# Climate Change Adaptation in Pennsylvania: Natural Resources

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# IPCC Emissions Scenarios

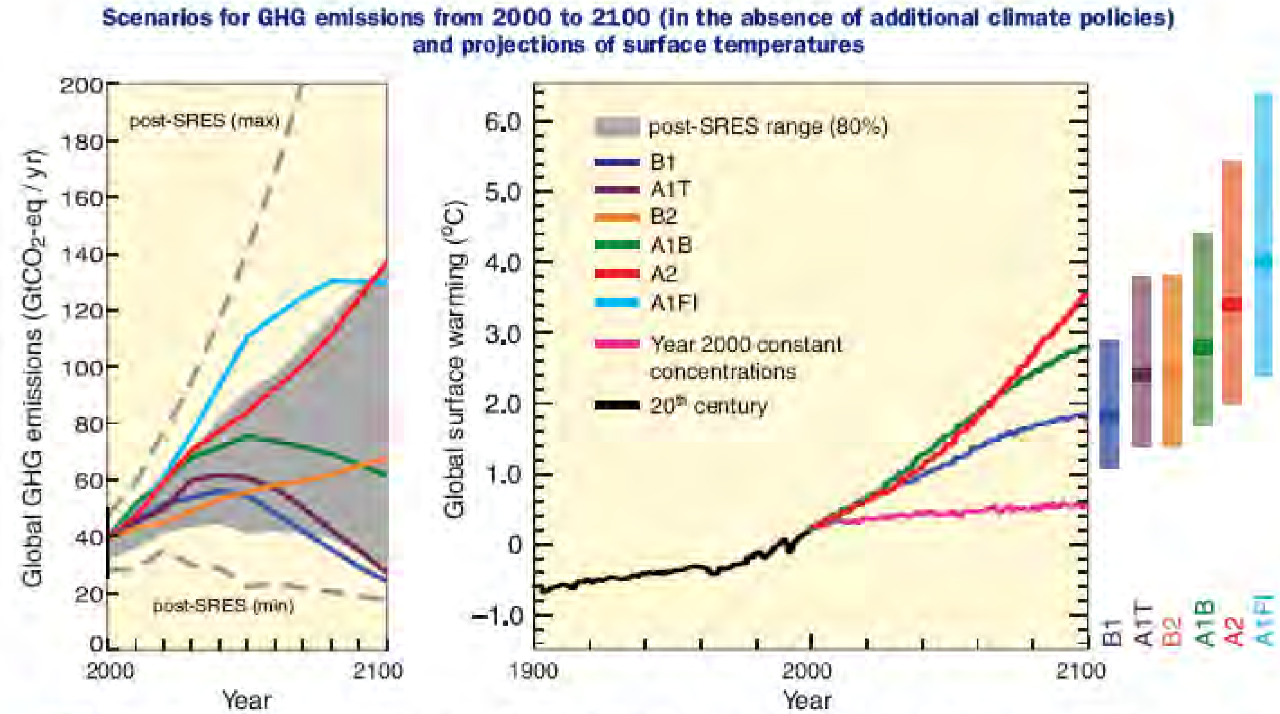
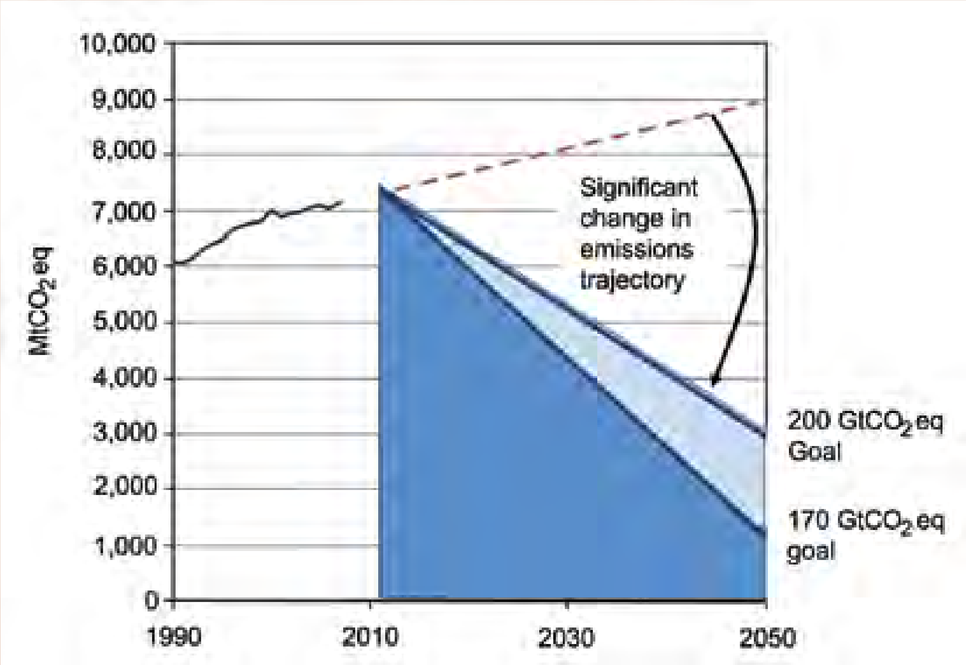



*Figure SPM.5.* **Left Panel:** *Global GHG emissions (in* $GtCO_2$*-eq) in the absence of climate policies: six illustrative SRES marker scenarios (coloured lines) and the 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include* $CO_2$, $CH_4$, $N_2O$ *and F-gases.* **Right Panel:** *Solid lines are multi-model global averages of surface warming for scenarios A2, A1B and B1, shown as continuations of the 20th-century simulations. These projections also take into account emissions of short-lived GHGs and aerosols. The pink line is not a scenario, but is for Atmosphere-Ocean General Circulation Model (AOGCM) simulations where atmospheric concentrations are held constant at year 2000 values. The bars at the right of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090-2099. All temperatures are relative to the period 1980-1999. {Figures 3.1 and 3.2}*

# Magnitude of Future Climate Change




- 170-220 Gt $CO_2$-eq between 2012 & 2050
- Current rate is 7 Gt/yr (~266 Gt net release)
- *Reduction of 17 to 36% of annual emissions (my math)*

NRC Report 2010, Limiting the Magnitude of Future Climate Change

# Magnitude of Future Climate Change

- Only 2 of 14 models were able to produce scenarios that attained the 450 goal (~2°C warming)
  - without immediate, full global participation and only then if an overshoot trajectory to the goal was allowed.
- Otherwise, no models could produce the scenario that met the 450 ppm $CO_2$-eq by 2100.
- Warming of ~3°C is more likely (550 ppm) or real warming may be higher (650 ppm)

NRC Report 2010, Limiting the Magnitude of Future Climate Change

# Adaptation

- "adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects"

# Adaptation

- Involves:
  - Projection of potential impacts from science
  - Scale of impacts and response
- Includes:
  - Building adaptive capacity
  - Transforming capacity into action

# Building Adaptive Capacity

- Communicating climate change information
- Building awareness of potential impacts
- Maintaining well-being
- Protecting property/land
- Exploiting new opportunities

# Adapting to the Impacts of Climate Change

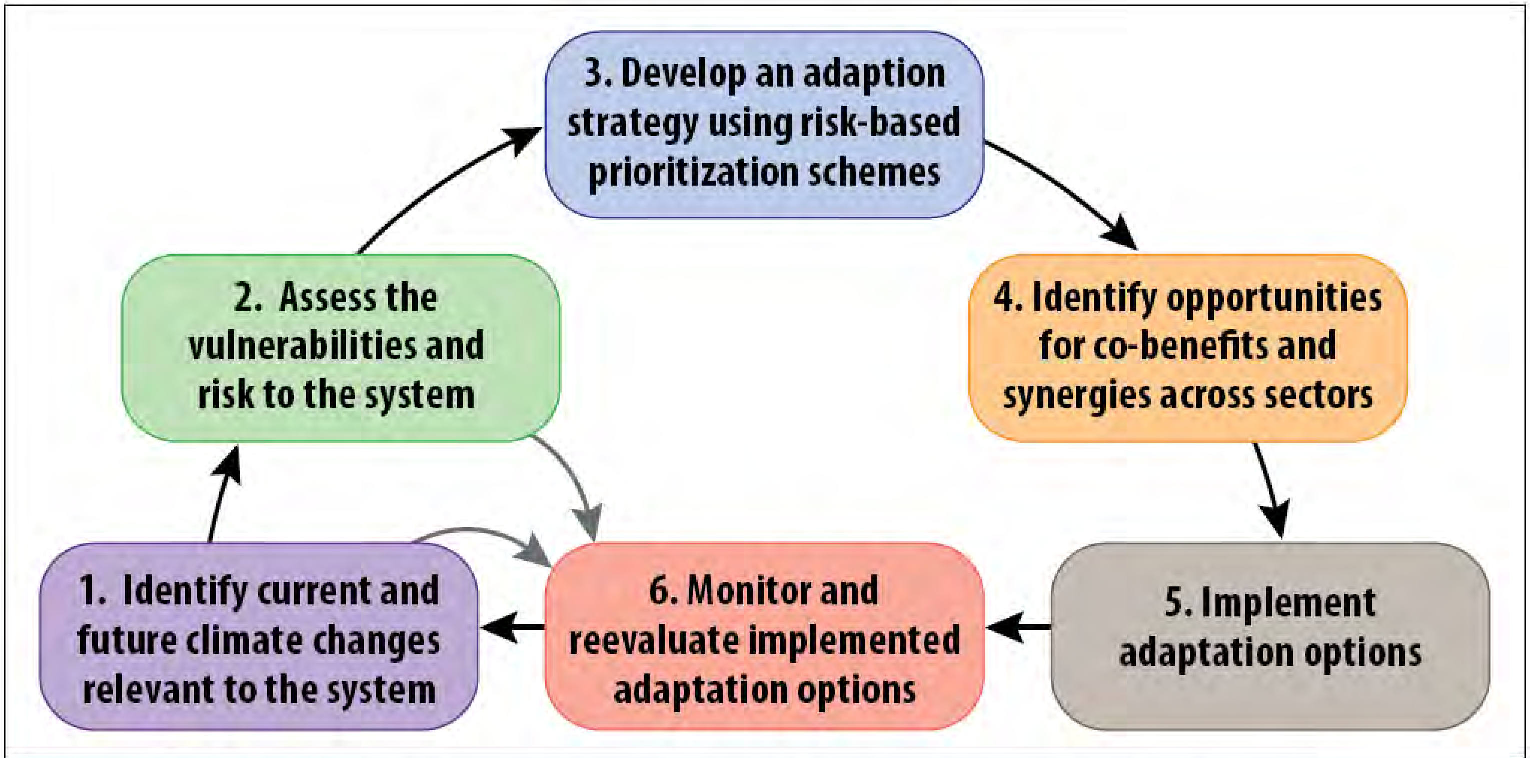
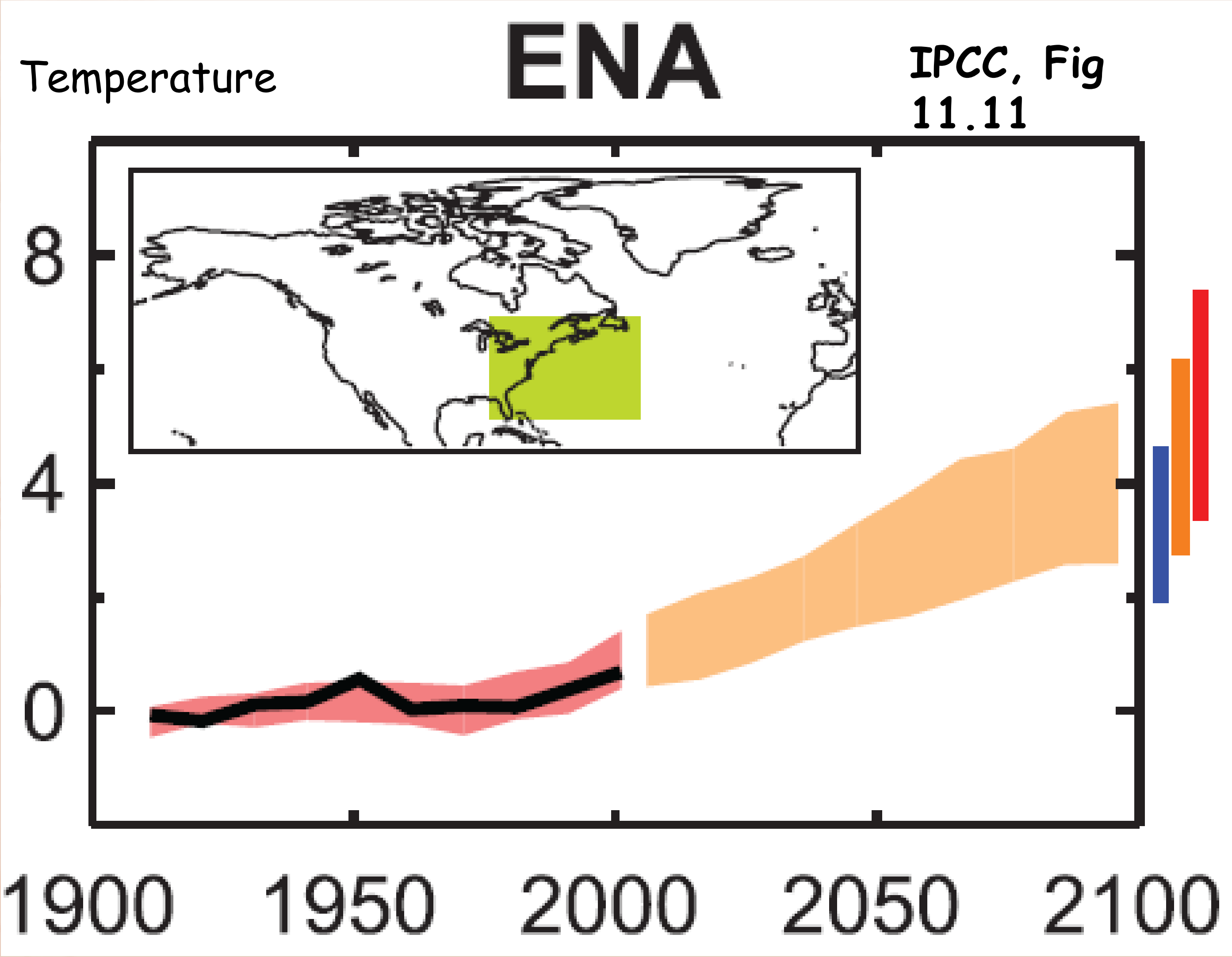



