Section 10-11: Tools for assessing future impacts

Reading: Ch 10-11

Learning outcomes

- understand and provide examples of
  - laboratory experiments
  - field experiments
  - modeling (various types)

Laboratory experiments of ↑CO2

FIGURE 10.3 **Laboratory and Greenhouse Experiments.**
Diffusers and enclosures may be used to maintain constant elevated CO_2 levels, whereas greenhouses or other warming devices may be used to manipulate temperature. *Courtesy of SCRI.*

Hannah, 2011

Effect of ↑CO2 for plants with different photosynthetic pathways

Biomass enhancement

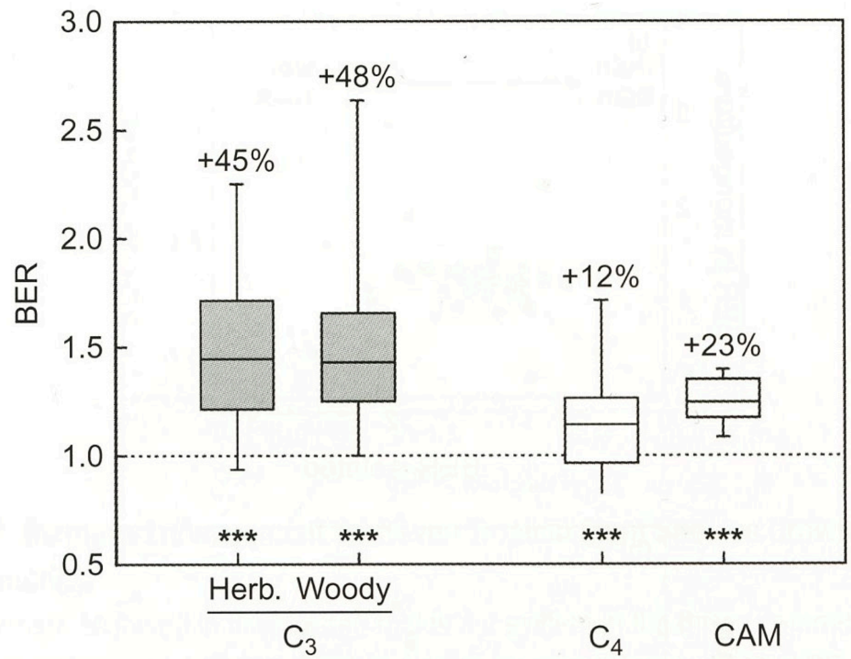


FIGURE 10.5 Increase in Biomass for Different Categories of Species (Herbaceous and Woody C_3 Plants, C_4 Species, and CAM Species).
Graphs show an increase in biomass enhancement ratio, a measure of increase in biomass. Boxplots such as these indicate the 5th (bottom horizontal line), 25th (bottom line of box), 50th (midline of box), 75th (top line of box), and 95th (upper horizontal line) percentile of the distribution. *From Poorter, H. and Navas, M. L. 2003. Plant growth and competition at elevated CO_2: On winners, losers and functional groups.* New Phytologist *157, 175–198.*

Hannah, 2011

Effect of ↑CO2 diminishes when other factors (here, competition) are present

When plants have high relative growth rate (RGR), effects of competition limit effects of CO2 fertilization

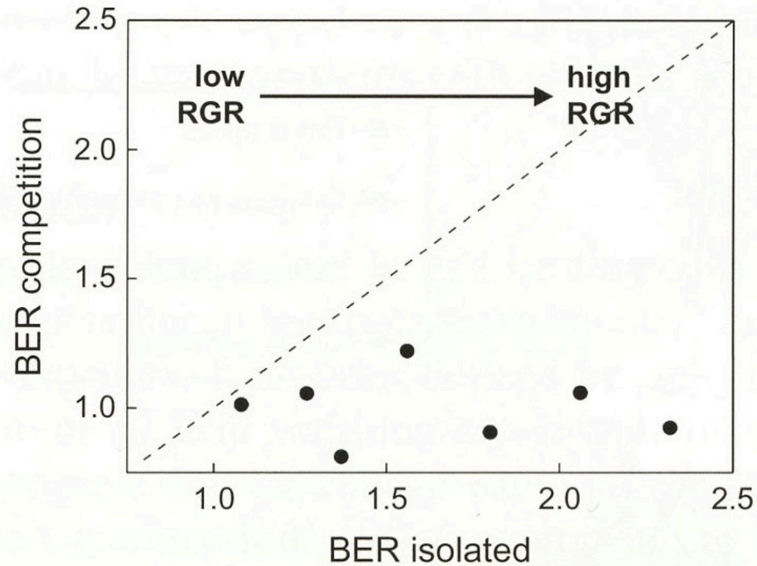


FIGURE 10.7 Biomass Enhancement for Seven Tropical Plant Species Grown in Isolation and in a Mixed Community.

The CO_2 enhancement observed in the isolated trial is not evident in the mixed community.

From Poorter, H. and Navas, M. L. 2003. Plant growth and competition at elevated CO_2: On winners, losers and functional groups. New Phytologist *157, 175–198.*

Hannah, 2011

Different field experimental methods

FIGURE 10.9 **Active (a) and Passive (b) Warming Experiments.**
The active warming devices include the use of infrared warming lamps. Passive warming depends on blocking of air circulation or intensification of sunlight to create warmth. Passive warming devices are often simply circles or boxes of glass or clear plastic, which act much like miniature greenhouses but allow multispecies interactions and have minimal impact on received precipitation. *(a) Courtesy of Charles Musil. (b) From the National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara.*

Hannah, 2011

Different field experimental methods

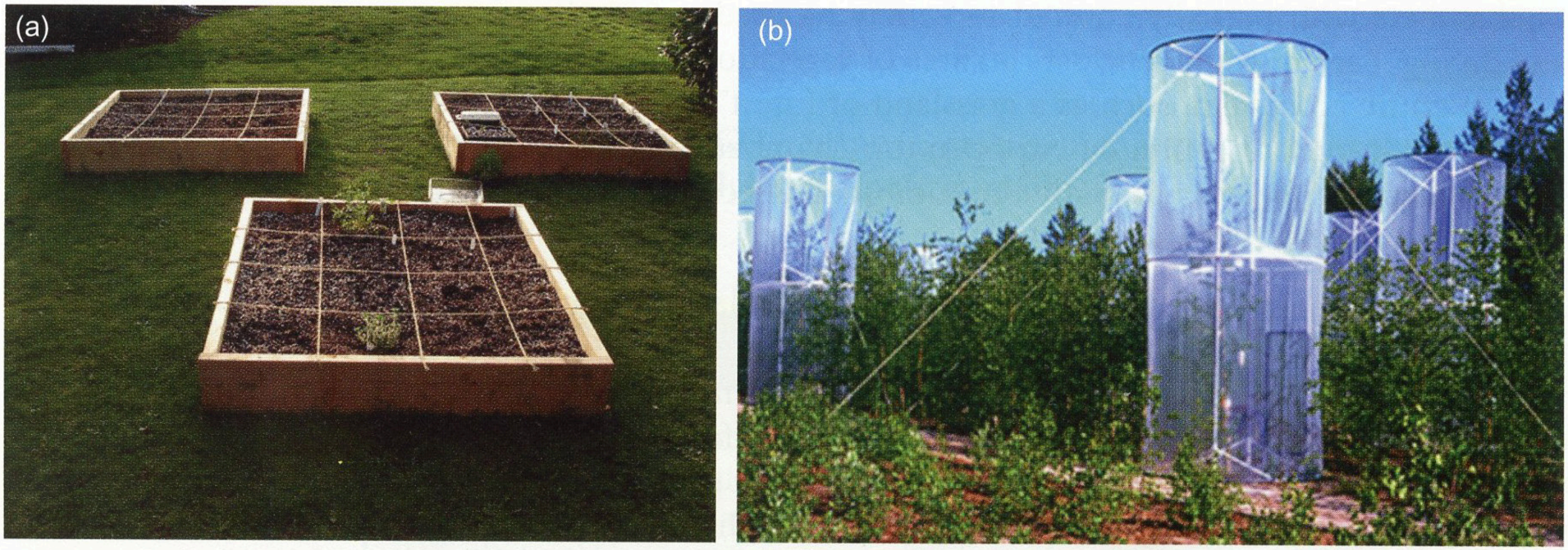


FIGURE 10.10 Transplantation and Open-top Chamber Experiments.
Transplantation preserves plant–plant interactions and soil properties. It is usually implemented with the movement of plants embedded in whole soil. Open-top chambers preserve plant and soil relationships over a limited area. *Source: Finnish Forest Research Institute.*

Hannah, 2011

Different field experimental methods

open-top chamber

cover to increase nighttime infrared radiation

http://sciencespace-wang.blogspot.com/2011_06_01_archive.html

Different field experimental methods

Free air CO2 enrichment (FACE) experiments

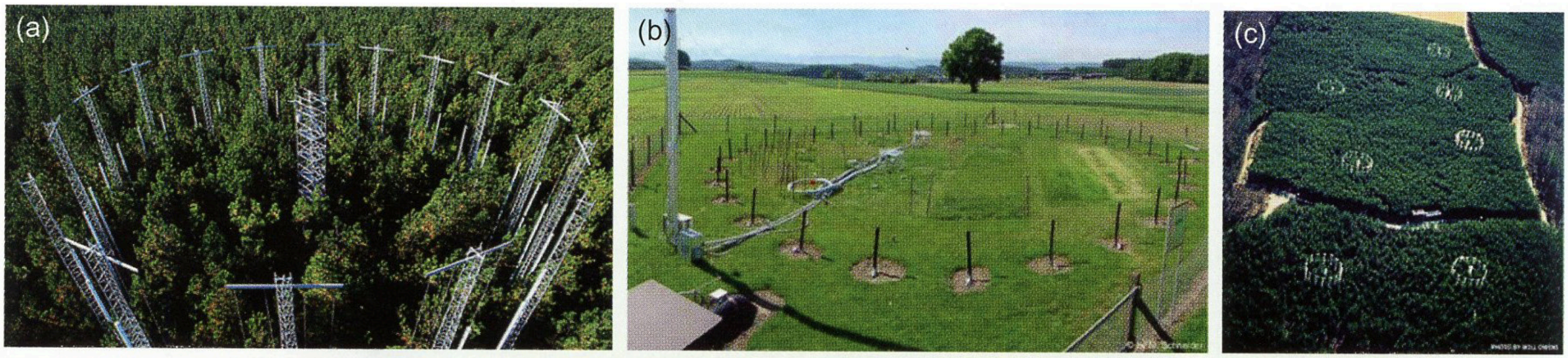


FIGURE 10.11 Free Air CO_2 Enrichment (FACE) Experiments.
FACE experiments use massive diffusers to elevate CO_2 concentrations over a large area. Diffusers are often arrayed around a central measurement tower. *(a) Courtesy of Jeffrey S. Pippen. (b) Courtesy of Professor Josef Nösberger, Swiss Face Experiment (ETH Zurich). (c) From Brookhaven National Laboratory.*

Hannah, 2011

Responses of ecosystem structure and function to ↑CO_2 among locations

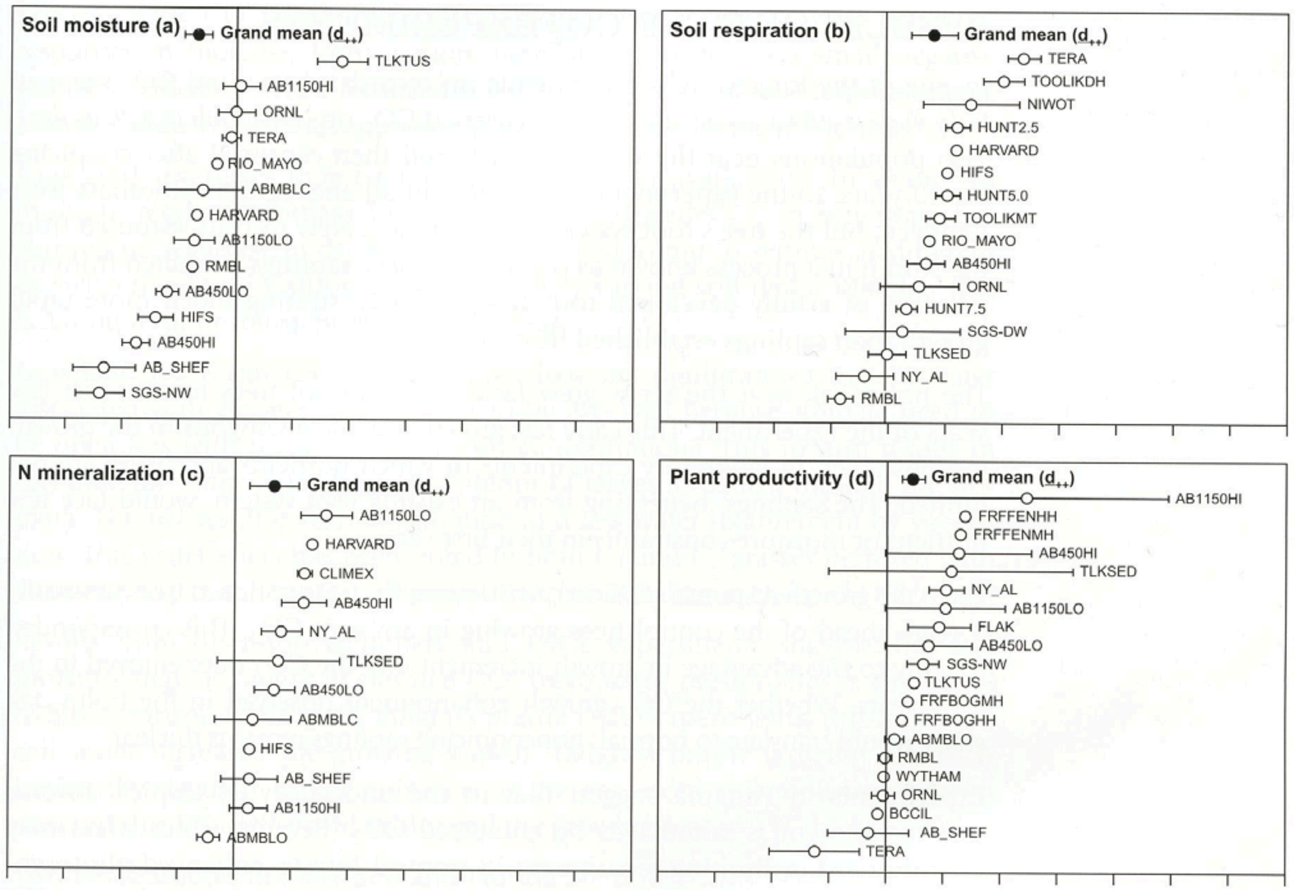


FIGURE 10.12 Response to Warming.
The effects of warming on soil moisture, soil respiration, mineralization, and plant productivity are shown for multiple studies from throughout the world. Measured mean effects at each study site are indicated by open circles; bars indicate 95% confidence intervals. The vertical line indicates no effect. *From Rustad, L. E., et al. 2001. A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming.* Oecologia *126, 543–562.*

