Plant of the Day

Selaginella lepidophylla (aka Resurrection plant, false rose of Jericho)

Species of desert plant in the spikemoss family (lycophytes evolved 400 million years ago and lack true leaves and roots)

Sold as a novelty plant

Selaginella moellendorffii genome sequenced (smallest plant genome yet 127Mbp)

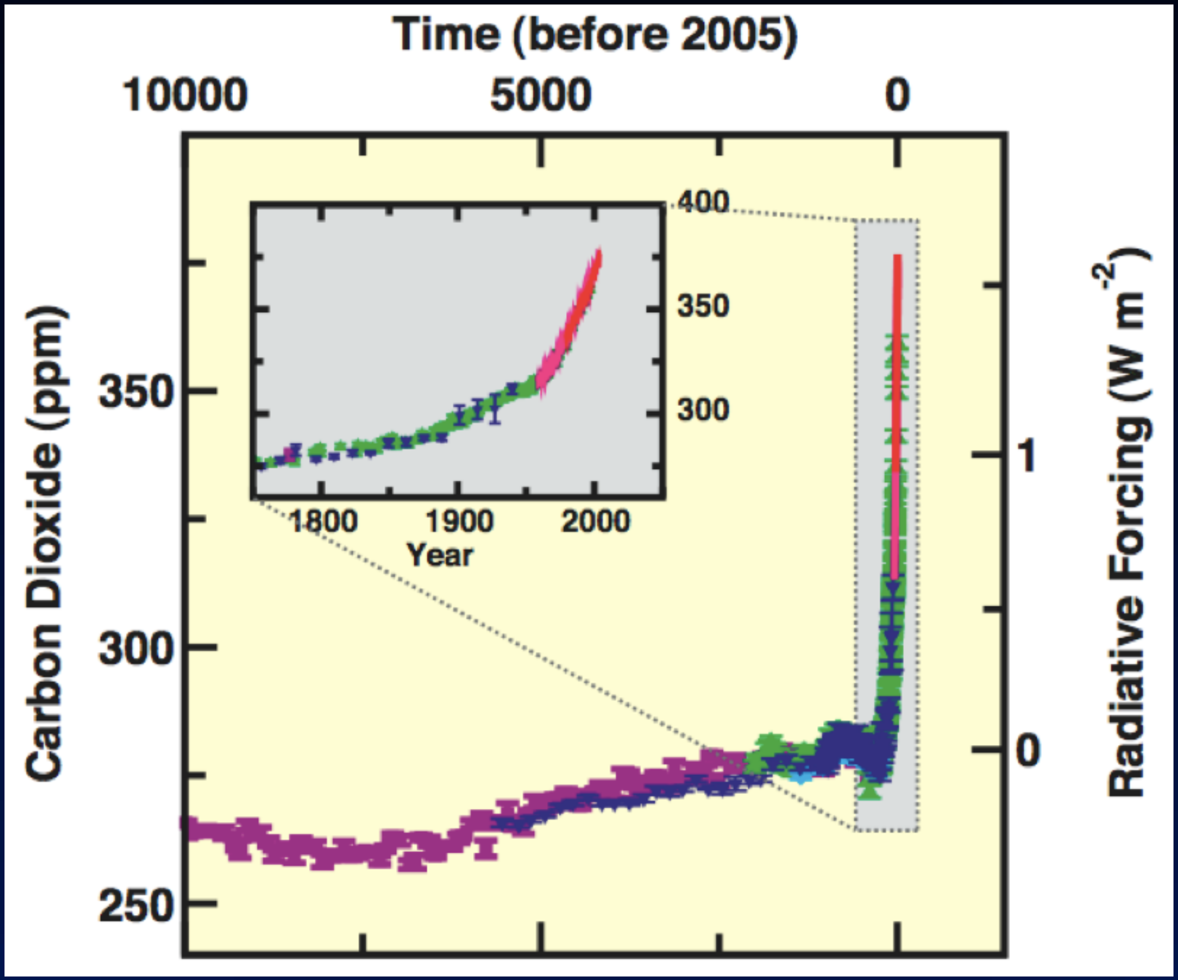
Used to identify genes for drought tolerance for use in crops

Plant Evolution and Climate change – Big Questions

The global selection experiment

- How will species, populations and communities respond to climate change?
- Can plants adapt or migrate fast enough to avoid extinction?
- How can we minimize extinction due to climate change?

$\uparrow CO_2$ "The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005." - IPCC Report, 2007



