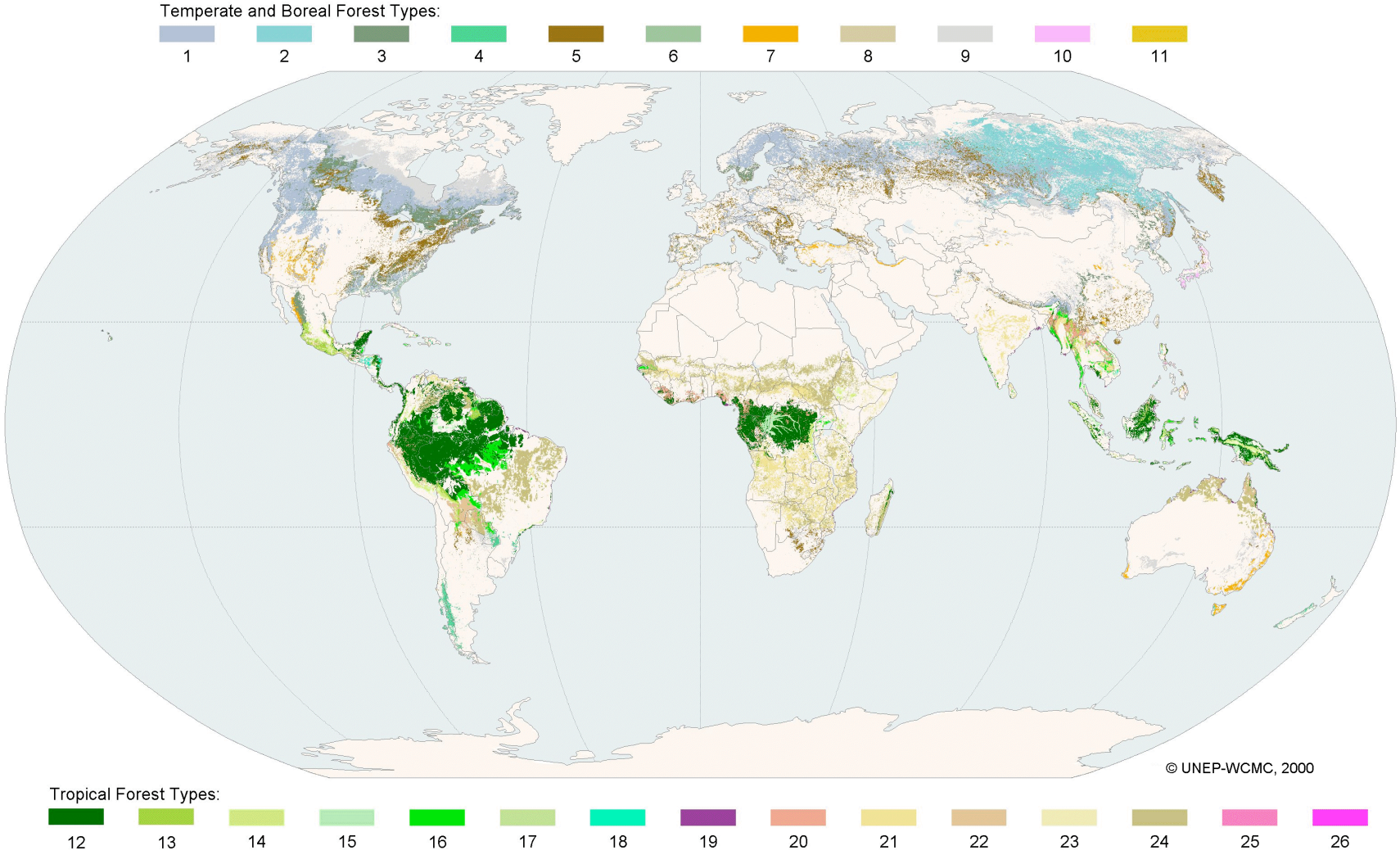

FORESTS IN FLUX
Cory Cleveland
Ecosystem & Conservation Sciences

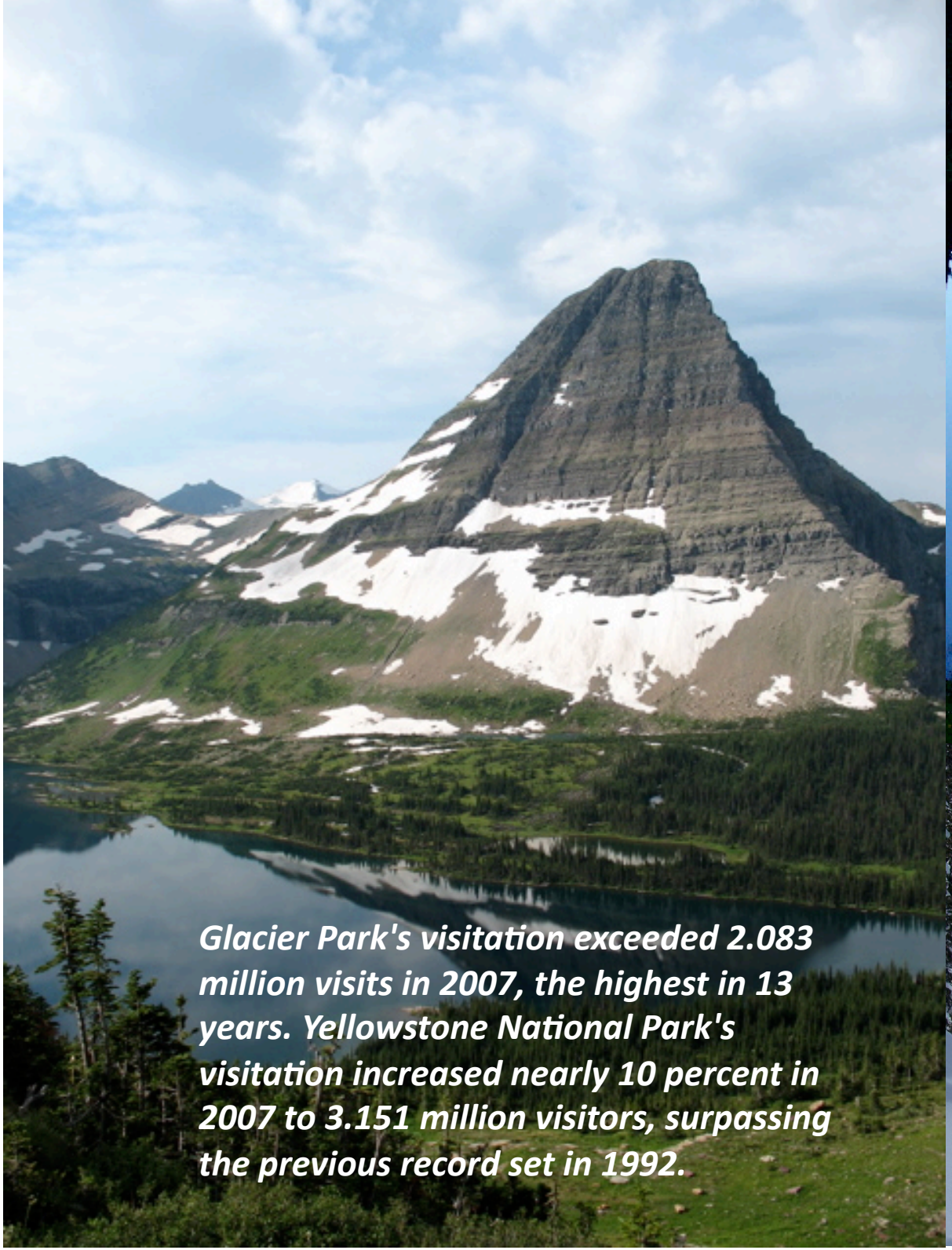
Global Forest Cover



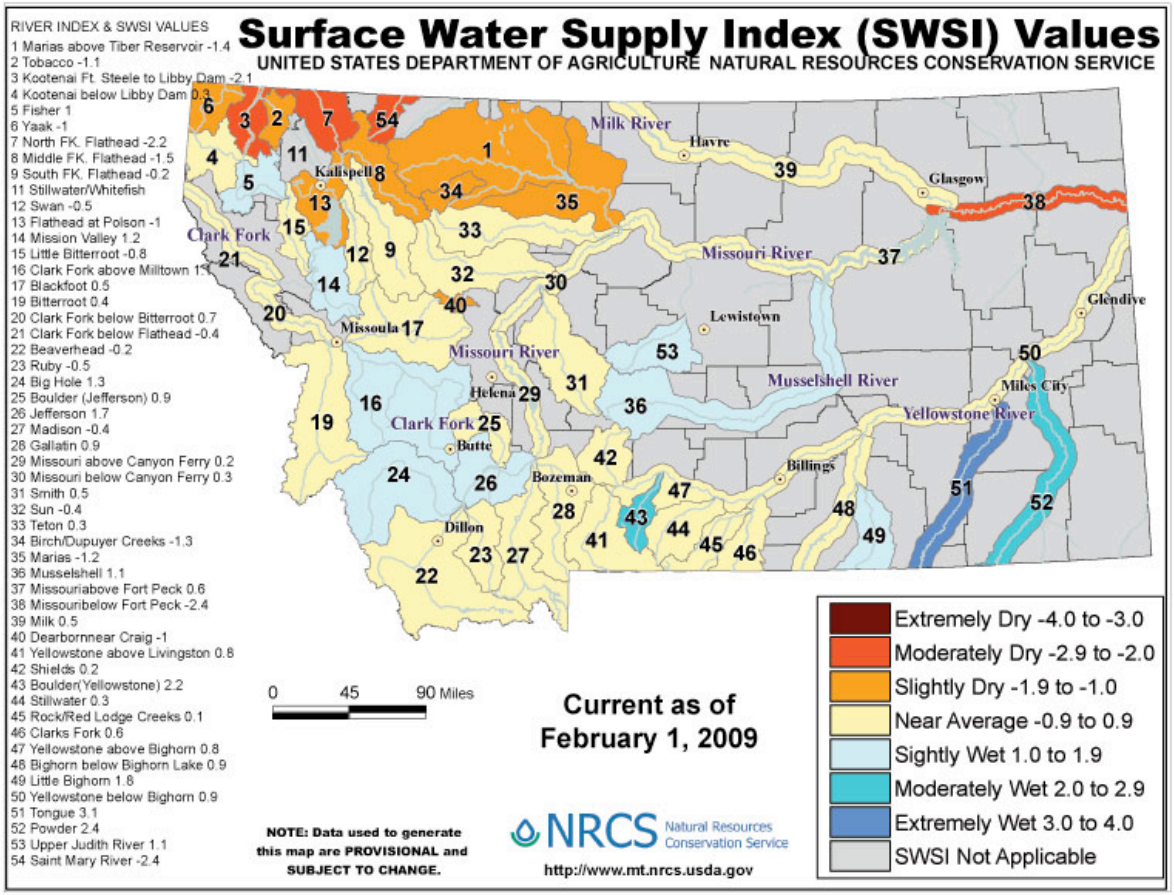
- 30% of land area, ~ 40 million km^2
- 6200 m^2 per person


Forest Ecosystems as Sources
of Goods & Services

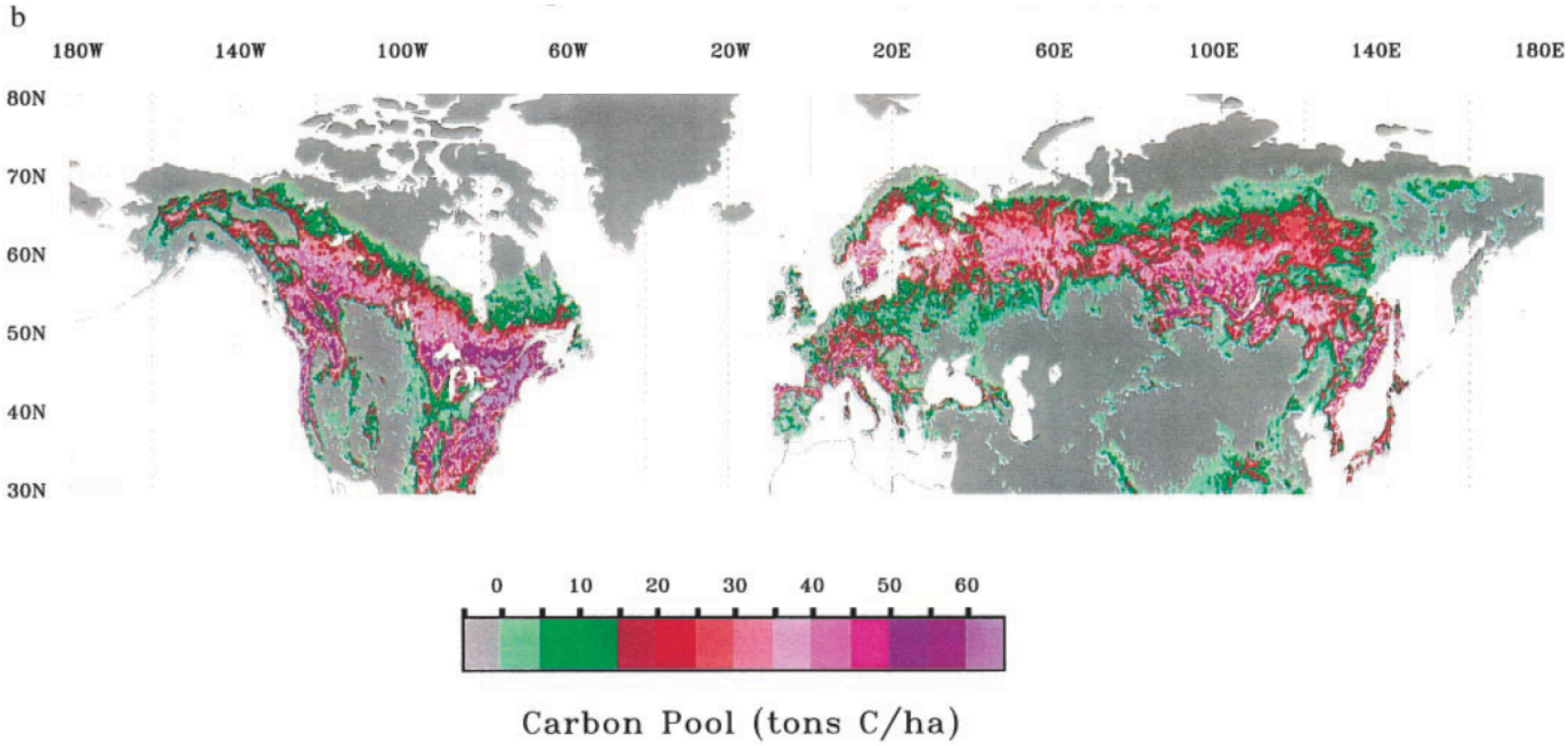
***Regardless of what Montana's timber industry eventually becomes, it currently employs approximately 9,000 people across the state, earning $400 million in labor income annually and accounting for 10 percent of the state's economic base, according to Todd Morgan, director of forest industry research for UM's Bureau of Business and Economic Research*.** **Flathead Beacon, 10/8/08**



Glacier Park's visitation exceeded 2.083 million visits in 2007, the highest in 13 years. Yellowstone National Park's visitation increased nearly 10 percent in 2007 to 3.151 million visitors, surpassing the previous record set in 1992.


Surface Water Supply Index (SWSI) Values
UNITED STATES DEPARTMENT OF AGRICULTURE NATURAL RESOURCES CONSERVATION SERVICE
RIVER INDEX & SWSI VALUES
1 Marias above Tiber Reservoir -1.4
2 Tobacco -1.1
3 Kootenai Ft. Steele to Libby Dam -2.1
4 Kootenai below Libby Dam 0.3
5 Fisher 1
6 Yaak -1
7 North FK. Flathead -2.2
8 Middle FK. Flathead -1.5
9 South FK. Flathead -0.2
11 Stillwater/Whitefish
12 Swan -0.5
13 Flathead at Polson -1
14 Mission Valley 1.2
15 Little Bitterroot -0.8
16 Clark Fork above Milltown 1.5
17 Blackfoot 0.5
19 Bitterroot 0.4
20 Clark Fork below Bitterroot 0.7
21 Clark Fork below Flathead -0.4
22 Beaverhead -0.2
23 Ruby -0.5
24 Big Hole 1.3
25 Boulder (Jefferson) 0.9
26 Jefferson 1.7
27 Madison -0.4
28 Gallatin 0.9
29 Missouri above Canyon Ferry 0.2
30 Missouri below Canyon Ferry 0.3
31 Smith 0.5
32 Sun -0.4
33 Teton 0.3
34 Birch/Dupuyer Creeks -1.3
35 Marias -1.2
36 Musselshell 1.1
37 Missouriabove Fort Peck 0.6
38 Missouribelow Fort Peck -2.4
39 Milk 0.5
40 Dearbornnear Craig -1
41 Yellowstone above Livingston 0.8
42 Shields 0.2
43 Boulder(Yellowstone) 2.2
44 Stillwater 0.3
45 Rock/Red Lodge Creeks 0.1
46 Clarks Fork 0.6
47 Yellowstone above Bighorn 0.8
48 Bighorn below Bighorn Lake 0.9
49 Little Bighorn 1.8
50 Yellowstone below Bighorn 0.9
51 Tongue 3.1
52 Powder 2.4
53 Upper Judith River 1.1
54 Saint Mary River -2.4
Milk River
Havre
Glasgow
Kalispell
Clark Fork
Missouri River
Lewistown
Glendive
Missoula
Missouri River
Musselshell River
Miles City
Helena
Yellowstone River
Clark Fork
Butte
Billings
Bozeman
Dillon
0 45 90 Miles
Current as of
February 1, 2009
NOTE: Data used to generate this map are PROVISIONAL and SUBJECT TO CHANGE.
NRCS Natural Resources Conservation Service
http://www.mt.nrcs.usda.gov
Extremely Dry -4.0 to -3.0
Moderately Dry -2.9 to -2.0
Slightly Dry -1.9 to -1.0
Near Average -0.9 to 0.9
Sightly Wet 1.0 to 1.9
Moderately Wet 2.0 to 2.9
Extremely Wet 3.0 to 4.0
SWSI Not Applicable

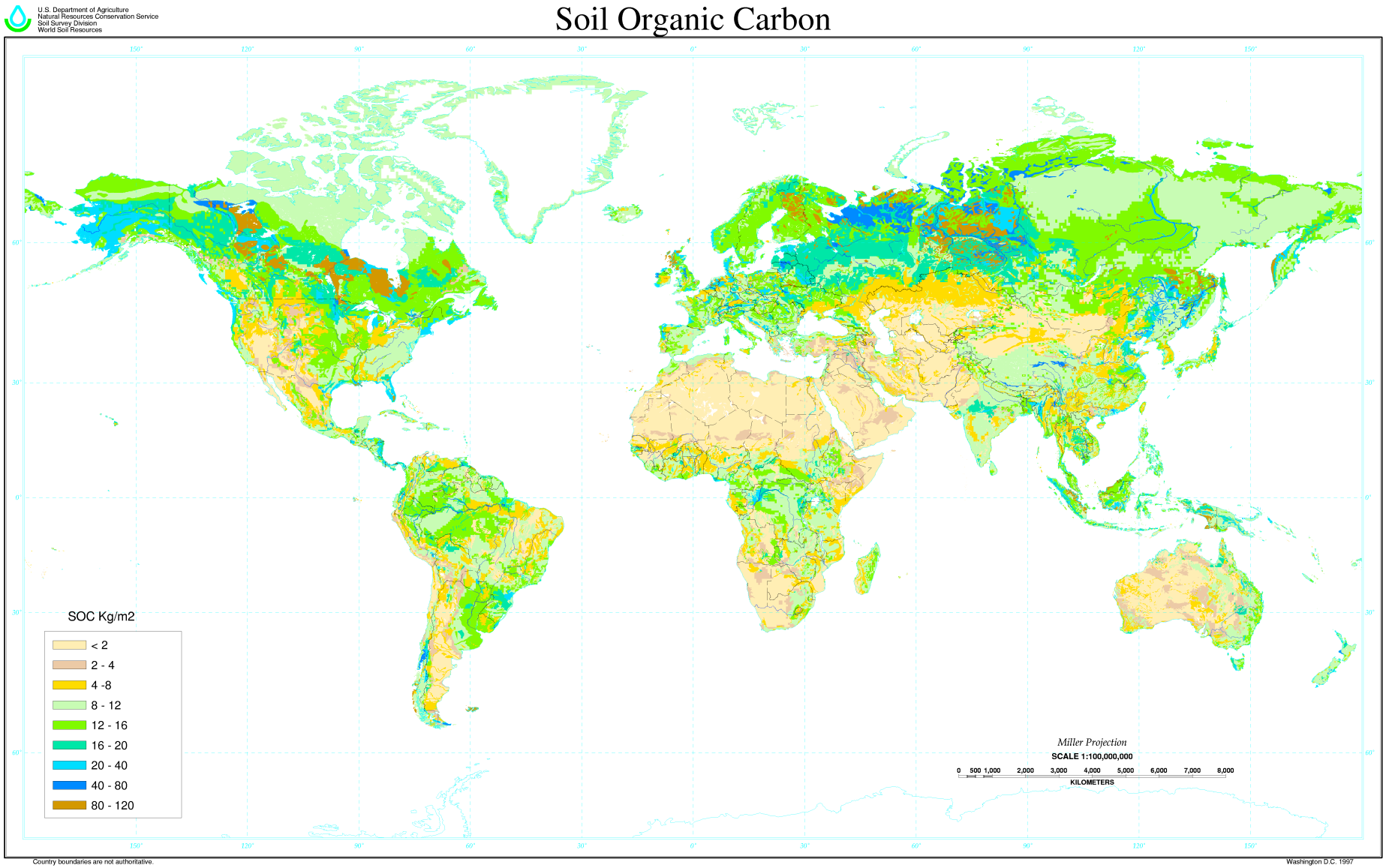
Forests Also Store A LOT of Carbon in Their Biomass…



For the 1.42 billion hectares of Northern forests, roughly above the 30th parallel, we estimate the biomass sink to be 0.68 billion tons of carbon per year

— Myneni et al (2001), PNAS

…And In Their Soils



What does all this carbon mean for the atmosphere in a warmer world?

What Regulates Forest Tree Distribution?

