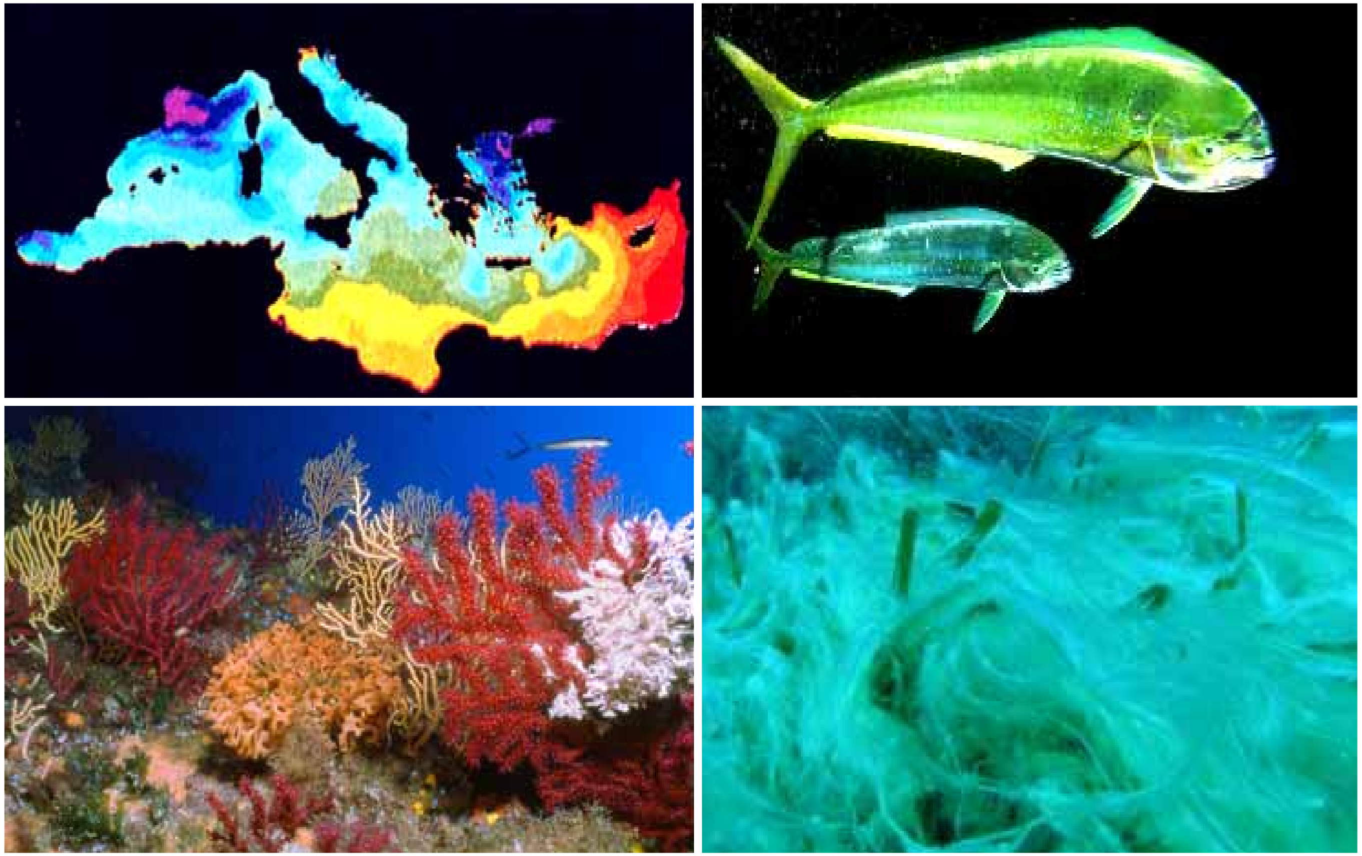
Impact of Climate Change on the biodiversity of the Mediterranean Sea



Thierry PEREZ
Institut de Biodiversité et d'Ecologie marine et continentale (IMBE), Station Marine d'Endoume

Workshop Biodivmex, 7-16 September 2014

Biological consequences of global warming: is the signal already

Increasing greenhouse gas concentrations are expected to have significant impacts on the world's climate on a timescale of decades to centuries. Evidence from long-term monitoring studies is now accumulating and suggests that the climate of the past few decades is anomalous compared with past climate variation, and that recent climatic and atmospheric trends are already affecting species physiology, distribution and phenology.

Lesley Hughes is at the Dept of Biological Sciences and Key Centre for Biodiversity and Bioresources, Macquarie University, NSW 2109, Australia (lhughes@rna.bio.mq.edu.au).

The prospect that increases in atmospheric concentrations of greenhouse gases will have measurable effects on the earth's climate over the next few decades has attracted a vast research effort. Climatologists have faced two main challenges. The first has been to distinguish the signal of human-induced climate change from the noise of interannual and decadal natural variability. The second has been to predict probable climate scenarios for the future. Climate monitoring over the past century and long-term reconstructions of climate over the past millennium indicate that the earth is indeed warming up (Fig. 1)[1]. Moreover, the recent patterns of warming and of changes in precipitation are generally consistent with the patterns predicted by global circulation models (Box 1)[1–7]. Physical features of the earth's surface, such as sea ice and glaciers, also appear to be responding in a predictable way to the warming trends (Box 2)[2,8–11].

For ecologists, physiologists and land managers, the challenge is to predict the effects of human-induced climate and atmospheric change on species and on communities. These predictions can be broadly summarized into four categories (Fig. 2):

(1) Effects on physiology: changes in atmospheric CO_2 concentration, temperature or precipitation will directly affect metabolic and developmental rates in many animals, and processes such as photosynthesis, respiration, growth and tissue composition in plants.

(2) Effects on distributions: a 3°C change in mean annual temperature corresponds to a shift in isotherms of approximately 300–400 km in latitude (in the temperate zone) or 500 m in elevation. Therefore, species are expected to move upwards in elevation or towards the poles in latitude in response to shifting climate zones.

(3) Effects on phenology: life cycle events triggered by environmental cues such as degree days might be altered, leading to decoupling of phenological relationships between species.

(4) Adaptation: species with short generation times and rapid population growth rates might undergo microevolutionary change *in situ*.

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REVIEWS AND SYNTHESES

The impacts of climate change in coastal marine systems

Christopher D. G. Harley,[1,2]* A. Randall Hughes,[3] Kristin M. Hultgren,[3] Benjamin G. Miner,[1] Cascade J. B. Sorte,[1] Carol S. Thornber,[3,4] Laura F. Rodriguez,[3] Lars Tomanek[3,5] and Susan L. Williams[1]

[1]*Bodega Marine Laboratory, University of California-Davis, Bodega Bay, CA 94923, USA*
[2]*Department of Zoology, University of British Columbia, Vancouver, BC, Canada V6T 1Z4*
[3]*University of California, Davis, CA 95616, USA*
[4]*University of Rhode Island, Kingston, RI 02881, USA*
[5]*California Polytechnic State University, San Luis Obispo, CA 93407-0401, USA*
**Correspondence: E-mail: harley@zoology.ubc.ca*

Abstract

Anthropogenically induced global climate change has profound implications for marine ecosystems and the economic and social systems that depend upon them. The relationship between temperature and individual performance is reasonably well understood, and much climate-related research has focused on potential shifts in distribution and abundance driven directly by temperature. However, recent work has revealed that both abiotic changes and biological responses in the ocean will be substantially more complex. For example, changes in ocean chemistry may be more important than changes in temperature for the performance and survival of many organisms. Ocean circulation, which drives larval transport, will also change, with important consequences for population dynamics. Furthermore, climatic impacts on one or a few 'leverage species' may result in sweeping community-level changes. Finally, synergistic effects between climate and other anthropogenic variables, particularly fishing pressure, will likely exacerbate climate-induced changes. Efforts to manage and conserve living marine systems in the face of climate change will require improvements to the existing predictive framework. Key directions for future research include identifying key demographic transitions that influence population dynamics, predicting changes in the community-level impacts of ecologically dominant species, incorporating populations' ability to evolve (adapt), and understanding the scales over which climate will change and living systems will respond.

Keywords

Anthropogenic climate change, carbon dioxide (CO_2), coastal oceanography, community structure, distributional shifts, marine ecosystems, ocean pH, population dynamics, synergistic effects, temperature.