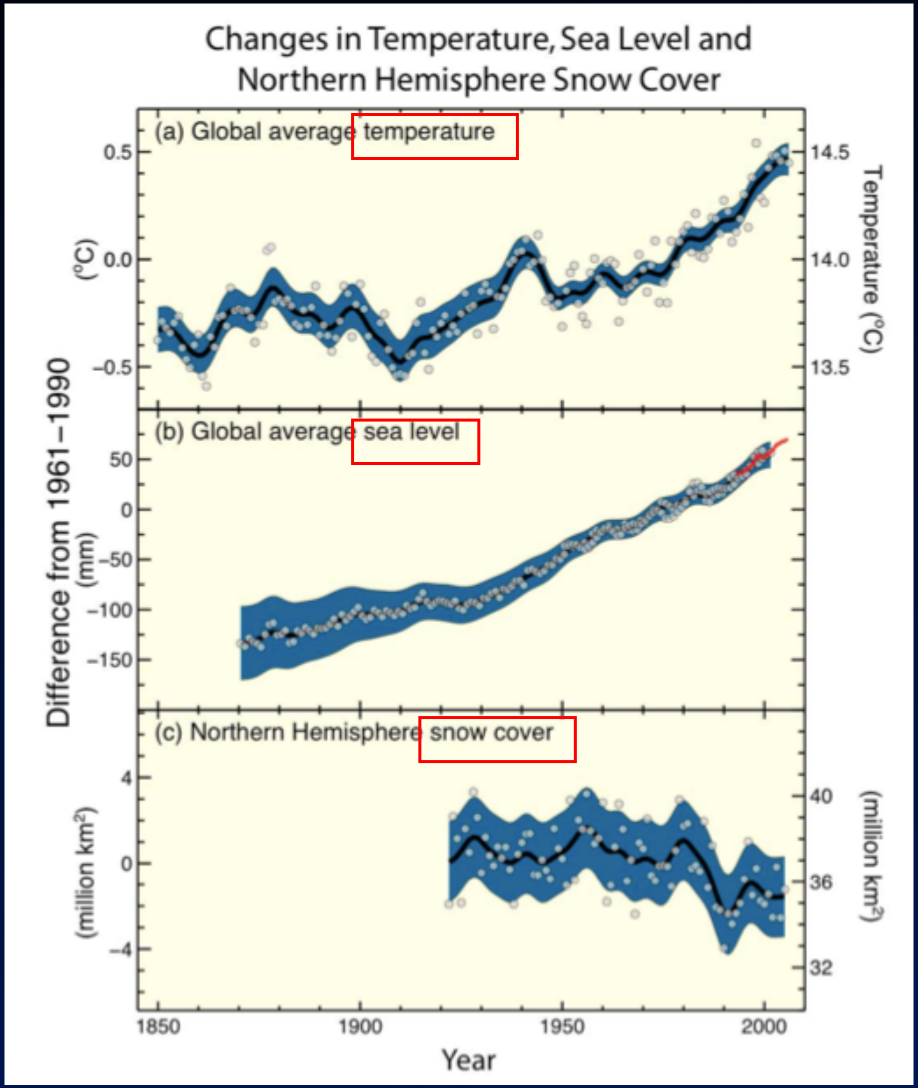
Methane and nitrous oxide show similar trends

Radiative forcing = the difference between the incoming radiation energy and the outgoing radiation energy in a given climate system

Wide-ranging effects of increased CO_2

Climatic changes

- Increase in plant growth rates
- Temperature increases
- Changes in seasonality
- Changes in precipitation
- Changes in growing season
- Extreme climatic events



Predicted changes in the bioclimatic envelopes of BC

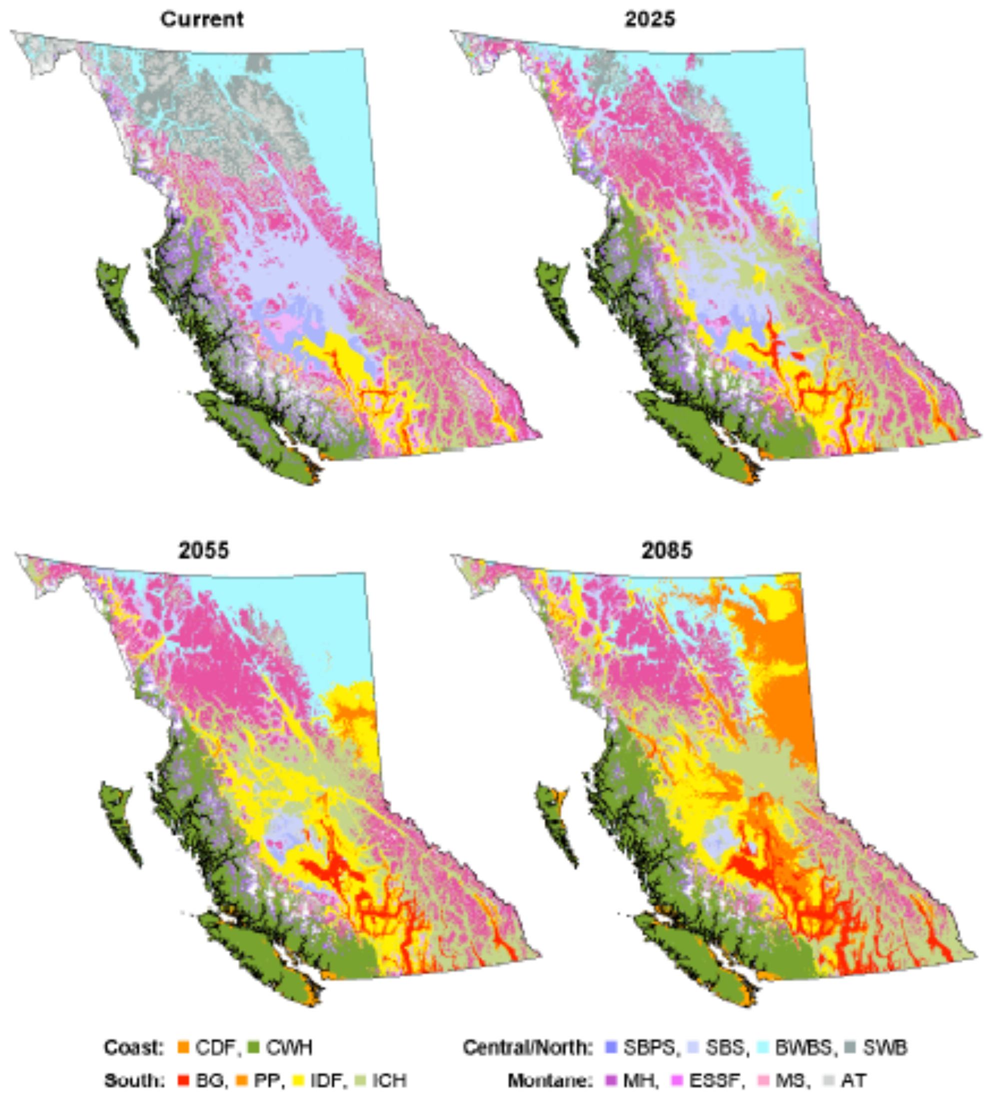


Fig. 2. Shift of the climatic envelope of ecological zones based on the ensemble simulation CGCM1gax for the normal periods 2011–2040 (2025), 2041–2070 (2055), and 2071–2100 (2085). The ecological zones are: CDF, Coastal Douglas-fir; CWH, Coastal Western Hemlock; BG, Bunchgrass; PP, Ponderosa Pine; IDF, Interior Douglas-fir; ICH, Interior Cedar–Hemlock; SBPS, Sub-boreal Pine and Spruce; SBS, Sub-boreal Spruce; BWBS, Boreal White and Back Spruce; MH, Mountain Hemlock; ESSF, Engelmann Spruce–Subapline Fir; MS, Montane Spruce; SWB, Spruce–Willow–Birch; AT, Alpine Tundra.

