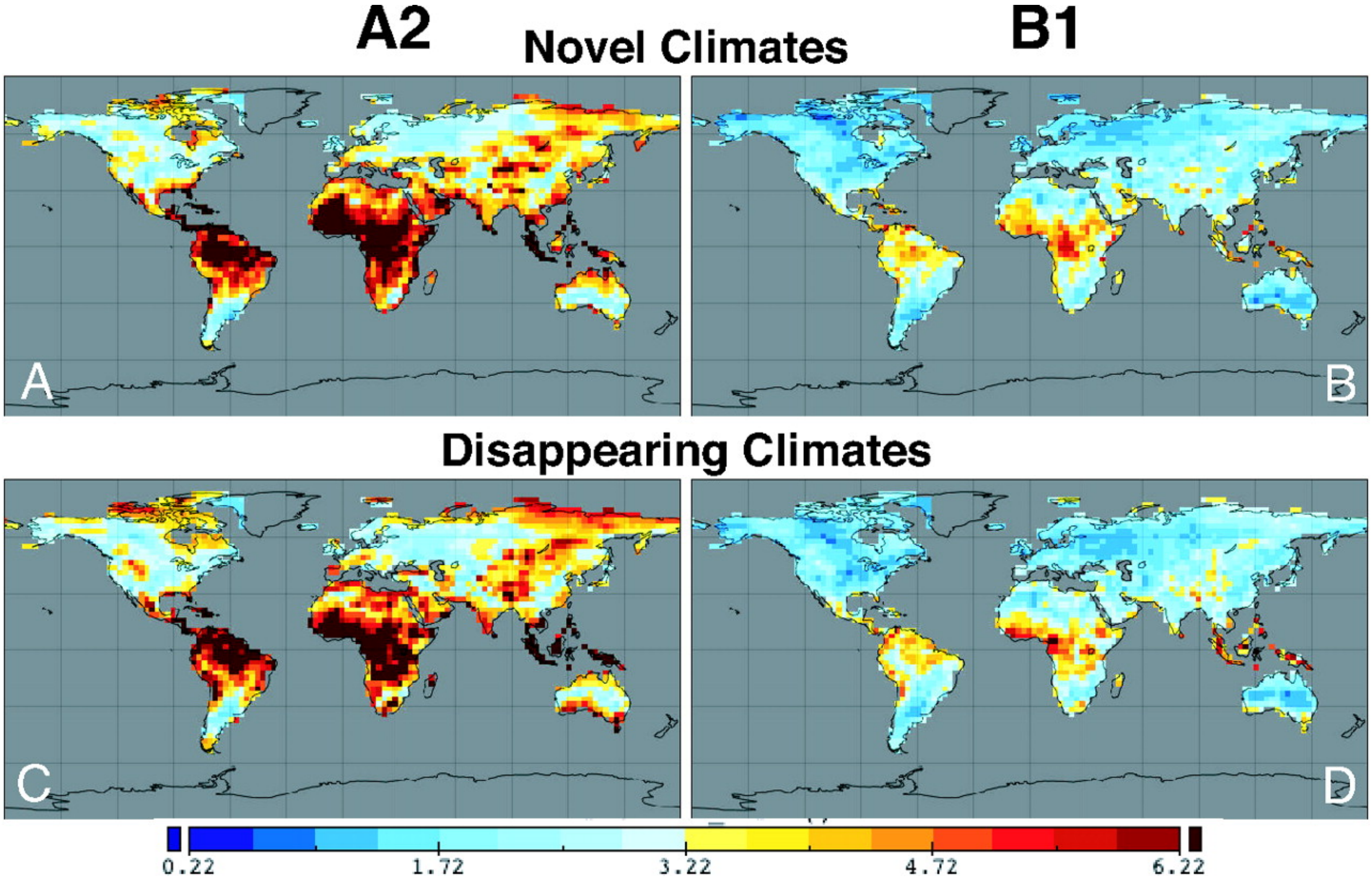
Climate Change

Climate and tectonic change are the most important factors influencing species distributions.

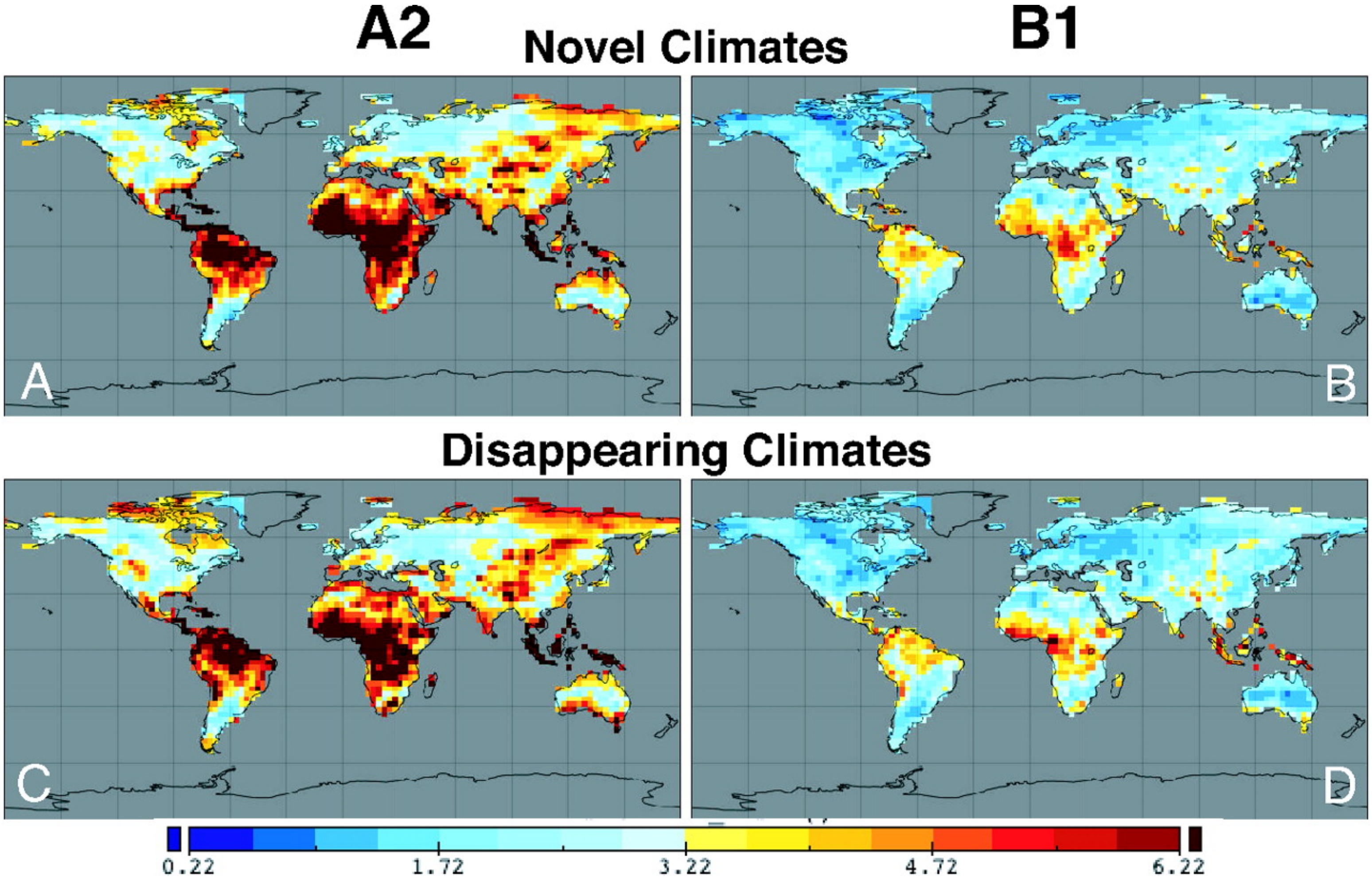


Williams et al. 2007

Climate Change

How does current (and future) climate change compare to previous climate change?

How and to what extent will this influence species distributions across the globe?



Williams et al. 2007

Climate Change

Outline of topics in this section:

1) Climate change
- Briefly reflect on past climate change
- Focus on data for current climate change using IPCC

2) Biogeographic effects of climate change

3) Predicting changes in distributions

Climate Change

Goals and learning objectives:

1) Understand and interpret the sources of information from the IPCC (and appreciate the depth of the assessment)

2) Consider the various ways that species may respond to climate change (e.g., extinction, distributional shifts, or evolution)

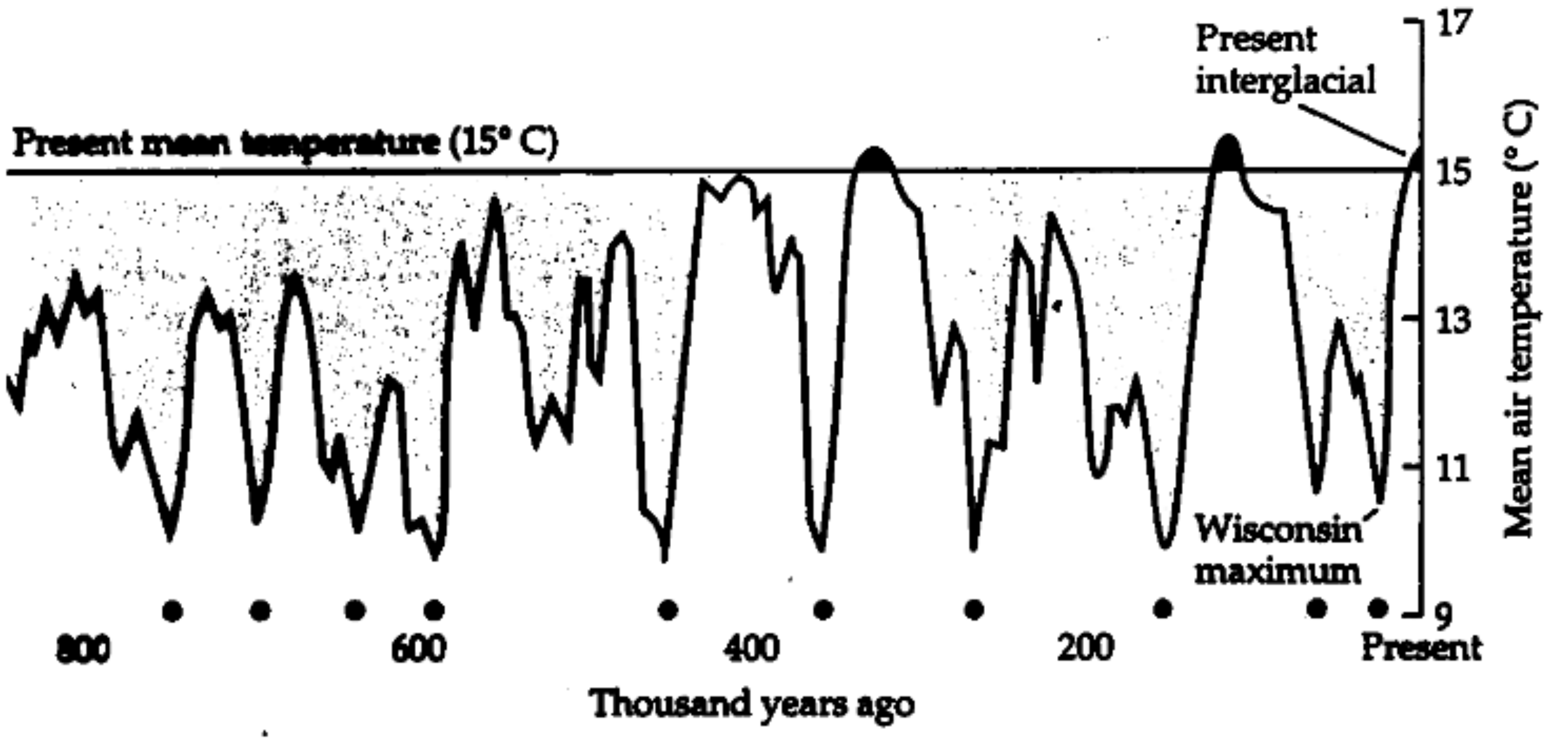
3) Address the complexity involved with predicting changes in distributions with climate change, and what various factors should be considered

Previous Climate Change

Global climate has changed frequently

Climate has changed with cycles of glaciation

Change since last glacial maximum has not exceeded ~ 1 ^{o}C per 1000 yrs



(From Gates 1993)

Previous Climate Change

Global climate has changed frequently

Biomes have shifted in location due to climate change

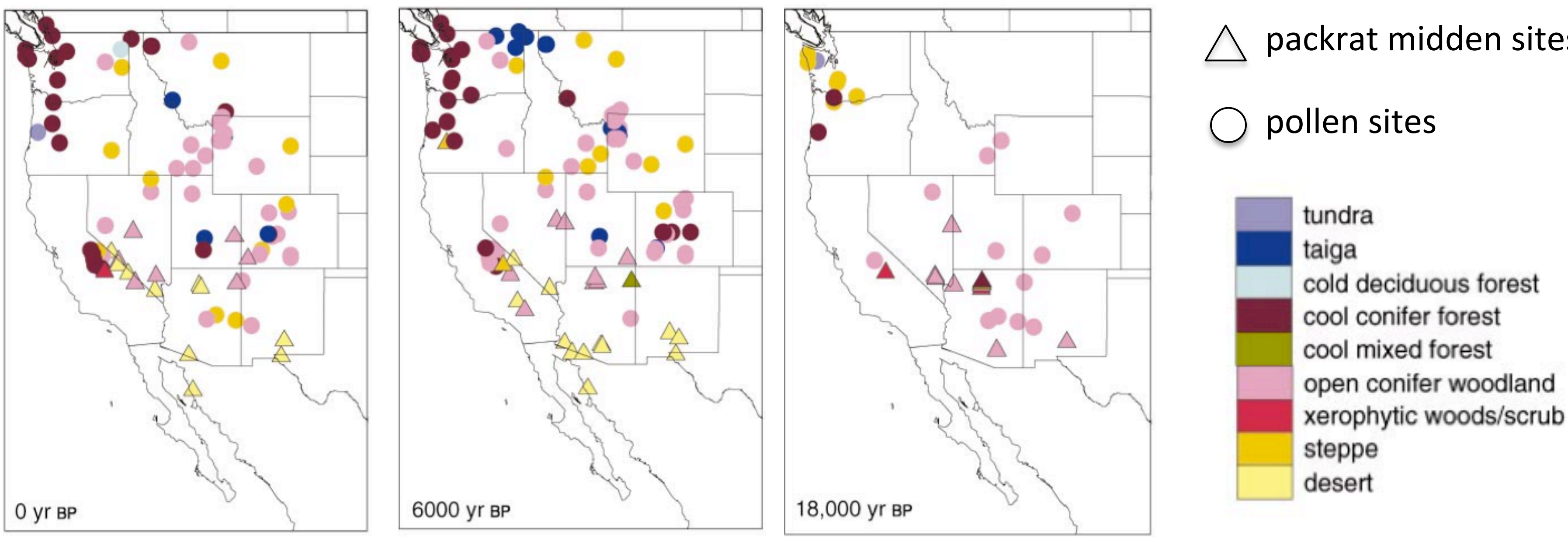


Figure from Thompson & Anderson 2000: Biomes of western North America at 18,000, 6000 and 0 ^{14}C yr BP, reconstructed from pollen and packrat midden data.

Current Climate Change

Series of reports from IPCC (Intergovernmental Panel on Climate Change)

https://www.ipcc.ch/index.htm

https://www.ipcc.ch/publications_and_data/publications_and_data.shtml

Fifth Assessment Report (AR5) released in 2014

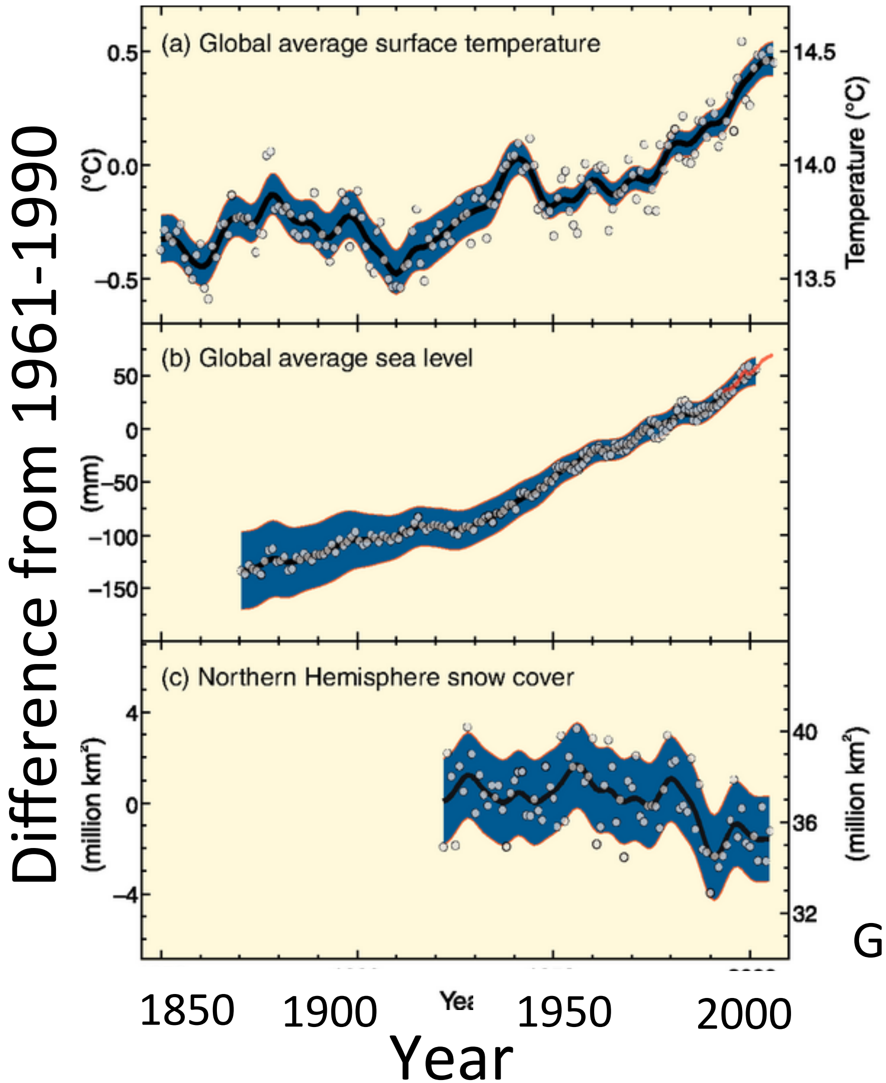
- Written by >830 scientists from >80 countries selected to form author teams to produce the report
- Draws on work of >1,000 contributing authors and >1,000 expert reviewers
- The AR5 assessed >30,000 scientific papers

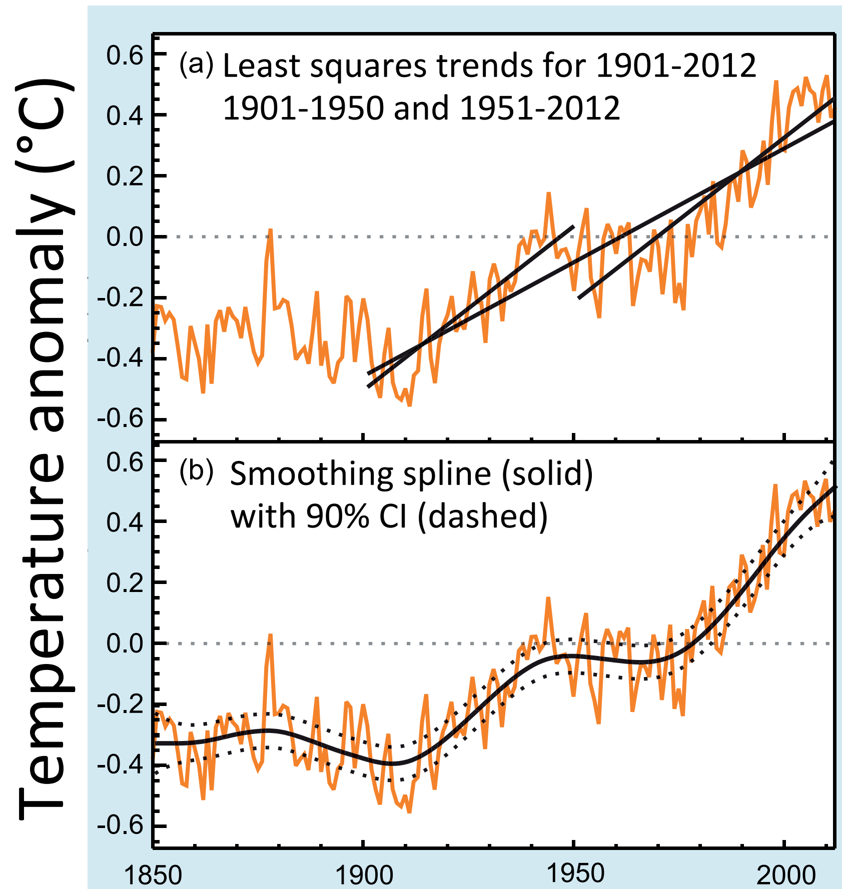
Evidence for climate change:

1) Sea level rise
2) Global temperature rise
3) Warming oceans
4) Shrinking ice sheets
5) Declining arctic sea ice
6) Glacial retreat
7) Extreme events
8) Ocean acidification

