Impact of Climate Change on seagrass meadows

Will warming set seagrass (*Posidonia oceanica*) on a collision course?

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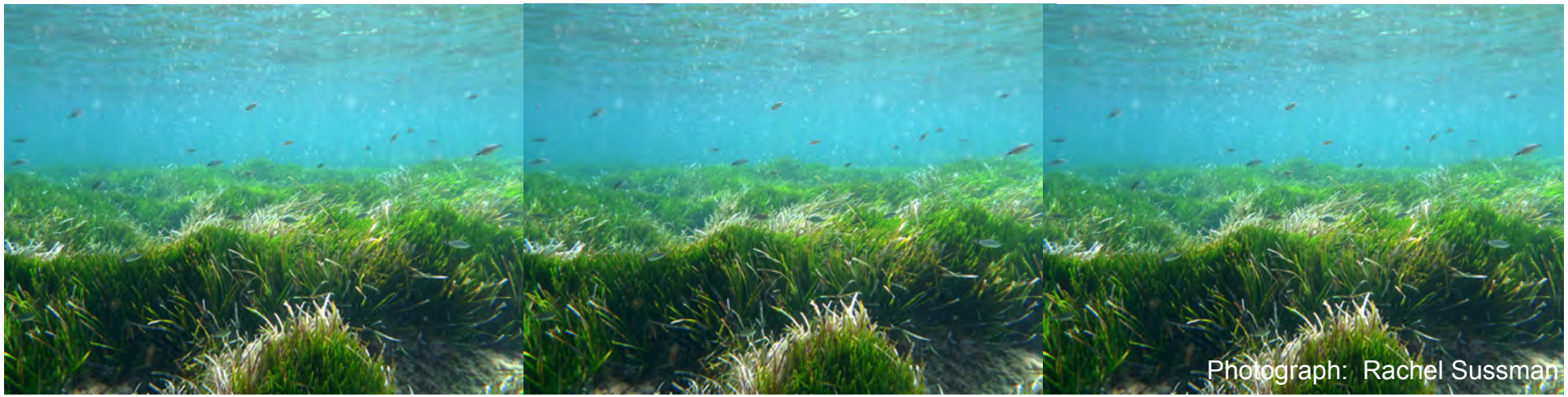
Photograph: Rachel Sussman

Structure

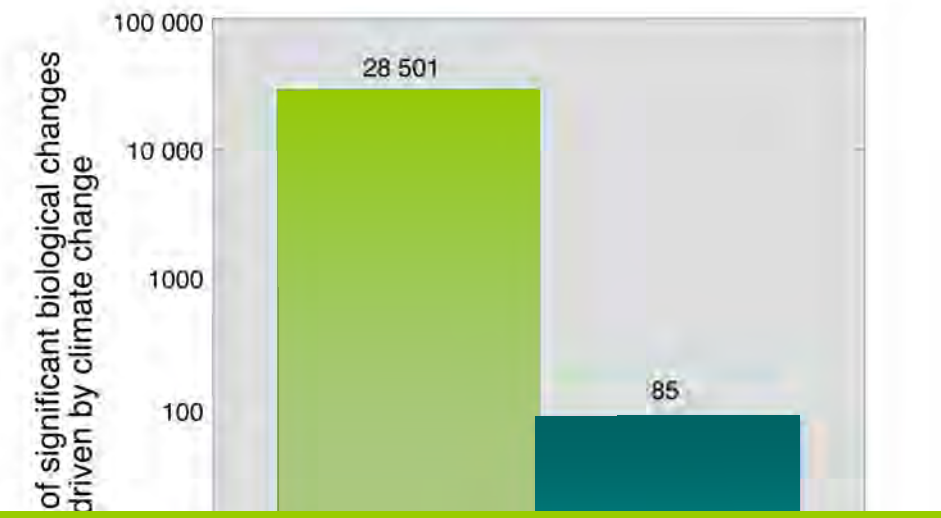
- Impacts of warming on *P. oceanica* demography (seasonally and interannually; Magaluf and Cabrera National Park, Balearic Islands)

- Effect of warming on *P. oceanica* sexual reproduction

- Effect of acidification / high CO_2 availability on *P. oceanica (theory, laboratory & vulcanic vents)*



Global warming is a global threat to biodiversity, with a major loss predicted as warming progresses along the 21st Century (*IPCC 2007*)



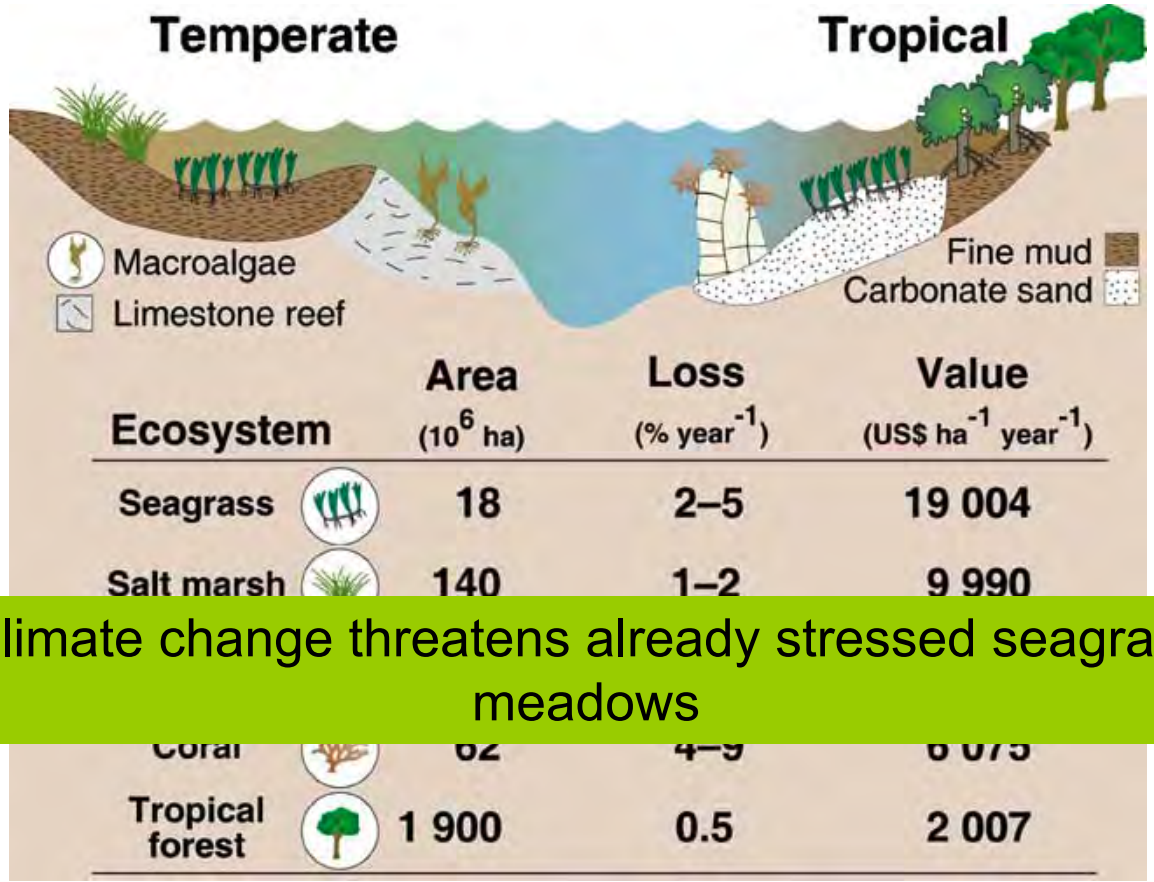
Evidence of climate change impacts on marine biodiversity mostly from corals, but other marine habitats vulnerable to climate change as well

Climate change may impact marine ecosystems already stressed by other pressures.

Duarte et al 2008, Estuaries and Coasts

Richardson and Poloczanska 2008 Science

Seagrass ecosystems rank amongst the most threatened marine habitats



Ecosystem	Area (10^6 ha)	Loss (% year^{-1})	Value (US$ ha^{-1} year^{-1})
Seagrass	18	2–5	19 004
Salt marsh	140	1–2	9 990
Coral	62	4–9	6 075
Tropical forest	1 900	0.5	2 007

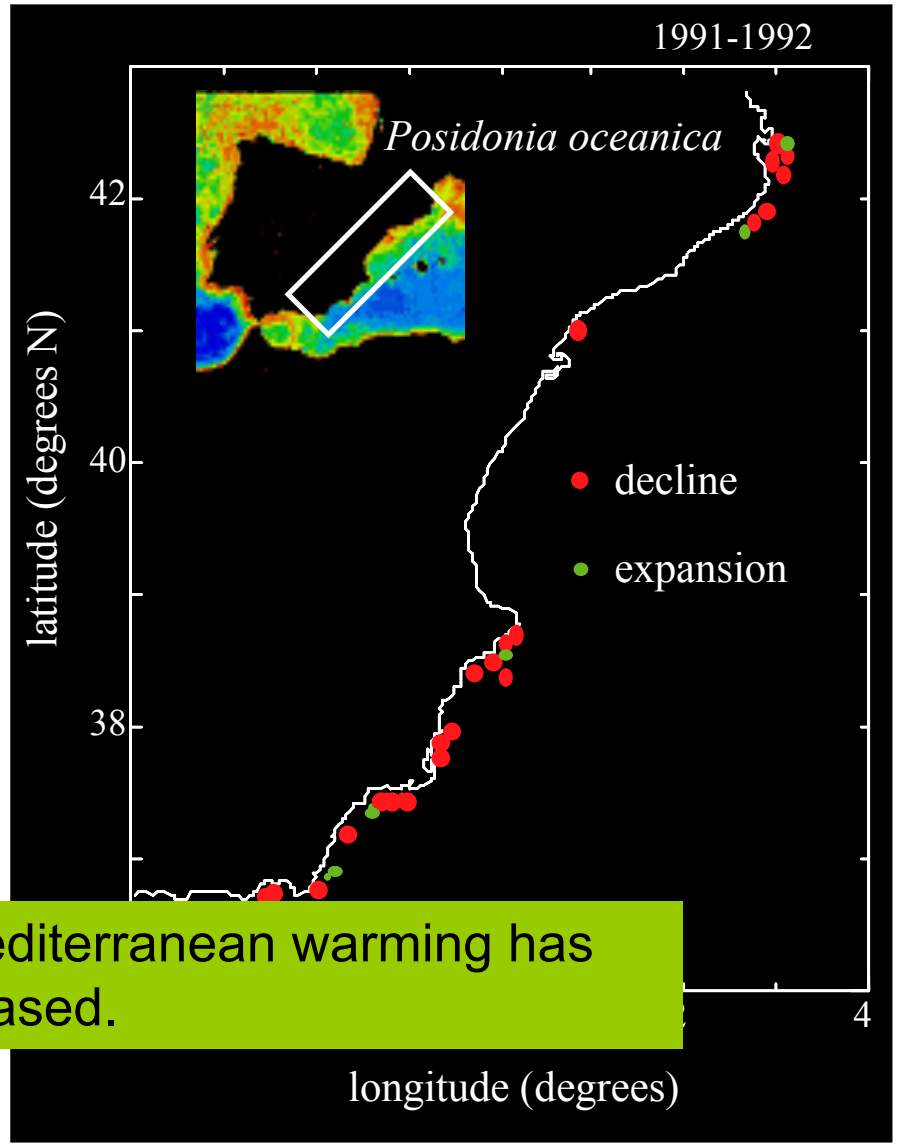
Duarte 08 Estuaries and Coasts

Climate change threatens already stressed seagrass meadows

Causes of global seagrass decline: cumulative processes
(Eutrophication, mechanical impacts, submarine erosion, *climate change*)

Study comparing 1970's and the end of 20th Century:

general decline in the Spanish Mediterranean, also in pristine areas



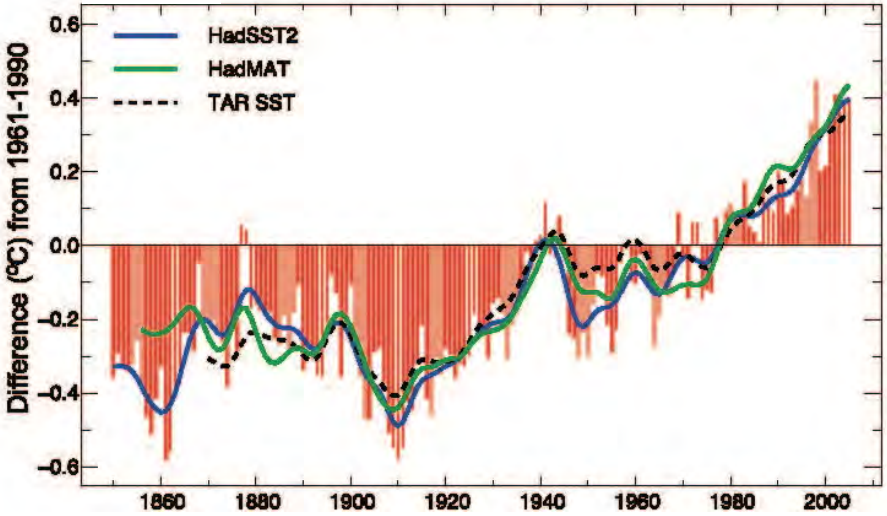
- 80 % of the meadows in decline
- Reduction of shoot density by 50

Since then, the rate of Mediterranean warming has increased.

