Section 5: Habitats, Communities, Ecosystems

Reading: Ch 3 (coral bleaching, ocean acidification, polar bear habitat); Ch 5

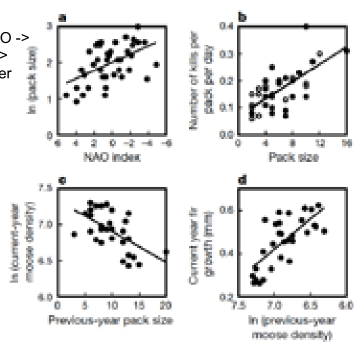
Learning outcomes

- understand definitions related to ecosystems
- explain how climate change affects biomes, and what the impacts are to ecosystem processes
- discuss examples of how climate change affects tropical, temperate, polar, freshwater, and marine ecosystems, and what the consequences of these changes are

"Ecosystem consequences of wolf behavioural response to climate"

(a) Higher NAO -> deeper snow -> hunting in larger pack

(b) larger pack size -> inc. kill efficiency per pack and per wolf

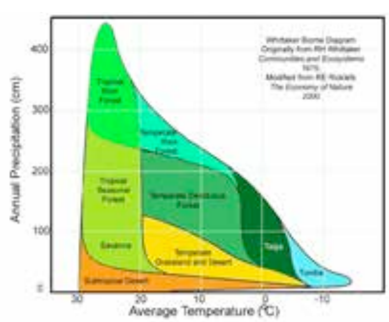


(c) larger packs, inc. kill efficiency -> fewer moose

(d) fewer moose -> higher fir growth

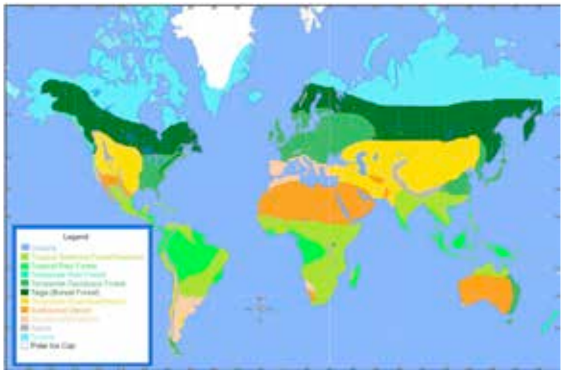
Post et al., 1999

Climate defines biomes



www.marietta.edu/~biol/biomes/biome_main.htm

Climate defines biomes



Climate Change Ecology

www.marietta.edu/~biol/biomes/biome_main.htm

4

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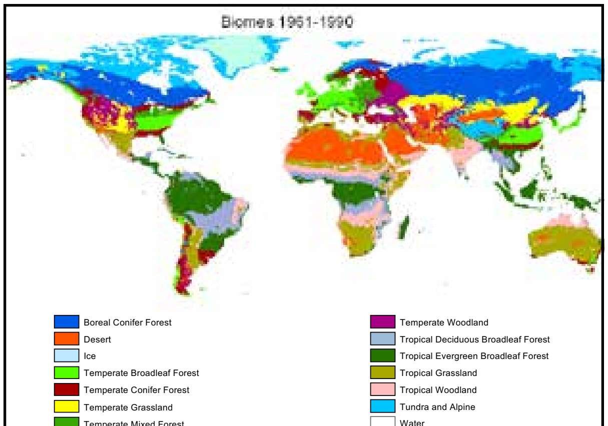
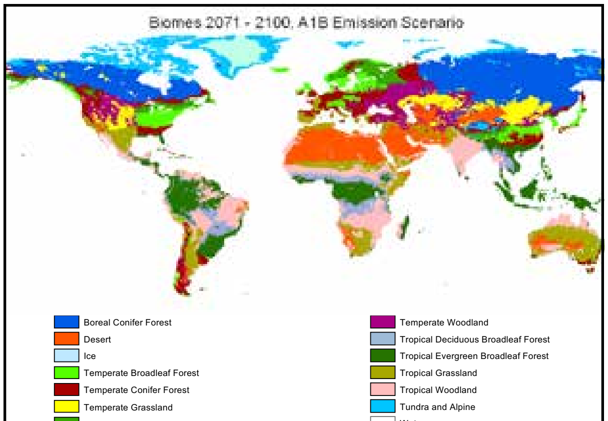
Biomes 1961-1990



Slide courtesy M. Jennings, TNC

Source: The Nature Conservancy Climate Change Initiative

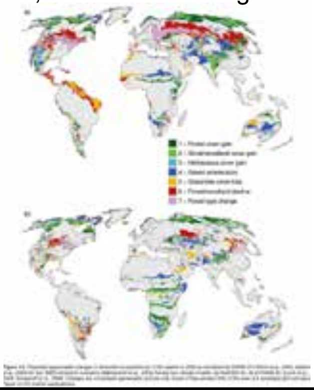
Biomes 2071 - 2100, A1B Emission Scenario



Slide courtesy M. Jennings, TNC

Source: The Nature Conservancy Climate Change Initiative

Uncertainty in projected future shifts of biomes: LPJ model, two climate change scenarios

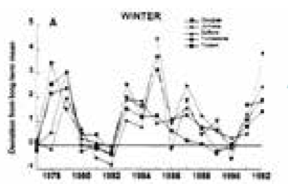


HADCM3 A2

ECHAM5 B1

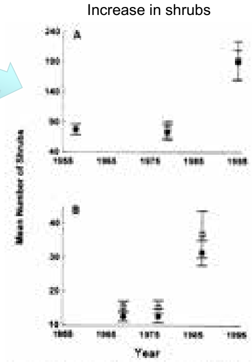
IPCC, WG II, AR4

Cascading impacts of changes: Arid ecosystems



Higher than average winter precip during 1977-1992

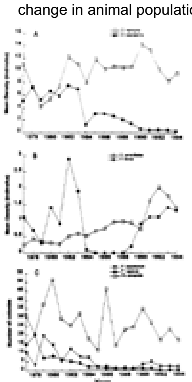
Increase in shrubs



Brown et al., 1997

Cascading impacts of changes: Arid ecosystems

Increases, decreases, and no change in animal populations

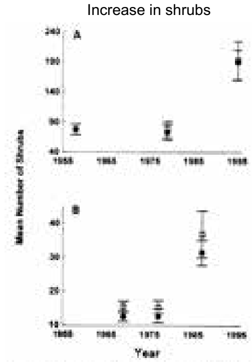


rodents

rodents

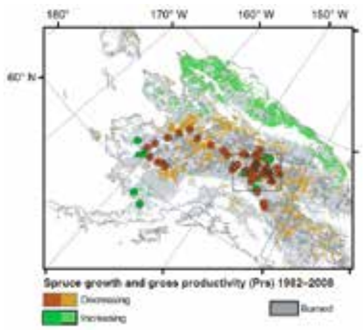
ants

Increase in shrubs



Brown et al., 1997

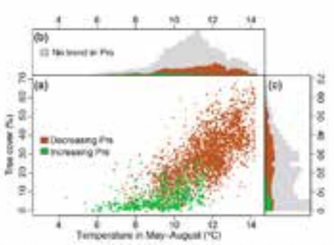
Evidence for biome shift: Tree expansion at northern treeline