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INTRODUCTION

Coastal marine systems are among the most ecologically and socio-economically vital on the planet. Marine habitats from the intertidal zone out to the continental shelf break are estimated to provide over US$14 trillion worth of ecosystem goods (e.g. food and raw materials) and services (e.g. disturbance regulation and nutrient cycling) per year, or *c*. 43% of the global total (Costanza *et al.* 1997). However, there is a strong scientific consensus that coastal marine ecosystems, along with the goods and services they provide, are threatened by anthropogenic global climate change (IPCC 2001). Recent climatic trends, which are only a fraction of the magnitude of predicted changes in the coming centuries, have already triggered significant responses in the Earth's biota (IPCC 2001). As these changes continue, we risk serious degradation of marine ecosystems, with far-reaching consequences for human health and welfare.

Given their global importance, coastal marine environments are a major focus of concern regarding the potential impacts of anthropogenic climate change. A pair of seminal reviews in the early 1990s (Fields *et al.* 1993; Lubchenco *et al.* 1993) summarized the then-current understanding of climate change impacts on marine systems. In both cases, the authors focused on the effects of rising temperatures on organismal- and to a lesser extent population-level processes, and they used natural cycles such as the El Niño-Southern Oscillation (ENSO) and the Pleistocene–Holocene transition as proxies for future change. The basic

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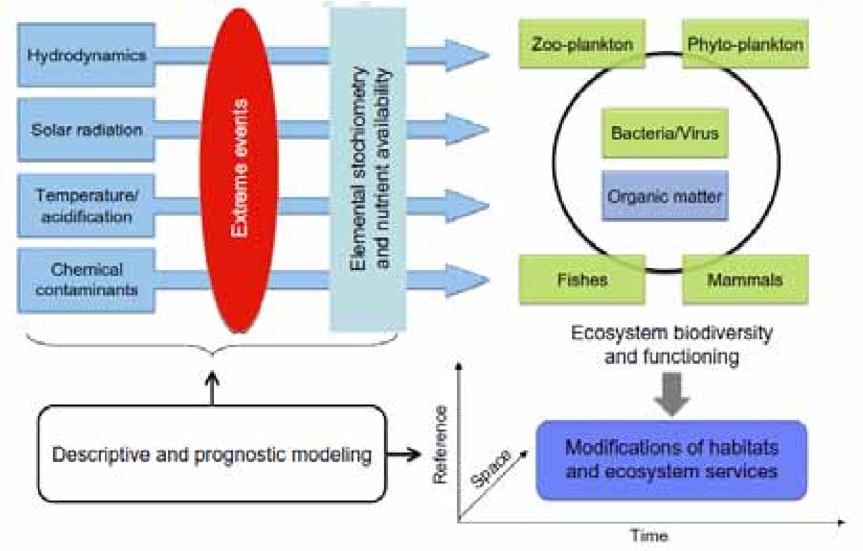
Review

Marine ecosystems' responses to climatic and anthropogenic forcings in the



Key forcing variables influencing the marine ecosystems' diversity and functioning

Climate change effects on a miniature ocean: the highly diverse, highly impacted Mediterranean Sea

Christophe Lejeusne[1], Pierre Chevaldonné[1], Christine Pergent-Martini[2], Charles F. Boudouresque[3] and Thierry Pérez[1]

[1]DIMAR, CNRS-Université de la Méditerranée, Centre d'Océanologie de Marseille, Station Marine d'Endoume, Rue Batterie des Lions, 13007 Marseille, France
[2]Regional Activity Centre for Specially Protected Areas (UNEP-MAP), Boulevard du Leader Yasser Arafat, 1080 Tunis cedex, Tunisia
[3]DIMAR, CNRS-Université de la Méditerranée, Centre d'Océanologie de Marseille, Campus de Luminy, 13288 Marseille cedex 9, France

Little doubt is left that climate change is underway, strongly affecting the Earth's biodiversity. Some of the greatest challenges ahead concern the marine realm, but it is unclear to what extent changes will affect marine ecosystems. The Mediterranean Sea could give us some of the answers. Data recovered from its shores and depths have shown that sea temperatures are steadily increasing, extreme climatic events and related disease outbreaks are becoming more frequent, faunas are shifting, and invasive species are spreading. This miniature ocean can serve as a giant mesocosm of the world's oceans, with various sources of disturbances interacting synergistically and therefore providing an insight into a major unknown: how resilient are marine ecosystems, and how will their current functioning be modified?

The Mediterranean: a miniature model of the world's oceans

The Mediterranean is a peculiar sea, a product of a tormented geological history, where continents collide and water masses come and go, a crossroads of biogeographical influences between cold temperate biota and subtropical species (see Box 1). During the Mesozoic, it also united the Atlantic and Pacific realms through a large ocean known as the Tethys. The legacy of the Tethys and later geological events have produced a marine life that is unusually diverse for such a small enclosed sea; it is now considered a 'biodiversity hotspot' [1,2] and a 'miniature ocean' by physical oceanographers [3].

However, the Mediterranean is a sea under siege. Today it is a place where urbanisation of the littoral zone, the most productive part of the sea, is reaching a climax on the northwestern shores. On the southern and eastern shores, runaway population growth is producing an unprecedented anthropic pressure on marine ecosystems (pollution, overfishing, habitat destruction and species introductions). These major disturbances, in addition to species introductions, severely impact the natural balance of ecosystems and have resulted in the extensive loss of biodiversity [4]. Climatic models [5] further predict that the Mediterranean basin will be one of the regions most affected by the ongoing warming trend and by an increase in extreme events. This makes the Mediterranean a potential model of more global patterns to occur in the world's marine biota, and a natural focus of interest for research. There are reasons to believe that the Mediterranean is already one of the most impacted seas in the world, since climate change interacts synergistically with many other disturbances.

Here, we will focus on the effects of climate change on the Mediterranean biota. As well as considering the effects of climate alterations *per se*, particularly rising temperatures, we will also look at two phenomena mechanically related to temperature: the emergence of pathogens and biological invasions. The evidence gathered here points towards complex interactions and synergies between the various disturbance factors at play. Whereas the different forcings are now well documented, major unknowns remain as to how they will ultimately affect the functioning of ecosystems through cascade effects.

Physical evidence of changes in the Mediterranean

The Mediterranean Sea displays a specific hydrology, with well-identified water masses in each sub-basin (Figure 1) and at different depths. One peculiarity is a homogeneous deep-water layer below ~250 m that does not get colder than 12–13 °C. The general thermohaline circulation of the Mediterranean is determined by the flux of incoming Atlantic water by the Gibraltar Straits and by the sinking of waters formed at the three coldest areas of the sea: the Gulf of Lions, the northern Adriatic and the North Aegean Sea. Over the past three decades, this general pattern has been disrupted in several ways.

The first definite signs of changes in sea temperature came from Mediterranean deep waters. A 30-year time-series (1959–1989) of deep-water temperatures acquired in the northwestern Mediterranean (NWM) demonstrated a general warming trend of ~0.12 °C (~0.004 °C per year), a possible result of human-induced global warming [6]. Later data have confirmed this trend [7,8]. Some unexpected effects on thermohaline circulation have been documented from 1987 through the 1990s; these changes have been

Corresponding author: Lejeusne, C. (christophe.lejeusne@univmed.fr).