**Figure 1.** Adaptation planning is envisioned as a cyclical, iterative process incorporating these six steps.

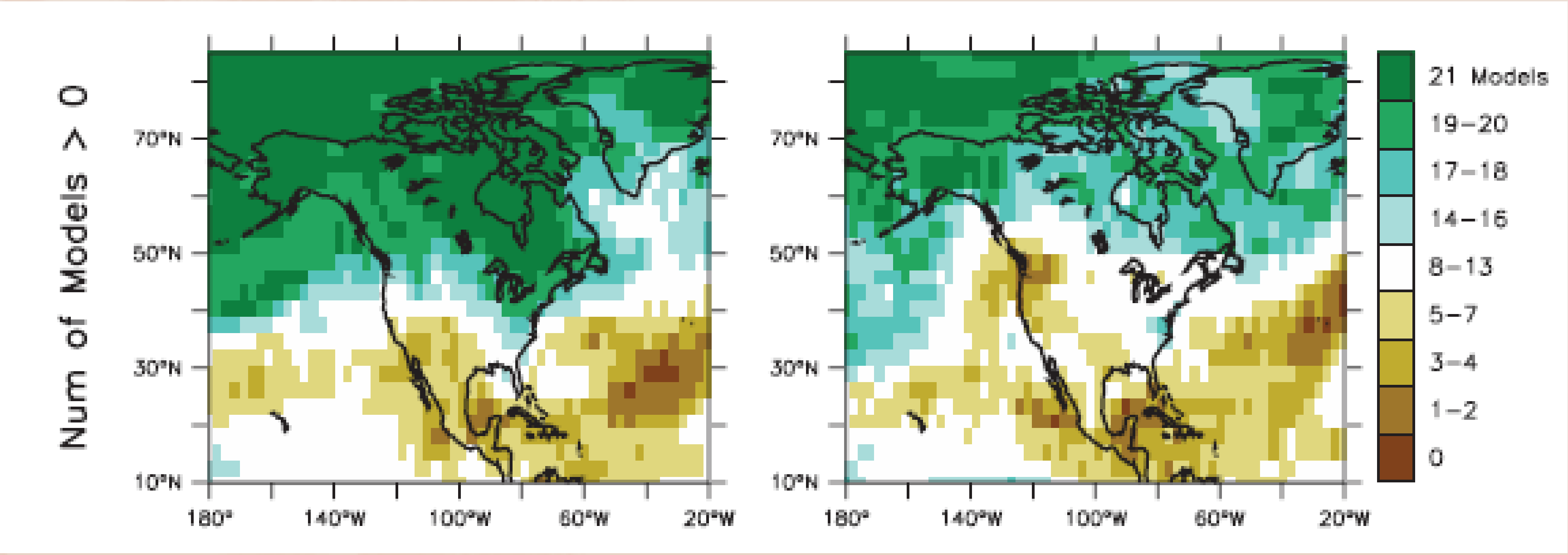
NRC Report 2010, Adapting to the Impacts of Climate Change

# Climate Projections



# Climate Projections

*Annual* *Jun-Jul-Aug*

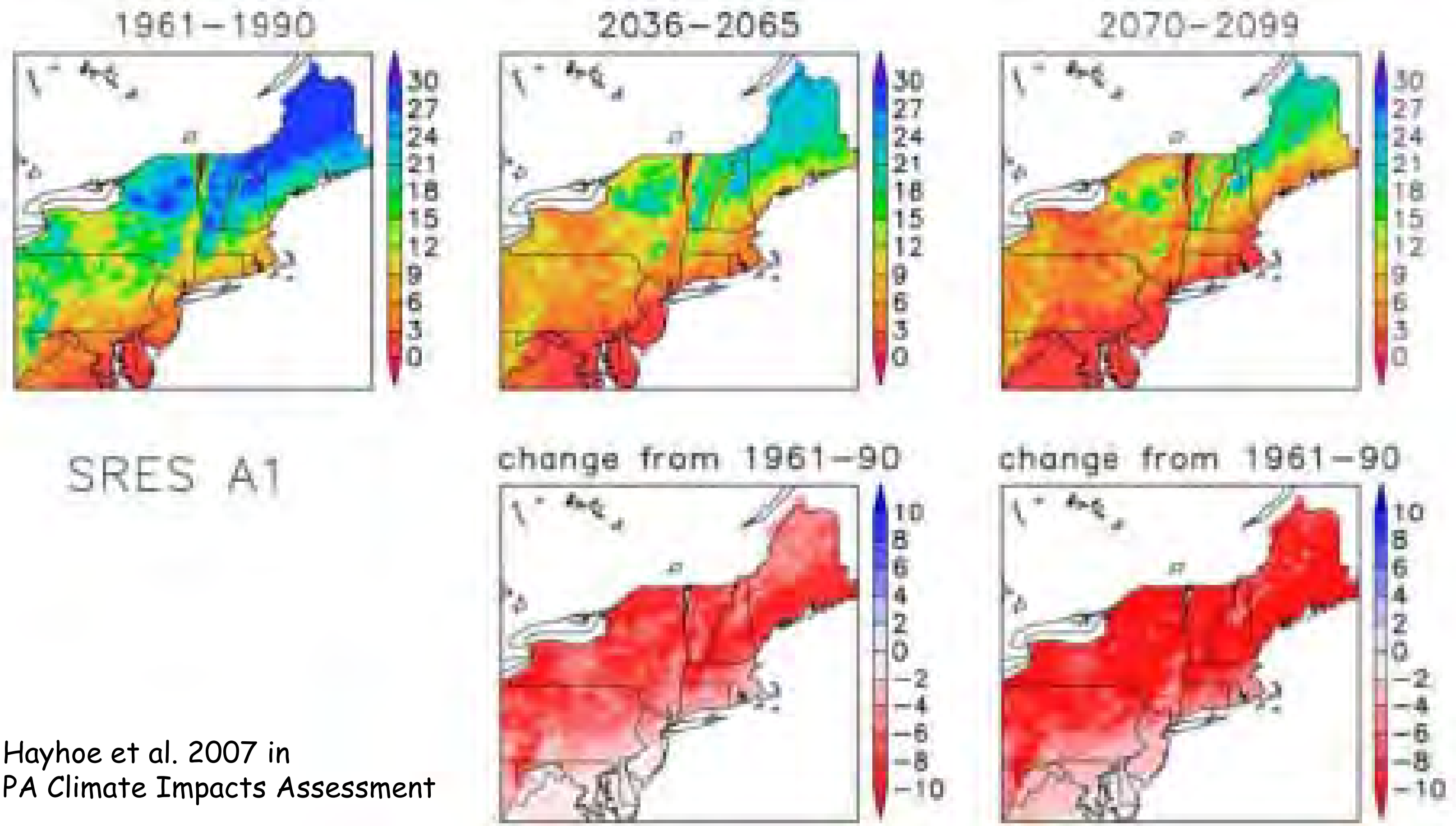



Model agreement: Precipitation

**IPCC, Fig 11.12**

# Climate Projections

Snow-covered days per month



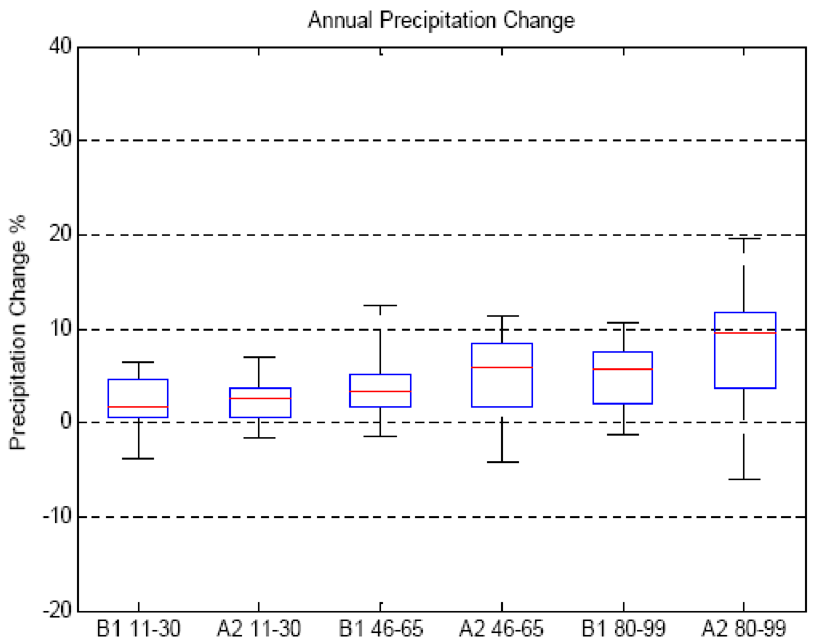

Hayhoe et al. 2007 in
PA Climate Impacts Assessment

# Climate Projections

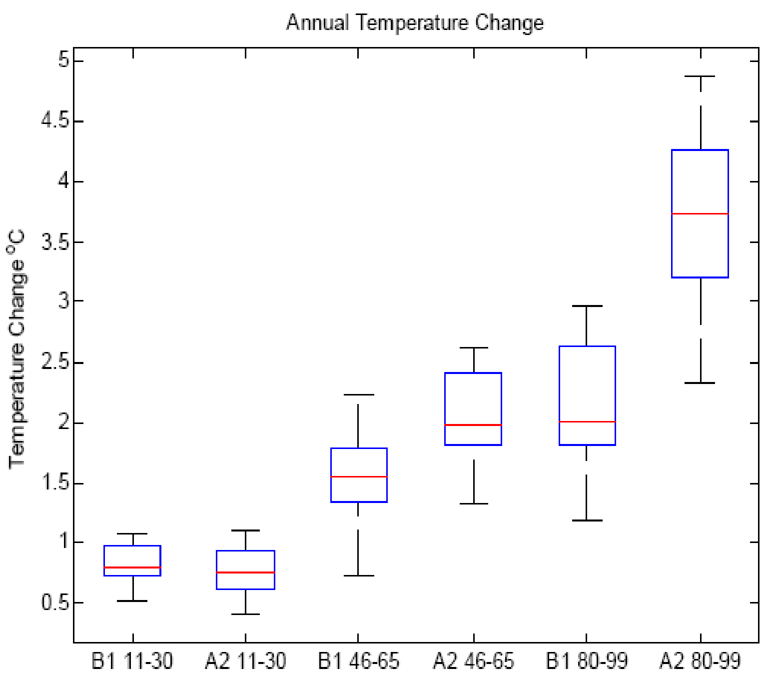
Pennsylvania Climate Impacts Assessment

- It is very likely that Pennsylvania will warm (7°F)
- It is likely that annual precipitation will increase