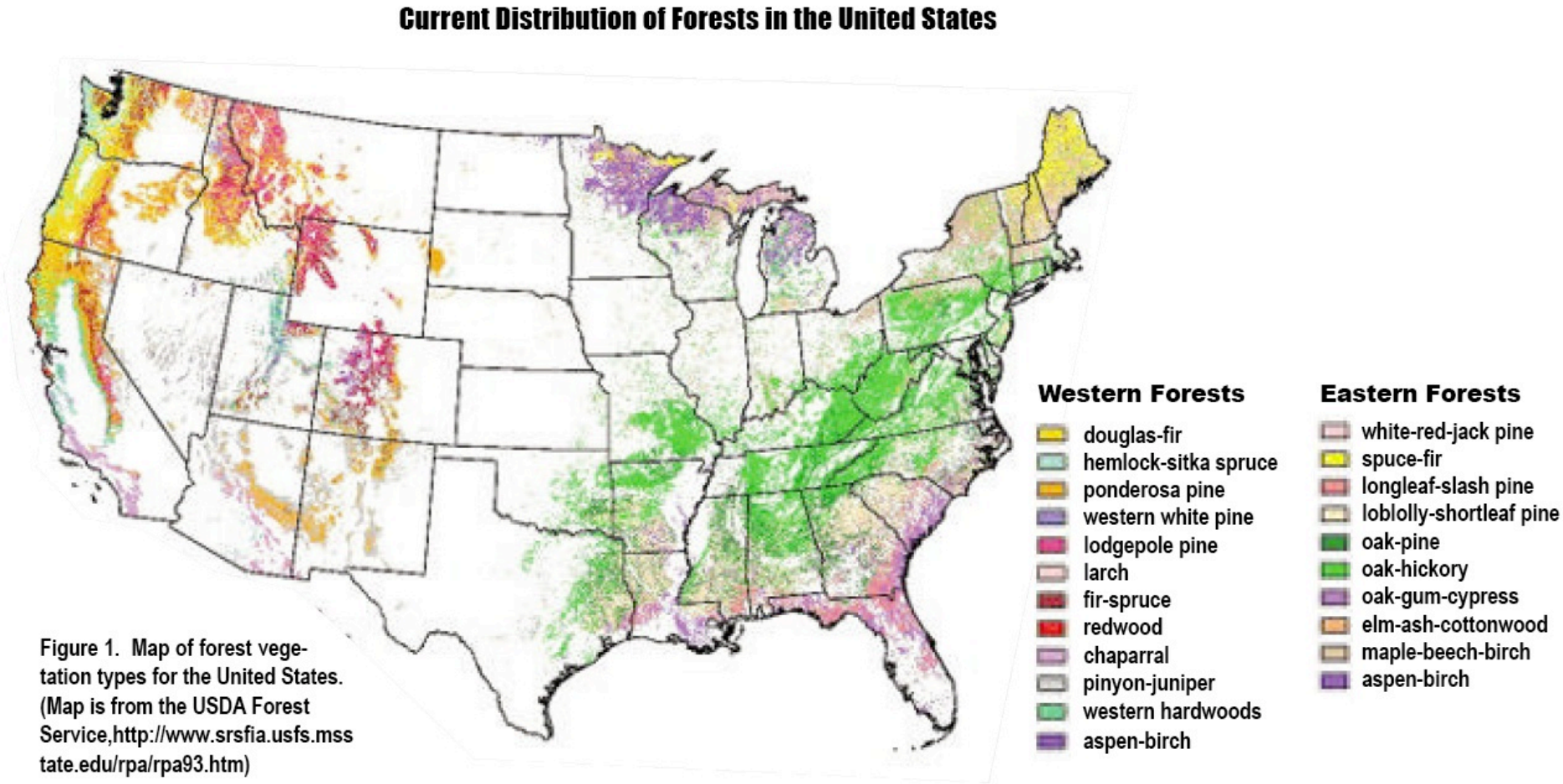
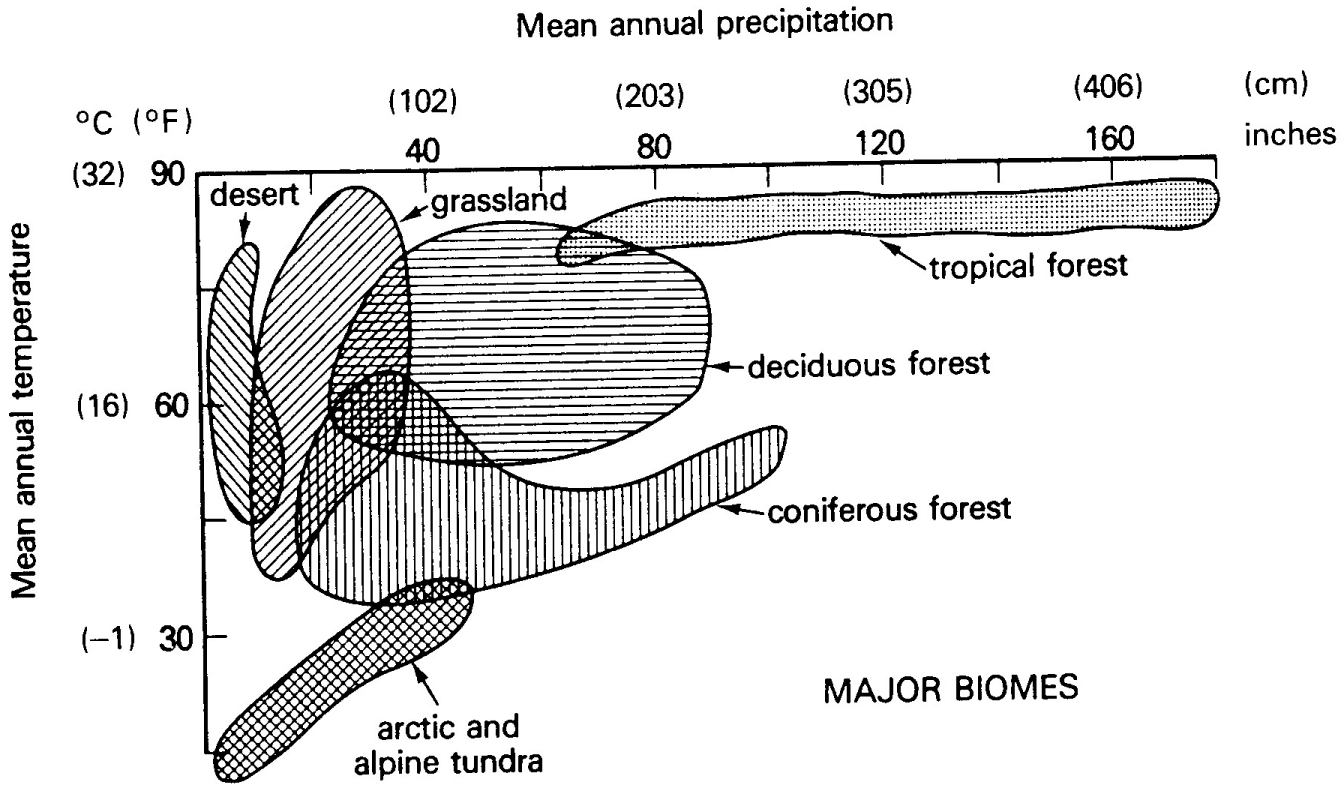


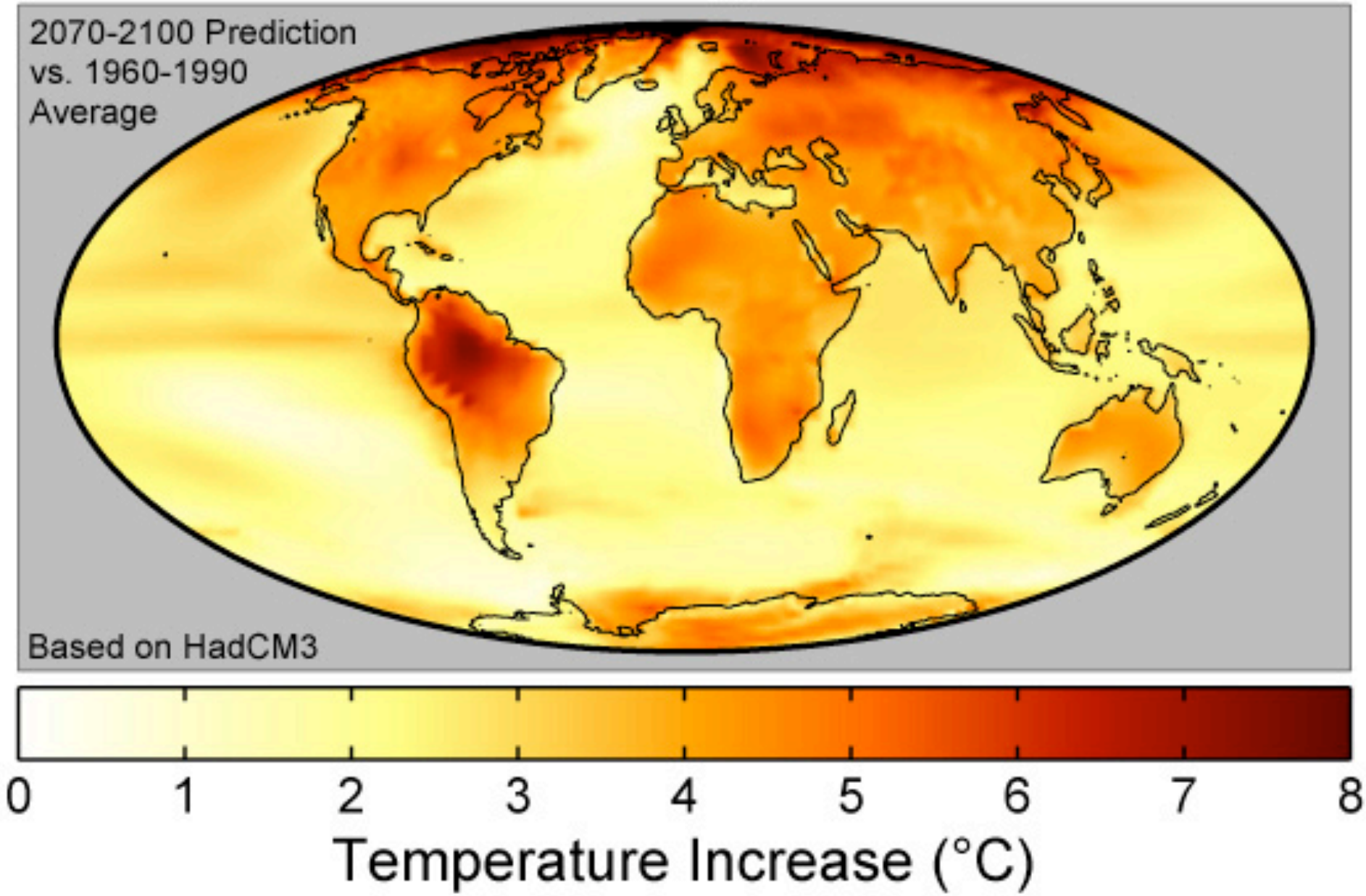
Figure 1. Map of forest vegetation types for the United States. (Map is from the USDA Forest Service,http://www.srsfia.usfs.msstate.edu/rpa/rpa93.htm)

The Relationship Between Climate & Vegetation



6.17. Diagram showing characteristics of major biomes with respect to annual mean temperature and rainfall.

Global Warming Predictions



Climate Change is Expressed in Multiple Ways

Temperature,

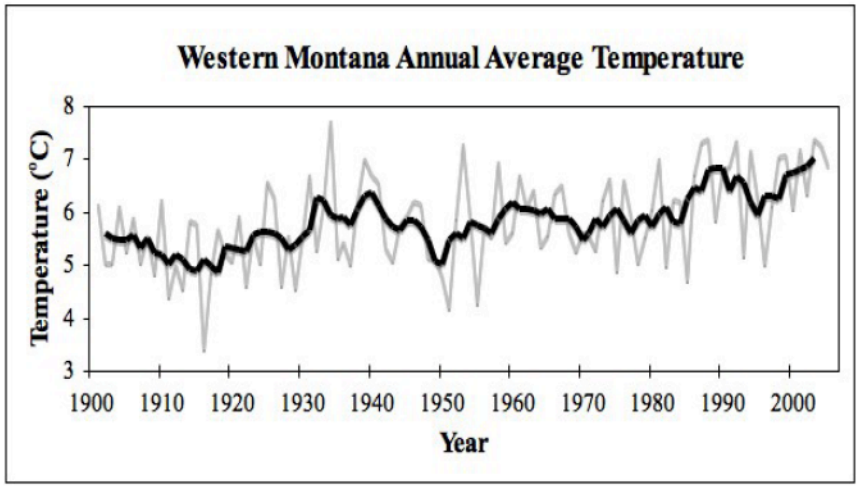


Fig. 3. Annual mean temperature trend for Western Montana. Dark line is a 5-year running average. Western Montana is currently 1°C warmer than 100 years ago.

Precipitation,

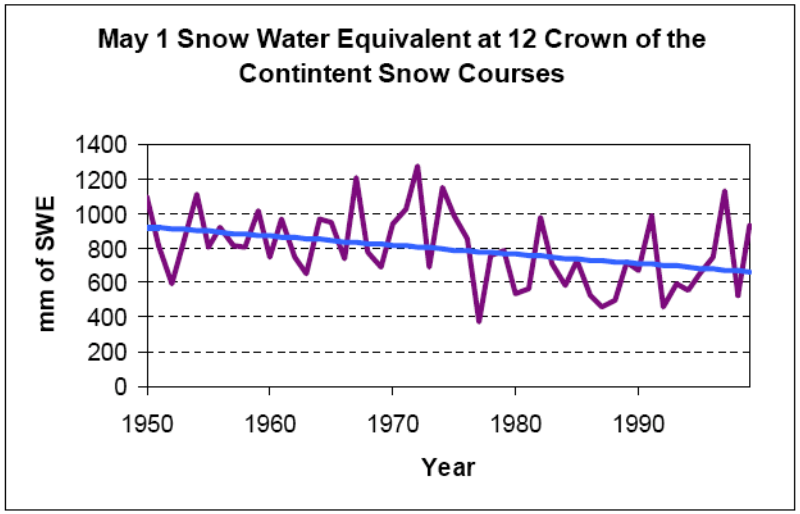
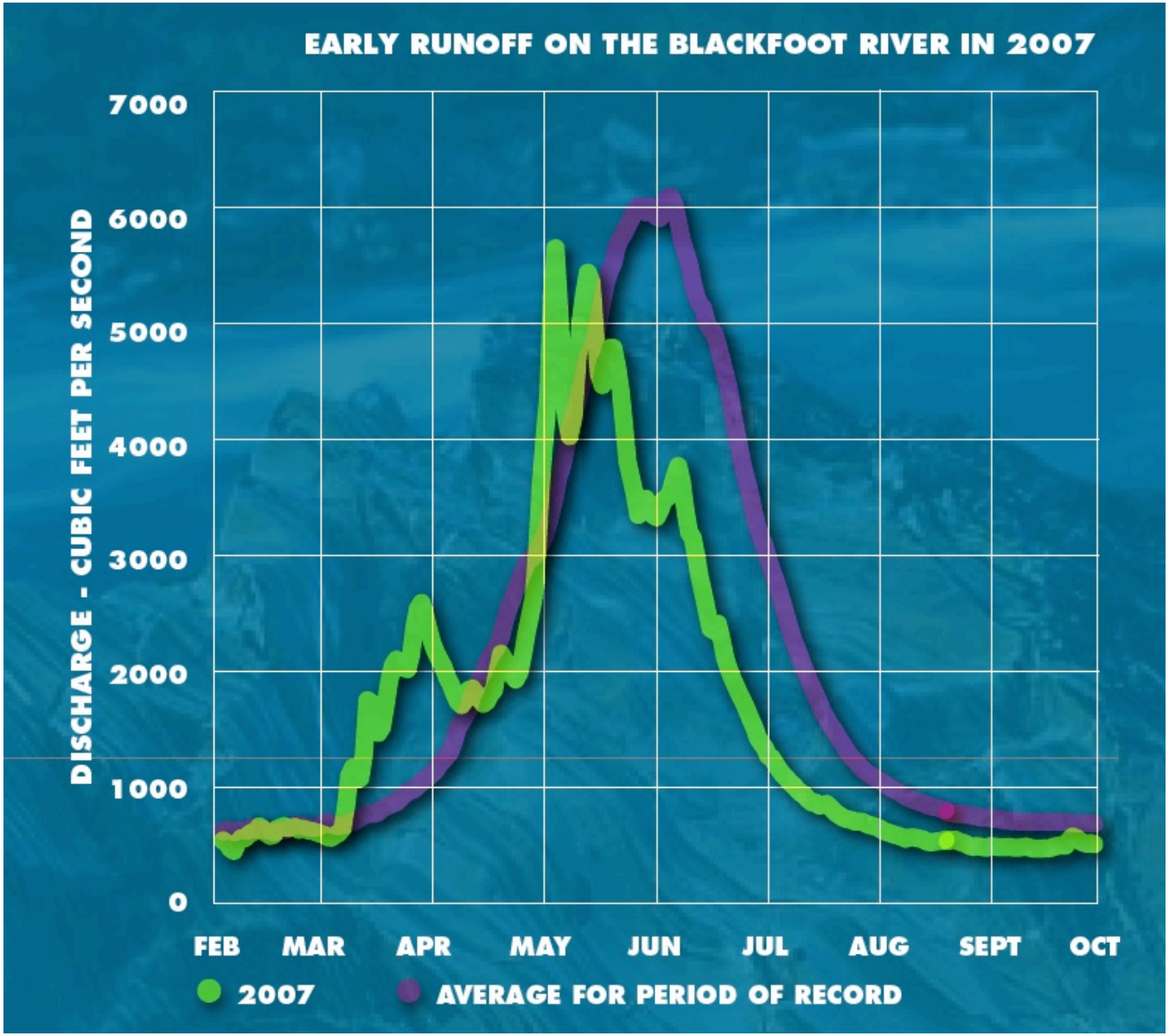
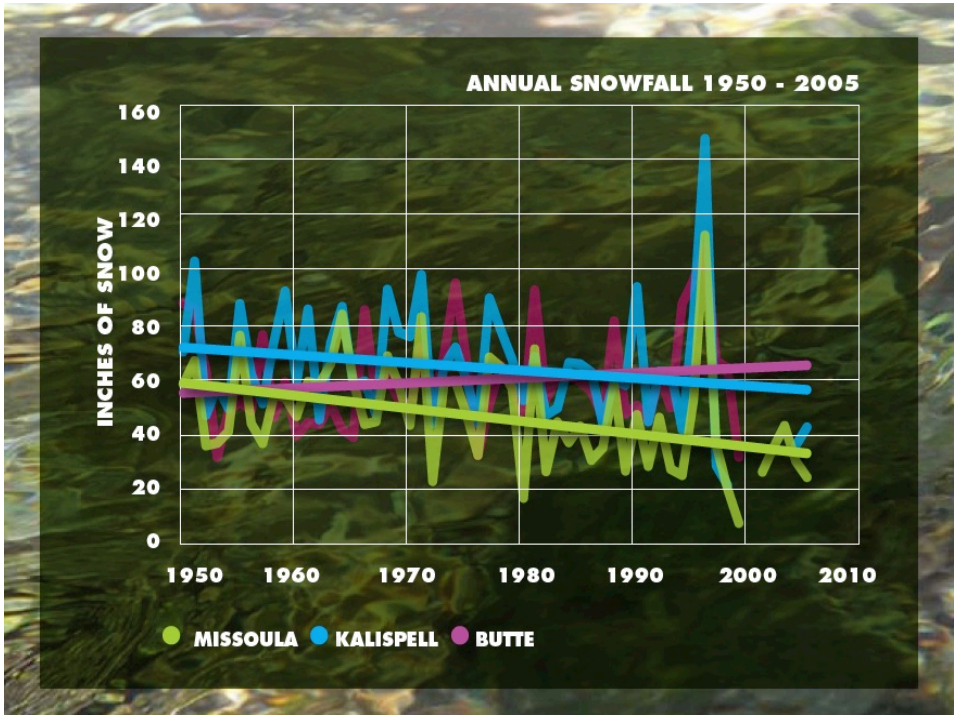


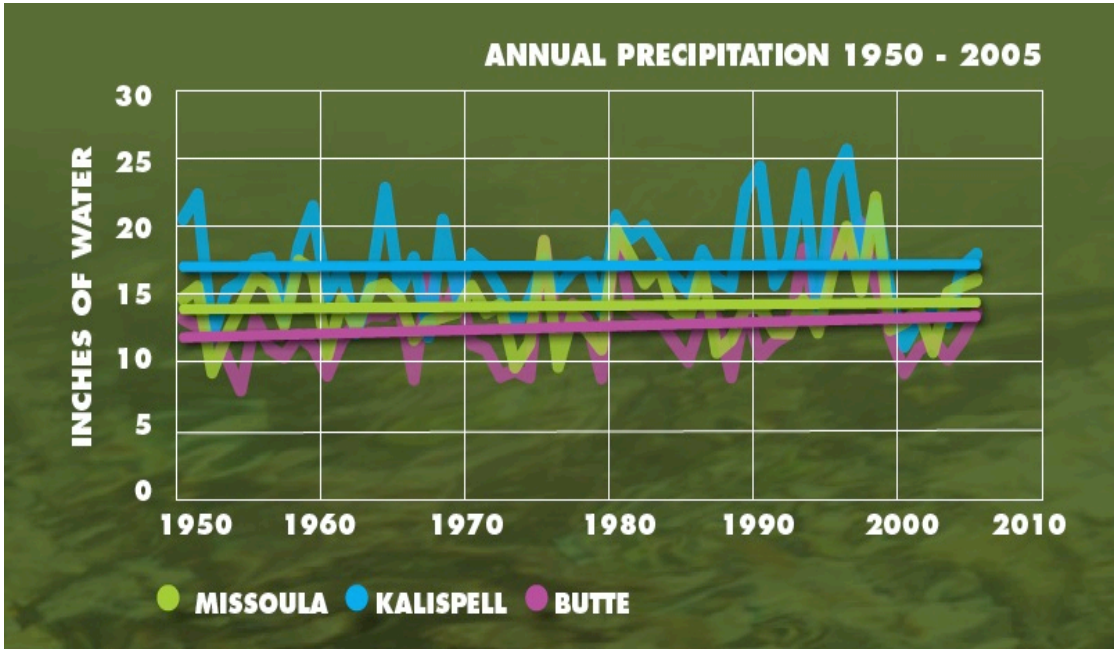
Fig. 4. Snow Water Equivalent (SWE) as measured on the first of May at snow courses in and surrounding GNP (the Crown of the Continent Area). Snow course measurements are made with a standardized sampling tube to obtain depth and density of snow.