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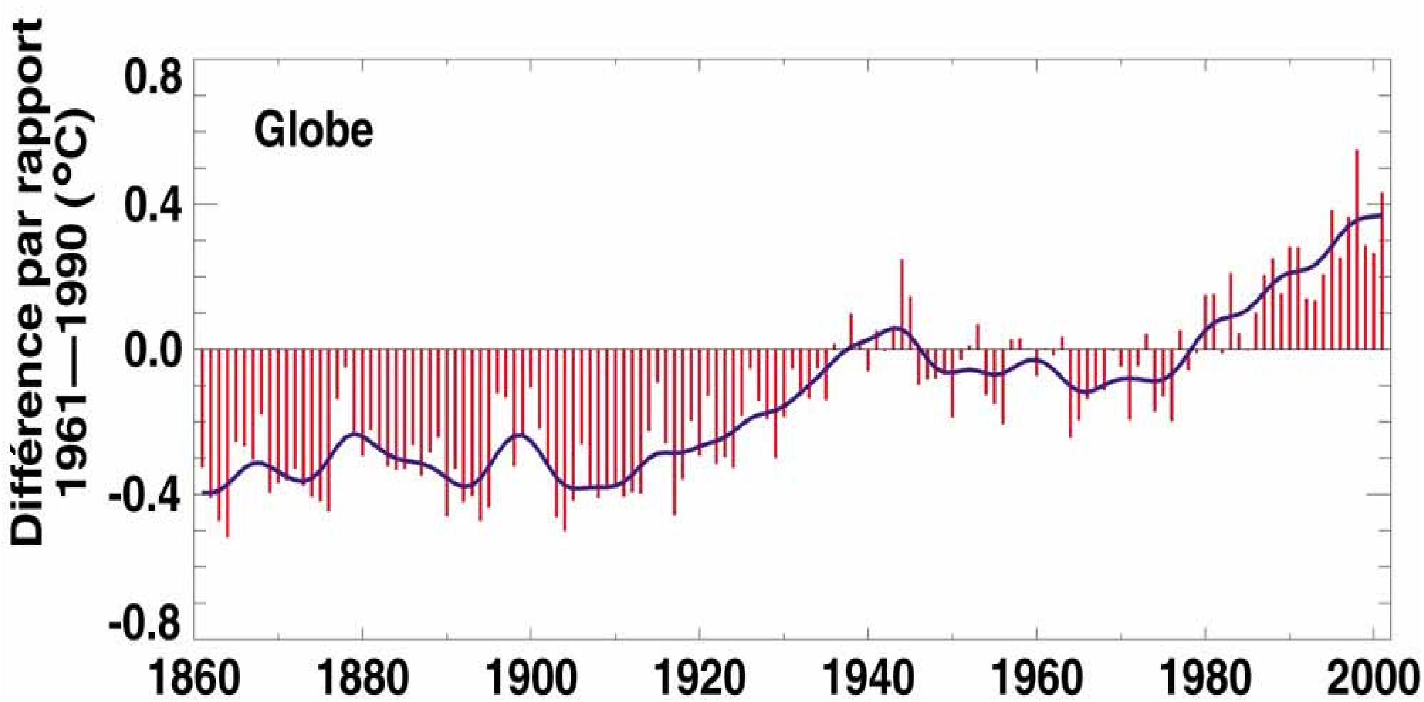
WE SHOULD WAIT
AND SEE IF CLIMATE CHANGE
IS HAPPENING BEFORE
WE DO ANYTHING

Global warming is real !

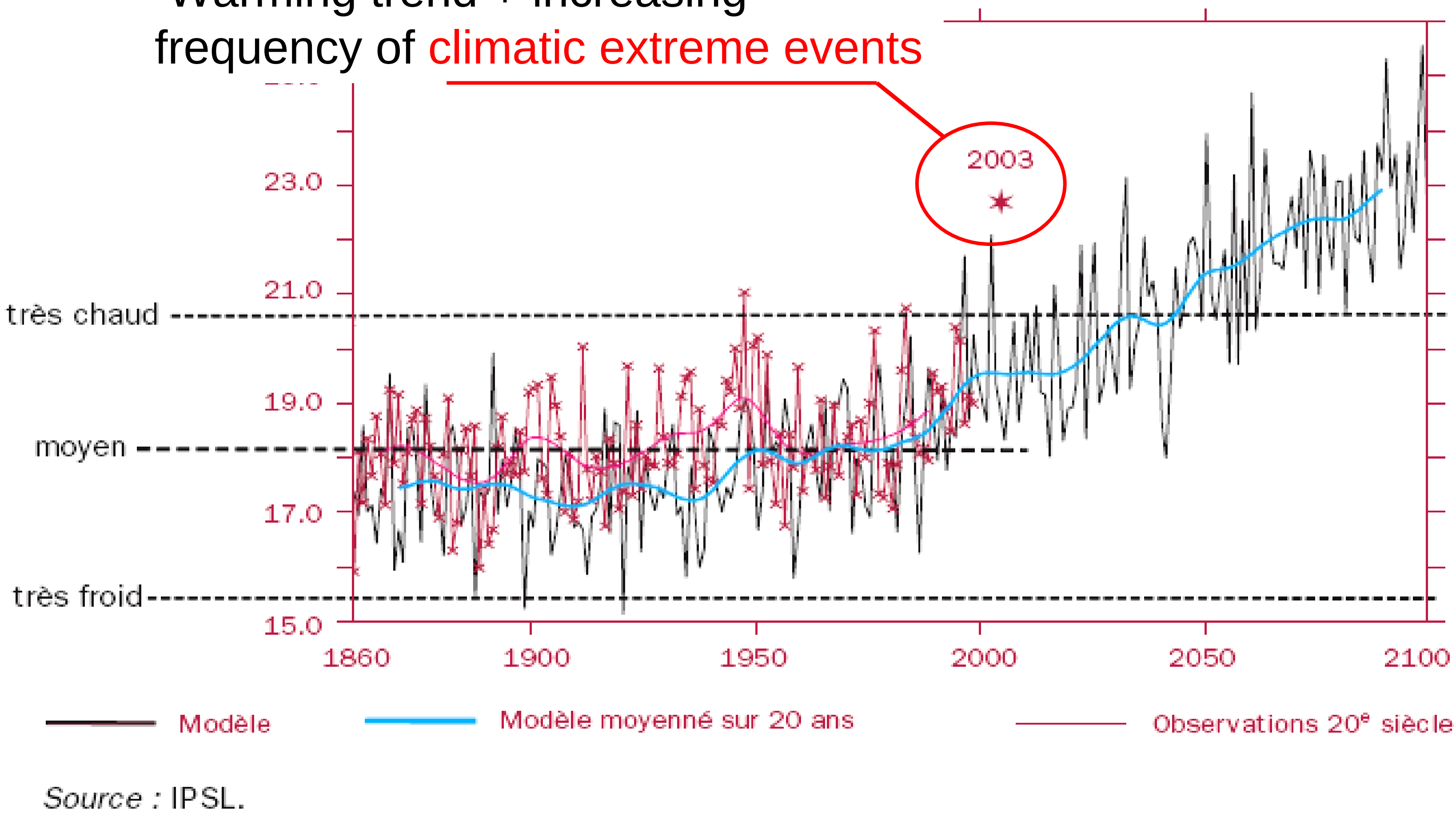
This last century

- **In average: 0.5 – 1°C**
- **2 main periods : 1910-1945 and 1976-today**
- **the warming trend is two times higher than in 1910-1945. No similar trend over the last millenium**



Quite pessimistic predictions

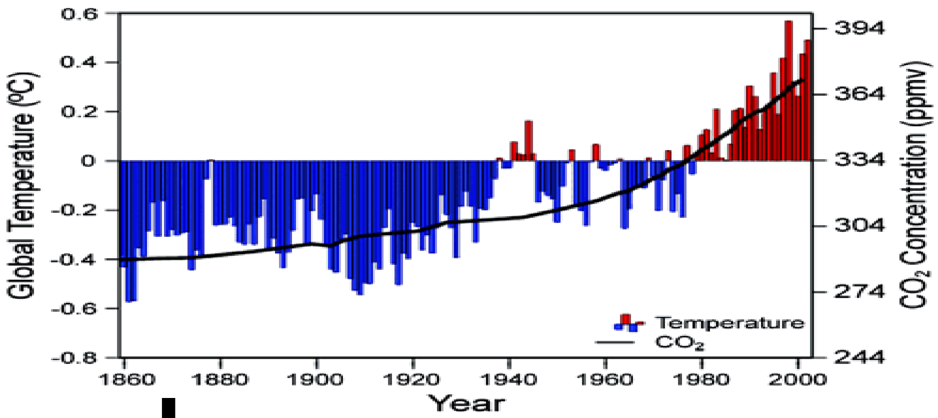
Warming trend + increasing frequency of climatic extreme events



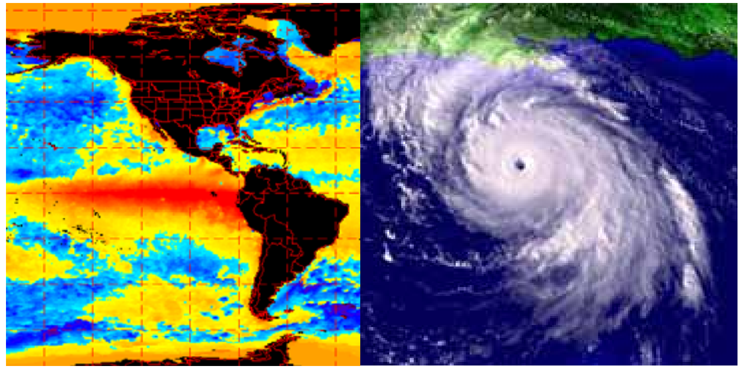
Mean summer temperature in France (june, july, august)
GIEC Climatic model A2 (*www.ipcc.ch*)

Impact of the global change on the biological systems

Global warming



Occurrence of extreme events



Cascading biological responses

Physiological stress, disease, mortality

↓

Shift in distribution, local extinction

Effect on life cycle, Adaptations

Effect on biodiversity
Ecosystem functioning

? Combined effect ?