*Annual Precipitation*




*Annual Temperature*

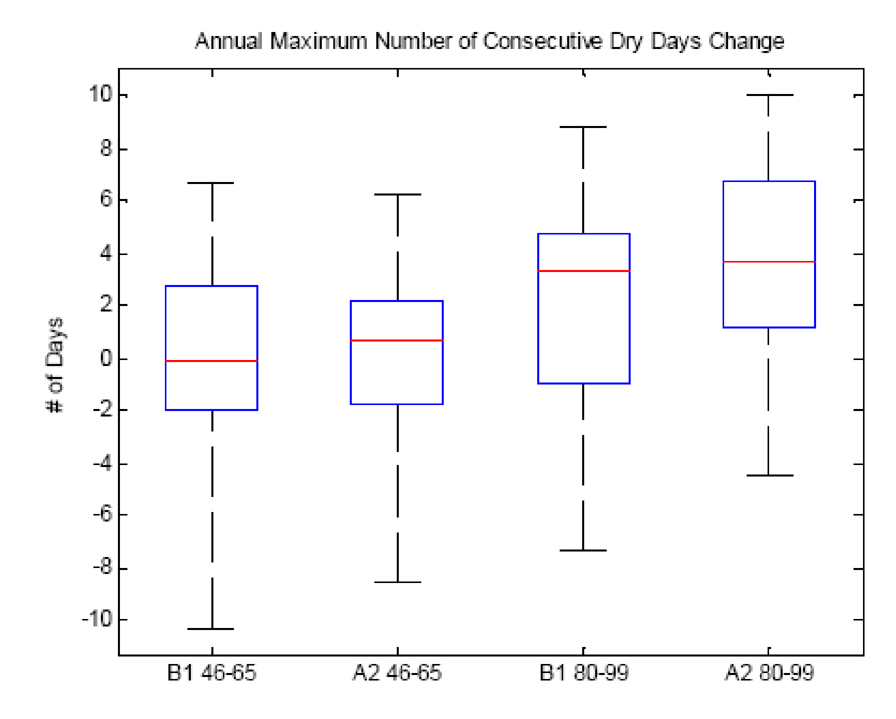


# Climate Projections

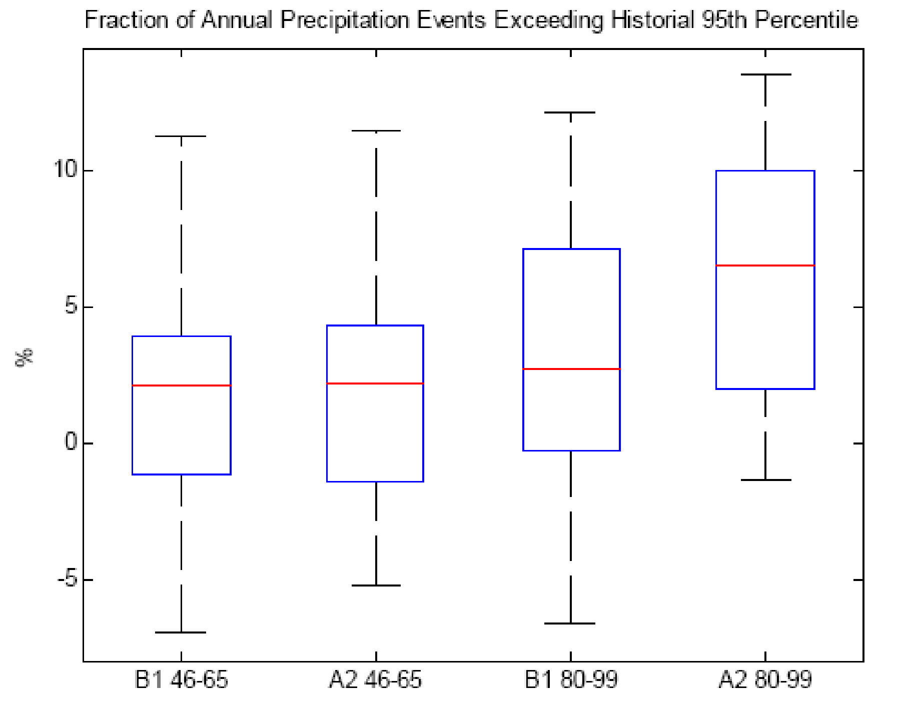
Pennsylvania Climate Impacts Assessment

- It is likely that Pennsylvania's precipitation will become more extreme, with longer dry periods and greater intensity of precipitation

*Consecutive Dry Days*




*Large Precipitation Events*

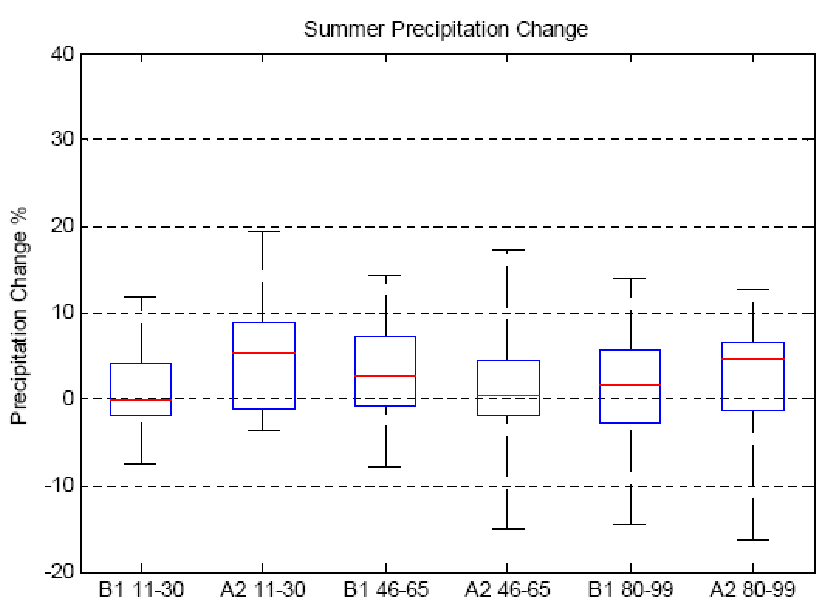


# Climate Projections

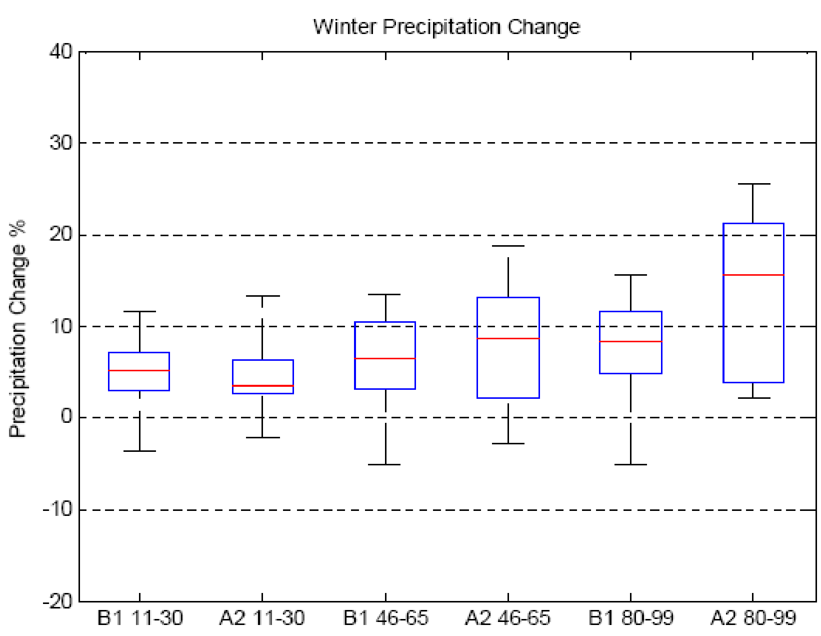


- It is very likely that winter precipitation will increase

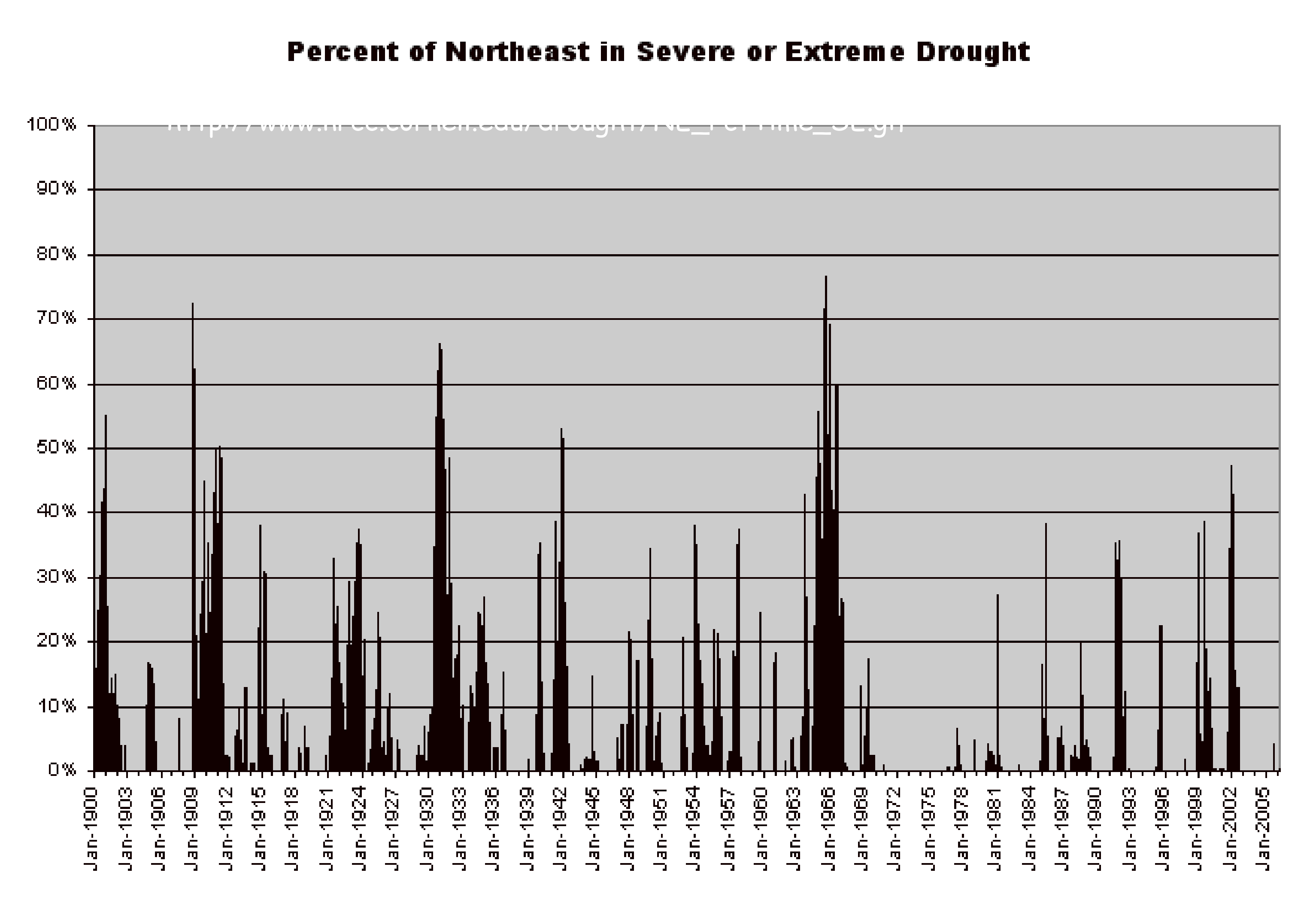
*Summer*




*Winter*



# Historical Analogues?



# Climate Projections Summary

- Getting warmer (0.65 to 0.75°C/decade) – especially in winter (Hayhoe et al. 2007)
- Increase in growing season (1 week); decrease in frost
- Increase in annual precipitation and heavy rain events (9.5mm), but droughts too