Runoff timing,



The form of precipitation,





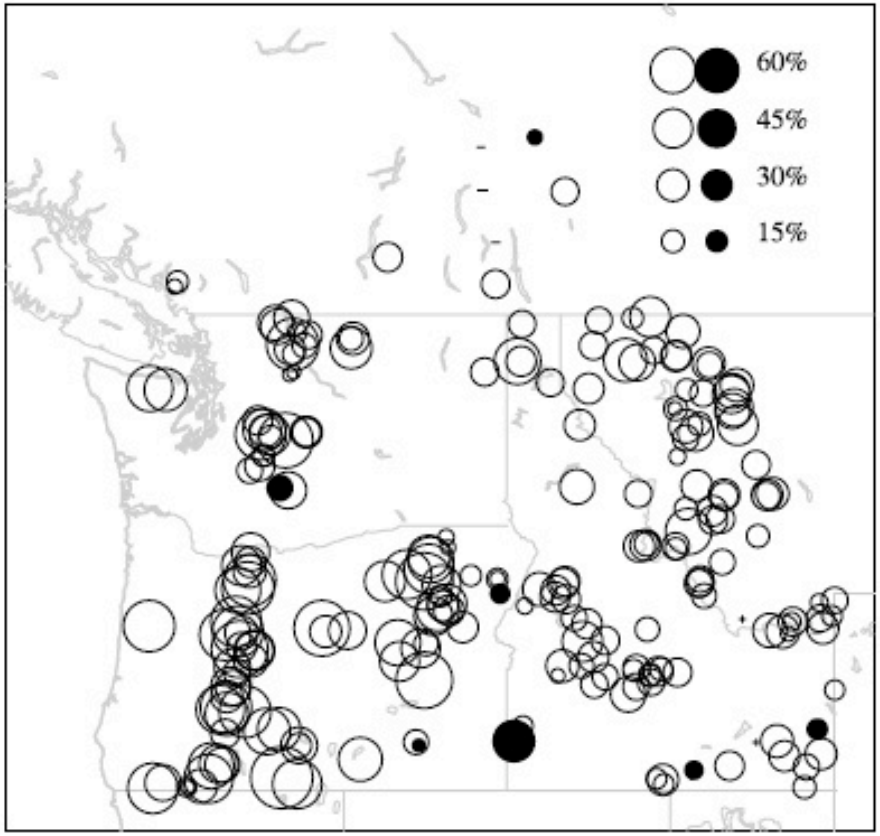


Figure 1. Linear trends, relative to starting value, in snow water equivalent (SWE) on April 1 over the period of record 1950–2000. Negative trends are shown as open circles, positive trends as solid circles; the magnitude of the trend is indicated by the area of the circle according to the legend. Trends less than 5% in absolute value are indicated by a + or – symbol.

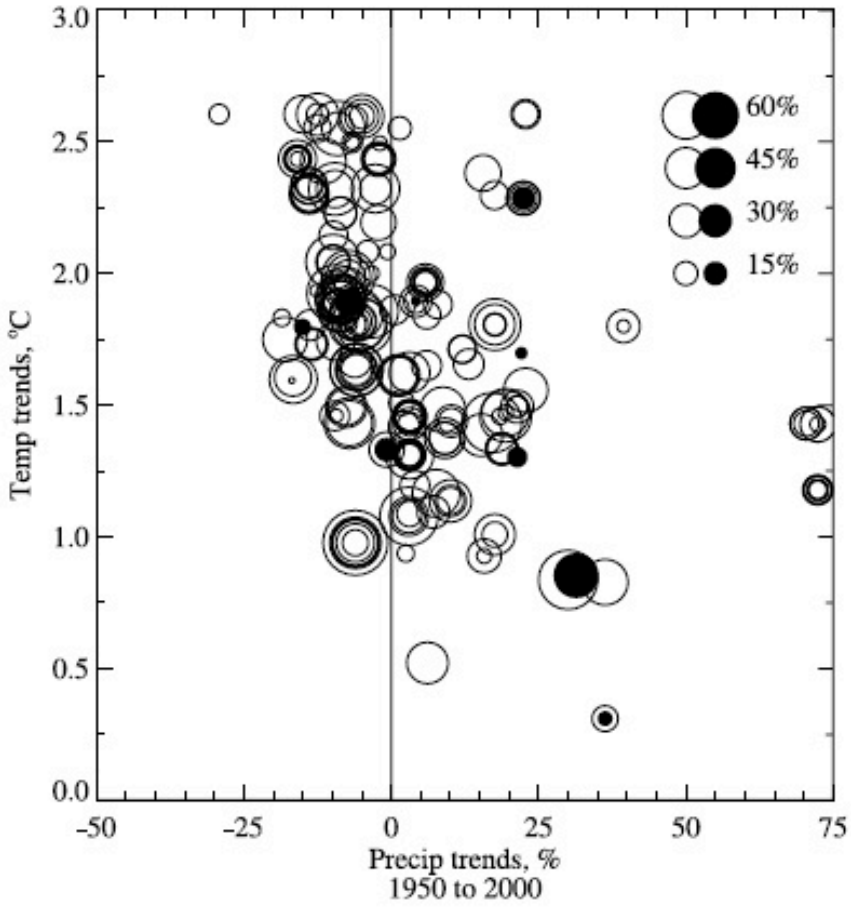
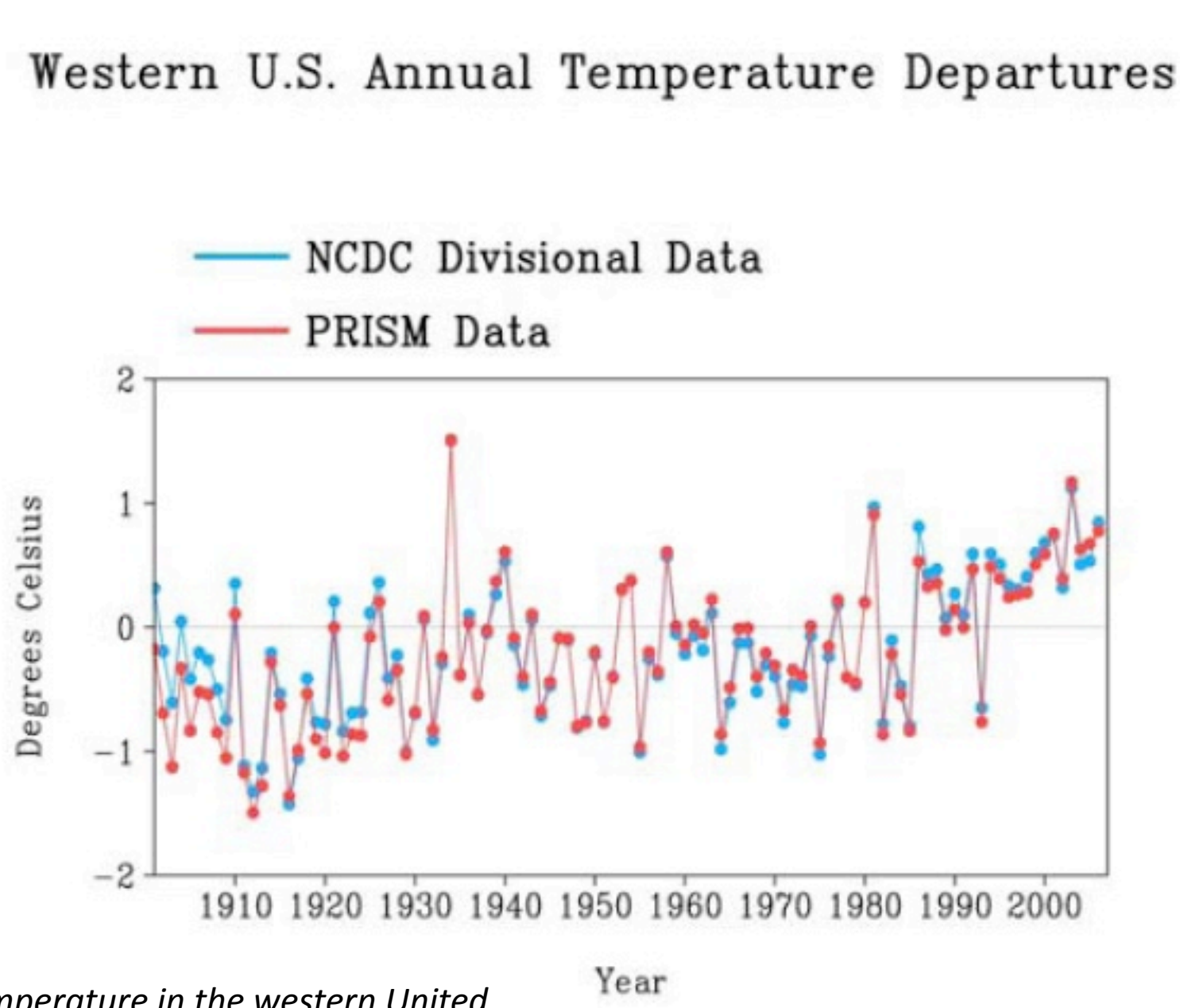


Figure 3. The same data as in Figure 1 are plotted against trends in NDJFM precipitation and temperature at nearby climate stations.

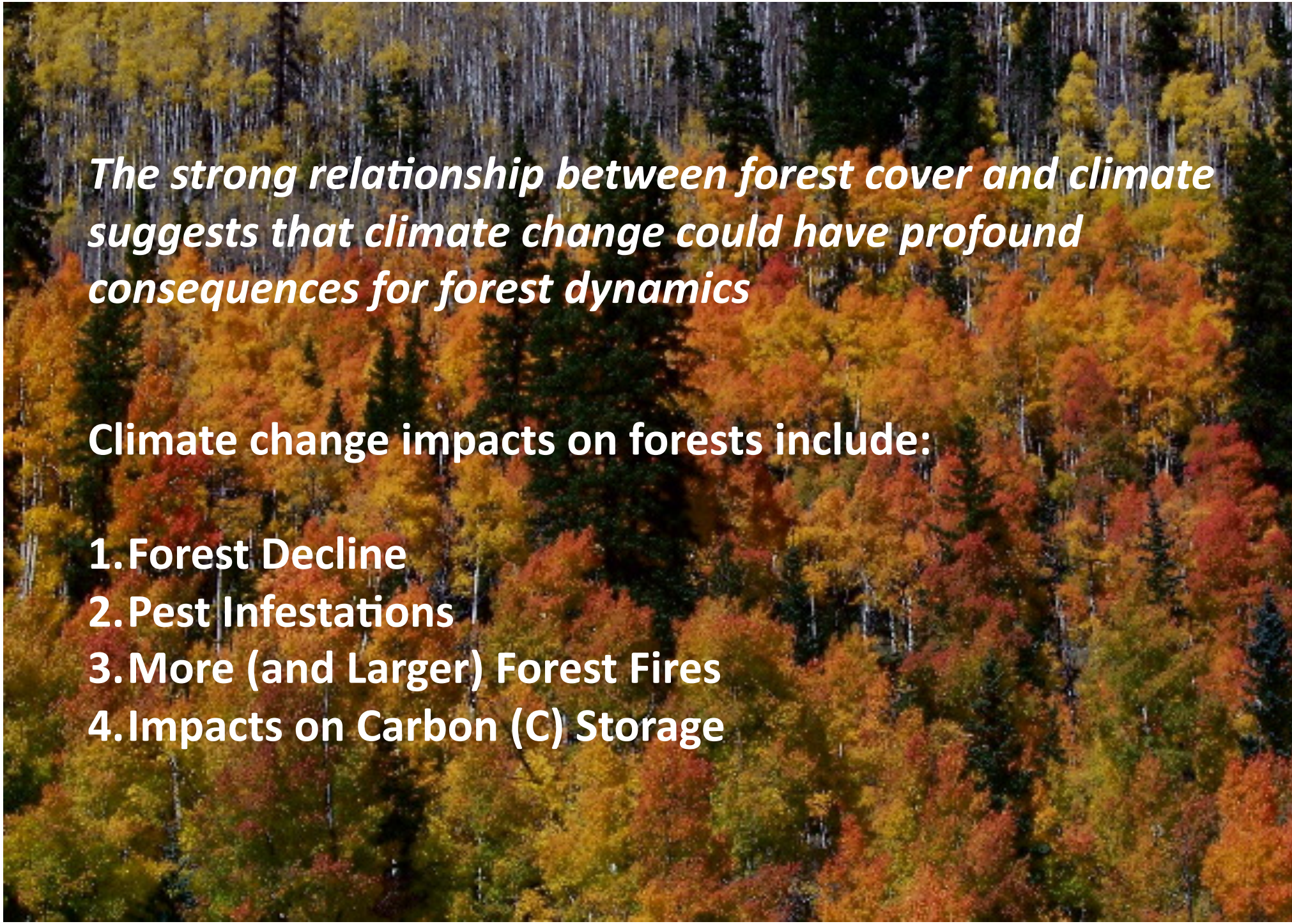
And these effects are occurring over broad scales

Mote (2003) J. Geophys. Res.



Average temperature in the western United States has risen considerably in the last 20 years—about 0.6C.

Diaz (2007), Geophys. Res. Lett



The strong relationship between forest cover and climate suggests that climate change could have profound consequences for forest dynamics

Climate change impacts on forests include:

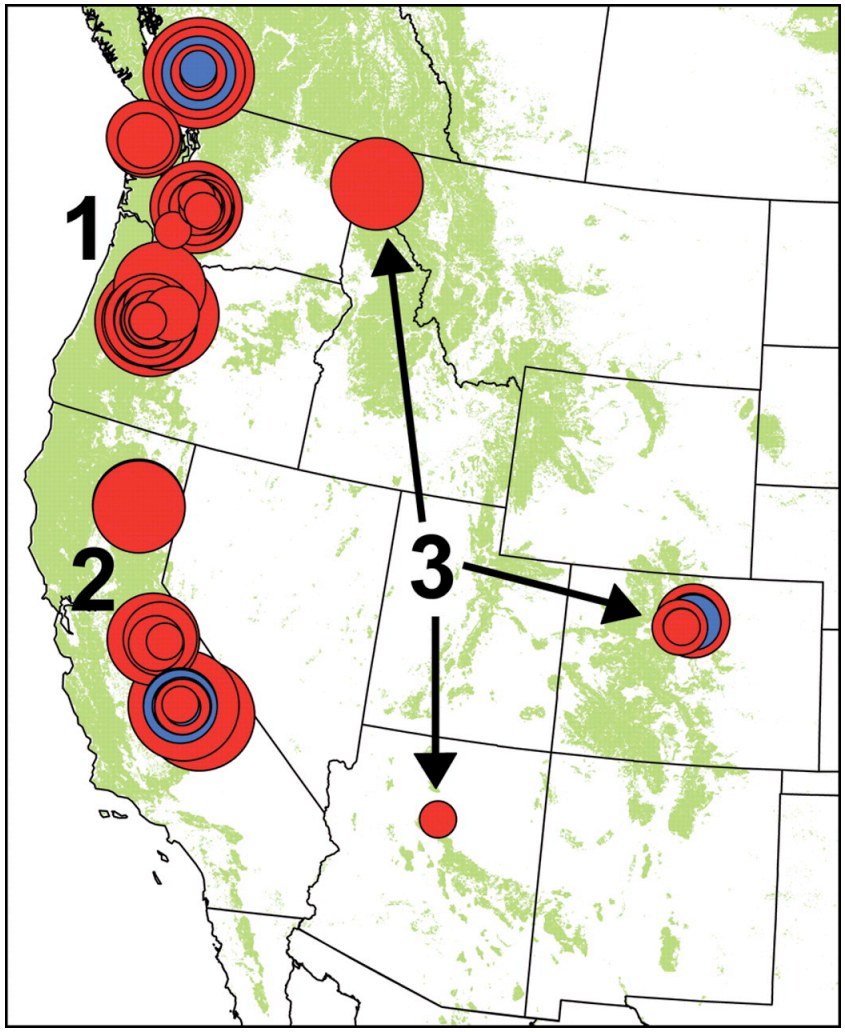
1. **Forest Decline**
2. **Pest Infestations**
3. **More (and Larger) Forest Fires**
4. **Impacts on Carbon (C) Storage**


Is there evidence that climate change is affecting forest dynamics?
Forest Decline?

Fig. 1. Locations of the 76 forest plots in the western United States and southwestern British Columbia

Increased Mortality

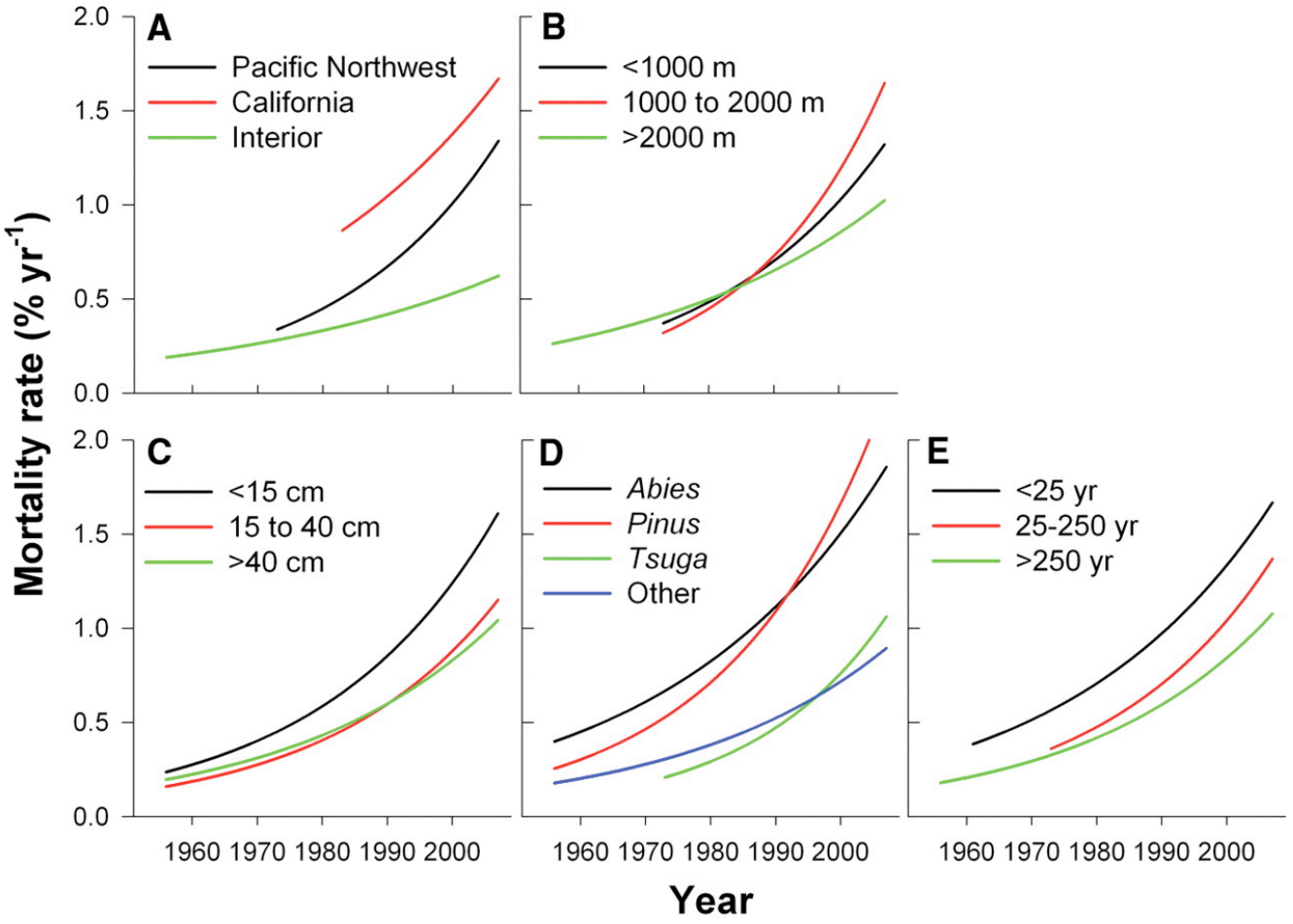
Increased Growth



P. J. van Mantgem et al., Science 323, 521 -524 (2009)

Published by AAAS

Fig. 2. Modeled trends in tree mortality rates for (A) regions, (B) elevational class, (C) stem diameter class, (D) genus, and (E) historical fire return interval class