Current Climate Change

Recent change has been exceptionally rapid



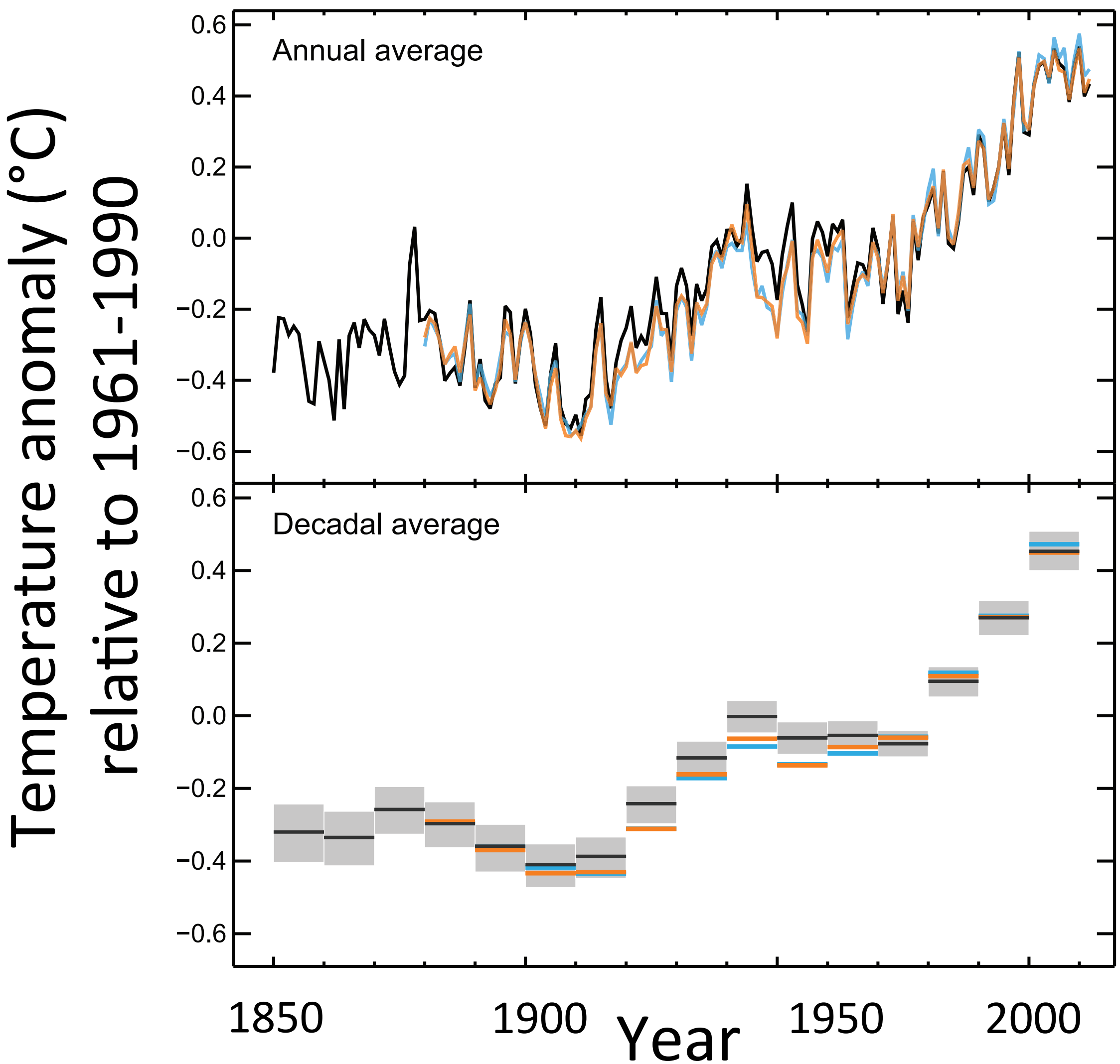


Global mean surface temperature anomalies relative to annual data from 1961-1990

From IPCC 2007 (left) and IPCC 2013 (right)

Current Climate Change

Observed globally averaged combined land and ocean surface temperature anomaly 1850-2012



From 3 datasets

Top: Annual mean values

Bottom: Decadal mean values with estimate of uncertainty for one of three datasets

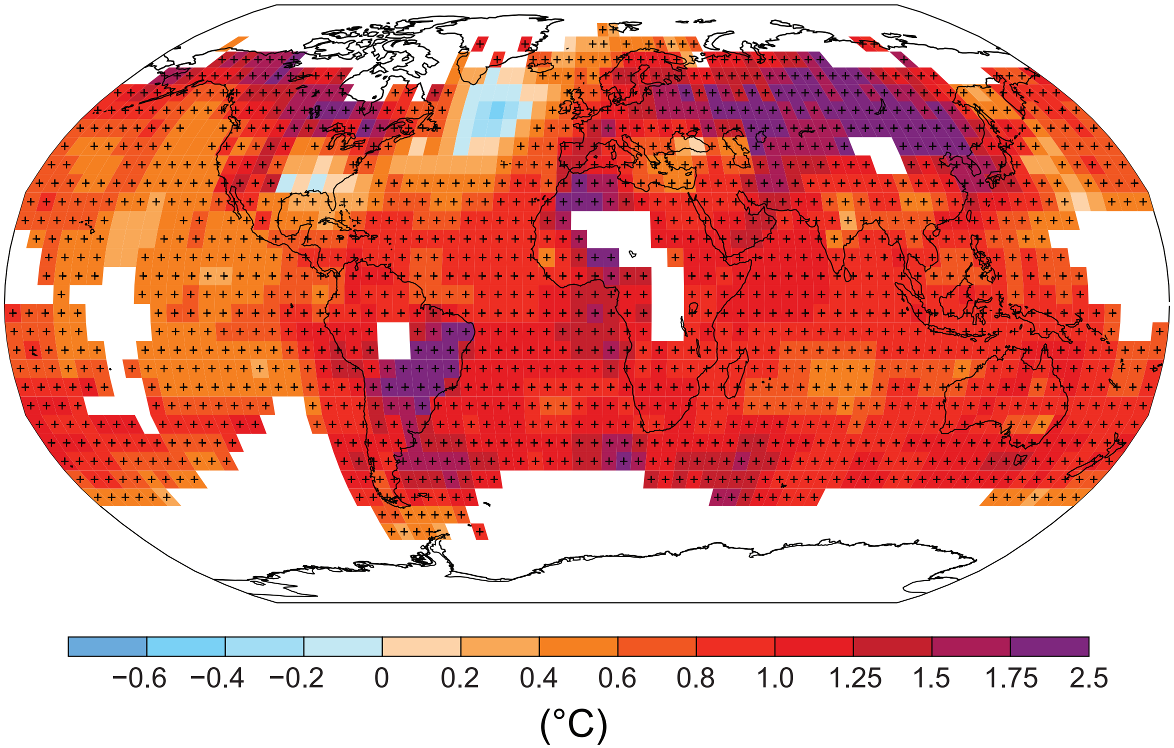
Anomalies are relative to the mean of 1961-1990

From IPCC 2013

Current Climate Change

All terrestrial areas have experienced increases in surface temperature, (+) indicates areas where trend is significant at the 10% level

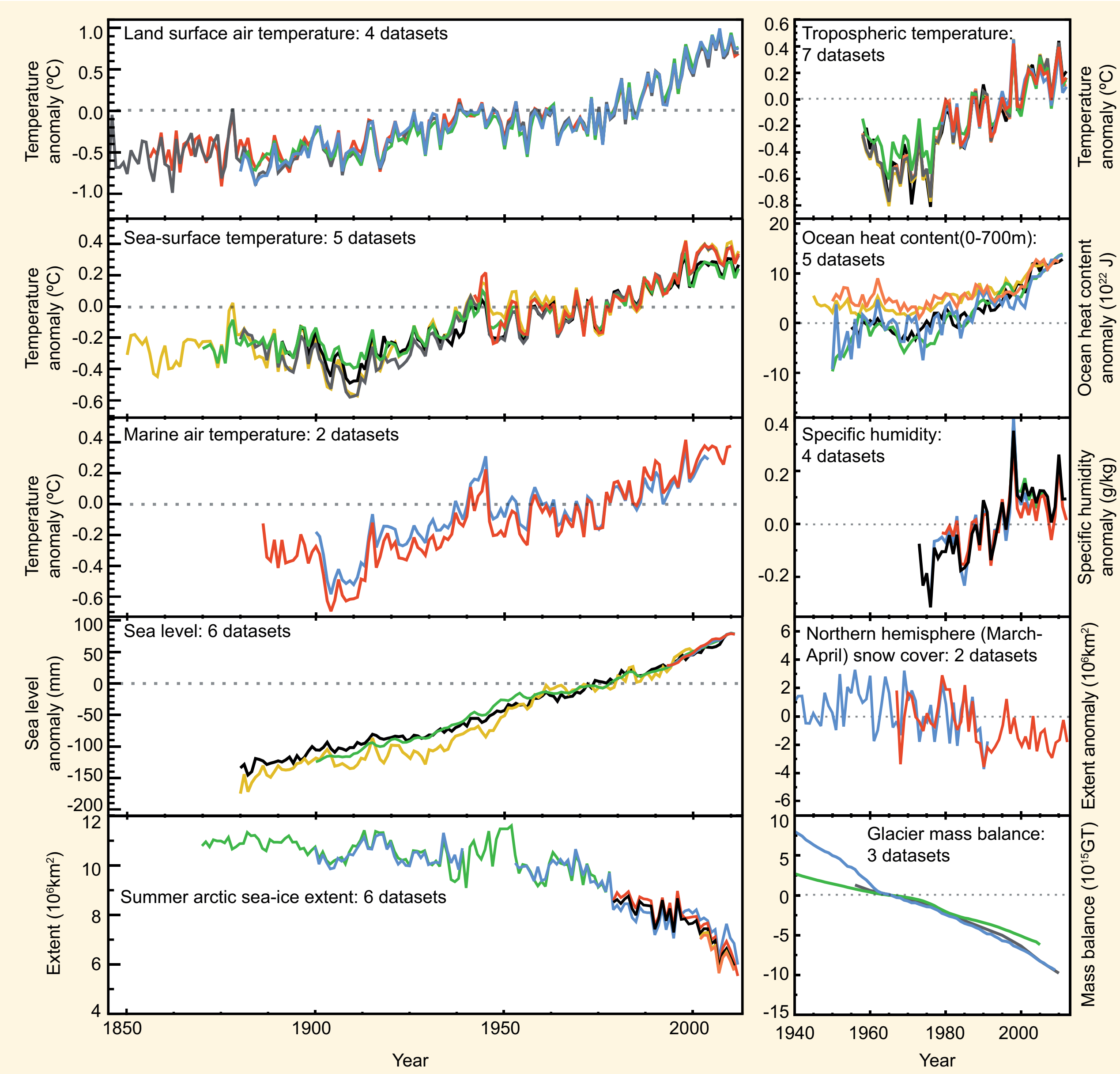
(b) Observed change in surface temperature 1901-2012



Derived from one of the previous datasets; White boxes show incomplete records

From IPCC 2013

Current Climate Change



Multiple independent indicators of changing global climate

From 1840:

- Land surface air temp
- Sea-surface temp
- Marine air temp
- Sea level
- Summer arctic sea-ice extent

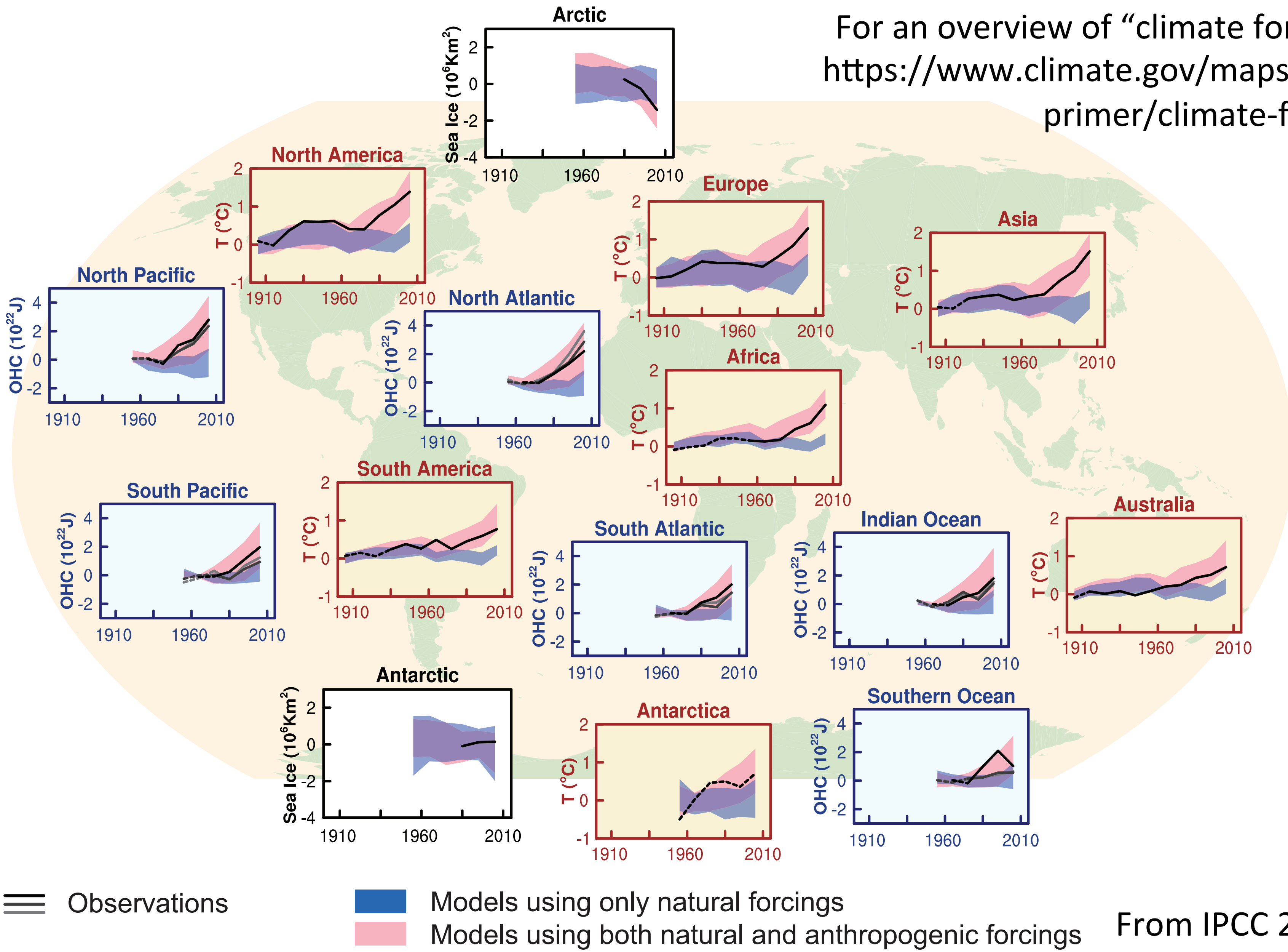
From 1940:

- Tropospheric temp
- Ocean heat content
- Specific humidity
- N. hemisphere snow cover
- Glacier mass balance

From IPCC 2013

Current Climate Change

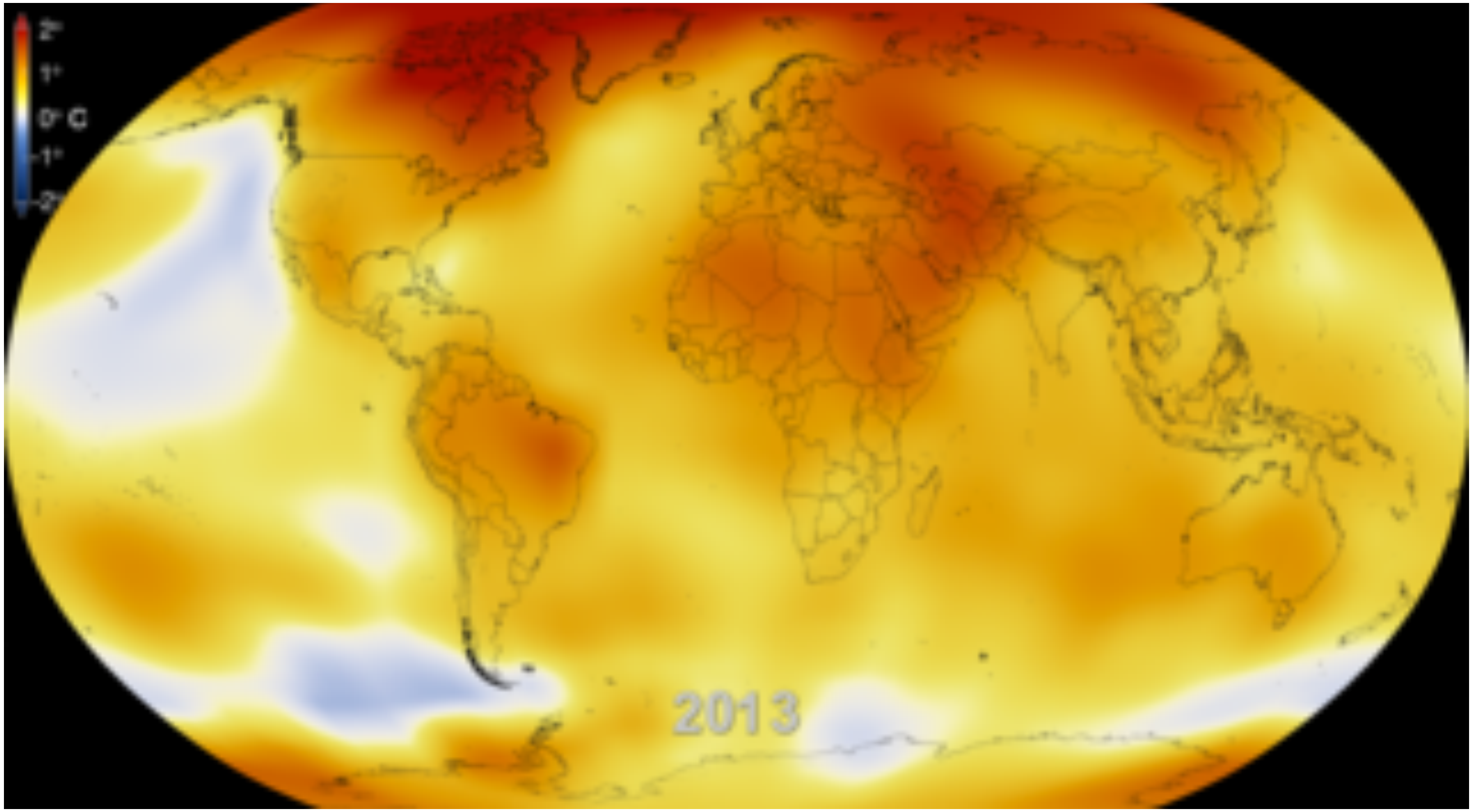
For an overview of "climate forcing": https://www.climate.gov/maps-data/primer/climate-forcing



From IPCC 2013

Five-Year Global Temperature Anomalies from 1880 to 2015

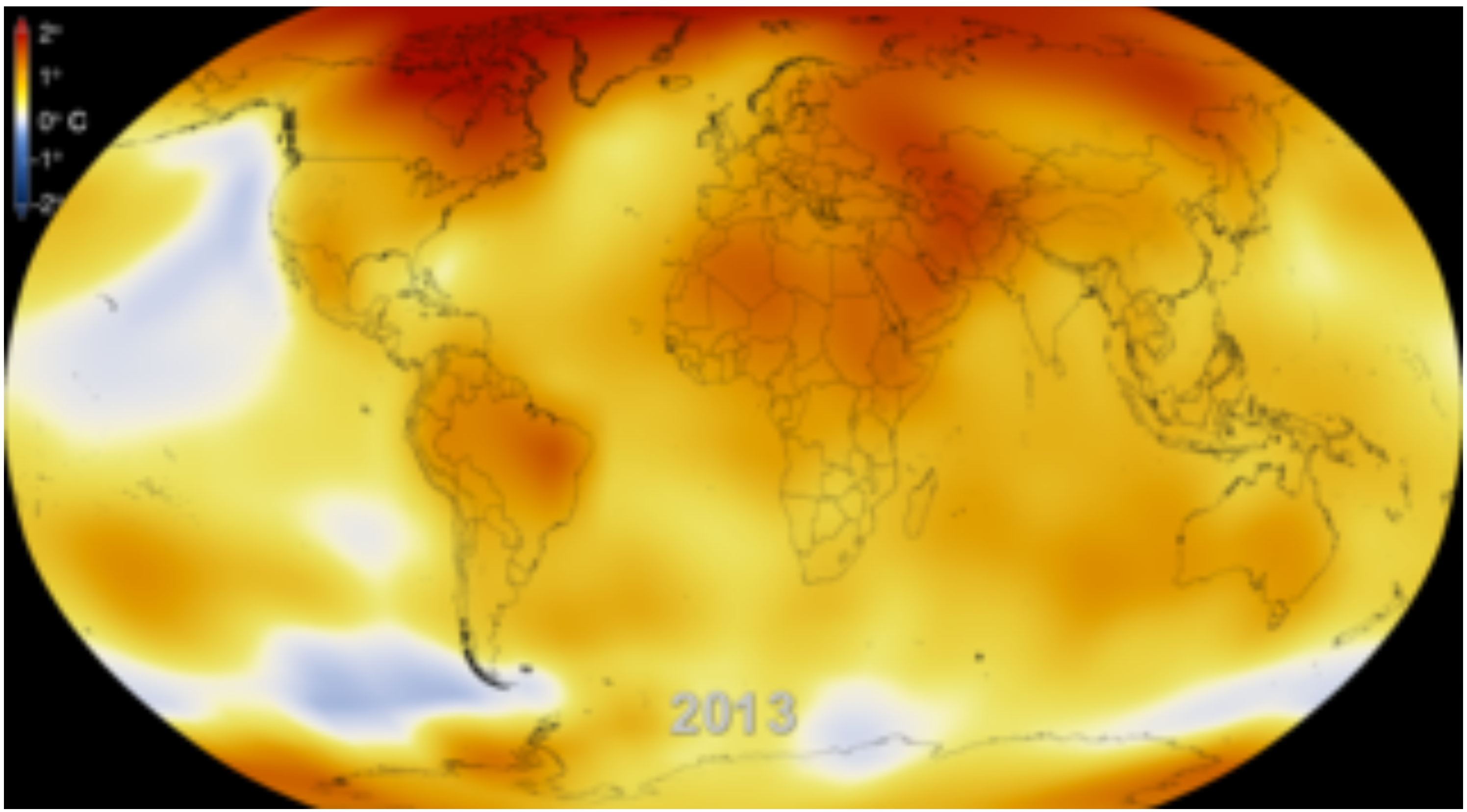
NASA: 2013 tied with 2009 and 2006 for the seventh warmest year since 1880. With the exception of 1998, the 10 warmest years in the 134-year record all have occurred since 2000, with 2010 and 2005 ranking as the warmest years on record.



