CLIMATE CHANGE AND SMALL RODENTS

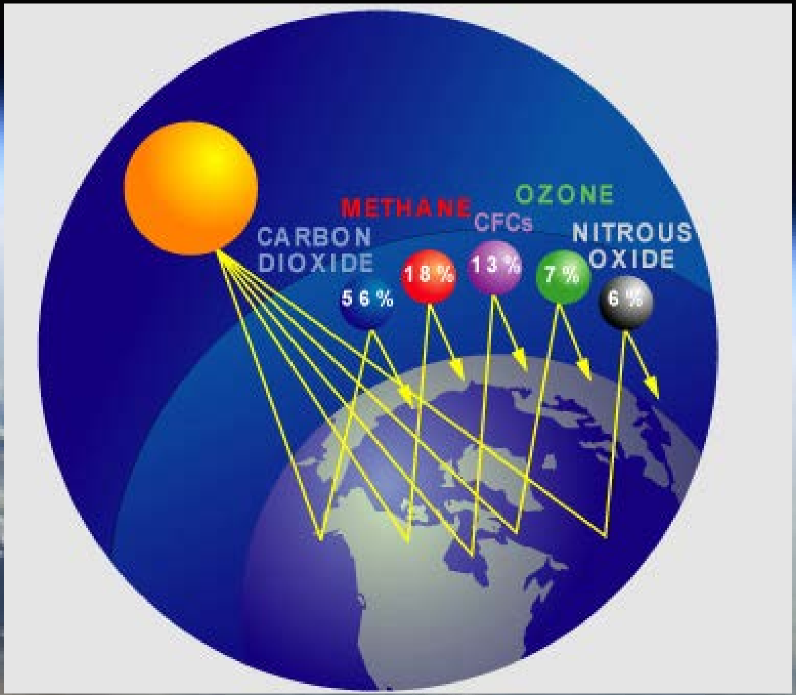
Otso Huitu, PhD, researcher
Natural Resources Institute Finland (Luke)
otso.huitu@luke.fi

Introduction

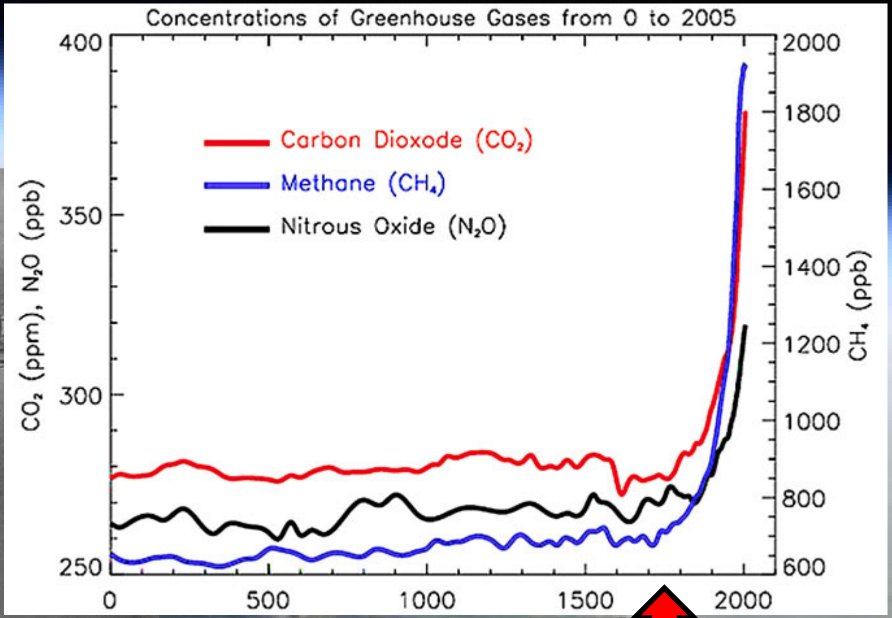
1. Physical basis of climate change
2. Ecological effects of climate change
3. Distribution changes
4. Phenology
5. Population dynamics, direct and indirect effects of climate change
6. Conclusions

Physical basis of climate change

- most important anthropogenic greenhouse gases: carbon dioxide CO_2, methane CH_4, halocarbons CFCs, nitrous oxide N_2O
- major emissions from fossil fuel burning, land-use, agriculture, deforestation
- accumulate into atmosphere, substantial increase following the industrial revolution