Local disturbances:

terrigenous inputs

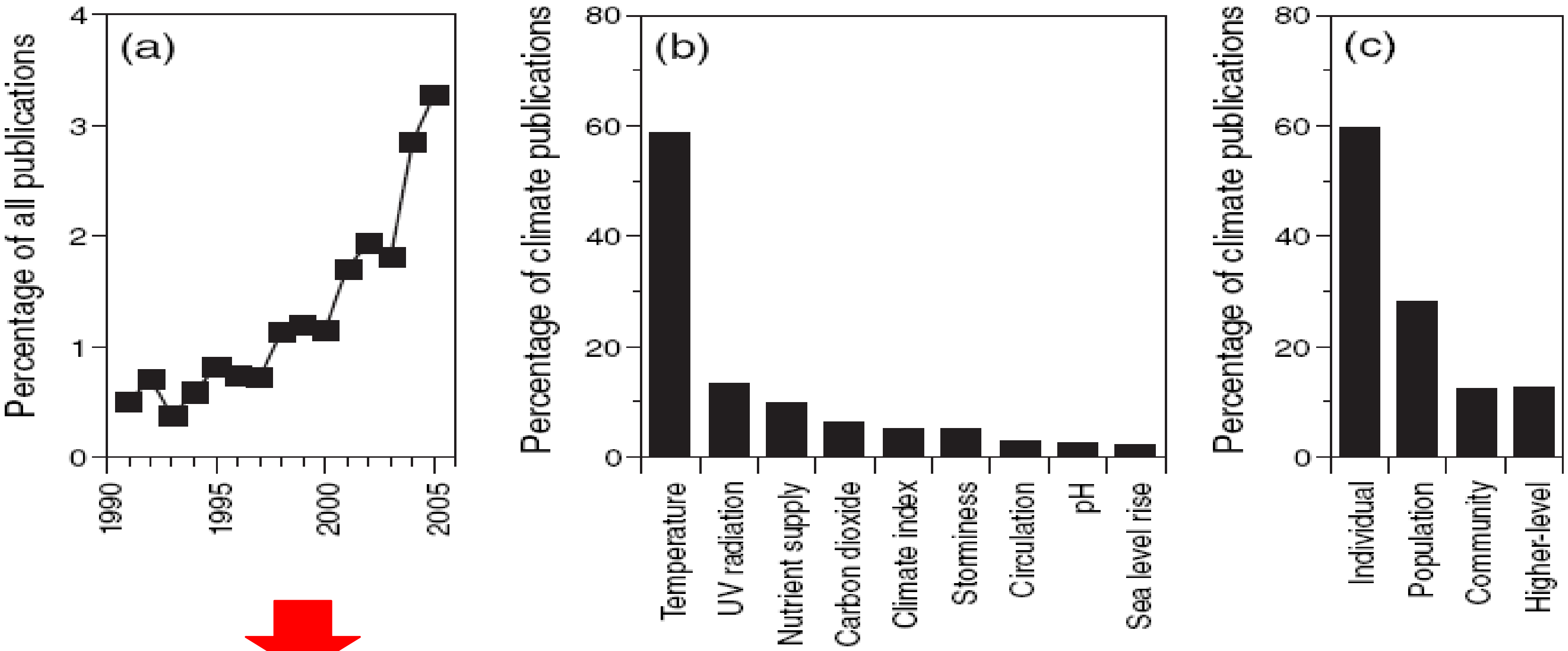
pollutants

biological invasions

Adapted from Hughes 2000

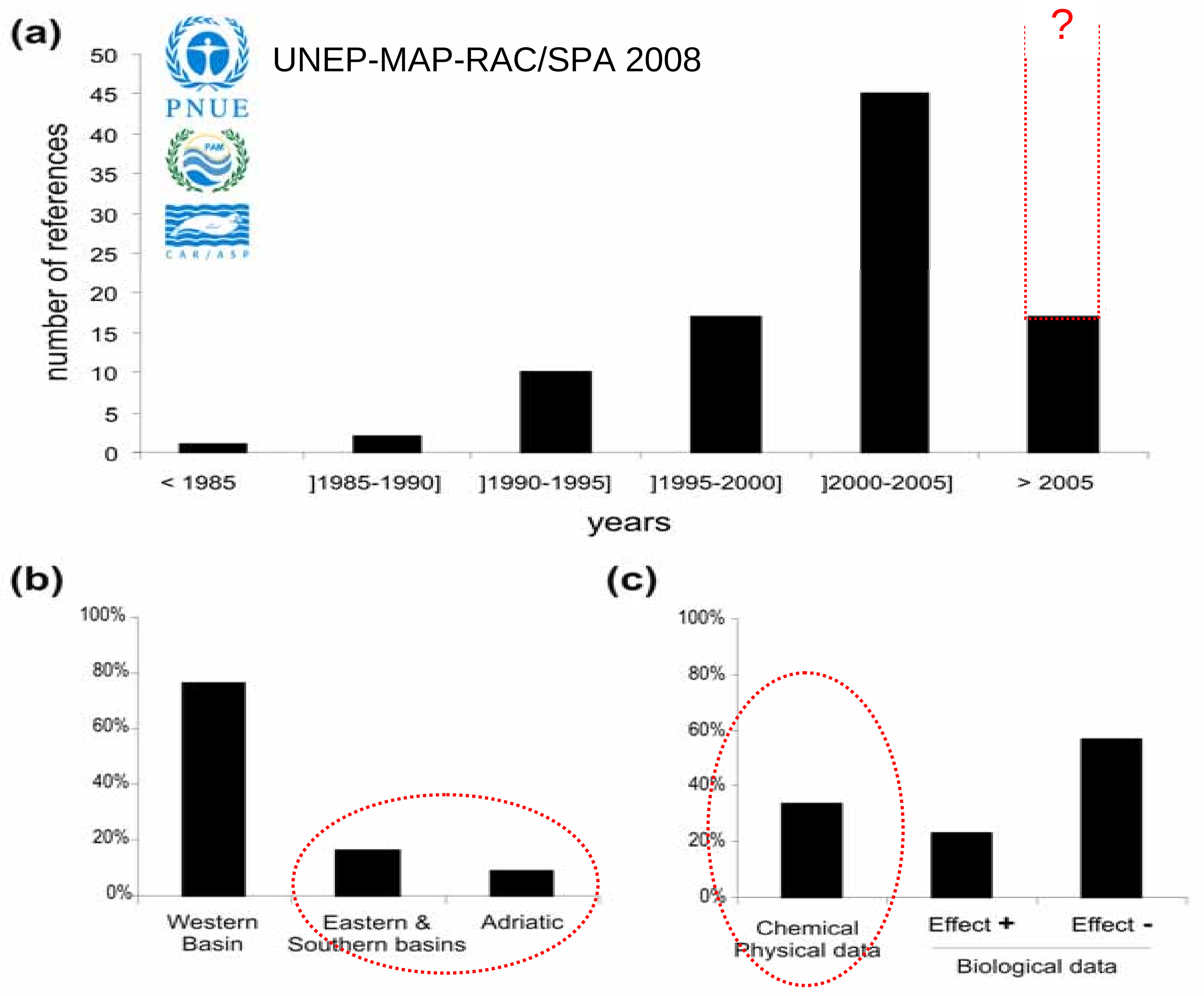
Climate-related publication trend in the marine ecology litterature

After Harley et al. 2006



Only 1 mediterranean reference cited

Climate-related publication trends in the Mediterranean marine ecology literature



