Overview: climate forcing on marine plankton

Climate shapes the pelagic ecosystem

- Surface temperature is a good proxy for nutrient enrichment in the ocean.
- Warming of surface waters makes the water column more stable, enhancing stratification and requiring more energy to mix deep, nutrient-rich water into surface layers.
- This results in nitrate, the principal nutrient that limits phytoplankton growth in the ocean, being negatively related to temperature globally.

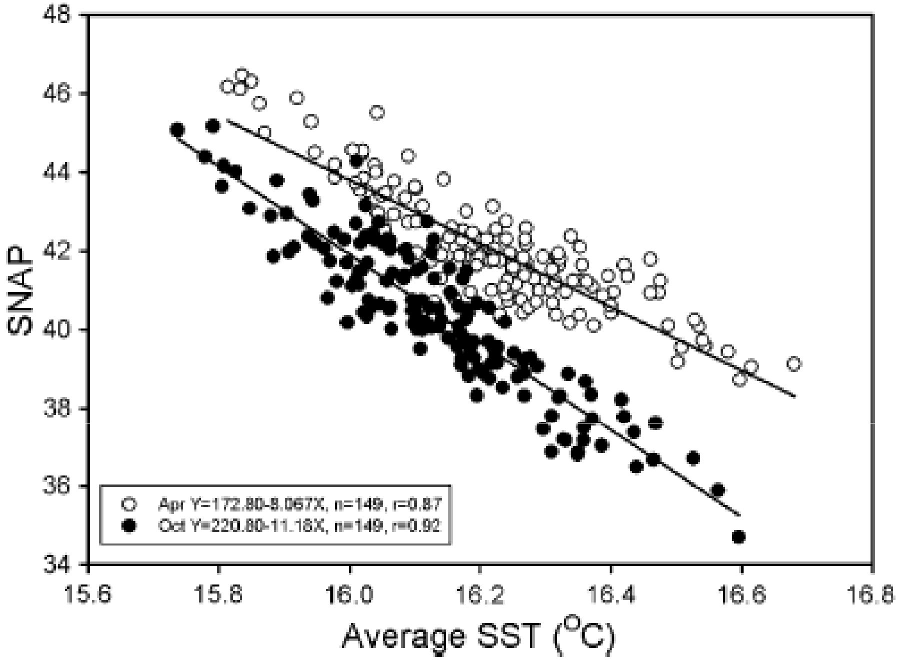
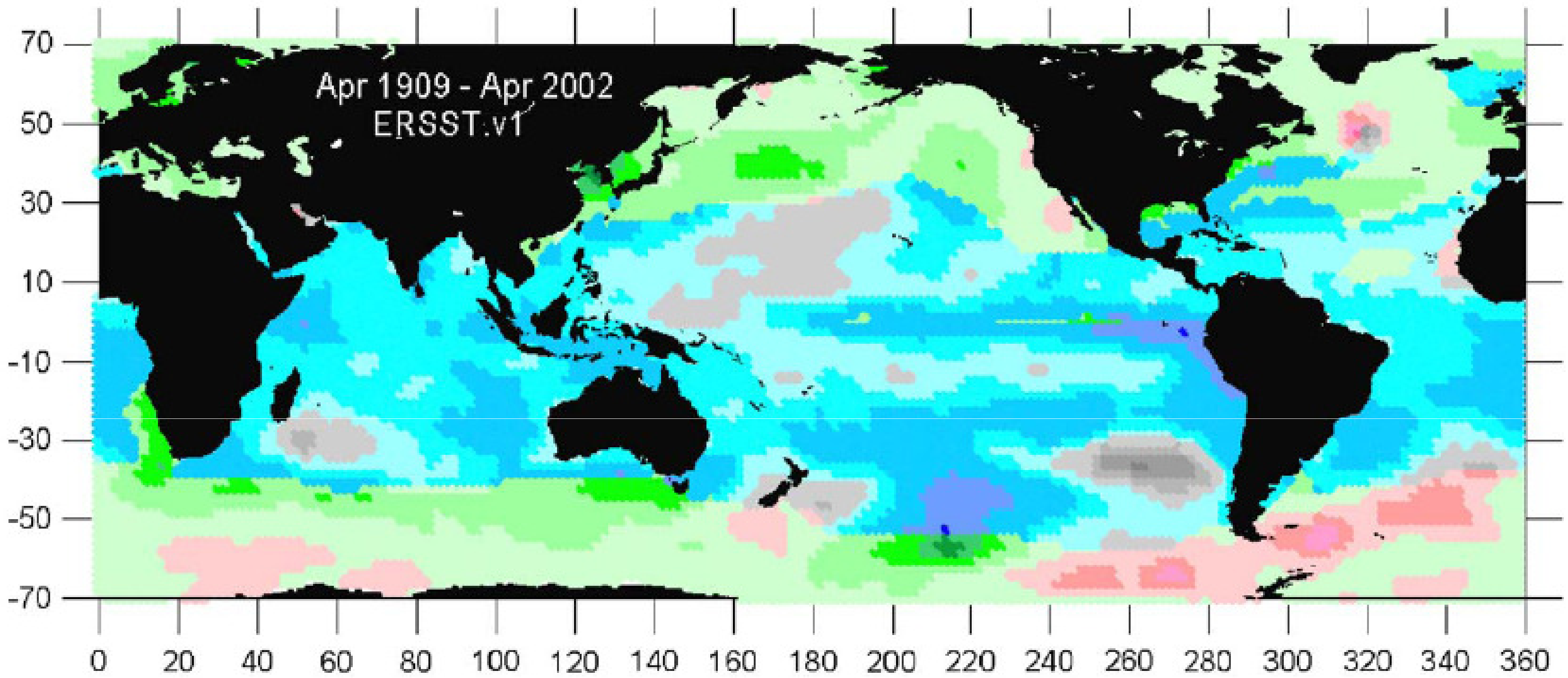


Fig. 10. A comparison of average global SST in °C from the ERSSTv1 data set and the corresponding SNAP for the time period 1854–2003. The symbol box provides the best-fit linear regression lines to each data set, the number of points, and the associated regression coefficients.

(Kamykowski and Zentara, 2005)

Climate shapes the pelagic ecosystem

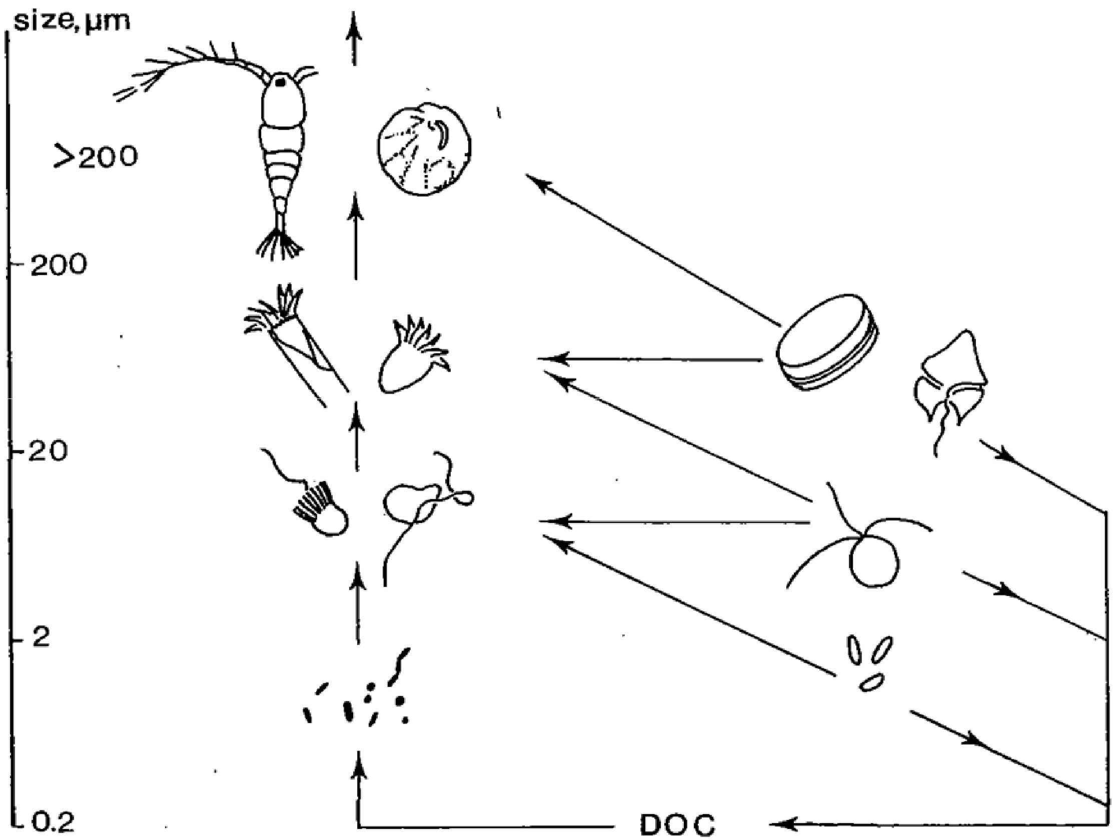


Extent of water column stratification – blue areas indicate higher stratification and lower nitrate availability in 2002 compared to 1909.

Extended Reconstruction (ER) of Sea Surface Temperature (SST) – monthly time series from 1854 to 2003

(Kamykowski and Zentara, 2005)

Climate shapes the pelagic ecosystem



Extent of water column stratification – how does it affect marine food webs?

