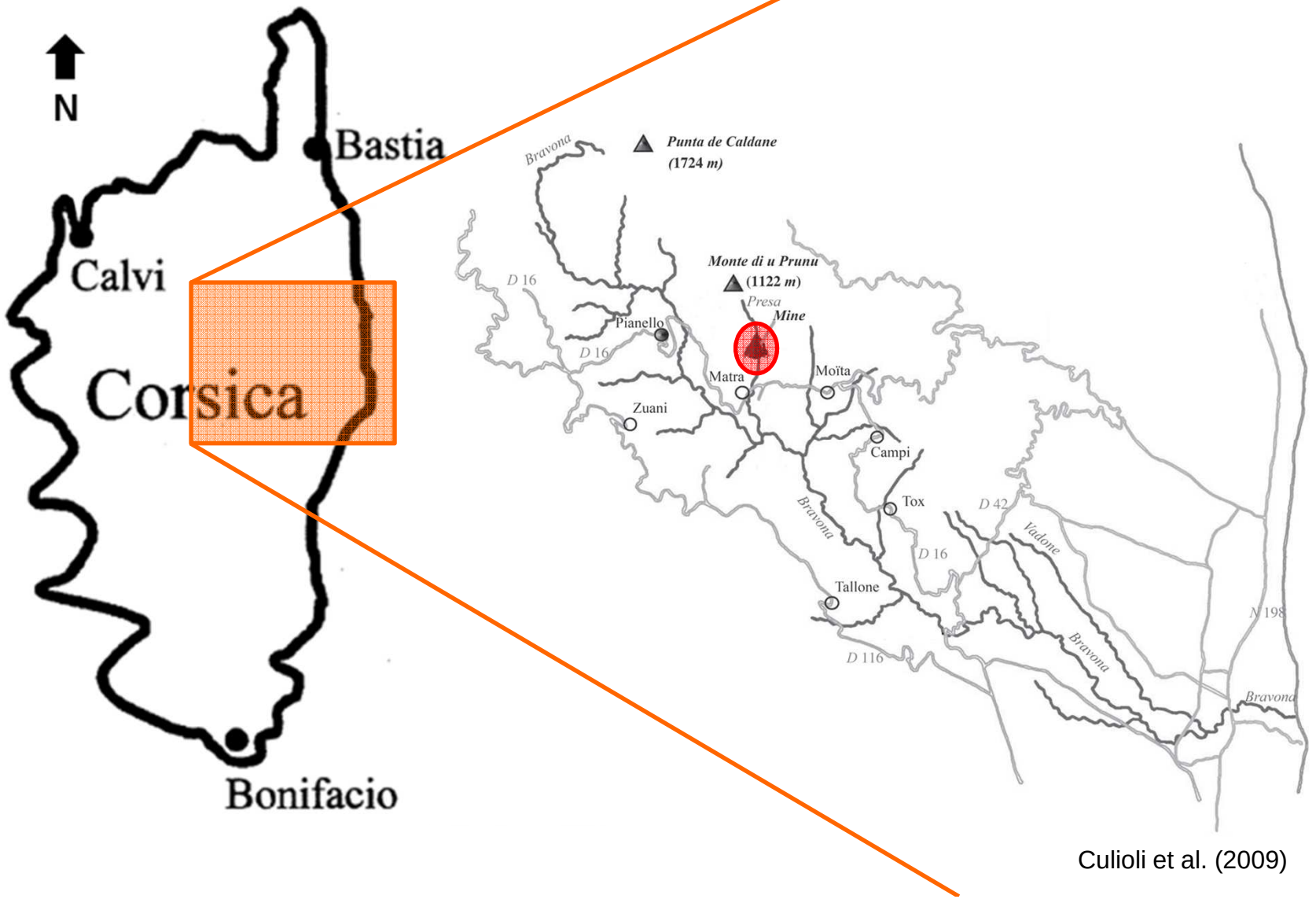

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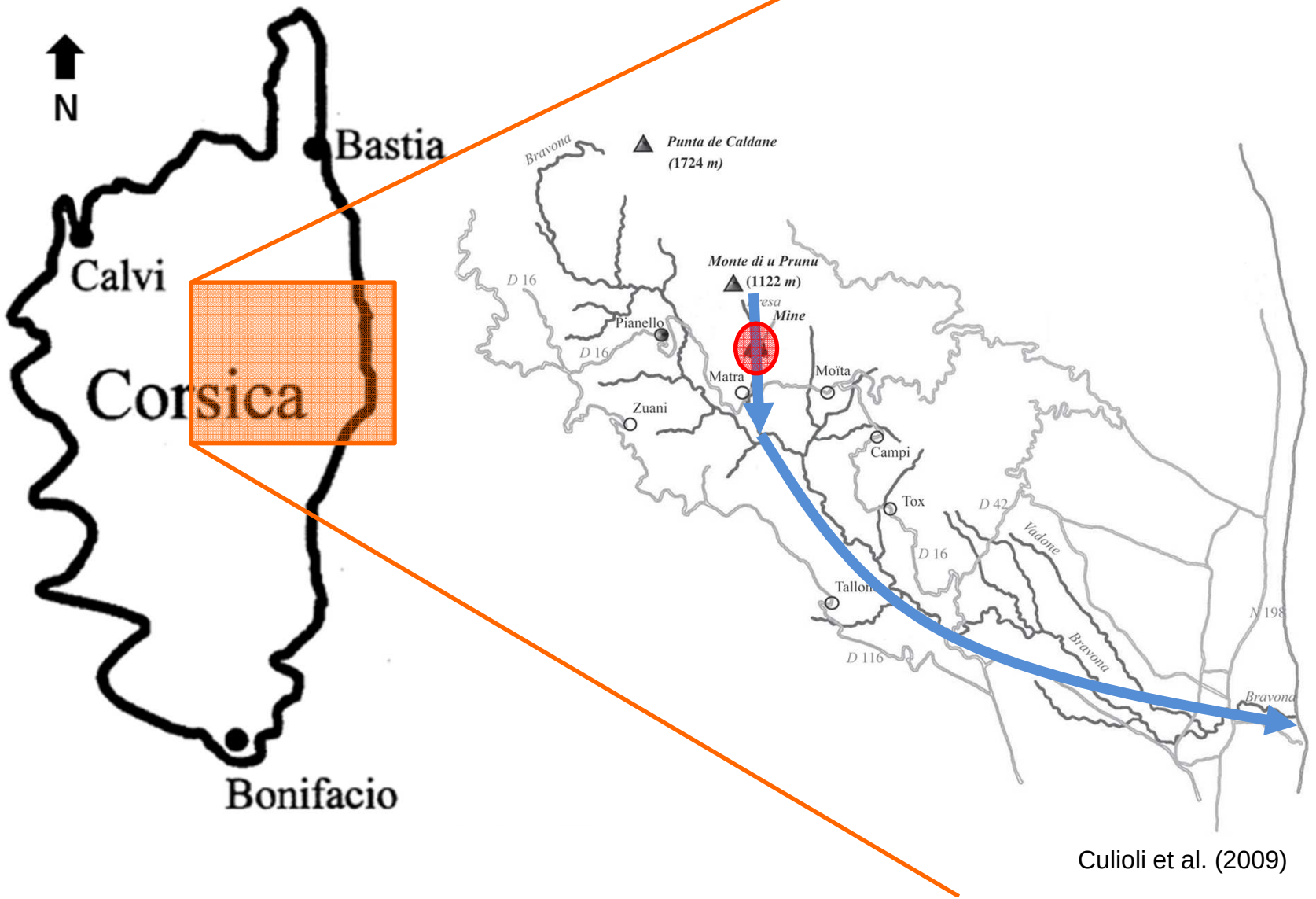

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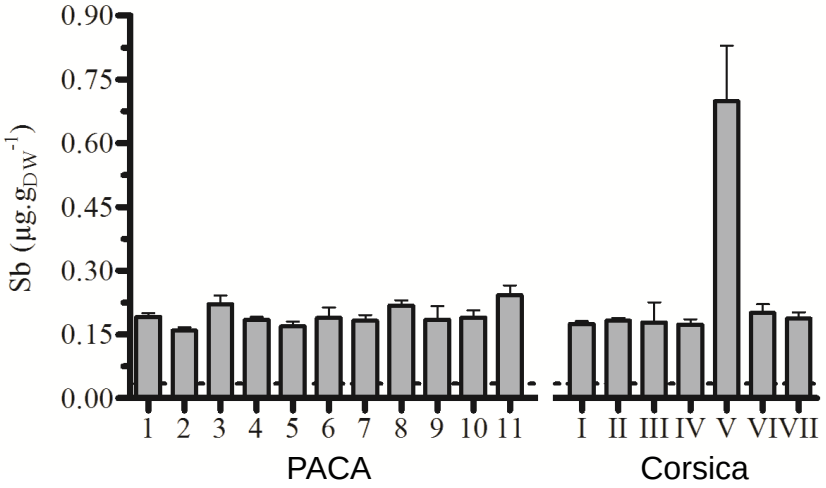

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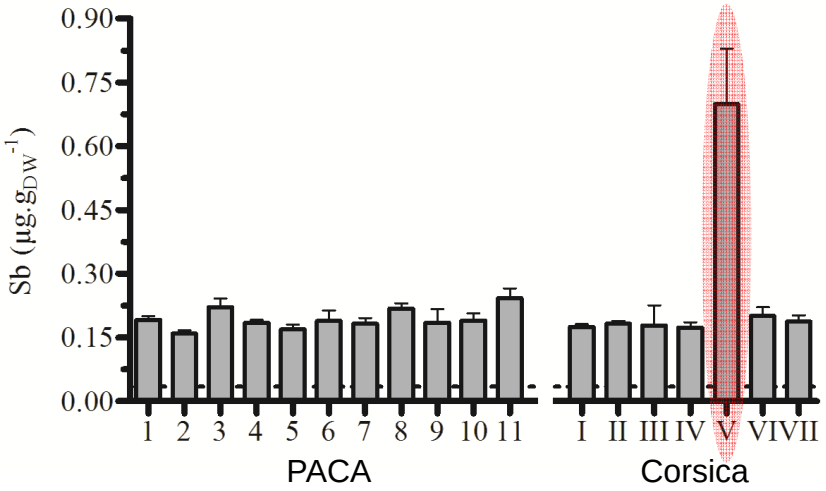

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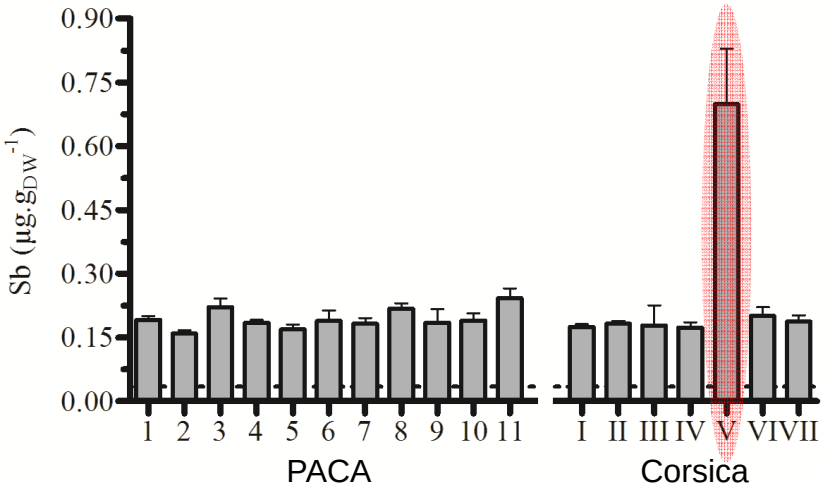

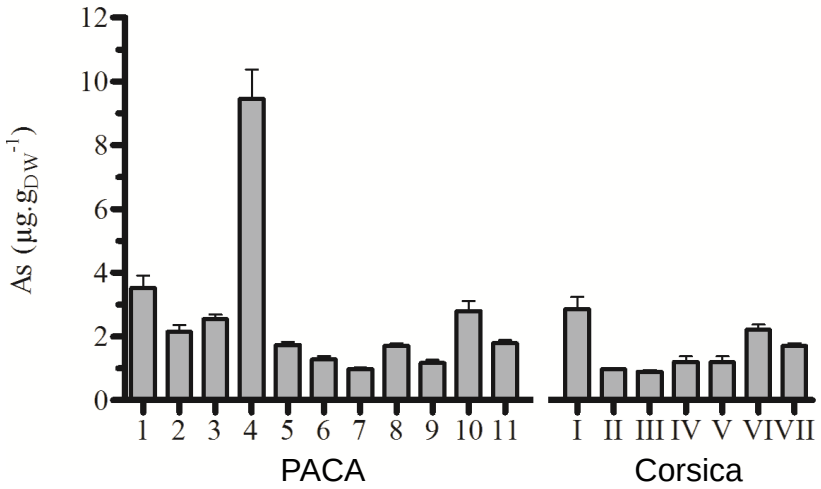

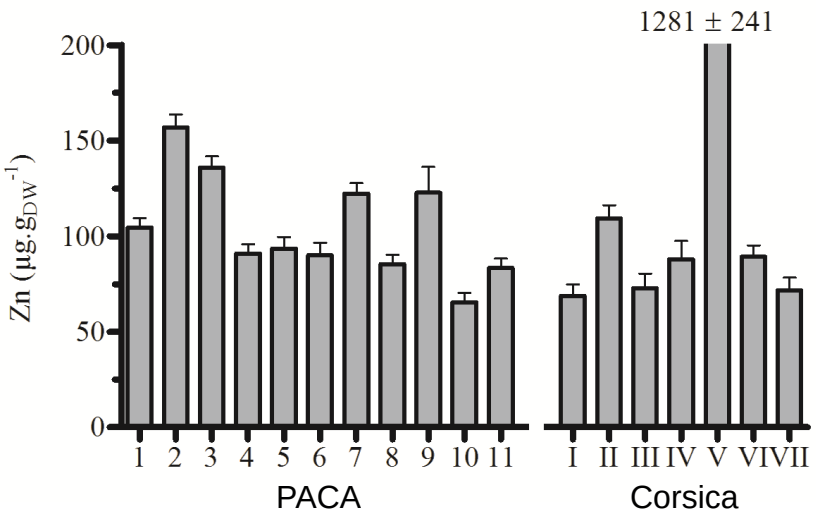

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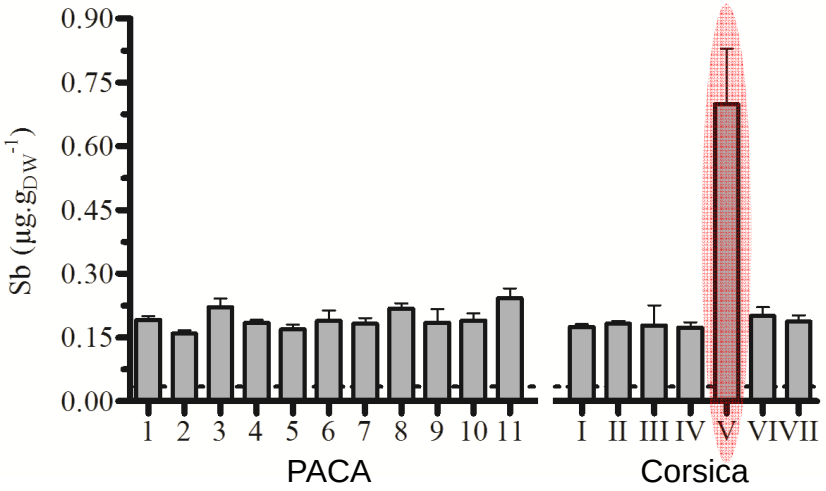
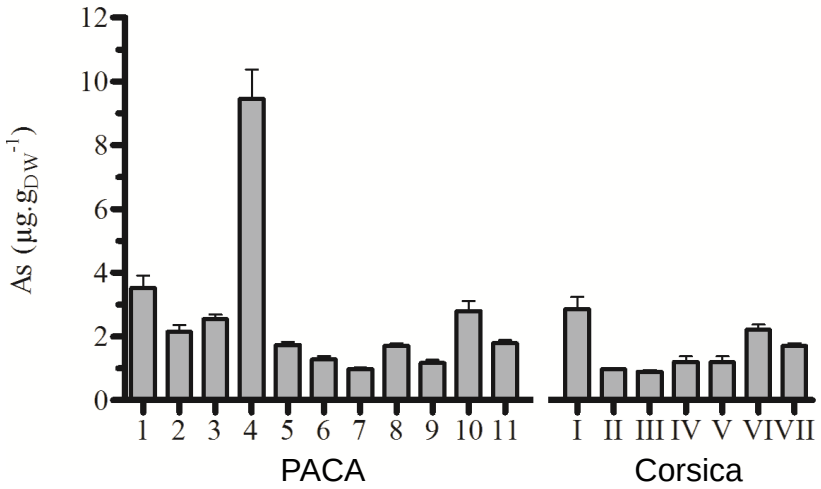
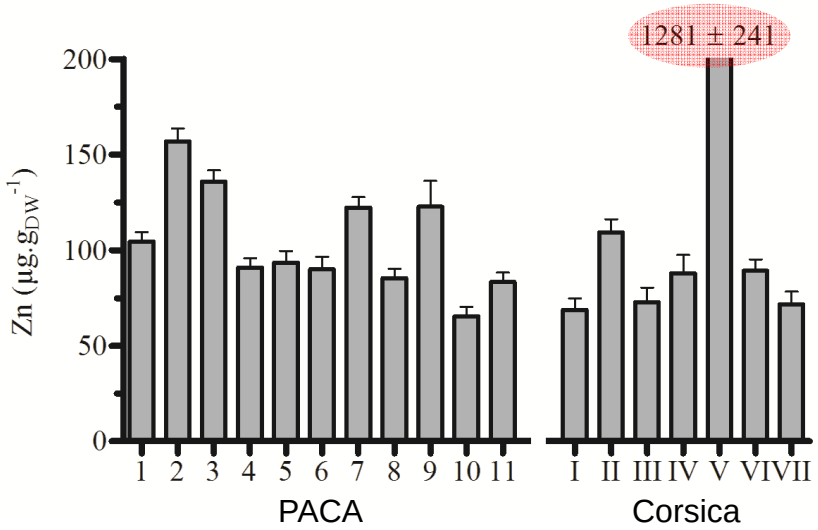
SPATIAL VARIATION







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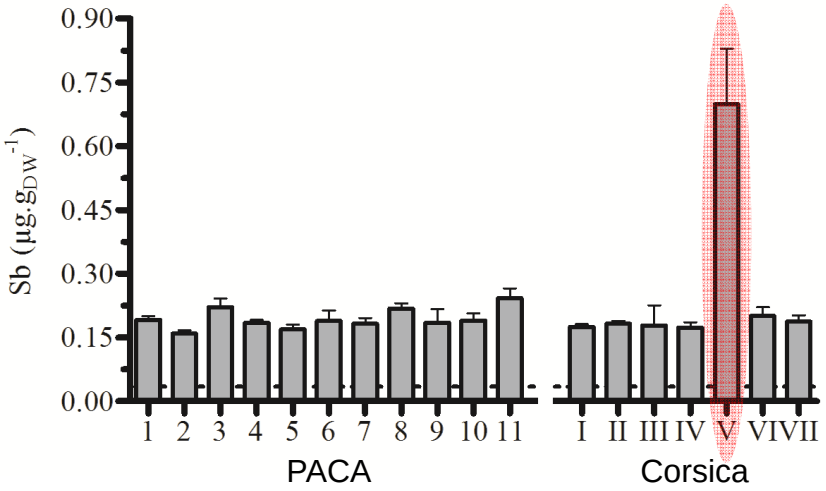

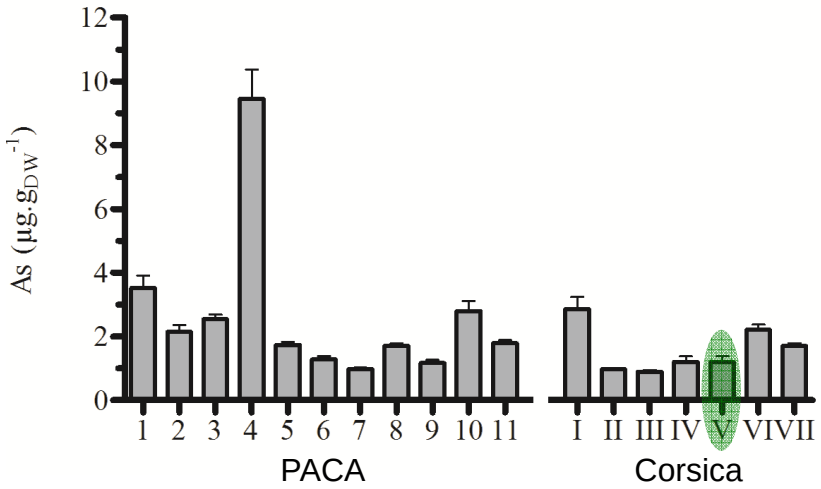

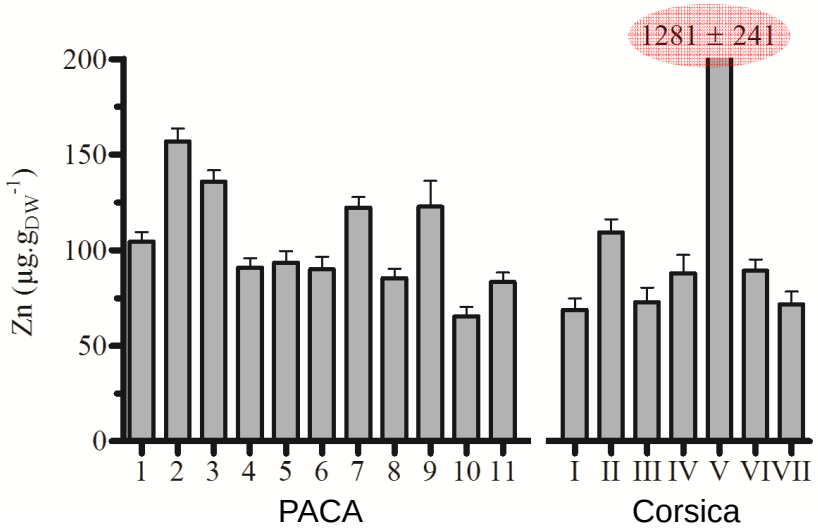

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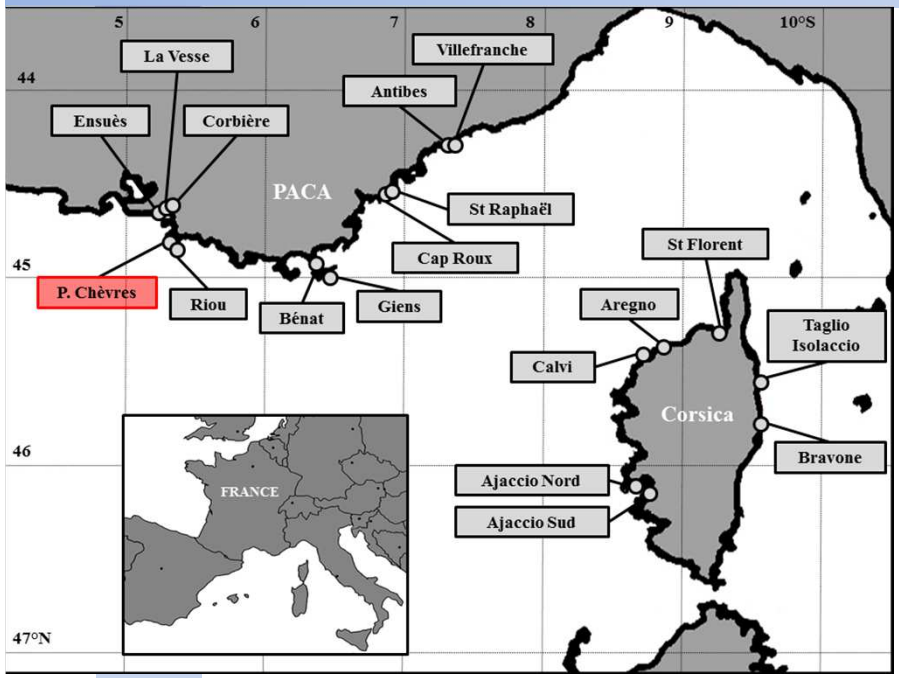
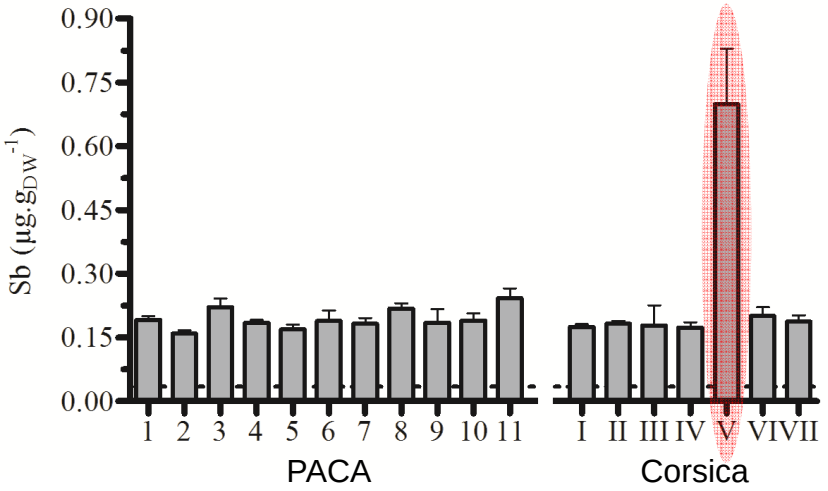
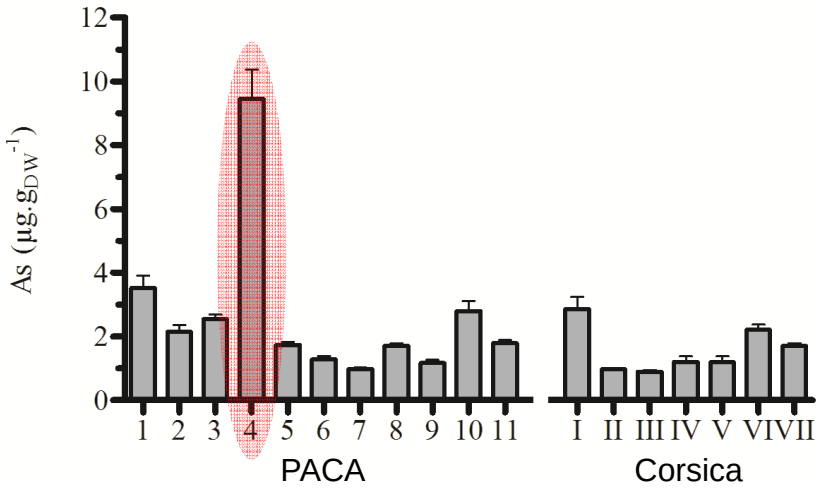
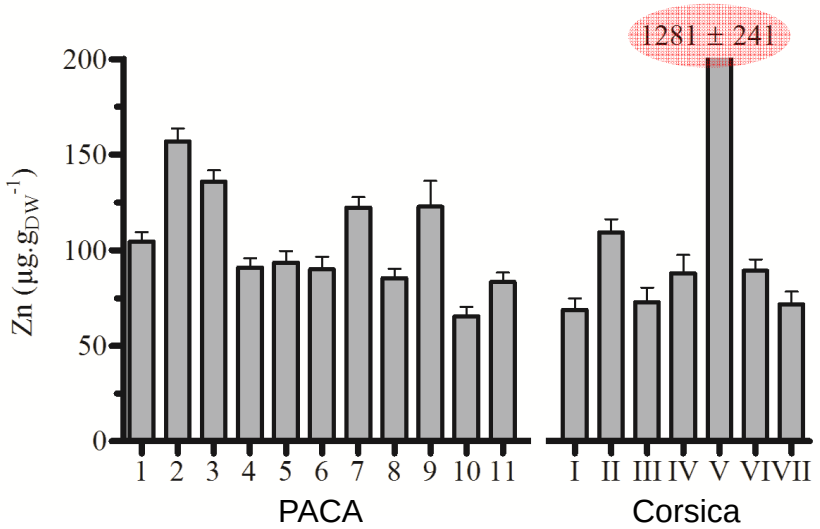
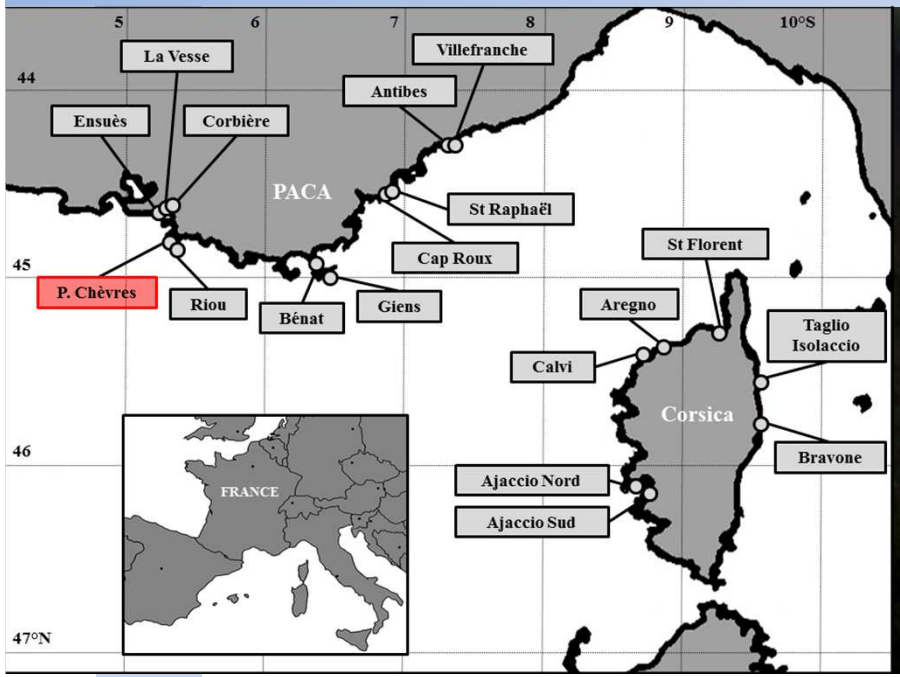


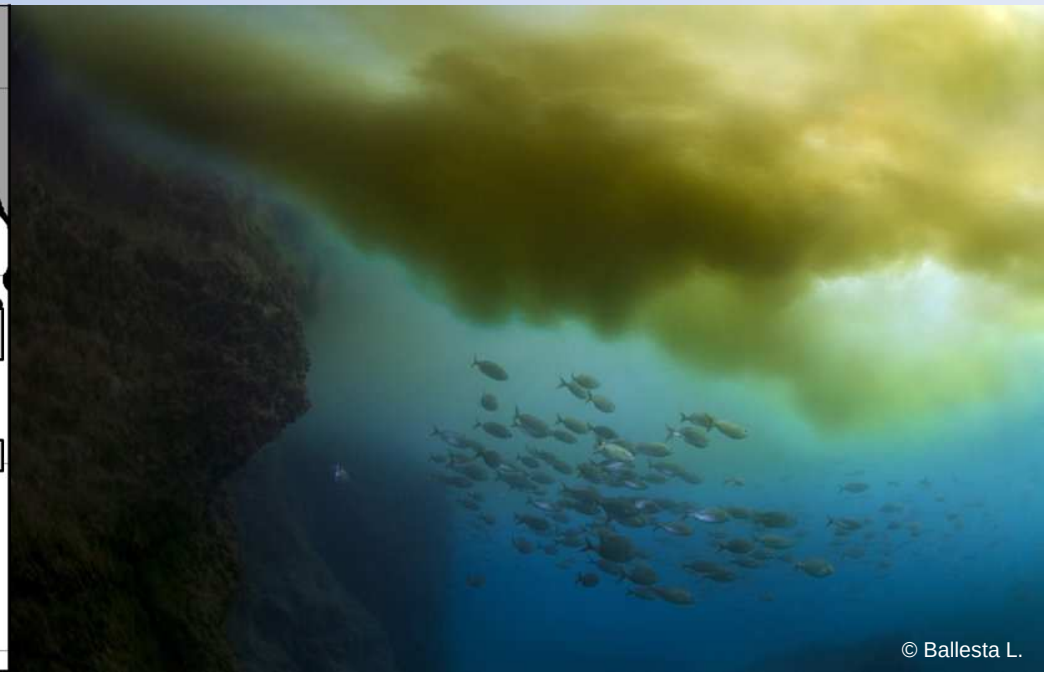


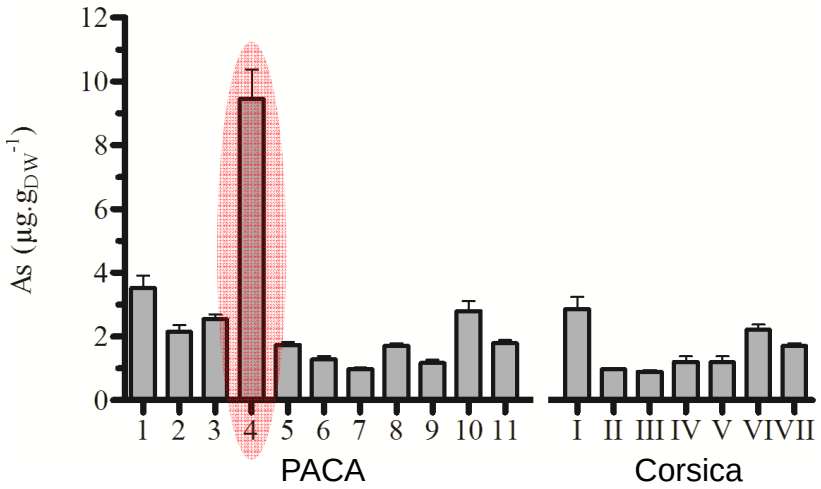




3 - cities and indutries (As, Bi)







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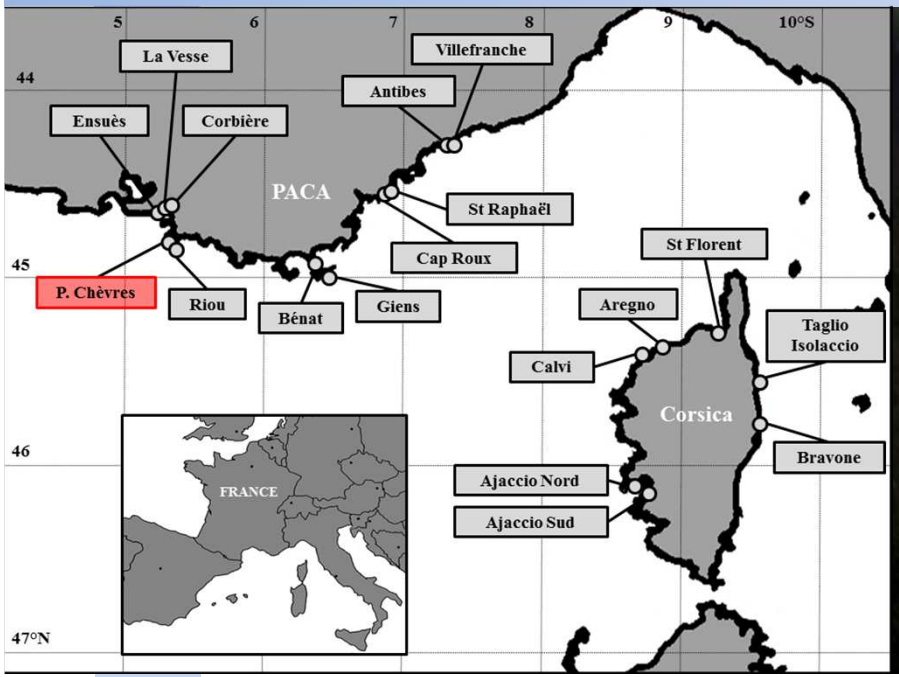

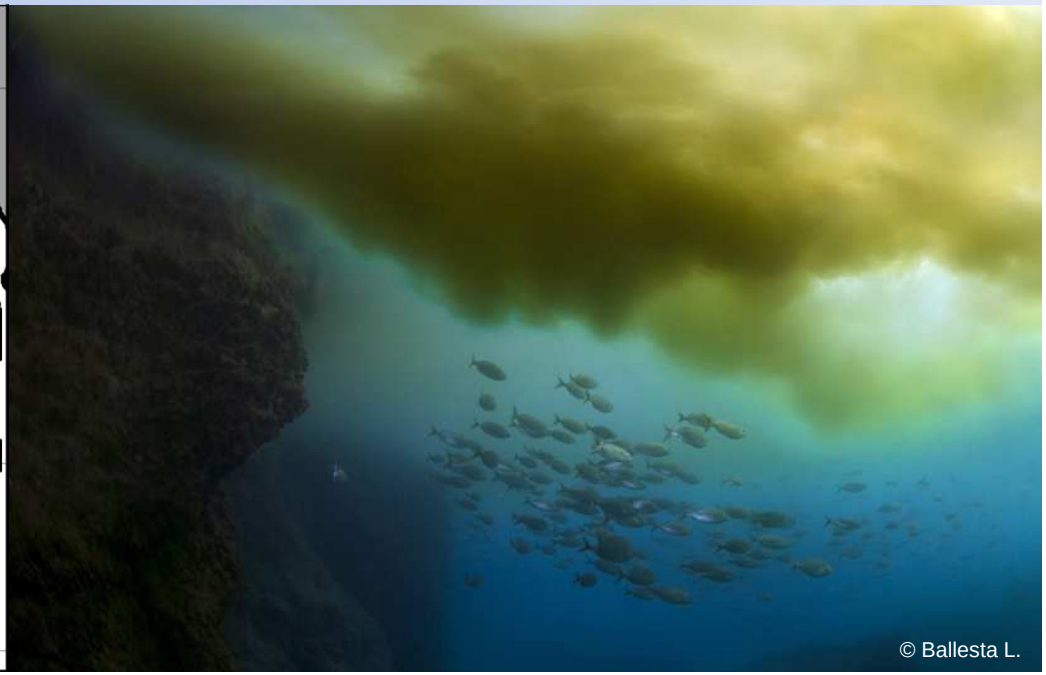

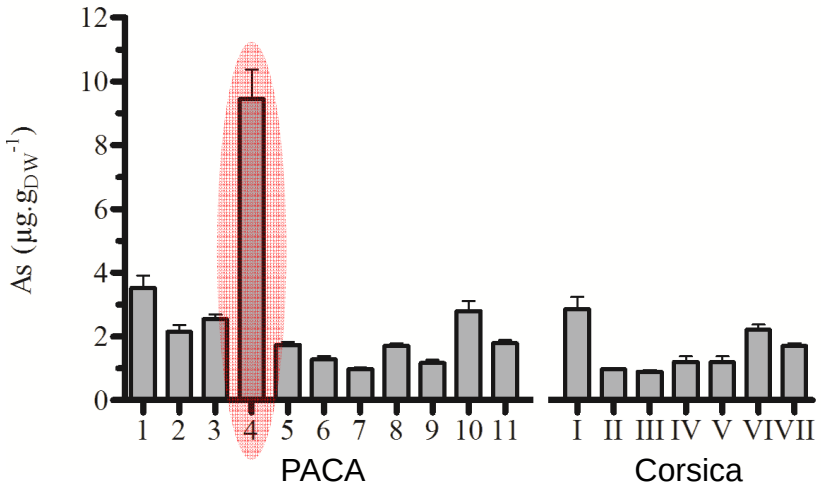

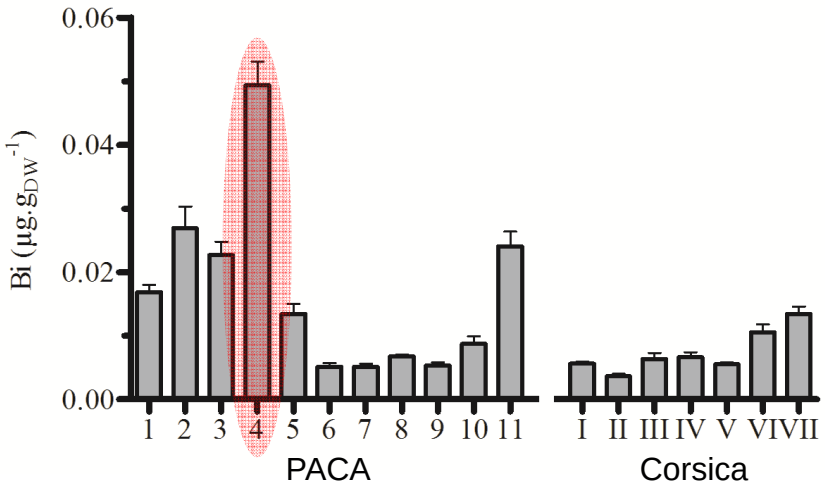

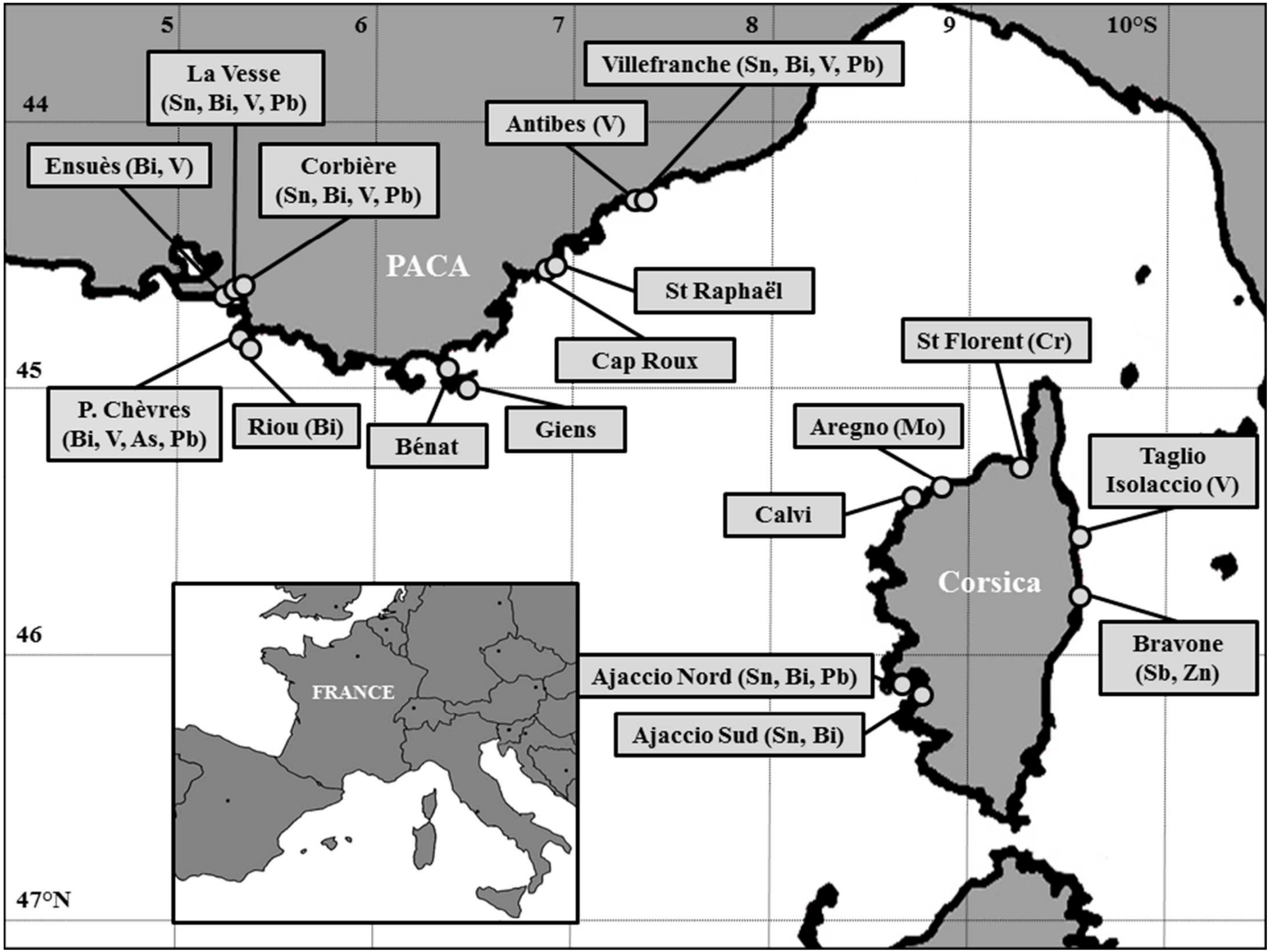
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10°S
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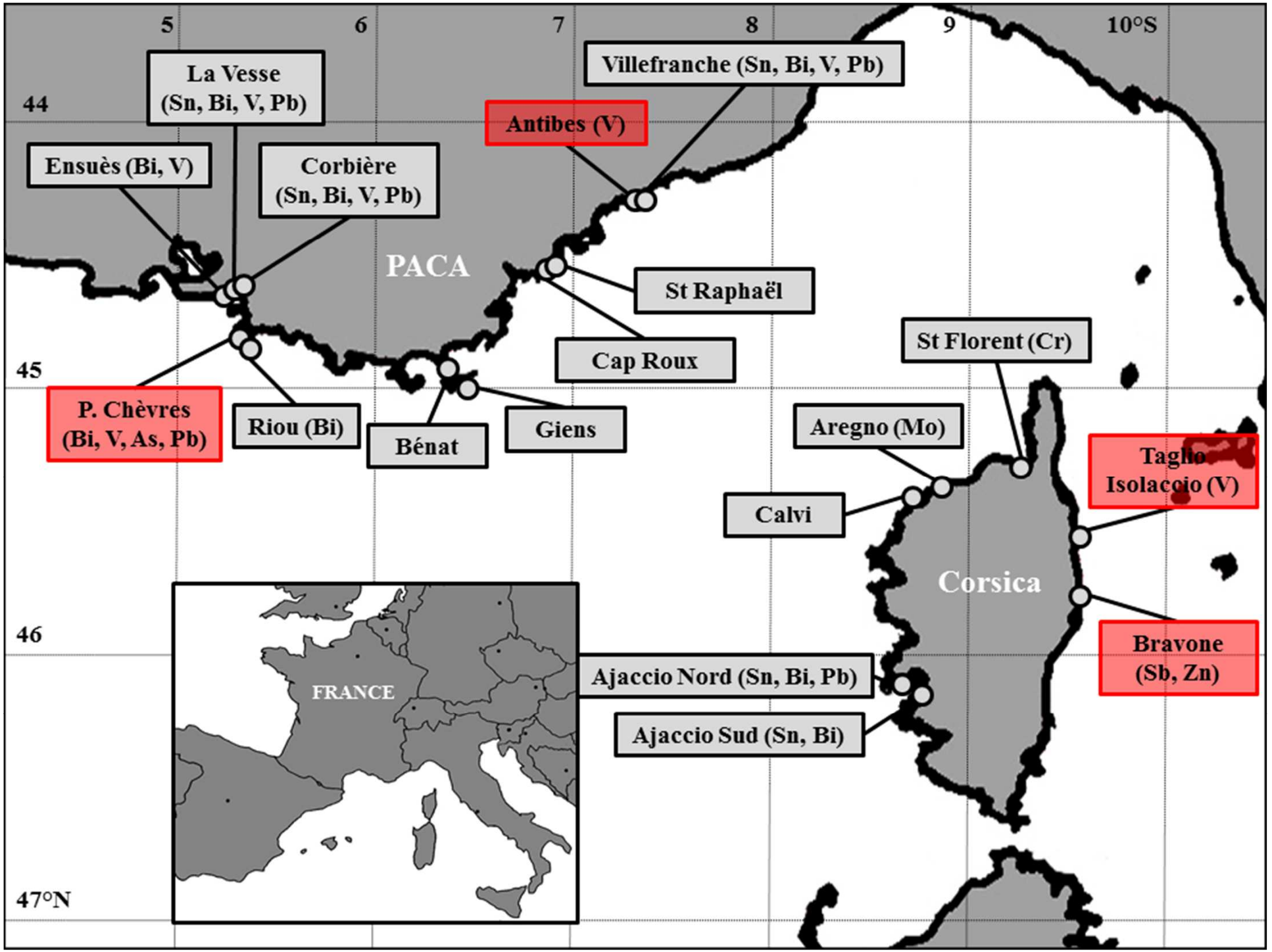
La Vesse
(Sn, Bi, V, Pb)
Villefranche (Sn, Bi, V, Pb)
Antibes (V)
Ensuès (Bi, V)
Corbière
(Sn, Bi, V, Pb)
PACA
St Raphaël
Cap Roux
St Florent (Cr)
P. Chèvres
(Bi, V, As, Pb)
Riou (Bi)
Bénat
Giens
Aregno (Mo)
Taglio
Isolaccio (V)
Calvi
Corsica
Bravone
(Sb, Zn)
FRANCE
Ajaccio Nord (Sn, Bi, Pb)
Ajaccio Sud (Sn, Bi)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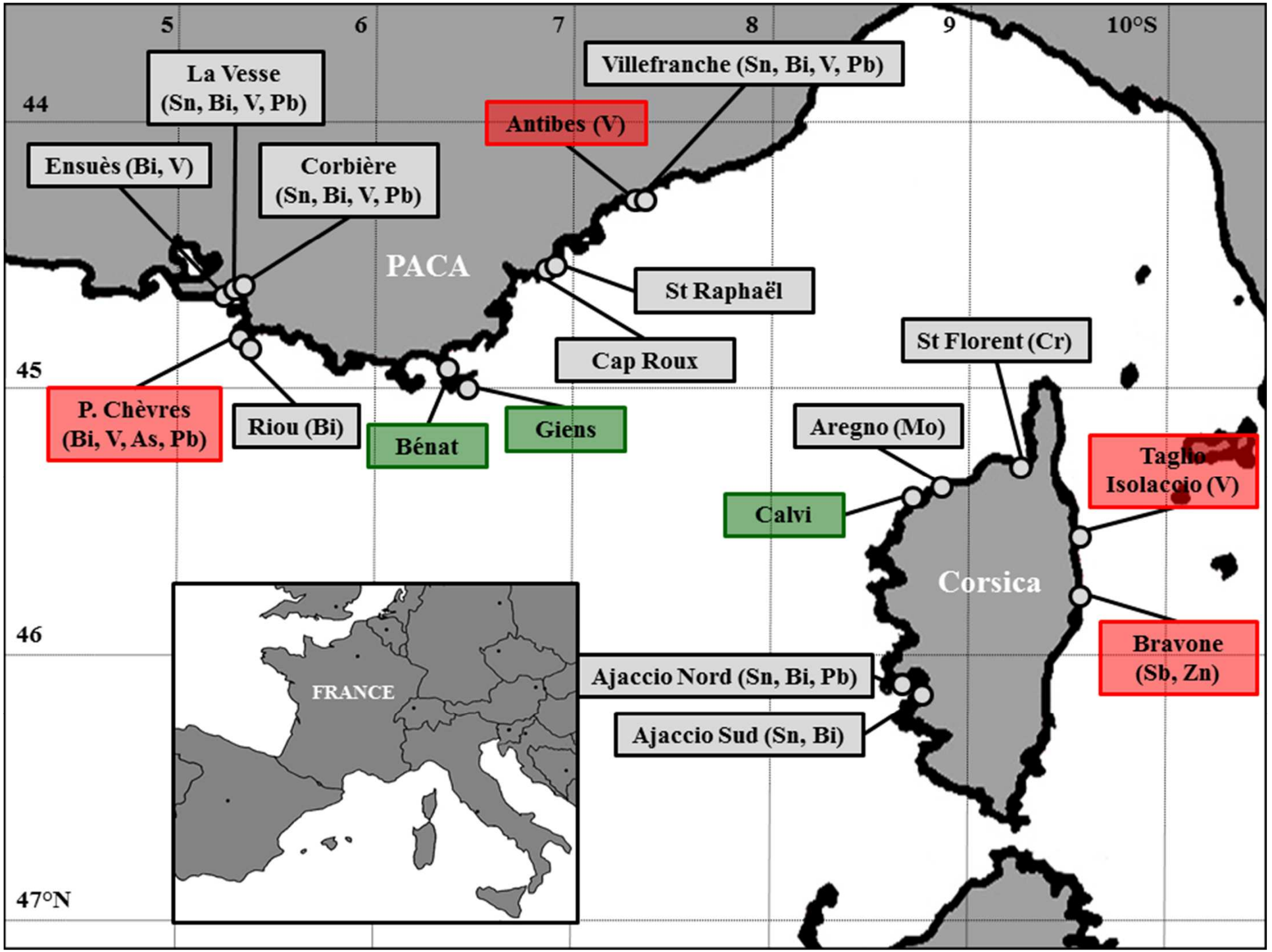
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Conclusions

SPATIAL VARIATION

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→ The French Mediterranean coasts are submitted to local (Sb, V), diffuse (Ag) and/or chronic (As) contaminations by trace elements.

Conclusions

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⟹ The French Mediterranean coasts are submitted to local (Sb, V), diffuse (Ag) and/or chronic (As) contaminations by trace elements.

⟹ trace elements of environmental emerging concern **ARE** of concern.

Conclusions

SPATIAL VARIATION

➟ The French Mediterranean coasts are submitted to local (Sb, V), diffuse (Ag) and/or chronic (As) contaminations by trace elements.

➟ trace elements of environmental emerging concern **ARE** of concern.

➟ Extension of the list of trace elements classically biomonitored to the 19 trace elements studied in this work (multielement analyser such as ICP-MS).

Specific objectives

REFERENCE

1. spatial variation of trace element levels in *P. oceanica* shoots along the French Mediterranean coasts ↔ polluting human activities;
2. definition of conditions/levels of reference for the Northwestern Mediterranean;
3. influence of *P. oceanica* and *M. galloprovincialis* lifestyle on trace element bioaccumulation behaviour;
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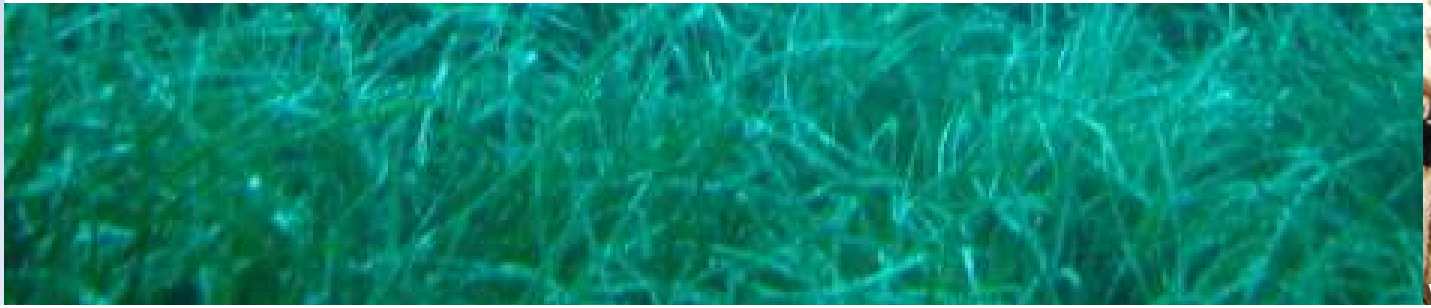

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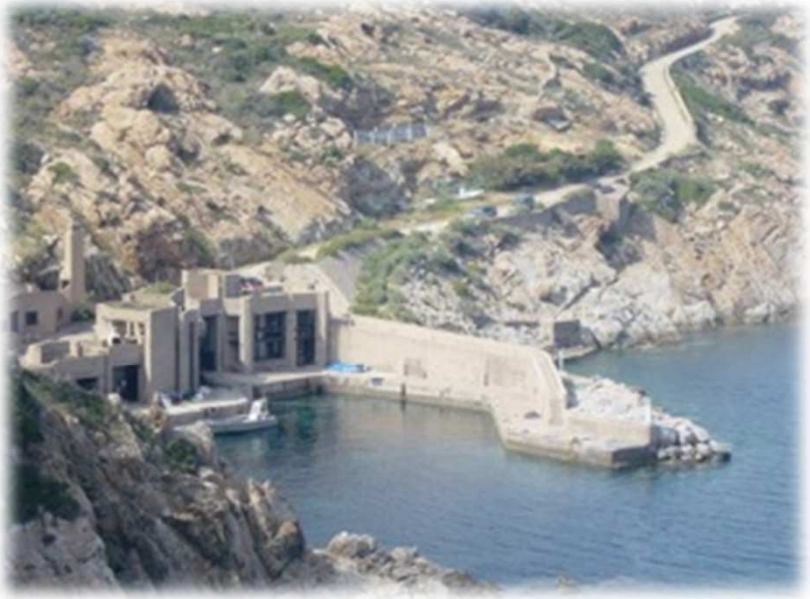
STARESO (Calvi, Corsica)

REFERENCE

STARESO (Calvi, Corsica)

REFERENCE



STARESO

Site of reference for the biomonitoring of the pollution by trace elements in the Northwestern Mediterranean?

