

Section 3:  
Species range shifts

Learning outcomes

- understand concepts and mechanisms of range shifts
- give examples of the direct effect of climate change on range shifts as well as the indirect effects
- describe how range shifts have been used as evidence for climate change

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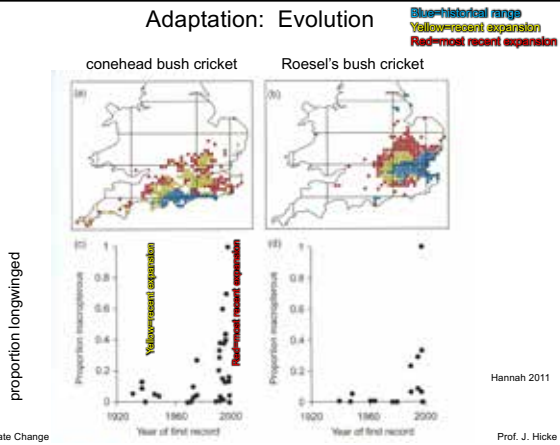
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Adaptation: Evolution



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The Human Footprint ver. 2

Wildlife Conservation Society

Global



The Human Footprint Index

The Human Footprint Index (HFI) is a composite of the following factors: (1) population density, (2) cropland, (3) built-up areas, (4) roads, (5) rivers, (6) and (7) the total number of large dams. The HFI is a measure of the total number of large dams.



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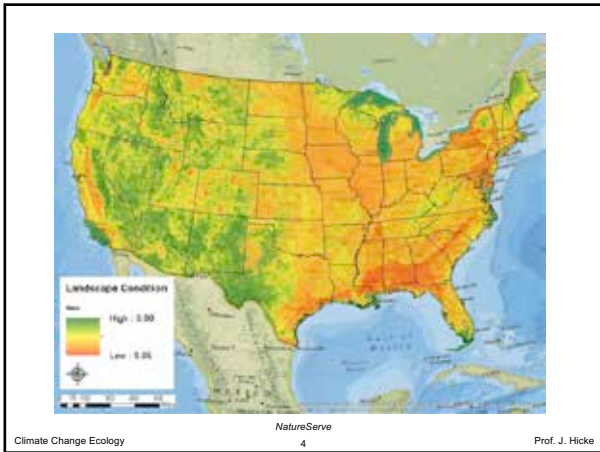
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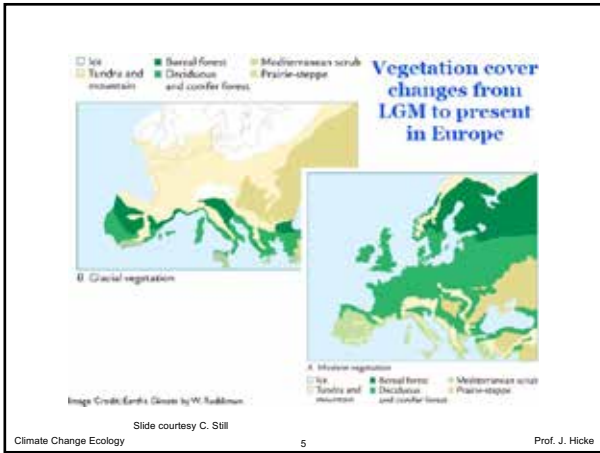
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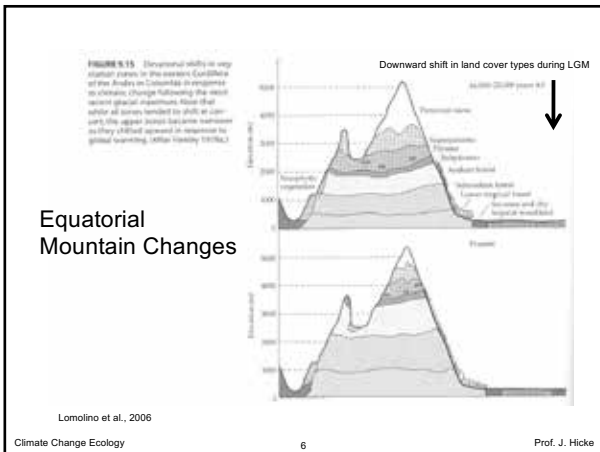
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**Differential species responses:  
rates, direction**

*different climate sensitivities? habitat requirements? predators/parasites?*

FIGURE 14 The mean distributions of eastern white-bellied sapsucker (Redpoll sapsucker) (left), hairy woodpecker (middle), and hairy woodpecker (right) in 1990 and 2000. The distributions of these species have shifted poleward and upward, poleward and downward, poleward and both up and down, or not at all. The distributions of these species have shifted poleward and both up and down, or not at all. The distributions of these species have shifted poleward and both up and down, or not at all. The distributions of these species have shifted poleward and both up and down, or not at all.