Nasa: https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4419

Five-Year Global Temperature Anomalies from 1880 to 2015

Earth's 2015 surface temperature was the warmest since modern record keeping in 1880, according to independent analyses from NASA and National Oceanic and Atmospheric Administration (NOAA) (map shows global surface temperature anomalies)

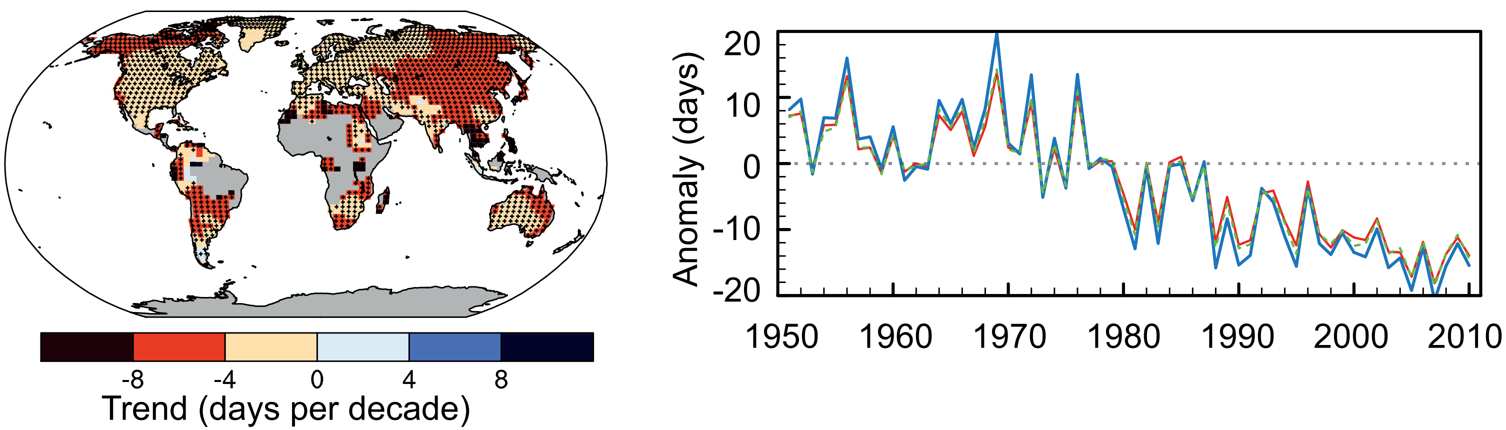


Globally averaged temps in 2015 shattered the previous mark set in 2014 by 0.13 Celsius

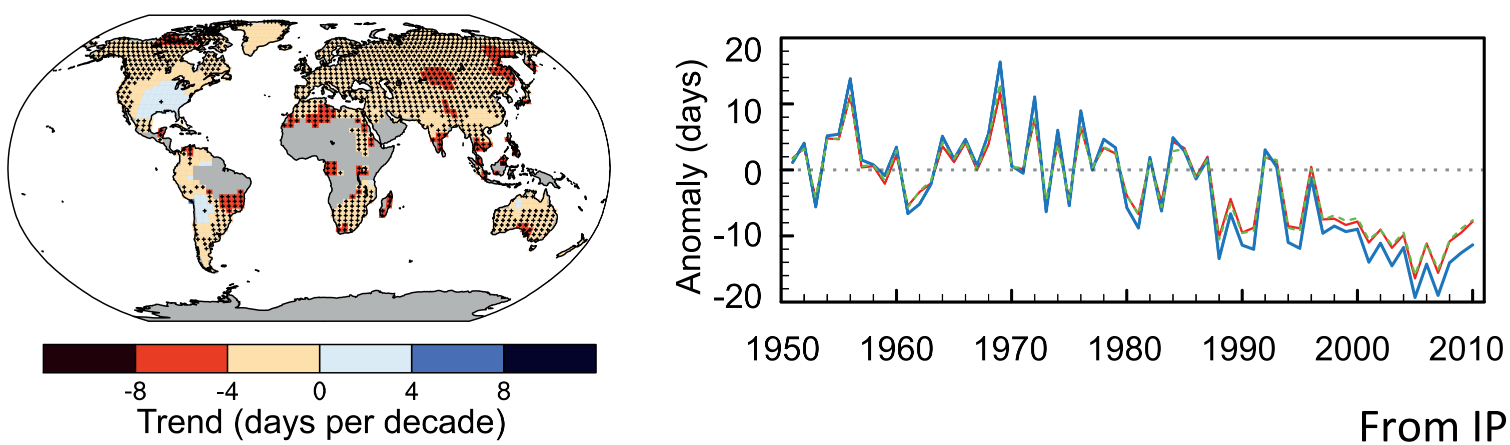
Current Climate Change

Trends in annual frequency of extreme temperatures from 1951 – 2010 for grid boxes with 40+ years of data existing through 2003 (grey = incomplete/ missing data; black (+) indicates significant trend outside 90% CI)

(a) Cold Nights



(b) Cold Days

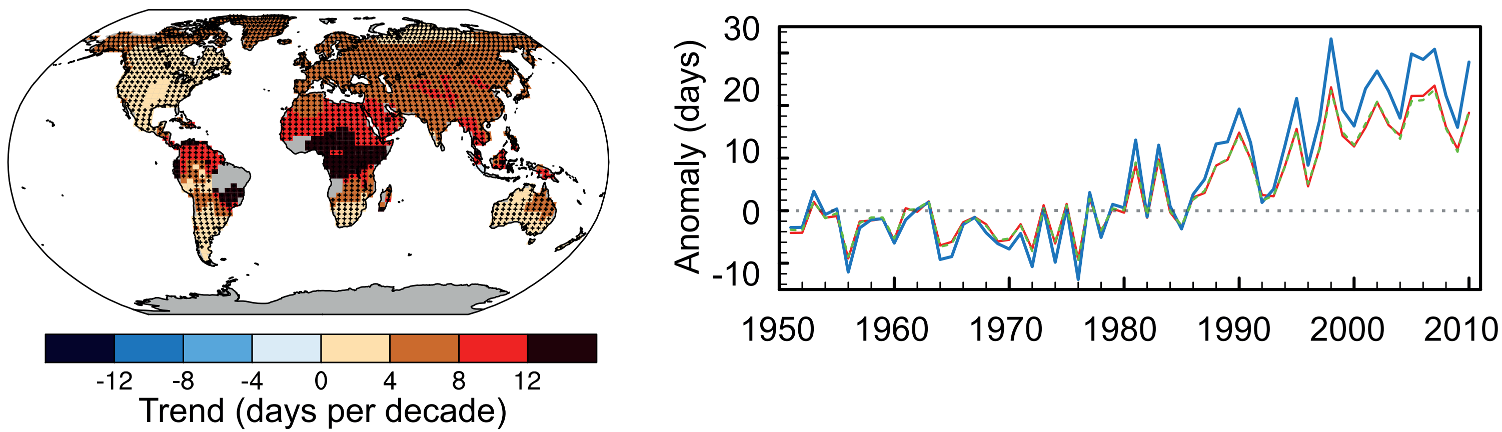


From IPCC 2013

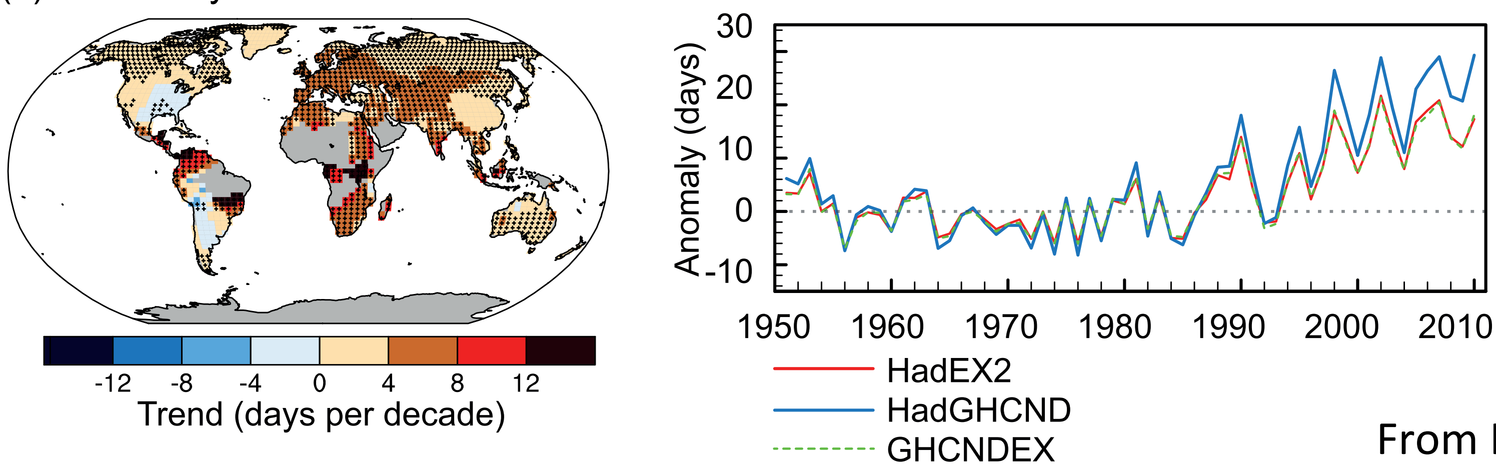
Current Climate Change

Trends in annual frequency of extreme temperatures from 1951 – 2010 for grid boxes with 40+ years of data existing through 2003 (grey = incomplete/ missing data; black (+) indicates significant trend outside 90% CI)

(c) Warm Nights

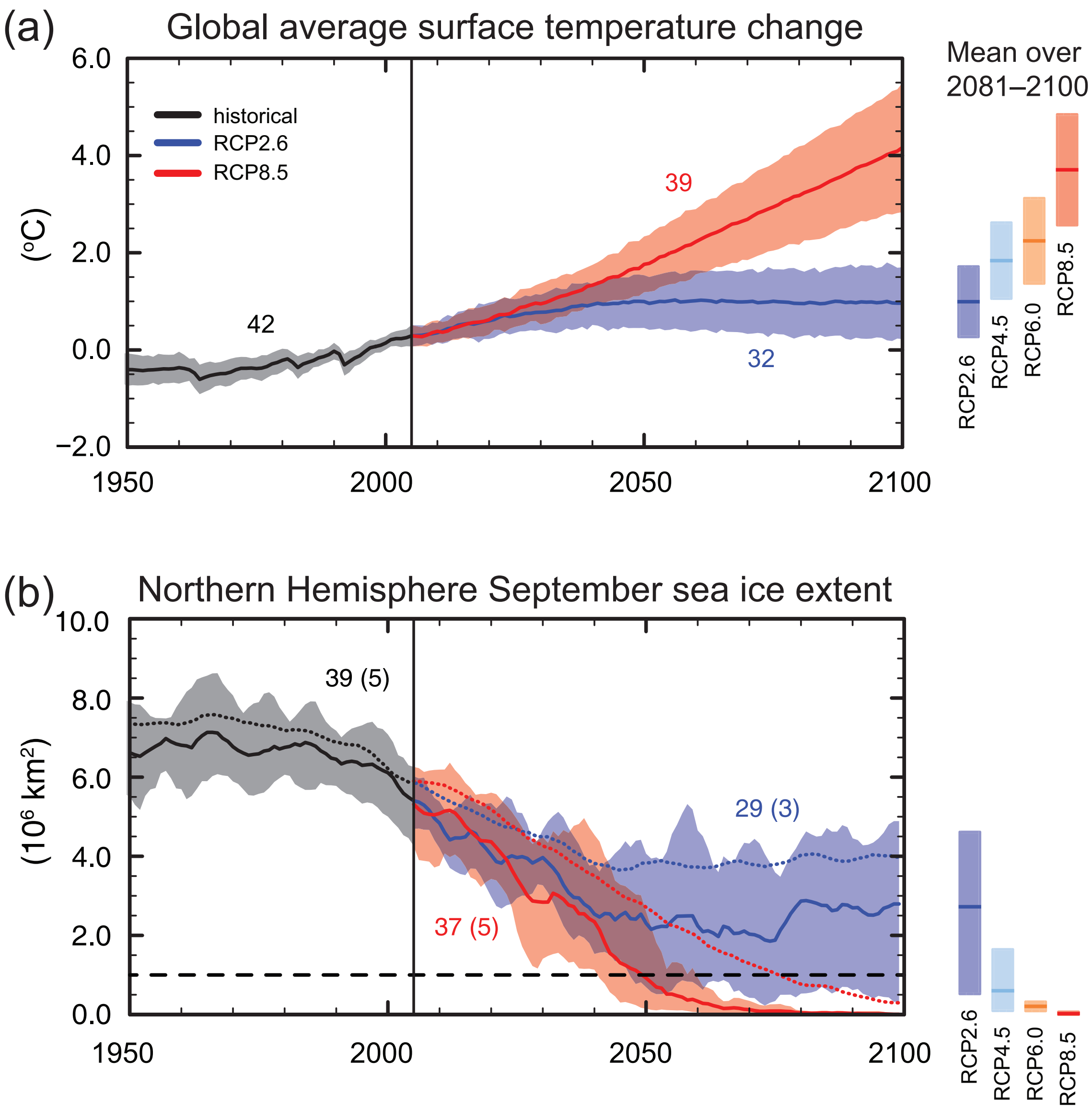


(d) Warm Days



From IPCC 2013

Future Climate Change



Change relative to 1986-2005

Black (grey shading) shows historical reconstructed forcing

RCP = Representative Concentration Pathway

Four scenarios based on future estimates of atmospheric greenhouse gas concentrations

RCP2.6 = low emission scenario
RCP8.5 = no carbon cuts

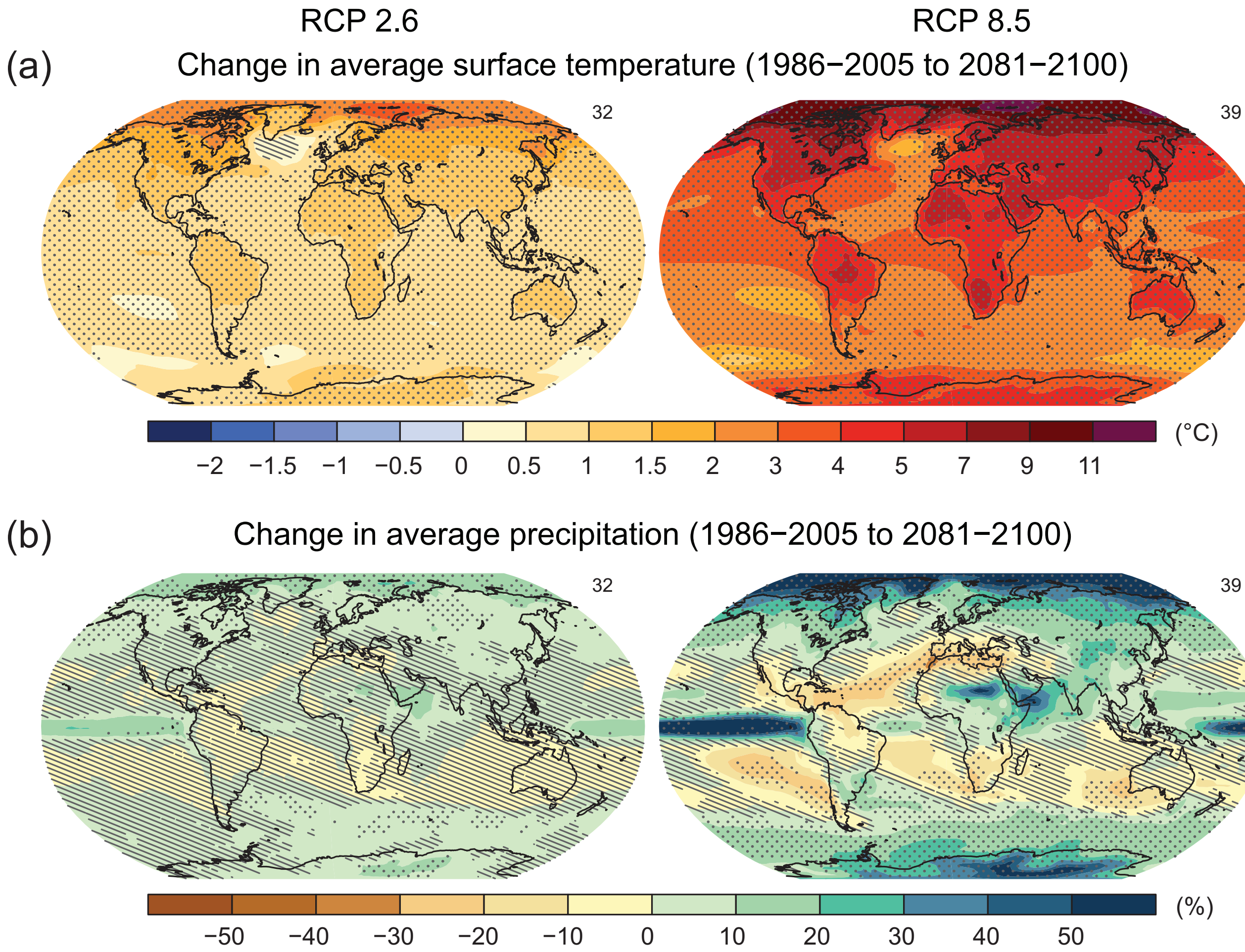
From IPCC 2013

Future Climate Change

Projected change in average surface temp and precipitation with two carbon emissions scenarios

Low emission scenario: carbon emission rapidly cut

High emission scenario: no carbon cuts

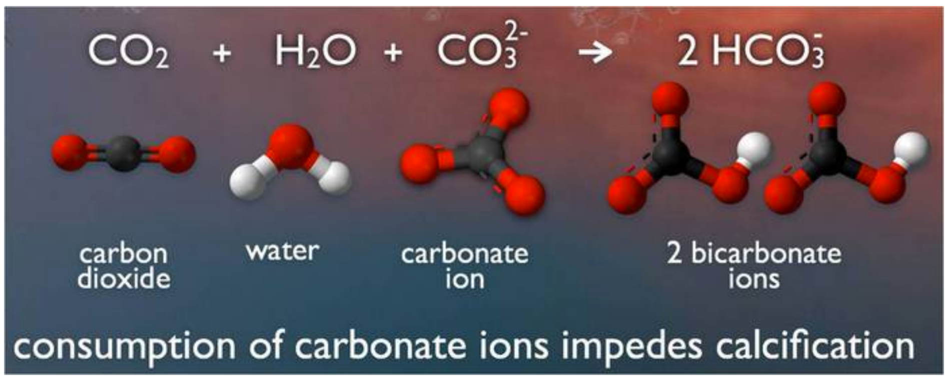


From IPCC 2013

Future Climate Change

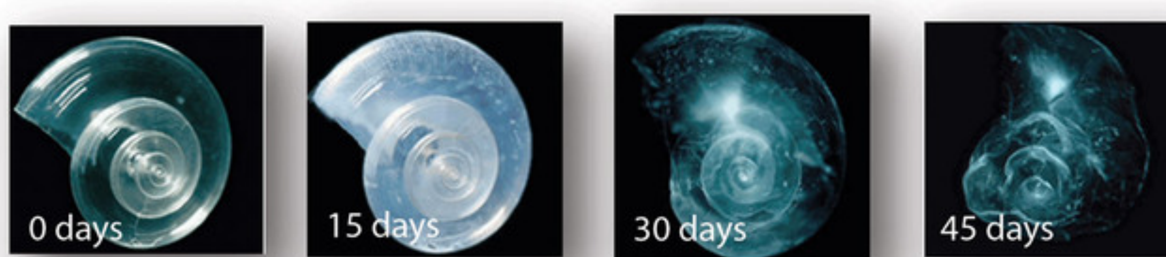
Projected change in northern hemisphere sea ice extent and ocean surface pH with two carbon emissions scenarios

In our oceans, higher CO2 emissions result in ocean acidification



Increased levels of carbonic acid reduces the pH levels in oceans.

Lower pH reduces availability of minerals like calcium carbonate (building blocks for shells and skeletons of many marine fauna)

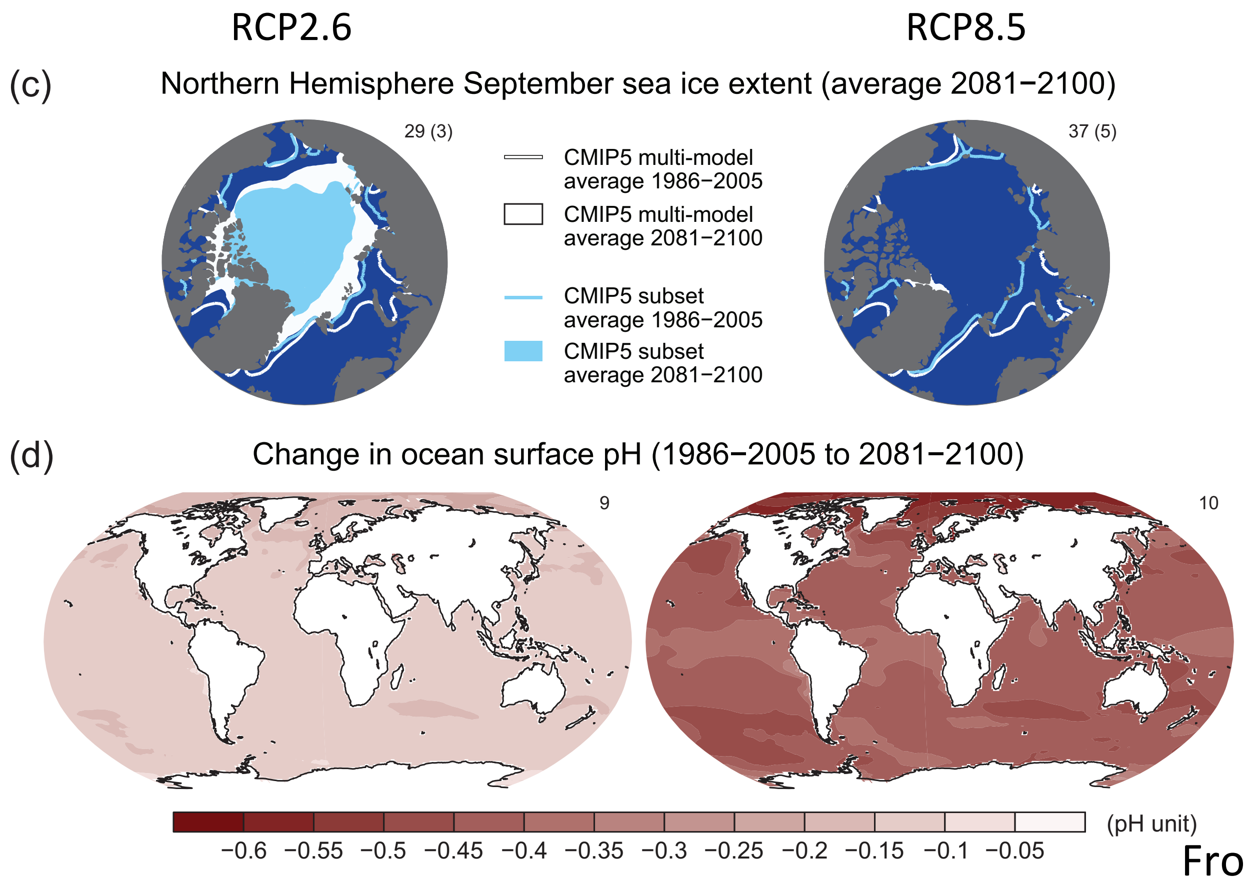


Future Climate Change

Projected change in northern hemisphere sea ice extent and ocean surface pH with two carbon emissions scenarios