Zooplankton in climate change studies

- Zooplankton are poikilothermic, so their physiological processes are controlled by ambient temperature (Q_{10});
- Most zooplankton species are short-lived (< 1 year): tight coupling of climate and population dynamics;
- Zooplankton are generally not commercially exploited;
- Distribution of zooplankton can accurately reflect temperature and ocean currents;
- Reproductive products of zooplankton are distributed by currents and not by vectors, as in terrestrial ecosystems;
- Bentho-pelagic coupling through meroplankton has influences on several marine phyla, including benthic species.

Food

Factors influencing secondary production

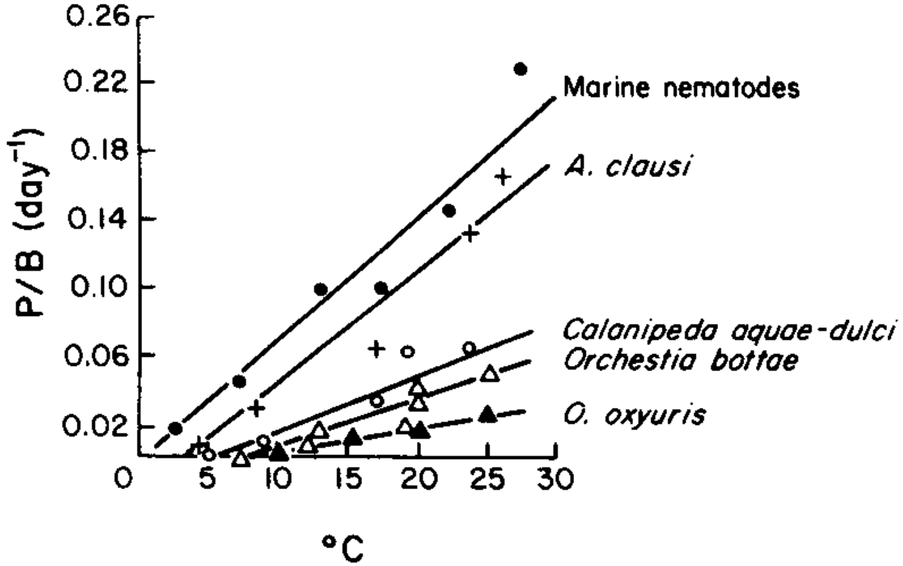
$$\Delta B = R + G - M + I - E$$

Temperature
Food (quant., qual.)
Body size

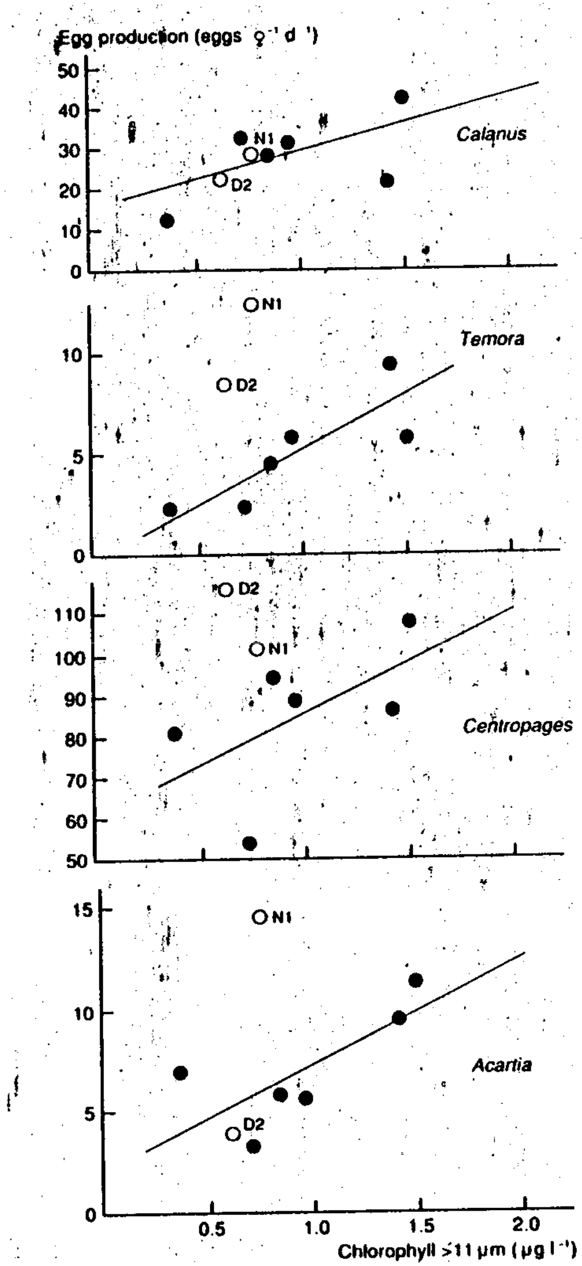
Predation
Cannibalism
Diseases

Advection

Temperature

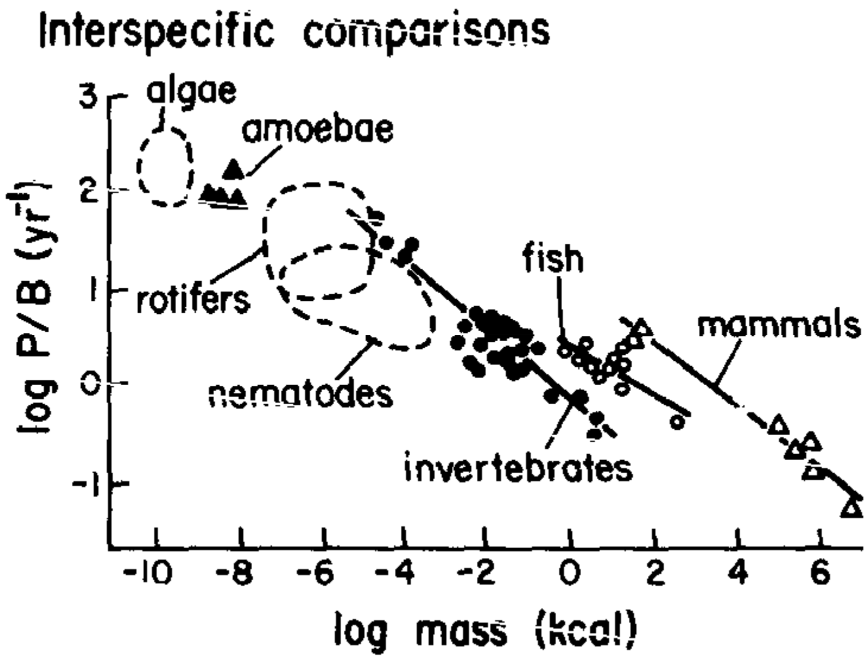


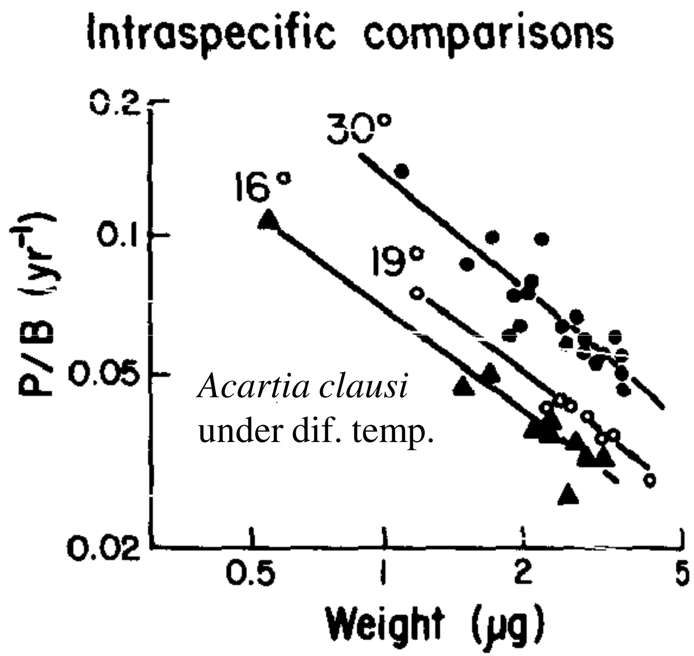
Valiela Fig. 7.23



Factors influencing secondary production –

body size **body size + temperature**





(1 kcal ≈ 1 g wet weight)

