

Climate Change Trends, Impacts, and Vulnerabilities along the Appalachian National Scenic Trail, USA

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Introduction

Greenhouse gas emissions from vehicles, power plants, deforestation, and other human activities have increased temperatures around the world and changed other aspects of climate (IPCC 2013). Published field research shows that climate change is also altering ecosystems by shifting biomes, contributing to species extinctions, and causing numerous other changes (IPCC 2007b). To assist the National Park Service (NPS) integrate climate change into resource management of the Appalachian National Scenic Trail, this report presents results of spatial analyses of historical and projected climate and a summary of published scientific findings on ecological changes related to climate change.

Historical Climate Changes

From 1901 to 2002, mean annual temperature increased across the United States (U.S.) (Figure 1) and showed a statistically significant increases along the entire length of the trail (Figure 2, Table 1). From 1901 to 2002, precipitation showed varying changes across the eastern U.S. (Figure 3) and no statistically significant trends along the trail (Figure 4).

Historical Ecological Impacts

A limited number of published field research efforts has detected ecological changes outside the historical range of variation and attributed the changes to human climate change, rather than urbanization or other factors. Tracking of forest composition at field plots in the Green Mountains of Vermont from 1964 to 2004 found a 90-110 m upslope shift of northern hardwood forest into boreal conifer forest (Beckage et al. 2008). Analyses of Audubon Christmas Bird Count data on 254 bird species across the U.S., including the areas around the Appalachian National Scenic Trail, detected a northward shift of winter ranges at an average rate of $0.5 \pm 2.4 \text{ km y}^{-1}$ from 1975 to 2004, attributable to climate change (La Sorte and Thompson 2007).

Future Climate Projections

The Intergovernmental Panel on Climate Change (IPCC) has coordinated research groups to project possible future climates under defined greenhouse gas emissions scenarios (IPCC 2013). Three IPCC greenhouse gas emissions scenarios evaluated here are B1 (lower emissions), A1B (medium emissions), and A2 (higher emissions). Actual global emissions are on a path above IPCC emissions scenario A2 (IPCC 2013, Raupach et al. 2007).

For the three emissions scenarios, projected 21st century temperature along the trail could increase two to eight times the amount of historical 20th century warming (Table 1, Mitchell and Jones 2005, Gonzalez et al. 2010). The set of available general circulation models (GCMs) of the atmosphere project increased precipitation along the trail under all three scenarios (Table 1). For emissions scenario A2, 13 to 17 out of 18 GCMs project increases in precipitation (Figure 5; historical average from Mitchell and Jones 2005, Hijmans et al. 2005; projections from IPCC 2007a, Tabor and Williams 2010, Conservation International; analysis by P. Gonzalez).

Projected Ecological Vulnerabilities

Analyses of climate projections and modeling of ecosystem and infrastructure changes indicate potential vulnerabilities of species, ecosystems, and other resources if we do not reduce our greenhouse gas emissions. Climate change could shift the ranges of numerous tree species in the Appalachian Mountains northward (Iverson et al. 2008, Mohan et al. 2009). Because cold winter temperatures reduce the survival and limit the range of the hemlock wooly adelgid, a pest that has killed extensive areas of forest, future warmer temperatures may favor substantial northward and upslope expansion across eastern North America (Fitzpatrick et al. 2012, Paradis et al. 2008). Modeling of the range of the invasive species kudzu (*Pueraria lobata*) indicates a potential increase in the Mid-Atlantic (Bradley et al. 2010). Experimental increases of atmospheric carbon dioxide in a North Carolina forest (Mohan et al. 2006) indicate that climate change could increase the growth and toxicity of poison ivy (*Toxicodendron radicans*). Among mammal species, moose and bats are vulnerable to increased mortality with warmer winters (Rodenhouse et al. 2009).