How will species, populations and communities respond to climate change?

1) Migration (of individuals or through seed dispersal)
2) Phenotypic plasticity (individual variability)
3) Evolutionary adaptation
4) Extinction

How are species, populations and communities responding to climate change?

Table 2 **Summary statistics and synthetic analyses derived from Table 1**

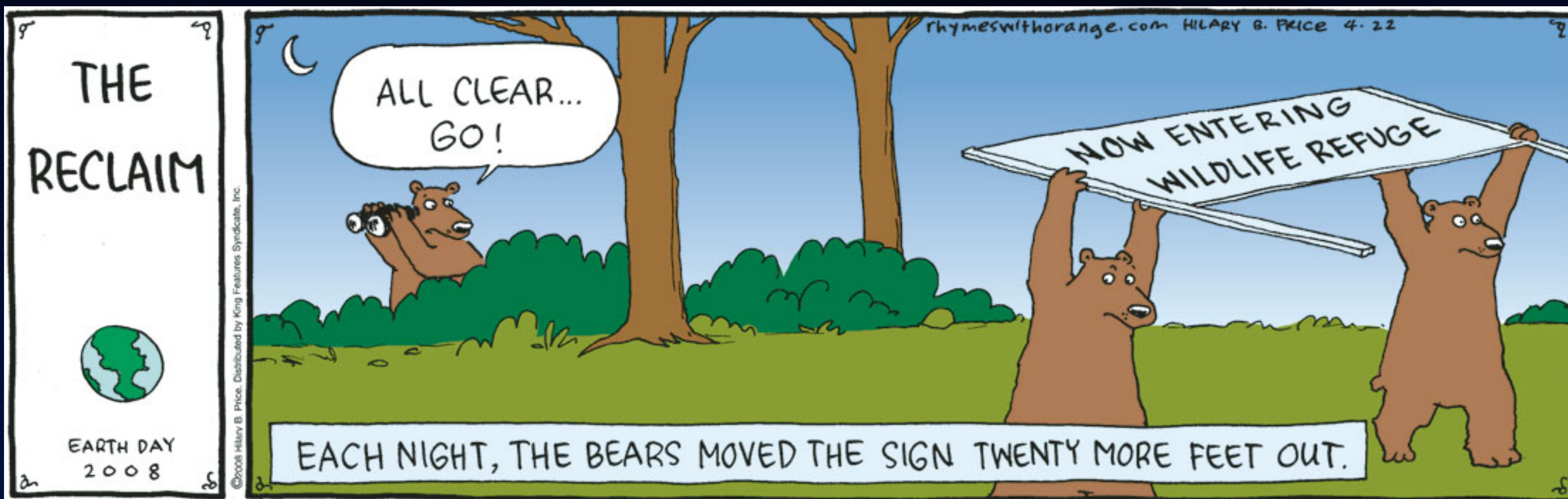
Type of change	Changed as predicted	Changed opposite to prediction	*P*-value
Phenological ($N = 484/(678)$)	87% ($n = 423$)	13% ($n = 61$)	$<0.1 \times 10^{-12}$
Distributional changes			
At poleward/upper range boundaries	81%	19%	–
At equatorial/lower range boundaries	75%	25%	–
Community (abundance) changes			
Cold-adapted species	74%	26%	–
Warm-adapted species	91%	9%	–
$N = 460/(920)$	81% ($n = 372$)	19% ($n = 88$)	$<0.1 \times 10^{-12}$
Meta-analyses			
Range-boundaries ($N = 99$)	6.1 km m^{-1} per decade northward/upward shift*		0.013
Phenologies ($N = 172$)	2.3 days per decade advancement*		<0.05

Data points represent species, functional groups or biogeographic groups. *N*, number of statistically or biologically significant changes/(total number species with data reported for boundary, timing, or abundance processes). The no prediction category is not included here.

*Bootstrap 95% confidence limits for mean range boundary change are 1.26, 10.87; for mean phenological shift the limits are −1.74, −3.23.