# Adapting to the Impacts of Climate Change

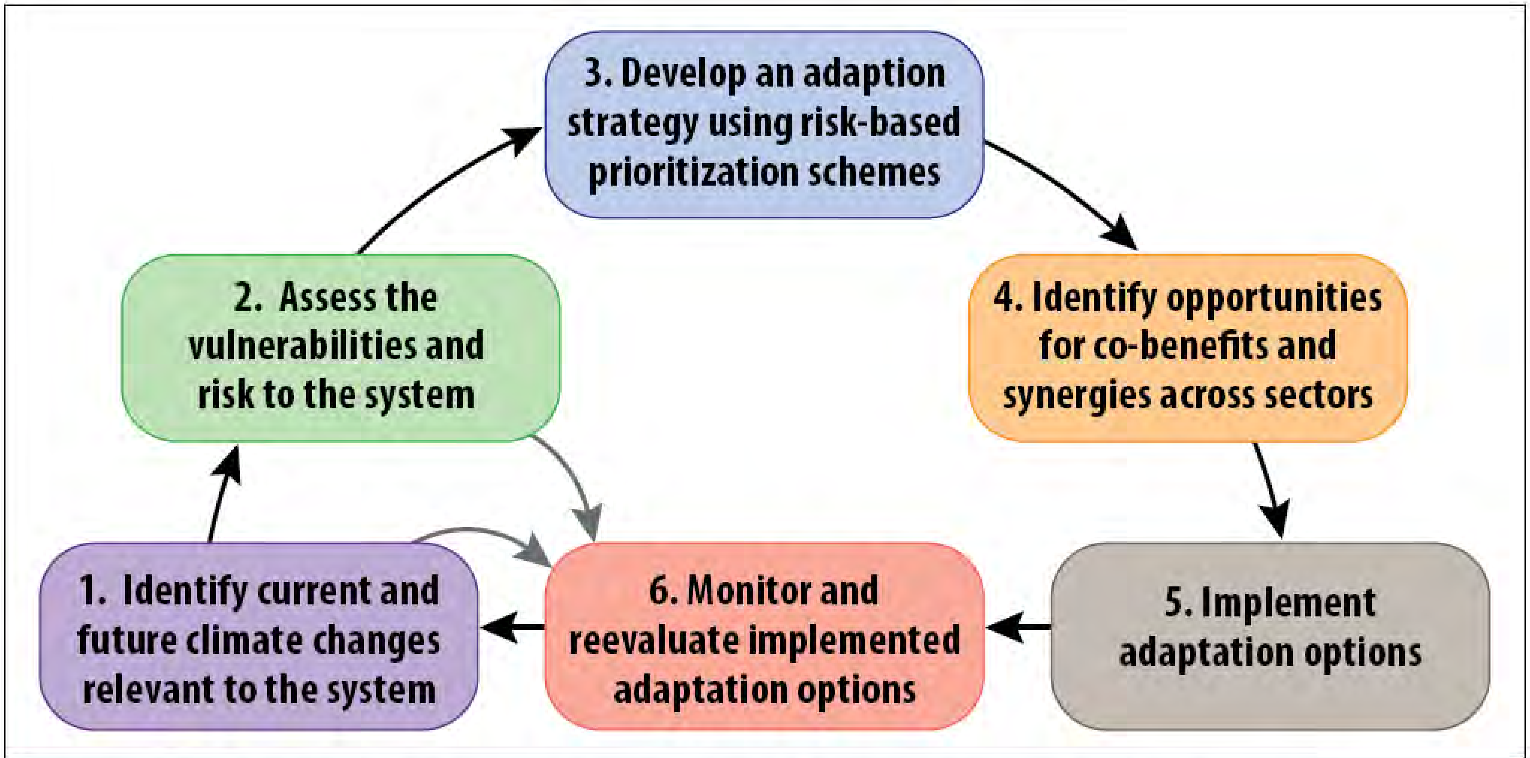


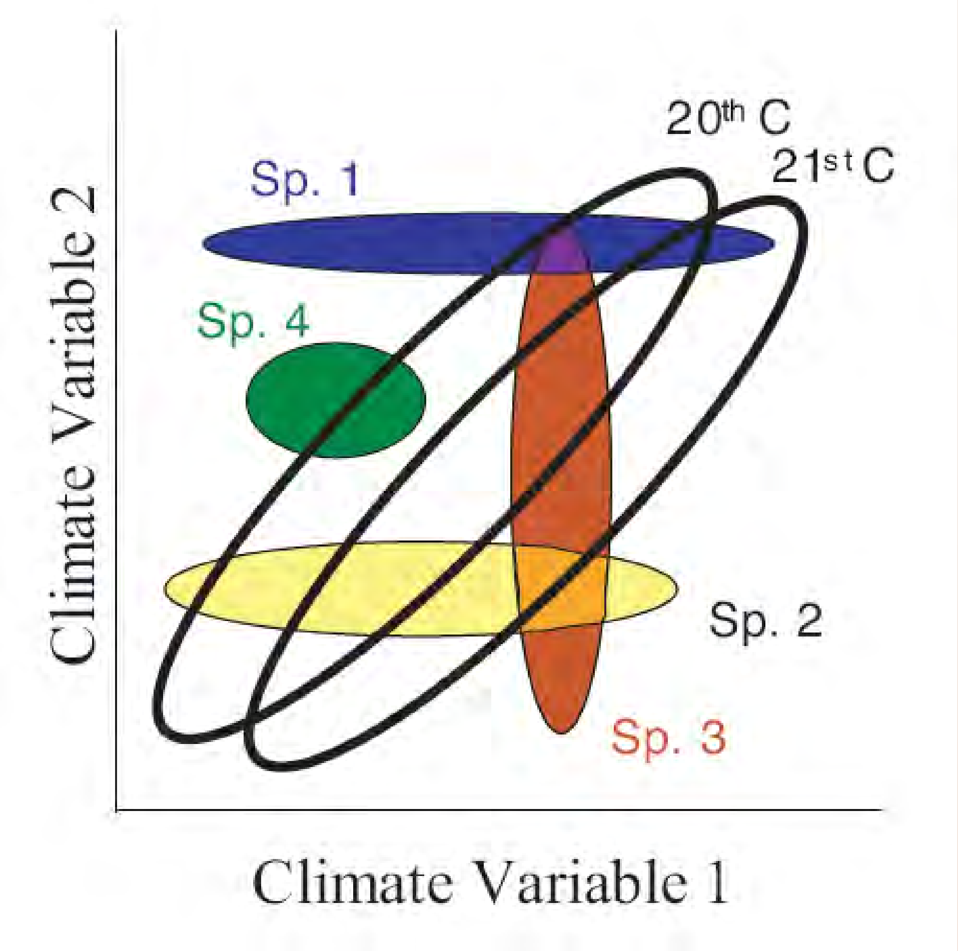

**Figure 1.** Adaptation planning is envisioned as a cyclical, iterative process incorporating these six steps.

NRC Report 2010, Adapting to the Impacts of Climate Change

# Vulnerabilities and Risks

- Species composition and ranges
- Disturbance regimes
- Growth rates and phenology
- Insect/disease dynamics
- Hydrology & earlier peak discharge
- Interactive factors
  - fragmentation, invasive species, nitrogen deposition