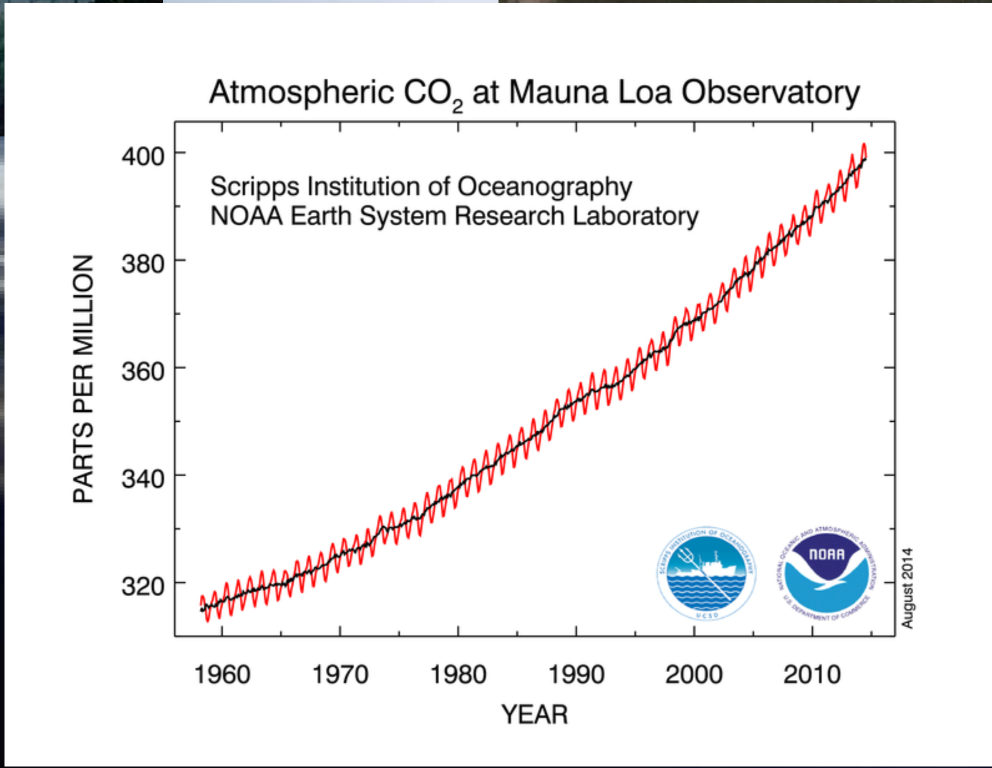


Observations: global CO_2

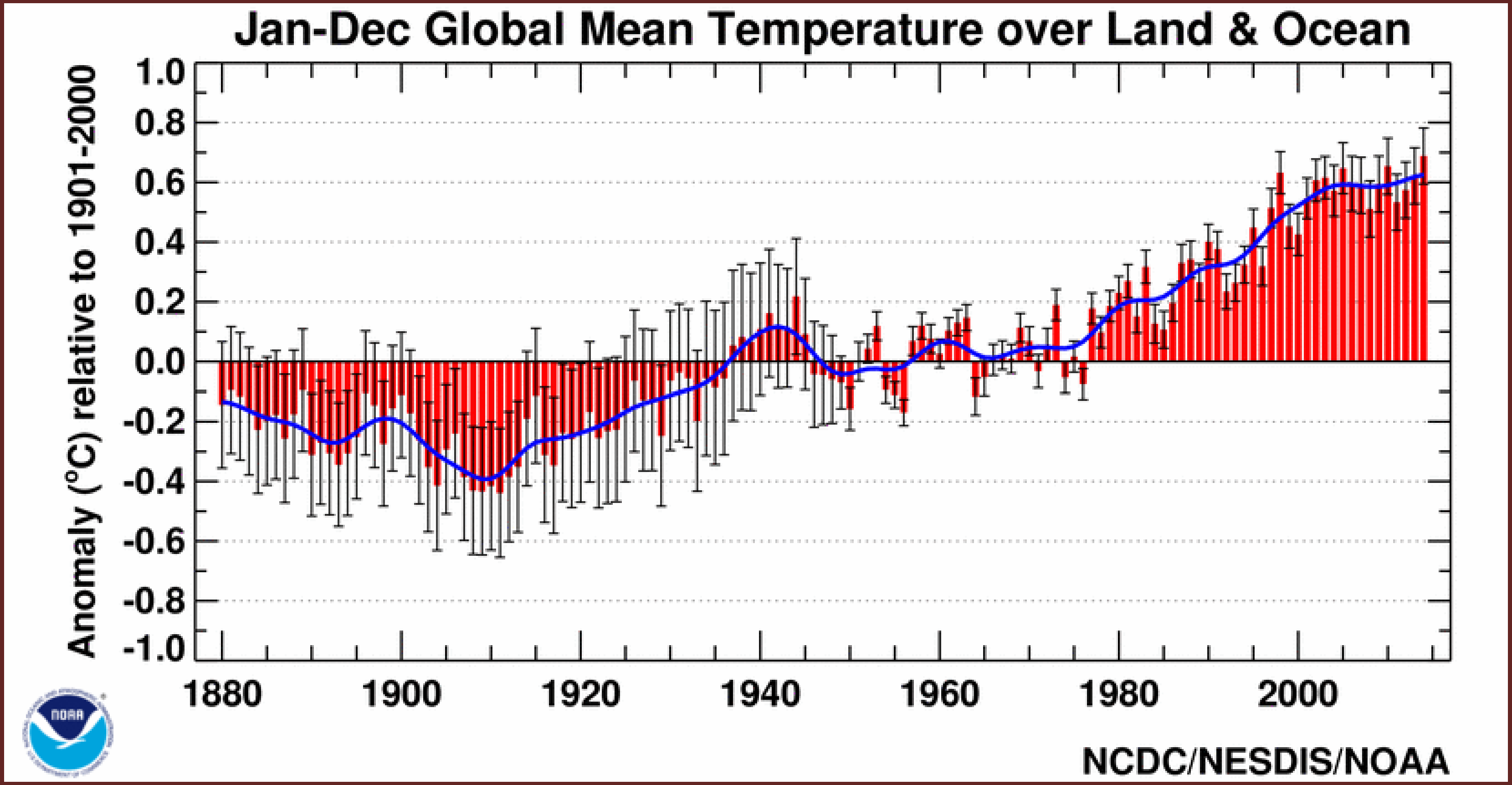


17th – 18th century ->

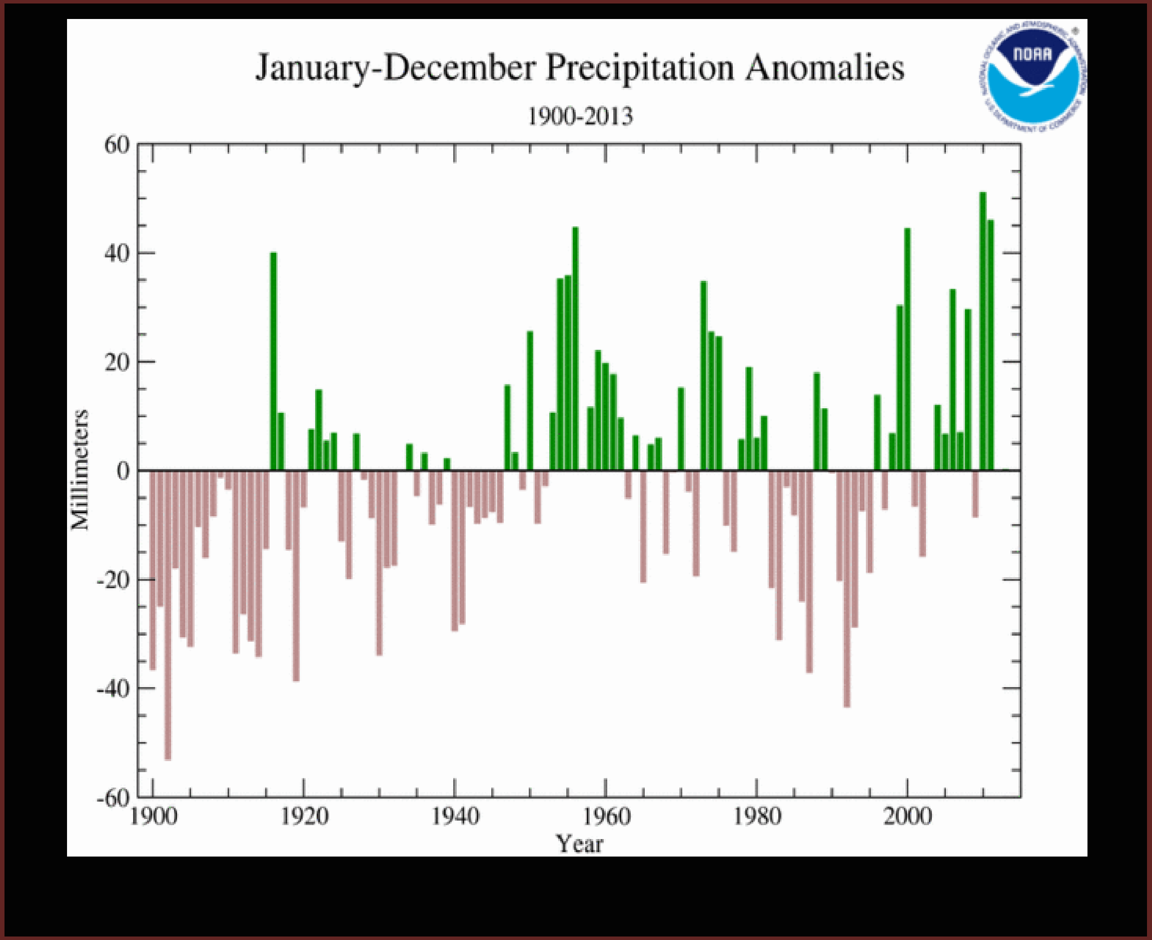
Observations: global CO_2



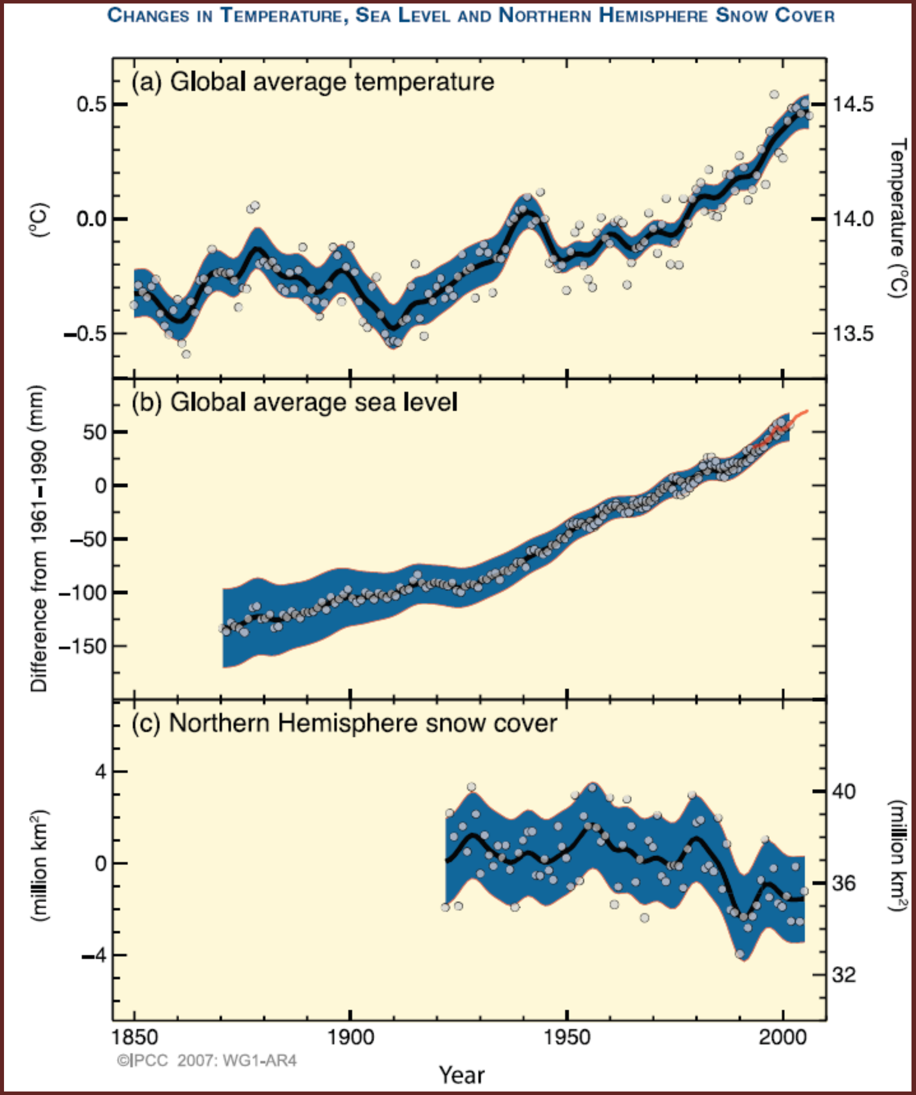
Observations: global temperature



Observations: global precipitation



Observations: global ice & snow



IPCC AR4

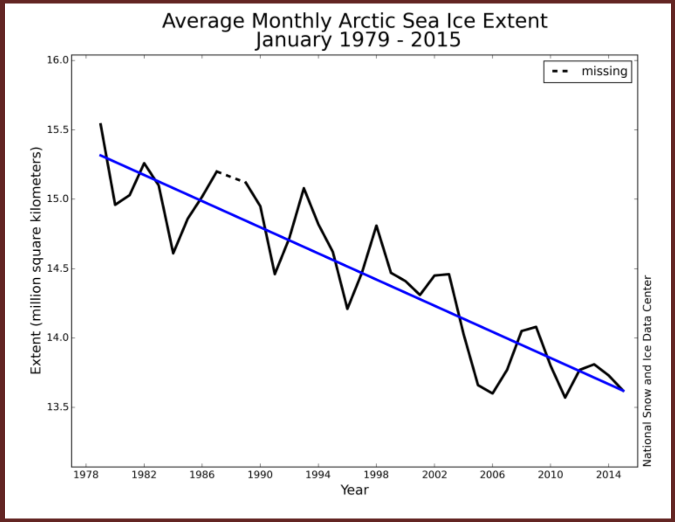
Observations: global ice & snow

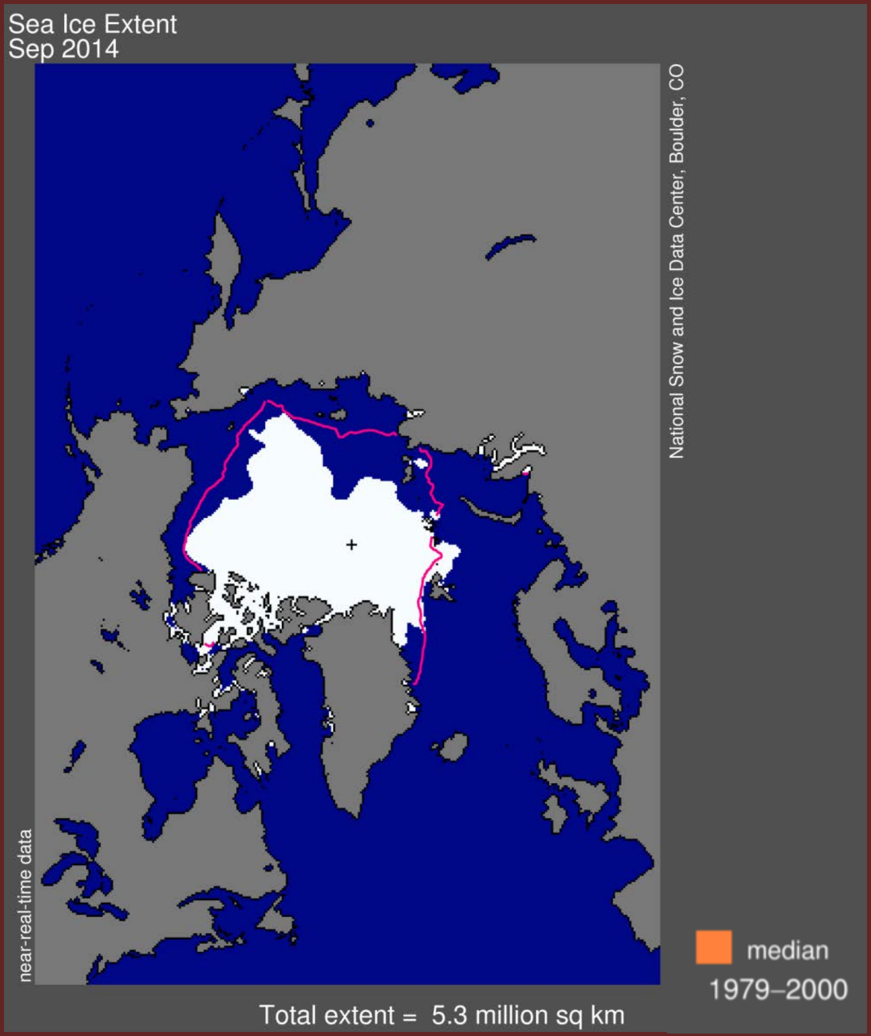
1928

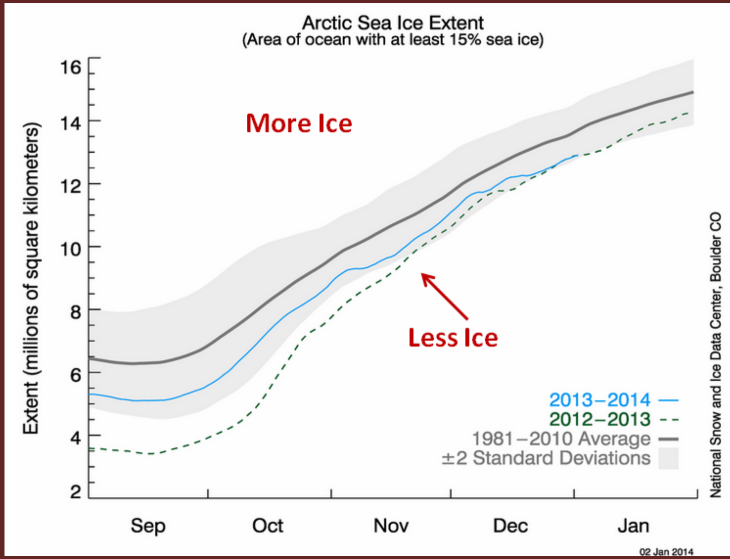
2004

Upsala glacier, Patagonia

Observations: global ice & snow

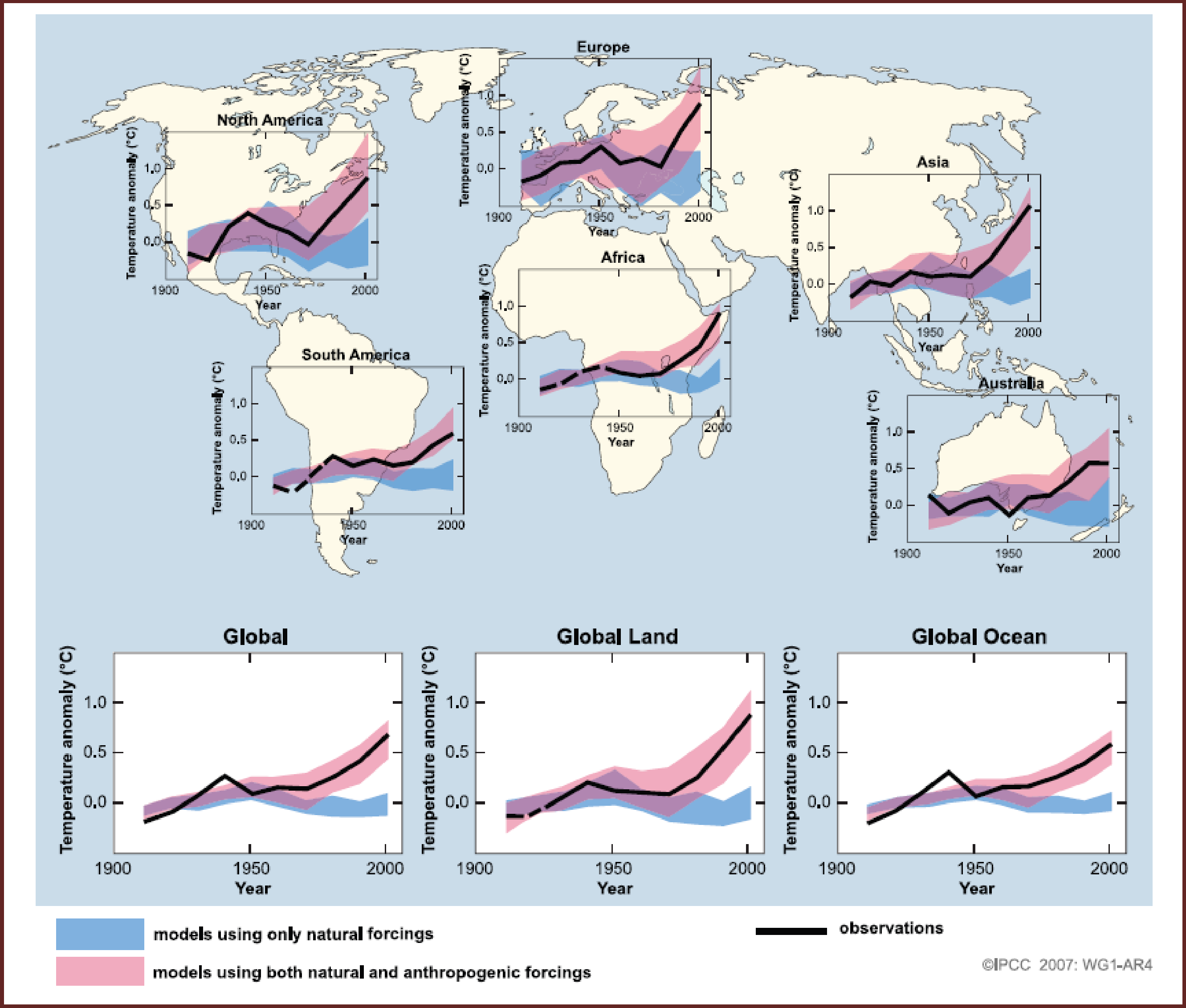






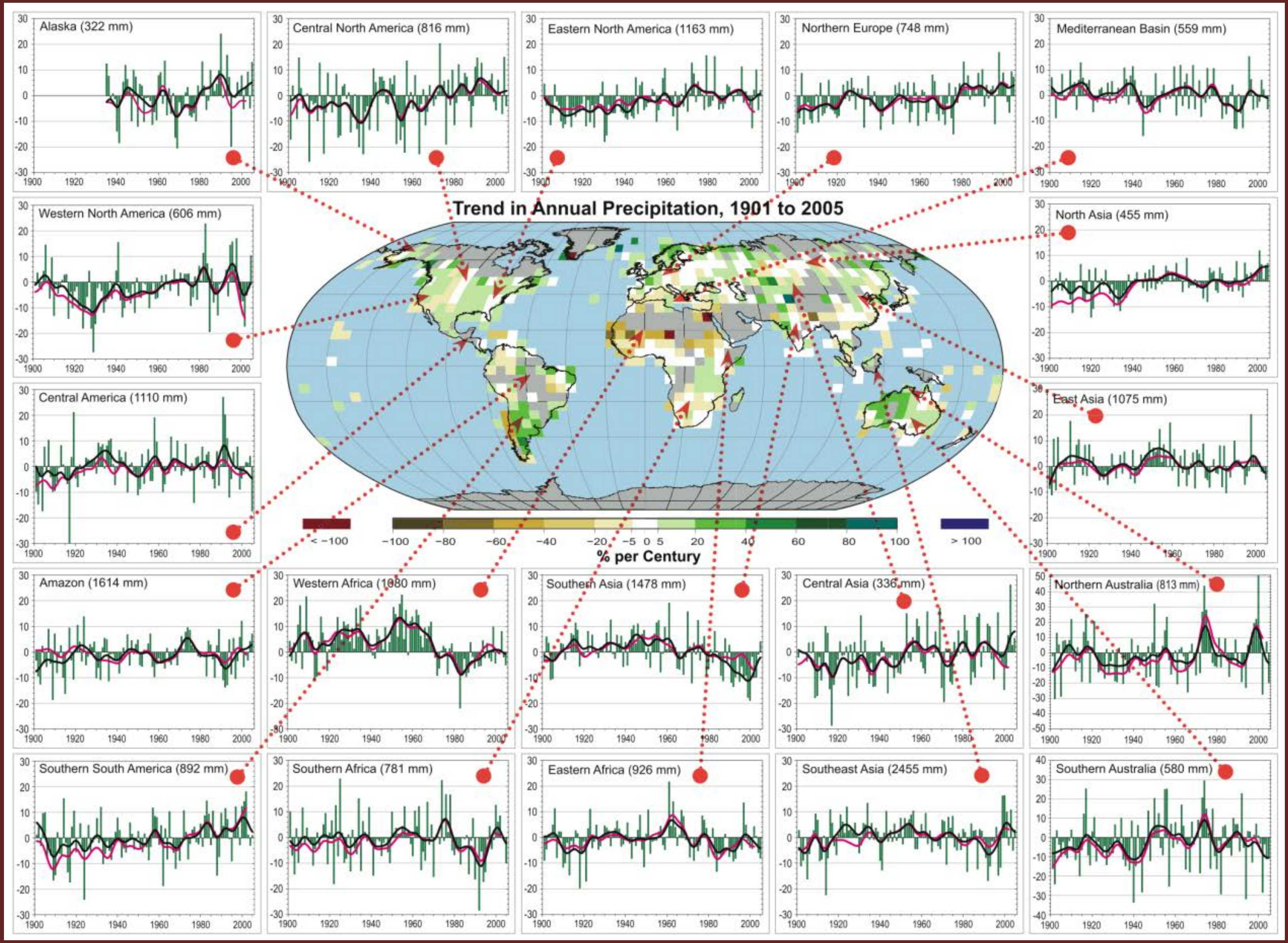
Observations: regional temperature

IPCC AR4



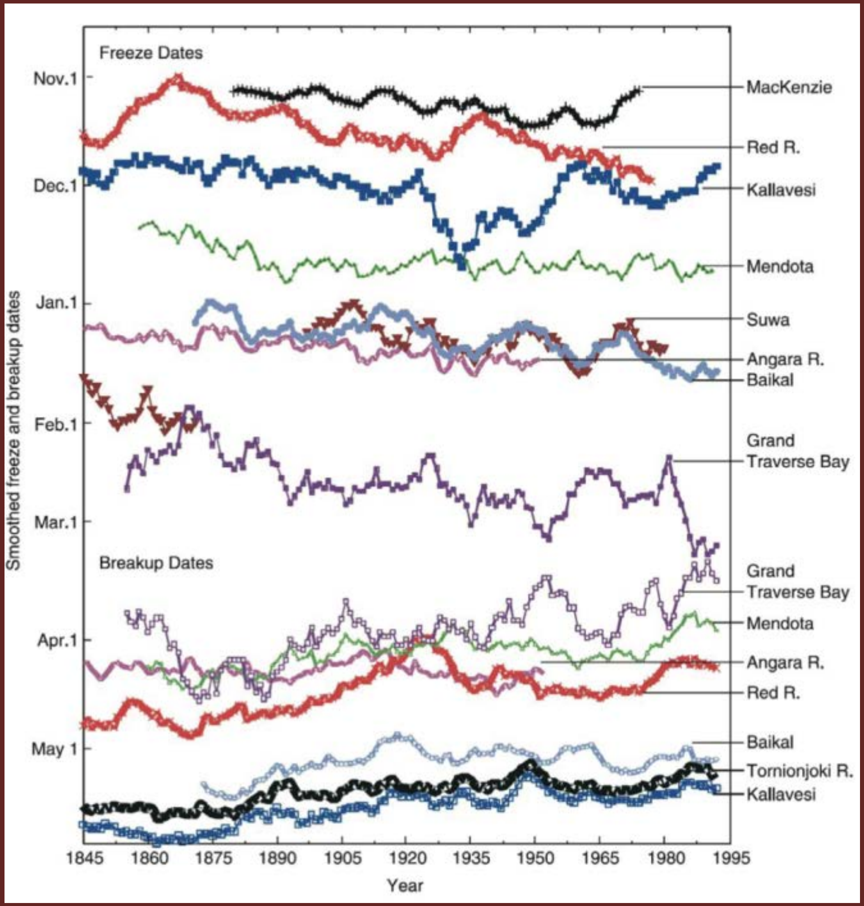
Observations: regional precipitation

IPCC AR4

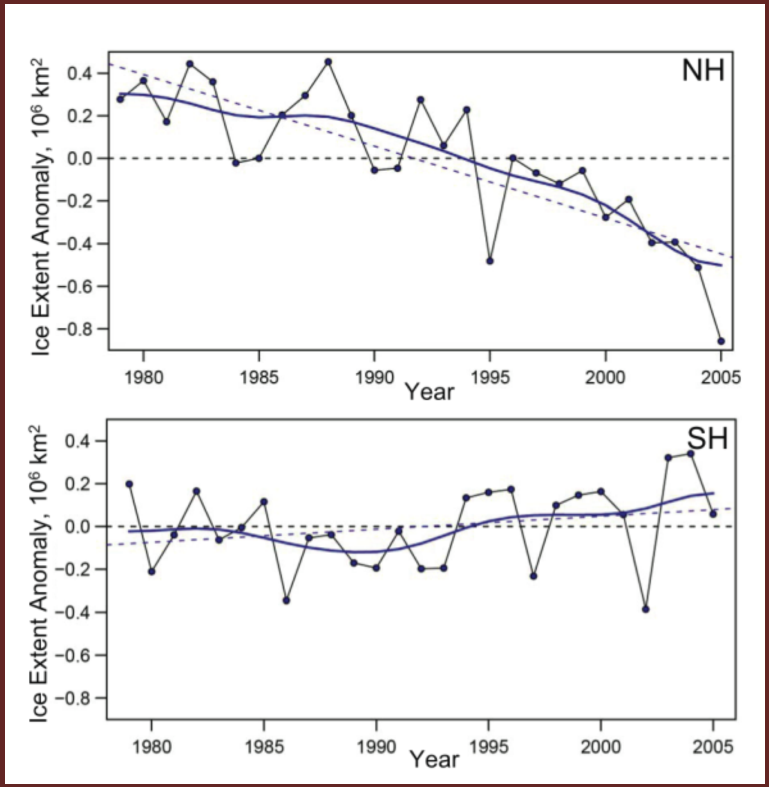


Observations: regional ice & snow

IPCC AR4



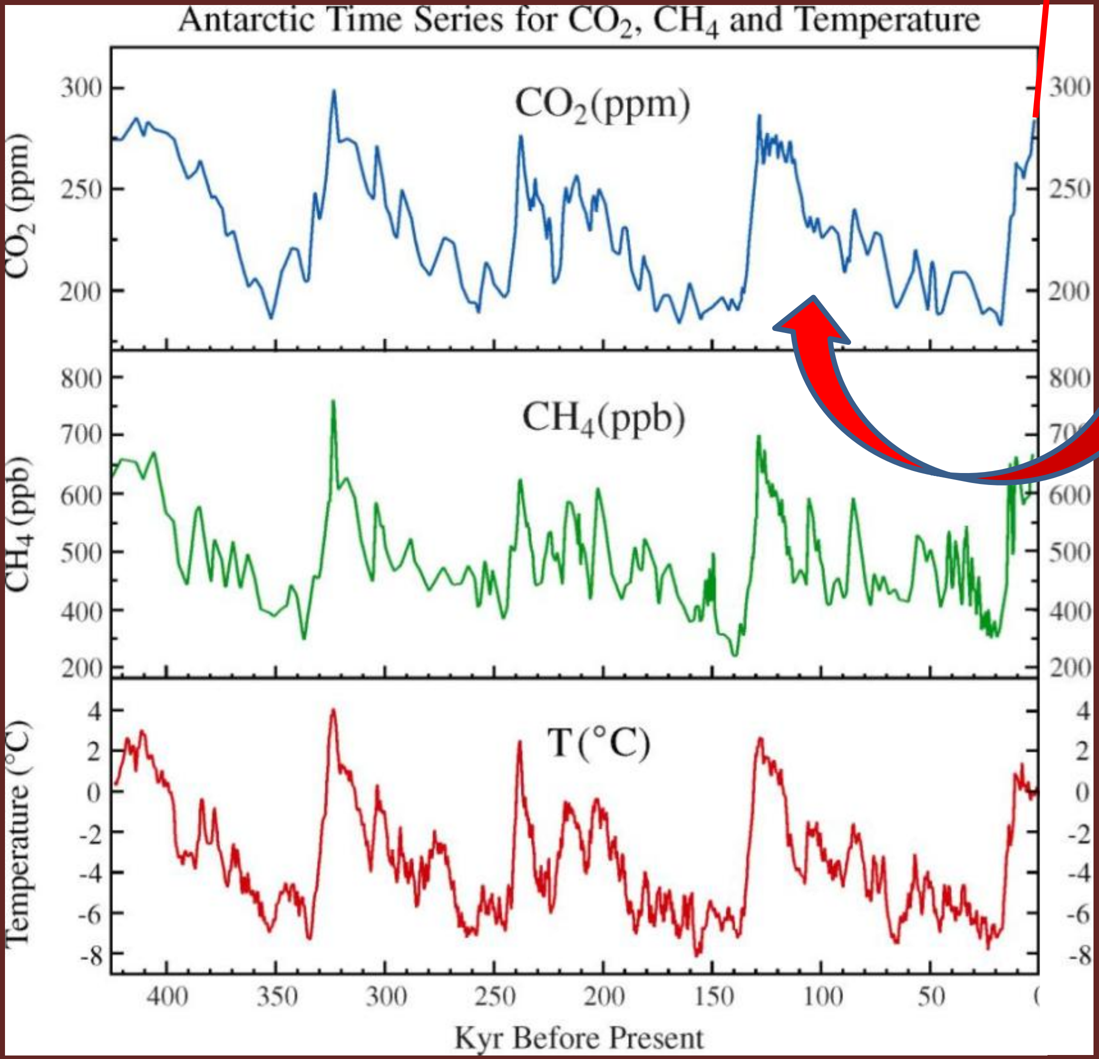
Freeze and breakup dates



Sea ice extent

Natural variation..?

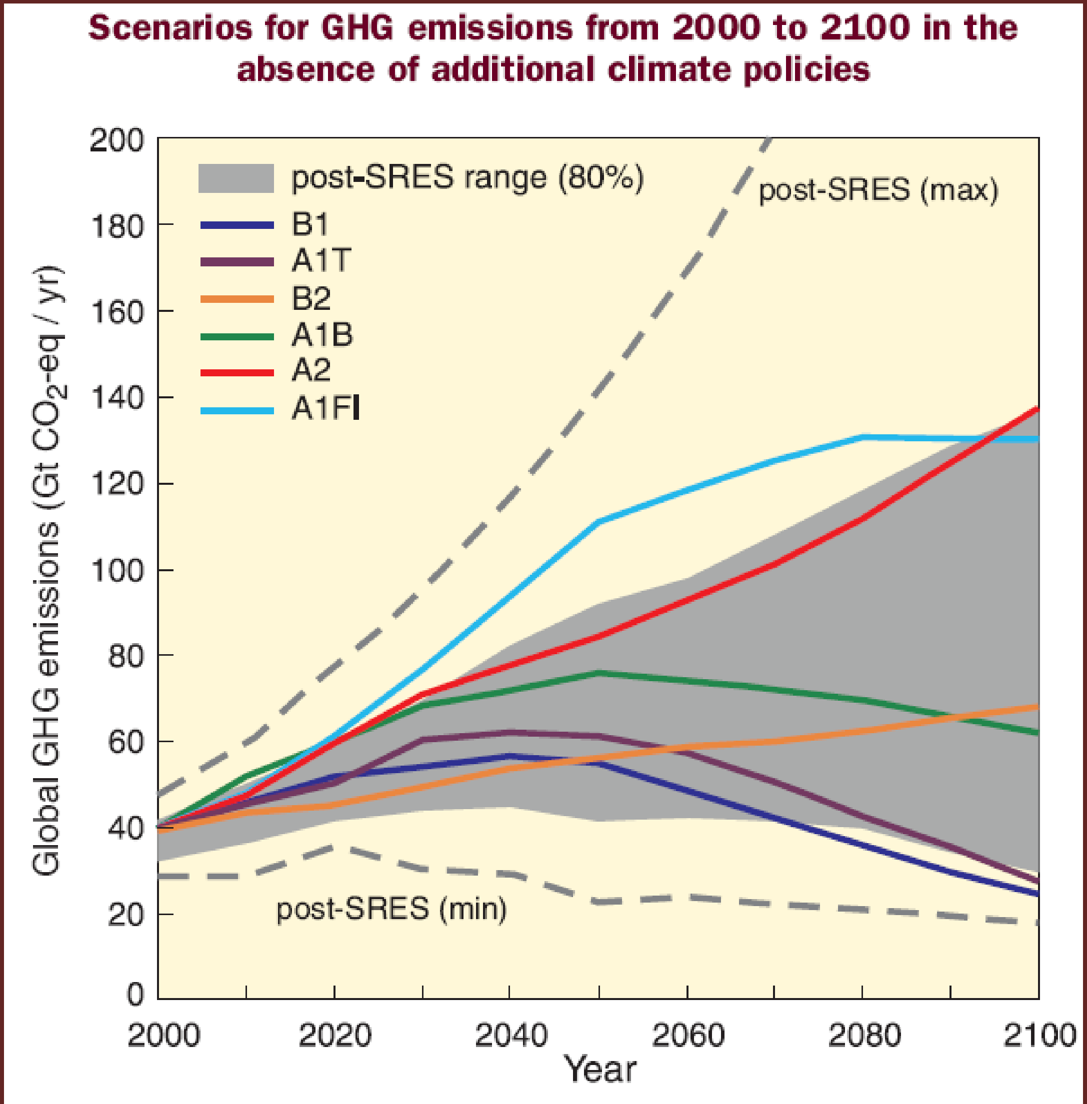
2013: 400 ppm!



