Impacts of climate change on biodiversity: a palaeo-perspective

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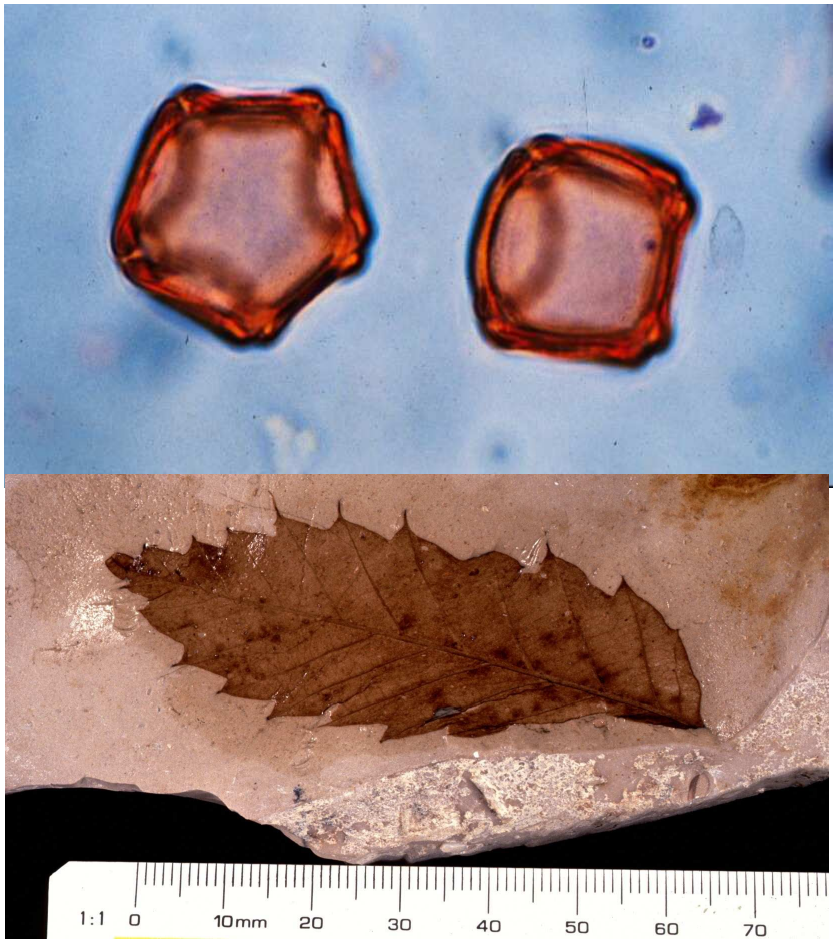
Palaeo-perspective



- Use of palaeoecological techniques to reconstruct long-term environmental change (> 50 years)
- Fossil pollen, stable isotopes ($\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$), sediment geochemistry, mineral magnetics and micro & macrofossil charcoal analysis
- This information used to address ecological questions on timescales ranging from 10's to millions of years

Brief

- How have climate and CO_2 changed in the past, at what rate and what has driven these changes?
- How has biodiversity responded to these changes?
- How do these changes compare to what we can expect with anthropogenically forced climate change?
- How can the paleo-record be used to inform our understanding of expected impacts to biodiversity from current and future climate changes?

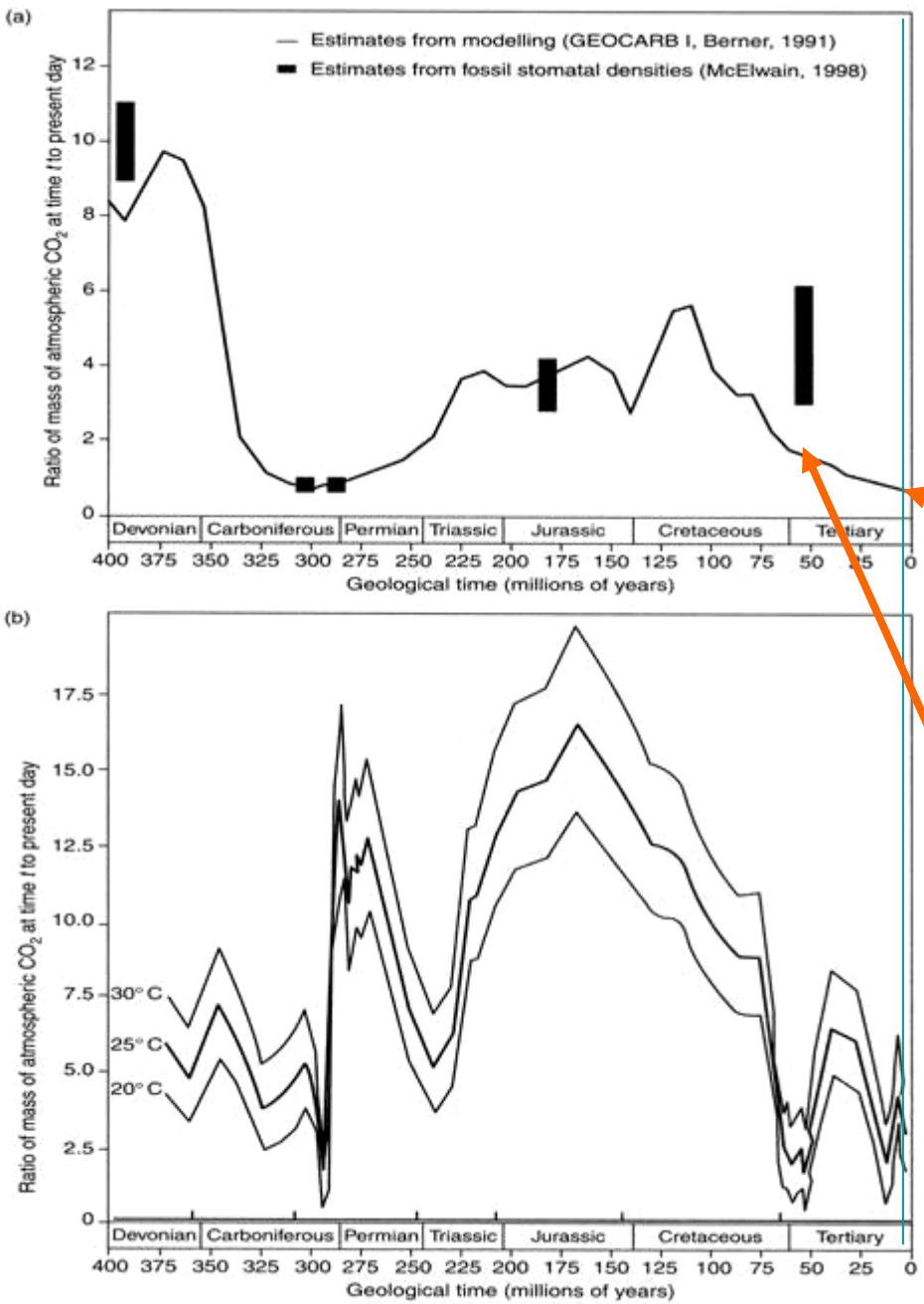
How have climate and CO_2 changed in the past, at what rate and what has driven these changes?

Timescales and mechanisms of climate change

- Four timescales to consider:
  - Tectonic (millions of years)
  - Orbital (hundreds of thousands of years)
  - Millennial (thousands of years)
  - Decadal (tens of years)
- Different predominant mechanism driving the change depending upon timescale

Timescale	Predominant driving mechanism	Rate of climate change
Tectonic	Plate tectonics, volcanic activity	Changes occurring over millions of years
Orbital	Changes in position of Earth's orbit around sun	100,000's to 1000's years (e.g. glacial-interglacial cycles)
Millennial	Solar variability, changes in ocean circulatory patterns (THC)	1000's to <100's years
Decadal	Sun-spot activity, changes in ocean circulatory patterns	100's to <10's years

Changes in atmospheric CO_2 over tectonic timescale



a) results from Geocarb model (Berner, 2004)