Marbà et al 1996 MEPS, 2005 Estuaries and Coasts

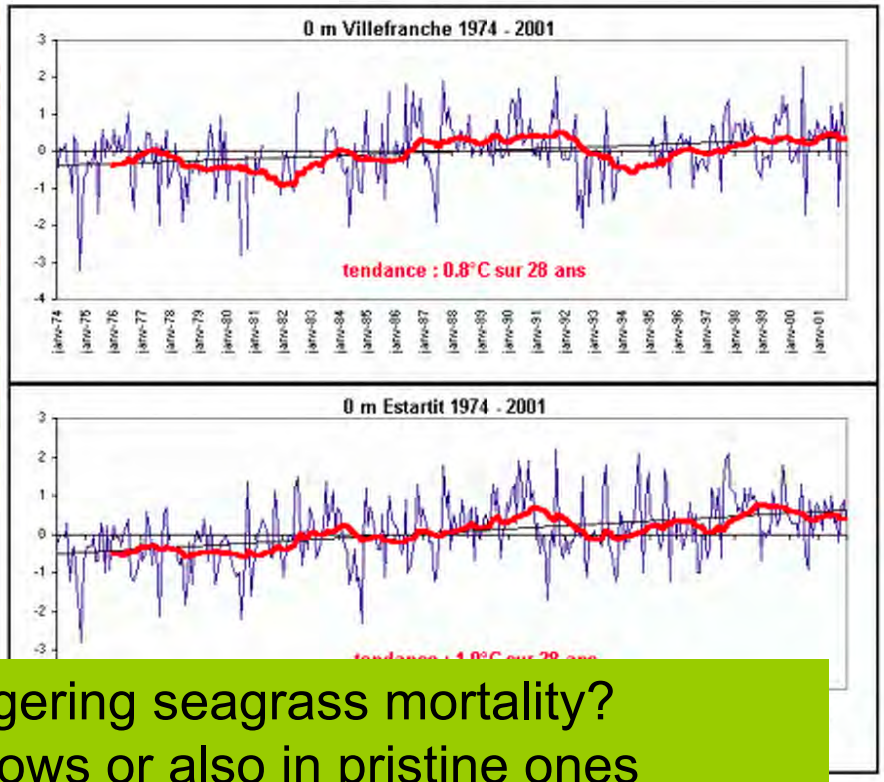
Rates of seawater warming > 2-fold those of the global ocean in the Mediterranean Sea

Globe



Mean Global SST

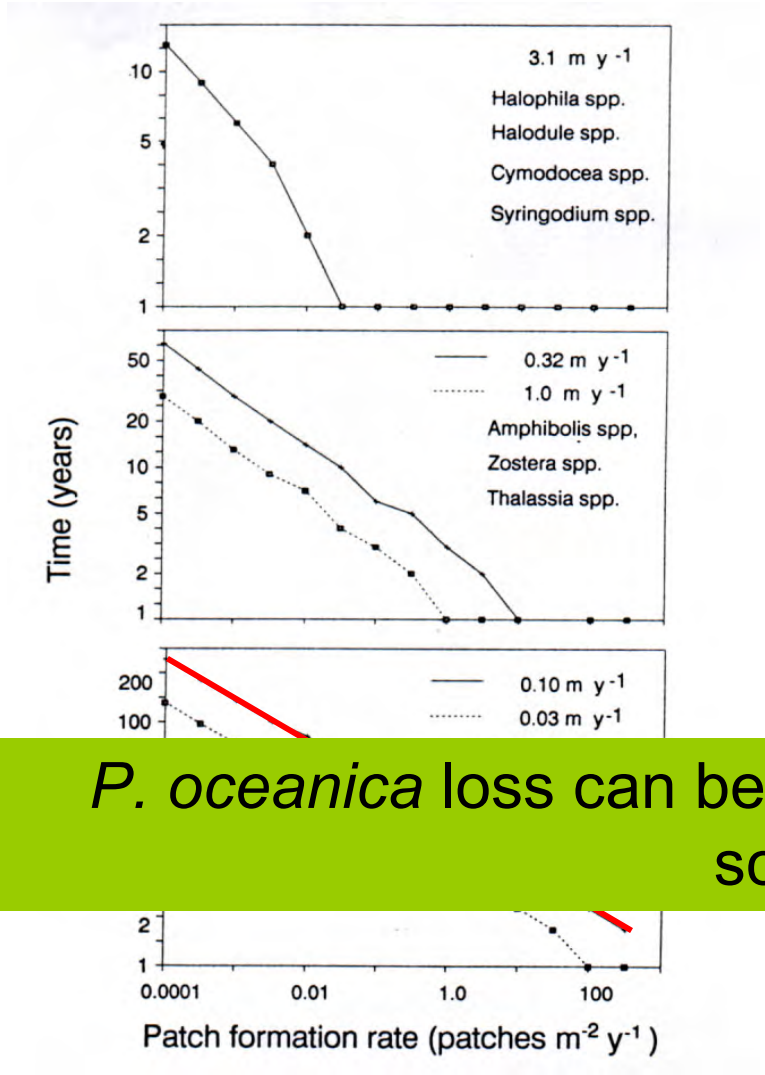
W Mediterranean

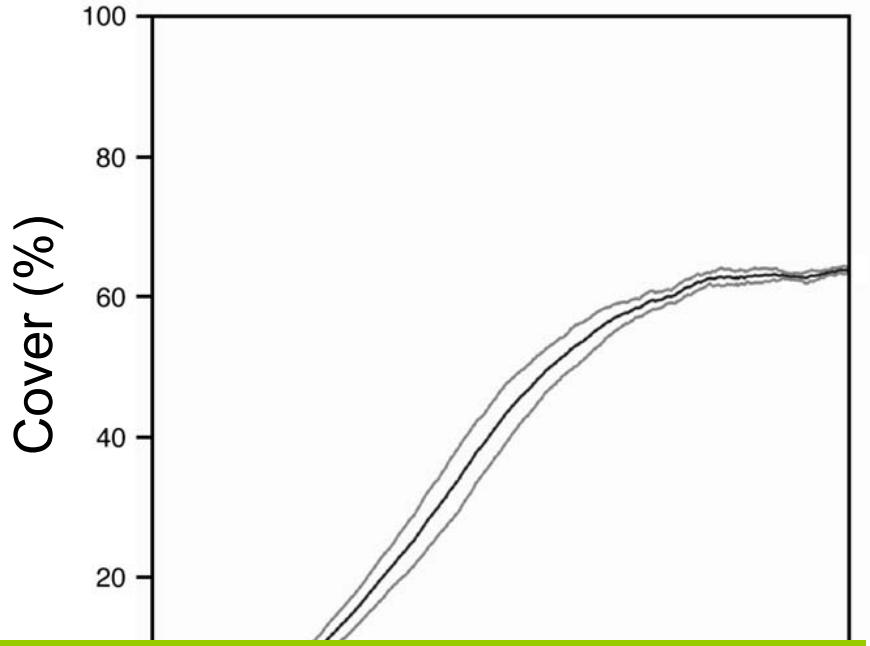


Is seawater warming triggering seagrass mortality?
in already impacted meadows or also in pristine ones

Mean SST warming ≈ 0.3 - 0.4 ºC per decade *(Boury-Esnault et al 2006)*

P. oceanica colonisation time scales of centuries





P. oceanica loss can be irreversible at human time scales

Iterations (years)

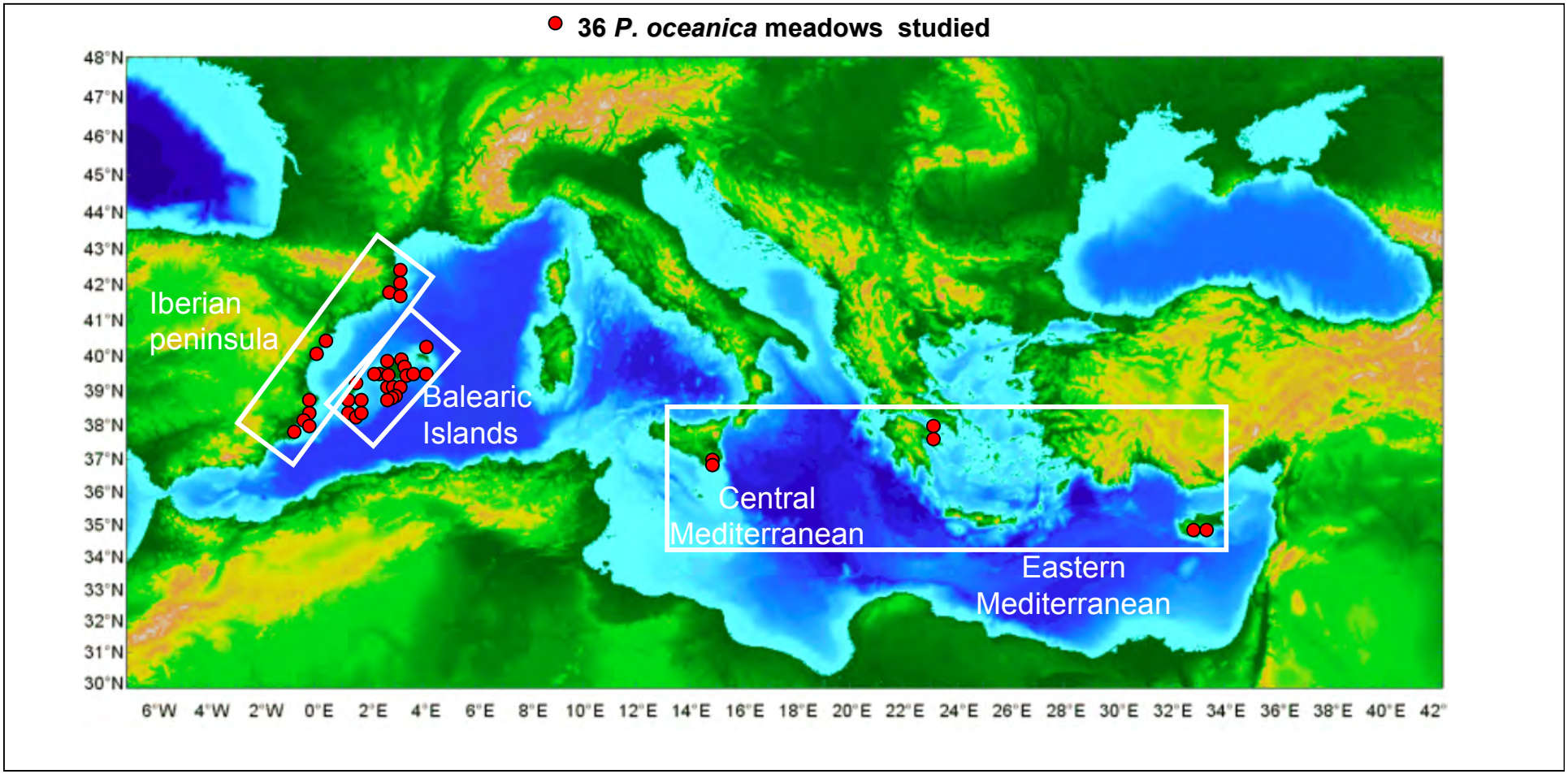
slow rate clone formation (0.004 - 0.02 patches m^{-2} yr^{-1})

very slow growth rate (1- 6 cm yr^{-1})

Duarte 1995

Kendrick et al 2005

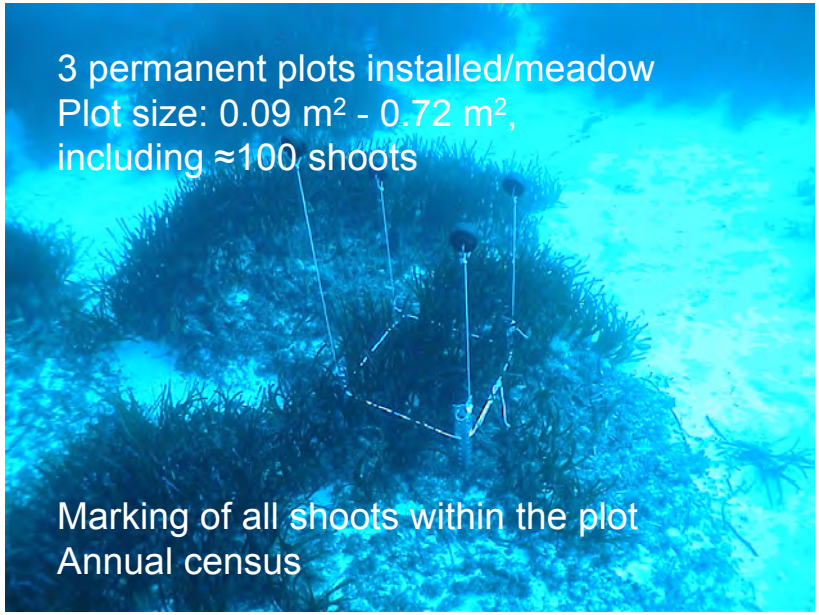
Distribution of studied *P. oceanica* meadows