Over time, the growth enhancement of ↑CO2 diminishes

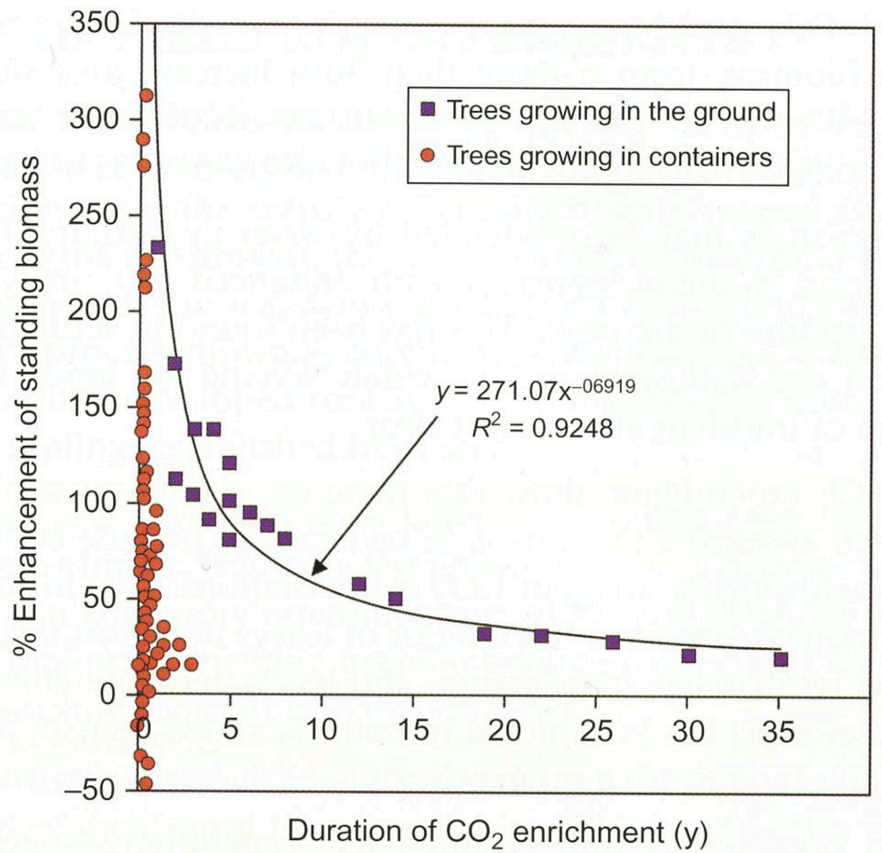


FIGURE 10.13 **Acclimation in Experimental and Natural Settings.**
Single-plant experiments seldom span long enough time frames to detect acclimation. Whole-ground experiments, usually conducted over longer time frames, clearly show the effect of acclimation.
From Idso, S. B. 1999. The long-term response of trees to atmospheric CO_2 enrichment. Global Change Biology *5, 493–495.*

Hannah, 2011

Field experiments: tree seedling viability

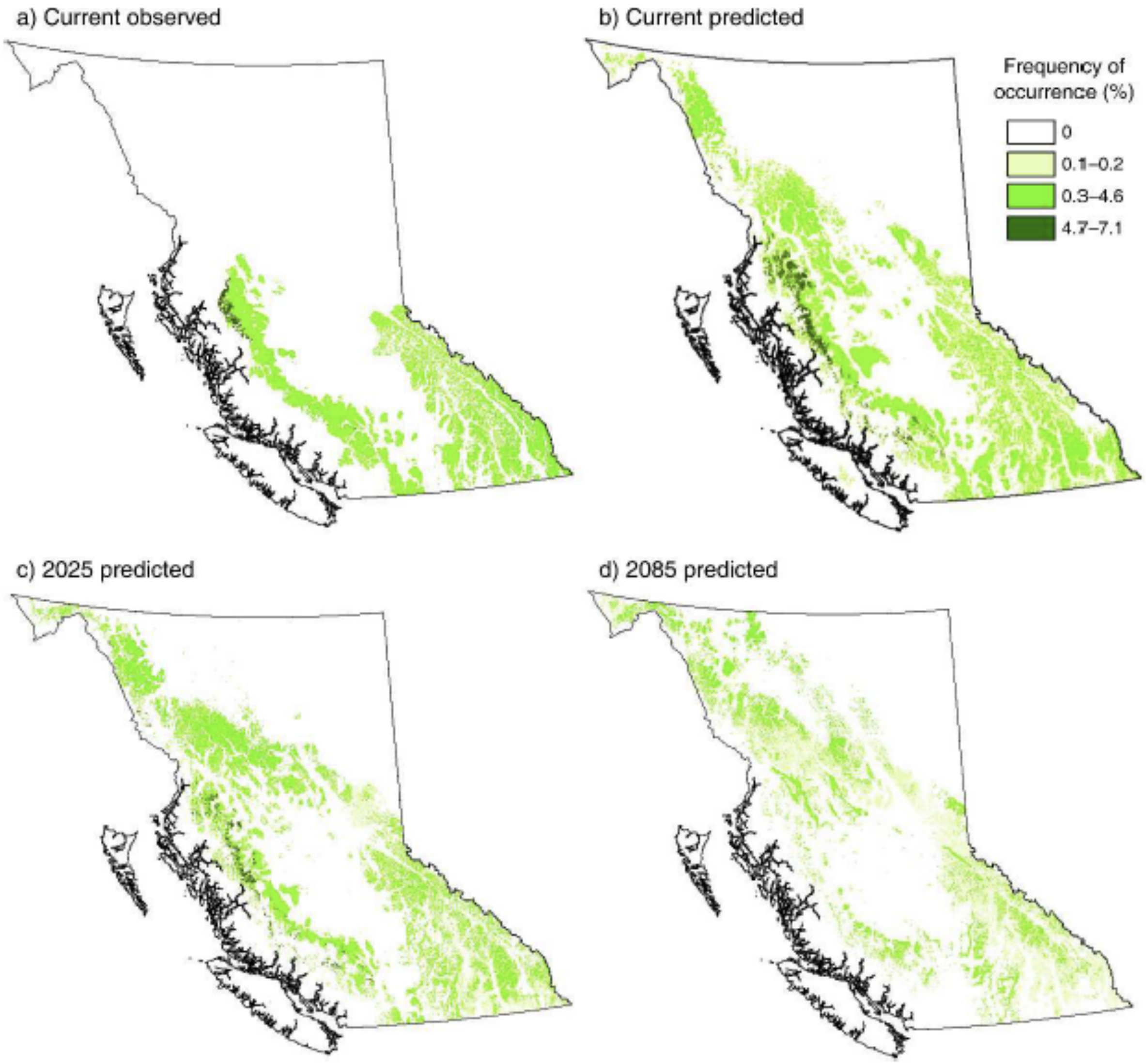


FIG. 1. Species distribution models depicting whitebark pine's (a) current observed range in British Columbia (BC), Canada, (b) current predicted range in BC based on 1961–1990 climate normals, and (c) 2025 and (d) 2085 future predicted ranges in BC based on IS92a CGCM1 GAX future-climate scenarios (Flato et al. 2000). The models were created by T. Wang (*unpublished models*) (University of British Columbia), using methods from Hamann and Wang (2006). See Fig. 2 for the 2055 predicted range, scale, and geographic location. See Appendix A for the model creation methods.

"Whitebark pine (*Pinus albicaulis*) assisted migration potential: testing establishment north of the species range"

McLane and Aiken, Ecol. Appl., 2012

Field experiments: tree seedling viability

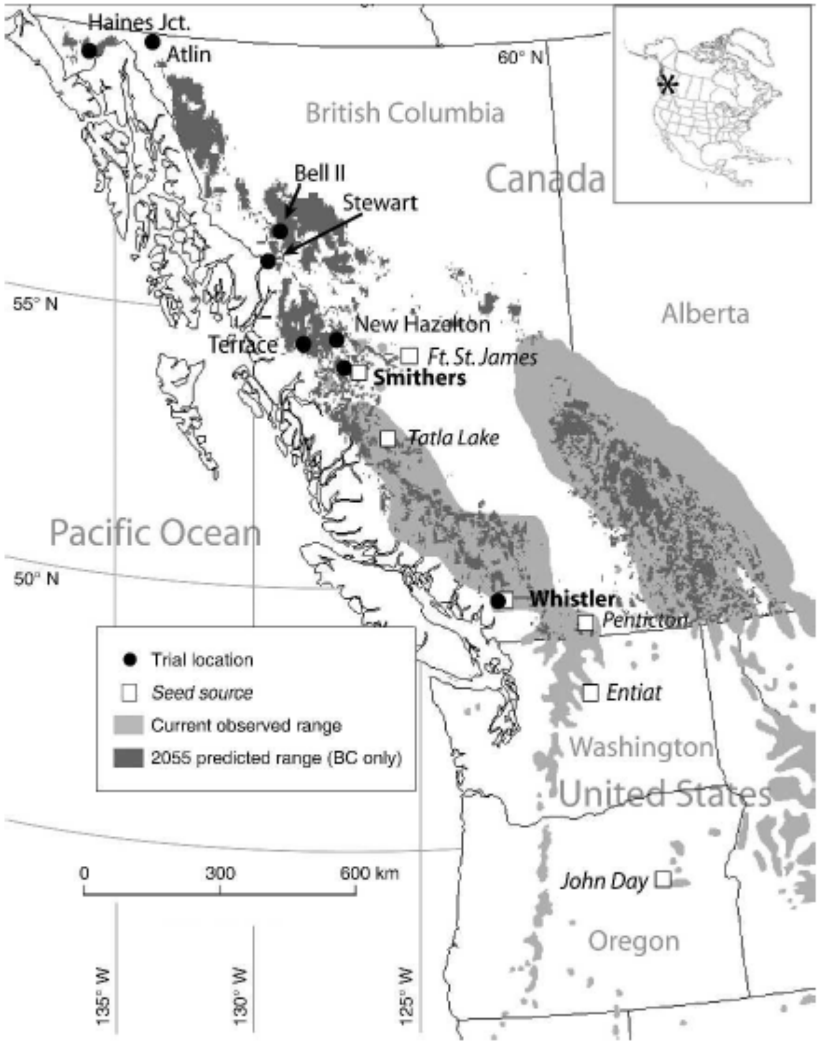


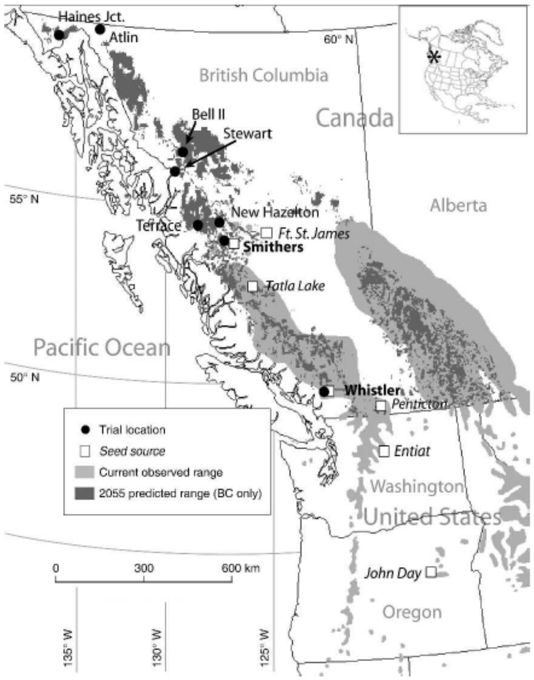
FIG. 2. Trial locations and provenances relative to the 1990s observed and 2055 predicted whitebark pine species range within British Columbia, Canada. Of the eight trial locations, two are within and six are north of the current species range. All trial locations are in areas predicted to be habitable under both present and 2055 climate regimes. The two locations in boldface type, Whistler and Smithers, are both trial locations and provenances. The predicted species range was created by T. Wang (*unpublished model*) (University of British Columbia), using methods from Hamann and Wang (2006), using the IS92a CGCM1 GAX future-climate scenario (Flato et al. 2000). The map scale is accurate in the map center but approximate at the boundaries due to projection skew.

Trial locations (black dots)

Seed sources (white squares)

McLane and Aiken, Ecol. Appl., 2012

Field experiments: tree seedling viability



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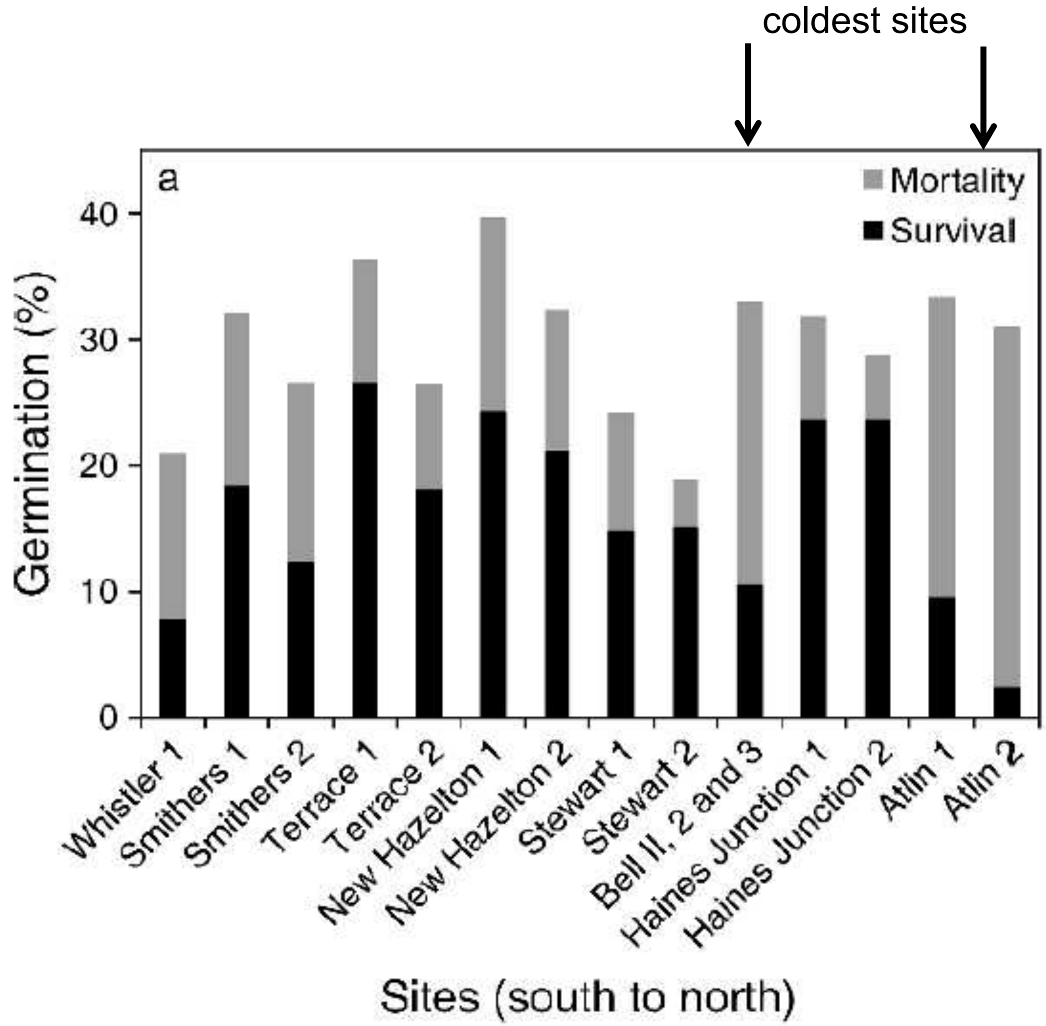
Results of trials