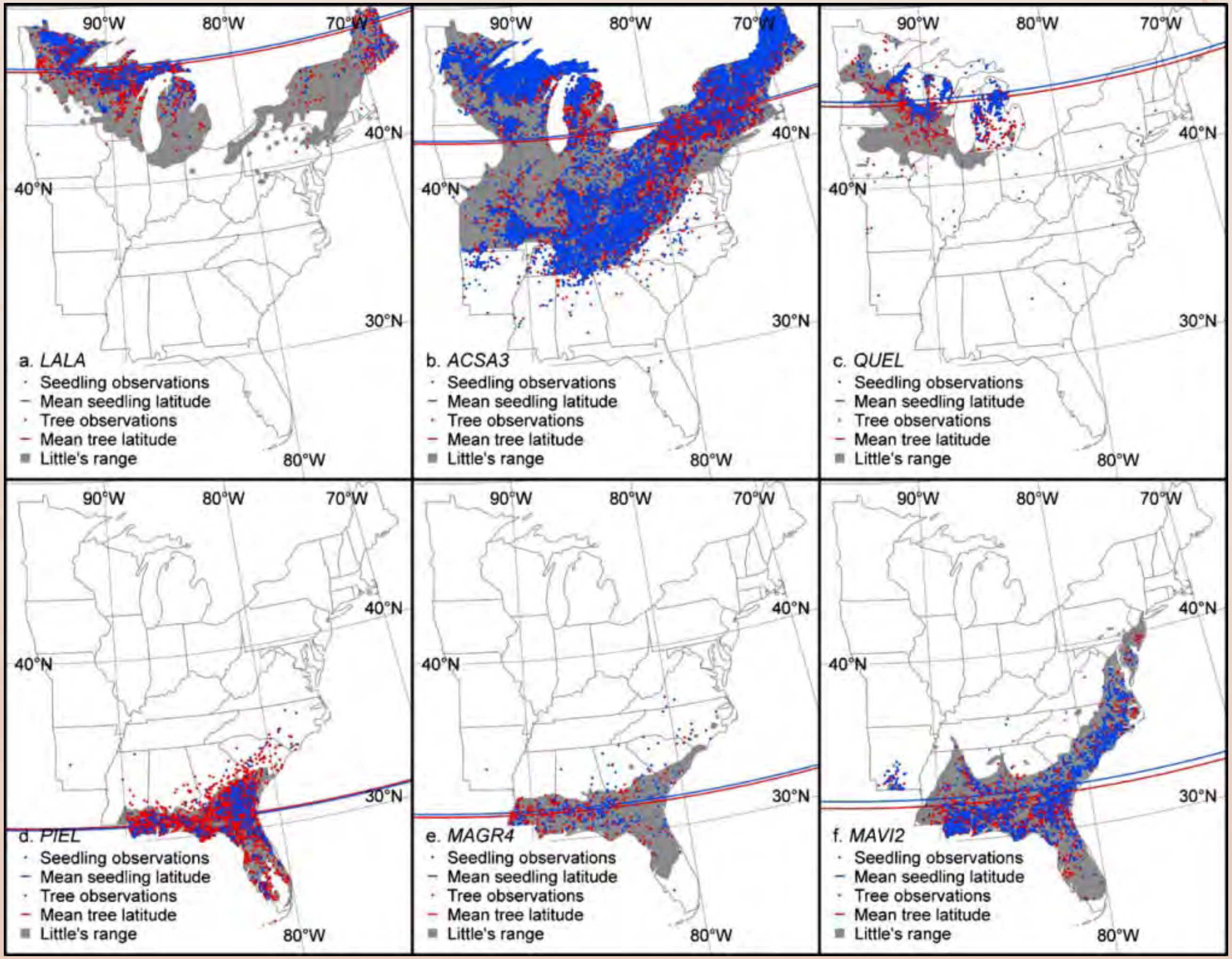
# Shifts in Species Ranges




Jack Williams et al. PNAS 2007

# Evidence for Range Shifts

Northward migration




Woodall et al. Forest Ecology and Management 2009

# Evidence for Range Shifts


Beckage et al. PNAS 2008

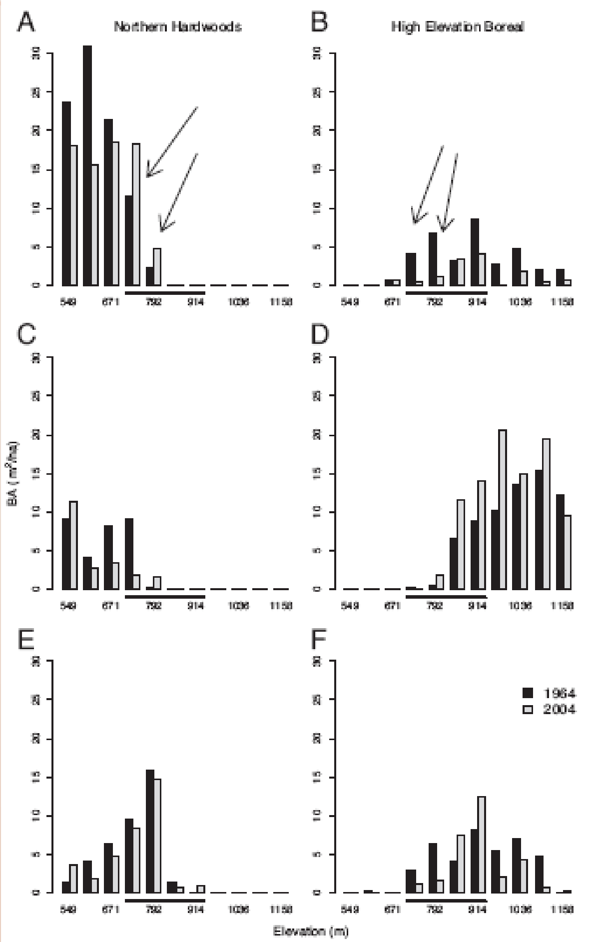
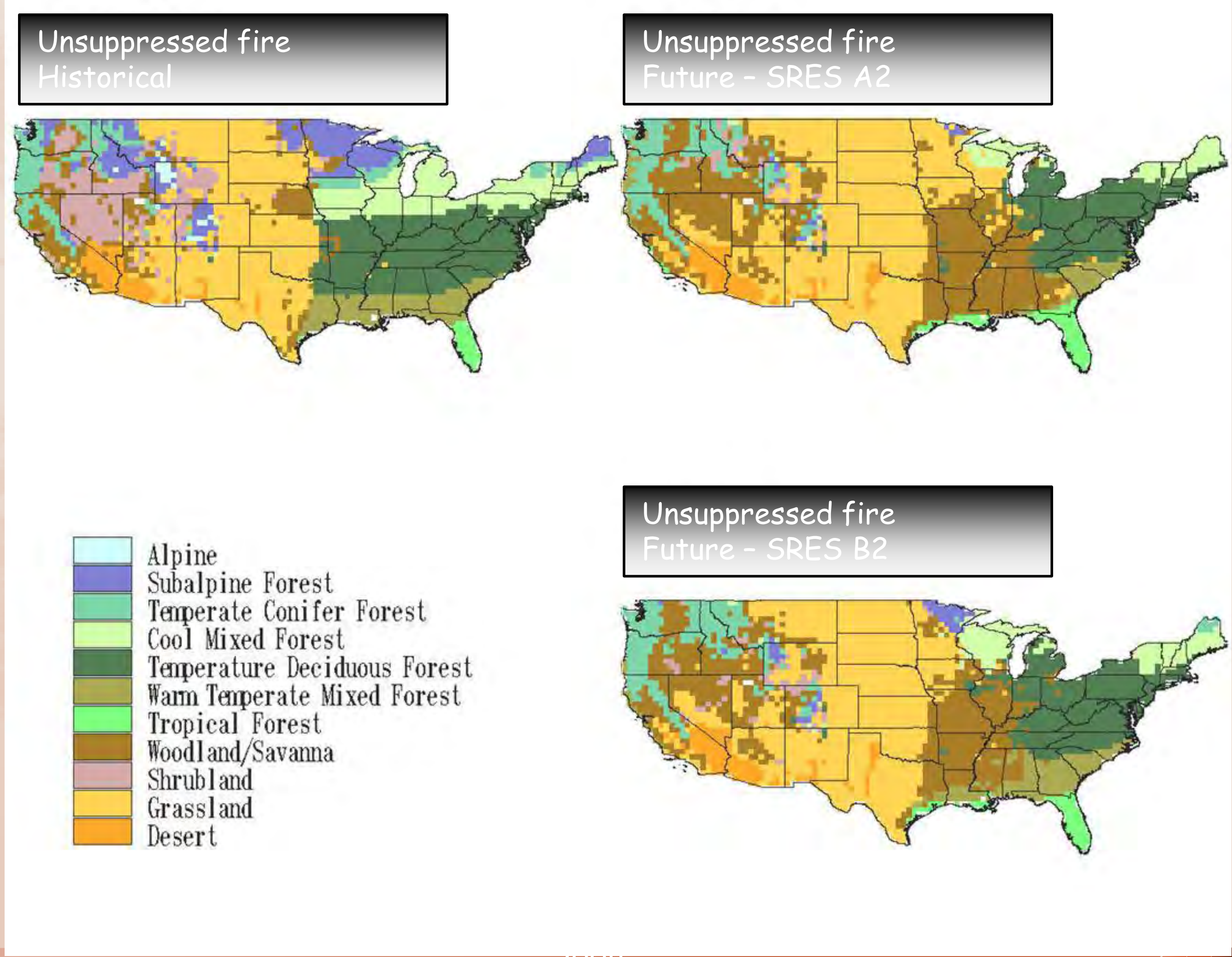



Fig. 3. Basal area of dominant tree species of northern hardwood (*A*, *C*, and *E*) and boreal (*B*, *D*, and *F*) forests by elevation for 1964 and 2004. Sugar maple (*A*), red spruce (*B*), American beech (*C*), balsam fir (*D*), yellow birch (*E*), and paper birch (*F*). The elevational range of the ecotone is indicated by the underscoring. The shift in the ecotone has been driven both by increases in northern hardwood species at their upper elevation limit (e.g., *A*, arrows) and decreases in boreal species at their lower limits (e.g., *B*, arrows).

# Shifts in Species Ranges

- Shifts in Biomes




2008

# Shifts in Species Ranges

- Shifts in forest types

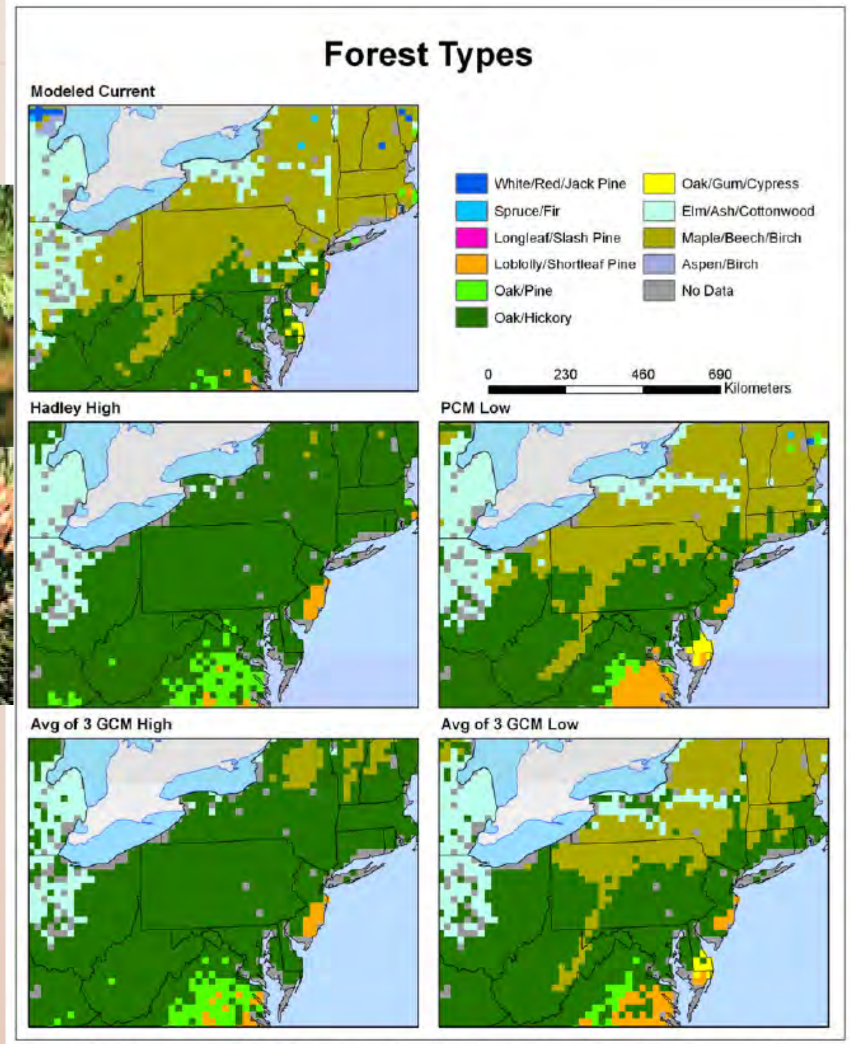
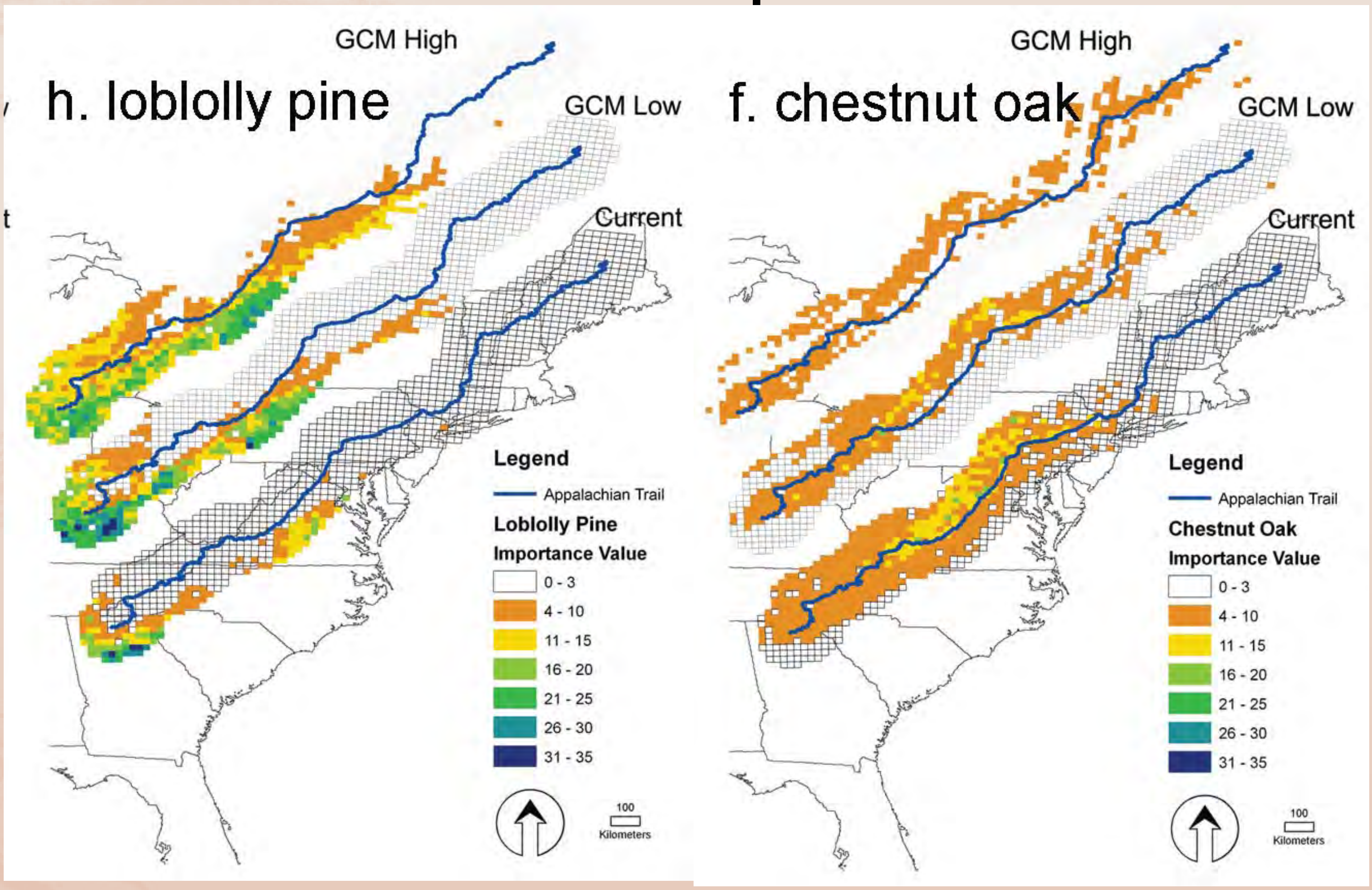



**Figure 7.1**. Current modeled forest type distribution in Pennsylvania and surrounding states and projected forest type shifts under four climate change scenarios (image provided by Louis Iverson and Matt Peterson).

