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Global change and the lower limit of the *Posidonia oceanica* meadow: a complex combination of natural and human-induced recent and ancient phenomena

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Context

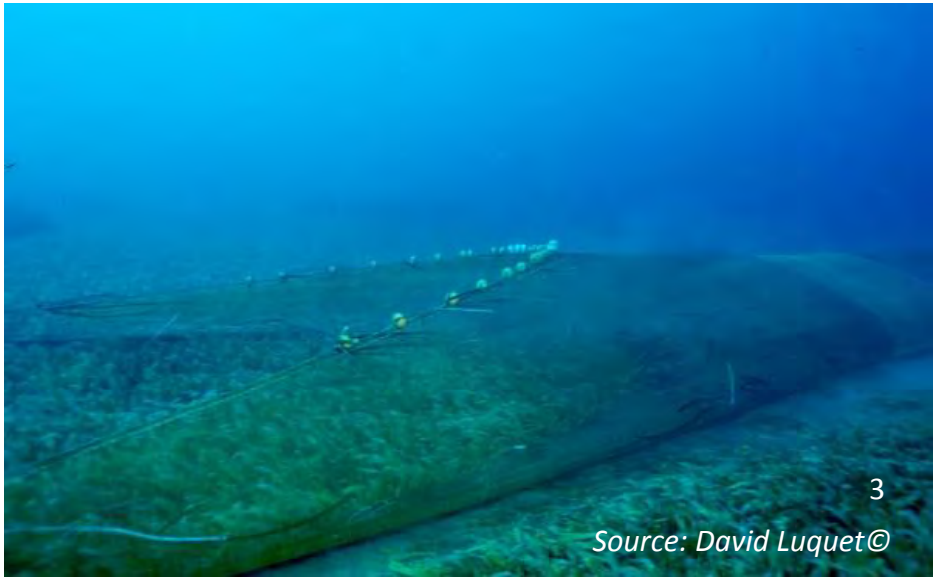
- Bay of Hyères (Provence): part of the Marine Adjacent Area of the Port-Cros National Park since 2012.
- *Posidonia oceanica* meadow: 10 000 ha surface area

Source : Port-Cros National Park

Context

- Bay of Hyères : High level and diversity of human impact, (Boudouresque *et al*., 2006, 2009 ; Astruch *et al*., 2014).
- Main impacting human activities

Source : Var matin



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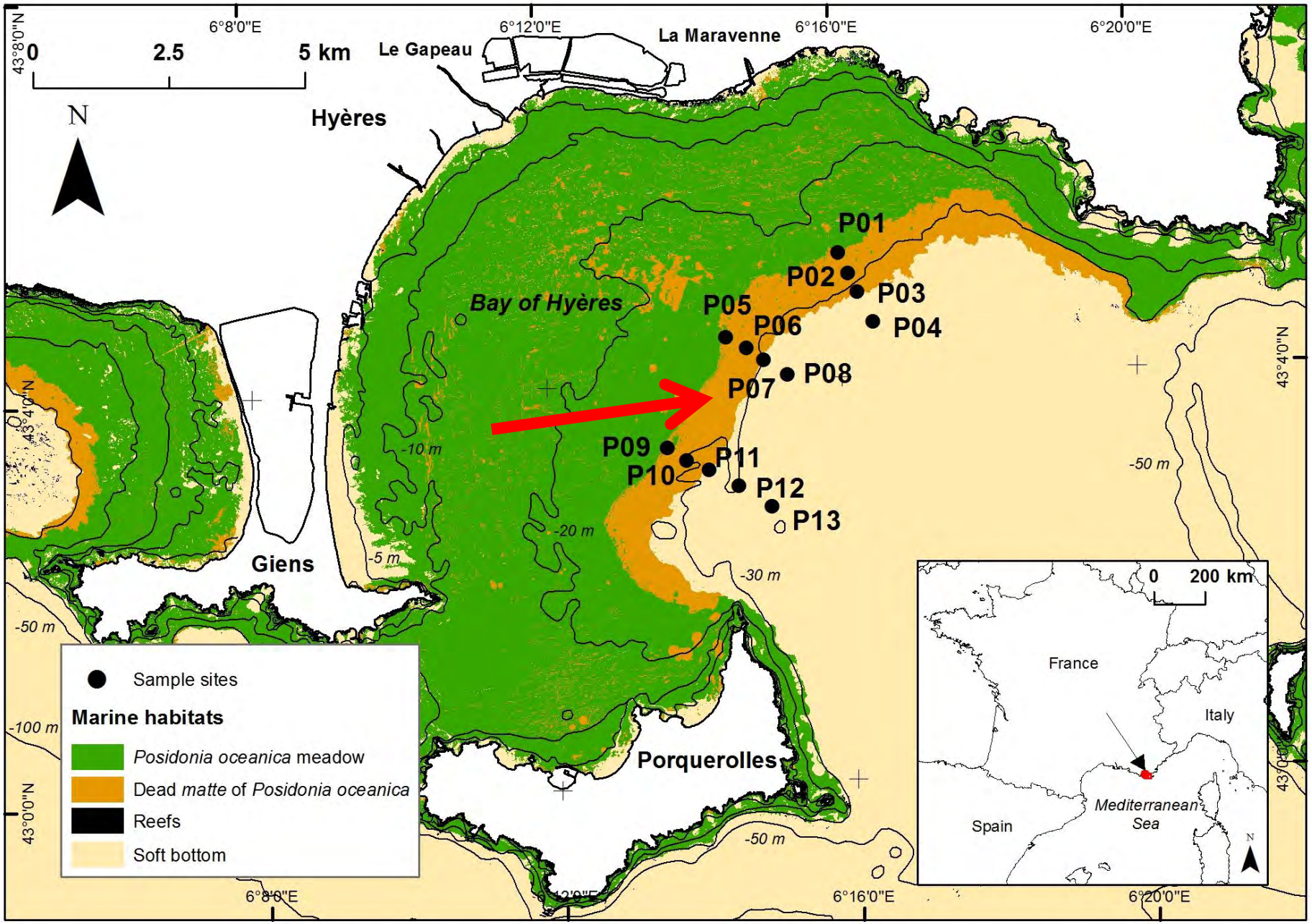


(Seabed map source : Andromède Océanologie, 2012)