Natural (ice age) cycles; pattern repeats about every 100,000 years

Vimeux et al EPSL2002

Predictions: global greenhouse gas emissions



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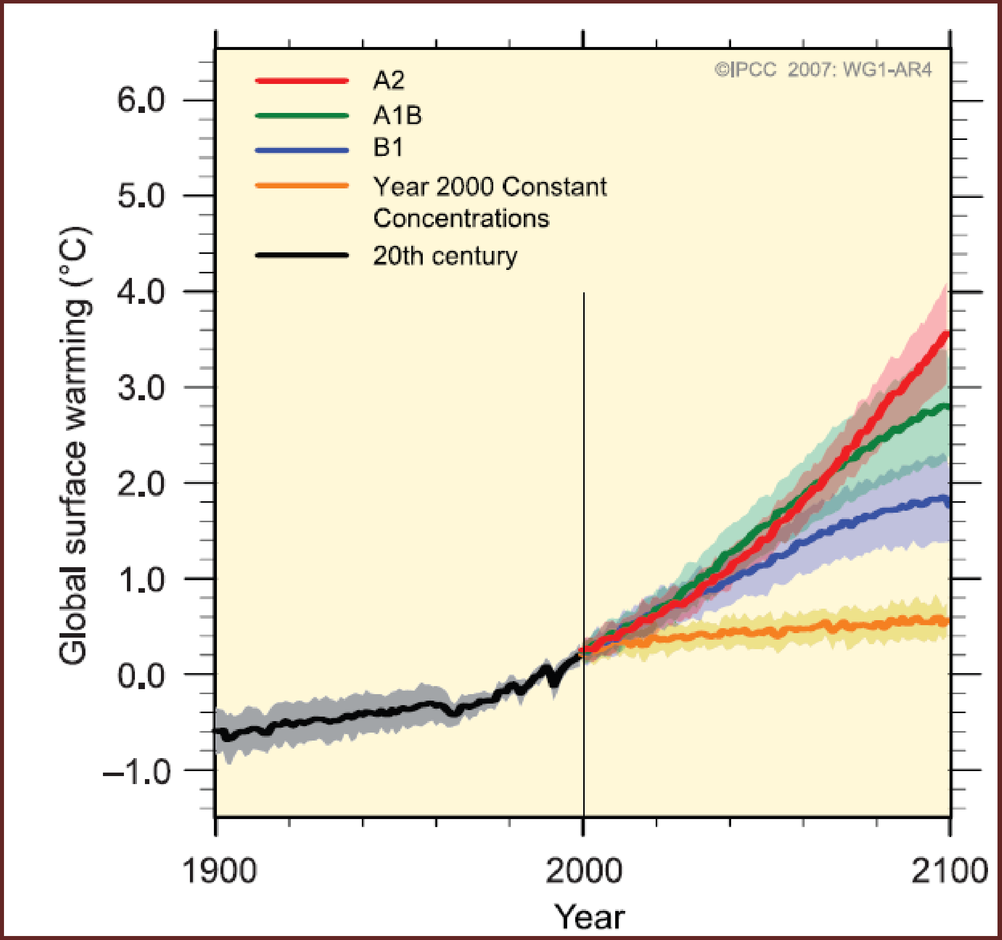
Predictions: temperature



For the next two decades, a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. {10.3, 10.7}

IPCC AR4

Predictions: temperature

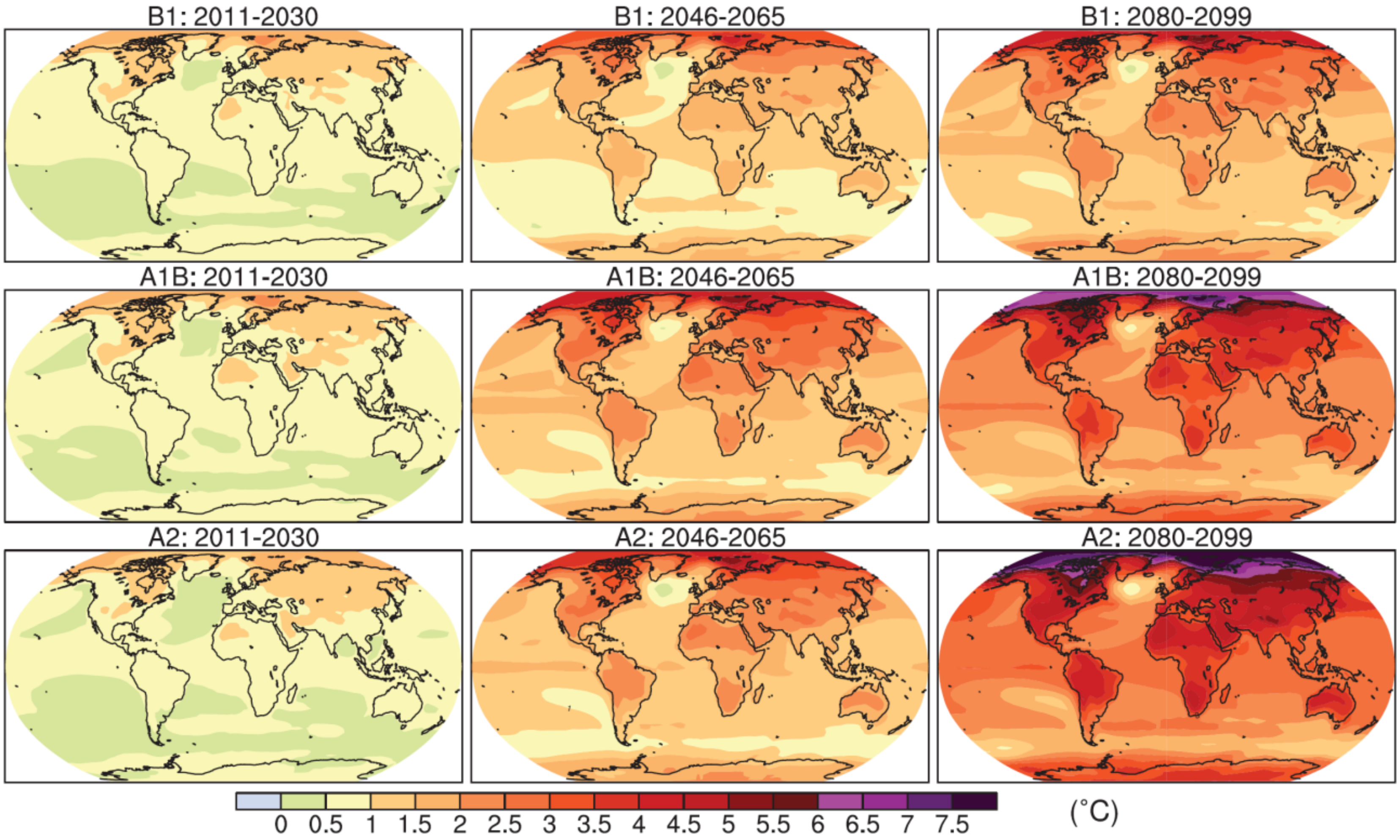


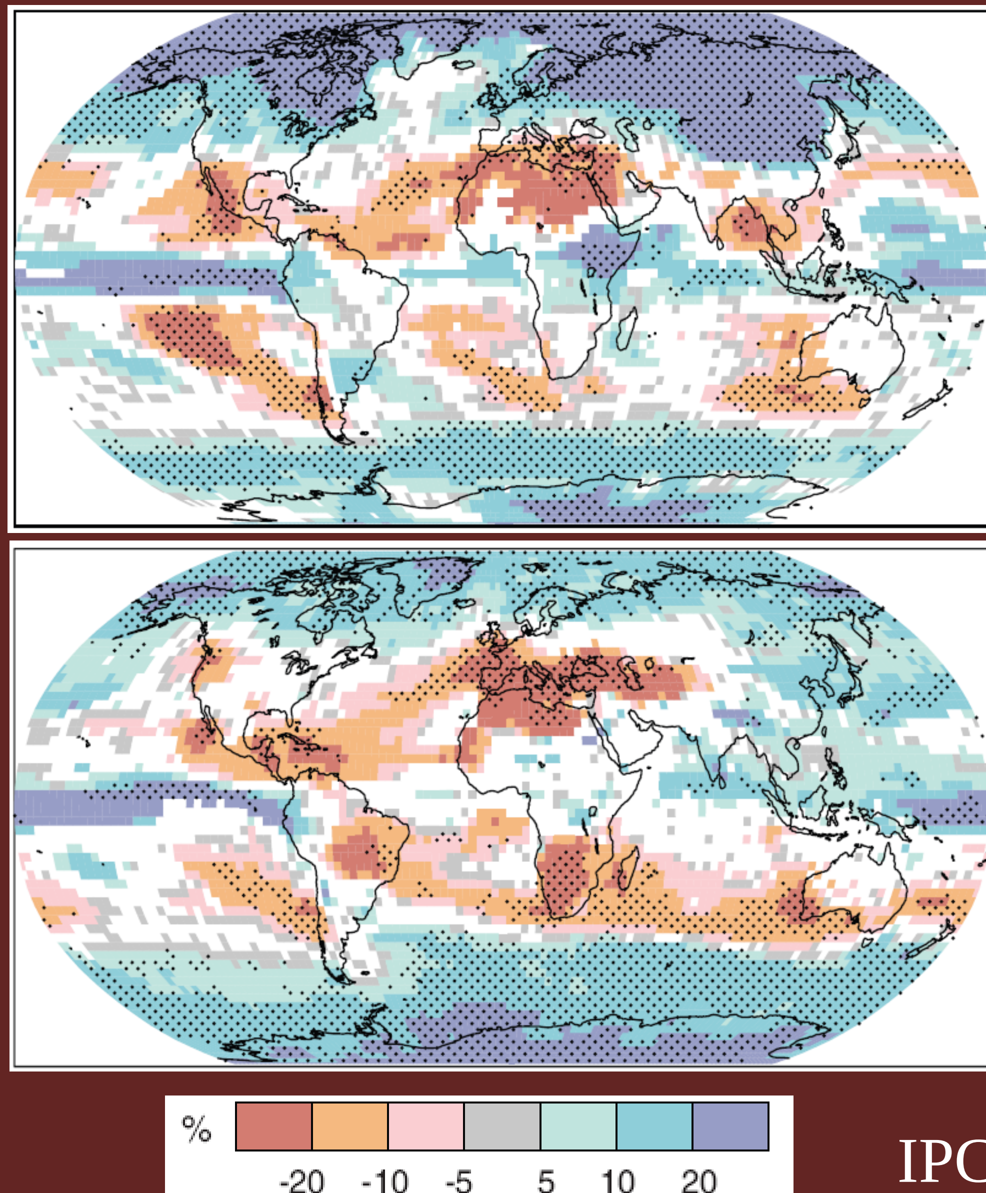
Figure 10.8. *Multi-model mean of annual mean surface warming (surface air temperature change, °C) for the scenarios B1 (top), A1B (middle) and A2 (bottom), and three time periods, 2011 to 2030 (left), 2046 to 2065 (middle) and 2080 to 2099 (right). Stippling is omitted for clarity (see text). Anomalies are relative to the average of the period 1980 to 1999. Results for individual models can be seen in the Supplementary Material for this chapter.*

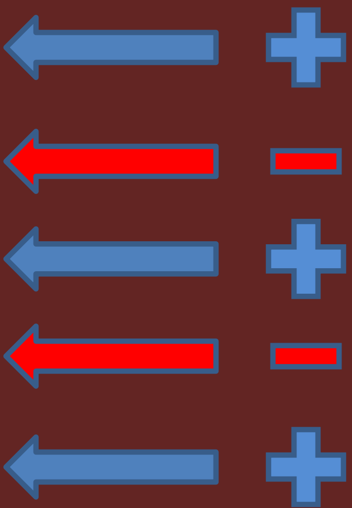
IPCC AR4

Predictions: precipitation

Winter DJF

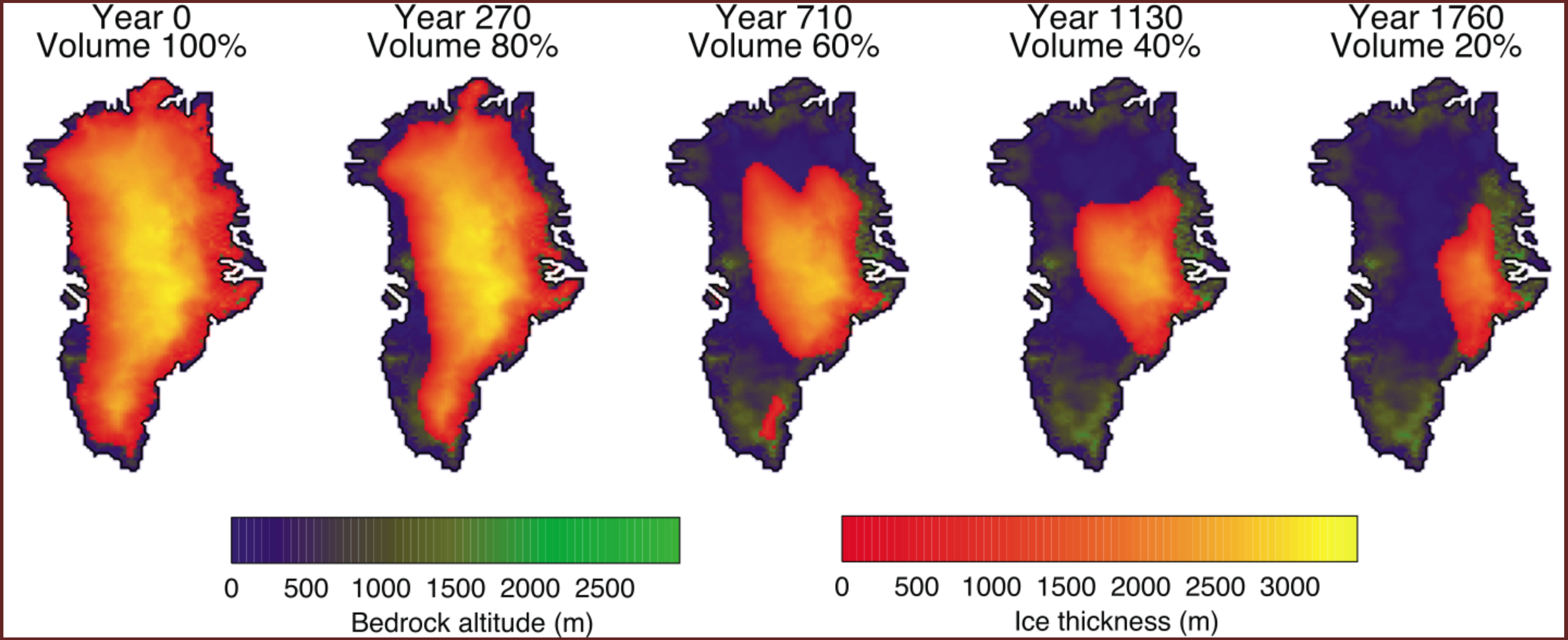
Summer JJA





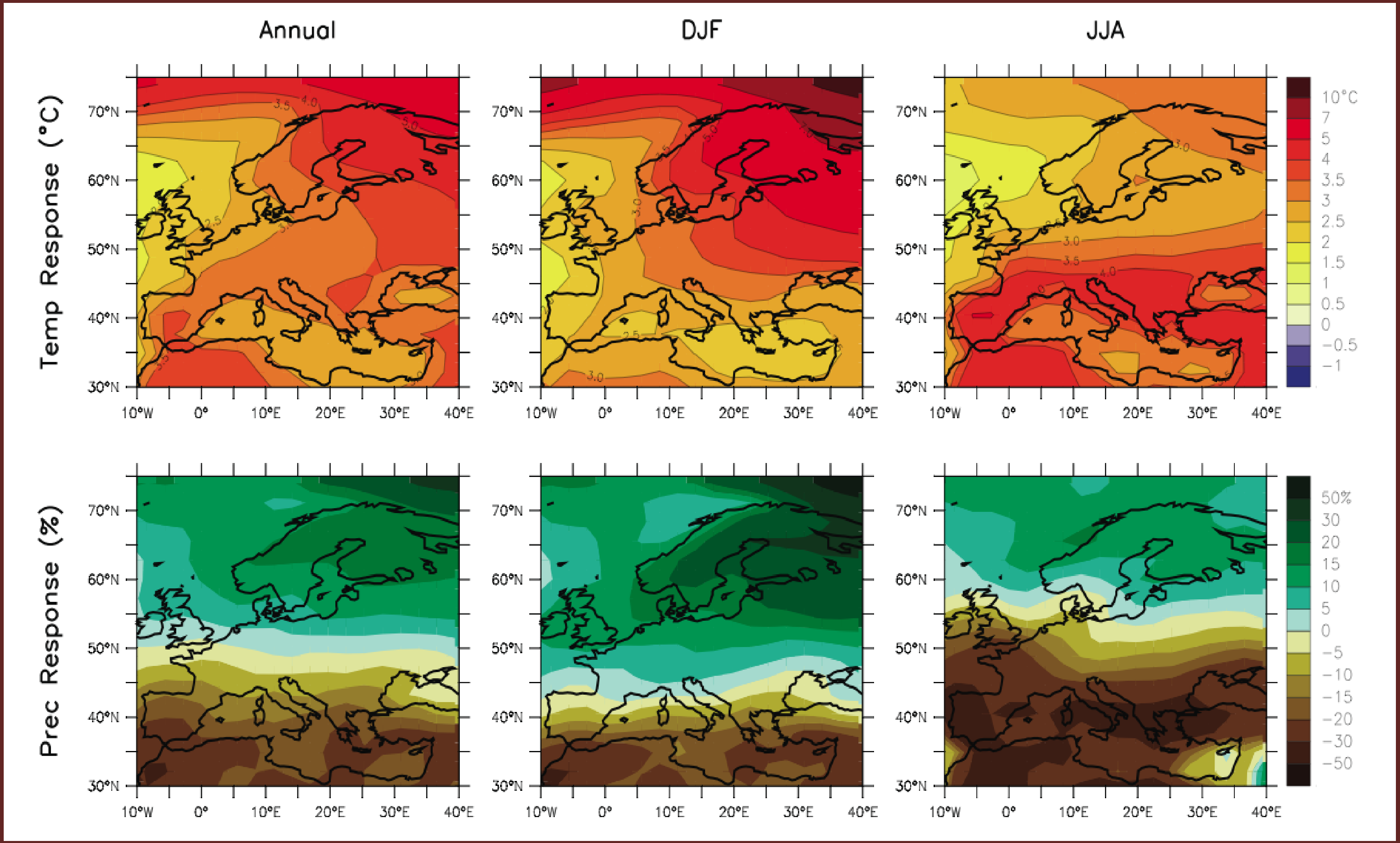
IPCC AR4

Predictions: ice & snow



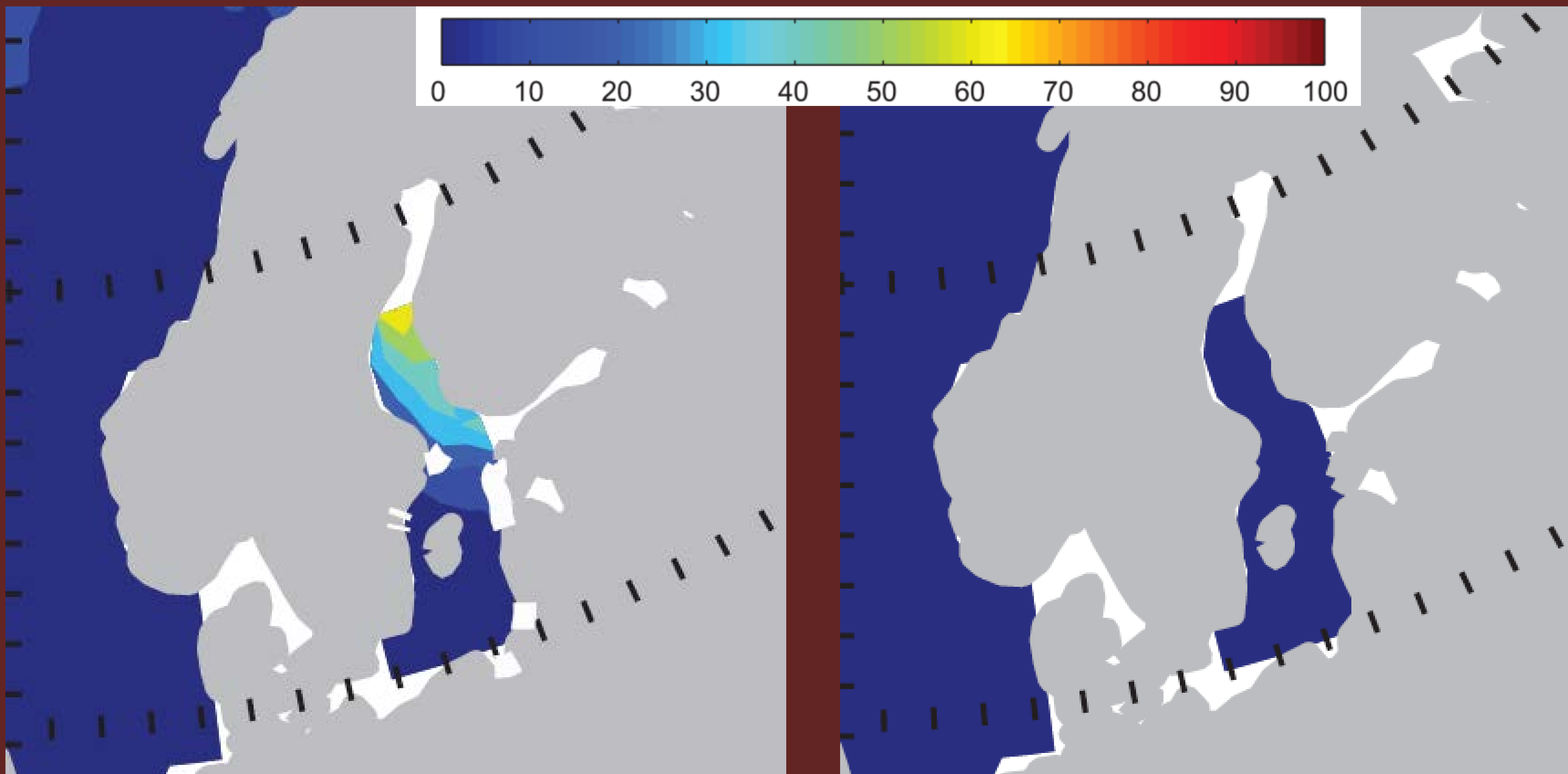
IPCC AR4

Northern Europe: what lies ahead?



Annual mean, DJF and JJA temperature change between 1980-1999 and 2080-2099

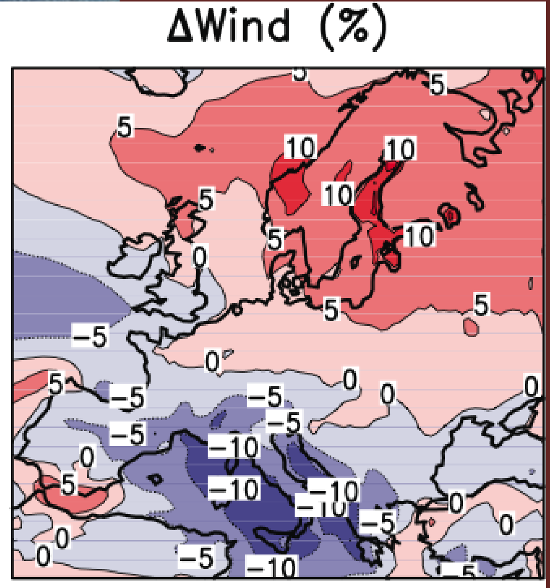
Northern Europe: what lies ahead?



mean 1980-2000

mean 2080-2100

Northern Europe: what lies ahead?