# Shifts in Species Ranges

- Shifts in individual species

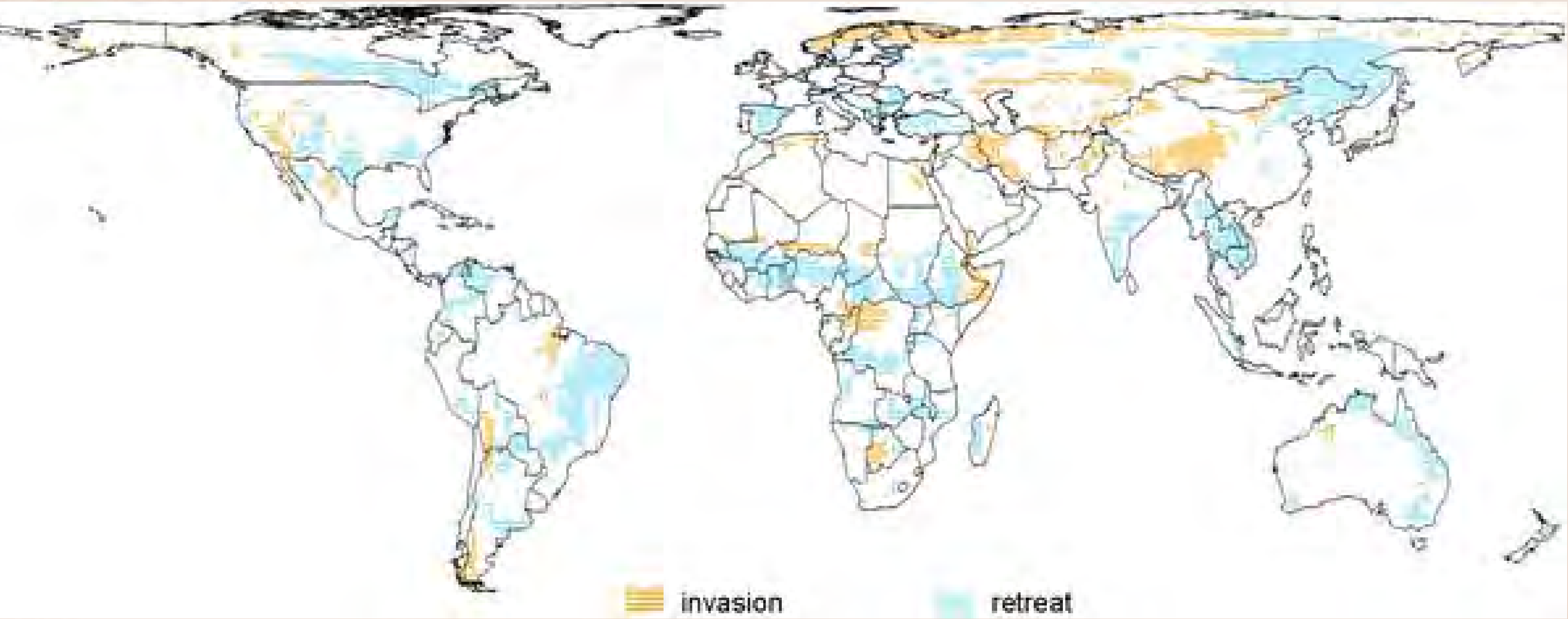


# Shifts in Species Ranges


As climate warms, many species in the United States are shifting their ranges northward and to higher elevations. The map shows the response of Edith's checkerspot butterfly populations to a warming climate over the past 136 years in the American West. Over 70 percent of the southernmost populations (shown in yellow) have gone extinct. The northernmost populations and those above 8,000 feet elevation in the cooler climate of California's Sierra Nevada (shown in green) are still thriving. These differences in numbers of population extinctions across the geographic range of the butterfly have resulted in the average location shifting northward and to higher elevations over the past century, illustrating how climate change is altering the ranges of many species. Because their change in range is slow, most species are not expected to be able to keep up with the rapid climate change projected in the coming decades.[245]

http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/full-report/climate-change-impacts-by-sector/ecosystems

# Changing Disturbance Regimes




The invasion (orange) and retreat (blue) of fire projected by 2010–2039 under the A2 (mid-high) emissions scenario and based on the $FIRE_{NPP}$ ensembles. Invasion was constrained to places with existing vegetation. (Krawchuk et al. PLoS One 2009)

# Changing Disturbance Regimes

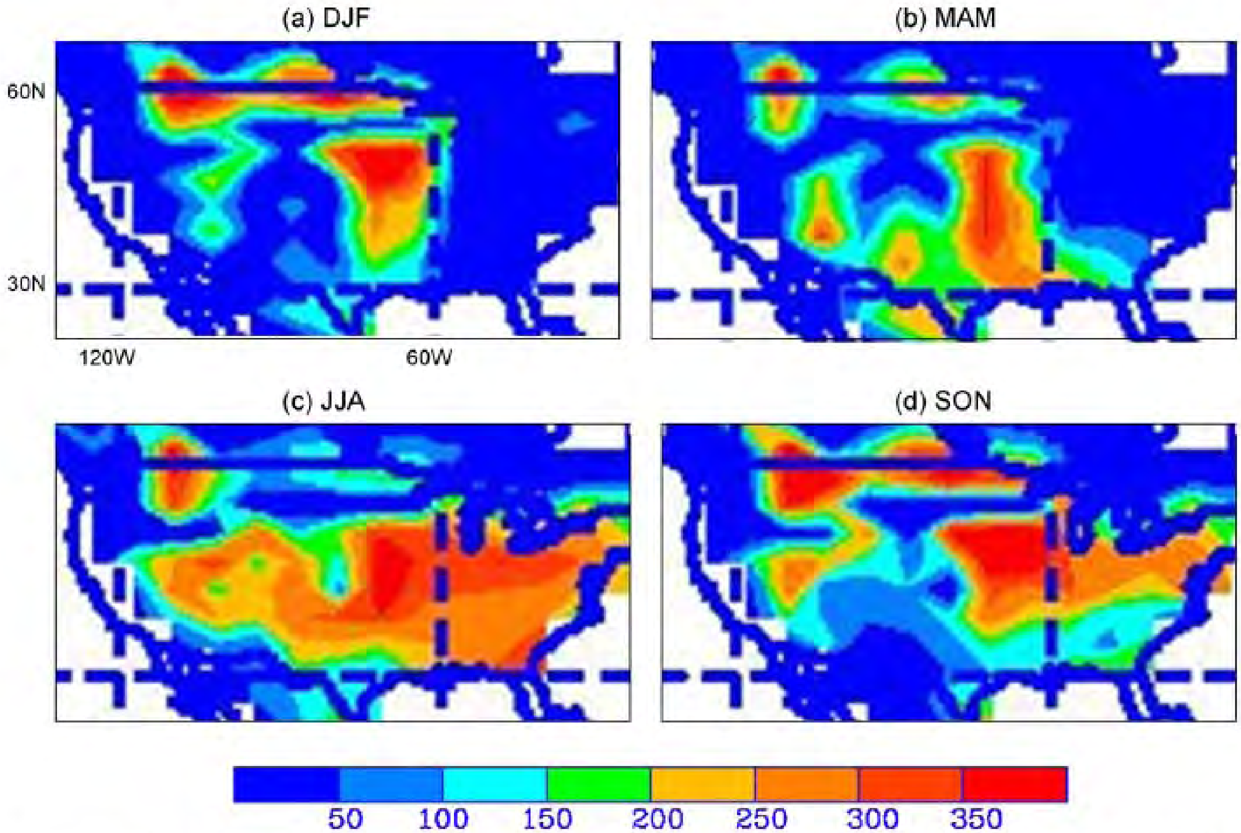



Fig. 5. The seasonal future KBDI changes in the United States. Panels (a–d) are winter, spring, summer and fall. The climate change is projected with HadCM3 with a2a scenario. The blue lines indicate latitudes and longitudes. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Liu et al. Forest Ecology and Management 2009

# Changing Disturbance Regimes

*Fuel loads*
*Fuel structure*
*Fuel type*
*Fuel chemistry*
*Fuel moisture*

# Adapting to the Impacts of Climate Change

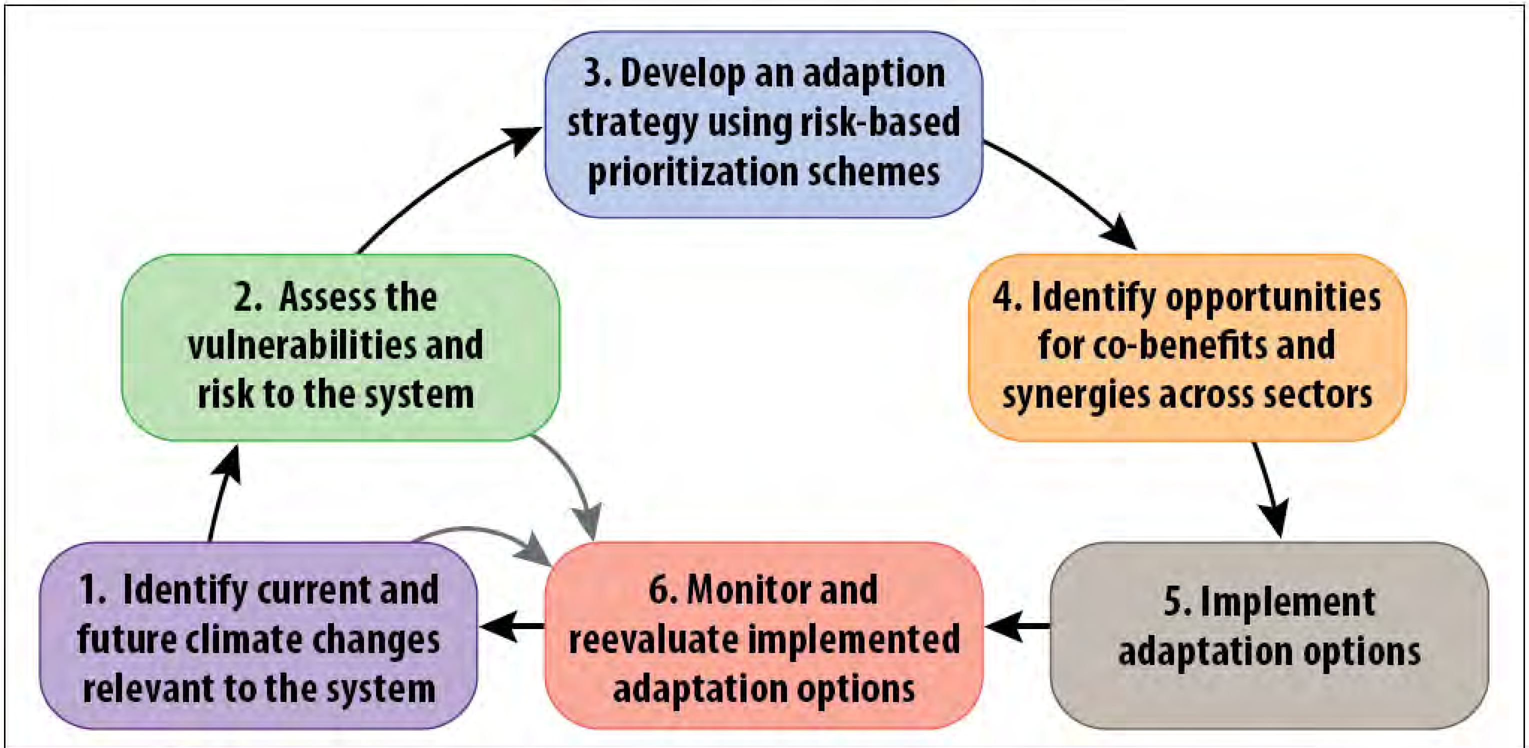



**Figure 1.** Adaptation planning is envisioned as a cyclical, iterative process incorporating these six steps.

# Adaptation Strategies Range Shifts

- **Conservation**
  - "Coarse-filter" approaches, resiliency
- **Restoration**
  - Larger seed zones, southern/drier species
- **Active Management**
  - Match species to future habitat suitability (e.g., facilitated migration)
  - Manage with/for disturbance (e.g., prescribed fire)