P. J. van Mantgem et al., Science 323, 521 -524 (2009)

Published by AAAS

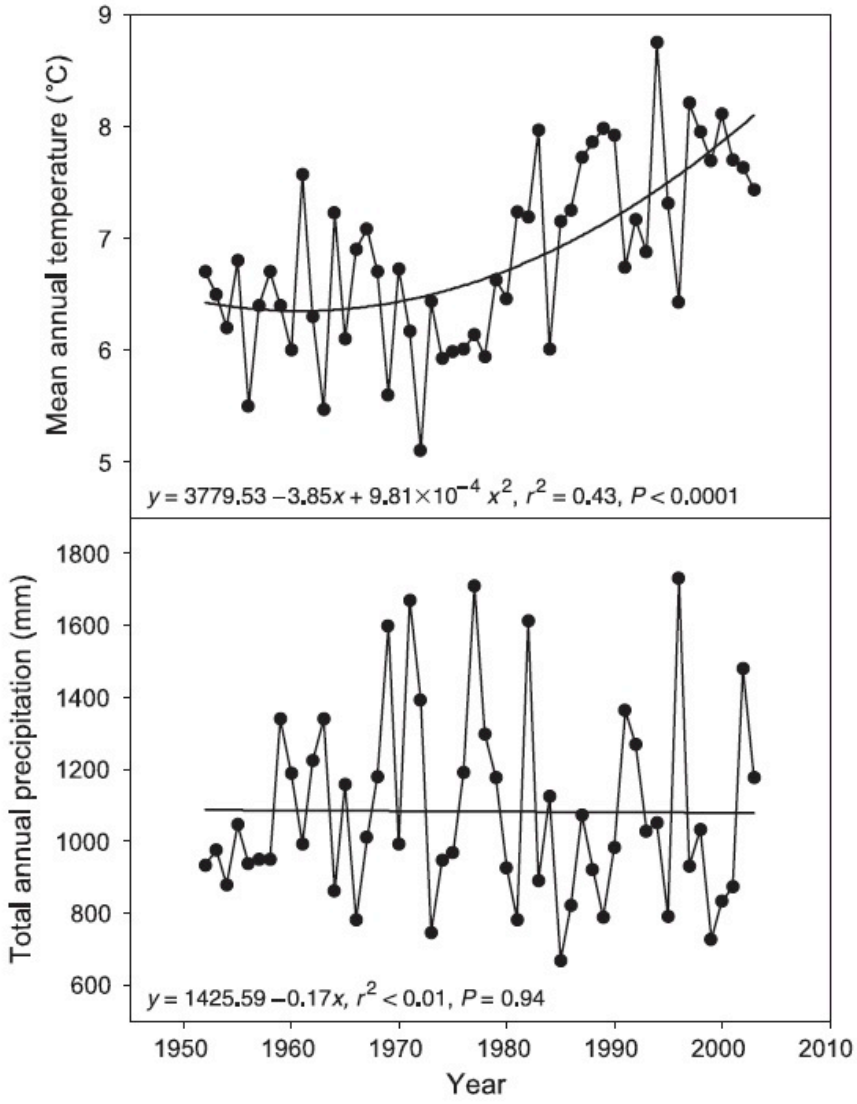
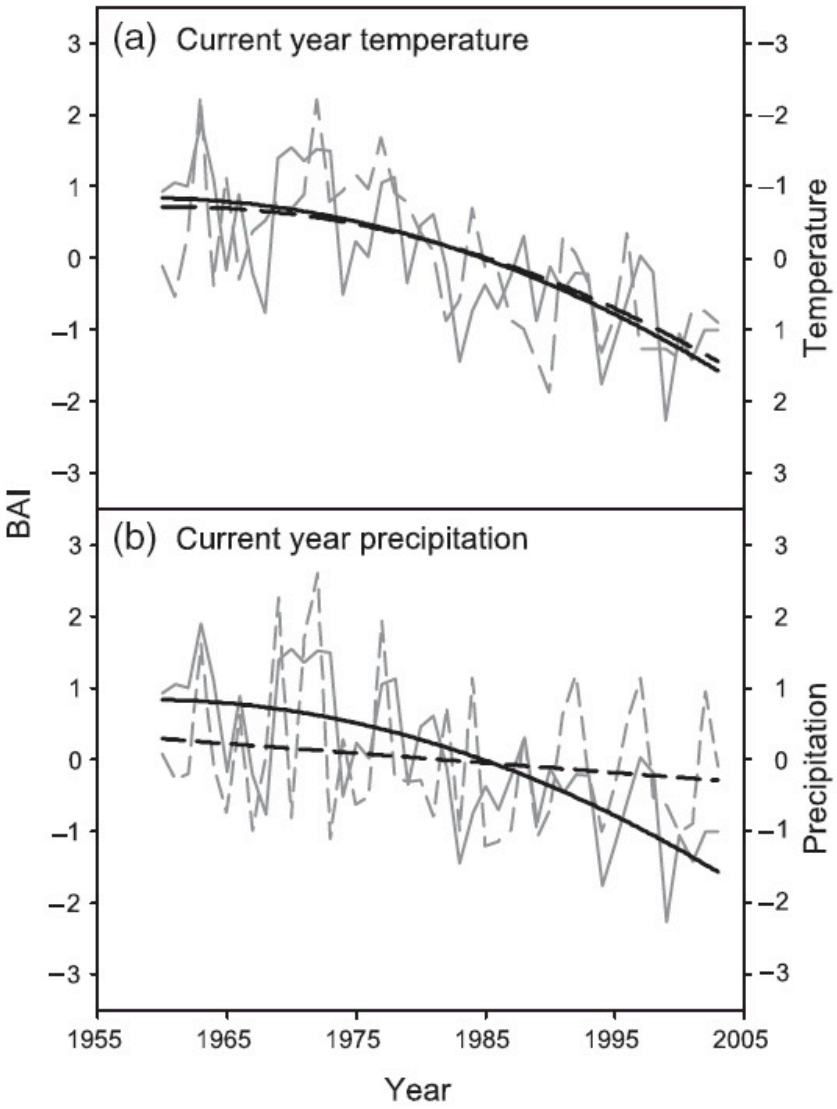
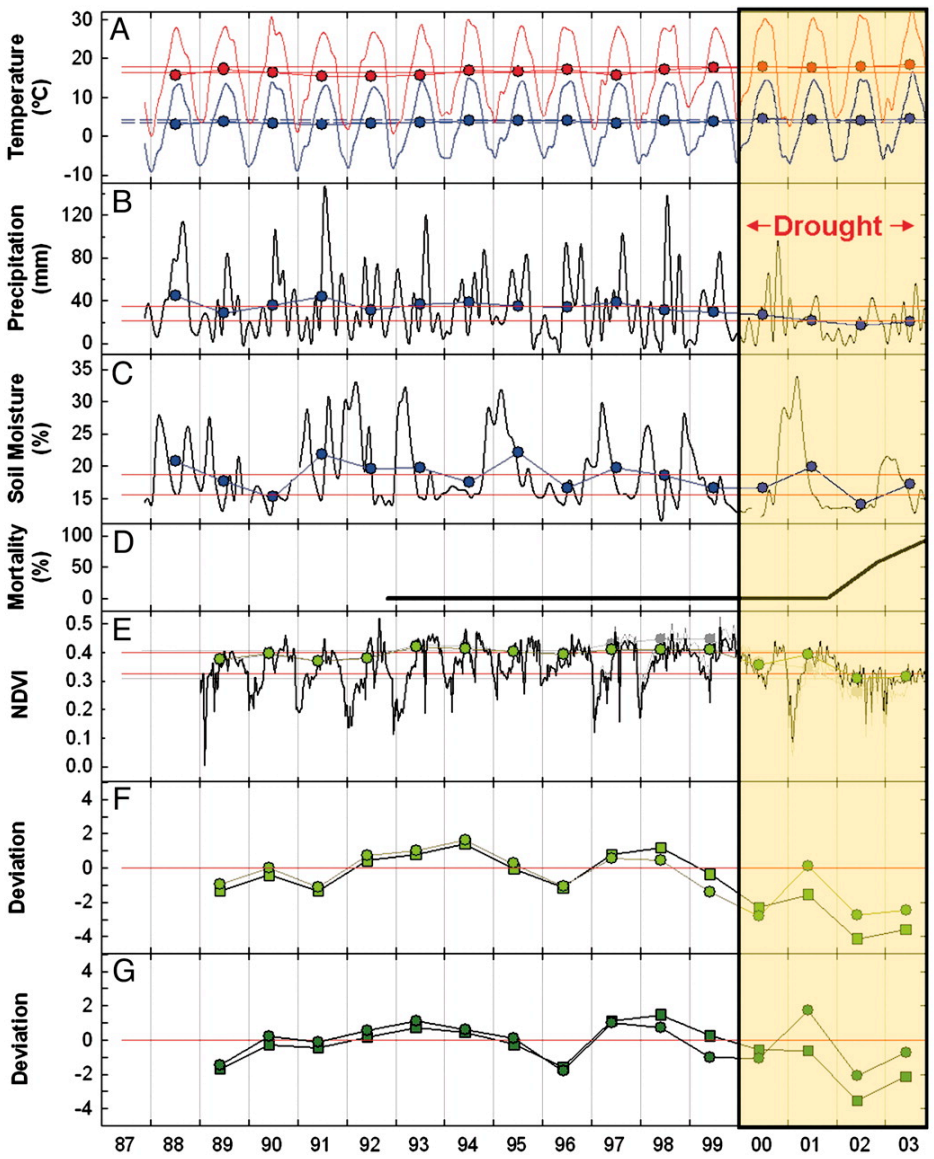


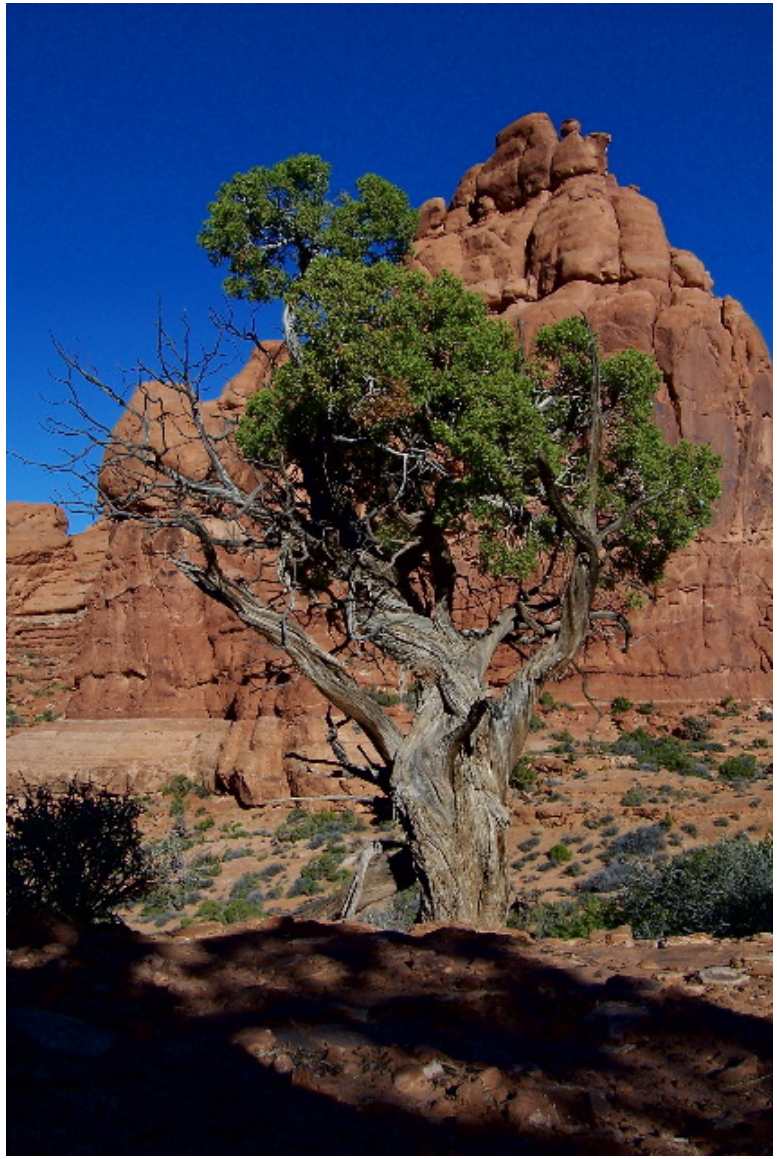
Fig. 2 Mean annual temperature and total annual precipitation at Turó de l'Home during the period 1952–2003. Temperatures show a significant warming trend beginning in the mid-1970s whereas no trend is seen for precipitation.



Jump et al. (2006), Global Change Biology, (Mediterranean Ecosystems)

Declines in Productivity Correlate with Climate Change in SW United States

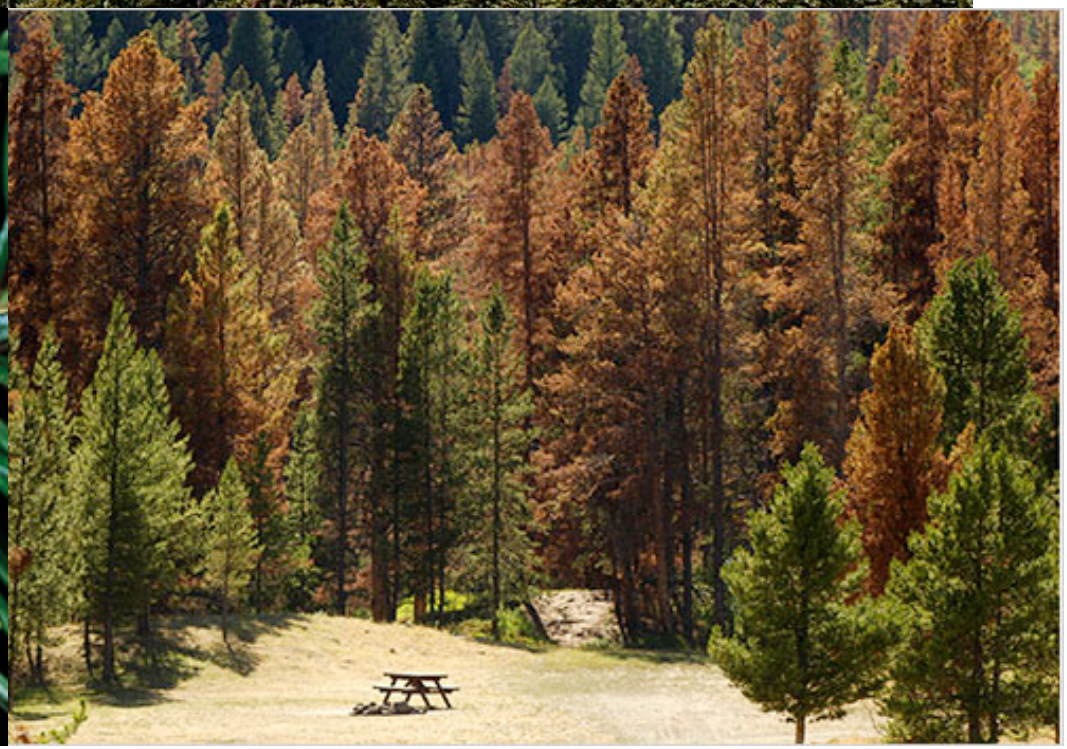




Breshears et al. (2005), PNAS


Is there evidence that climate change is affecting forest dynamics?
Forest Decline?
Yes, compelling evidence

Is there evidence that climate change is affecting forest pest dynamics ?

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Rocky Mountain News
ROCKYMOUNTAINNEWS.COM

Colorado pine beetle infestation swells to almost 2 million acres

By Jerd Smith

Saturday, January 17, 2009

Mountain pine beetles are chewing through Colorado's high-altitude forests at a slightly slower pace but are more active on the Front Range, according to a survey released Friday by the U.S. and Colorado forest services.

The beetles spread to 400,000 more acres in 2008, bringing the total area infected to about 2 million acres since 1996, when foresters first began tracking the outbreak.

The New York Times
nytimes.com

November 18, 2008

Bark Beetles Kill Millions of Acres of Trees in West

By JIM ROBBINS

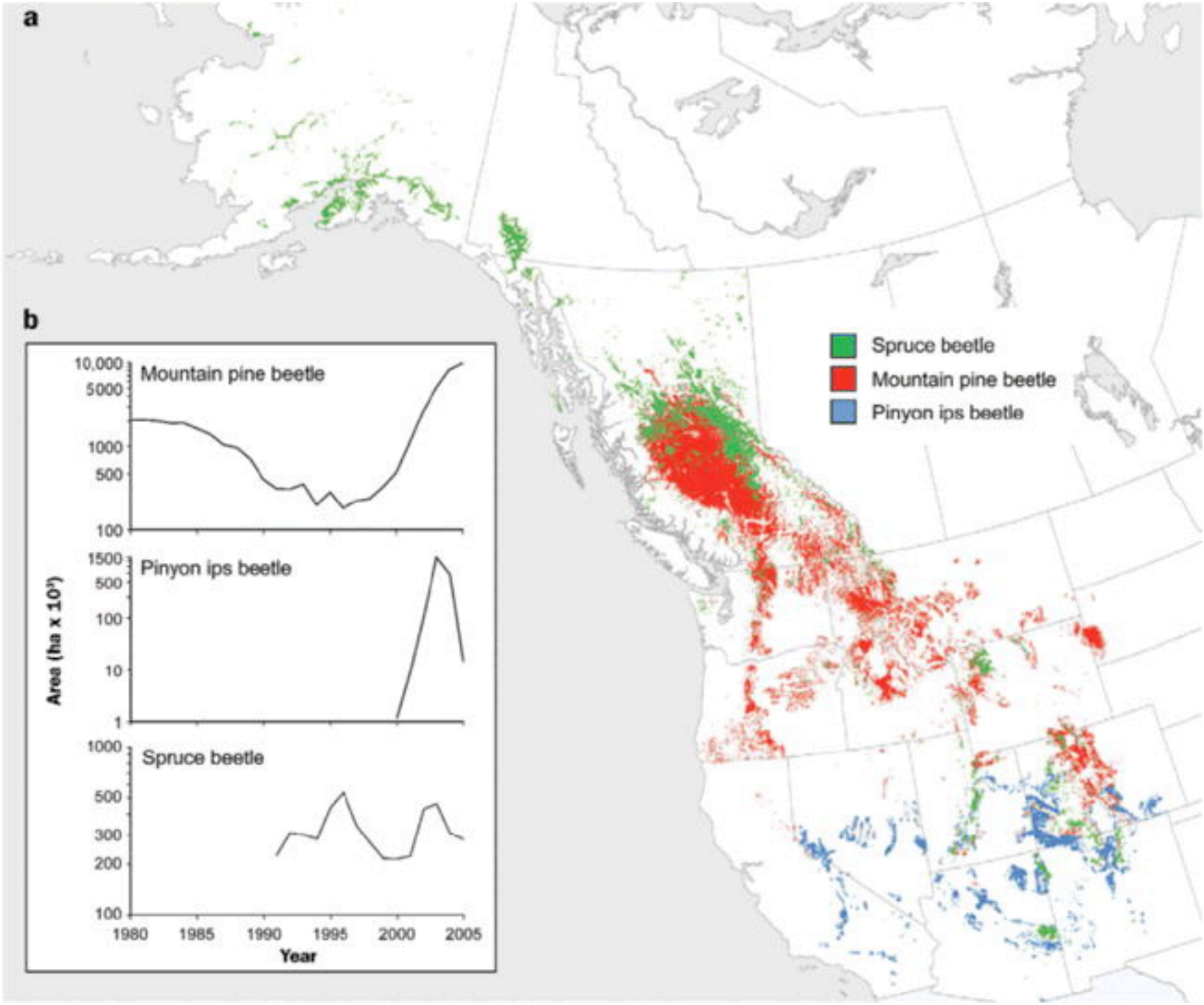
HELENA, Mont. — On the side of a mountain on the outskirts of Montana's capital city, loggers are racing against a beetle grub the size of a grain of rice.

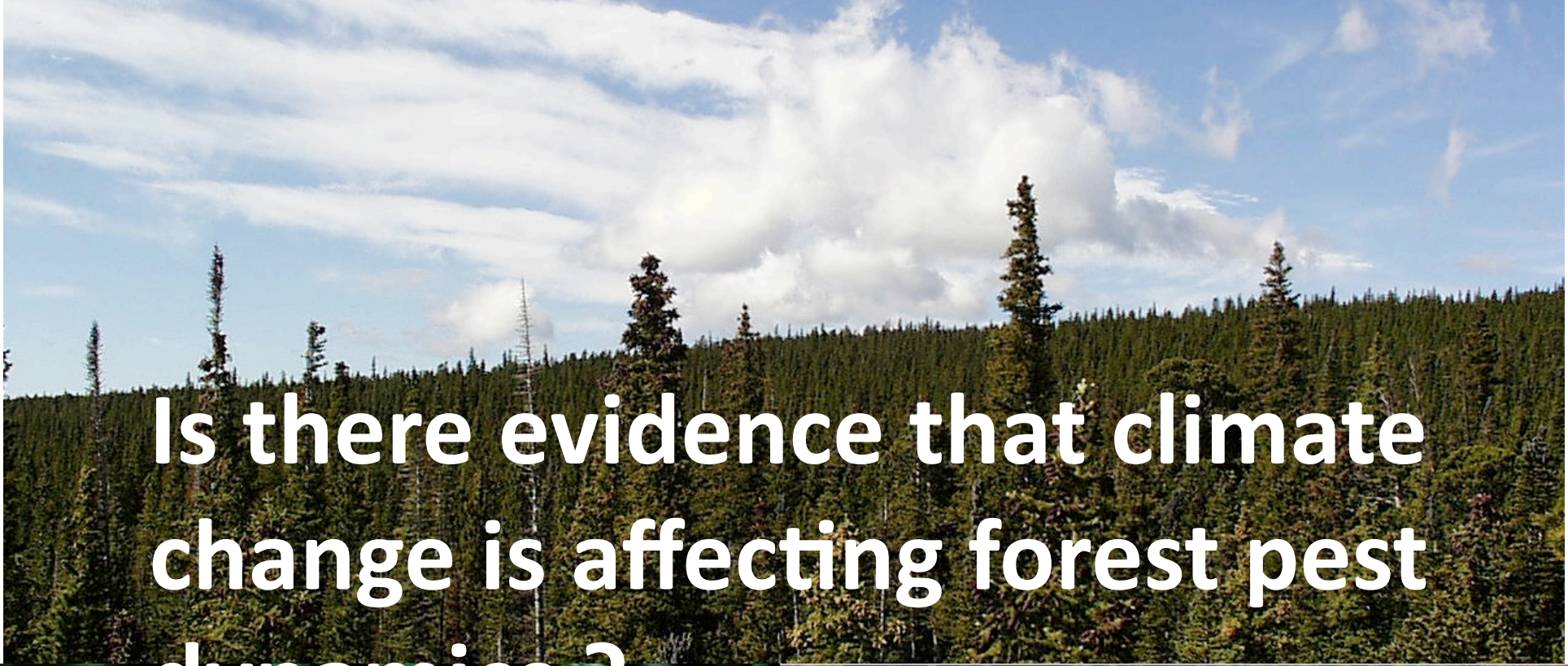
From New Mexico to British Columbia, the region's signature pine forests are succumbing to a huge infestation of mountain pine beetles that are turning a blanket of green forest into a blanket of rust red. Montana has lost a million acres of trees to the beetles, and in northern Colorado and southern Wyoming the situation is worse.

"We're seeing exponential growth of the infestation," said Clint Kyhl, director of a Forest Service incident management team in Laramie, Wyo., that was set up to deal with the threat of fire from dead forests. Increased construction of homes in forest areas over the last 20 years makes the problem worse.

In Wyoming and Colorado in 2006 there were a million acres of dead trees. Last year it was 1.5 million. This year it is expected to total over two million. In the Canadian provinces of British Columbia and Alberta, the problem is most severe. It is the largest known insect infestation in the history of North America, officials said. British Columbia has lost 33 million acres of lodgepole pine forest, and a freak wind event in 2006 blew mountain pine beetles, a species of bark beetle, over the Continental Divide to northern Alberta. Experts fear that the beetles could travel all the way to the Great Lakes.