Low emission scenario: carbon emission rapidly cut

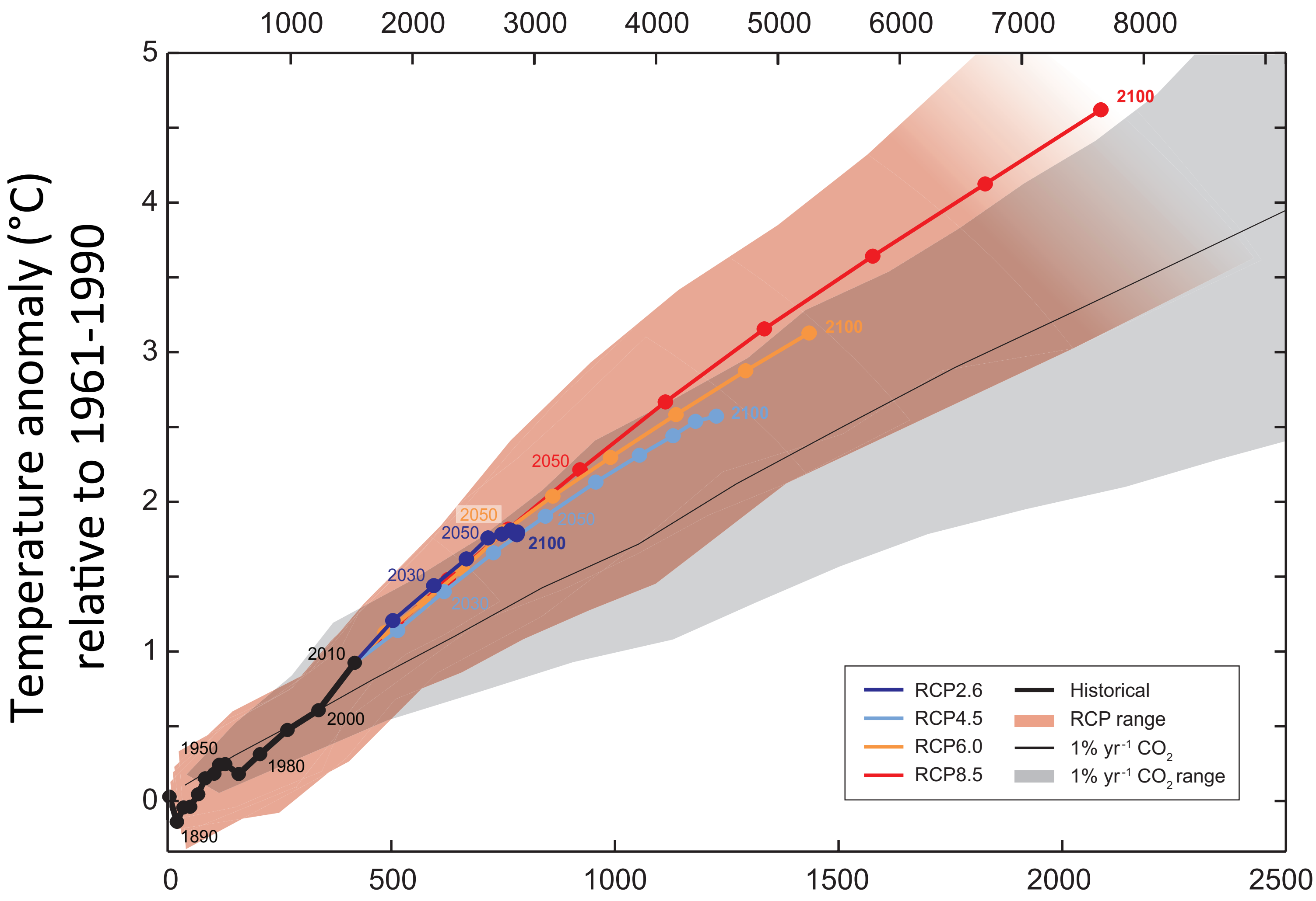
High emission scenario: no carbon cuts



From IPCC 2013

Future Climate Change

Global mean surface temperature increase as a function of cumulative total global CO2 emissions from various lines of evidence



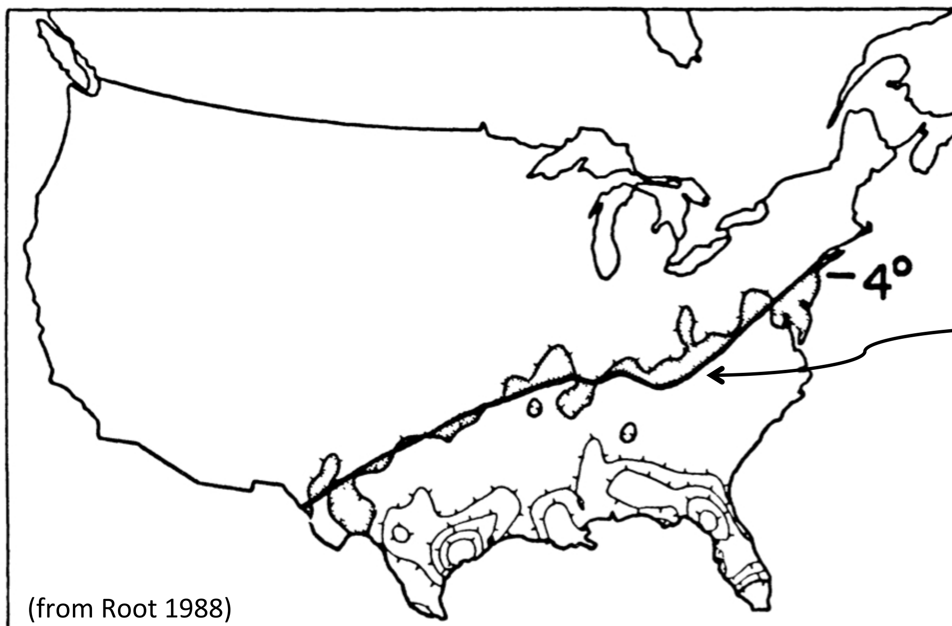
Cumulative total anthropogenic CO2 emissions from 1870

From IPCC 2013

Biogeographic Effects of Climate Change

Climate may have direct impacts on range limits of species
For example, some species range boundaries appear to be directly linked to temperature thresholds and physiological tolerance

Eastern Phoebe

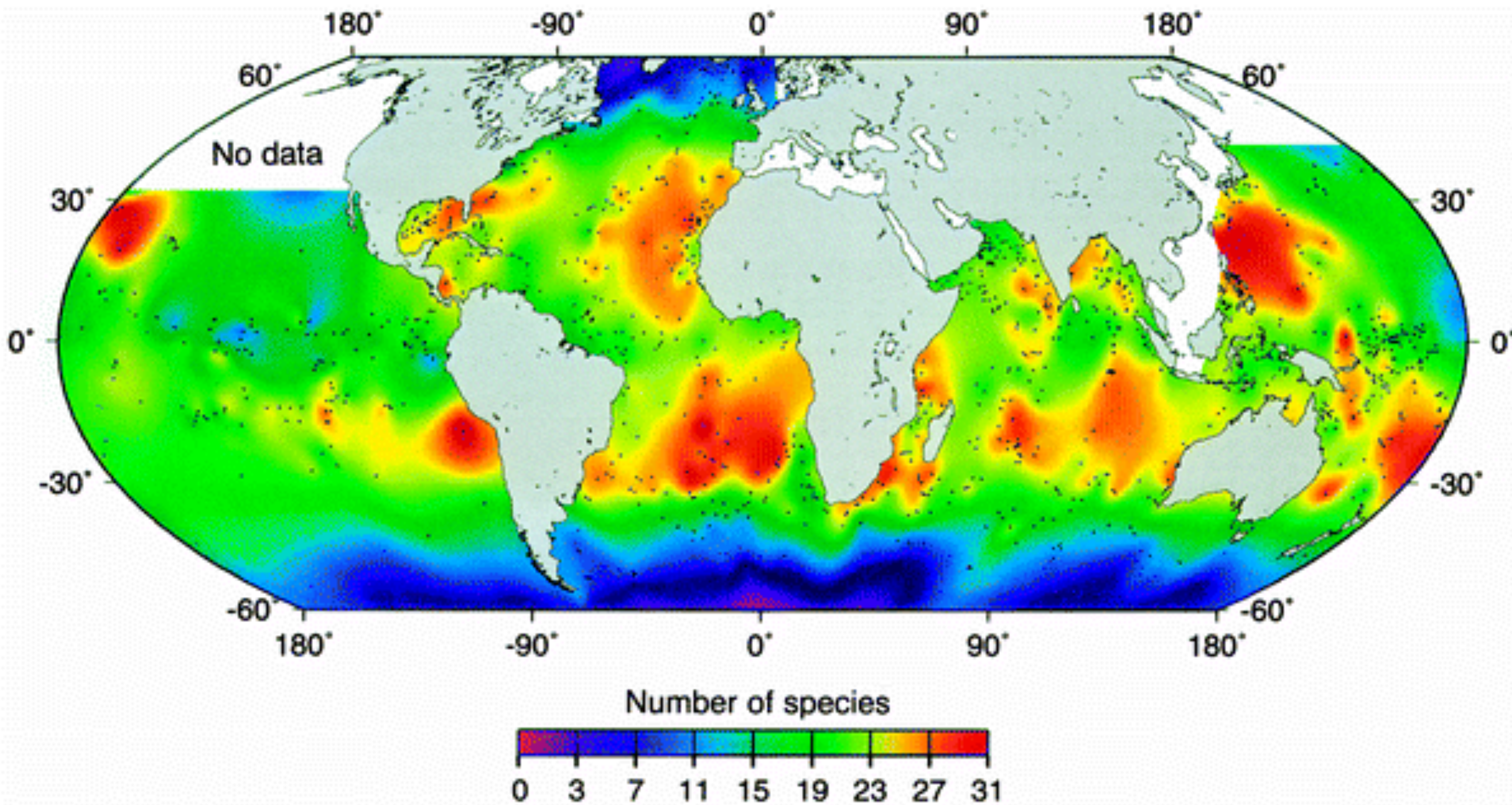


-4°C January minimum isotherm

But most species range limits and distribution shifts are likely to be much more complex with climate change…

Biogeographic Effects of Climate Change

Distributions of taxon diversity: oceanic zooplankton species diversity is strongly correlated with sea-surface temperature

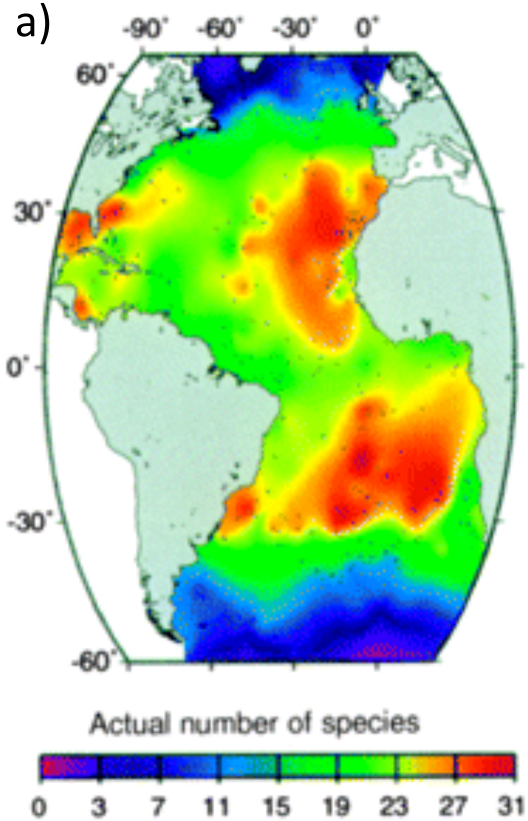


Rutherford et al. 1999

Biogeographic Effects of Climate Change

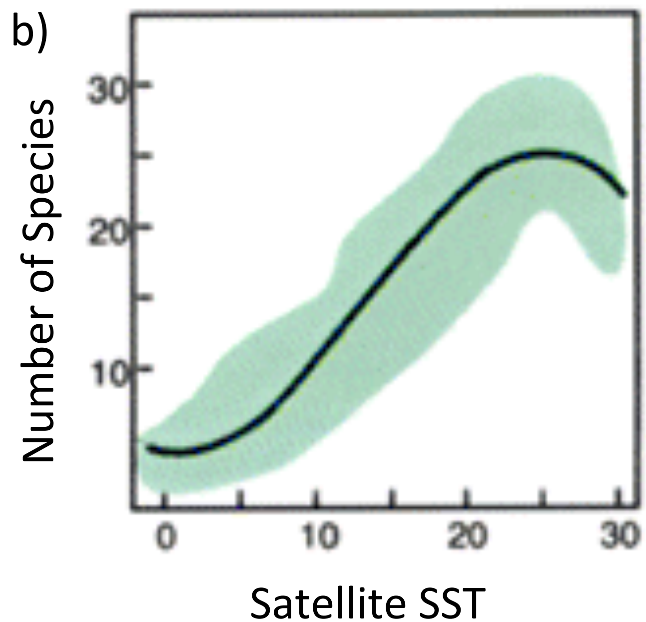
Distributions of taxon diversity: oceanic zooplankton species diversity is strongly correlated with sea-surface temperature (SST)

a)



Nonlinear relationship between satellite SST and diversity (solid line) and the distribution of the data (shaded area)

b)



Positive relationship between SST and diversity between -2 and 27 °C (negative > 27 °C)

Rutherford et al. 1999

Biogeographic Effects of Climate Change

How do species and communities respond to climate change?

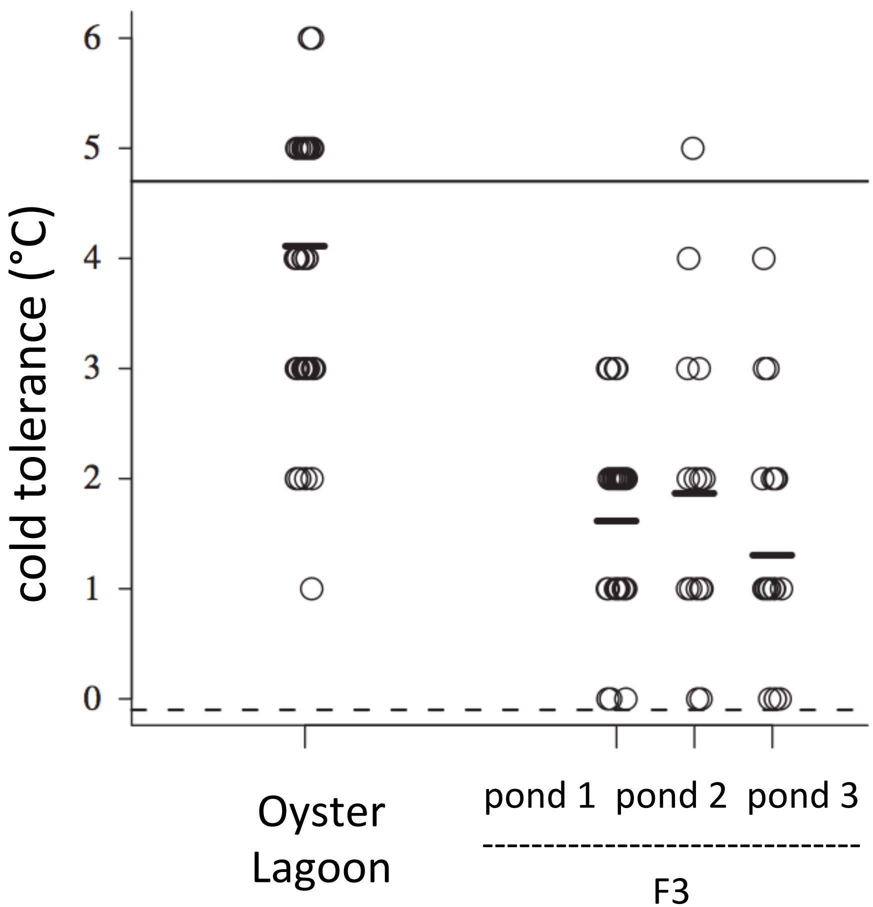
Three options:

1. Extinction (local, regional or global)
2. Emigration (e.g., distributional shift)
3. Evolution (given sufficient genetic variation)

Biogeographic Effects of Climate Change

How do species and communities respond to climate change? Three options:

1. Extinction
2. Emigration
3. **Evolution**



Rapid evolution of cold tolerance in a marine population of stickleback transplanted to freshwater

Biogeographic Effects of Climate Change

Three potential patterns of distributional shifts:

Range retraction: range retracts towards center at one or both boundaries without expansion at the other boundary (eventual conclusion is extinction).

Range expansion: range expands at one or both boundaries without retraction at the other boundary.

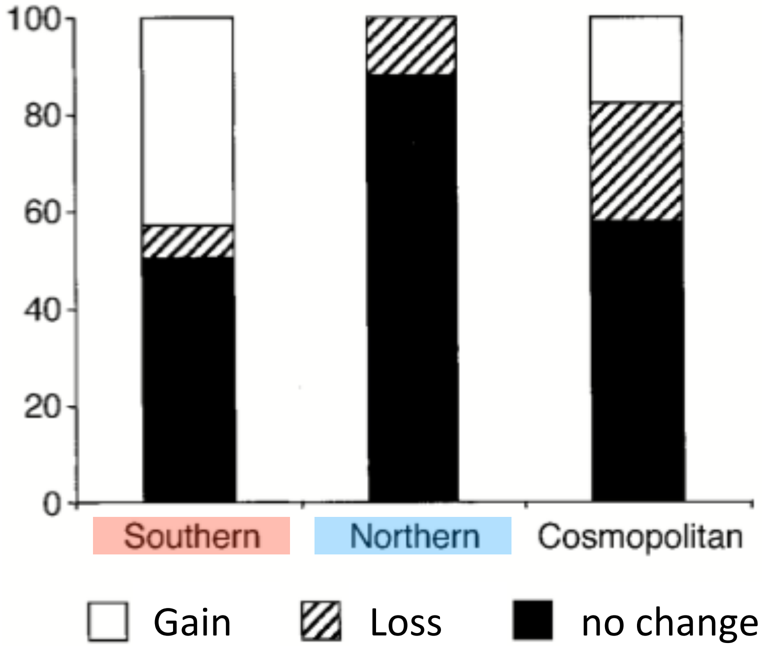
Range shift: entire range shifts with retraction at one boundary and expansion at the opposite boundary.

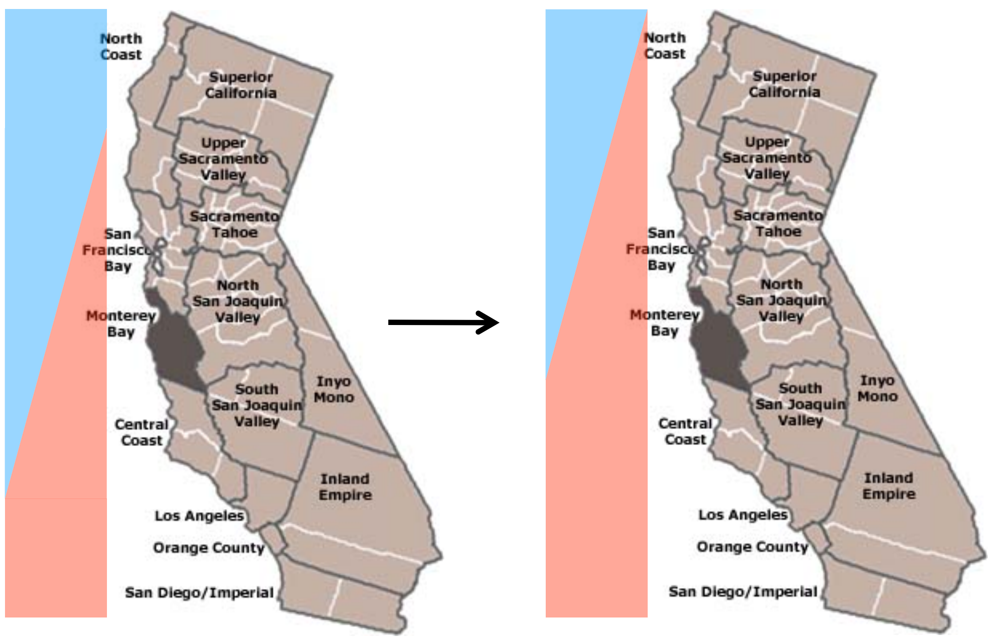
Biogeographic Effects of Climate Change

Records of distributional change: benthic invertebrates at Monterey Bay in 1930's and 1990's:

Resurveyed 57 transect plots in the intertidal community

Species composition change at Monterey Bay:

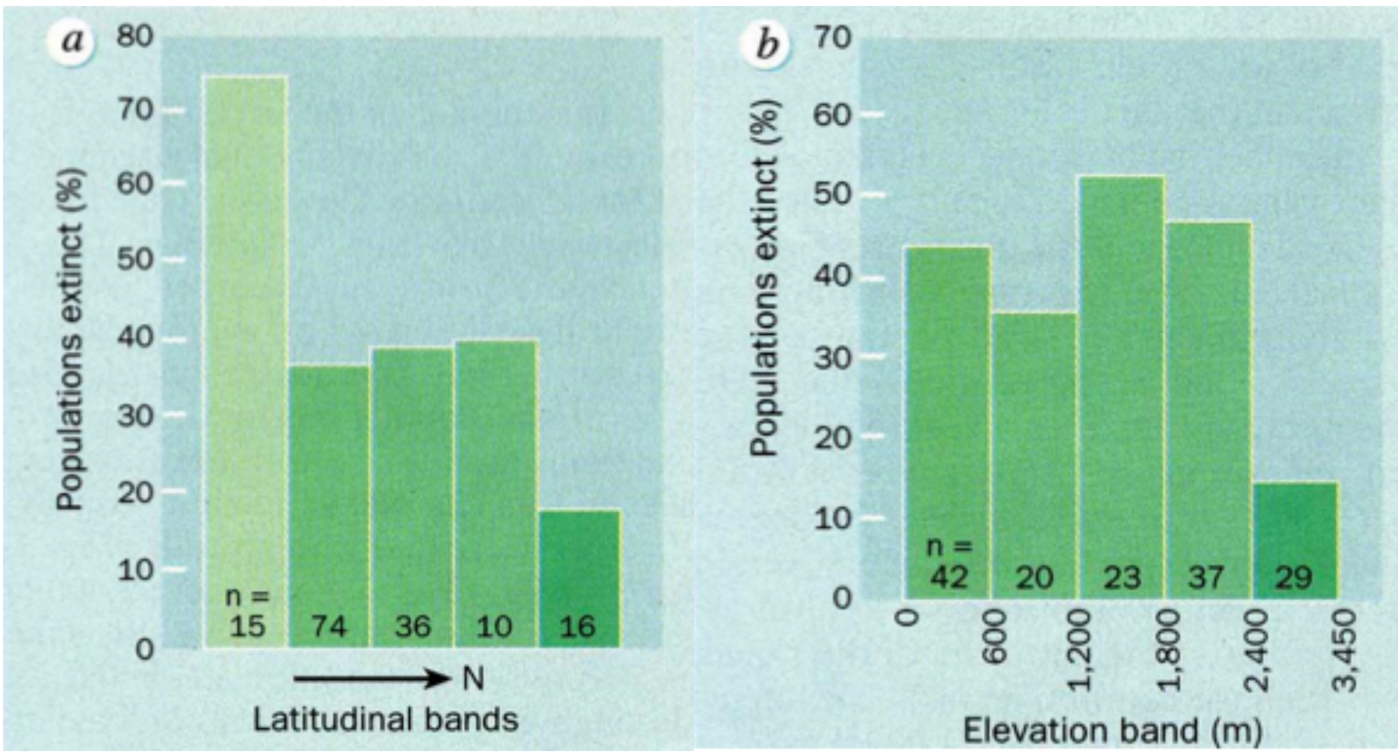




Sagarin *et al.* 1999

Biogeographic Effects of Climate Change

Records of extinctions: records of extinctions of populations of Edith's checkerspot butterfly (*Euphydryas editha*) from museums, private collections, and researchers' field notes – compared to contemporary surveys.