Approx. present day values

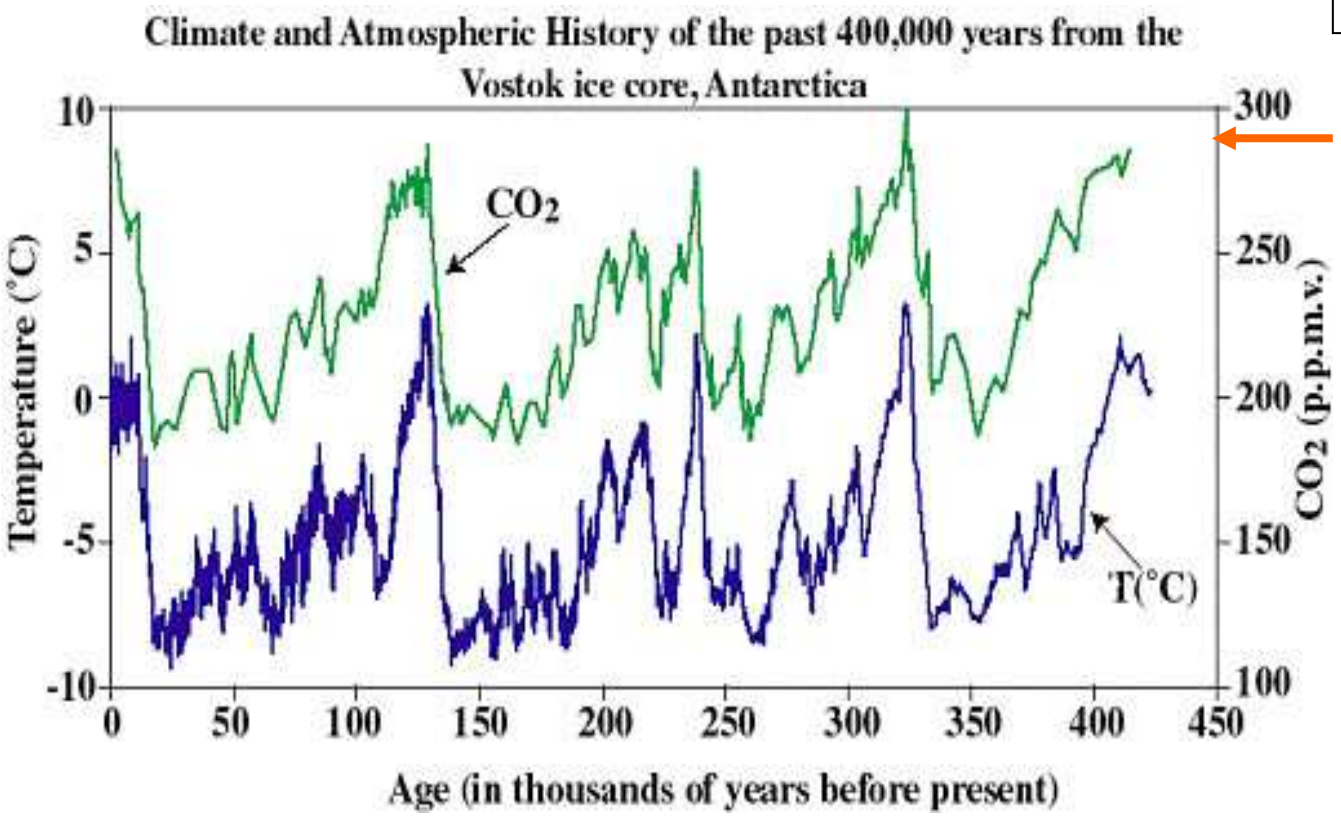
2050 values

b) results from fossil soil carbonates (Ekart *et al.*, 1999)