MacDonald 2009

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### Examples of recent range shifts

Edith's checkerspot butterfly: northward and upward in elevation shift

FIGURE 14.1 Edith's Checkerspot Butterfly (*Pararge aethina*)

FIGURE 14.2 Edith's Checkerspot Butterfly Range Shift

Hannah 2011

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### Examples of recent range shifts

pika: a cautionary tale

- sensitive to summer temperature
- recently, lower elevation populations have disappeared
- but pikas exist in hot places

*Tricky to understand the role of climate change!*

Hannah 2011

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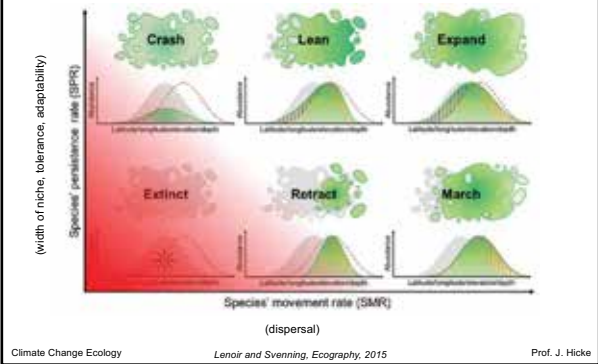
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Theoretical framework for characterizing different range shift responses to climate change




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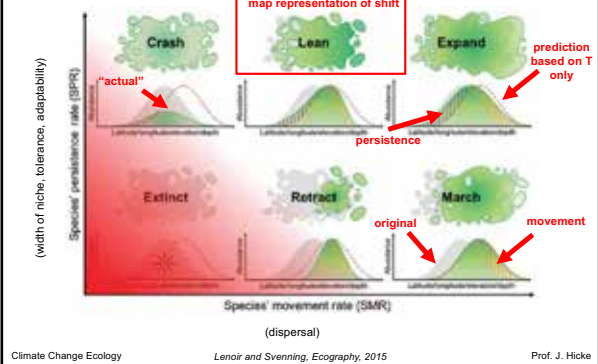
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Theoretical framework for characterizing different range shift responses to climate change




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Indirect effects of climate change that lead to range shifts

increase in burned area for 1° C increase in temperature



Littell et al., *Ecological Applications*, 2009; National Academies, *Climate Stabilization Targets*, 2010

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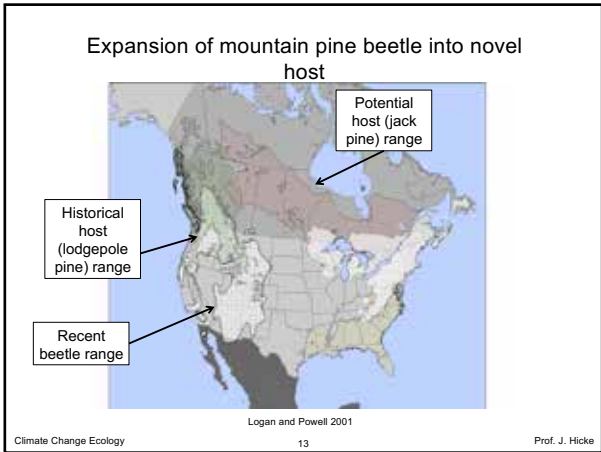
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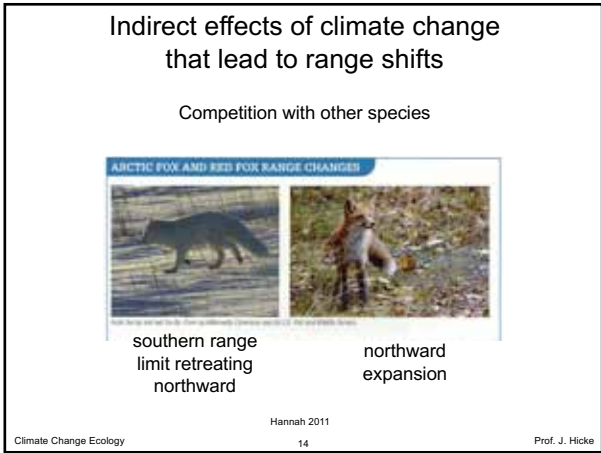
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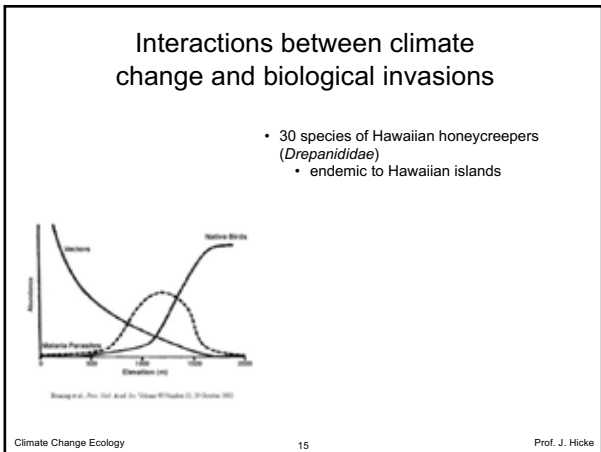
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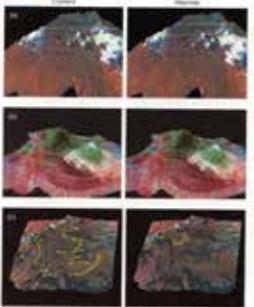
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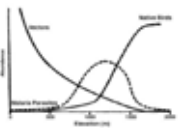
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**MALARIA**