Valiela Fig. 7.21

Observed global climate change

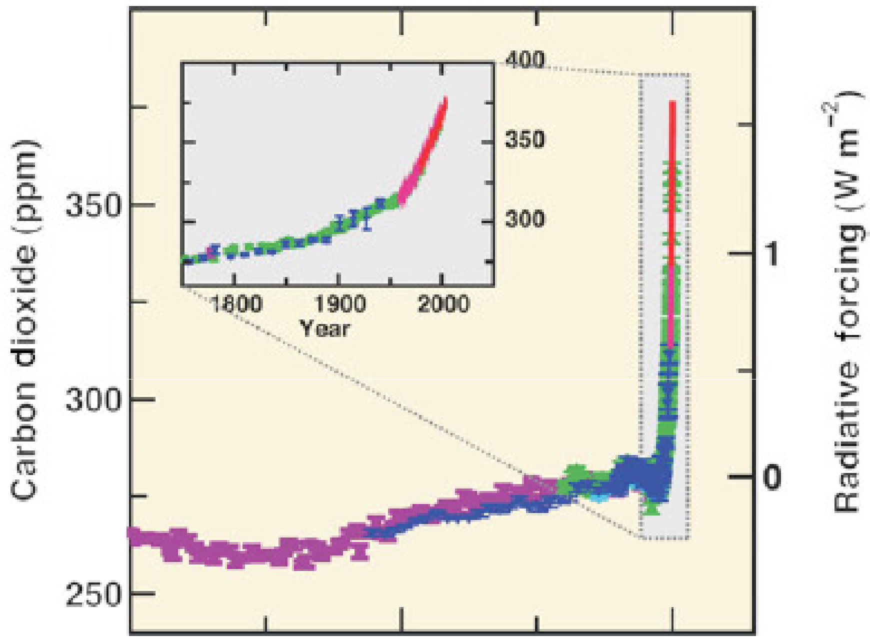
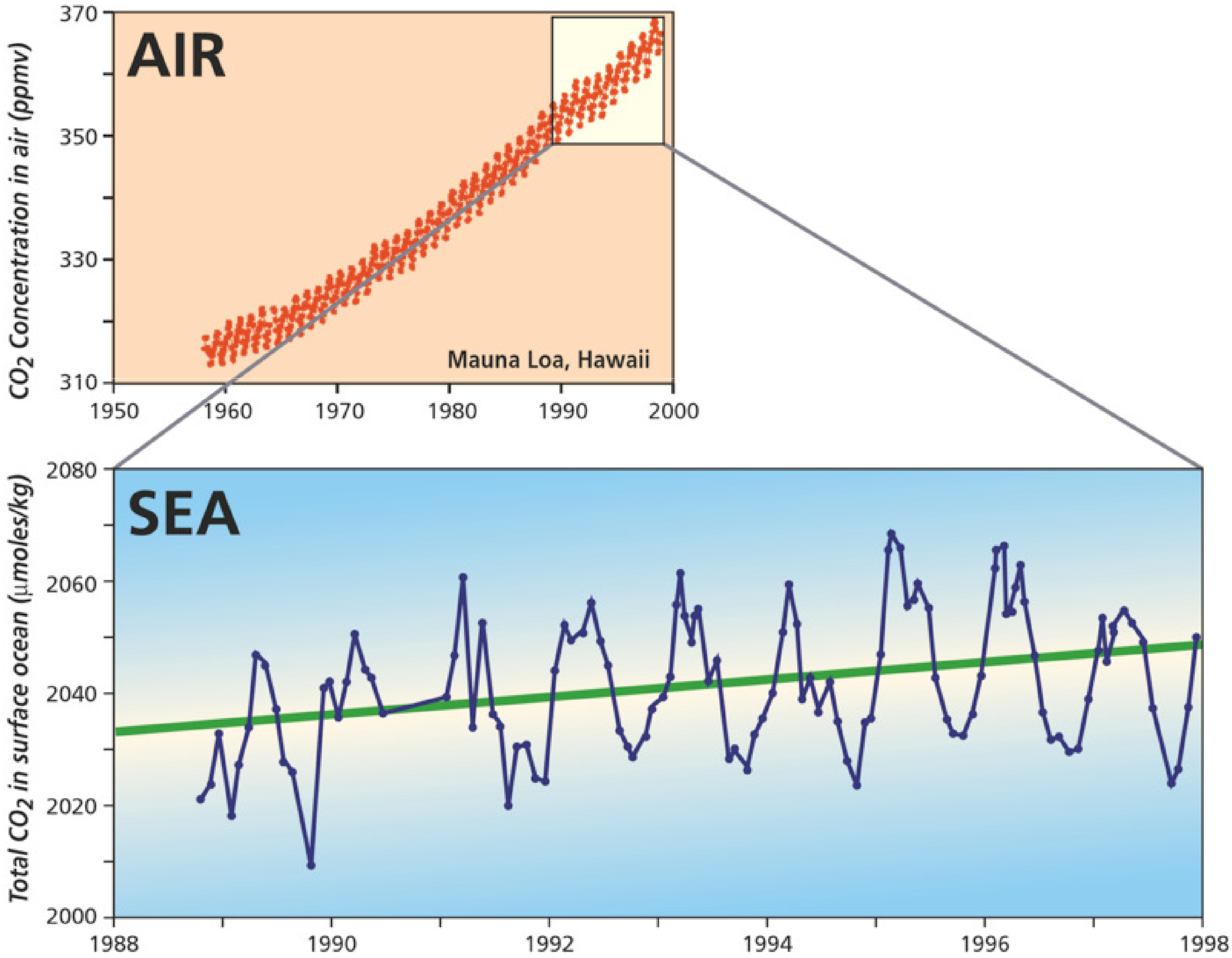


Figure 1. Atmospheric concentration of carbon dioxide over the past 10 000 years (large panel) and since 1750 (inset panel). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcing is shown on the right axes of the large panel (from IPCC, 2007a, with permission).

Observed global climate change



Observed global climate change

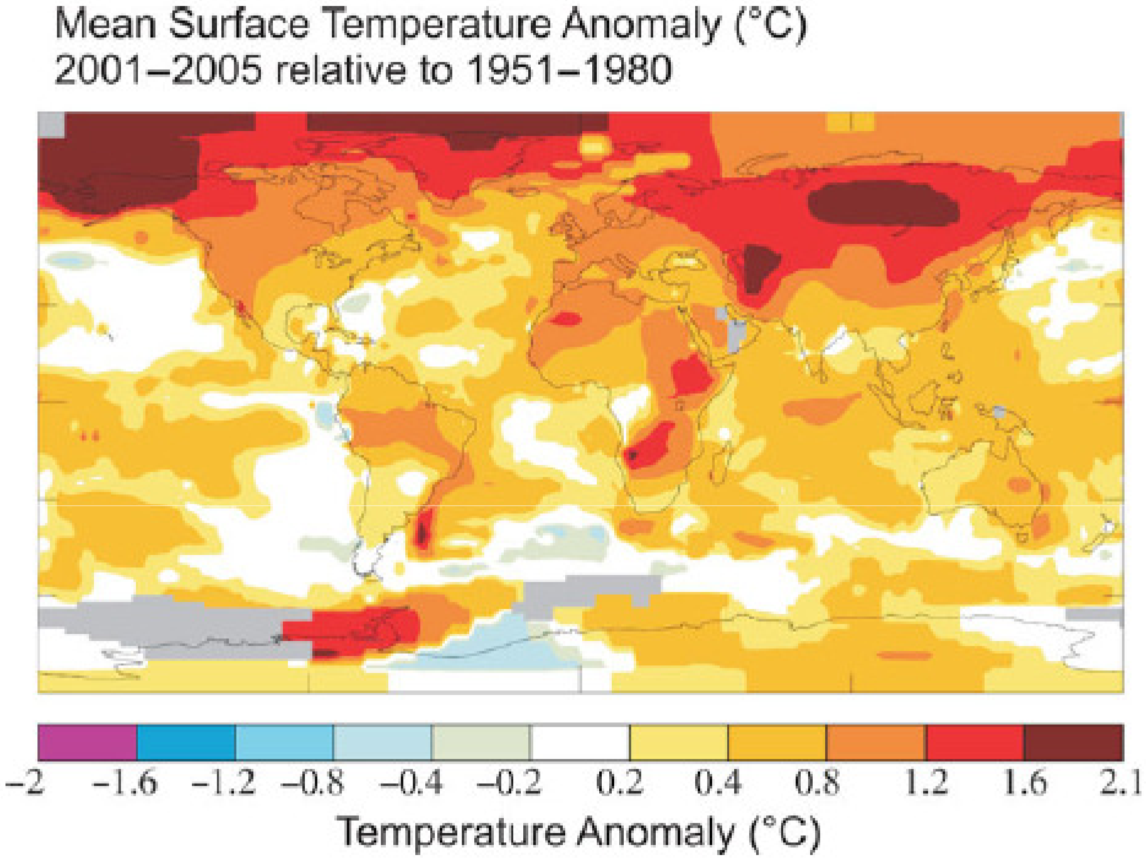


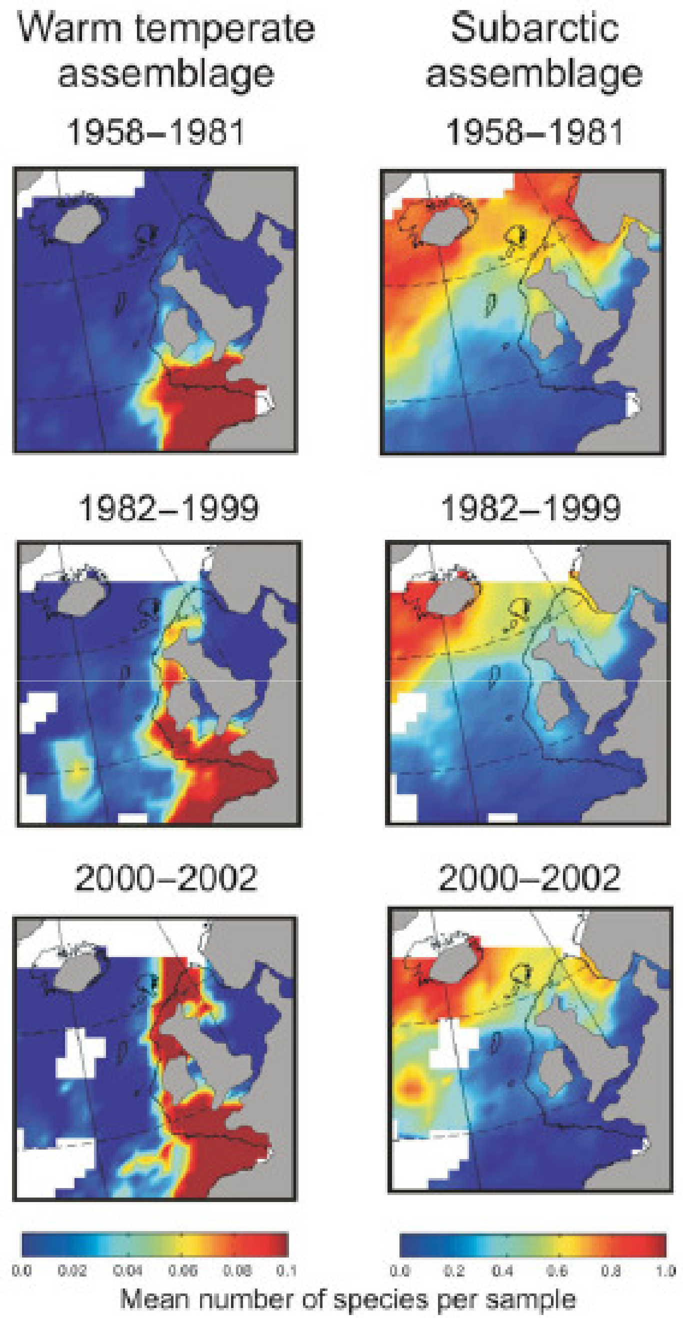
Figure 2. Mean surface temperature anomalies for 2001–2005 relative to 1951–1980 from surface air measurements at meteorological stations and ship and satellite sea surface temperature measurements (from Hansen *et al.*, 2006; National Academy of Sciences, USA).