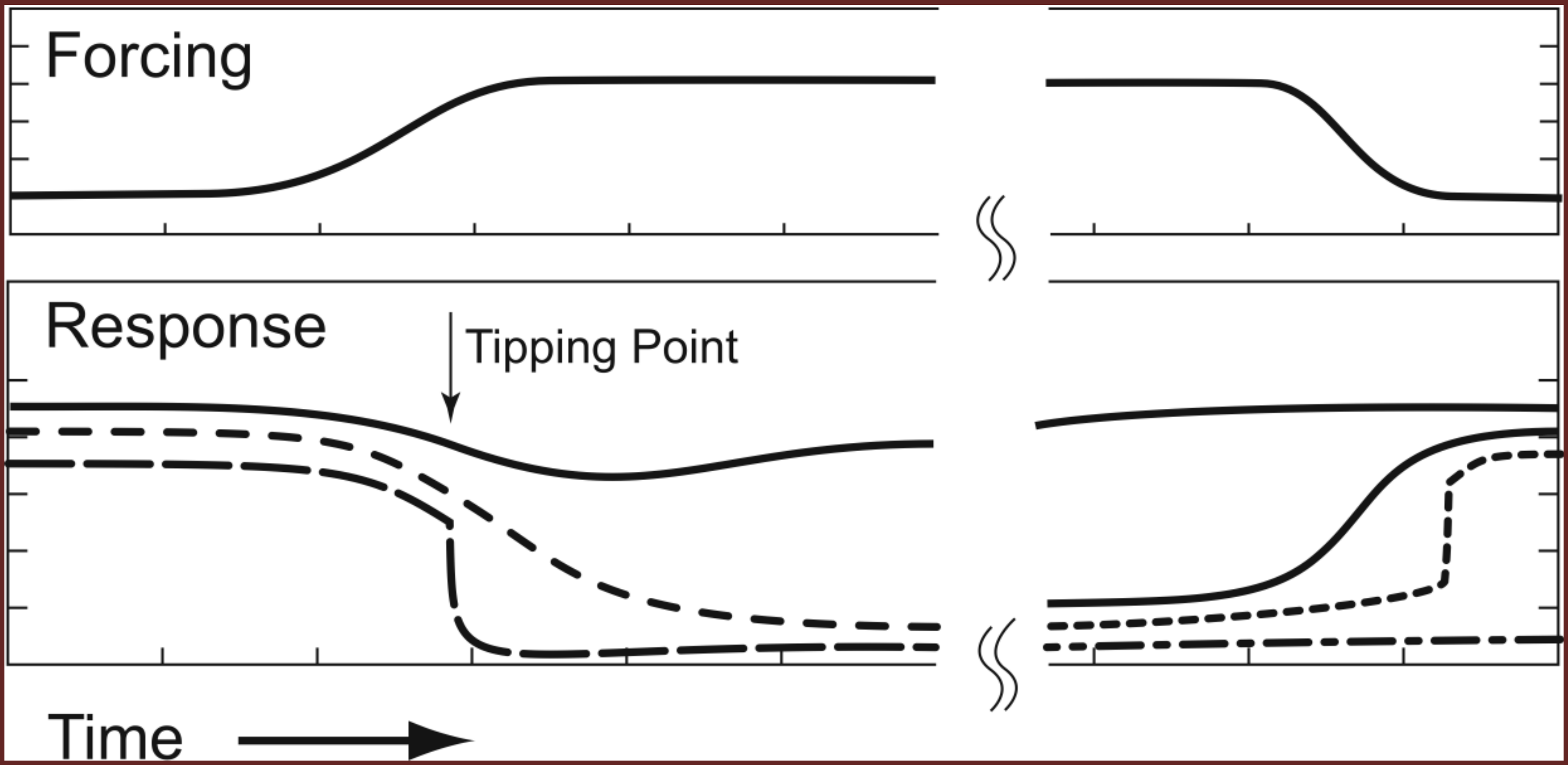


Gudrun-storm, southern Sweden Jan 2005: max wind speeds 165 km/h, 75 million m^3 forest destroyed

Finland: what lies ahead?

- temperature increase in near future ca. 0.4 ± 0.1° C / decade
- winters become shorter
- increased likelihood of extreme high temperatures
- precipitation increases particularly in winter, but summer rains still more abundant
- heavy rainfall events become stronger in all seasons
- snow cover will diminish especially in early and late winter
- interior and northern Finland may initially get more snow in nearest decades

Nature of change



- Various responses of a climate variable to forcing
- smooth or threshold transition; return likewise or impossible

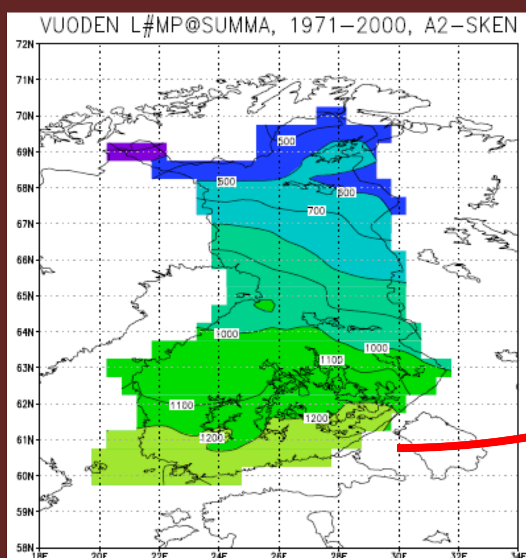
Ecological effects of climate change

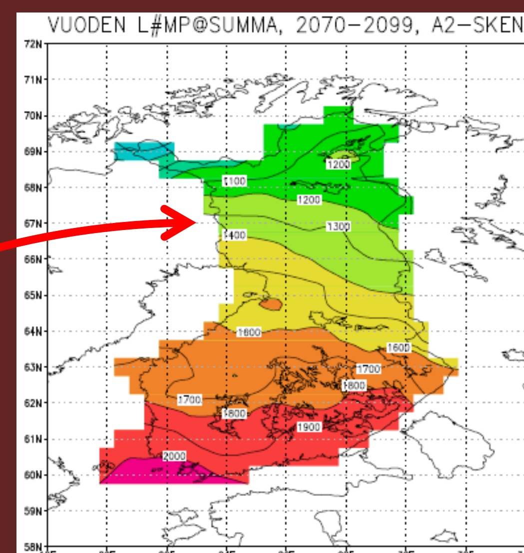
- distribution shifts, range limitations
- phenology
- population and community dynamics, including trophic interactions
- traits, incl. behaviour

Distribution shifts

- species limited by physical constraints of the environment
- temperature, precipitation, nutrients, length of growing season
- interactions within & among trophic levels (e.g. prey distribution)

temp. sum 1971-2000





temp. sum 2070-2099

Distribution shifts; examples

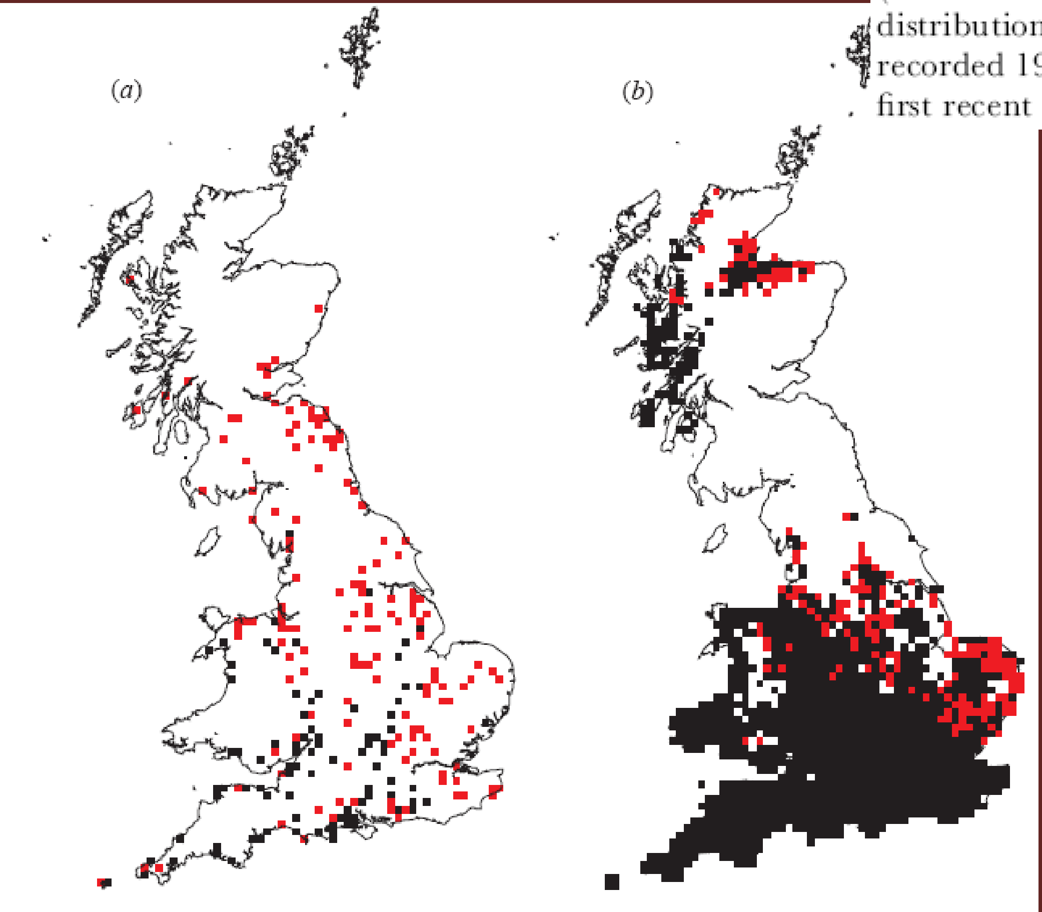


Figure 1. Distribution of *P. aegeria* in the UK at a grid resolution of 10 km. (*a*) Historical distribution: red squares, pre-1915 distribution; black squares, most restricted distribution (1915–1939). (*b*) Current recorded distribution: black squares, species recorded 1940–1989; red squares, first recent record 1990–1997.

Pre-1939

Current (-1997)

Hill et al. PRSL1999

Distribution shifts; examples

Lindgren et al. EHP2000

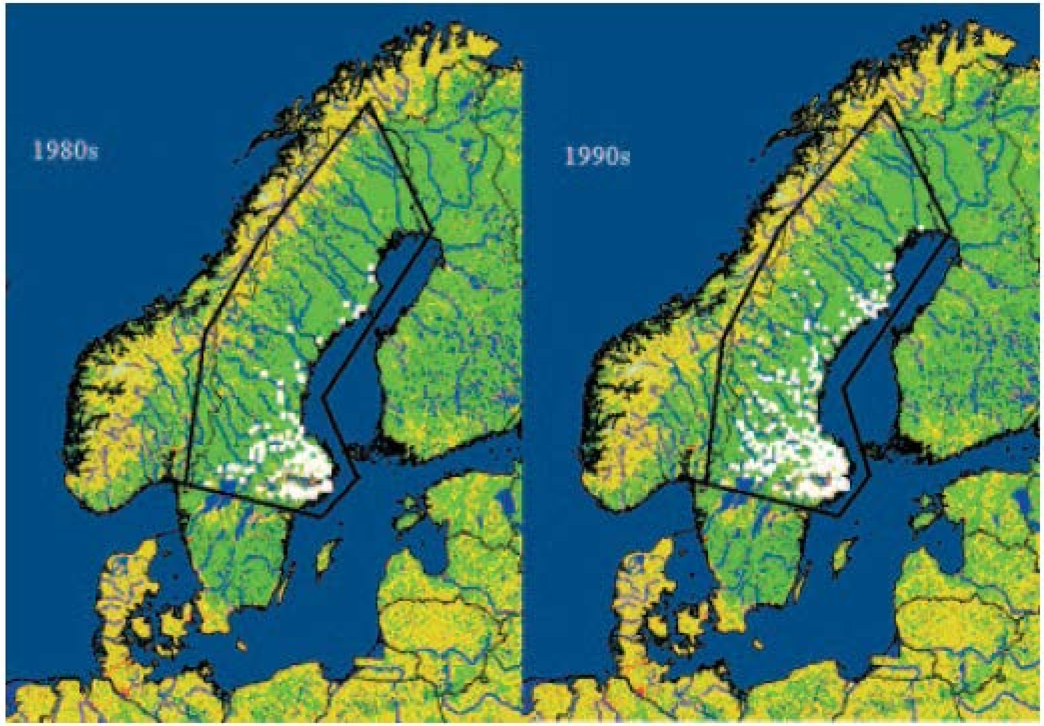
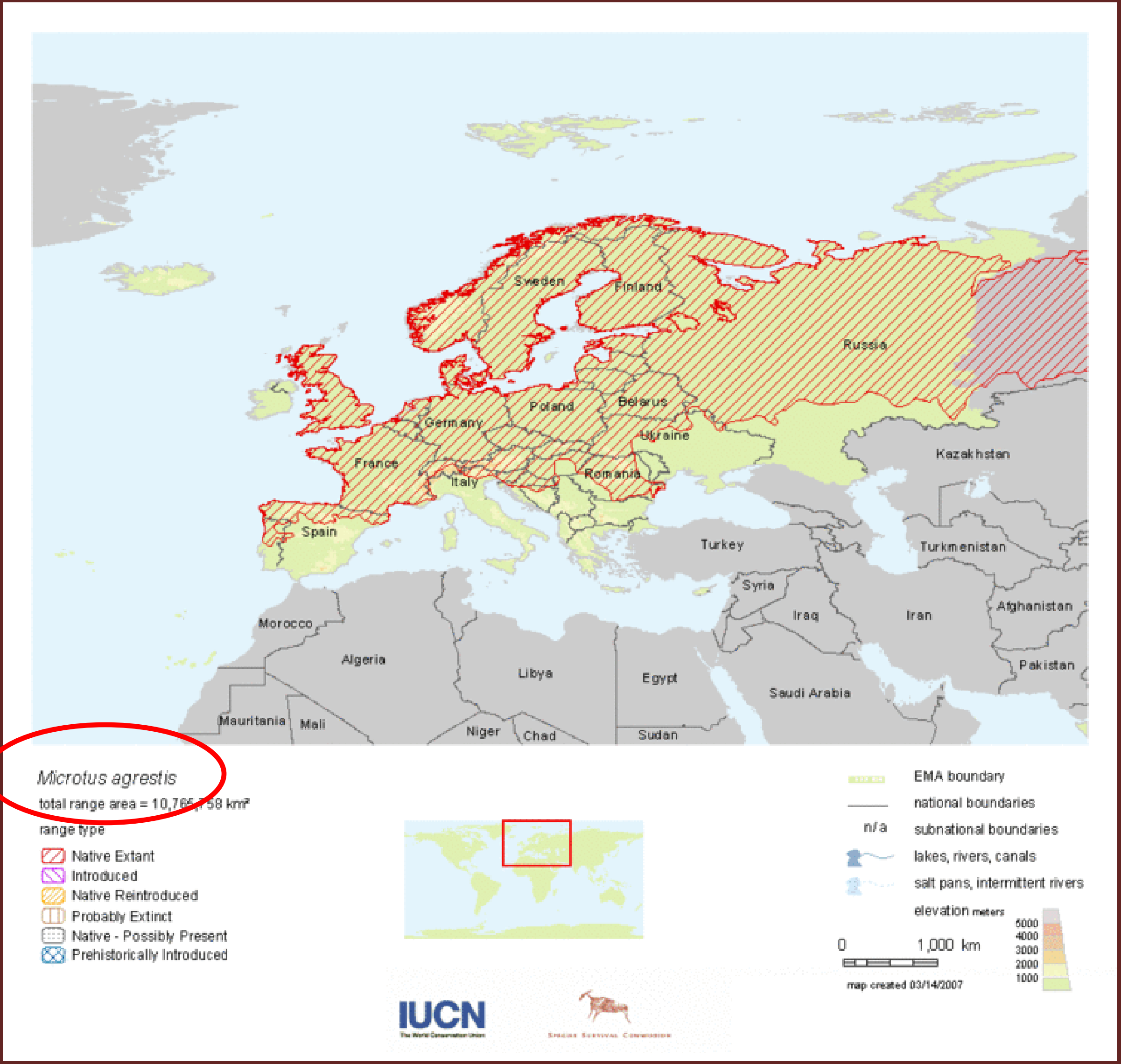


Figure 1. White dots illustrate districts in Sweden where ticks were reported to be present (*A*) in the early 1980s and (*B*) in the mid-1990s. The study region is within the black line.

to the 1980s. Our results indicate that the reported northern shift in the distribution limit of ticks is related to fewer days during the winter seasons with low minimum temperatures, i.e., below -12°C. At high latitudes, low winter temperatures had the clearest impact on tick distribution. Further south, a combination of mild winters (fewer days with minimum temperatures below -7°C) and extended spring and autumn seasons (more days with minimum temperatures from 5 to 8°C) was related to increases in tick density. We conclude that the relatively mild climate of the 1990s in Sweden is probably one of the primary reasons for the observed increase of density and geographic range of *I. ricinus* ticks. *Key words*: climate change, geographic distribu-

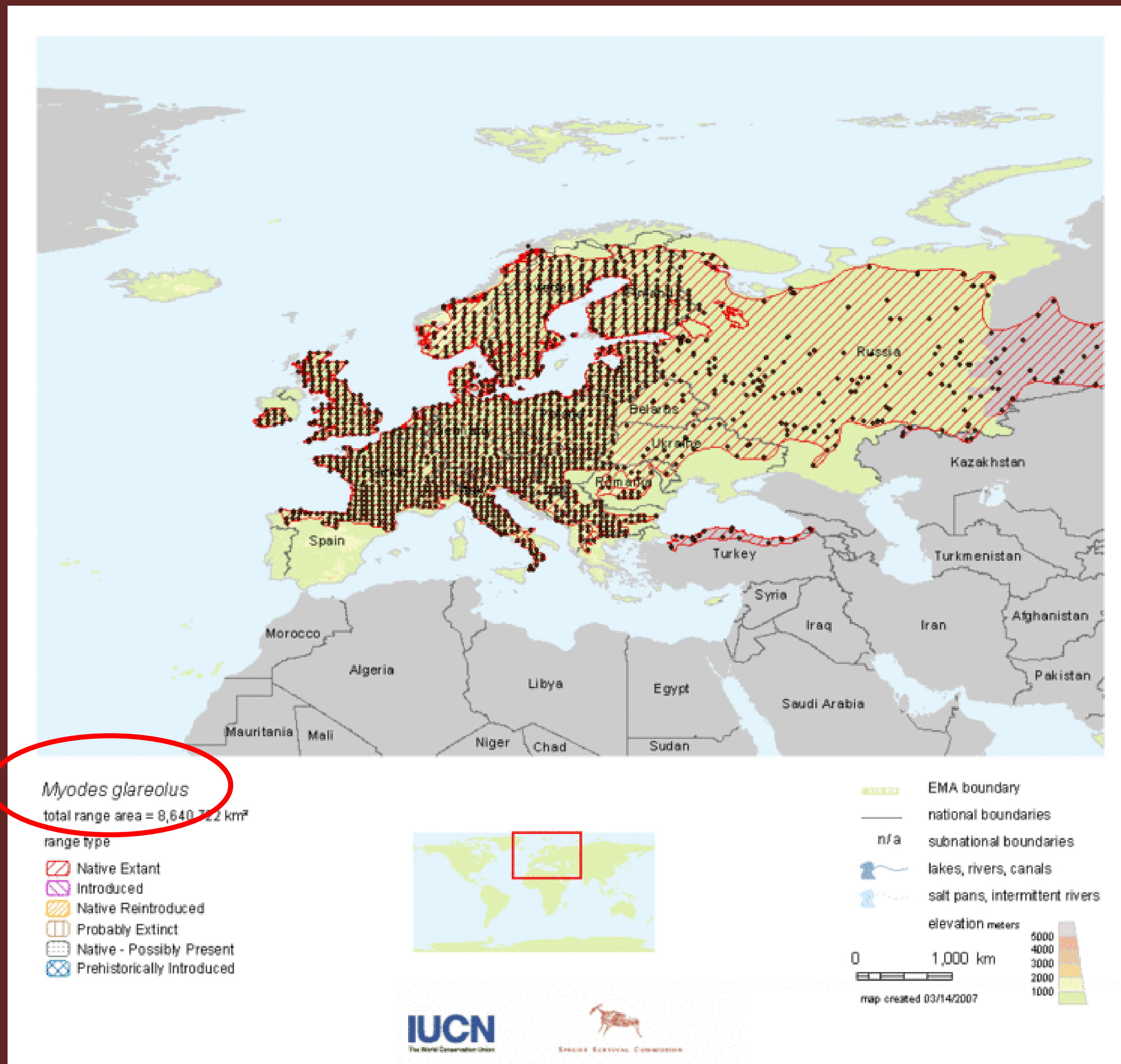
Distribution shifts due? Finnish voles

field vole



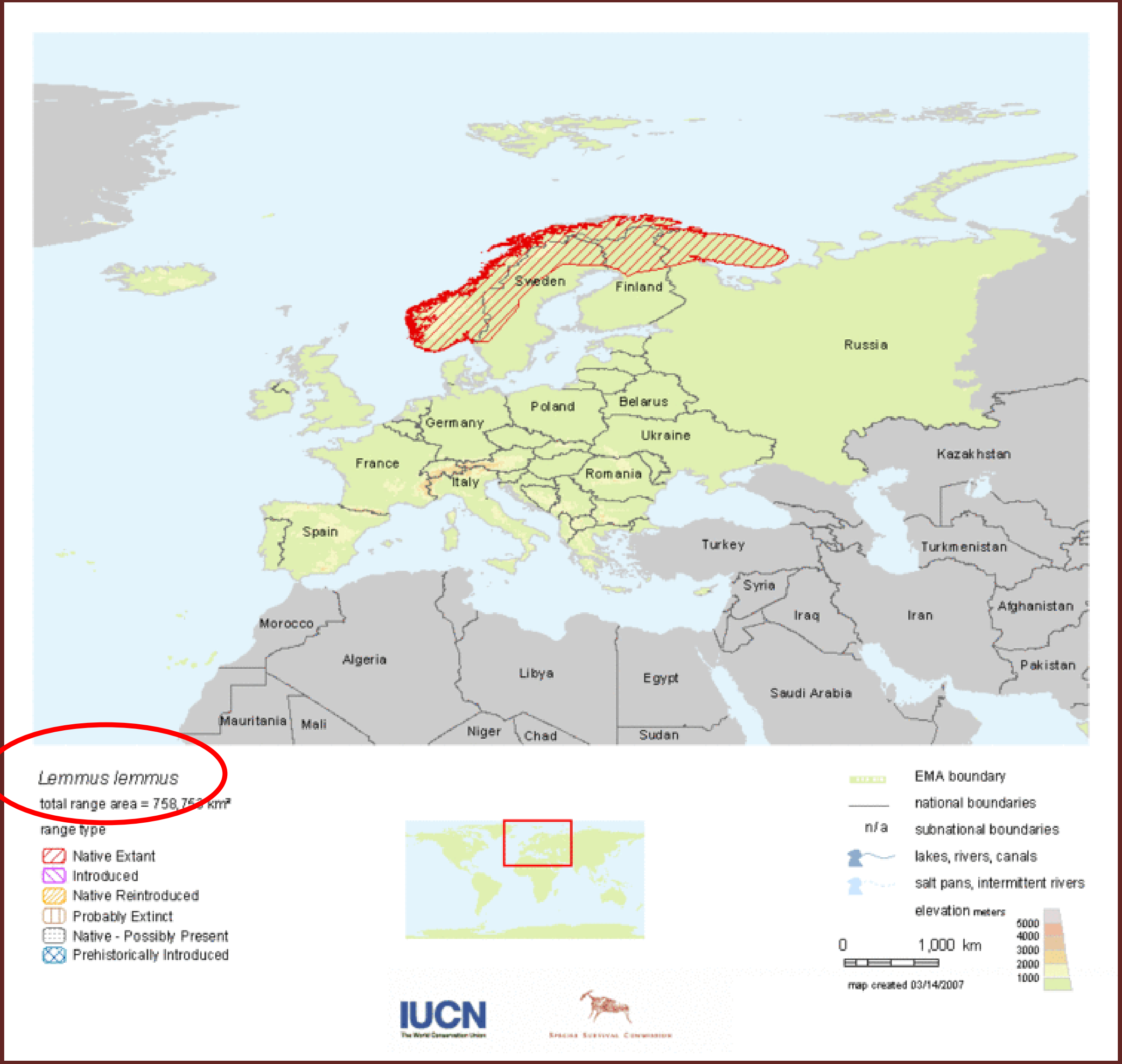
Distribution shifts due? Finnish voles

bank vole



YES!