Beck et al., 2011

Climate Change Ecology 10 Prof. J. Hicke

Evidence for biome shift: Tree expansion at northern treeline



Why does this figure provide evidence supporting tree expansion at northern treeline?

Beck et al., 2011

Climate Change Ecology 11 Prof. J. Hicke

Recent shrub expansion in the Arctic

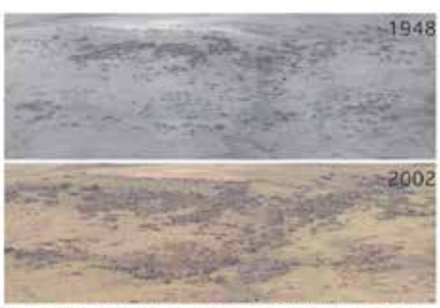


Figure 1. Increasing abundance of shrubs in arctic Alaska. The photographs were taken in 1948 and 2002 at identical locations on the Colville River (68° 57.9' north, 155° 47.4' west). Dark objects are individual shrubs 1 to 2 meters high and several meters in diameter. Similar changes have been detected at more than 200 other locations across arctic Alaska where comparative photographs are available. Photographs (1948) US Navy, (2002) Ken Tape.

Sturm et al., 2005

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Impact of biome shift on ecosystem functioning: Arctic shrub expansion

Table 2. Key differences in properties between shrubby and nonshrubby tundra.

Properties	Nonshrub tundra	Shrub tundra
Snow depth/duration	Shallower/shorter	Deeper/longer, more snow runoff
Albedo	Higher	Lower
Summer active-layer depth	Deeper	Shallower (because of shading)
Summer active-layer temperature	Warmer	Cooler
Soil temperature	Higher in summer, lower in winter	Lower in summer, higher in winter
Nutrient (nitrogen) cycling	Faster	Slower
Carbon cycling	Faster	Slower
Caribou forage access and quality	Higher	Lower
Winter CO_2 flux	Lower	Higher
Summer CO_2 exchange	Lower	Higher

CO_2, carbon dioxide.

Sturm et al., 2005

Impact of biome shift on ecosystem functioning: Arctic shrub expansion

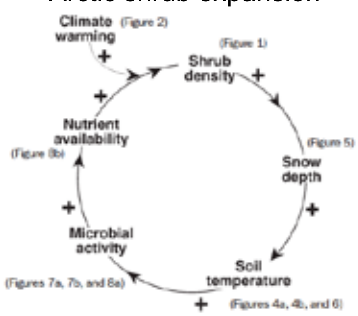
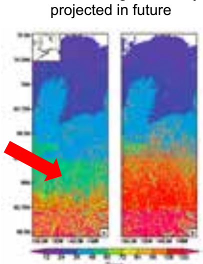


Figure 9. The snow–shrub–soil–microbe feedback loop (based on Sturm et al. 2001b).

Sturm et al., 2005

Impact of biome shift on ecosystem functioning: Arctic shrub expansion

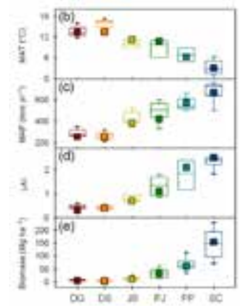
more soil biological activity projected in future



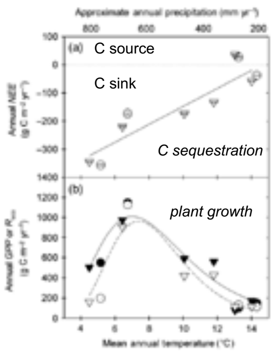
Sturm et al., 2005

Impact of biome shift on ecosystem functioning

New Mexico Environmental Gradient



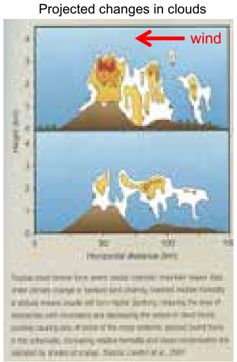
Desert Grass; Desert Shrub; Juniper Savanna; Pinyon-Juniper; Ponderosa Pine; Subalpine Conifer



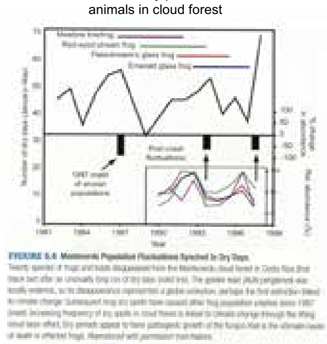
Climate Change Ecology *Anderson-Teixeira et al., 2011* Prof. J. Hicke

Tropical ecosystems: cloud forests

Projected changes in clouds



Effects of dry periods on animals in cloud forest



Hannah, 2011

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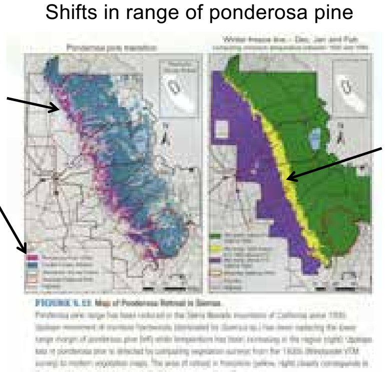
Temperate forest ecosystems