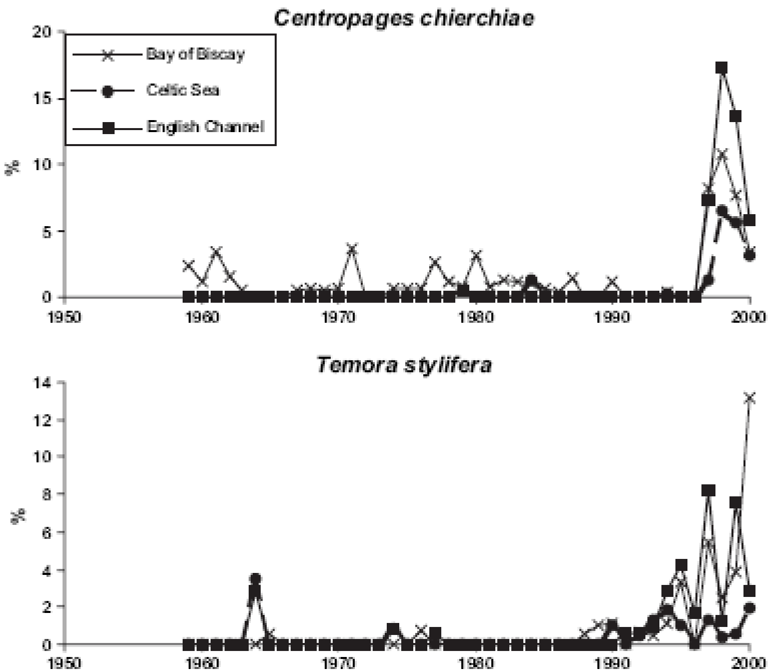
Effects on plankton

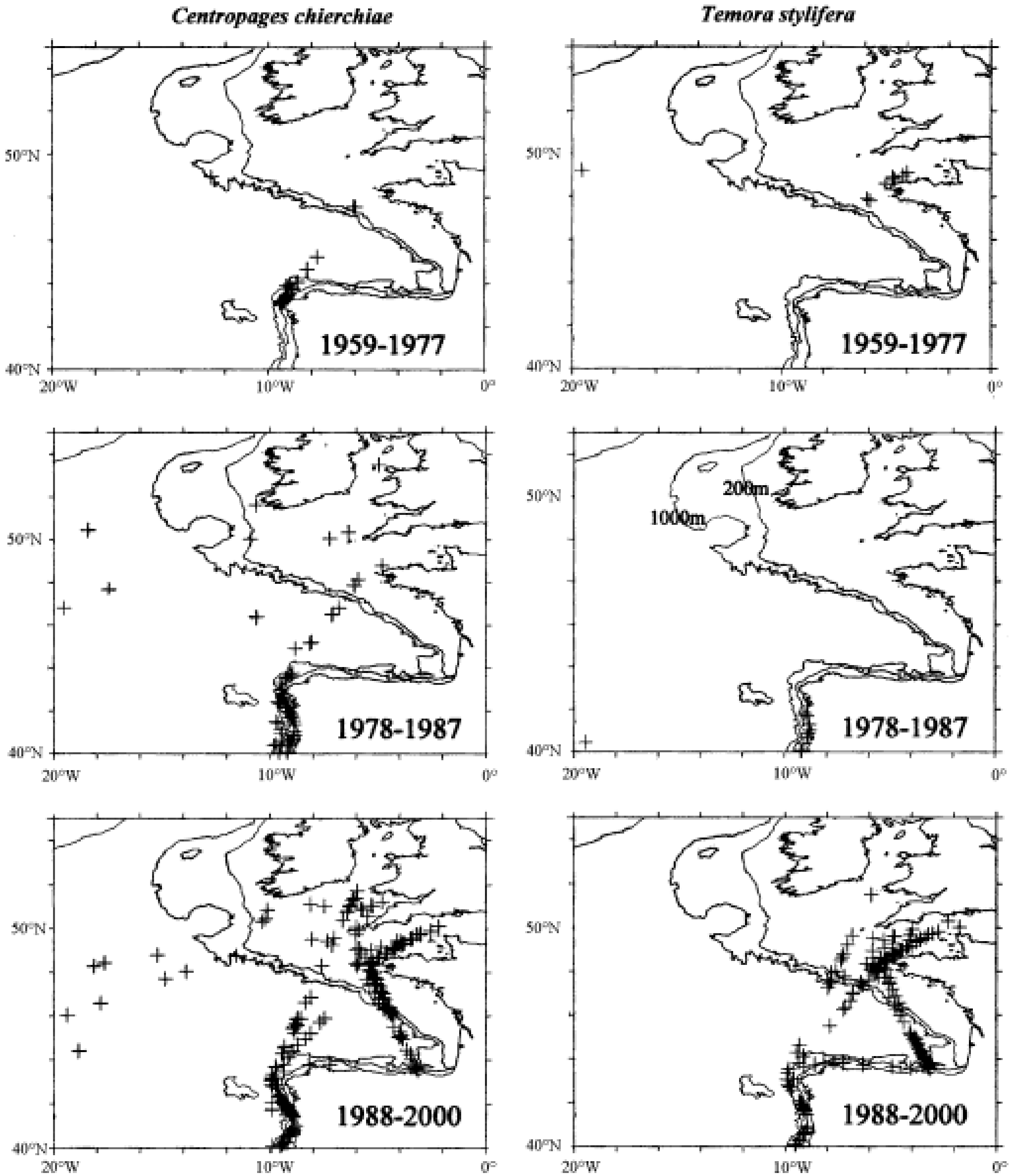
- Known, reported impacts of global warming on plankton are manifest:
  - as poleward movements in the distribution of individual species and assemblages,
  - in the earlier timing of important life cycle events or phenology, and
  - as changes in abundance and community structure.

Effects on plankton: distribution

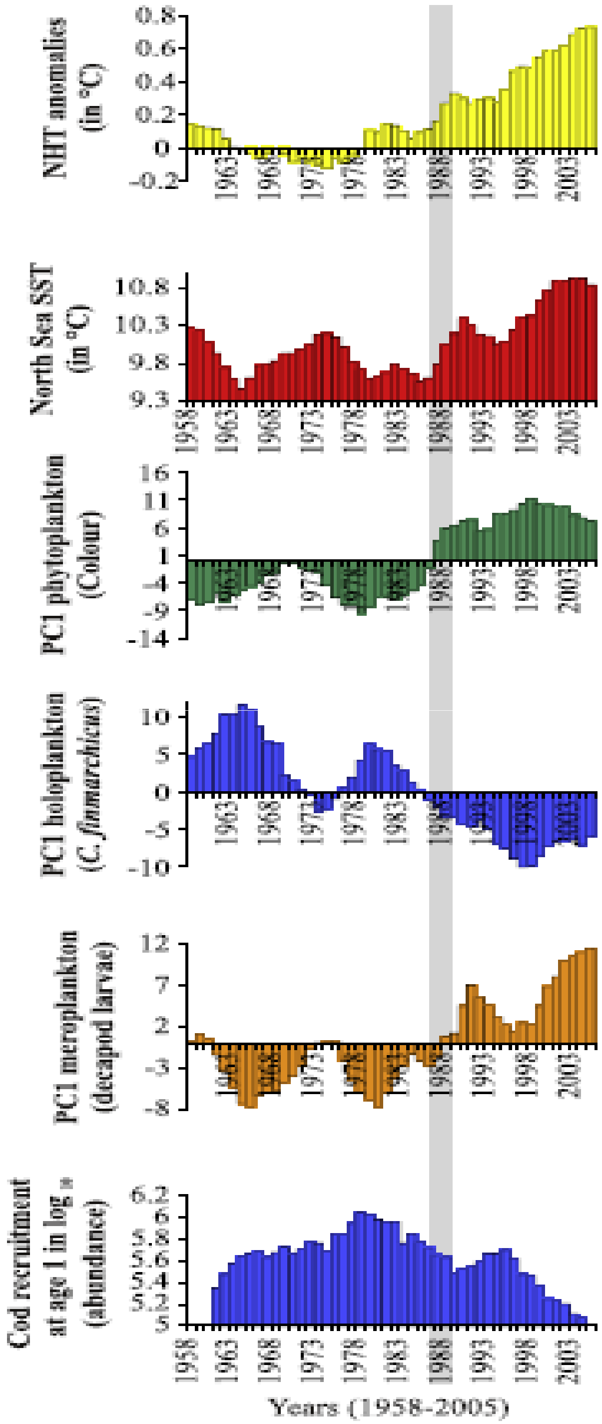
The general trend, as on land, is for animals to expand their ranges polewards as temperatures increase (Beaugrand, 2008)