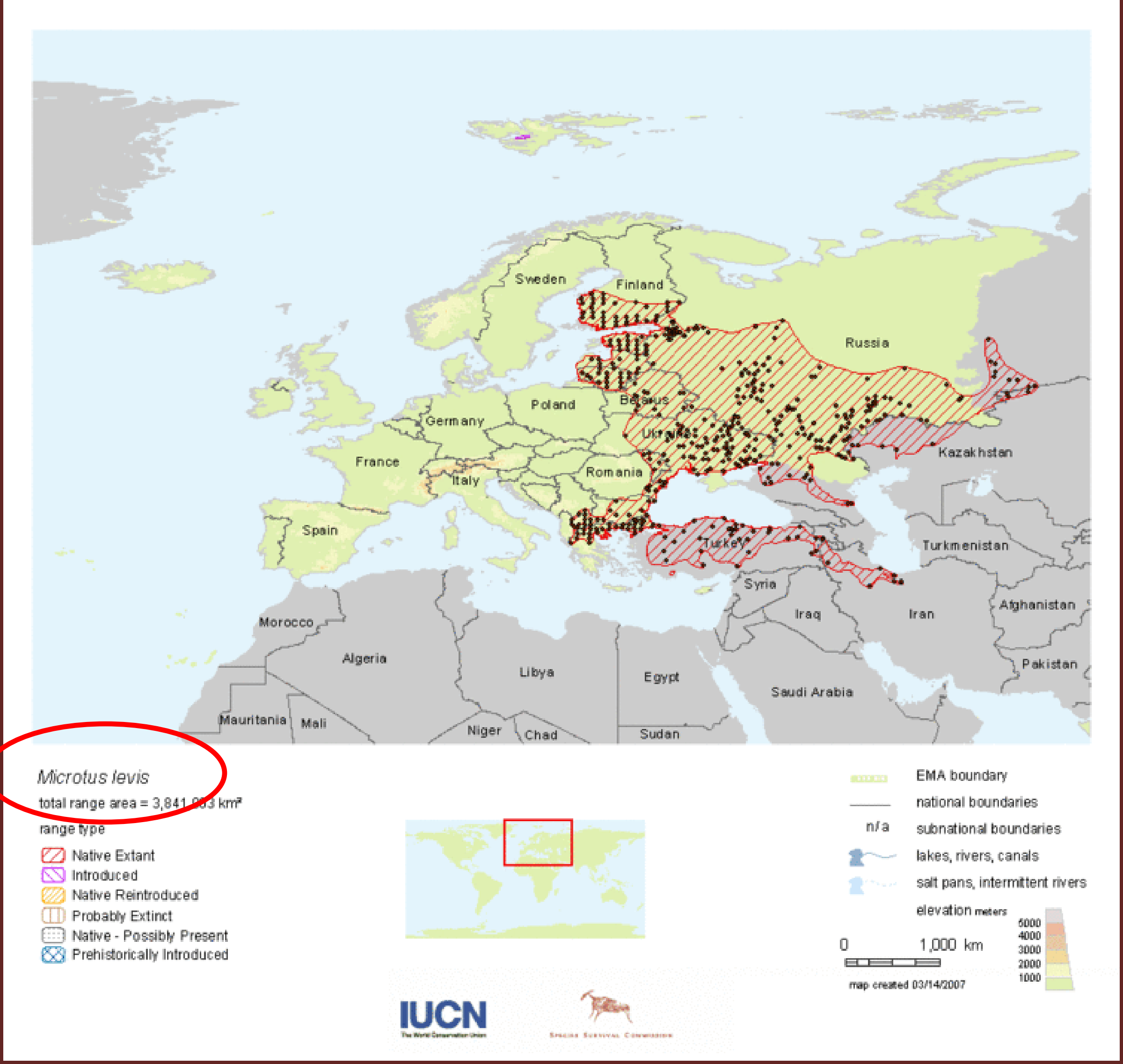
Distribution shifts due? Finnish voles



Norw. lemming

YES!

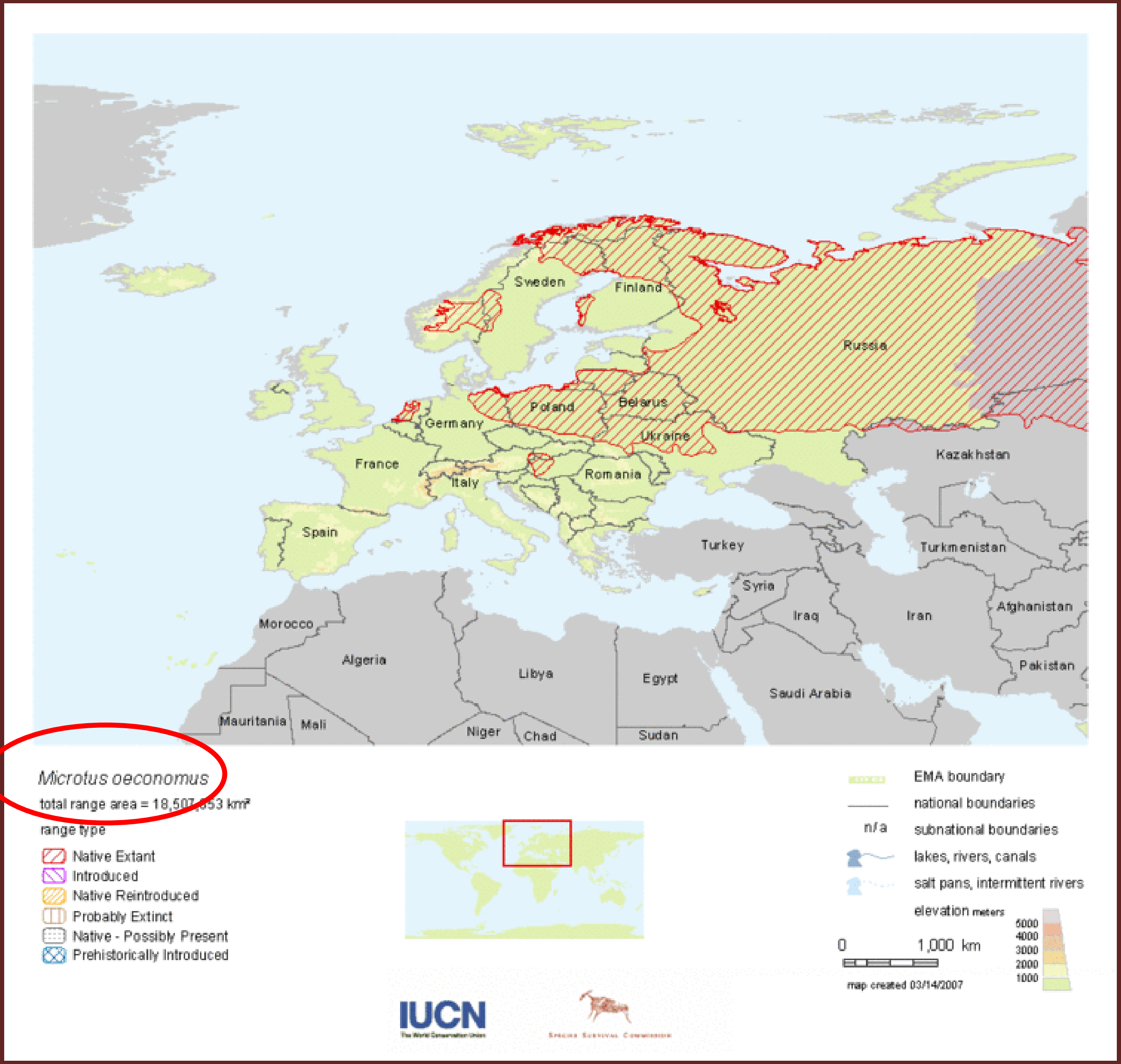
Distribution shifts due? Finnish voles



sibling vole

YES!

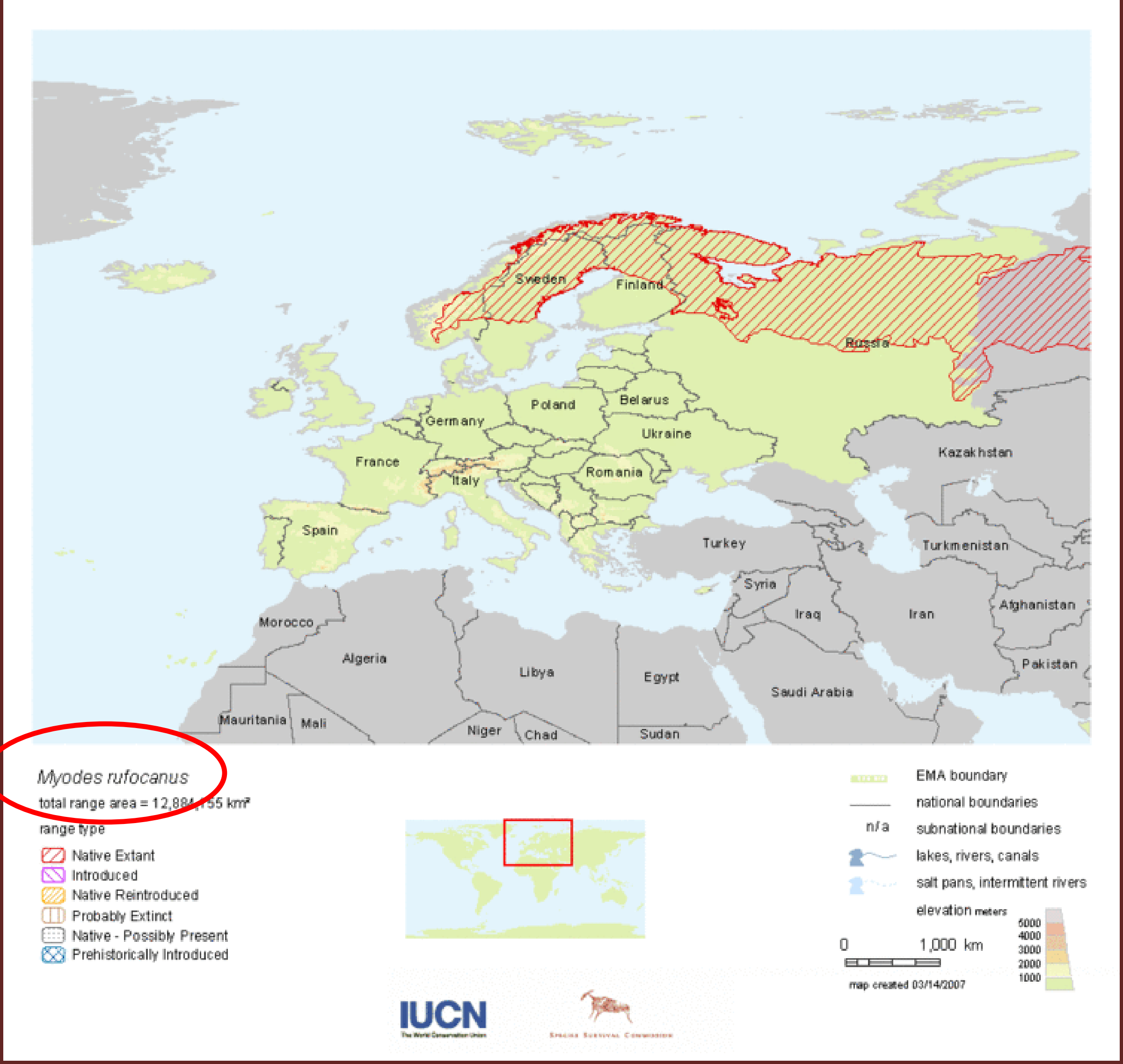
Distribution shifts due? Finnish voles



root vole

YES!

Distribution shifts due? Finnish voles

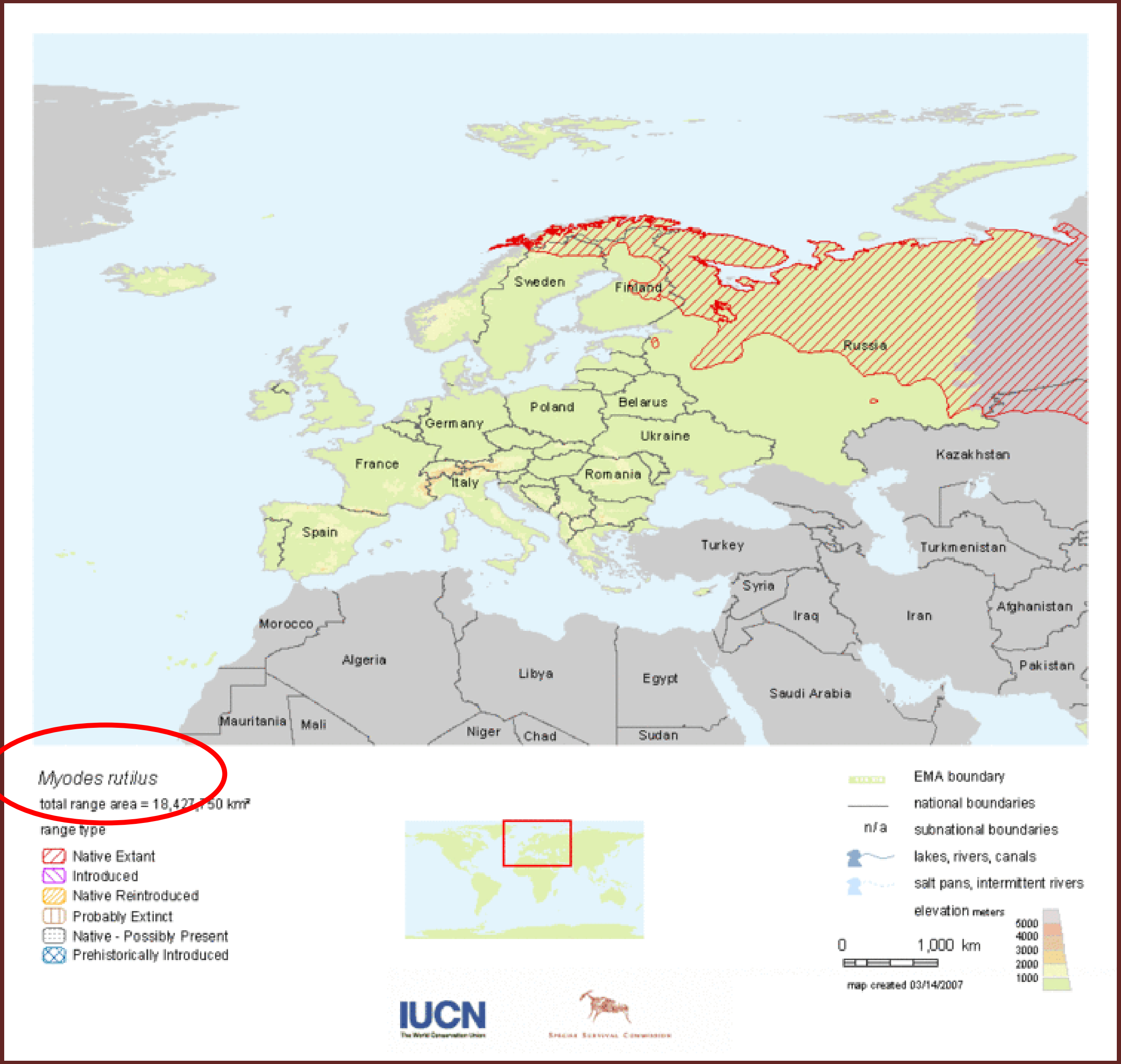


grey-sided vole

YES!

Distribution shifts due? Finnish voles

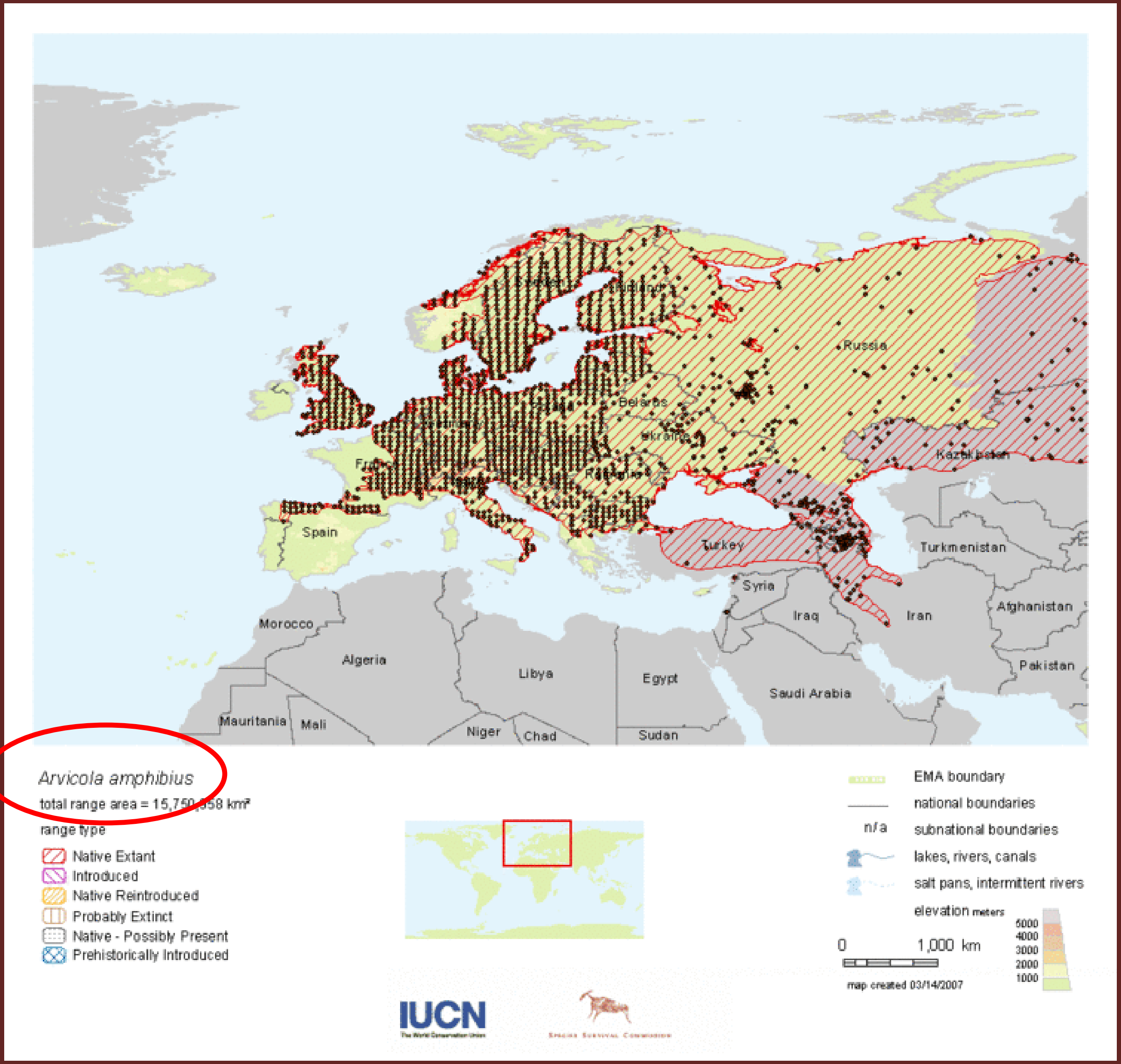
red vole



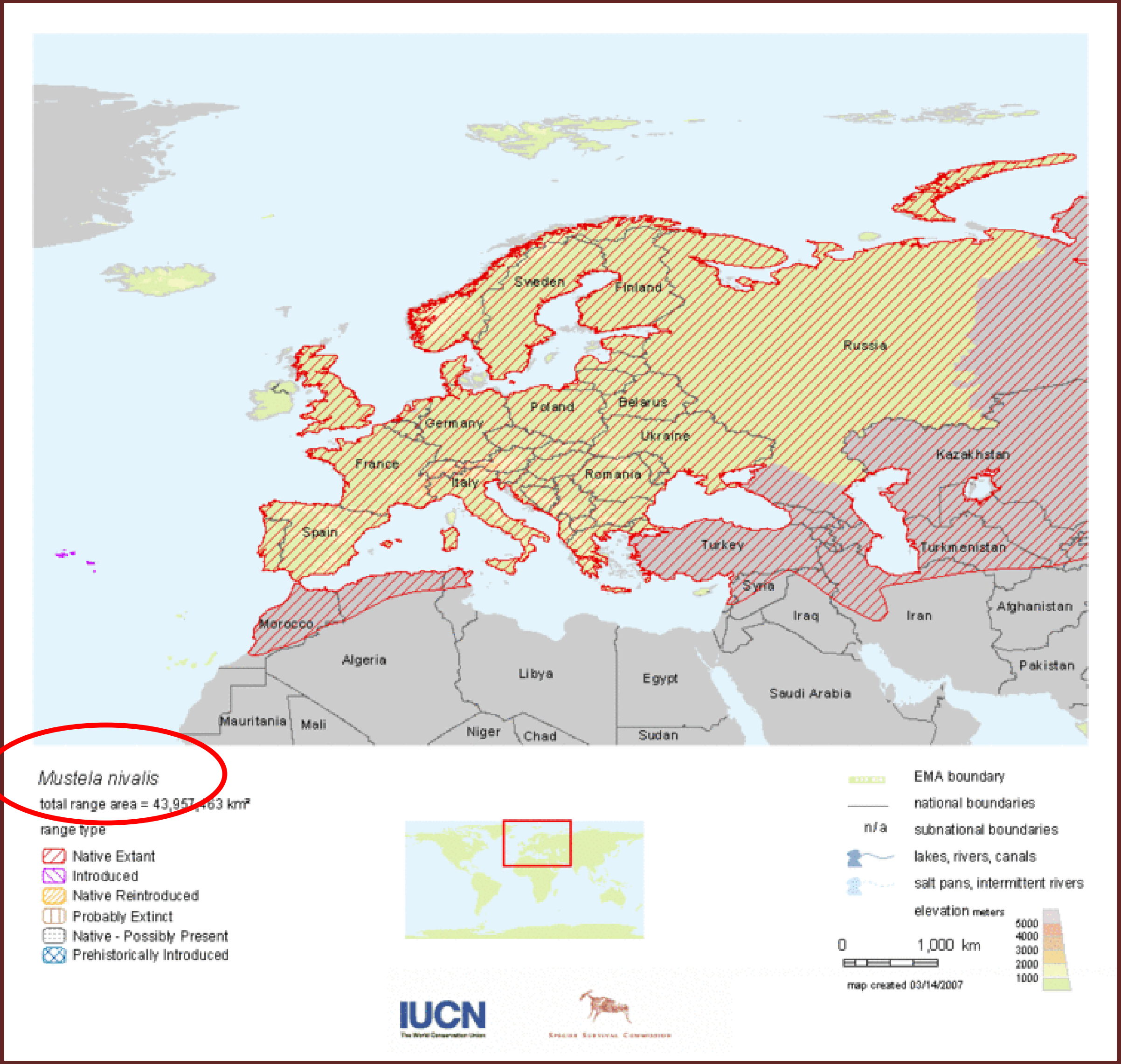
YES!