Changes in atmospheric CO_2 and temperature over orbital timescales

Currently at 380 ppmv

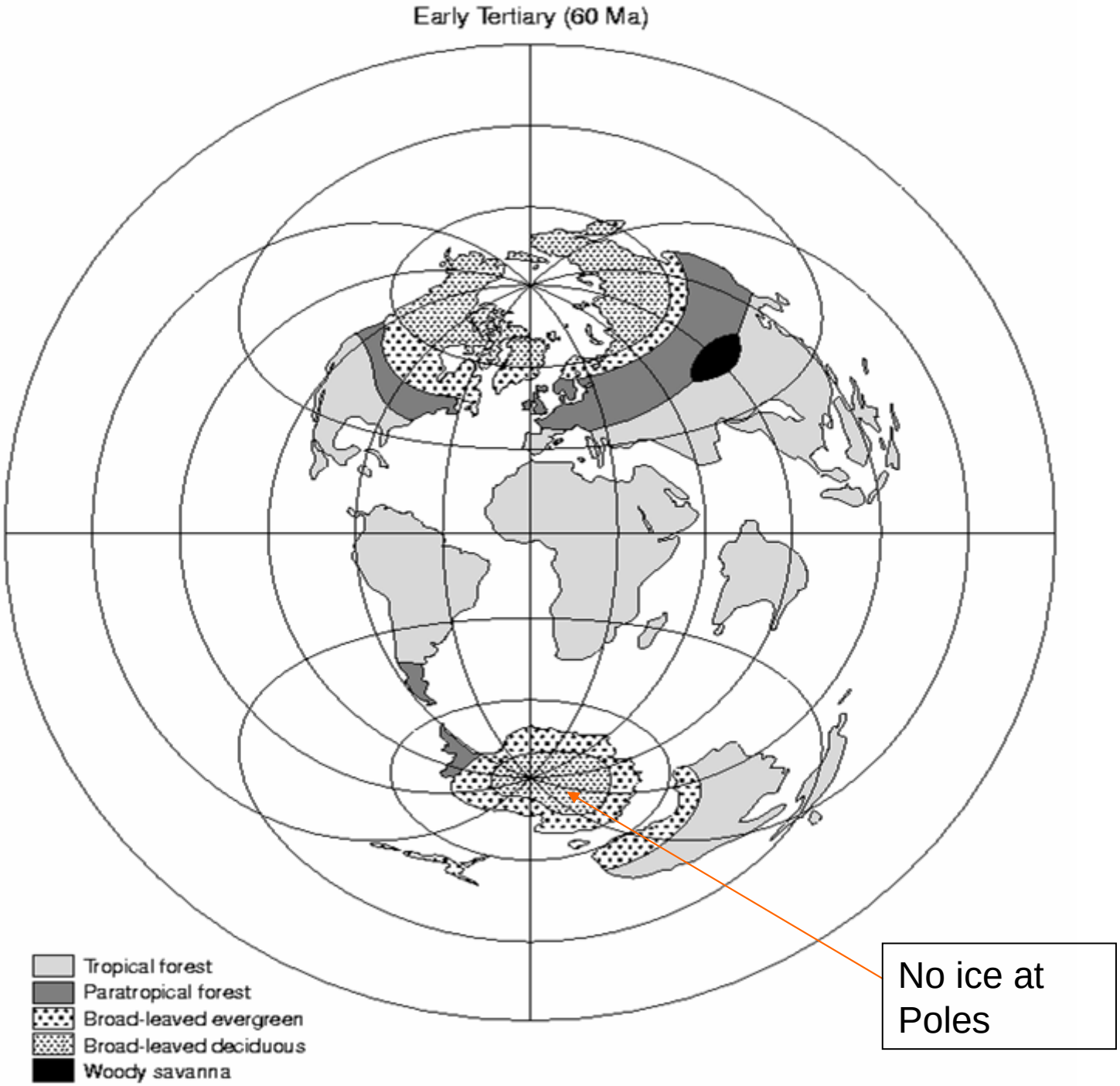
Pre-industrial levels

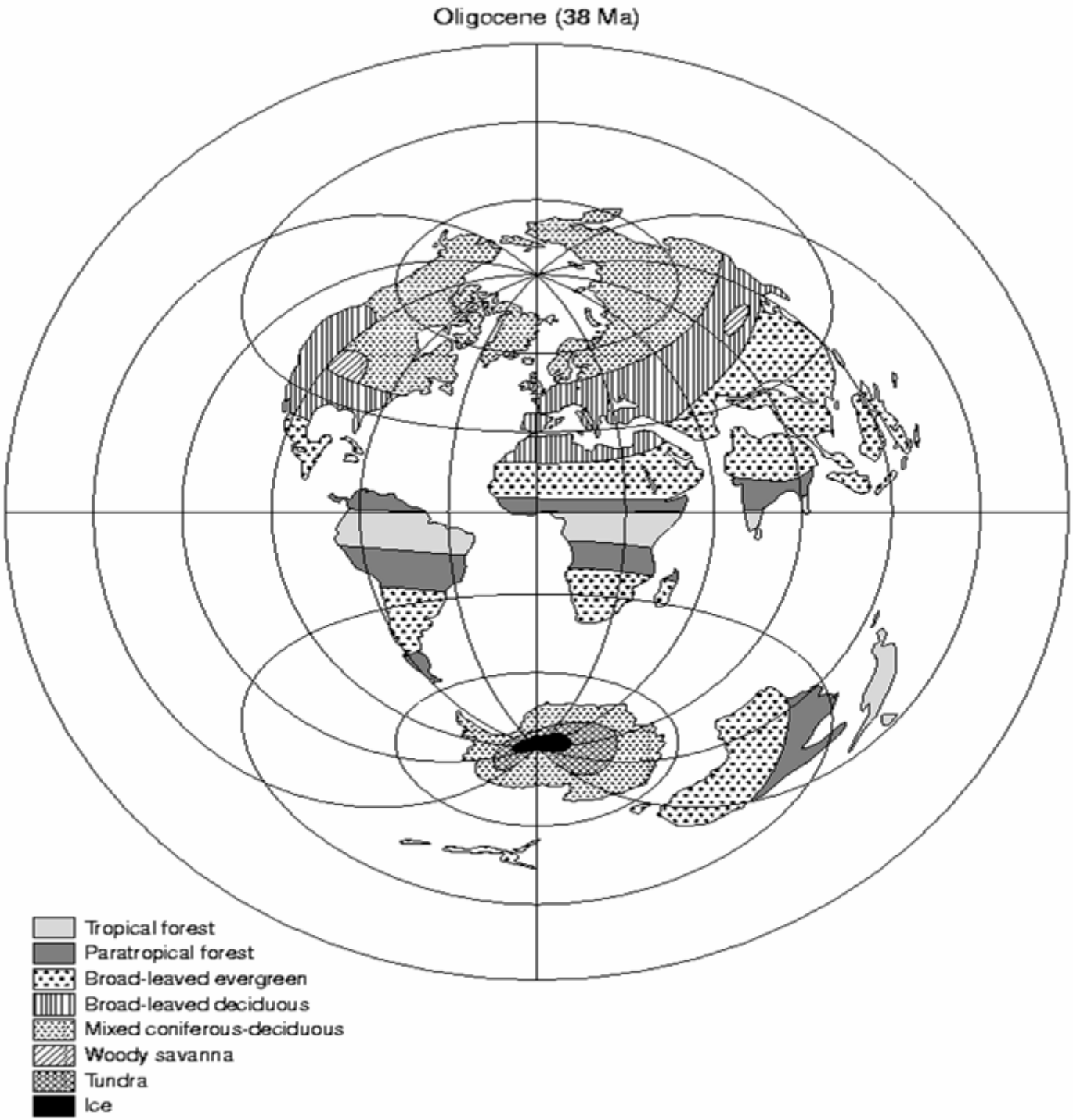


Petit et al., 1999, Nature,

How has biodiversity responded to these changes?

- Five predominant responses:
  - Changes in distribution
  - Rates of population turnover
  - Abundance/richness
  - Extinctions
  - Speciations
- At the local and region scale plants & animals tend to respond individualistically
- At the global scale, major biome re-distribution

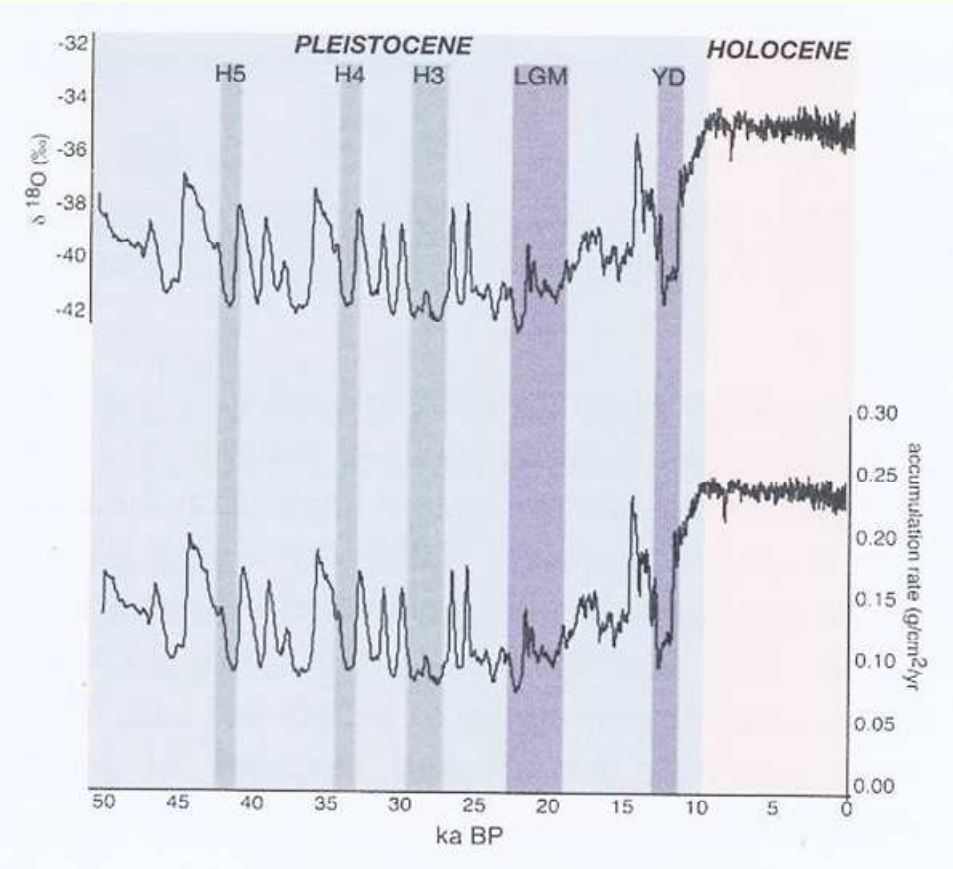

Early Tertiary (60 Ma)
Tropical forest
Paratropical forest
Broad-leaved evergreen
Broad-leaved deciduous
Woody savanna
No ice at Poles


Oligocene (38 Ma)
Tropical forest
Paratropical forest
Broad-leaved evergreen
Broad-leaved deciduous
Mixed coniferous-deciduous
Woody savanna
Tundra
Ice

How do these changes compare to what we can expect with anthropogenically forced climate change?

Last glacial (Younger Dryas)–interglacial (Holocene) transition = Pleistocene–Holocene transition.

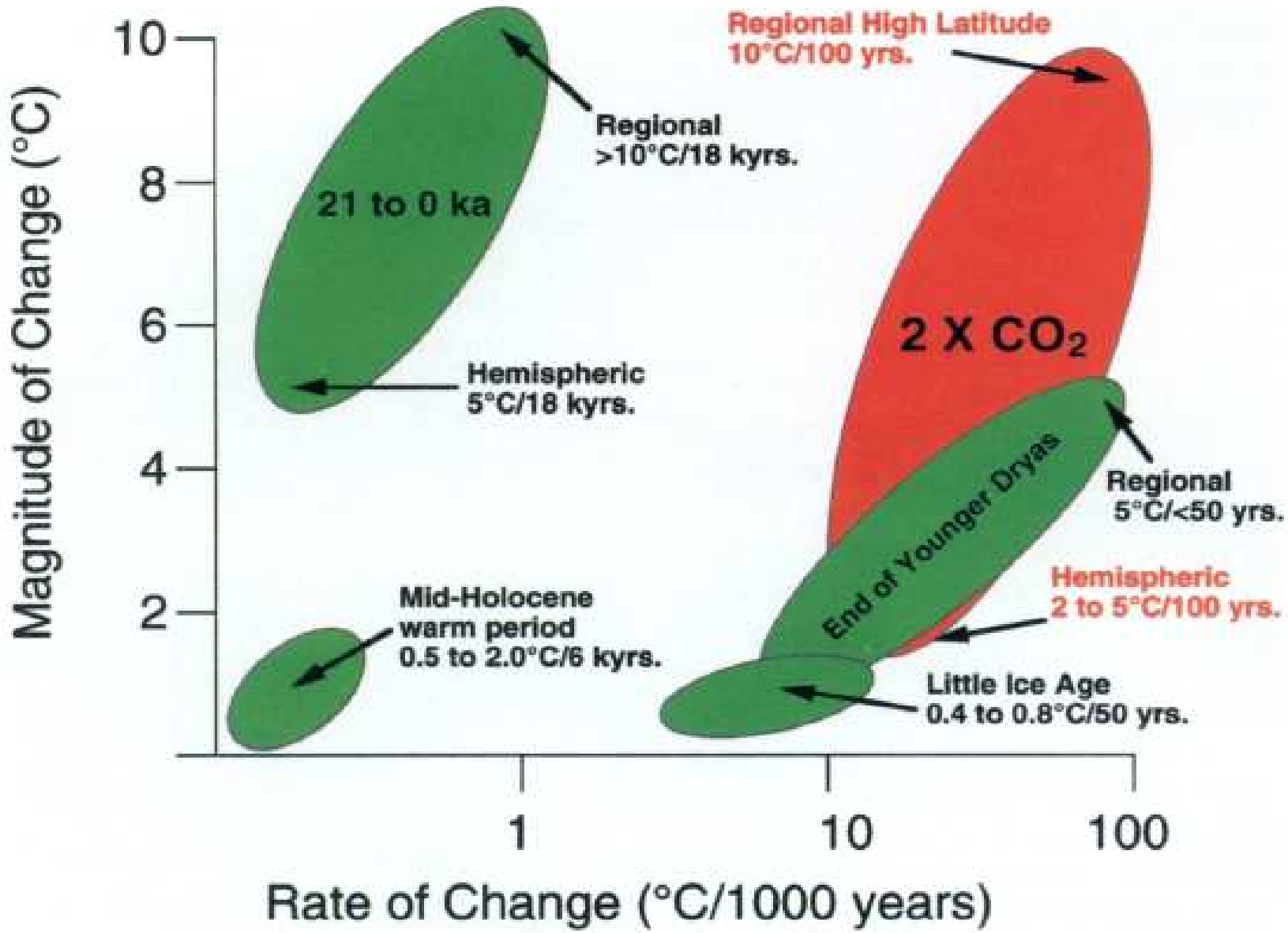
Occurred in 30-50 years with an amplitude of about 15-20ºC according to Greenland ice-core records.