Problematic

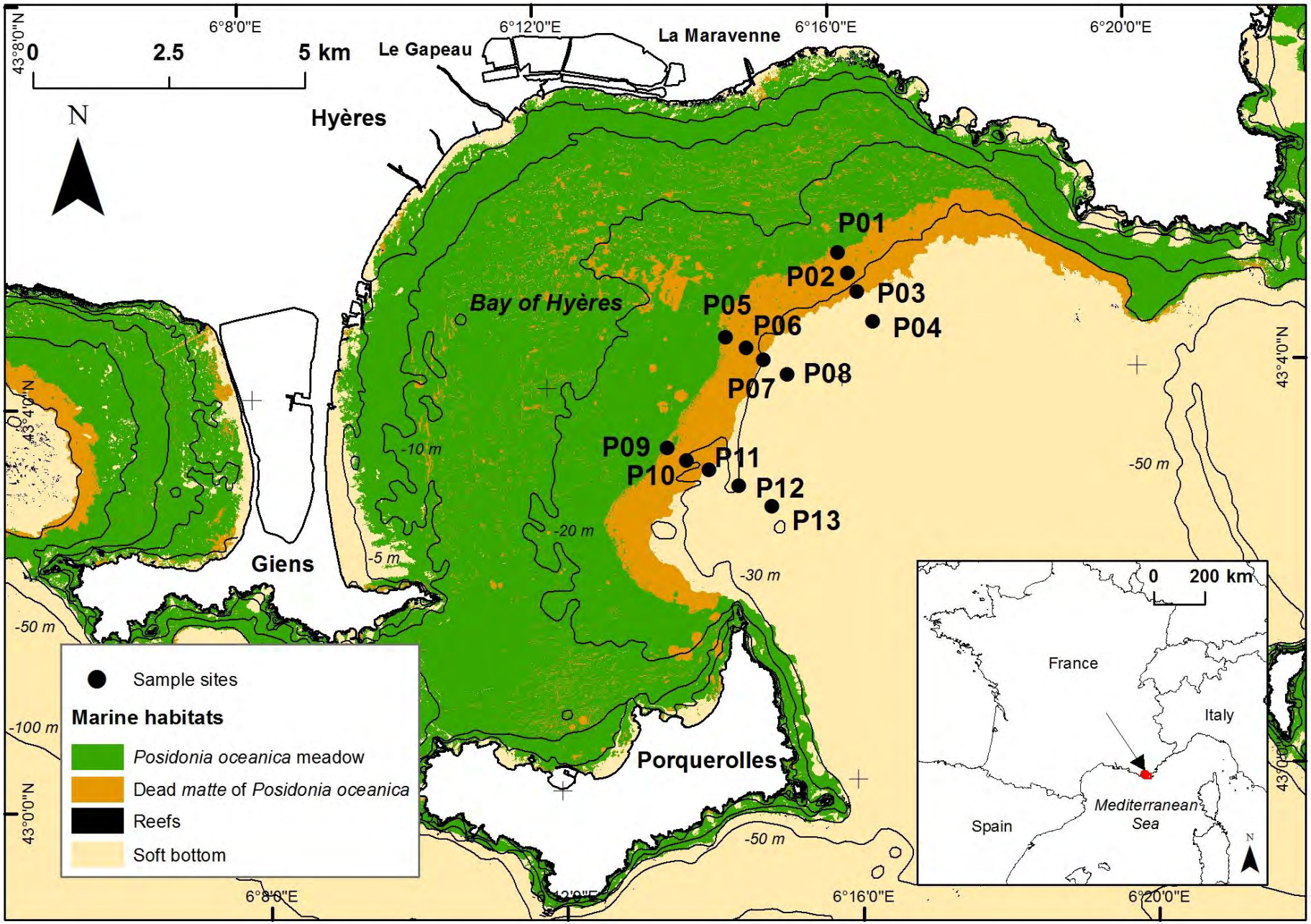
- *P. oceanica* meadow lower limit withdrawal observed in various areas, even pristine ones (Mayot *et al*., 2006 ; Meinesz *et al*., 2008 ; Boudouresque *et al*., 2009 ; Astruch *et al*., 2014 ; Pergent *et al*., 2014)

- Within the Bay of Hyères, what are the possible factors of such a withdrawal?

- When has occurred the death of the meadow?

Material and Methods

- Dating the death of the meadow using Radiocarbon analysis (^{14}C)
- 13 samples of dead matte (roots and rhizomes) : superficial layer 5-10 cm thick near and beyond the current limit between 26 and 37 m depth.
- Samples were cleaned of macroalgae and sediment to avoid contamination then dried 48 h at 70°C.
- Analyses were done by Geochron lab (USA)


0
2.5
5 km
N
Le Gapeau
La Maravenne
Hyères
Bay of Hyères
Giens
Porquerolles
P01
P02
P03
P04
P05
P06
P07
P08
P09
P10
P11
P12
P13
-10 m
-5 m
-20 m
-30 m
-50 m
-100 m
6°8'0"E
6°12'0"E
6°16'0"E
6°20'0"E
43°8'0"N
43°4'0"N
43°0'0"N
Sample sites
Marine habitats
Posidonia oceanica meadow
Dead matte of Posidonia oceanica
Reefs
Soft bottom
0 200 km
France
Italy
Spain
Mediterranean Sea