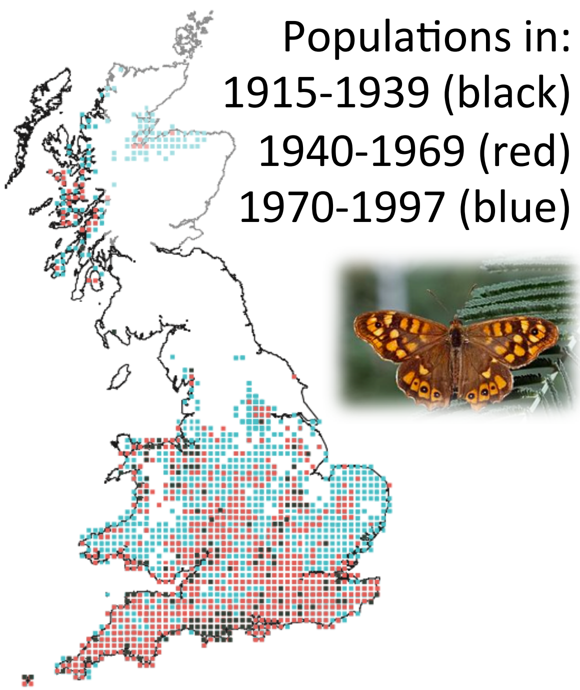


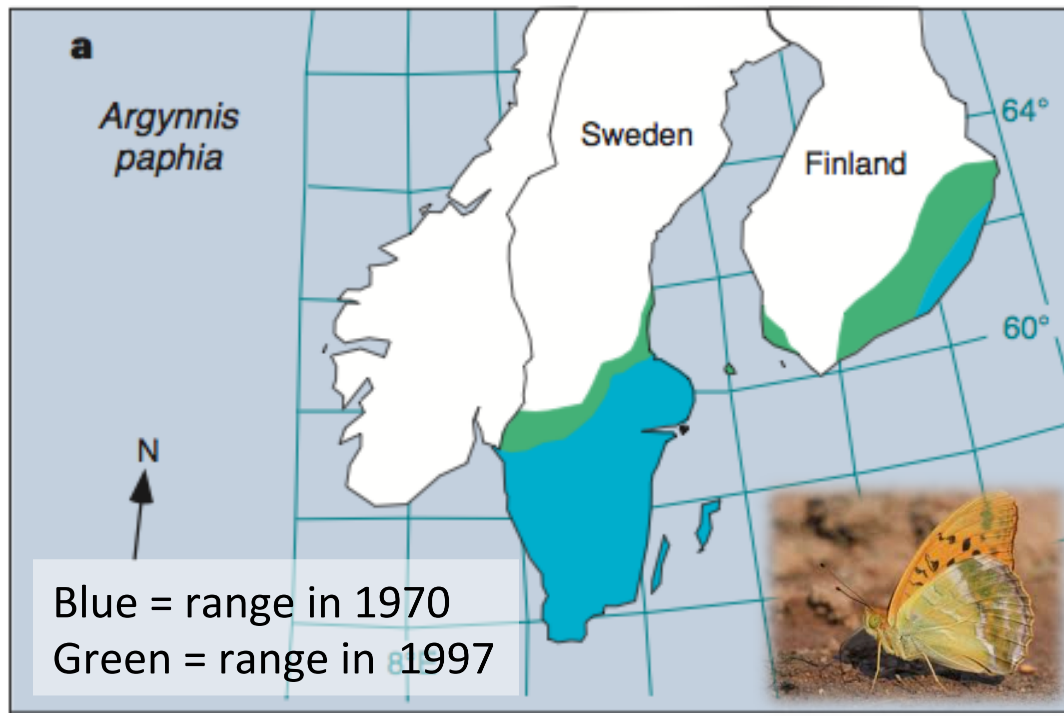
Parmesan *et al.* 1996

Biogeographic Effects of Climate Change

Records of distributional change: good records of range shifts in European butterflies

Of 35 non-migratory European butterflies, 63% have shown range shifts to the north by 35–240 km during this century (only 3% have shifted to the south).



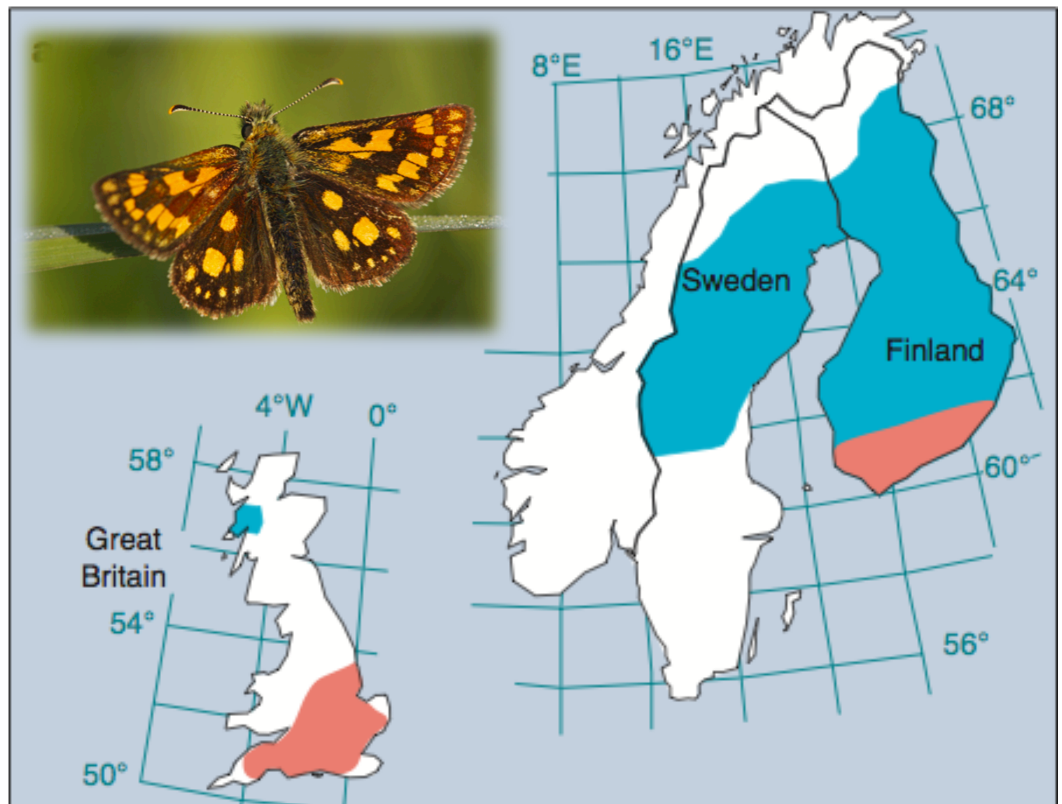


Northward range shifts of *Pararge aegeria* in Great Britain and *Argynnis paphia* in Scandanavia (Parmesan *et al.* 1999)

Biogeographic Effects of Climate Change

Records of distributional change: good records of range shifts in European butterflies.

Some butterfly species did not shift their range (blue) – southern populations went extinct at the southern edge (red).



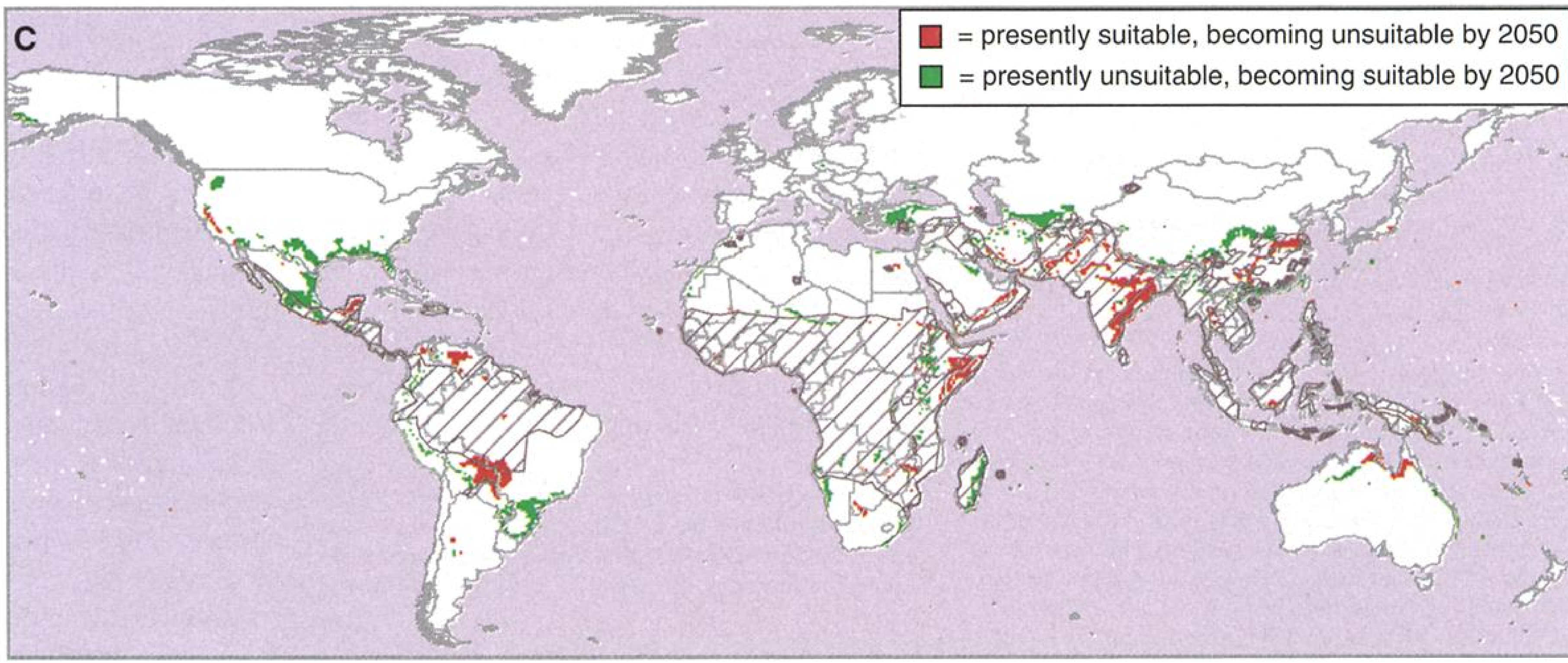
Parmesan *et al.* 1999

Non-shifting distribution of *Carterocephalus palaemon*

Biogeographic Effects of Climate Change

Potential spread of diseases due to warming climate.

Predicted suitability maps for malaria (hatched area shows current global distribution)



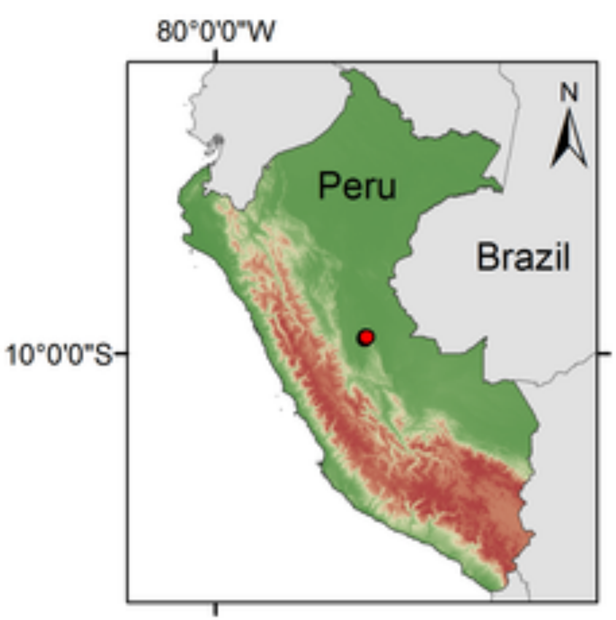
Rogers and Randolf 2000

Biogeographic Effects of Climate Change

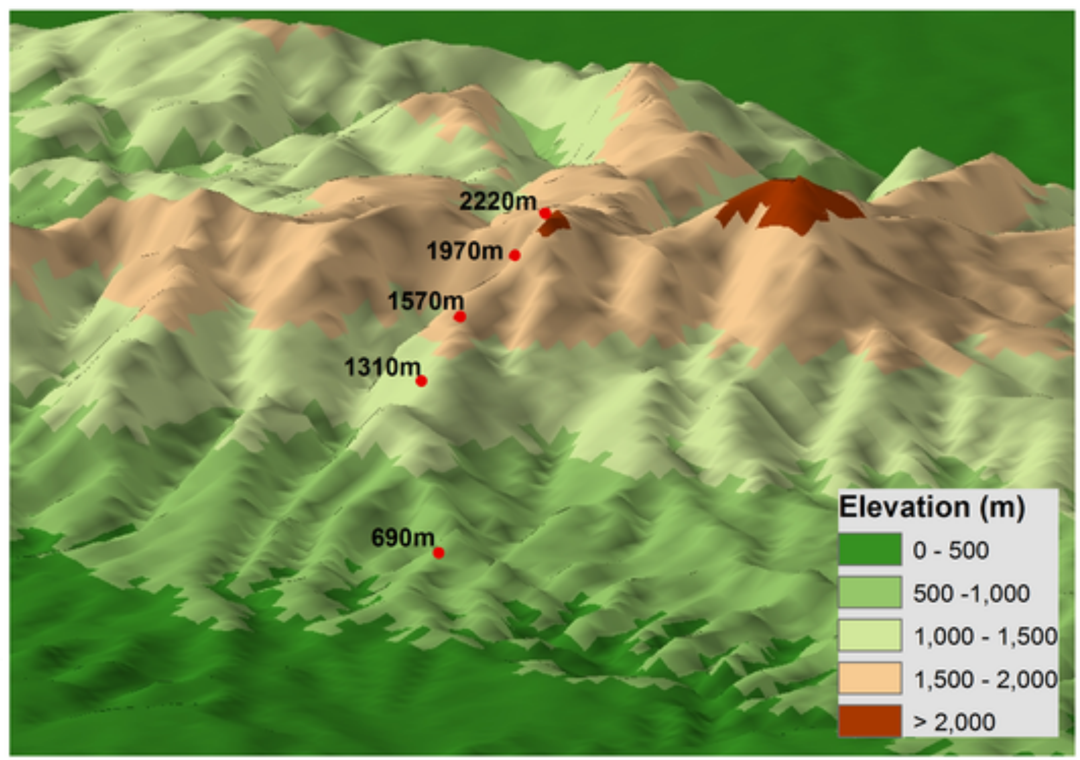
Some species or communities may lag behind temperature changes

Range shifts are observed, but do not keep pace with climate change.

Sampling locations for birds along an elevation gradient in the Cerros del Sira, Peru



sampling locations



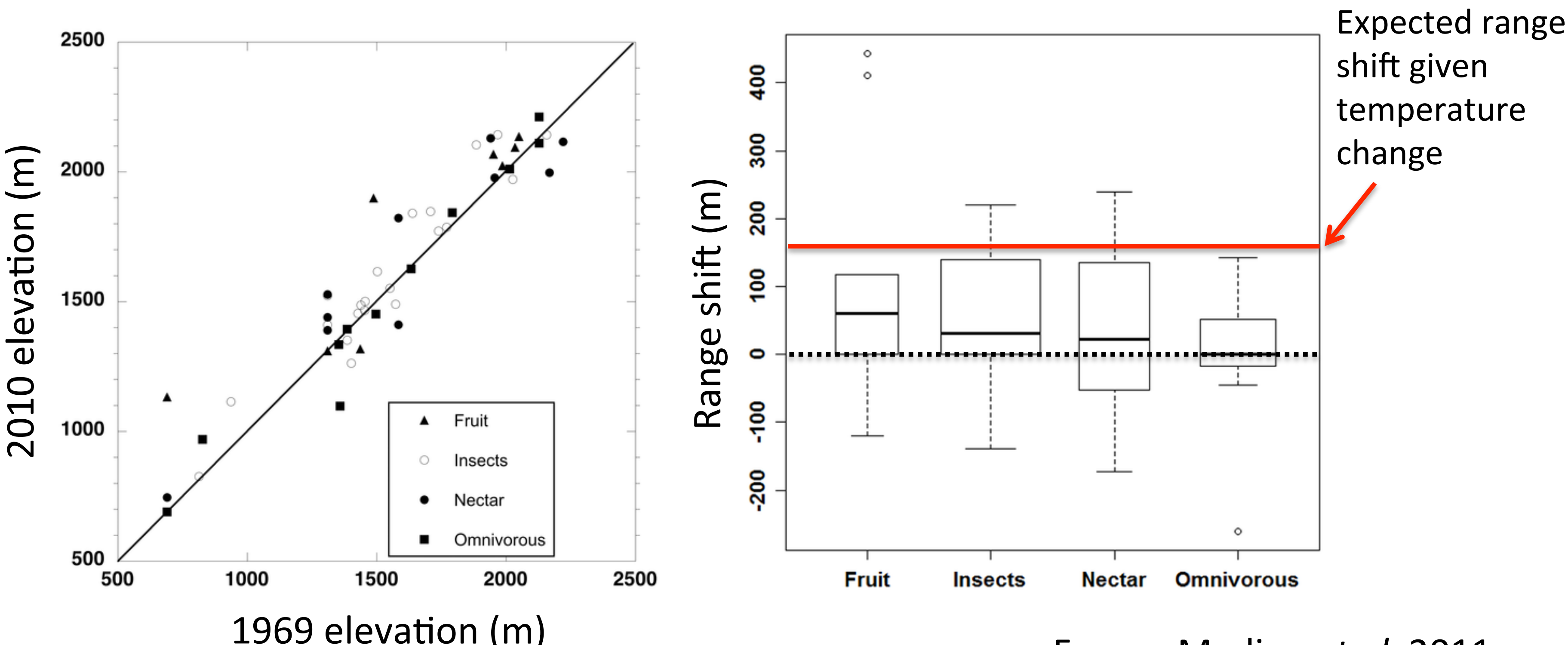
Forero-Medina *et al*. 2011

Biogeographic Effects of Climate Change

Some species or communities may lag behind temperature changes

Range shifts are observed, but do not keep pace with climate change.

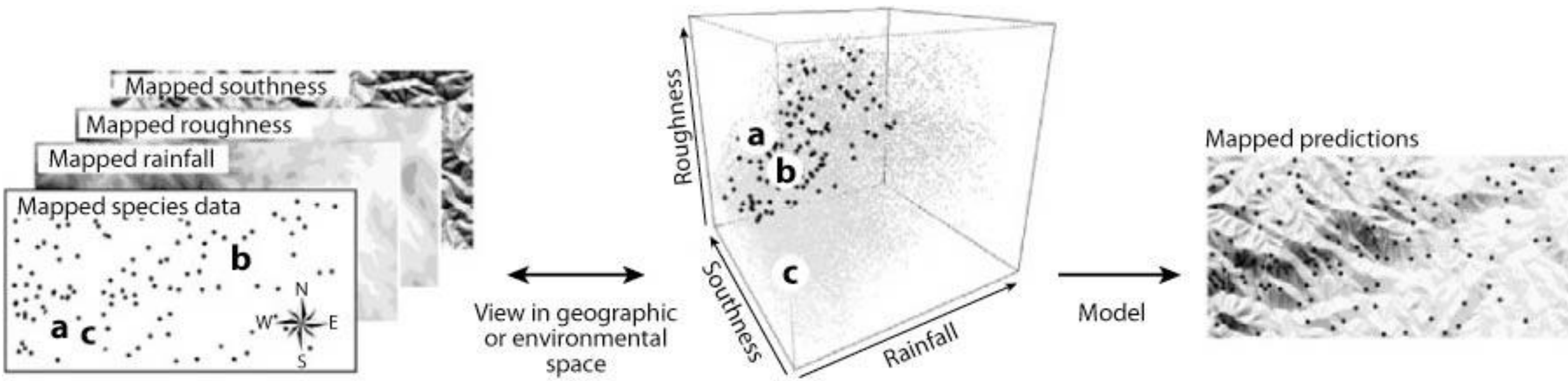
Some species show range shifts, but lag behind temperature change



Forero-Medina *et al*. 2011

Predicting Species Distributions

Maps of species occurrences are associated with environmental variables (climate envelope).



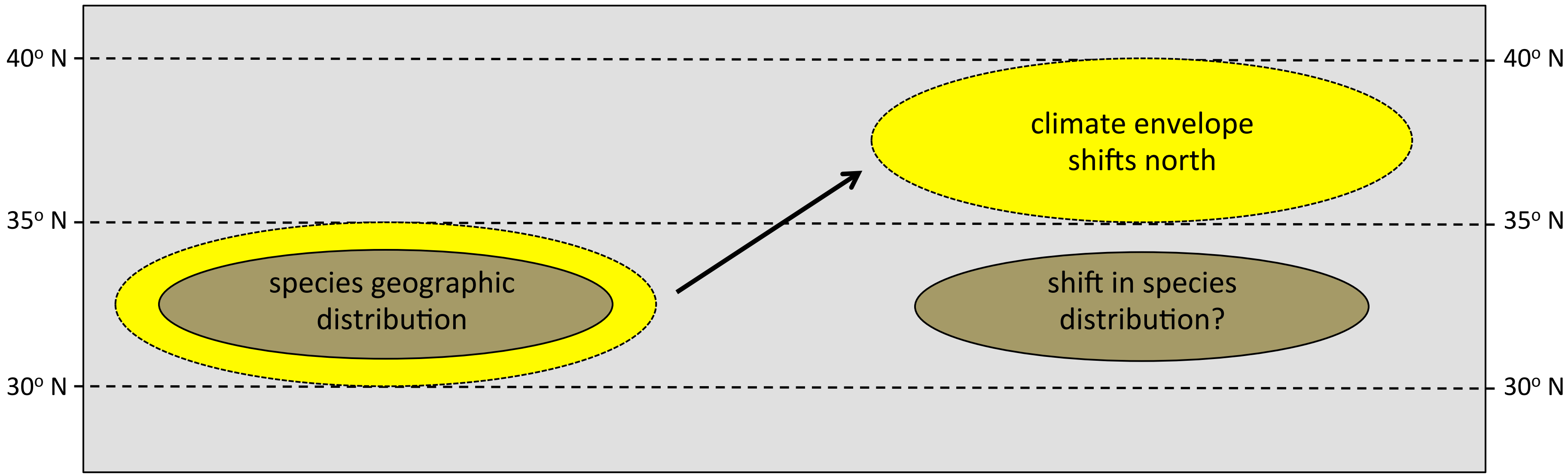
To predict distributional shifts, spatial change in environment is projected into future under different scenarios, and species distributions are recast.