Plots installed between 2000 and 2003, re-visited annually or bi-annually (depending on the meadow) since installation

Temperature recorded continuously at 4 meadows since 2002

Annual monitoring of *Posidonia oceanica* demography



Annual shoot recruitment

$$R = \frac{(\ln(NT_1 / NS_1)) \cdot 365}{t_1 - t_0} \quad (yr^{-1})$$

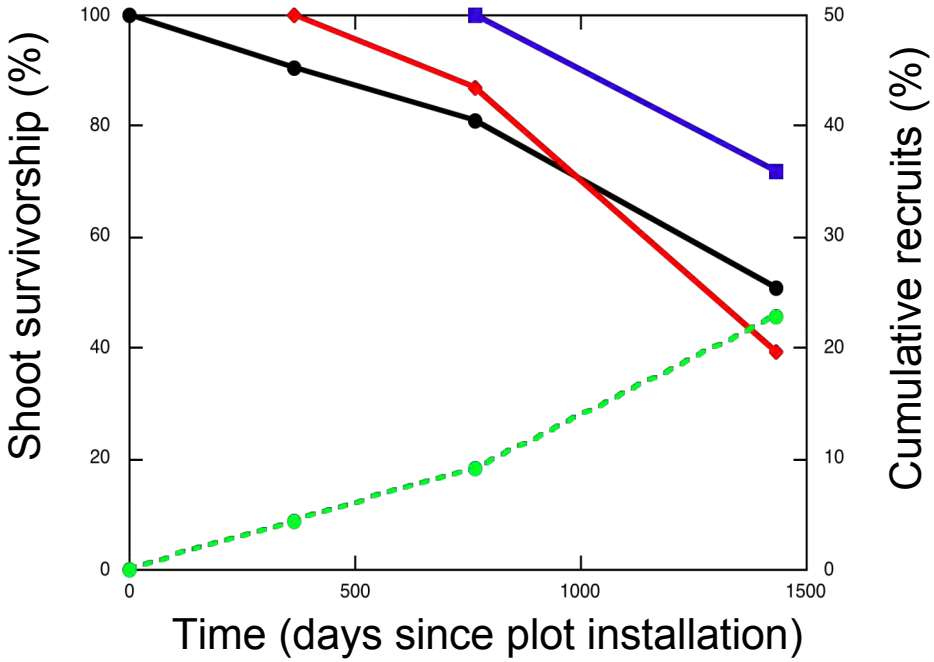
Annual shoot mortality

$$M = \frac{(\ln(NT_0 / NS_1)) \cdot 365}{t_1 - t_0} \quad (yr^{-1})$$

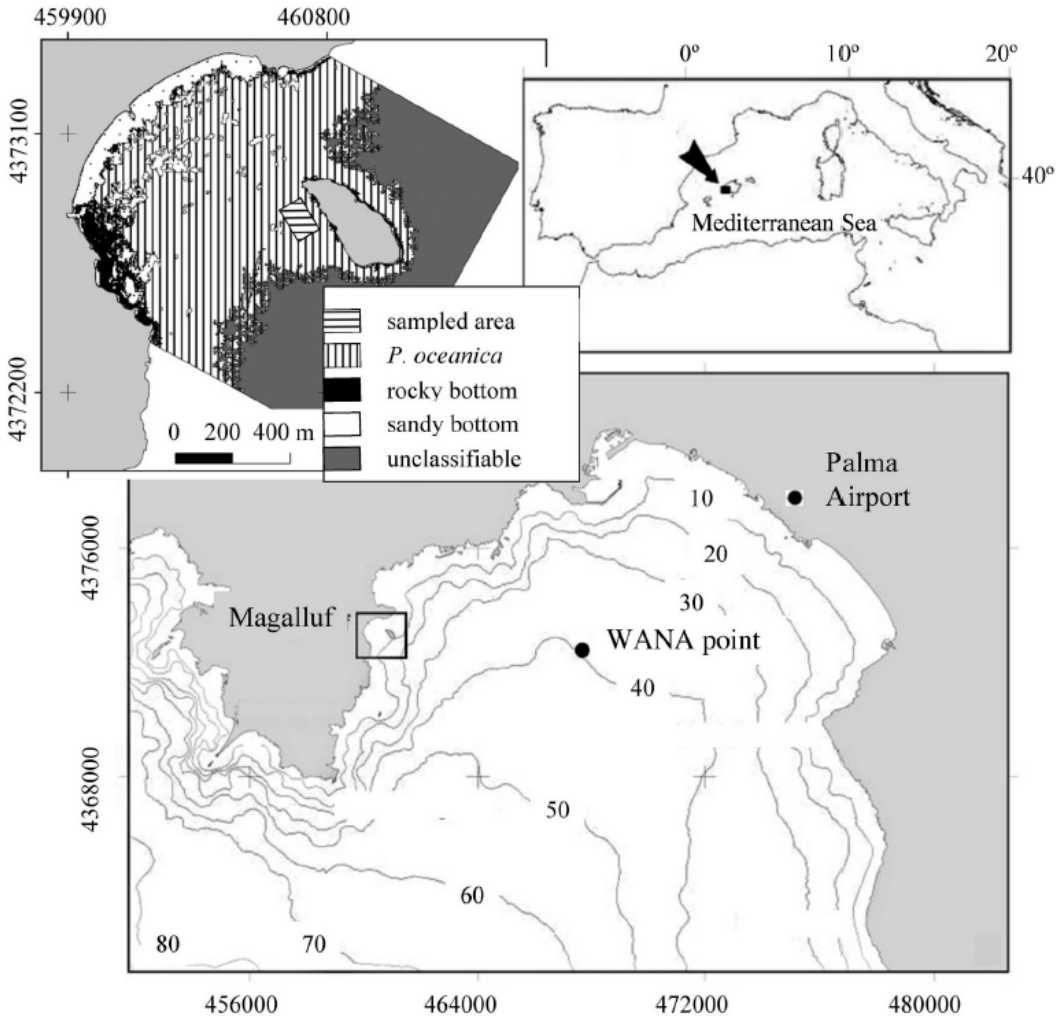
Annual net population growth

$R_{net} = R - M$

$R_{net} > 0$ expanding
$R_{net} < 0$ declining
$R_{net} = 0$ steady-state



Study site: MAGALUF, tourist destination

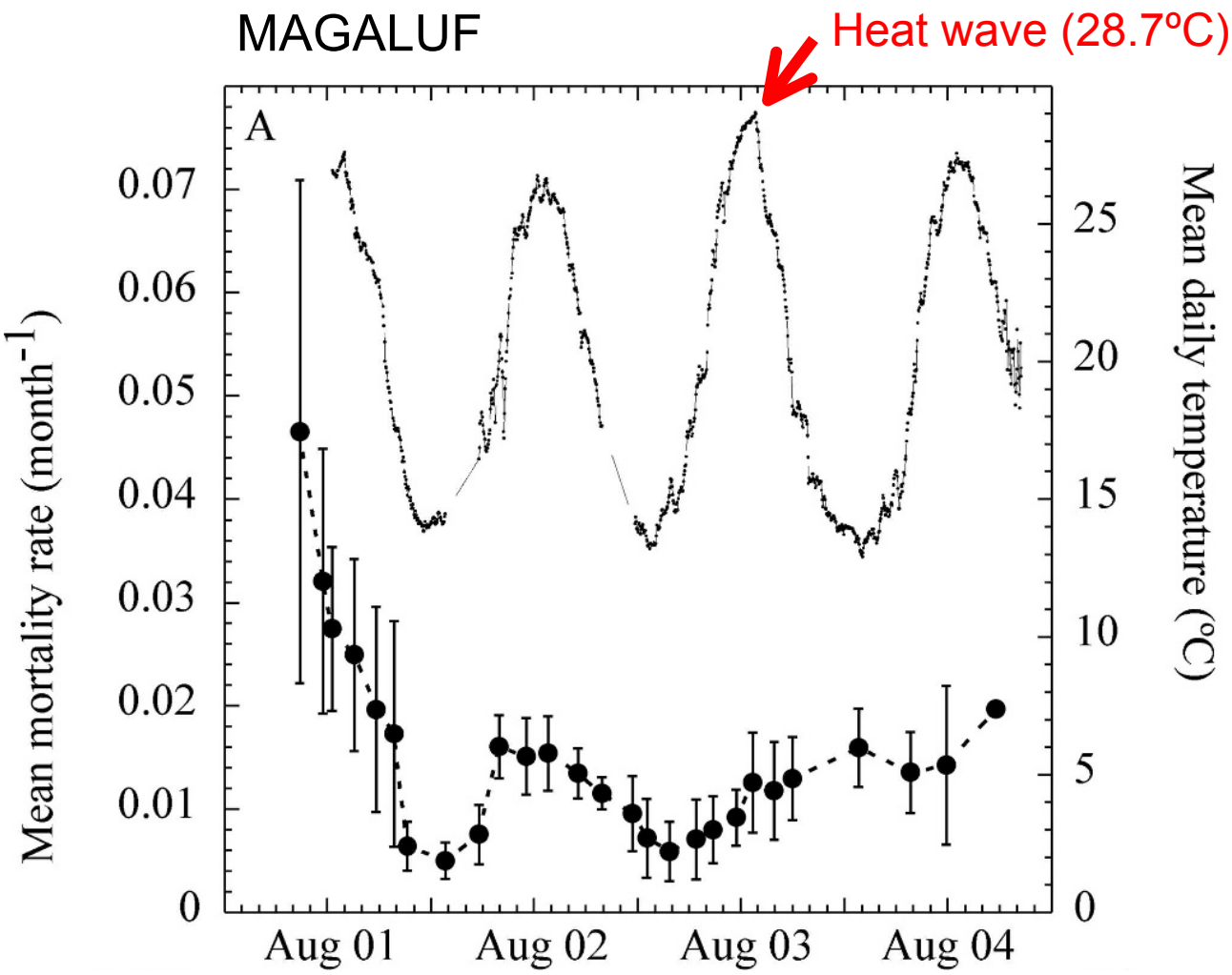


12 permanent plots (7m depth) for 3.5 years

Temperature since year 2002, annual T_{max}

Díaz-Almela et al 2009, L&O

Shoot mortality fluctuated seasonally, peaking in summer



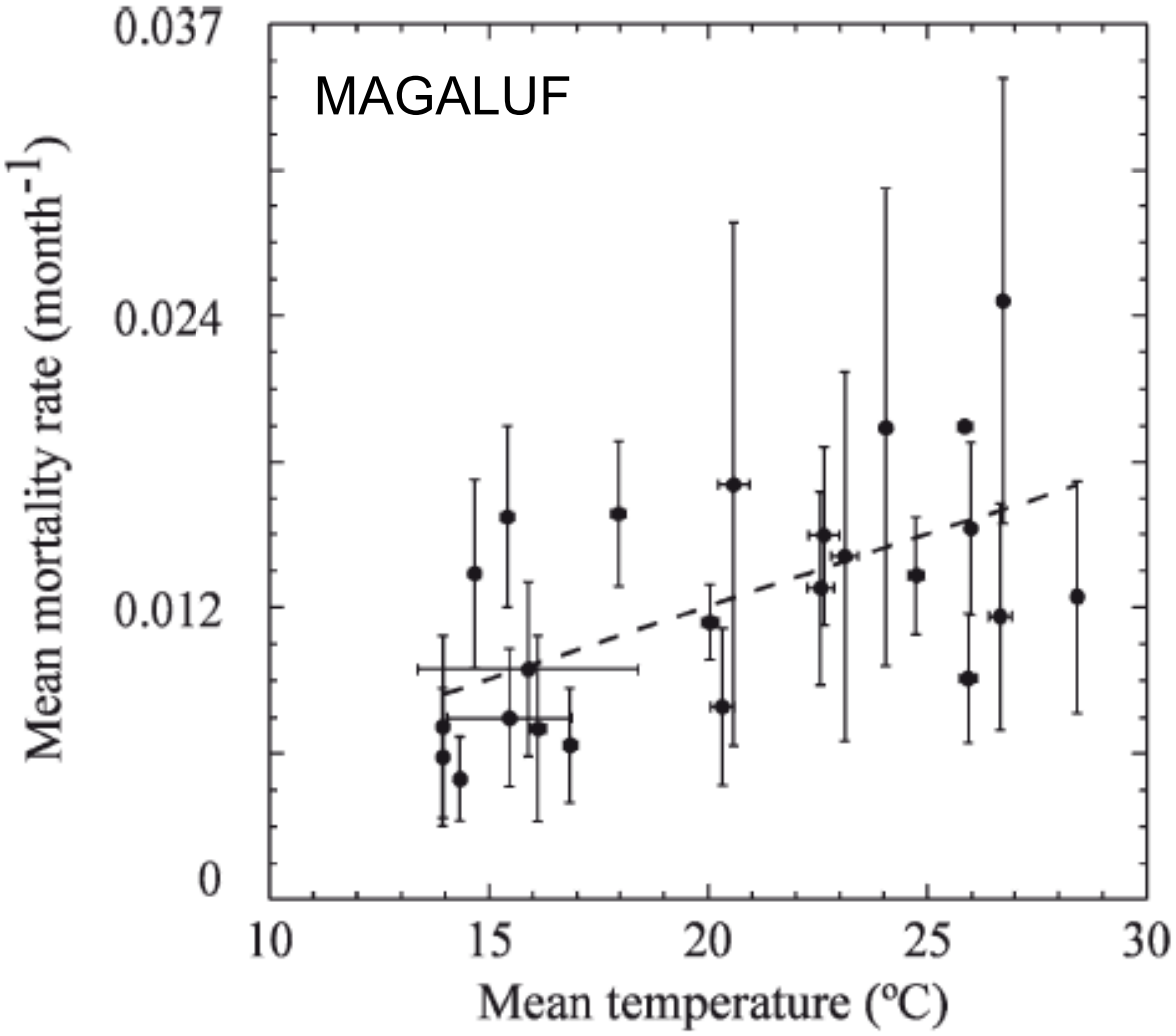
Monthly shoot mortality rate:

0% - 12.2% (mean 1.2 %)

Shoot mortality prevailed and rose after summer 2003

Díaz-Almela et al 2009, L&O

Shoot mortality increases linearly with increasing seawater temperature



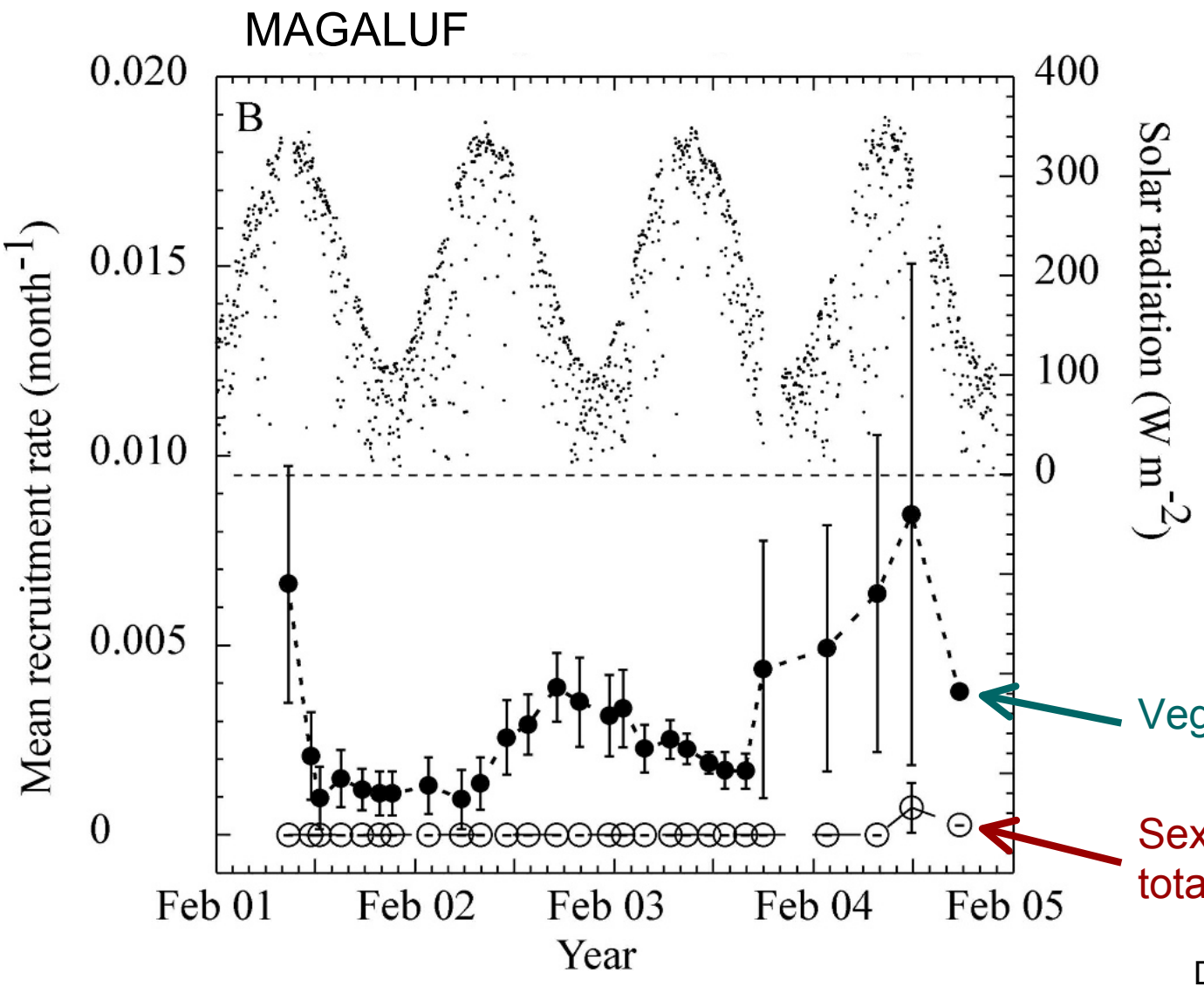
rate of increasing mortality by warming:

0.00023 month^{-1} ºC^{-1}
(or 0.0028 yr^{-1} ºC^{-1})

0.00098 month^{-1} ºC^{-1}
(or 0.0117 yr^{-1} ºC^{-1})

Díaz-Almela et al 2009, L&O

Large temporal variability in shoot recruitment without exhibiting seasonality



One order of magnitude lower than mortality rate

Independent of seawater temperature or solar radiation

Sharp recruitment increase in 2004 (after enhanced mortality)

Vegetative recruits

Sexual recruits (2% of total recruits)

Díaz-Almela et al 2009, L&O

Massive flowering and fruiting event of *Posidonia oceanica* meadows in the Western Mediterranean in year 2003

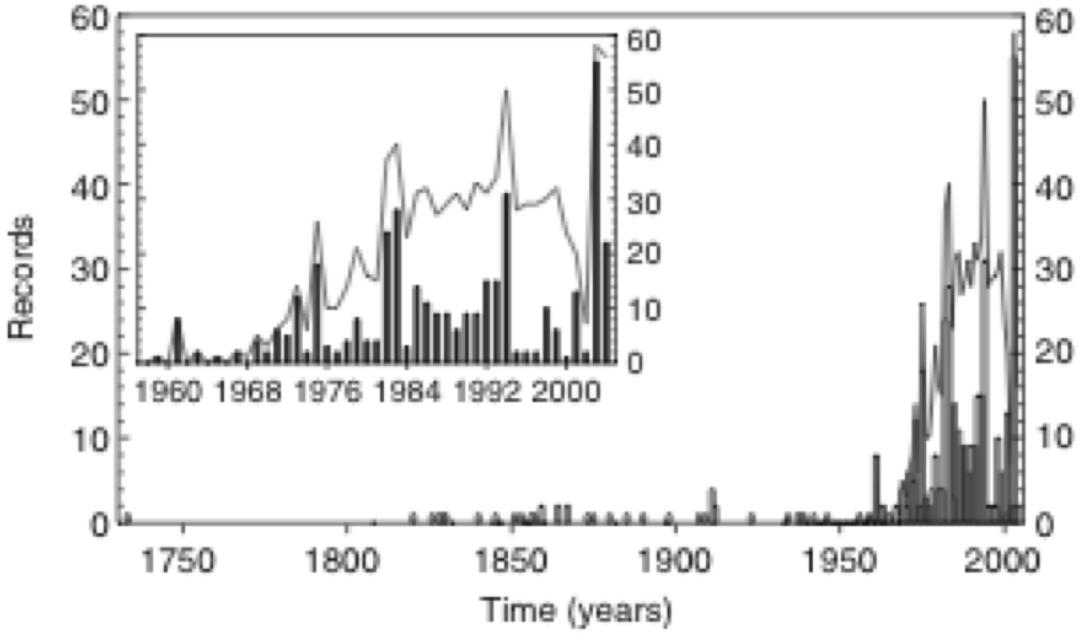
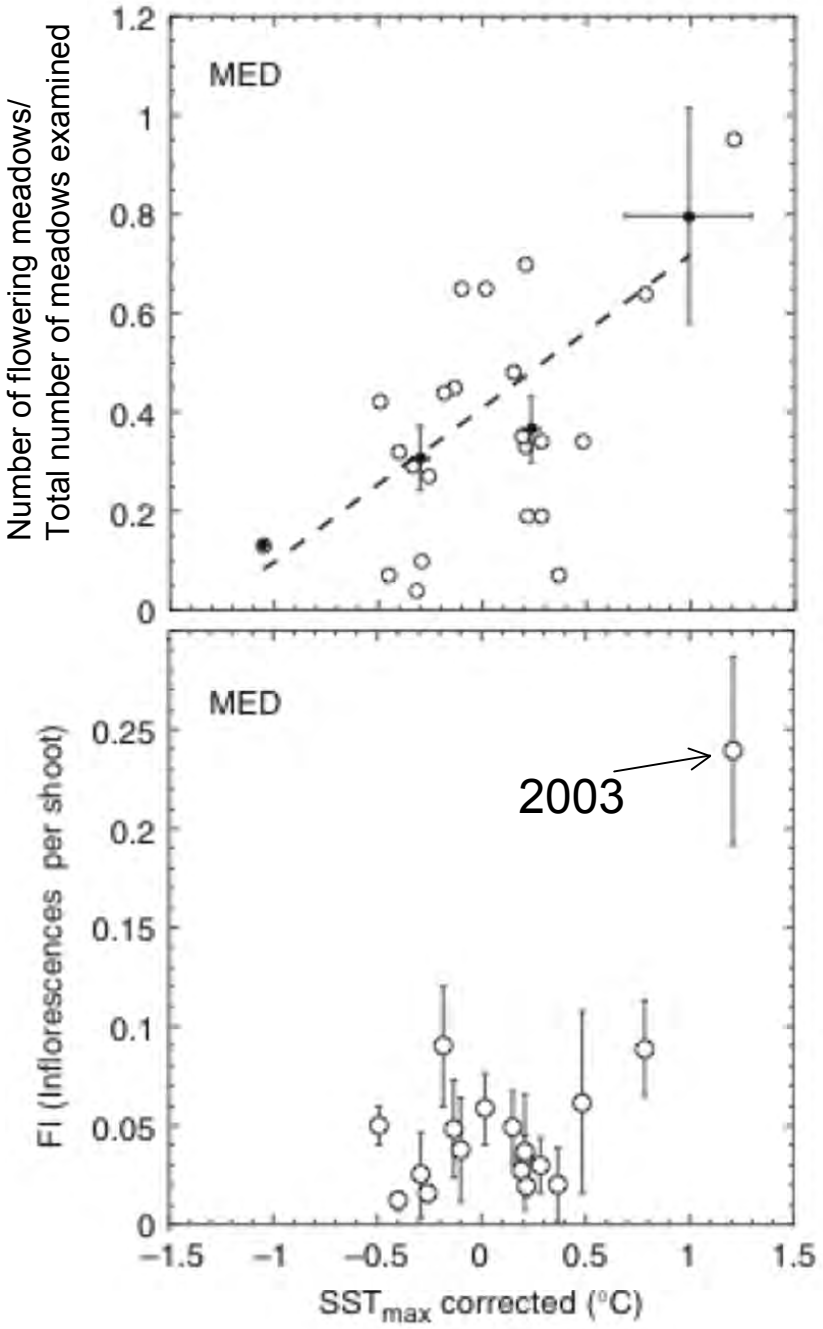


Fig. 4 Evolution of annual flowering records (bars) and observation effort (line represents total records) based on the available literature database (see Appendix S1).

Diaz-Almela et al 2007, GCB

Posidonia oceanica

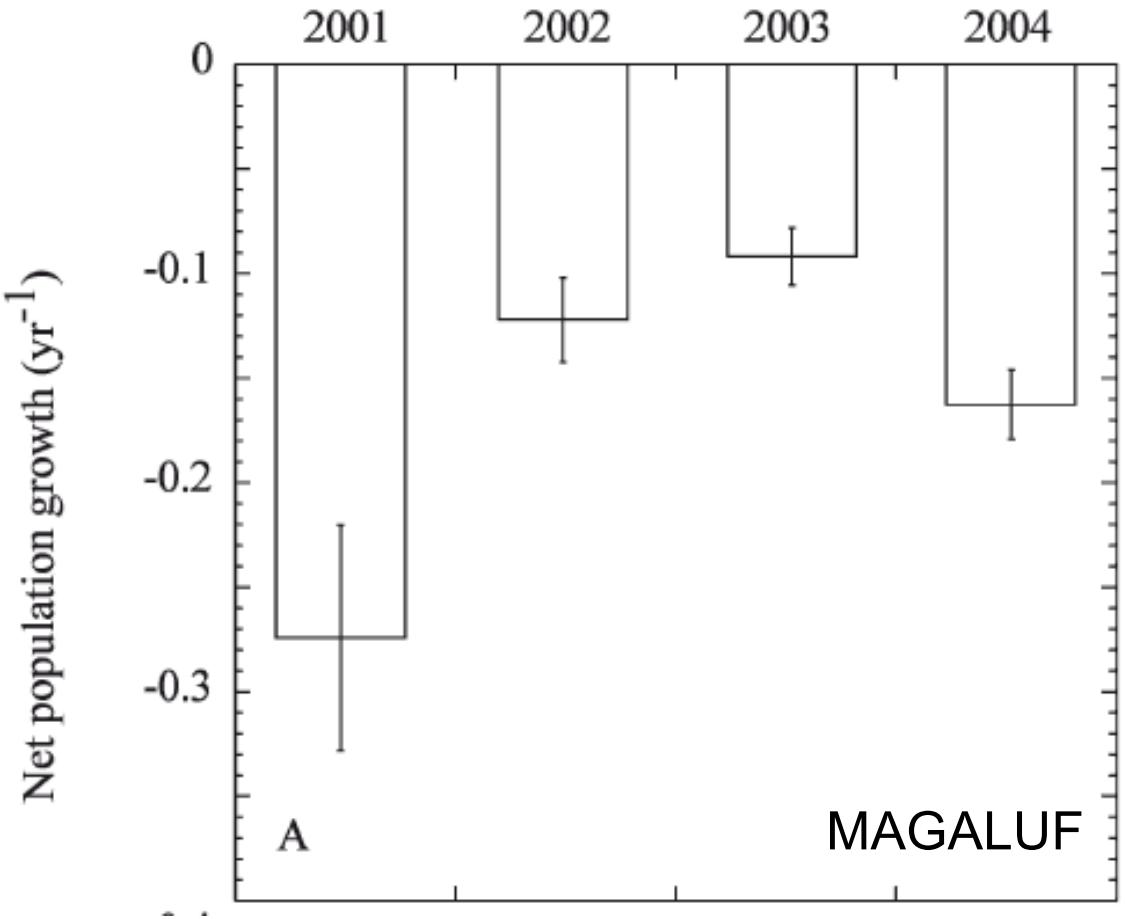


The number of flowering meadows and flowering intensity increase with increasing SSTmax

Is flowering a response of *P. oceanica* to thermal stress?