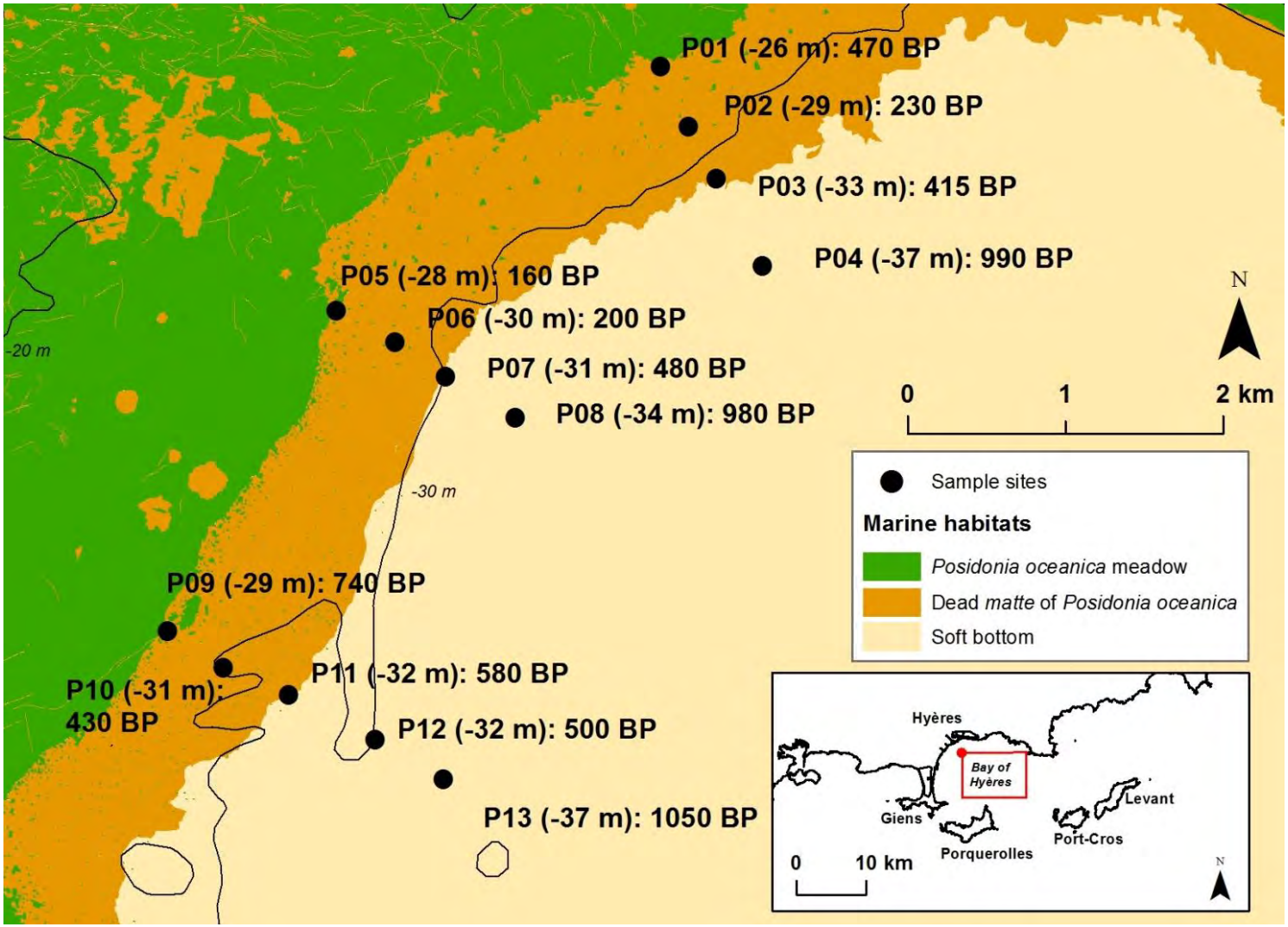
Material and Methods

Field observations during sampling:

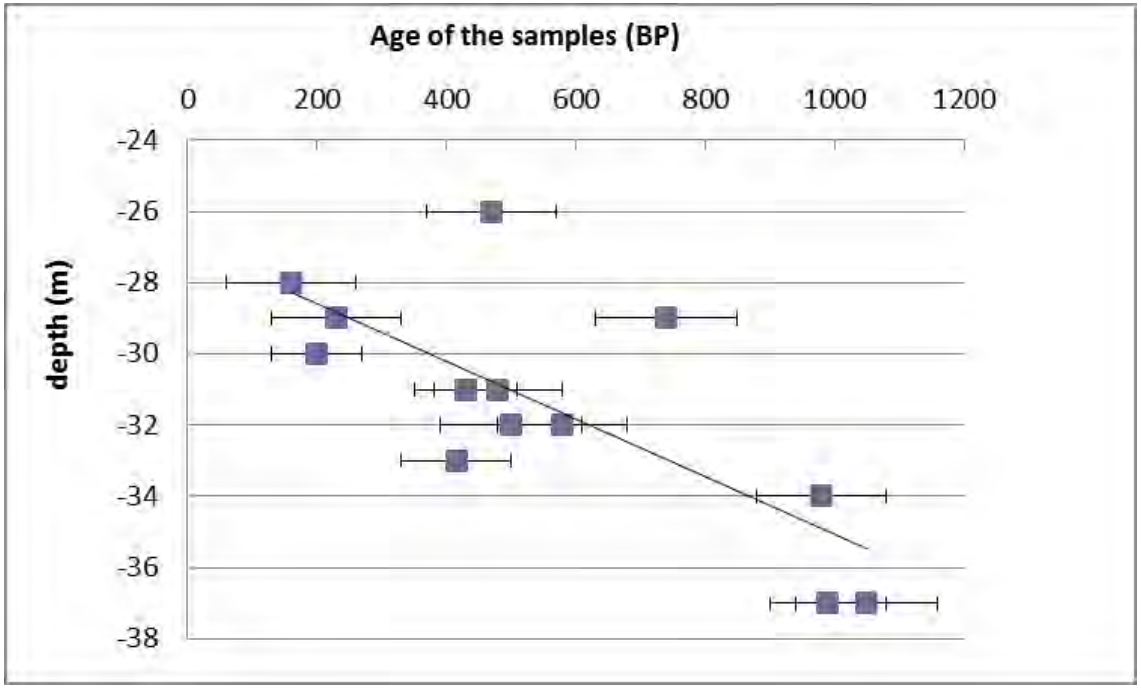
- Presence of the invasive species *Caulerpa cylindracea*
- Trawling marks
- Macro-wastes
- Sparse meadow and patches of *P. oceanica* found deeper than the current lower limit

Results

Radiocarbon analysis: Dating from **160 BP to 1050 BP** years old.



The deeper was the sample, the older it was (Spearman's rank correlation, p = 0.01)