Oxygen isotopes

Ice accumulation

Alverson *et al*. (2003)



S.T. Jackson & J. T. Overpeck, 2000, Paleobiology, 26, 194

How can the paleo-record be used to inform our understanding of expected impacts to biodiversity from current and future climate changes?

Temporal scale of recently published biodiversity assessments and reports

Table 1. Recently published biodiversity assessments and reports

Biodiversity Assessment/report	Commissioning organization	Author/Year/Web address	Longest temporal data set used
Living Planet Report 2002;	WWF	Loh, J. (2002) http://www.wwf.org.uk/filelibrary/pdf/livingplanet2002.pdf	30 years (1972–2002)
Red List of Threatened Species: Global Species Assessment	IUCN	IUCN (2004); http://www.iucnredlist.org	8 years (1996–2004)
Global Environment Outlook (GEO-3)	UNEP	UNEP (2002); http://www.unep.org/geo/geo3/	30 years (1970–2000)
Millennium Ecosystem Assessment	UNDP, UNEP, World Bank and WRI	UNEP (2001); http://www.millenniumassessment.org/en/global.condition.aspx	45 years (1960–2005)
Global Forest Resources Assessment 2000	FAO	FAO (2001); Forest Resource Assessment http://www.fao.org/forestry/site/7949/en	10 years (1990–2000)
World Atlas of Biodiversity	UNEP-WCMC	See [12].	30 years (1970–2000)
Measuring Biodiversity for Conservation	Royal Society, London	Royal Society Working Party (2003); http://www.royalsociety.org/document.asp	52 years (1950–2002)

K.J. Willis, et al. 2005, TREE, 20, 107-108

Why do we need records greater than 50 years?

- Average time of PhD research project
  - **4 yrs**
- Average time of research-council funded project
  - **5-10 yrs**
- ‘Long-term’ ecological plots
  - **10-50 years**
- Average generation times of most trees
  - **50-100 yrs**

Harvard forest – present day

Harvard forest – 120 yrs ago

Convention on Biological Diversity

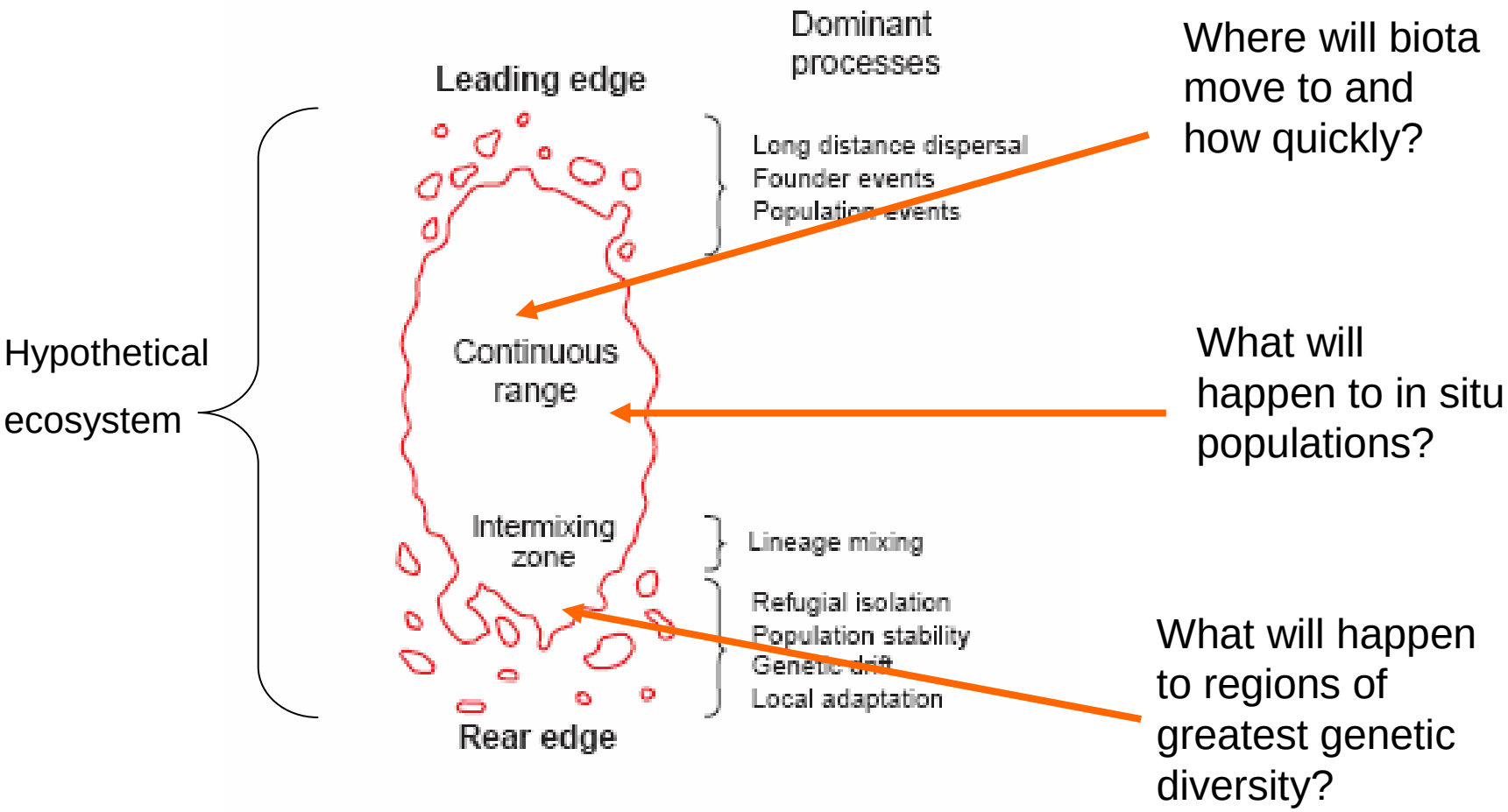
Recent CBD report suggested key action plans that are needed in response to current and future climate change:

i) to conserve biodiversity that is especially sensitive to climate change;

ii) to preserve habitats so as to facilitate the long-term adaptation of biodiversity;

iii) to improve our understanding of climate change – biodiversity linkages

To improve our understanding of climate change – biodiversity linkages



K.J. Willis & H.J.B. Birks, *Science*, 2006, 314

Where will biota move to in response to climate change?