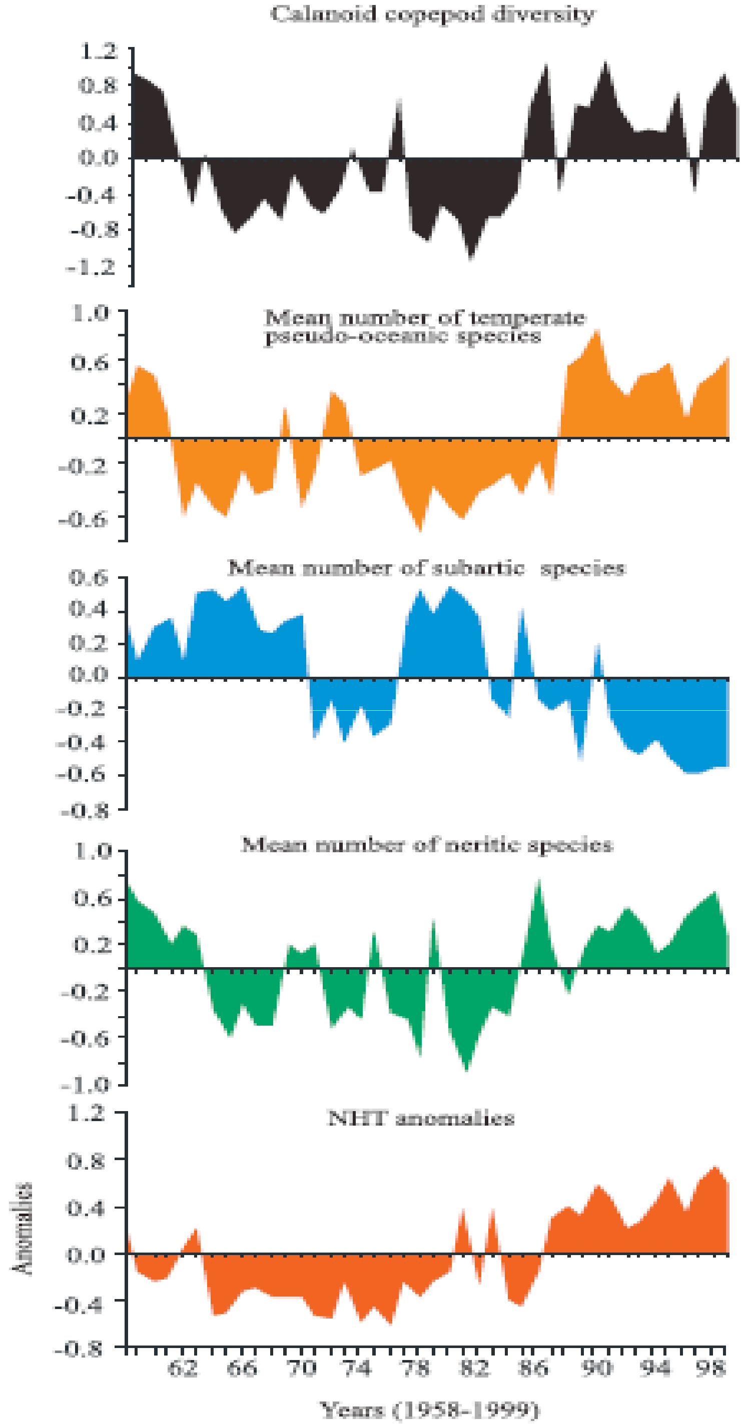




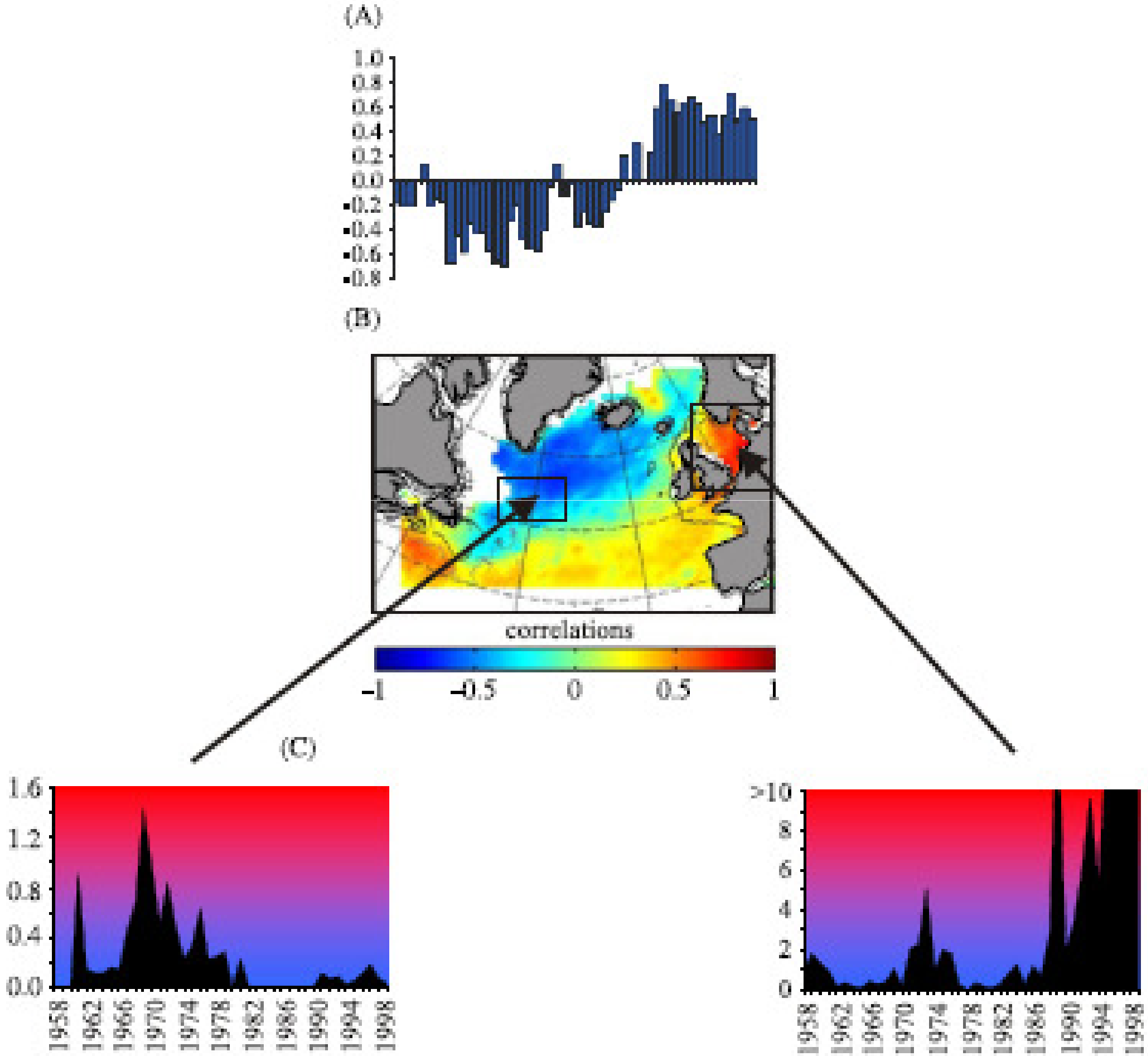


Centropages chierchiae and *Temora stylifera* both moved north from the vicinity of the Iberian Peninsula in the 1970s and 1980s to the English Channel in the 1990s (6^{o} of latitude); Lindley and Daykin, 2005.


NHT anomalies (in °C)
North Sea SST (in °C)
PC1 phytoplankton (Colour)
PC1 holoplankton (C. finmarchicus)
PC1 meroplankton (decapod larvae)
Cod recruitment at age 1 in log₁₀ (abundance)
Years (1958-2005)

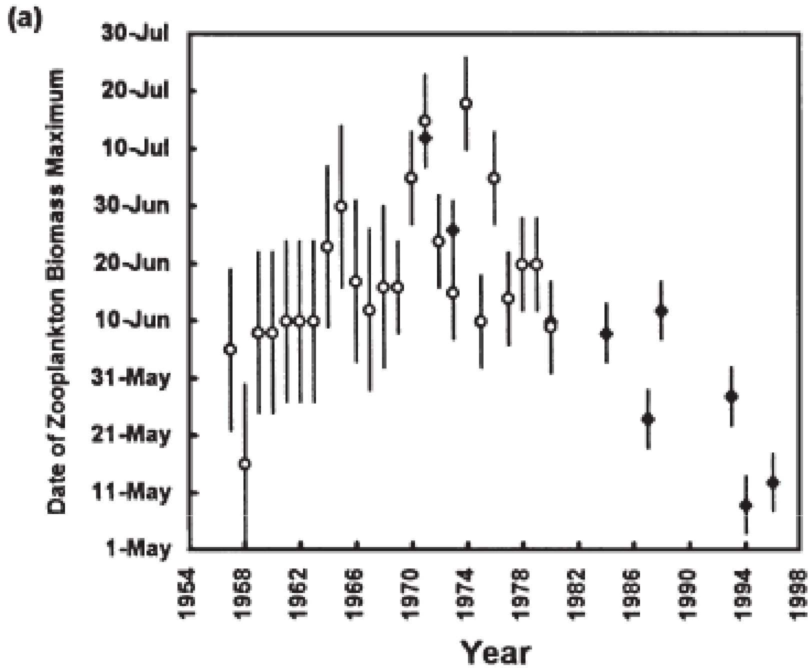

Calanoid copepod diversity
Mean number of temperate pseudo-oceanic species
Mean number of subartic species
Mean number of neritic species
NHT anomalies
Anomalies
Years (1958-1999)

Effects on plankton: large-scale distribution



Effects on zooplankton phenology

- Climate-driven changes in phenology is evident in the Subarctic North Pacific Ocean.
- Here, a single copepod species, *Neocalanus plumchrus*, dominates the zooplankton biomass.