Distribution shifts due? Finnish voles

water vole

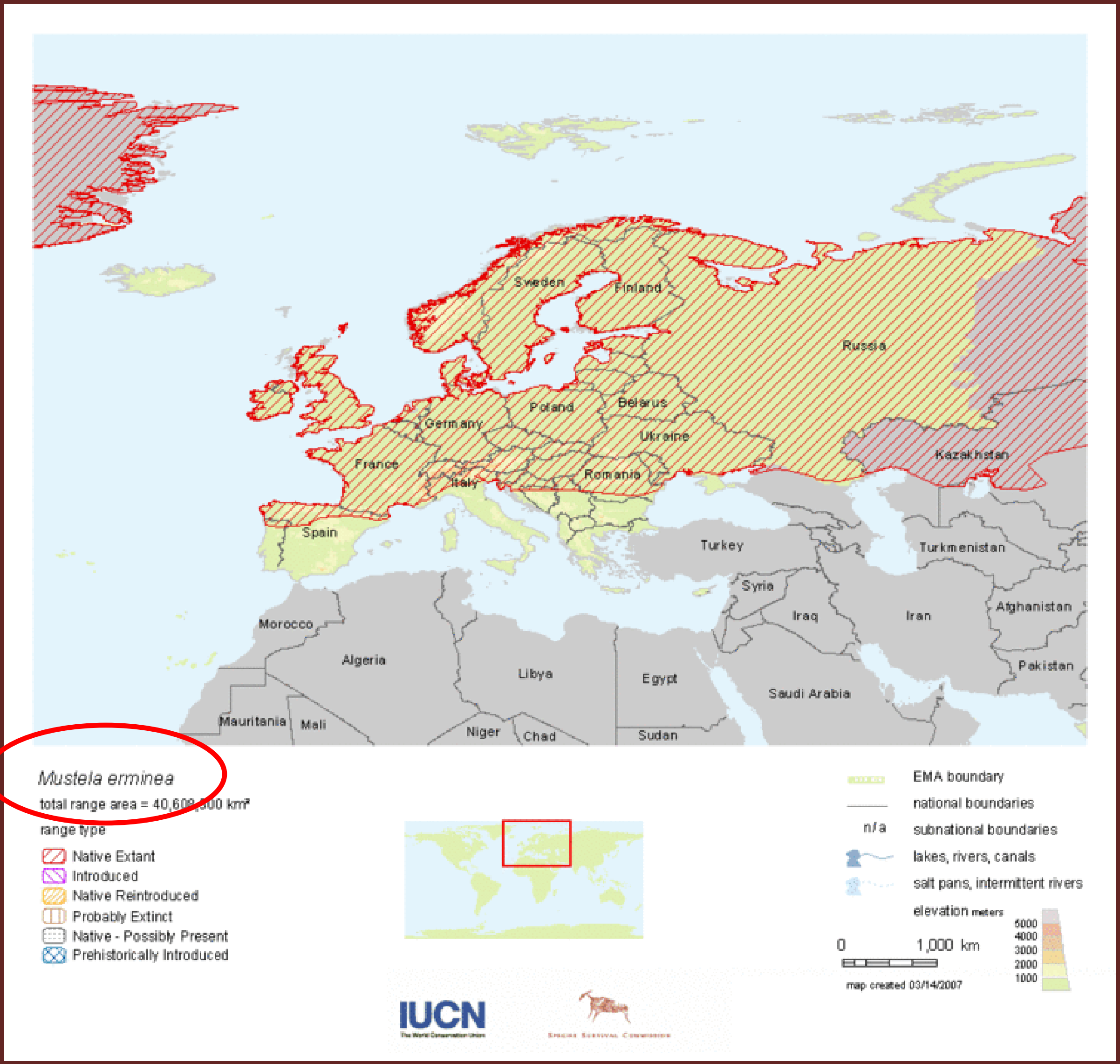


Distribution shifts due? Finnish voles



least weasel

Distribution shifts due? Finnish voles



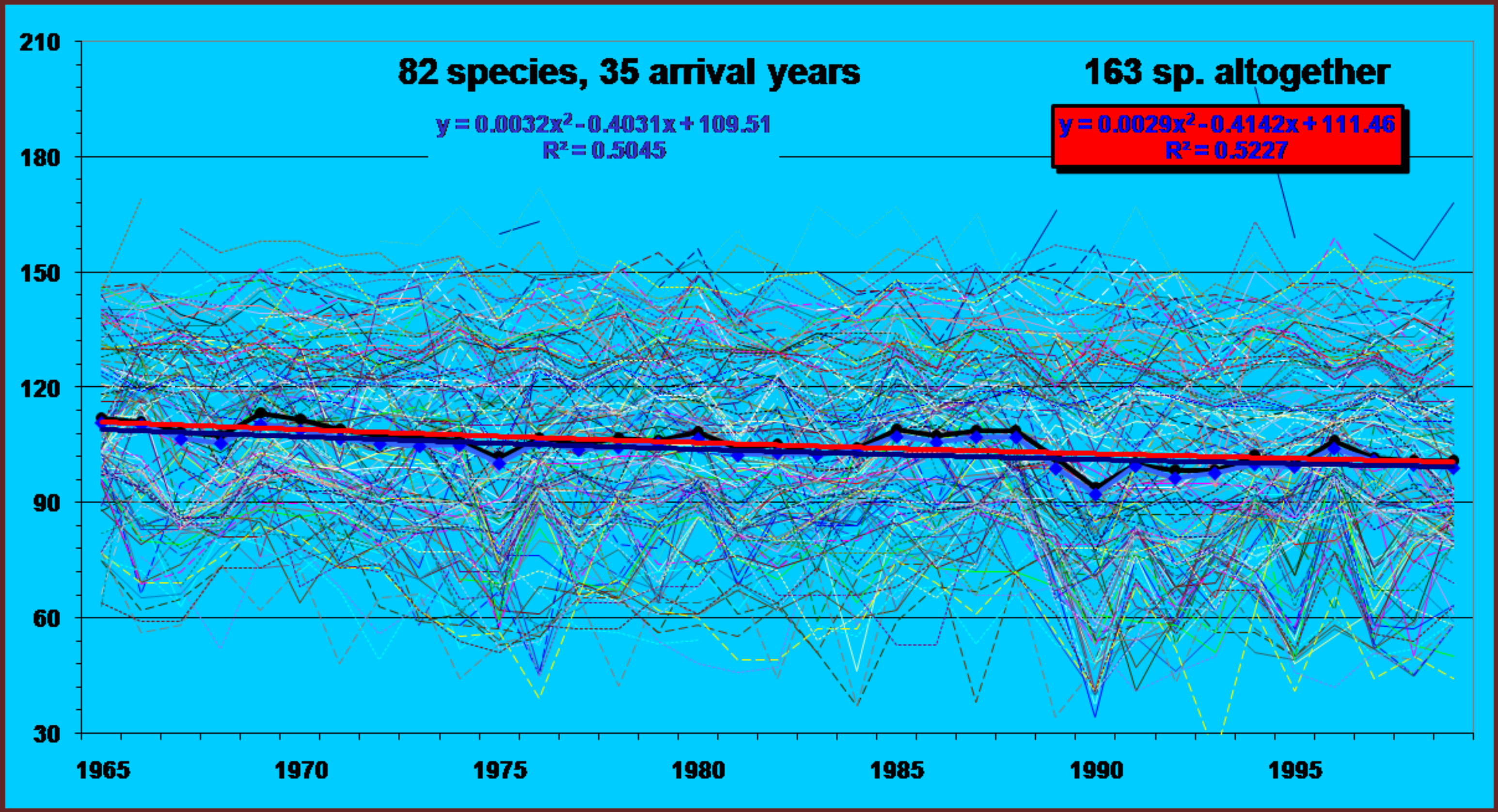
stoat

Phenological changes

- many biological processes governed by seasonal cues, e.g. temperature sum
- vegetation, budburst
- migration, moult
- breeding
- voles: migratory raptors & owls

Phenological changes; examples

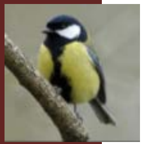
- Finnish migratory birds have advanced spring arrival by ~1 day / decade (median arrival date)

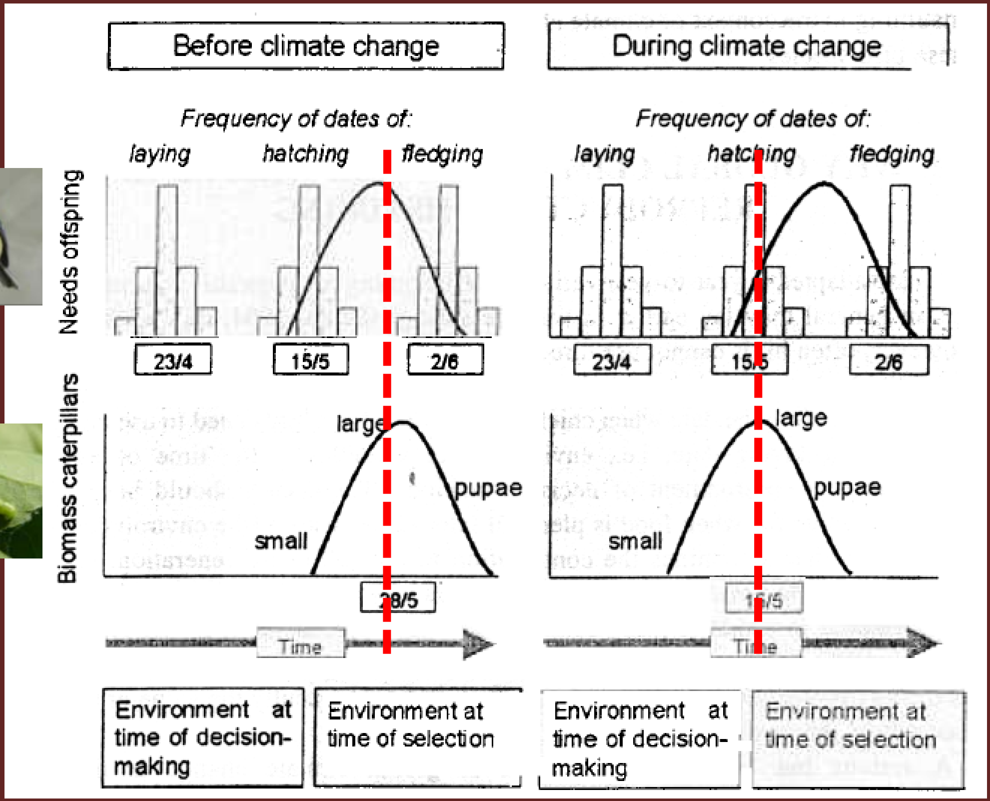


E. Lehikoinen, unpubl.

Phenology and trophic interactions

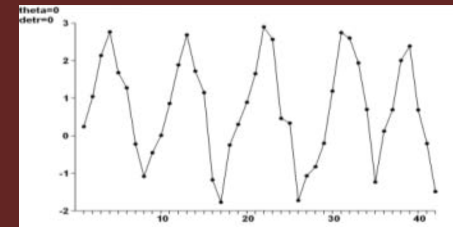
- organisms adapted to current environmental food conditions
- climate change will not necessarily affect all components of food chains/webs simultaneously
- responses by organisms may not match
  ->mismatch





Visser et al. ARE2004

Changes in population dynamics



- larch budmoth; typically cyclic forest insect
- cyclic dynamics for 1100 years, absence of outbreaks since early 1980’s -> temperature rise?

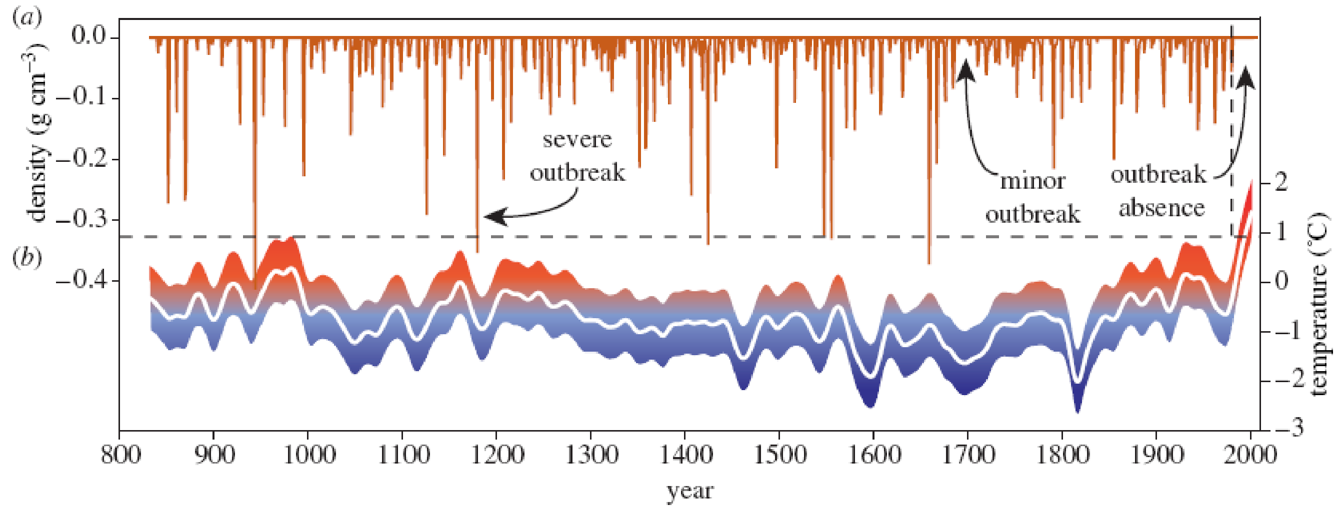


Figure 3. Long-term LBM and temperature reconstructions for the European Alps. (*a*) MXD-based LBM outbreak reconstruction since AD 832. Time-series is the age-corrected difference series between gap-filled and original MXD data (for details on gap-filling and age-correction procedures, see the electronic supplementary material). Values less than -0.005 g cm^{-3} are shown. (*b*) The temperature model (white curve) is shown together with the standard error (coloured band) derived from the fit with instrumental data. Dashed lines indicate the last LBM mass outbreak in 1981 (vertical) and the upper standard error limit recorded in the late ninth century (horizontal).

Esper et al. PRSL2007

Seasonality and population dynamics

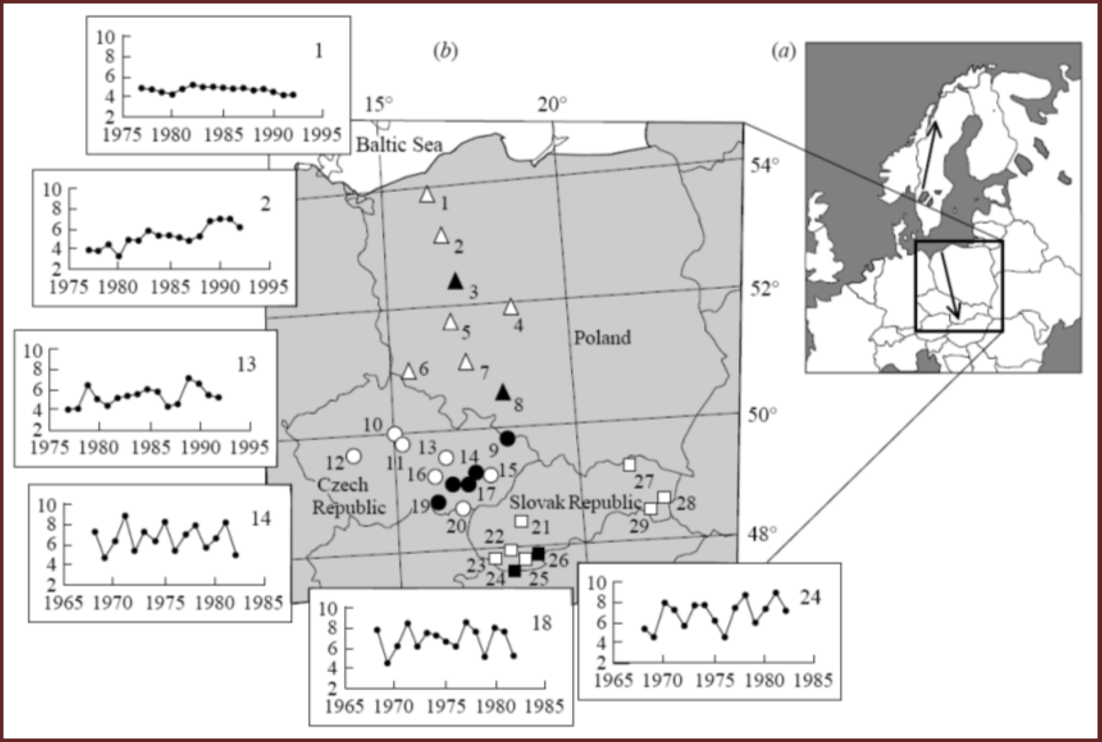
- cyclicity in small rodents strongly affected by seasonality
- density dependence (dd) structures vary seasonally, strong direct and delayed dd in population growth in winter, also in summer

summer involves breeding, population growth, access to diverse growing food sources, and interaction with more predators. In contrast, the winter is characterized by less diverse and nonreplenishing food sources, aging, and elevated importance of mustelid predators that specialize in hunting below the snow cover. These factors are not likely to change in compensatory fashion as the length of seasons change.

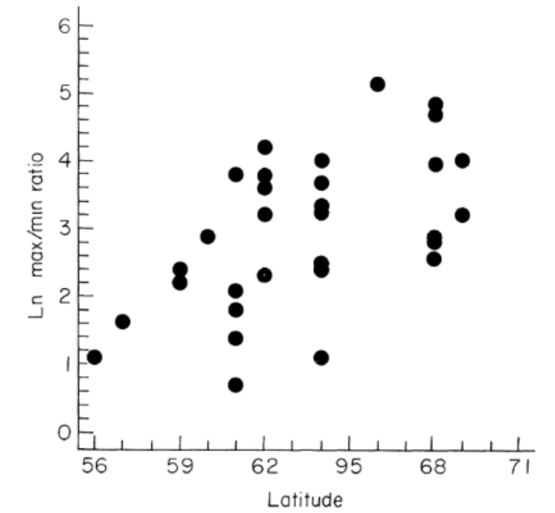
Hansen et al. AmNat1999

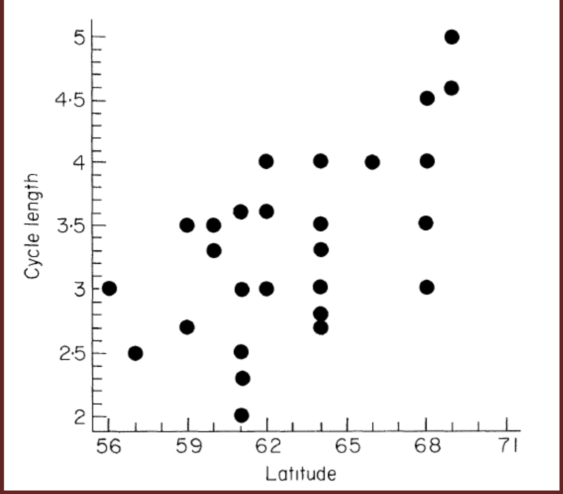
Seasonality and population dynamics

- seasonality = cyclicity



Tkadlec & Stenseth PRSL2001

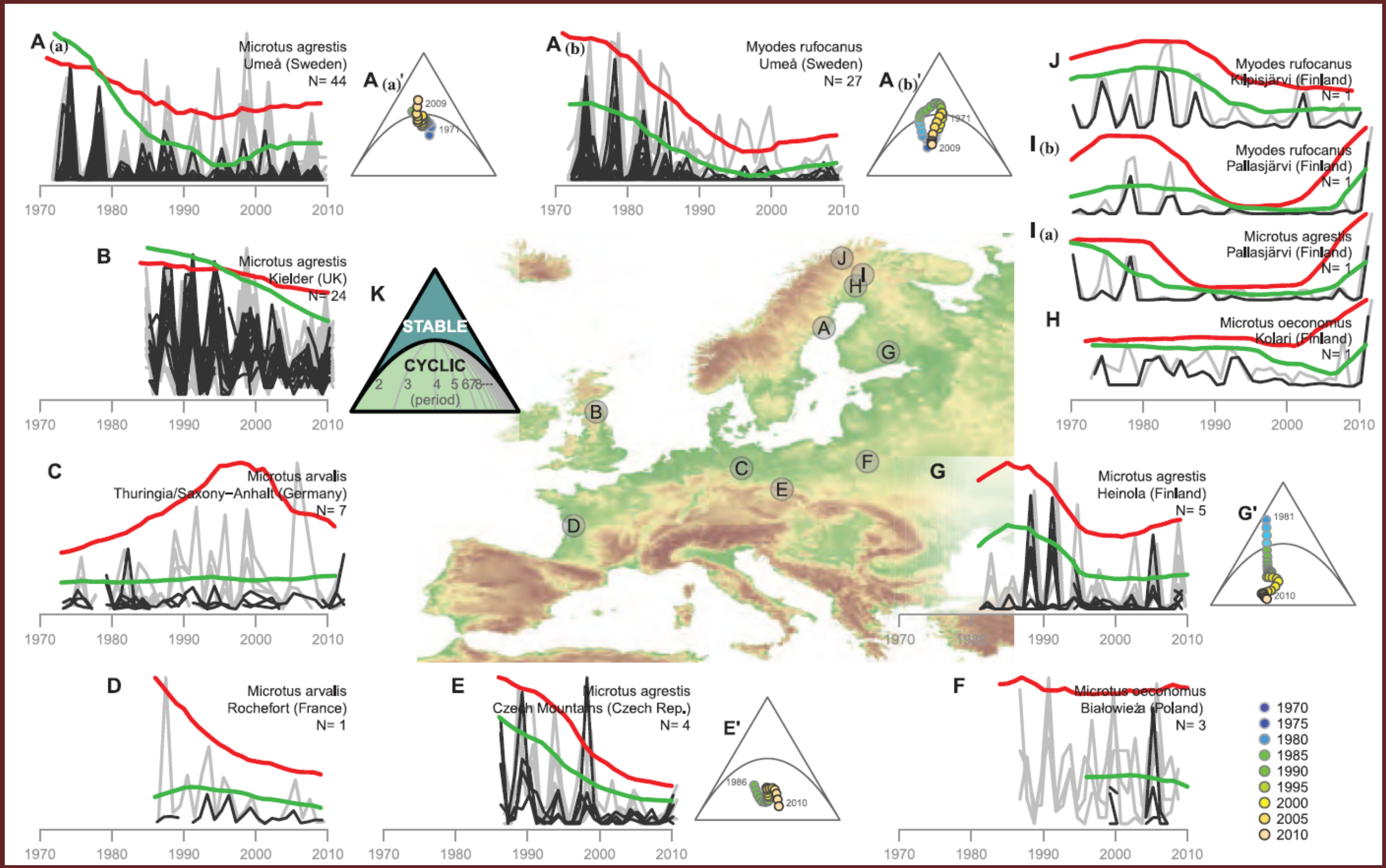




Hansson & Henttonen Oecologia1985

Seasonality and population dynamics

- recent findings show disappearing cycles across Europe



Cornulier et al Science 2013

Seasonality and population dynamics

- destructive sampling
- natural fluctuation pattern
- habitat fragmentation
- adverse winter
- predation increase
- food/shelter decrease
- food-quality decrease
- environmental stress/disease