Warming => upward expansion of avian malaria parasite

Implications for native birds???



Projections change in 10° latitude and 10° longitude resolution. Risk is the probability of a population being exposed to a suitable environment. Risk is shown in green (low risk) and red (high risk). Map of Malaria Risk (see text for details) and the global maps (left and right) of the world. (Hickie et al., 2011, PLoS ONE 6(12): e28000. doi:10.1371/journal.pone.0028000)

Hannah 2011

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Climate change will facilitate invasions of exotic species

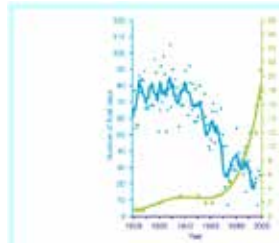




Figure 2. Invasions of 484 exotic species (birds, mammals, reptiles, amphibians, and fish) into the United States from 1950 to 2000. The blue line is the number of invasions per year, and the green line is the year. The number of invasions per year is shown on the left y-axis, and the year is shown on the right y-axis. The x-axis is the year from 1950 to 2000. The number of invasions per year is shown as a blue line, and the year is shown as a green line. The number of invasions per year is shown as a blue line, and the year is shown as a green line.

Walther et al., 2002

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**Climate change and extinctions**

IPCC AR5 WG 2 (Intergovernmental Panel on Climate Change, Fifth Assessment Report (2013), Working Group 2 (Impacts, Adaptation, and Vulnerability)):

“Climate change may have already contributed to the extinction of a small number of species, such as frogs and toads in Central America, but the role of climate change in these recent extinctions is the subject of considerable debate.”

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### Rapid Range Shifts of Species Associated with High Levels of Climate Warming

I-Ching Chen,<sup>1,2</sup> Jane K. Hill,<sup>3</sup> Ralf Ohlemüller,<sup>4</sup> David S. Roy,<sup>5</sup> Chris D. Thomas<sup>1\*</sup>

The distributions of many terrestrial organisms are currently shifting in latitude or elevation in response to changing climate. Using a meta-analysis, we estimated that the distributions of species have recently shifted to higher elevations at a median rate of 11.0 metres per decade, and to higher latitudes at a median rate of 16.9 kilometres per decade. These rates are approximately two and three times faster than previously reported. The distances moved by species are greatest in studies showing the highest levels of warming, with average latitudinal shifts being generally sufficient to track temperature changes. However, individual species vary greatly in their rates of change, suggesting that the range shift of each species depends on multiple internal species traits and external drivers of change. Rapid average shifts derive from a wide diversity of responses by individual species.

median rate of 16.9 km decade<sup>-1</sup> (mean = 17.4 km decade<sup>-1</sup>, SE = 2.9, N = 22 species group + region combinations, one-sample t test versus zero shift, *t* = 4.10, *P* = 0.0003). Weighting each study by the diameter of species in the group-region combination gave a mean rate of 16.9 km decade<sup>-1</sup>. For elevations, there was a median shift to higher elevations of 11.0 m upshift decade<sup>-1</sup> (mean = 12.2 m decade<sup>-1</sup>, SE = 1.8, N = 36 species groups + regions, one-sample t test versus zero shift, *t* = 7.04, *P* = 0.0001). Weighting elevations studies by diameter of species gave a mean rate of upshift movement of 11.2 m decade<sup>-1</sup>.