REFERENCE

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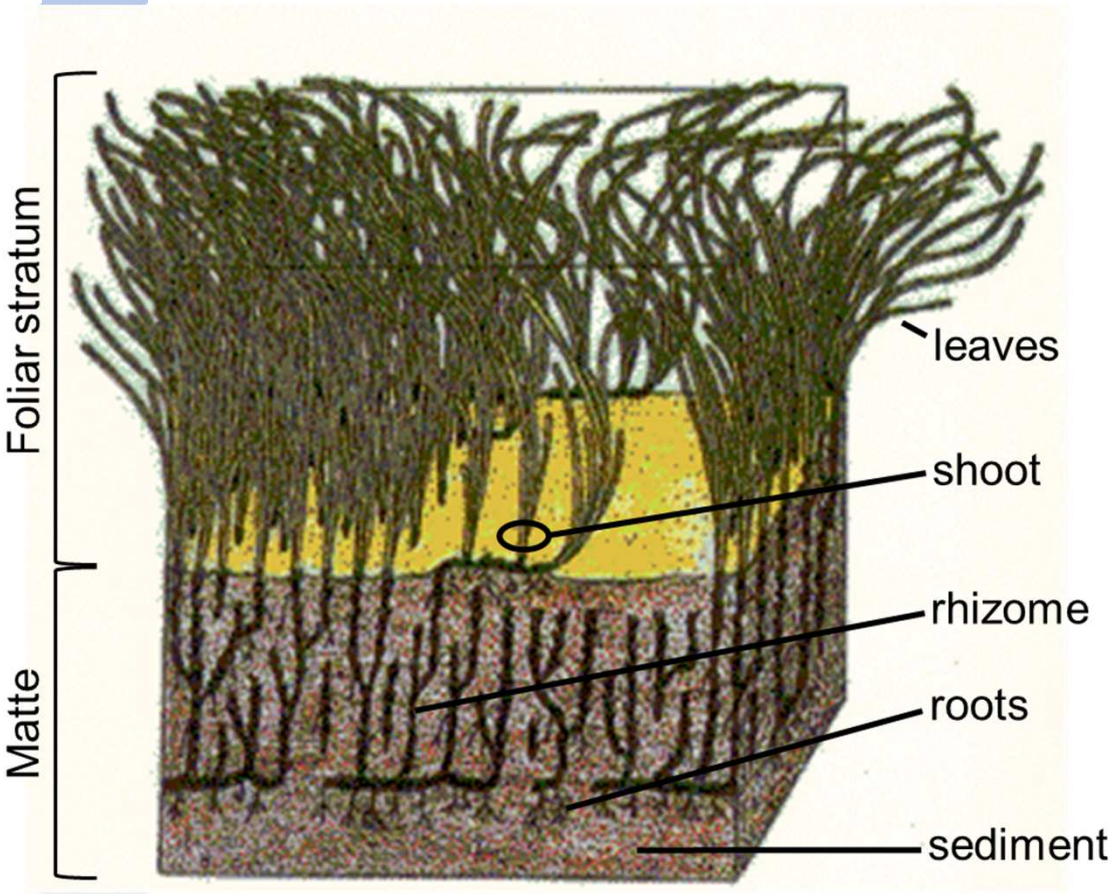

STARESO

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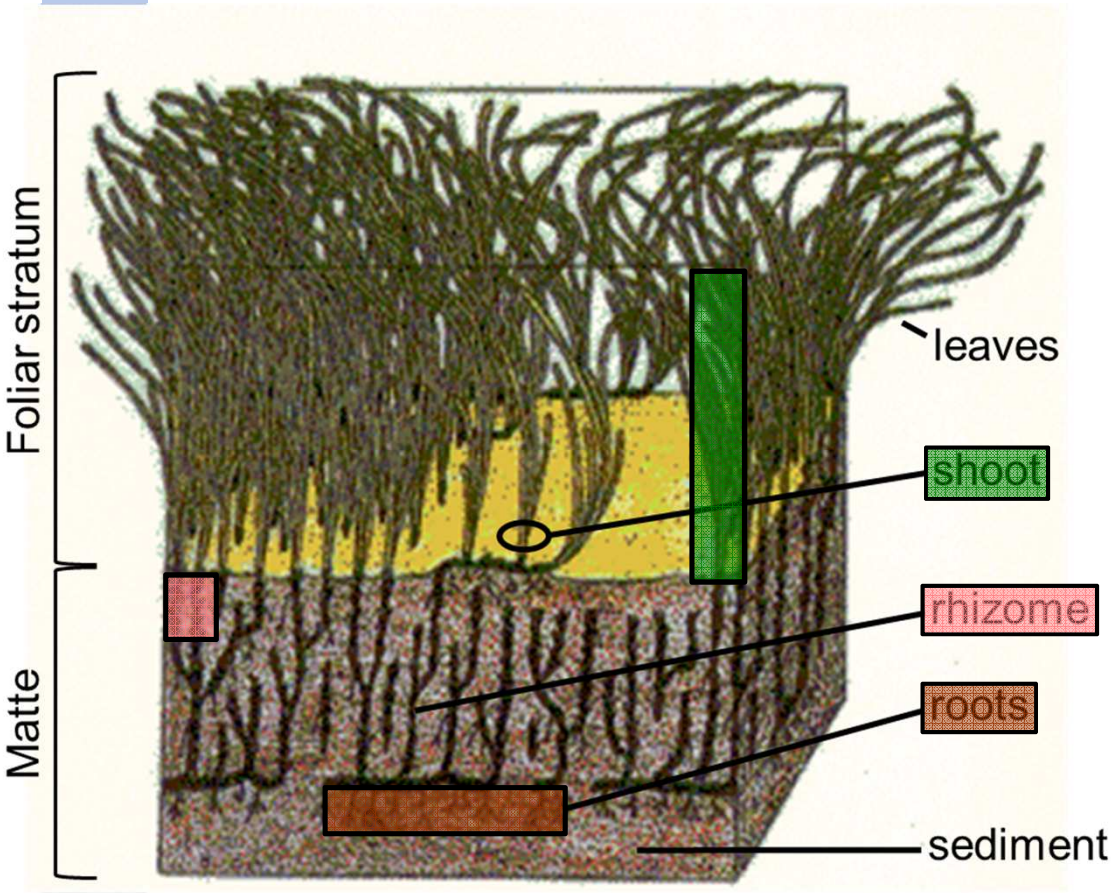
- *P. oceanica* shoots, rhizome and roots;



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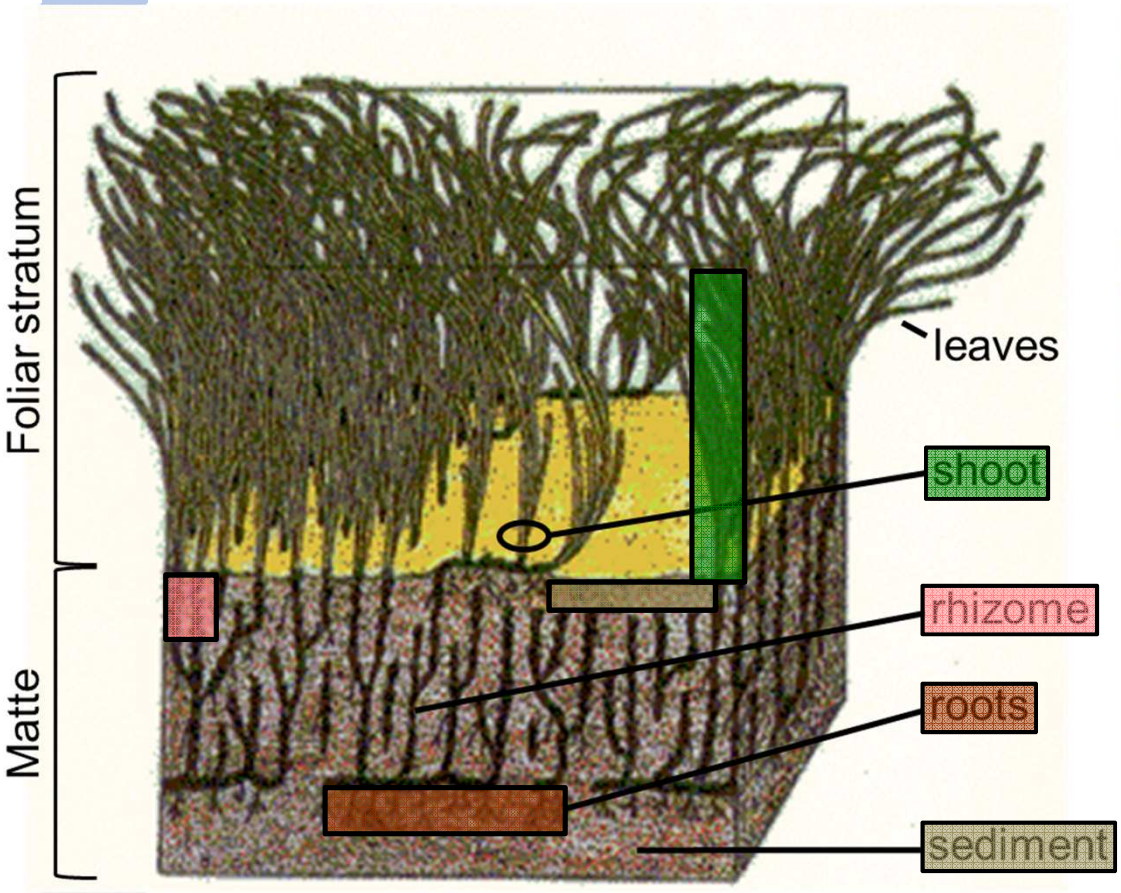
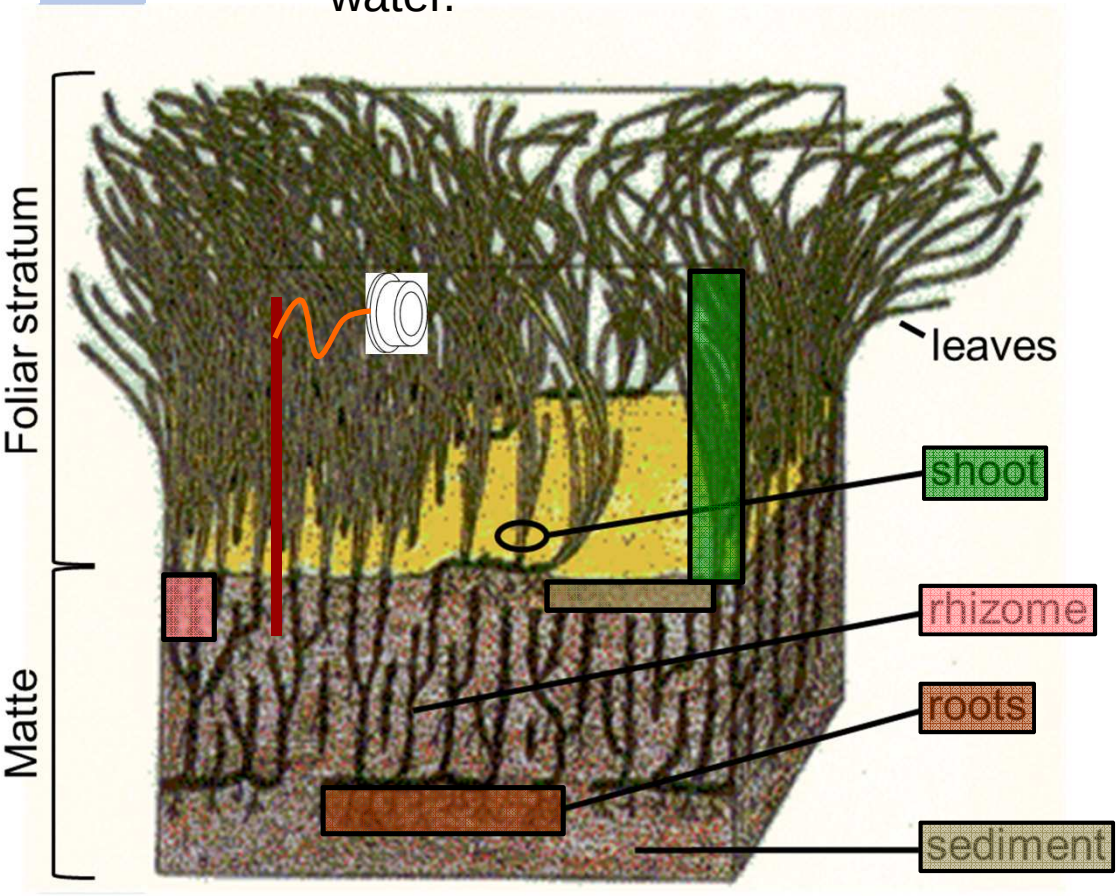


STARESO

Site of reference for the biomonitoring of the pollution by trace elements in the Northwestern Mediterranean?

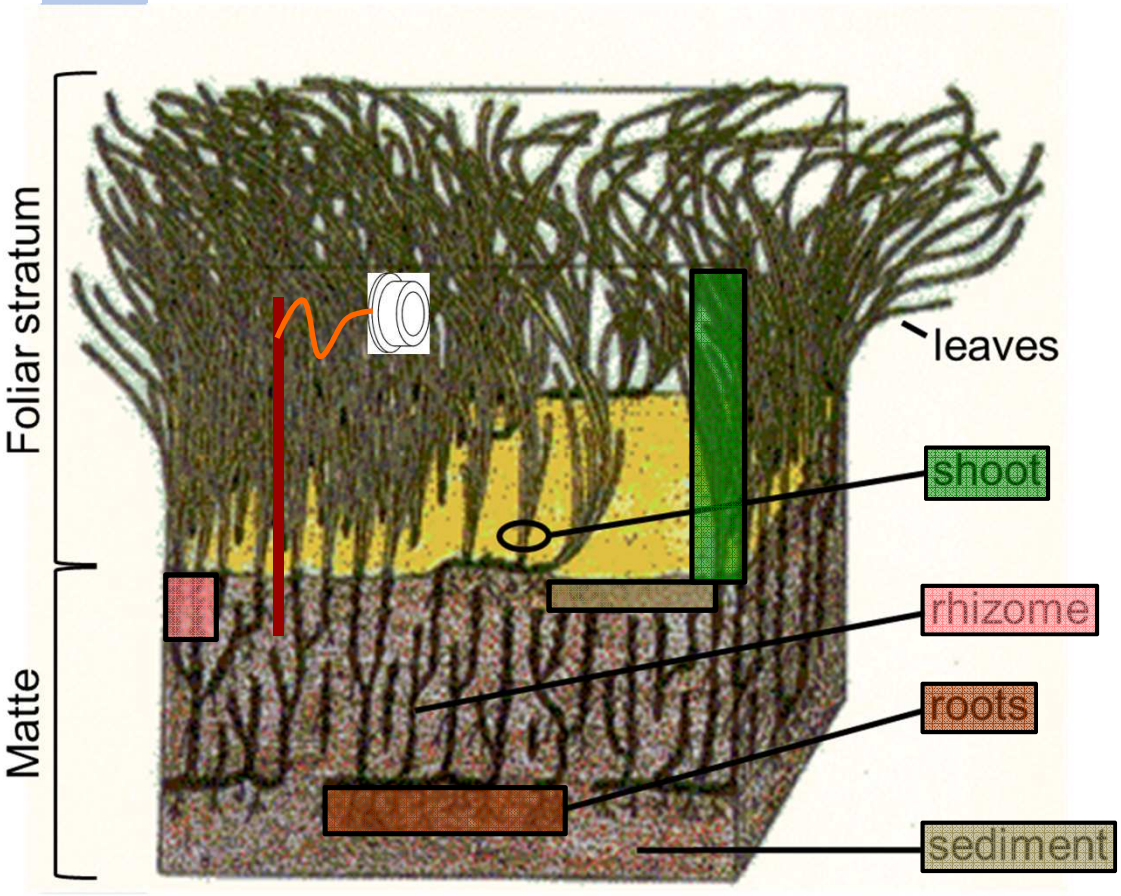
- *P. oceanica* shoots, rhizome and roots;
- superficial sediments;
- water.



STARESO

Site of reference for the biomonitoring of the pollution by trace elements in the Northwestern Mediterranean?

► [trace elements] low to very low → YES: site of reference.



REFERENCE

Trace element concentrations in *P. oceanica* shoots (in $\mu g.g^{-1}_{DW}$)

Site	Pb	Zn	V	Bi	Ref.
Sounion (Greece)					Sanz-Lázaro et al. (2012)
Spanish coasts					Sanchiz et al. (2000)
Favignana Island (Sicily)					Campanella et al. (2001)
Stareso (Corsica)					This study
General mean: French Med. coasts					This study
Maximum: French Med. coasts					This study

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Spanish coasts	1.3	99	-	-	Sanchiz et al. (2000)
Favignana Island (Sicily)	0.9	105	-	-	Campanella et al. (2001)
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Stareso (Corsica)	0.9	70	3.8	0.007	This study
General mean: French Med. coasts	2.1	98	7.2	0.011	This study
Maximum: French Med. coasts	4.8	1282	18.6	0.049	This study

Conclusions

REFERENCE

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→ STARESO = reference site in the Northwestern Mediterranean sub-basin for the monitoring of the pollution by trace elements.

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→ STARESO = “a good reference monitoring site”, as defined in the SeagrassNet Monitoring Manual (Short et al. 2002).

→ STARESO meadow shelter an abundant, complex and diverse community of amphipod crustaceans (Michel 2011, Sturaro 2012).

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BIOACCUMULATION

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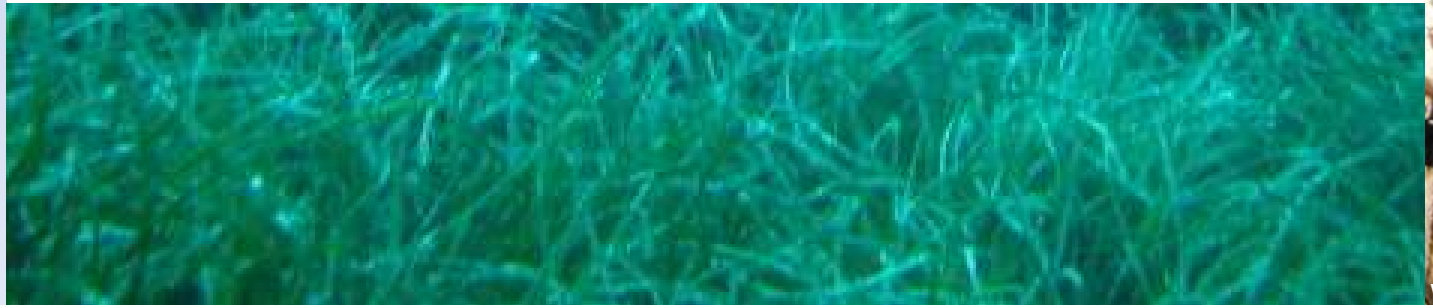


P. oceanica vs. *M. galloprovincialis*

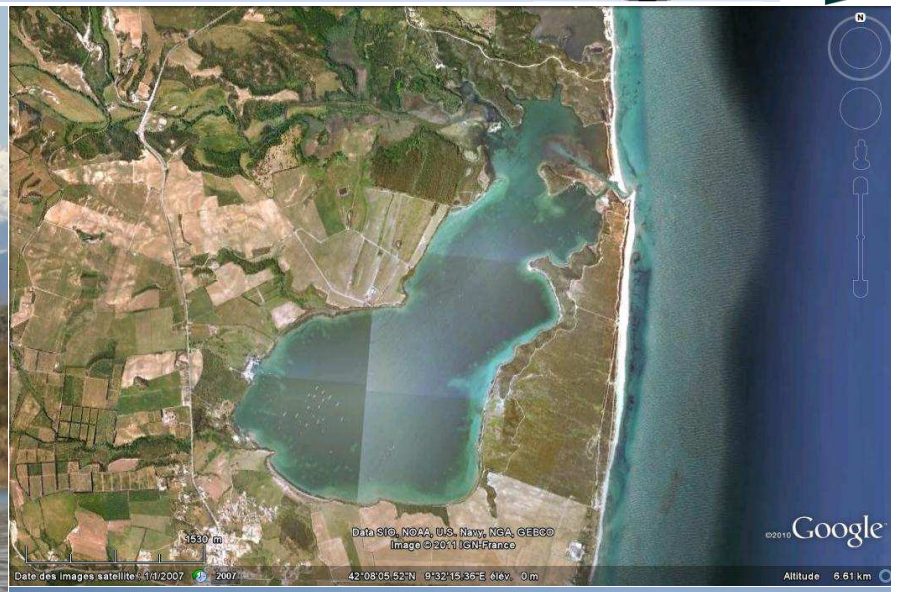
BIOACCUMULATION

P. oceanica vs. *M. galloprovincialis*

BIOACCUMULATION

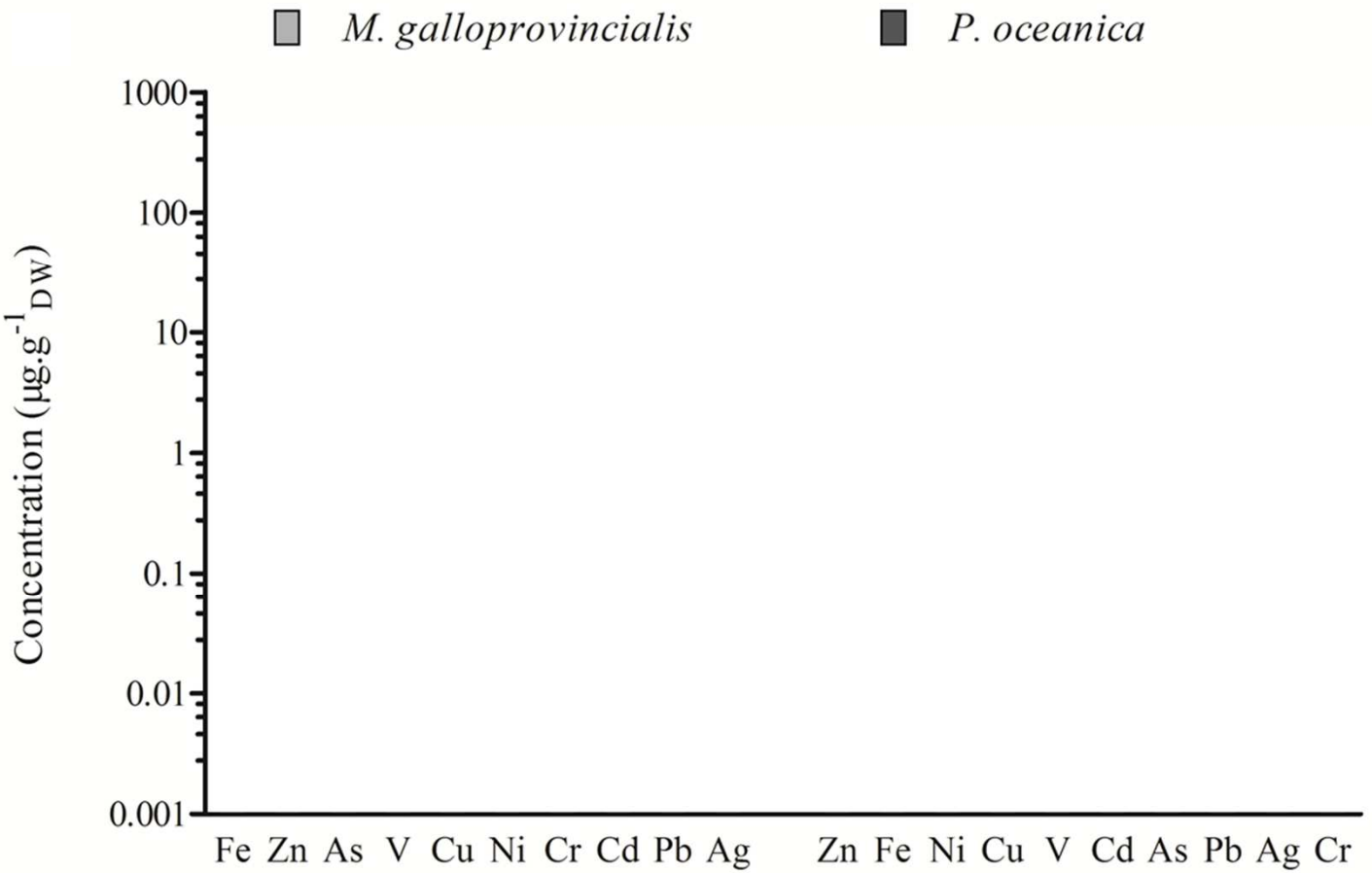
Diane pond

BIOACCUMULATION



Trace elements broadly studied

BIOACCUMULATION



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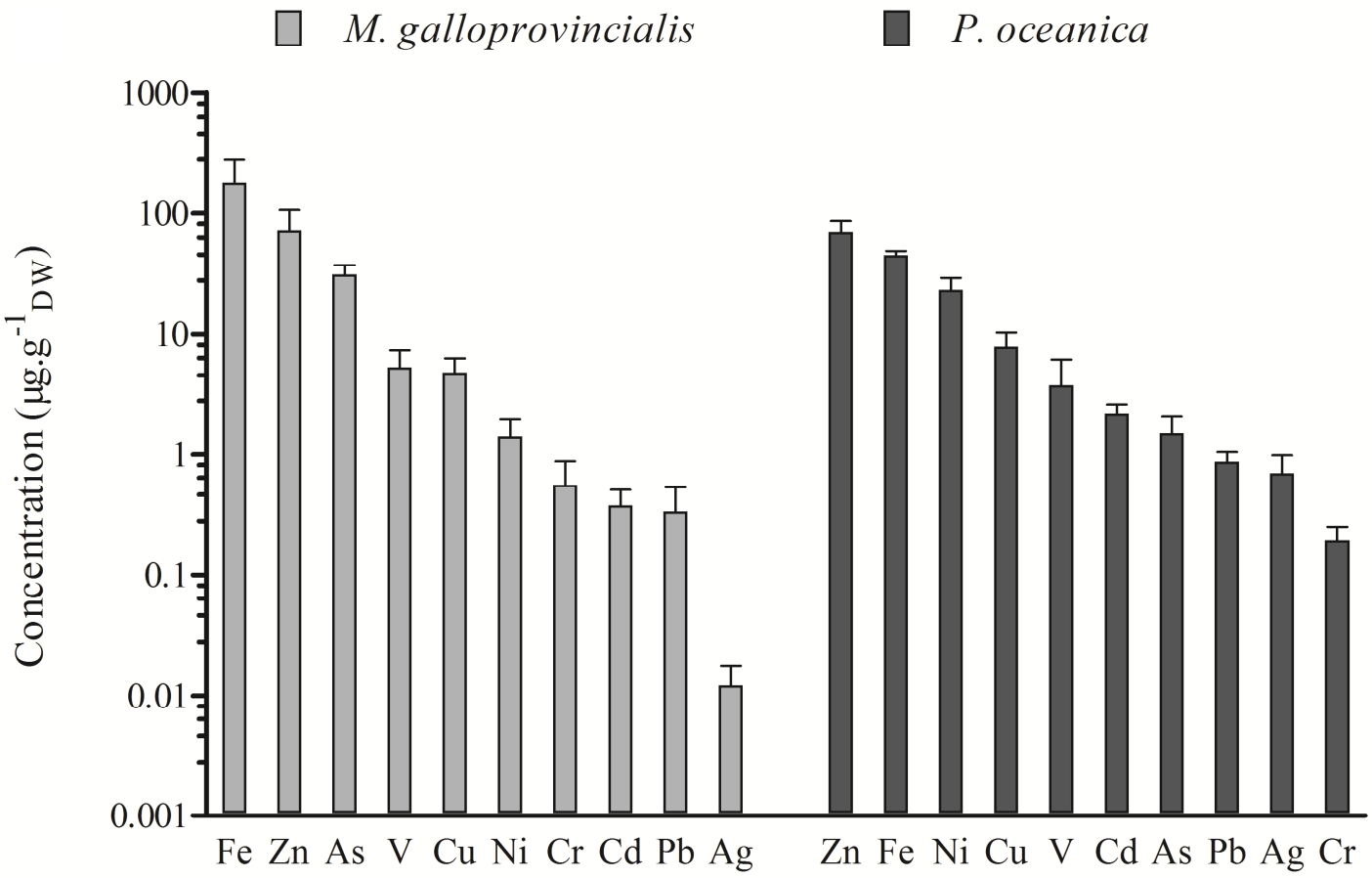
BIOACCUMULATION



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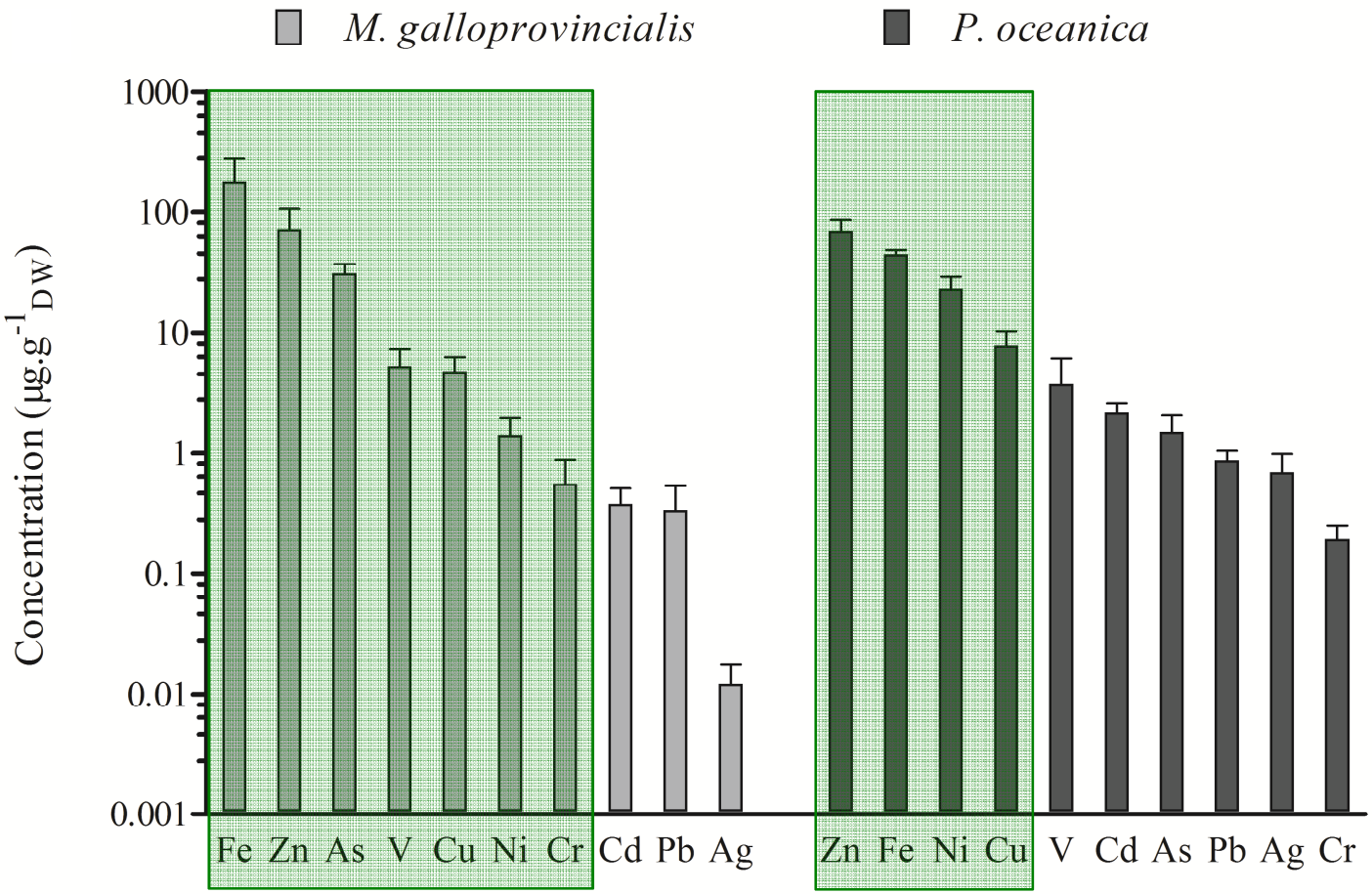
BIOACCUMULATION



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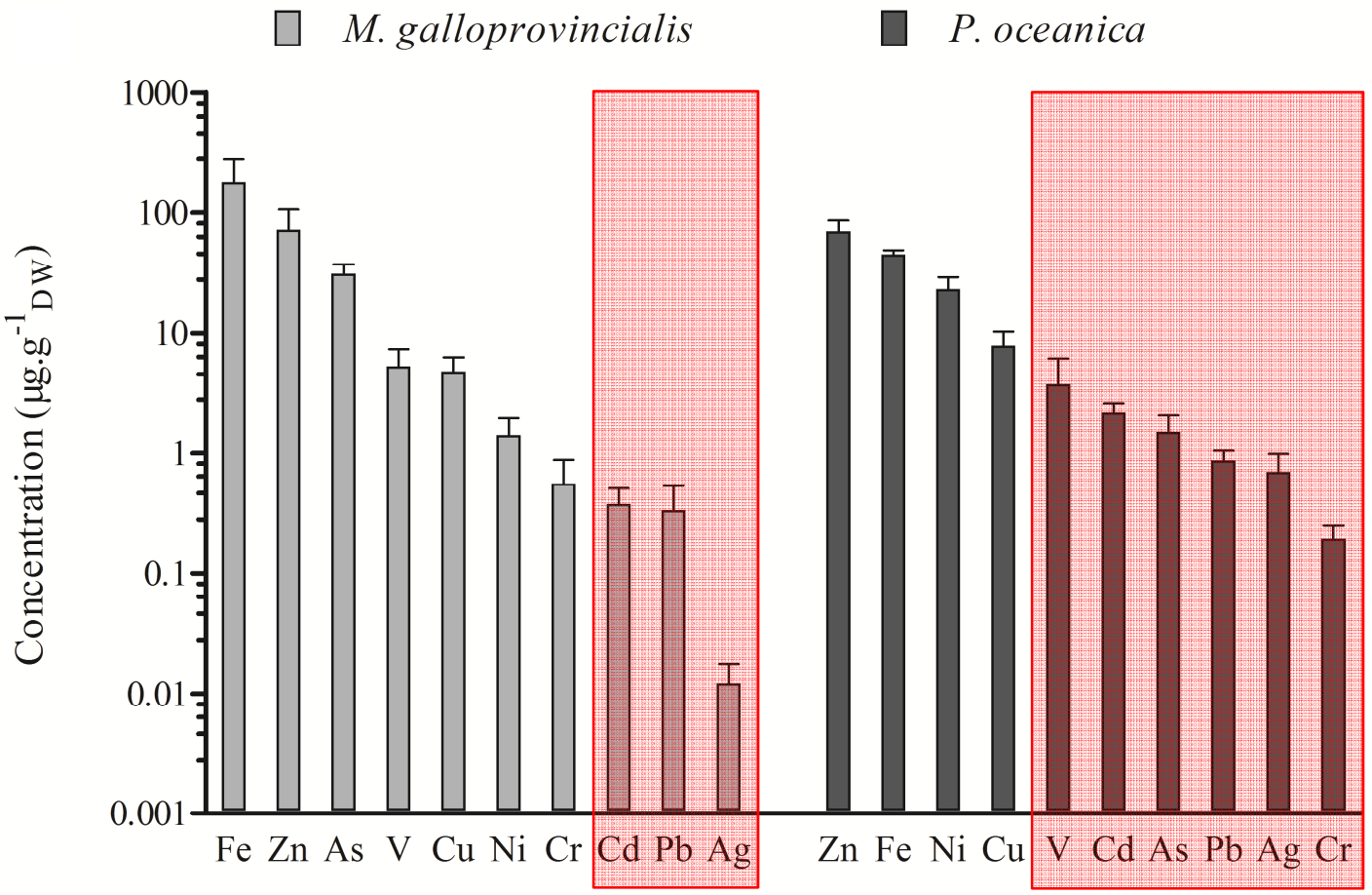
BIOACCUMULATION



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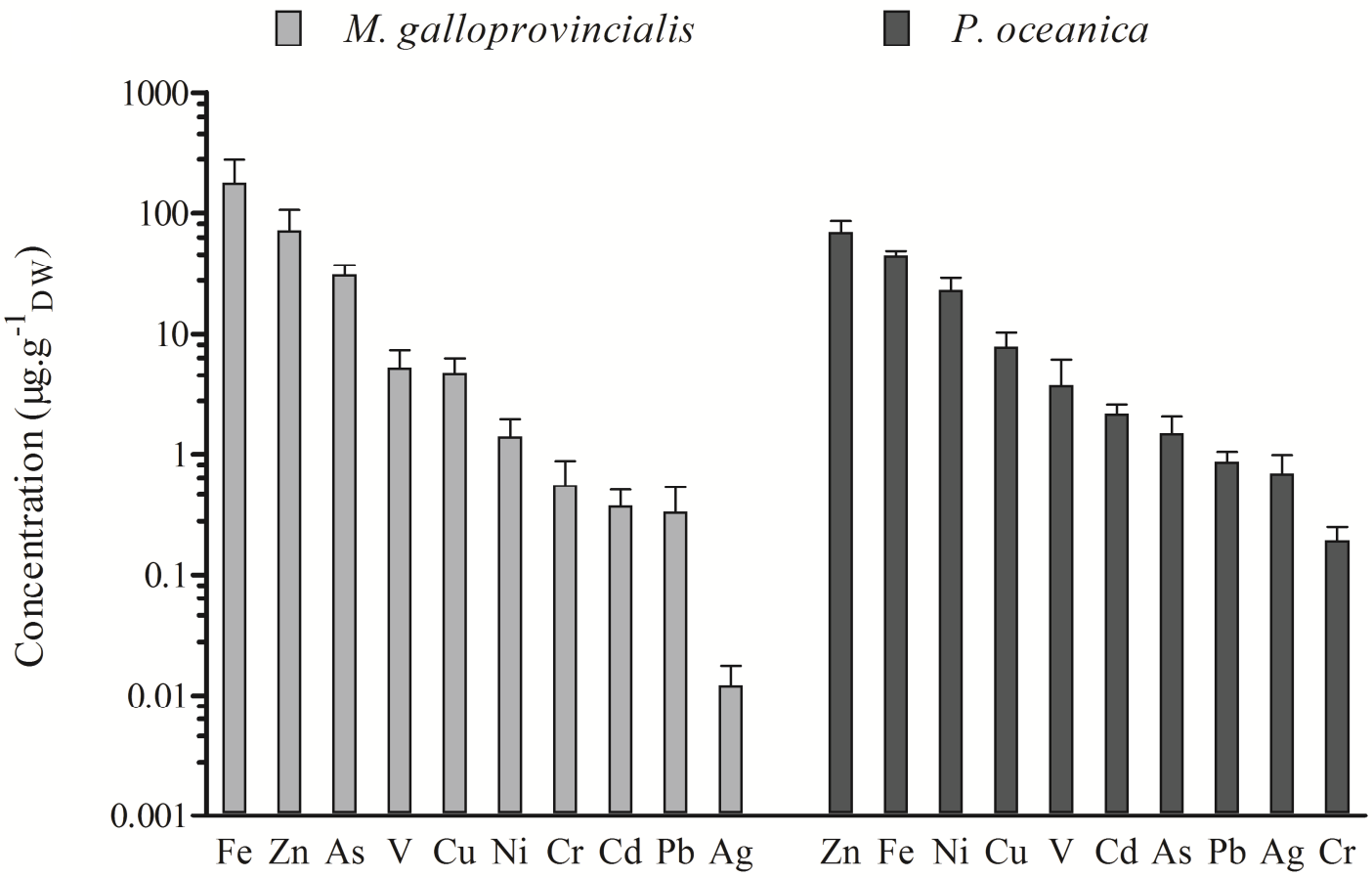
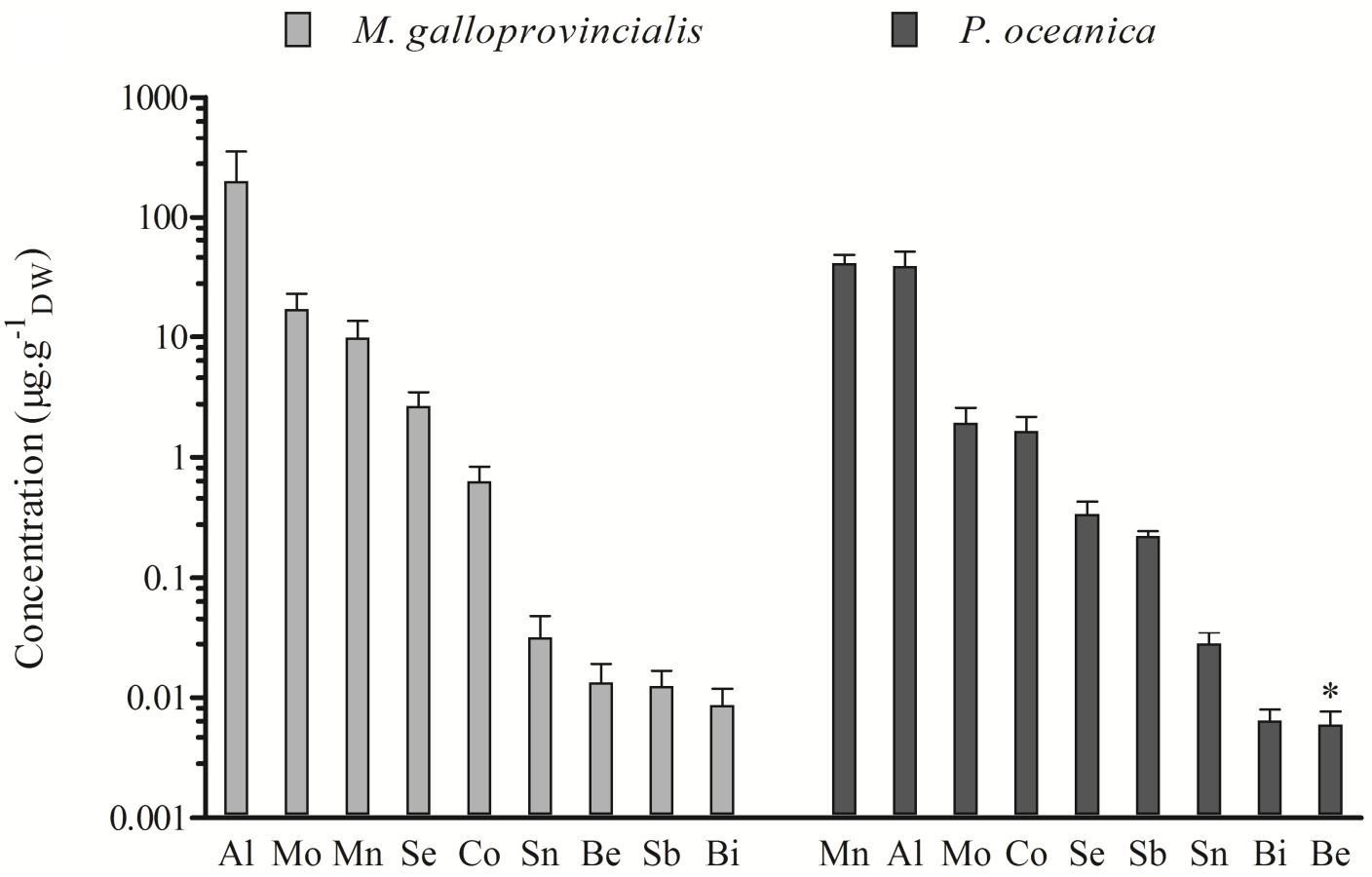


Bioaccumulation factors from seawater to:

- *M. galloprovincialis* = 2.7 10^4
- *P. oceanica* = 2.5 10^4

Trace elements little monitored

BIOACCUMULATION



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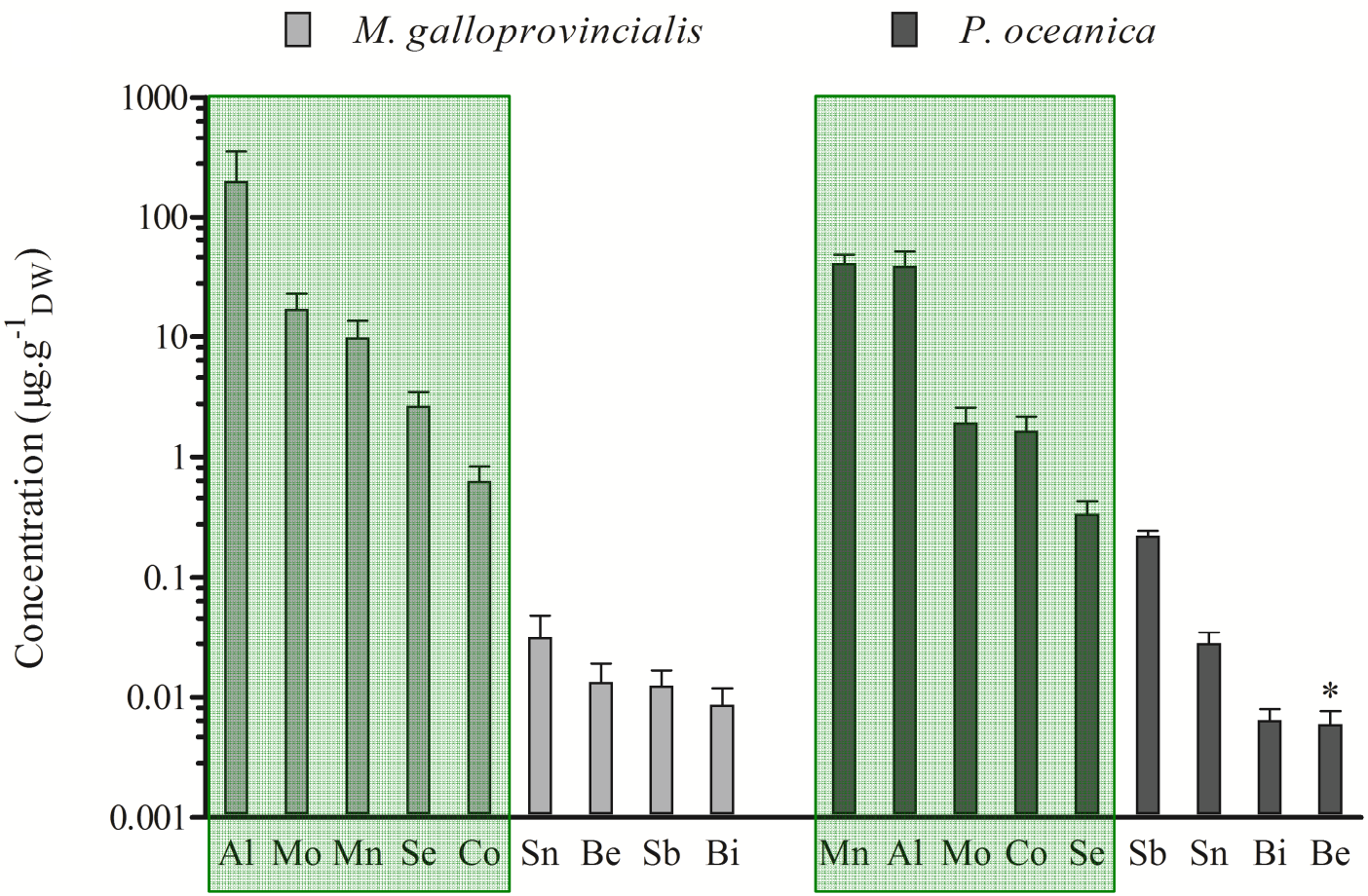

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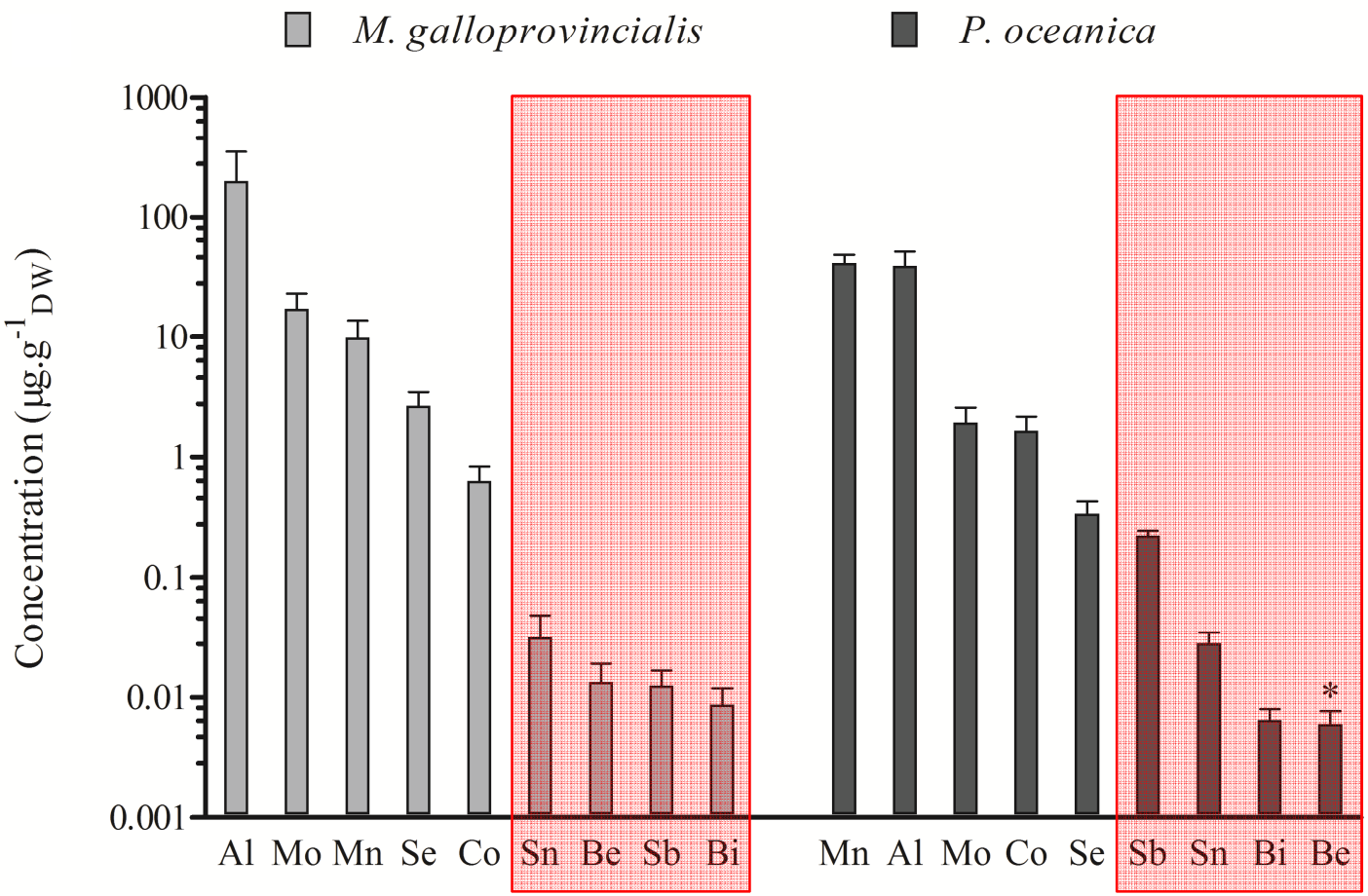
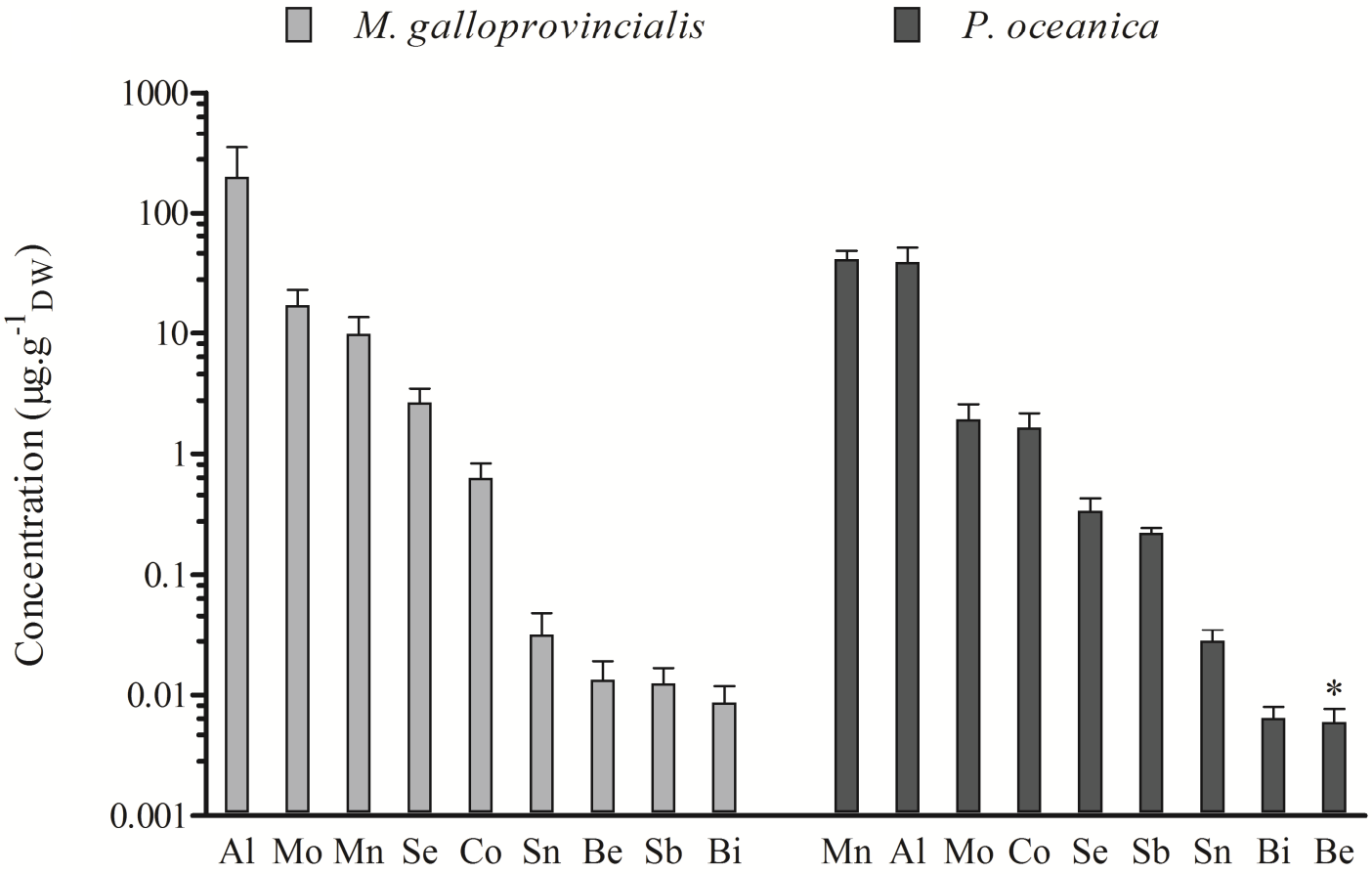


Trace elements little monitored

BIOACCUMULATION

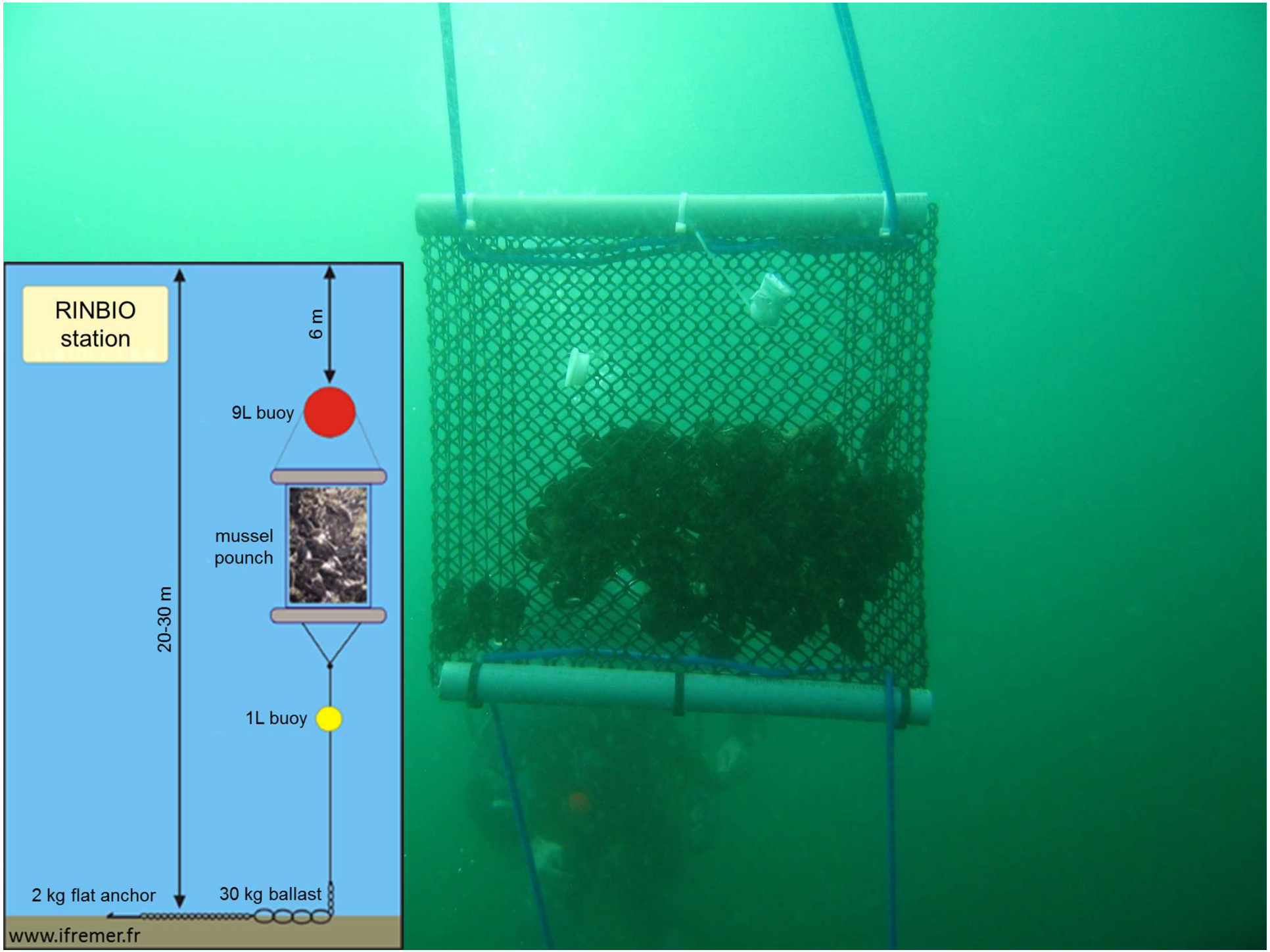


Bioaccumulation factors from seawater to:

- *M. galloprovincialis* = 5.2 10^4
- *P. oceanica* = 3.1 10^4

Mussel caging

BIOACCUMULATION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9L buoy
mussel
pounch
20-30 m
1L buoy
2 kg flat anchor
30 kg ballast
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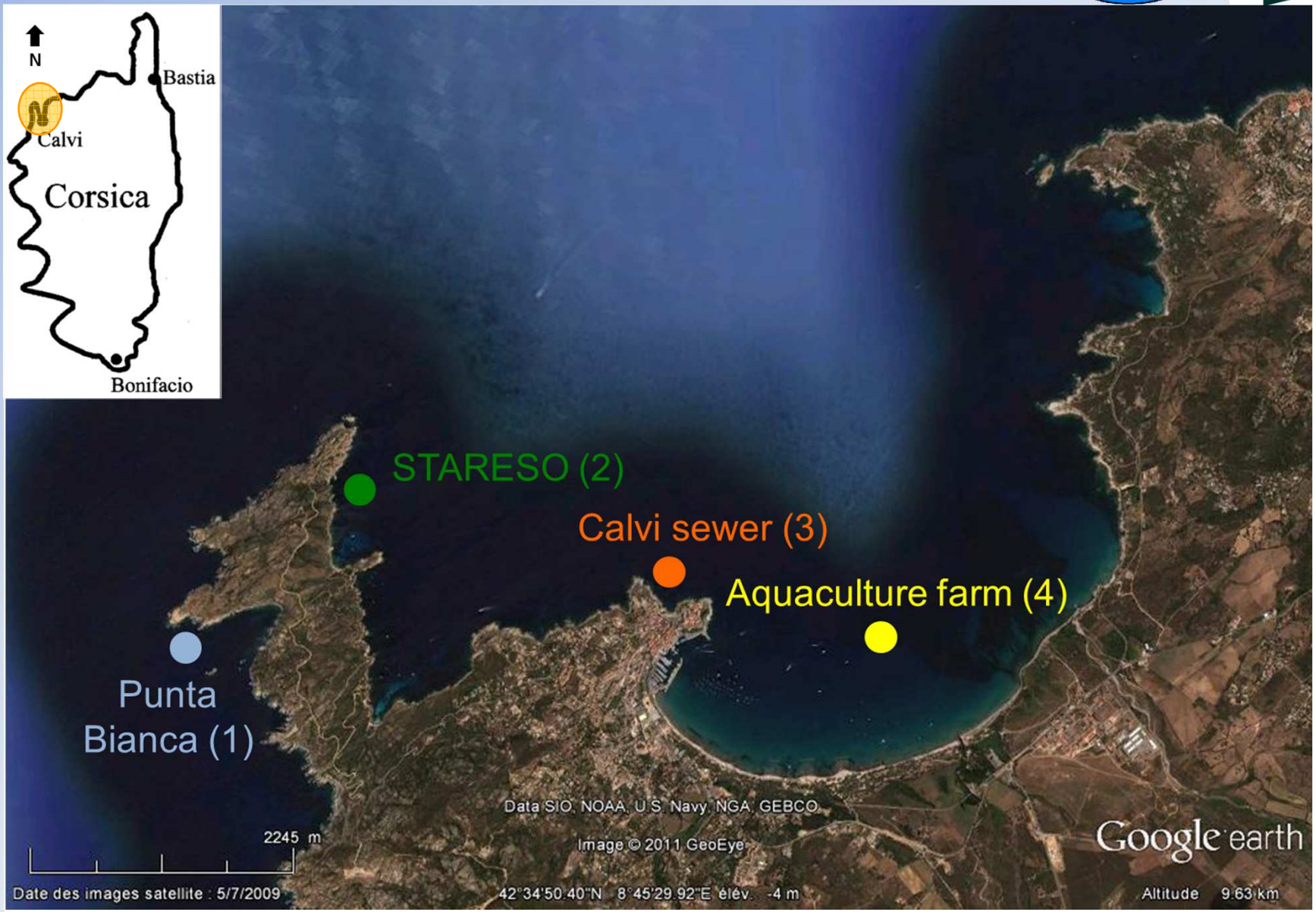
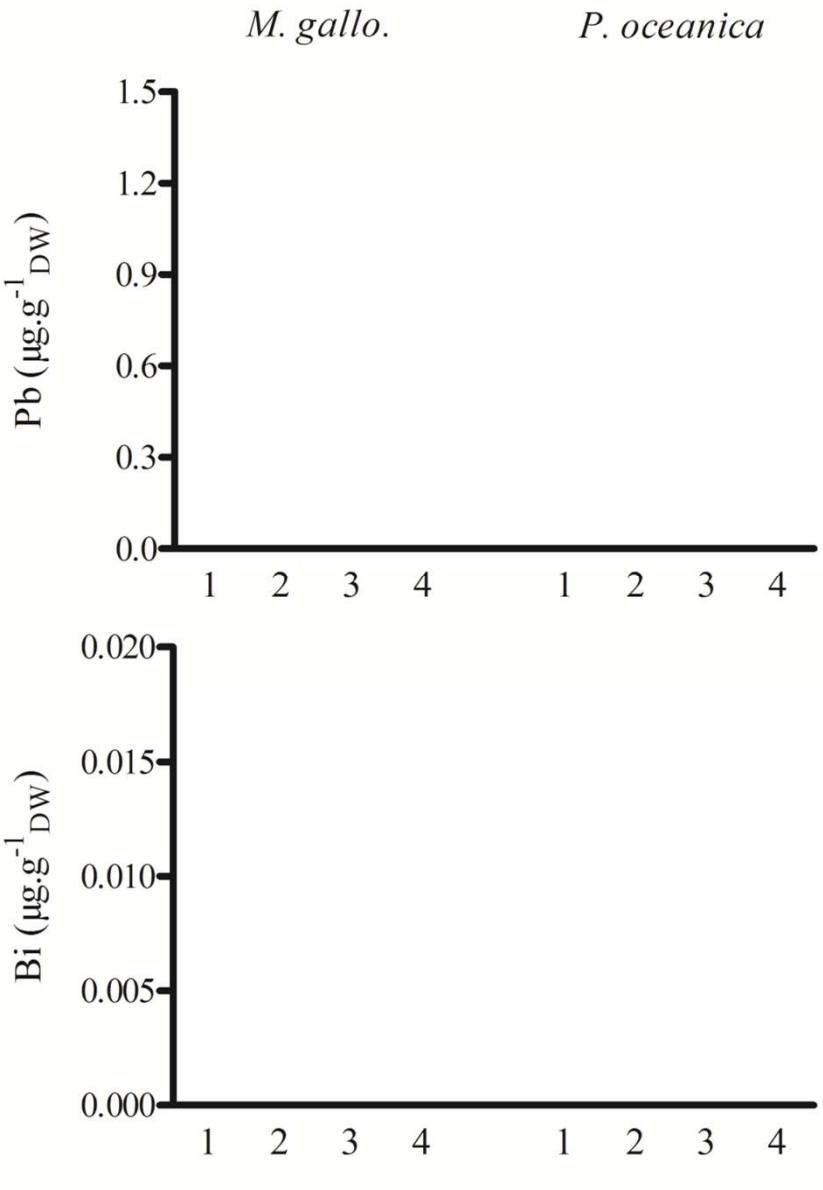
Mussel caging

BIOACCUMULATION



Mussel caging

Lifestyle of organisms

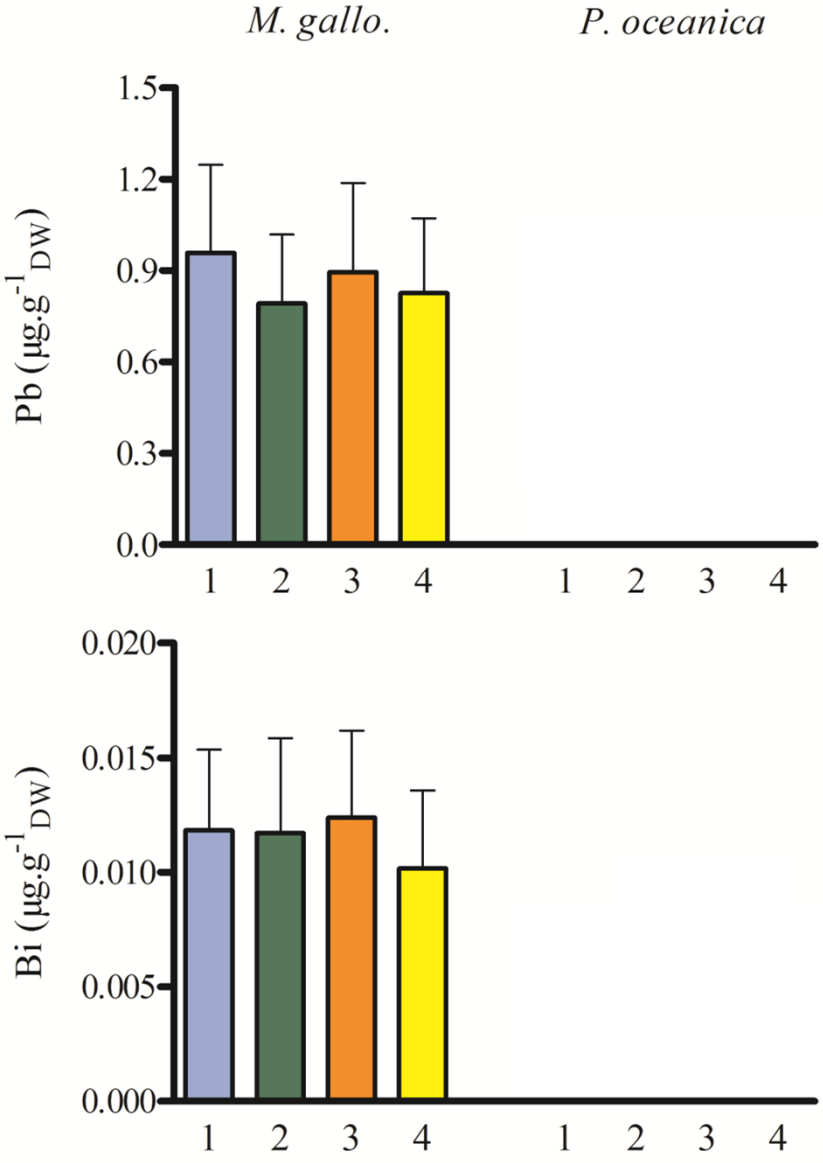


Mussel caging

Lifestyle of organisms

- *M. galloprovincialis* = filter feeder

→ homogenous and clean status of the water column;



Mussel caging

Lifestyle of organisms

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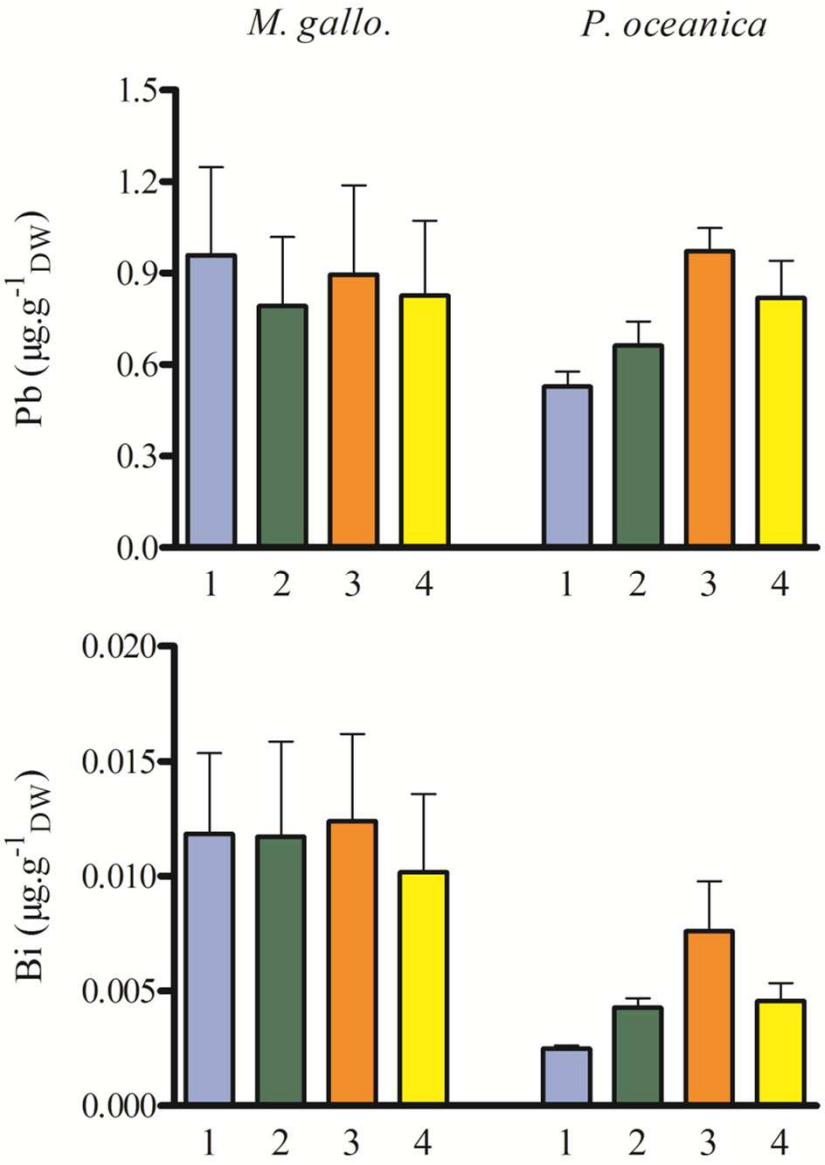
→ weak point sources of long-term accumulations of pollutants in sediments.



Mussel caging

Lifestyle of organisms

- *M. galloprovincialis* = filter feeder

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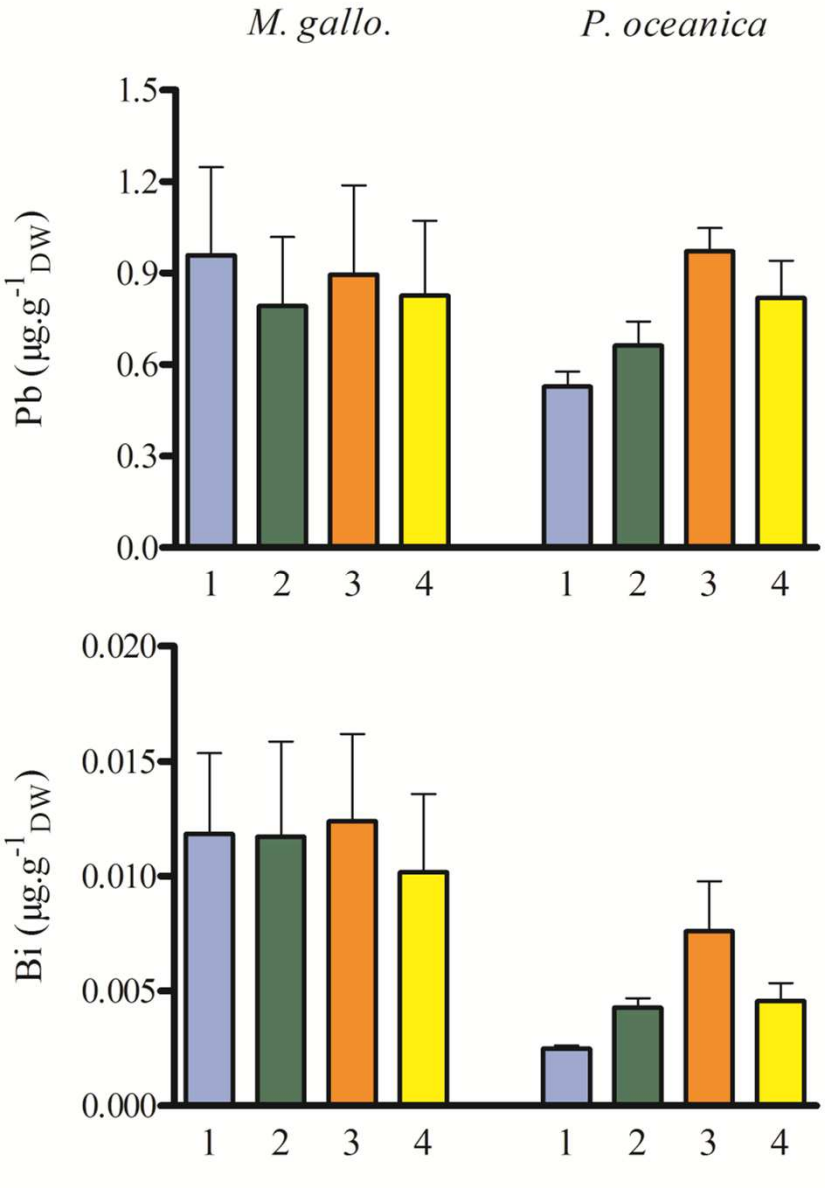
► 2 complementary species concomitantly used.



Conclusions

BIOACCUMULATION

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⟹ Both bioindicators effectively bioaccumulate trace elements and give complementary information on the health status of their environment → lifestyle.

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Conclusions

BIOACCUMULATION

⟹ Both bioindicators effectively bioaccumulate trace elements and give complementary information on the health status of their environment → lifestyle.

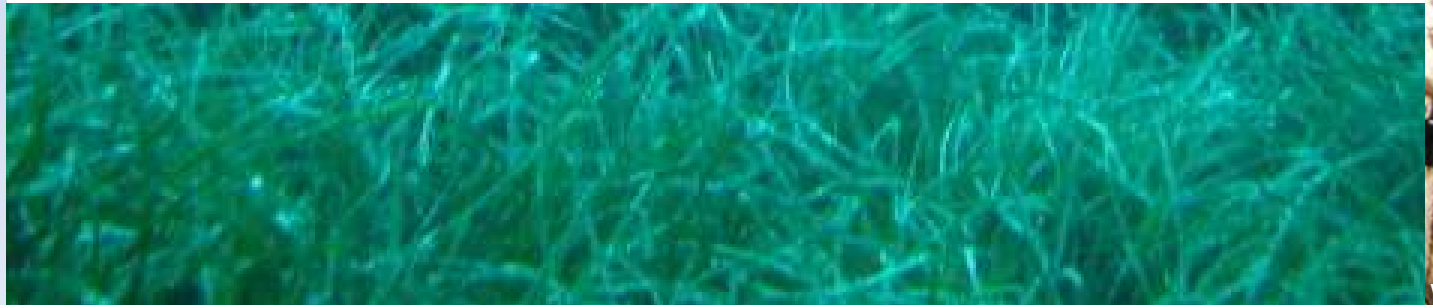
⟹ *M. galloprovincialis*: overall health status of the water body; *P. oceanica*: time-integrated response to weak human impact.

⟹ Important to sample appropriate stations to properly determine the health status of a specific site, mostly in monitoring surveys using *P. oceanica*.

Trace element kinetics

KINETICS

1. spatial variation of trace element levels in *P. oceanica* shoots along the French Mediterranean coasts ↔ polluting human activities;
2. definition of conditions/levels of reference for the Northwestern Mediterranean;
3. influence of *P. oceanica* and *M. galloprovincialis* lifestyle on trace element bioaccumulation behaviour;
4. trace elements uptake and loss kinetics by both species.



In situ contamination of *P. oceanica*

KINETICS

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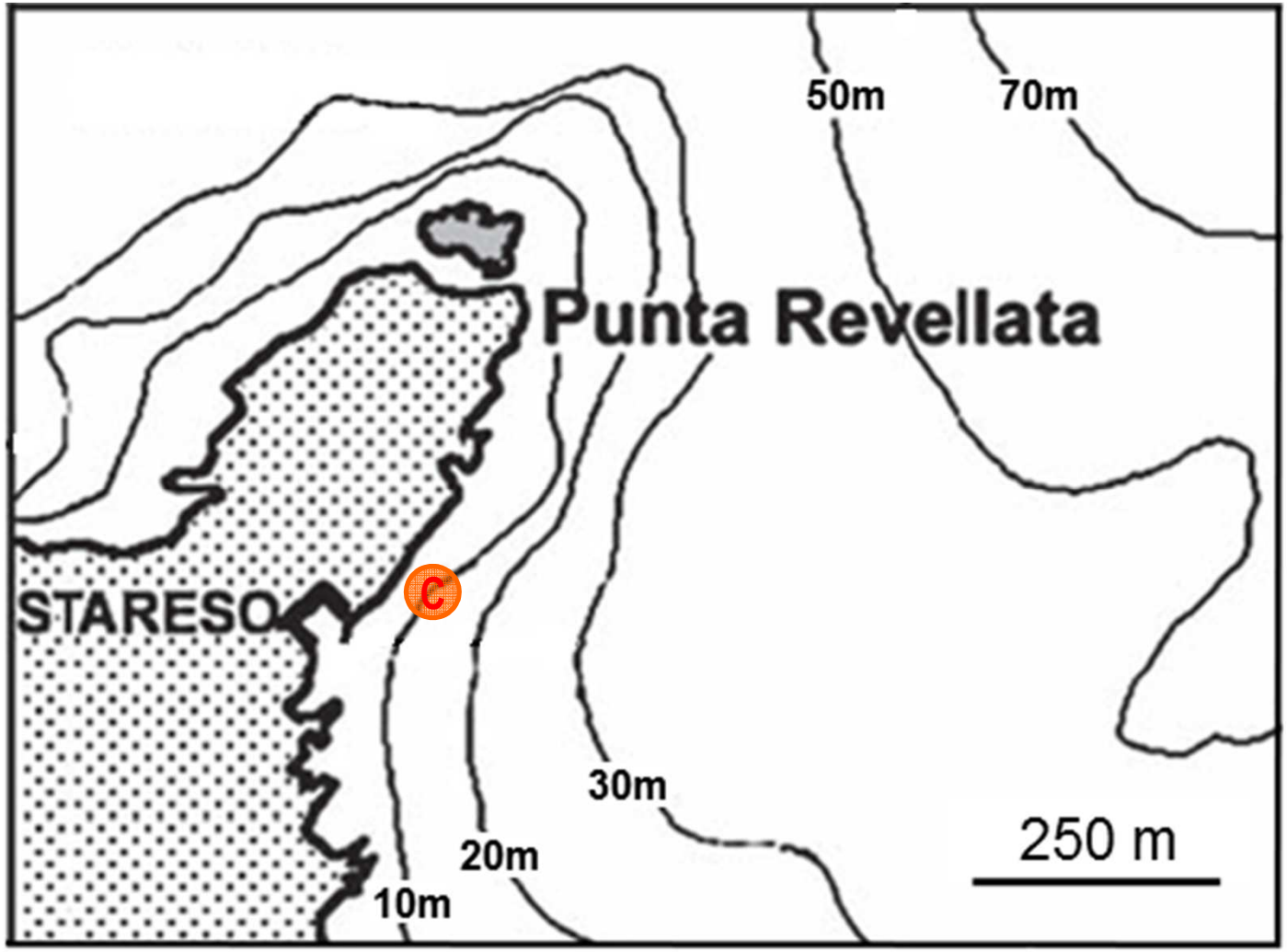
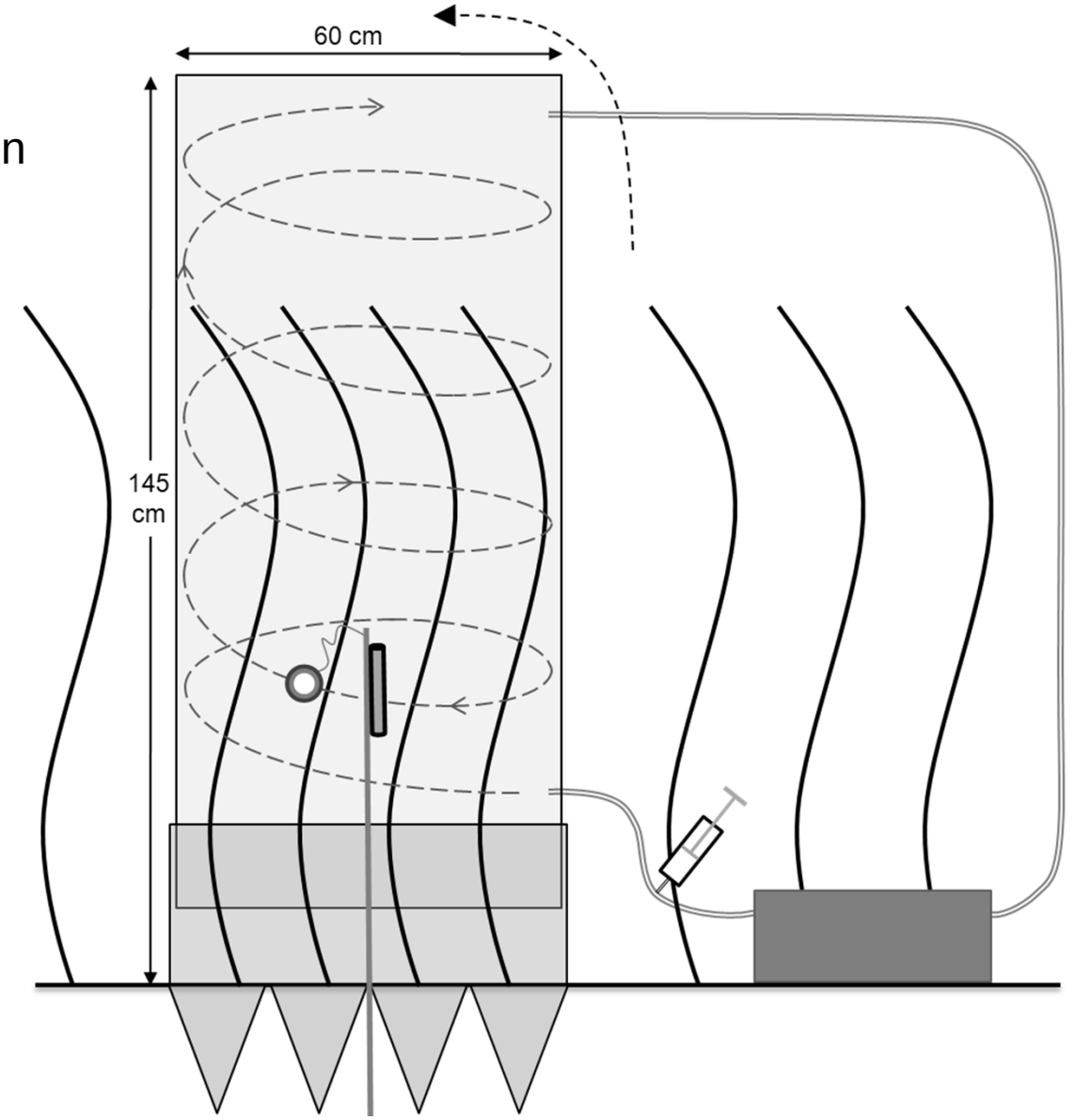
KINETICS



Mesocosm

KINETICS

- 5 days of contamination in June 2009;
- 410L bell-shaped mesocosm;
- Contamination every 12 hours (9am-9pm);
- 15 days of decontamination.

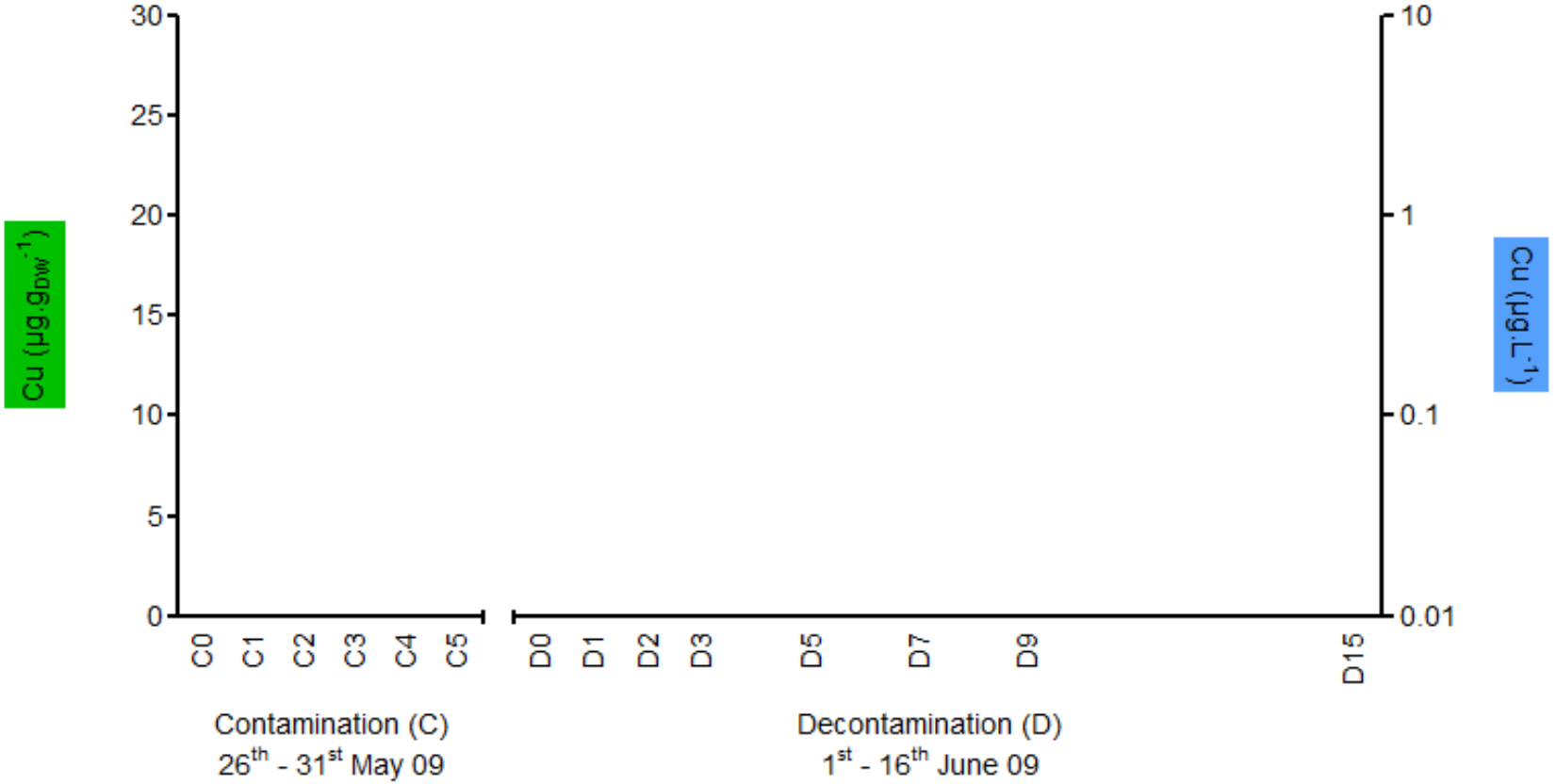


Mesocosm

KINETICS

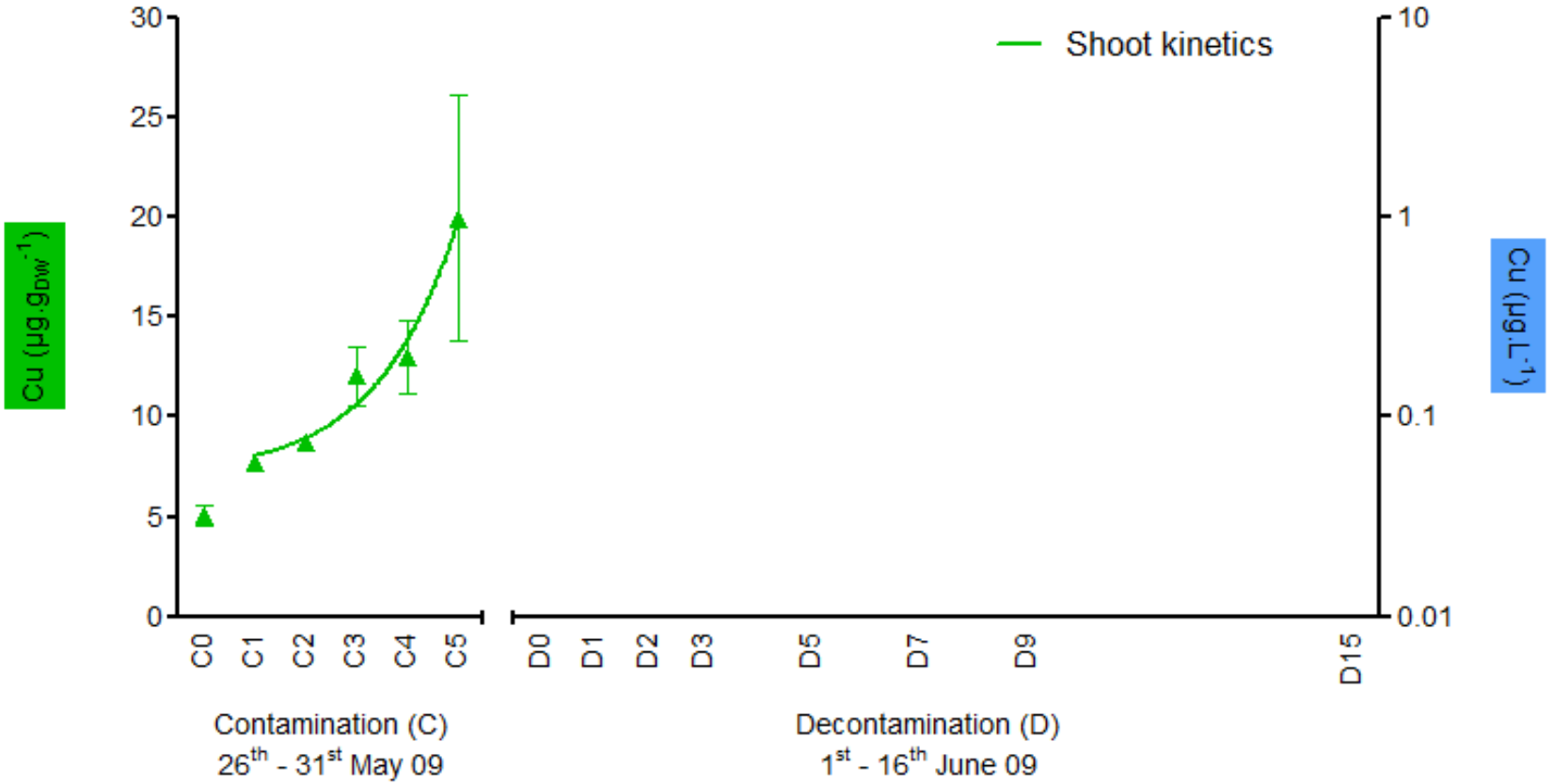
Cu in shoots

KINETICS



Cu in shoots

KINETICS



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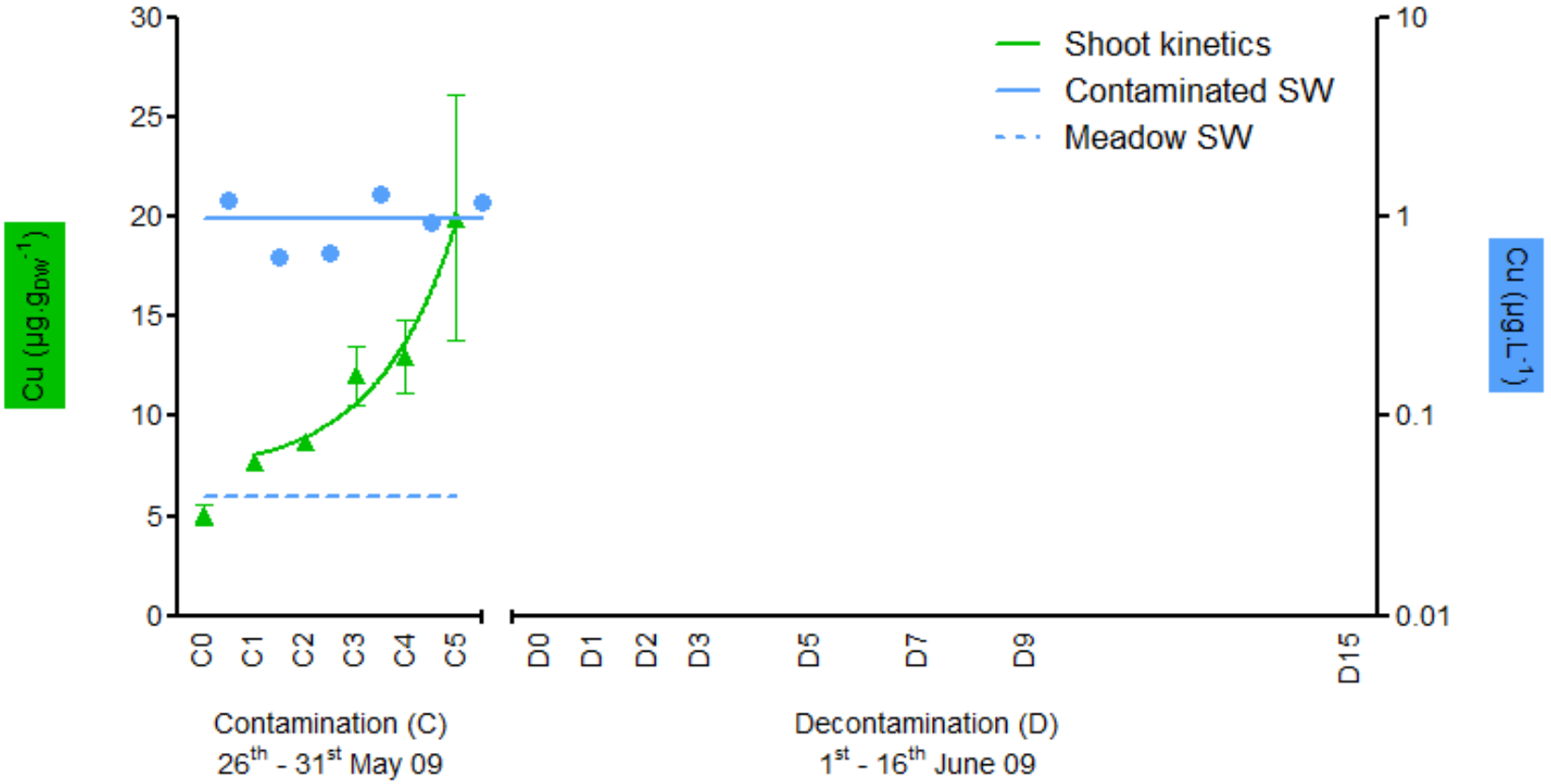

Cu in shoots

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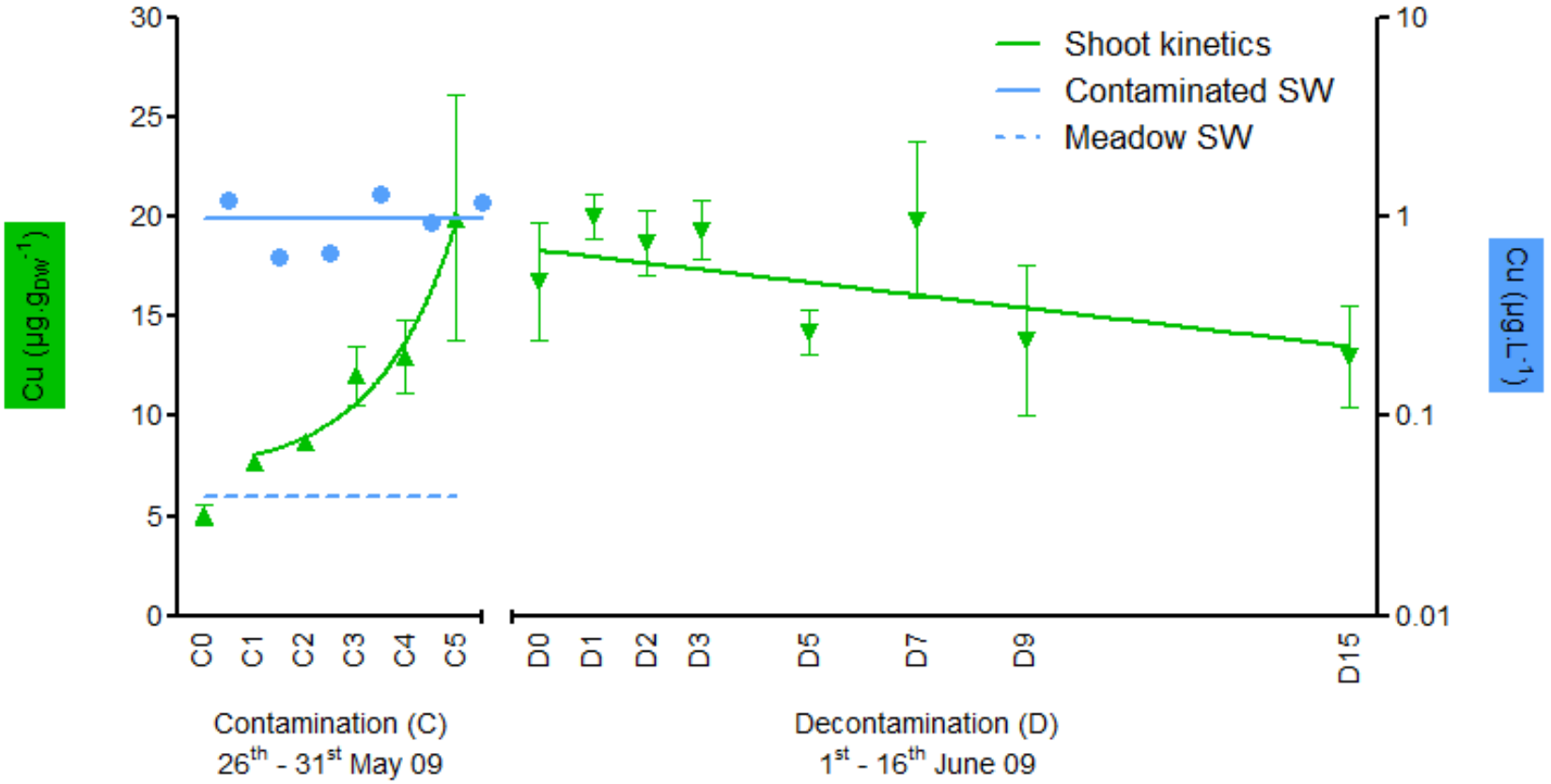

Cu in rhizomes

KINETICS

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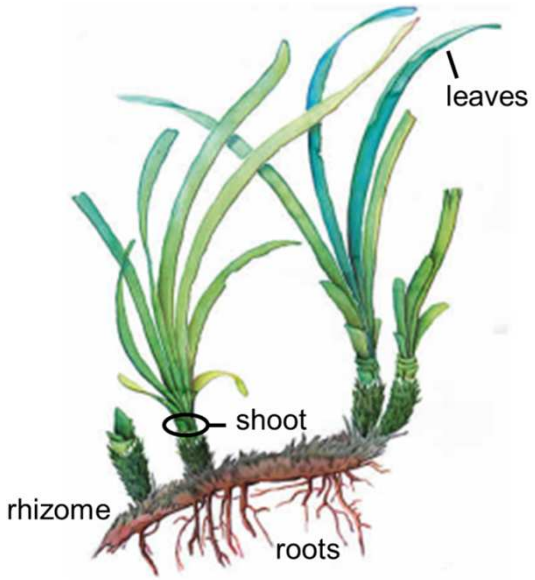
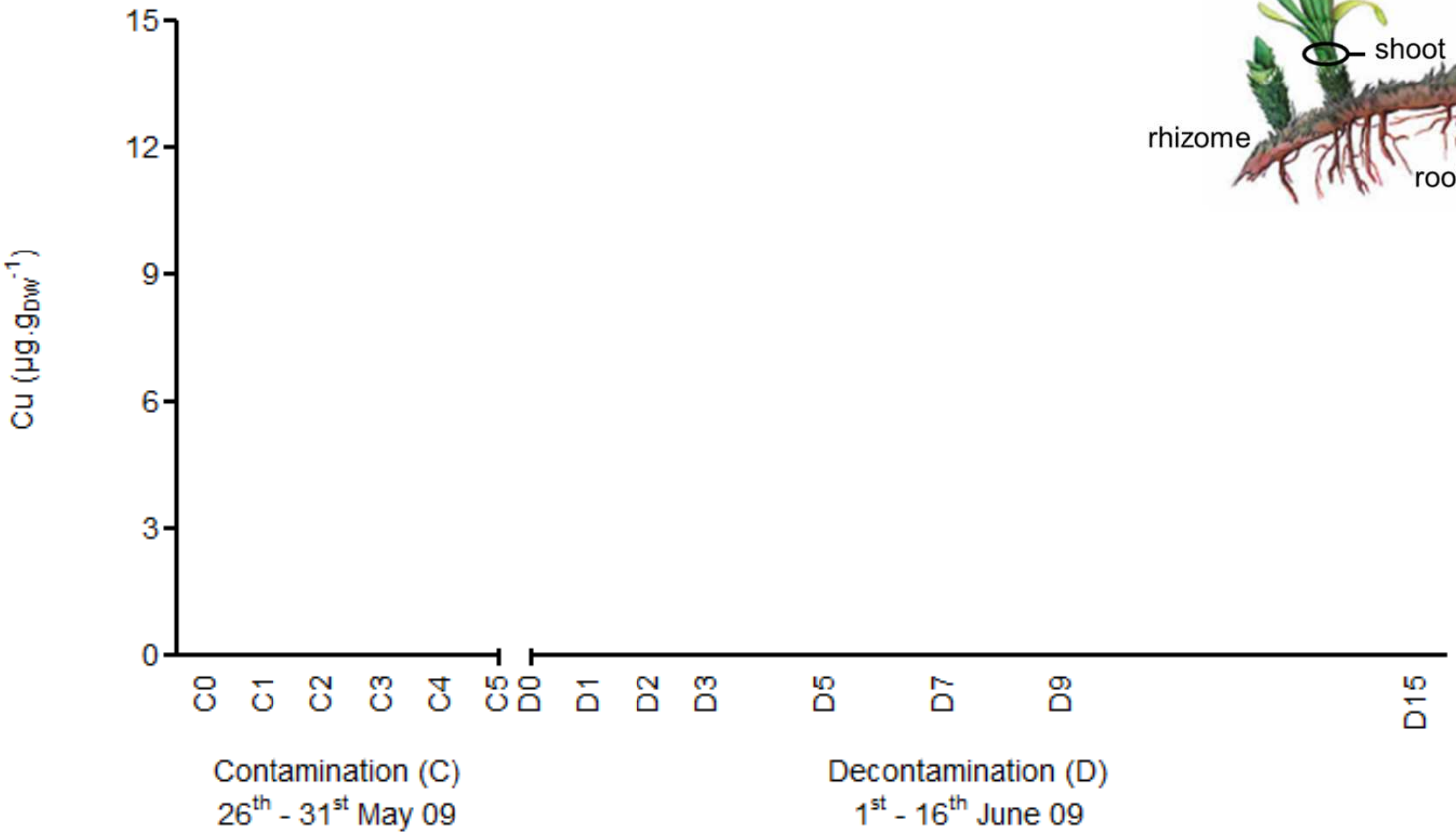
KINETICS





Cu in rhizomes

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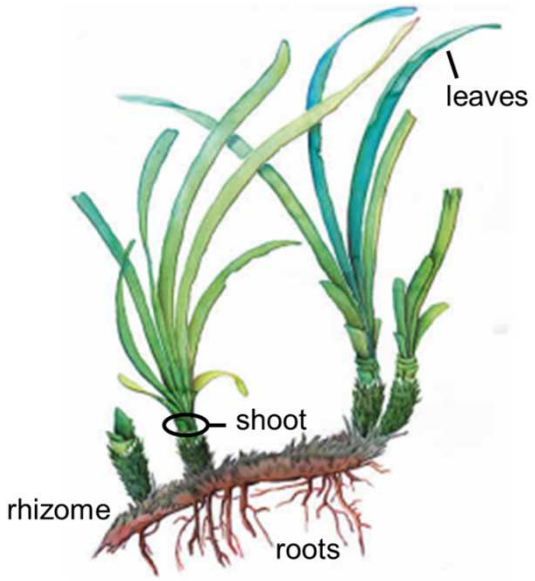
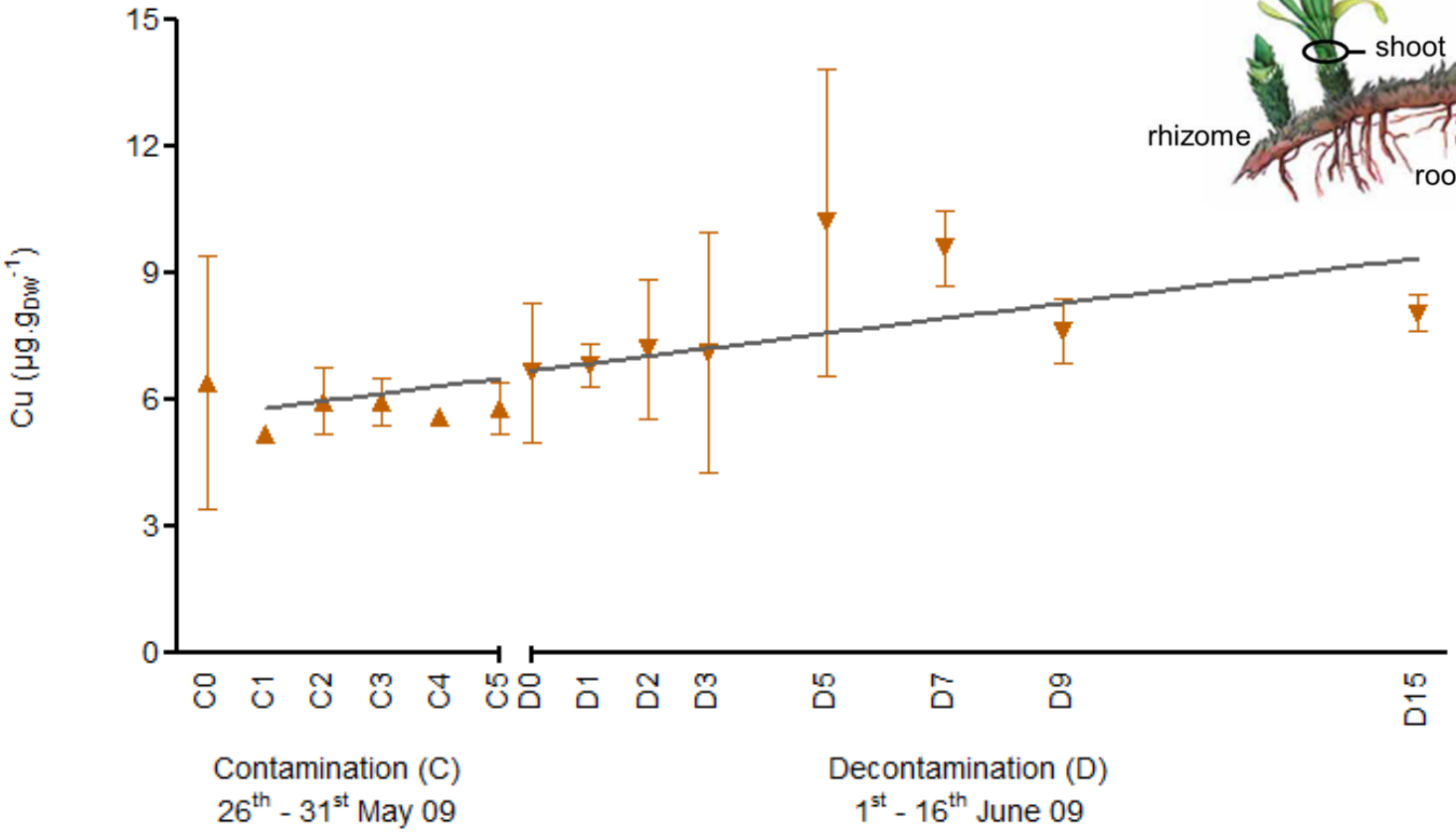
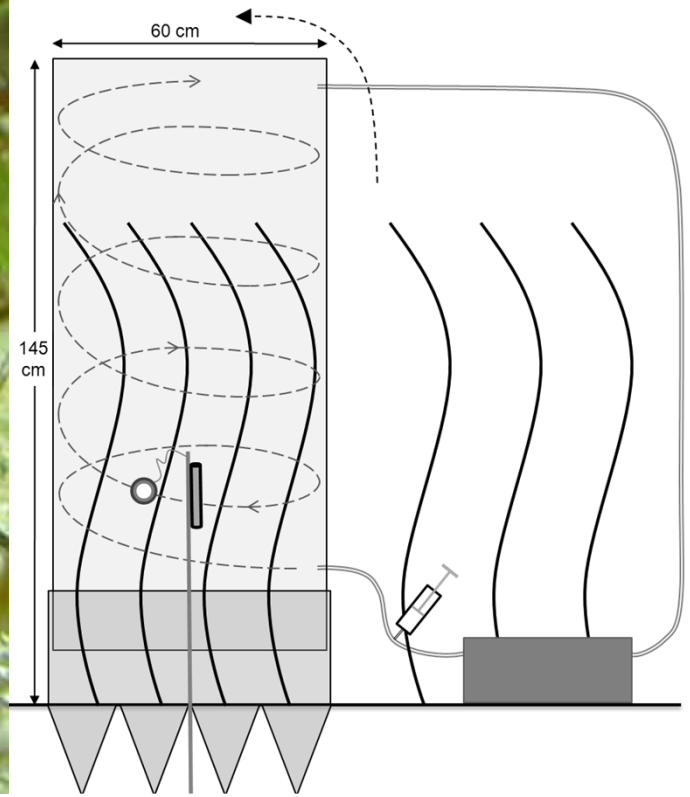




KINETICS

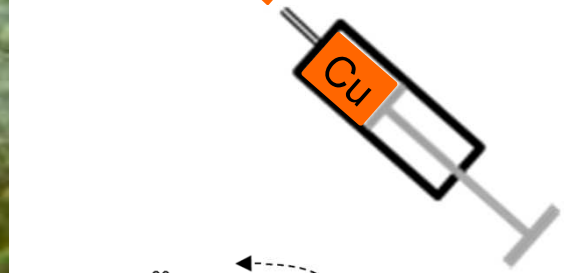
acropetal translocation

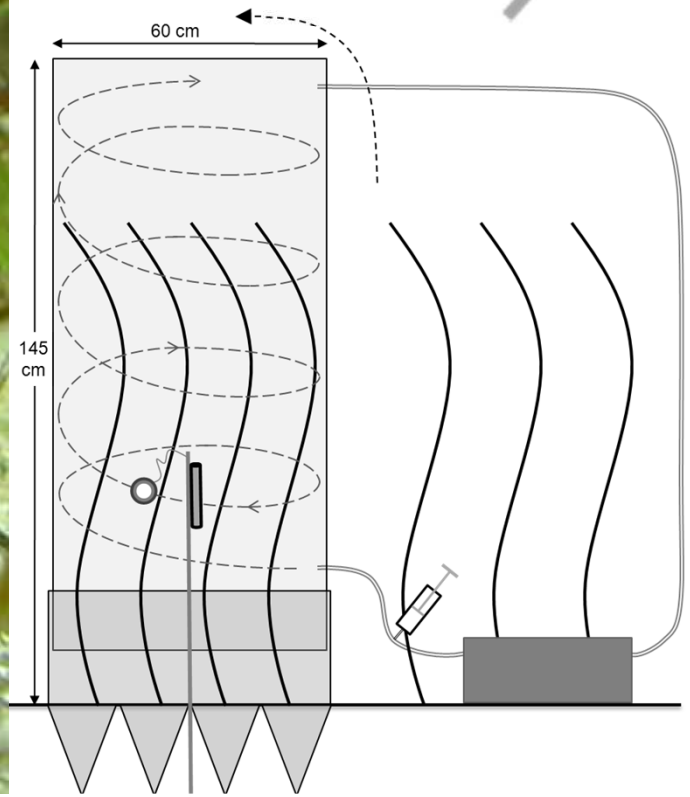
© Mrkvicka A.