Elith & Leathwick 2009

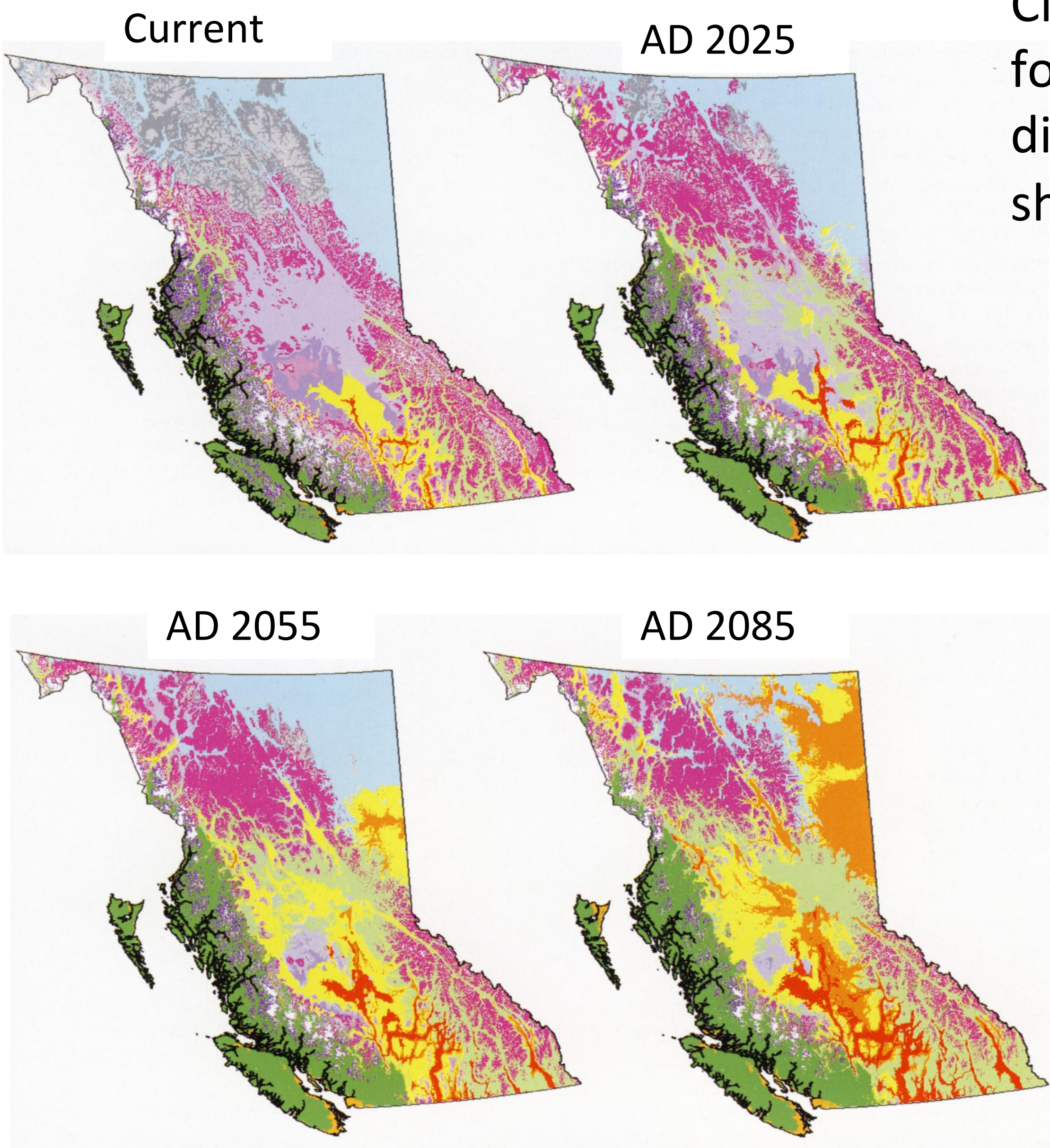
Predicting Changes in Distributions

An analog of the concept of the fundamental niche is the concept of the *climate envelope*, which has been used to compute an *ecoclimatic index.*

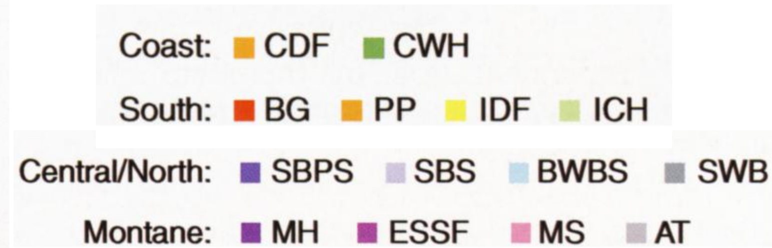
Ecoclimatic Index: a measure of the overall climatic favourability of a location for permanent establishment by a taxon based on developmental and distributional responses to temperature, moisture, and day length. In short, a measure that predicts the extent to which a location has the potential to support a taxon.



Predicting Changes in Distributions



Climate envelope model for BC forests predict some types will disappear (forest types in bold show major area reductions)



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 Black Spruce
MH Mountain Hemlock
ESSF Engelmann Spruce-Subalpine Fir
MS Montane Spruce
SWB Spruce-Willow-Birch
AT Alpine Tundra

Hamann & Wang 2006

Predicting range shifts of montane species with climate change

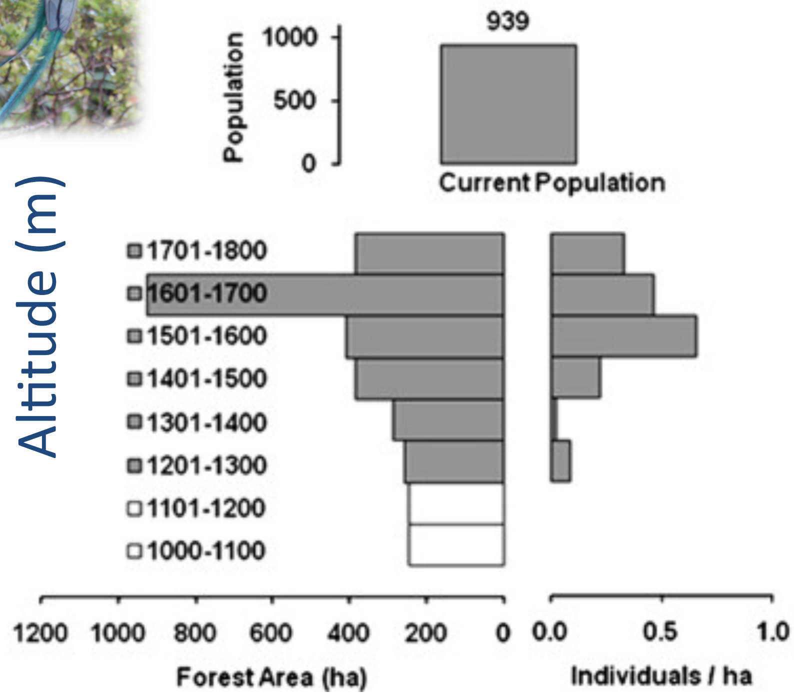
Resplendent Quetzal (*Pharomachrus mocinno*)

Moderate climate change scenario predicts ~3°C warming in next century

Temperature decreases ~6°C per 1000 m elevation

If species track changing environments, predicted range shift of 500 m elevation

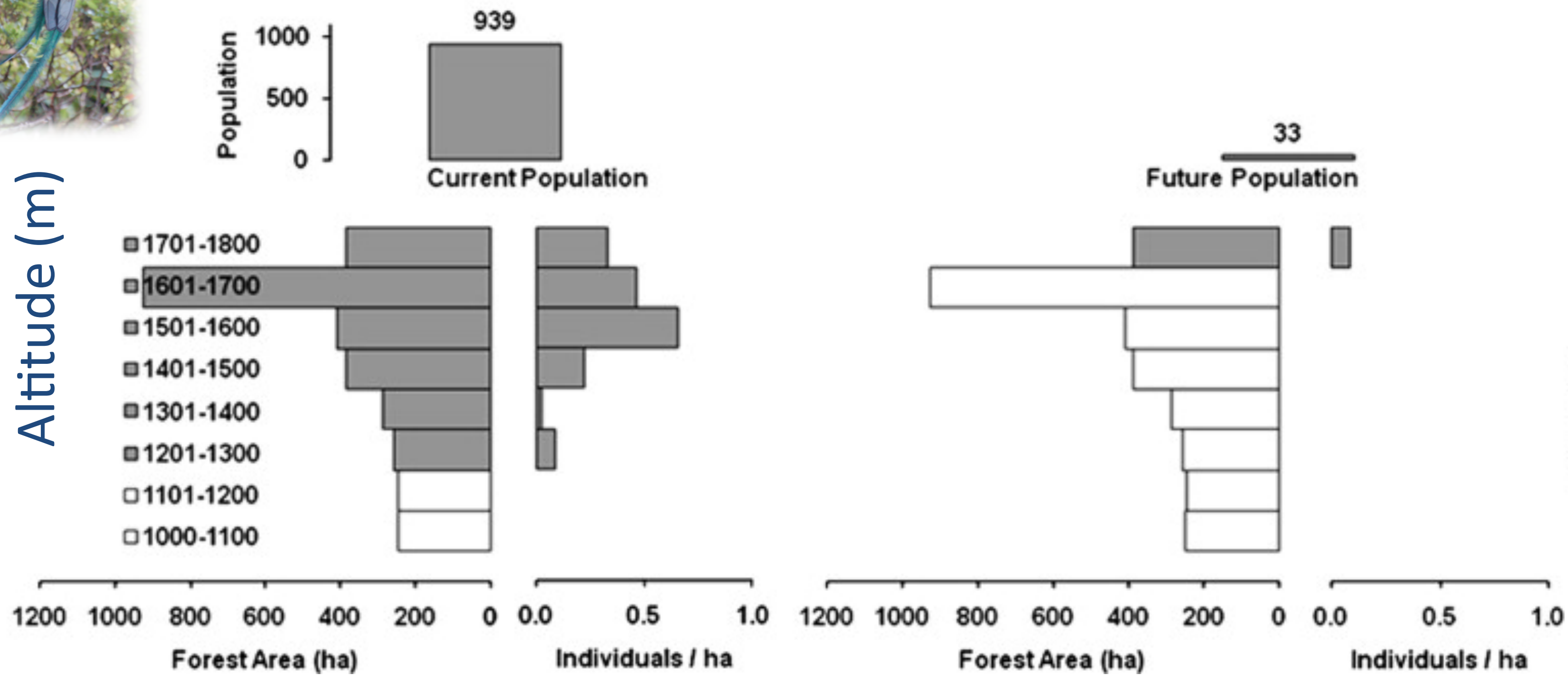
Predicting range shifts of montane species with climate change



Resplendent Quetzal (*Pharomachrus mocinno*)

Gasner et al. 2010 *Biol. Cons.*

Predicting range shifts of montane species with climate change



Resplendent Quetzal (*Pharomachrus mocinno*)

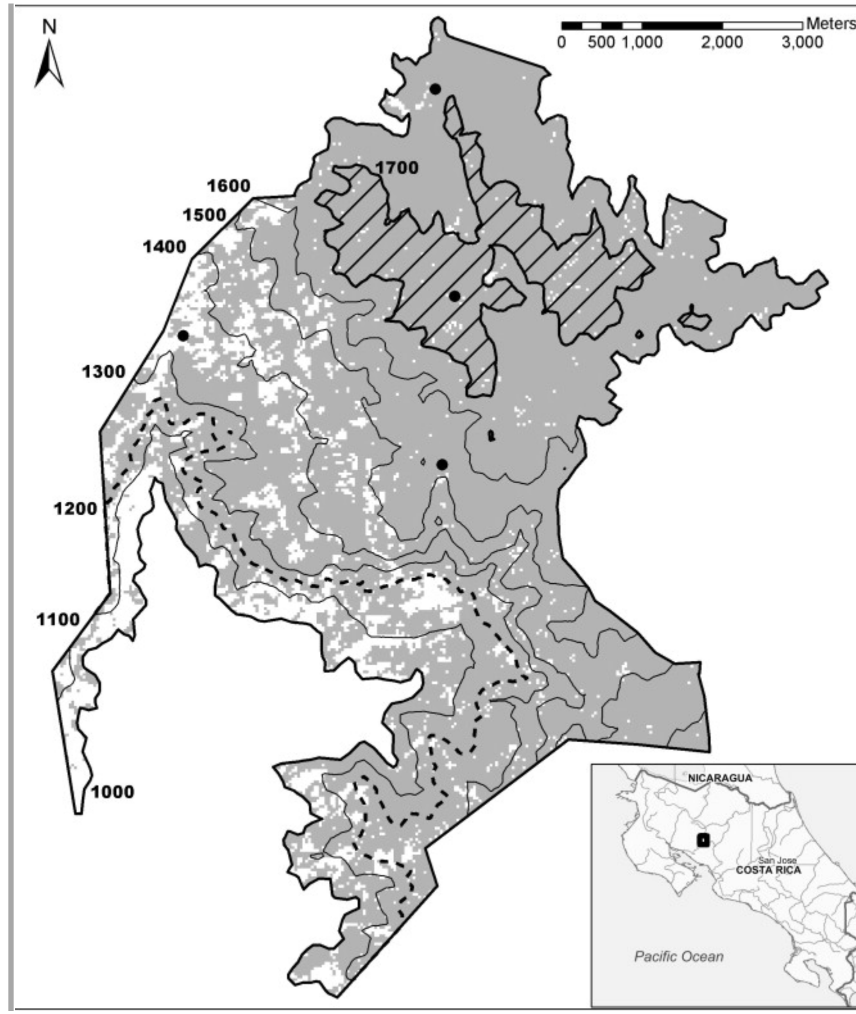
Gasner et al. 2010 *Biol. Cons.*

Current and predicted distributions of the Resplendent Quetzal in Monteverde

Forested areas

Current distribution

Predicted distribution

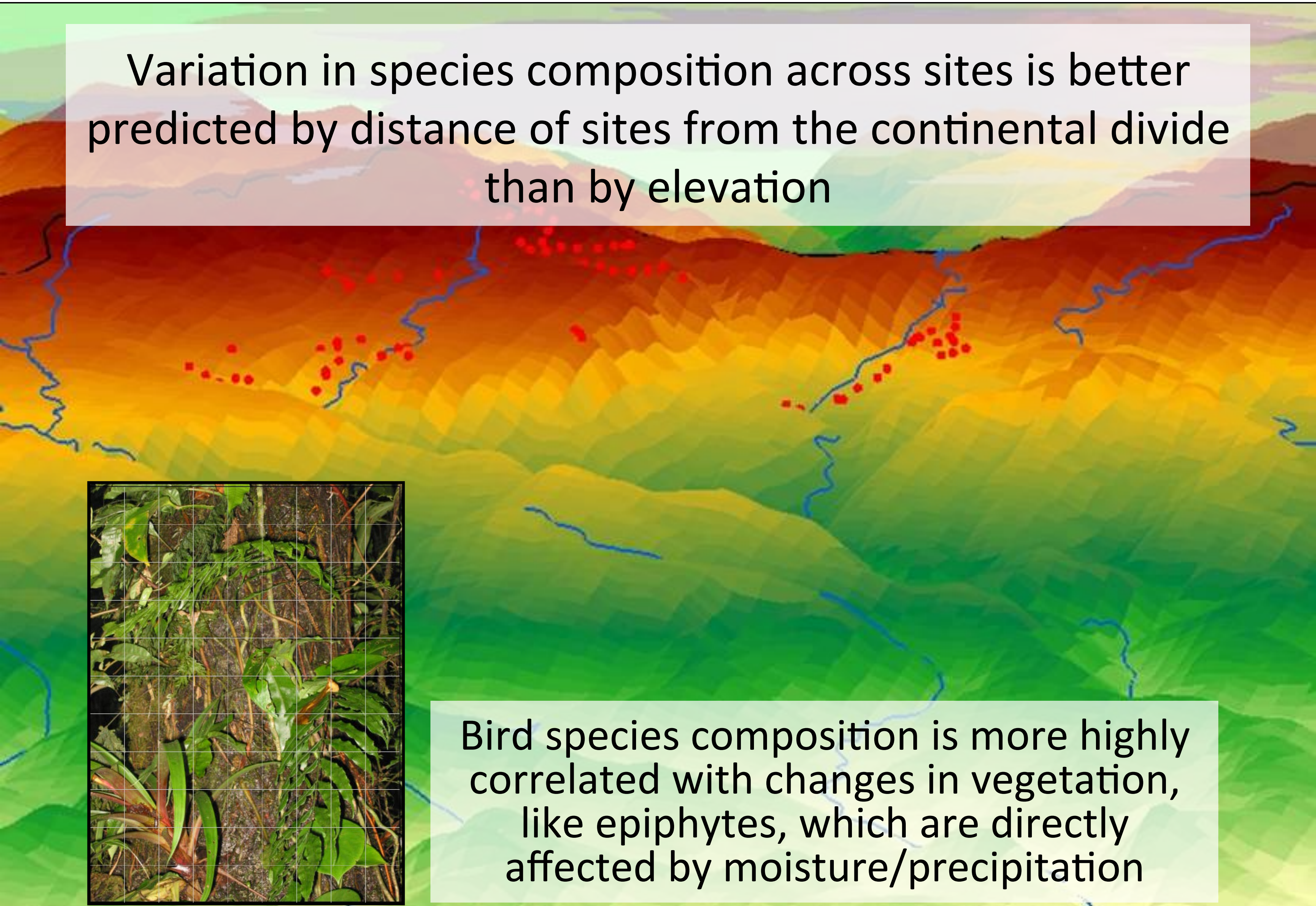


Gasner et al. 2010 *Biol. Cons.*

Predicting range shifts of montane species with climate change…which variables?

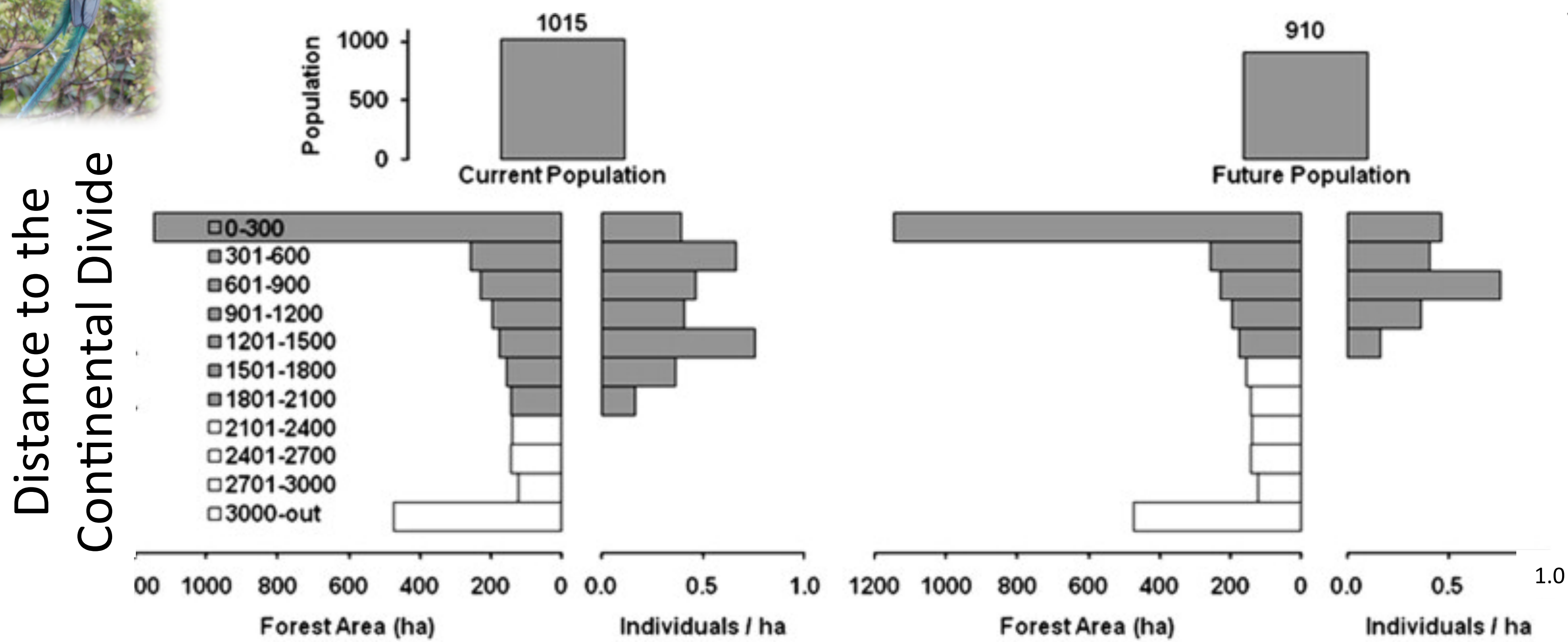
In this mountain range, cloud moisture is predicted by how far a site is from the continental divide.

Variation in species composition across sites is better predicted by distance of sites from the continental divide than by elevation



Bird species composition is more highly correlated with changes in vegetation, like epiphytes, which are directly affected by moisture/precipitation

Predicting range shifts of montane species with climate change…which variables?