Beetles devastate forests in response to drought


a
b
Spruce beetle
Mountain pine beetle
Pinyon ips beetle
Mountain pine beetle
Pinyon ips beetle
Spruce beetle
10,000
5000
1000
500
100
1500
500
100
10
1
1000
500
300
200
100
Area (ha x 10³)
1980
1985
1990
1995
2000
2005
Year

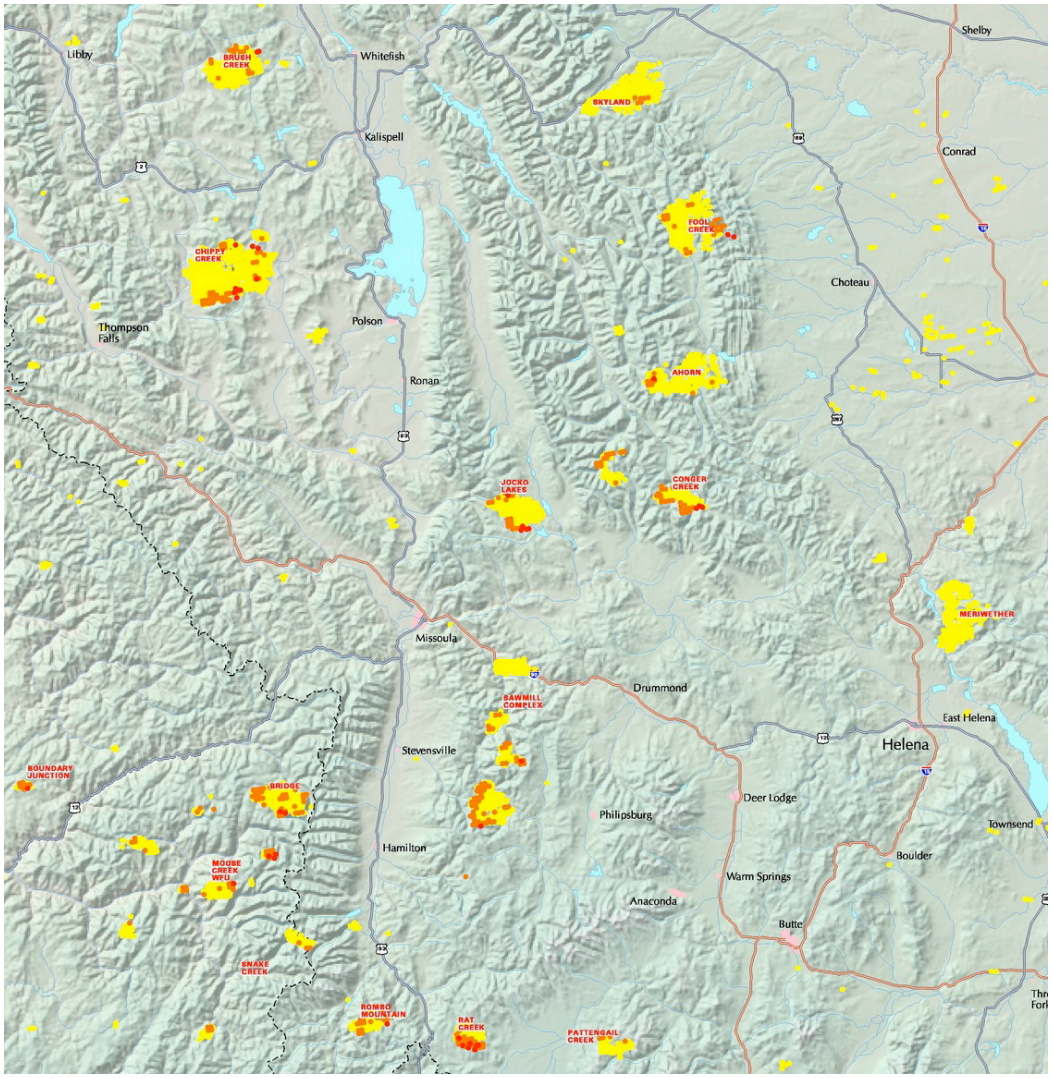


Is there evidence that climate change is affecting forest pest dynamics ?

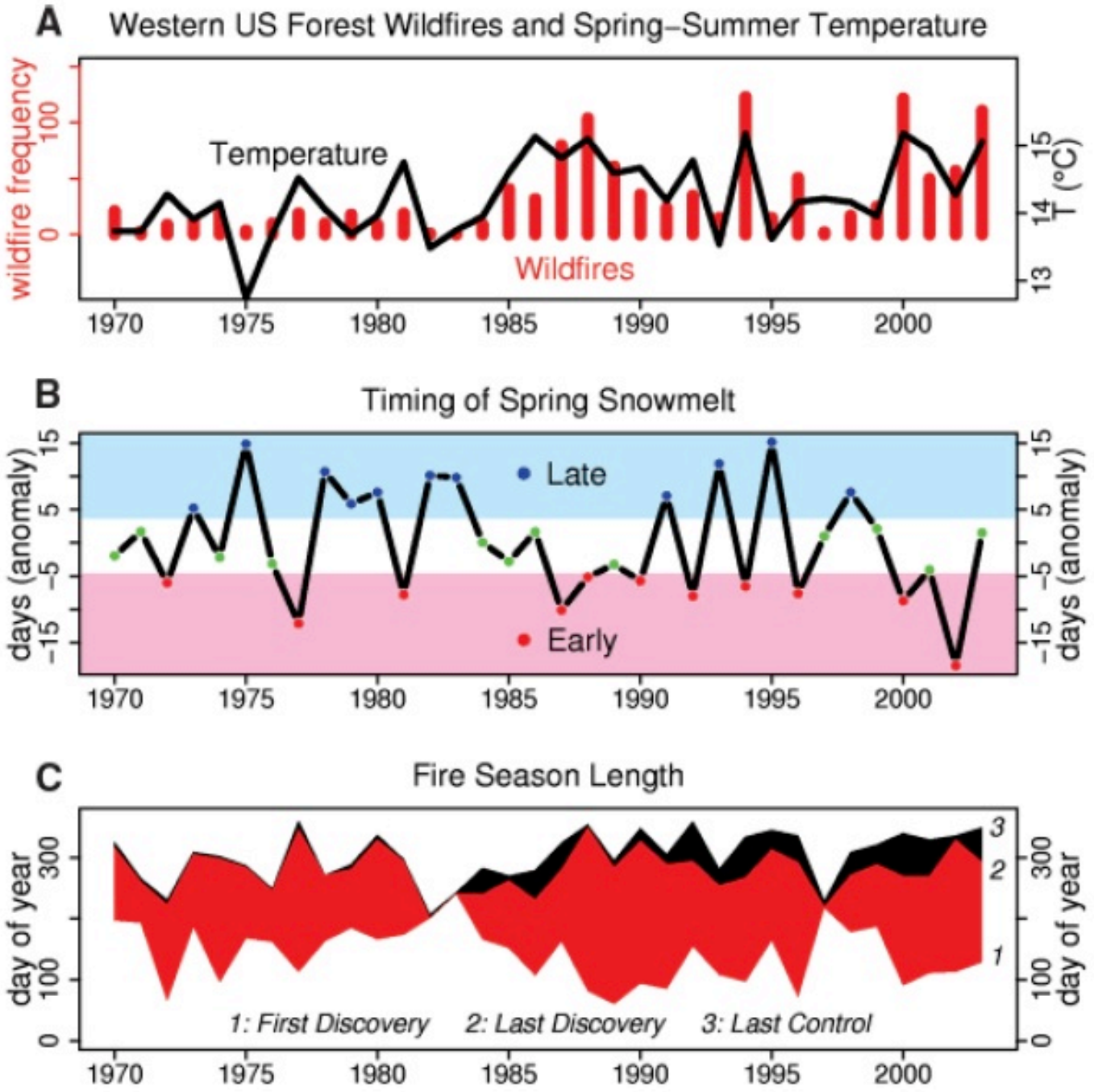
Definitely, but the causes are complex


Is there evidence
that
climate
change is
causing more/
larger wildfires?

Summer 2007 Montana Wildfires



Research has linked drought, rising temperatures, earlier melting of snowpack, and fuel buildups due to past fire suppression to the extreme fire seasons of recent years

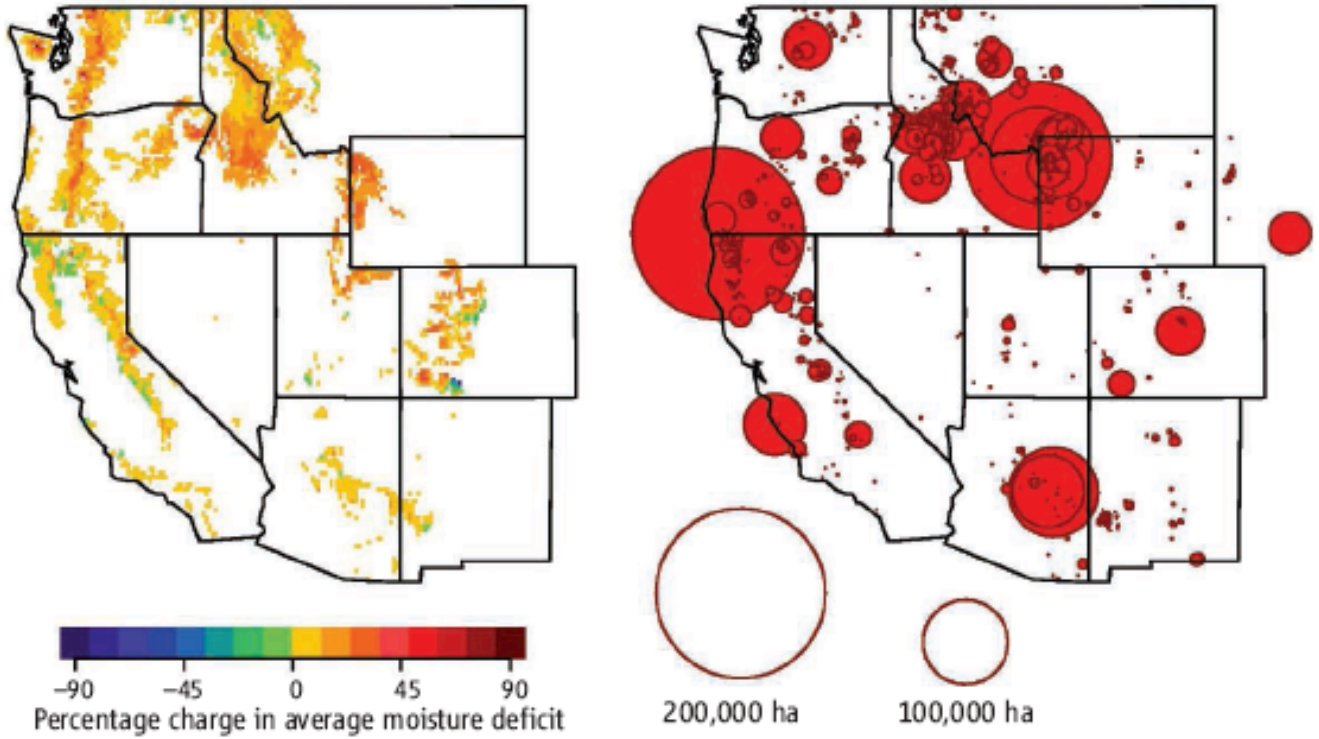

A
Western US Forest Wildfires and Spring–Summer Temperature
wildfire frequency
0
100
Temperature
Wildfires
13
14
15
T (°C)
1970
1975
1980
1985
1990
1995
2000
B
Timing of Spring Snowmelt
days (anomaly)
−15
−5
5
15
Late
Early
C
Fire Season Length
day of year
0
100
300
1: First Discovery
2: Last Discovery
3: Last Control
1
2
3

CLIMATE CHANGE

Is Global Warming Causing More, Larger Wildfires?

Higher spring and summer temperatures and earlier snowmelt are extending the wildfire season and increasing the intensity of wildfires in the western United States.

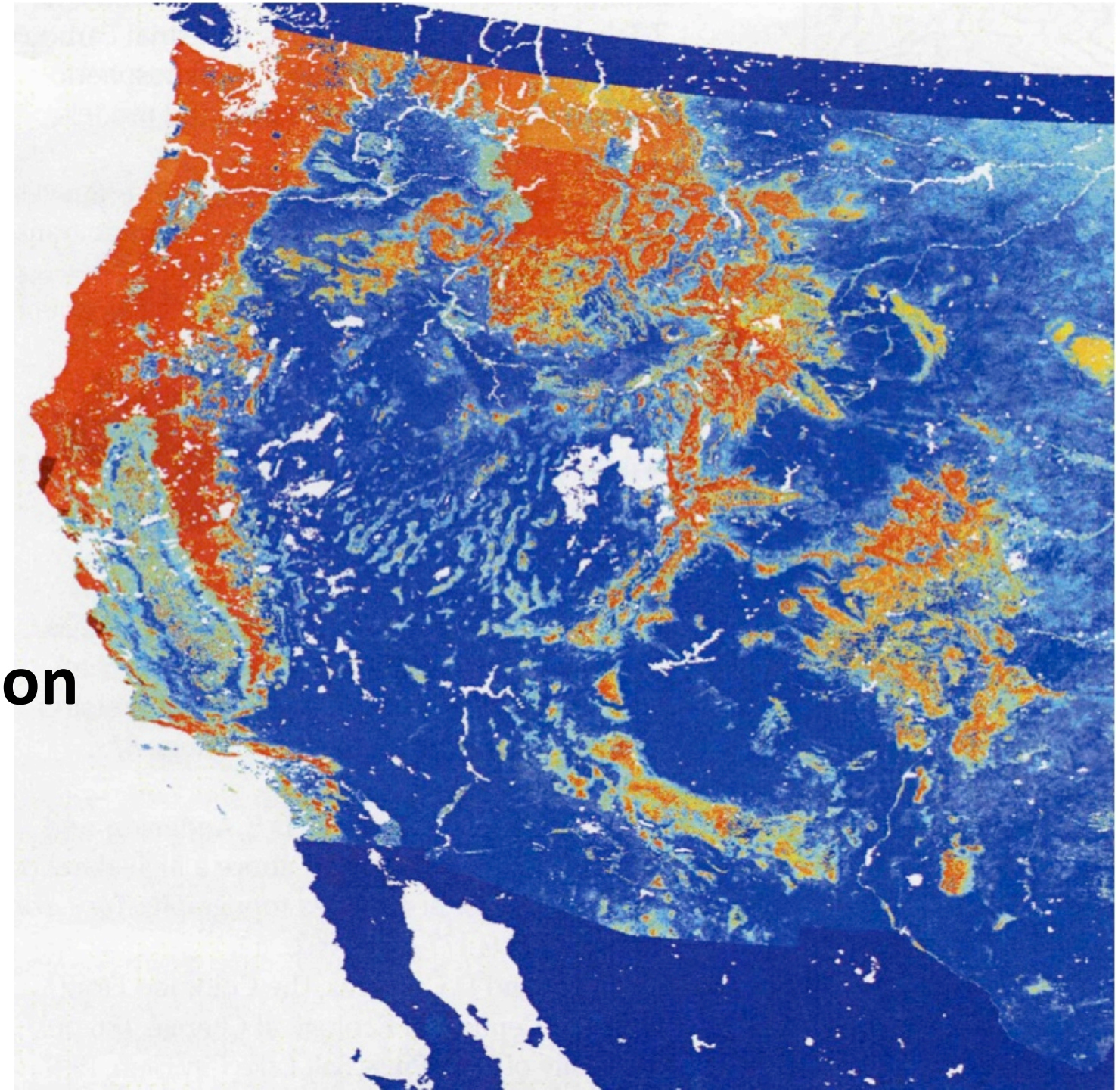
Steven W. Running



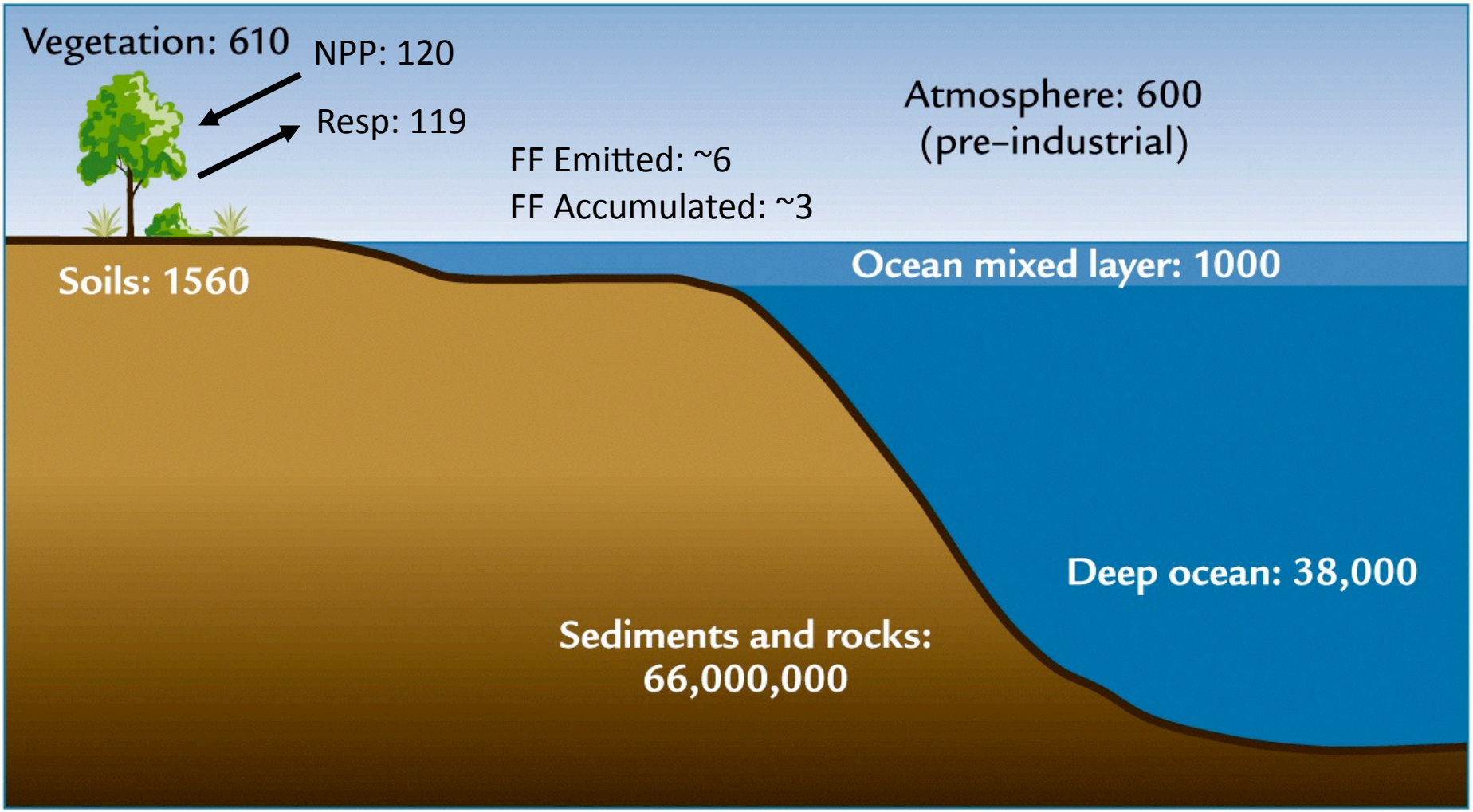
Less moisture—more fires. Between 1970 and 2003, spring and summer moisture availability declined in many forests in the western United States (**left**). During the same time span, most wildfires exceeding 1000 ha in burned area occurred in these regions of reduced moisture availability (**right**). [Data from (*4*)]


Is there evidence that climate change is causing more/ larger wildfires?
Yes, and compelling

How is climate change affecting forest carbon dynamics?