Shifts in range of ponderosa pine

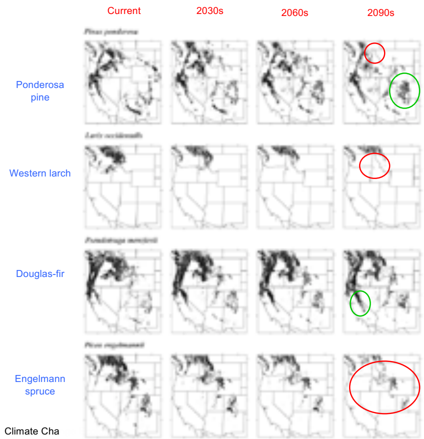
loss of PIPO



new areas with T>0 deg C

Hannah, 2011

Climate Change Ecology 18 Prof. J. Hicke



Predictions of major tree species in the West in response to climate change

expansions and contractions

Rehfeldt et al., 2006

Predictions of plant communities in the West in response to climate change

Rehfeldt et al., 2006

Climate influences regional fire years

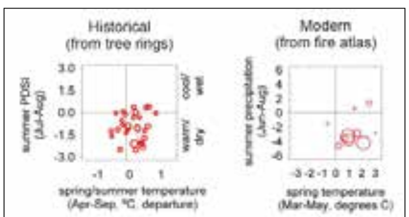
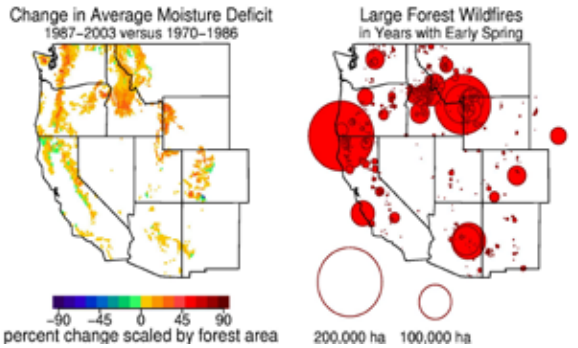


Figure 5. Interaction between spring and summer climate for historical (left) and modern (right) regional fire years. Circles are proportional to the degree of synchrony (25 to 57% of sites for historical fires and 81 ha to 1,167,458 ha for the fire atlas).

For roughly the past four centuries, regional fire years were ones of warm springs that were followed by dry summers (Figure 5).

Morgan et al., 2008

Early snowmelt and longer, drier summers => more large fires



Westerling et al Science 2006, Running, Science 2006

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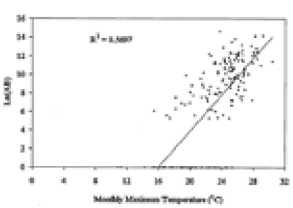
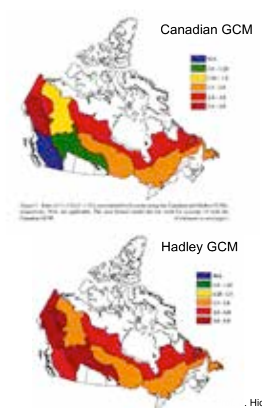
Climate is a major driver of Canadian wildfires





Flannigan et al., 2005

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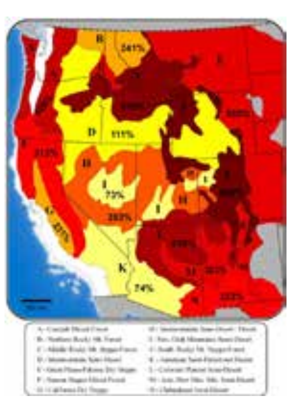
Wildfire: Projections based on future climate change

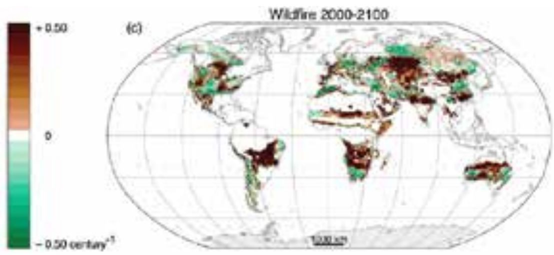


increase in burned area for 1º C increase in temperature

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

Climate Change Ecology 24 Prof. J. Hicke

Projected future wildfire frequency



Average of three GCMs

Gonzalez et al., 2010

Observed tree dieoff from climate change

IPCC AR5, WG 2, 2013

Bark beetle outbreaks are widespread and extensive in western North America

Meddens et al., 2012; Hicke et al., 2016

Mountain pine beetle outbreak

Central Colorado

August 2007

QuickBird satellite imagery

100 km/62 miles north-south

Factors influencing mountain pine beetle epidemics

Factors related to trees:
- presence of host tree species
- stem density
- stand age
- drought stress on trees

Safranyik et al. 1975; Shore and Safranyik 1992; Carroll et al. 2004; Logan and Powell 2001