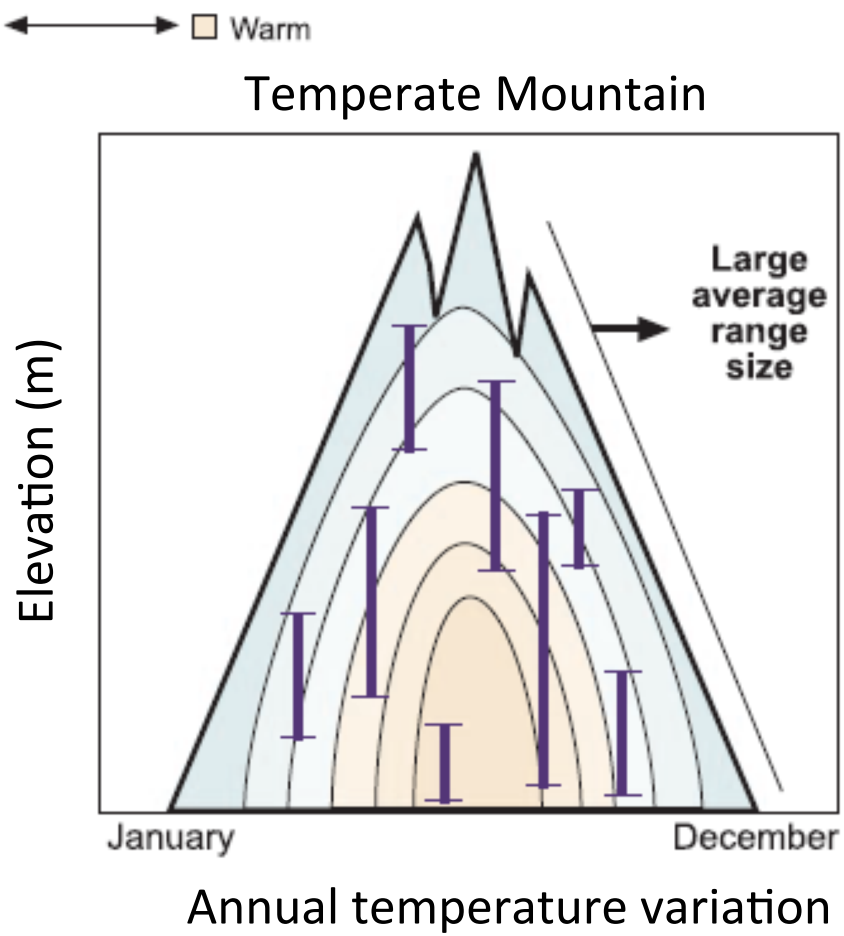
Resplendent Quetzal (*Pharomachrus mocinno*)

We see a very different picture of population trajectories, depending on how species shift their ranges with respect to habitat variables…

Gasner et al. 2010 *Biol. Cons.*

Predicting Changes in Distributions - Physiology

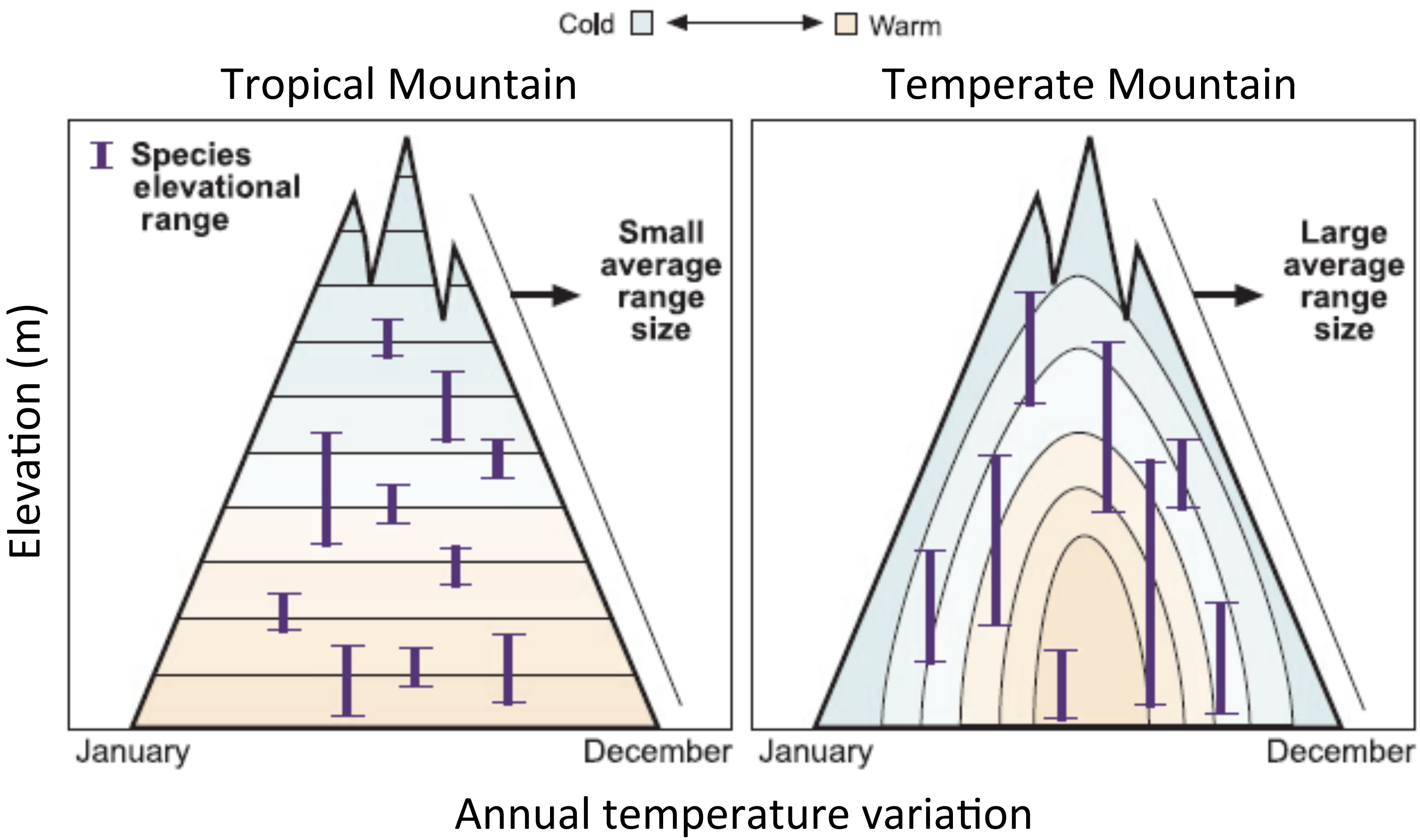
Recall Janzen's hypothesis: Temperate regions have higher overlap in thermal regimes across seasons compared to tropical regions.



McCain 2009, *Ecol. Letters*; Janzen 1967, *American Naturalist*

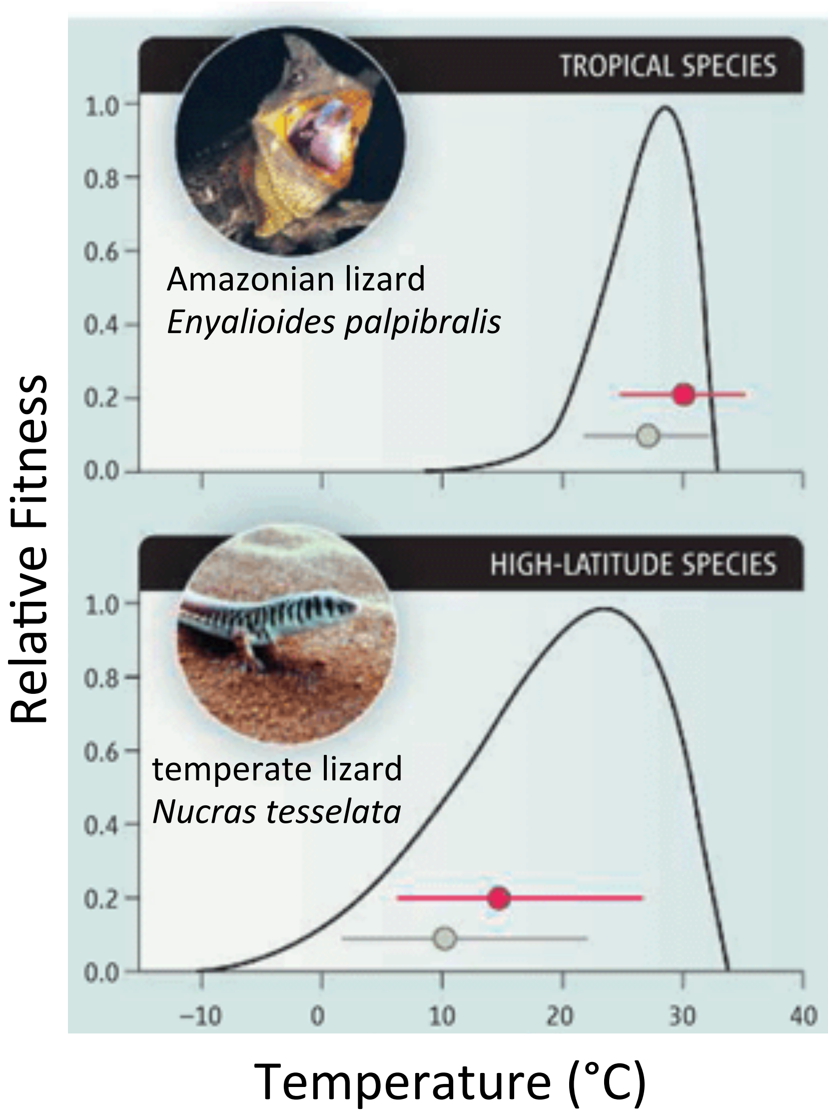
Predicting Changes in Distributions - Physiology

Recall Janzen's hypothesis: Temperate regions have higher overlap in thermal regimes across seasons compared to tropical regions.



McCain 2009, *Ecol. Letters*; Janzen 1967, *American Naturalist*

Predicting Changes in Distributions - Physiology



Data from diverse tropical ectotherms (e.g., fish, insects, reptiles, amphibians) suggest that tropical species living in stable aseasonal climates have:

1) narrower thermal tolerances than higher-latitude species

2) live in climates closer to their physiological optima

Current mean temperature

Current temperature range

Predicted mean temperature in 2100

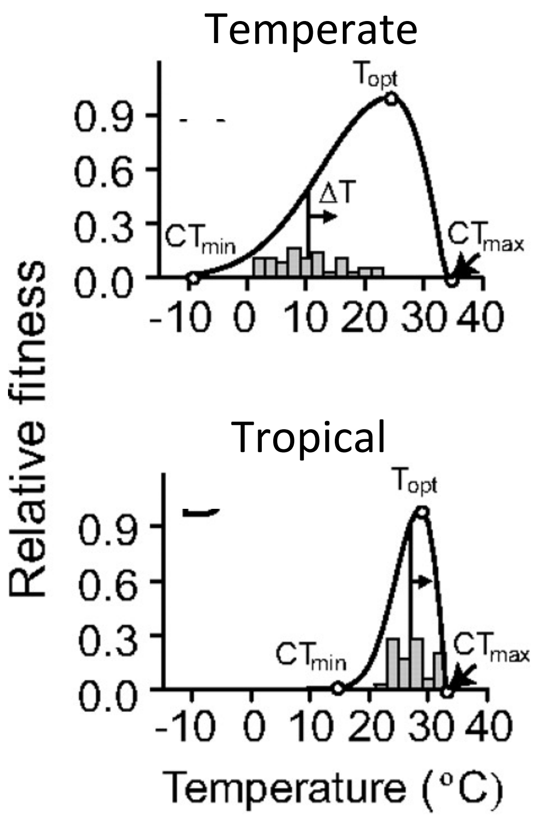
Predicted temperature range in 2100

Tewksbury et al. 2008, *Science*

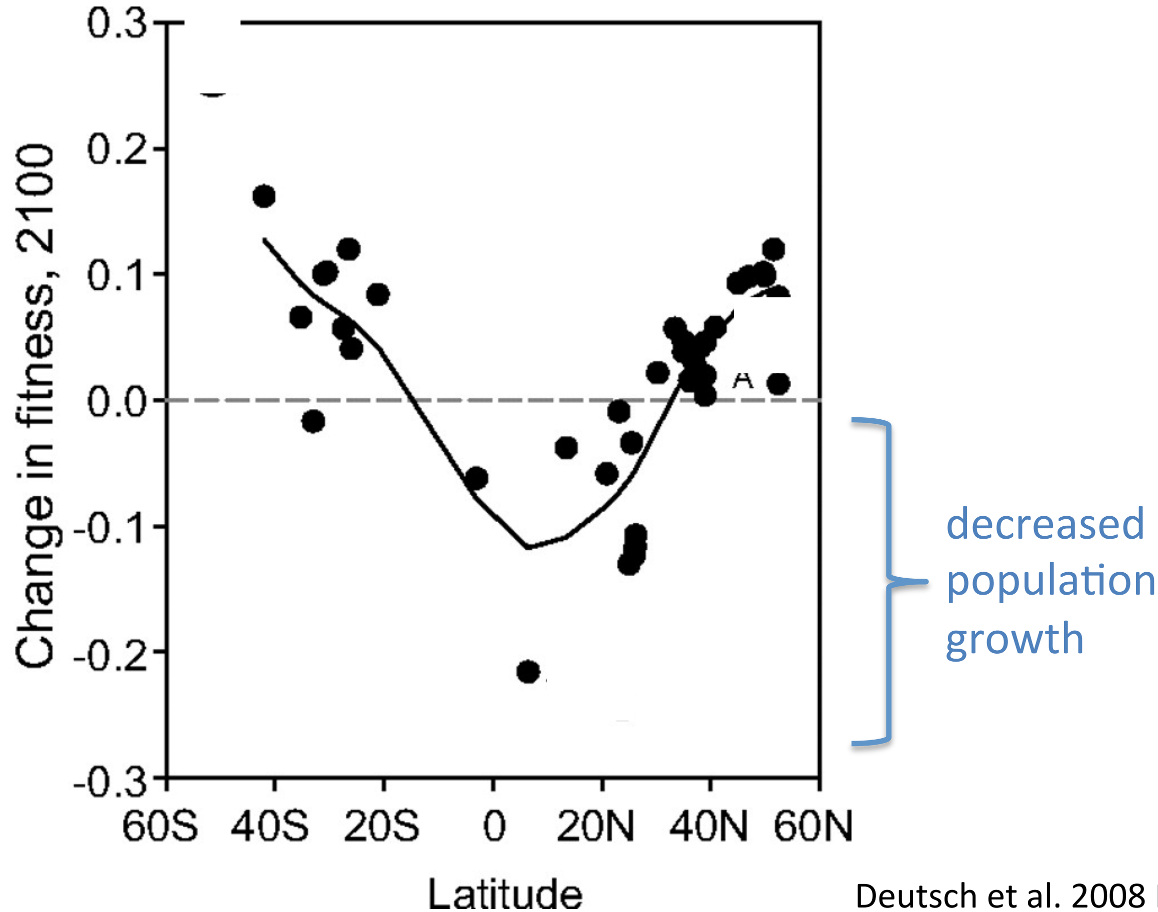
Predicting Changes in Distributions - Physiology

In ectotherms (e.g., insects, herps), basic physiological functions like locomotion, growth and reproduction are strongly influenced by environmental temperature
→ Climate change has direct impacts that can be readily predicted

Fitness curves for insects

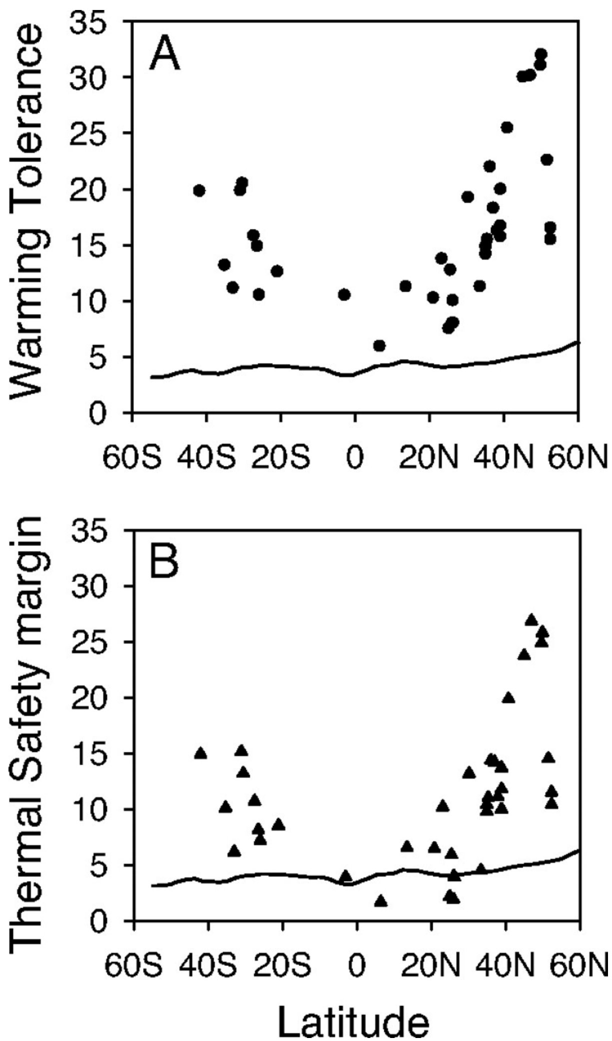


Change in fitness across latitudes due to climate warming



Deutsch et al. 2008 PNAS

Predicting Changes in Distributions - Physiology



Warming tolerance ($CT_{max} – T_{hab}$)

Thermal Safety Margin ($T_{opt} – T_{hab}$)

Black line represents level of warming (ΔT) by 2100

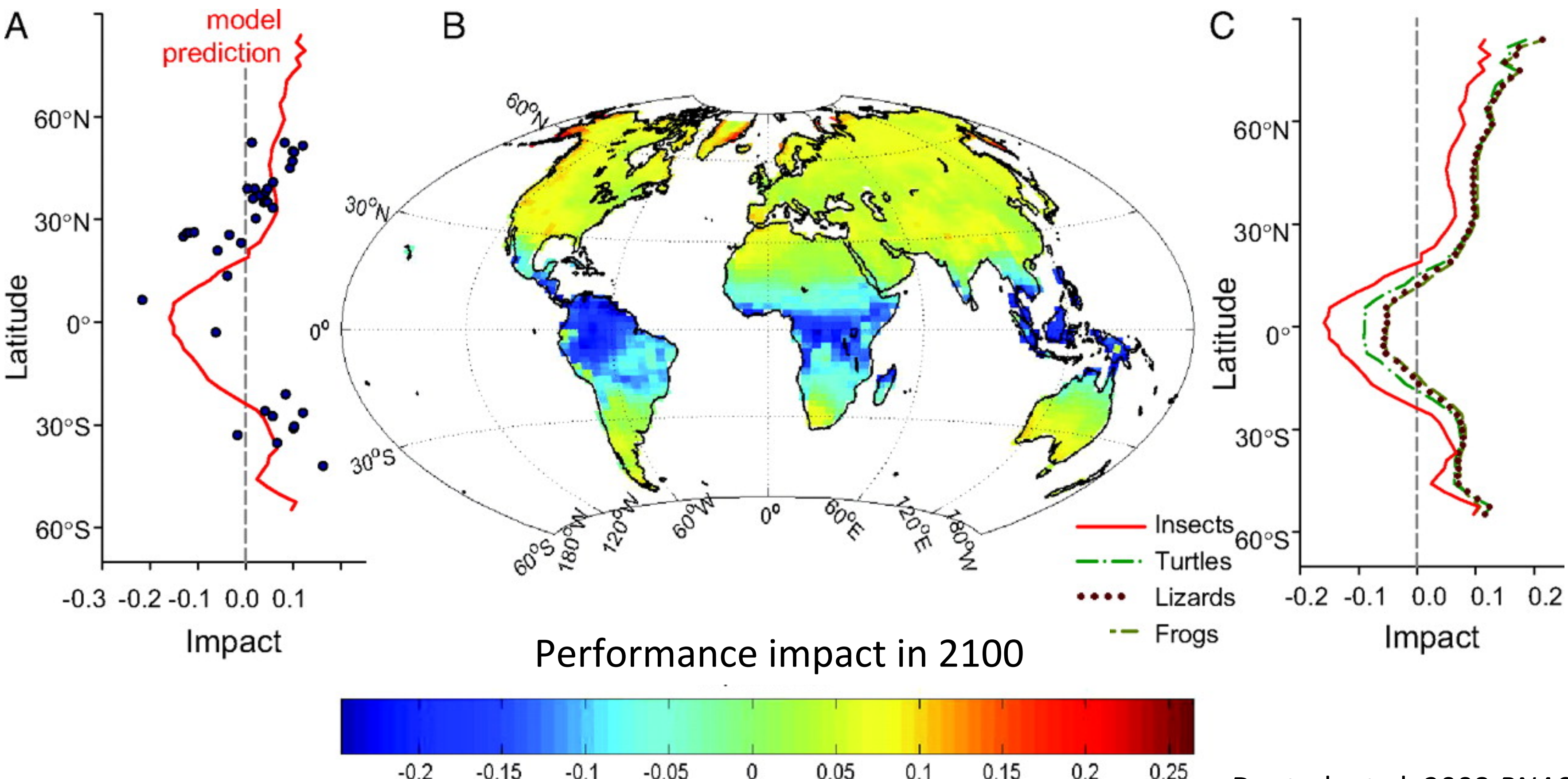
Insects at higher latitudes will remain high above thermal safety margin

Tropical insects will approach near-lethal temperatures

Deutsch et al. 2008 PNAS

Predicting Changes in Distributions - Physiology

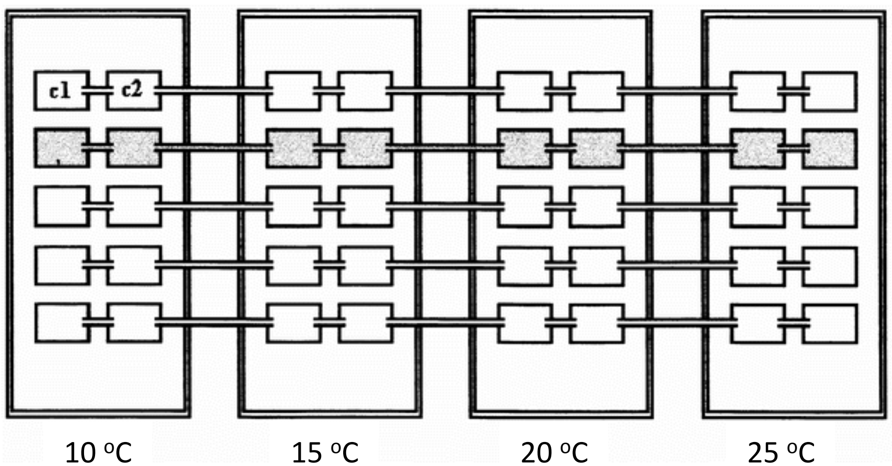
Climate change is predicted to be most deleterious for tropical representatives from these four ectothermic taxa. Performance should increase at mid- and high-latitudes



Deutsch et al. 2008 *PNAS*

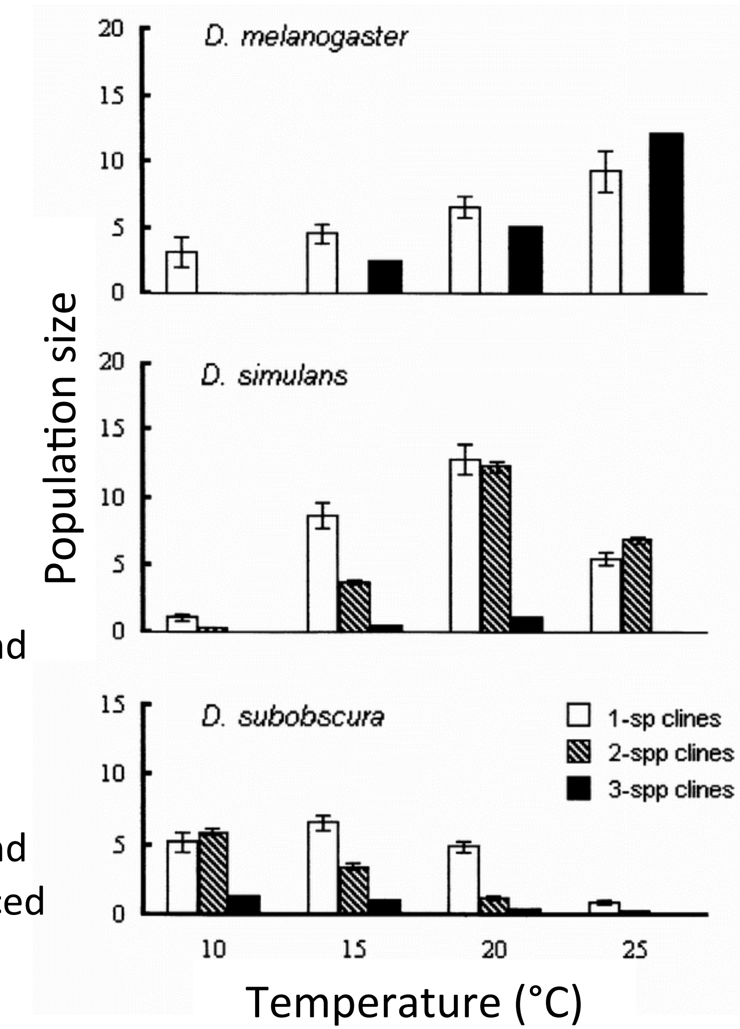
Predicting Changes in Distributions – Biotic processes

Biotic interactions make predictions of distributional change difficult
Experiment using three species of *Drosophila* (Davis *et al* 1998).