Evidences of a global change in the Mediterranean Sea

Bethoux et al. 1990
Bethoux & Gentili 1996

0.12°C / 30 years

Annual mean: 0.004°C

The first clues of a Mediterranean Sea warming came from the deep sea

Time series in coastal waters

- **Villefranche-sur-mer** (since 1957)
- **Levant Island** (National Park of Port-Cros, Marine Nationale)
- **Estartit serie**
  Salat & Pascual 2002

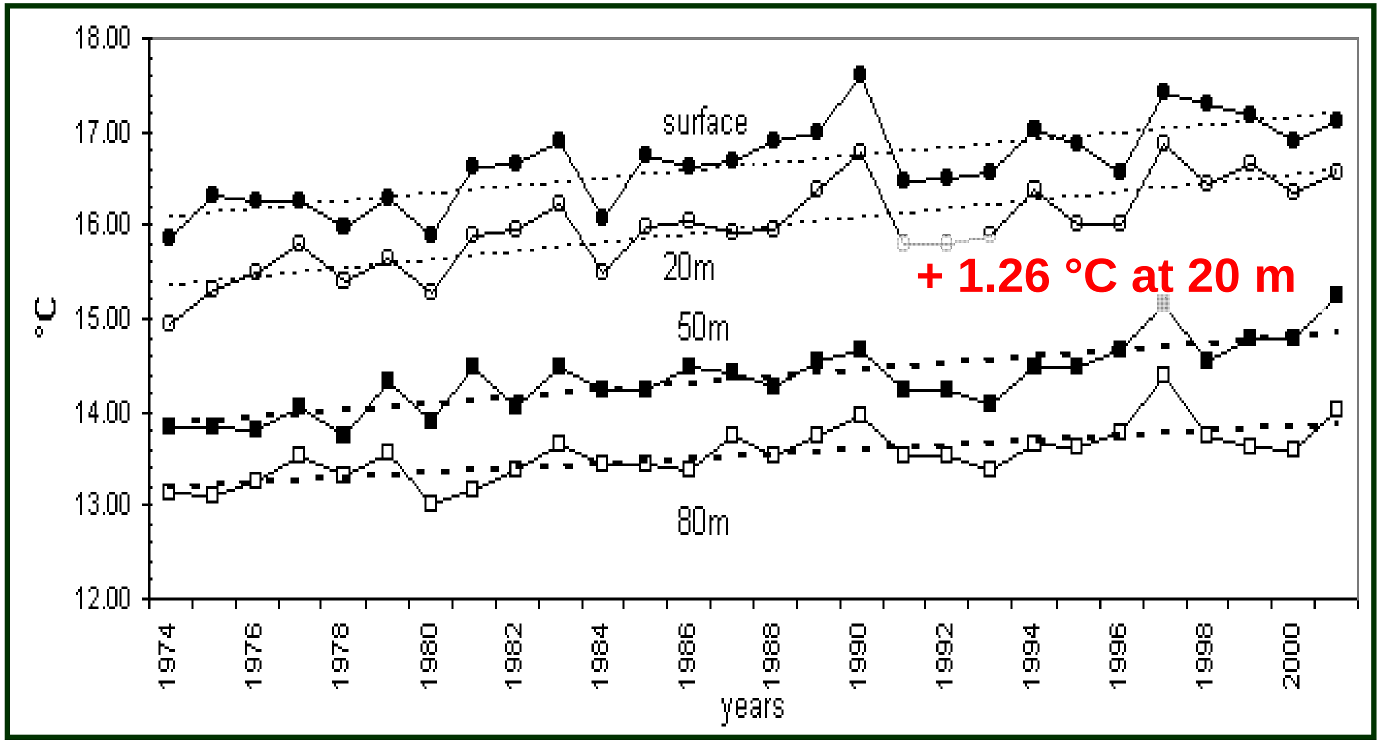
About + 1°C ces 30 dernières années

- **Marseille** (1884-1967)
Romano & Lugrezi 2007

Same trend, but 3 times less rapid

Evidences of a global change in the Mediterranean Sea: Warming trend of the coastal waters

Several time series available in the NW Mediterranean
Ex. Estartit (Catalonia, Spain, since1974)



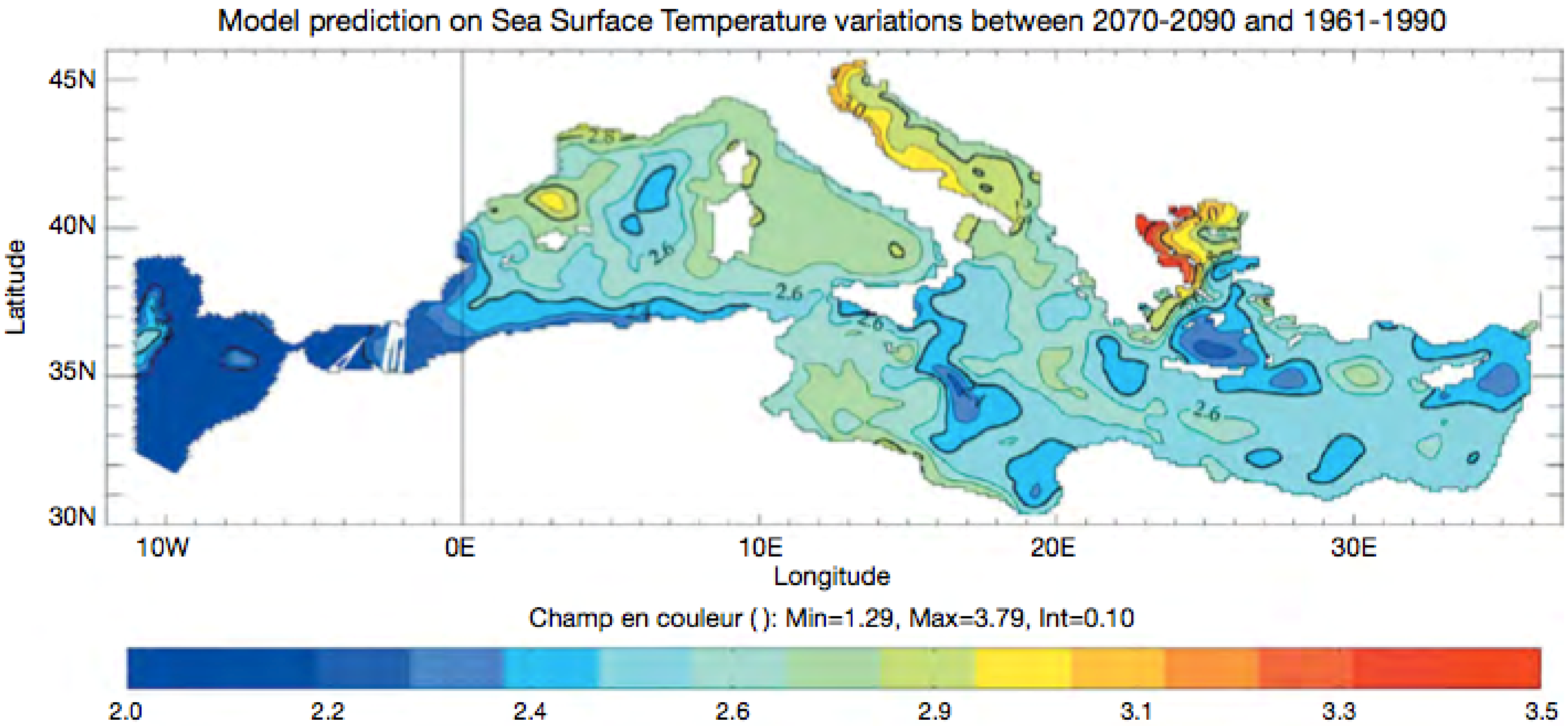
Salat & Pascual 2002 ; Coma et al. 2009

Lack of available data from the South and the East of the Mediterranean Sea

Evidences of a global change in the Mediterranean Sea: Warming trend of the coastal waters