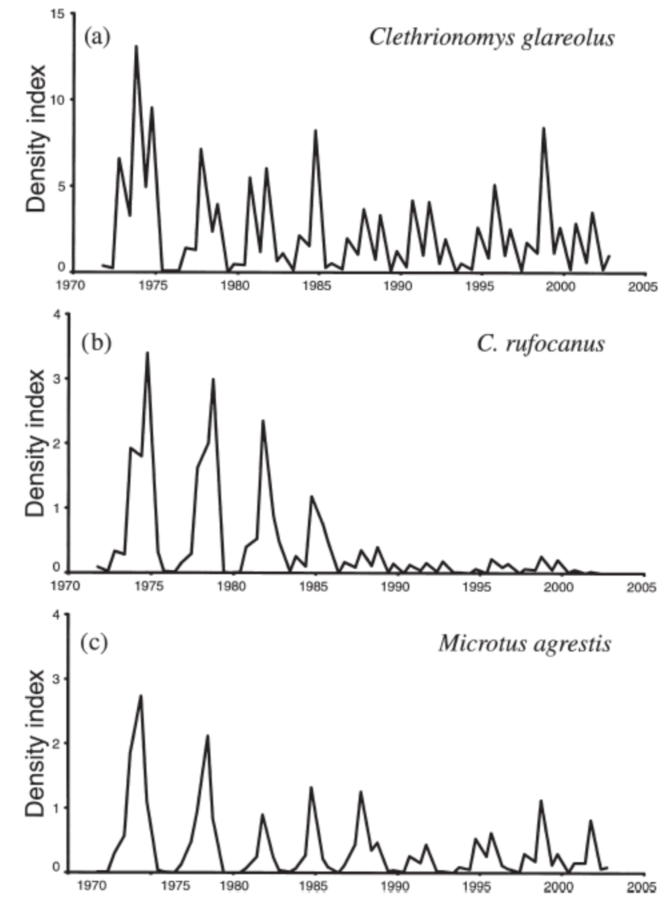
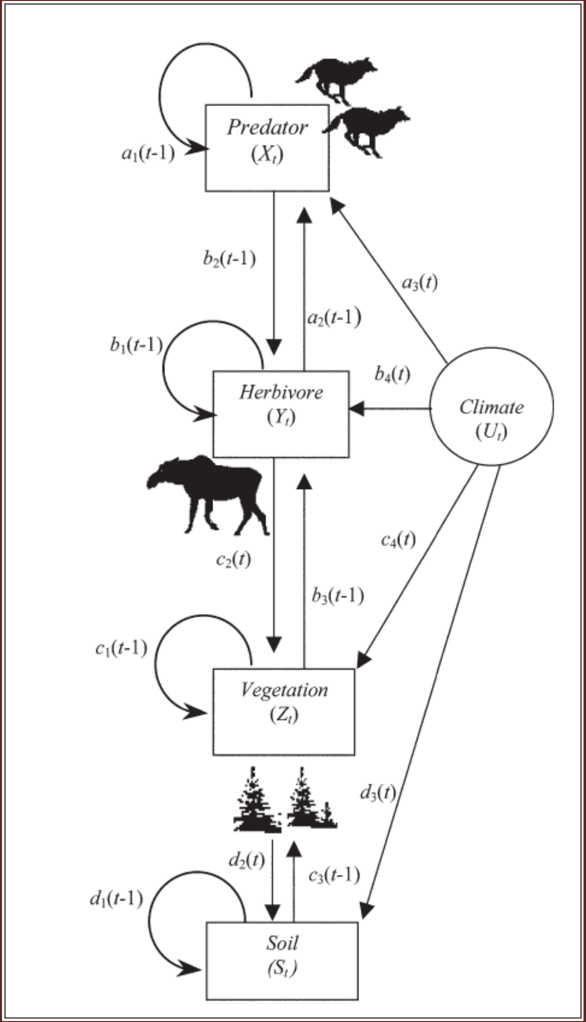


Fig. 1. Trapping indices for (a) *Clethrionomys glareolus*, (b) *C. rufocanus* and (c) *Microtus agrestis* in spring and fall from fall 1971 to fall 2002.

Hörnfeldt Oikos2004

Direct vs. indirect effects of climate change

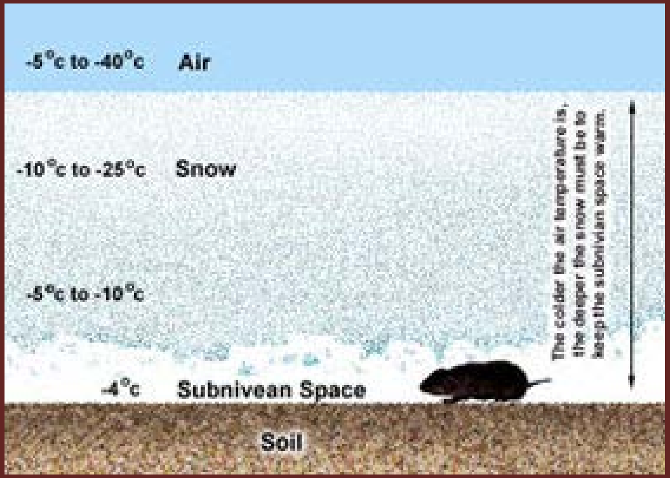
- direct: changing abiotic environmental conditions have an immediate effect on organisms
- indirect: changes in focal species are mediated by changes on other trophic levels (vegetation, predation, parasitism, etc.)
- top-down vs. bottom-up
- non-exclusive, very difficult to tease apart



Schmitz et al. BioScience2003

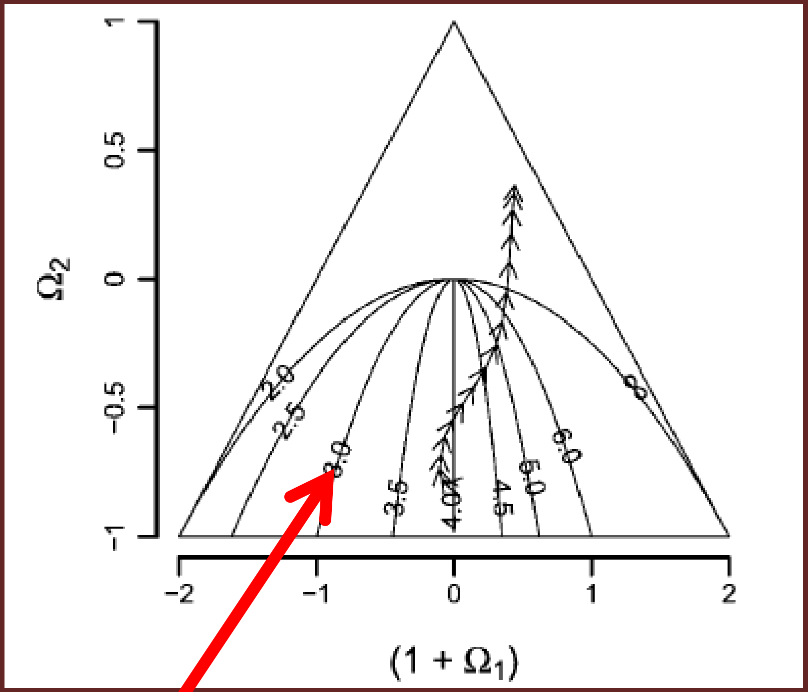
Direct effects of climate on rodent dynamics

- boreal and arctic mammals: thermo-regulation
- (extreme) cold or heat (e.g. moose experience heat stress in winter when temp > -5°C, in summer when > 14°C)
- precipitation , drought
- snow depth
- catastrophies
- in small rodents: snow cover critical; provides shelter from predators and insulates!



Direct effects of climate on rodent dynamics

- disappearing field vole cycles in the UK
- gradual decline in strength of both direct and delayed density dependence
- also decline in degree of spatial autocorrelation
- major changes occurred in winter



Bierman et al. 2006

region of cyclicity: under parabola

Direct effects of climate on rodent dynamics

Kielder Forest, UK

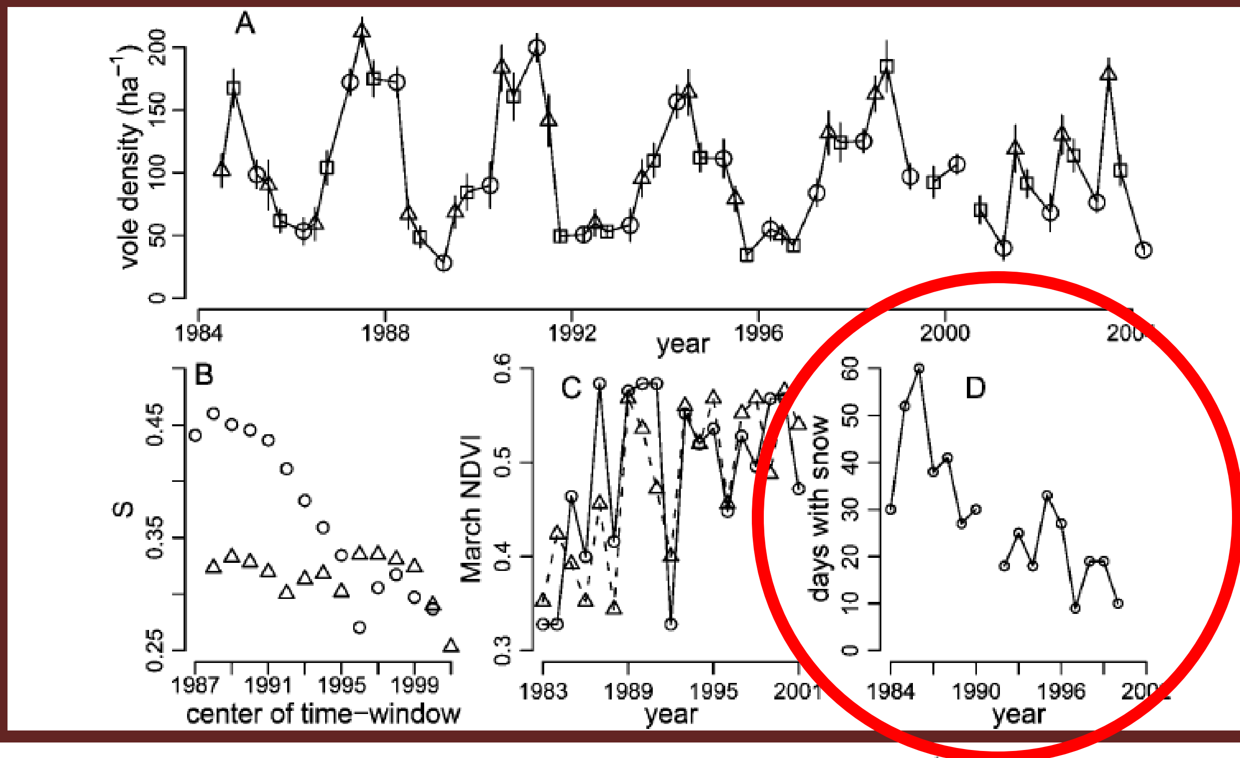


Figure 1: *A*, Mean (SE given by vertical lines) of the estimated seasonal log densities (in voles ha^{-1}) of the vole populations on all locations in Kielder Forest from 1984 to 2004. *Triangles*, summer; *squares*, autumn; *circles*, spring. *B*, Changes over time in the crude variability in population densities in these seasons given by the *s* index (=SD of $\log_{10}$ density estimates) in consecutive time windows of the time series of spring (*circles*) and autumn (*triangles*) population densities of lengths of 6 years. *C*, Normalized difference vegetation index values in the month of March in two sites approximately 10 miles east of Kielder Forest (and at a similar altitude). The sites consist of grasslands (grazed by sheep) and have a vegetation similar to that in clear-cut areas in Kielder Forest that provide habitat for field voles (*triangles and dashed line*, site 1; *circles and solid line*, site 2). *D*, Number of days with ground snow cover in Kielder Forest from November 1 to March 31 during the winter from 1984–1985 to 2000–2001.

Bierman et al. 2006

Direct effects of climate on rodent dynamics

- recurrent melting and freezing episodes detrimental to vole overwinter survival; density-independent phenomenon
- ice formation on ground reduces thermal insulation and accessibility to food resources
- also predisposes to spring flooding
- stabilising effect on dynamics -> loss of cyclicity?

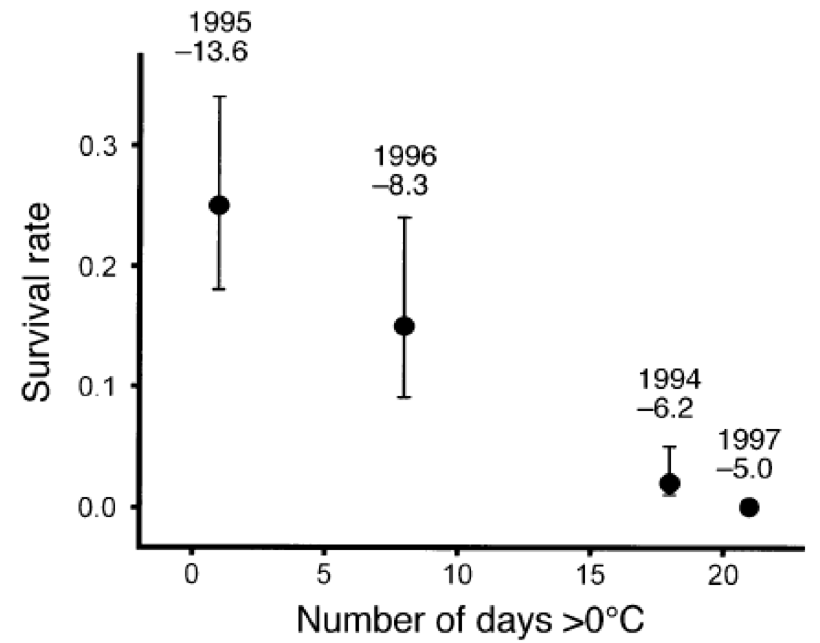
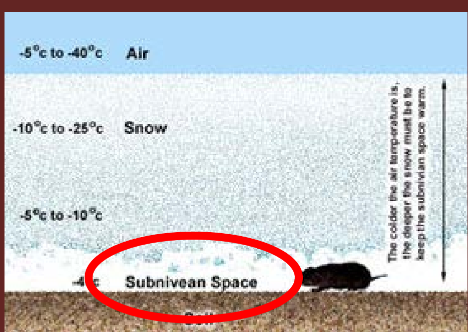


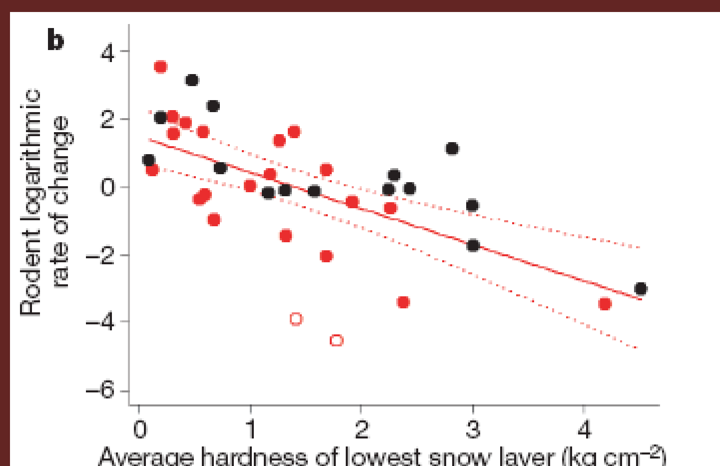
FIG. 3. Yearly winter tundra vole survival rate (with 95% confidence intervals) plotted against the number of days with temperatures above 0°C during midwinter (December–February). Mean winter temperature and the year are denoted above the survival rate estimates.

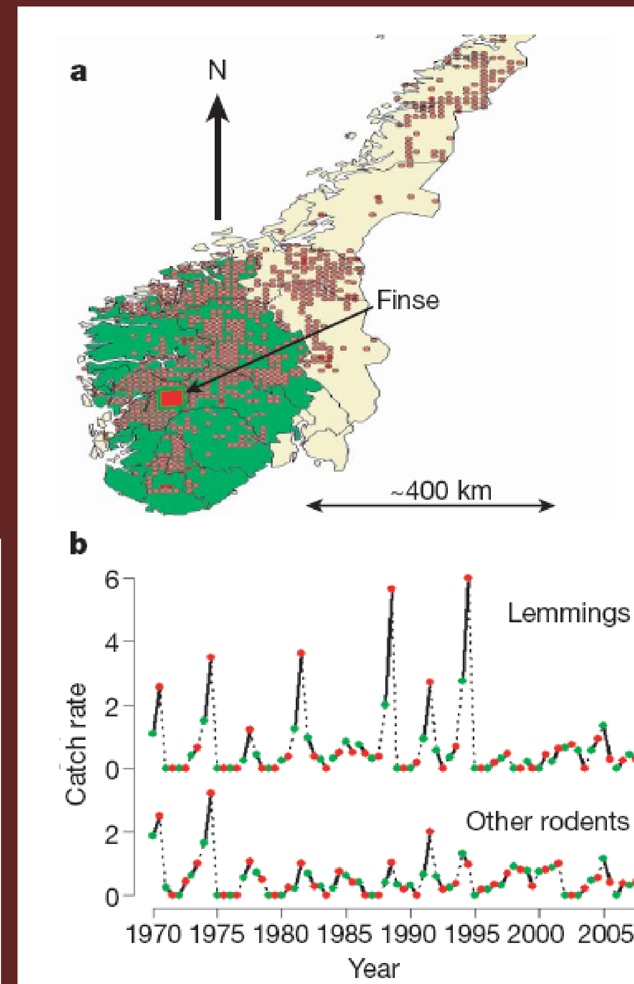
Aars & Ims Ecology2002

Direct effects of climate on rodent dynamics

- lemming dynamics cyclic between 1970-1994, non-cyclic since
- winter weather and snow conditions (incr. temperature and humidity) -> wetter conditions in the subnivean space -> population dynamics