McLane and Aiken, Ecol. Appl., 2012

Different field experimental methods

Amazon drought experiment

http://earthobservatory.nasa.gov/Features/AmazonDrought/stealing_rain3.php, photos by D. Nepstad

Different field experimental methods

Experiment effectively reduced rainfall

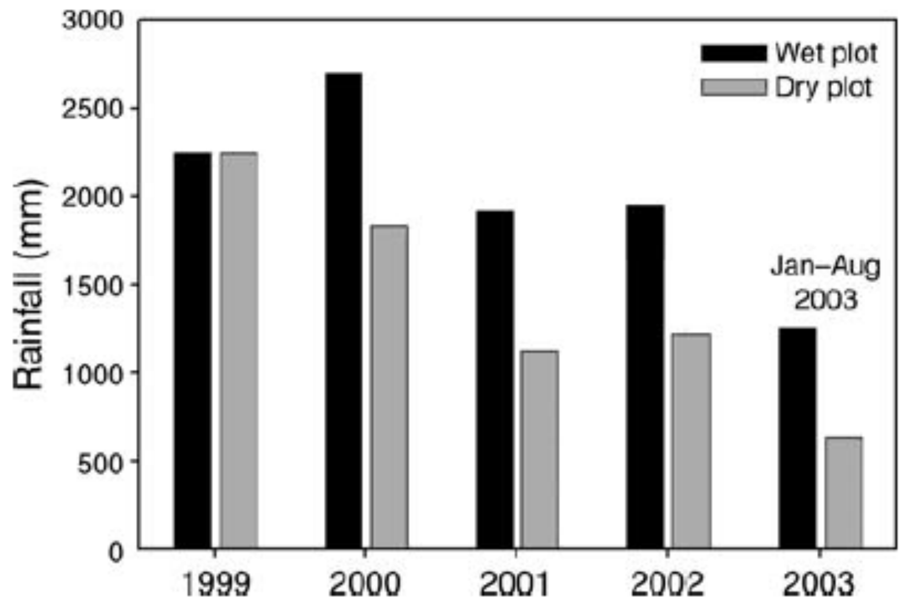


FIG. 1. Annual rainfall (measured in wet plot) and effective rainfall (rainfall minus water excluded by plastic panels; measured in dry plot) during 3.75 years of the throughfall exclusion experiment.

http://earthobservatory.nasa.gov/Features/AmazonDrought/stealing_rain3.php, photos by D. Nepstad; Nepstad et al., Ecology, 2007

Reduced rainfall led to decreased soil moisture

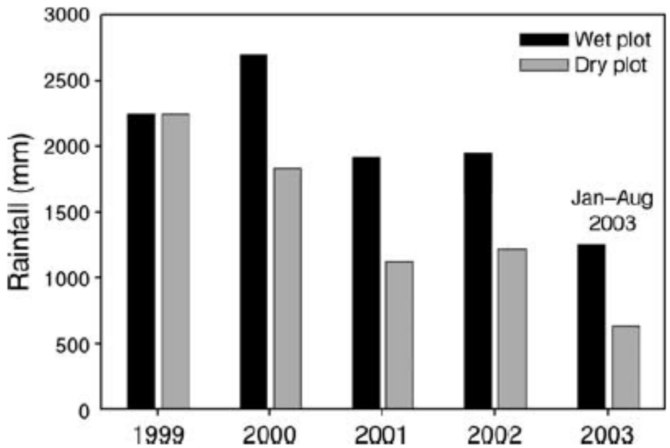


FIG. 1. Annual rainfall (measured in wet plot) and effective rainfall (rainfall minus water excluded by plastic panels; measured in dry plot) during 3.75 years of the throughfall exclusion experiment.

Nepstad et al., Ecology, 2007

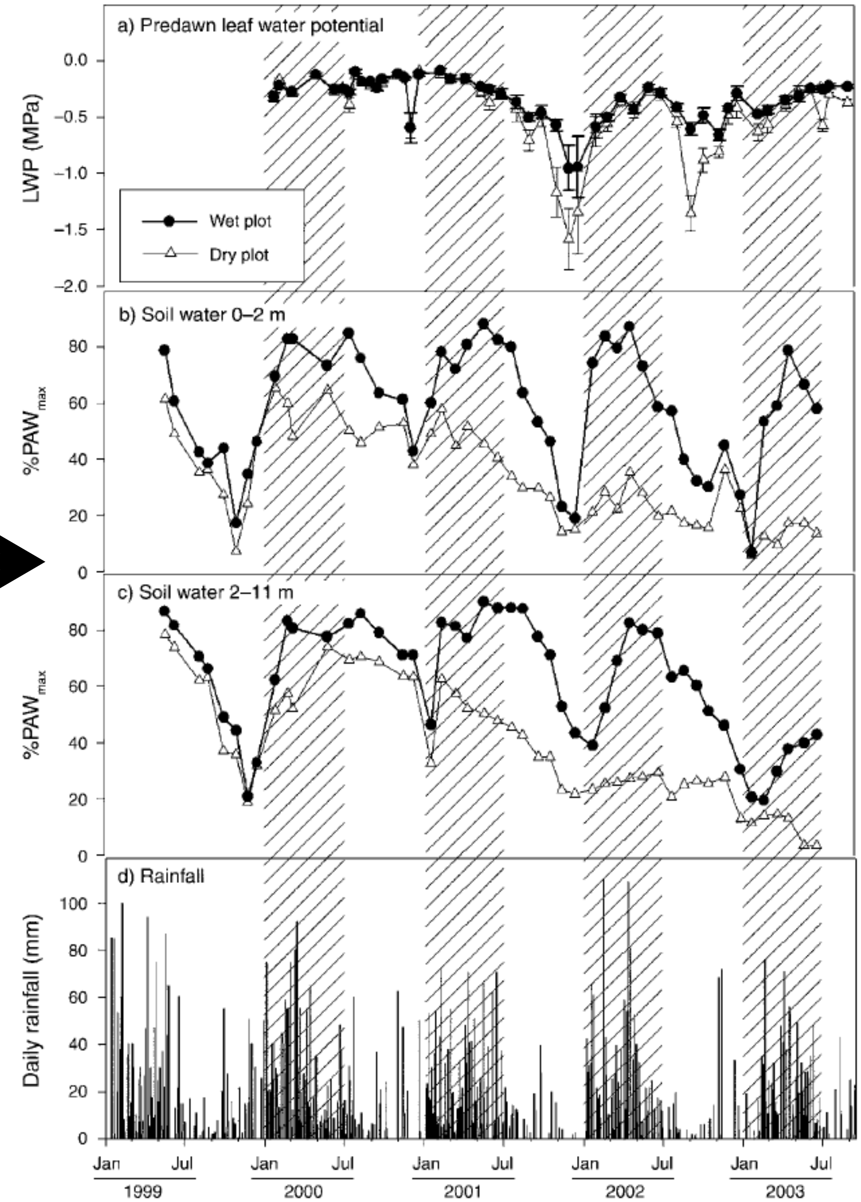
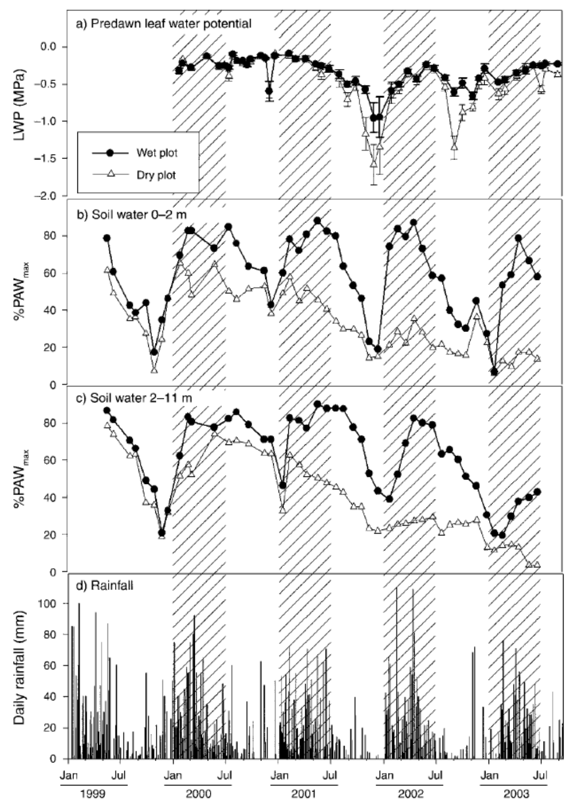


FIG. 2. Selected components of the water balance within the wet (W) and dry (D) plots at the Tapajós throughfall exclusion experiment, showing (a) predawn leaf water potentials averaged across six species (mean ± SE; $n = 3$ trees per species, $n = 4$ leaves per tree) in both plots; (b) plant-available soil water as a percentage of the maximum value (%PAW_{max}) for 0–2 m; (c) %PAW_{max} for 2–11 m in the soil profile; and (d) daily precipitation. Vertical hatching indicates periods when the throughfall exclusion system was functioning during the wet season.

Reduced soil moisture led to plant mortality



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Nepstad et al., Ecology, 2007

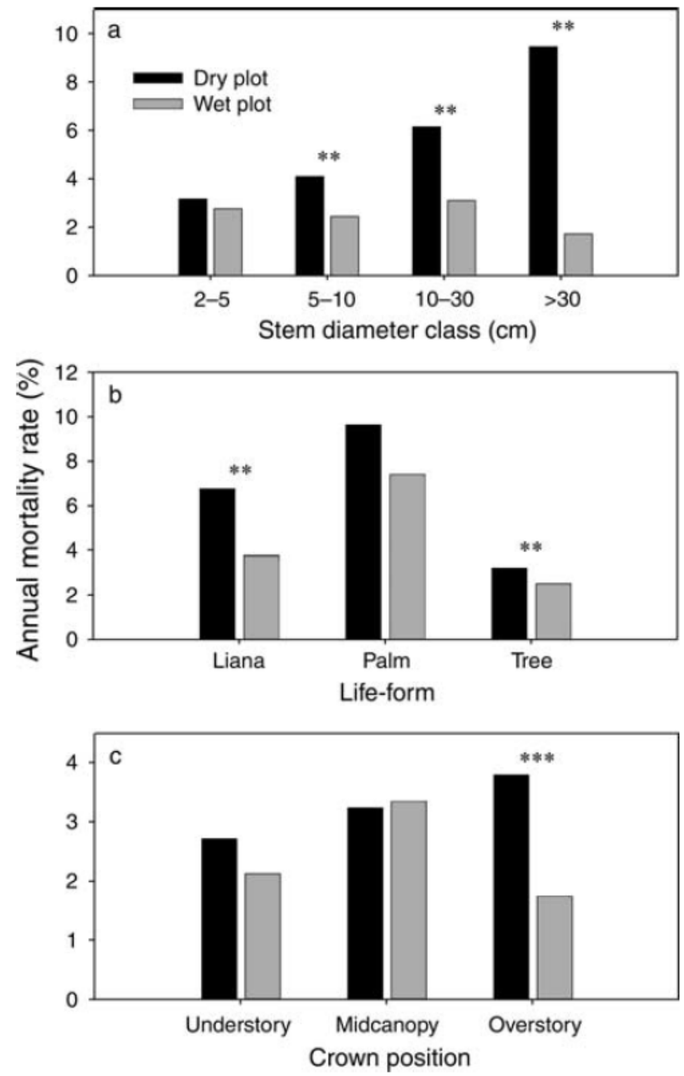
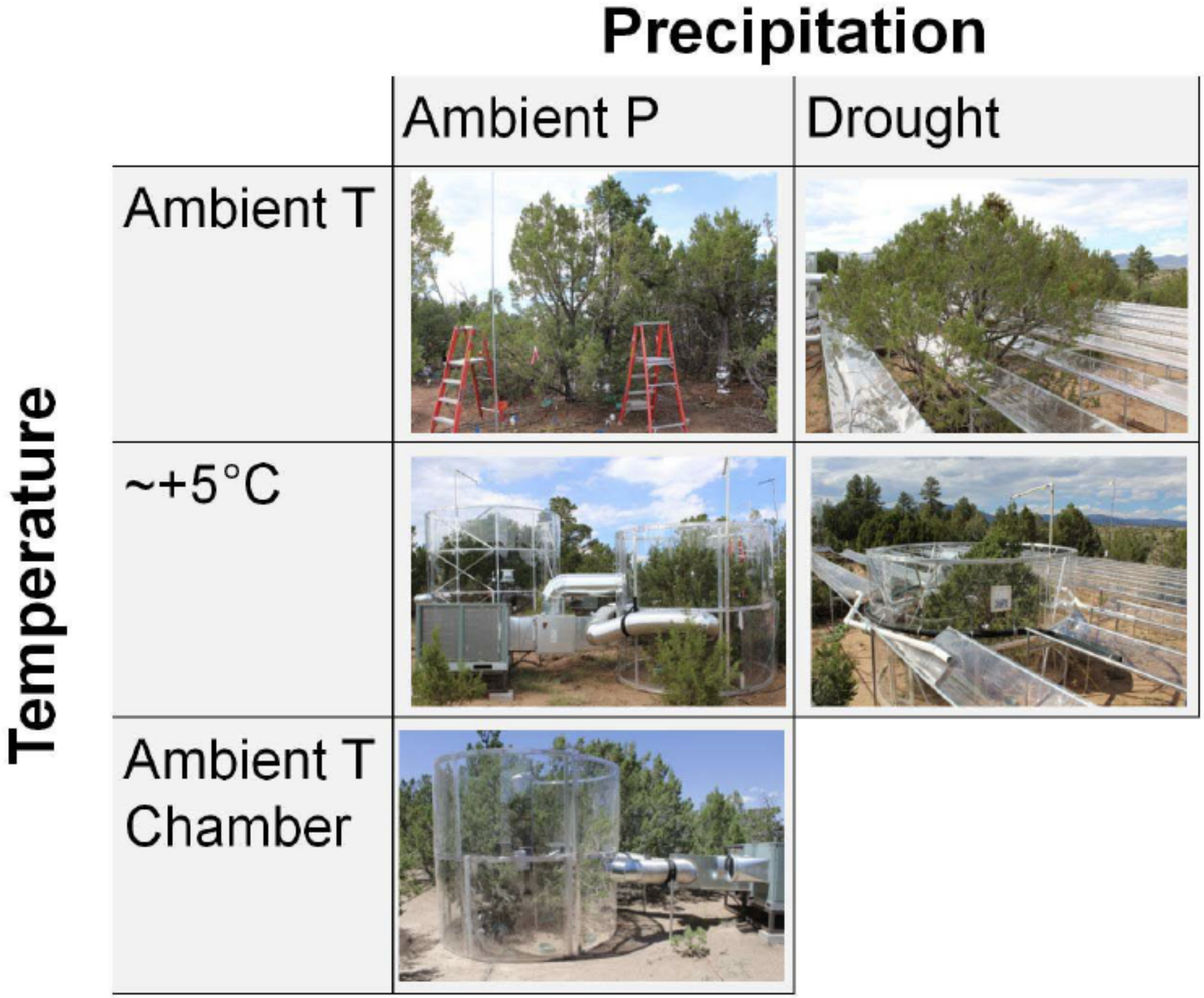


FIG. 4. Annual mortality rates for different groupings of vegetation in the wet (W) and dry (D) plots. Groupings include (a) four diameter size classes, (b) three life forms, and (c) three tree canopy positions. Asterisks above the paired bars indicate a significantly higher mortality rate in the D than in the W plot (one-tailed Fisher's exact test: ** $P < 0.01$, *** $P < 0.001$).