- Bioclimatic envelope models to predict future distribution of species in response to climate change
- Use data from present day species distribution in relation to climate to build models
- Now a suite of predictive models to determine biogeographic effects of changes in climate
- Number of conservation strategies associated with the output from these models
  - ensuring that reserve boundaries allow for potential species range shifts
  - designing dispersal corridors among reserves

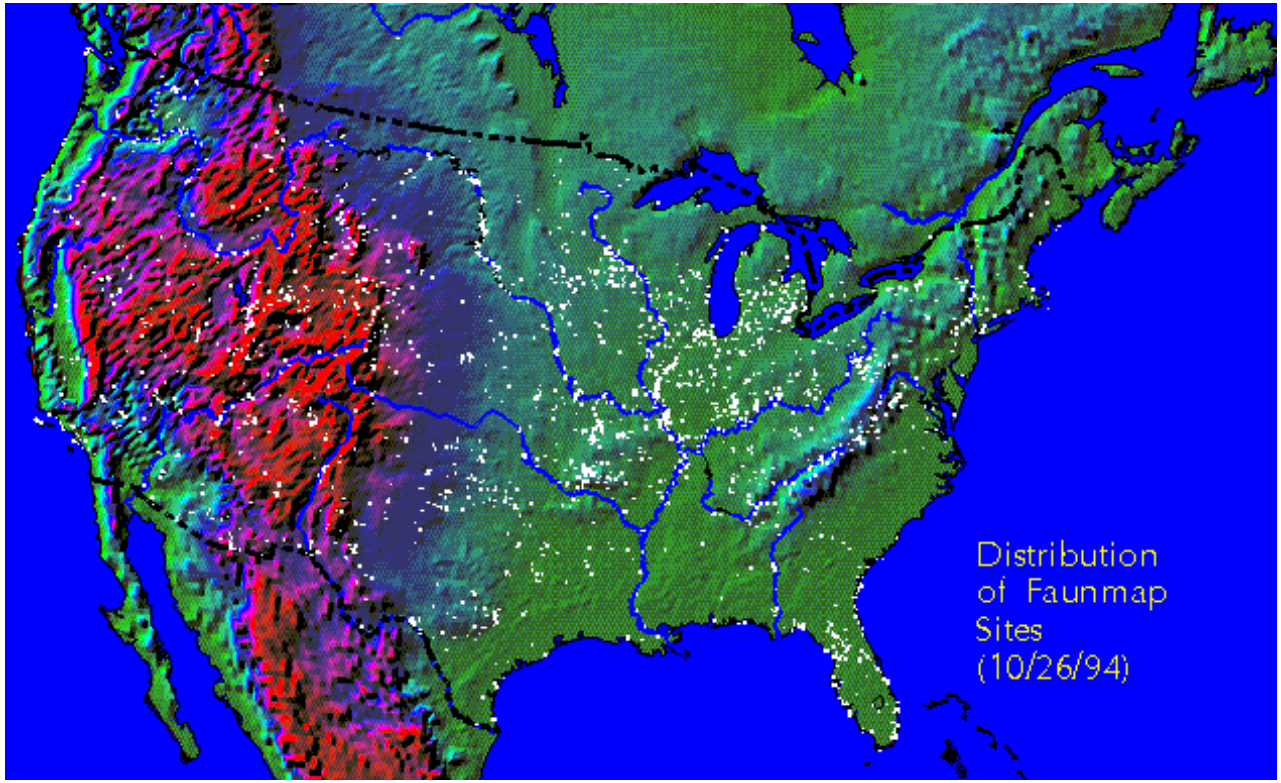
Where will biota move to in response to climate change?

- However, these models are highly sensitive to the ‘assumptions, algorithms and parameterizations of different methods’ (Araújo et al., 2005)

- Understanding the percentage of error in the predictions is an area where temporal studies have much to offer climate change conservation strategies

- Through the backward prediction of the models (hind-casting), results can be compared to fossil evidence and accuracy of the models tested

Case study: Distributional shifts in mammal species across 48 states of United States



http://www.museum.state.il.us/research/faunmap/aboutfaunmap.html

Paleo Start Date: 40 ka
Paleo Stop Date: 0 ka
Chrono Unit: QUATERNARY

E. Martinez-Meyer et al. 2004, *Global Ecology & Biogeography*, 13, 305-314

Case study: Distributional shifts in mammal species across 48 states of United States

- An ecological niche model was run backwards for the time interval Last Full Glacial (14,500-20,500 year BP) for 23 extant mammal species in the USA

- Predicted distribution was compared to actual distribution records obtained from the fossil database FAUNMAP

- The model was also run in reverse (i.e. using fossil data and palaeoclimatic data to predict present distribution) and similar comparisons made.

E. Martinez-Meyer et al. 2004, *GEB*, 13, 305-314

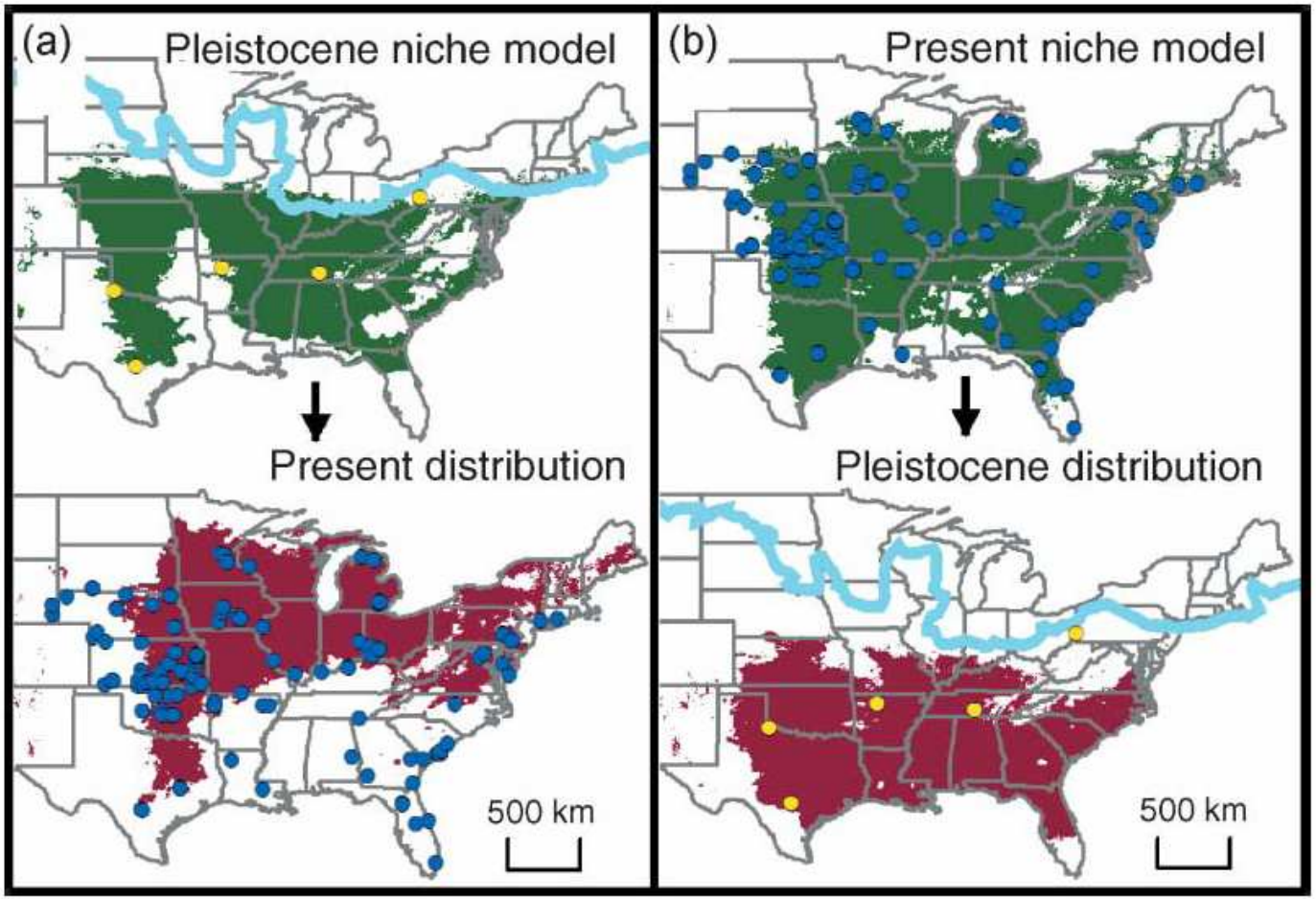


Figure 1 Inter-temporal predictions for the eastern mole (*Scalopus aquaticus*) for which predictivity between time periods was statistically significant ($P \geq 0.001$). (a) Niche model and prediction for the Pleistocene (top) and its projection to present climatic conditions (bottom). (b) Niche model and prediction for the present (top) and its projection to the Pleistocene climatic conditions (bottom). Yellow and blue dots are known occurrences in the Pleistocene and present, respectively. The blue line in the Pleistocene maps represents the ice sheet boundaries 18 000 year BP.