Table 1. Historical and projected climate trends for the area that includes the Appalachian National Scenic Trail (Mitchell and Jones 2005, IPCC 2013, Gonzalez et al. 2010). Historical climate and projections for IPCC emissions scenarios B1 and A1B calculated for the 50 x 50 km pixels that include the park (Gonzalez et al. 2010). Climate under emissions scenario A2 calculated for the 4 x 4 km pixels that include the park (data from Conservation International, using method of Tabor and Williams (2010)). Standard error given for historical trends; standard deviation (SD) given for other variables. NPS trail segments, from north to south: New England (including Maine, New Hampshire, Vermont), Mid-Atlantic (including New York, New Jersey, Pennsylvania, Maryland, West Virginia, northern Virginia), Southwestern Virginia (Virginia south of Shenandoah National Park), South (North Carolina, Tennessee, Georgia).

	New England	Mid- Atlantic	SW Virginia	South	units
Historical (1901-2002)					
temperature annual average	5.1 ± 0.8	10 ± 0.7	11 ± 0.7	13 ± 0.6	°C
temperature linear trend	1.5 ± 0.2	0.8 ± 0.2	0.5 ± 0.2	-0.1 ± 0.2	°C/century
precipitation annual average	1100 ± 100	1100 ± 100	1000 ± 100	1300 ± 200	mm/y
precipitation linear trend	5 ± 3	0 ± 3	-4 ± 4	1 ± 4	%/century
Projected (1990-2100)					
IPCC B1 scenario (lower emissions)					
temperature change in annual average	2.9 ± 1.0	2.7 ± 0.9	2.4 ± 1.0	2.3 ± 0.9	°C/century
precipitation change in annual total	8 ± 5	7 ± 6	4 ± 6	3 ± 6	%/century
IPCC A1B scenario (medium emissions)					
temperature change in annual average	4.0 ± 1.0	3.8 ± 0.9	3.6 ± 1.0	3.5 ± 0.9	°C/century
precipitation change in annual total	9 ± 5	8 ± 6	5 ± 6	4 ± 6	%/century
IPCC A2 scenario (higher emissions)					
temperature change in annual average	4.6 ± 1.0	4.4 ± 0.9	4.2 ± 1.0	4.0 ± 0.9	°C/century
precipitation change in annual total	8 ± 5	8 ± 6	7 ± 6	4 ± 6	%/century

Figure 1.