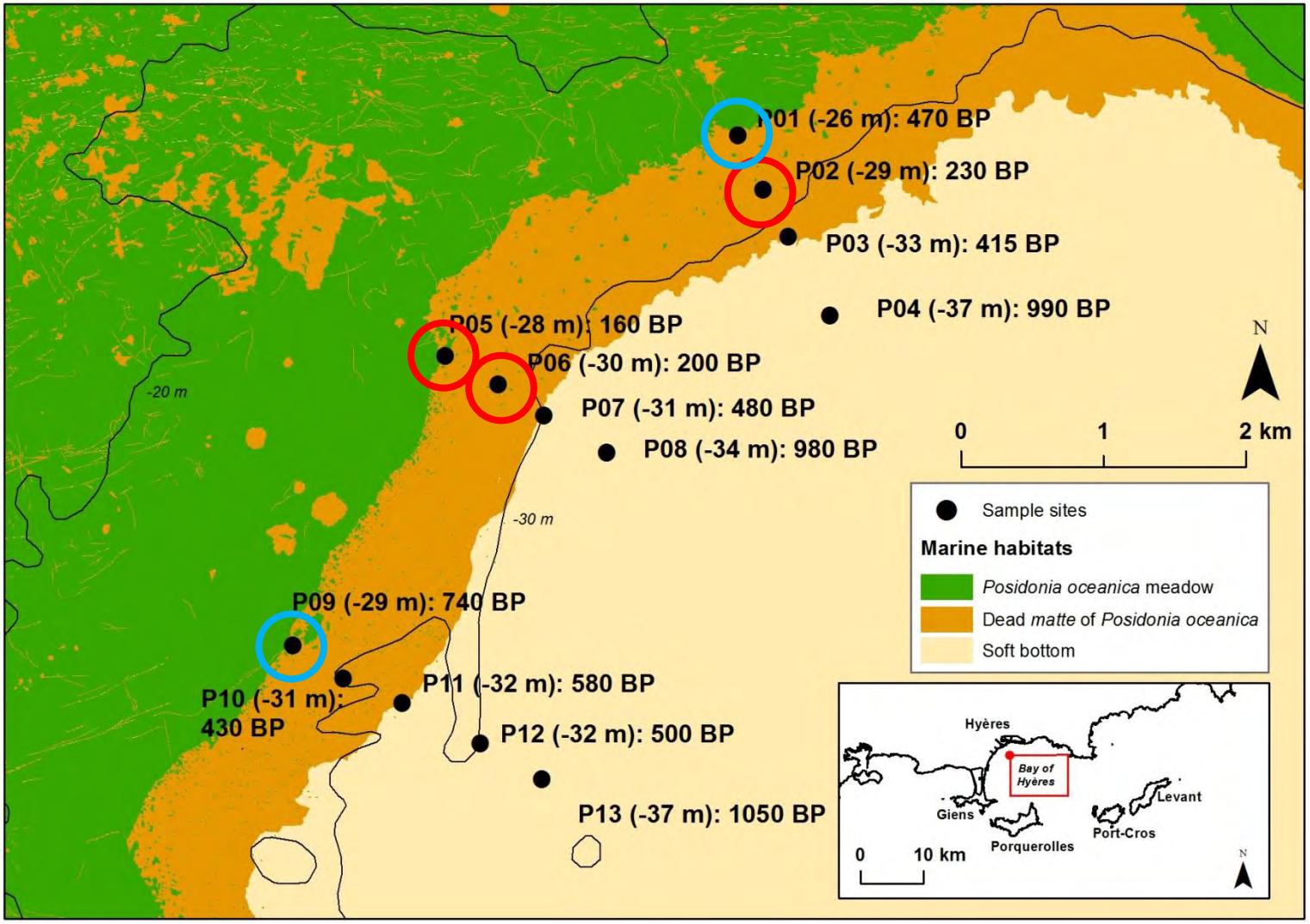


Age less than 3 times the standard deviation : contemporaneous death (3 sites close to the lower limit, 28-30 m depth)

Proportion of remains of dead *P. oceanica* in the sample (roots, rhizomes and sheet) was significantly lower at deeper samples.

Contemporaneous death of the meadow

Older than the following sample at depth



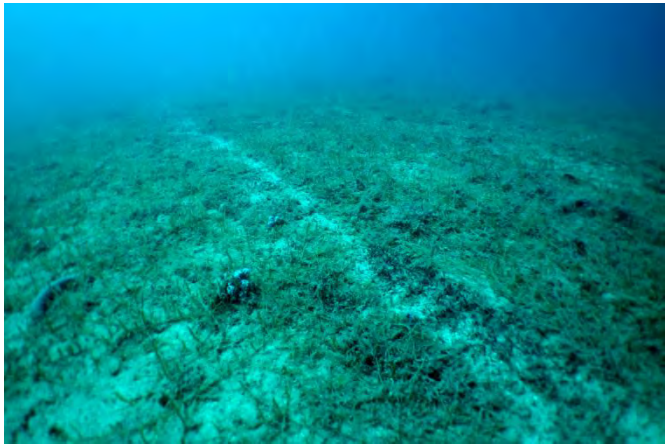
Field observations

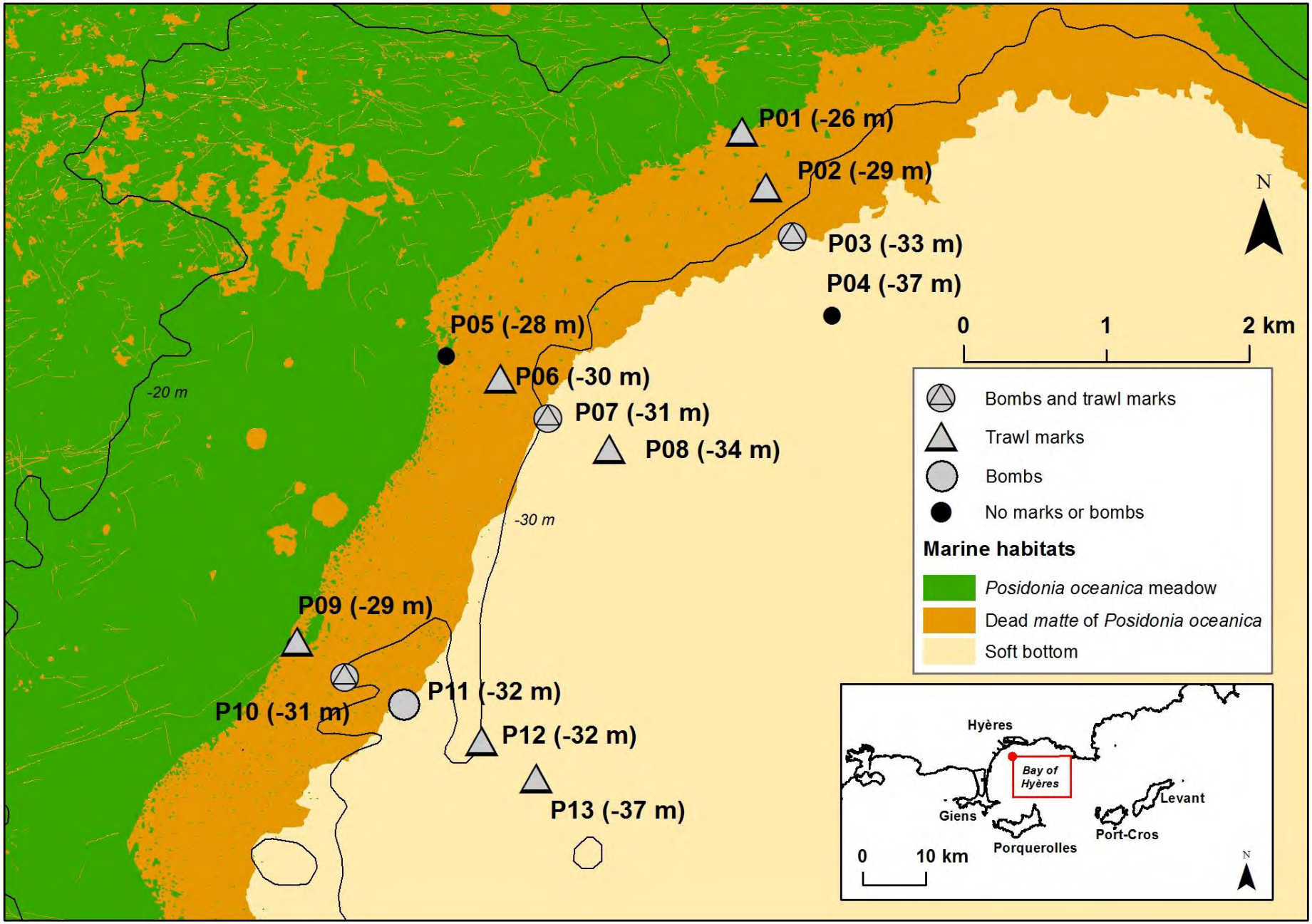
- Living meadow (patches or sparsed shoot with low vitality) far (up to 1.5 km) and deeper (up to 34 m depth) from the current mapped lower limit (26-29 m depth)

- *Caulerpa cylindracea* was observed on every sample sites, excepting the 2 deepest (37 m depth, matte covered by sandy detritic bottom)

- Trawl marks = 10/13 sites (ancient?)