SUMO: Survival Mortality experiment in New Mexico



www.youtube.com/watch?feature=player_embedded&v=6-eyL1AIMoM

Figure courtesy N. McDowell, LANL

Dangers of misinterpreting experiments

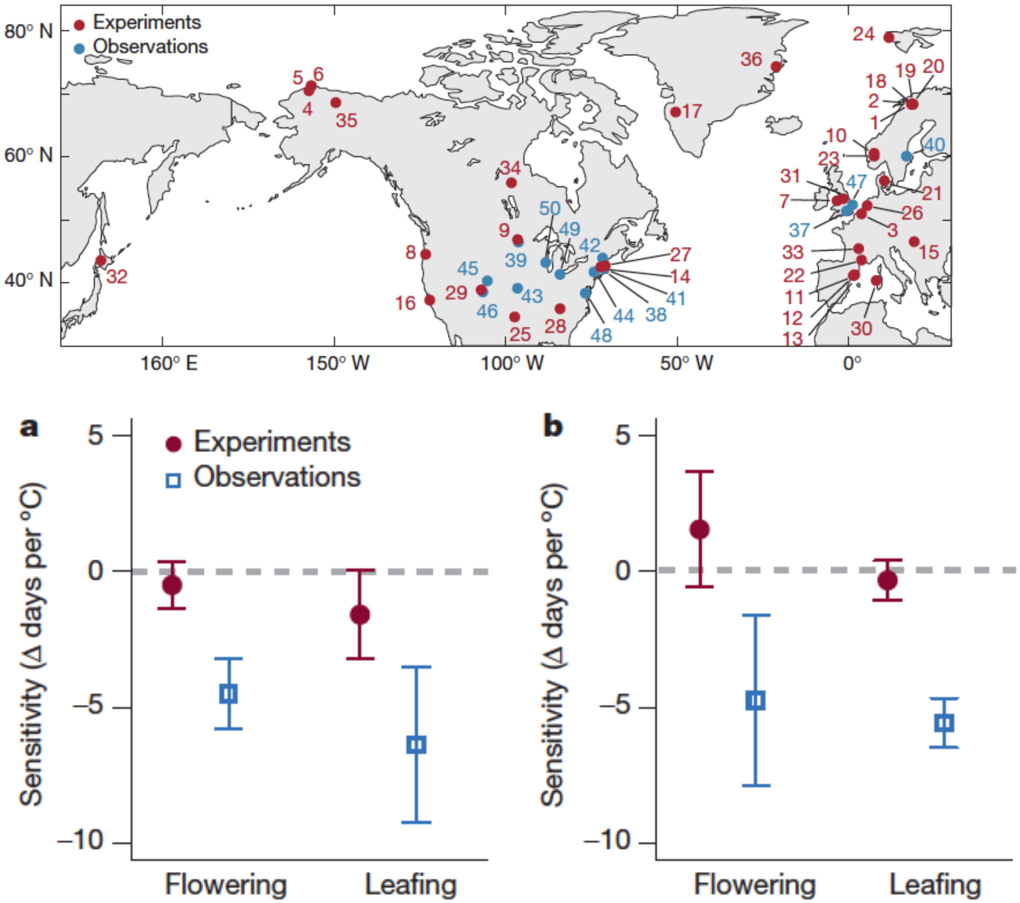


Figure 2 | Estimates of the flowering and leafing sensitivities. The estimates from the mixed effects model (presented as mean ± s.e.m.), including the random effects of site and species, show that experiments underpredict the magnitude of plant responses to interannual temperature variation for all species sampled (**a**) and for the species that are common to both the experimental and the observational data sets (**b**). The region above the dashed grey line represents positive sensitivities, meaning that the species' phenological events are delayed with warming, whereas the region below the line represents negative sensitivities, meaning that the species' events advance with warming.

LETTER

doi:10.1038/nature11014

Warming experiments underpredict plant phenological responses to climate change

E. M. Wolkovich[1], B. I. Cook[2,3], J. M. Allen[4], T. M. Crimmins[5], J. L. Betancourt[6], S. E. Travers[7], S. Pau[8], J. Regetz[8], T. J. Davies[9], N. J. B. Kraft[10,11], T. R. Ault[12], K. Bolmgren[13,14], S. J. Mazer[15], G. J. McCabe[16], B. J. McGill[17], C. Parmesan[18,19], N. Salamin[20,21], M. D. Schwartz[22] & E. E. Cleland[1]

<u>Possible explanations</u>

- experiments focused on T, not on correlated factors that may drive changes in observed phenology (sunshine, snowpack/snowmelt, soil moisture)
- issues with meta-analyses (devil is in the details)
- use of mean annual temperature

Prof. J. Hicke

How to develop a species distribution model

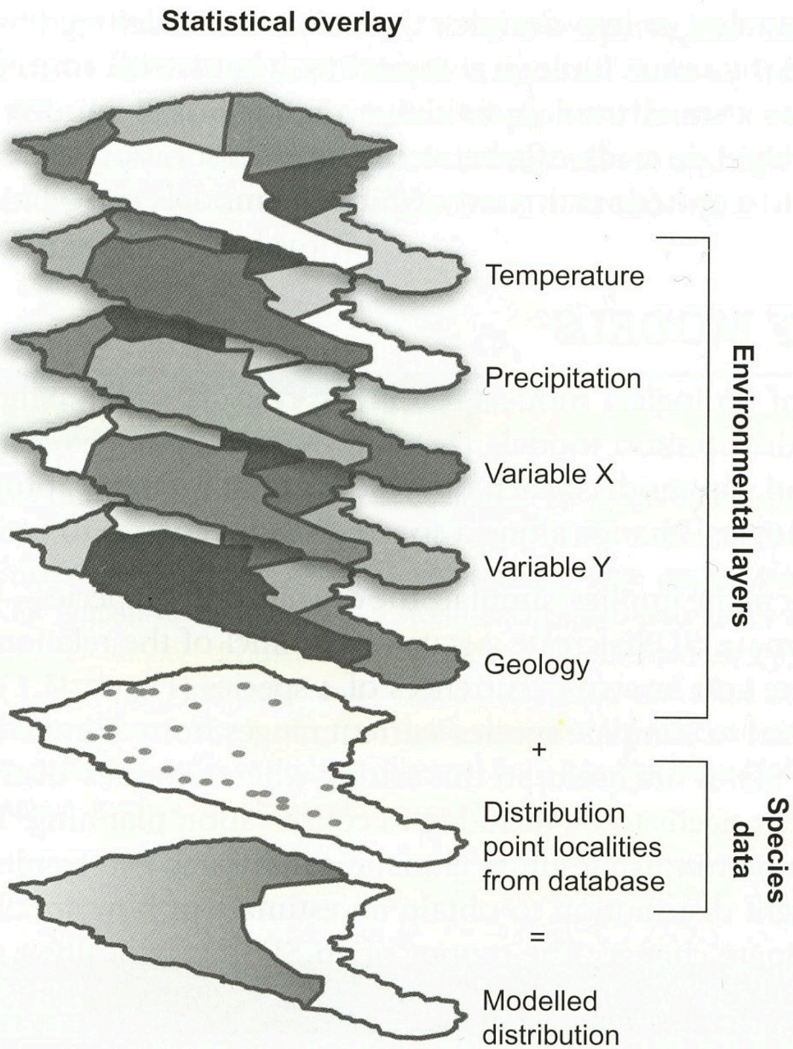


FIGURE 11.1 Schematic of an SDM.
Species distribution modeling begins with selection of a study area (left). The study area is usually selected to be large enough to include the complete ranges of species of interest to ensure that data sampling the entire climate space the species can tolerate are included. Climate variables and other factors constraining species distribution (shaded layers on right) are then correlated with known occurrences of the species of interest (layer with points). This statistical relationship can be projected geographically to simulate the species' range (bottom shaded area). Repeating this process using GCM-generated future climate variables allows simulation of range shifts in response to climate change.

Hannah, 2011

Example application of species distribution model

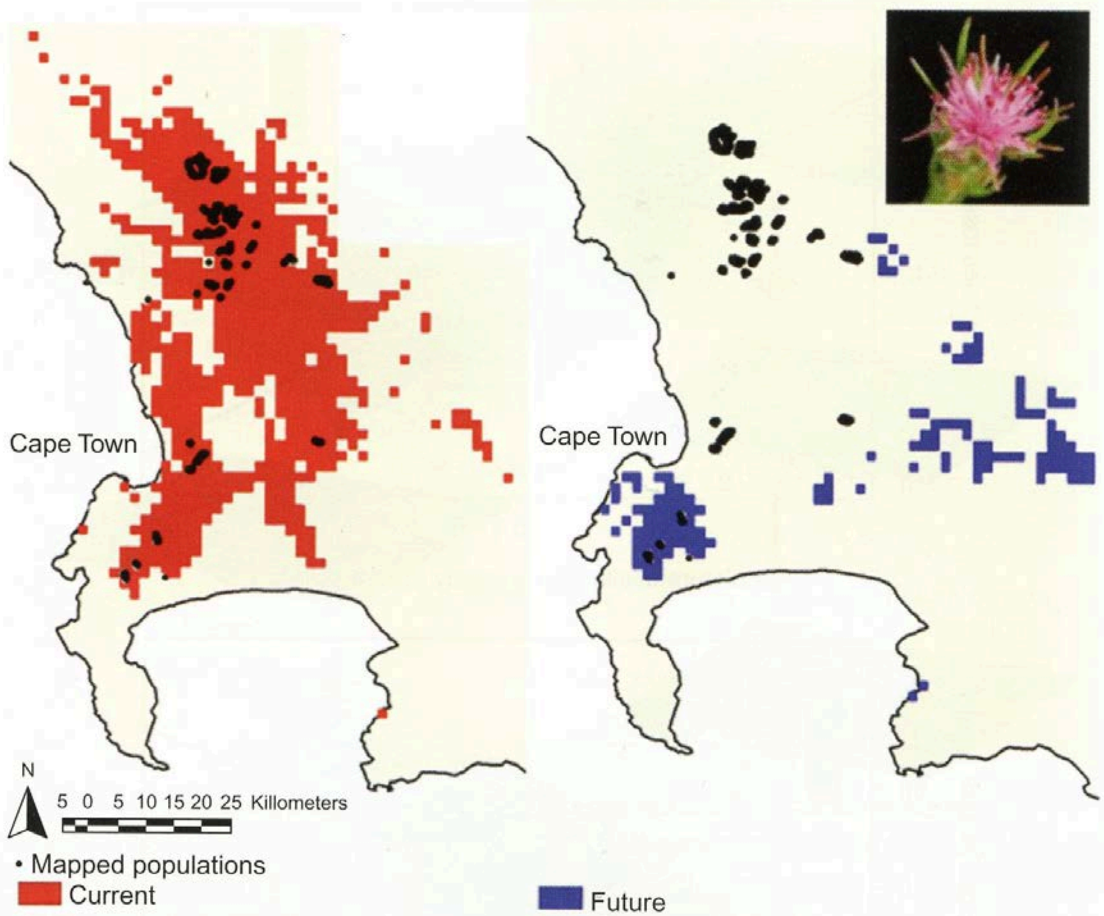


FIGURE 11.8 **Example of SDM Output.**
SDM output for a protea (pictured) from the Cape Floristic Region of South Africa. Current modeled range is shown in red, and future modeled range is shown in blue. Known occurrence points for the species are indicated by black circles. *Figure courtesy Guy Midgley.*

Hannah, 2011

Evaluating species distribution models with historical observations

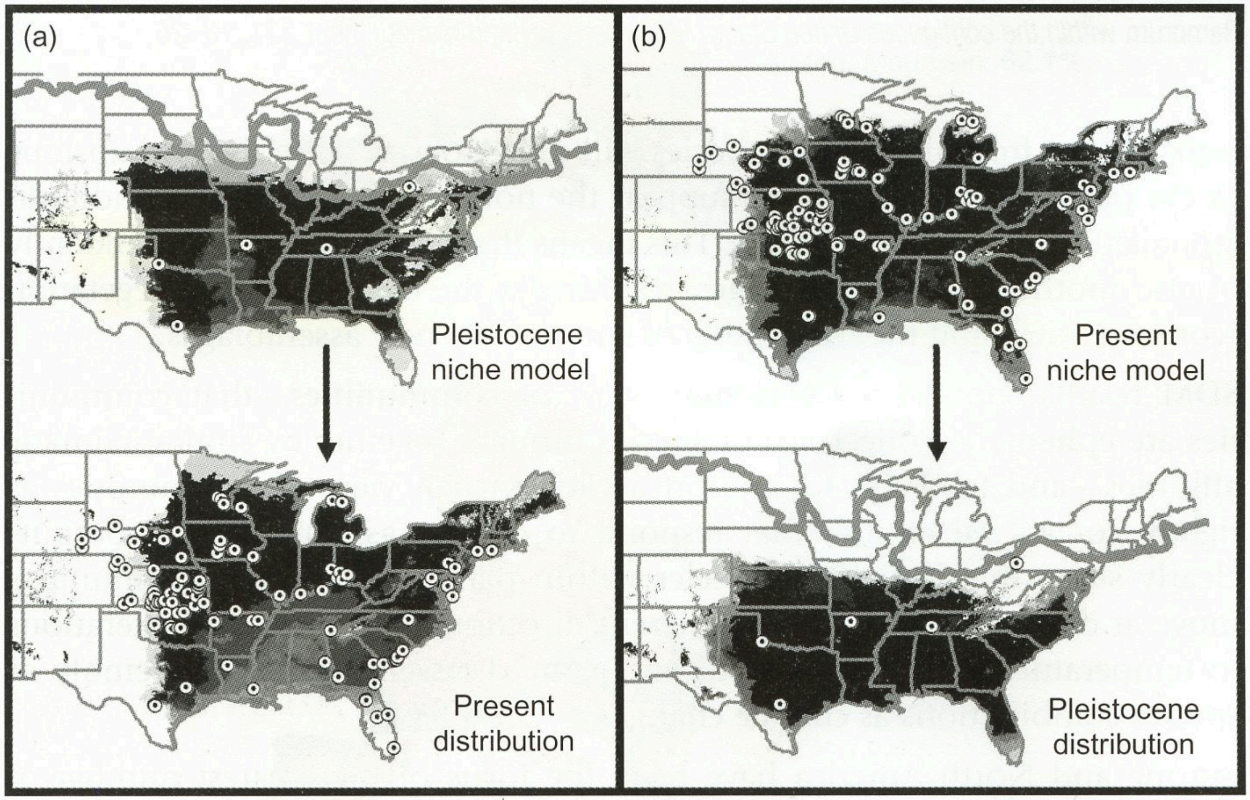


FIGURE 11.9 **Backwards and Forwards Modeling of Eastern Mole (*Scalopus aquaticus*).** (A) SDM created from known Pleistocene occurrences predicts present distribution. (B) SDM created from known current distribution predicts known fossil occurrences. *From Martinez-Meyer, E., et al. 2004. Ecological niches as stable distributional constraints on mammal species, with implications for Pleistocene extinctions and climate change projections for biodiversity.* Global Ecology and Biogeography *13, 305–314.*