Whitebark pine: Ecologically important

A keystone and foundation species


Photo P. Buotte


Photo P. Buotte

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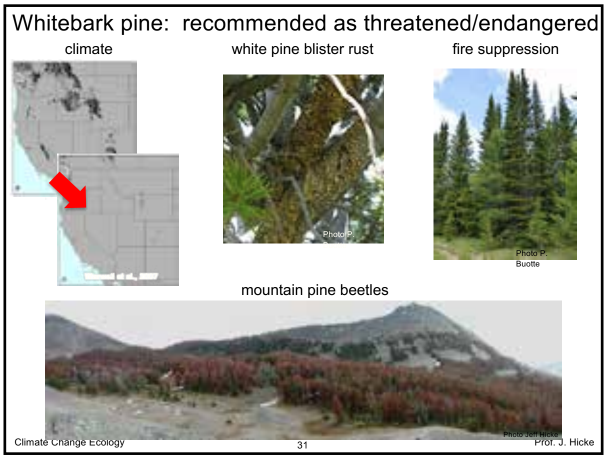
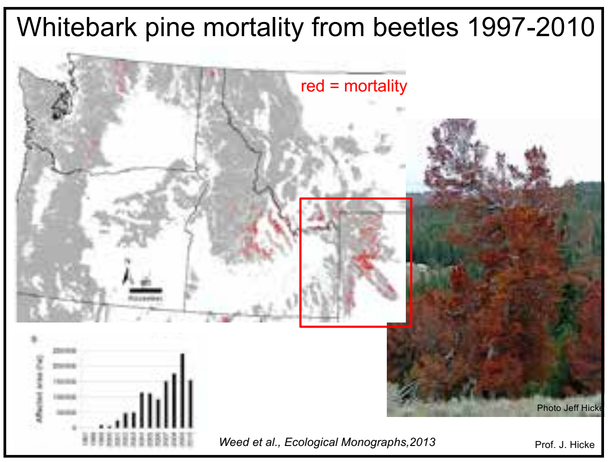
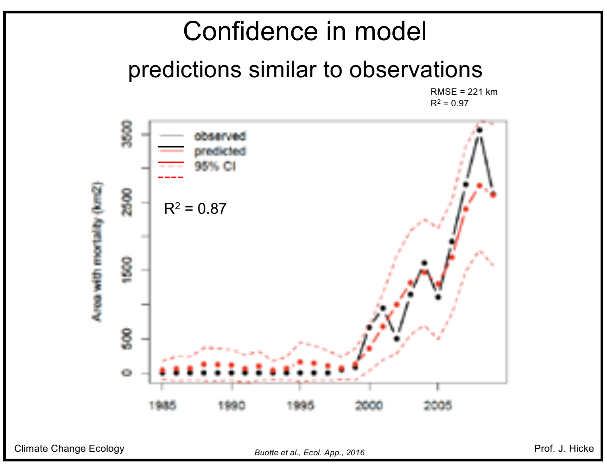
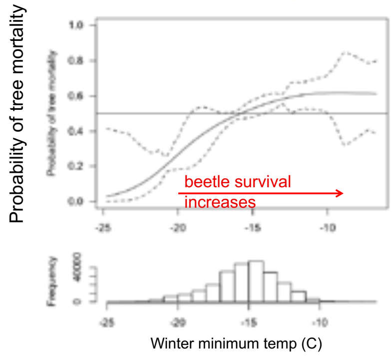

Whitebark pine: recommended as threatened/endangered
climate
white pine blister rust
fire suppression
mountain pine beetles
Climate Change Ecology
31
Prof. J. Hicke


Whitebark pine mortality from beetles 1997-2010
red = mortality
Photo Jeff Hicke
Weed et al., Ecological Monographs,2013
Prof. J. Hicke


Confidence in model
predictions similar to observations
RMSE = 221 km
R² = 0.97
observed
predicted
95% CI
R² = 0.87
Area with mortality (km2)
Climate Change Ecology
Buotte et al., Ecol. App., 2016
Prof. J. Hicke

1. Climate-beetle relationships



Climate Change Ecology | *Buotte et al., Ecol. App., 2016* | Prof. J. Hicke

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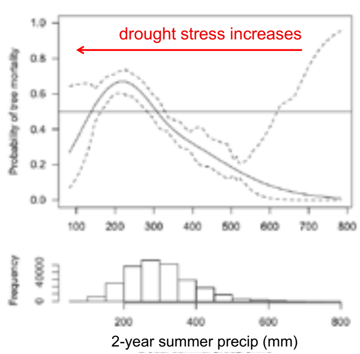

Climate Change Ecology | *Buotte et al., Ecol. App., 2016* | Prof. J. Hicke

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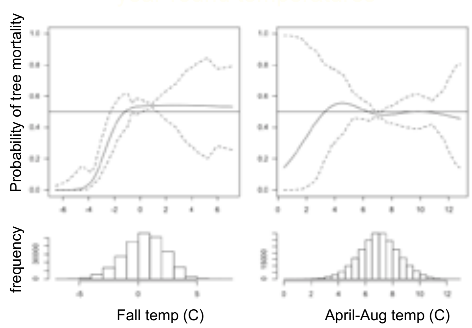
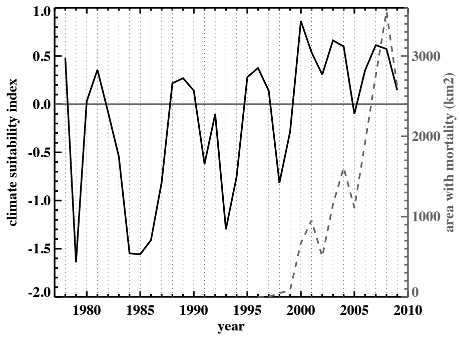


Climate Change Ecology | *Buotte et al., Ecol. App., 2016* | Prof. J. Hicke

2. Climate influences on recent outbreak



Climate Change Ecology

Buotte et al., Ecol. App., 2016

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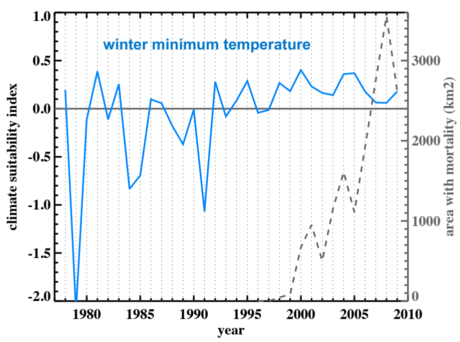

Climate Change Ecology

Buotte et al., Ecol. App., 2016

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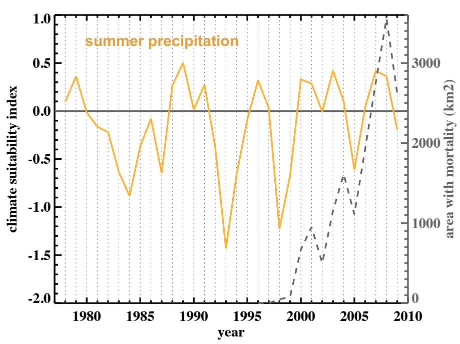

Climate Change Ecology

Buotte et al., Ecol. App., 2016

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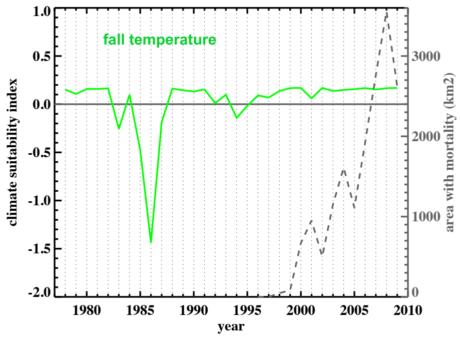
2. Climate influences on recent outbreak



Climate Change Ecology

Buotte et al., Ecol. App., 2016

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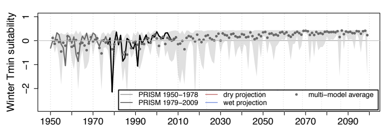
3. Estimates of future climate suitability