- Macrowastes ➔ mainly bombs from WW II = 4/13 sites, but very frequent within the meadow at shallower depth (15-25 m)




P01 (-26 m)
P02 (-29 m)
P03 (-33 m)
P04 (-37 m)
P05 (-28 m)
P06 (-30 m)
P07 (-31 m)
P08 (-34 m)
P09 (-29 m)
P10 (-31 m)
P11 (-32 m)
P12 (-32 m)
P13 (-37 m)
-20 m
-30 m
N
0
1
2 km
Bombs and trawl marks
Trawl marks
Bombs
No marks or bombs
Marine habitats
Posidonia oceanica meadow
Dead matte of Posidonia oceanica
Soft bottom
Hyères
Bay of Hyères
Giens
Porquerolles
Port-Cros
Levant
0
10 km
N

Discussion

- Meadow at lower limit : recent impact linked to human activities

- Withdrawal identified since at least 1 000 years ago.

The withdrawal has started since the Holocene sea level rise 20 000 years ago (last SL minimum is 120 m below the actual).

Which hypotheses could explain our results?

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The meadow death is recent

- *Post mortem* erosion of the roof of the dead matte:

  - Matte rise = 1-2 mm a^{-1} (Boudouresque and Jeudy de Grissac, 1983; Mateo *et al*., 1997, 2002; etc.) explained by matte compaction overtime and perishability of remains of *P. oceanica* (Kall *et al*., 2016). Thus, erosion should have **removed 1.1-2.1 m thick layer of matte** (P13)

➔ Cannot be excluded

Which hypotheses could explain our results?

The meadow death is recent

1

Living *P. oceanica* meadow (*e.g.* last century?)

Matte rise (1-2 mm a^{-1})

0 BP
-35-36 m?

1000 BP
-37 m

Which hypotheses could explain our results?

The meadow death is recent

1

Living *P. oceanica* meadow (*e.g.* last century?)

2

Meadow death (Recent human activities)

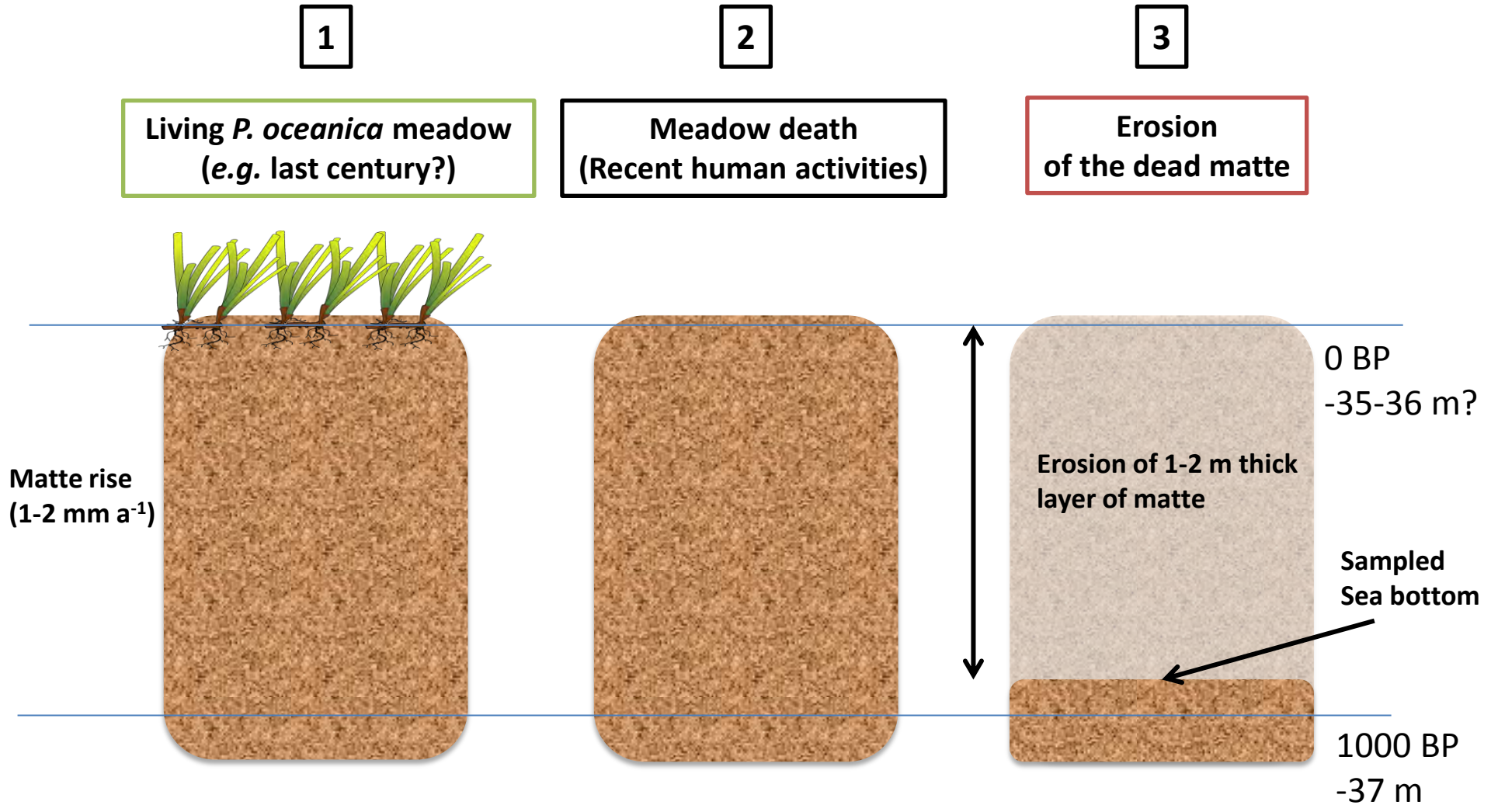
Matte rise (1-2 mm a^{-1})

0 BP
-35-36 m?

1000 BP
-37 m

Which hypotheses could explain our results?

The meadow death is recent



Which hypotheses could explain our results?