Diaz-Almela et al 2007, GCB

The exceptional production of sexual and asexual recruits after summer 2003 was insufficient to compensate mortality losses



Shoot abundance exhibited a net decline during the entire study period

Net population growth rate decreased with increasing warming at a rate of:

-0.00024 month^{-1} ºC^{-1}

-0.00099 month^{-1} ºC^{-1}

Díaz-Almela et al 2009, L&O

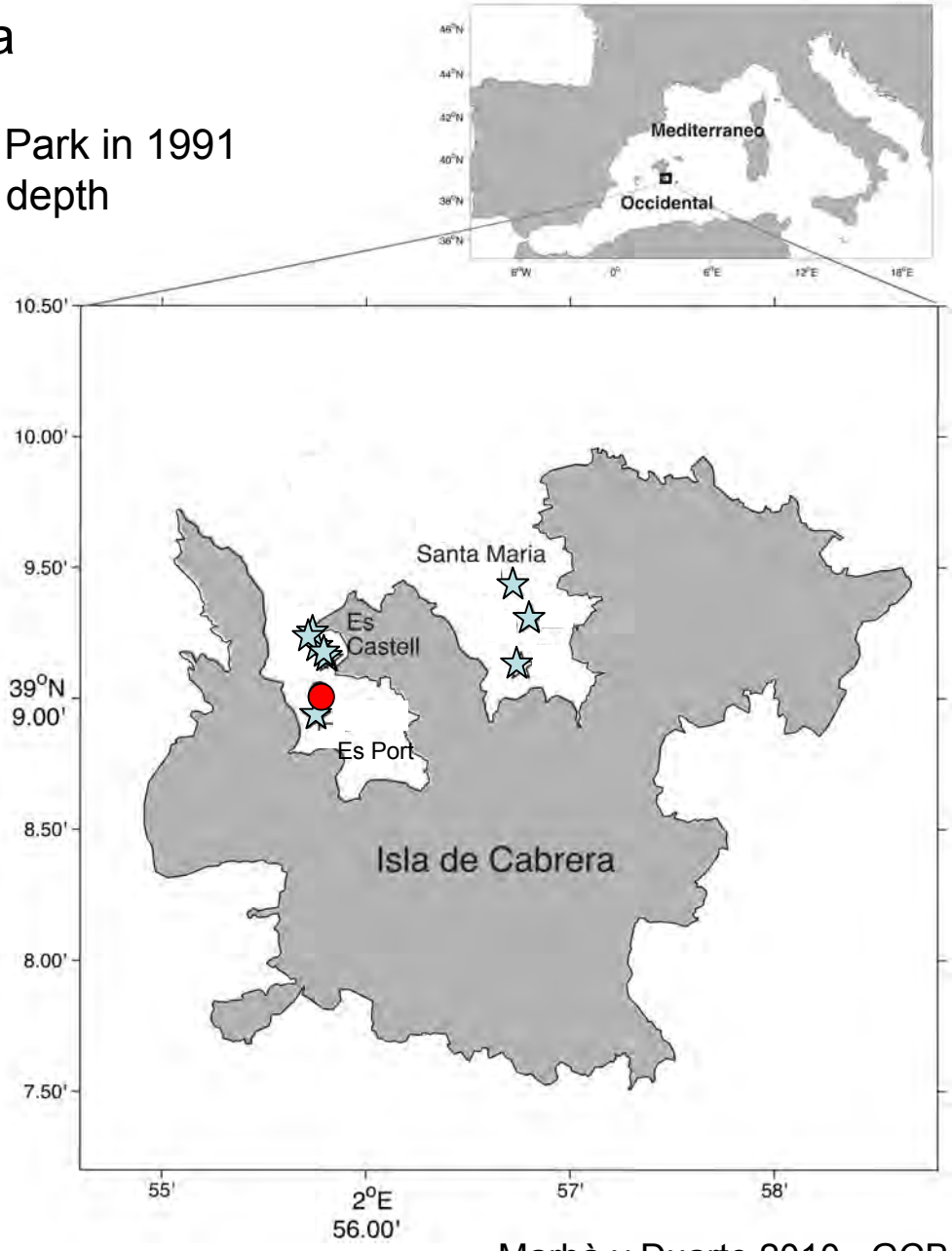
Study site – Pristine area

Archipelago declared National Park in 1991
P. oceanica meadows to 45 m depth

☆ Annual monitoring of *Posidonia oceanica* demography in 9 stations (5m - 25 m depth)

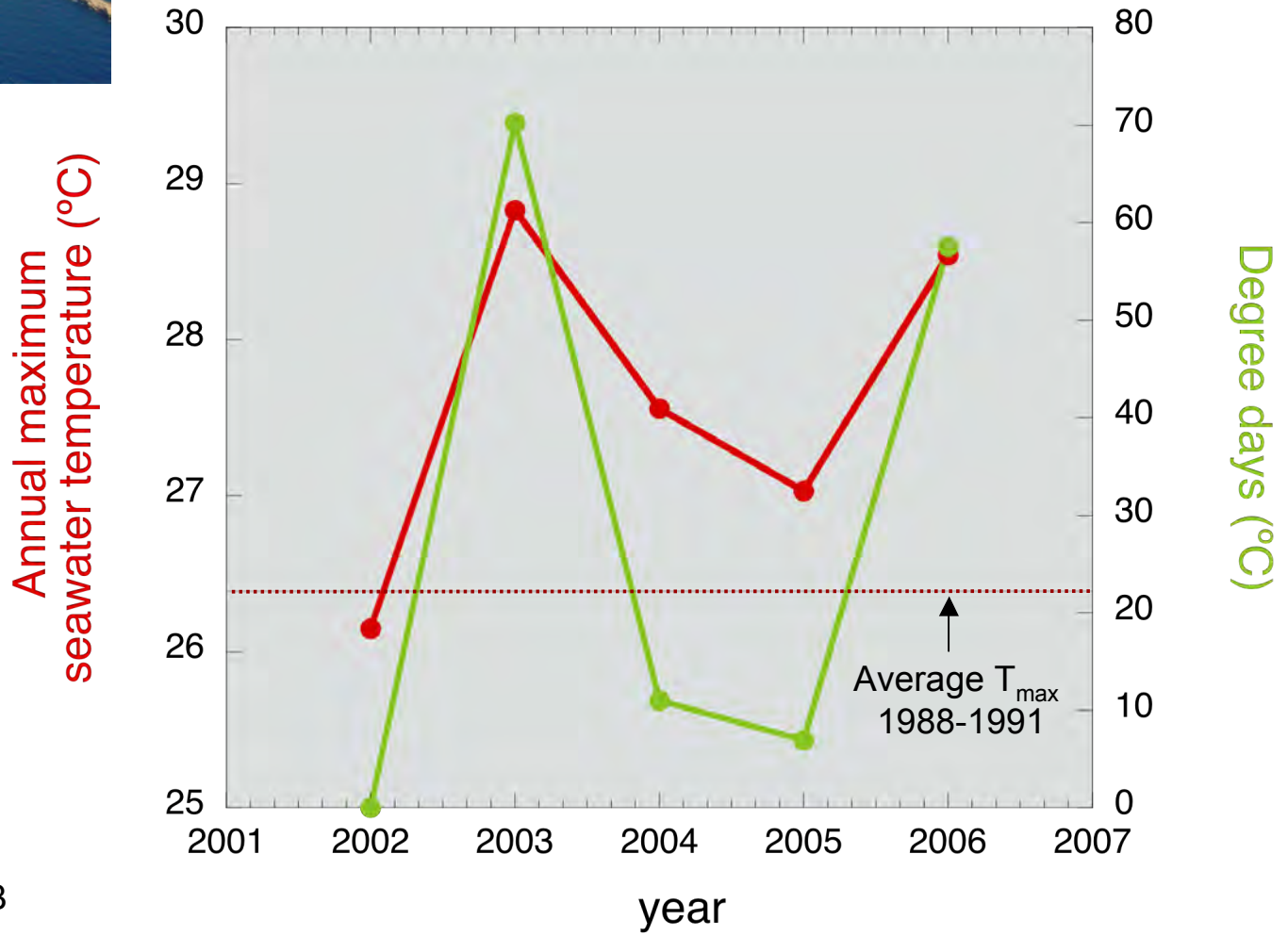
● Temperature recorded continuously in 1 station since year 2002 (17 m depth)