Hannah, 2011

Example application of gap model

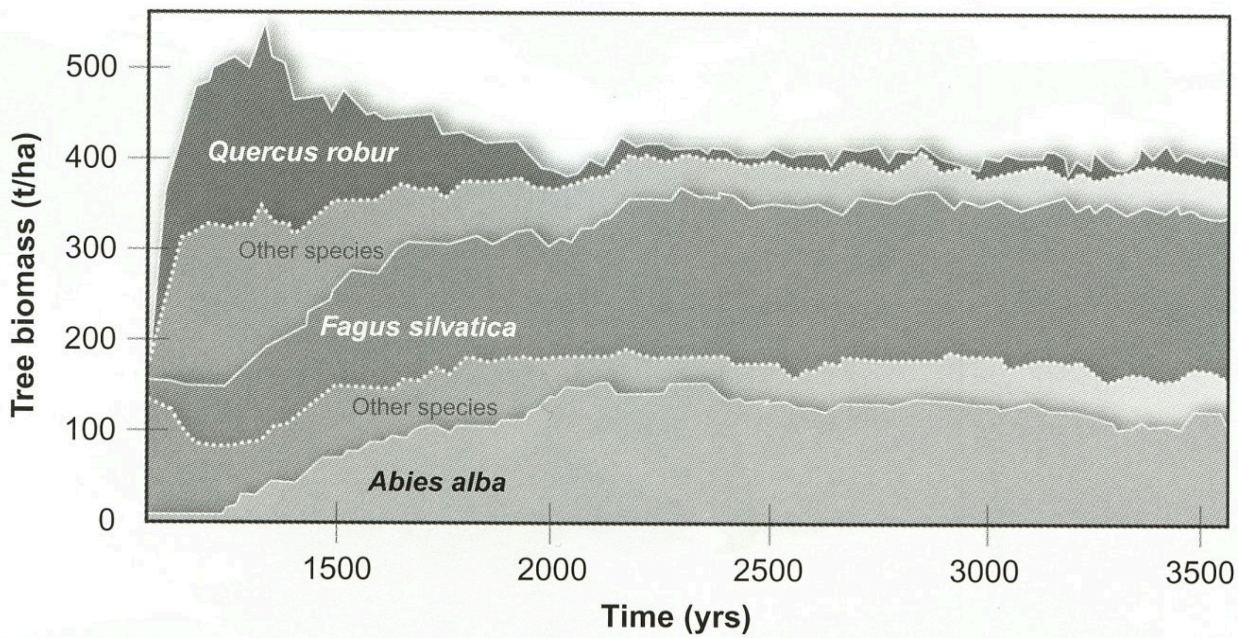
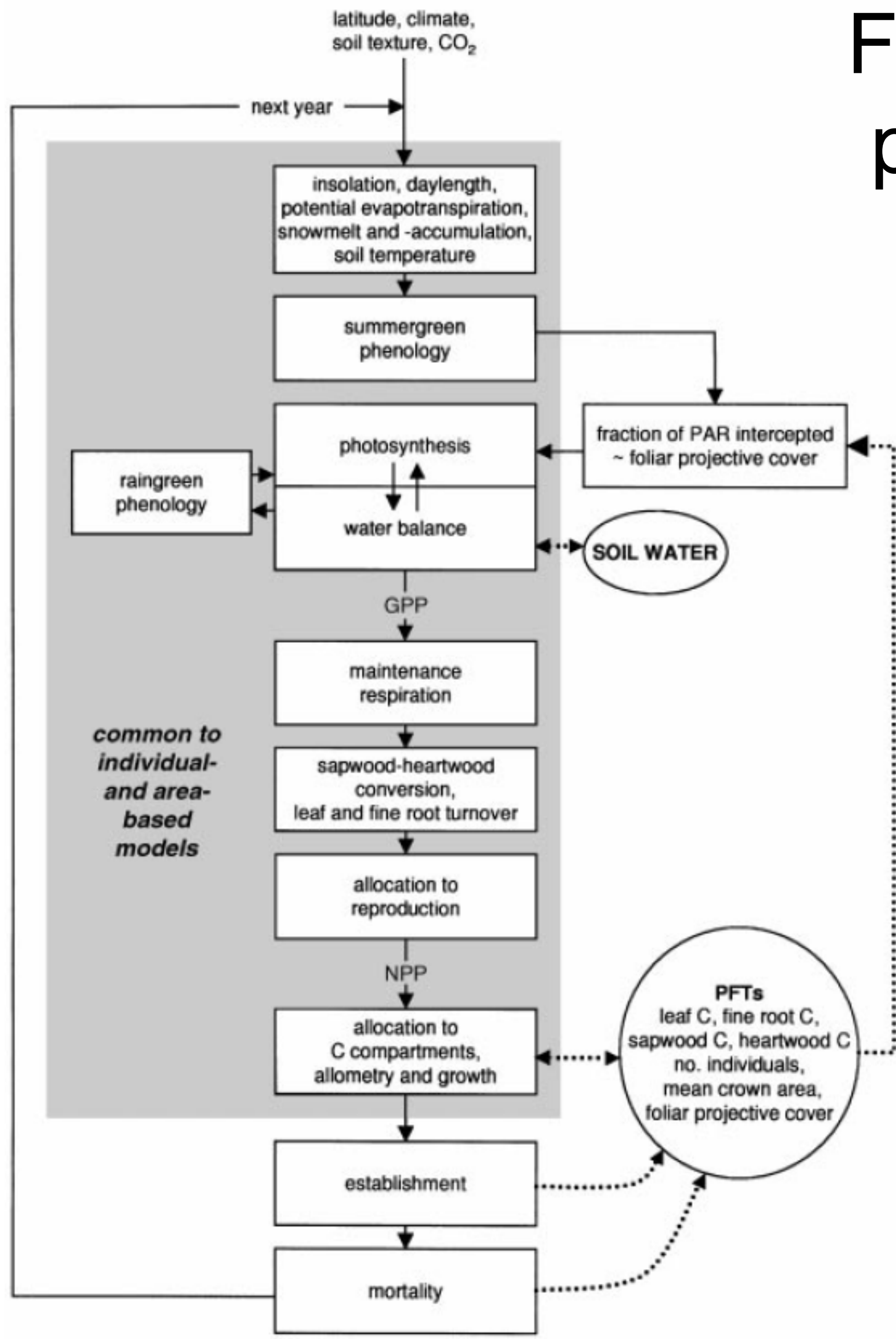


FIGURE 11.3 **Gap Model Output.**
This gap model of forest composition in Switzerland under climate change shows an early peak in oak abundance, giving way to a mixed fir–beech forest with little oak. *Copyright 1998, Massachusetts Institute of Technology, by permission of MIT Press.*

Hannah, 2011



Flow diagram of process-based ecosystem model

Smith et al., Global Ecology & Biogeography, 2001

Example application of dynamic global vegetation model

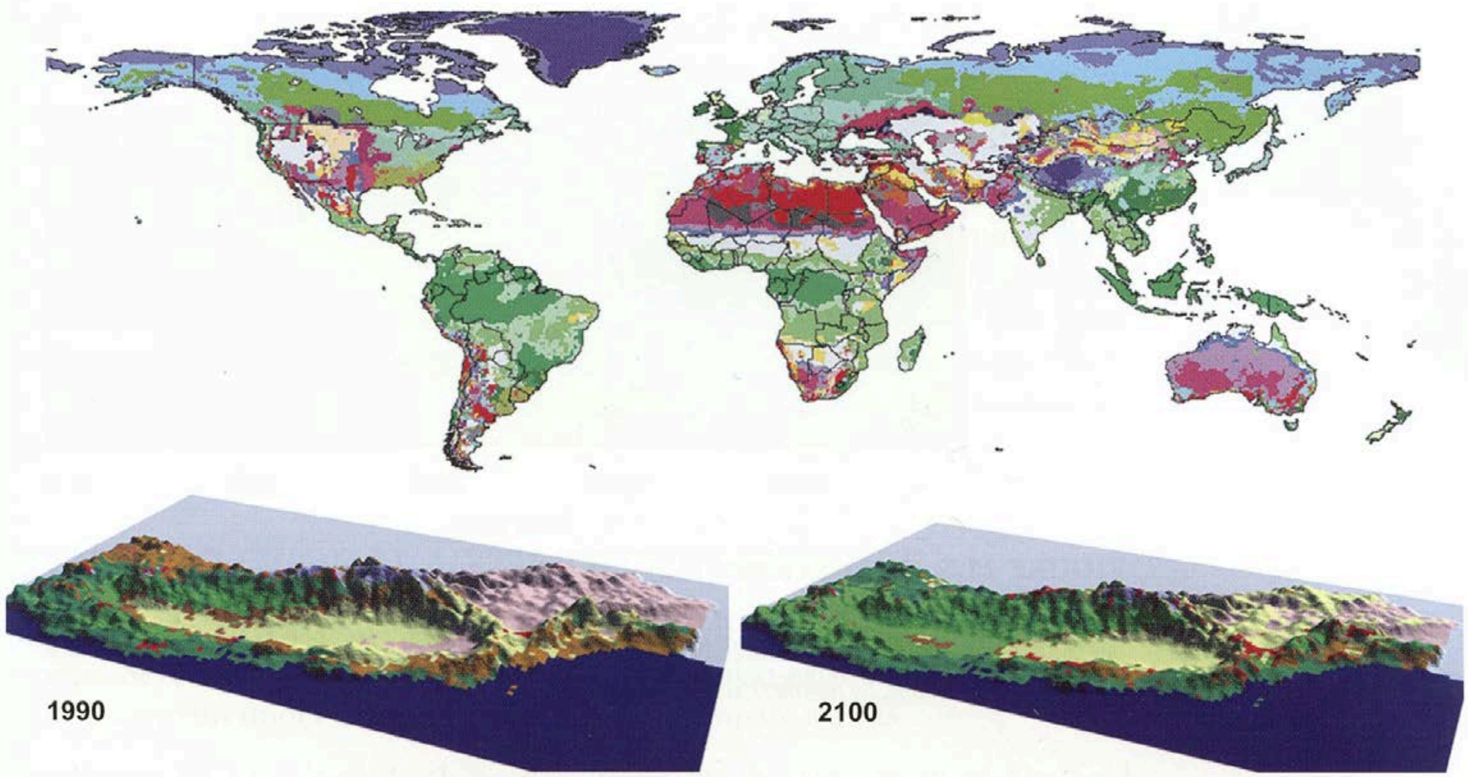
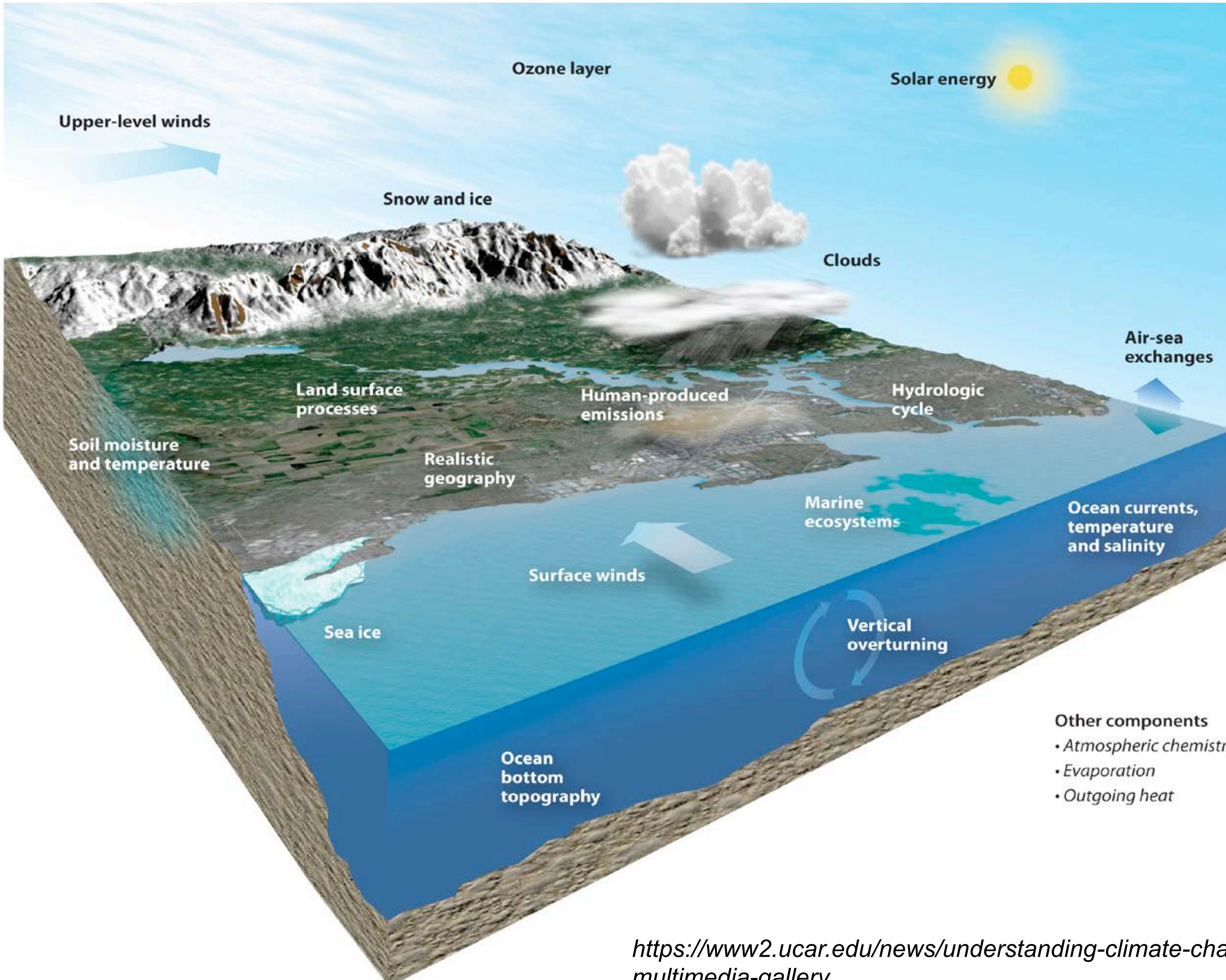