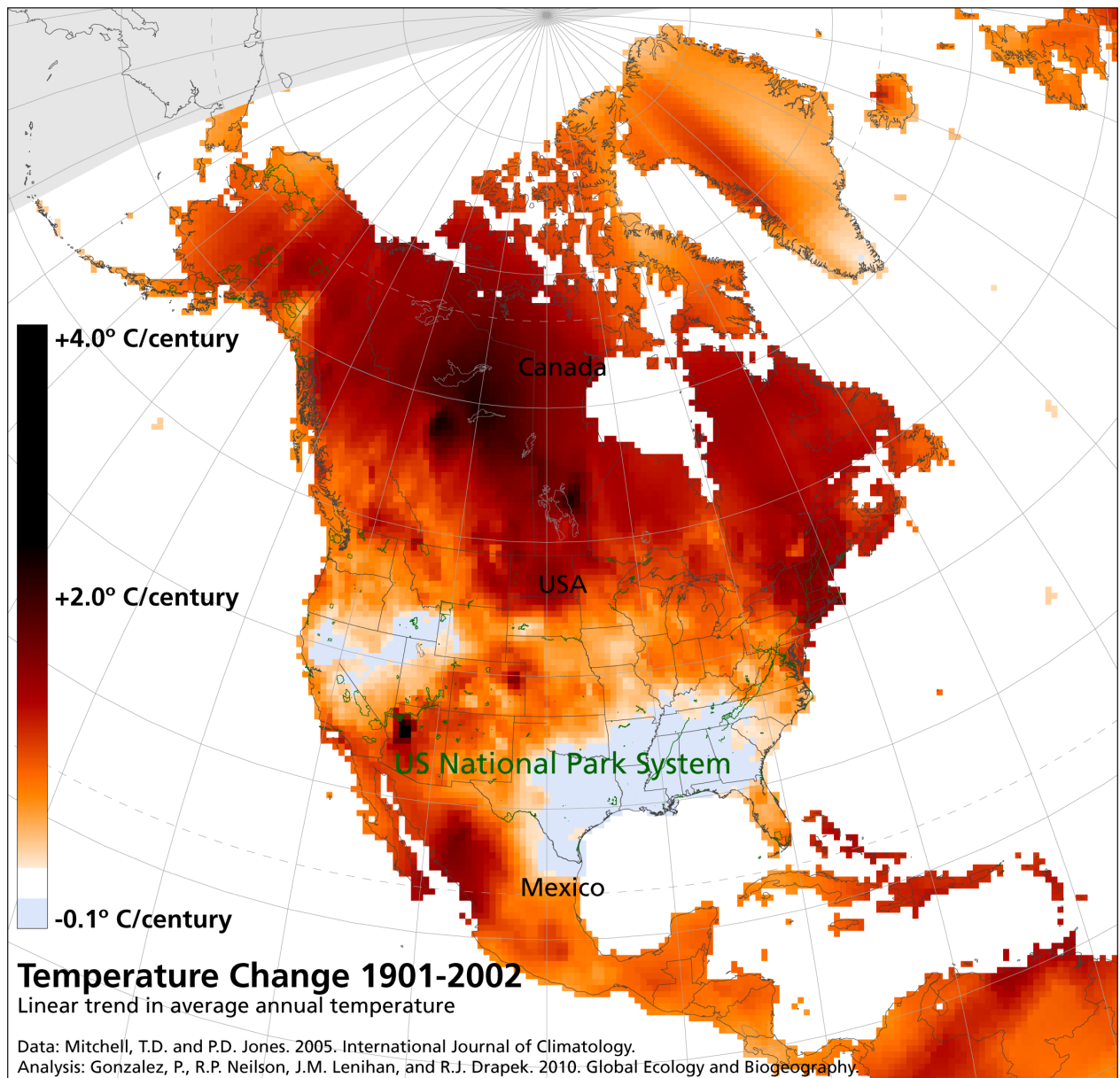


Figure 2.