KINETICS

acropetal translocation





KINETICS

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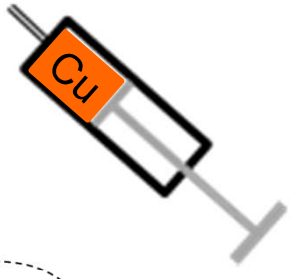

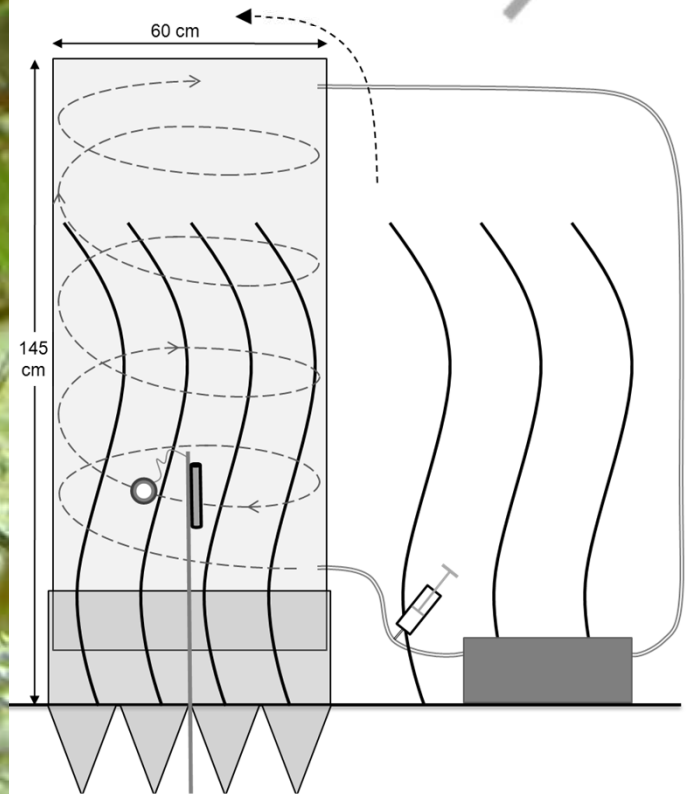

P. oceanica: environment vs. biological cycle

KINETICS

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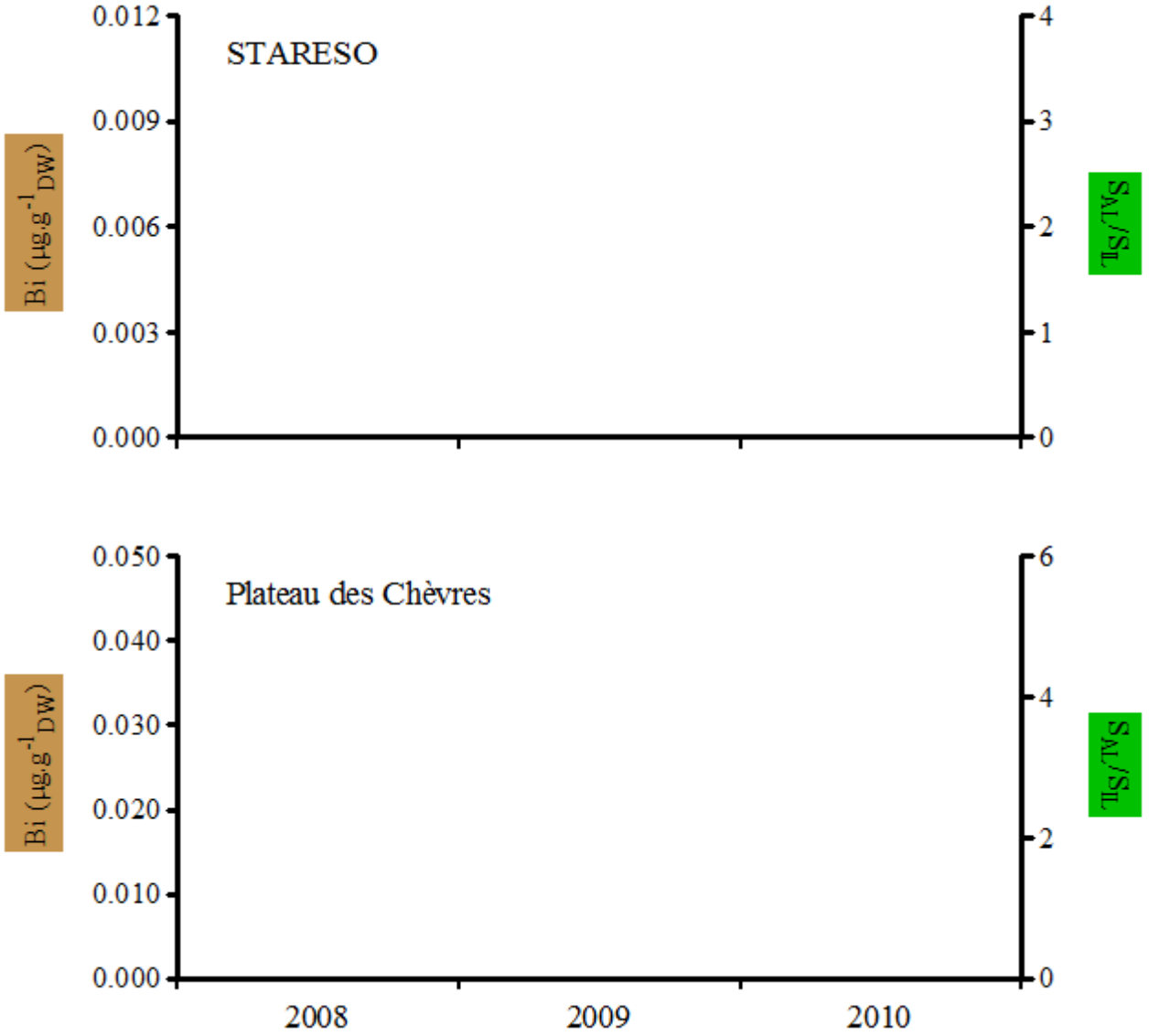

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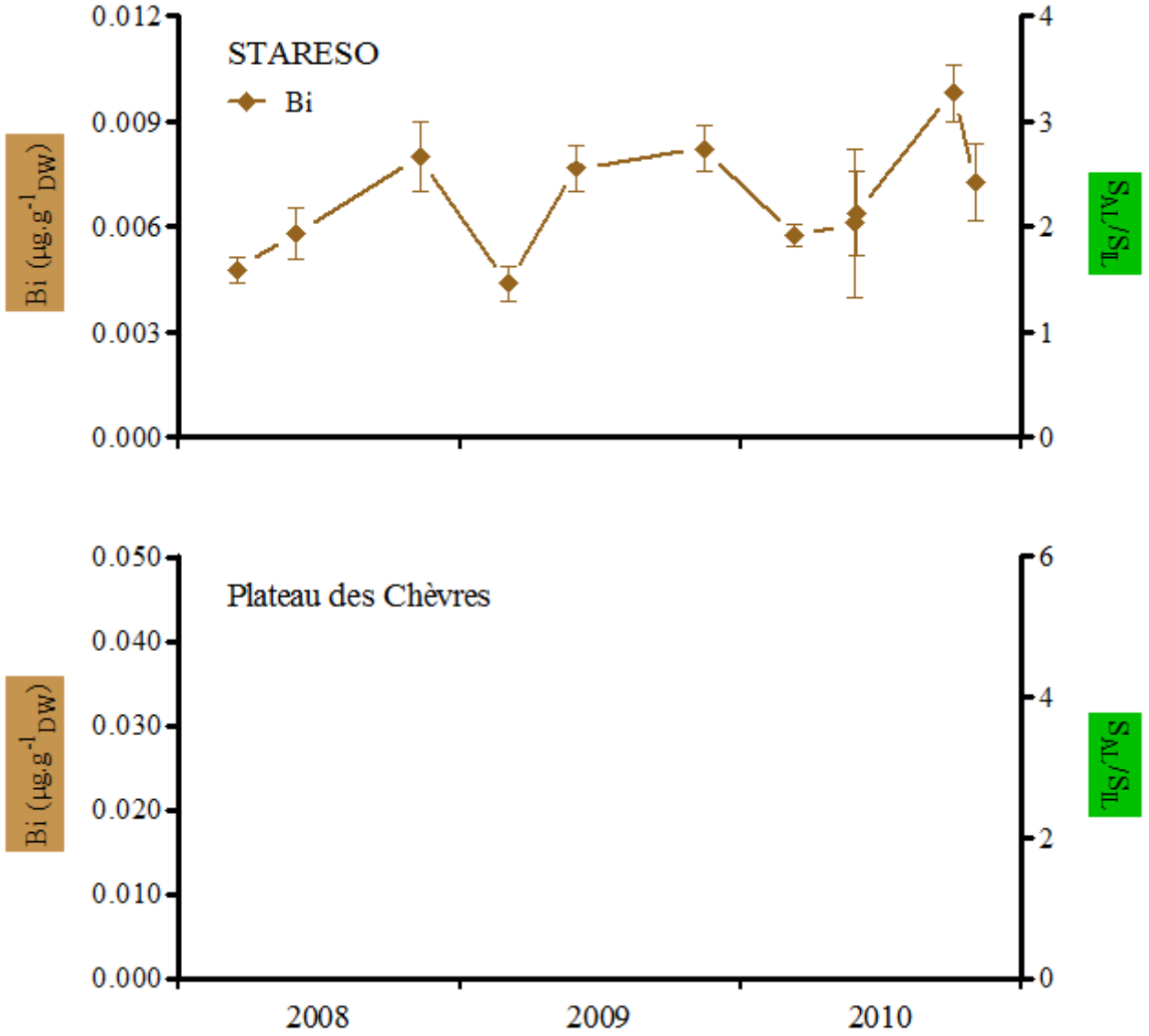

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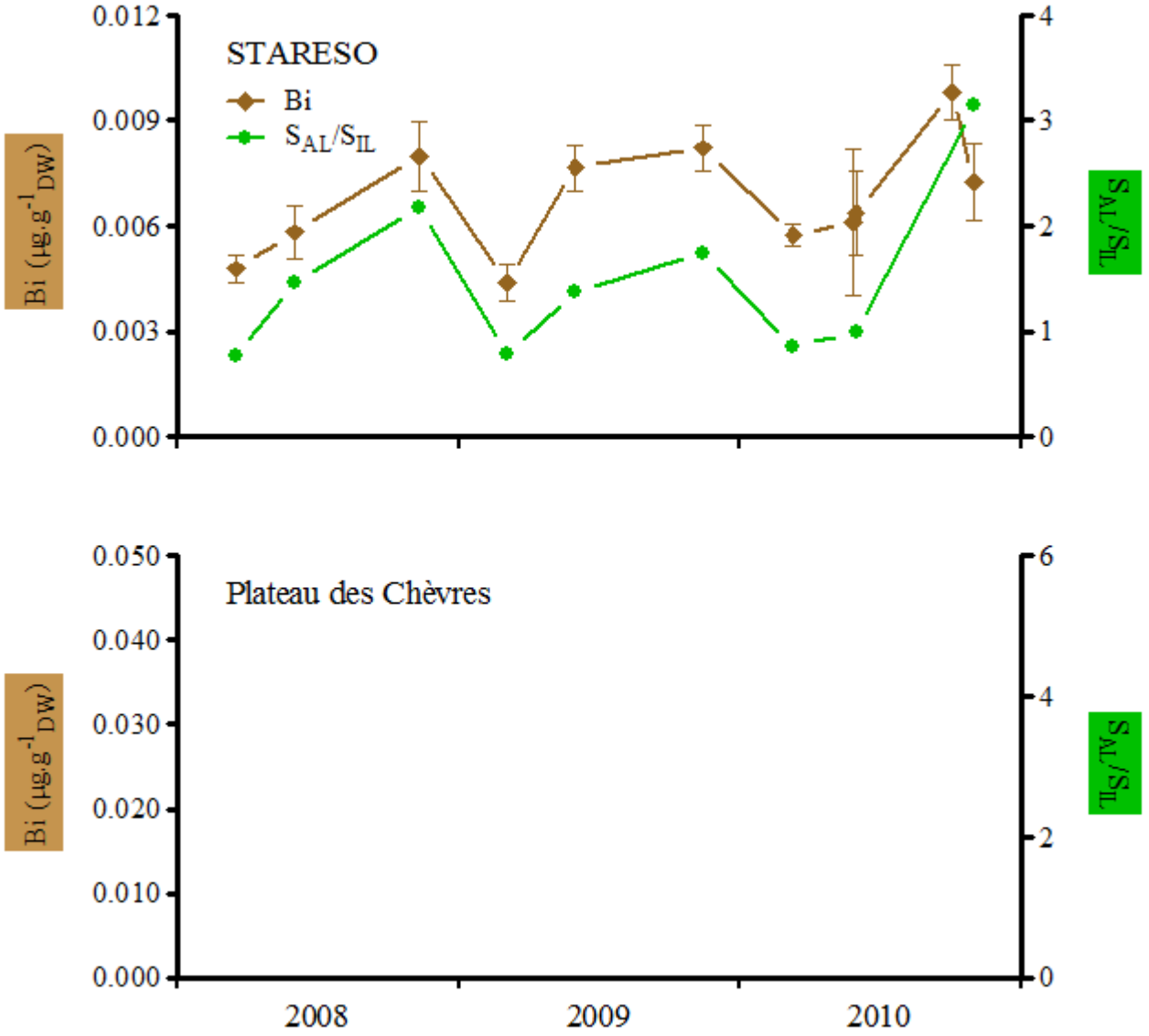

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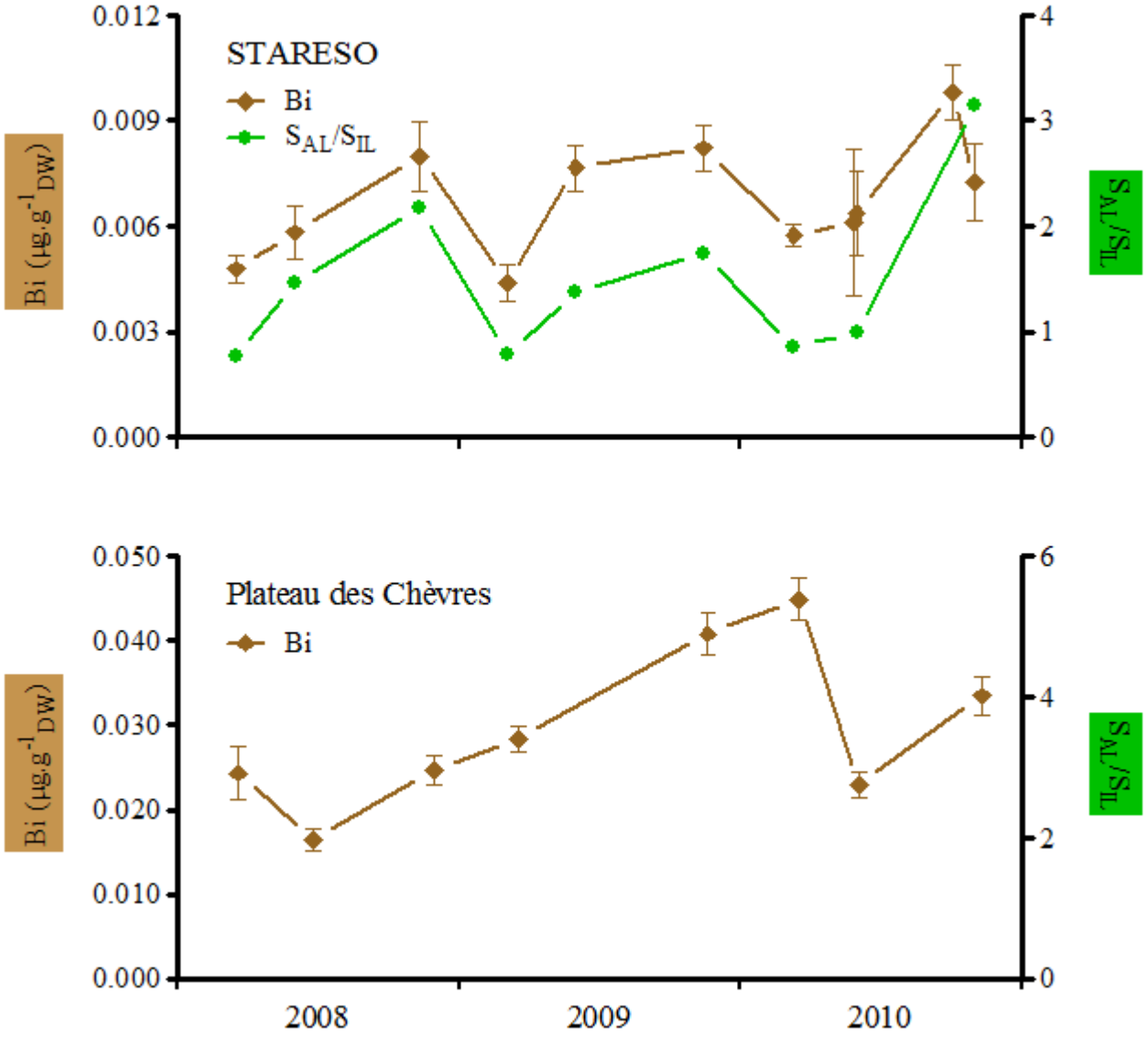

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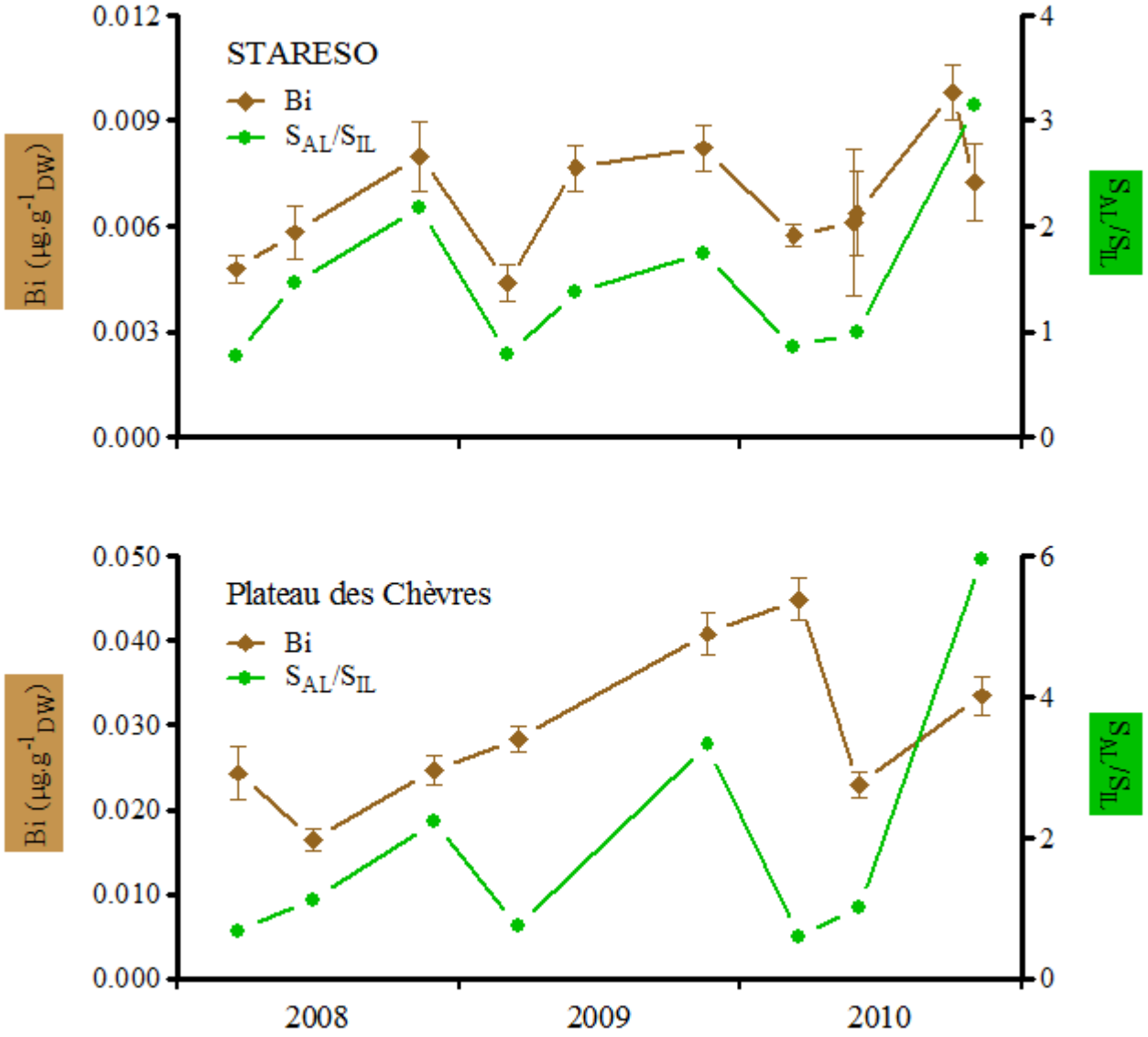

Mussel caging

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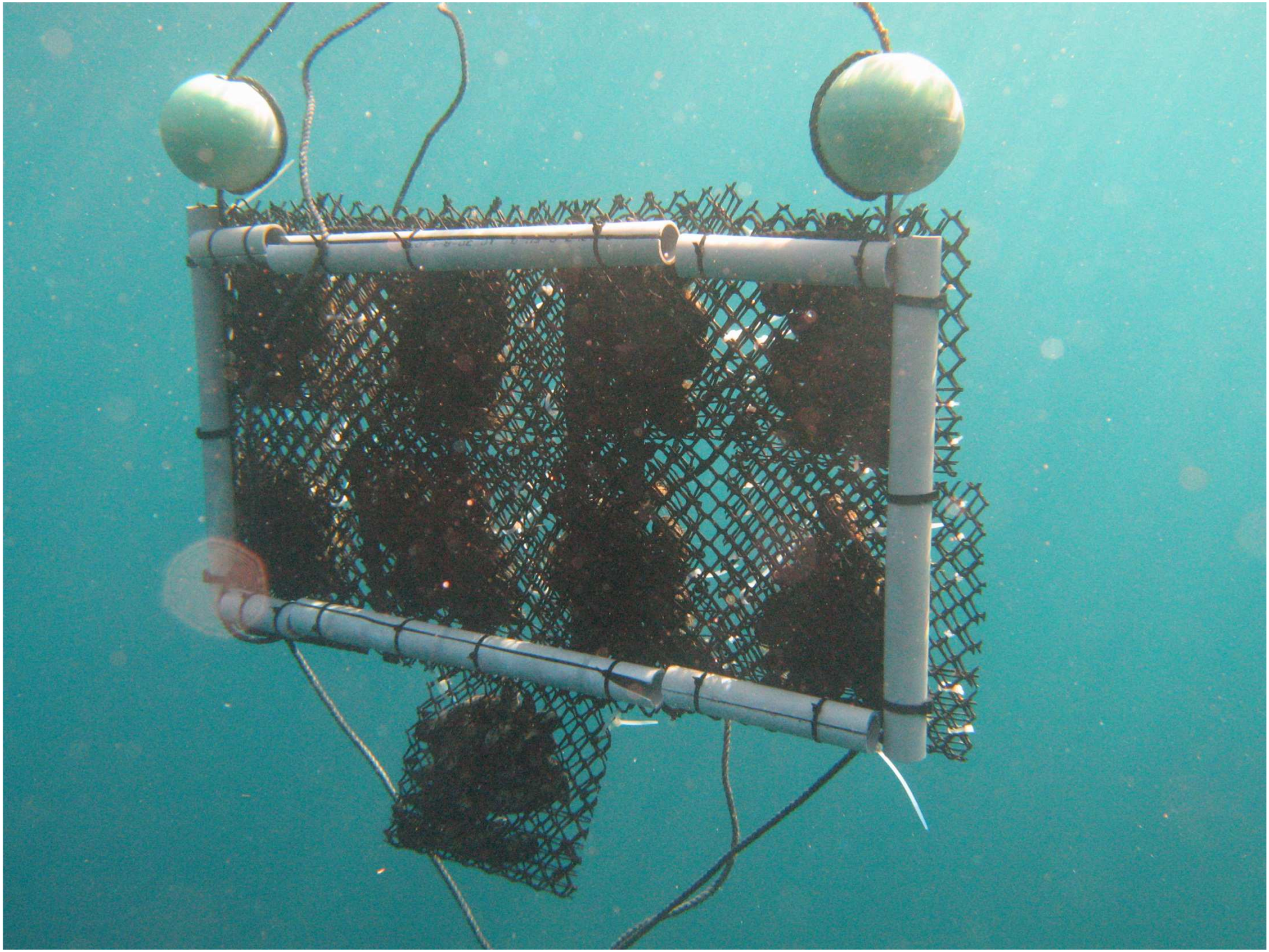

M. galloprovincialis: environment vs. biological cycle

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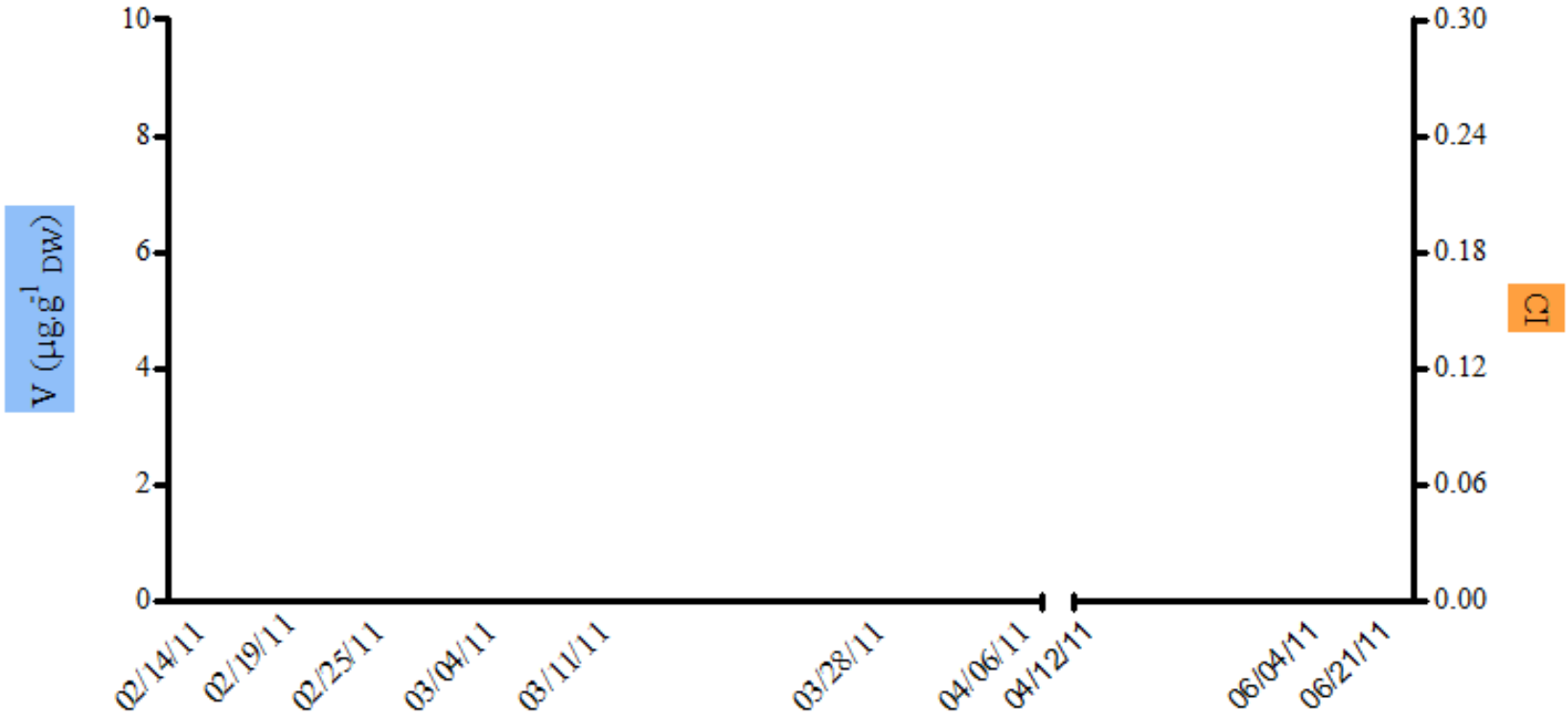

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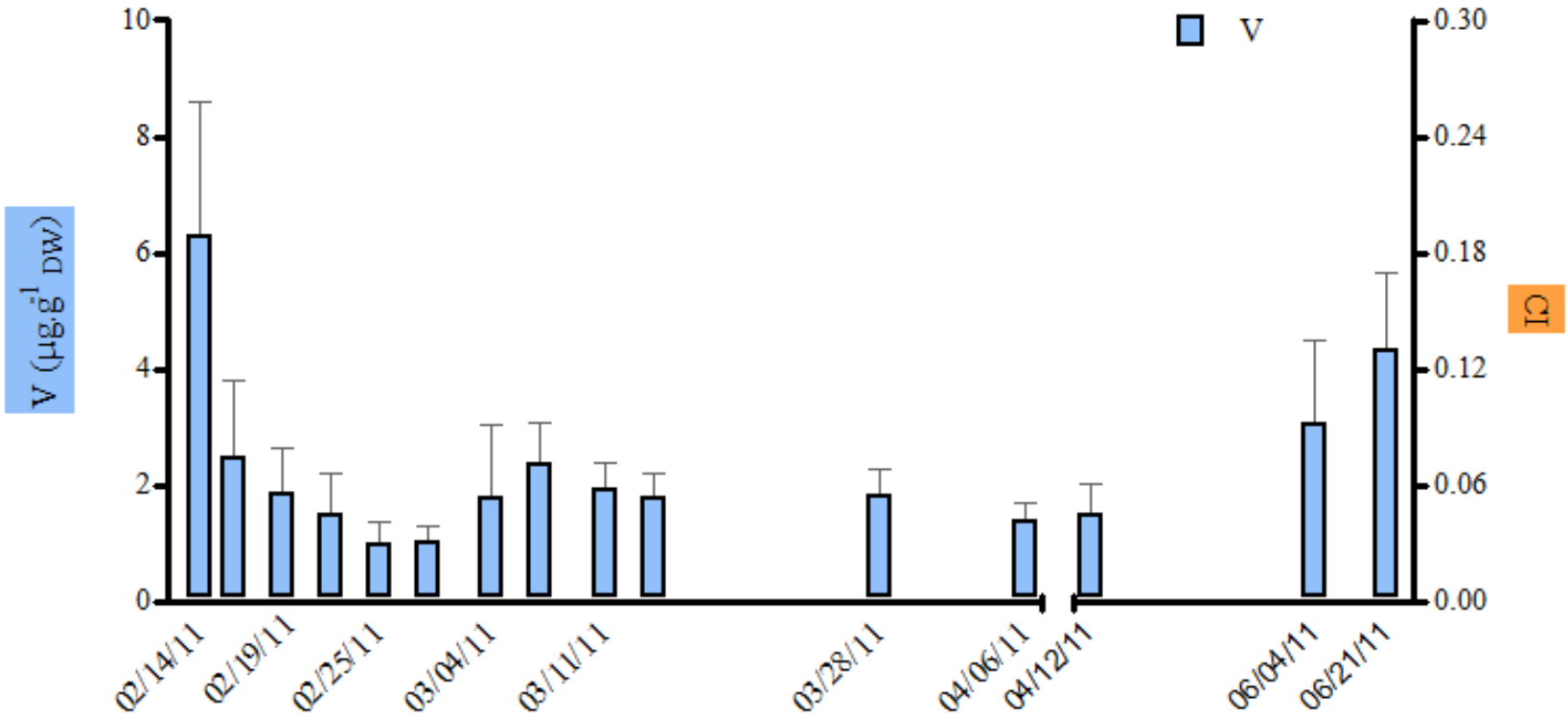

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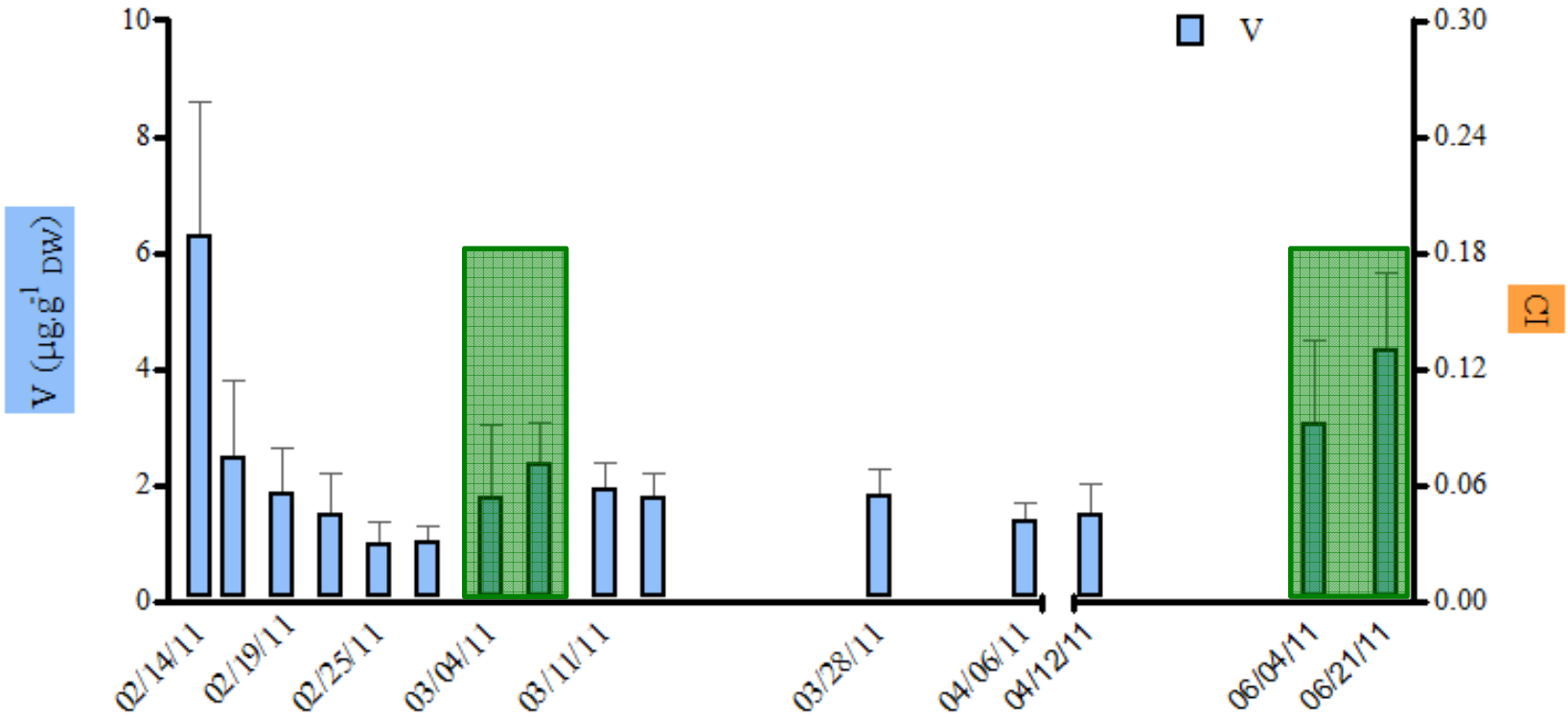

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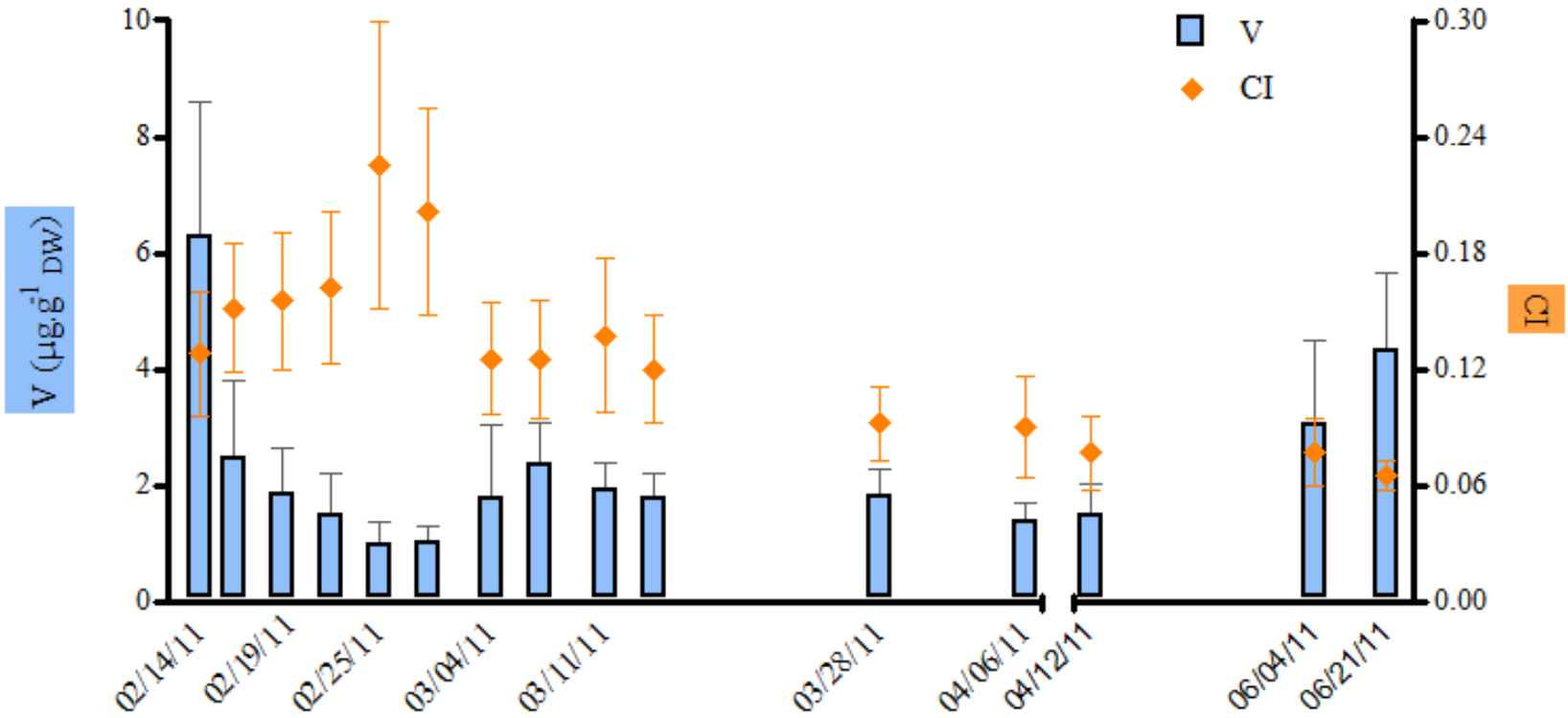

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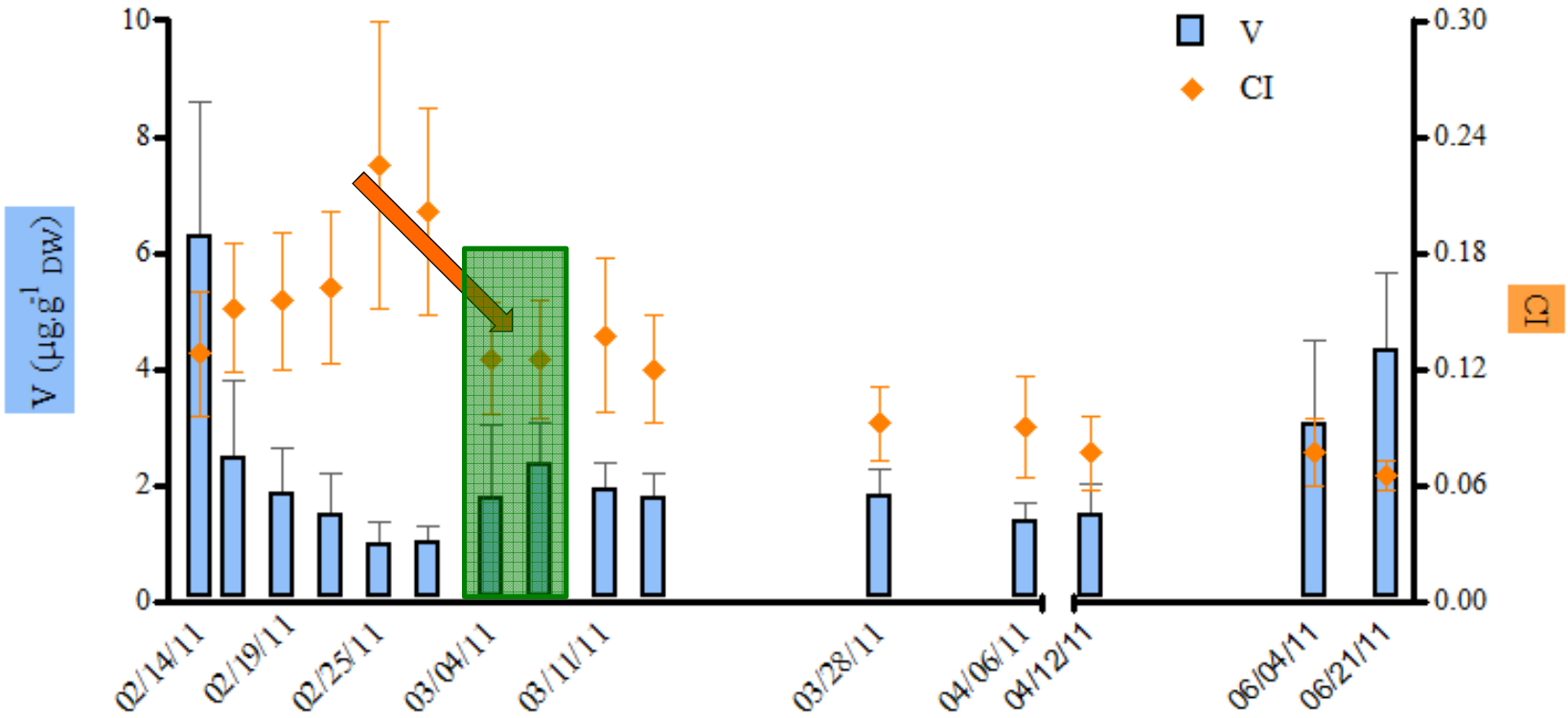
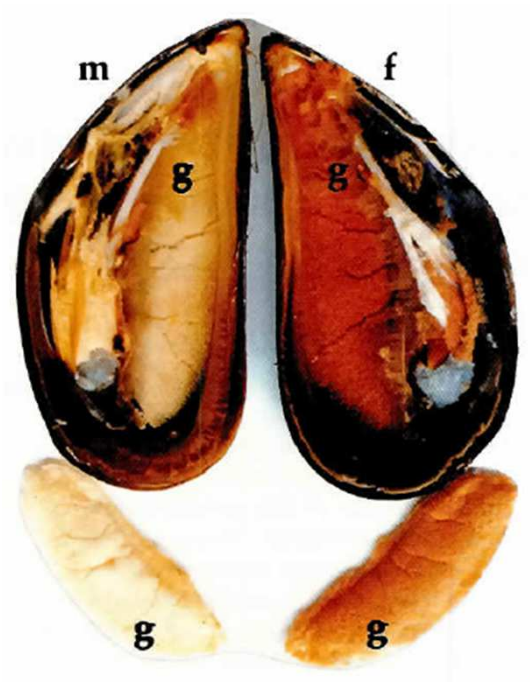


Sea, sex and size …

KINETICS

Sea, sex and size …

- Influence of size on TE accumulation by mussels grown on ropes:
  - → YES?
  - → NO?
- Influence of sex on TE accumulation prior to spawn:
  - → males vs females.



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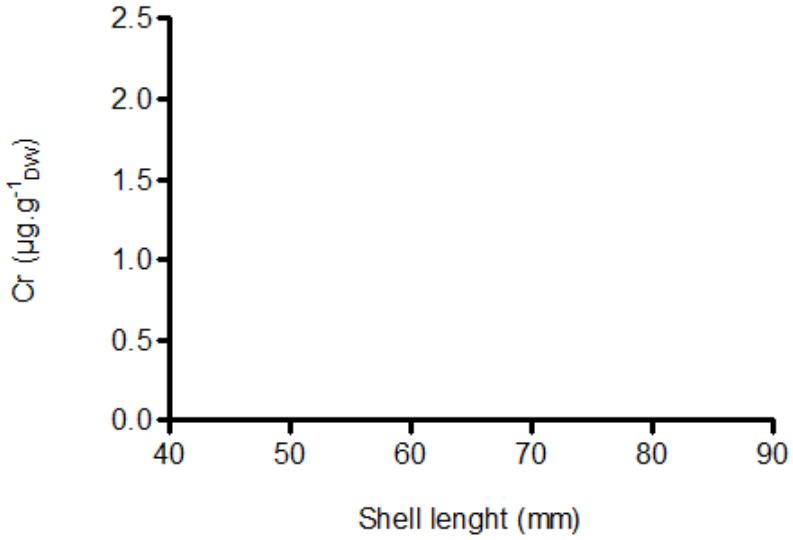

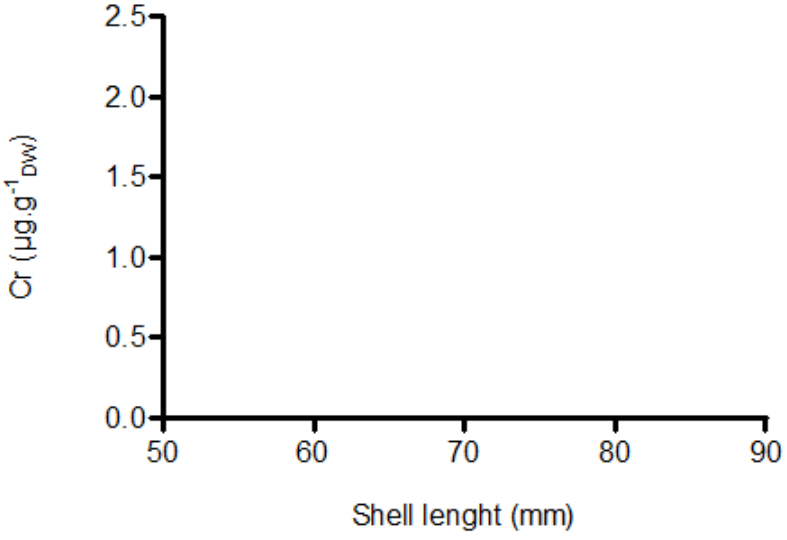

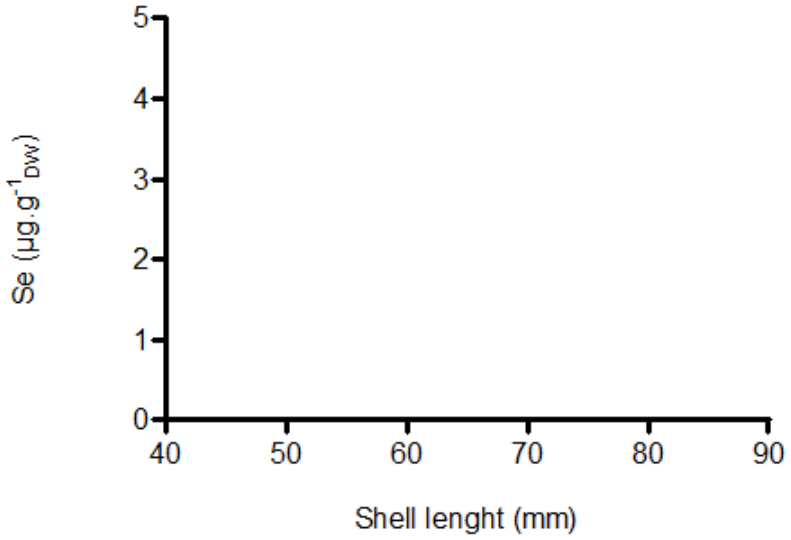

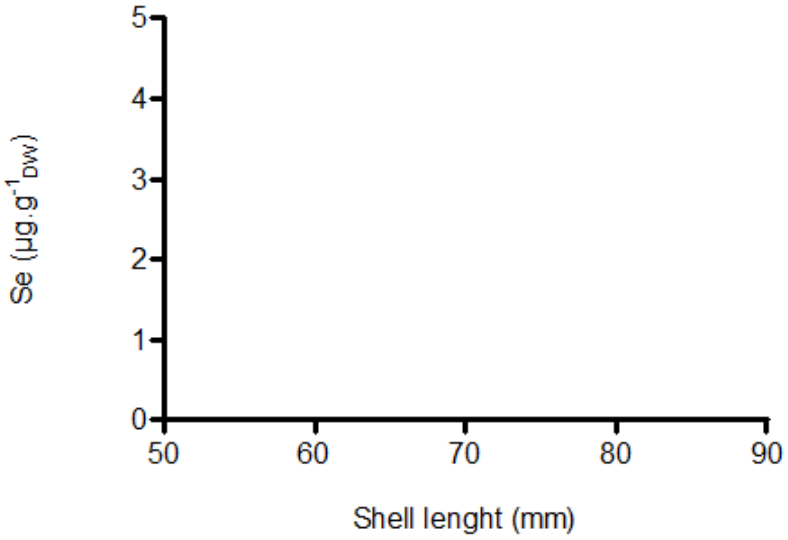

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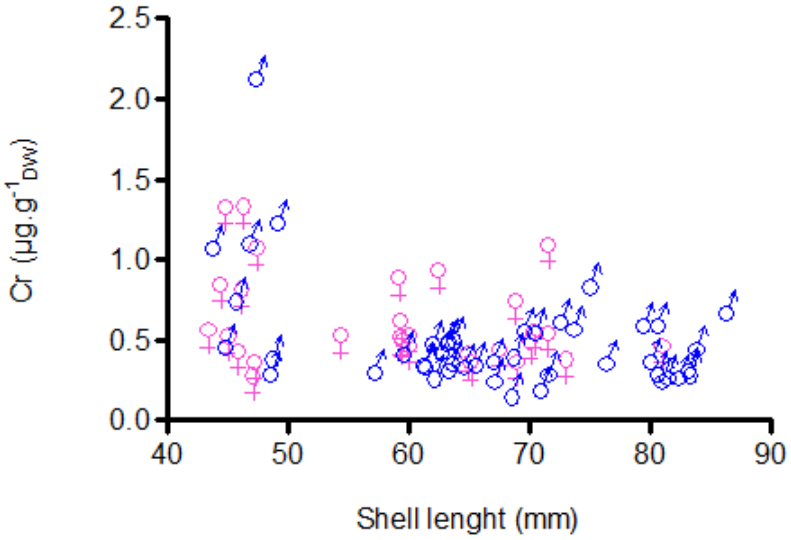

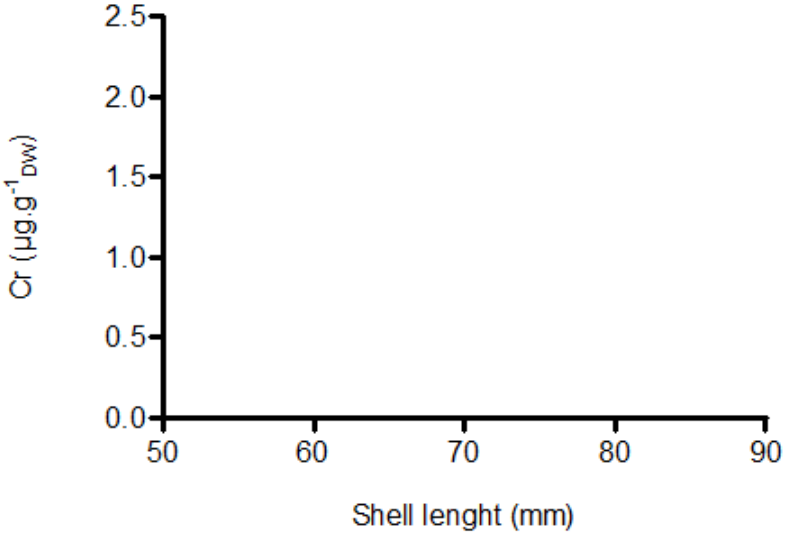

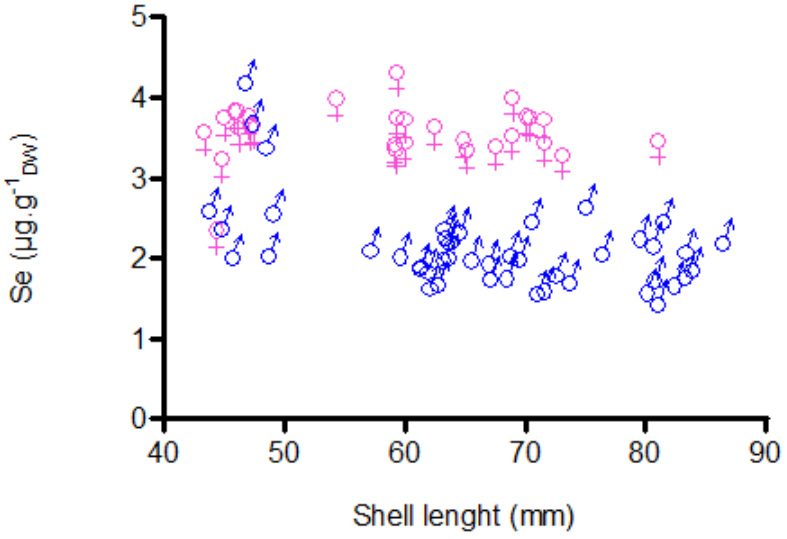

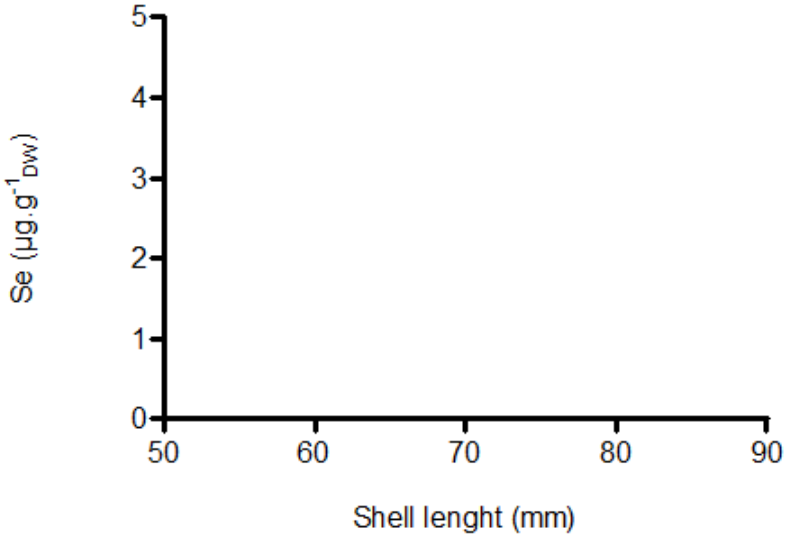

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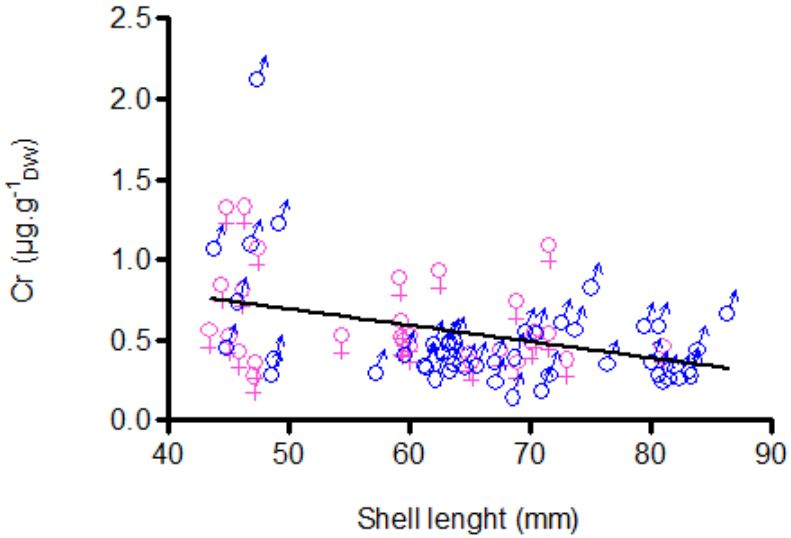

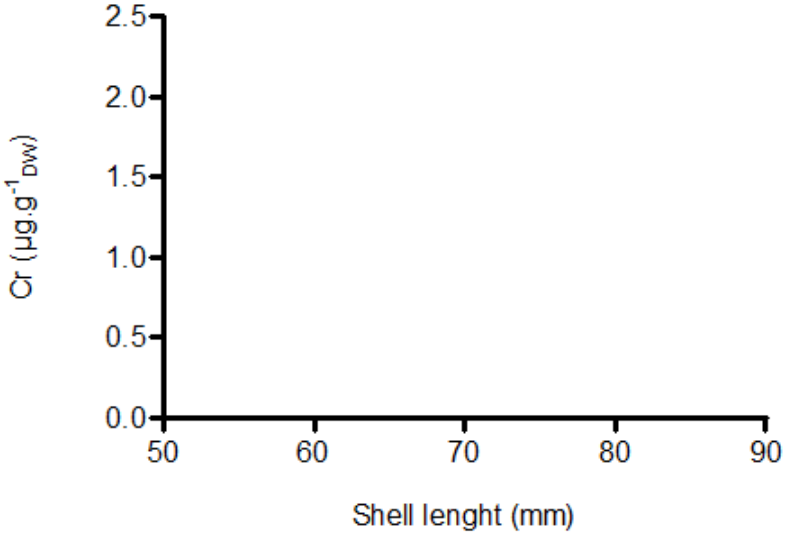

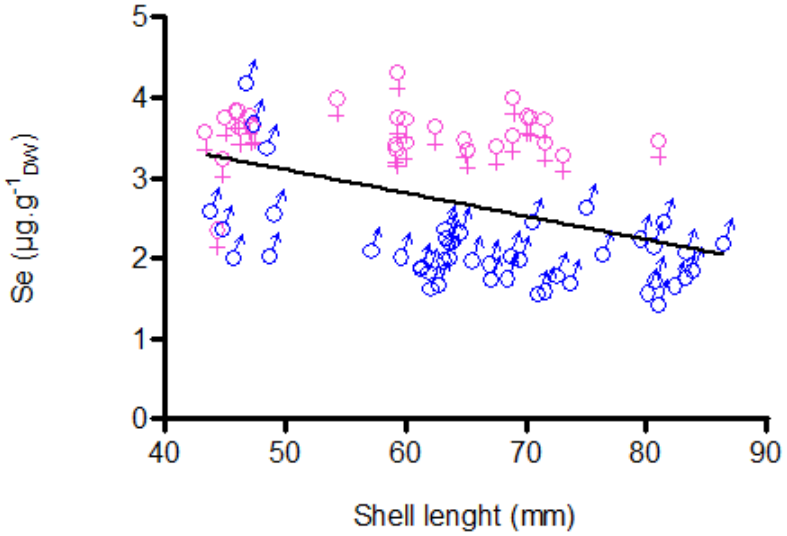

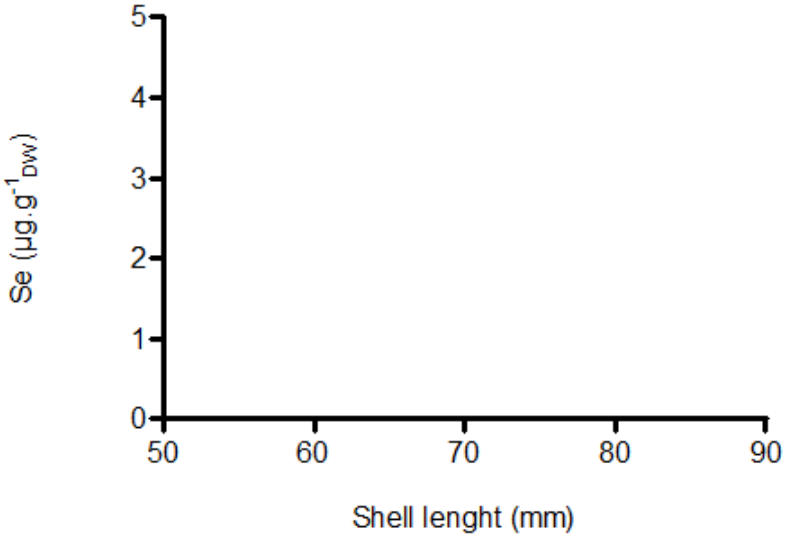

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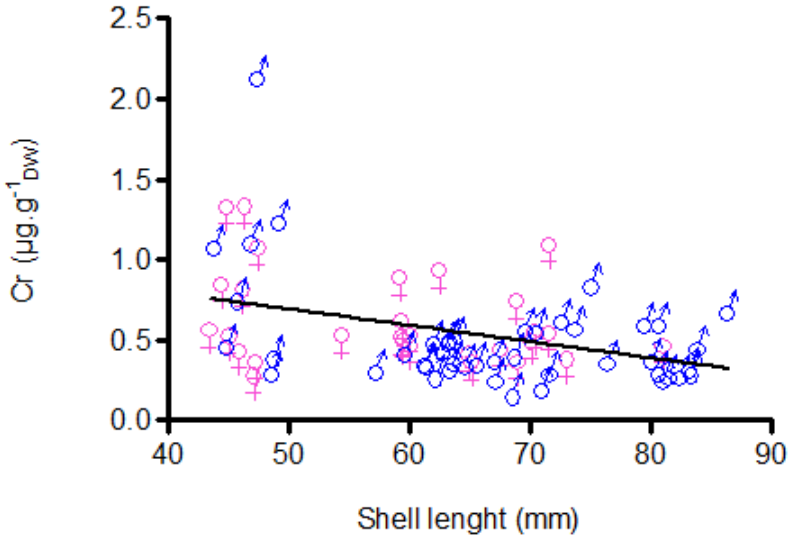