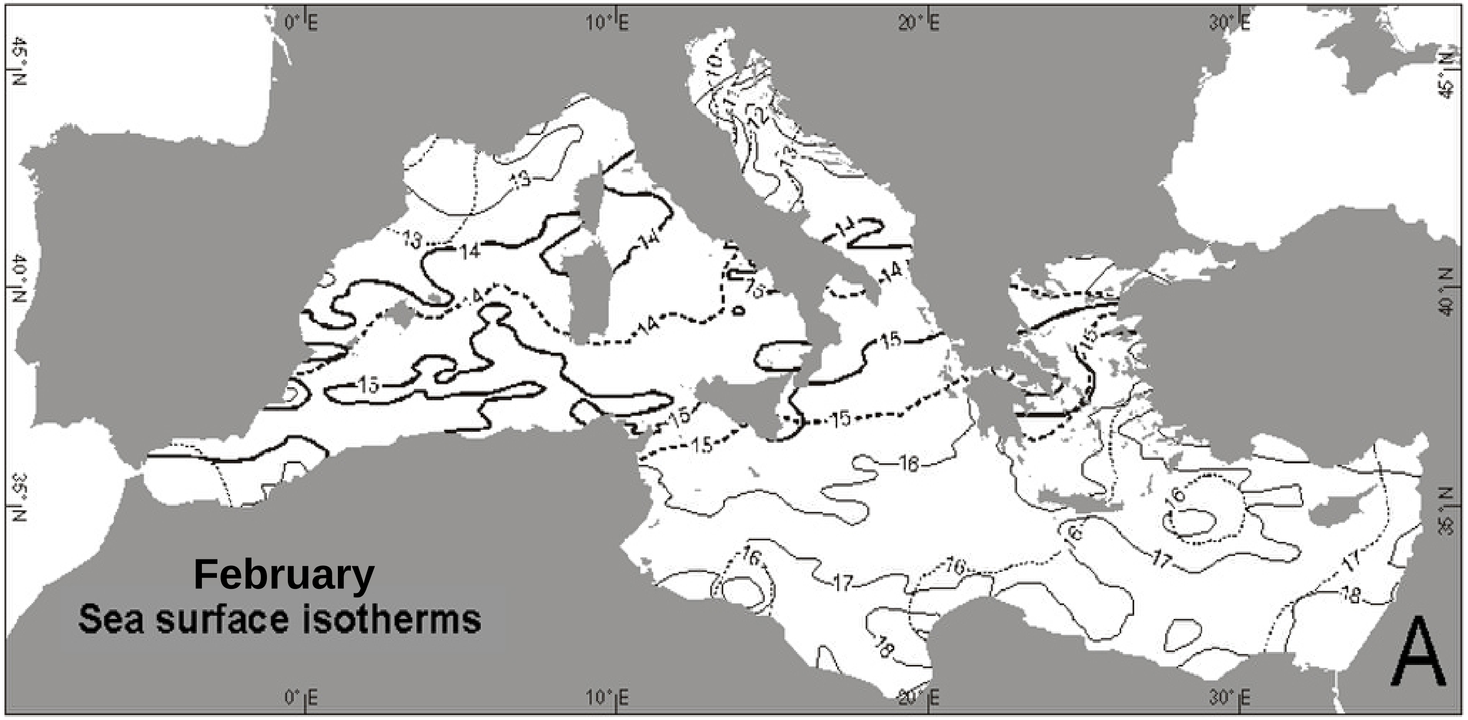
Model predictions on SST by the end of the 21st century:

some will like it hot !



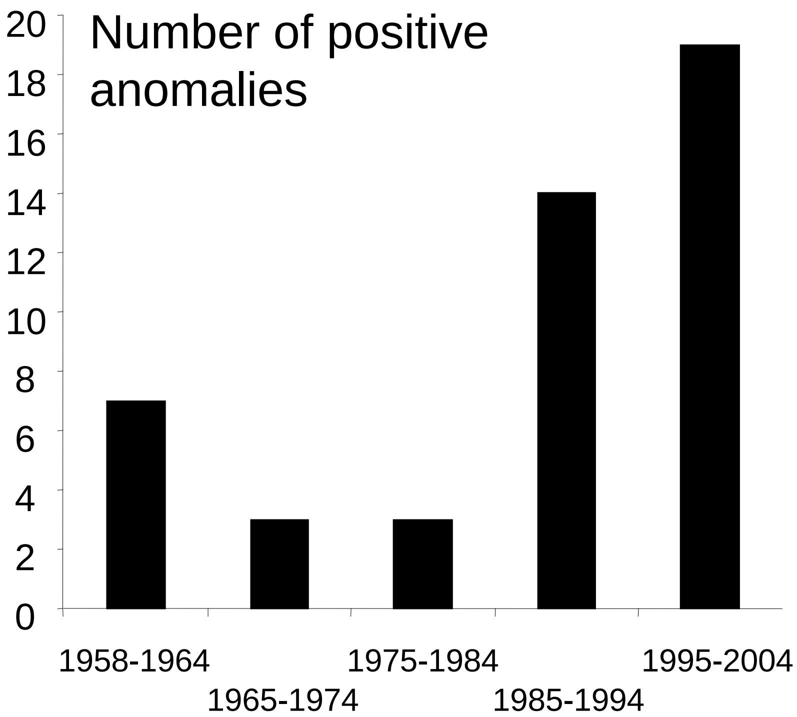
Lionello (Ed.) 2012

Evidences of a global change in the Mediterranean Sea: Warming trend of the coastal waters



Northward shifting of sea surface isotherms is affecting the Mediterranean biogeography

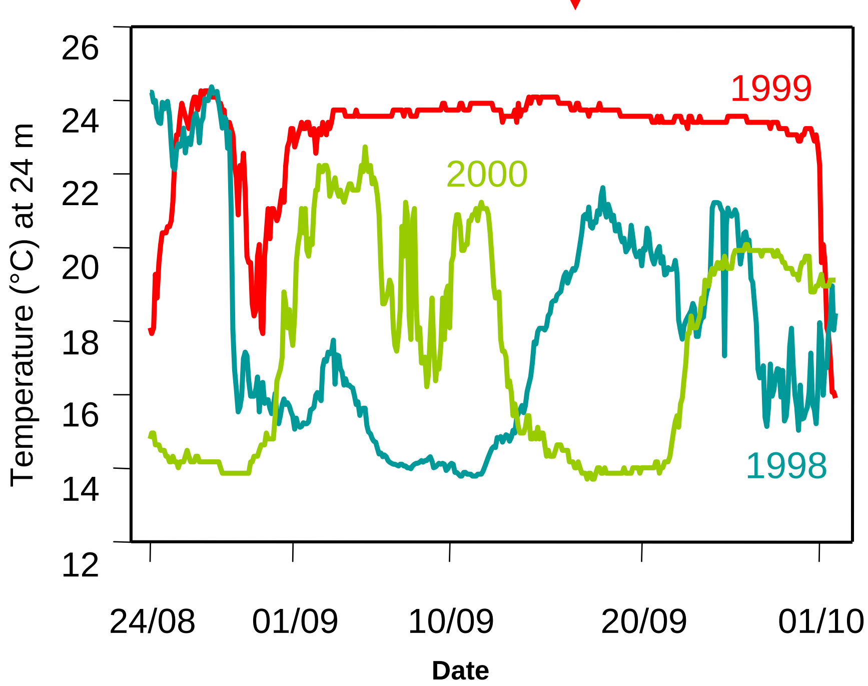
Evidences of a global change in the Mediterranean Sea:
Increasing frequency of climatic events



Villefranche sur Mer Series, since 1958

From Boury-Esnault et al. 2006

Summer 1997, 1999, 2003



Series IFB / Medchange, since 1998

From Pérez 2001

Some evidences in the South and in the East of the Mediterranean Sea !