annual T_{max}

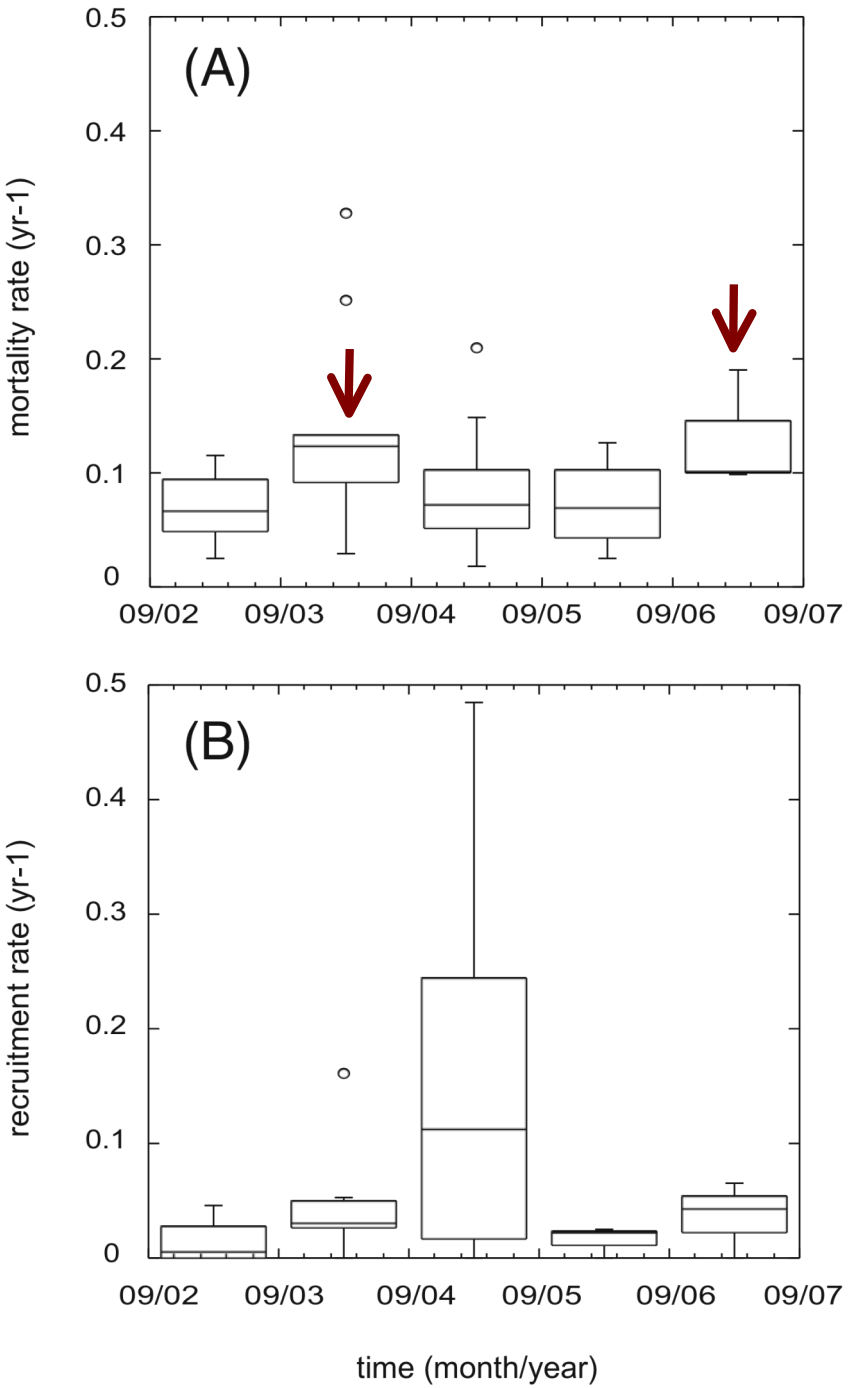


Marbà y Duarte 2010 , GCB

During 2002-2006 seawater was warmer than during 1988-1991



Marbà y Duarte 2010 , GCB

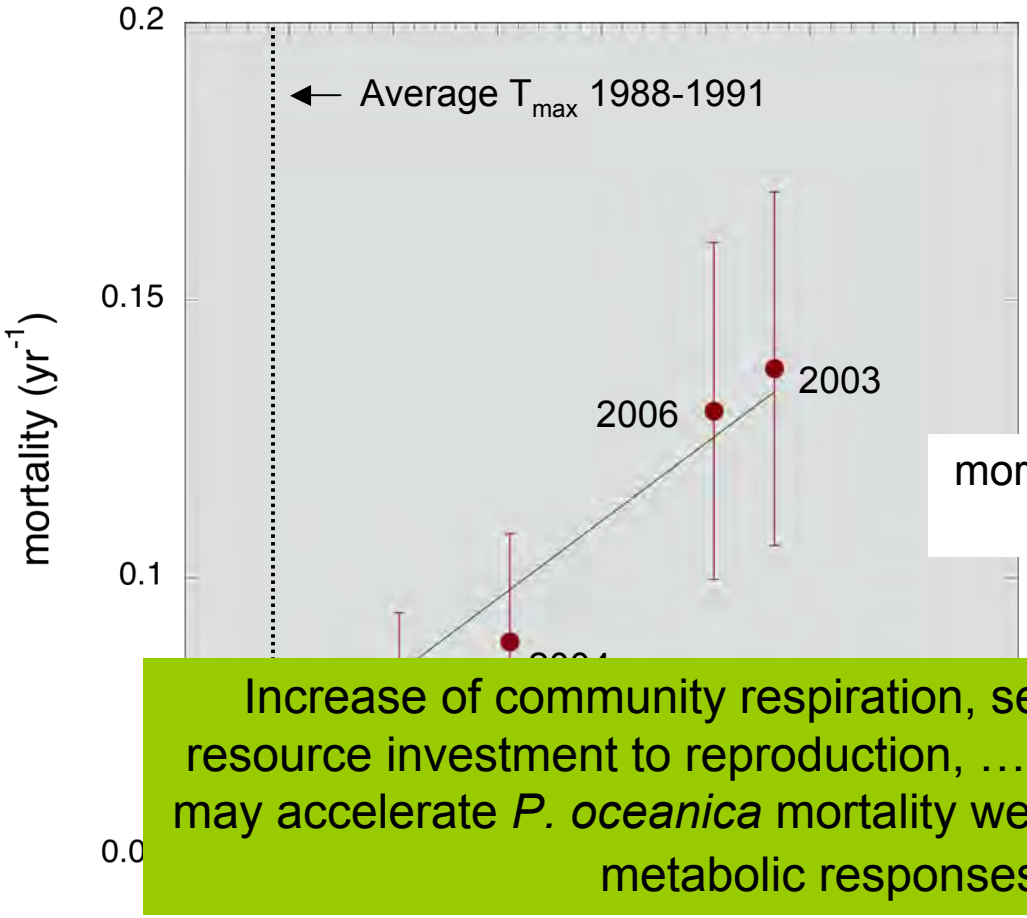


CABRERA NPark

Shoot density decline is due to enhanced shoot mortality by heat waves despite the enhanced vegetative shoot recruitment in shallow meadows in the following year

Marbà y Duarte 2010 , GCB

P. oceanica mortality increased by 0.03 yr^{-1} for each degree of warming (by 3-fold with a 3ºC increase SST_{max})



High mortality rates
T > 27.5-28 ºC

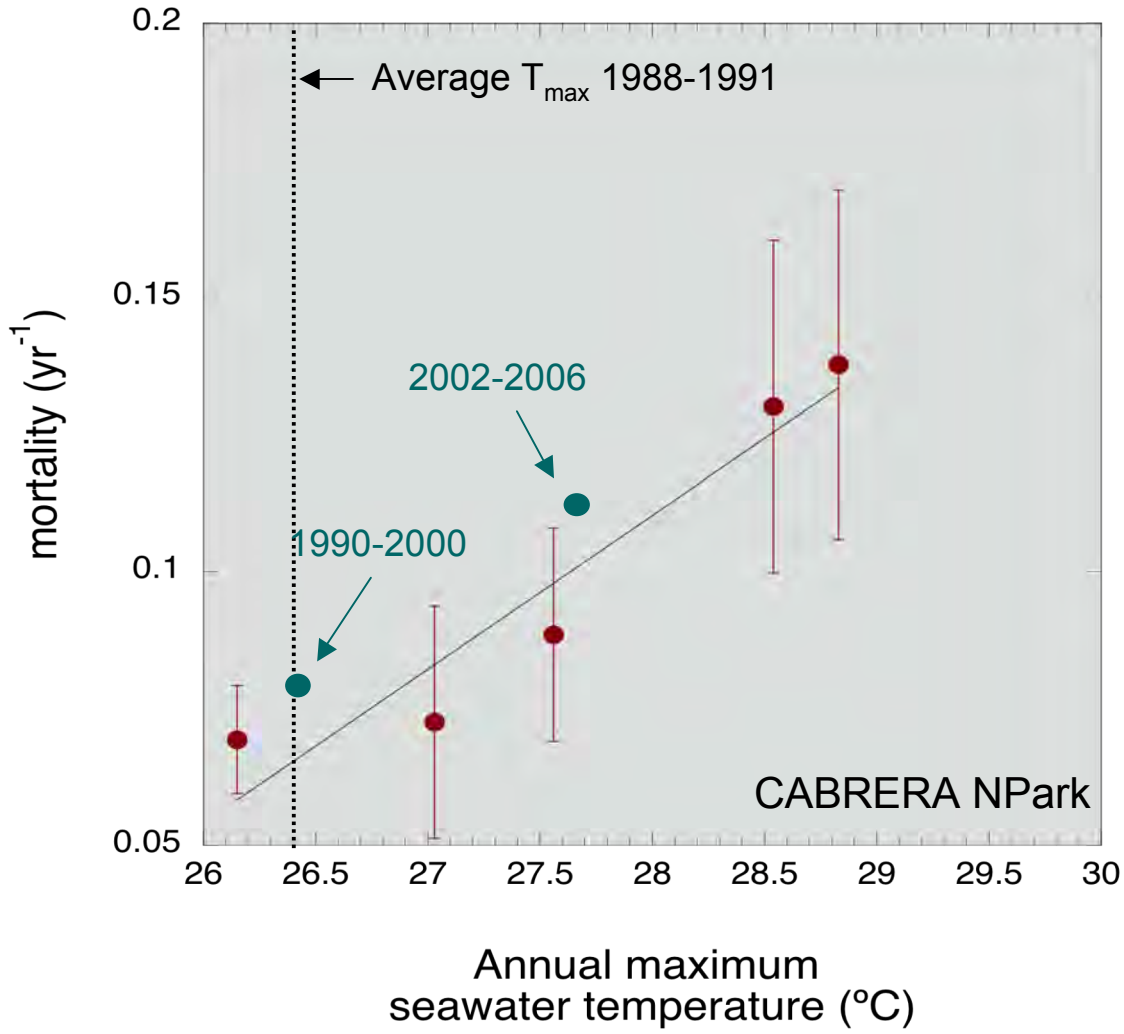
mortality (yr^{-1}) = -0.71 + 0.03 (±0.004) T_{max} (ºC)
R^2 = 0.90; P < 0.005

Increase of community respiration, sediment sulfate reduction rate, resource investment to reproduction, … enhanced by seawater warming may accelerate *P. oceanica* mortality well above the levels expected from metabolic responses to warming.

Annual maximum
seawater temperature (ºC)

Marbà y Duarte 2010 , GCB

Average shoot mortality since yr 2002 has been 35 % higher than that during the 1990's



Shoot recruitment similar (or even slightly lower)

Rates of shoot loss ~ 4-fold faster than 1990's.

Marbà y Duarte 2010, GCB
Marbà et al 2002 EnvironCons

Conclusions based on temperature increase

- Clear relationship seagrass mortality and increased warming
  - *P. oceanica* losses following heat waves double those in other years.
- seawater warming enhances sexual reproduction -> not sufficient to compensate for shoot losses.
- recovery time scales of *P. oceanica* meadows centuries, -> losses by climate change irreversible.
- IPCC scenarios: rapid warming of seawater in the Mediterranean
  - on average, 3ºC – 4ºC seawater warming by the end of 21st century.
- Rapid international action needed to reduce emissions!

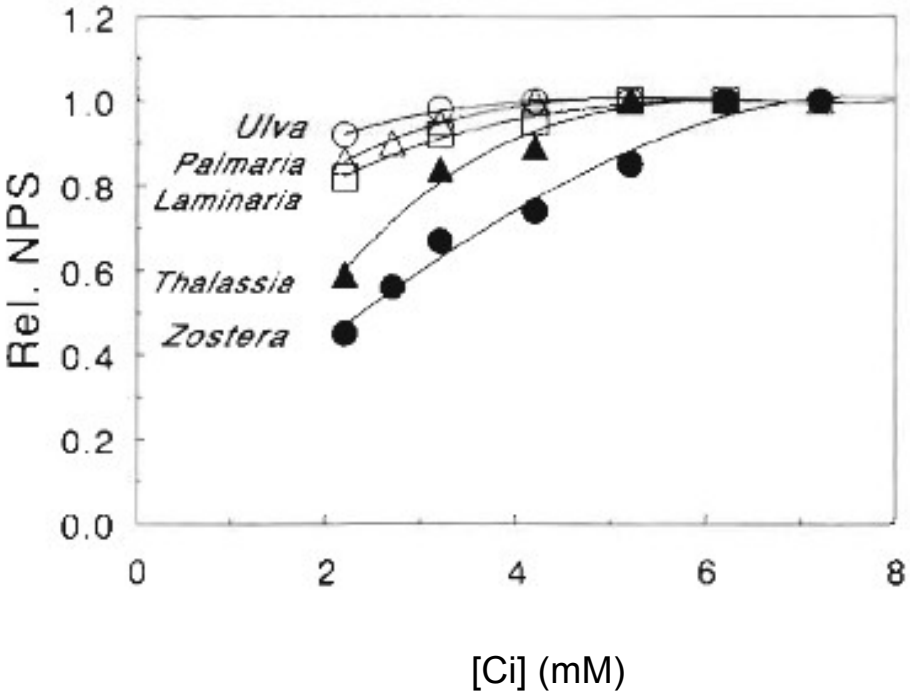
Can Ocean Acidification mitigate the degrading effects of warming?

Theory:

Seagrasses unlike algae are
CO_2 limited

= increase photosynthetic rates

= more plant production
at lower pH



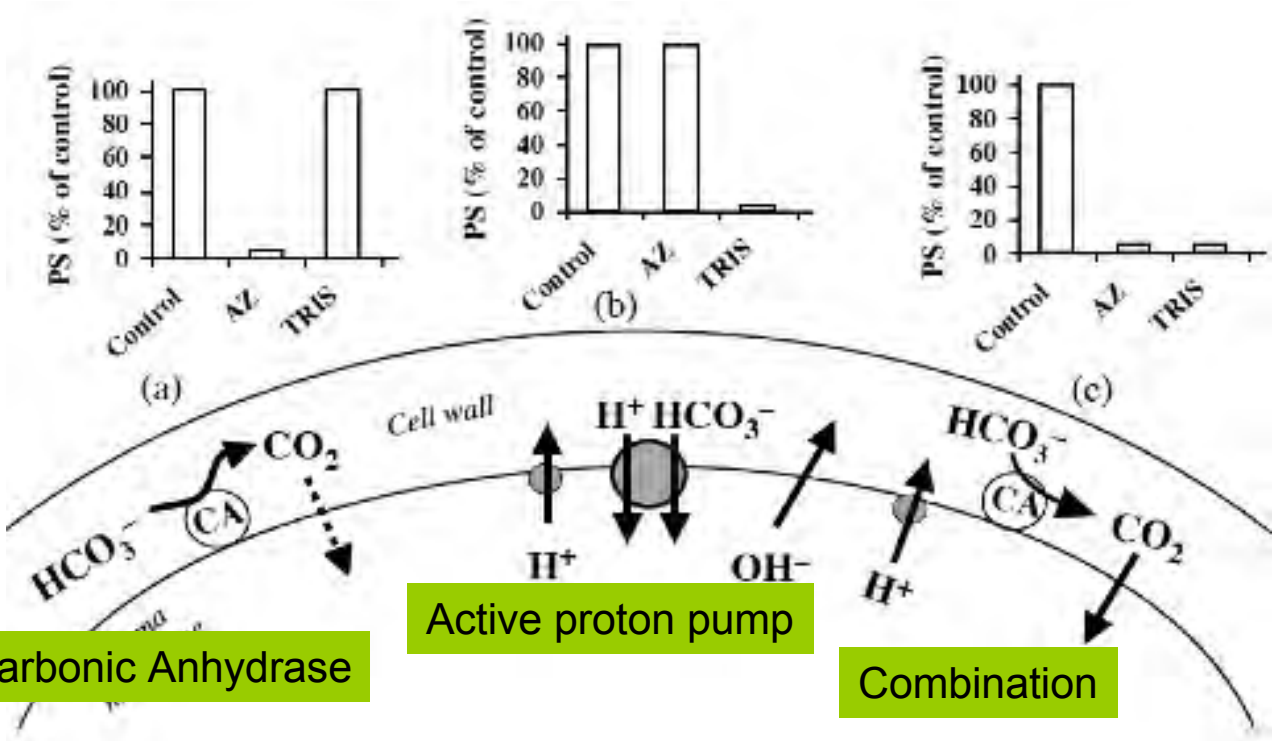
Beer & Koch. 1996 MEPS 141:199-204

Carbon Concentration Mechanisms

But, experiments demonstrating Carbon limitation done in laboratory, using buffers

Buffers influence carbon uptake

Uptake HCO_3^- vs CO_2



Conversion HCO_3^- by Carbonic Anhydrase

Active proton pump

Combination

Beer et al. 2002 Funct. Plant Biol. 29:349-354

Downregulation photosynthesis

Under high CO_2 down regulation CCM?