Winter temperature: increased suitability for outbreaks



Buotte et al., Ecol. App., 2016

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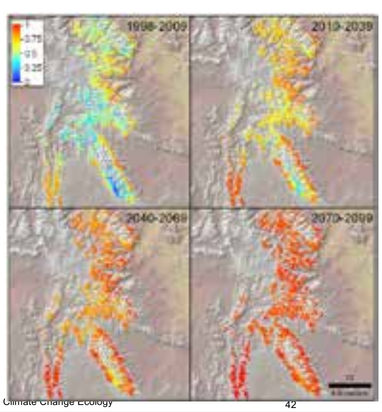

fraction of years with winter temperature suitable for beetle outbreaks

Buotte et al., Ecol. App., 2016

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42

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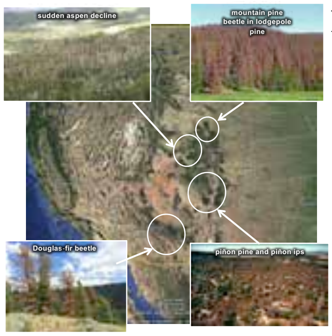
For some dieoff types, drought more important

Type 1: drought, no biotic agents

Type 3: drought triggers outbreaks



Type 4: outbreaks caused by multiple factors

Type 2: drought, with beetles present

Photos: J. A. Hicke; W. R. L. Anderegg; C. D. Allen
Background image: Landsat, Google Earth

Drought: Texas drought in 2011

Dr. Ron Billings, Texas Forest Service

Drought: Tree mortality in Texas



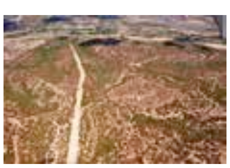
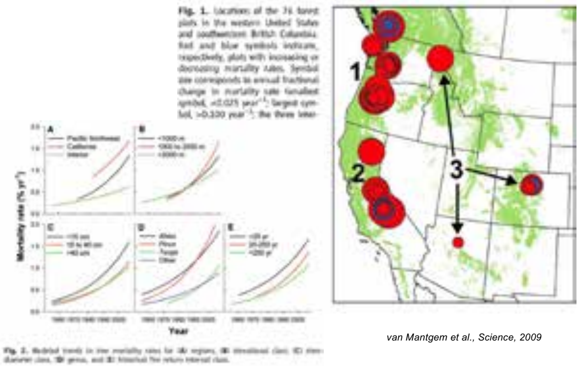


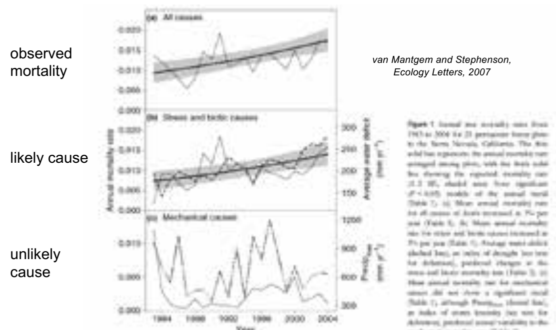

Photo credits: Dr. Ron Billings, Texas Forest Service

Increase in tree mortality rates in old-growth forests



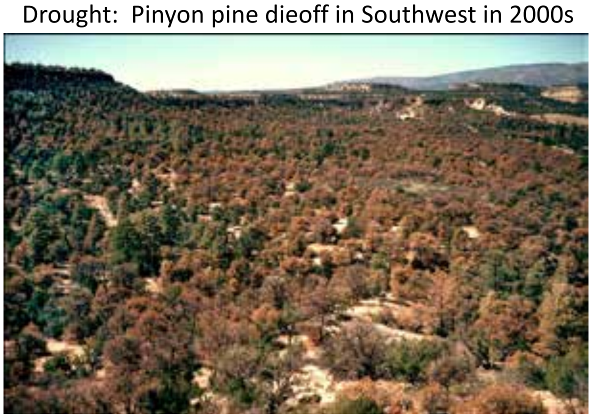
van Mantgem et al., Science, 2009

Increase in tree mortality rates in old-growth forests due to warming (stress, biotic causes)



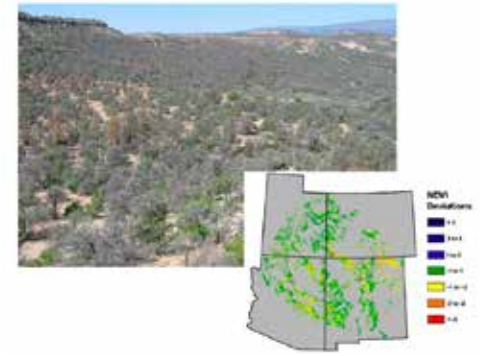
van Mantgem and Stephenson, Ecology Letters, 2007

Drought: Pinyon pine dieoff in Southwest in 2000s



Jemez Mts. near Los Alamos, October 2002 **Photo: Craig D. Allen, USGS**

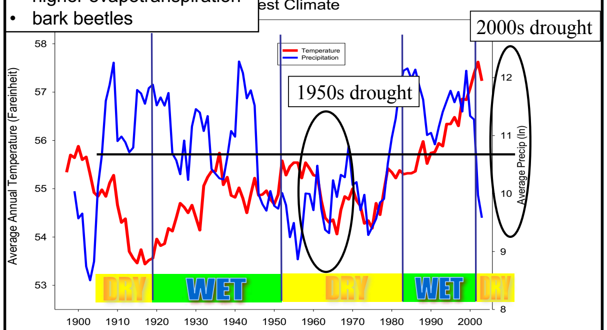
Drought: Pinyon pine dieoff in Southwest in 2000s



Breshears et al., 2011

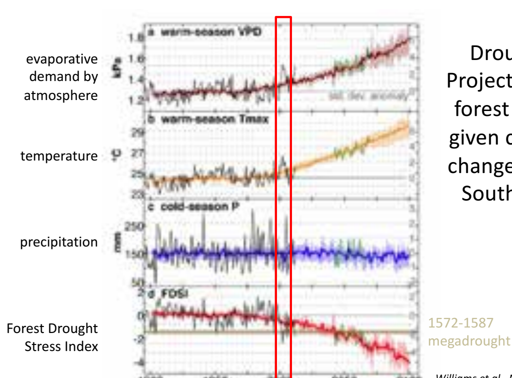
Drought: Tree dieoff in Southwest

Warming:
- higher evapotranspiration
- bark beetles



Breshears et al. PNAS, October 18, 2005, vol. 102, no. 42, 15144-15148, and graphic from Neil Cobb