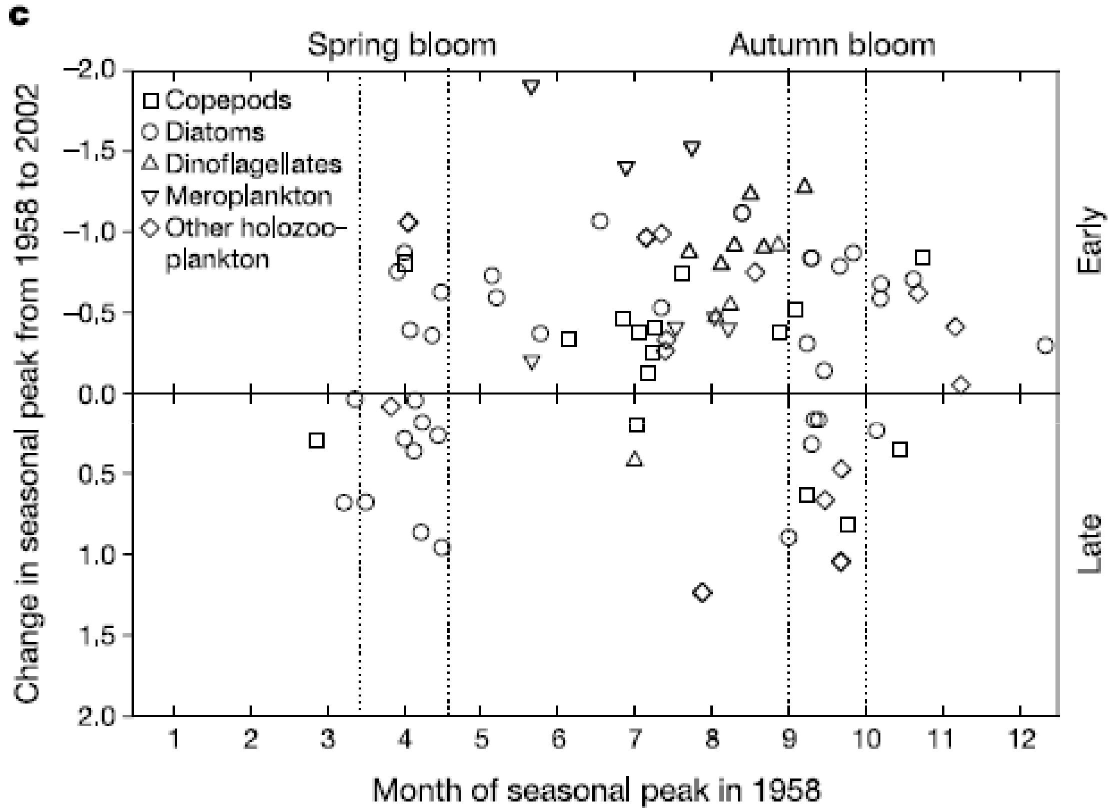
Mackas & Tsuda, 1999

The timing of the zooplankton biomass peak is likely to be ecologically significant because it influences the availability of large copepodites to upper-ocean predators such as salmon, herring, hake, and seabirds.

Effects on zooplankton phenology

Central North Sea:

Meroplankton (cirripedes, cyphonautes, decapods, echinoderms, fish, and lamellibranchs) have advanced their appearance in the plankton by 27 days over the past 45 years.



Edwards and Richardson, 2004

Effects on zooplankton phenology

- Estuarine environment of Narragansett Bay (USA). Here, the timing of the first appearance of the top predator *Mnemiopsis leidyi* has advanced by 59 days between 1951 and 2003, whereas the timing of one of its major prey items, Acartia tonsa, has remained unchanged over this time (Costello et al., 2006) ==

  Mismatch due to differential warming of surface and bottom layers.

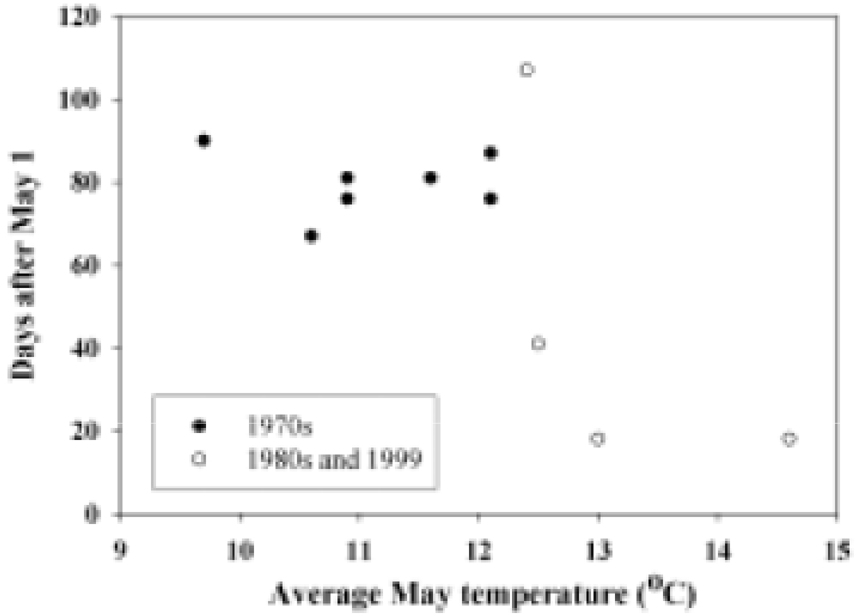


Figure 1. First appearance (Days after May 1) of *Mnemiopsis leidyi* ctenophores versus average May water temperature in Narragansett Bay, Rhode Island in 1970–1999 (drawn from data in Sullivan et al., 2001).

Effects on zooplankton phenology

- On land: invertebrates, amphibians, birds, and trees = mean phenological changes of 3–6 days per decade.
- In contrast, the mean phenological change observed for zooplankton is dramatically and significantly greater, at 7.6 days per decade

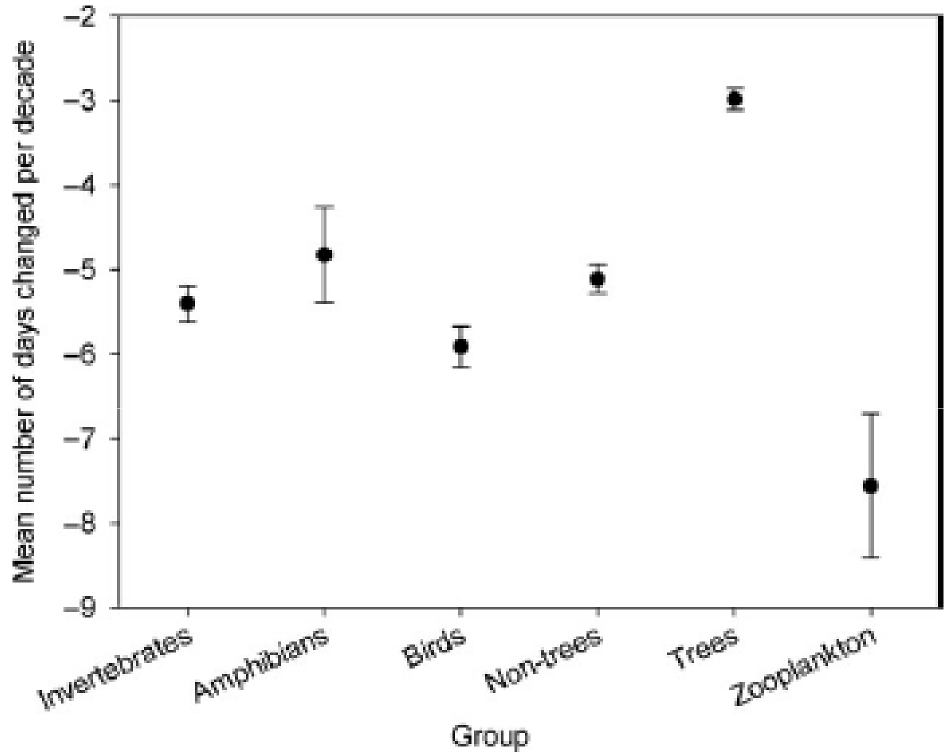


Figure 5. Changes in phenology from different studies (mean ± s.e.). Data for zooplankton from this study and other groups from Root *et al.* (2003).