Decrease in Rubisco concentration?

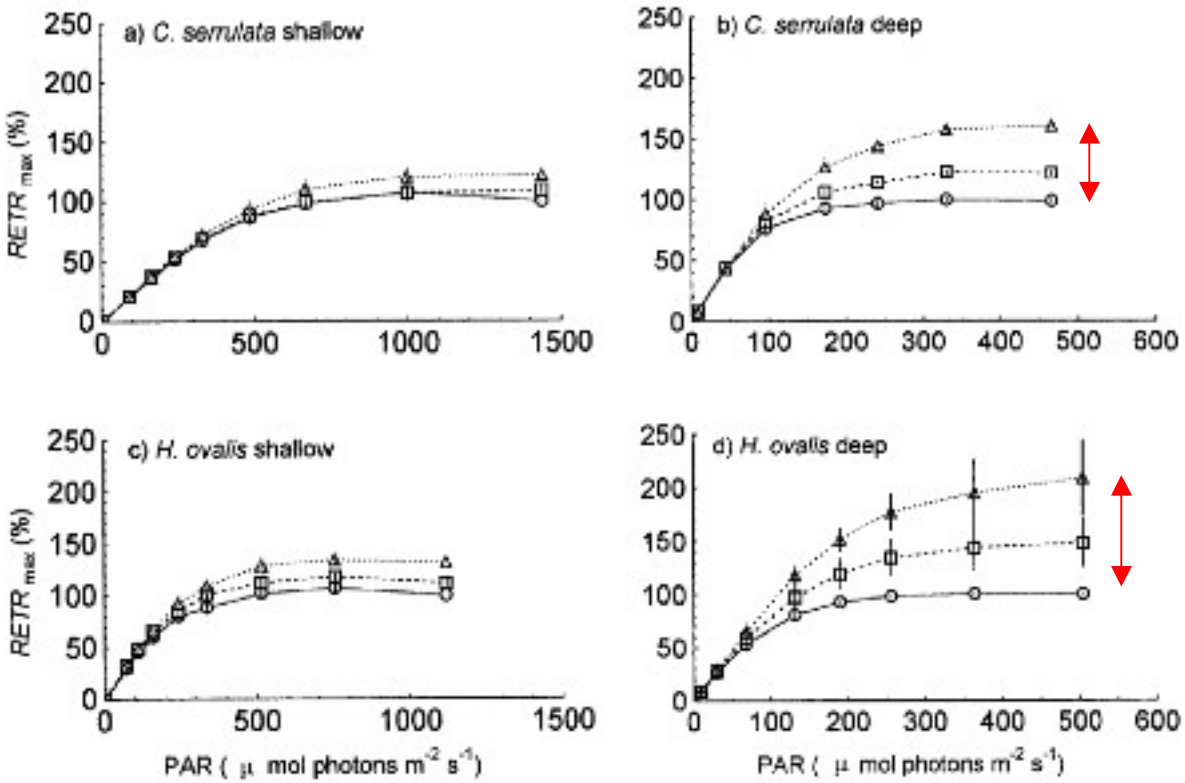
Long term growth responses ≠ instantaneous rates

Beardall et al. Bot. Mar (1998) 41:113-123

Species specific differences (use HCO_3^- vs. CO_2, efficiency)

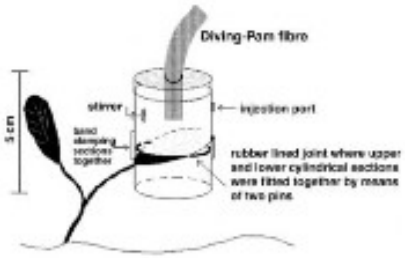
Field experiment carbon limitation seagrass

Cymodocea serrulata



Halophila ovalis

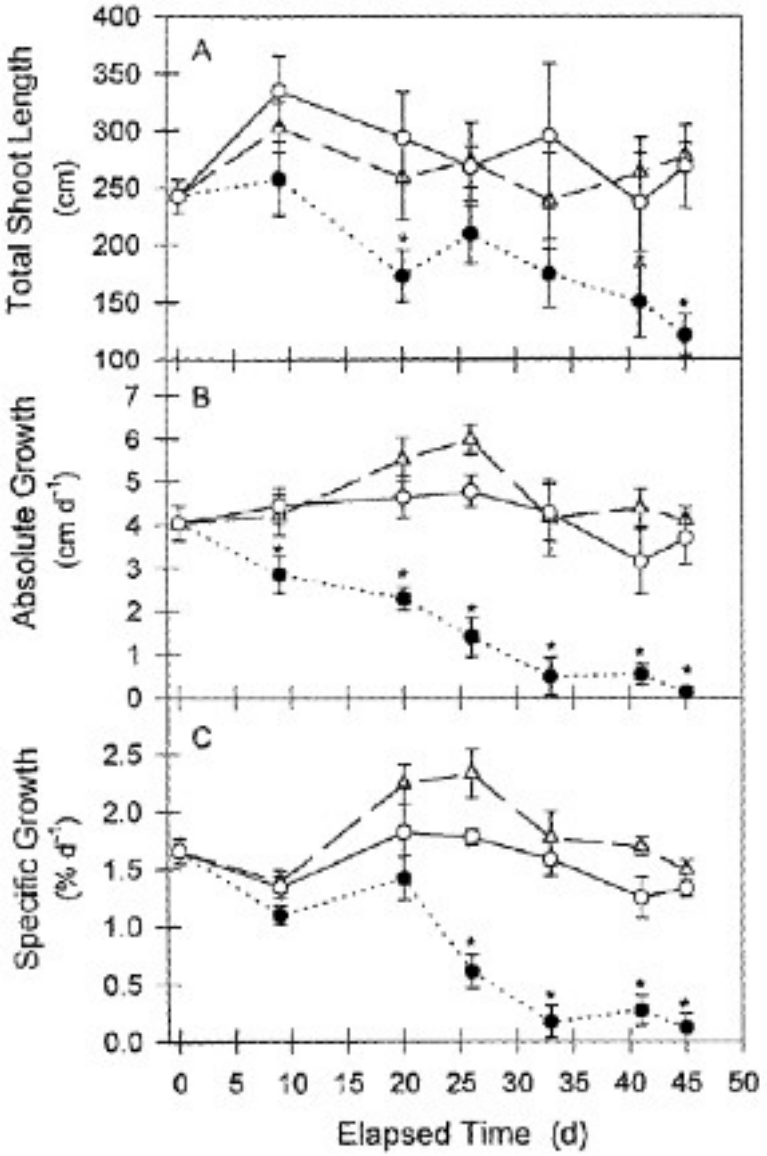
Carbon limitation in light limited (deep) site



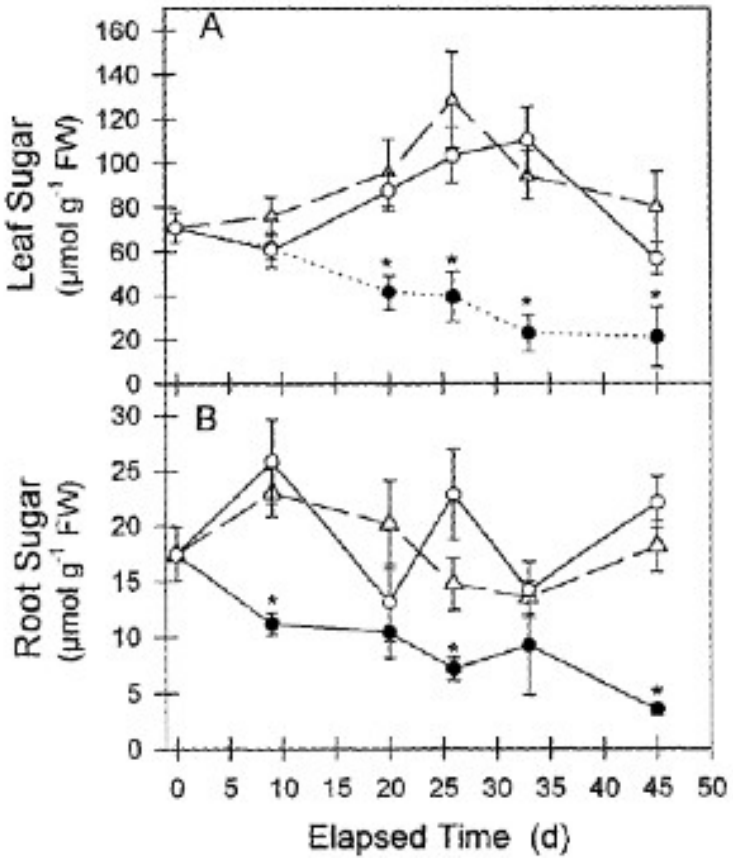
Schwartz et al. Mar Biol (2000) 137:755-761

Zostera marina: more growth under CO_2 enrichment.

Exp 45 days



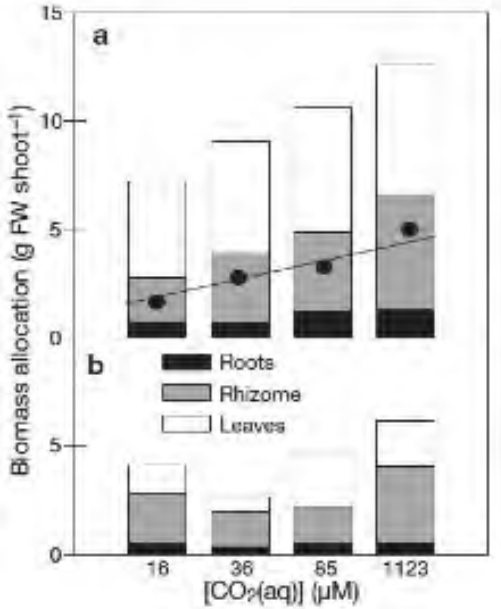
Storage in roots & rhizomes

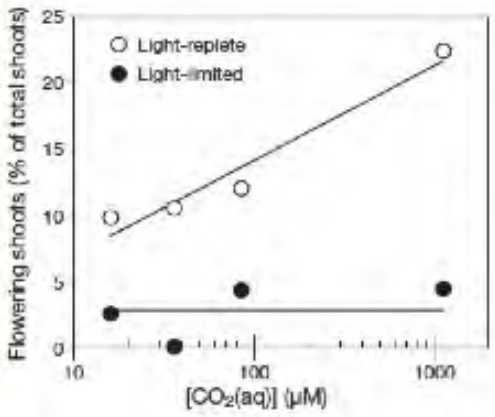


Zimmerman et al. Plant Physiol. 115:599-607

Long term effects?

- *Zostera marina (1 year)*
  - No effect leaf growth
  - Belowground storage increased
  - 5 x flower production increase
  - Dependent on light availability





Palacios & Zimmerman (2007) MEPS 344 1-13

Long term effects?

- *Cymodocea nodosa* (5 M)
  - Santos et al. Ramalhete field station Faro Portugal
  - Photosynthetic rates affected by CO_2
  - No effect CO_2 on growth
  - Growth N-limited

Master thesis Faisal Kahn, unpublished results

Long term effects?