Implementation of temperature recorders, CIESM « tropical Signals »

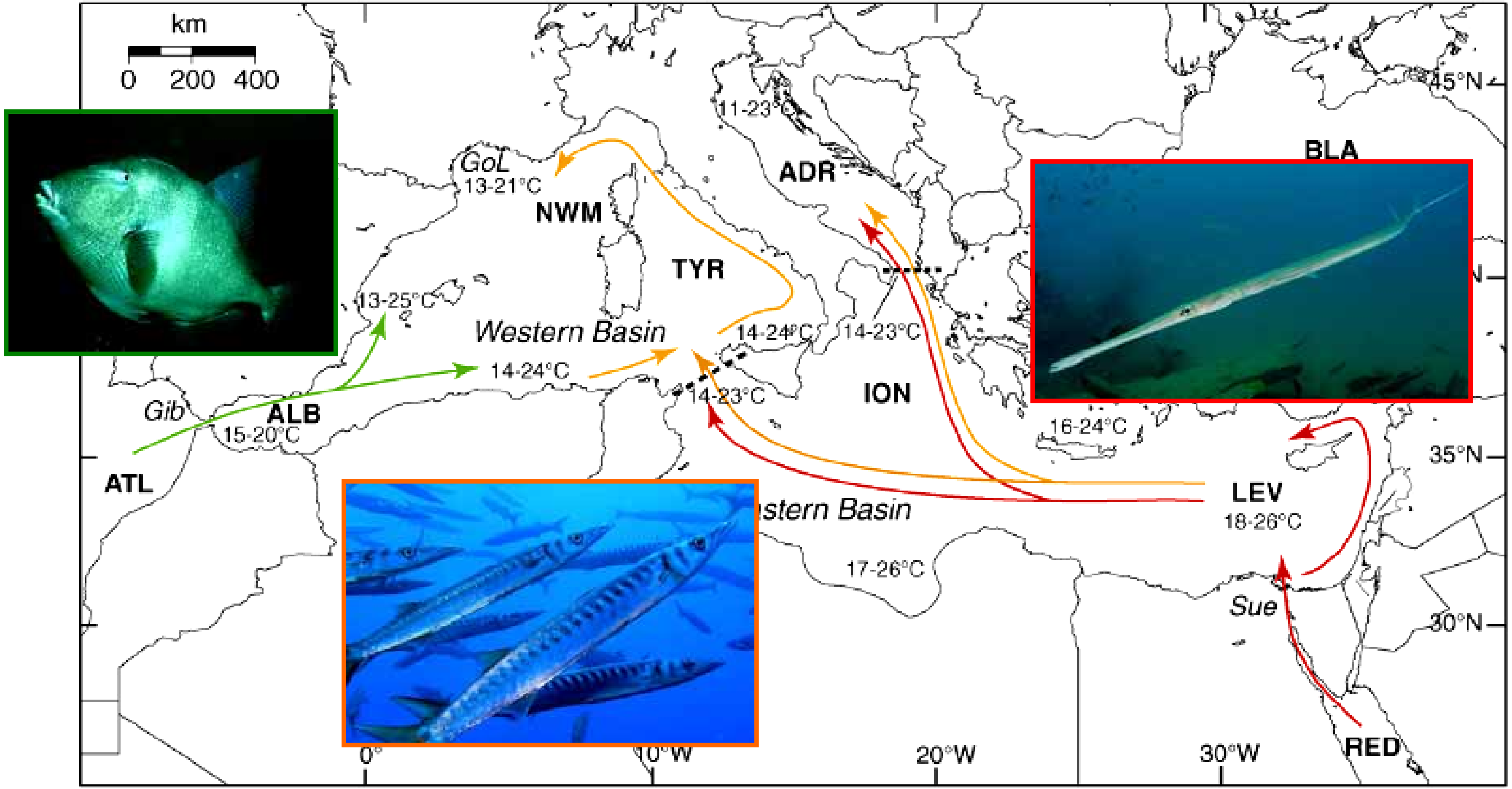
Tropical Signals

High frequency recordings + Survey of biological indicators

Some indicators of a « meridionalisation » of the Mediterranean sea: homogenisation of the Mediterranean biota with thermophilic species

Main routes of species range expansion

→ mediterranean natives → atlantic migrants → lessepsian migrants

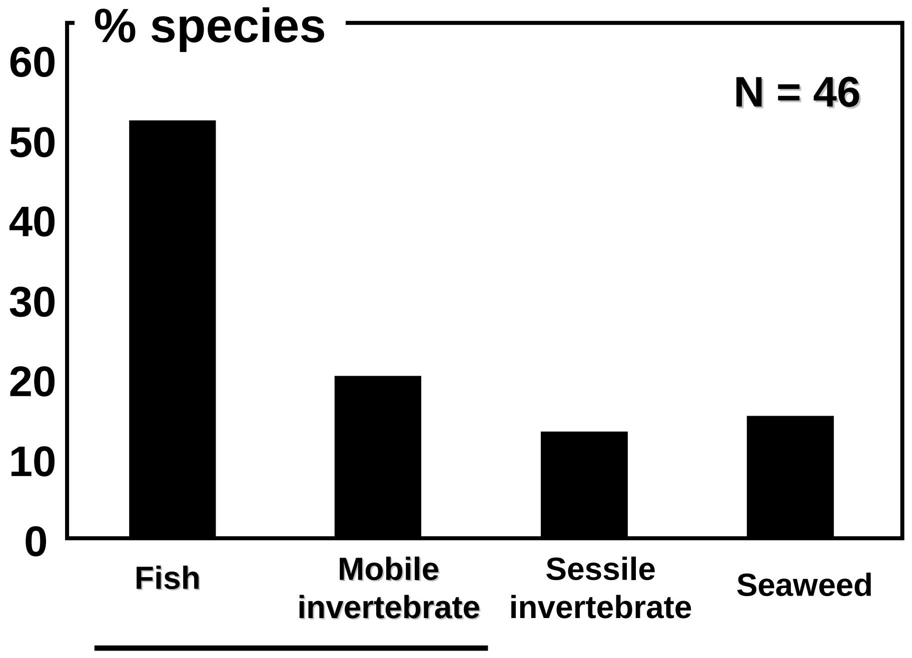


TRENDS in Ecology & Evolution

Some indicators of a « meridionalisation » of the Mediterranean sea: homogenisation of the Mediterranean biota with thermophilic species

Shift in distribution range (towards North)

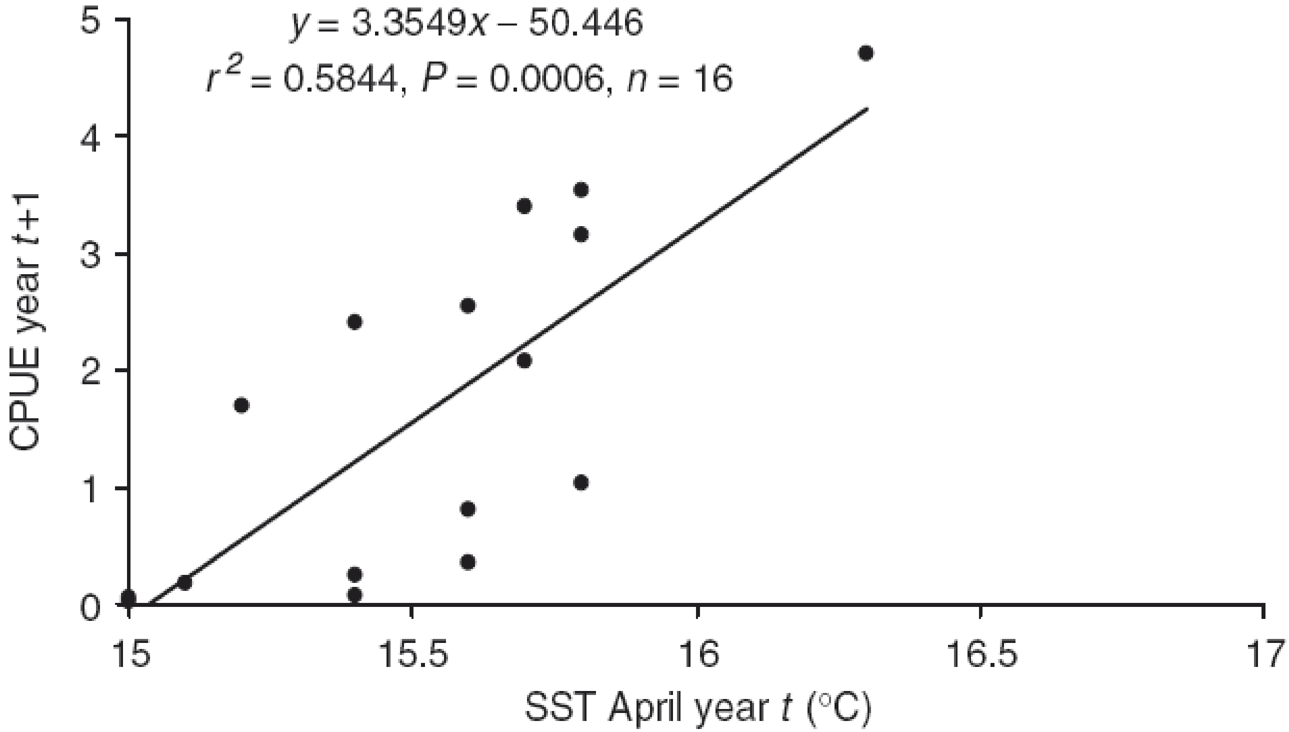
An inventory in the NW Mediterranean Sea (from Garrabou et al. 2003)