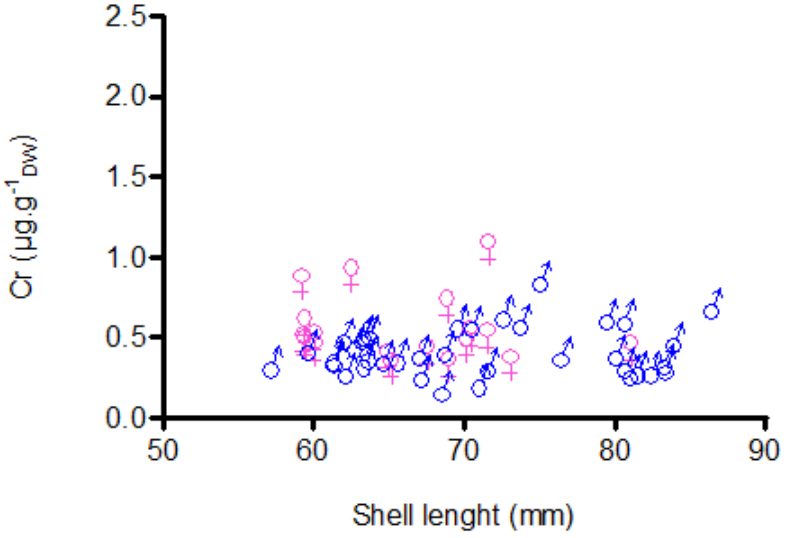

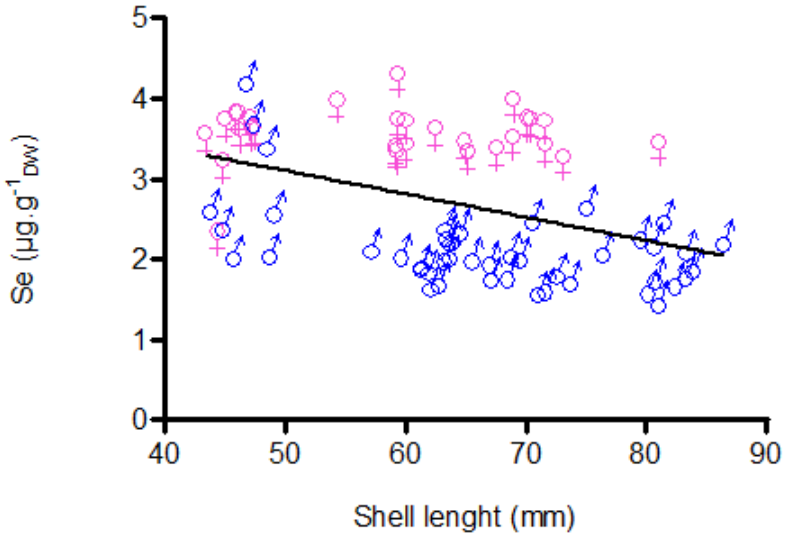

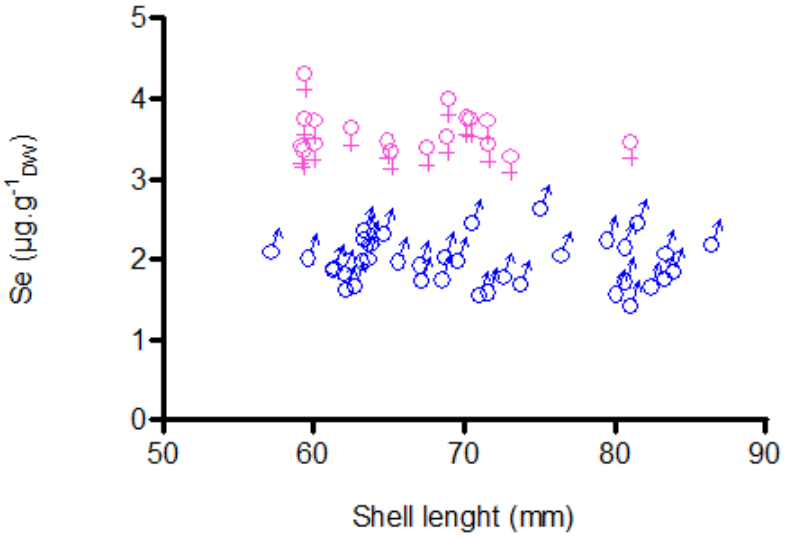

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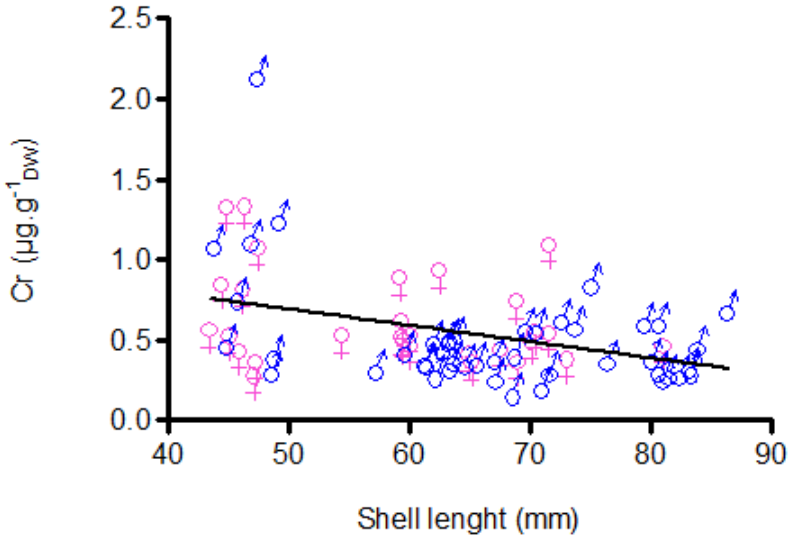

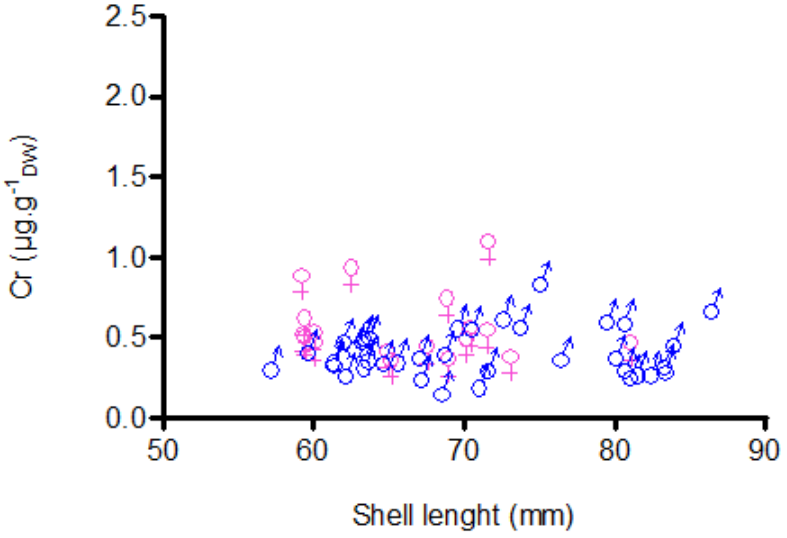

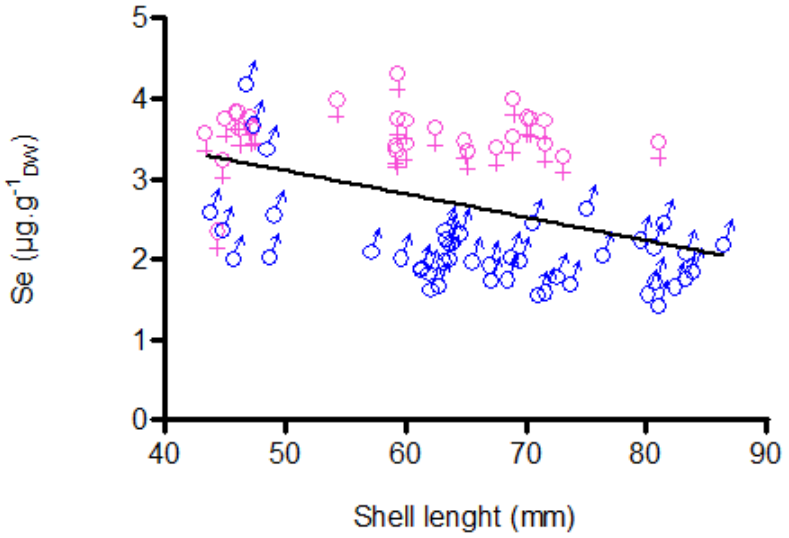

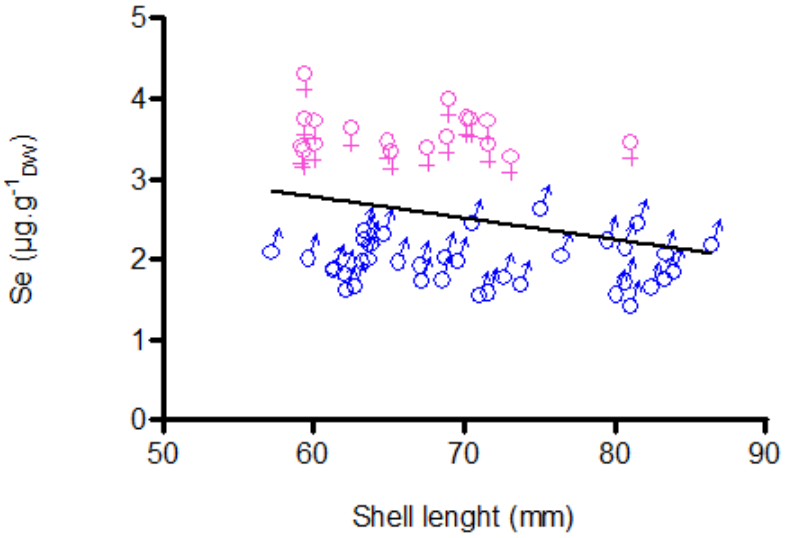

Conclusions

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Conclusions

→ *M. galloprovincialis* and *P. oceanica* = complementary bioindicator species (lifestyle) that can be used concomitantly.

KINETICS

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→ TE kinetics under the influence of various parameters that interact: environmental conditions, physiology of the species etc.

Conclusions

KINETICS

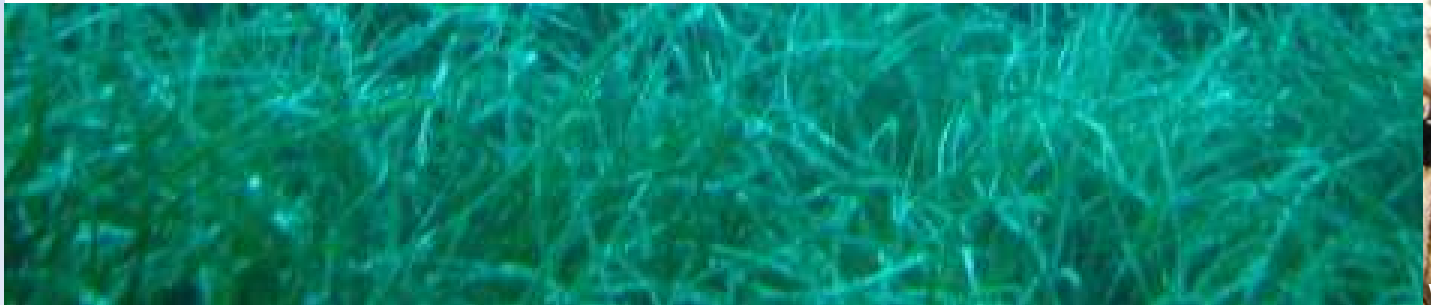
→ *M. galloprovincialis* and *P. oceanica* = complementary bioindicator species (lifestyle) that can be used concomitantly.

→ TE kinetics under the influence of various parameters that interact: environmental conditions, physiology of the species etc.

→ *M. galloprovincialis*: consensual monitoring protocols (e.g. sexual dormancy) and kinetic models (Casas et al. 2005, 2006, 2008); *P. oceanica*: no general rule → common rules of use in monitoring surveys.

General conclusions

CONCLUSIONS



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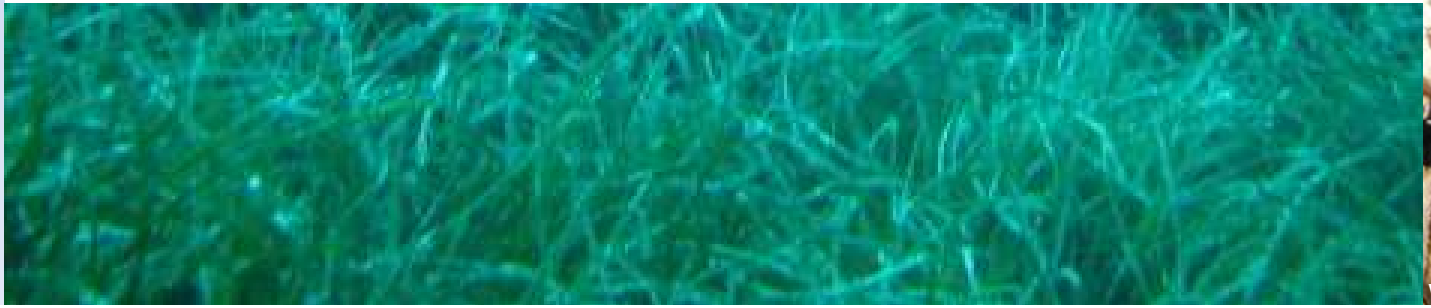
General conclusions

CONCLUSIONS

1. Contamination of the French Mediterranean coasts:

   TEs of emerging concern ARE of concern.



www.wwfsassi.co.za/

General conclusions

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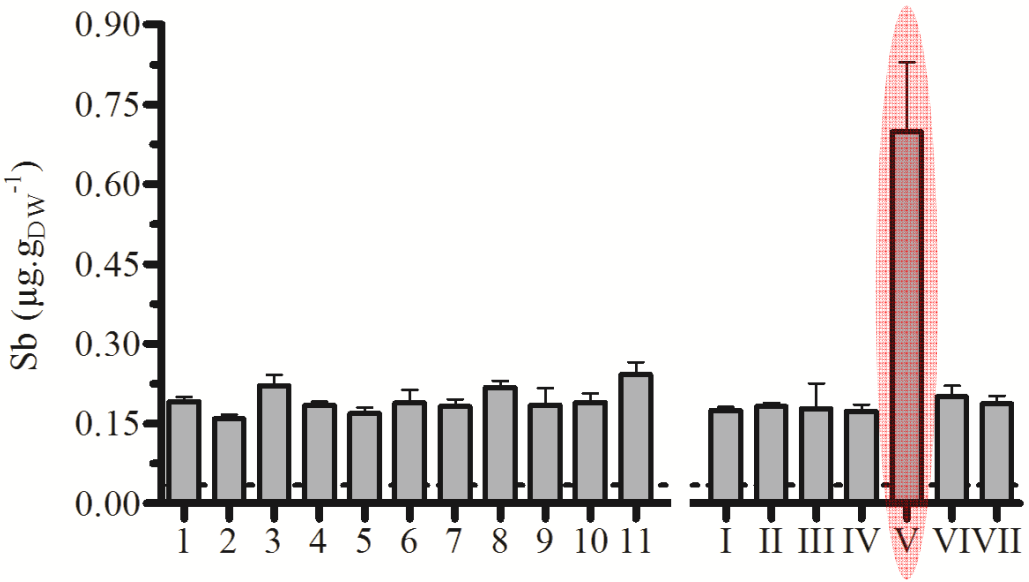

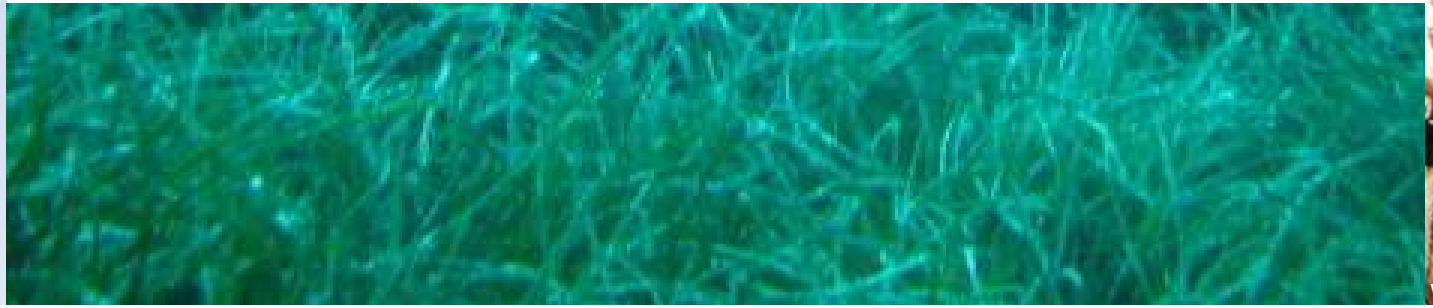

General conclusions

CONCLUSIONS

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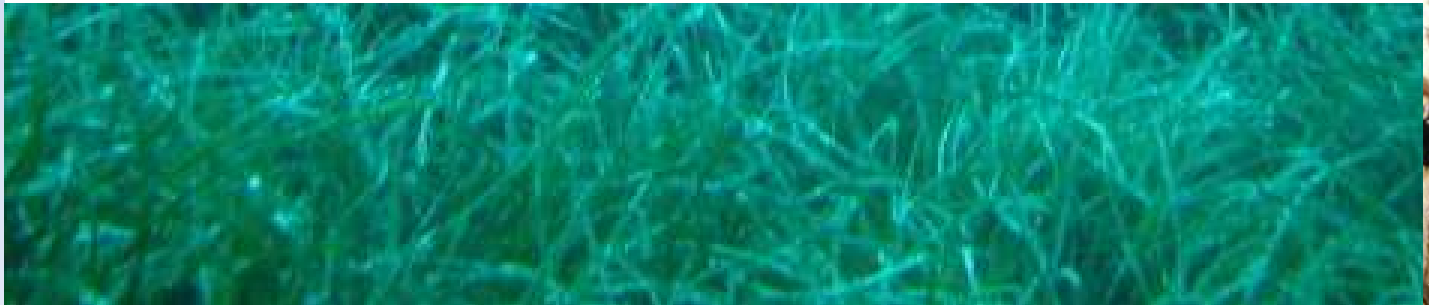

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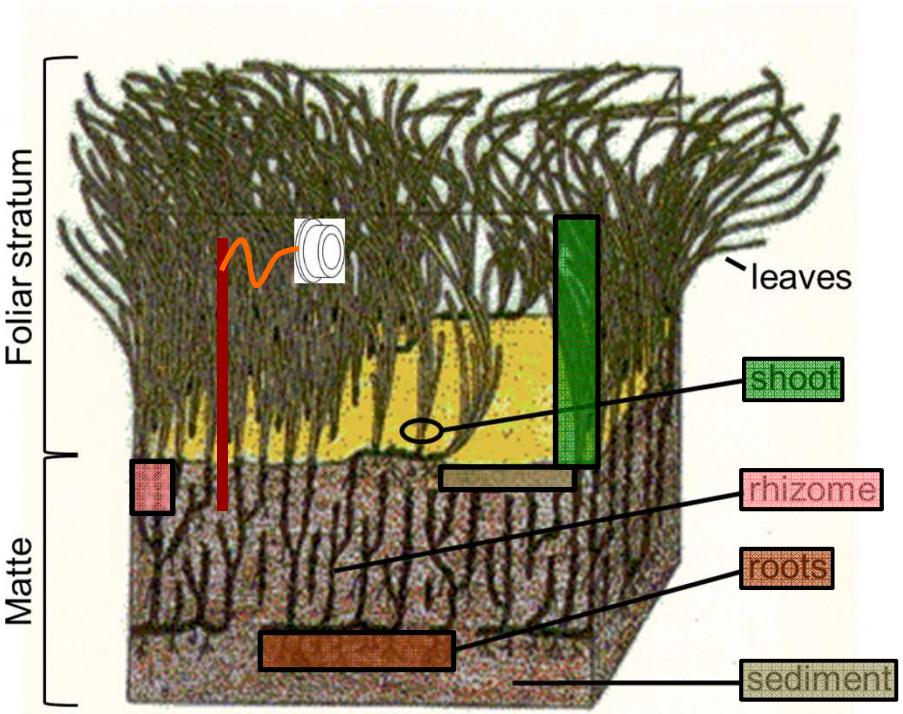

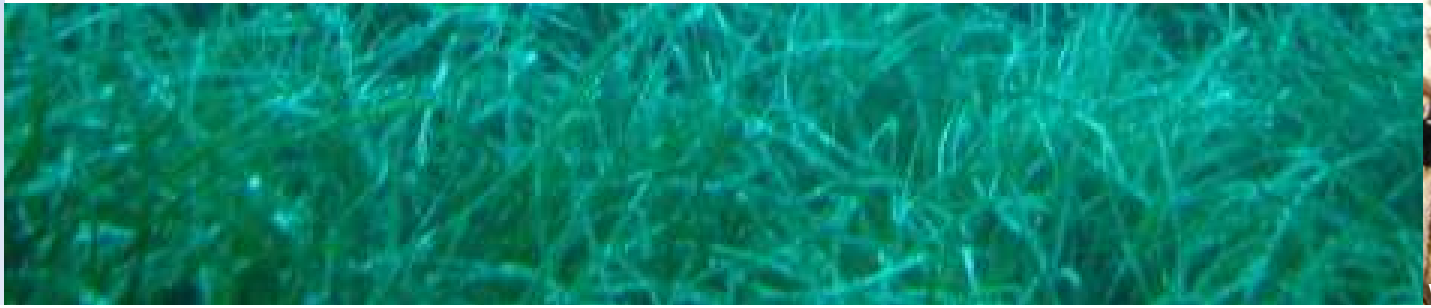

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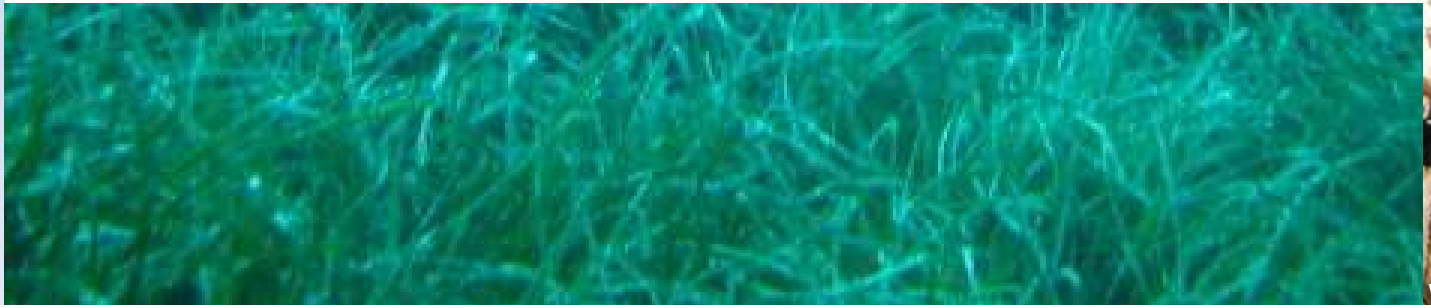

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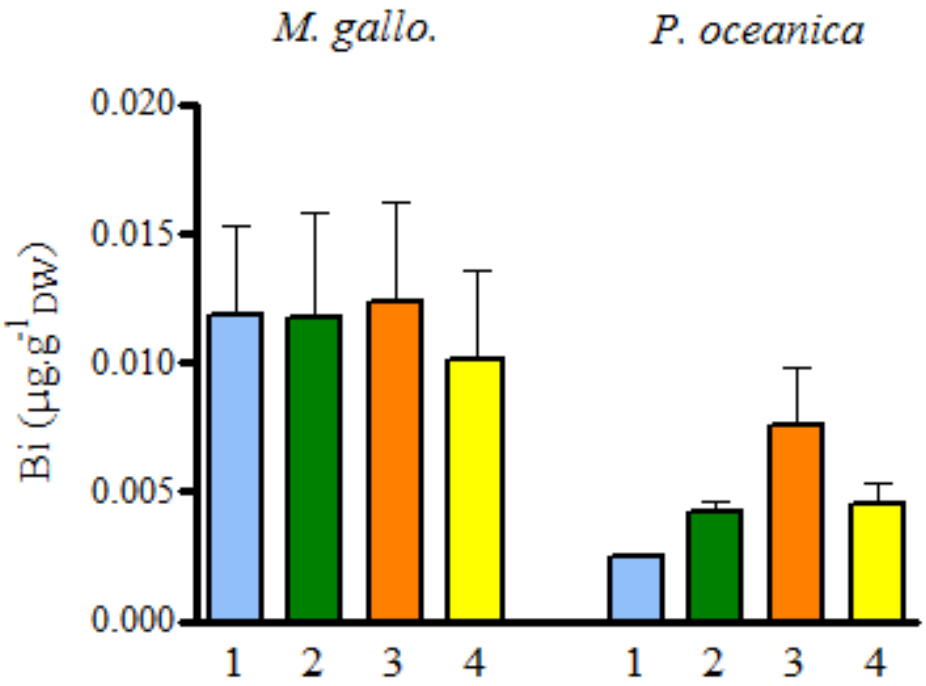

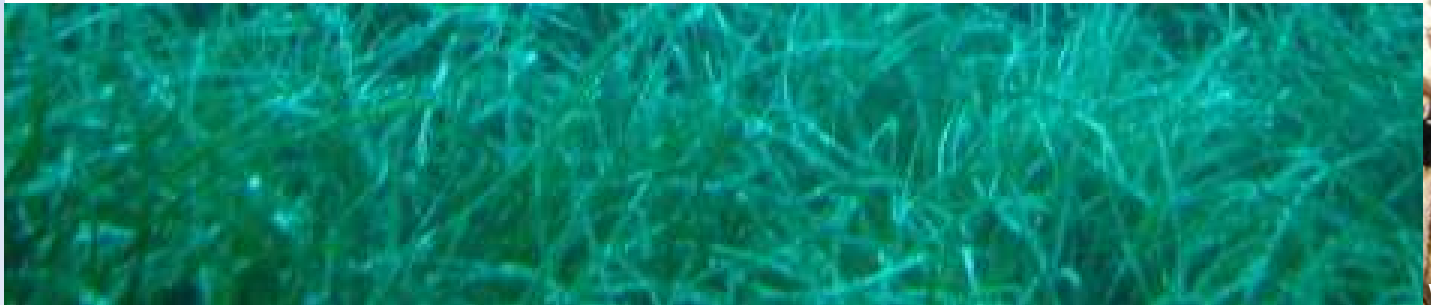

General conclusions

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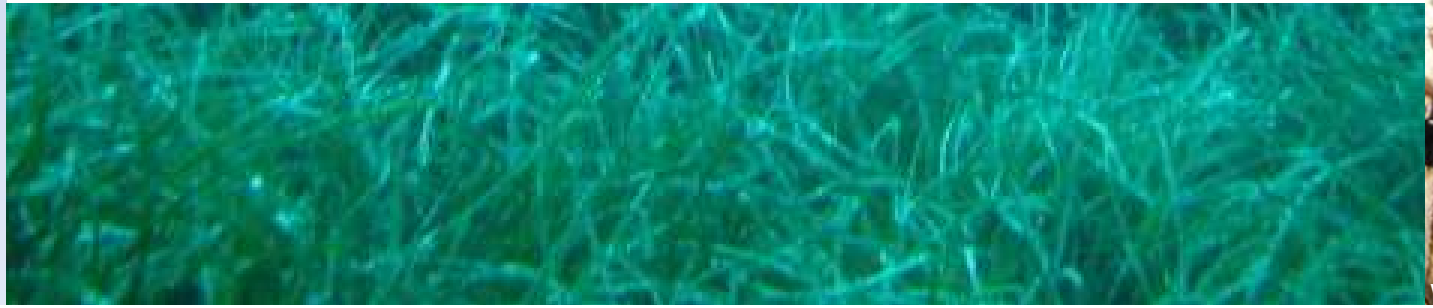

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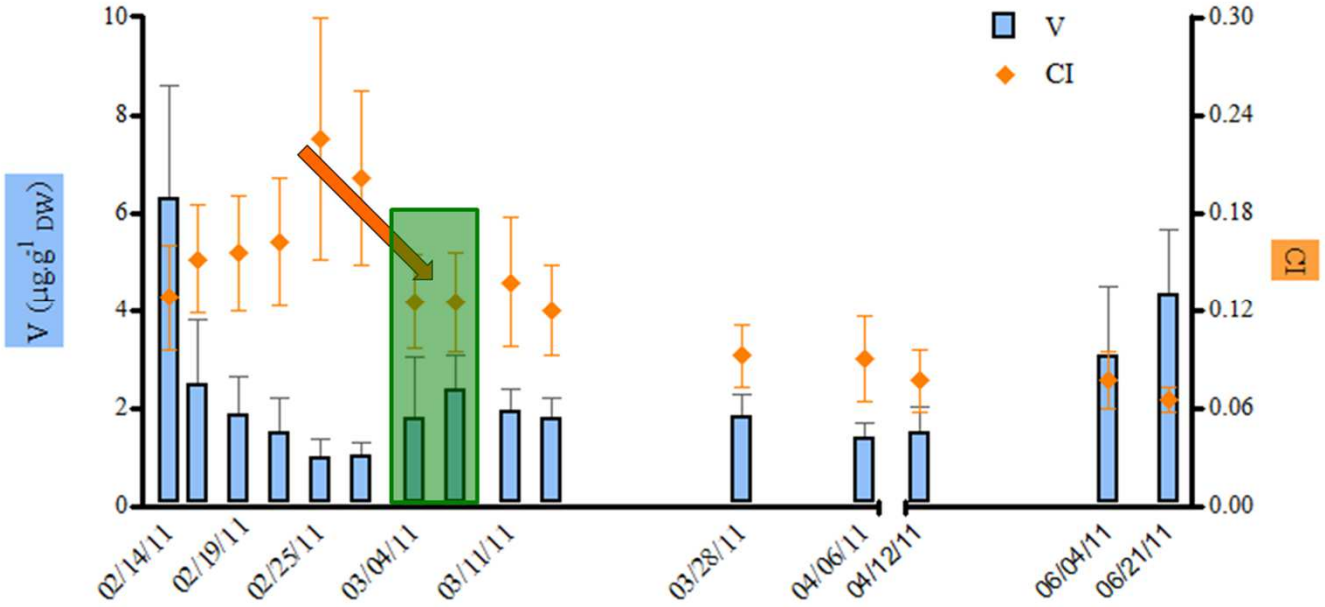

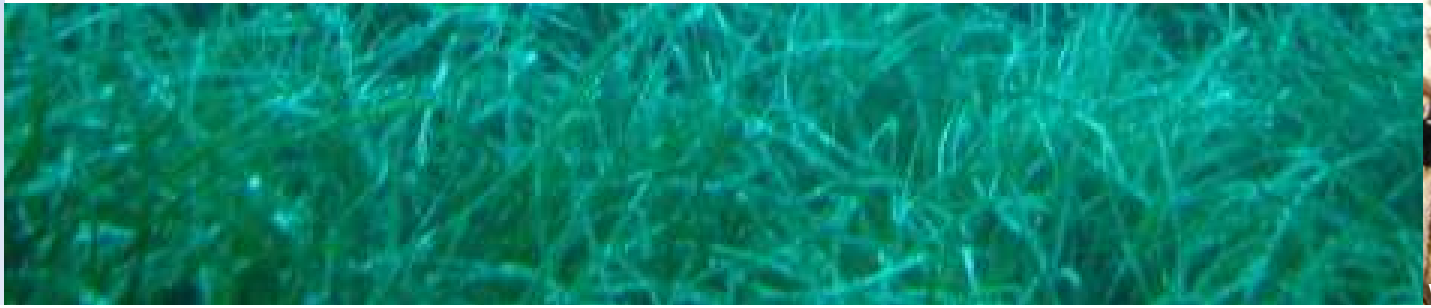

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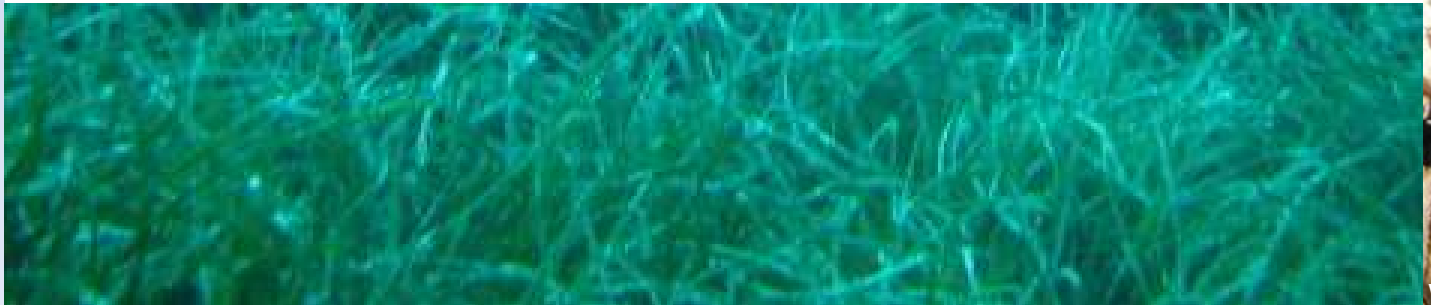

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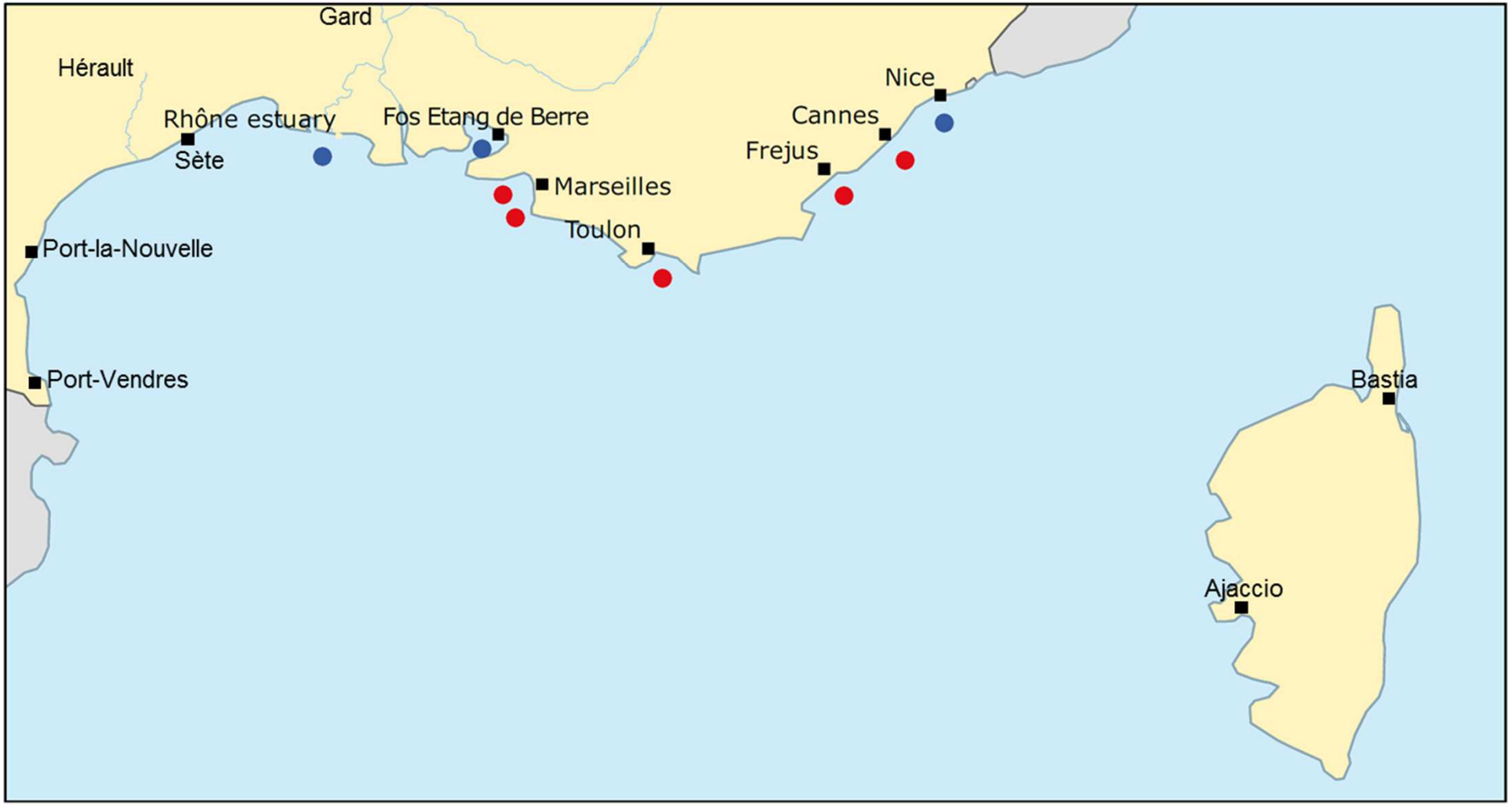
Questions

QUESTIONS

Pollution of the Mediterranean French coasts



Zoom on the Mediterranean coastlines of France. Full red circles: pollution hot spots; blue full circles: areas of major concern; full black squares: coastal cities (modified from EEA 2006).

Trace elements

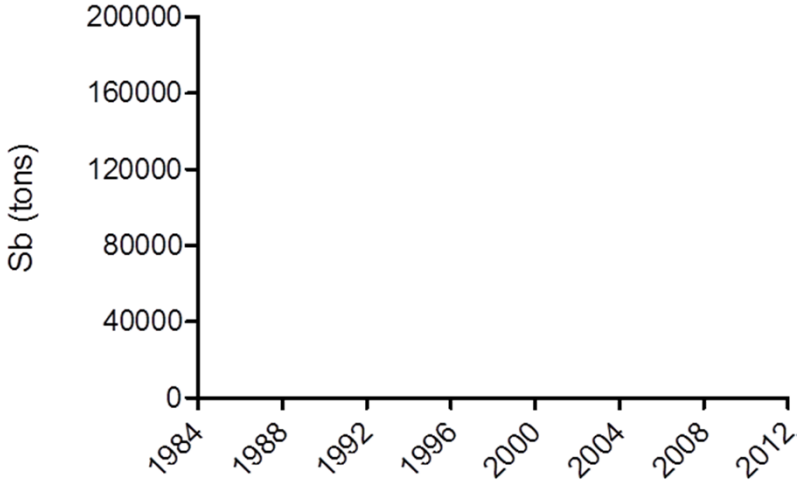
INTRODUCTION

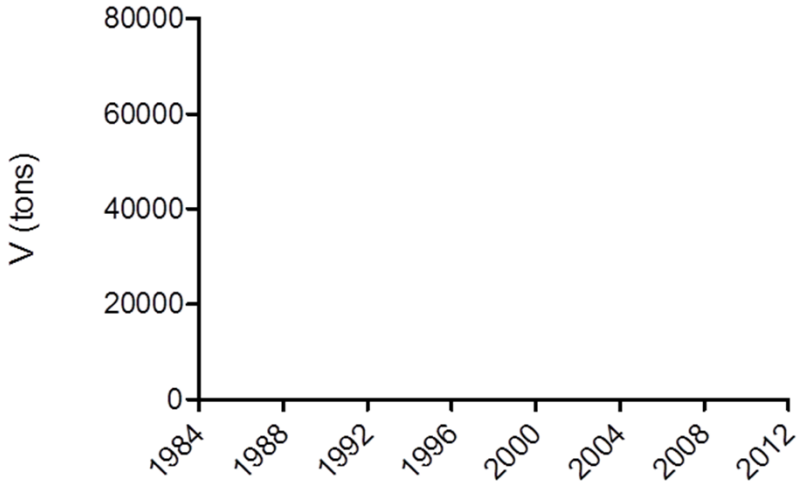
Trace elements

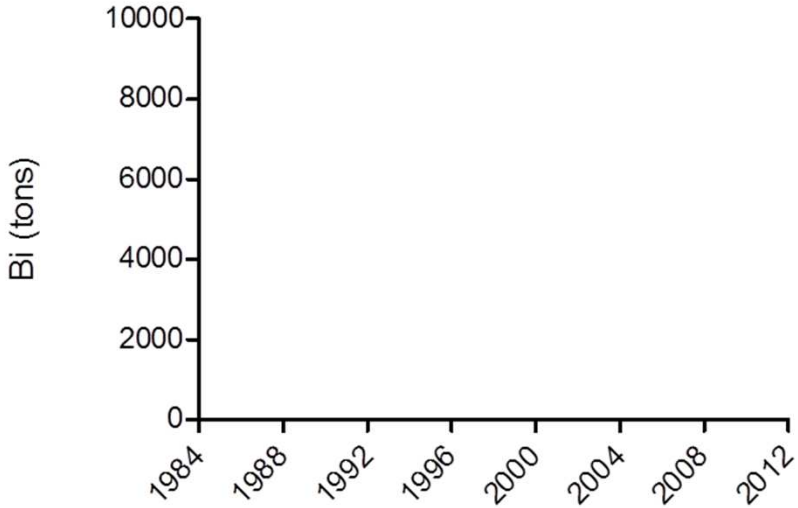
- Geophysicochemistry
  - fluxes;
  - spatial distribution;
  - speciation, balances, …
- Ecology
  - ecosystems;
  - organisms.
- Ecotoxicology
  - adverse effects;
  - pollution, …

World production of trace elements

INTRODUCTION

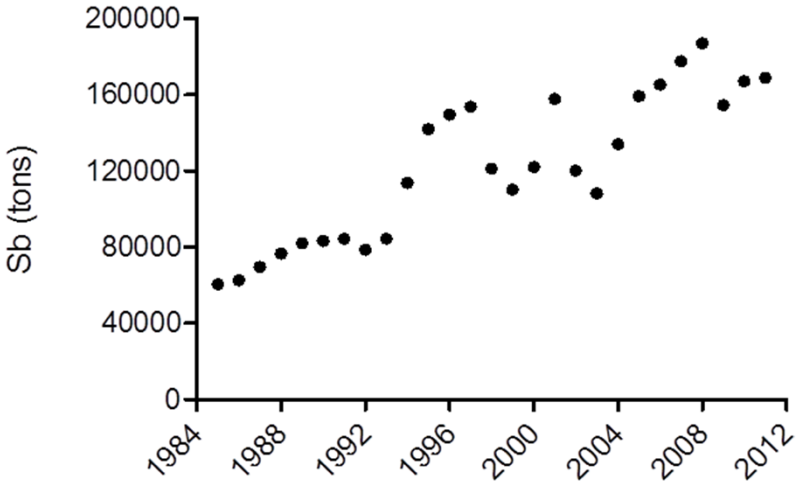


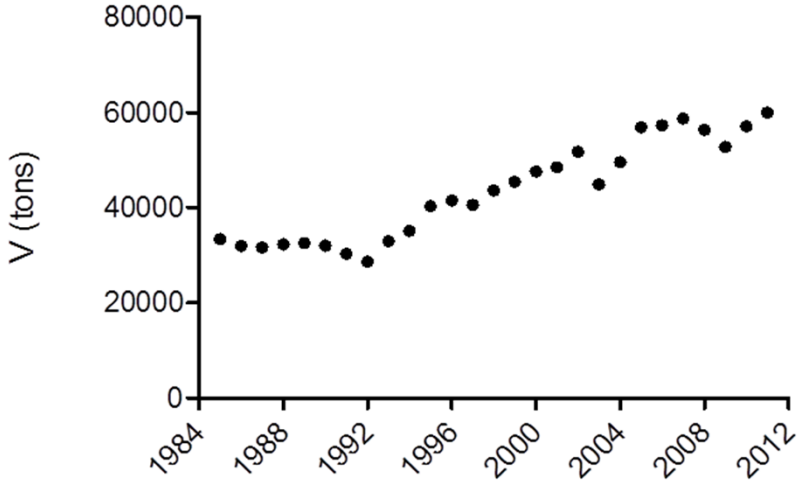


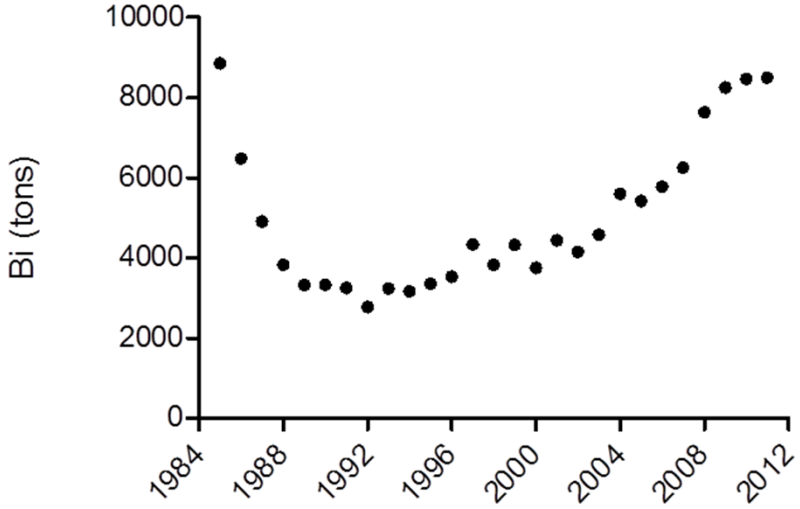


World production of trace elements

INTRODUCTION

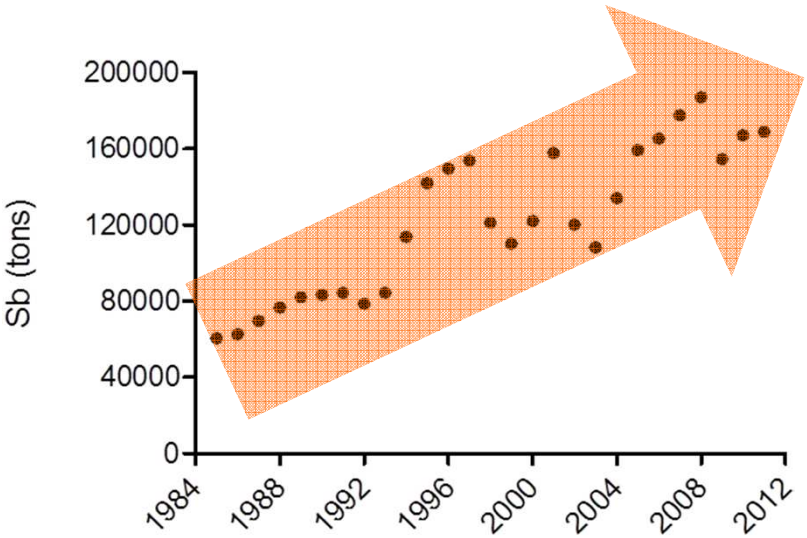


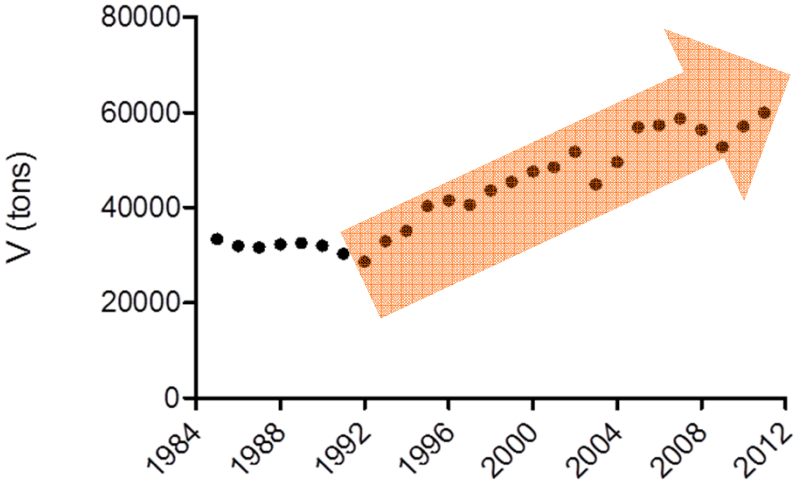


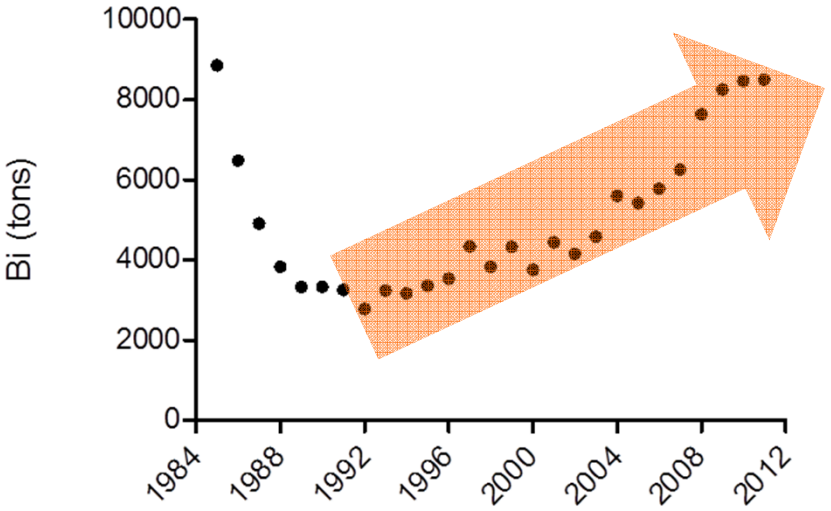


World production of trace elements

INTRODUCTION

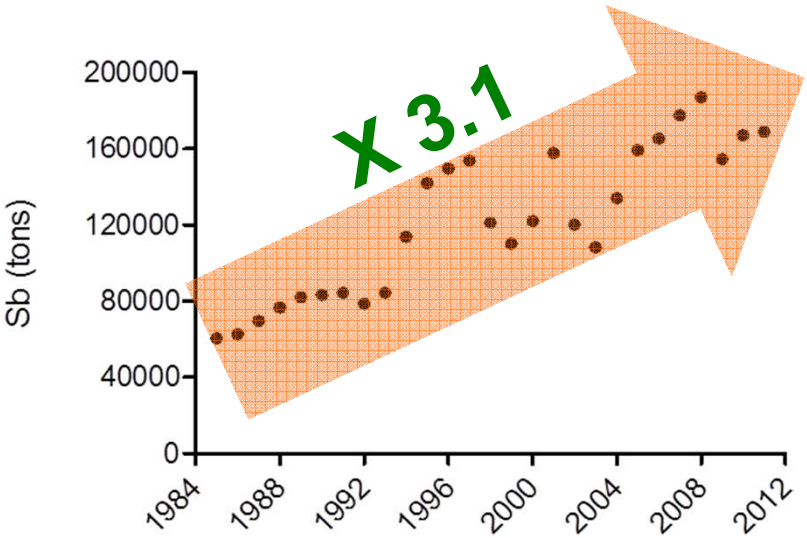


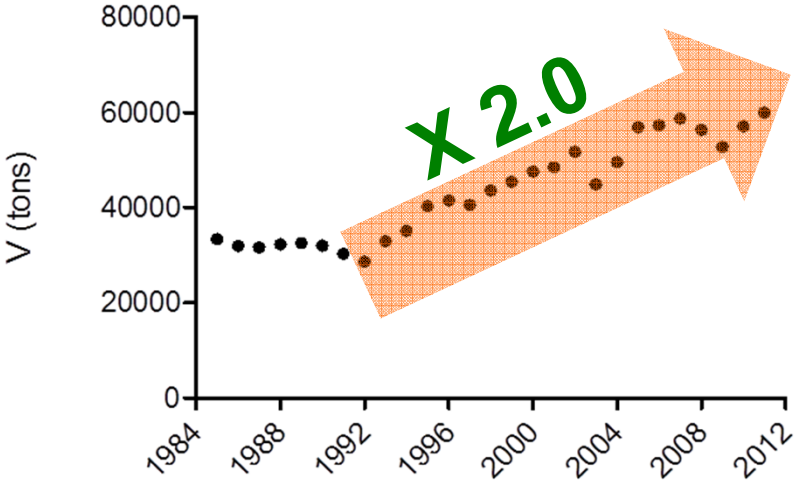


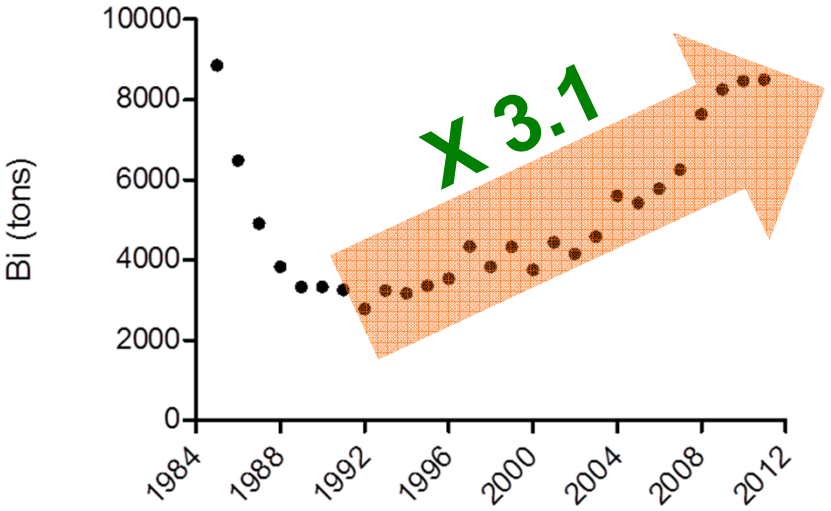


World production of trace elements

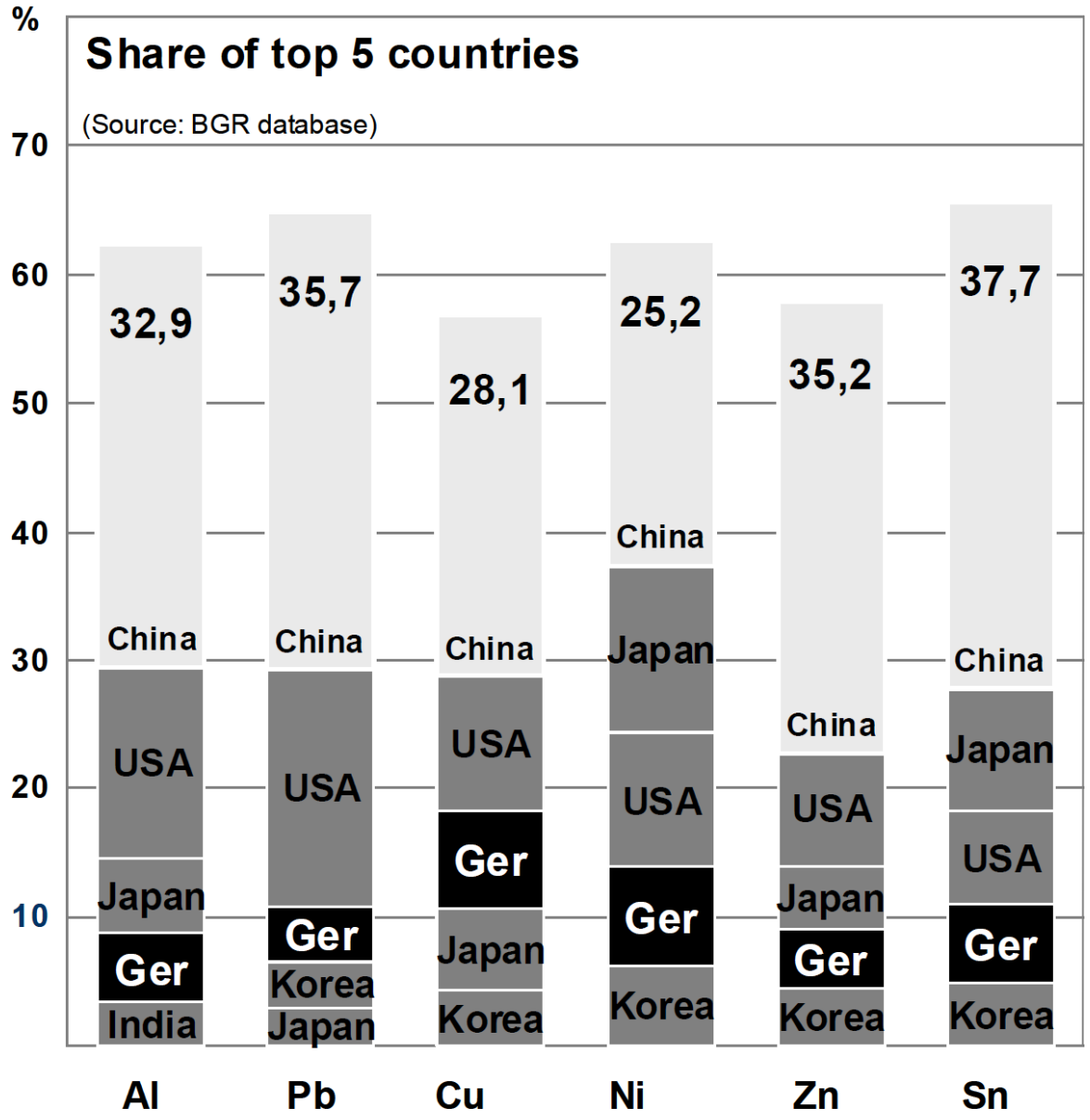
INTRODUCTION







World consumption of trace elements



(modified after Sievers et al. 2010)

Biomonitoring

INTRODUCTION

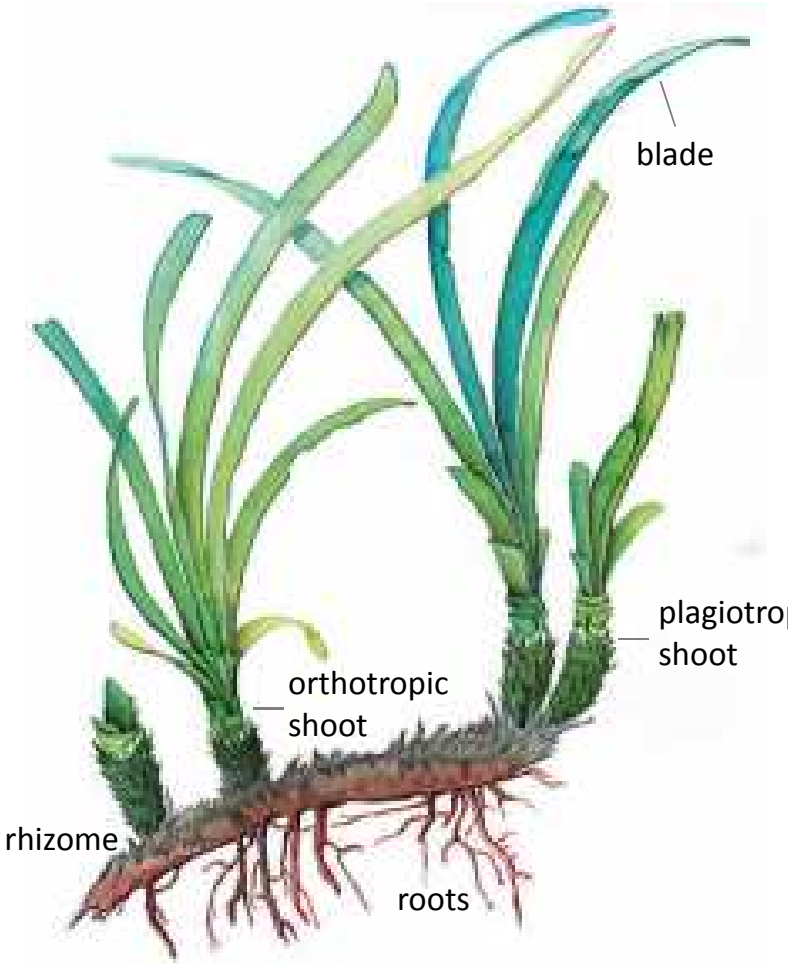
Number of references (1975-2010) on trace elements studied in *Posidonia oceanica*

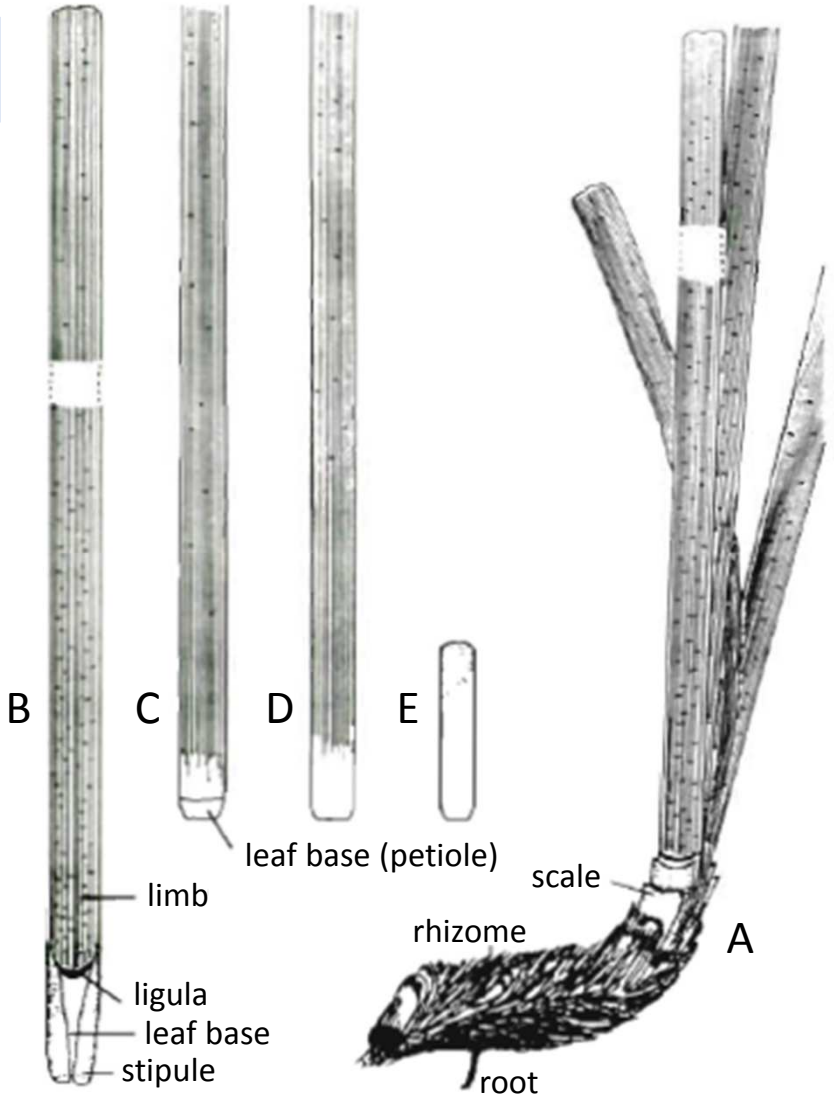
TE	Cd	Pb	Cu	Zn	Cr	Fe	Ni
# ref.	34	29	27	25	22	14	13

TE	As	Se	Ag	Co	Mn	Al
# ref.	3	3	2	2	2	1
TE	**Be**	**Bi**	**V**	**Mo**	**Sn**	**Sb**
# ref.	0	0	0	0	0	0

INTRODUCTION

Posidonia oceanica

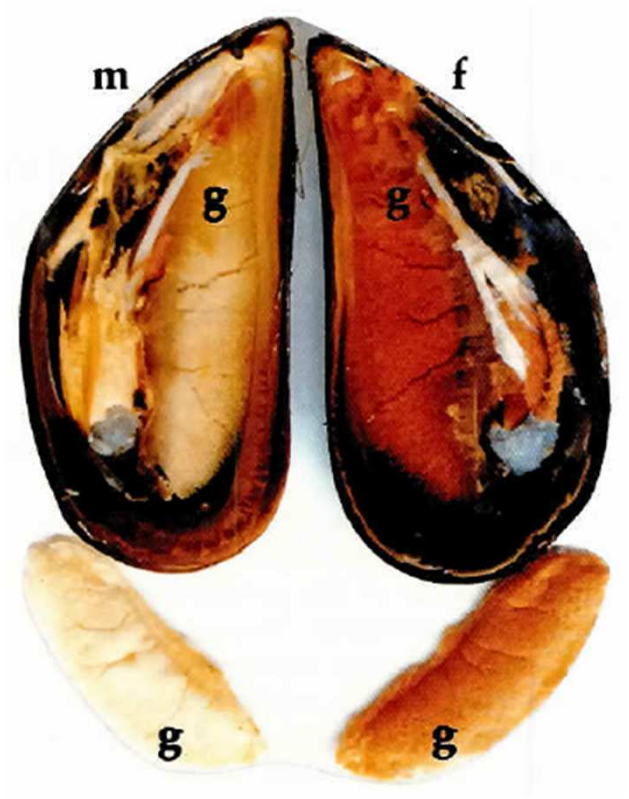




Left: *P. oceanica* shoots fixed on a plagiotropic rhizome. Right: (A) shoot of leaves on a plagiotropic rhizome; (B, C) adult leaves; (D) intermediate leaf; (E) juvenile leaf (modified after Libes and Boudouresque 1987).