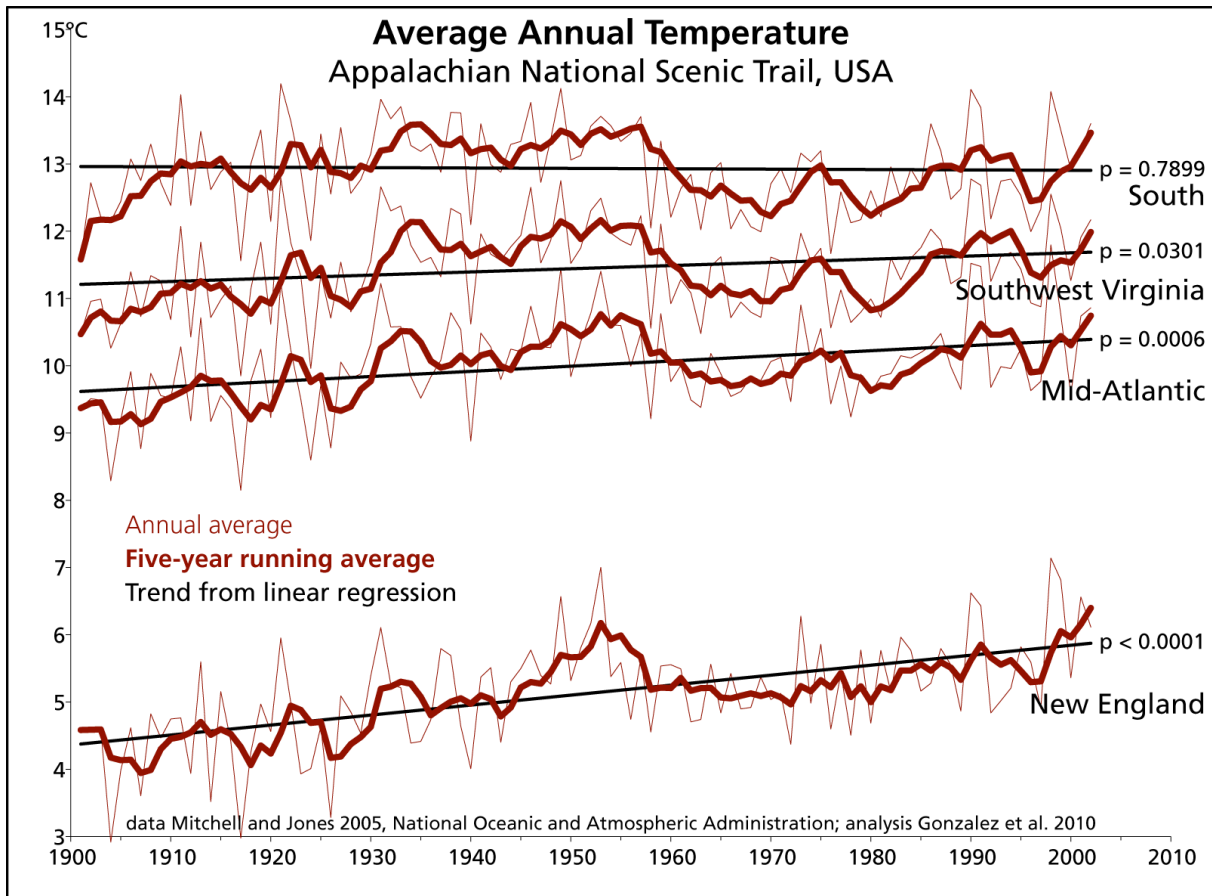


Figure 3.