- Some similar indications in the Adriatic Sea (e.g. Lipej & Dulcic 2001)
- List of indicator species and protocols, CIESM « Tropical Signals »
- Effect + and - on fisheries (phenology) (*e.g.* Bonbace 2001, Sabates et al. 2006)

Some effect on Mediterranean fisheries

Case of the small pelagic fish, *Sardinella aurita*, in the western Med



• landings catches in relation to air temperature anomalies (1950-2003)

• the maximal catches are related to the Sea Surface Temperature of April the year before (Sabates et al. 2006)

Negative effects on « cold stenotherm » pelagic species

Examples:

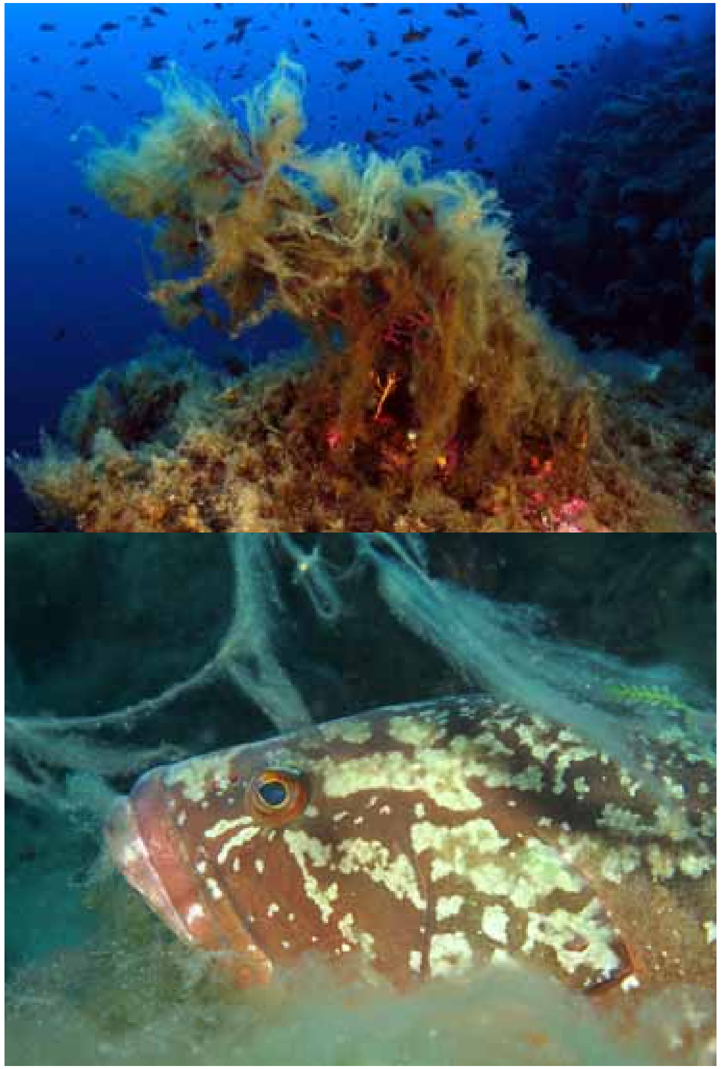
• **Sprat** in the Adriatic and Gulf of Lion

• **Anchovies** in Adriatic

Francour et al 1994; Bonbace 2001

Mediterranean Sea warming and biological pollutions

Mucilagenous blooms



Frequent events in N Mediterrannean and Adriatic

Enigmatic triggering factors

Variable effects on overgrown erect species (+++ gorgons)

Three main species:

- *Nematochrysopsis marina*
- *Chrysonephos lewisii*
- *Acinetospora crinita*

Schiaparelli et al. 2007

2003 Bloom, *A. crinita* is highly dominant, **related to the 2003 thermal anomaly**, effect on several sponge, coral and algal species (bleaching !)

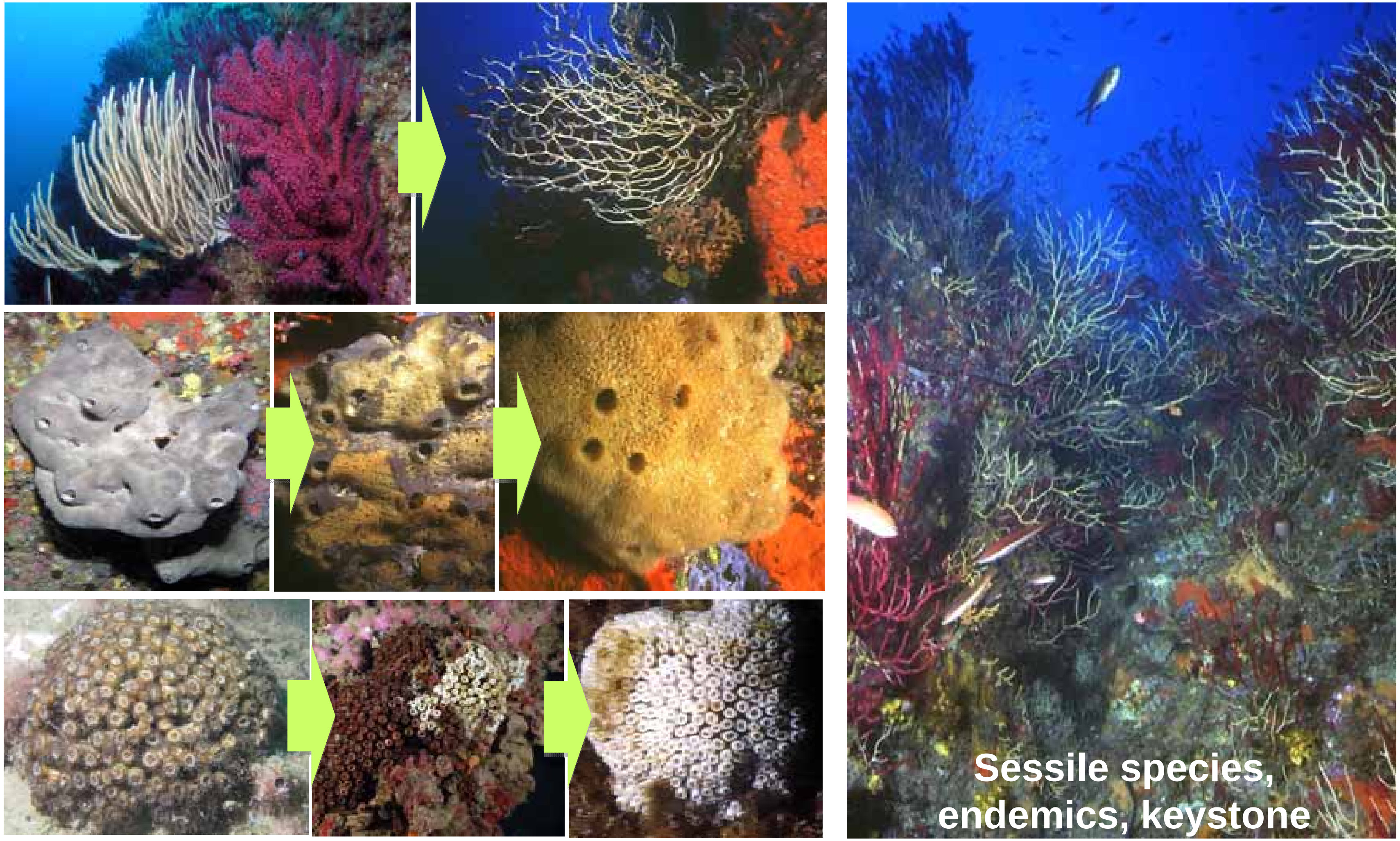
See also Sartoni & Sonni, 1991 ; Guliani et al. 2005

Disease outbreaks and invertebrates mass mortality events

Disease outbreaks and invertebrates mass mortality events

Numerous reports from 1999 and 2003

Two unprecedented extreme events



e.g. Cerrano et al. 2000; Pérez et al. 2000; Garrabou et al. 2001; Coma et al. 2006; Garrabou et al. 2009