Mytilus galloprovincialis

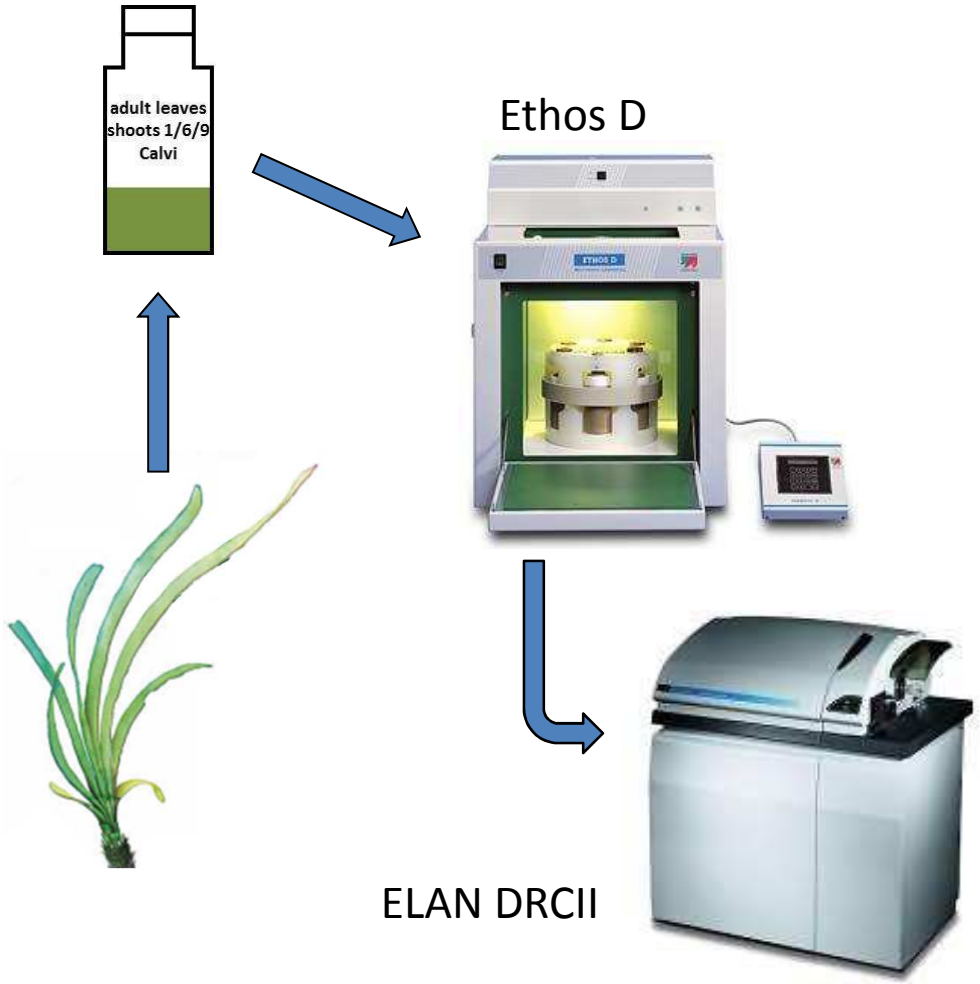
INTRODUCTION



Tissue morphology in *M. galloprovincialis*. **Left** - opened sexually matured male (m) and female (f) mussels and isolated gonads (g) (Mikhailov et al. 1995). **Right** - 1 = mantle (gonad), 2 = muscular mantle edge, 3 = foot, 4 = hepatopancreas, 5 = labial palps, 6 = gills, 7 = visceral mass, 8 = foot retractor muscle, 9 = posterior adductor muscle, *circles* = gonad follicle regions spread over the mantle, *small white lines* = indicate gonad duct). Scale bar 1 cm (Torrado and Mikhailov 2000).

Laboratory analyses

MATERIAL - METHODS



Analytical steps:

- homogeneous sample
- acidic digestion in a microwave oven
- measures :
  - inductively coupled plasma mass spectrometer

PREI: 42 sites sampled in april 2007 at 15m

SPATIAL VARIATION

List of metrics used in the PREI, unit and methodology used to obtain the results for each metric.

PREI metrics and units	Methodology and references
Shoot density (shoot m^{-2})	Quadrat 20 × 20 cm Soullard et al. (1994) 20 measurements at 15 m depth
Lower depth limit (m)	Noted *in situ* by scuba diver
Type of this limit (regressive, progressive, stable)	Noted *in situ* by scuba diver according to the classification of Meinesz and Laurent (1978)
E/*L*	On 20 shoots sampled at 15 m depth: measurement of total dry weight of epiphyte and leaf (adult + intermediate) Dauby and Poulicek (1995)
Leaf surface area (cm^2 $shoot^{-1}$)	On 20 shoots sampled at 15 m depth: measurement of total leaf surface area according to the methodology of Giraud (1979)

SPATIAL VARIATION

Sampling strategy:

PREI: 42 sites sampled in april 2007 at 15m

PREI values calculated in Corsica and PACA.

CORSICA		PACA	
Station	PREI	Station	PREI
Cargèse	0.668	Ponteau	0.360
Tiucca	0.630	Couronne	0.525
Ajaccio-nord	0.564	Carry	0.680
Ajaccio-sud	0.495	Ensuès	0.686
Porto Pollo	0.386	La Vesse	0.465
Figari-Bruzzi	0.619	Corbière	0.305
Piantarella	0.597	Nord Pomègues	0.628
Sant'Amanza fdb	0.542	Prado	0.636
Sant'Amanza eb	0.671	P. Chèvres	0.477
Large Diana	0.689	Riou	0.677
Bravone	0.779	Calanque	0.584
Taglio Isolaccio	0.690	Cassis	0.563
Large Biguglia	0.721	Figuerolle	0.660
Erbalunga	0.741	Bandol	0.682
Maccinagio	0.650	Brusc	0.634
St Florent	0.478	Carqueiranne	0.708
Aregno	0.789	Garonne	0.583
Calvi	0.724	Levant	0.802
		Giens	0.819
		Bénat	0.764
		St Raphael	0.690
		Cap Roux	0.847
		Antibes	0.560
		Villefranche	0.280

Boundaries and colour codes for the different levels of ecological status.

EQR	Ecological status	Color code
1–0.775	High	Blue
0.774–0.550	Good	Green
0.549–0.325	Moderate	Yellow
0.324–0.100	Poor	Orange
<0.100–0	Bad	Red

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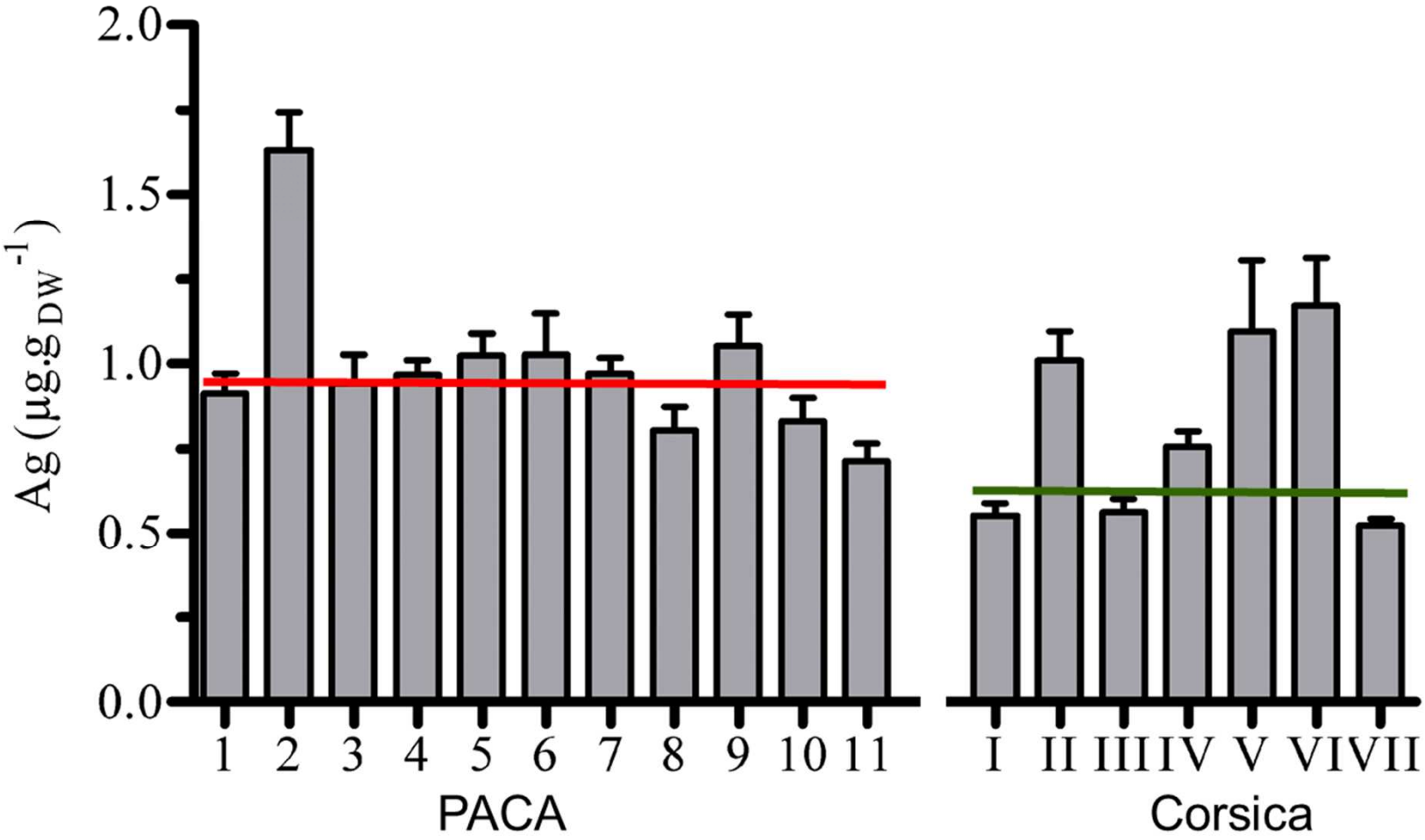
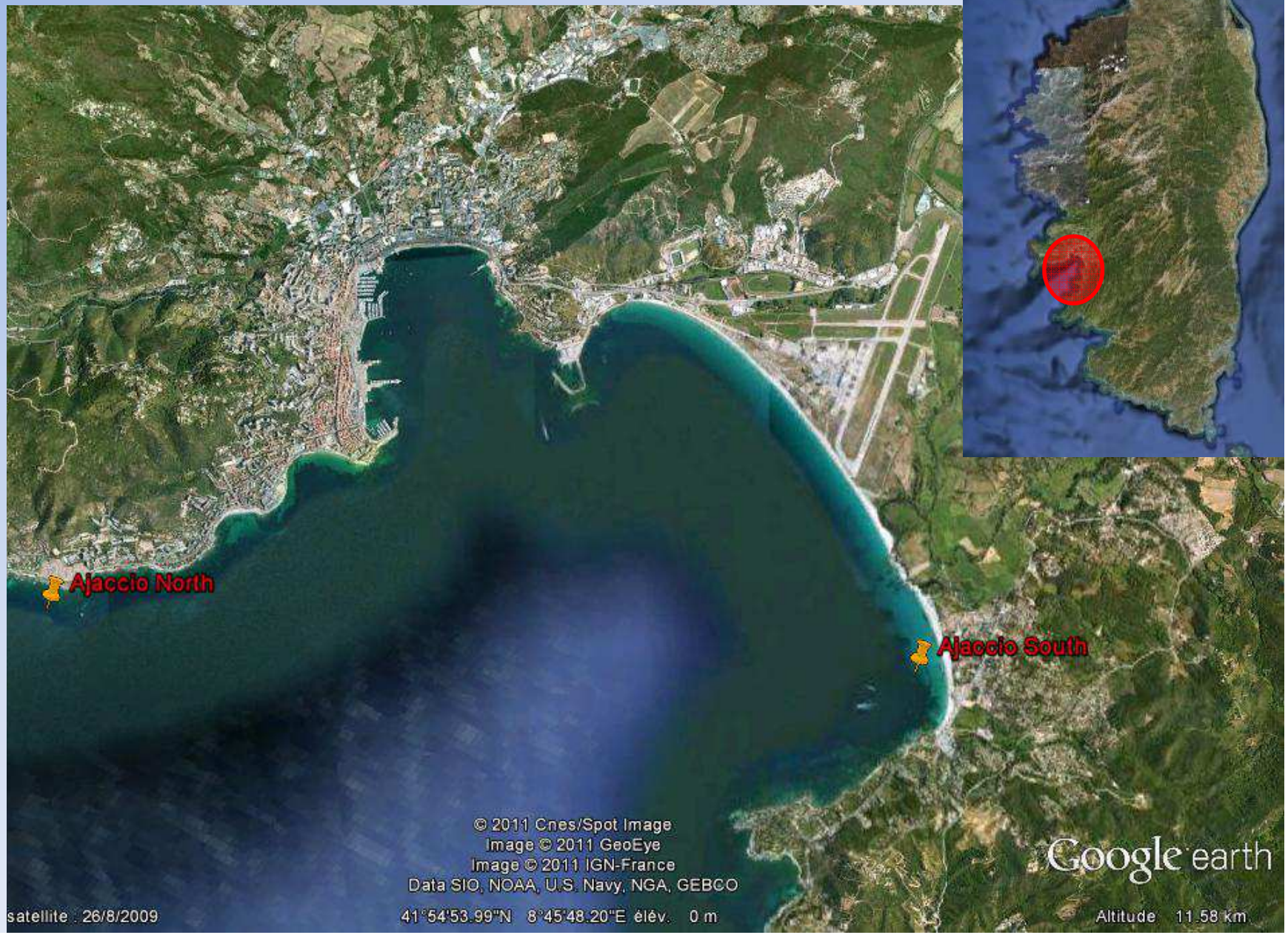
Ag - diffuse pollution

SPATIAL VARIATION



Small scale cartography

BIOACCUMULATION



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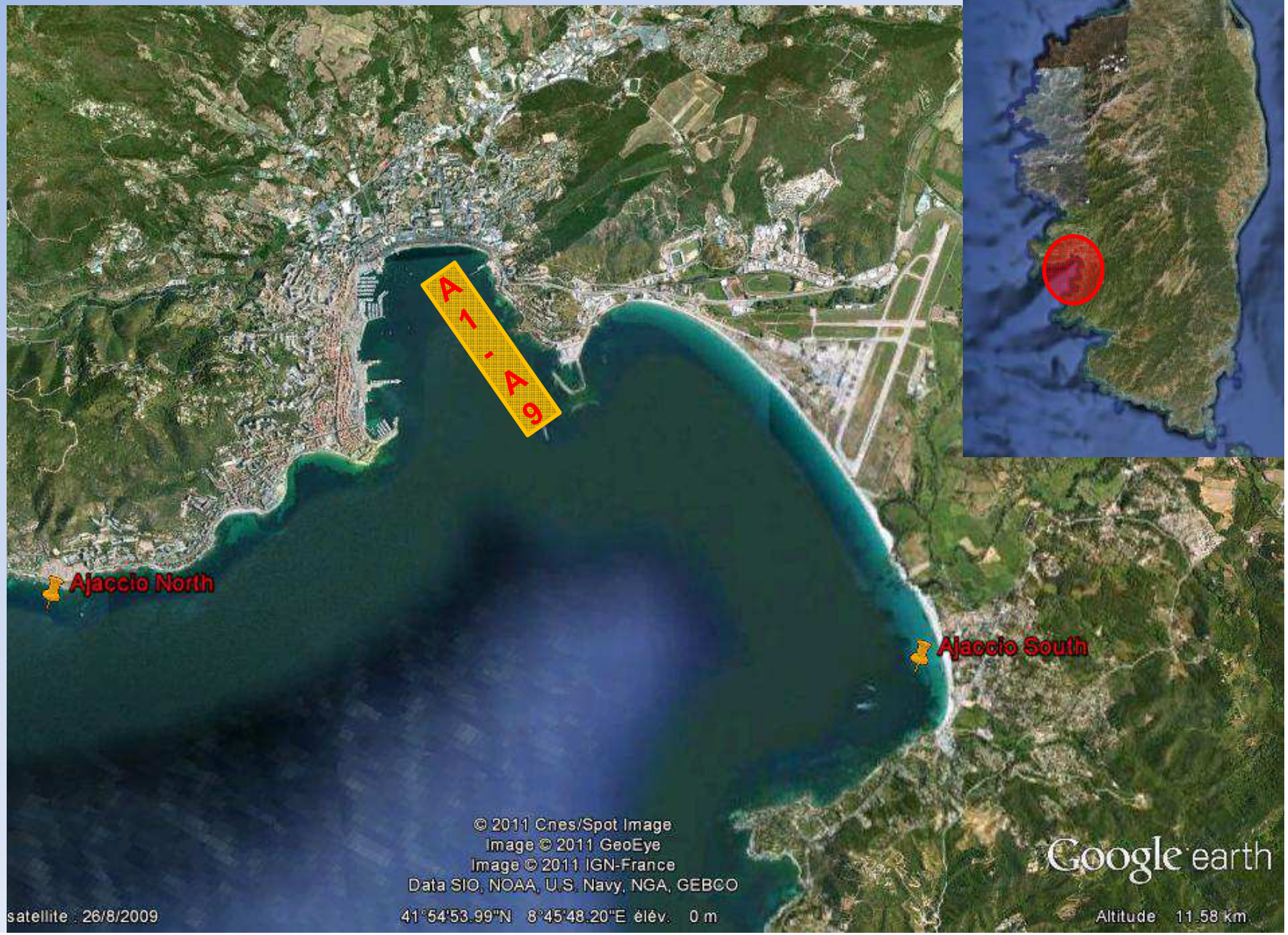

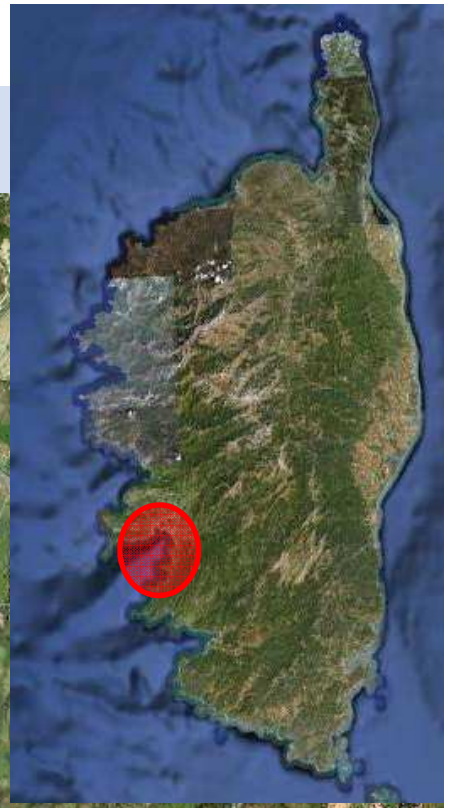

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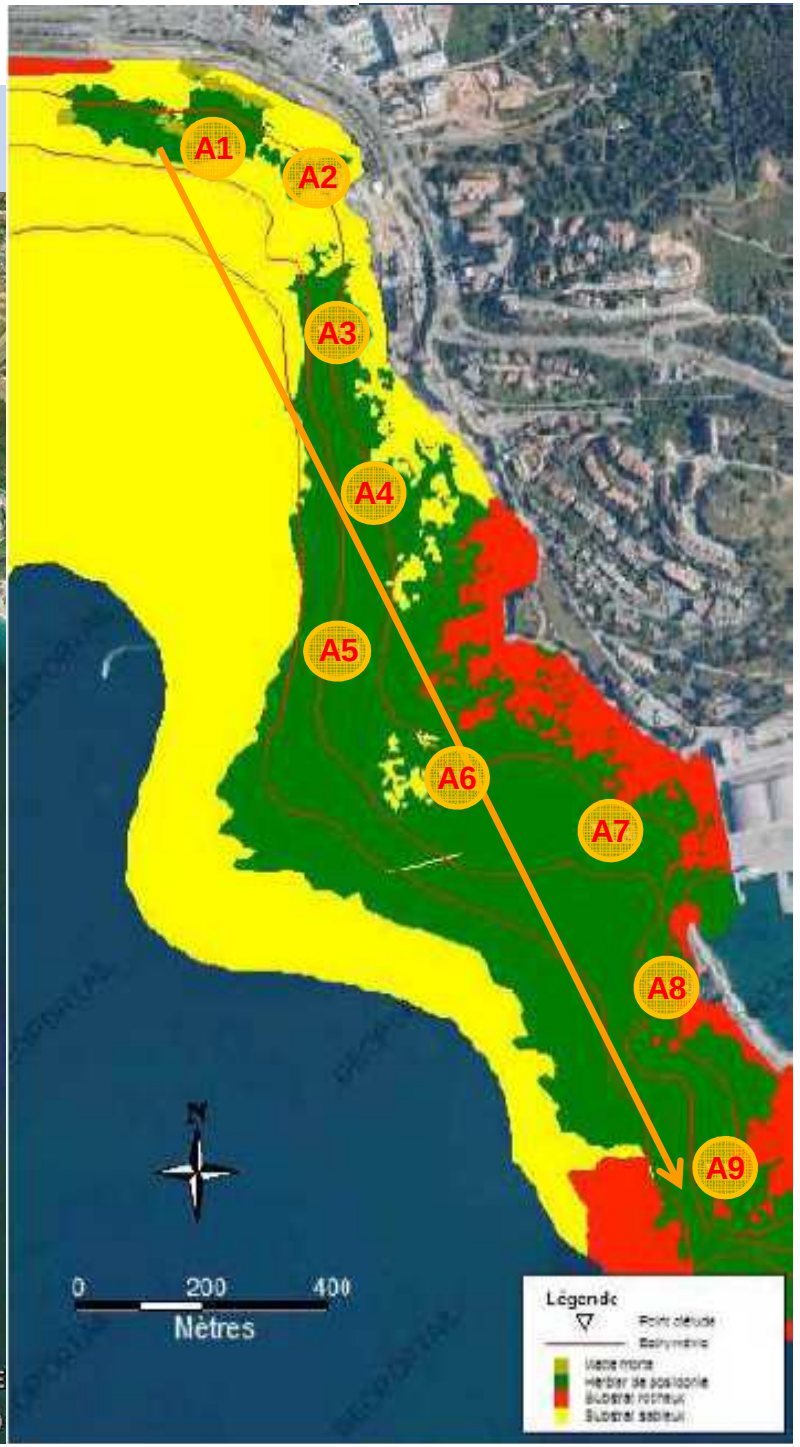

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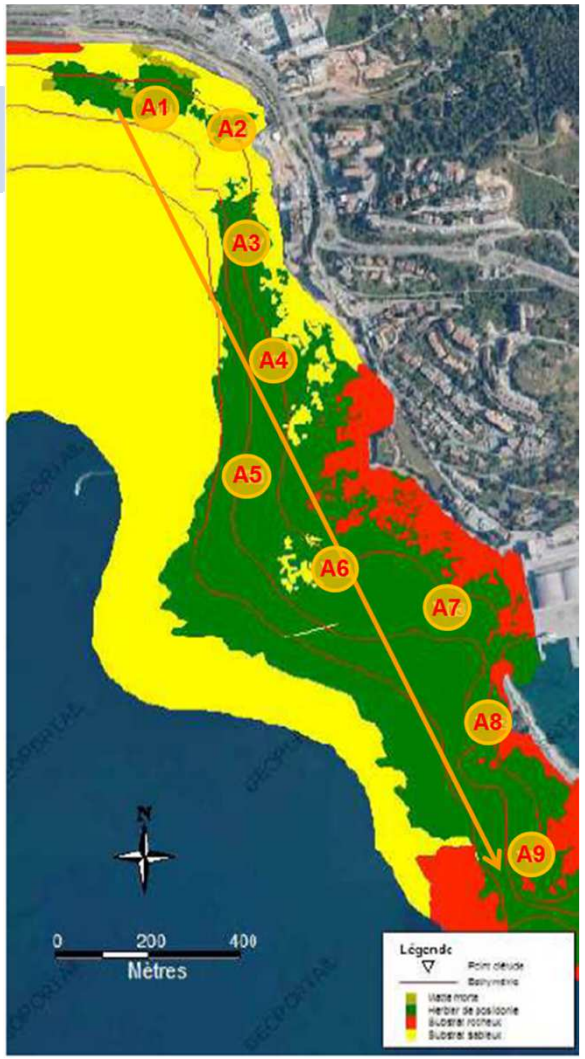

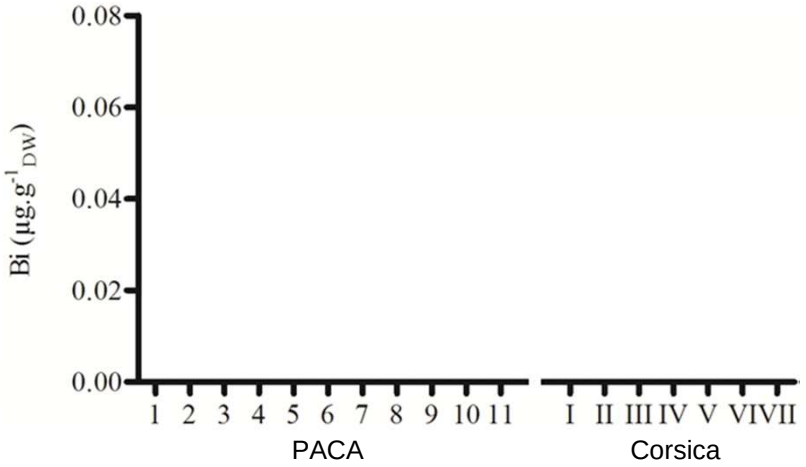

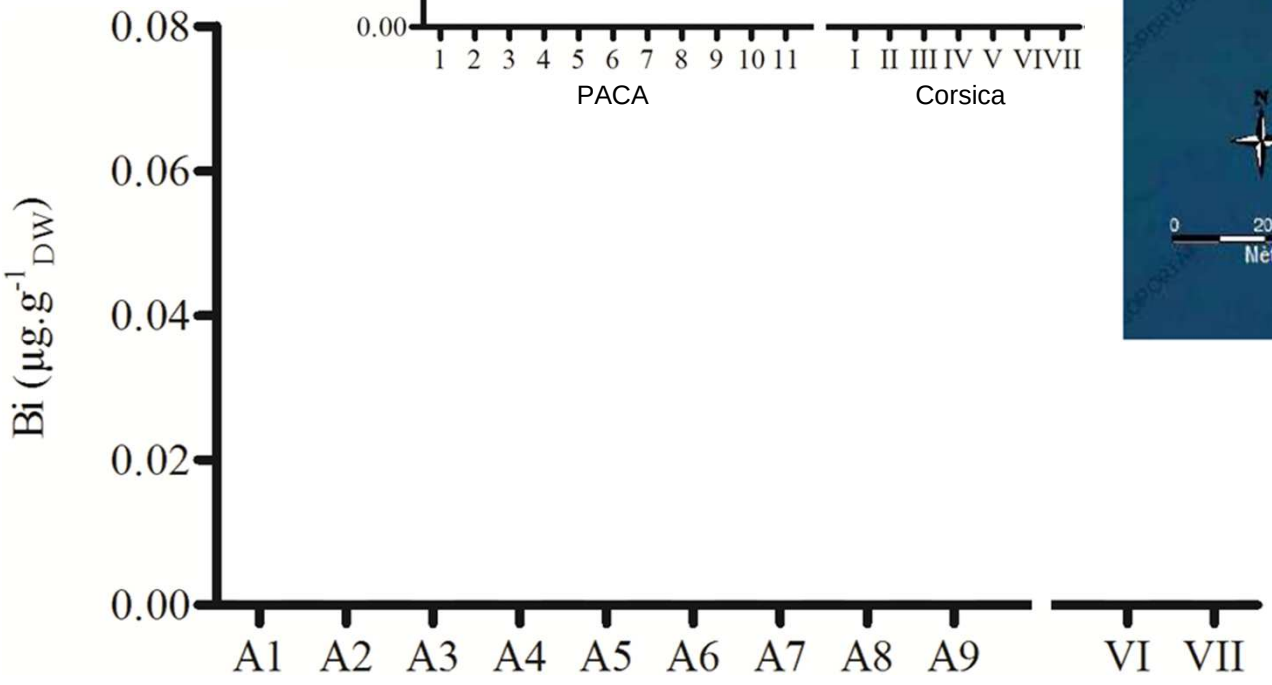

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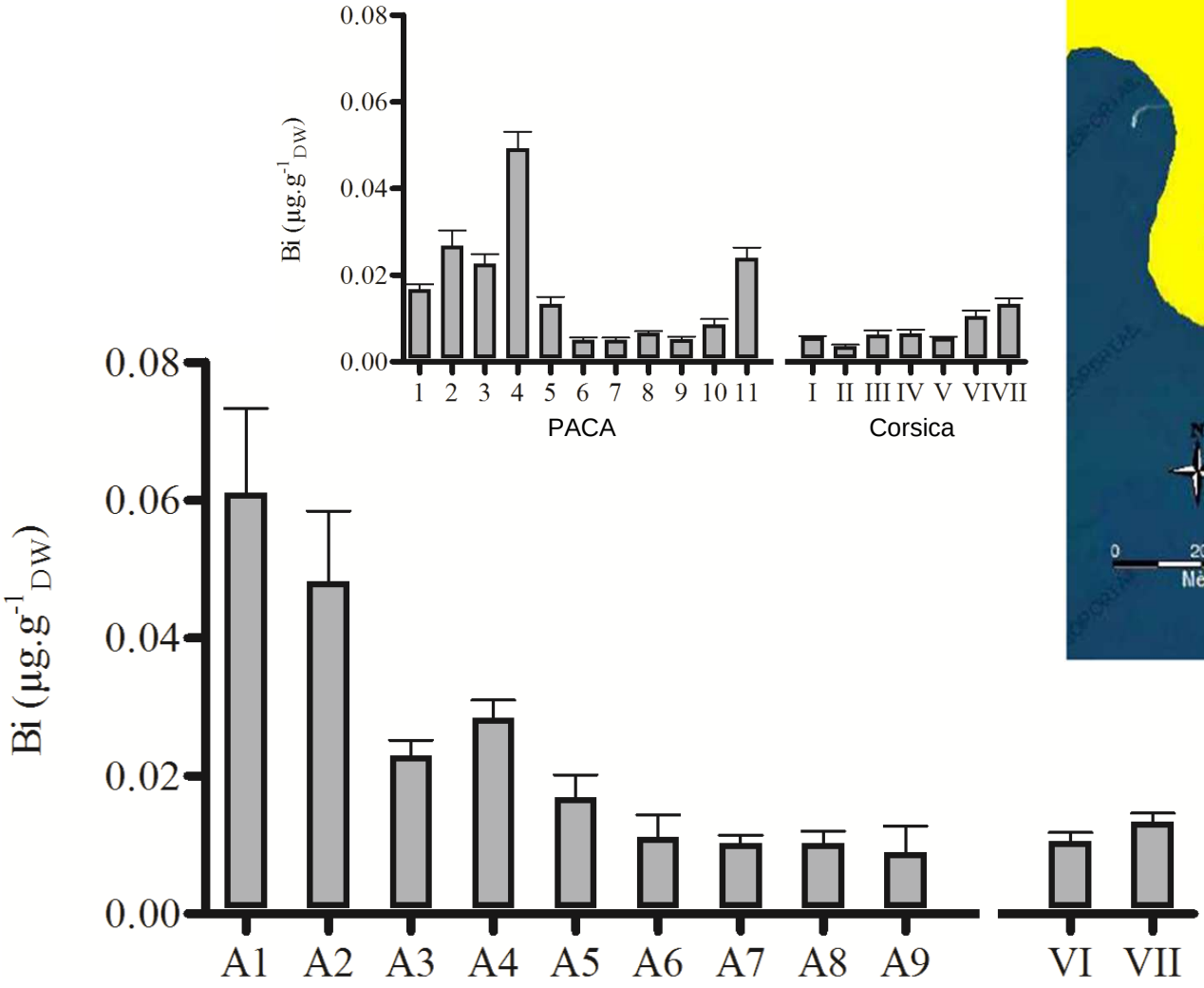

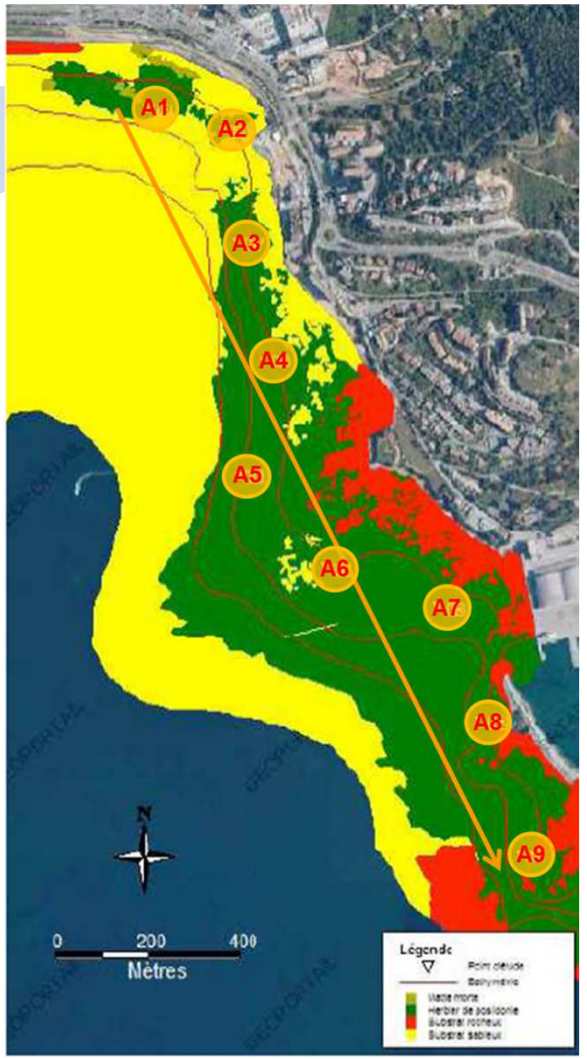

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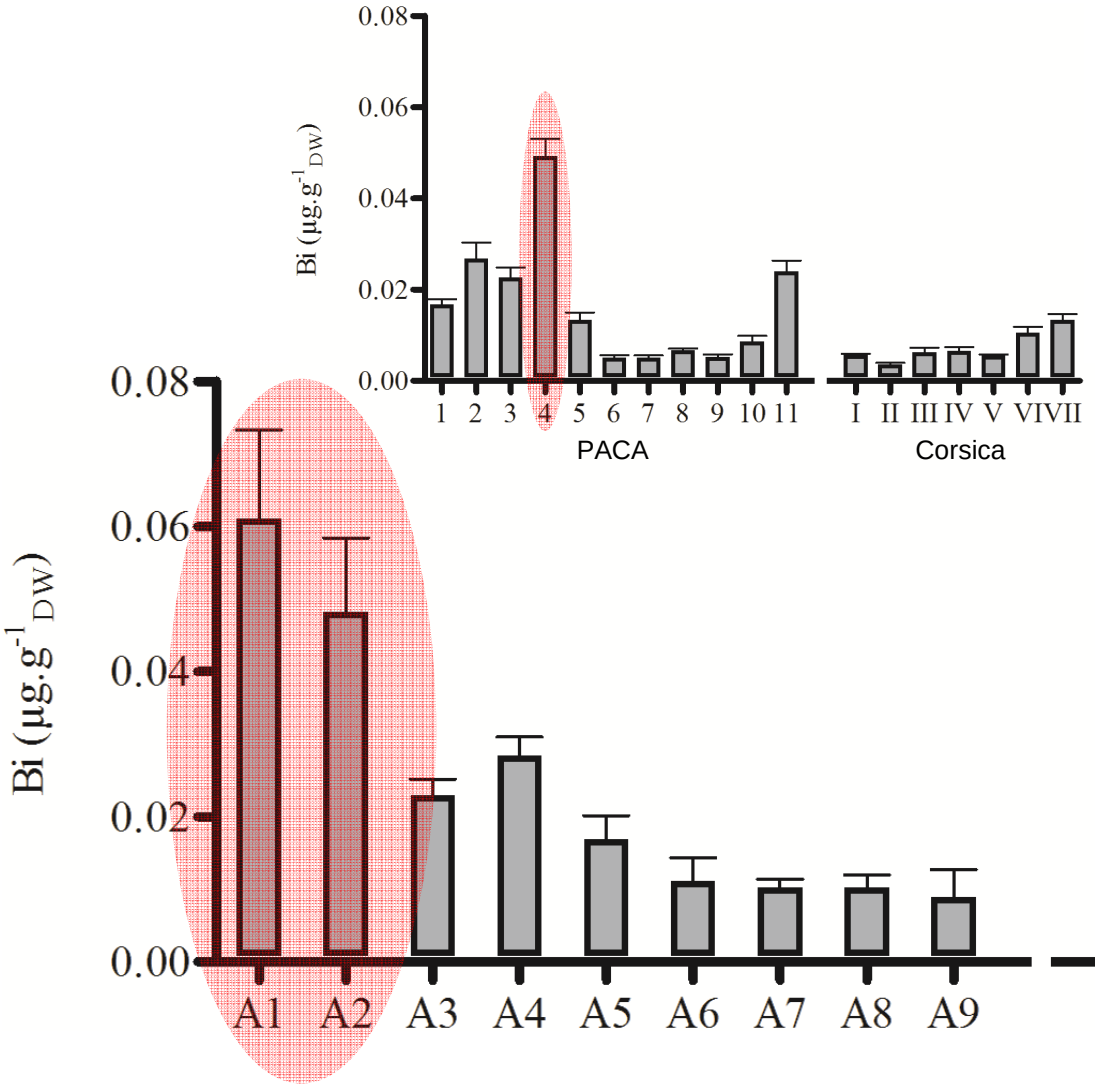

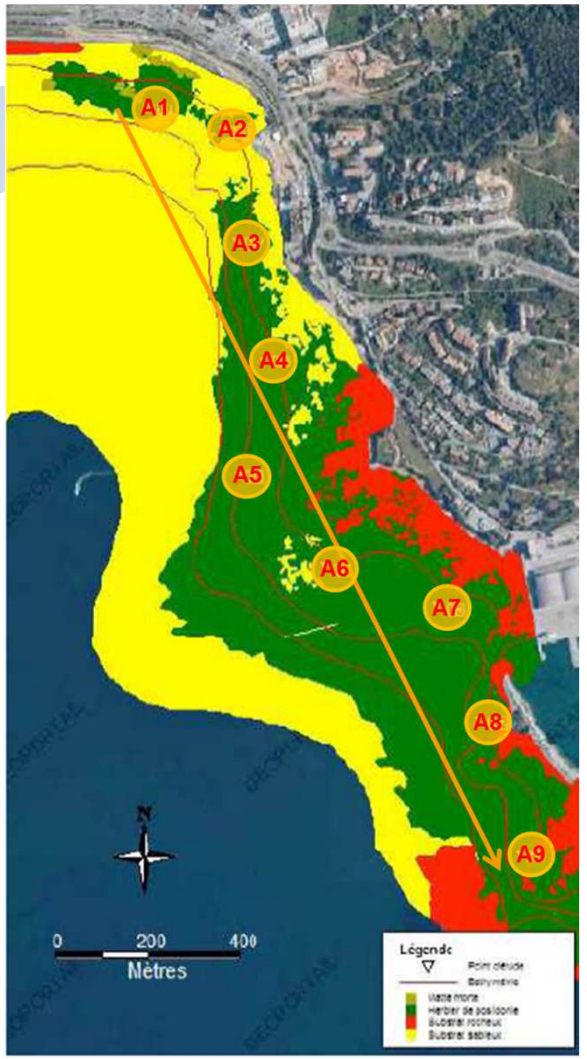

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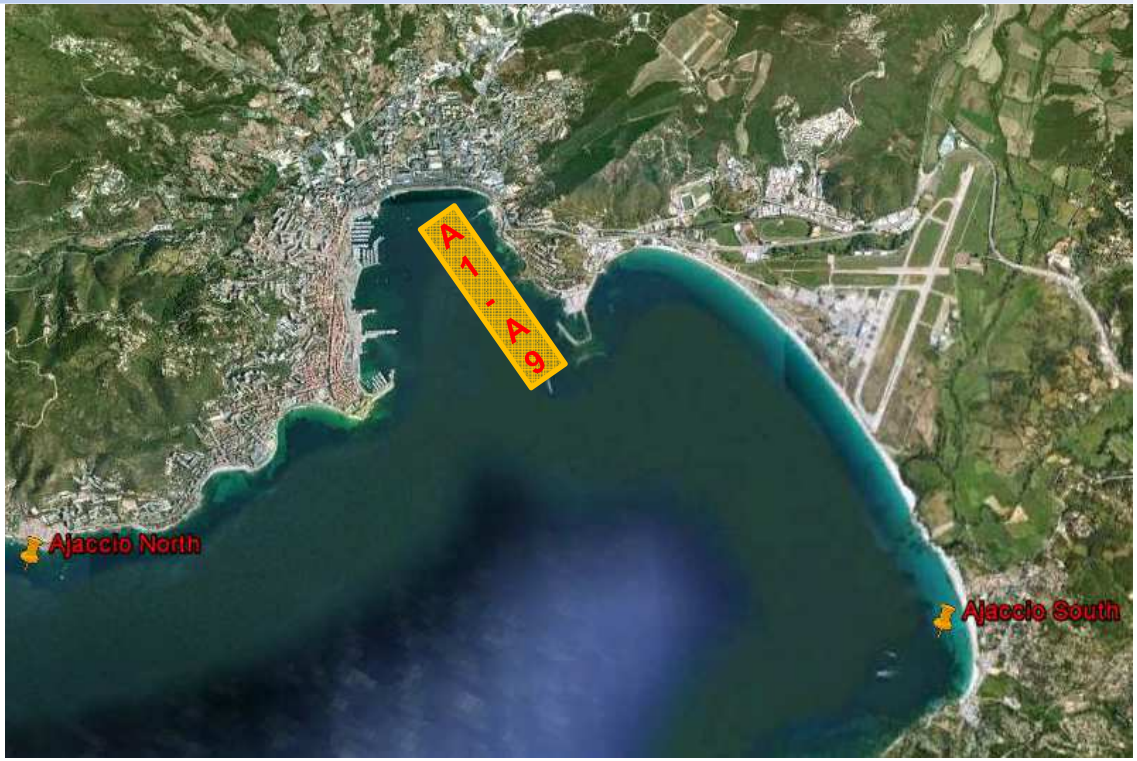
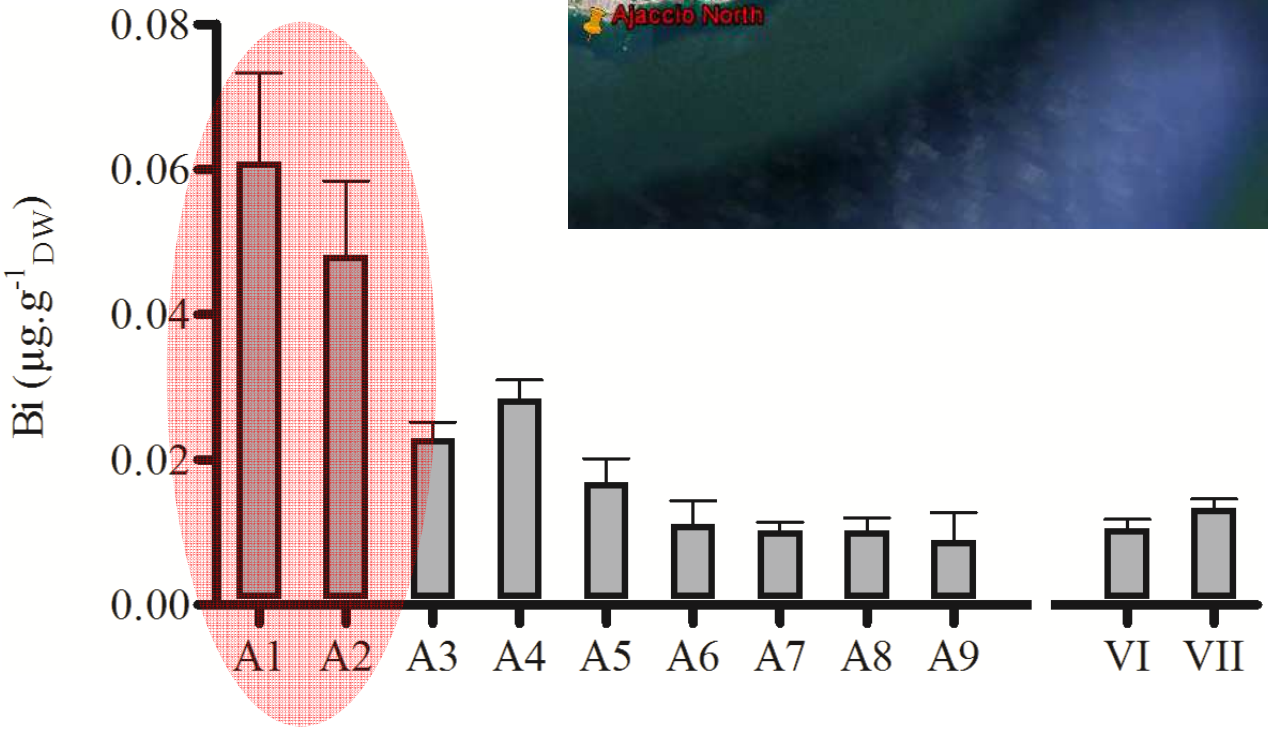
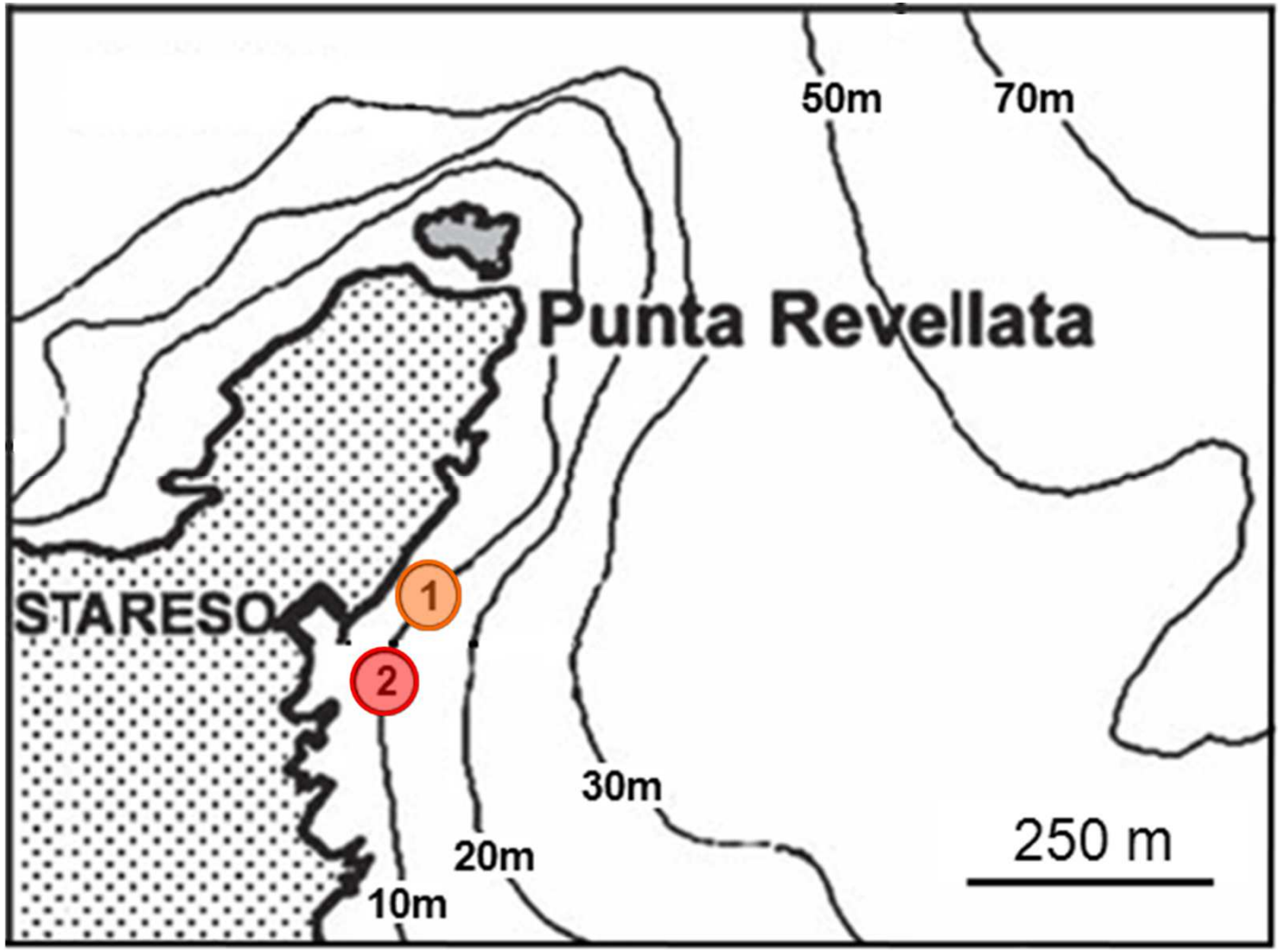