Drought: Tree dieoff in Southwest

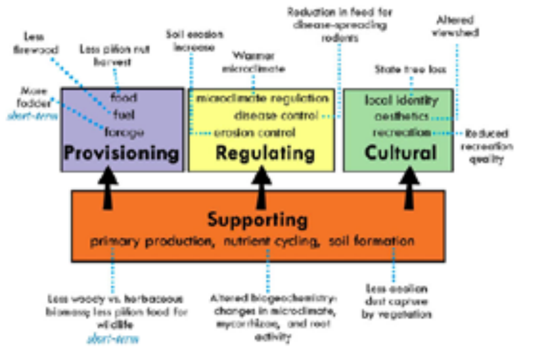


Drought: Projections of forest stress given climate change in the Southwest

Williams et al., Nature Climate Change, 2012

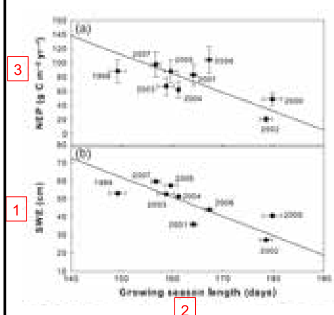
Drought: Tree dieoff in Southwest

Tree die-off effects on ecosystem processes and services



Climate Change Ecology — *Breshears et al., 2011* — Prof. J. Hicke

Warming leads to longer growing season but reduced plant growth



Shallower snowpack => 1

longer growing season length but less water availability => 2

less plant growth (dependence on snow melt water) =>

less carbon storage (lower Net Ecosystem Productivity) 3

Hu et al., Global Change Biology, 2010

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Reliance of trees on snow melt water, not summer precip in this area

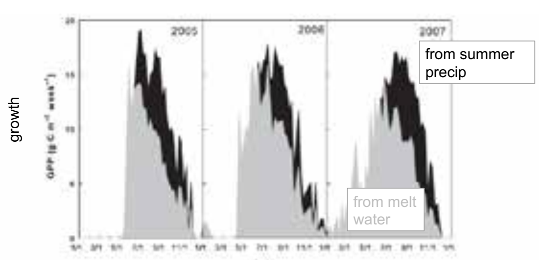
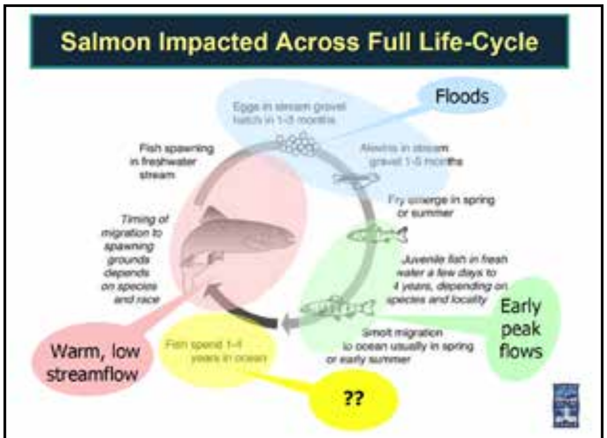


Fig. 7 Gross primary productivity (GPP) modeled using SIPNET for 2005, 2006, and 2007. Gray areas represent snow contributed GPP and black areas represent rain contributed GPP. Annual net ecosystem productivity (NEP) for each year is as follows: 2005 (88 gC m−2 yr−1), 2006 (104 gC m−2 yr−1), and 2007 (98 gC m−2 yr−1).

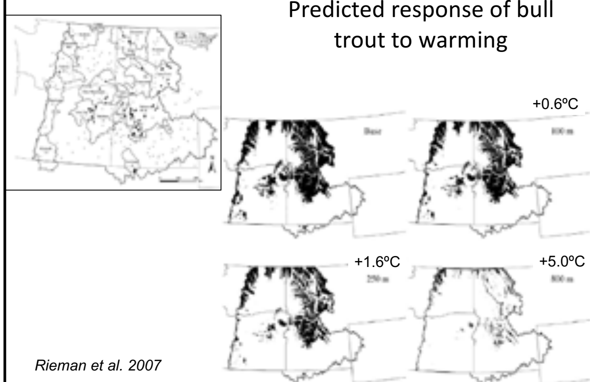
Hu et al., Global Change Biology, 2010

Climate Change Ecology — 54 — Prof. J. Hicke



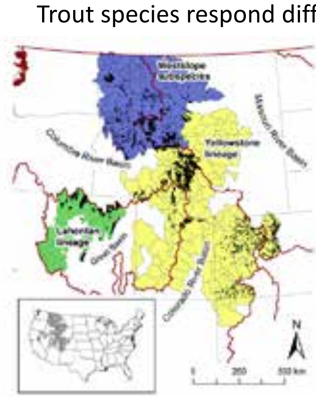
Source: Climate Impacts Group, University of Washington, www.cses.washington.edu/cig

Predicted response of bull trout to warming



Rieman et al. 2007

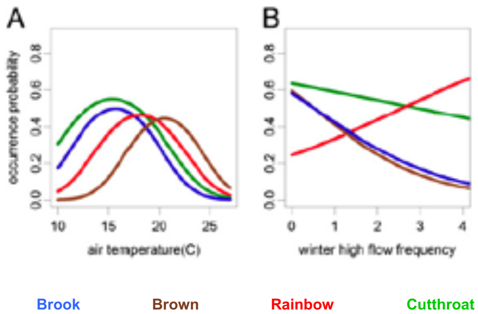
Trout species respond differently to warming



fishandboat.com/trout.htm; fieldguide.mt.gov

Wenger et al. 2011

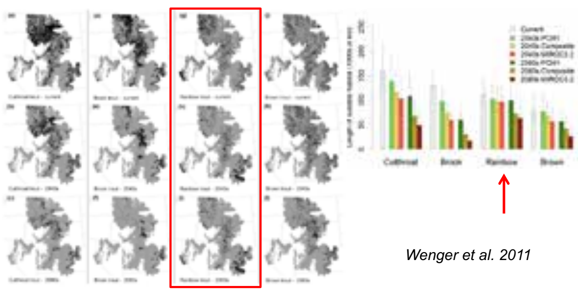
Species responses to air temperature, streamflow