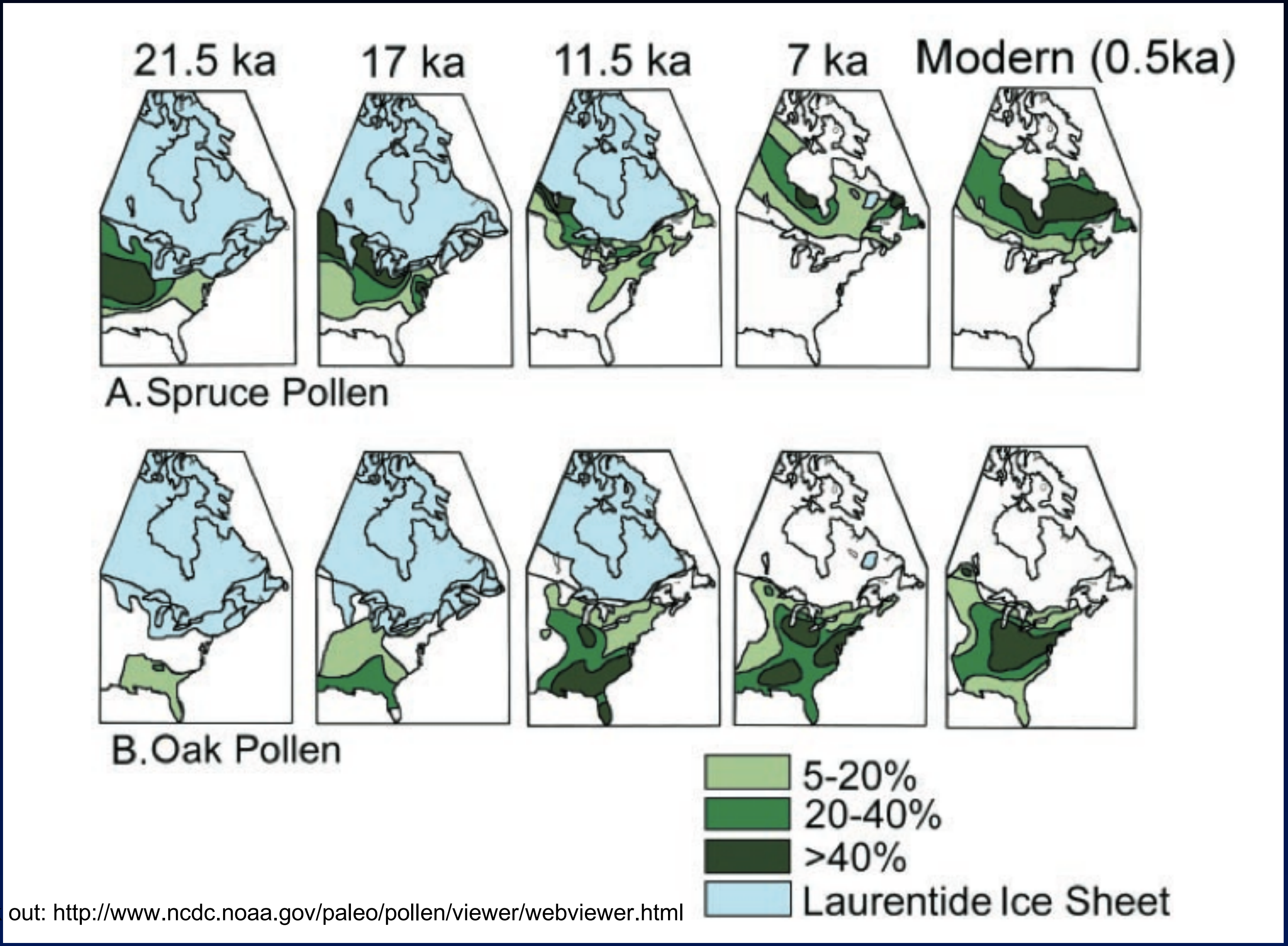
Parmesan and Yohe Nature 2003

Migration


THE RECLAIM
EARTH DAY 2008
©2008 Hilary B. Price. Distributed by King Features Syndicate, Inc.
rhymeswithorange.com HILARY B. PRICE 4.22
ALL CLEAR... GO!
NOW ENTERING WILDLIFE REFUGE
EACH NIGHT, THE BEARS MOVED THE SIGN TWENTY MORE FEET OUT.

How quickly have trees moved in the past?

Pollen records suggested up to 200 m/year



Check out: http://www.ncdc.noaa.gov/paleo/pollen/viewer/webviewer.html

Davis & Shaw, Science 2001

Are estimated migration rates fast enough?

To track climatic changes in the future, range limits would need to move northward 100 km per °C warming, or about 300 km per century, an order of magnitude faster than range extension occurred in the past.

Upshot: warming may be too fast for many tree species to track northward shift of their climatic envelope

What type of species will be able to track changes in climate?

Davis, Climatic Change 1989

What limits the speed of migration?

- Seed dispersal
- Pollen movement
- Biotic constraints
- Habitat fragmentation
- Geographical barriers

Phenotypic Plasticity

Walker *et al.*, PNAS 2006

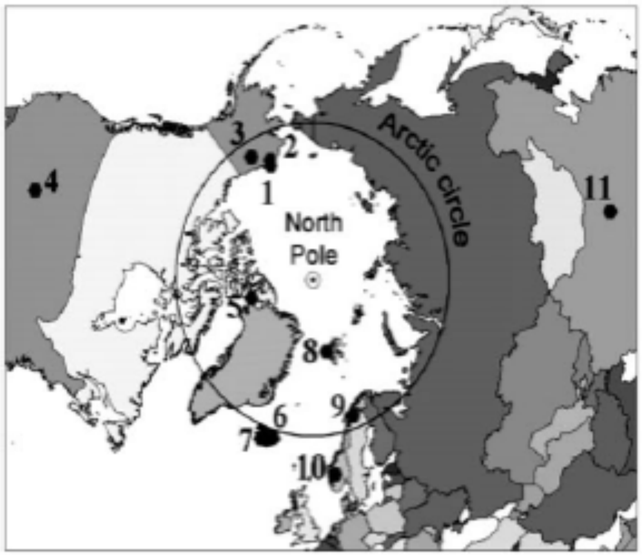


Fig. 1. Location of the sites included in this analysis: 1, Barrow, United States; 2, Atqasuk, United States; 3, Toolik Lake, United States; 4, Niwot Ridge, United States; 5, Alexandra Fiord, Canada; 6, Audkuluheidi, Iceland; 7, Thingvellir, Iceland; 8, Svalbard, Norway; 9, Latnjajaure, Sweden; 10, Finse, Norway; and 11, Tibetan Plateau, China. Basic site characteristics are given in Table 1.

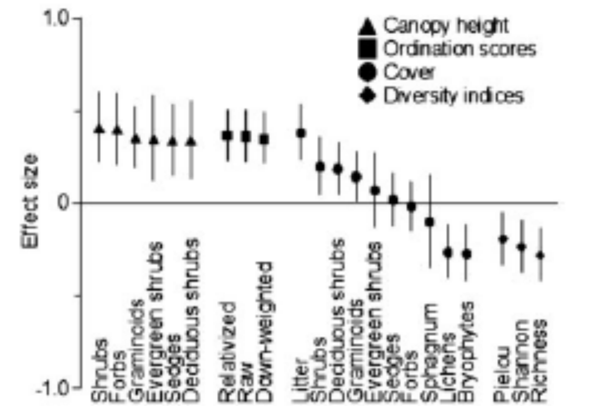


Fig. 2. Response of tundra plant community variables to experimental warming. The values represent the mean effect size and 95% confidence interval from metaanalyses of the 22 variables measured in all studies, where studies consisted of the site and each of the growing seasons in which measurements were made. Effect sizes for cover were in the range considered small by metaanalysis convention, indicating a small magnitude of response. Moderate effect sizes were found for canopy height, ordination scores, and diversity indices, indicating a larger magnitude of response. Note that only the magnitude is important for the ordination scores.