FIGURE 11.2 Global and Regional Vegetation Simulation of a DGVM.
The global distribution of PFTs (top) can be simulated in a coarse-scale DGVM. The same DGVM run at finer resolution can simulate PFT distribution with many local features resolved (bottom left). Driving the DGVM with projected future climates from a GCM provides simulation of change in PFT distribution due to climate change at either global or regional (bottom right) scales. *From Ronald P. Neilson, USDA Forest Service.*

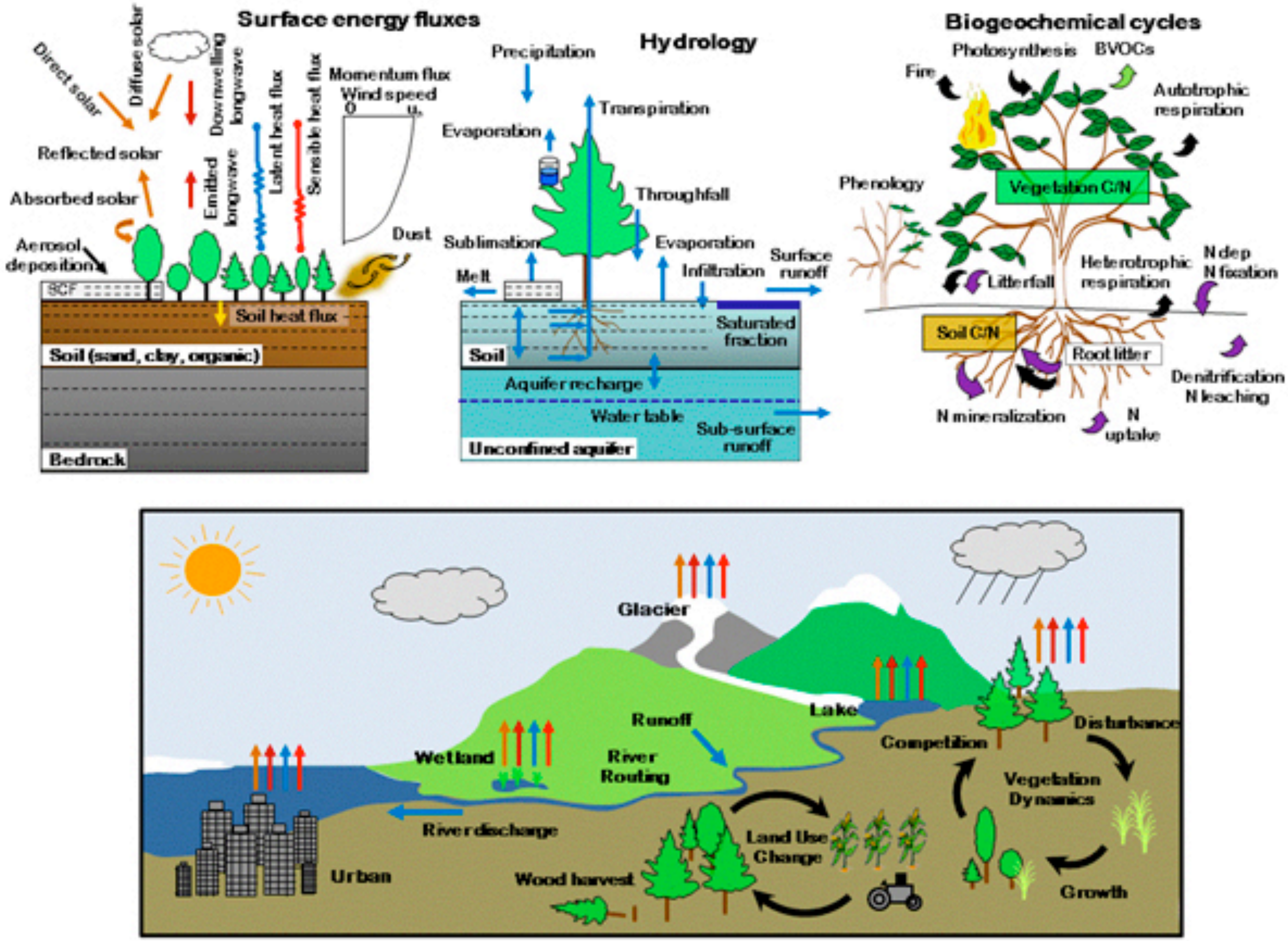
Hannah, 2011

Example of an Earth system model



https://www2.ucar.edu/news/understanding-climate-change-multimedia-gallery

Example of an Earth system model



www.cesm.ucar.edu/models/clm

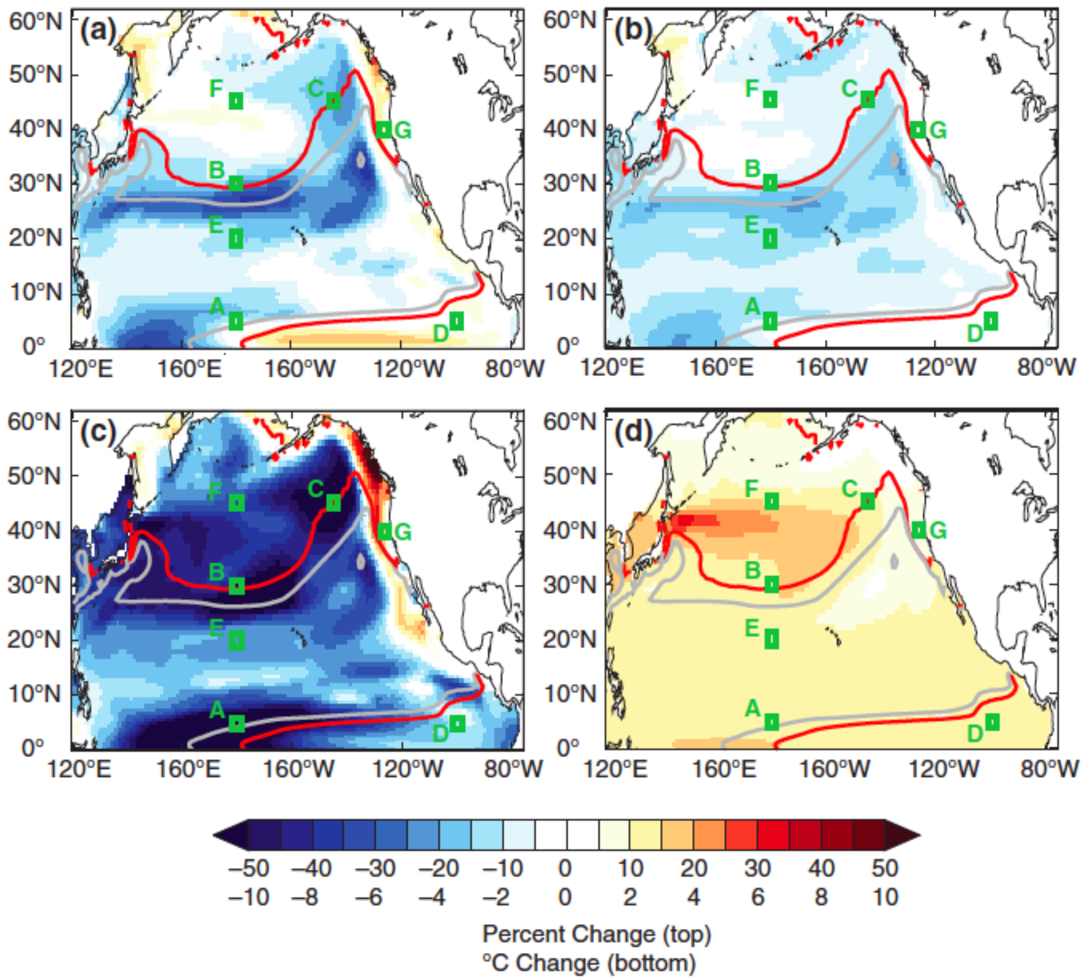
Example application of an Earth system model: climate change impacts on fish catch

%change in primary production

%change in sea small phytoplankton density

%change in sea large phytoplankton density

change in sea surface temperatures

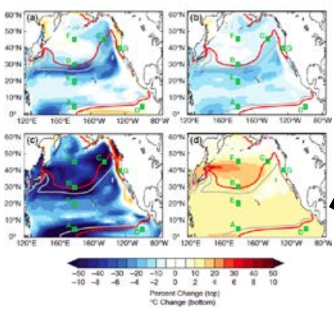


Woodworth-Jefcoats et al., Global Change Biology, 2012

Fig. 1 Change, in percent or °C as noted, from the beginning to the end of the 21st century (2001–2020 and 2081–2100 means) for (a) primary production (%), (b) small phytoplankton density (%), (c) large phytoplankton density (%), and (d) SST (°C). Biome boundaries at the beginning and end of the century are marked in gray and red, respectively. Green boxes and letters identify the seven 2° × 2° regions examined in this article.

Example application of an Earth system model: climate change impacts on fish catch

SST, circulation



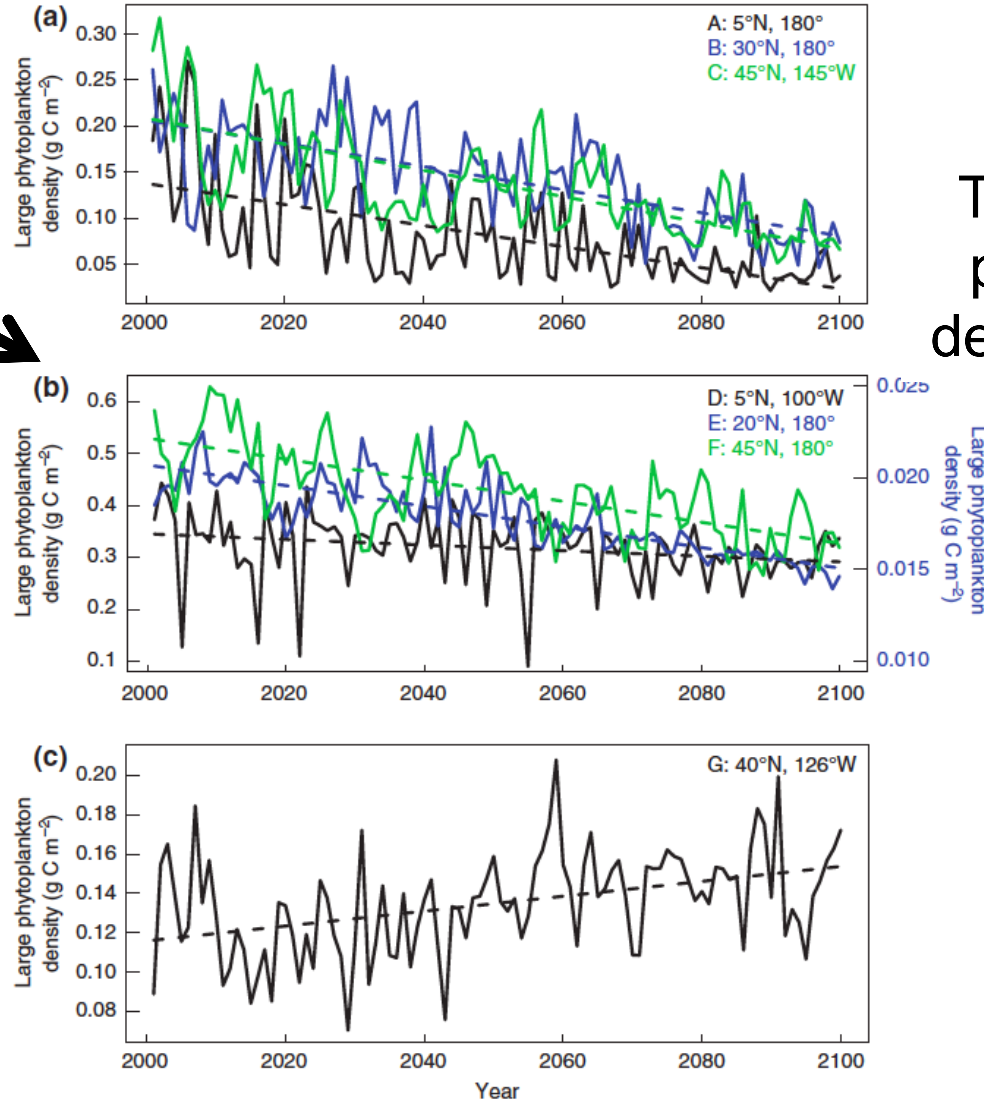


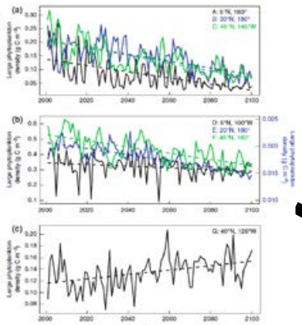
Fig. 2 Annual mean large phytoplankton density (solid) and linear trend line for significant ($P < 0.05$) fits (dashed) for (a) biome boundary, (b) biome interior, and (c) California Current (CC) regions. Right-hand axis in *b* applies only to region E, 20°N, 180°.