Richardson (2008) after Root et al. (2003)

Effects on zooplankton abundance

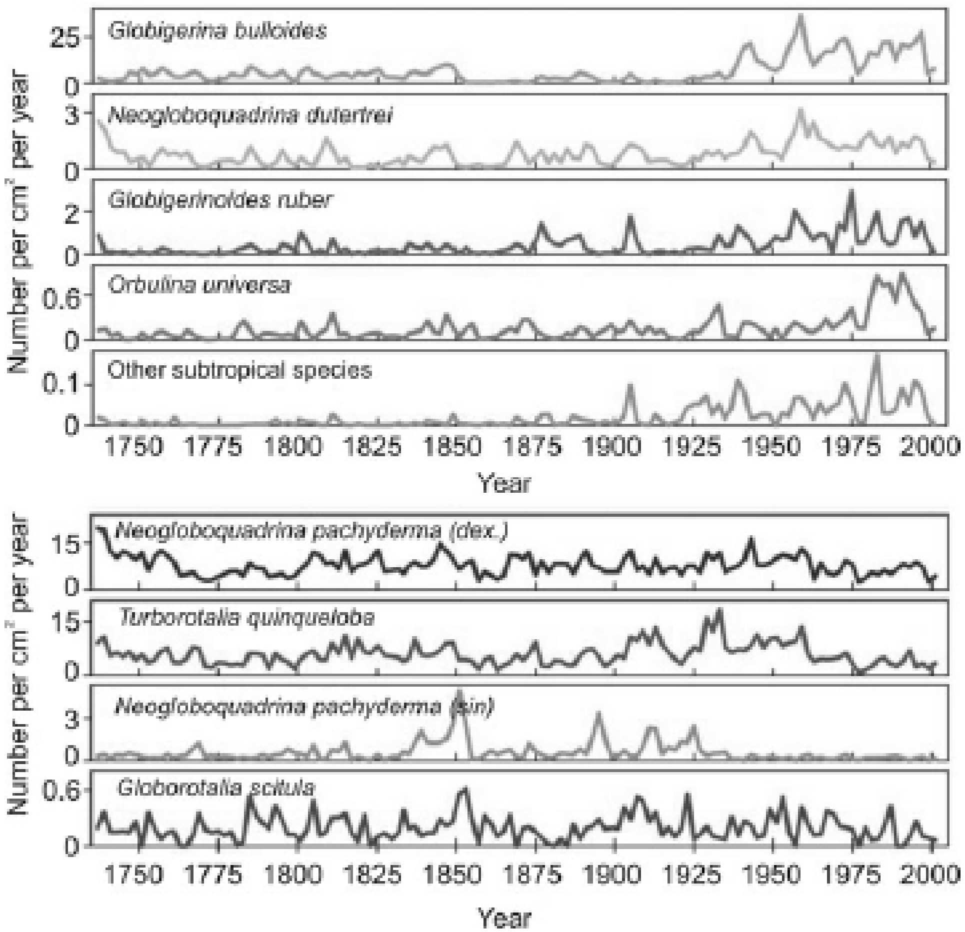


Figure 6. Fluxes of planktonic foraminifera in Santa Barbara Basin sediments. Top panel shows increased abundances of tropical – subtropical foraminifera in the 20th century. Bottom panel shows no temporal trend in temperate-polar foraminifera in the 20th century. Reprinted from Field *et al.* (2006), by permission of AAAS.

Changes in abundance in response to long-term warming:

Foraminifera in the California Current (Field et al., 2006)

Throughout the 20th century, the number of tropical/subtropical species has been increasing, reflecting a warming trend; this phenomenon is most dramatic after the 1960s

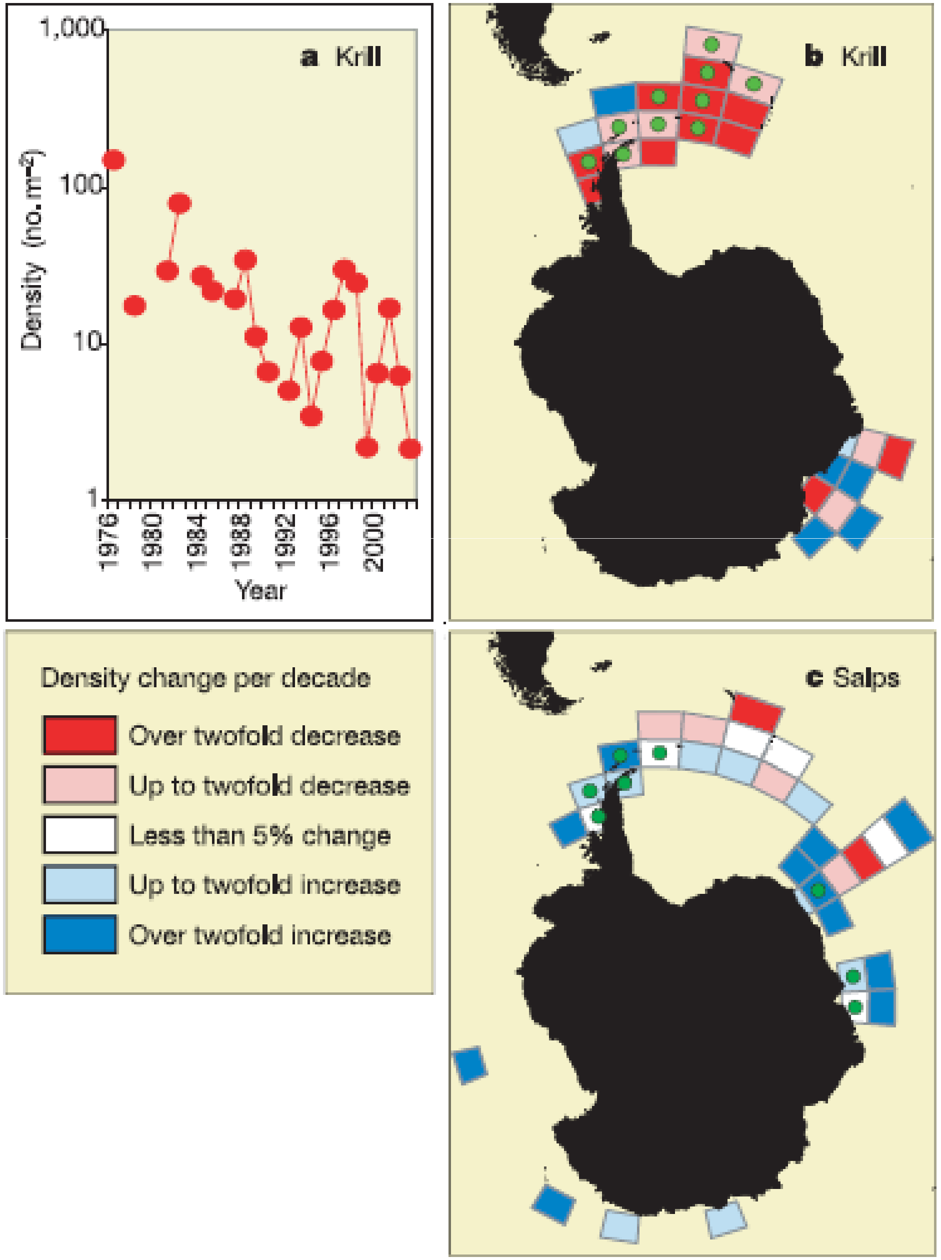
Effects on zooplankton abundance

- In the North Sea, phytoplankton become more abundant with warming of cool, windy, and well-mixed regions, probably because warmer temperatures boost metabolic rates and enhance stratification, thereby increasing the amount of time phytoplankton cells spend in the euphotic zone.

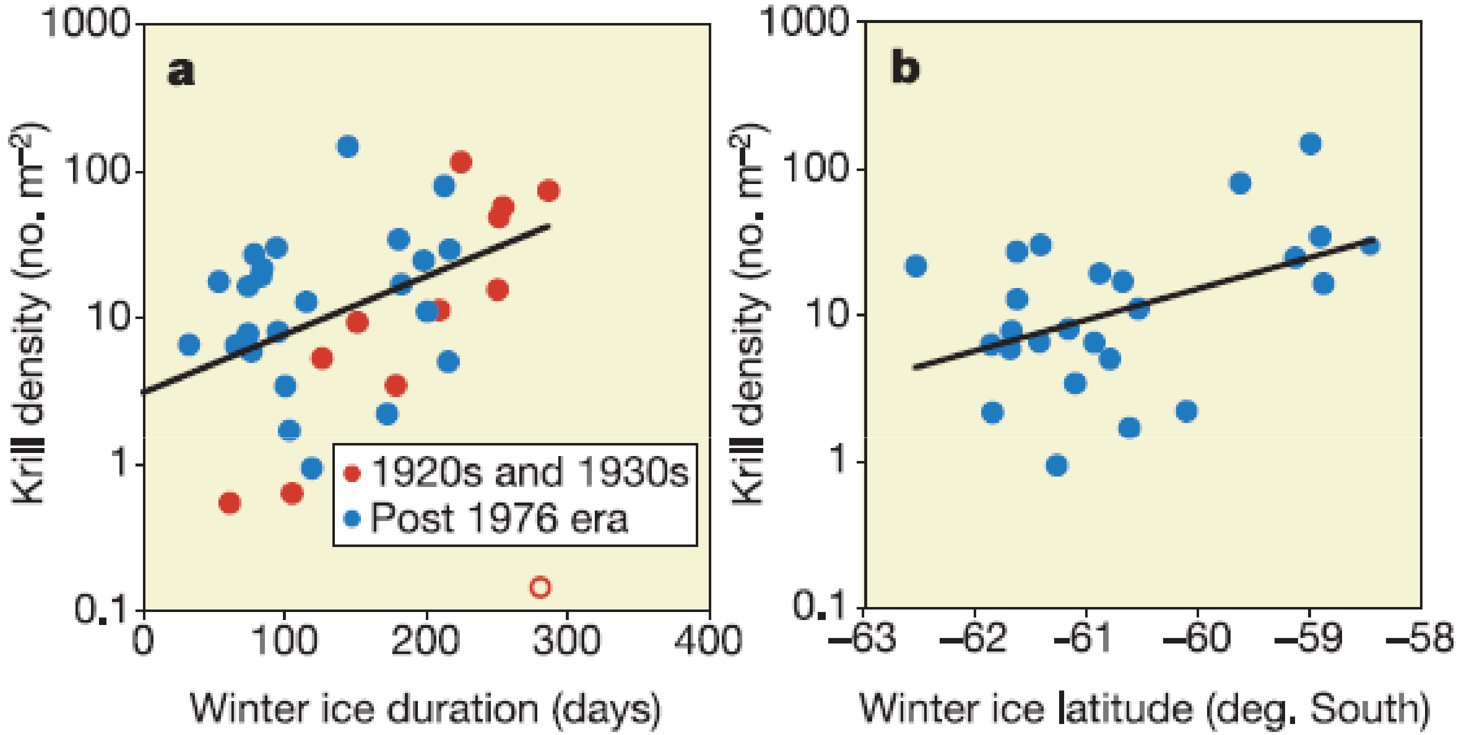
- However, phytoplankton become less abundant when already warm regions get even warmer, probably because warmer surface water blocks further nutrient-rich deep water from rising to the euphotic layer. This regional phytoplankton response is transmitted up the plankton foodweb to herbivorous copepods and carnivorous zooplankton.