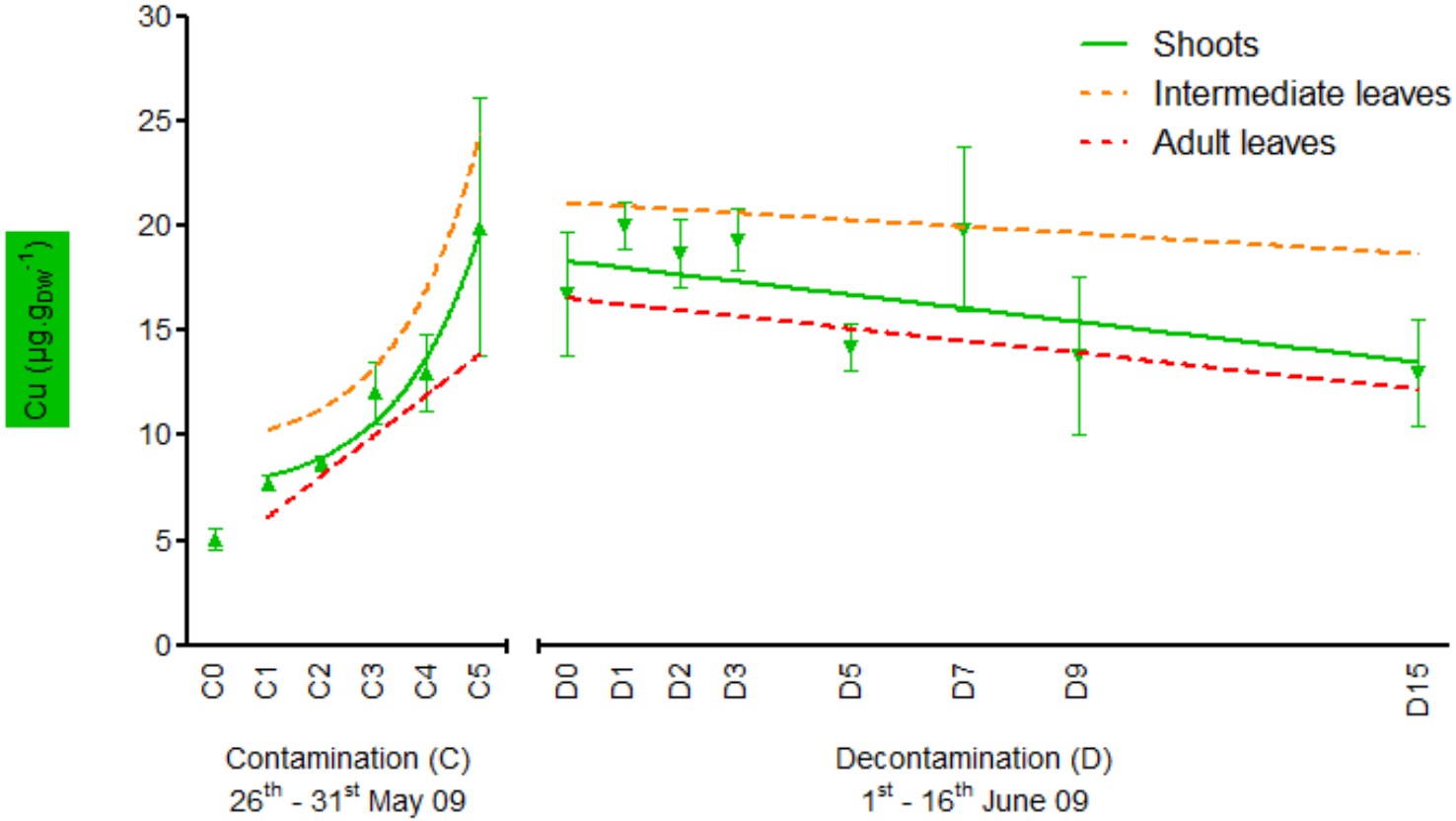
In situ contaminations of *P. oceanica*

KINETICS



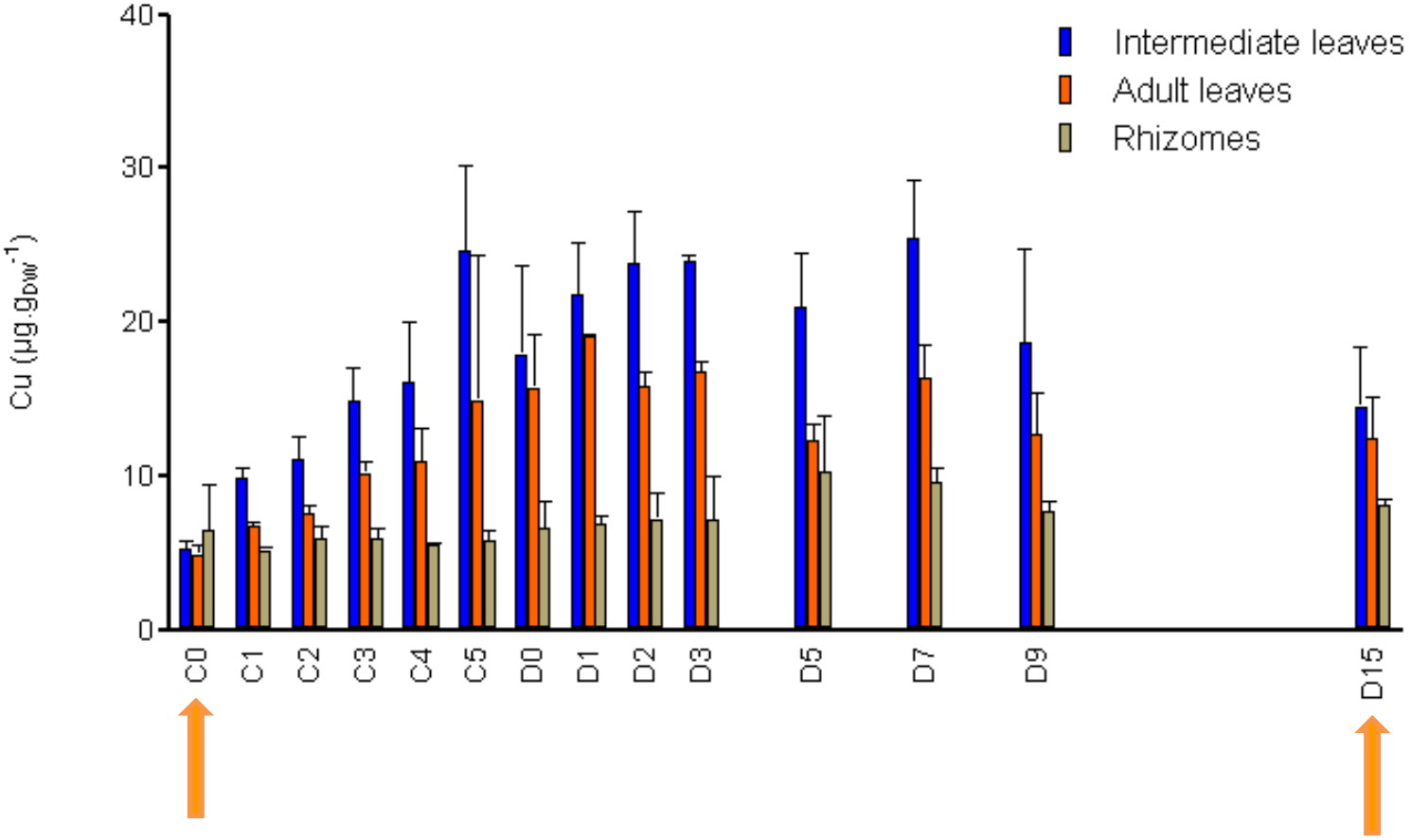
Cu: moderate conta. - shoots and leaves

KINETICS



Cu: moderate conta. - compartmentalization

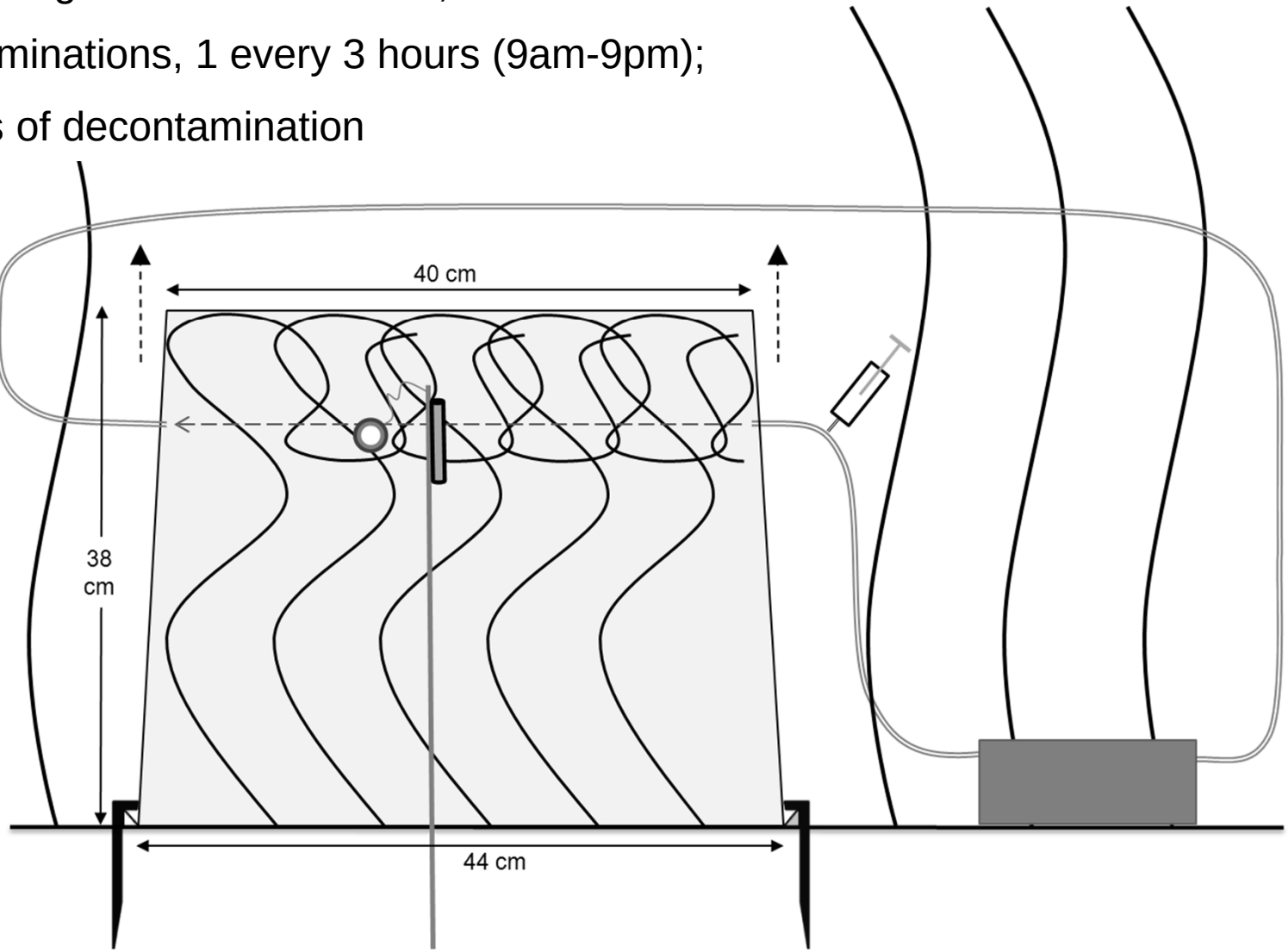
KINETICS



Acute mesocosm

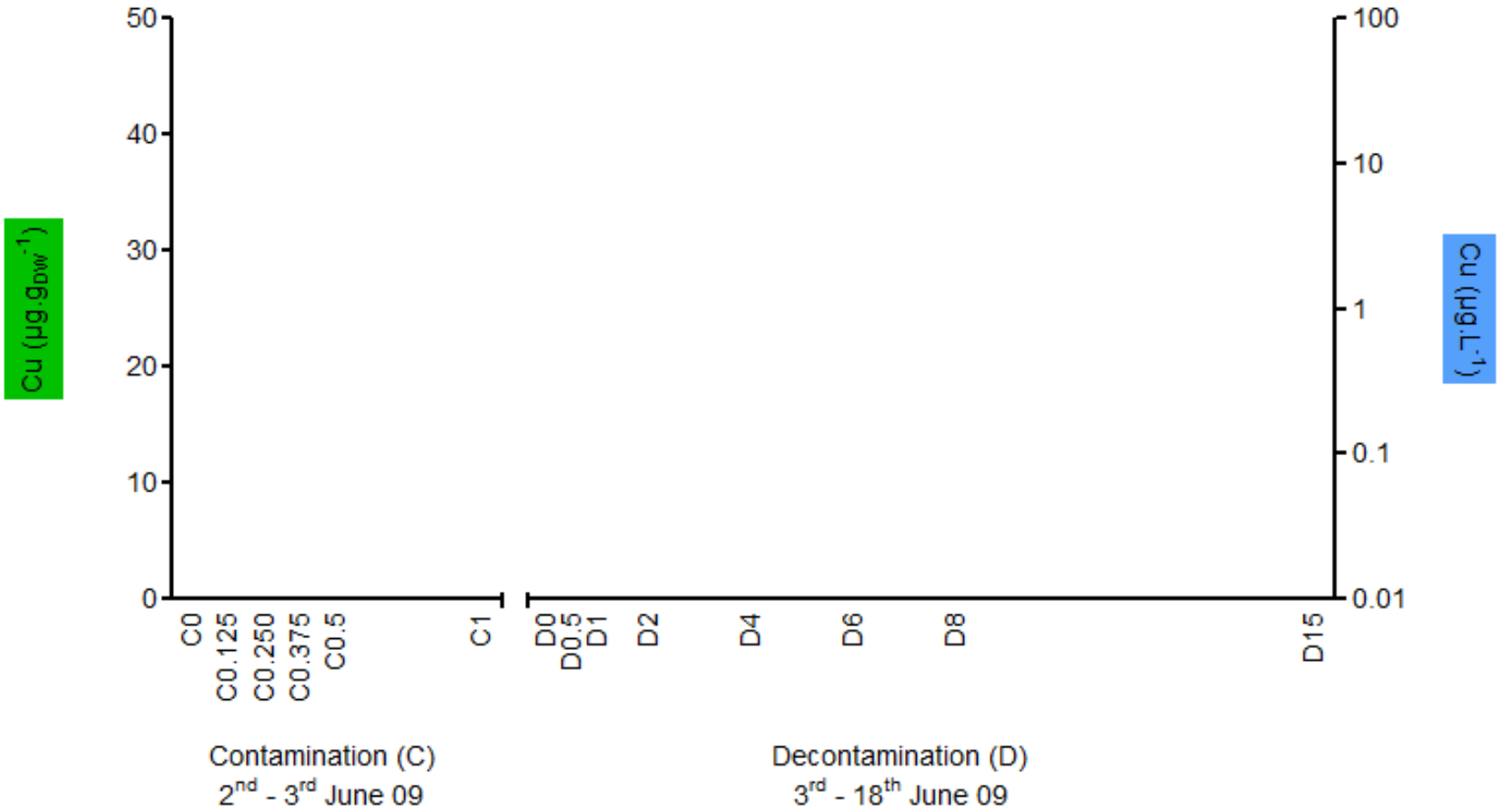
- 24h00 of contamination in June 2009;
- 54L rectangular-box mesocosm;
- 5 contaminations, 1 every 3 hours (9am-9pm);
- 15 days of decontamination

KINETICS



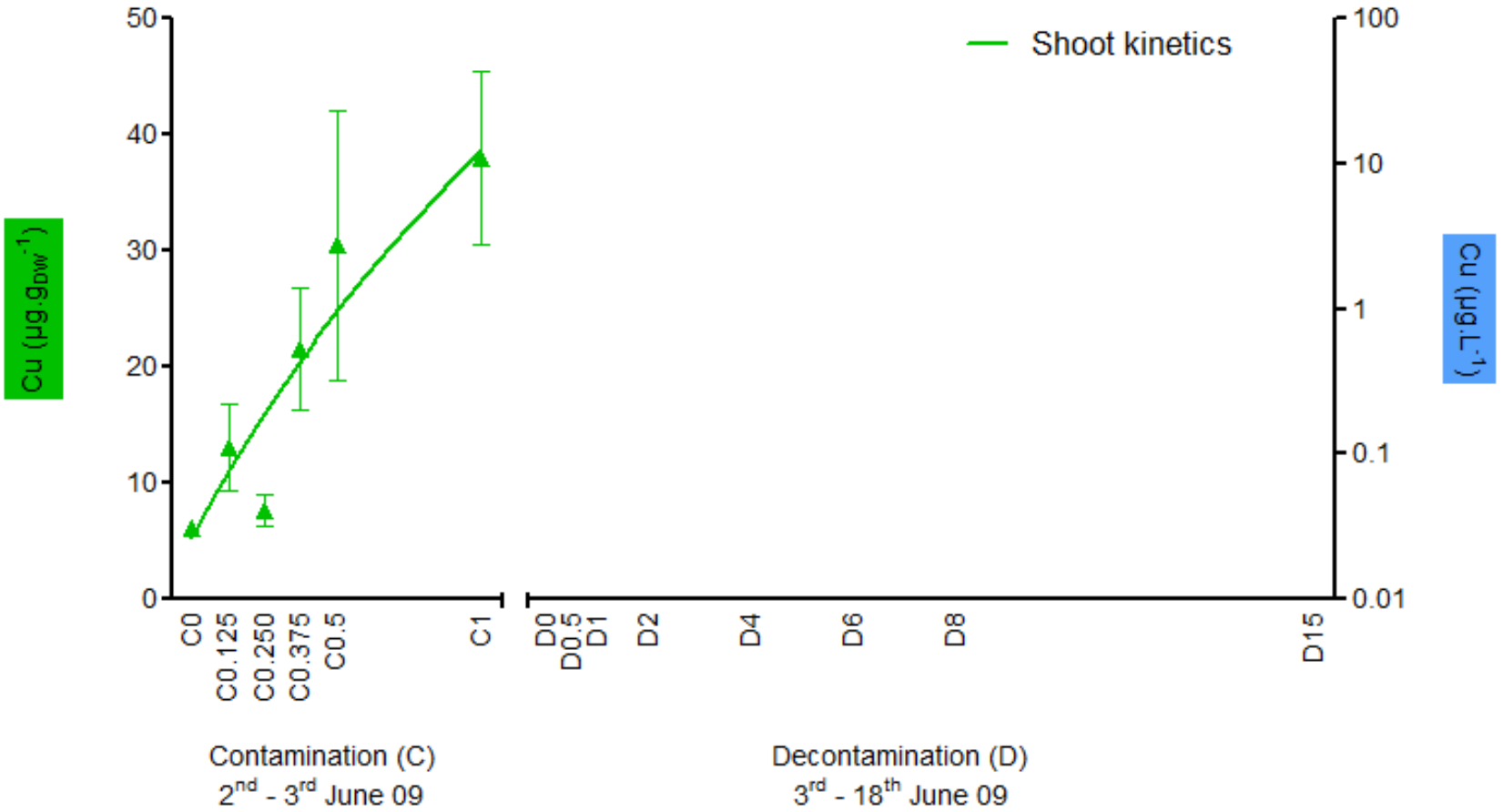
Cu: acute contamination - shoots

KINETICS



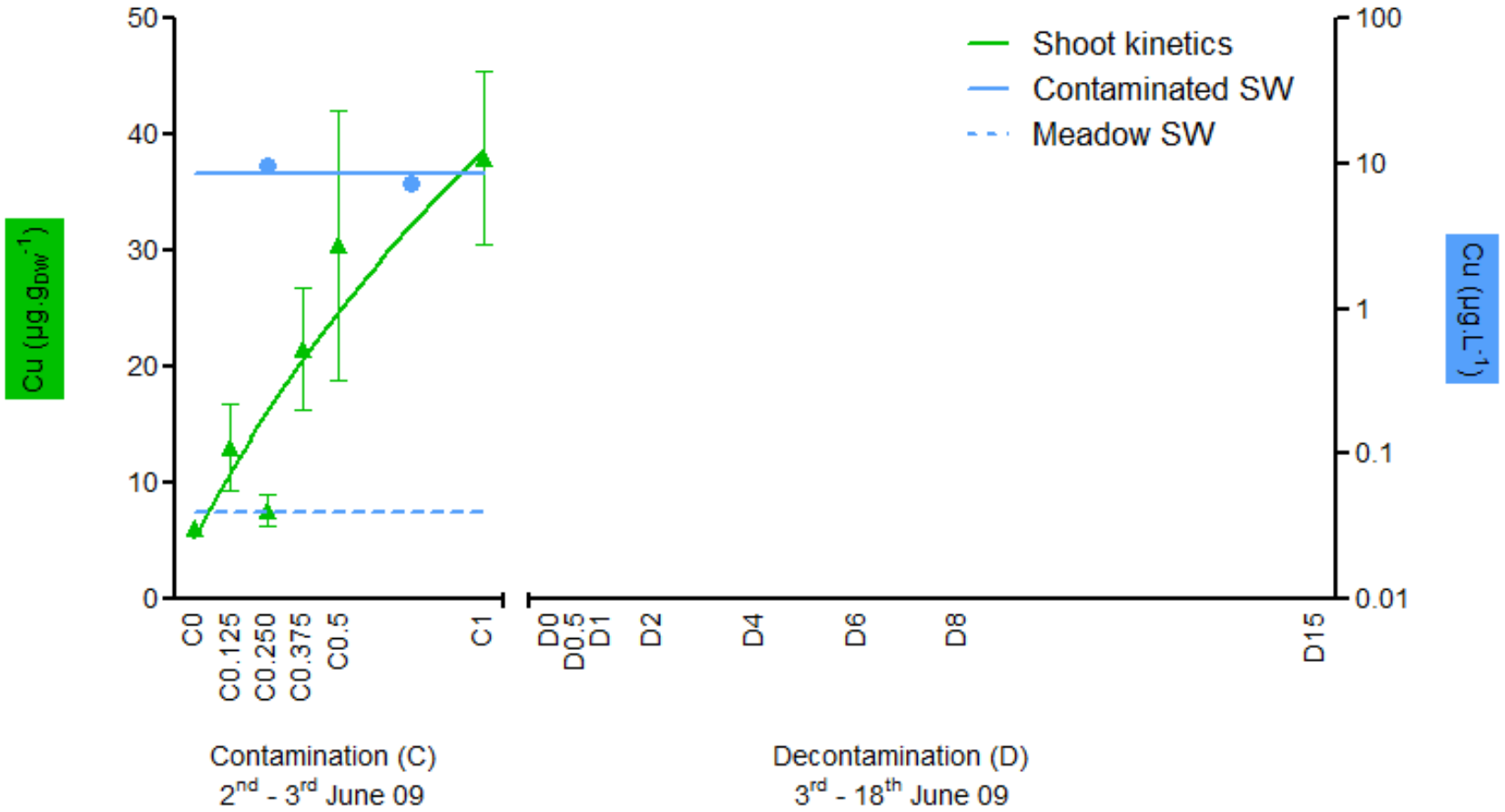
Cu: acute contamination - shoots

KINETICS



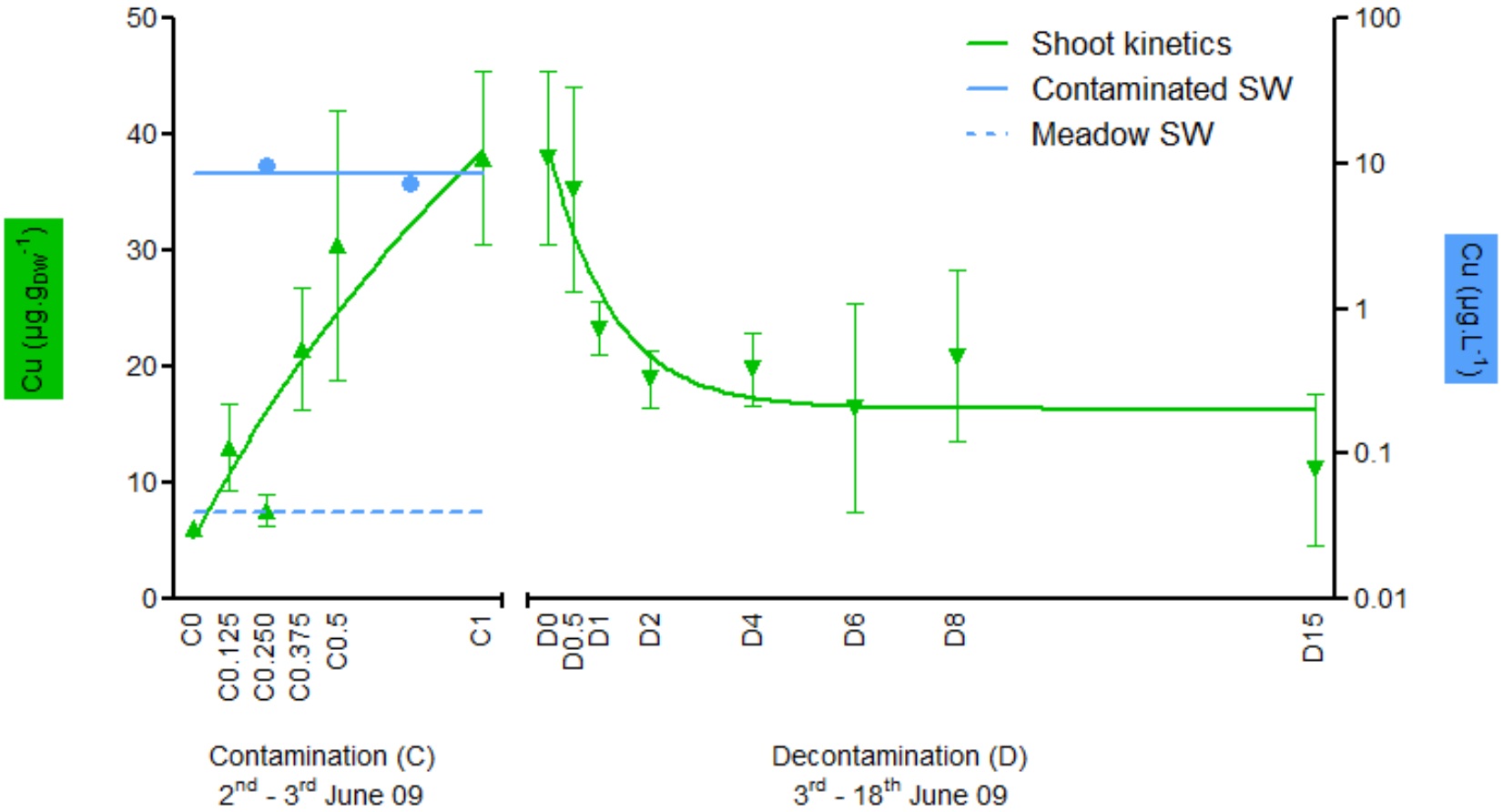
Cu: acute contamination - shoots

KINETICS



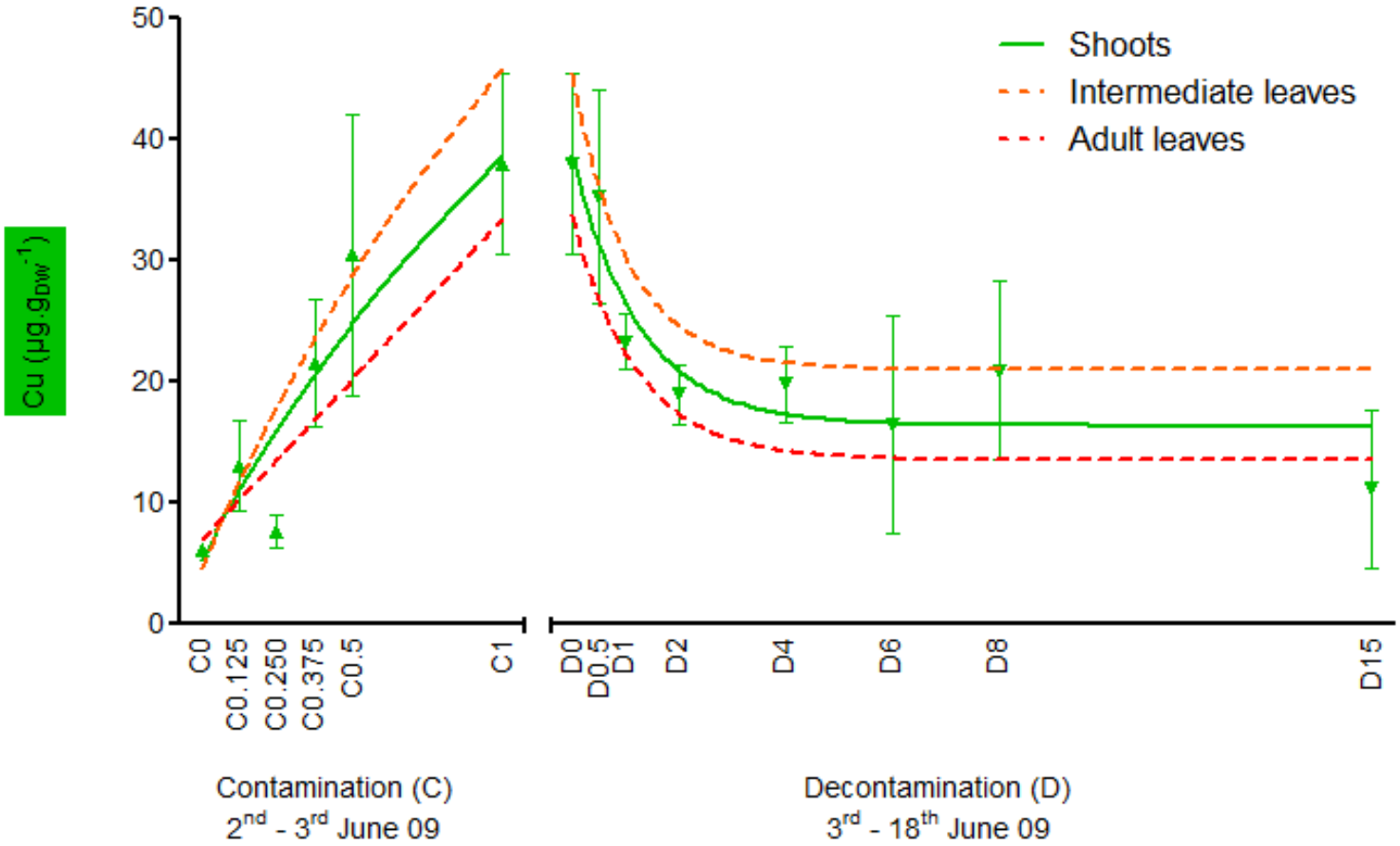
Cu: acute contamination - shoots

KINETICS



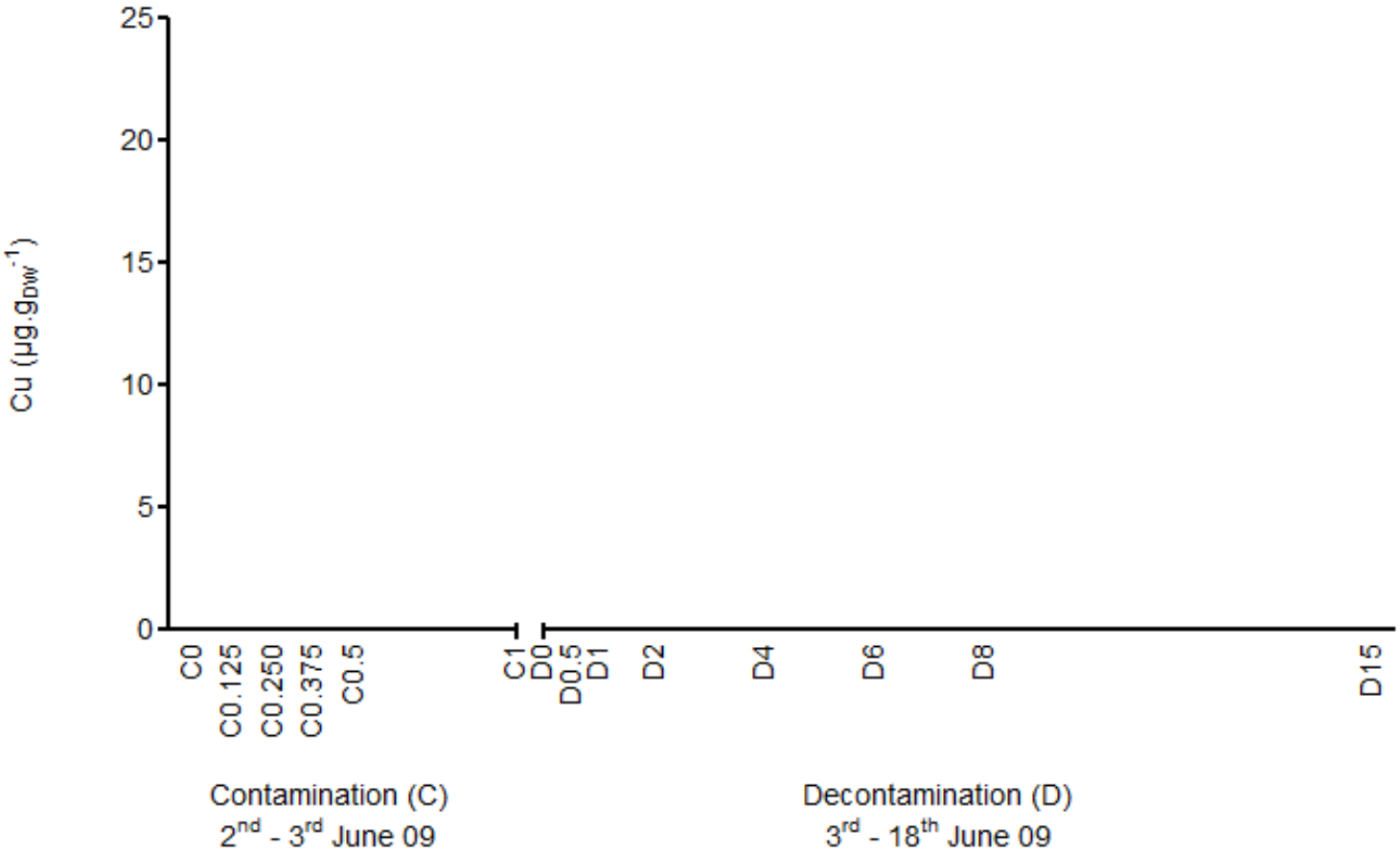
Cu: acute contamination – shoots and leaves

KINETICS



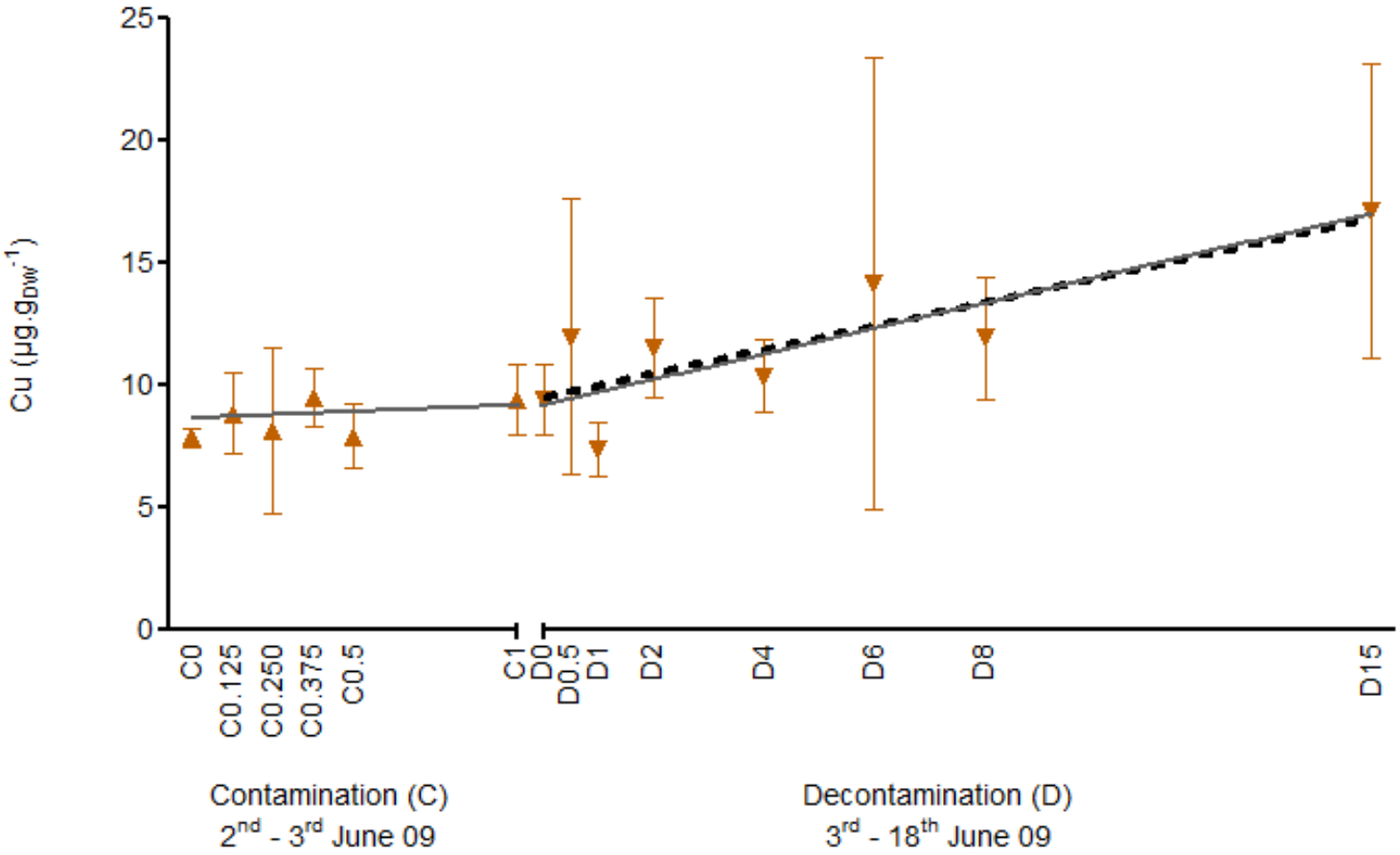
Cu: acute contamination - rhizomes

KINETICS



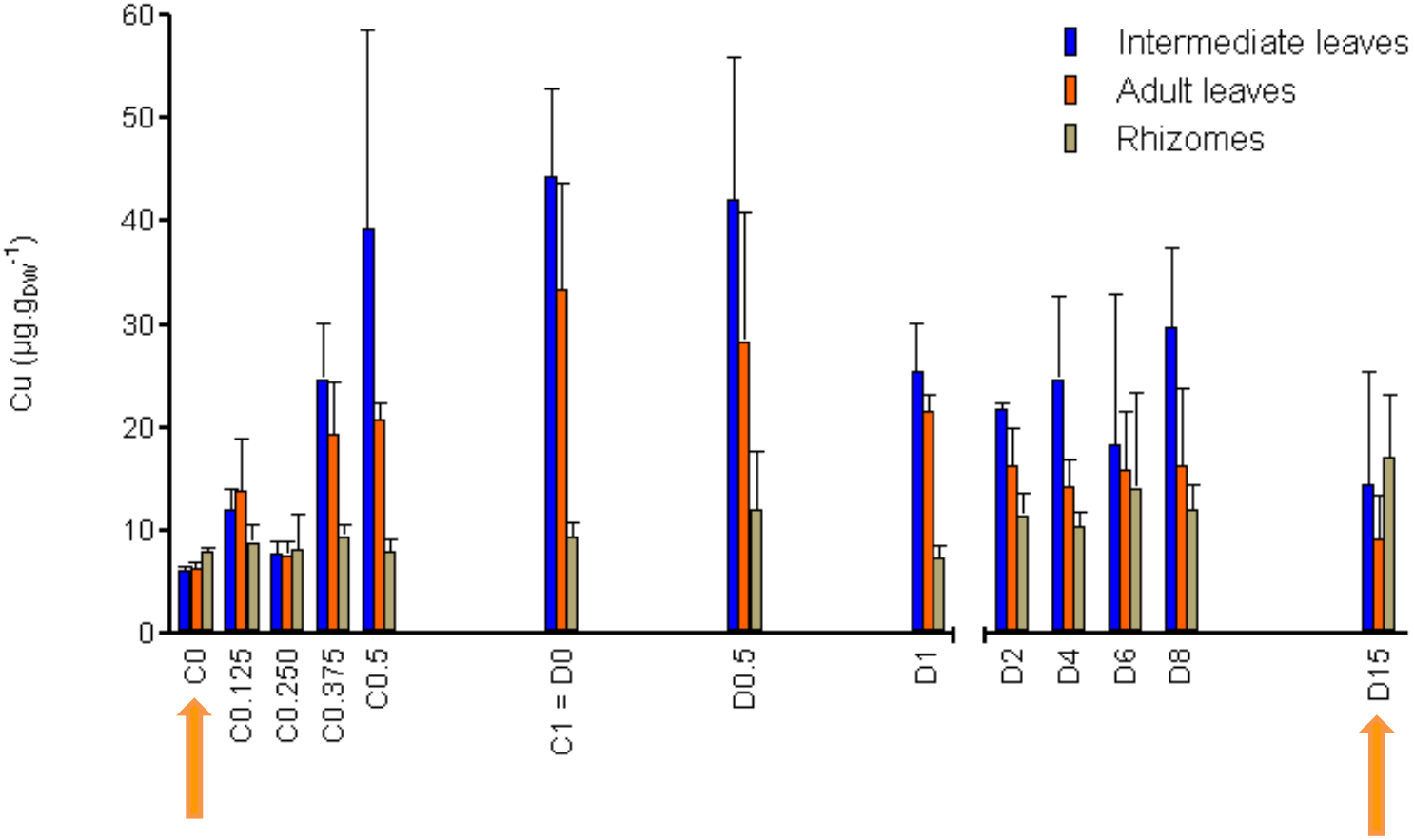
Cu: acute contamination - rhizomes

KINETICS



Cu: acute conta. - compartmentalization

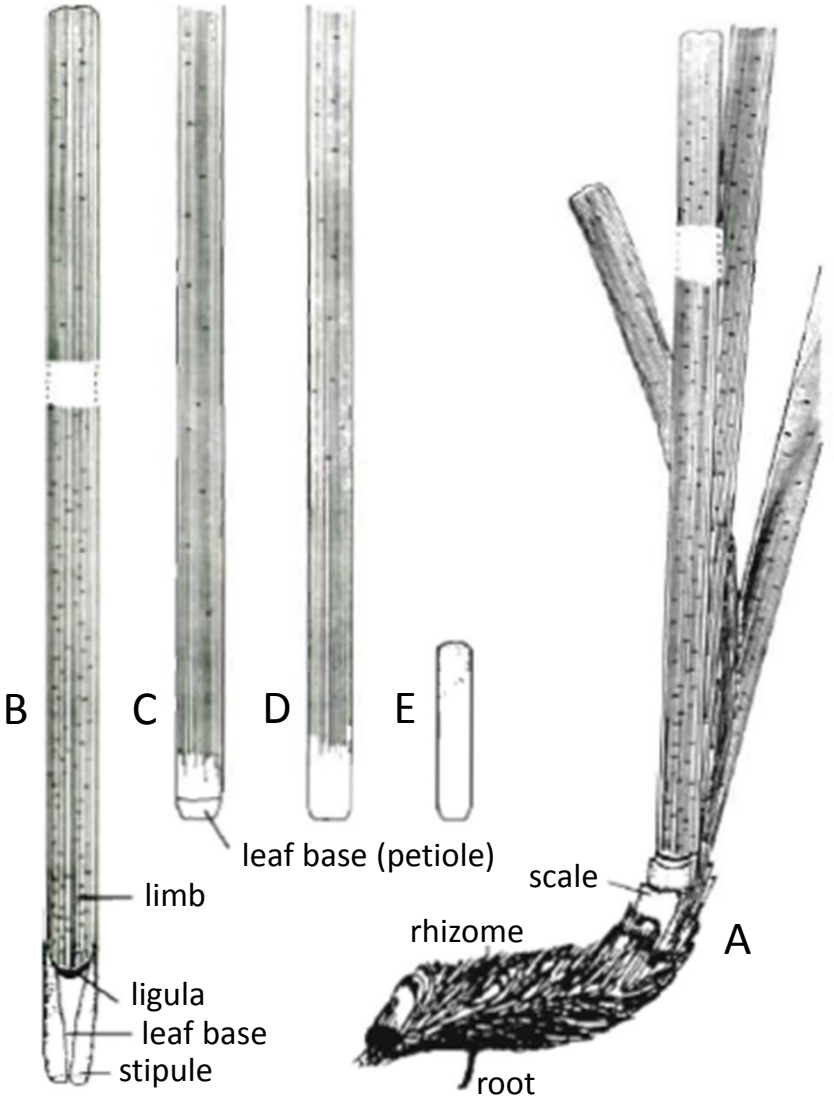
KINETICS



Tissue compartmentalization

COMPARTMENTALIZATION

1 = mantle (gonad), 2 = muscular mantle edge, 3 = foot, 4 = hepatopancreas, 5 = labial palps, 6 = gills, 7 = visceral mass, 8 = foot retractor muscle, 9 = posterior adductor muscle, *circles* = gonad follicle regions spread over the mantle, *small white lines* = indicate gonad duct) (Torrado and Mikhailov 2000).

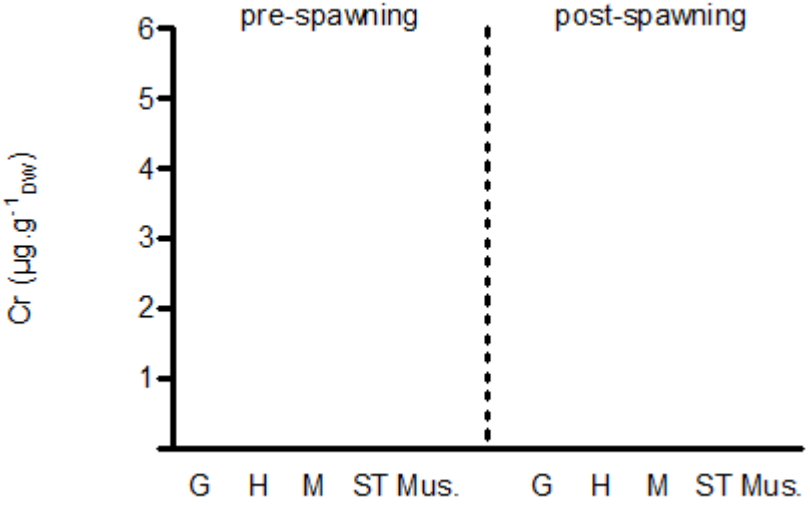


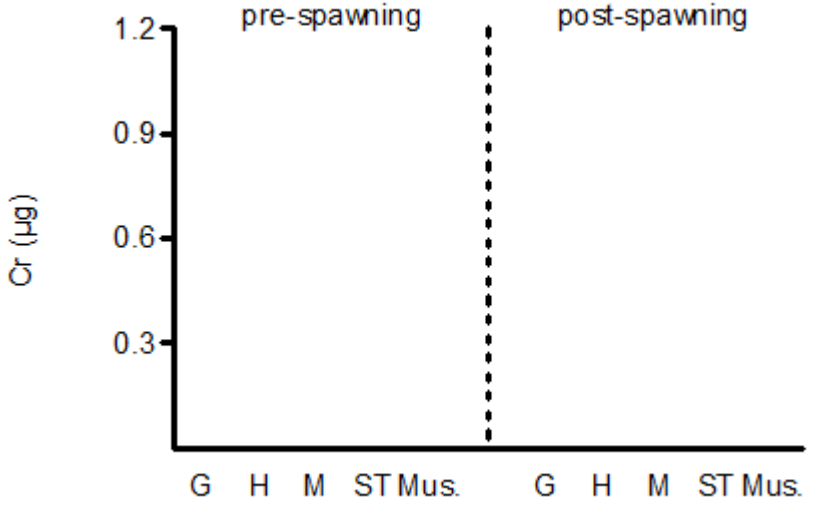
(A) shoot of leaves on a plagiotropic rhizome; (B, C) adult leaves; (D) intermediate leaf; (E) juvenile leaf (modified after Libes and Boudouresque 1987).

M. galloprovincialis

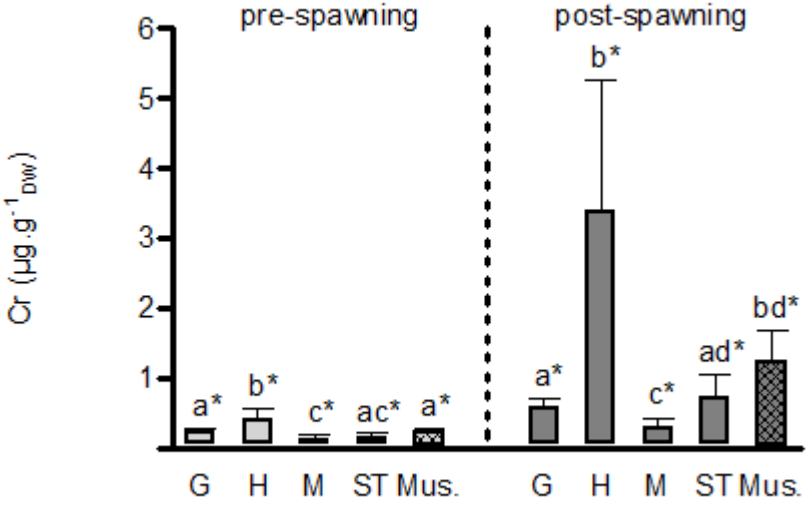
COMPARTMENTALIZATION

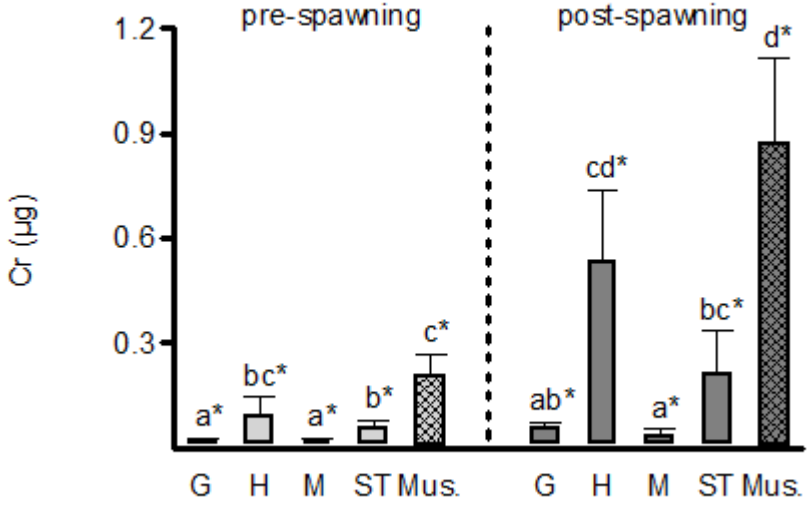
M. galloprovincialis





M. galloprovincialis





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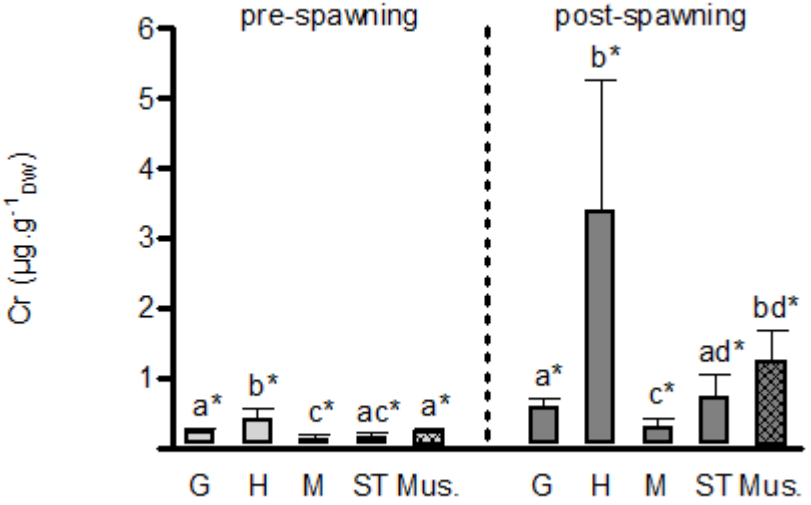

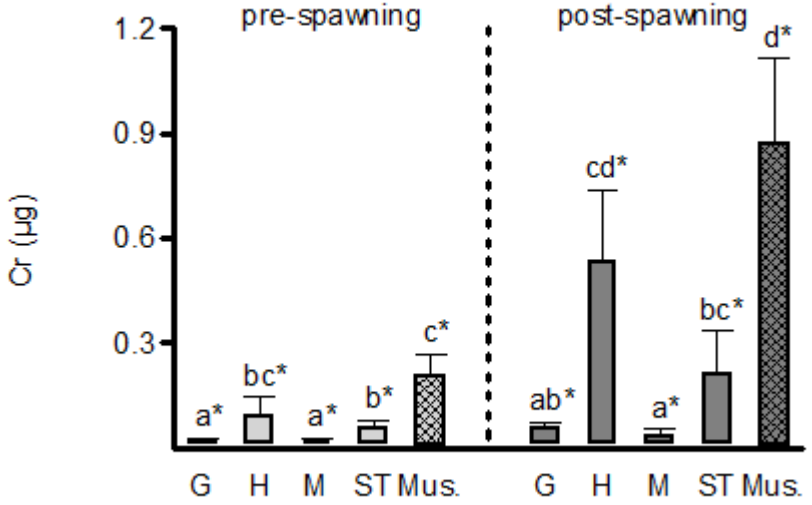

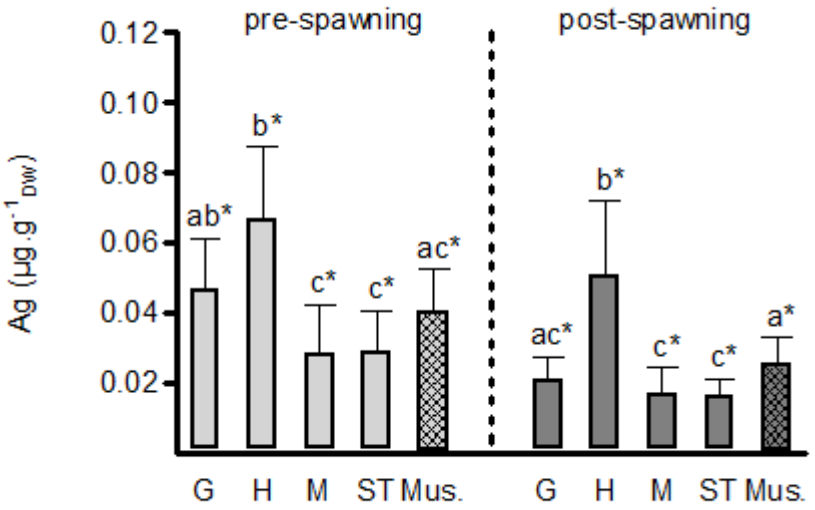

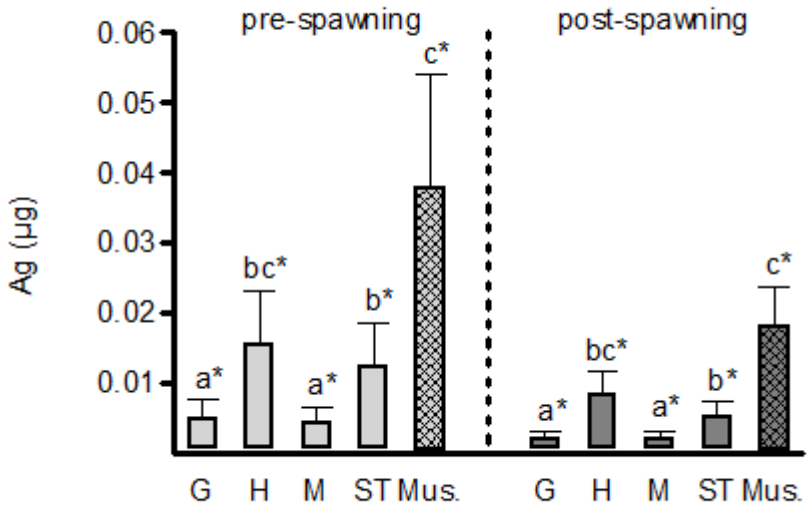

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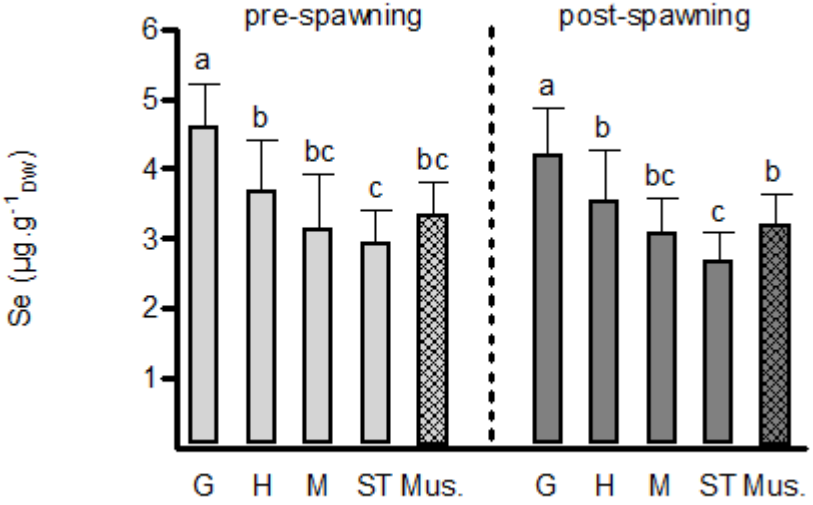

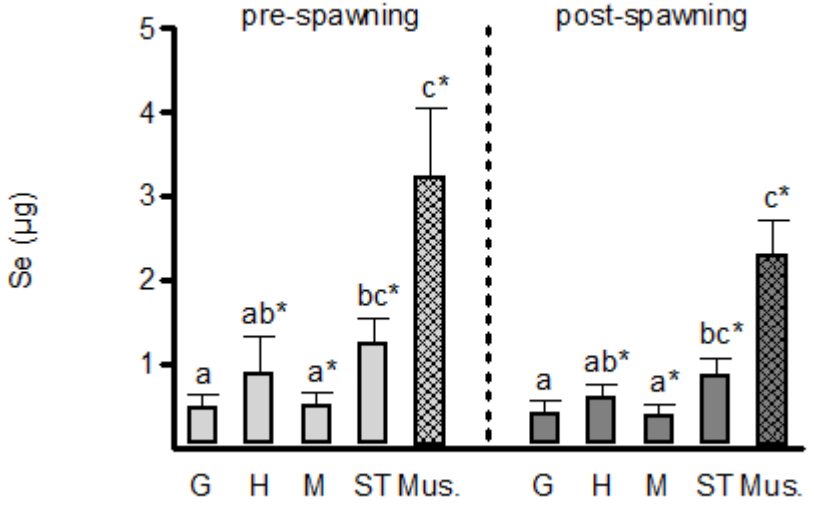

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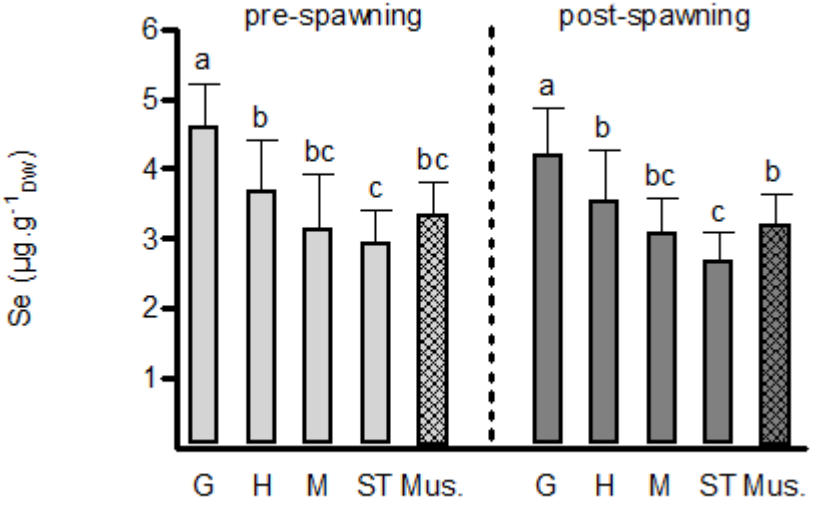
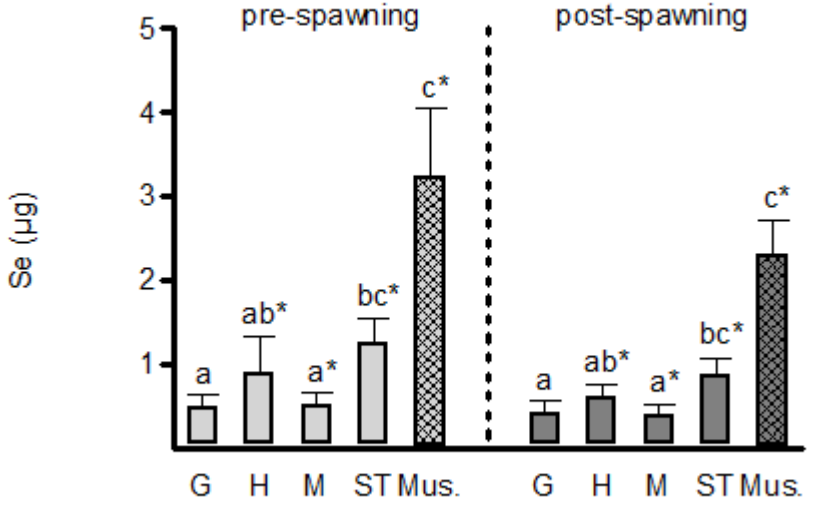
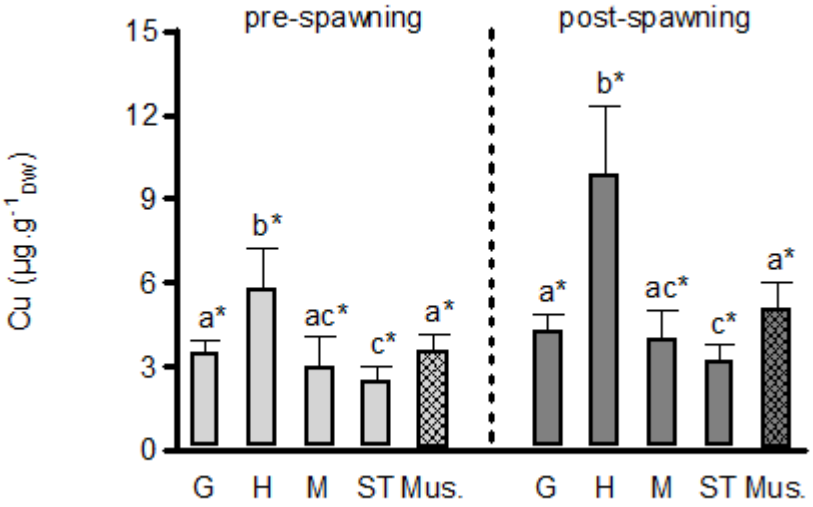
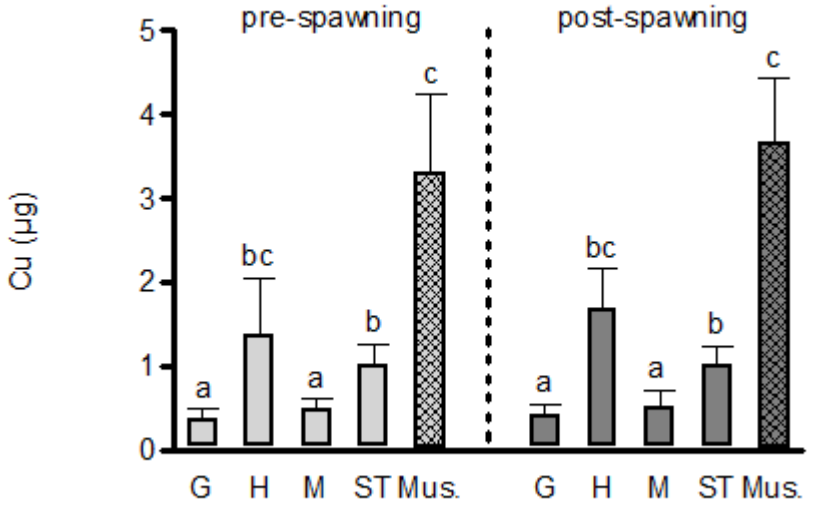