Wenger et al. 2011

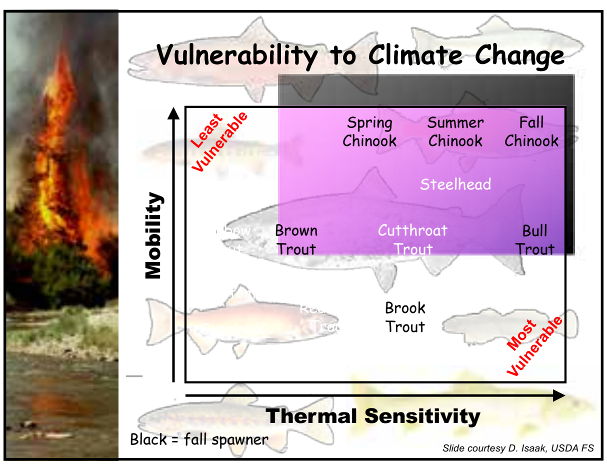
Predictions using future climate projections

Overall: 47% decrease by 2080



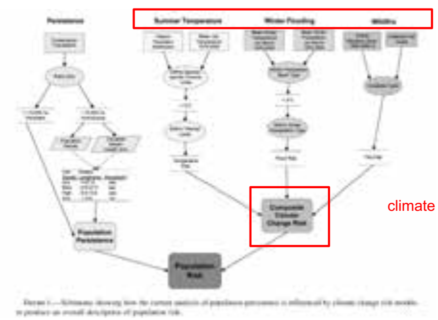
Wenger et al. 2011

Rainbow: negative T offset by flow changes that are beneficial (spring, not fall, spawners)



Cutthroat trout risk analysis that includes climate change

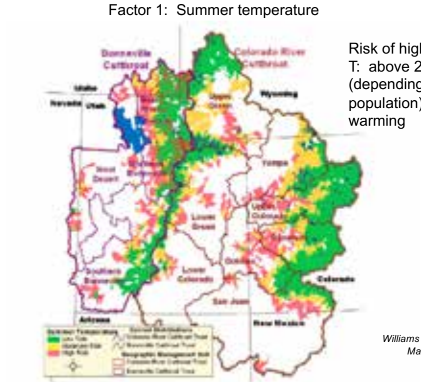
Factors influencing risk of losing cutthroat trout populations:
Adding climate change



Williams et al., NAJ Fish. Manag., 2009

Cutthroat trout risk analysis that includes climate change

Factor 1: Summer temperature

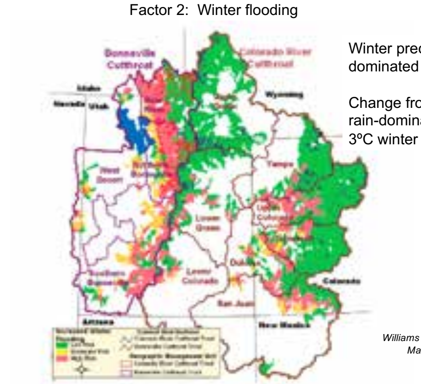


Risk of higher summer T: above 22º or 24ºC (depending on population) after 3ºC warming

Williams et al., NAJ Fish. Manag., 2009

Cutthroat trout risk analysis that includes climate change

Factor 2: Winter flooding



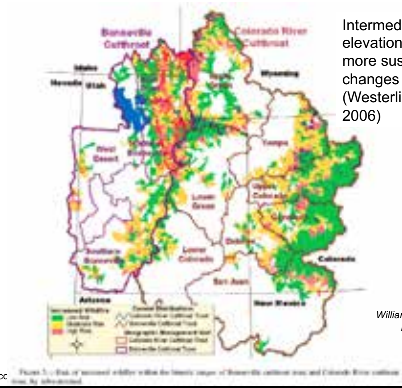
Winter precip-dominated watersheds

Change from snow- to rain-dominated with 3ºC winter warming

Williams et al., NAJ Fish. Manag., 2009

Cutthroat trout risk analysis that includes climate change

Factor 3: Wildfire impacts



Intermediate elevations may be more susceptible to changes in fire regime (Westerling et al., 2006)

Williams et al., NAJ Fish. Manag., 2009

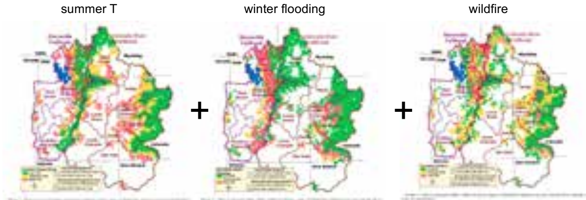
Cutthroat trout risk analysis that includes climate change

Composite risk = max of three climate risks

Bonneville subspecies: 73% in high risk

Colorado subspecies: 29% in high risk

More change from flooding, fire than from summer warming

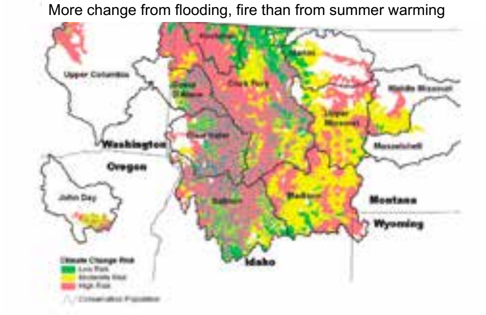


Williams et al., NAJ Fish. Manag., 2009

Cutthroat trout risk analysis that includes climate change

Westslope subspecies: 65% in high risk

More change from flooding, fire than from summer warming



Williams et al., NAJ Fish. Manag., 2009

Coral bleaching

Hannah, 2011

Coral bleaching

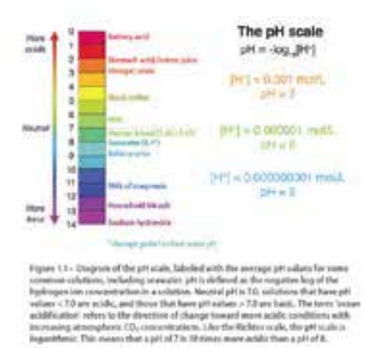
FIGURE 3.2 1997 – 1998: A Deadly Year for Corals.
The right panel shows corals bleached in the El Ni ñ o event of 1997 – 1998. The left panels show a single coral head pre- and postbleaching: (a) prebleaching, (b) bleached coral head, (c) partially recovered coral head, and (d) fully recovered postbleaching. *Left Source: Manzello et al., 2007; Right Source: Courtesy U.S. National Oceanic and Atmospheric Administration.*