Rapid response to climate warming

- 2 growing seasons at 1-3 degree increase
- Vascular plants will grow taller and become more massive
- Some species will increase in frequency (e.g. deciduous shrubs)
- Others (e.g. lichens) will decline, leading to a decrease in diversity

Limits to the extent of plasticity

A plant can only grow so tall or flower so early → constrained by genetics.

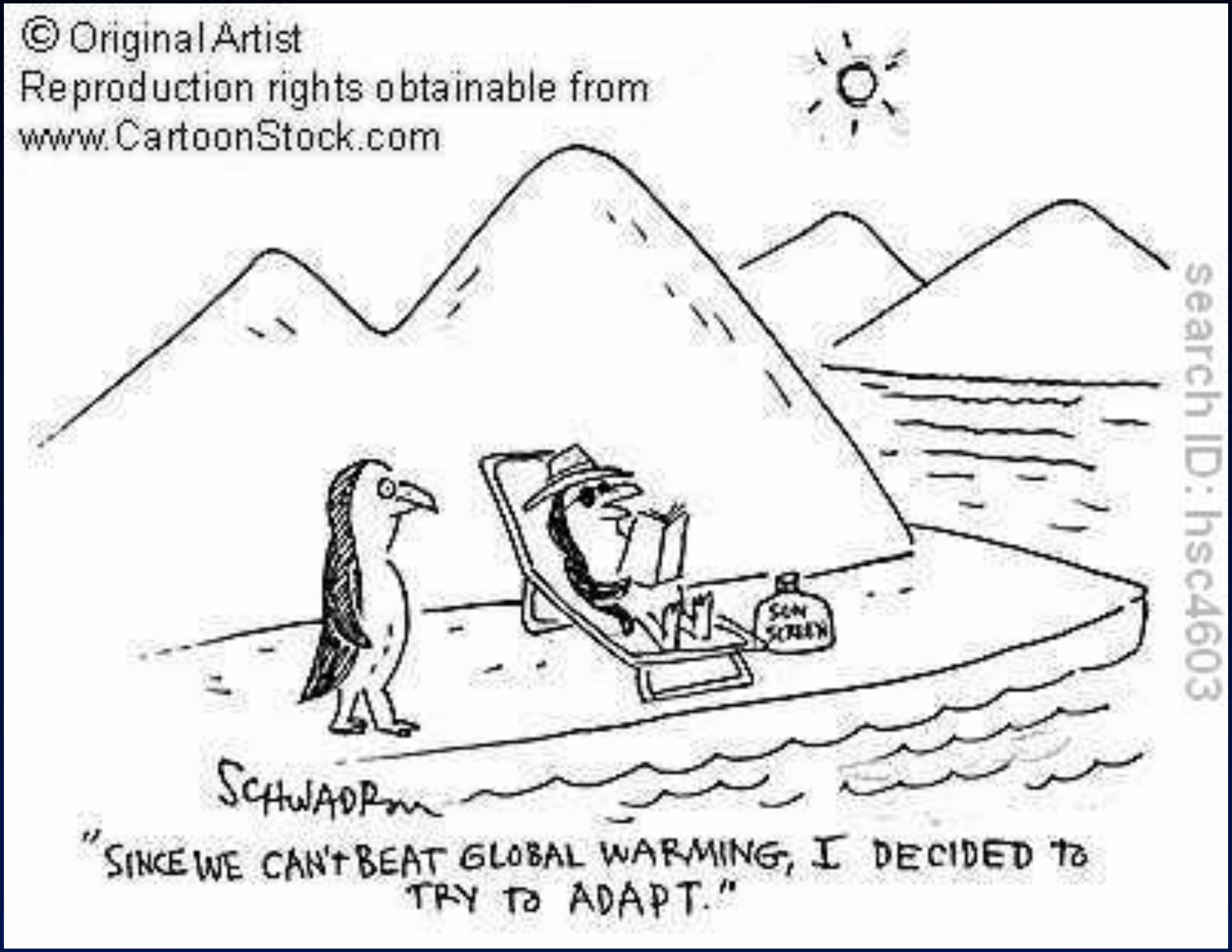
Plasticity can slow adaptive change

Why?

Plasticity is a trait that could be selected for

Selection for genotypes able to withstand increasingly variable environments

Adaptation



© Original Artist
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www.CartoonStock.com
SUN SCREEN
search ID: hsc4603
SCHWADRON
"SINCE WE CAN'T BEAT GLOBAL WARMING, I DECIDED TO TRY TO ADAPT."

Adaptation

Adaptation has the potential to help reduce the effects of climate change on extinction