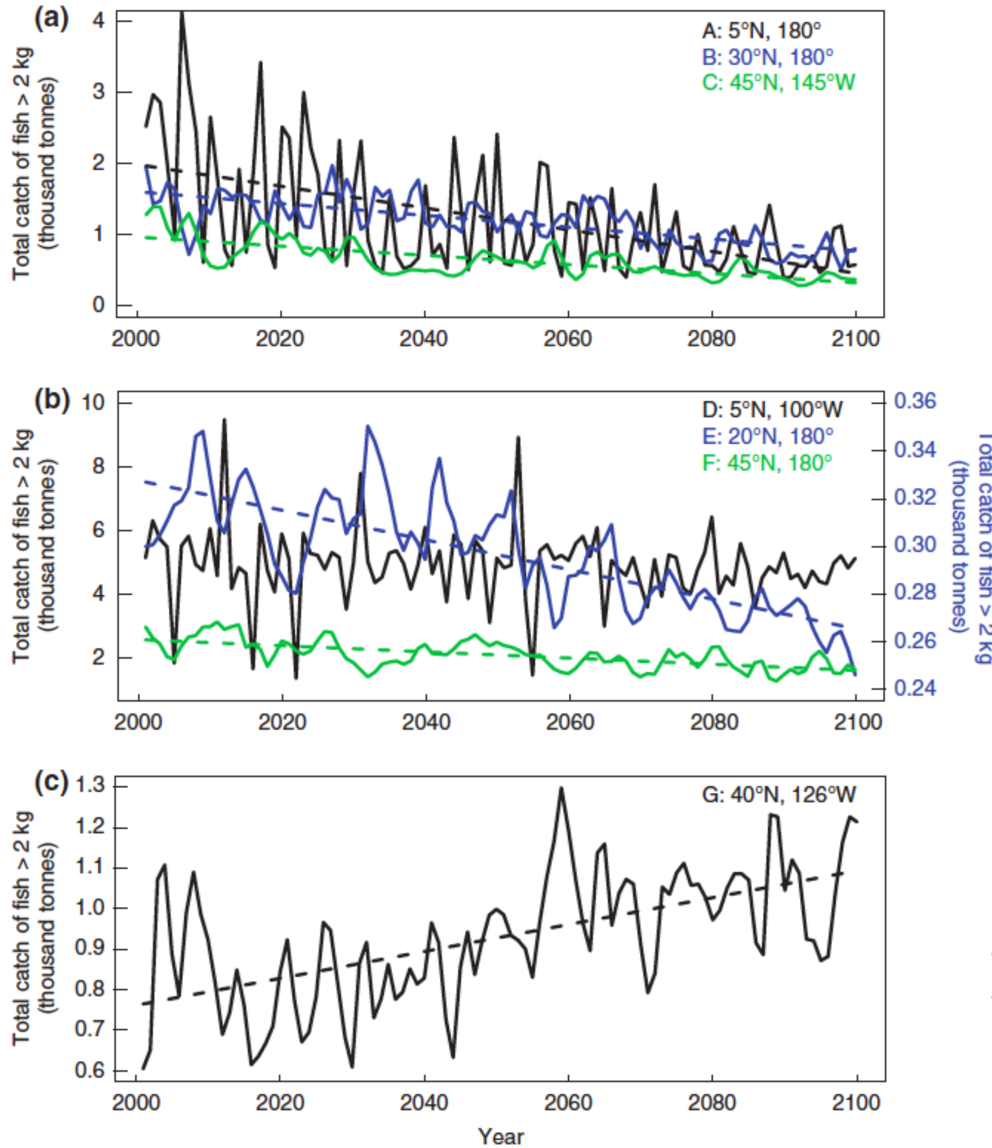
Trends in large phytoplankton density by region

Woodworth-Jefcoats et al., Global Change Biology, 2012

Example application of an Earth system model: climate change impacts on fish catch

phytoplankton





Trends in fish catch by region

Woodworth-Jefcoats et al., Global Change Biology, 2012

Fig. 3 Annual mean catch (solid) and linear trend line for significant ($P < 0.05$) fits (dashed) for (a) biome boundary, (b) biome interior, and (c) California Current (CC) regions. Right-hand axis in *b* applies only to region E, 20°N, 180°.

How can modeling support assessments of impacts of climate change?

Example: How has/will climate change influence(d) wildfire in the West?

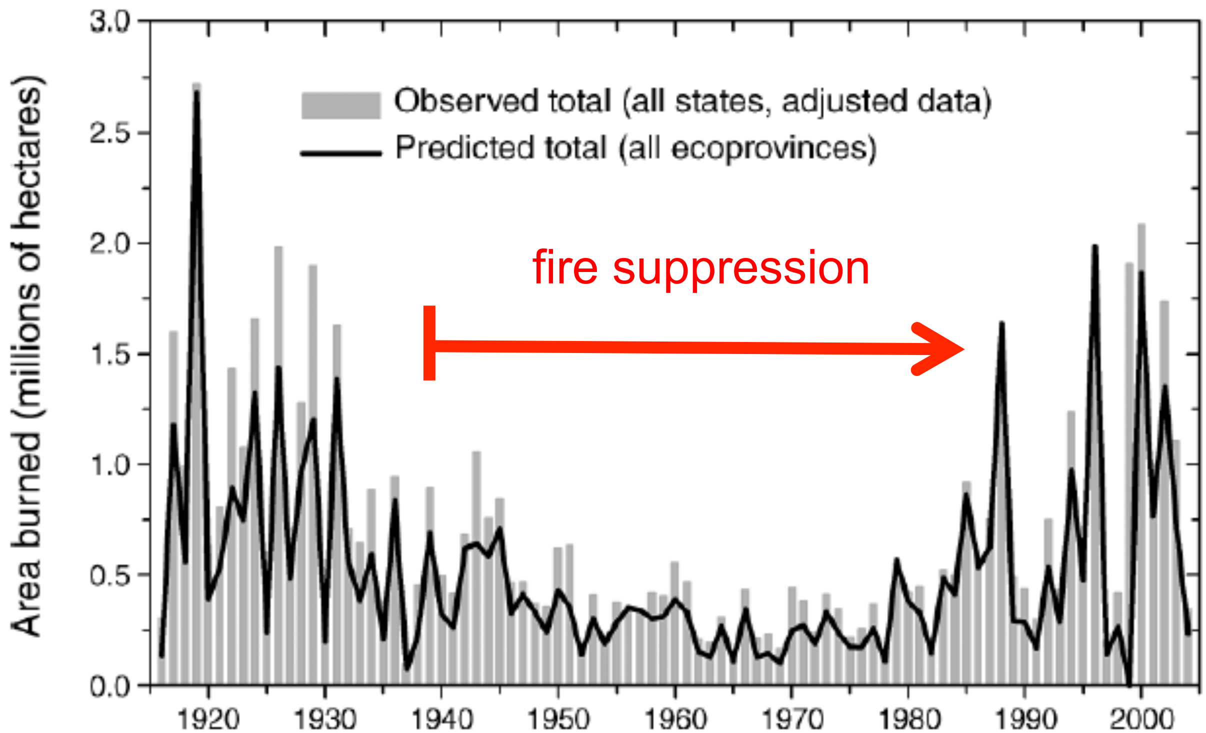
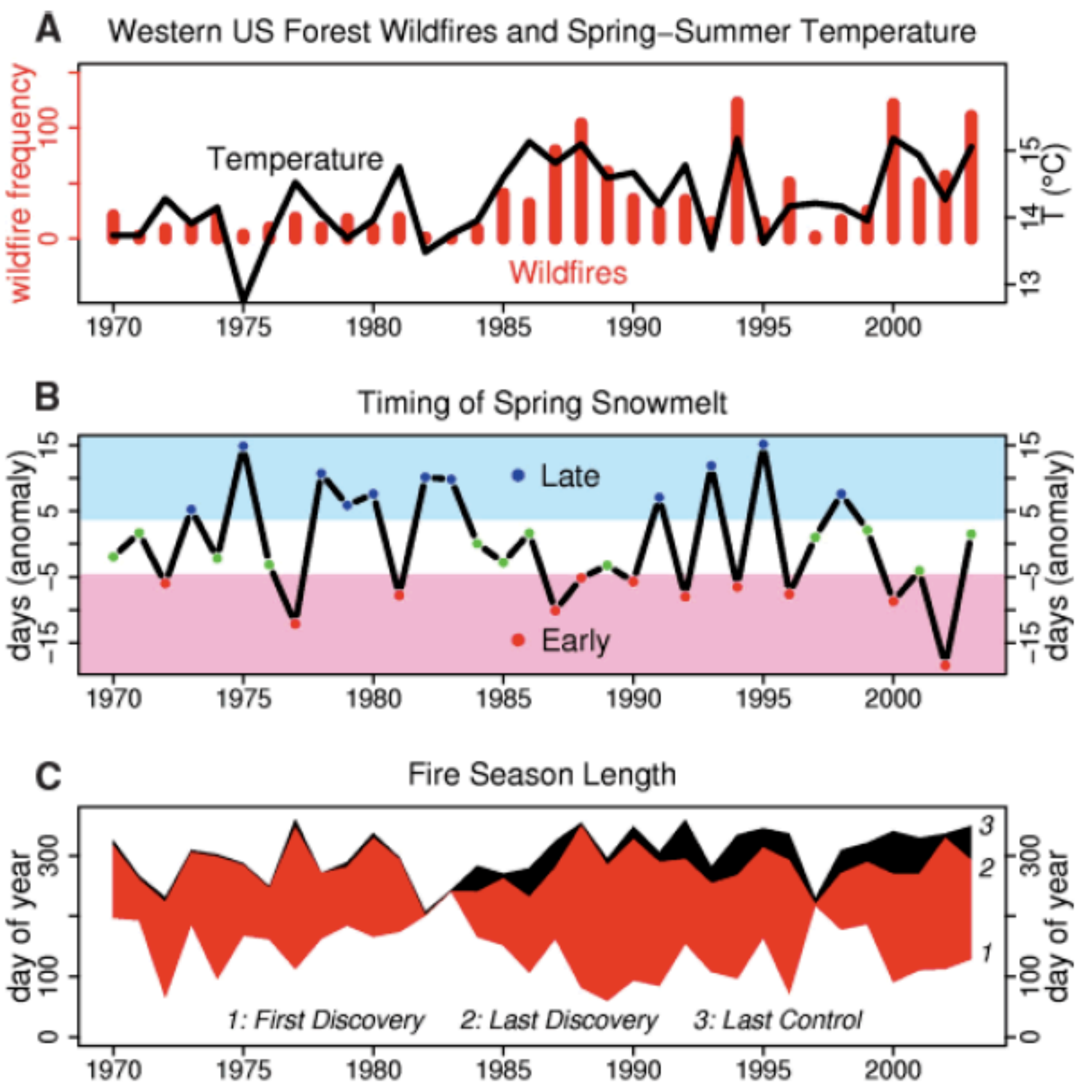


FIG. 1. Observed and reconstructed area-burned comparison. Time series of observed total wildfire area burned (WFAB) for 11 western U.S. states (bars, adjusted for area reporting bias) and reconstructed total WFAB for 16 ecoprovinces (line) for the period 1916–2004.

Littell et al., EA, 2009



Wildfire: Recent observations

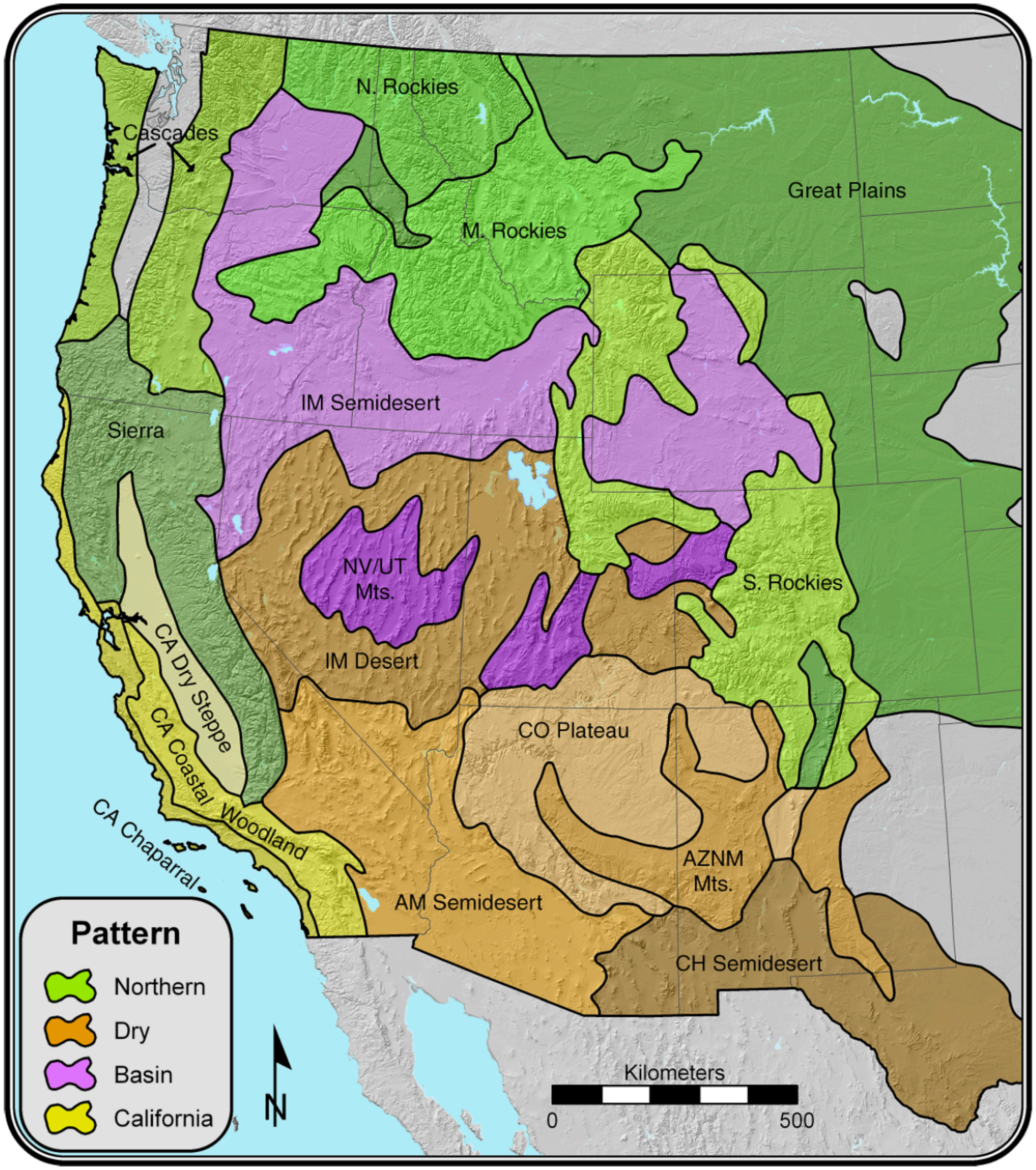
earlier snowmelt =>

more moisture stress on plants =>

longer fire season =>

more fires

Westerling et al., *Science*, 2006



- statistical analysis assessing which climate factors influence burned area in the last several decades
- different assessments for different ecoprovinces (vegetation types)

Littell et al., EA, 2009

Important climate variables: PPT, T (depending on ecoprovince)