Hannah, 2011

Coral bleaching

Marshall, Schuttenberg, 2006

Ocean acidification

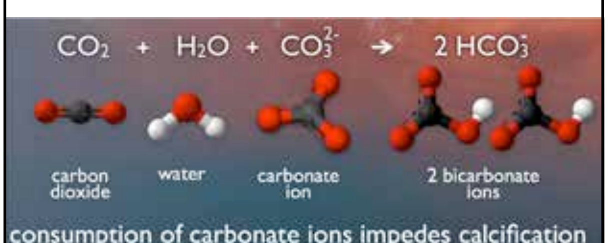


NOAA, State of Washington Report on Ocean Acidification, 2012

Inc. atm. CO2 leads to inc. H⁺

http://www.whoi.edu/OCB-OA/page.do?pid=112076

Inc. atm. CO2 leads to dec. carbonate ions



http://pmel.noaa.gov/co2/files/oareaction.jpg

Ocean acidification

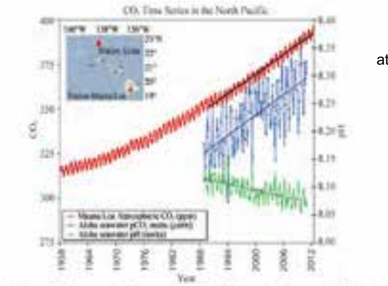


Figure 1.3 • Time series of atmospheric CO_2 at Mauna Loa (in ppm; mole fraction in dry air) and surface ocean pH and pCO_2 (µatm) at Ocean Station Aloha in the subtropical North Pacific Ocean. Note that the increase in oceanic CO_2 over the last 19 years is consistent with the atmospheric increase within the statistical limits of the measurements. Mauna Loa data: Dr. Pieter Tans, NOAA/ESRL (http://www.esrl.noaa.gov/gmd/ccgg/trends); HOTS/ALOHA data: Dr. John Dore, University of Hawaii (http://hahana.soest.hawaii.edu).

Recent changes in atmospheric CO2, CO2 in seawater, and pH

NOAA, State of Washington Report on Ocean Acidification, 2012

Climate Change Ecology 73 Prof. J. Hicke

Ocean acidification

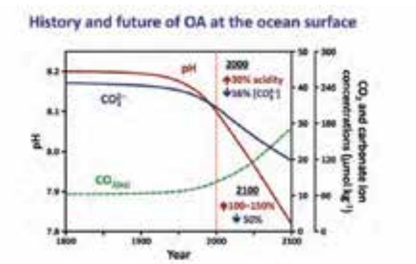


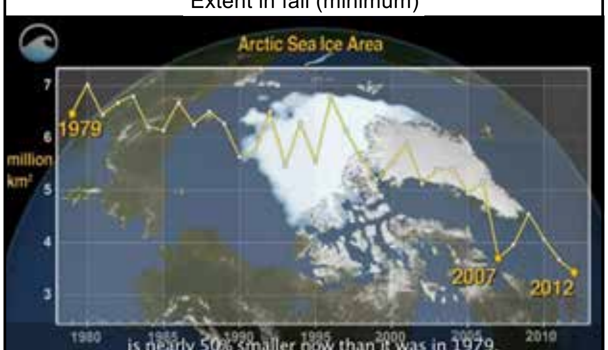
Figure 1.4 • Schematic diagram of the changes in pH, CO_3^{2-}, and $CO_{2(aqueous)}$ of the surface oceans under a high CO_2 emission scenario out to 2100 (after Wolf-Gladrow et al., 1999). The pH has declined by about 0.1 (equivalent to a hydrogen ion concentration increase of about 30%) since the beginning of the industrial era.

NOAA, State of Washington Report on Ocean Acidification, 2012

Climate Change Ecology 74 Prof. J. Hicke

Arctic sea ice retreat

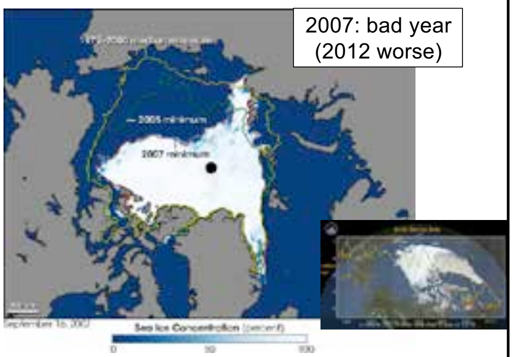
Extent in fall (minimum)



oceantoday.noaa.gov/welcome.html

Climate Change Ecology 75 Prof. J. Hicke

Arctic sea ice retreat



globalwarmingart.com

Arctic sea ice retreat

Models do not predict retreat as fast as observed (worrying)

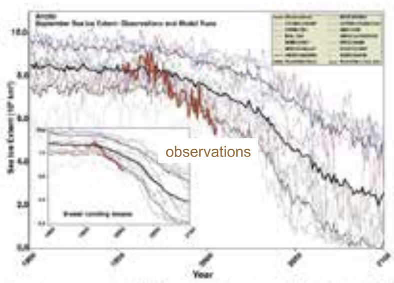


Figure 1. Arctic September sea ice extent (× 10^6 km^2) from observations (thick red line) and 13 IPCC AR4 climate models, together with the multi-model ensemble mean (solid black line) and standard deviation (dotted black line). Models with more than one ensemble member are indicated with an asterisk. Inset shows 9-year running means.

Stroeve et al., GRL, 2007

Climate change effects on Antarctic food webs

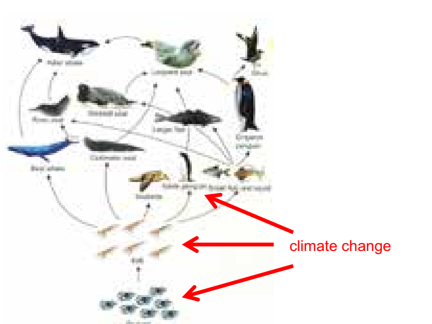


FIGURE 5.17 Example of an Antarctic Food Web.

Hannah, 2011