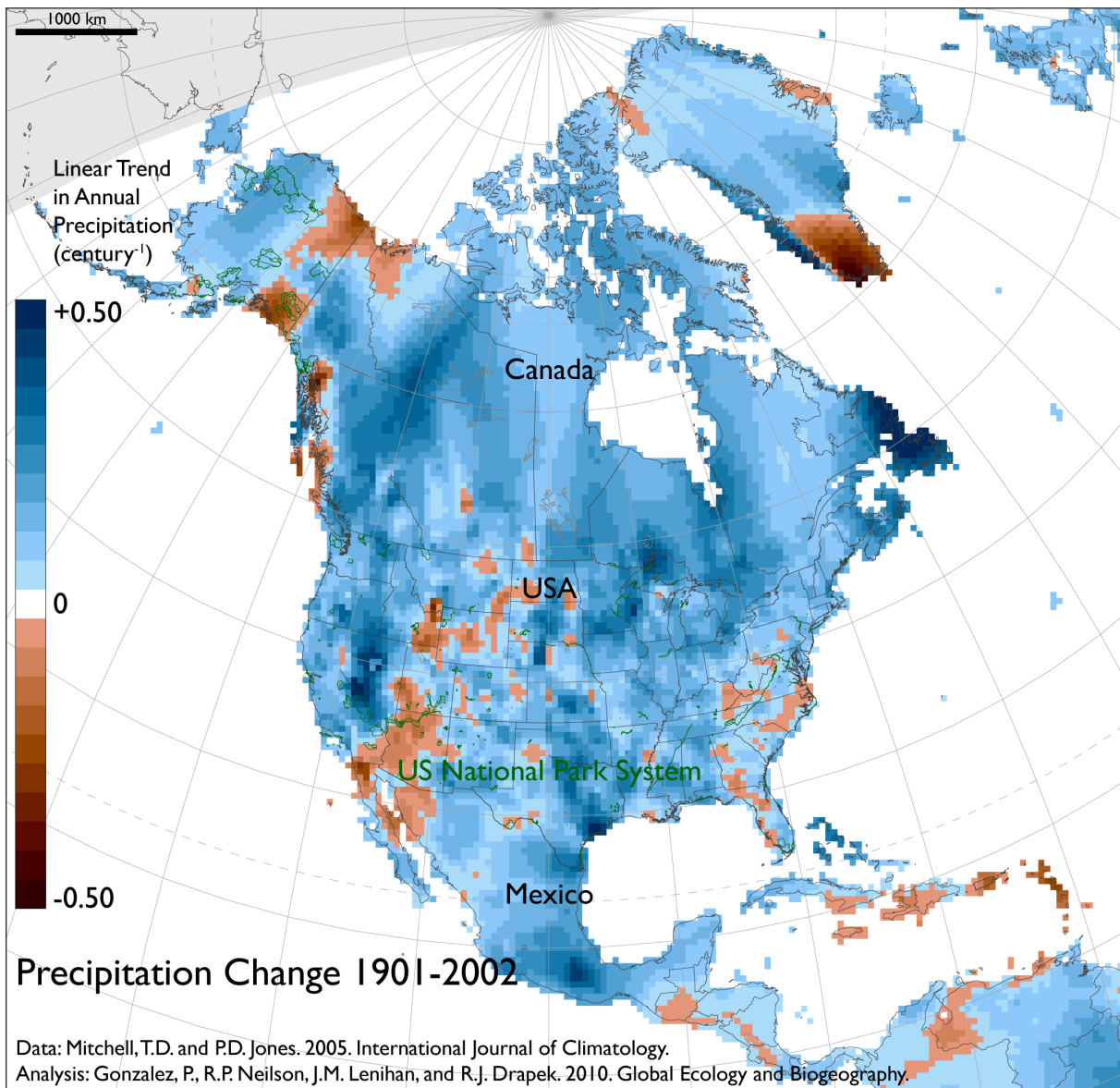


Figure 4.