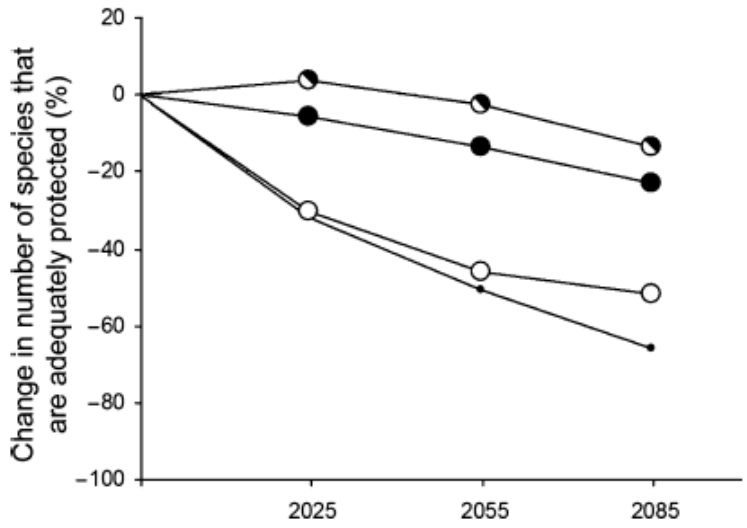
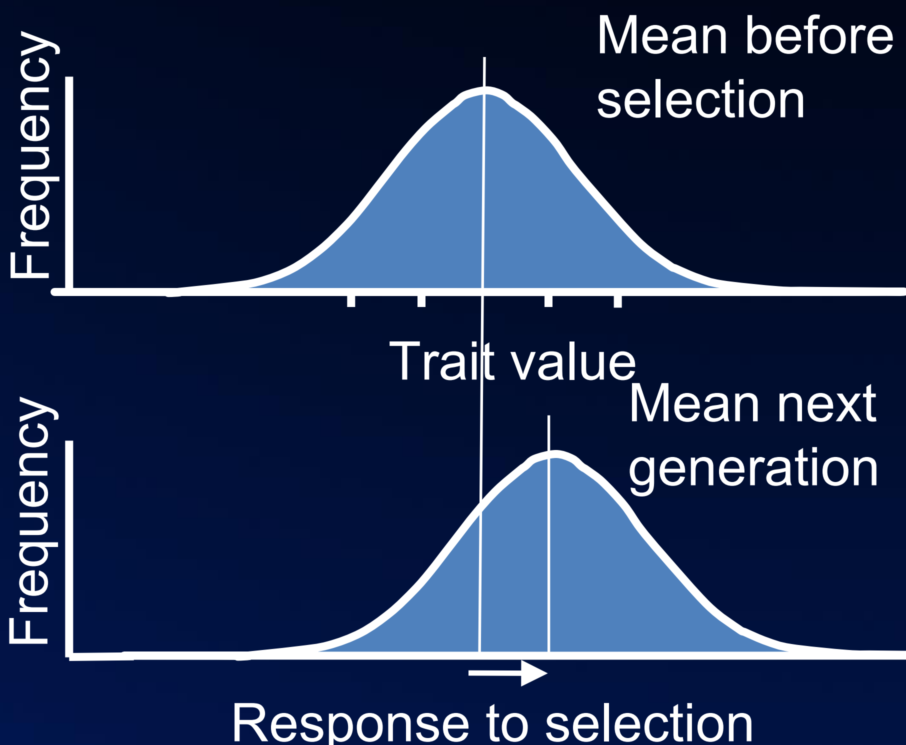


Figure 1 Change in the number of tree species predicted to be adequately conserved (cumulative cover of 10 ha, Hamann and Wang 2006) into the future, under the assumption that species are capable to adapt to changed climate, (●), migrate to suitable habitat within a reserve, (○), both, migrate and adapt, or neither (•). The analysis is based on bioclimatic envelope models for 49 tree species and 906 protected areas in British Columbia (Hamann and Wang 2006; A. Hamann and S.N. Aitken, unpublished manuscript.).

Aitken et al 2008

What is the Sustainable Rate of Adaptation?

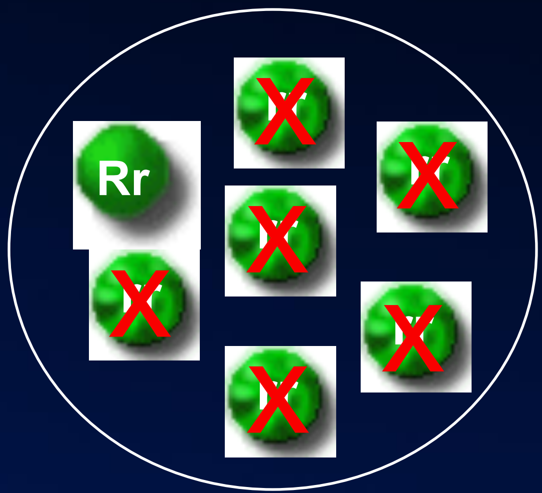


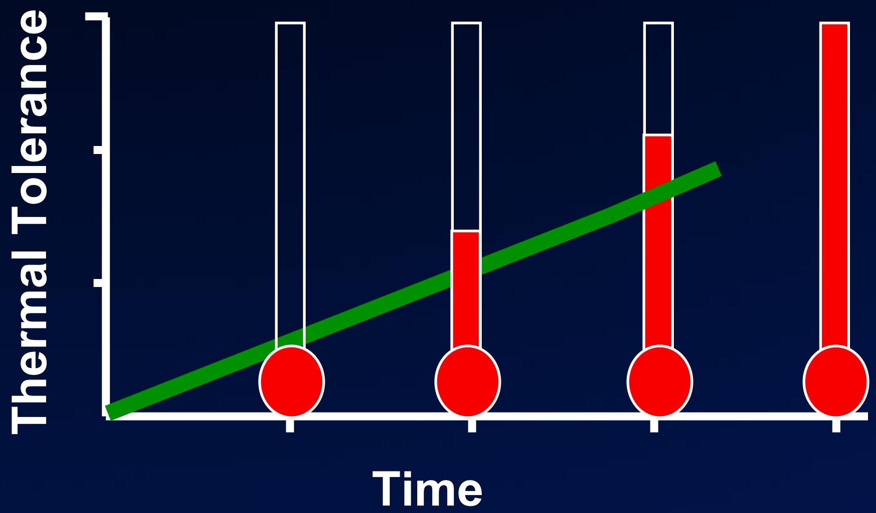
- Large populations: “a few percent” of a phenotypic standard deviation per generation (Lynch, 1996).

- Small populations: < 1% of a phenotypic standard deviation per generation (Burger and Lynch, 1995).

Why is it so slow?

- Depletion of beneficial genetic variation
- Cost of selection (Haldane, 1957)
  - The rate of adaptation is limited by the number of selective deaths that have to occur to replace one allele with another.





– If selection is too strong, the population will go extinct.