- FOCE Florida (*Thallassia testudinum, 1 y*)
  - Campbell, Fourqurean

  - No effect of leaf growth
  - Belowground

  sugar content increases

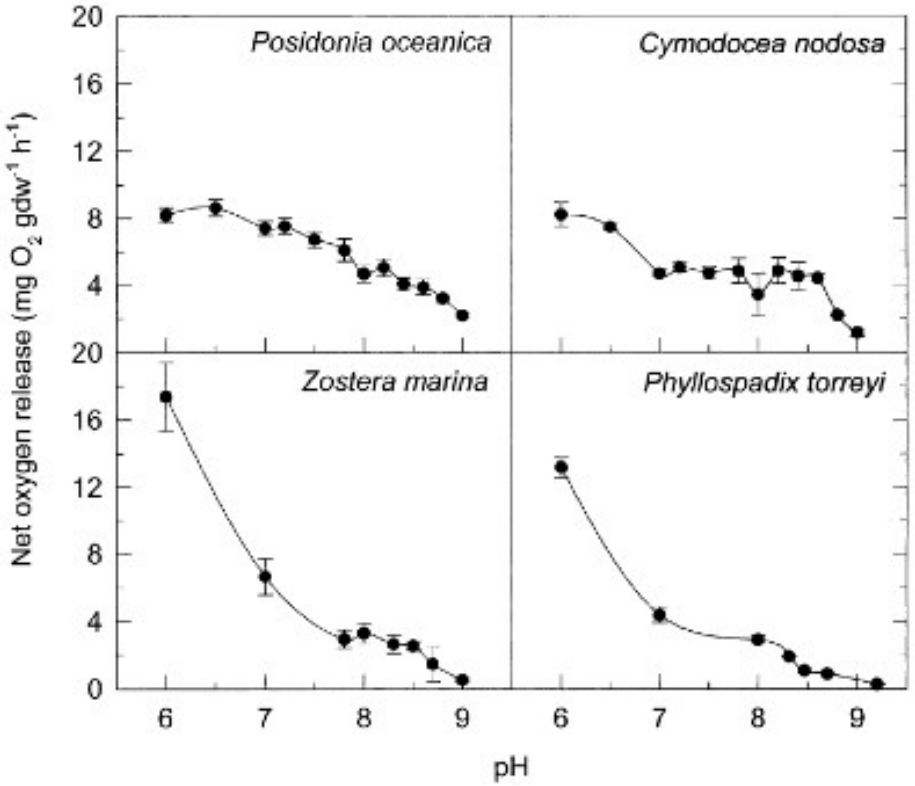
LIMNOLOGY
and
OCEANOGRAPHY: METHODS

Novel methodology for in situ carbon dioxide enrichment of benthic ecosystems

Justin E. Campbell[1]* *and James W. Fourqurean*[1]
[1]Department of Biological Sciences, Florida International University, Marine Sciences Program, 3000 NE 151 Street, North Miami, FL 33181, USA

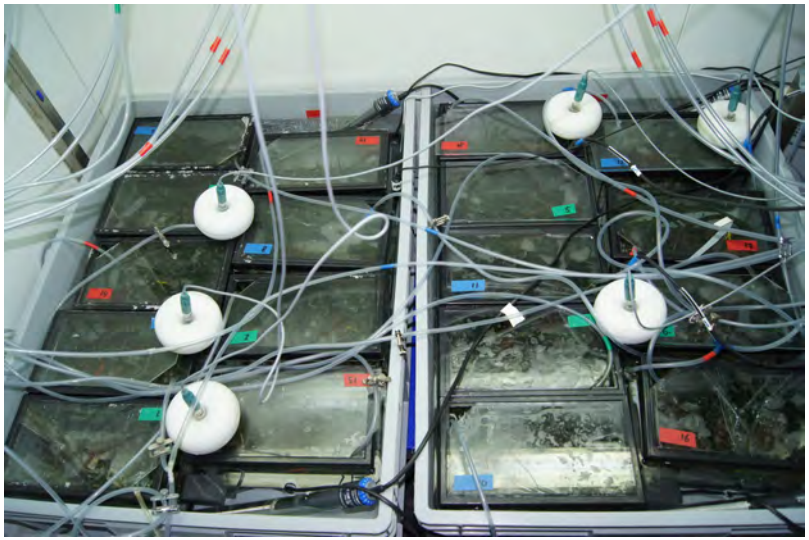
Theory vs. results

- Species effects: *Zostera* vs. *Posidonia* and *Cymodocea*?
- Short term (photosynthesis) vs. Long-term (growth)

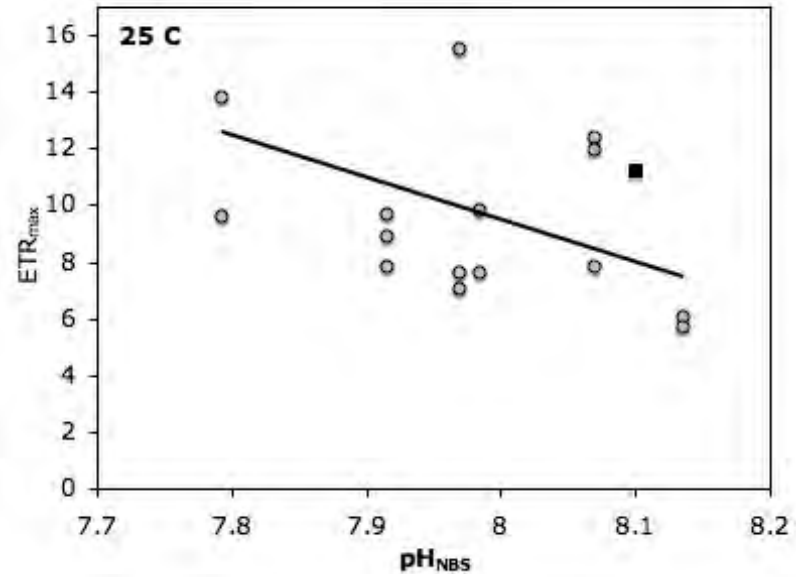


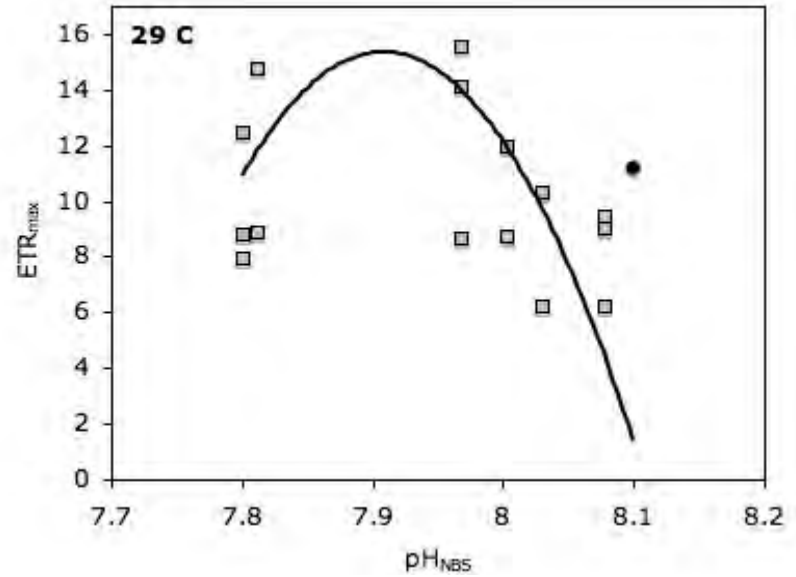
Invers et al. JEMBE (2001) 265:203-217

Experimental results *Posidonia oceanica* (3wks)



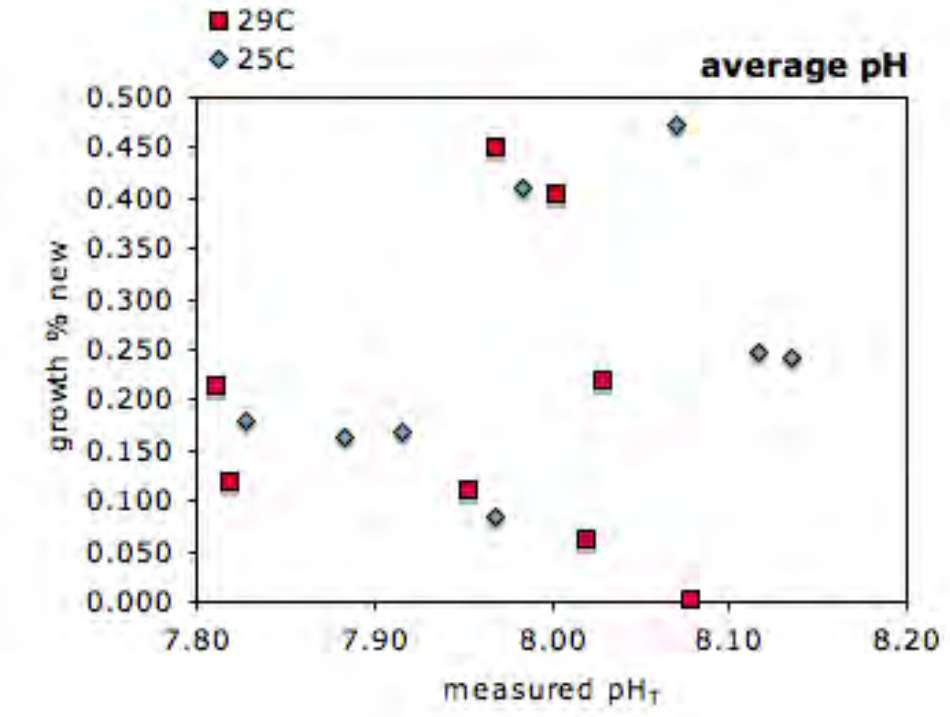
- Short term experiments indicate effect CO_2 on photosynthesis is modificated by temperature
- Light limited conditions (150 µmol s^{-1} m^{-2} PAR)





Experimental results *Posidonia oceanica* (3wks)

Short term experiments indicate no effect CO_2 on growth



Other factors

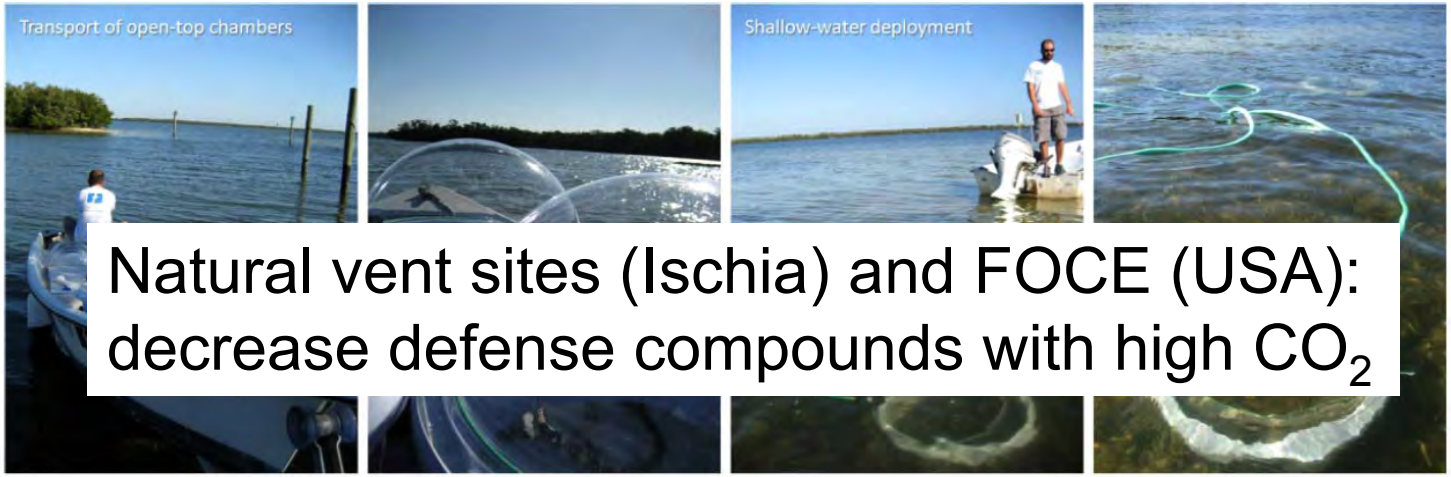
- Nutrient limitation
  - Storage excess sugars in belowground biomass
- Phenolic compounds
  - less defenses against grazers
- Light limitation (*Zostera marina*)
- Shoaling thermocline ~ decreased prod. Phytoplankton ~ slower sinking ~ oxygen consumption higher in water column ~ hypoxic waters ~ lower N:P ratio

OPEN ACCESS Freely available online

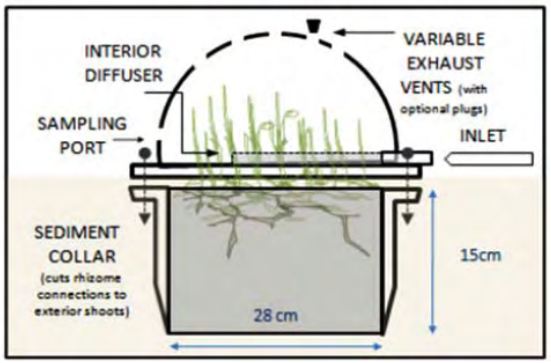
PLoS one

Ocean Acidification and the Loss of Phenolic Substances in Marine Plants

Thomas Arnold[1,2]*, Christopher Mealey[1], Hannah Leahey[1], A. Whitman Miller[2], Jason M. Hall-Spencer[3], Marco Milazzo[4], Kelly Maers[1]



Natural vent sites (Ischia) and FOCE (USA): decrease defense compounds with high CO_2



Cymodocea nodosa, *Ruppia maritima* & *Potomageton perfoliatus*

Conclusions

- Ocean acidification will not mitigate negative temperature effects for *Posidonia oceanica*
- Rapid international action needed to reduce emissions!