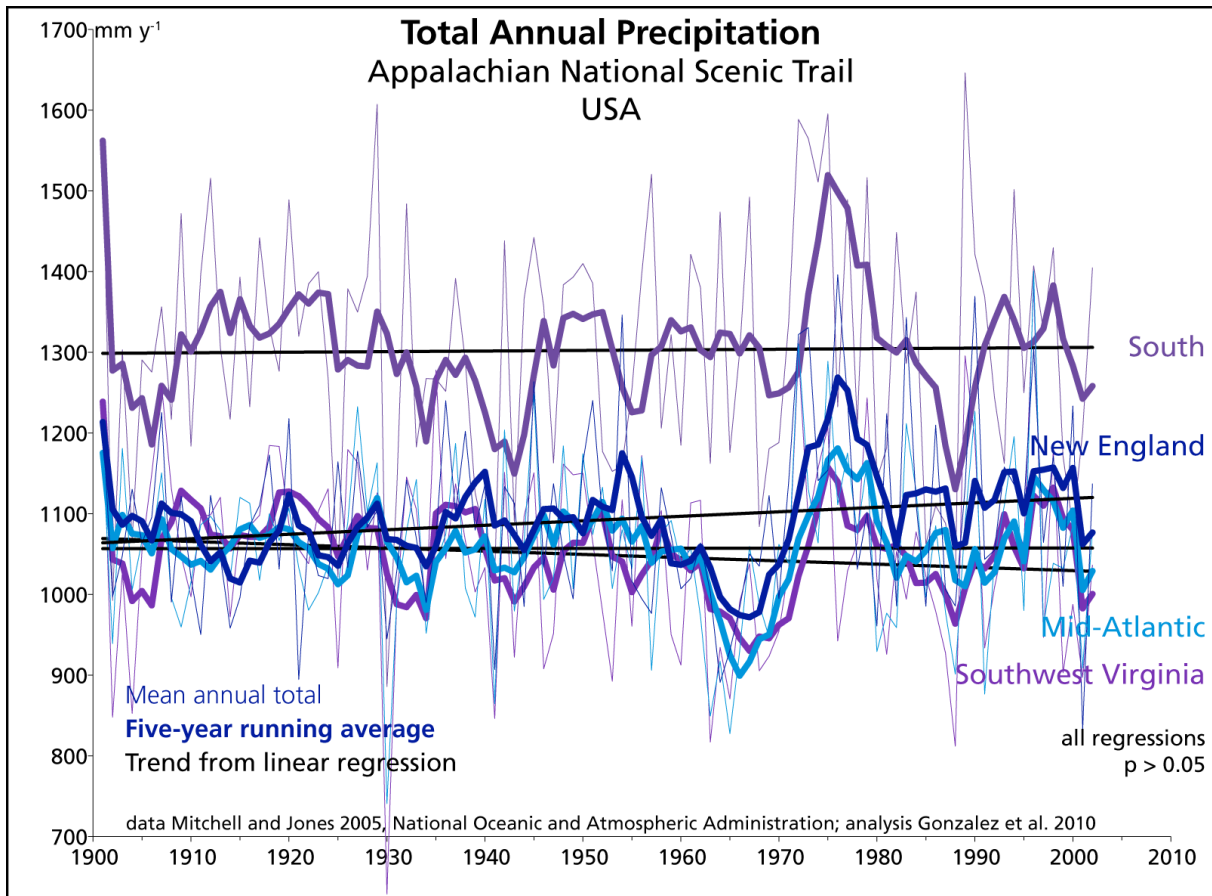
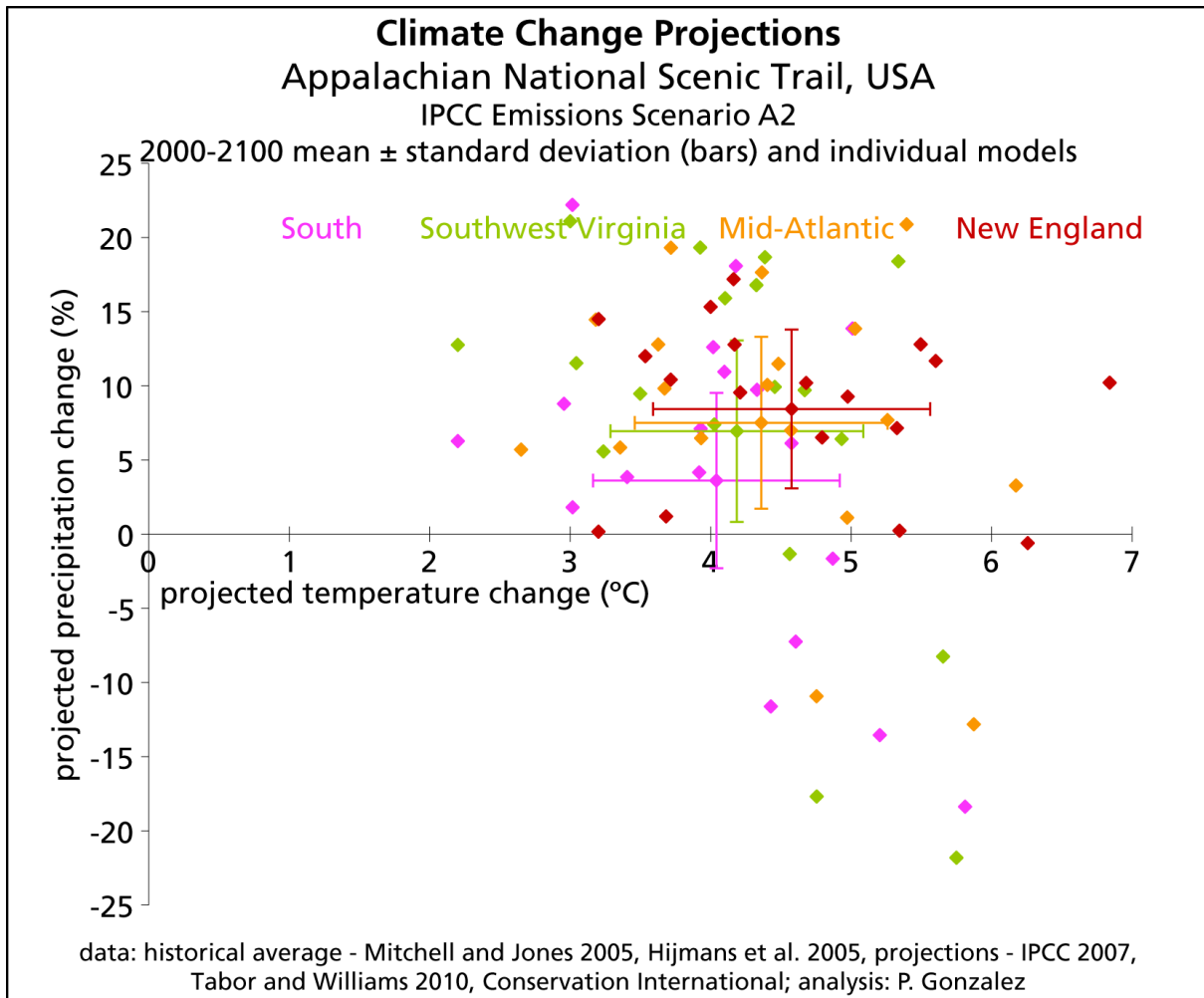