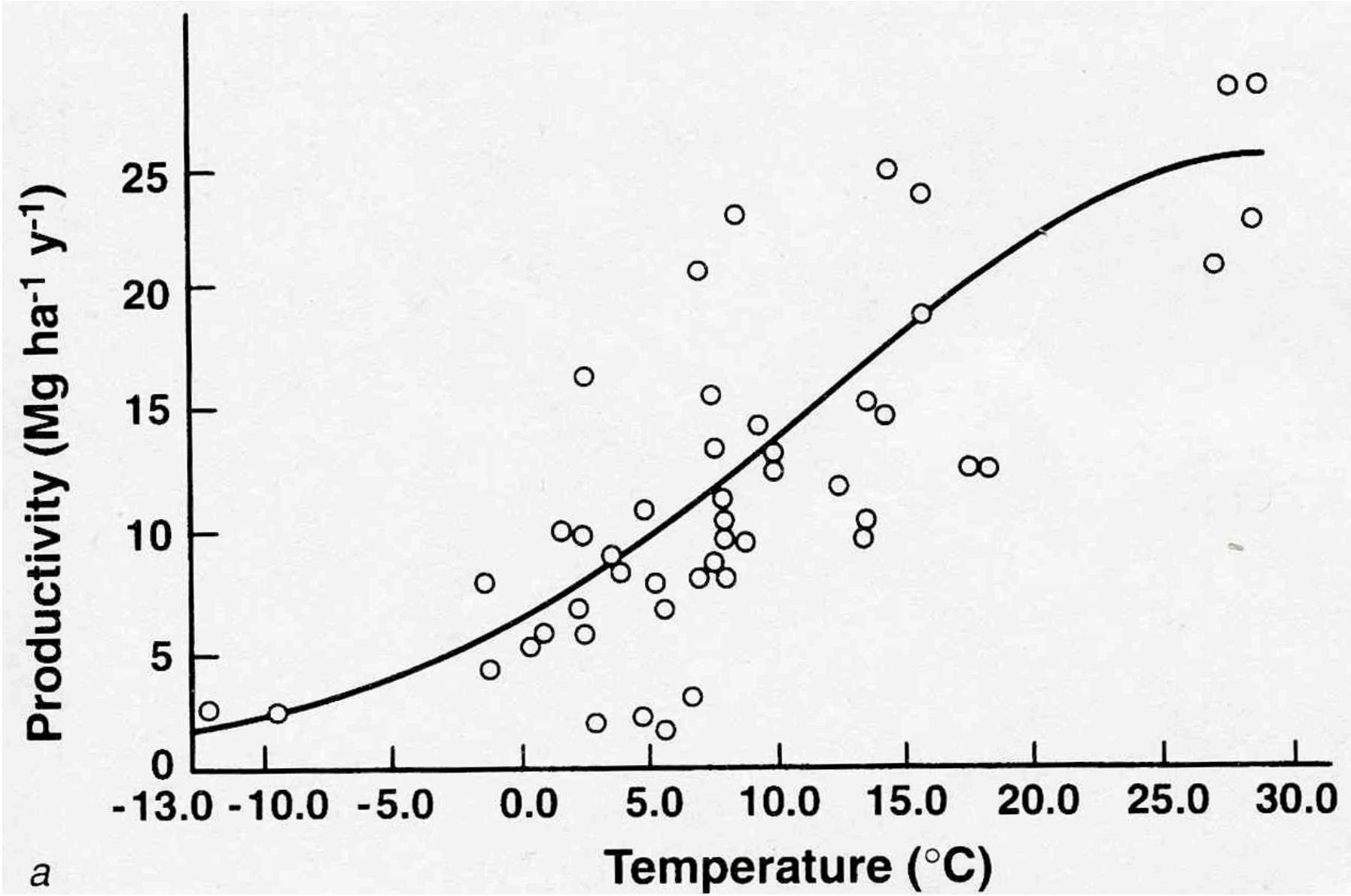
Carbon Cycling in Terrestrial Ecosystems



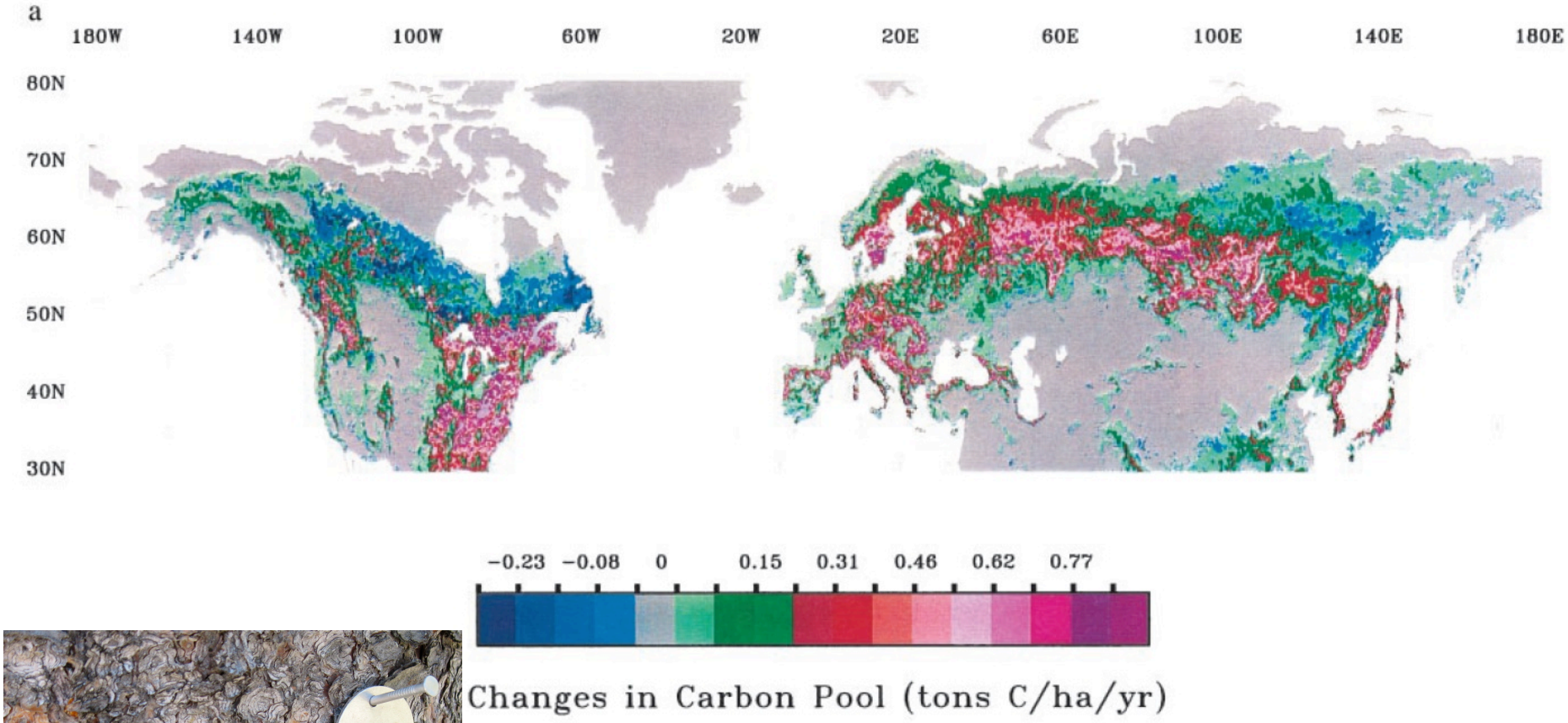
A Major carbon reservoirs (gigatons)

Forests are helping us by absorbing some of our CO2 ('Carbon sink'). How?

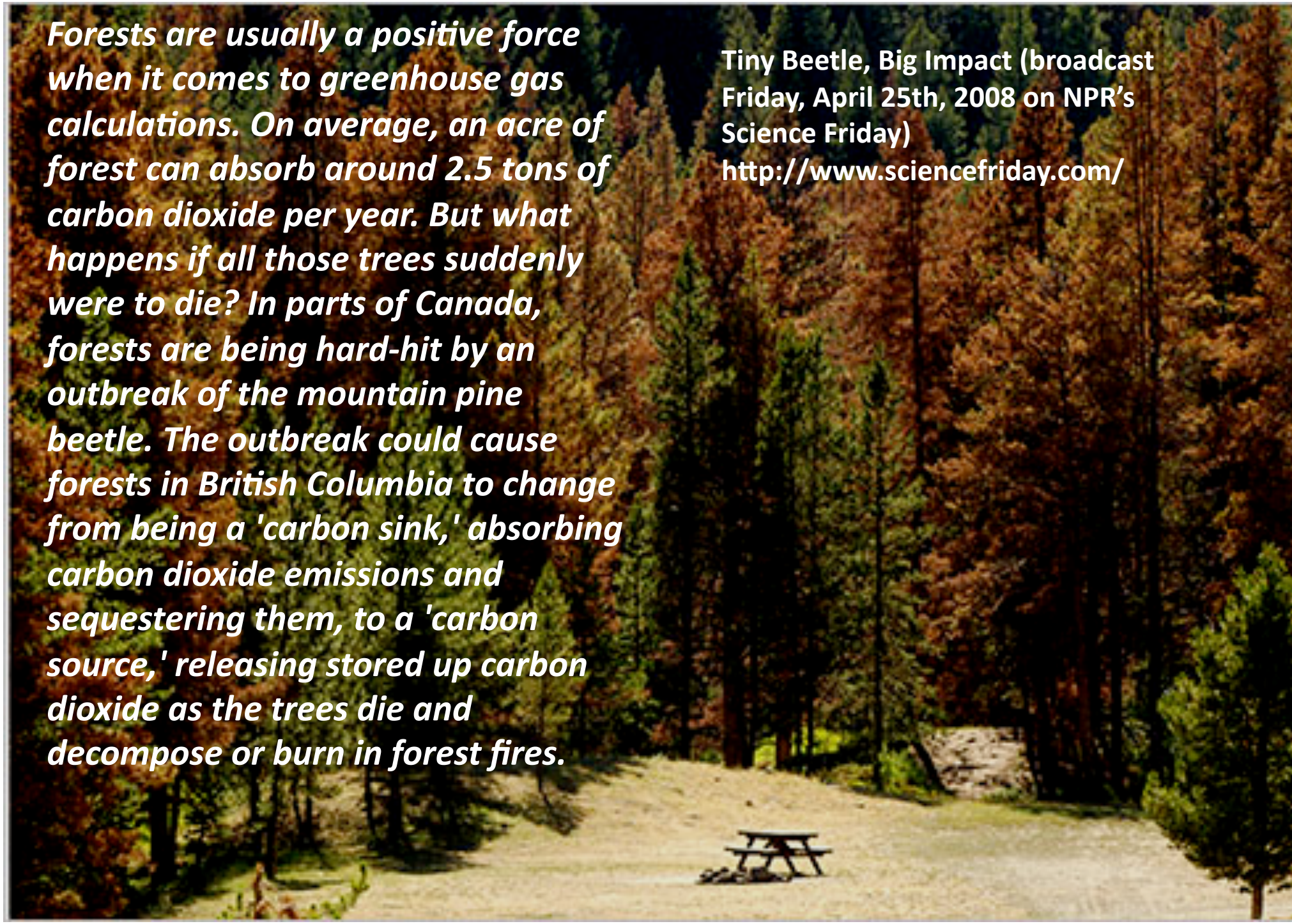
The Effects of Temperature on Plant Production (NPP)



Increased Carbon Storage in High Latitude Forests



Can we expect this “discount” to last?



Forests are usually a positive force when it comes to greenhouse gas calculations. On average, an acre of forest can absorb around 2.5 tons of carbon dioxide per year. But what happens if all those trees suddenly were to die? In parts of Canada, forests are being hard-hit by an outbreak of the mountain pine beetle. The outbreak could cause forests in British Columbia to change from being a 'carbon sink,' absorbing carbon dioxide emissions and sequestering them, to a 'carbon source,' releasing stored up carbon dioxide as the trees die and decompose or burn in forest fires.

Tiny Beetle, Big Impact (broadcast Friday, April 25th, 2008 on NPR's Science Friday)
http://www.sciencefriday.com/

Summary, Part I

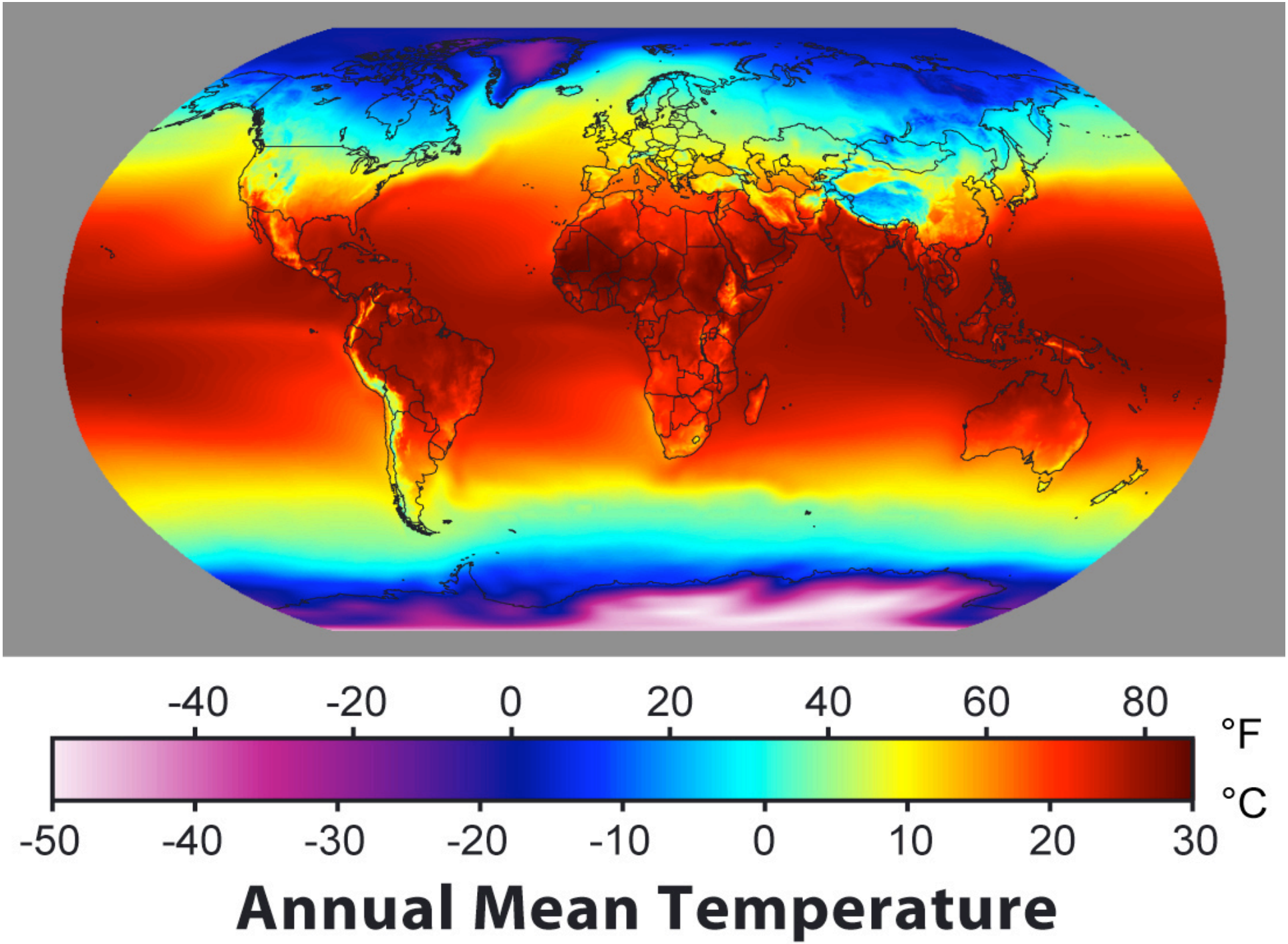
1. Evidence from long-term forest plots that forest mortality rates are increasing, and warming seems to be the dominant contributor

3. Pest infestations are becoming more common, and climate change appears to be partially responsible, although there are multiple interactions

3. Climate change indices are correlated with increases in fire frequency and magnitude, but there are also other controlling factors (e.g., fire suppression)

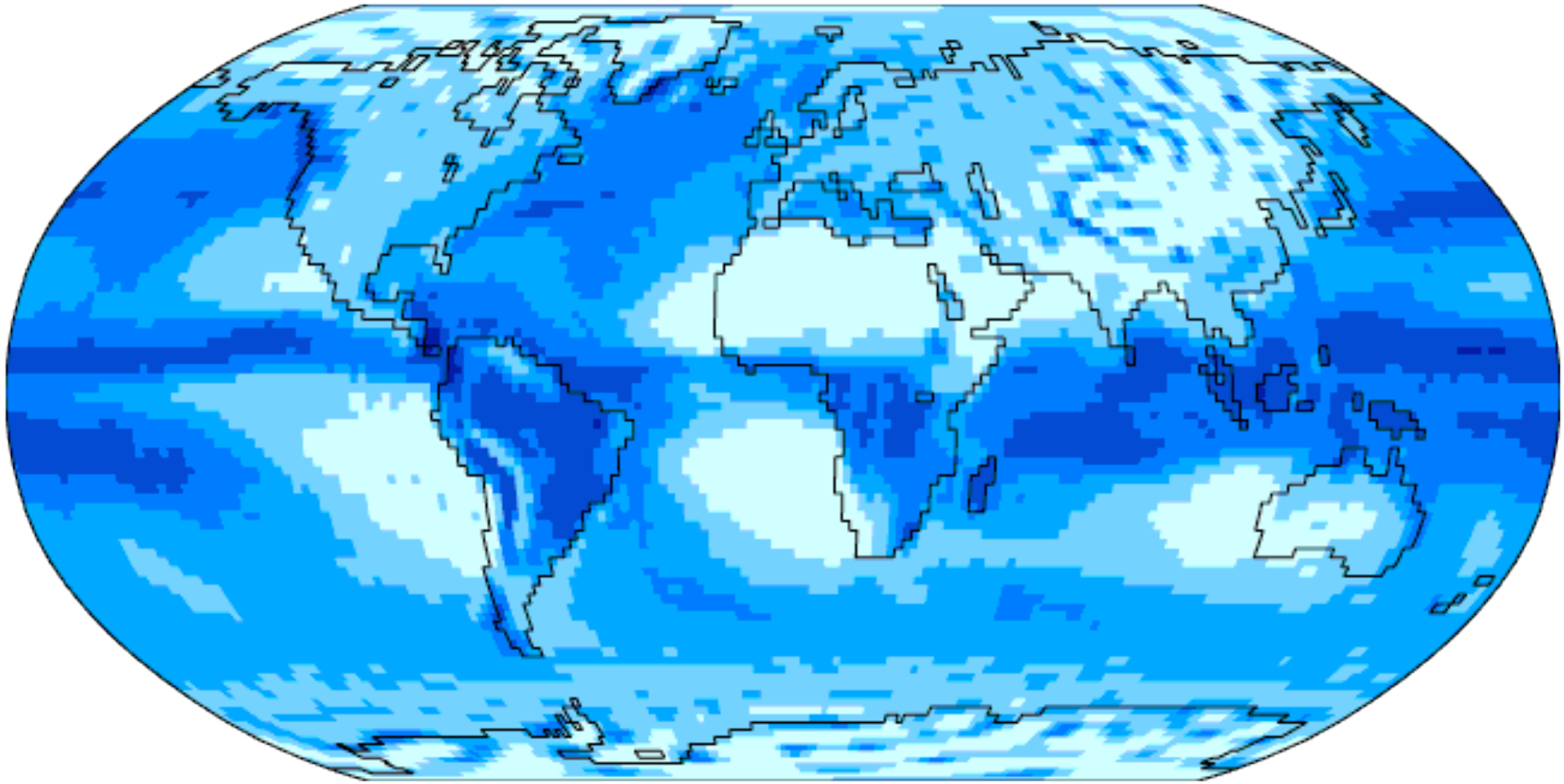
4. A little bit of global warming could be good for northern hemisphere forest C storage (with some important caveats)


What About Tropical Forests?


-40
-20
0
20
40
60
80
°F
°C
-50
-40
-30
-20
-10
0
10
20
30
Annual Mean Temperature

Precipitation

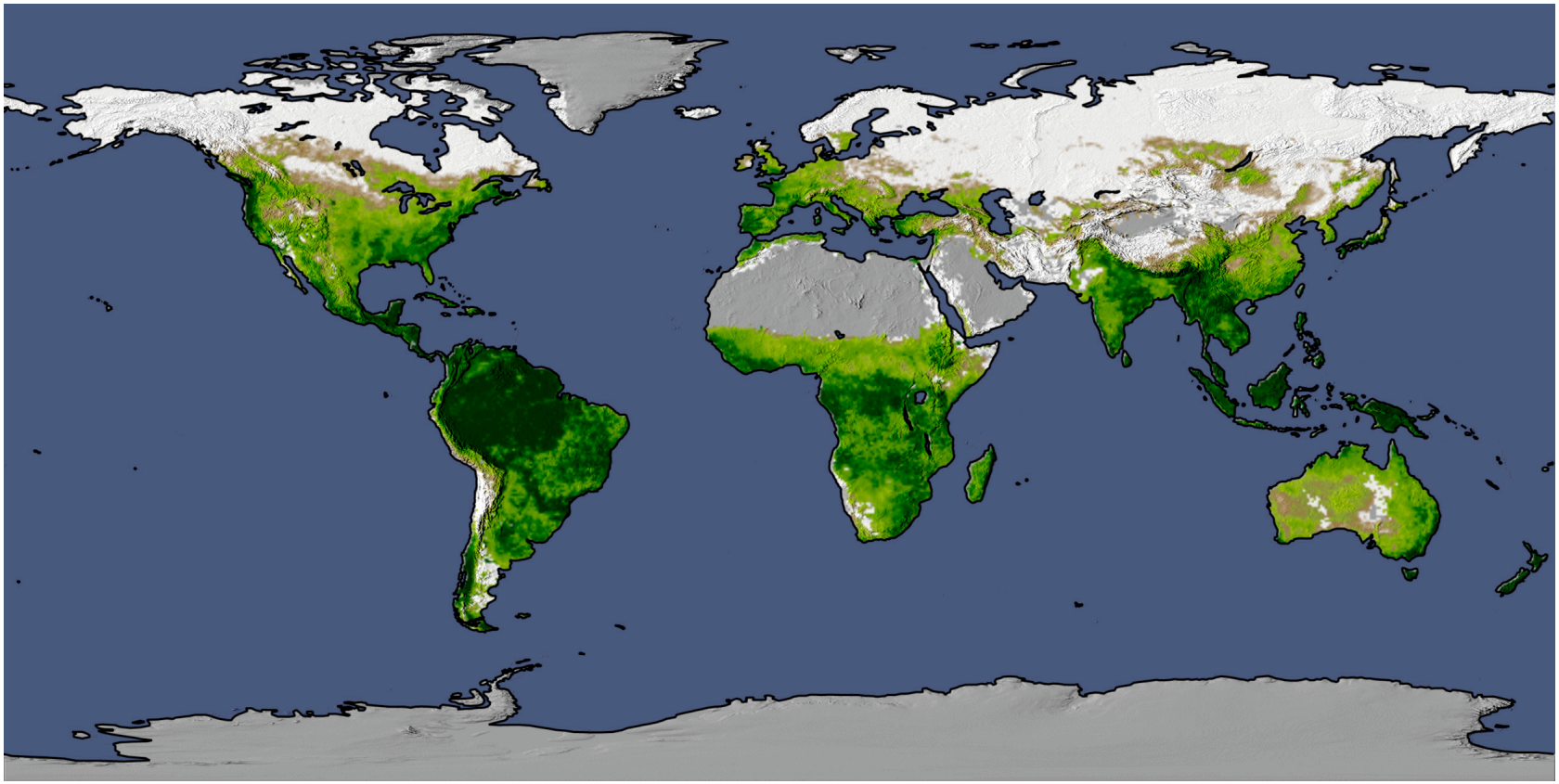
Dec



10 50 100 200 400 mm

Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000

They exchange more C, energy and water than any other biome,



Net Primary Productivity (kgC/m^2)