E. Martinez-Meyer et al. 2004, *GEB*, 13, 305-314

Case study: Distributional shifts in mammal species across 48 states of United States

- For 9 species the model was able to accurately predict both Pleistocene distributions from the present-day data and *vice versa*.

- The remaining 14 faunal species either had significant predictions only one way but not the other (9 species) or were not significant in either direction (5 species)

- Using the fossil record, therefore possible to identify those species whose distribution could be predicted effectively and those which could not.

E. Martinez-Meyer et al. 2004, *GEB*, 13, 305-314

Where will biota move to in response to climate change?

- The question of why some species distribution cannot be predicted accurately using species-climate modelling can also be potentially answered from palaeoecological studies

- Case study: Regional spread and stand-scale establishment of *Fagus sylvatica* and *Picea abies* in Scandinavia

R. H. W. Bradshaw & M. Lindbladh, 2005, *Ecology*, 86, 1675-1686

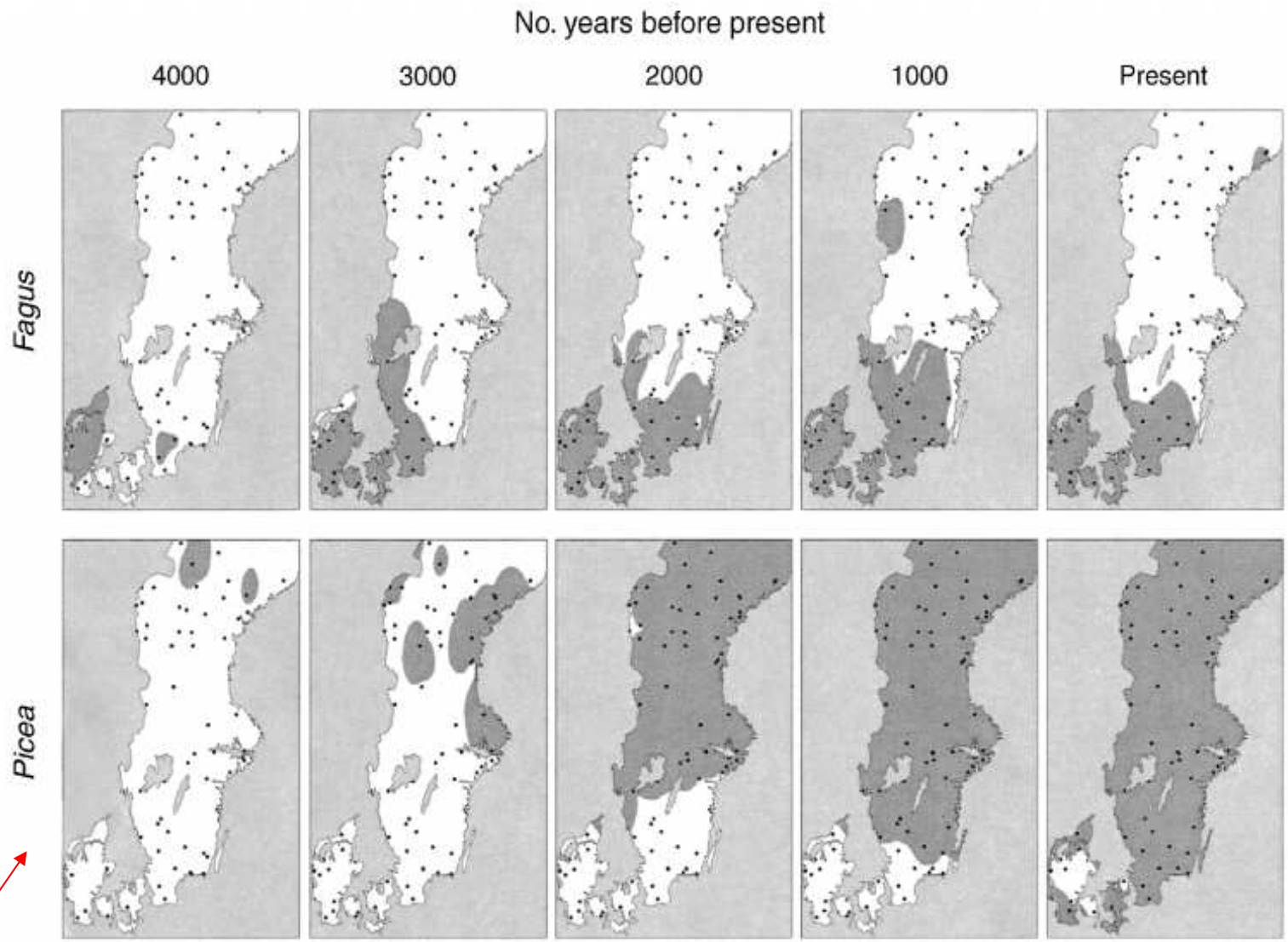


FIG. 2. South Scandinavian distributions (dark gray shading) of *Picea abies* and *Fagus sylvatica* reconstructed from regional pollen data for the last 4000 years. The point symbols show the regional pollen sites included in the database.

Picea closely tracks the changing area of suitable regional climate

R. H. W. Bradshaw & M. Lindbladh, 2005, *Ecology*, 86, 1675-1686

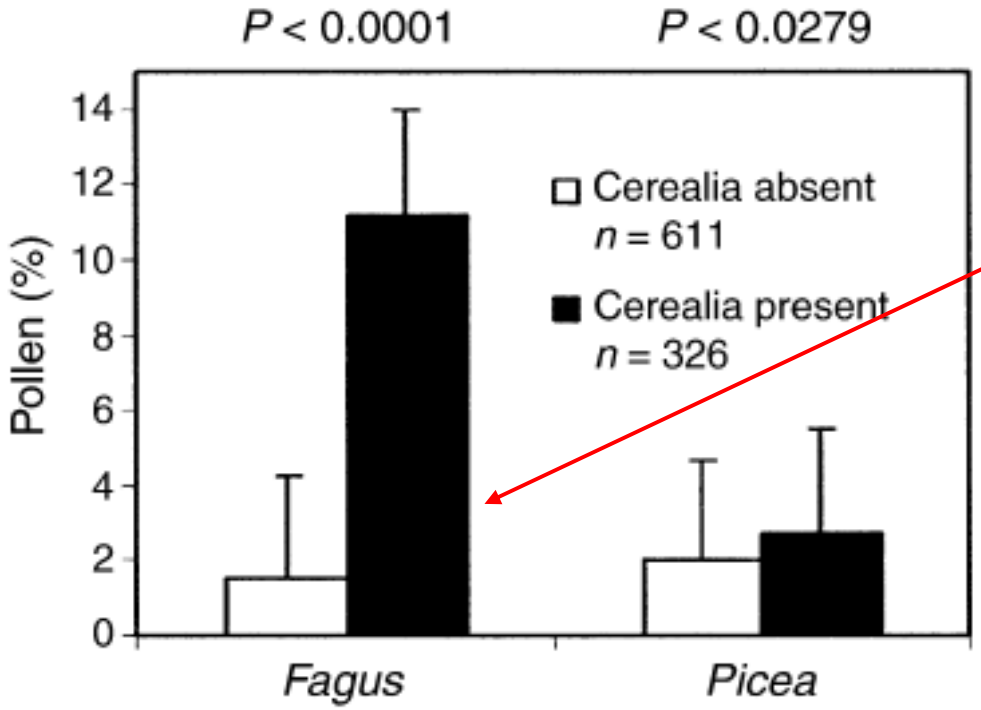
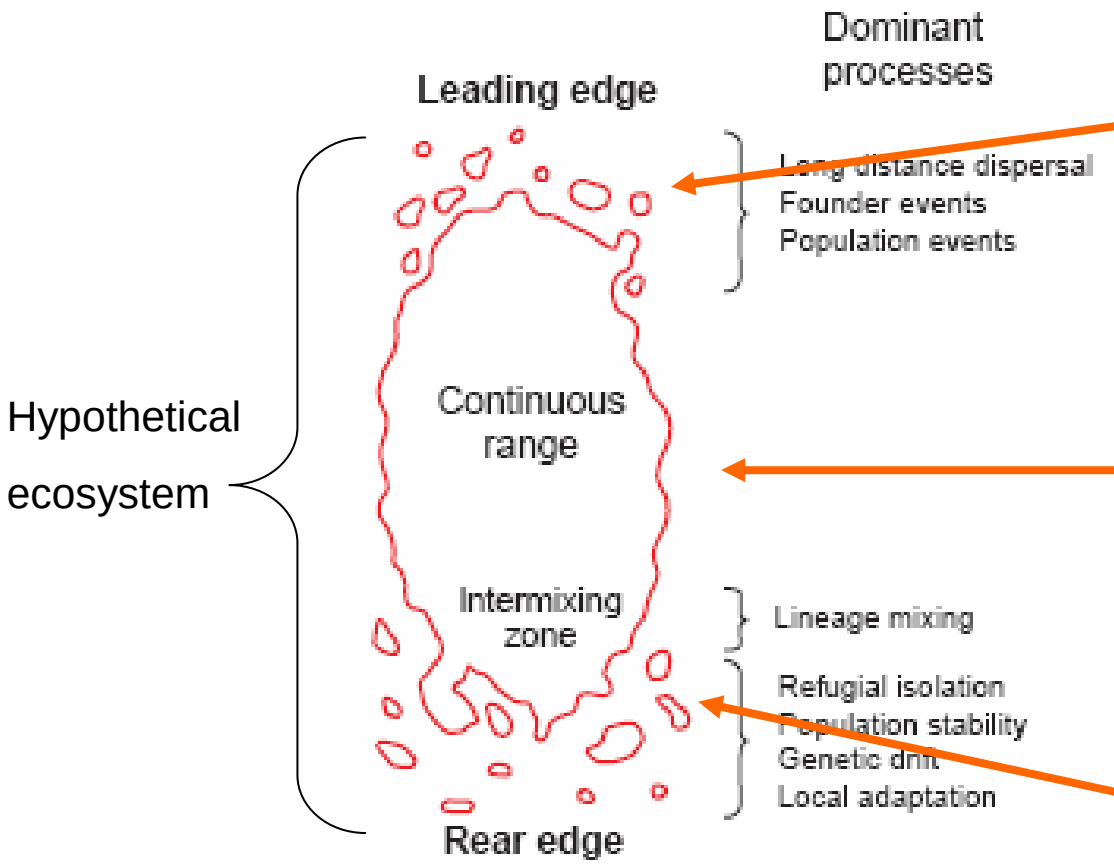