2-spp clines: *D. subobscura* and *D. simulans* were affected at different temps

3-spp clines: *D. subobscura* and *D. simulans* were highly reduced with *D. melanogaster*



Predicting Changes in Distributions – Biotic processes

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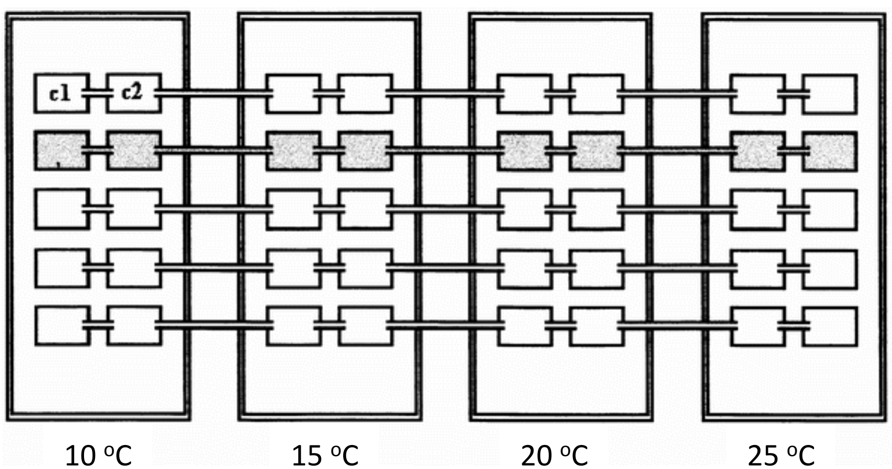
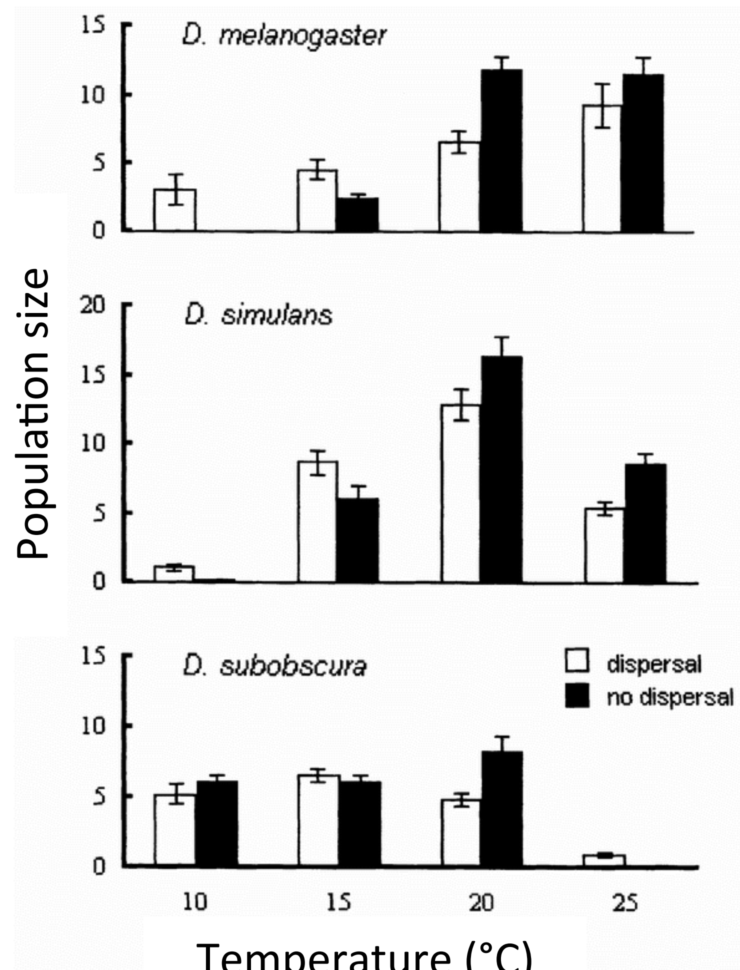
Experiment using three species of *Drosophila* (Davis *et al* 1998).



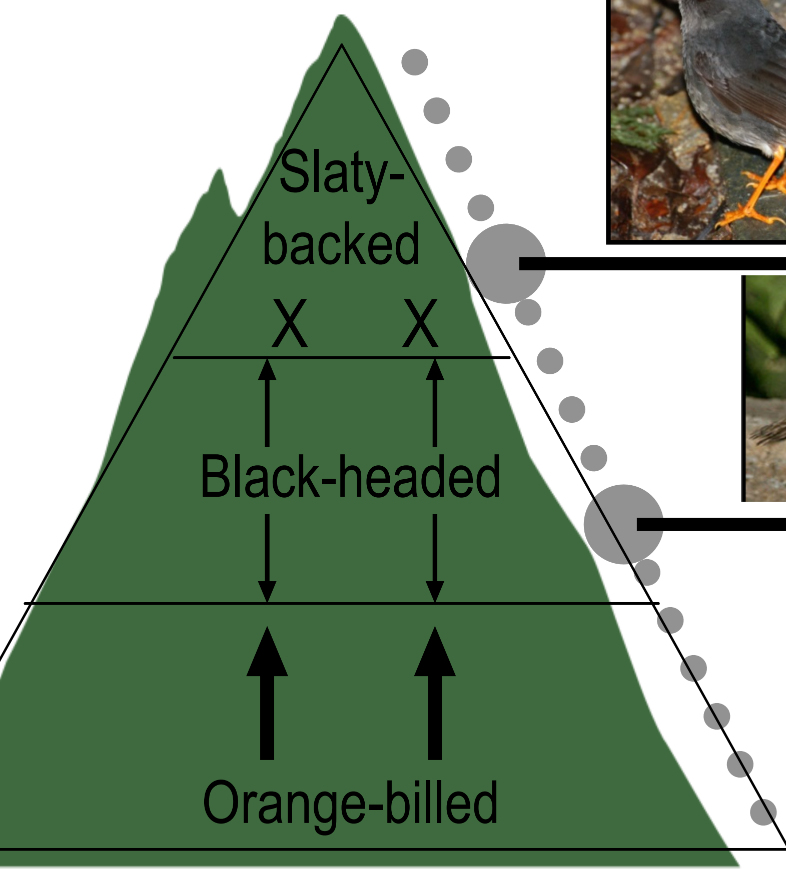
Without dispersal populations at extreme temperatures went extinct.

Dispersal maintains sink populations.



Predicting Changes in Distributions – Biotic processes

Biotic interactions may be primary drivers of species range shifts and loss



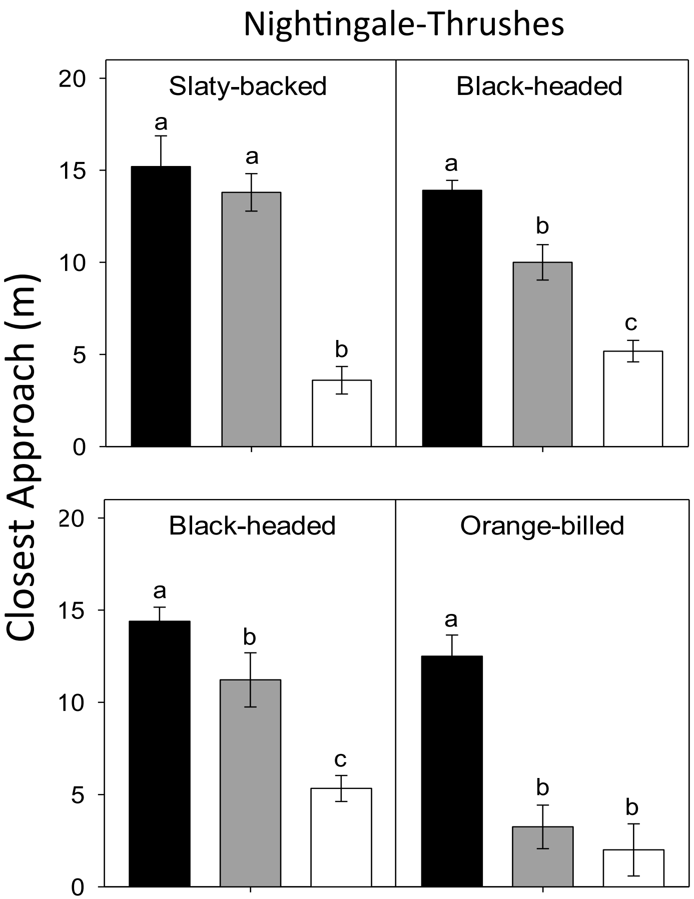
Slaty-backed
Nightingale-Thrush

Black-headed
Nightingale-Thrush

Orange-billed
Nightingale-Thrush

Predicting Changes in Distributions – Biotic processes

Biotic interactions may be primary drivers of species range shifts and loss

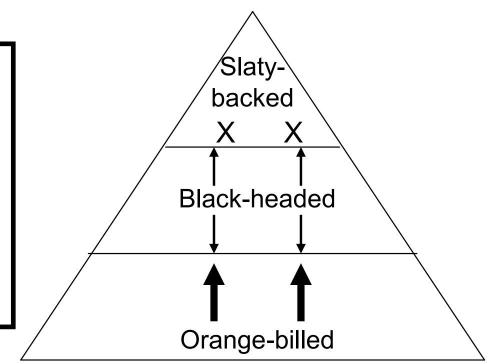


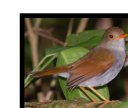
Recall song playback experiments and closest approach to speaker as a metric of aggression.

For Nightingale-Thrushes, interspecific competition is asymmetric (lower elevation species more aggressive).

Expected that lower species (Orange-billed NT) will invade higher elevations, facilitated by climate change.

Song played to bird:
- Control
- Congener (other species)
- Conspecific (same species)

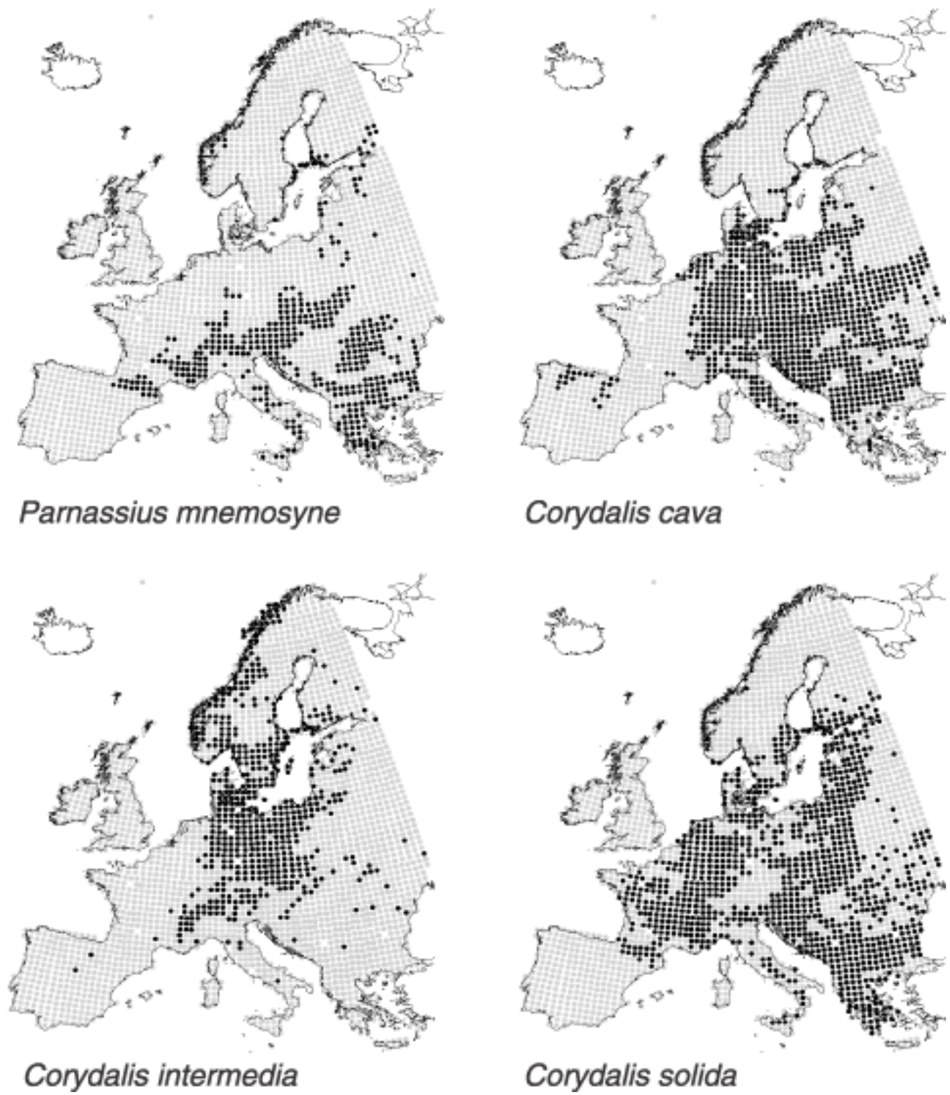




Jankowski *et al.* 2010

Predicting Changes in Distributions – Biotic processes

Biotic interactions may be primary drivers of species range shifts and loss

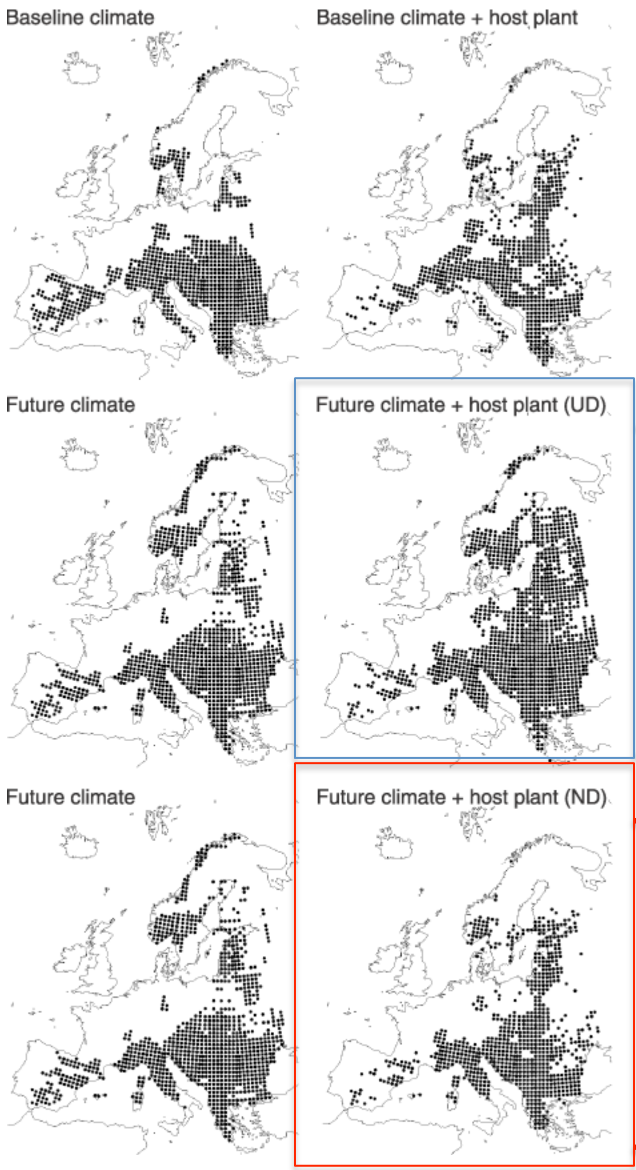


European distribution of the clouded Apollo butterfly (*Parnassius mnemosyne*) and three species of the genus *Corydalis* that act as larval host plants.

Araújo & Luoto 2007

Predicting Changes in Distributions – Biotic processes

Biotic interactions may be primary drivers of species range shifts and loss



Unlimited dispersal

No dispersal

Modelled distribution based on baseline and future (2050) conditions assuming unlimited dispersal (UD) and no dispersal (ND) among *Corydalis* spp. larval host plants

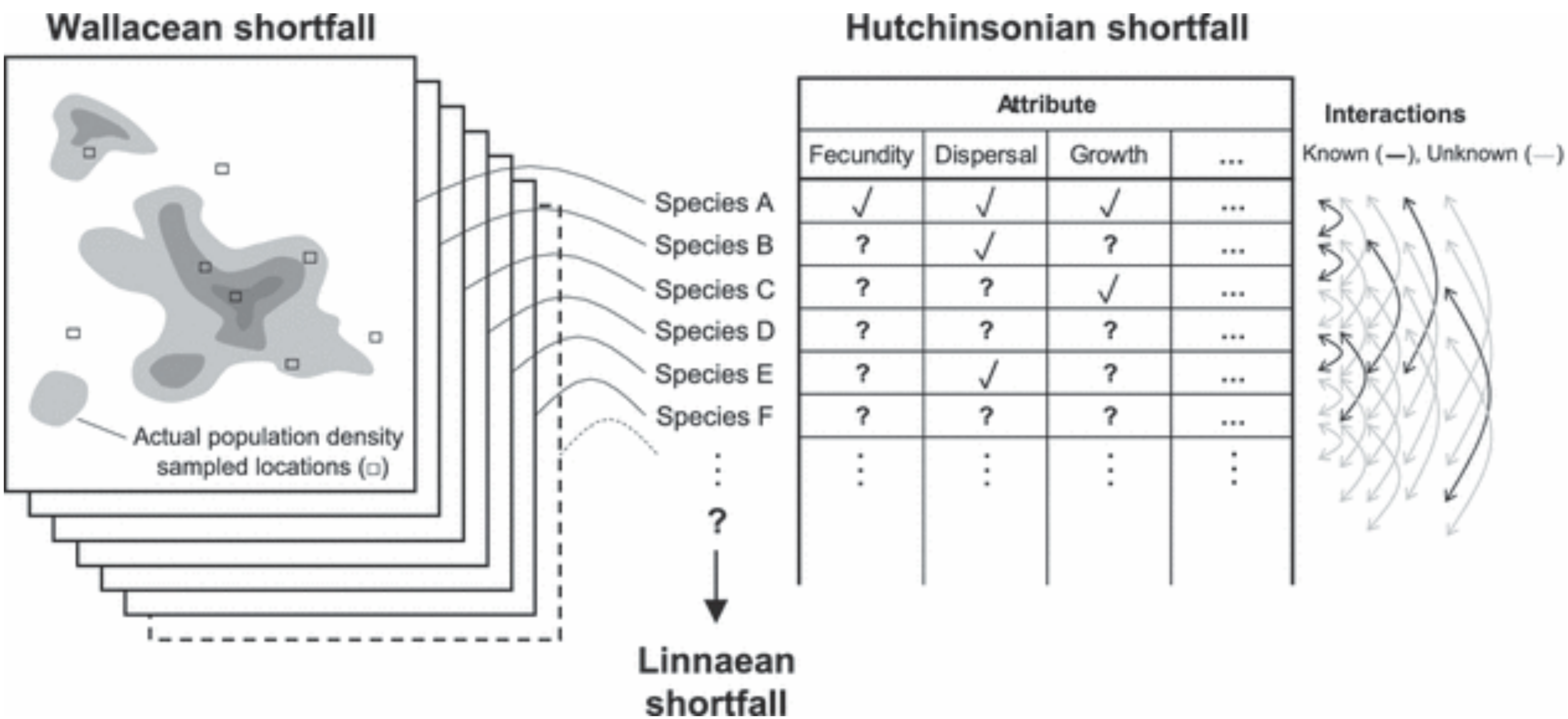
Distributions and projections depend upon variables used in model (climate vs. climate + host plant) as well as unlimited or no dispersal

Araújo & Luoto 2007

Predicting Changes in Distributions - Challenges

Lack of knowledge of explicit spatial distributions of species

Lack of knowledge of attributes of species and their interactions



Shortcomings in the discovery and description of new species

Mokany & Ferrier 2011

Climate Change

References for this section:

Araújo, M. B., & Luoto, M. 2007. The importance of biotic interactions for modelling species distributions under climate change. Global Ecology and Biogeography, 16: 743-753.

Barrett, R. D., Paccard, A., Healy, T. M., Bergek, S., Schulte, P. M., Schluter, D., & Rogers, S. M. 2011. Rapid evolution of cold tolerance in stickleback. *Proceedings of the Royal Society B: Biological Sciences* 278: 233-238.

Davis, A.J. *et al.* 1998. Making mistakes when predicting shifts in species range in response to global warming. *Nature* 391: 783-786.

Deutsch, C. A., Tewksbury, J. J., Huey, R. B., Sheldon, K. S., Ghalambor, C. K., Haak, D. C., & Martin, P. R. 2008. Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences* 105: 6668-6672.

Elith, J., & Leathwick, J. R. 2009. Species distribution models: ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution, and Systematics* 40: 677-697.

Forero-Medina, G., Terborgh, J., Socolar, S. J., & Pimm, S. L. 2011. Elevational ranges of birds on a tropical montane gradient lag behind warming temperatures. *PloS one* 6: e28535.

Gates, D.M. 1993. *Climate Change and its Biological Consequences*. Sunderland, MA: Sinauer Assoc.

Hamann, A., & Wang, T. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. *Ecology* 87: 2773-2786.

IPCC Report 2013. https://www.ipcc.ch/report/ar5/wg1/

Jankowski, J. E., Robinson, S. K., & Levey, D. J. 2010. Squeezed at the top: interspecific aggression may constrain elevational ranges in tropical birds. *Ecology* 91: 1877-1884.

Janzen, D.H. 1967. Why mountain passes are higher in the tropics. *American Naturalist* 233-249.

Lomolino, M.V., B.R. Riddle, R.J. Whittaker, & J.A. Brown. 2010. *Biogeography* (4th ed., Chapter 2). Sinauer Associates, Inc., Sunderland, Mass.

McCain, C.M. 2009. Vertebrate range sizes indicate that mountains may be 'higher' in the tropics. *Ecology Letters* 12: 550-560.

McDonald, K. A., & Brown, J. H. (1992). Using montane mammals to model extinctions due to global change. Conservation Biology, 6(3), 409-415.

Climate Change

References for this section:

Mokany, K., & Ferrier, S. 2011. Predicting impacts of climate change on biodiversity: A role for semi-mechanistic community-level modelling. *Diversity and Distributions* 17: 374-380.

Parmesan, C. 1996. Climate and species ranges. *Nature* 382: 765-766.

Parmesan, C. *et al.* 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature* 399: 579-583.

Rogers, D.J., and S.E. Randolph. 2000. The global spread of malaria in a future, warmer world. *Science* 289: 1763-1766.

Root, T. 1988. Environmental factors associated with avian distributional boundaries. *Journal of Biogeography* 15(3): 489-505.

Rutherford, S. et al. 1999. Environmental controls on the geographic distribution of zooplankton diversity. *Nature* 400: 749-753.

Sagarin, R.D. et al. 1999. Climate-related change in an intertidal community over short and long time scales. *Ecol. Mono.* 69: 465-490.

Tewksbury, J. J., Huey, R. B., & Deutsch, C. A. 2008. Putting the heat on tropical animals. *Science* 320: 1296.

Thompson, R. S., & Anderson, K. H. 2000. Biomes of western North America at 18,000, 6000 and 0 14C yr BP reconstructed from pollen and packrat midden data. *Journal of Biogeography* 27: 555-584.