# Adaptation Strategies Range Shifts

- Consider resistance, resilience, and facilitation
  - **Resistance**
    - Increasing water supply; mitigate drought stress
    - Reduce herbivory/invasives
    - Fight insect/disease outbreaks
    - Promote regeneration following disturbance
  - **Resilience**
    - Buffers: reduce specific impacts, promote connectivity
    - Identify climate refuges and movement networks (pay attention to topography)
  - **Facilitation**

# Selecting tree species for testing climate change migration hypotheses using forest inventory data

C.W. Woodall [a,*], C.M. Oswalt [b], J.A. Westfall [c], C.H. Perry [a], M.D. Nelson [a], A.O. Finley [d]

**Table 2**
Difference in latitude results (mean seedling latitude – mean biomass latitude) and associated bootstrap standard errors and probabilities for all study species, eastern U.S.

| Tree species | Mean seedling latitude (°) | Mean biomass latitude (°) | DIL (°) | DIL SE (°) | *t* | Probability |
|---|---|---|---|---|---|---|
| Balsam fir | 46.0095 | 46.0853 | −0.0758 | 0.0090 | −8.4037 | <0.001 |
| Eastern redcedar | 35.9834 | 36.5485 | −0.5651 | 0.0373 | −15.1492 | <0.001 |
| Black Spruce | 46.7393 | 46.7368 | 0.0024 | 0.0162 | 0.1505 | 0.8805 |
| Red spruce | 44.9218 | 44.8786 | 0.0432 | 0.0203 | 2.1273 | 0.0346 |
| Shortleaf Pine | 34.8013 | 34.5993 | 0.2020 | 0.0635 | 3.1822 | 0.0017 |
| Slash pine | 30.655 | 30.7319 | −0.0769 | 0.0553 | −1.3890 | 0.1664 |
| Longleaf pine | 31.8671 | 31.7042 | 0.1629 | 0.0815 | 1.9989 | 0.047 |
| Red Pine | 45.4607 | 45.2686 | 0.1922 | 0.0636 | 3.0219 | 0.0028 |
| Eastern white pine | 43.1911 | 43.0218 | 0.1693 | 0.0536 | 3.1567 | 0.0018 |
| Loblolly pine | 33.2556 | 33.3208 | −0.0652 | 0.0193 | −3.3763 | 0.0009 |
| Virginia pine | 36.0456 | 36.3318 | −0.2862 | 0.0484 | −5.9079 | <0.001 |
| Baldcypress | 32.1483 | 32.0193 | 0.1290 | 0.1536 | 0.8399 | 0.402 |
| Northern white-cedar | 46.1646 | 46.0193 | 0.1453 | 0.0221 | 6.5811 | <0.001 |
| Eastern hemlock | 43.3309 | 42.8959 | 0.4350 | 0.0595 | 7.3146 | <0.001 |
| Striped maple | 43.3127 | 43.1007 | 0.2120 | 0.0654 | 3.2401 | 0.0014 |
| Red maple | 39.1311 | 39.8713 | −0.7402 | 0.0303 | −24.4684 | <0.001 |
| Silver maple | 40.2962 | 41.1289 | −0.8327 | 0.2344 | −3.5522 | 0.0005 |
| Sugar maple | 42.4914 | 42.3539 | 0.1375 | 0.0262 | 5.2540 | <0.001 |
| Yellow birch | 44.9369 | 44.6440 | 0.2929 | 0.0364 | 8.0526 | <0.001 |
| Sweet birch | 40.0891 | 39.8633 | 0.2258 | 0.0661 | 3.4170 | 0.0008 |
| Paper birch | 45.9419 | 45.7901 | 0.1518 | 0.0259 | 5.8656 | <0.001 |
| American hornbeam | 37.7515 | 36.4356 | 1.3160 | 0.0664 | 19.8223 | <0.001 |
| Bitternut hickory | 39.4203 | 39.5577 | −0.1374 | 0.0642 | −2.1390 | 0.0337 |
| Pignut hickory | 36.0611 | 36.5066 | −0.4455 | 0.0386 | −11.5410 | <0.001 |
| Shagbark hickory | 38.7979 | 38.8010 | −0.0031 | 0.0640 | −0.0487 | 0.9612 |
| Mockernut hickory | 35.4868 | 35.9003 | −0.4135 | 0.0327 | −12.6547 | <0.001 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Sweetbay | 32.395 | 32.0203 | 0.3746 | 0.0521 | 7.1900 | <0.001 |
| Blackgum | 35.5336 | 35.4969 | 0.0367 | 0.0292 | 1.2595 | 0.2093 |
| Swamp tupelo | 32.3321 | 32.2472 | 0.0849 | 0.0742 | 1.1442 | 0.2539 |
| Eastern hophornbeam | 40.5129 | 40.9216 | −0.4087 | 0.0571 | −7.1643 | <0.001 |
| Sourwood | 35.8631 | 35.6038 | 0.2592 | 0.0361 | 7.1907 | <0.001 |
| Sycamore | 35.8859 | 36.6765 | −0.7905 | 0.1611 | −4.9085 | <0.001 |
| Bigtooth aspen | 44.9178 | 44.4084 | 0.5095 | 0.0637 | 7.9984 | <0.001 |
| Quaking aspen | 46.0486 | 45.8636 | 0.1850 | 0.0175 | 10.5948 | <0.001 |
| Black cherry | 39.571 | 39.2192 | 0.3518 | 0.0430 | 8.1733 | <0.001 |
| White oak | 37.0316 | 37.4117 | −0.3802 | 0.0319 | −11.9069 | <0.001 |
| Scarlet oak | 36.8328 | 37.1596 | −0.3269 | 0.0485 | −6.7373 | <0.001 |
| Southern red oak | 33.7992 | 34.1693 | −0.3702 | 0.0295 | −12.5559 | <0.001 |
| Cherrybark oak | 33.2757 | 33.5323 | −0.2566 | 0.0623 | −4.1177 | 0.0001 |
| Laurel oak | 31.6754 | 31.578 | 0.0974 | 0.0360 | 2.7049 | 0.0074 |
| Bur oak | 45.577 | 44.9085 | 0.6685 | 0.0971 | 6.8822 | <0.001 |
| Water oak | 32.7041 | 32.6432 | 0.0609 | 0.0176 | 3.4724 | 0.0006 |
| Willow oak | 33.9288 | 34.0494 | −0.1206 | 0.0509 | (2.3708 | 0.0187 |
| Chestnut oak | 37.2196 | 37.5600 | −0.3404 | 0.0420 | (8.1051 | <0.001 |
| Northern red oak | 40.8104 | 40.6762 | 0.1342 | 0.0457 | 2.9407 | 0.0037 |
| Post oak | 34.9866 | 35.2379 | −0.2513 | 0.0404 | −6.2164 | <0.001 |
| Black oak | 37.6027 | 38.1147 | −0.5120 | 0.0411 | −12.4530 | <0.001 |
| Black locust | 37.918 | 38.1418 | −0.2238 | 0.1040 | −2.1525 | 0.0326 |
| Sassafras | 36.8242 | 37.5858 | −0.7616 | 0.0418 | −18.2017 | <0.001 |
| American basswood | 44.0135 | 43.4555 | 0.5580 | 0.0799 | 6.9834 | <0.001 |
| Winged elm | 34.4151 | 34.4376 | −0.0224 | 0.0242 | −0.9257 | 0.3557 |
| American elm | 40.2414 | 40.3487 | −0.1073 | 0.0597 | −1.7979 | 0.0737 |

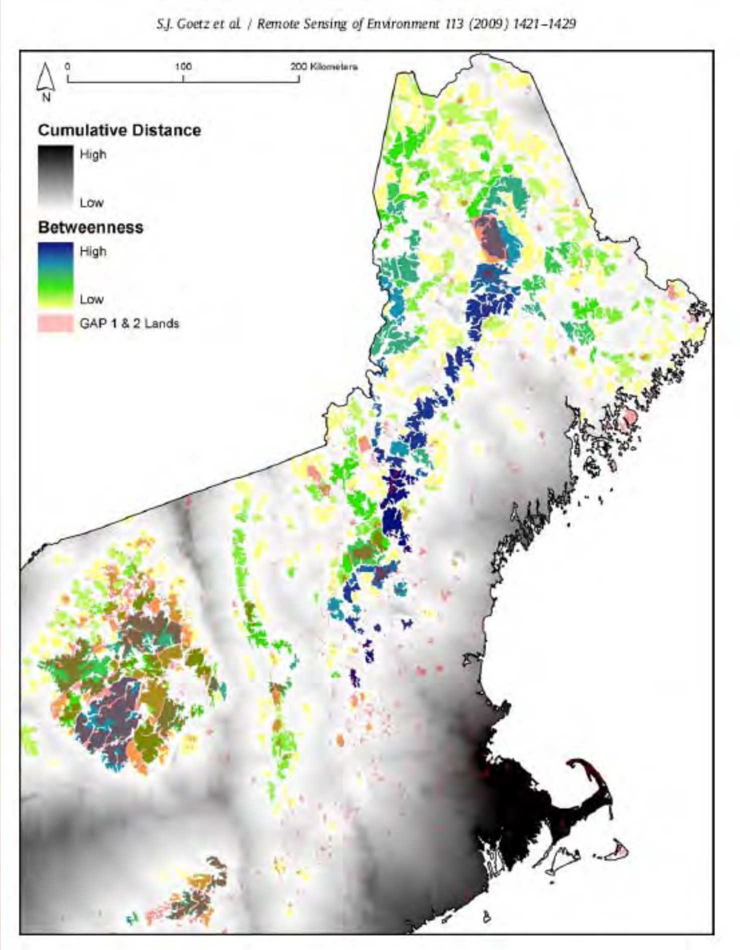
# Adaptation Strategies
# Range Shifts

- **Conservation Actions**
  - "Coarse-filter" approach
    - Expand reserves that lack adequate environmental heterogeneity
    - Focus on future desired forest functions, rather than species
  - Prioritize climate refuges; buffer small reserves
  - Maintain high biodiversity to promote resiliency
    - Manage forests for multi-species, multi-ages
    - Genetic diversity

# Adaptation Strategies Range Shifts

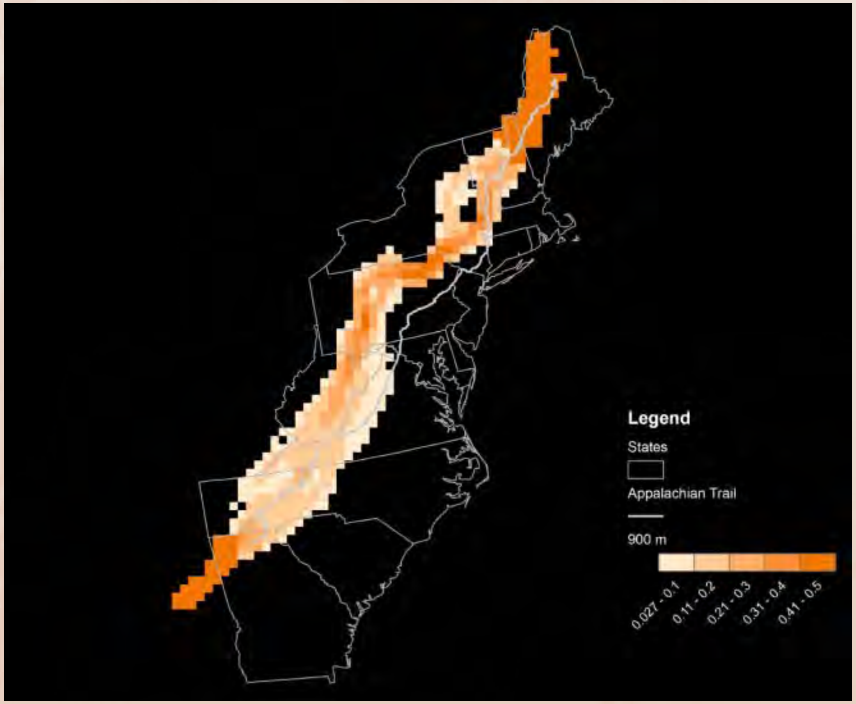
- **Conservation Networks**
  - Link to climate-proof networks
    - Link isolated habitat that is within a new suitable climate zone to the nearest climate-proof network
  - Increase colonizing capacity
    - in the overlap zone, the part of a network that remains suitable in successive time frames
  - Optimize sustainable networks in climate refugia
    - the part of a species range where climate remains stable