– Density-dependent “soft” selection provides a buffer against extinction.

Factors that affect speed of adaptation

Speed of adaptation

- Large Populations: ⇑ beneficial mutations
- Large Number of Genes : ⇑ beneficial mutations
- High Rate of Recombination (in large populations)
- Strong Selection: ⇑ initial rate of adaptation
- Constant Selection

- Small Populations: ⇓ beneficial mutations, drift, inbreeding depression
- Fluctuating selection
- Low trait heritability

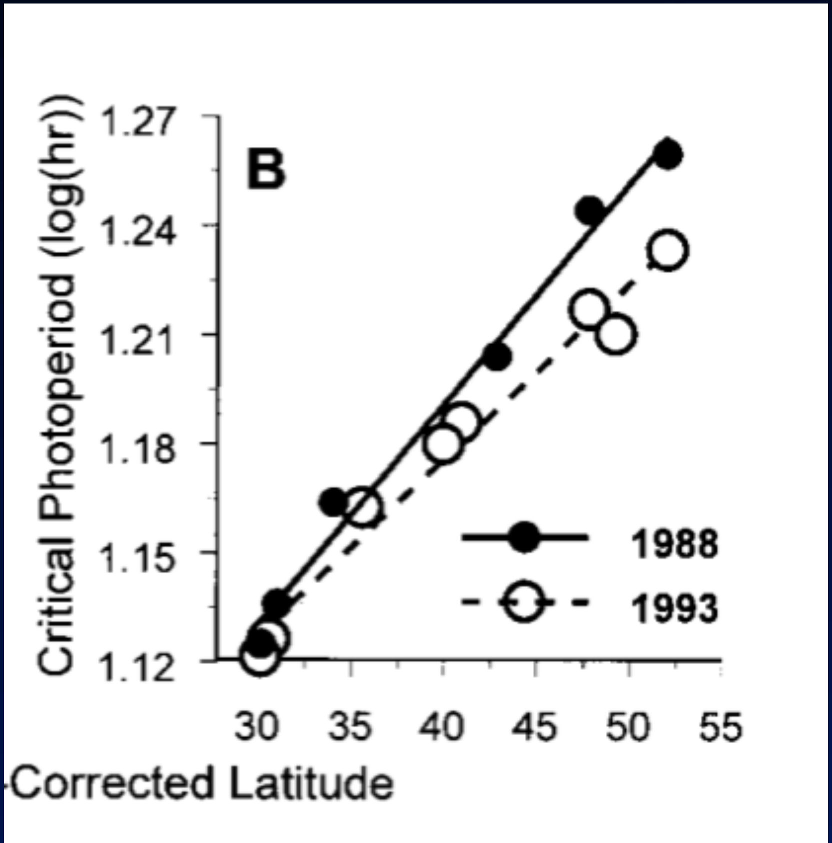
- Gene flow: increases variability, but reduces efficiency of selection
- Genetic correlations

Has adaptation to climate change already occurred?

Very little evidence of this so far (largely a lack of proper tests)

Mosquito example: shifts toward shorter critical photoperiods (more southern phenotypes) increased with latitude as growing seasons lengthen

Pitcher-plant mosquito



Bradshaw & Holzapfel, PNAS 2001

So, how will climate change affect species?

Because the rate of change is so rapid, completely new assemblages of species (communities) will develop

But which species/lineages will survive?

Those that can evolve quickly

- large populations, high fecundity
- high genetic diversity within the populations
- high heritability of traits
- short generation times

Those that can migrate quickly

- current large ranges
- high mobility
- easily dispersed seeds (long-distance dispersal)

Those with extremely plastic phenotypes

How do we use this information to minimize species extinctions as a result of climate change?

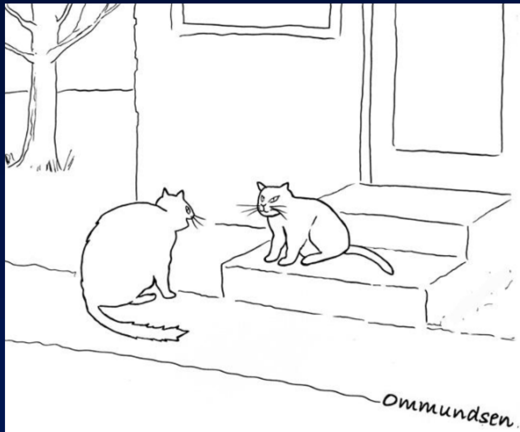
1. Conserve genetic diversity and capacity for adaptation

- Conserve locally adapted *populations* (not just species)
- Preserve large and *heterogeneous* habitats