The meadow death at lower limit is ancient

- **Rise of the sea level (RSL):**
  - Since 1 000 CE, RSL is estimated from 40 cm to 1 m (Morhange, 2001; Miller *et al*., 2005; Dalongeville et al., 2007).
  - *P. oceanica* meadow has moved following the SL rising leaving behind dead matte from natural origin. Could be confused with recent withdrawal (Boudouresque et al., 2009).
  - Very low slope within the Bay of Hyères: 0.4 m SL rise = 200 m withdrawal; 1 m SL rise = 500 m withdrawal
  - Observed withdrawal is up to 1.5-2 km

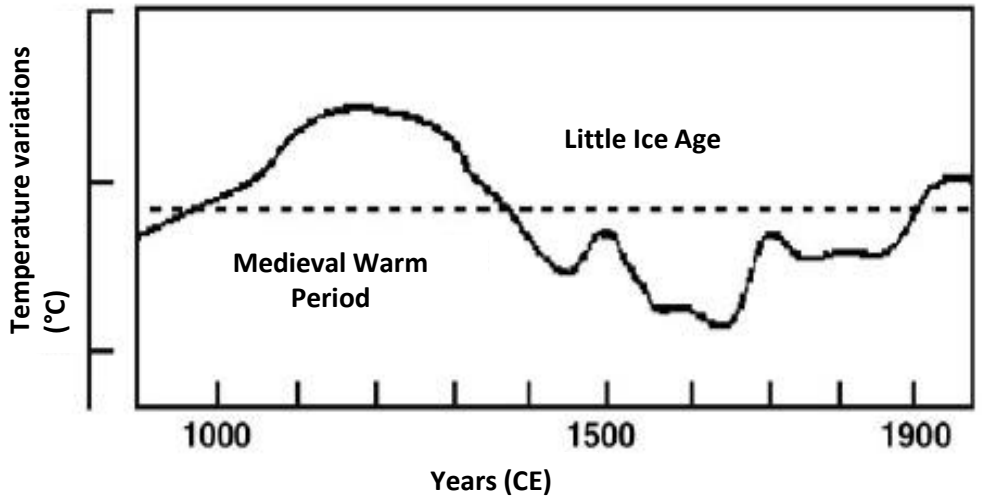
➔RSL could explain the withdrawal but **only partially**

Which hypotheses could explain our results?

The meadow death at lower limit is ancient

- **Past Climate changes (last millenium)** (Esper et al., 2002)
  - Medieval Warm Period (950-1350 CE)
  - Little Ice Age (1300-1850 CE)
  - *P. oceanica* is sensitive to low and sudden increases in temperature (Boudouresque *et al*., 2009; Marbà *et al*., 2010)

➔A withdrawal linked with past climate changes is consistent



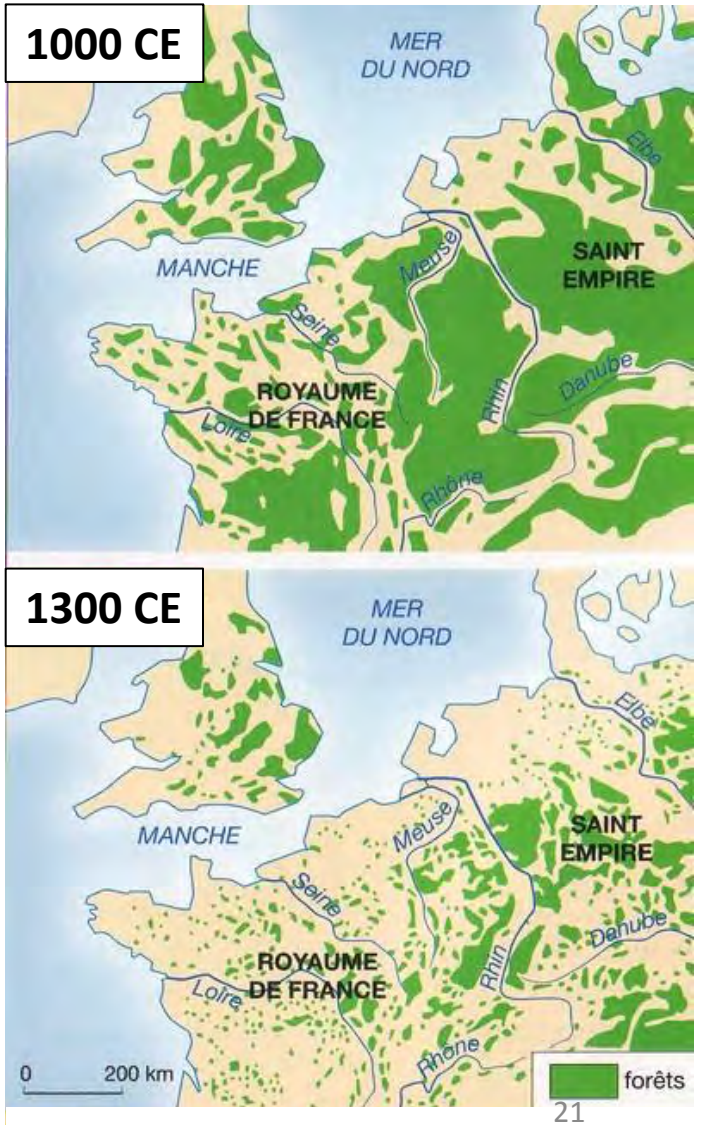
Which hypotheses could explain our results?

The meadow death at lower limit is ancient

Middle age human-induced changes

- Political stability period after the 9th century of the French Kingdom
- Fast and unprecedented demographic growth (spread of cultured fields and cities extent) (Petit, 1953)
- Massive **deforestation**
- Bay of Hyères has likely endured a massive flooding: **decreased water transparency and compensation limit** of *P. oceanica*