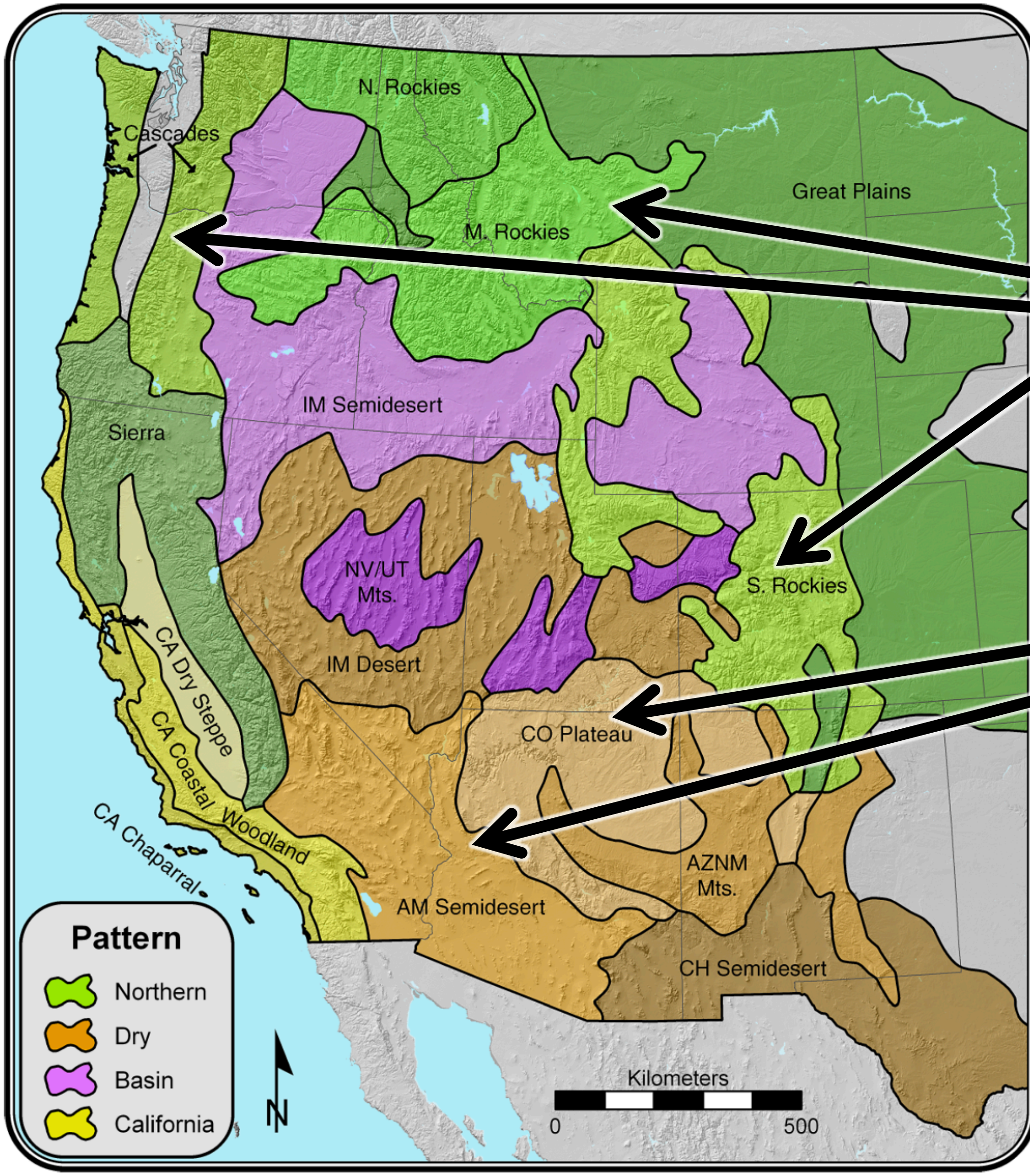
TABLE 3. Climate-fire diagnostic regression models for 1977–2003.

Ecoprovince	1977–2003 model†	R^2	RMSE/SD
AM Semidesert	−GS.PPT + −Spr.PPT + −Spr.*T* + −L1.GS.PPT + L1.Wnt.PDSI	0.72	1.42
AZNM Mts	−Ann.PDSI + −Sum.PPT + L1.Wnt.PPT + L1.Spr.*T* + L2.Sum.*T*	0.74	1.62
CA Chaparral	−Wnt.PDSI + −Sum.PPT + Wnt.PDSI : Sum.PPT + −L2.Spr.*T*	0.54	1.81
CA Woodland	−Sum.PPT + L1.Wnt.*T* + −L1.Spr.*T* + L1.Sum.PPT	0.47	1.41
CA Dry Steppe	−Sum.PPT + −Spr.PPT + Spr.PDSI + −Wnt.PPT	0.59	0.78
Cascades	−GS.PPT + L1.Wnt.PPT + −L1.Wnt.*T* + L2.Wnt.PPT + −L2.Sum.PPT	0.65	1.27
CH Semidesert	−Ann.PDSI + Wnt.PPT + L1.Spr.PDSI + Ann.PDSI : Wnt.PPT	0.80	1.07
CO Plateau	−Sum.PPT + −Sum.PDSI + −L1.GS.PPT + L1.Ann.PPT + L2.GS.*T*	0.63	1.35
Great Plains	−Sum.PPT + −Spr.PPT + −Wnt.PPT + L1.Wnt.*T* + −L1.Spr.PPT + L1.Sum.PDSI	0.87	0.56
IM Semidesert	−GS.PPT + L1.Spr.PDSI + L2.Wnt.PDSI + L2.Spr.*T*	0.56	2.08
IM Desert	Wnt.PPT + Wnt.*T* + L2.Spr.*T* + L2.Wnt.PDSI + L2.Wnt.*T* + Wnt.PPT : Wnt.*T*	0.71	1.64
M. Rockies	−Sum.PDSI + Wnt.PPT + L2.Spr.*T* + L2.Spr.PDSI + −L2.Sum.PPT + −L2.Ann.*T*	0.81	0.64
NV/UT Mts	L1.Ann.PPT + L2.Spr.*T* + L2.GS.PPT	0.33	1.31
N. Rockies	−Sum.PDSI + Wnt.*T* + −L1.Sum.PPT + −L1.GS.*T*	0.74	0.79
Sierra	−Sum.PDSI + L1.Wnt.PPT + −L1.GS.PPT + L1.Wnt.PPT : L1.GS.PPT	0.53	1.11
S. Rockies	−Spr.PPT + −Sum.PPT + Wnt.*T* + −Spr.*T* + L2.Spr.PDSI + Spr.PPT : Sum.PPT	0.77	0.69

Notes: A + followed by − refers to the additive regression effect of a negative predictor; the absence of a − symbol indicates that the predictor is positive. RMSE stands for root mean square error. Model abbreviations are: Ann, annual (water year), October–September; Sum, summer, June–August; GS, growing season, May–September; Spr, spring, March–May; Wnt, winter, October–March; L1, lag 1, or year prior; L2, lag 2; *T*, mean temperature; PPT, precipitation; PDSI, Palmer drought severity index. See Table 1 for an explanation of the ecoprovince abbreviations.

† All models are statistically significant; all $P < 0.02$ for $\alpha = 0.05$.

Climate drivers of historical burned area



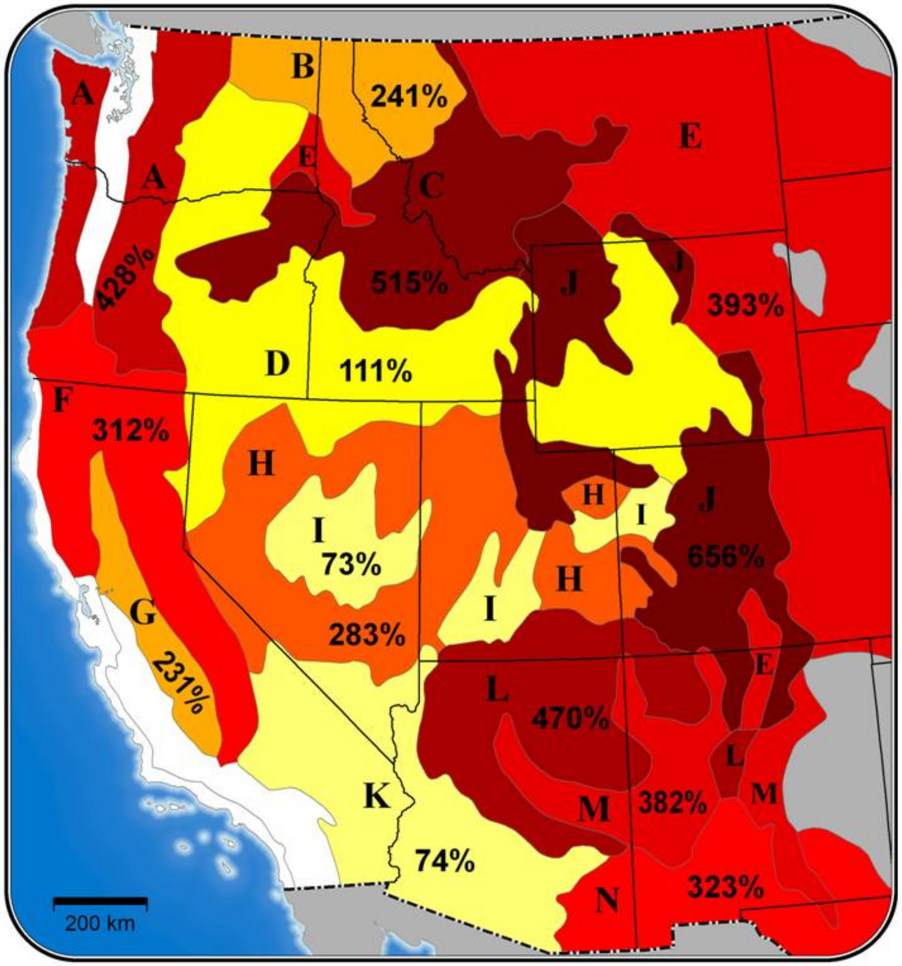
<u>mountains</u>: burned area negatively correlated with year-of-fire precip, positively correlated with year-of-fire T

- drying of existing fuels

<u>grass/shrub</u>: burned area positively correlated with antecedent precip

- also fuels production

Littell et al., EA, 2009



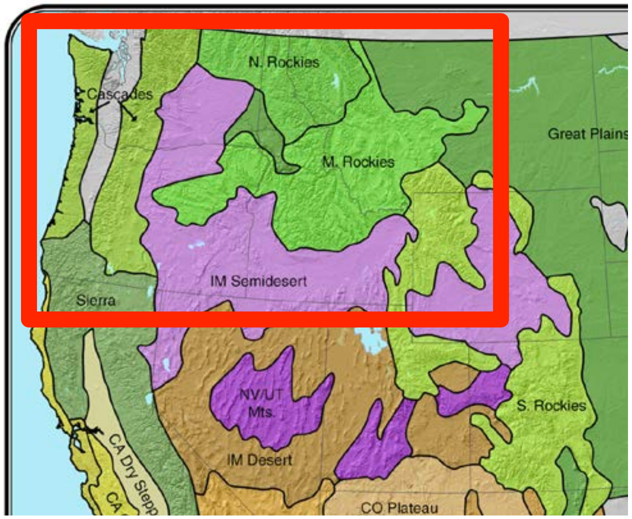
A - Cascade Mixed Forest
B - Northern Rocky Mt. Forest
C - Middle Rocky Mt. Steppe-Forest
D - Intermountain Semi-Desert
E - Great Plains-Palouse Dry Steppe
F - Sierran Steppe-Mixed Forest
G - California Dry Steppe
H - Intermountain Semi-Desert / Desert
I - Nev.-Utah Mountains-Semi-Desert
J - South. Rocky Mt. Steppe-Forest
K - American Semi-Desert and Desert
L - Colorado Plateau Semi-Desert
M - Ariz.-New Mex. Mts. Semi-Desert
N - Chihuahuan Semi-Desert

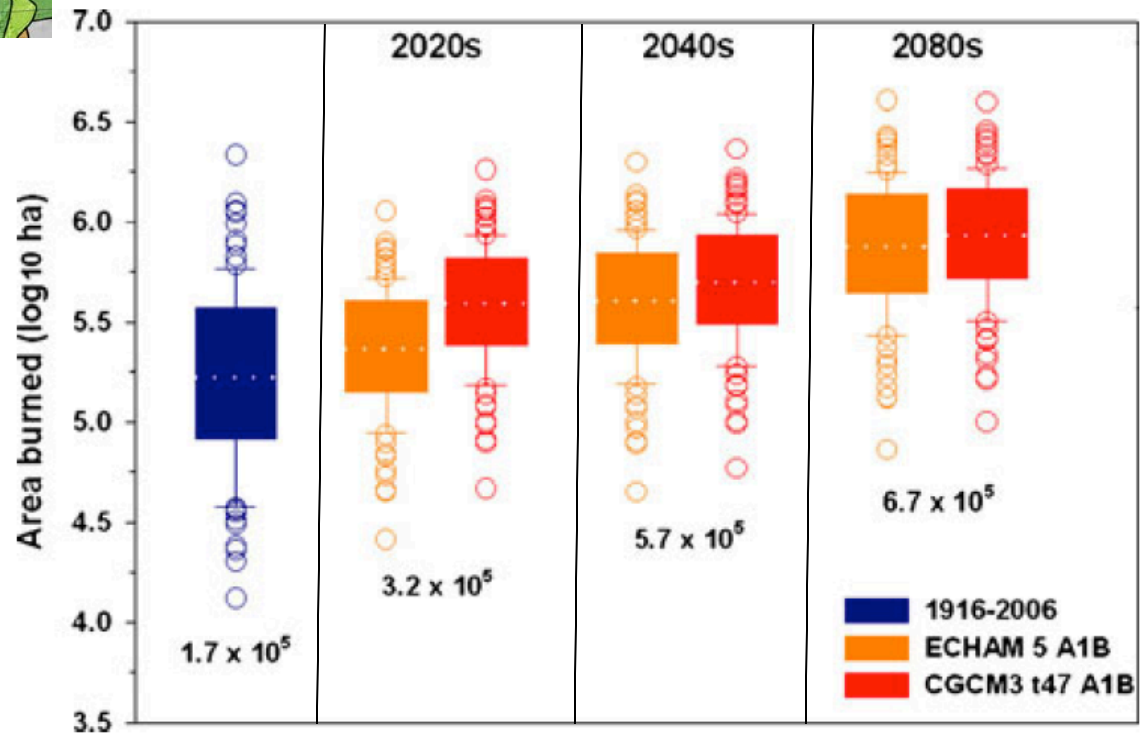
Wildfire: Projections based on future climate change

increase in burned area for 1º C increase in temperature

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

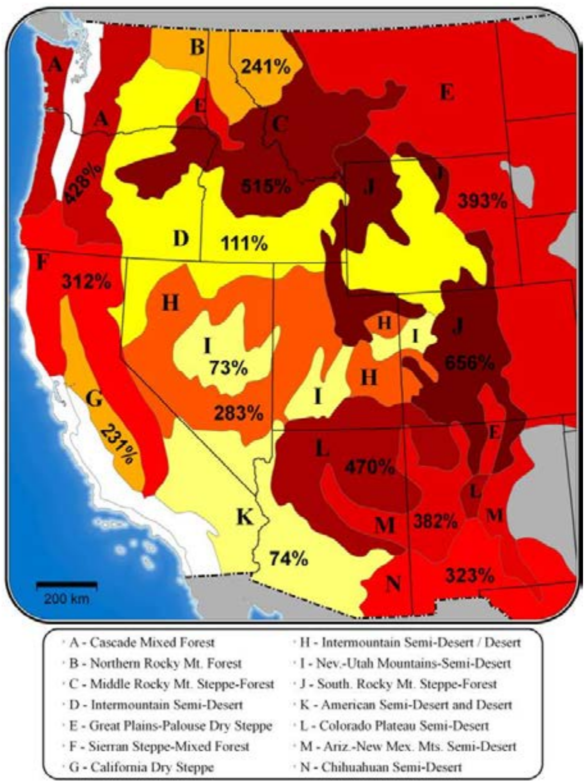
Burned area in Pacific Northwest increases substantially in future





Littell et al., Climatic Change, 2010

Summary of using modeling to study climate change and wildfire



- multiple factors influenced the observed increase in burned area
  - attribution: difficult
- multiple types of studies guide our understanding of climate influences on wildfire
- although recent climate change has likely (but not definitively) caused increased wildfire in the past, we are more certain that continued climate change will increase wildfire in the future