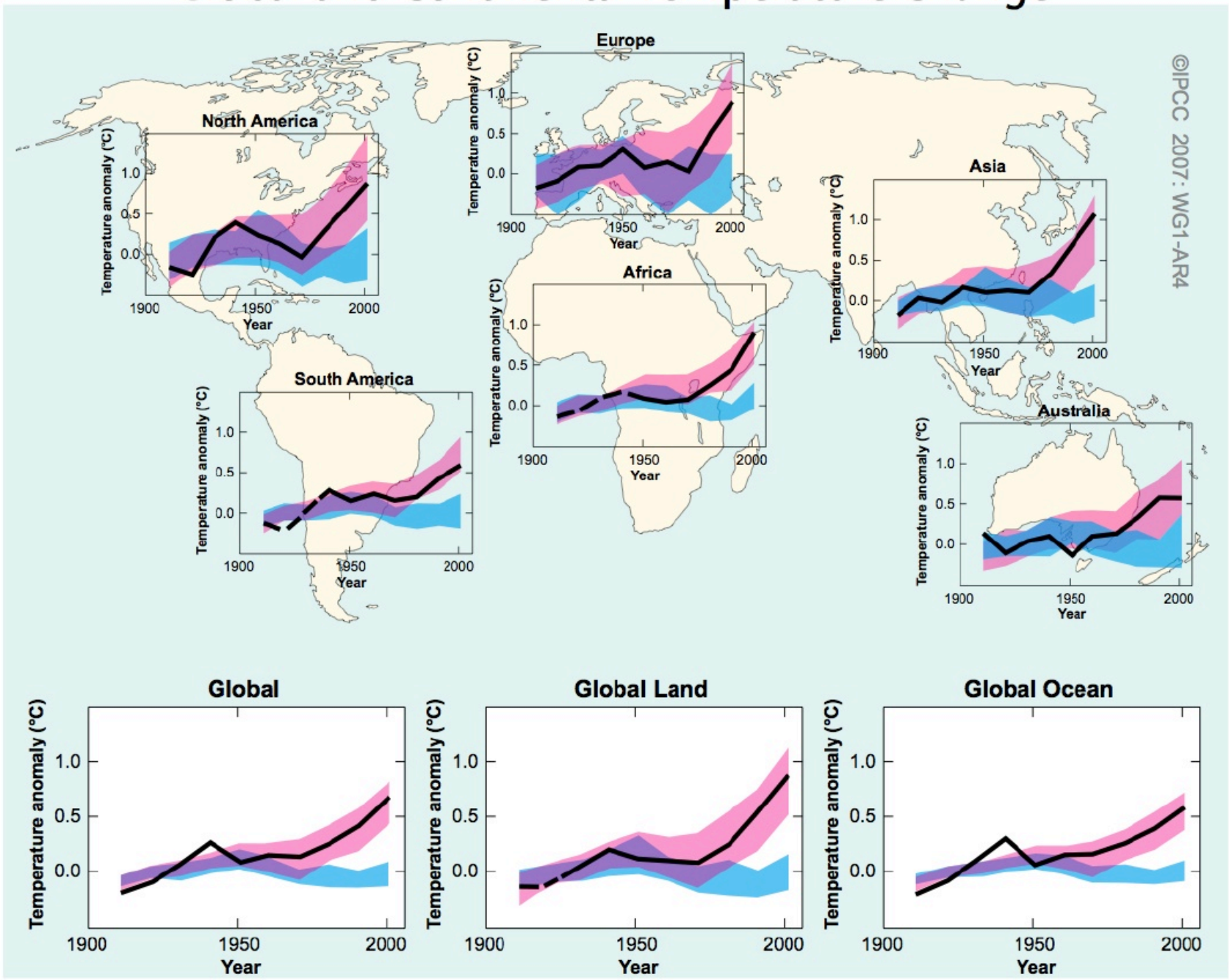
0 0.5 1.0

http://earthobservatory.nasa.gov


they contain ~ half of the
world's biomass C,

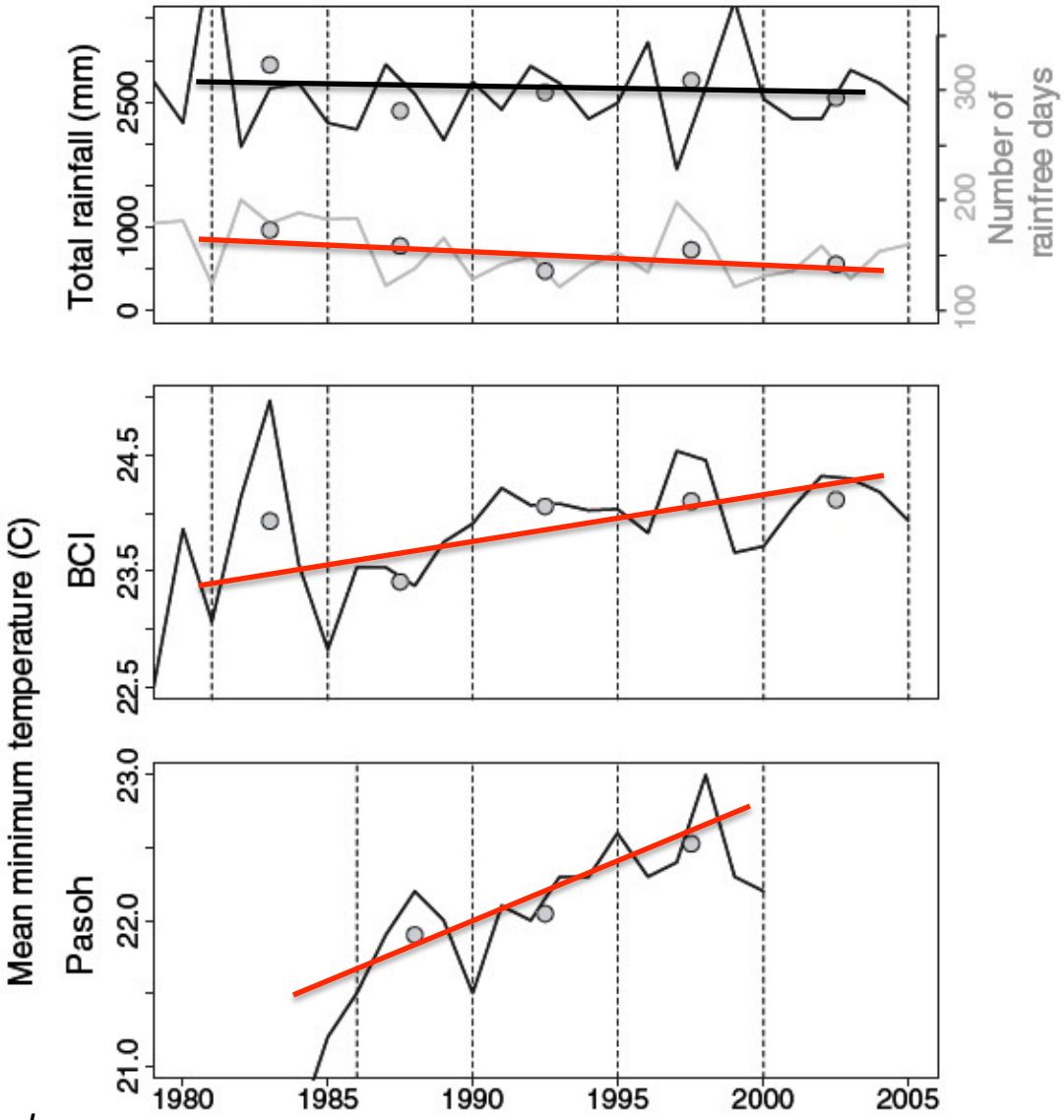

…and they store ~ 30% of the worlds soil C

Global and Continental Temperature Change



Some Evidence for Climate Change in the Tropics

Changes in growth were significantly associated with regional climate changes



Feeley et al. (2007), Ecol. Lett.

Climate Change & Tree Growth In Costa Rica

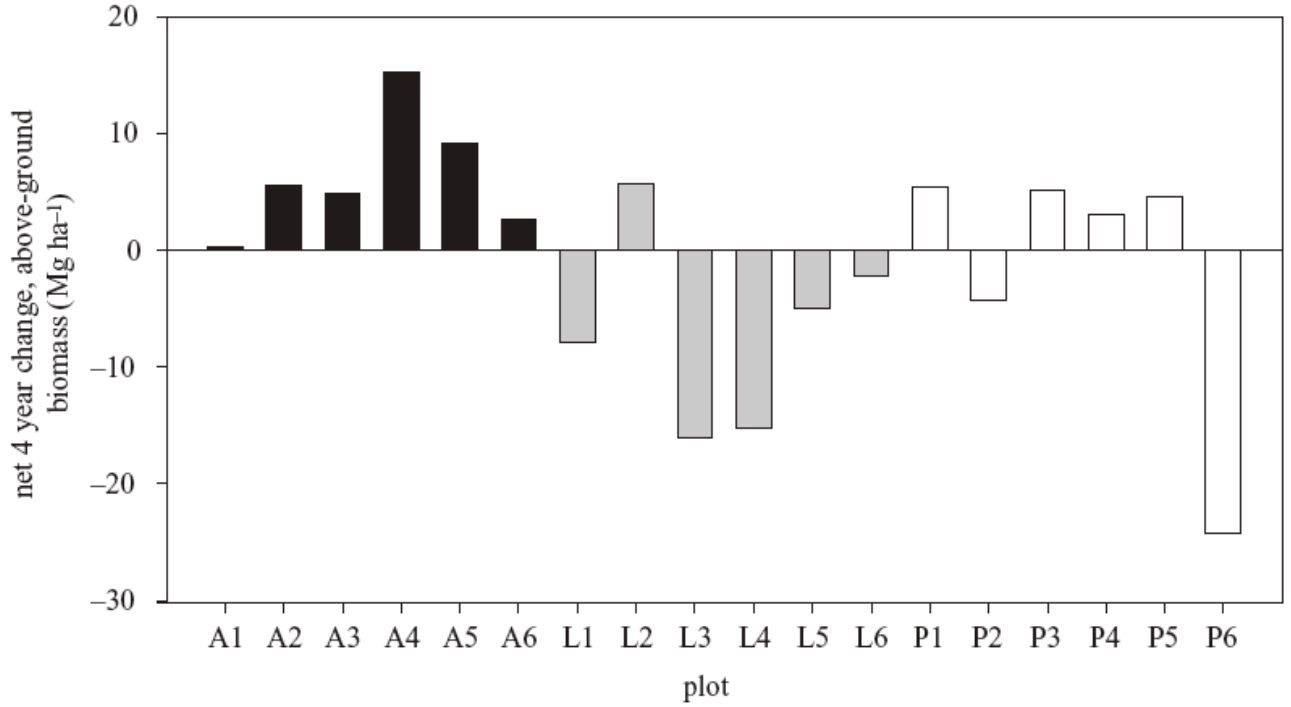


Figure 3. Net 4 year change (1997–2001) in estimated above-ground biomass (Mg ha^{-1}) in eighteen 0.5 ha plots stratified across an old-growth tropical wet forest landscape (the CARBONO Project plots, La Selva, Costa Rica; D. B. Clark and D. A. Clark, unpublished data). Black bars, inceptisol plots: mean change +6.3 Mg ha^{-1}; grey bars, ultisol plateau plots: mean change −6.8 Mg ha^{-1}; white bars, ultisol slope plots: mean change −1.7 Mg ha^{-1}. The above-ground biomass of each tree was estimated by using the tropical wet forest allometric equation of Brown (1997). The mean 4 year net change in estimated above-ground biomass ($n = 18$ plots) was −0.7 Mg ha^{-1} (95% confidence interval: +3.8 to −4.6 Mg ha^{-1}).

Field observations indicate decreased forest productivity and increased tree mortality in recent years of peak temperatures and drought

D. Clark (2003), Proc. Roy. Soc. London B

Climate Change & Tree Growth In Costa Rica

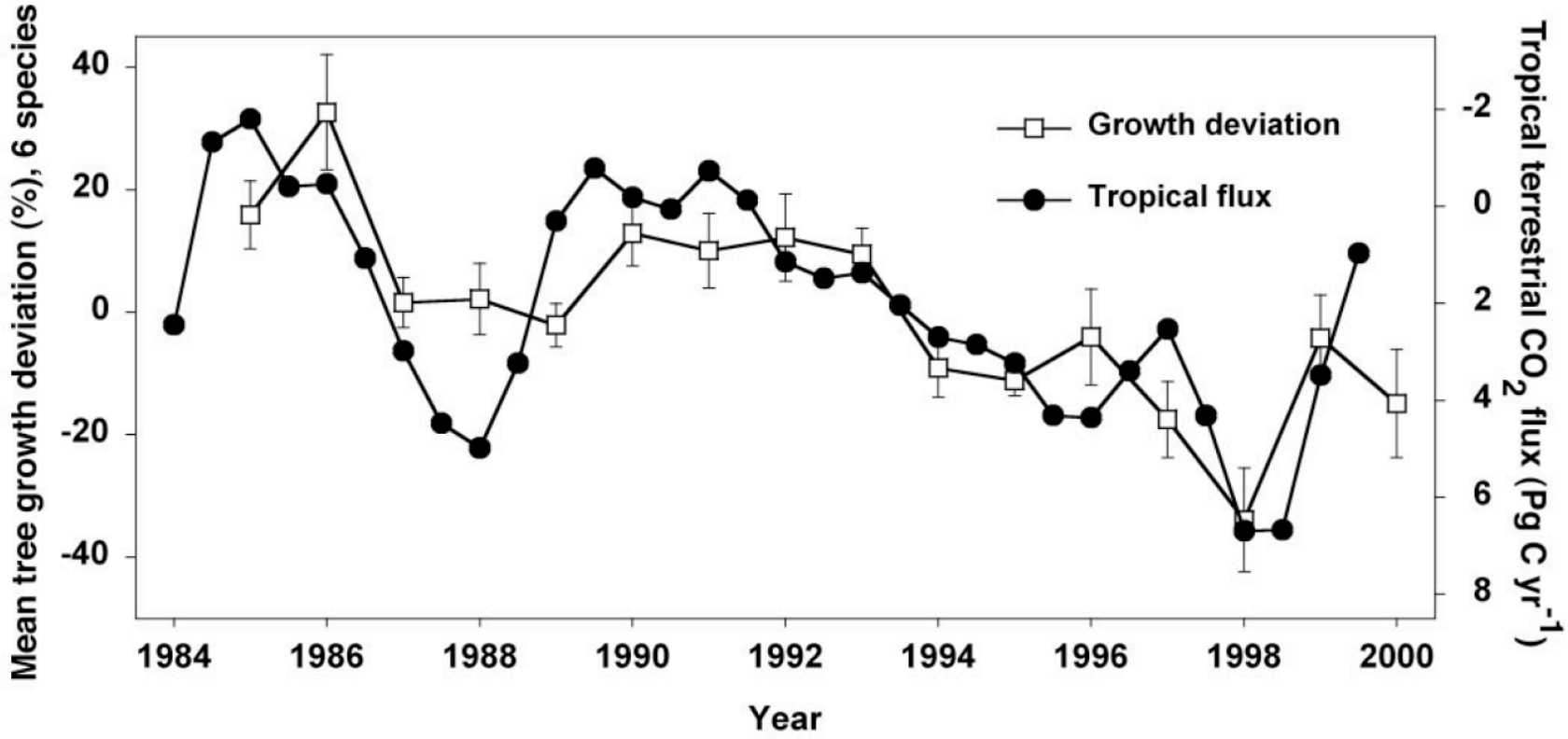


Fig. 2. The relation between the annual mean tree growth deviation (±1 SE) at La Selva, Costa Rica, averaged over the six species, and the net CO_2 flux from the terrestrial tropics (note inverted *y* axis), as inferred from an inverse model calculation [ref. 24; annual means centered on January 1 and June 1 each year; positive values (lower part of the *y* axis) indicate net flux to the atmosphere]. Pearson's $r = -0.77$, $n = 15$ yr, $P < 0.001$ for the correlation between annual fluxes (centered on January 1) and annual mean growth deviations for the six tree species (centered on October 1, previous year). *x* axis: yr 2 of tree measurement years.

These and other recent findings are consistent with decreased net primary production in tropical forests in the warmer years of the last two decades. As has been projected by recent process model studies, such a sensitivity of tropical forest productivity to on-going climate change would accelerate the rate of atmospheric CO2 accumulation.

WHY???

Clark et al. (2003) PNAS

Climate Change & Tree Growth In Costa Rica

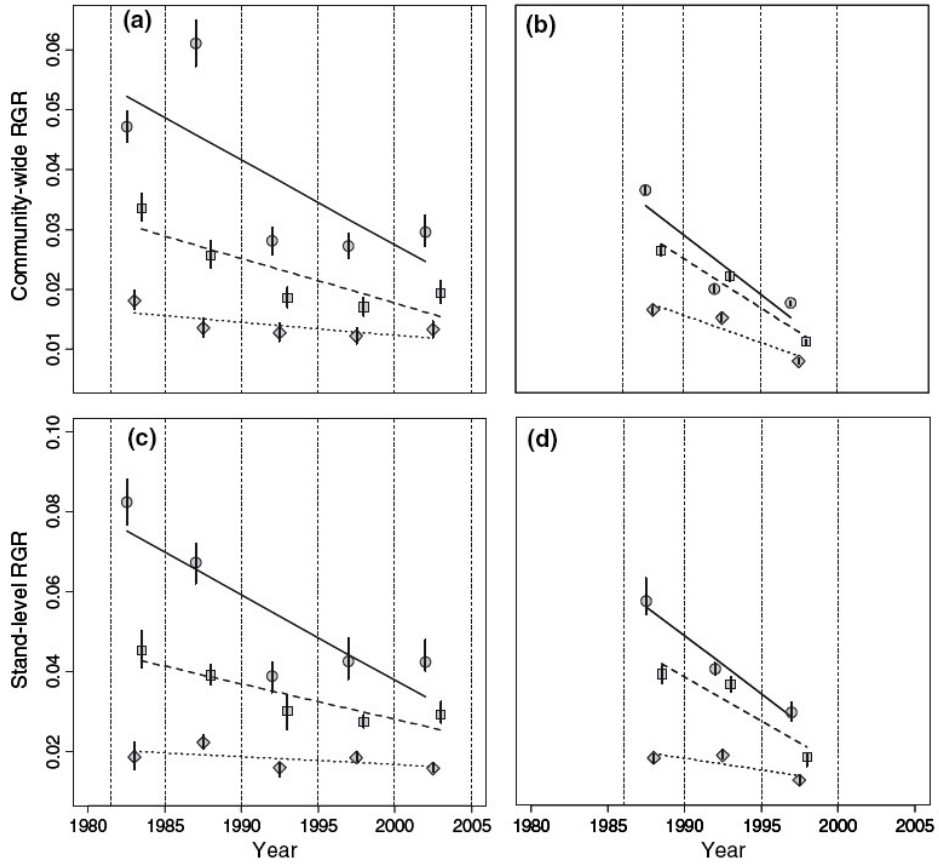


Figure 3 Estimates for stand- and community-level relative basal area growth rates (RGR_{stand} and RGR_{comm}) for saplings (circles, solid line), poles (squares, dashed line), and trees (diamonds, dotted line) at BCI (a and c) and Pasoh (b and d). Symbols indicate the median. Vertical bars indicate the 95% confidence intervals based on bootstrapping in (a) and (b) and the 95% credible intervals in (c) and (d). Lines depict the relationships between RGR and date. For all three size classes of stems and at both sites, growth rates decreased significantly over time (i.e. β significantly < 0). Vertical lines indicate census years. Symbols are offset horizontally to improve clarity.

"Our working hypothesis right now," says Oberbauer, who set up the original Carbono study with the Clarks and now runs the tower research, "is that trees are getting too warm to photosynthesize. The temperature optimum for these things is not very high."

Effects of Climate (Temperature) Change on Tropical Tree Growth

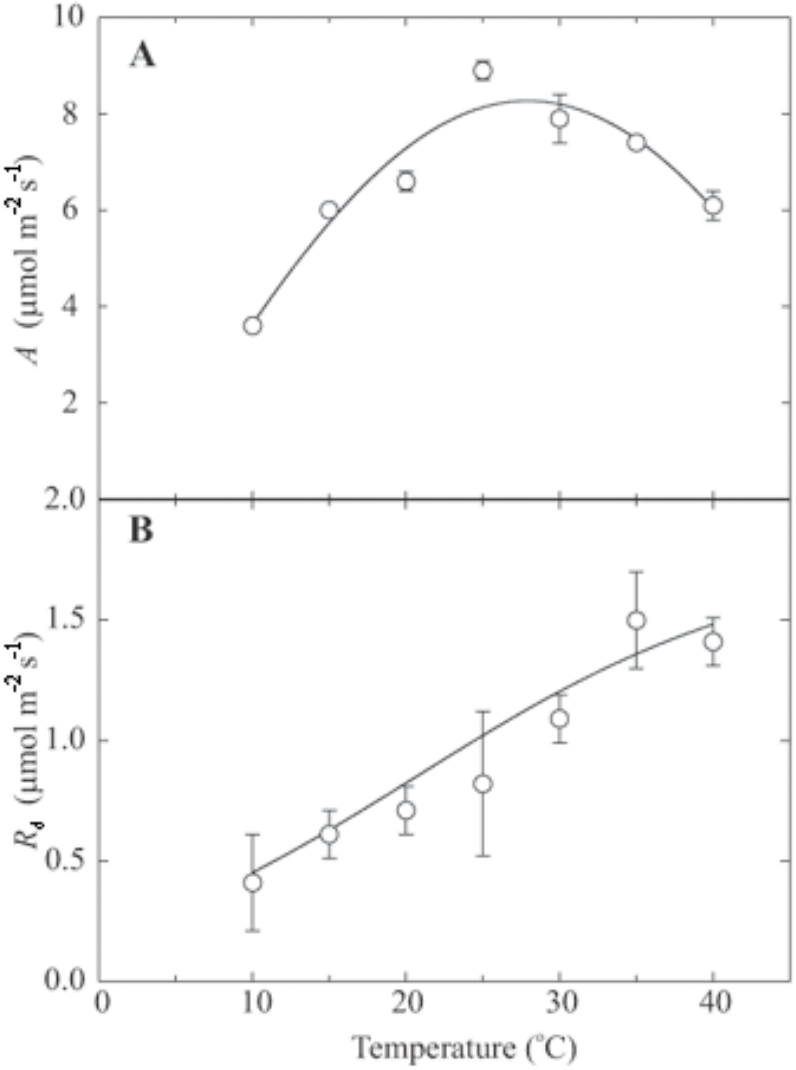
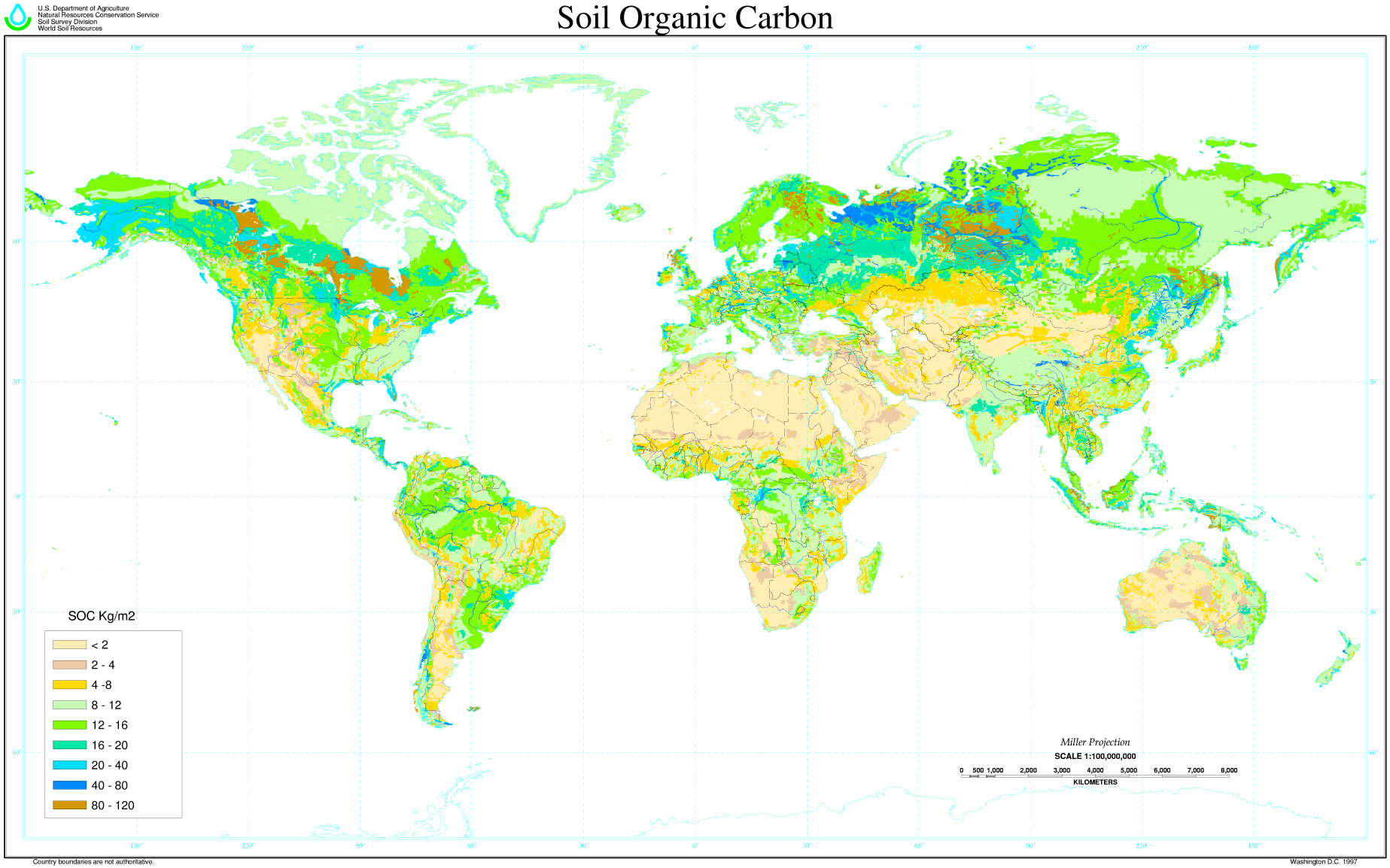
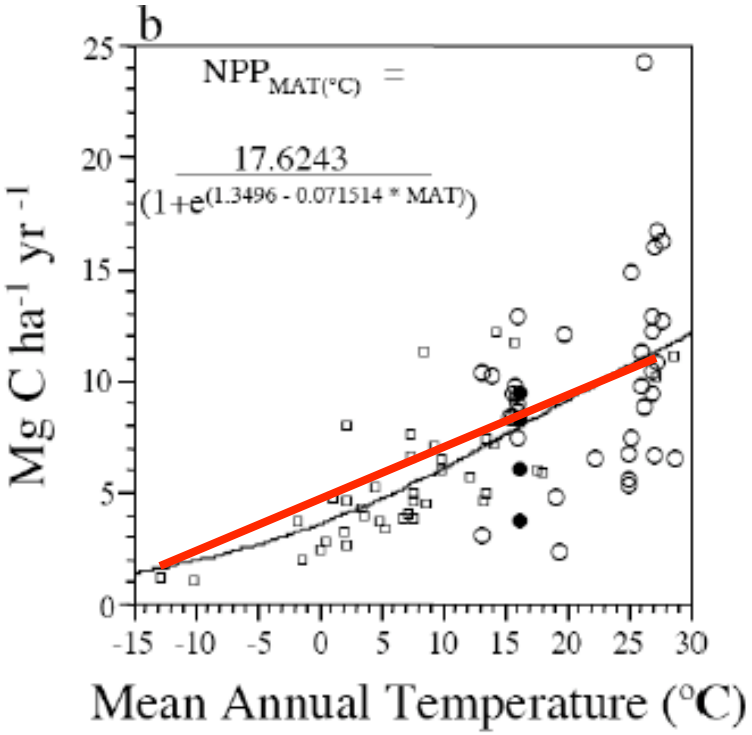