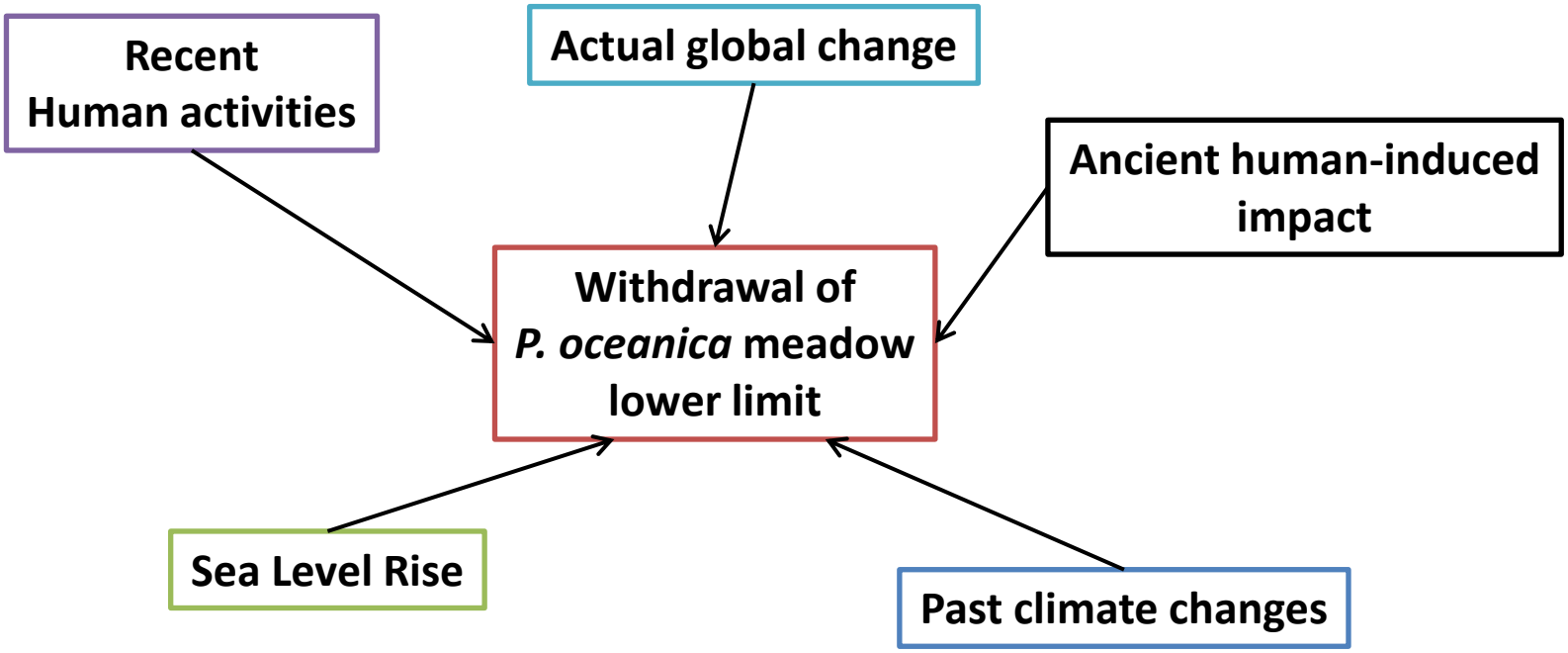
➔ Possible reason for the 1000 years old lower limit withdrawal



Which hypotheses could explain our results?

The meadow death at lower limit is ancient

- Withdrawal is probably explained by a **combination of all these hypotheses**



Discussion

- More samples are required from other areas with different contexts (well preserved, highly impacted)
- In any case, a **human-induced impact is observed**

- EBQI index (Personnic *et al*., 2014) ➔ the low value is of concern in the Bay of Hyères

➔ Not only the structure of the meadow but **the entire ecosystem is affected**

- Need to better understand the factors behind the evolution of *P. oceanica* meadows

- Importance of Ecosystem quality to evaluate the efficiency of carbon fixation

Perspectives

- Management of **coastal trawling** impacting both structure of the meadow and fish assemblages

- Management of **mooring** activities (military and cruise ships) highly impacting

- Monitoring of **global change consequences** (alien species, community shift)

- Which incidences on **ecosystemic services**?
  - Ecological functionality (fish nurseries, spawning area, shelter)
  - Protection against beach erosion, control of sediment fluxes
  - Carbon sequestration and fixation
  - Etc.

Thank you for your attention

Perspectives

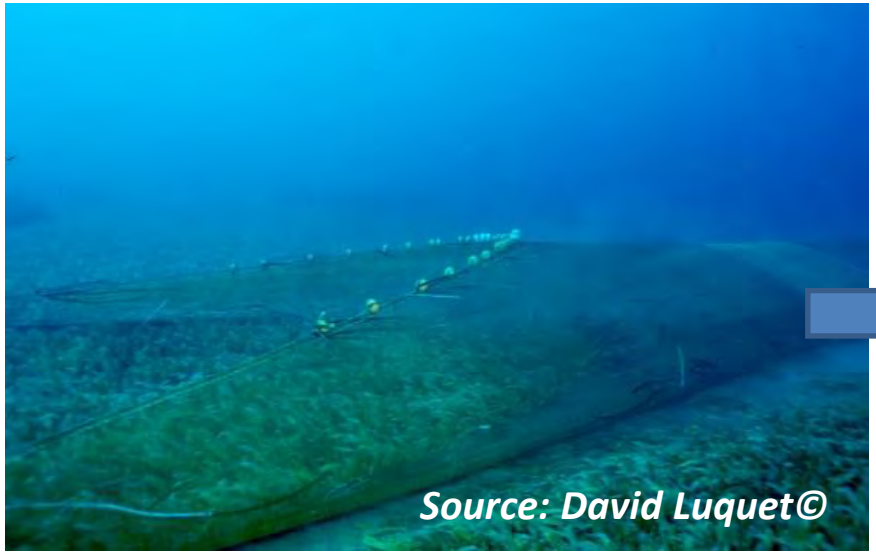
Source : l'Encre de mer

- **Management of coastal trawling**

- Impacting both habitat structure and fish assemblages

- Small coastal trawlers that target fish assemblages of *P. oceanica* meadow ('soupe', labrids, scorpaenids)