Figure 5.



References

- Fitzpatrick, M.C., E.L. Preisser, A. Porter, J. Elkinton, and A.M. Ellison. 2012. Modeling range dynamics in heterogeneous landscapes: invasion of the hemlock woolly adelgid in eastern North America. *Ecological Applications* 22: 472-486.
- Gonzalez, P., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2010. Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. *Global Ecology and Biogeography* 19: 755-768.
- Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25: 1965-1978.
- Intergovernmental Panel on Climate Change (IPCC). 2007a. *Climate Change 2007: The Physical Science Basis*. Cambridge University Press, Cambridge, UK.
- Intergovernmental Panel on Climate Change (IPCC). 2007b. *Climate Change 2007: Impacts, Adaptation, and Vulnerability*. Cambridge University Press, Cambridge, UK.
- Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2013: The Physical Science Basis*. Cambridge University Press, Cambridge, UK.
- Mitchell, T.D. and P.D. Jones. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology* 25: 693-712.
- Mohan, J.E., R.M. Cox, and L.R. Iverson. 2009. Composition and carbon dynamics of forests in northeastern North America in a future, warmer world. *Canadian Journal of Forest Research* 39: 213-230.
- Paradis, A., J. Elkinton, K. Hayhoe, and J. Buonaccorsi. 2008. Role of winter temperature and climate change on the survival and future range expansion of the hemlock woolly adelgid (*Adelges tsugae*) in eastern North America. *Mitigation and Adaptation Strategies for Global Change* 13: 541-554.
- Raupach, M.R., G. Marland, P. Ciais, C. Le Quéré, J.G. Canadell, G. Klepper, and C.B. Field. 2007. Global and regional drivers of accelerating CO₂ emissions. *Proceedings of the National Academy of Sciences of the USA* 104:10 288-10 293.
- Rodenhouse, N.L., L.M. Christenson, D. Parry, and L.E. Green. 2009. Climate change effects on native fauna of northeastern forests. *Canadian Journal of Forest Research* 39: 249-263.
- Tabor, K. and J.W. Williams. 2010. Globally downscaled climate projections for assessing the conservation impacts of climate change. *Ecological Applications* 20: 554-565.