A previous meta-analysis (17) of distribution changes analysed individual species, rather than the averages of taxonomic groups + regions that we used, and also included data on latitudinal and elevational shifts in the same analysis (18). It concluded that ranges had shifted toward

- 23 taxonomic groups, 764 species
- found that most studies indicated expected shifts in response to warming

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### Meta-analyses of impacts

- latitude
  - 17 km/decade
  - range shifts of many species can keep up with warming
- elevation
  - 11 m/decade
  - range shifts of many species cannot

*expected based on climate change*

Fig. 1. Relationship between observed and expected range shifts in response to climate change, for 20 latitudinal and 86 elevational. Points represent the mean response (SD) of species in a particular taxonomic group, in a given region. Further values indicate shifts toward the pole and to higher altitudes. Diagonals represent 1:1 lines, where expected and observed responses are equal. Open circles, birds; open triangles, mammals; solid circles, amphibians; solid inverted triangles, plants; solid square, bryozoa; solid diamond, fish; solid triangle, molluscs.

Climate Change Ecology Chen et al., Science, 2011 Prof. J. Hicke

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### Meta-analyses of impacts

- substantial variability in species
- related to
  - time delays in responses
  - different physiological constraints
  - other drivers of change

Fig. 2. Observed latitudinal shifts of the northern range boundaries of species within four example taxonomic groups, recorded each year from 1970 to 2000. (A) Spiders, (B) ground beetles, (C) butterflies, (D) grasshoppers. The width of the bars shows the width (and median) of the observed shifts. The width of the bars shows the width (and median) of the expected shifts. The width of the bars shows the width (and median) of the observed shifts.

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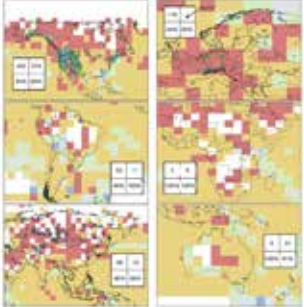
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### Meta-analyses of impacts



- physical and biological responses with observed changes
- 90% were consistent with warming
- consistent across continents
- very unlikely to be caused by natural climate variability

Rosenzweig et al., Nature, 2008  
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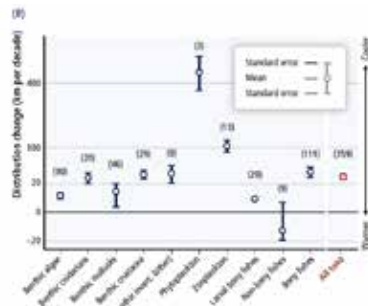
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### Meta-analyses of impacts

#### Rate of range shifts for marine taxa, 1900-2010



Climate Change Ecology 23 IPCC AR5 WG2, 2013 Prof. J. Hicke

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### Section 3: Species range shifts

Patterns within the Patterns

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"In the species-by-species study, the overwhelming majority of species showed the poleward and upslope shifts expected with warming. In 1700 species studied, poleward range shifts averaged 6 km per decade. A total of 279 of the species showed responses that tracked climate change—poleward shift during warming periods and shift away from the poles in cooling periods—but a net poleward shift. This gives strong indication of climate causality."

(Hannah p 72-73)  
Hannah, Lee. *Climate Change Biology, 2nd Edition*. Academic Press, 11/2014. VitalBook file.

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articles
A globally coherent fingerprint of climate change impacts across natural systems

Camillo Parmesan & Gary Yohe

1 Institute of Biology, University of Leicester, University of Leicester, Leicester LE1 7RH, UK
2 John F. Bland Professor of Geosciences, Scripps Institution of Oceanography, 3101 La Jolla Village Drive, San Diego, California 92093, USA

Causal attribution of recent biological trends to climate change is complicated because non-climatic influences dominate local, short-term biological changes. Any underlying signal from climate change is likely to be revealed by analyses that seek systematic trends across diverse systems and geographic regions...

Nature, 2003

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Table 1 Summary of data analyzing phenological and distributional changes of wild species. Table with columns: Type, No. species, System of analysis, Spatial scale, Time scale, Change in direction, Change in amplitude, Standard deviation, No. predictions. Rows include Phenological changes, Distributional changes, Marine invertebrates, Marine amphibians, Marine vertebrates.

Climate Change Ecology Parmesan and Yohe, Nature, 2003 Prof. J. Hicke

Table 1 Summary of data analyzing phenological and distributional changes of wild species. Table with columns: Type of change, Change as predicted, Change as predicted in proportion, P-value. Rows include Distributional changes, Marine invertebrates, Marine amphibians, Marine vertebrates. Includes text: out of 1700 species, 920 had data about distribution or abundance changes...