- Un-selective method (high percentage of juveniles)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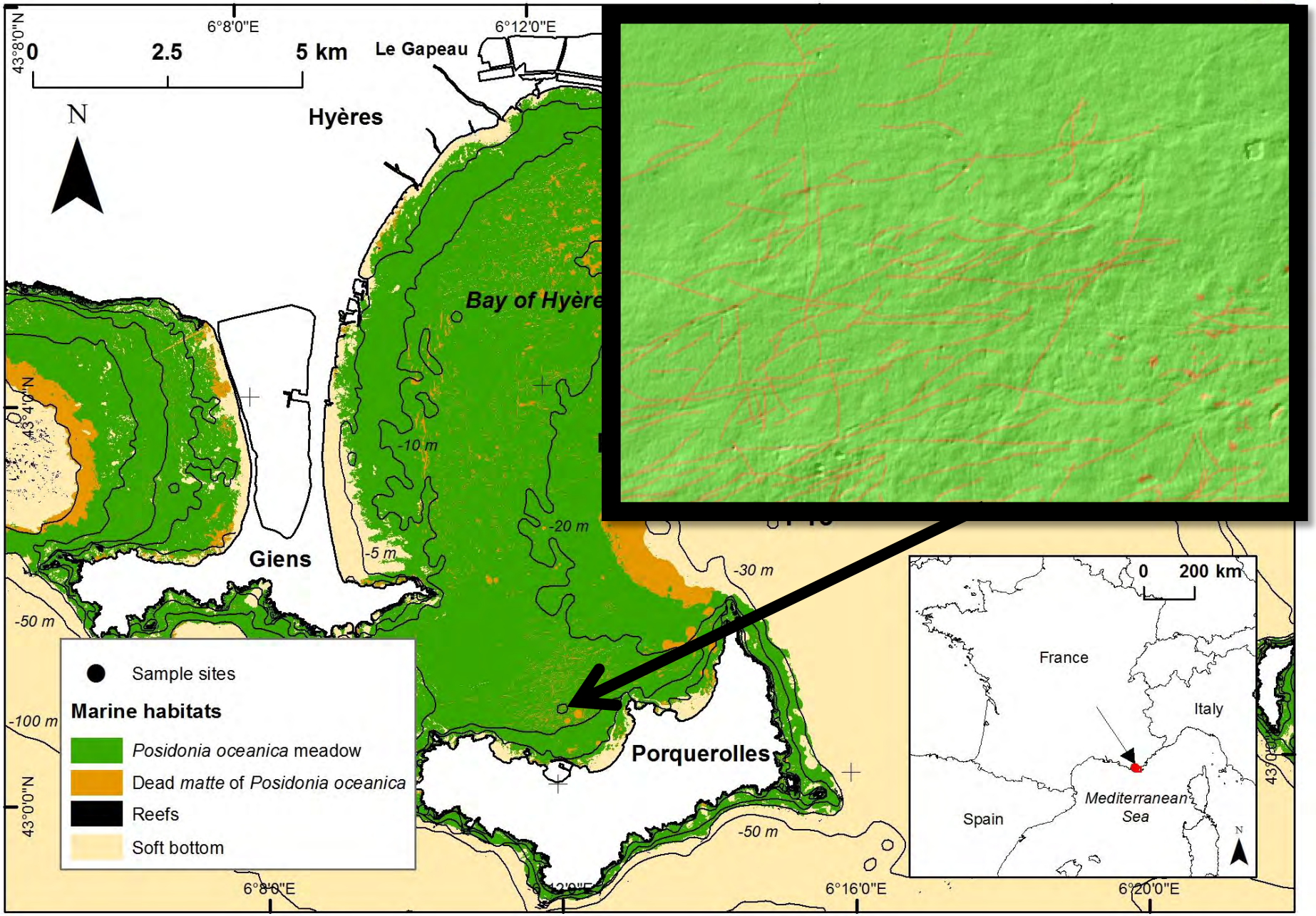
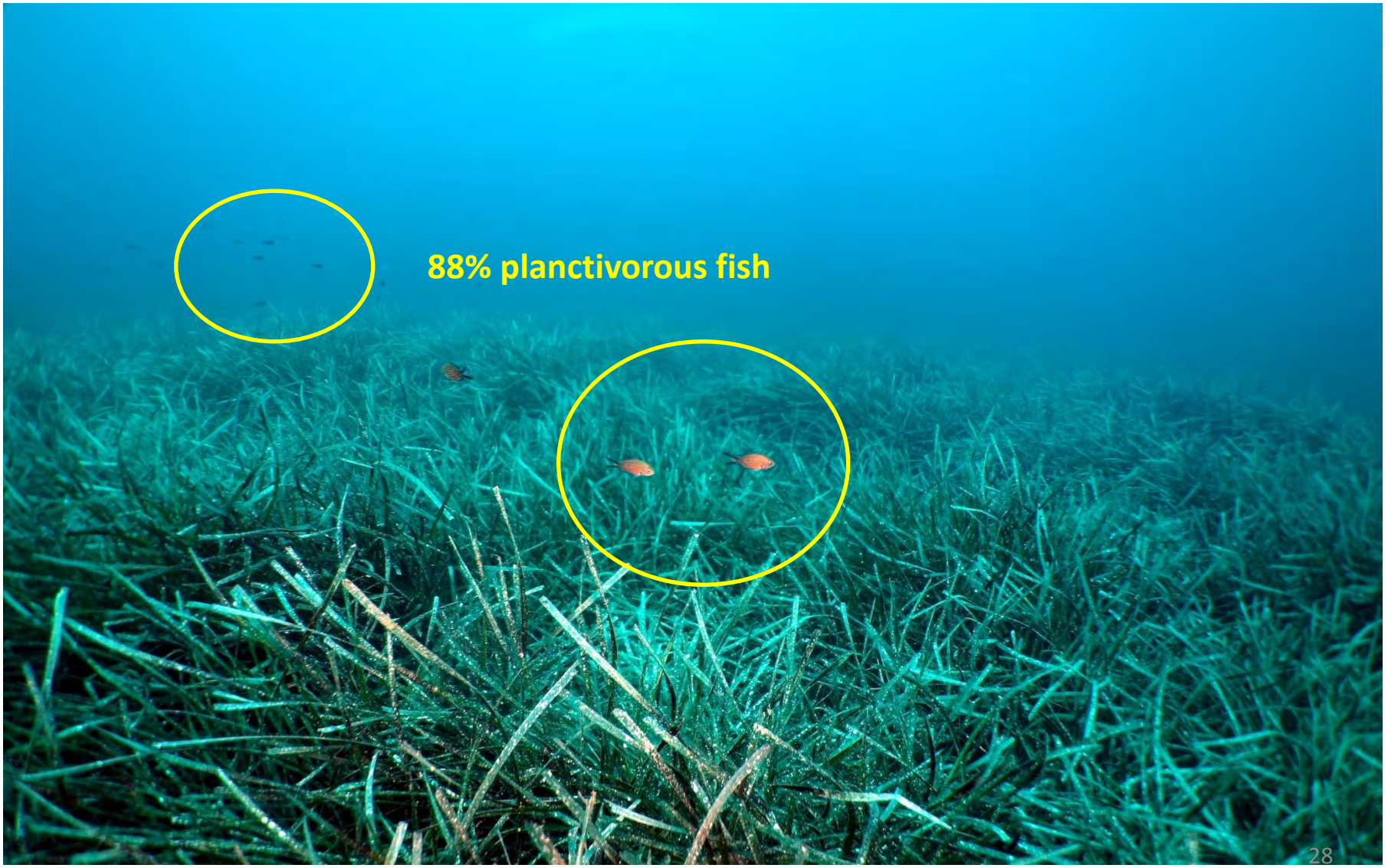


Sources : CARTHAM, Andromède Océanologie, GIS Posidonie, LITTO3D

Bay of Hyères (Astruch *et al.*, 2014)**: Poor fish assemblages**



Some comparisons (*P. oceanica* fish assemblages)

Calanques (Marseille, Astruch *et al*., 2009): **density x2**

Réserve naturelle de **Scandola** (Corsica; Francour, 1993) :
biomass x 5 (no take area), **biomass x2** (out of the reserve)

Port-Cros island (National Park): (Astruch *et al.,* 2015), **biomass x 6**