FIG. 5. Pollen percentage values (mean + SD) with a total terrestrial pollen sum for *Picea abies* and *Fagus sylvatica* in small hollow samples with and without cereal grain (Cerealia) pollen. Levels of significance in the differences between the mean values are indicated for each species.

Changes in distribution of *Fagus* over past 4000 years more closely linked to anthropogenic factors & burning than climate

To improve our understanding of climate change – biodiversity linkages

Key questions:

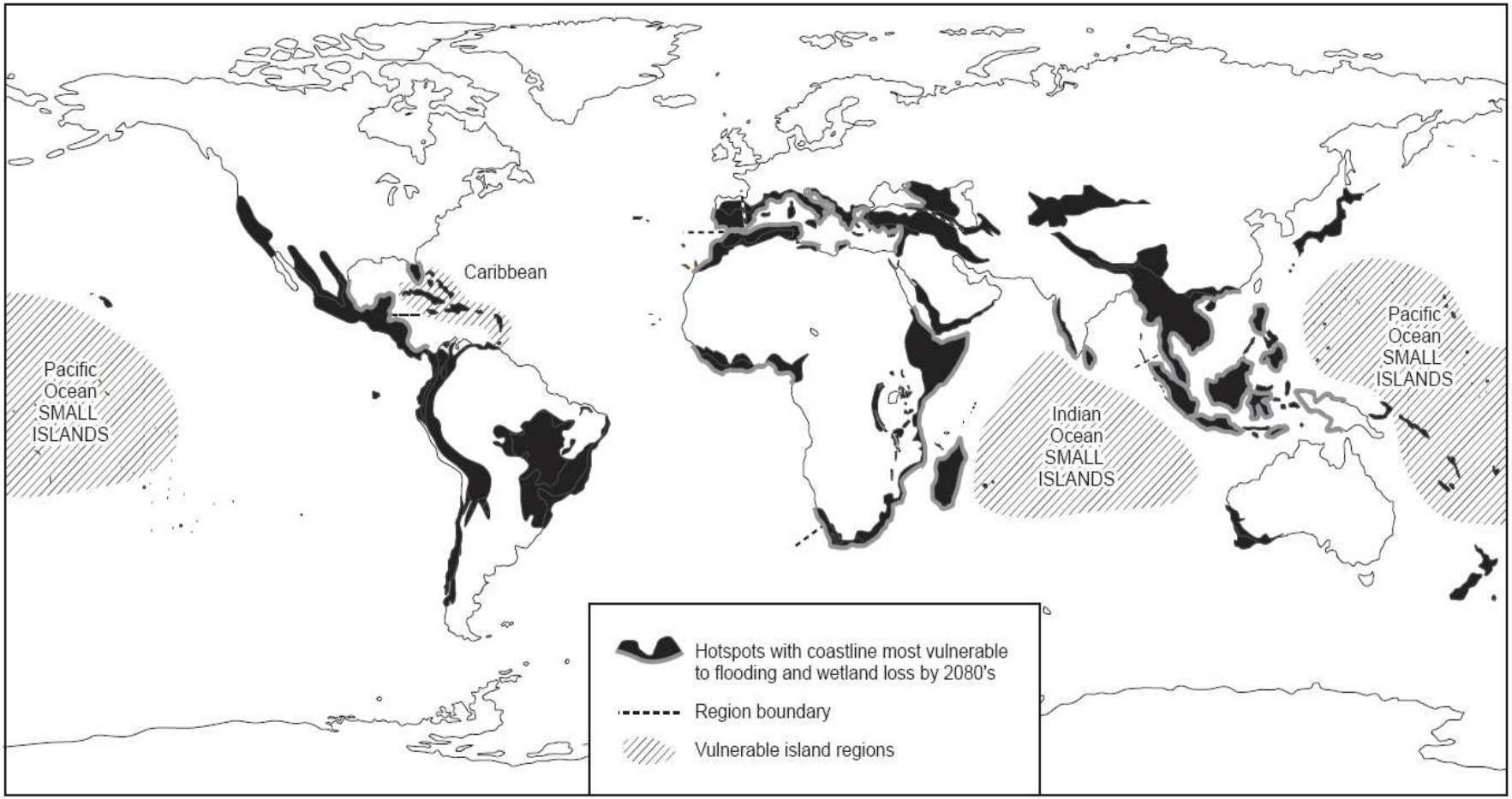


Where will biota move to and how quickly?

What will happen to *in situ* populations?

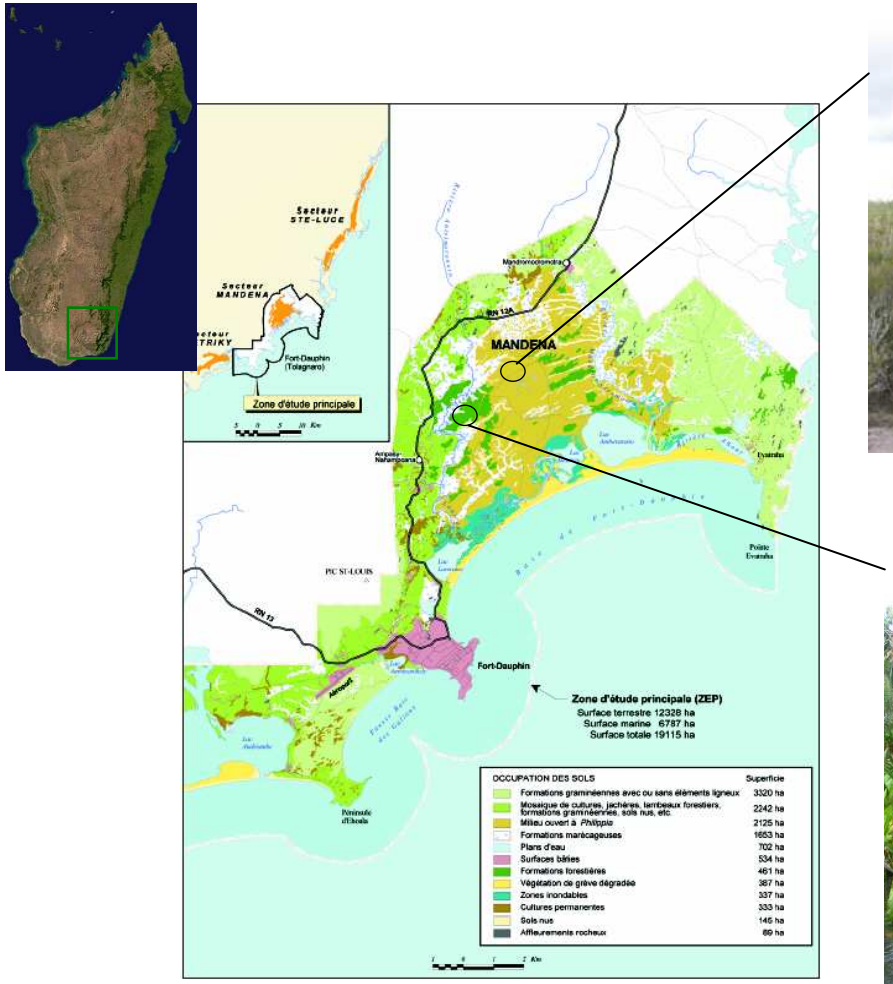
What will happen to regions of greatest genetic diversity?