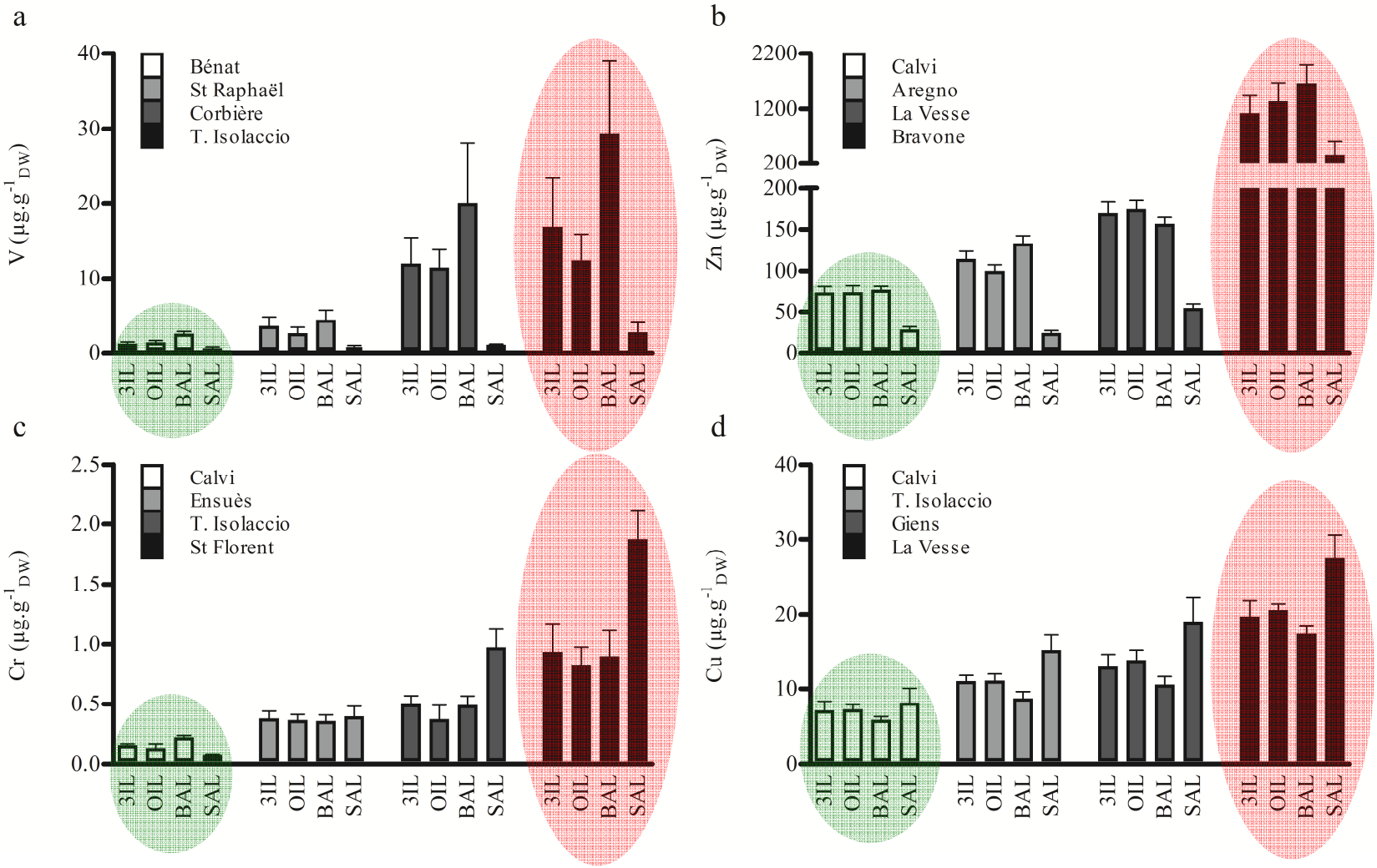


P. oceanica

COMPARTMENTALIZATION

P. oceanica

COMPARTMENTALIZATION



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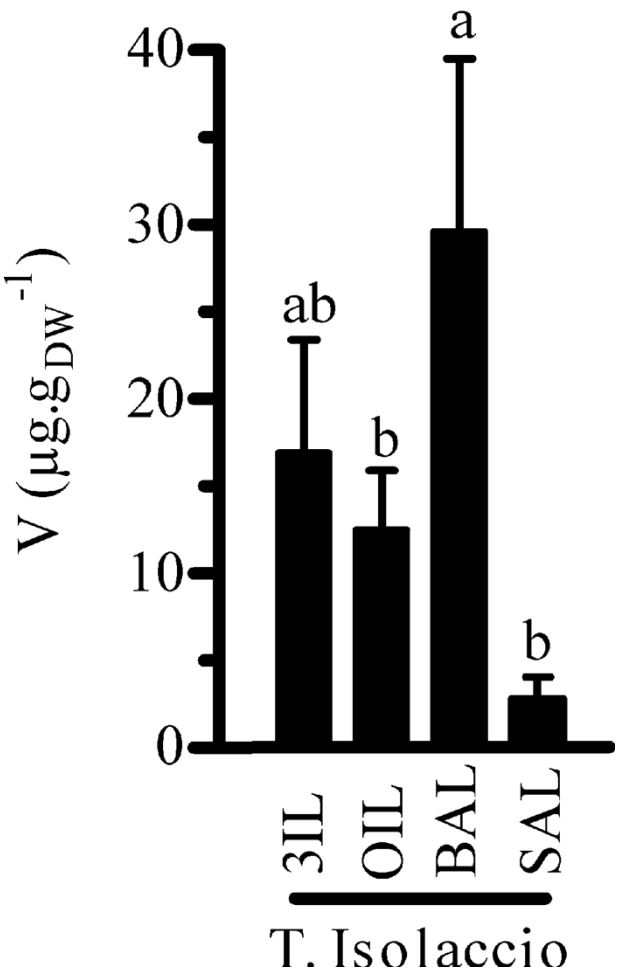
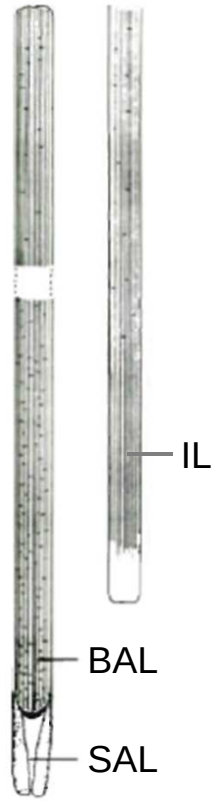
COMPARTMENTALIZATION

1. V (Mn, Co, Ni, As, Se, Mo, Sb, Pb, Bi).





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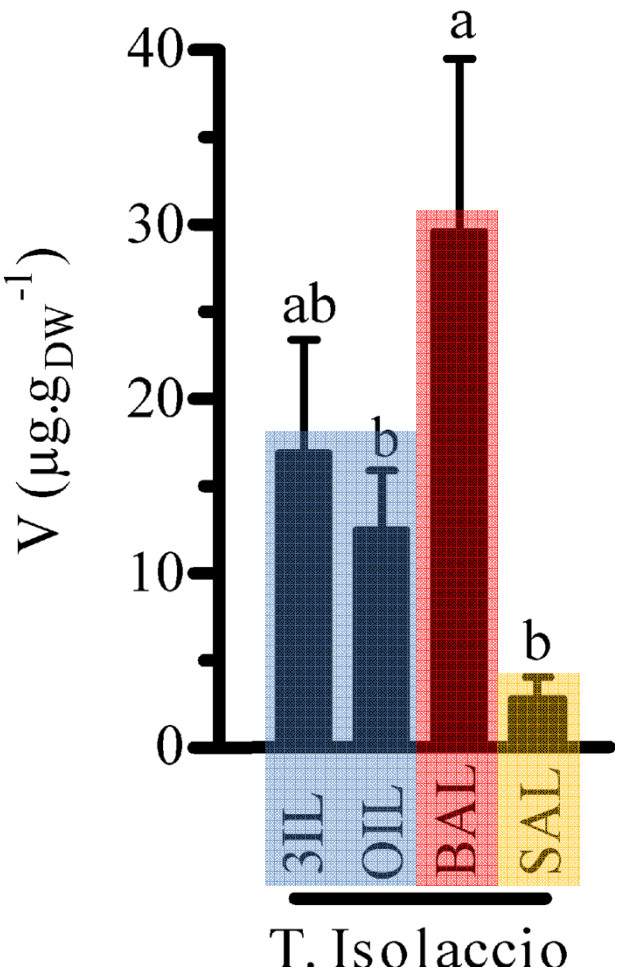

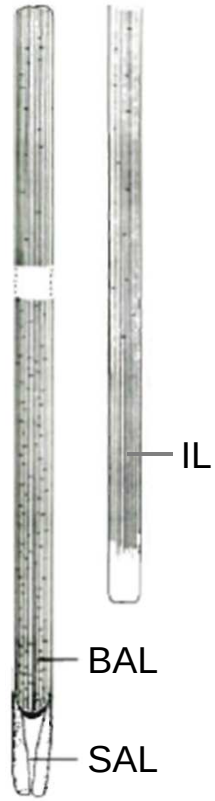

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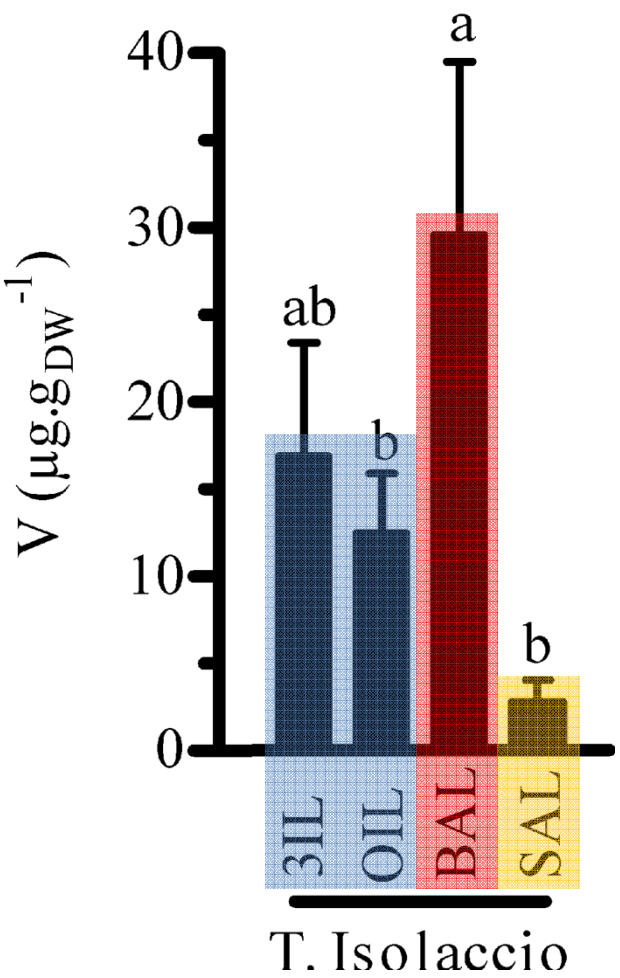
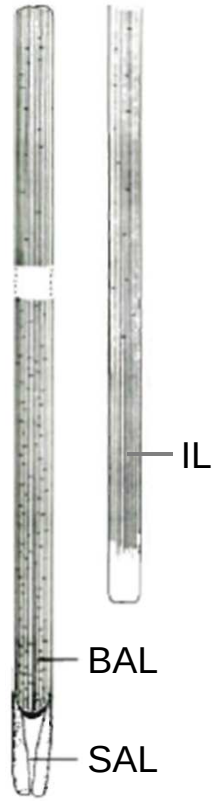


Hypotheses:

- water column accumulation
- residence time
- dilution effect



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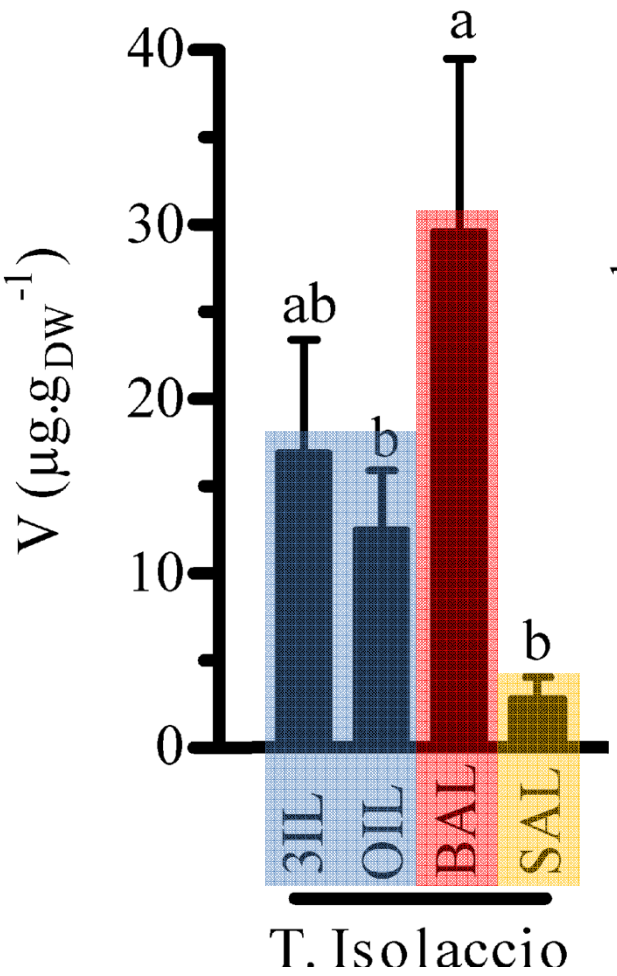
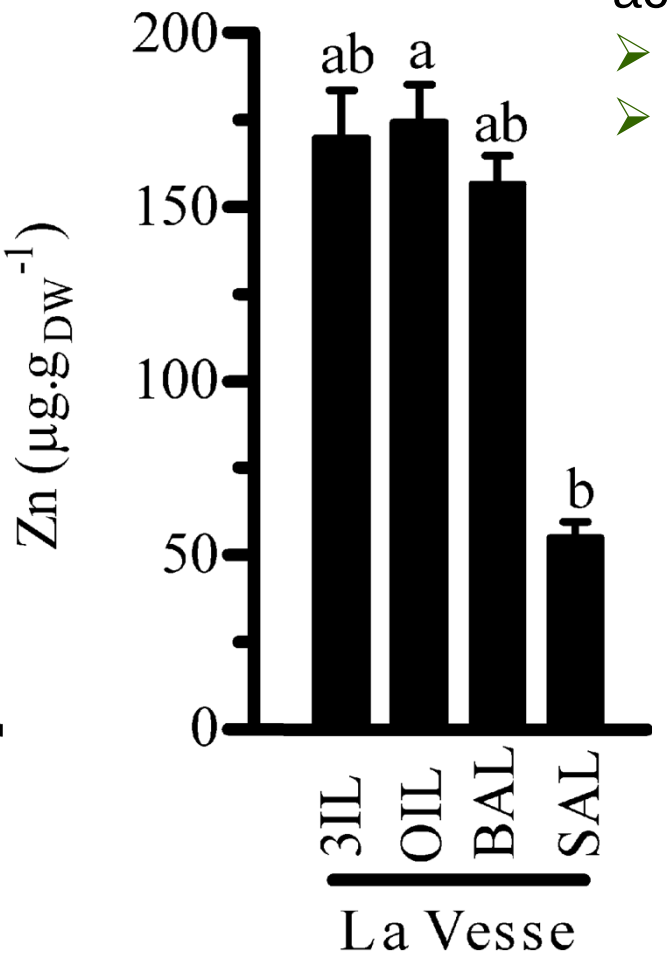


2. Zn (Se, Cd).



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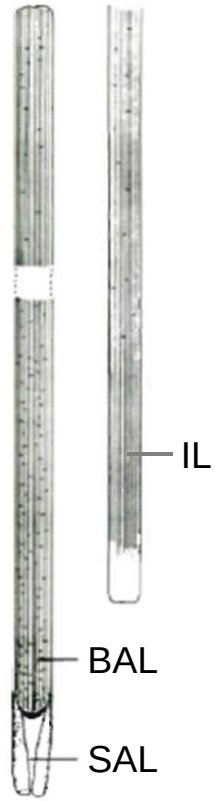

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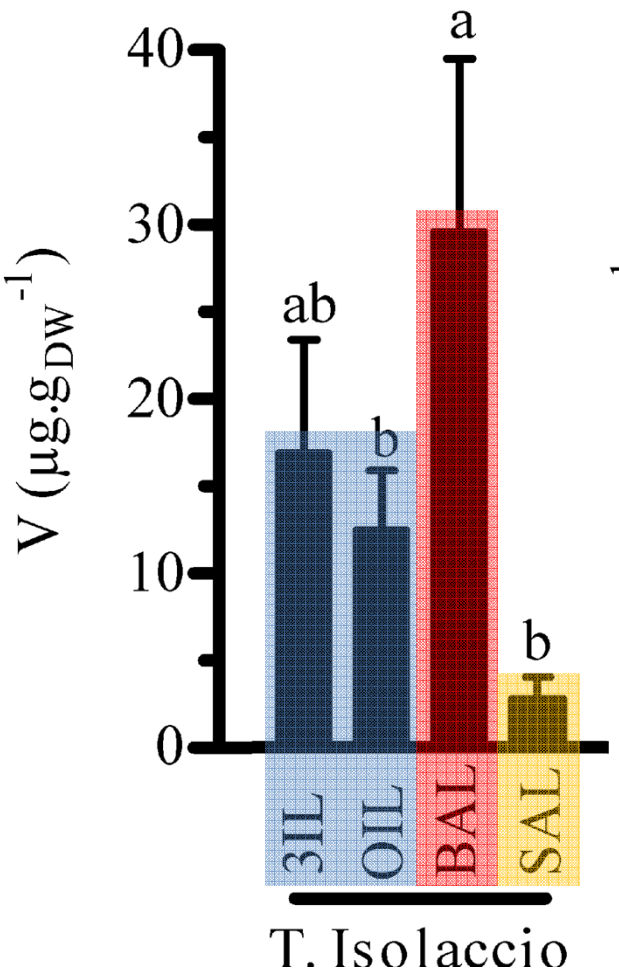

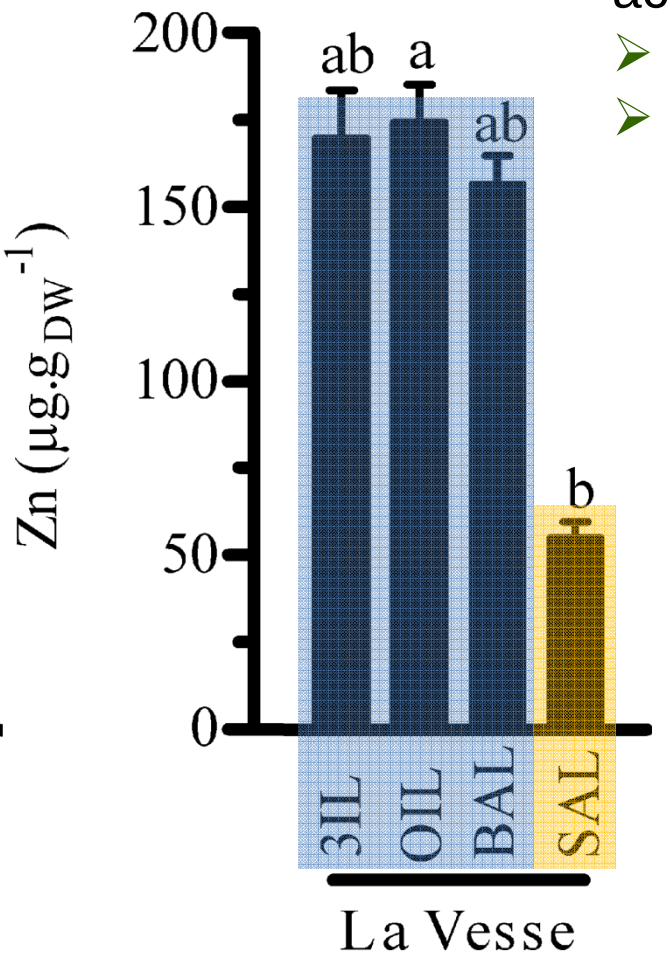

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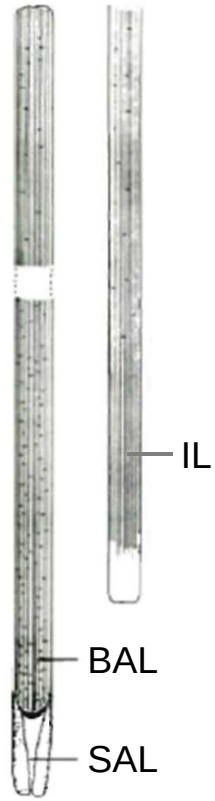

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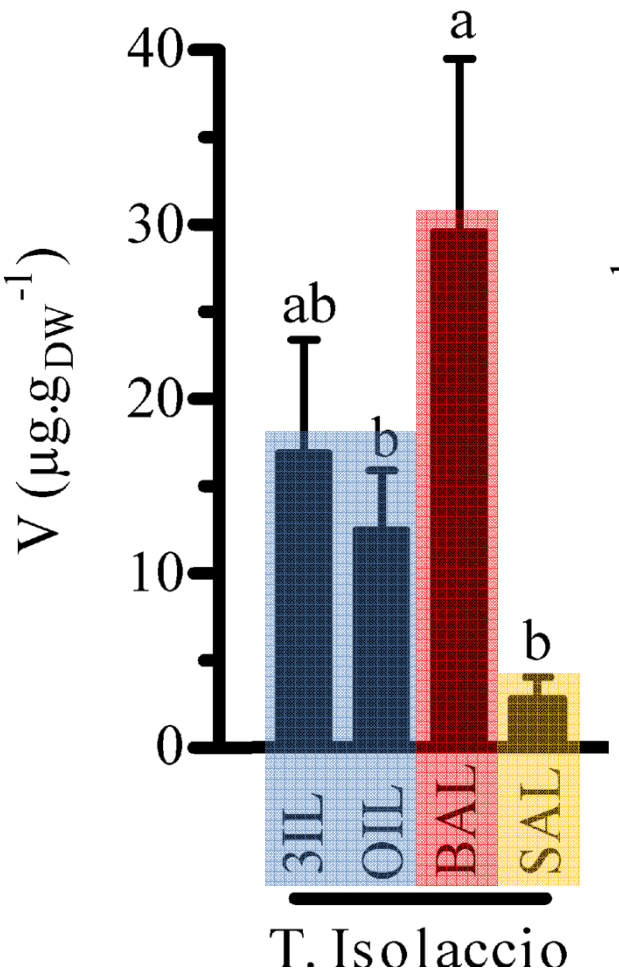

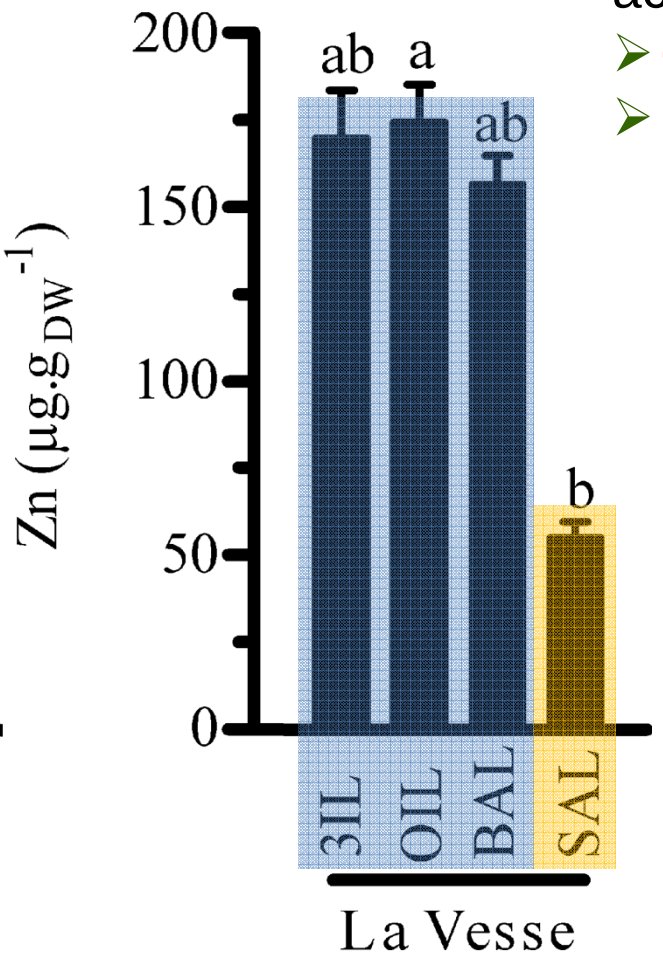

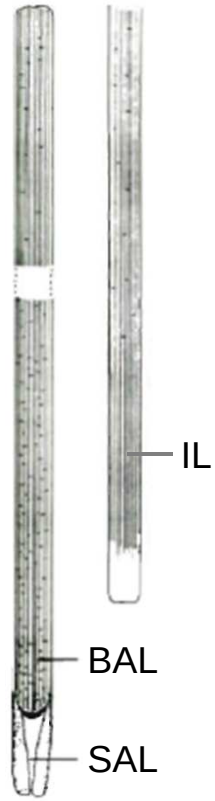

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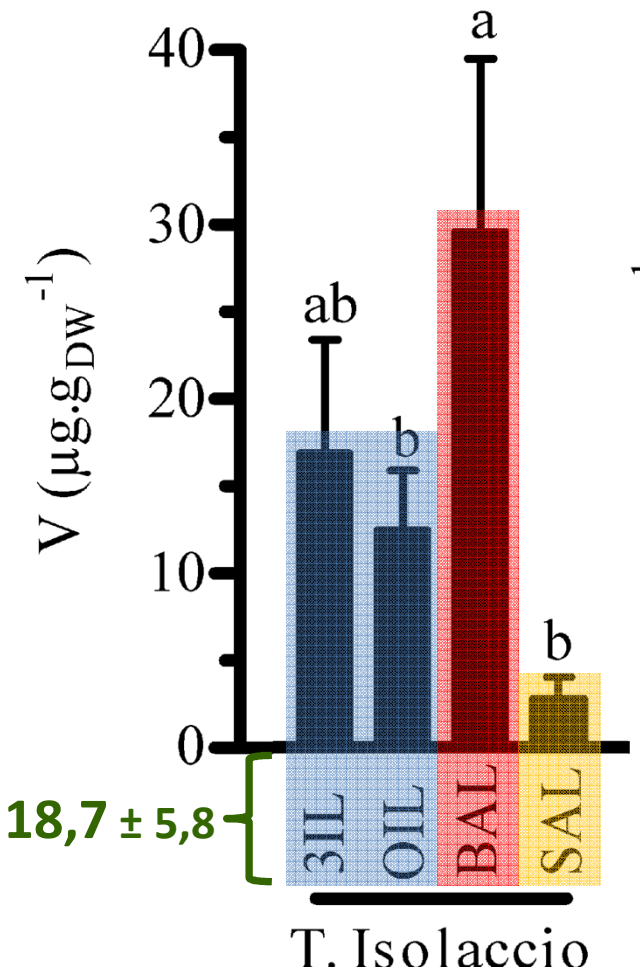
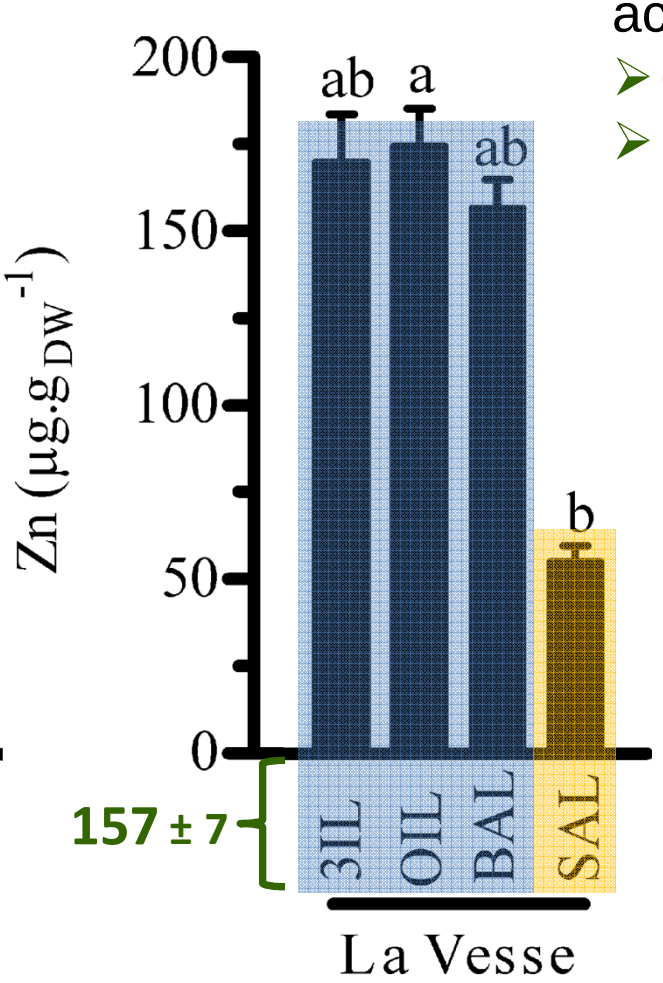
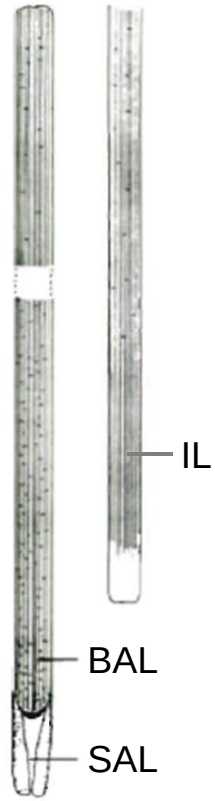


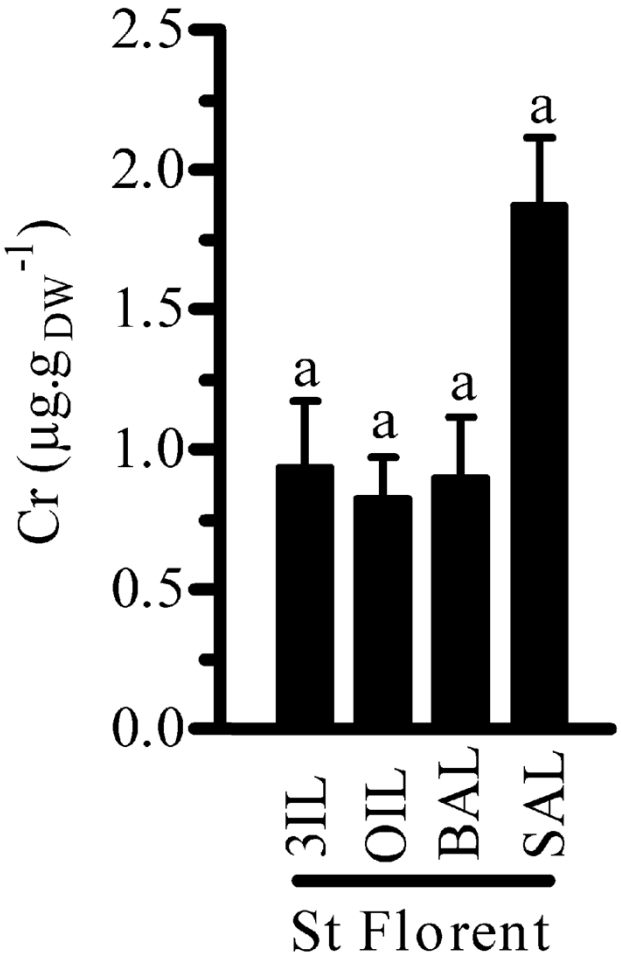


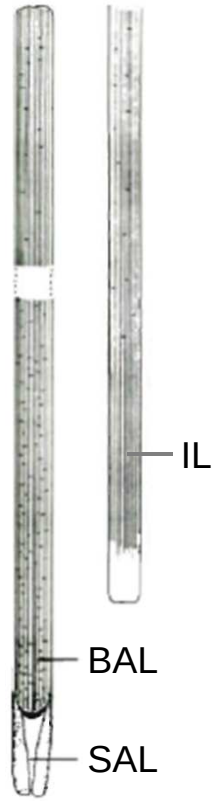


P. oceanica

COMPARTMENTALIZATION

3. Cr (Al, Fe, Ag).





P. oceanica

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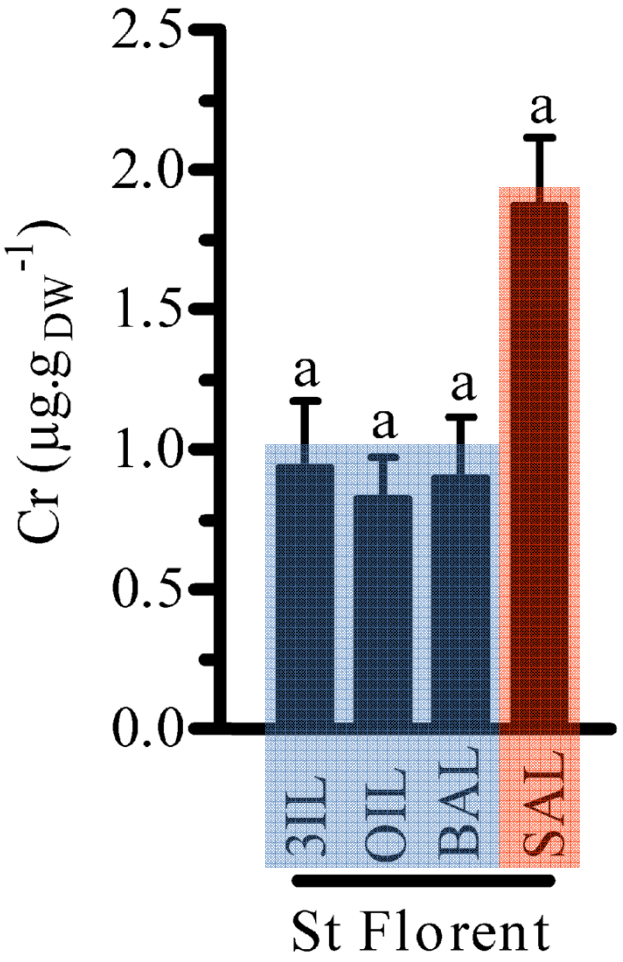

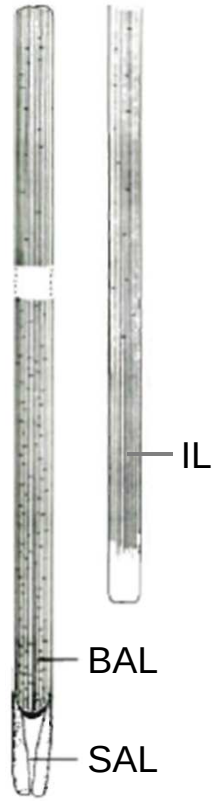

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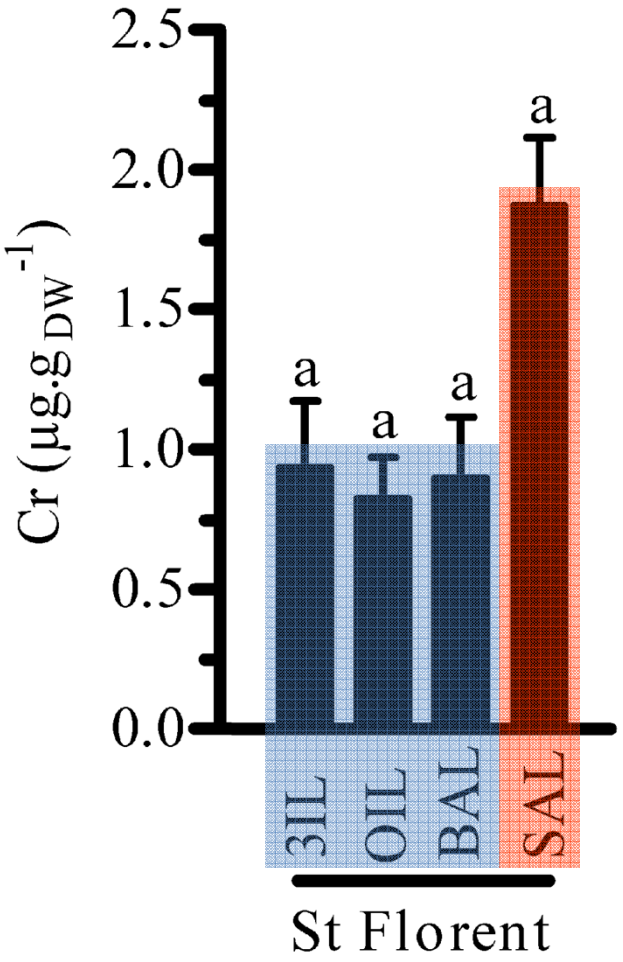
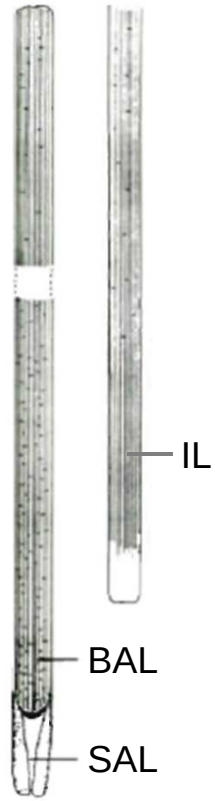


Hypotheses:

- sediment accumulation



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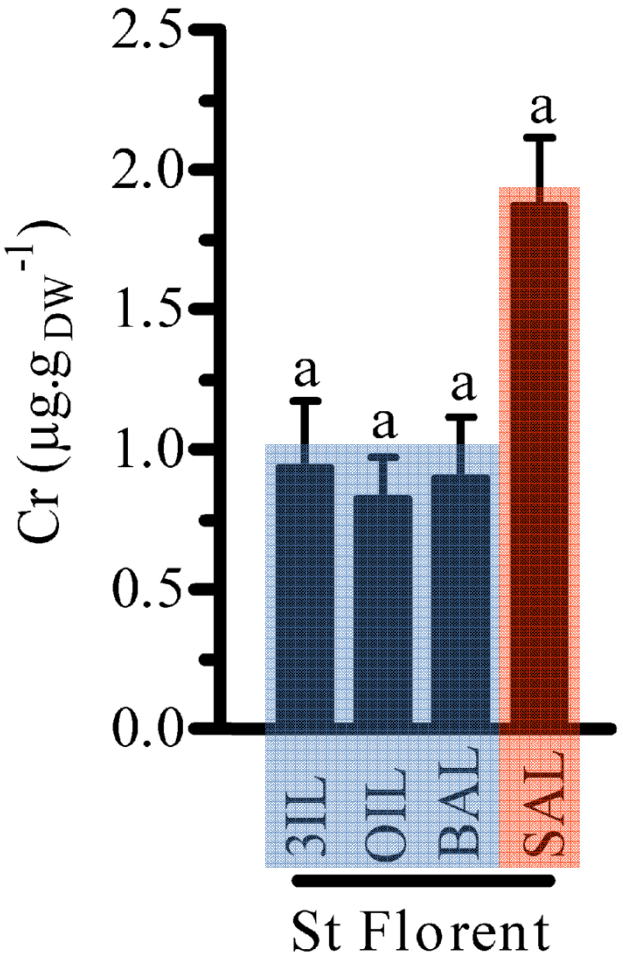

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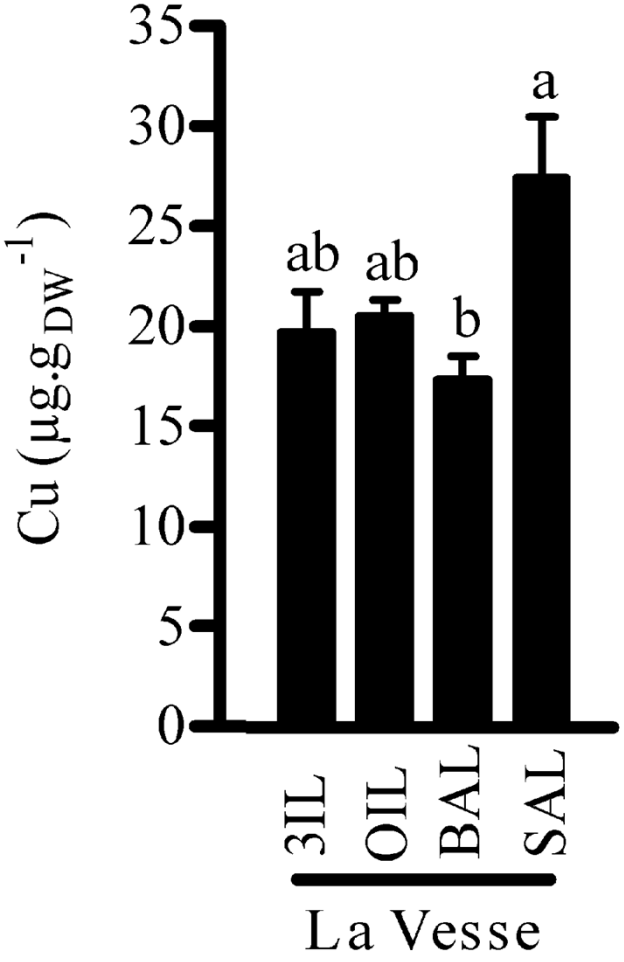

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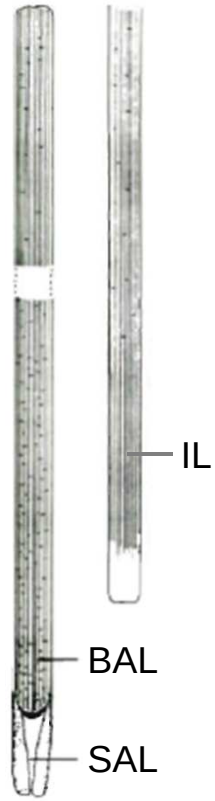

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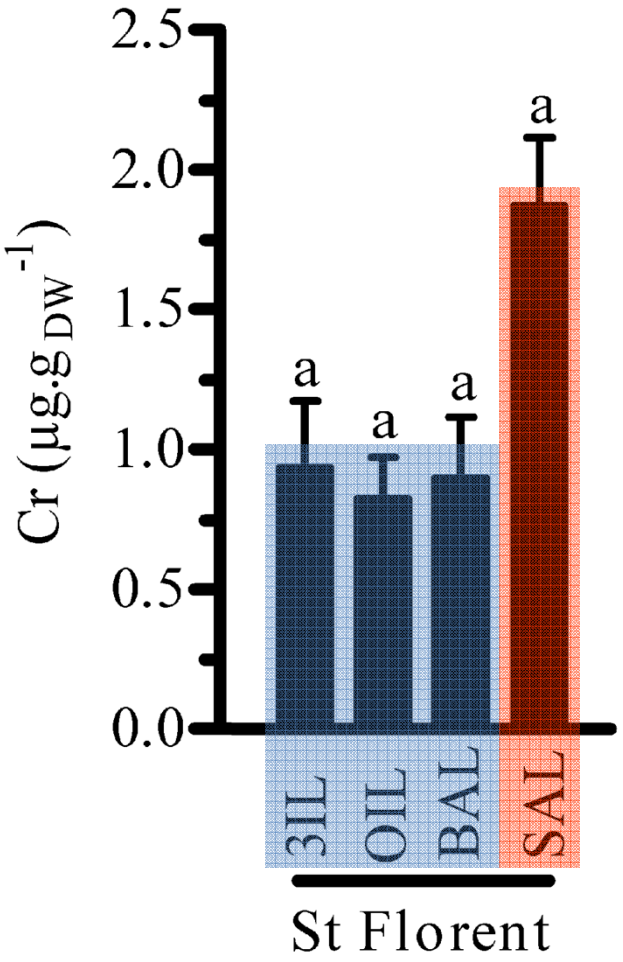

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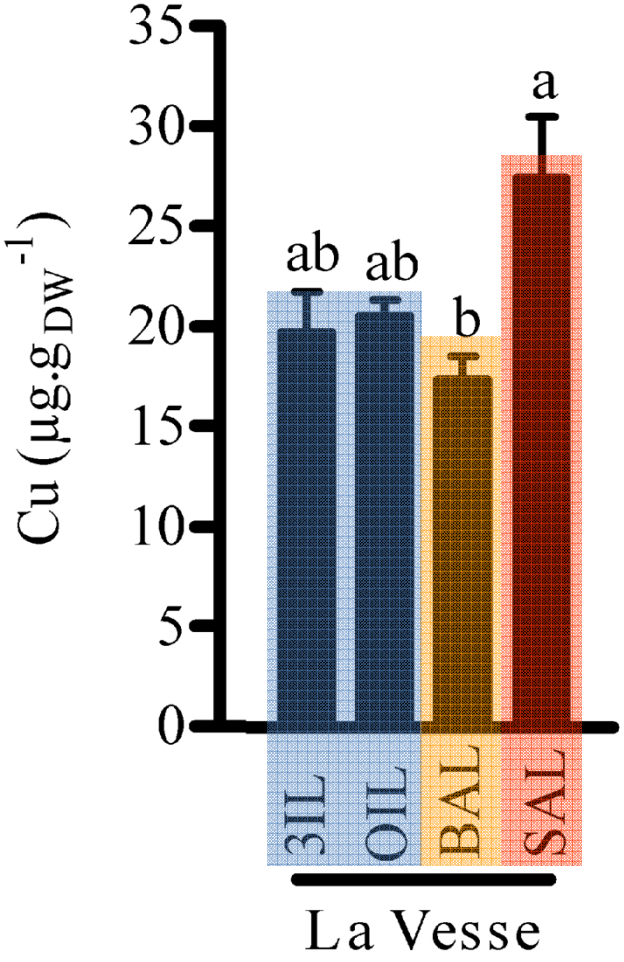

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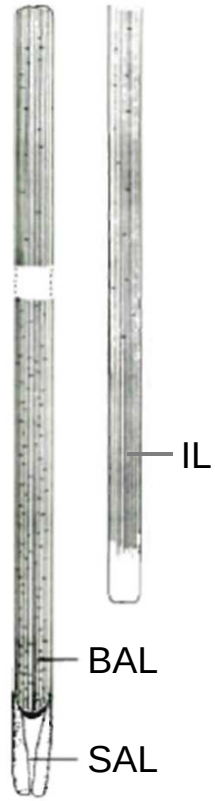

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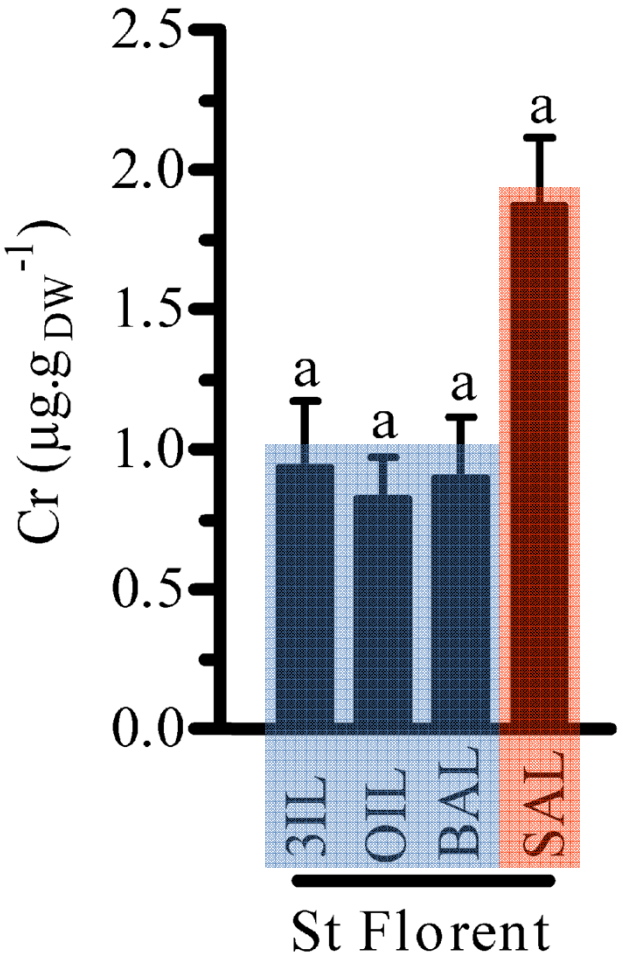
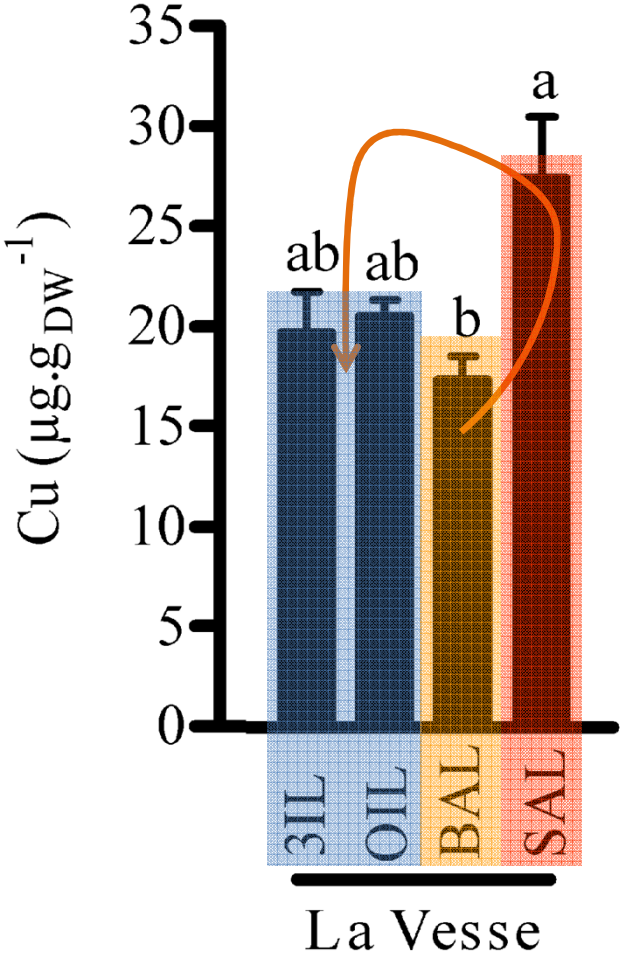
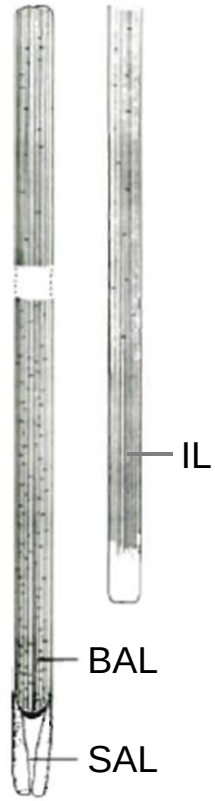


4. Cu.



Hypotheses:

- sediment accumulation
- Cu = essential micronutrient



P. oceanica

COMPARTMENTALIZATION

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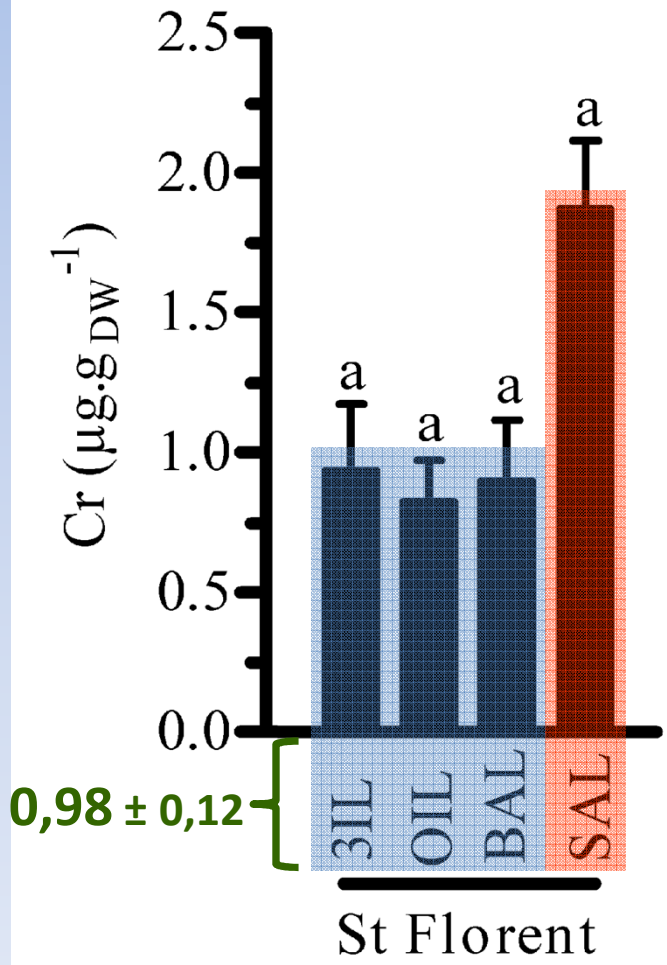

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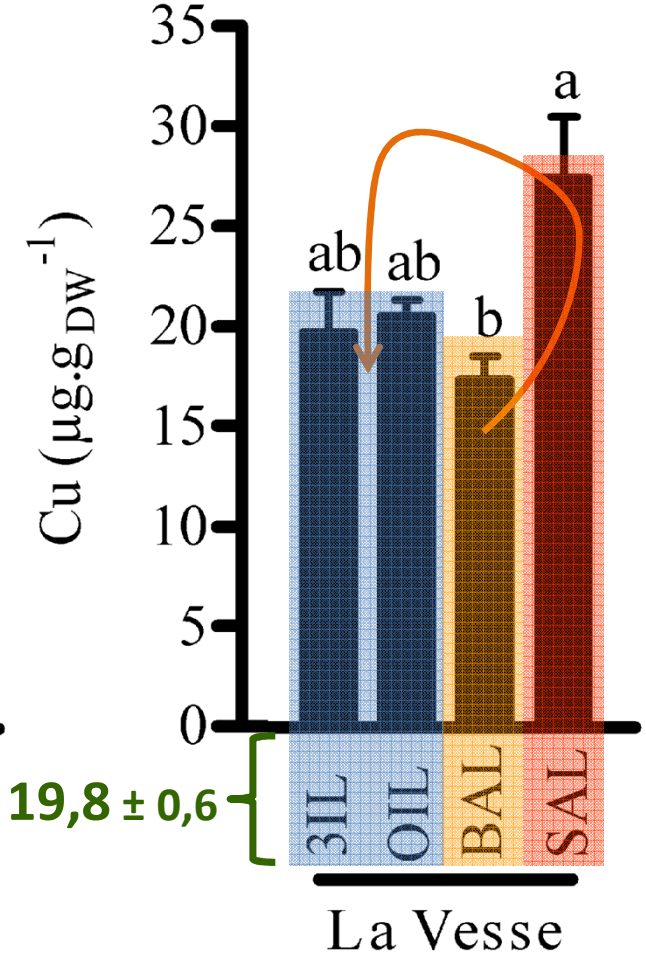

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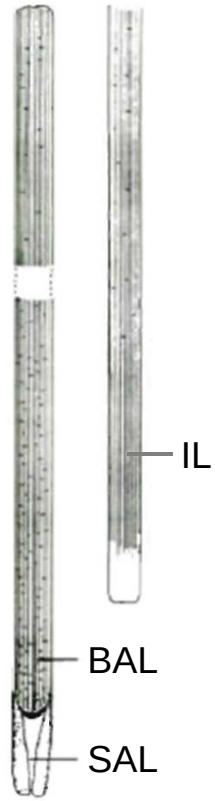

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Use entire individuals in monitoring surveys