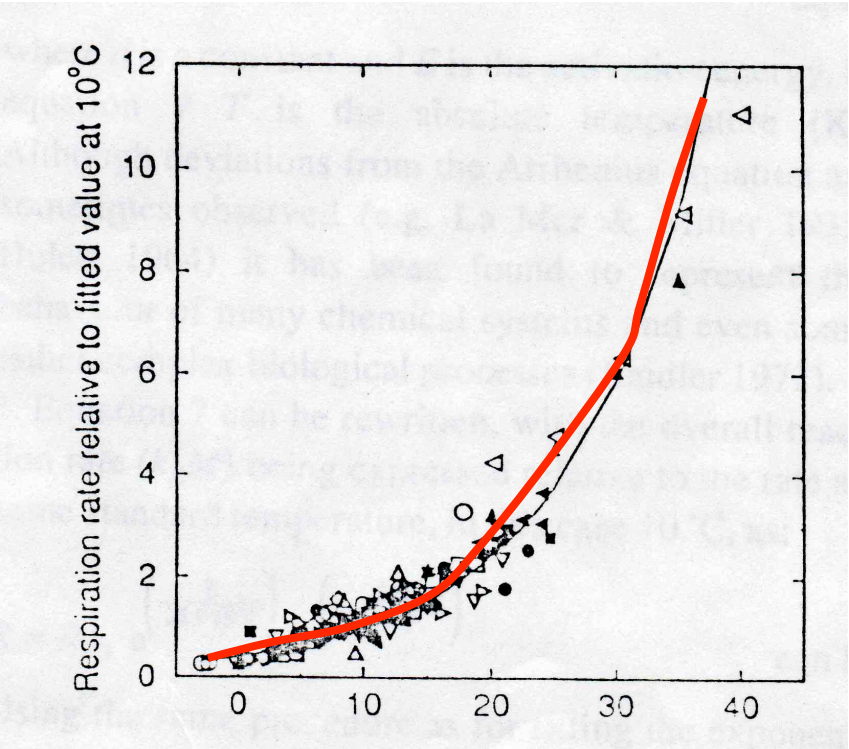
Figure 3. Temperature response of (**A**) CO_2 assimilation rate (A) and (**B**) dark respiration (R_d), determined from gas exchange measurements on *Citrus limon*. $n = 3 \pm$ SD.

What About Tropical Soil C?



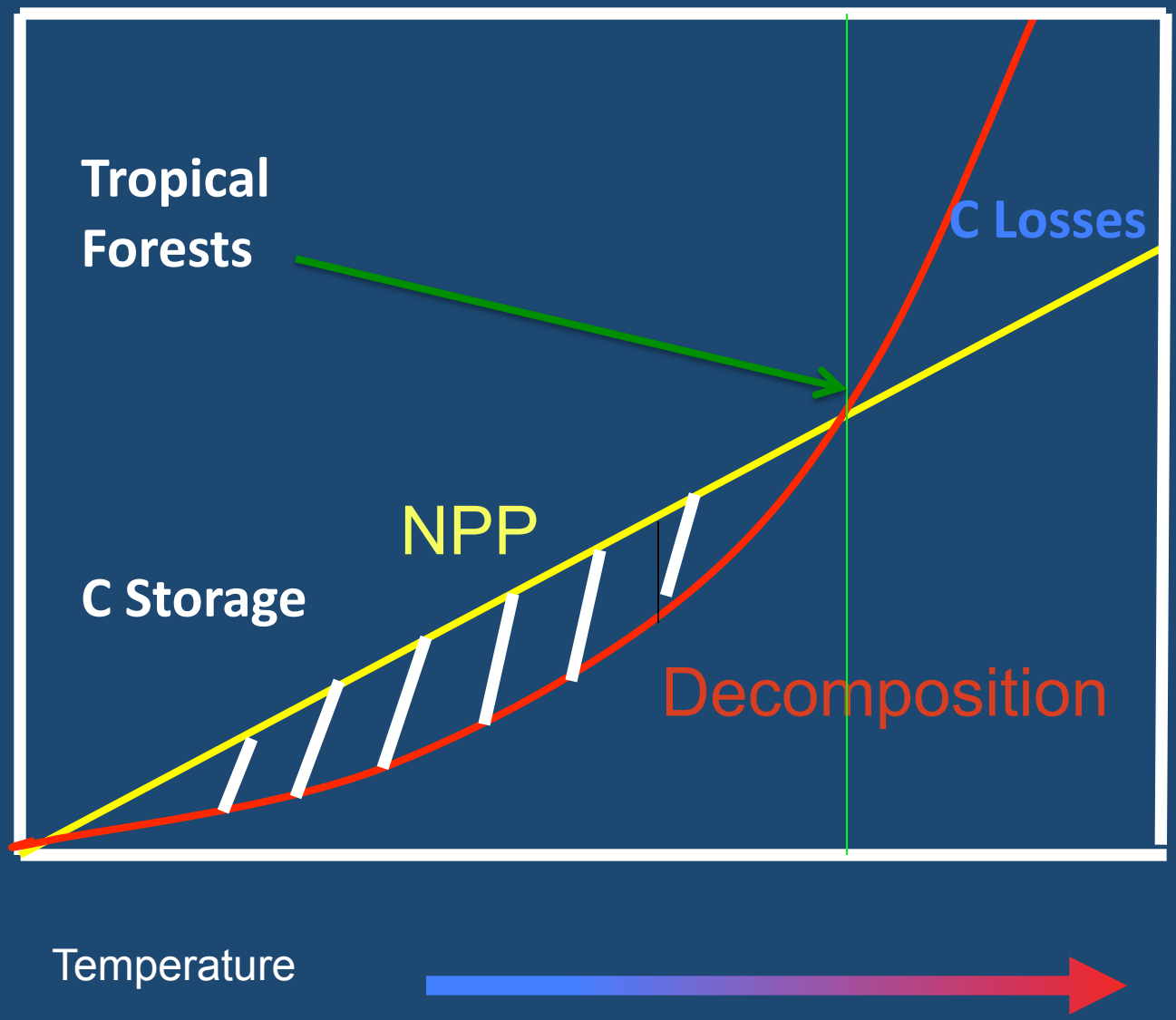
Are tropical soils a carbon "time bomb"?



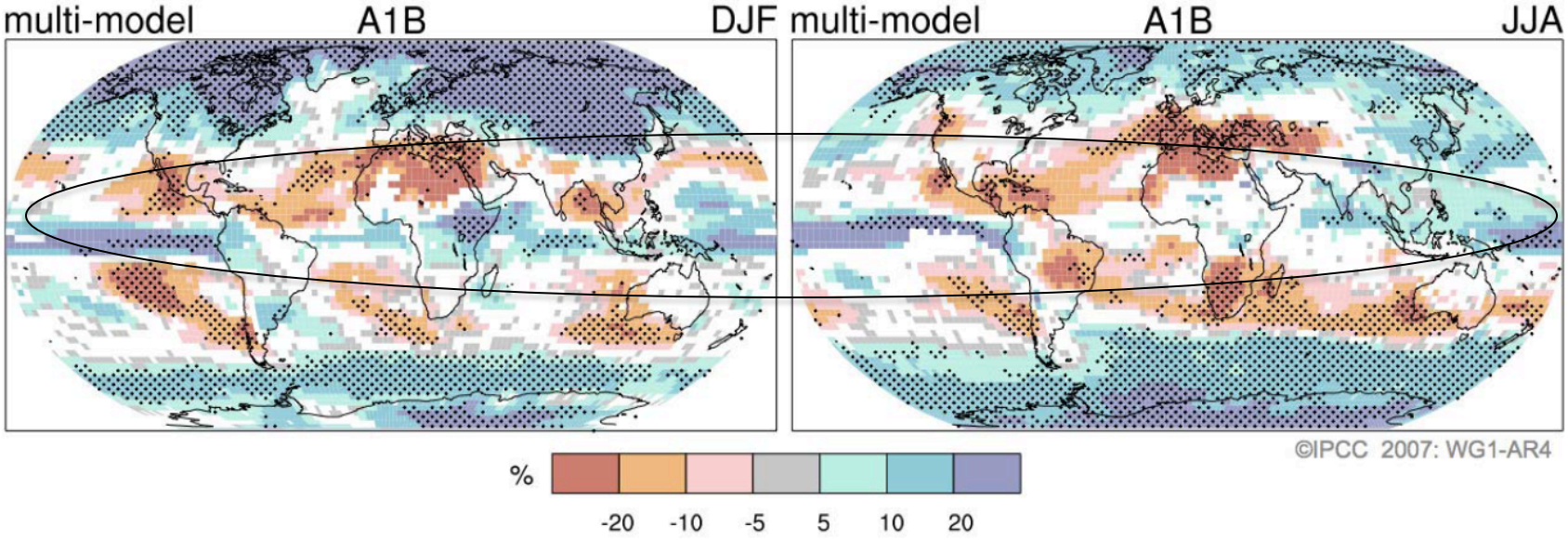


Temperature increases have different effects on NPP and decomposition!

How Tropical C Cycle Respond to Global Warming?



Projected Patterns of Precipitation Changes



Tropical C Cycle and Precipitation?

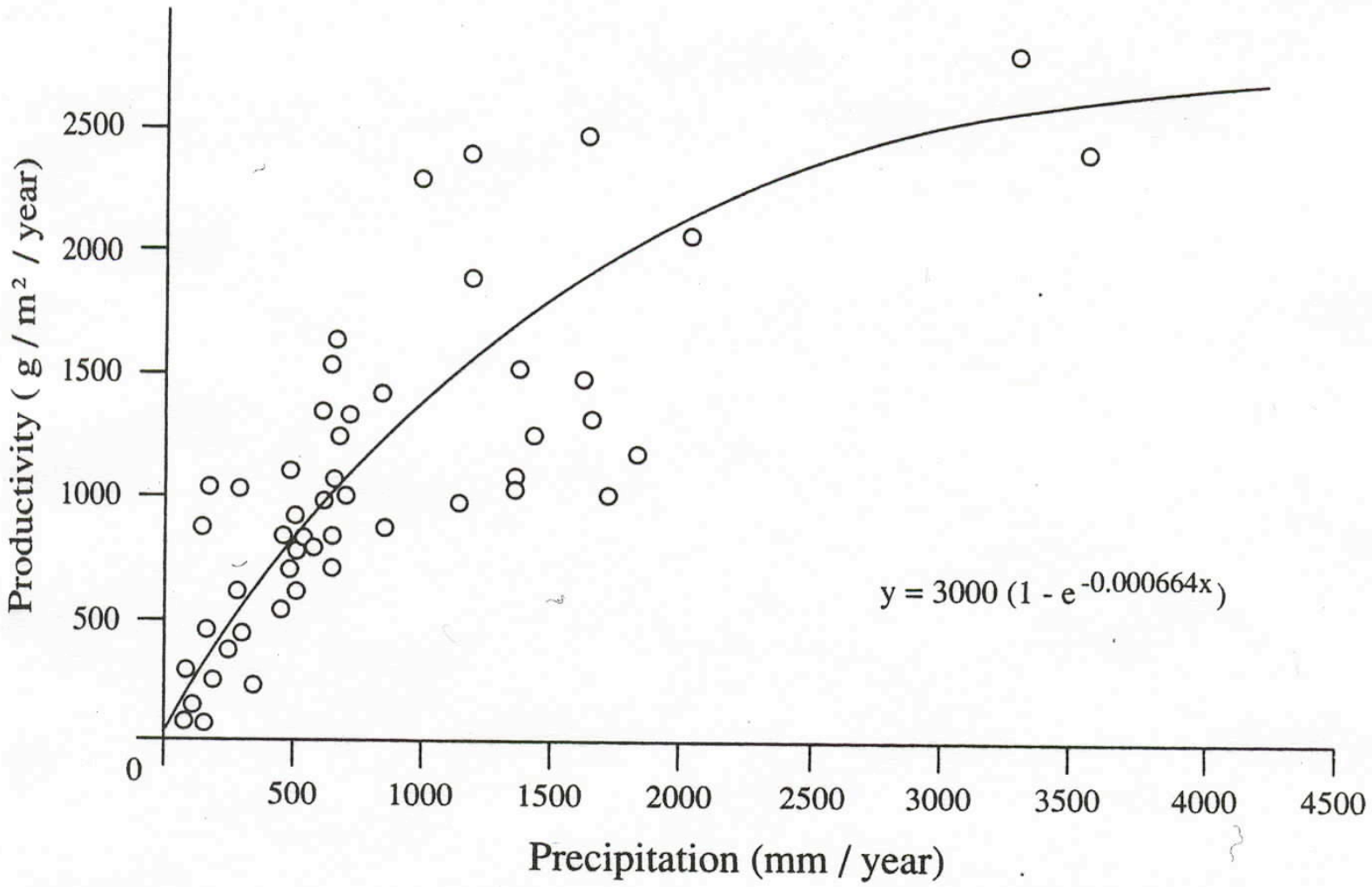


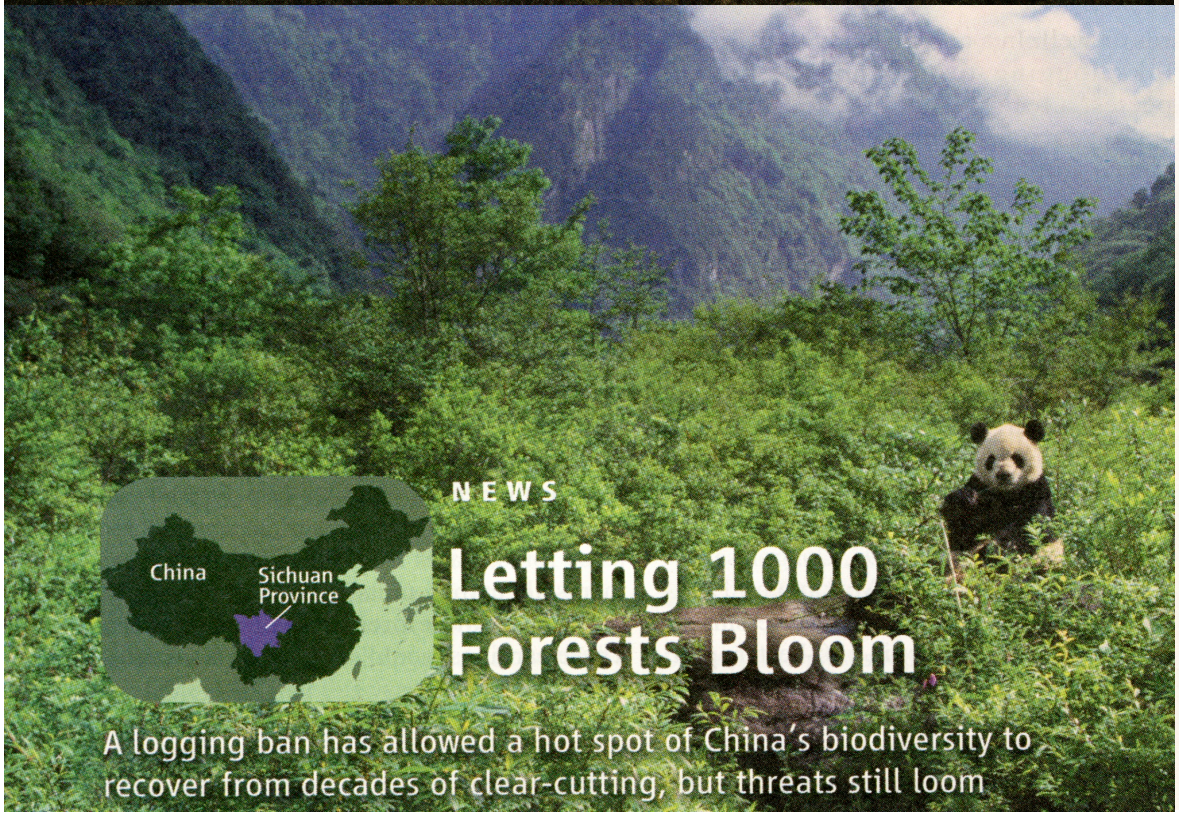
Figure 5.11 Relationship between NPP and mean annual precipitation for 52 locations around the world. From Lieth (1975).


Is there any
good
news???

NEWS

A Second Chance for Rainforest Biodiversity

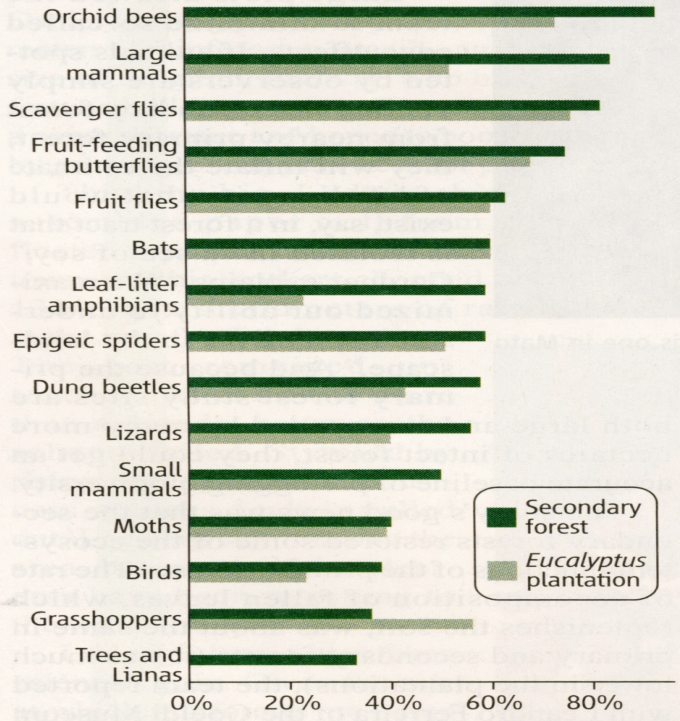
As ever more of the Amazon falls under the ax, a large-scale project is helping to clarify how well various tropical species survive in recovering forests



NEWS

Letting 1000 Forests Bloom

A logging ban has allowed a hot spot of China's biodiversity to recover from decades of clear-cutting, but threats still loom



Biodiversity index. The percentage of old-growth forest species that survive in *Eucalyptus* plantations (*above*) and secondary forests varies from group to group, habitat to habitat.

For More Information, please visit:

Forests & Global Climate Change: Potential Impacts on U.S. Forest Resources
(The Pew Center)
http://www.pewclimate.org/global-warming-in-depth/all_reports/forests_and_climate_change

Forests in Flux. *Science*, 13 June 2008, Volume 5882: 1381-1544.

US National Assessment of the Potential Consequences of Climate Variability and Change: Forests
(US Global Change Research Program)
http://www.usgcrp.gov/usgcrp/nacc/forests/default.htm