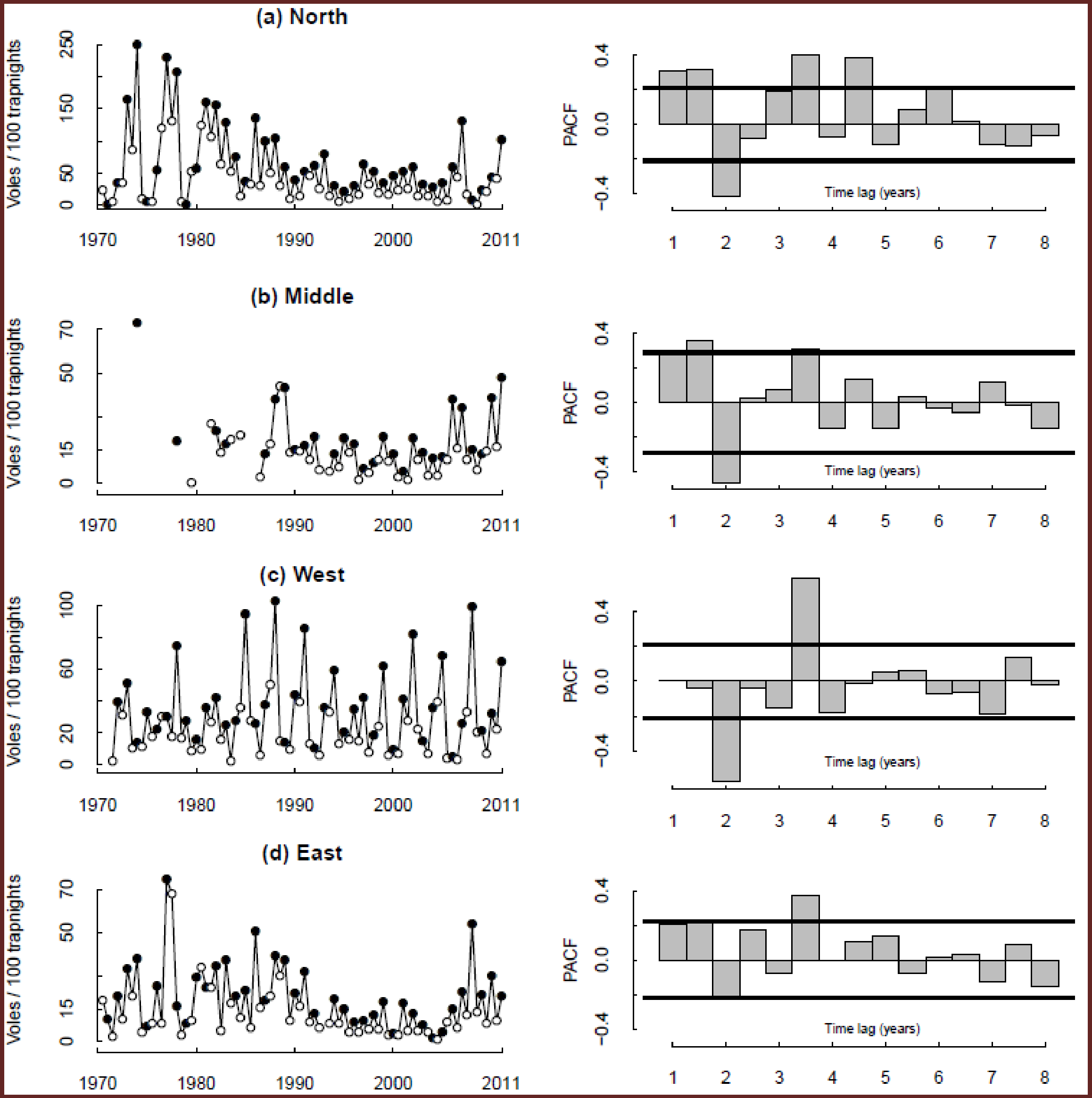






Kausrud et al. 2008

Direct effects of climate on rodent dynamics



cyclic – temporary disappearance

weakly cyclic, no change

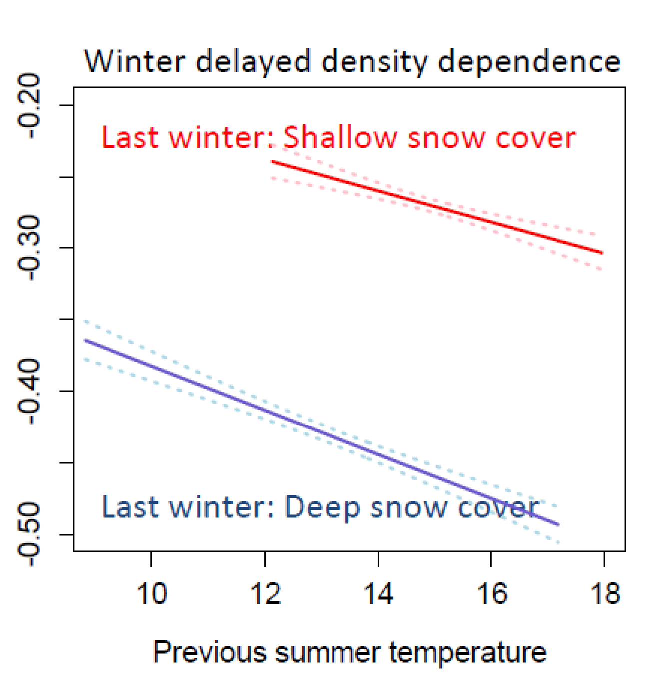
increasingly strong cycle

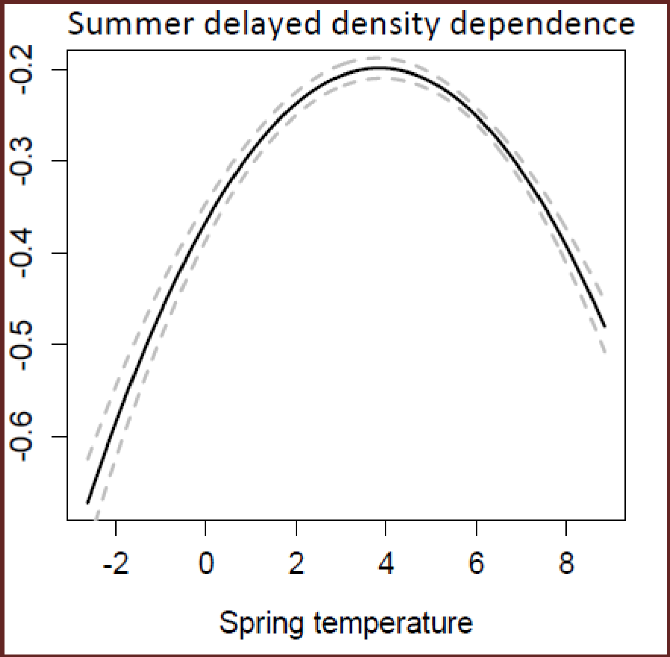
weakening cyclicity

Korpela et al. 2013

Direct effects of climate on rodent dynamics

- both winter and summer delayed density dependence is influenced by growing season conditions
- breeding season determines population dynamics



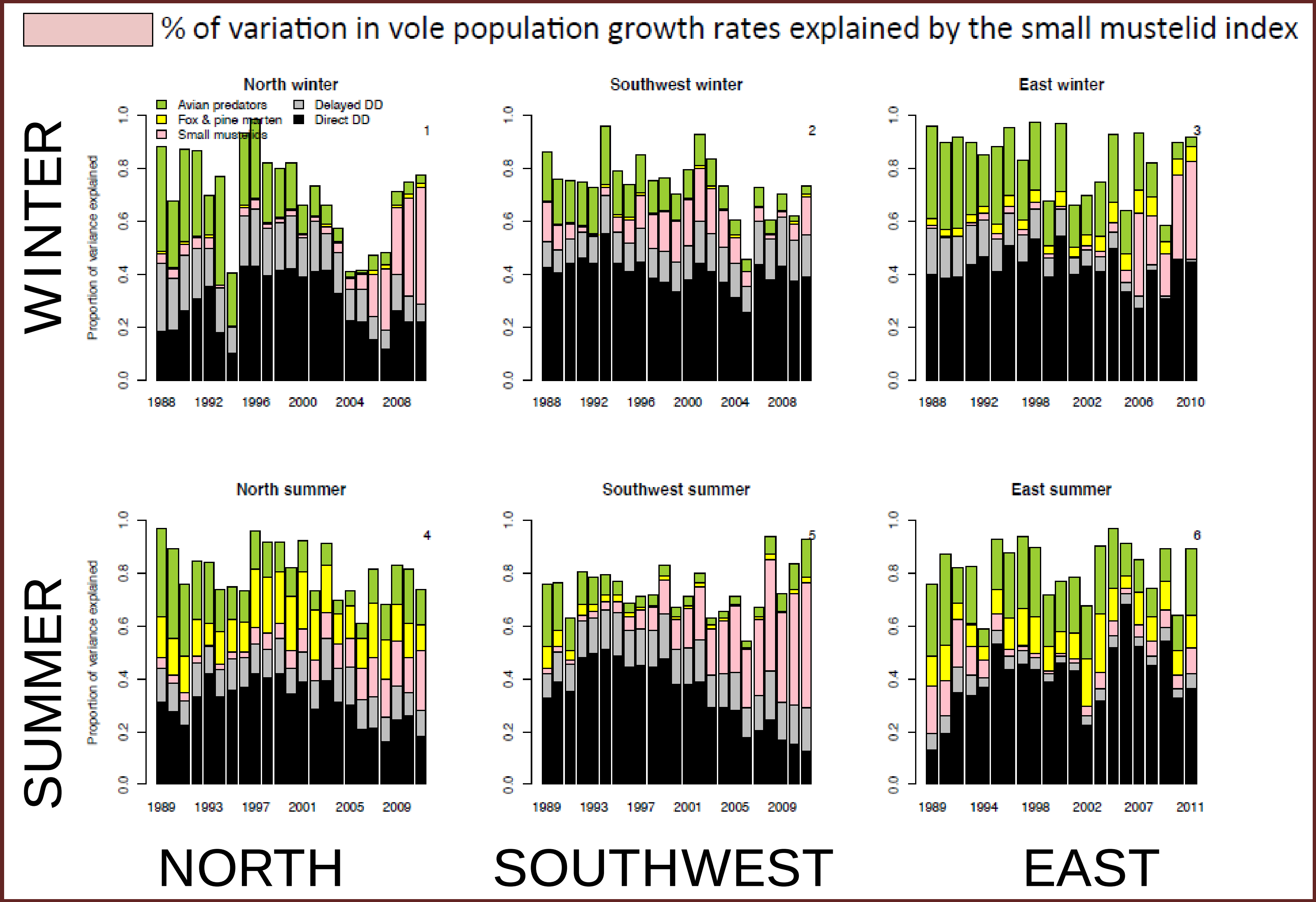


Korpela et al. 2013

Indirect effects of climate on rodent dynamics

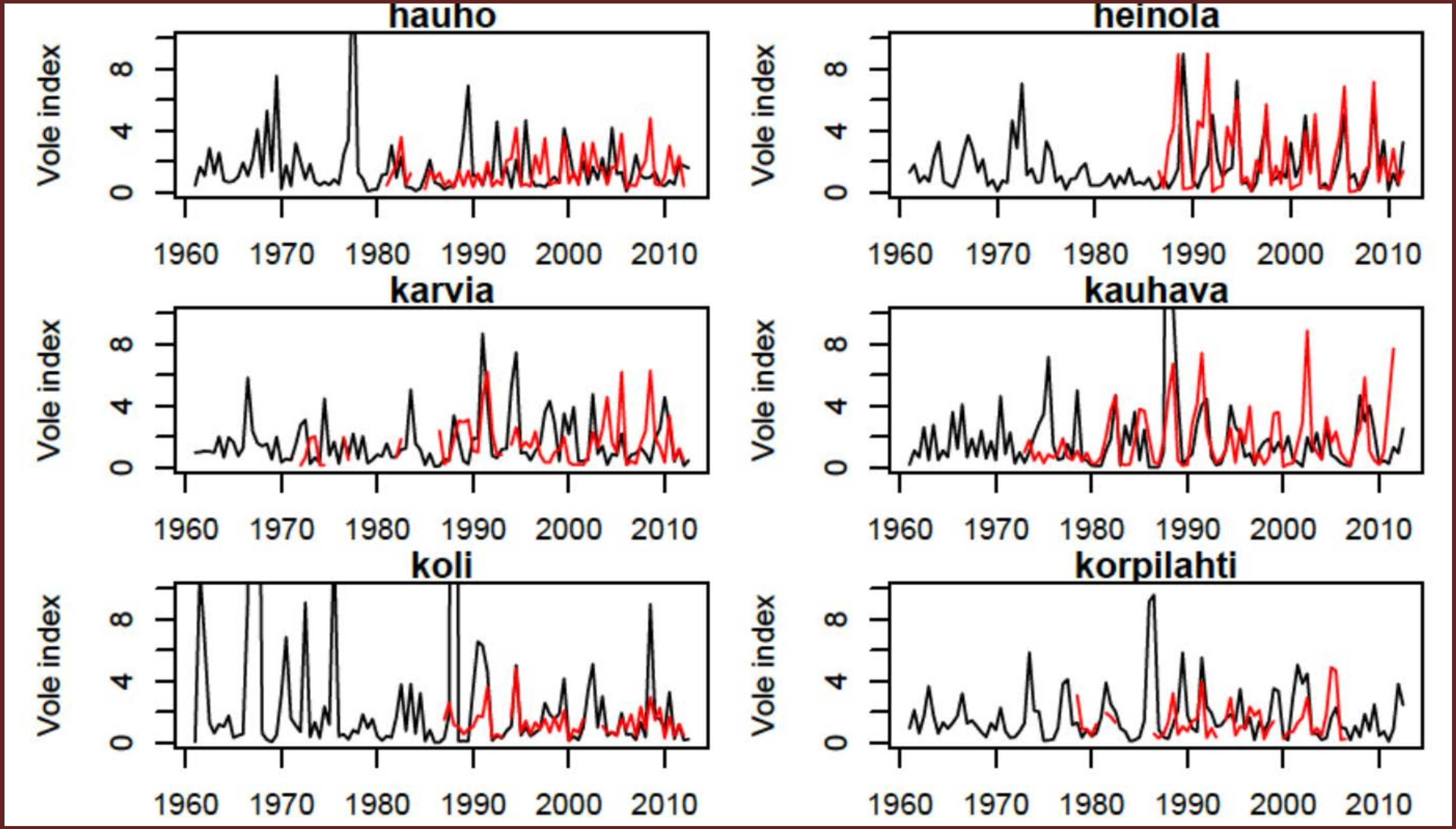
- top-down: trophic levels above focal species affected -> cascades
- owl phenology; temperatures and snow pack may influence breeding
- owl hunting success governed by snow pack hardness
- mustelids not likely to be directly affected (winter pelage..?)

Indirect effects of climate on rodent dynamics



Korpela et al. 2013

Indirect effects of climate on rodent dynamics

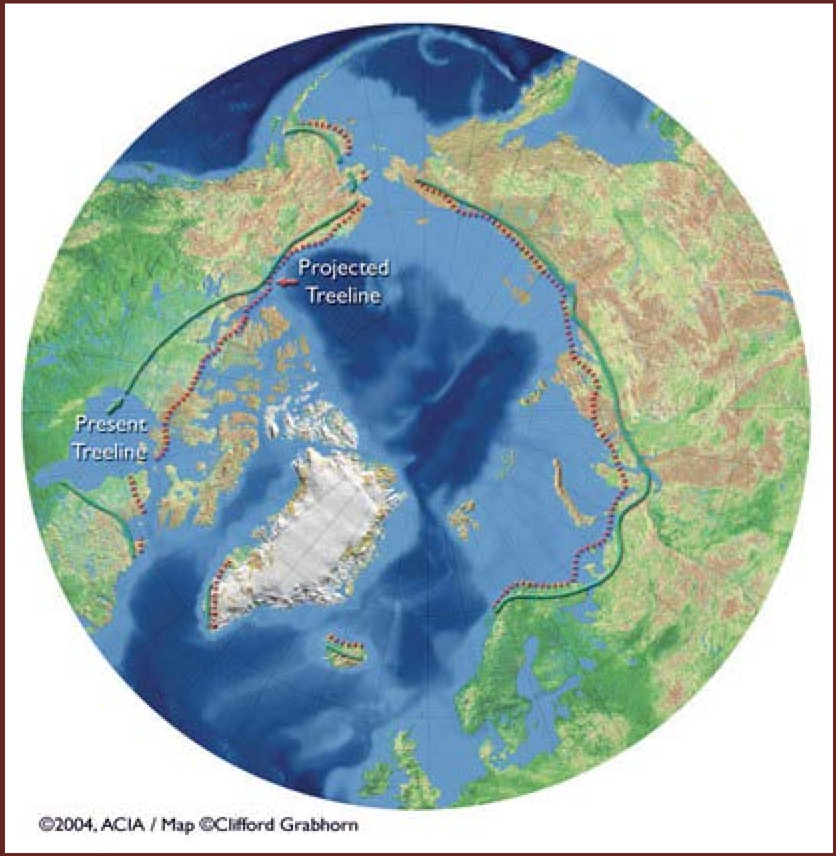


voles × predators × climate –model provides best fit to data.

Korpela et al. 2015

Indirect effects of climate on rodent dynamics

- changes in vegetation species composition, range shifts
- spatial mismatch between resource and consumer
- productivity will increase in N Europe -> high arctic ecosystems particularly vulnerable (lemmings!)
- vegetation responses: growth vs. defenses



Indirect effects of climate on rodent dynamics: feedbacks

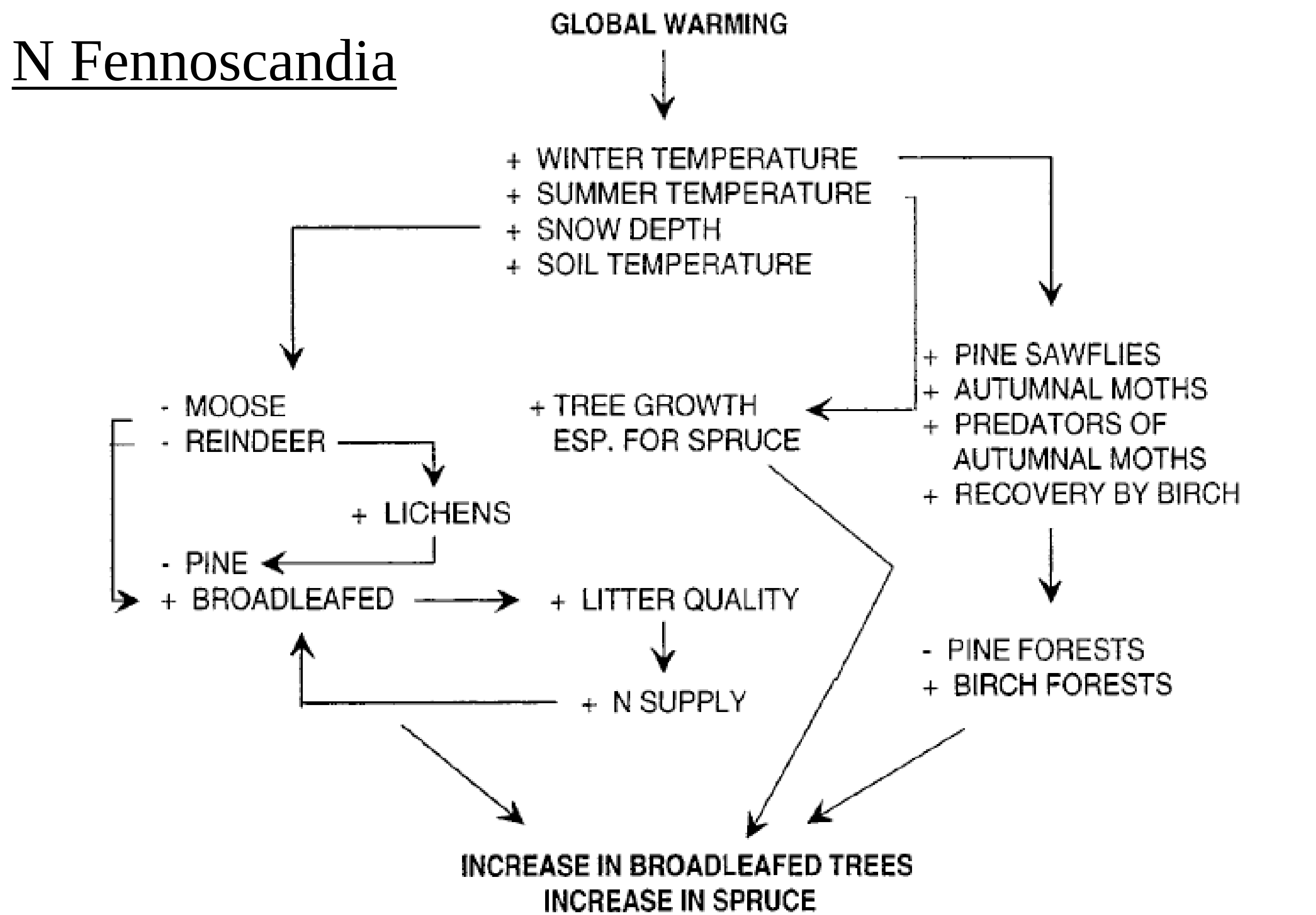
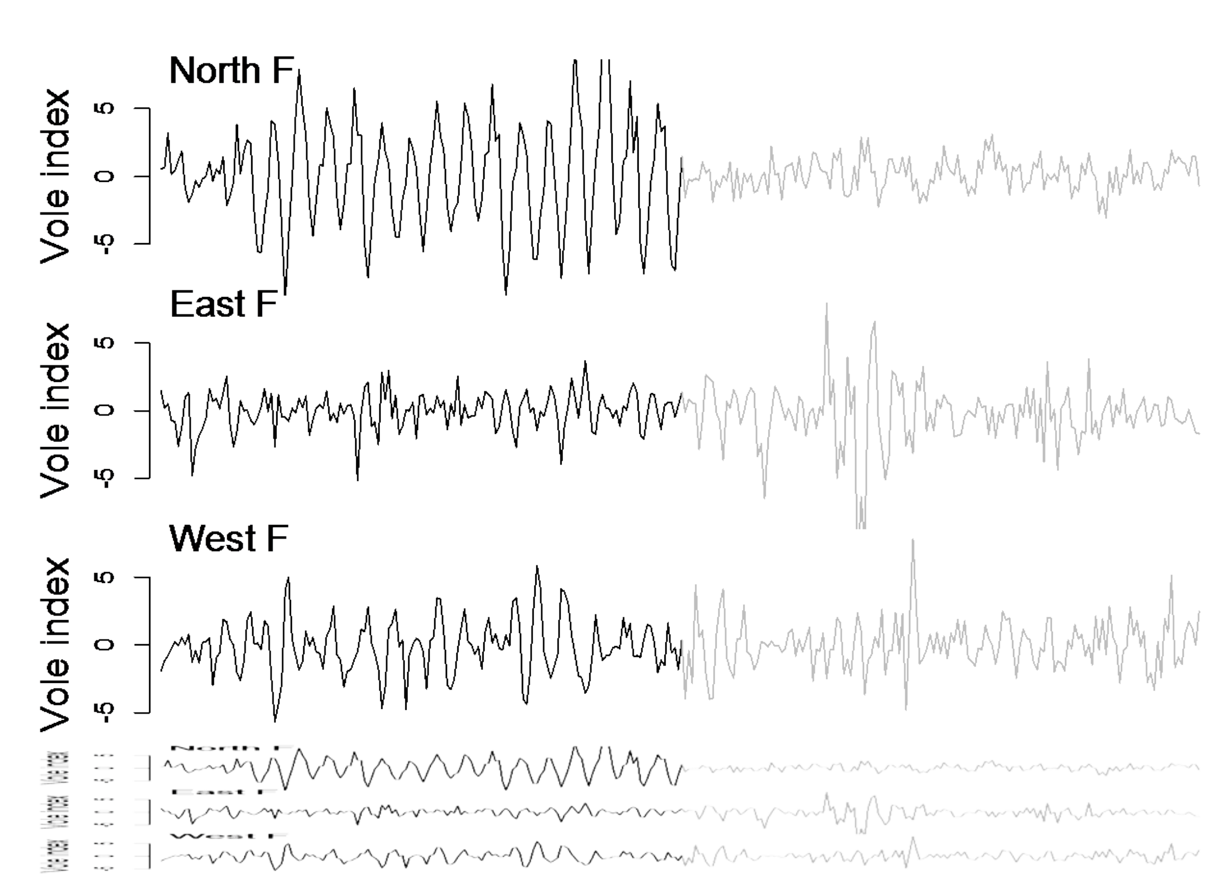


Figure 2. Effects of climatic warming on those biotic interactions likely to influence forest composition in northern Fennoscandia.

Niemelä et al. ClimChange2001

Climate and rodent dynamics: predictions



cycles lost...

irregular fluctuations & outbreaks...

Korpela et al. 2015

Conclusions

1. global temperature is rising, changes in precipitation patterns
2. northern Europe will experience warmer summers and winters, more precipitation especially in winter; ecotones shift north
3. small rodent species' ranges will change
4. breeding phenology might change -> mismatch with resources
5. population dynamics change / cycles lost; seasonality is key
6. direct effects: thermoregulation, precipitation, snow depth etc.
7. indirect effects: changes in natural enemies or vegetation