Climate Change Ecology Parmesan and Yohe, Nature, 2003 Prof. J. Hicke

**Table 3 Biological fingerprint of climate change impacts**

| Sign-switching pattern   | Percentage of species showing diagnostic pattern |
|--|--|
| <b>Community</b><br>Abundance changes have gone in opposite directions for cold-adapted compared with warm-adapted species. Usually local, but many species in each category. Diverse taxa, <i>n</i> = 282*  | 80%  |
| <b>Temporal</b><br>Advancement of 311 g of northward expansion in warm decades (1900s/40s and 1990s/00s). Delay of timing or southward contraction in cool decades (1950s/60s). 30–132 years per species. Diverse taxa, <i>n</i> = 44*   | 100%   |
| <b>Ecotope</b><br>Species exhibit different responses at extremes of range boundary during a particular climate phase. Data are from substantial parts of both northern and southern range boundaries for each species. All species are northern hemisphere taxa. <i>n</i> = 37* | 100%   |

[in locations of overlapping ranges, polar (cold-adapted) species have responded negatively to warming whereas temperate (warm-adapted) species have responded positively]

out of 334 species, 279 showed one of these biological fingerprints

Parmesan and Yohe, *Nature*, 2003

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### Sudden aspen decline

distribution of fundamental niche of aspen based on species distribution model

Worrall et al., *Forest Ecology and Management*, 2013

### Sudden aspen decline

Photo courtesy of W. Anderegg

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### Sudden aspen decline

locations of SAD



Climate Change Ecot Worrall et al., Forest Ecology and Management, 2013 Prof. J. Hicke

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### Sudden aspen decline

stress induced by recent changes in climate



Climate Change Ecology 32 Worrall et al., Forest Ecology and Management, 2013 Prof. J. Hicke

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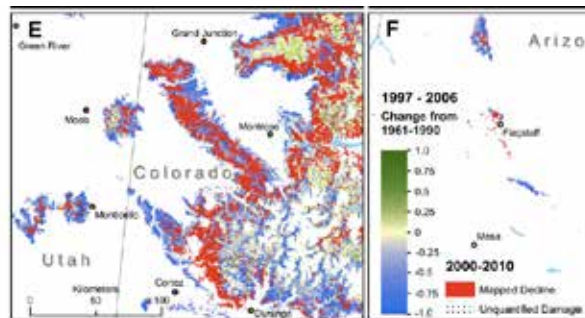
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### Sudden aspen decline

modeled stress (blue) and observed decline (red)



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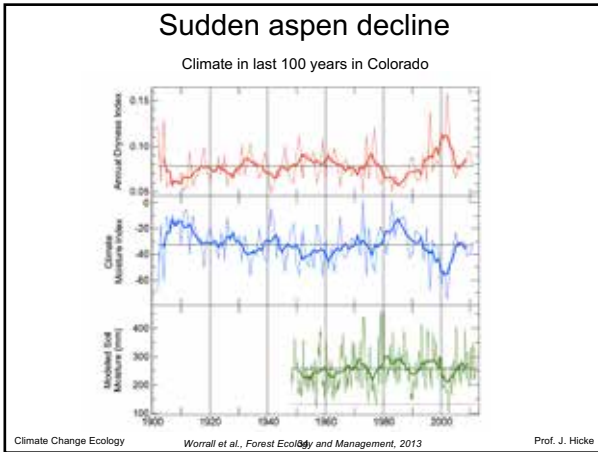
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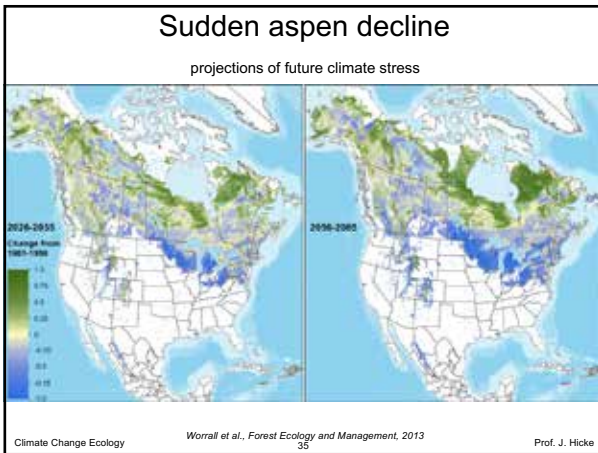
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