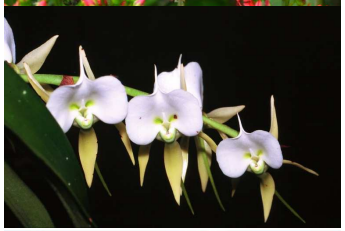
Biodiversity changes in response to rising sea-levels



K.J. Willis et al., 2007, *Phil Trans Roy Soc B*., 362, 175.

Fragmentation, resilience and recovery of Madagascar's littoral forest to late Holocene sea level rise





M. Virah-Sawmy & K.J. Willis, unpublished

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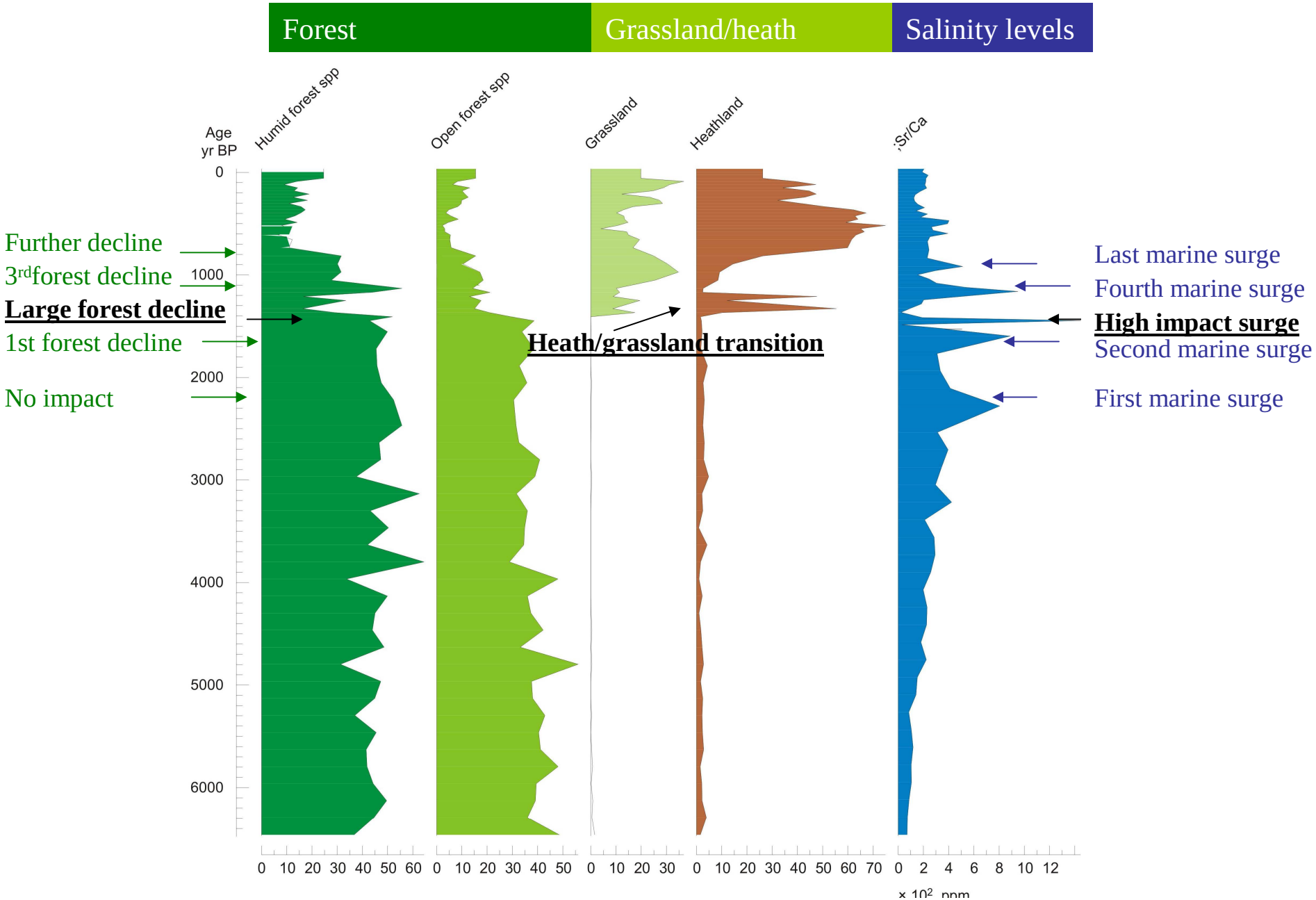
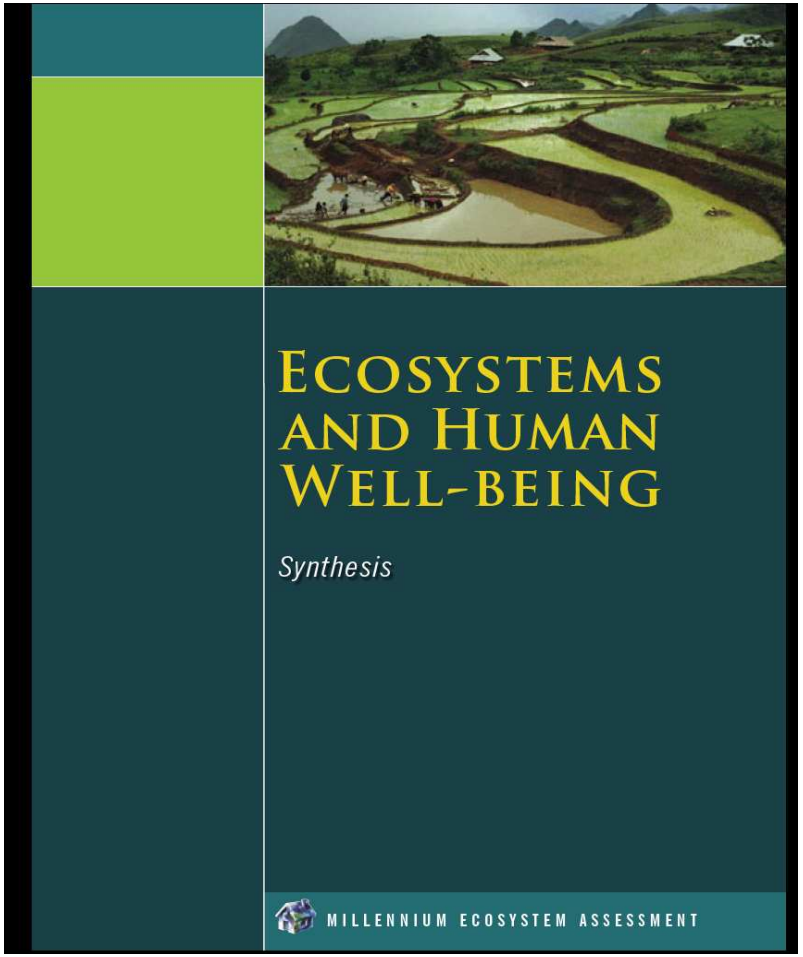


Conclusions



- Throughout Earth's history there have been climate features similar to those seen currently (higher CO_2, rapid climate change, no ice at the Poles).
- Biodiversity responses to these climate changes have been varied & dynamic
- Most studies examining the interactions between biodiversity-climate change use only v. short-term records (<50 years)
- These may be of limited relevance for many organisms because they often are shorter than a single generation of the organism being studied
- Interactions between climate change and biodiversity are often non-linear and it is important to identify thresholds and irreversible changes
- A palaeo-perspective can start to provide such information and should routinely be sought alongside spatial data