Effects on zooplankton abundance

- Since the 1970s, there has been a decline in krill (*Euphausia superba*) biomass in the Southern Ocean and a concomitant increase in salps, which occupy less productive and warmer regions (Atkinson et al., 2004).



Effects on zooplankton abundance



This is related to the decrease in the extent and duration of winter sea ice.

Effects on zooplankton abundance

- Jellyfish: aggregations are a natural feature of healthy pelagic ecosystems, but evidence is accumulating that the severity and frequency of outbreaks is increasing in many areas, including the Bering Sea, northeastern US shelf, Gulf of Maine, Gulf of Mexico, Azov Sea, Black Sea, Caspian Sea, Northern Benguela upwelling ecosystem, East China and Yellow seas, Sea of Japan, and Seto Inland Sea [see reviews by Mills (2001), Purcell et al. (2007)].

- Global warming could lead to jellyfish increases because of their physiological response and its effect on plankton foodwebs.

IPCC - Under the A2 scenario, climate models predict that most of the world's oceans will have warmed by 2–3.5 °C by the end of this century

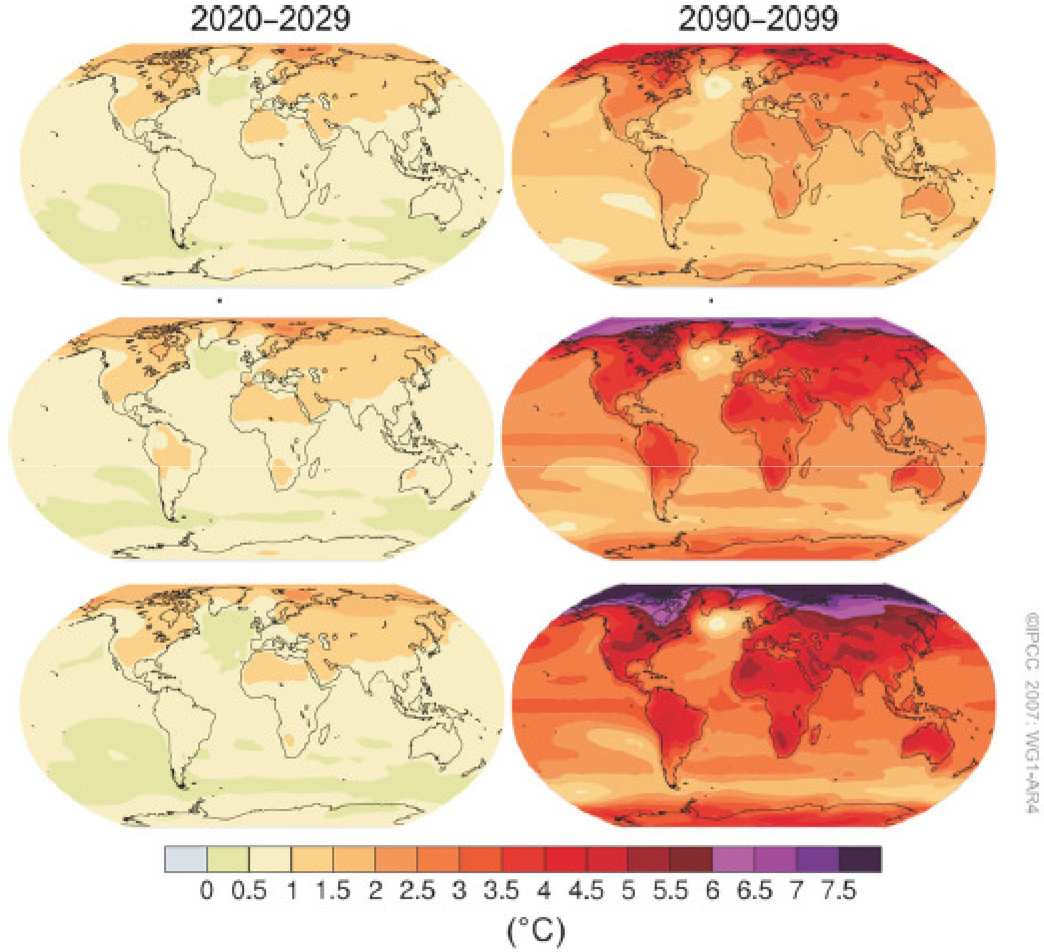
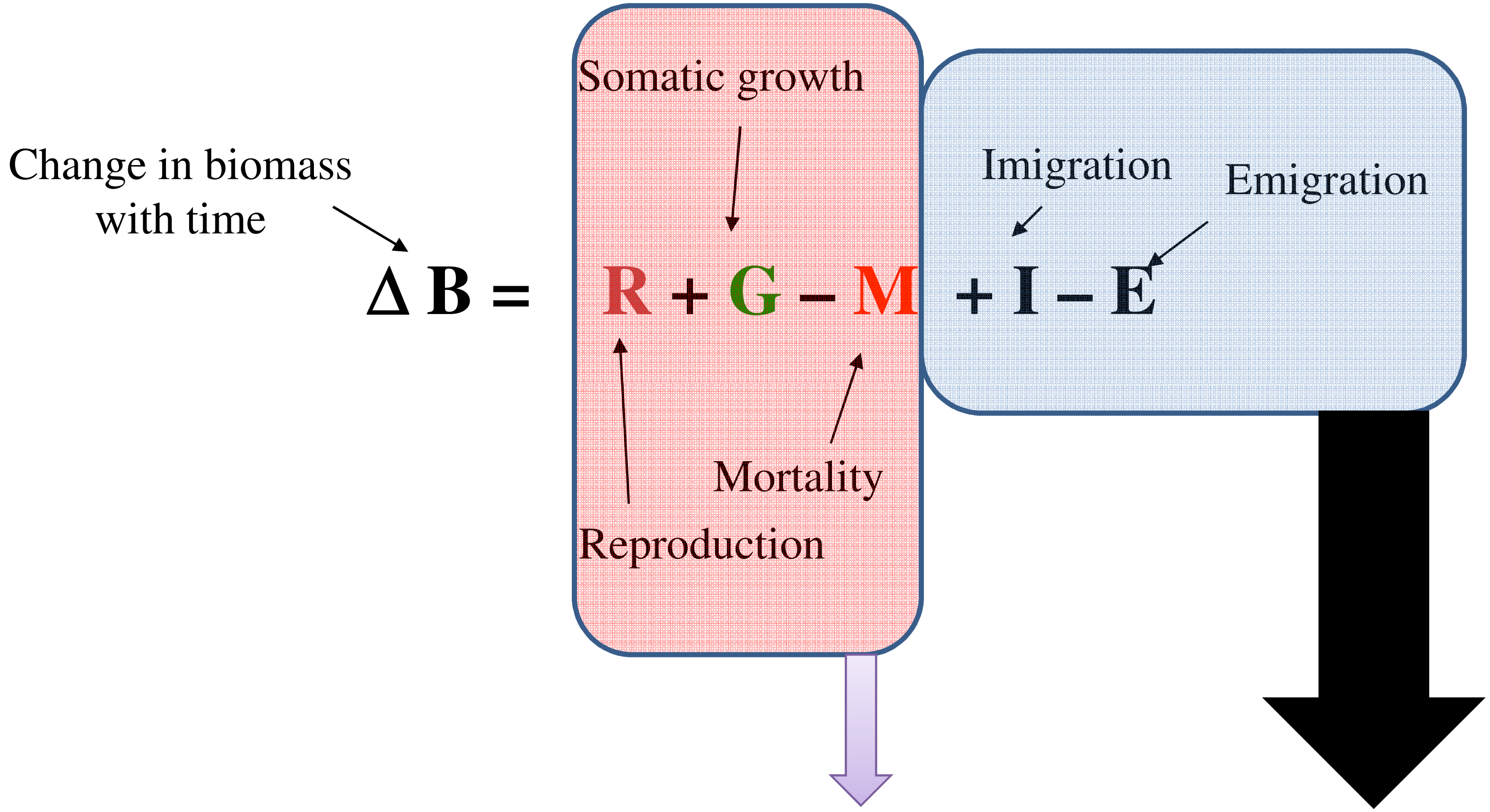


Figure 8. Projected surface temperature changes for decades early (2020 – 2029, left) and late (2090 – 2099, right) in the 21st century relative to 1980 – 1999. Panels show the GCM multimodel average projections for the B1 (top), A1B (middle), and A2 (bottom) emission scenarios. The three scenarios range from a relatively low emissions scenario (B1), through an intermediate scenario (A1B), to a high-emissions future (A2; from IPCC, 2007a, with permission).

Scaling the effects on zooplankton



CLIMATE CHANGE SCIENCE