2. Maintain dispersal/migratory abilities of organisms

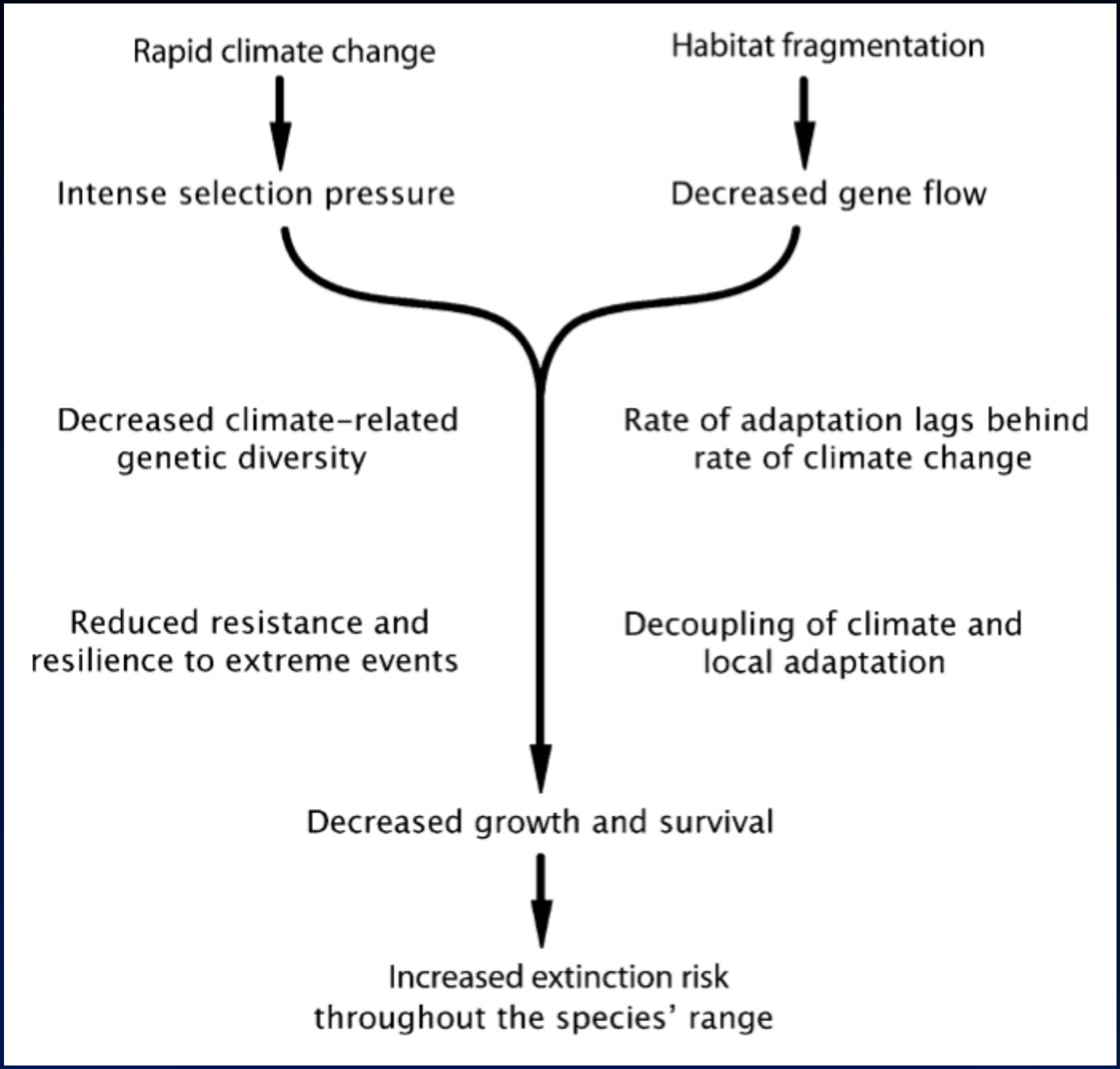
- Create connected network of habitat patches
- Assisted migration?

3. Hit politicians over head with blunt object



"I found a place with a great menu. It's called a biodiversity corridor."

Climate change and the risk of extinction



Jump & Peñuelas 2005

Local adaptation and phenotypic plasticity in an alpine plant

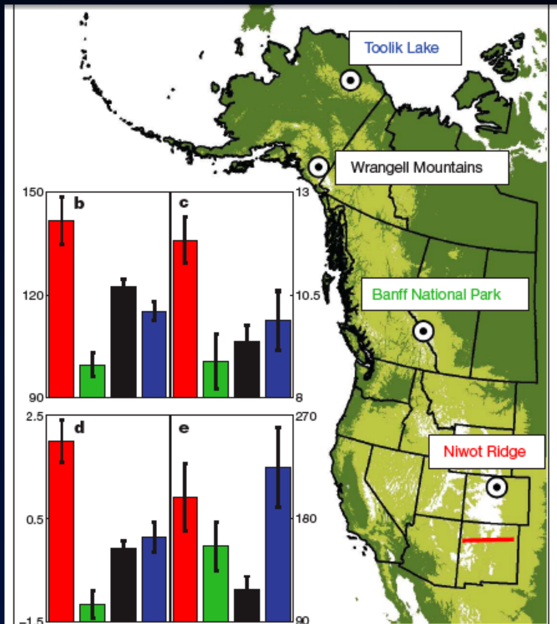
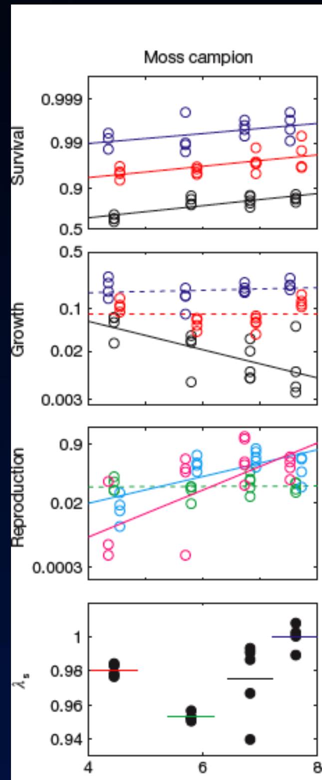


Figure 1 | Locations and climate patterns of field sites. **a**, Map of field sites. The red line south of Niwot Ridge indicates the southern range limits. Elevations: green, ≤500 m; tan, >500 m and ≤2,000 m; white, >2,000 m. **b**, Mean length (±1 s.e.m.) of the snow-free period in days per year for each region (coloured as in **a**). **c**, Mean July temperature (°C ± 1 s.e.m.) for each region. **d**, Mean (±1 s.e.m.) of the first principal component of snow-free period and mean July temperature for each region. **e**, Mean total precipitation (mm ± 1 s.e.m.) during the snow-free period for each region. $n = 5$ yr per bar in **b**–**e**.



Distance from equator

Silene acaulis

Morris and Doak 2010 Nature

- Differences in climate along a latitudinal gradient
- High growth rates in young plants compensates for lower overall survival in southern populations
- Poor performance across sites in warm years

Unanswered questions

1) Are many populations of plants already maladapted to their current environment?

1) What is the relative importance of migration, phenotypic plasticity and adaptation in responding to climate change?

1) What selection pressures are likely to be the main cause of extinction (temperature, drought, biotic, etc.)?