# Conservation Networks




- Connectivity metrics (graph theory) among core conservation areas
- 1/3 of core habitat is not protected
- Currently protected areas are typically isolated, but buffered
- Connectivity is vulnerable to development

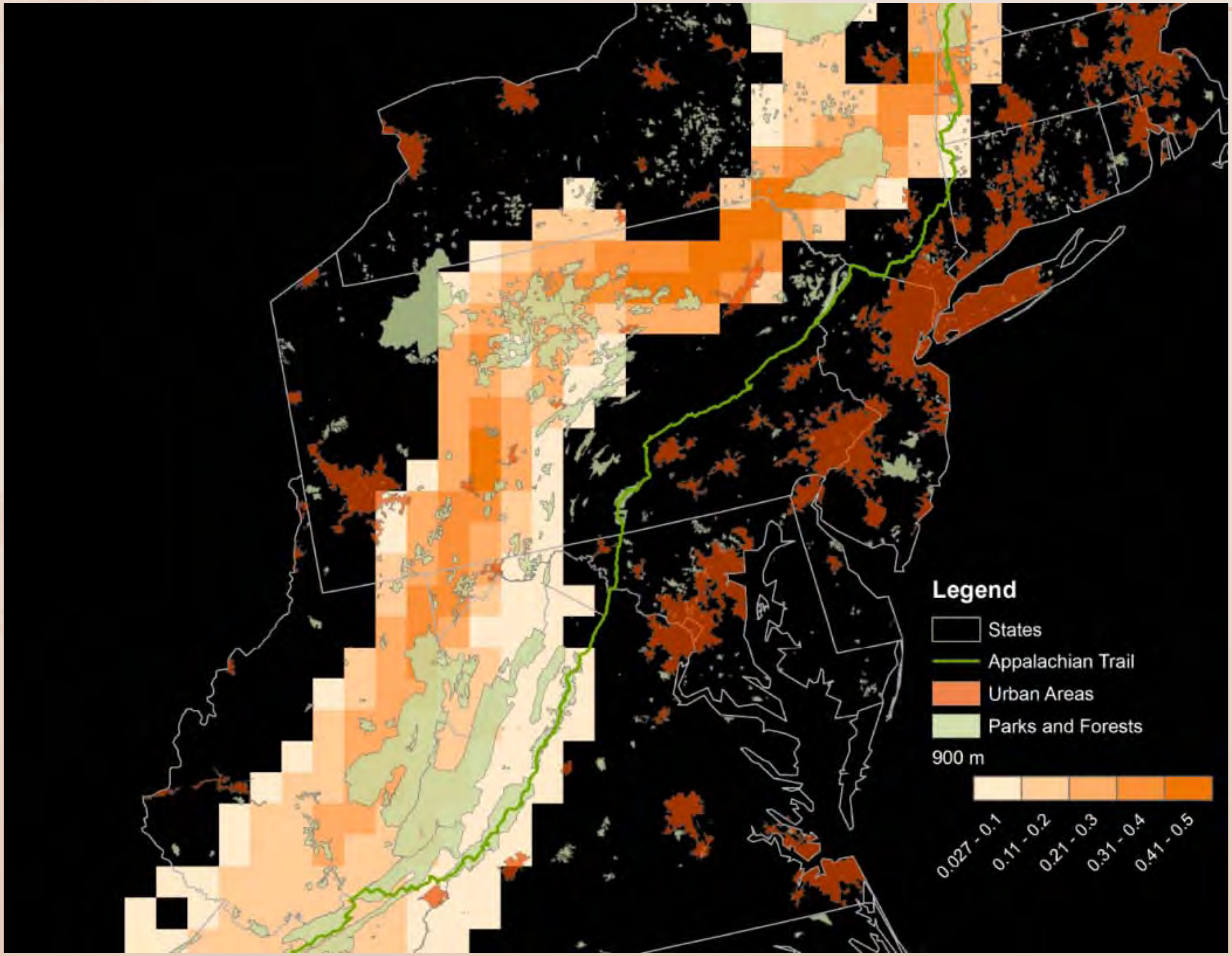
# Conservation Networks




E. Crisfield/Smithwick, unpublished data

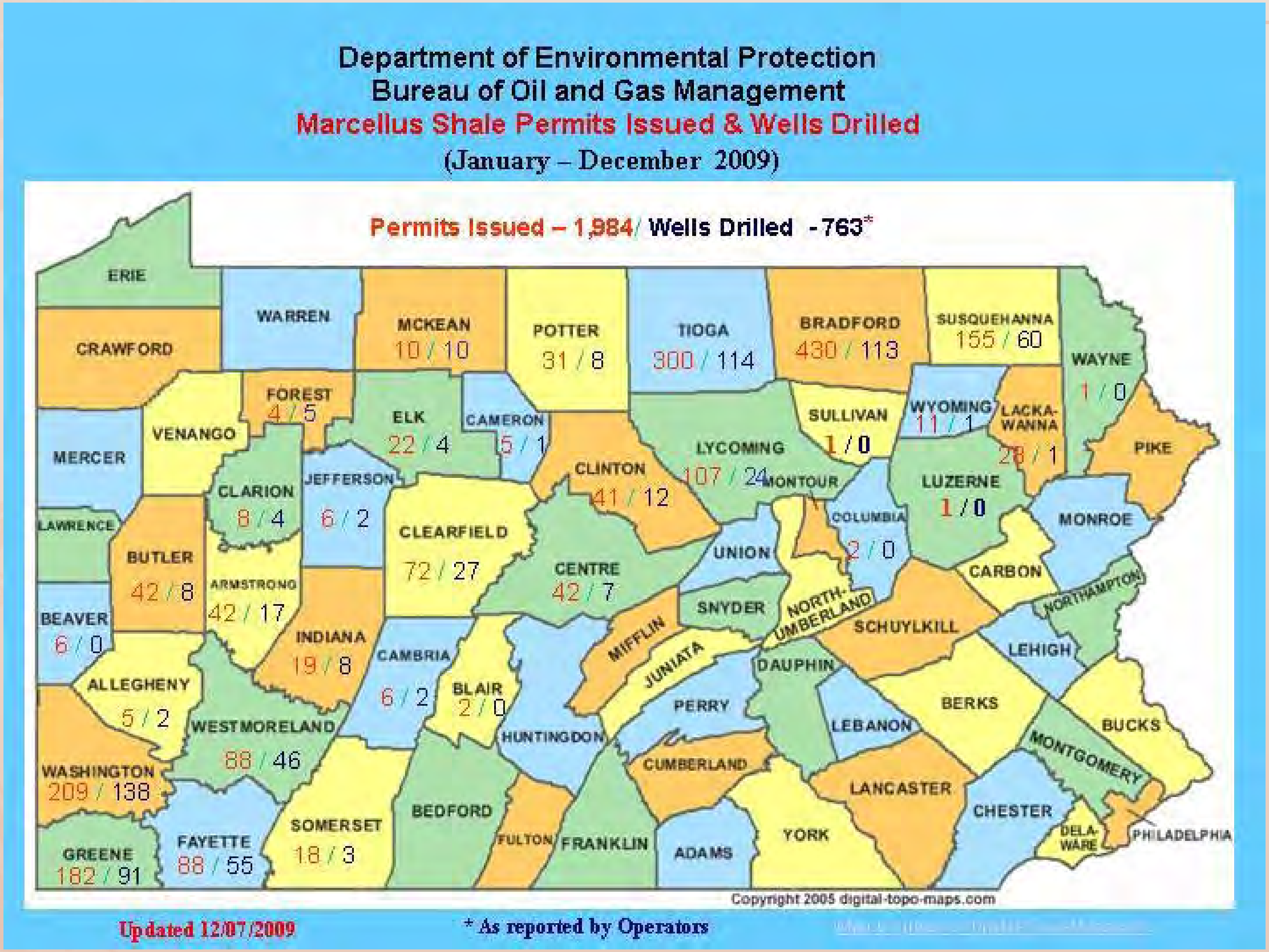
- High elevation communities in the Southern Appalachians are particularly vulnerable - limited upward migration
- Northward migration, while slower than upslope migration, may be important
- Mid-Atlantic Appalachians may present some hurdles, both because it is lower elevation by comparison (max. elevation around 1000 m) and is narrower.
- Narrow pathway for northward migration is limited to 900-1000 m; follows Allegheny Plateau through Pennsylvania

# Conservation Networks




E. Crisfield/Smithwick, unpublished data

# Land Planning Tradeoffs



# Adaptation Strategies
# Range Shifts

- Restoration
  - Mitigation (increase carbon storage)
  - Build resiliency
  - To what?
    - Historic ranges of variability still relevant?
    - Focus on function/service/natural capital?
    - Manage for future species/functions?

# Adaptation Strategies Range Shifts

**Table 1.** Ecosystem functions with examples of processes, goods, and services (adapted from de Groot et al. 2002).

| *Ecosystem Function* | *Ecosystem Process and Components* | *Goods and Services* |
|---|---|---|
| Regulation functions | Maintenance of essential ecological processes and life support processes | |
| Gas regulation | Biogeochemical cycling | UVb protection by ozone |
| Climate regulation | Influence of land-cover vegetation type | Maintenance of a favorable climate |
| Water supply | Filtering, retention, and storage of water | Provision of water for consumption |
| Habitat functions | Providing habitat for plant and animal species | |
| Refugium function | Niche availability | Maintenance of biological and genetic diversity (and hence most other functions) |
| Production functions | Provision of food and fiber | |
| Raw materials | Conversion of solar energy into edible plants and animals | Fuel, structural materials |
| Information functions | Providing opportunities for cognitive development | |
| | Cultural and artistic information | Use of nature as motive in books, film, and painting |



Harris, Restoration Ecology, 2006

# Adaptation Strategies Range Shifts

- Facilitated Migration

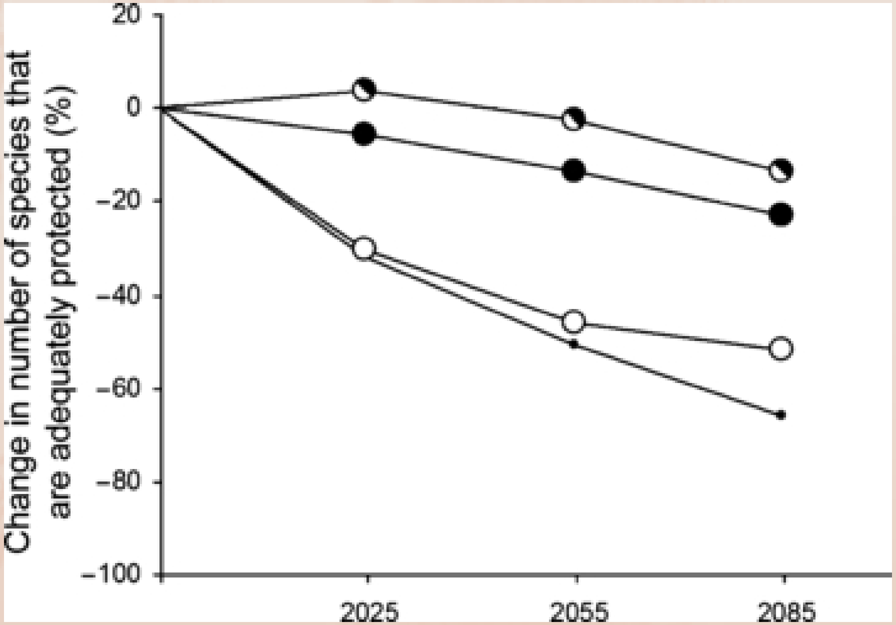



**Figure 1** Change in the number of tree species predicted to be adequately conserved (cumulative cover of 10 ha, Hamann and Wang 2006) into the future, under the assumption that species are capable to adapt to changed climate, (•), migrate to suitable habitat within a reserve, (○), both, migrate and adapt, or neither (•). The analysis is based on bioclimatic envelope models for 49 tree species and 906 protected areas in British Columbia (Hamann and Wang 2006; A. Hamann and S.N. Aitken, unpublished manuscript.).

- Species that occur in small, fragmented populations, or those with low fecundity or late age of sexual maturity, reproductive characteristics more typical of later successional species and high-elevation habitats, will likely suffer greater adaptational lag.

# Adapting to the Impacts of Climate Change

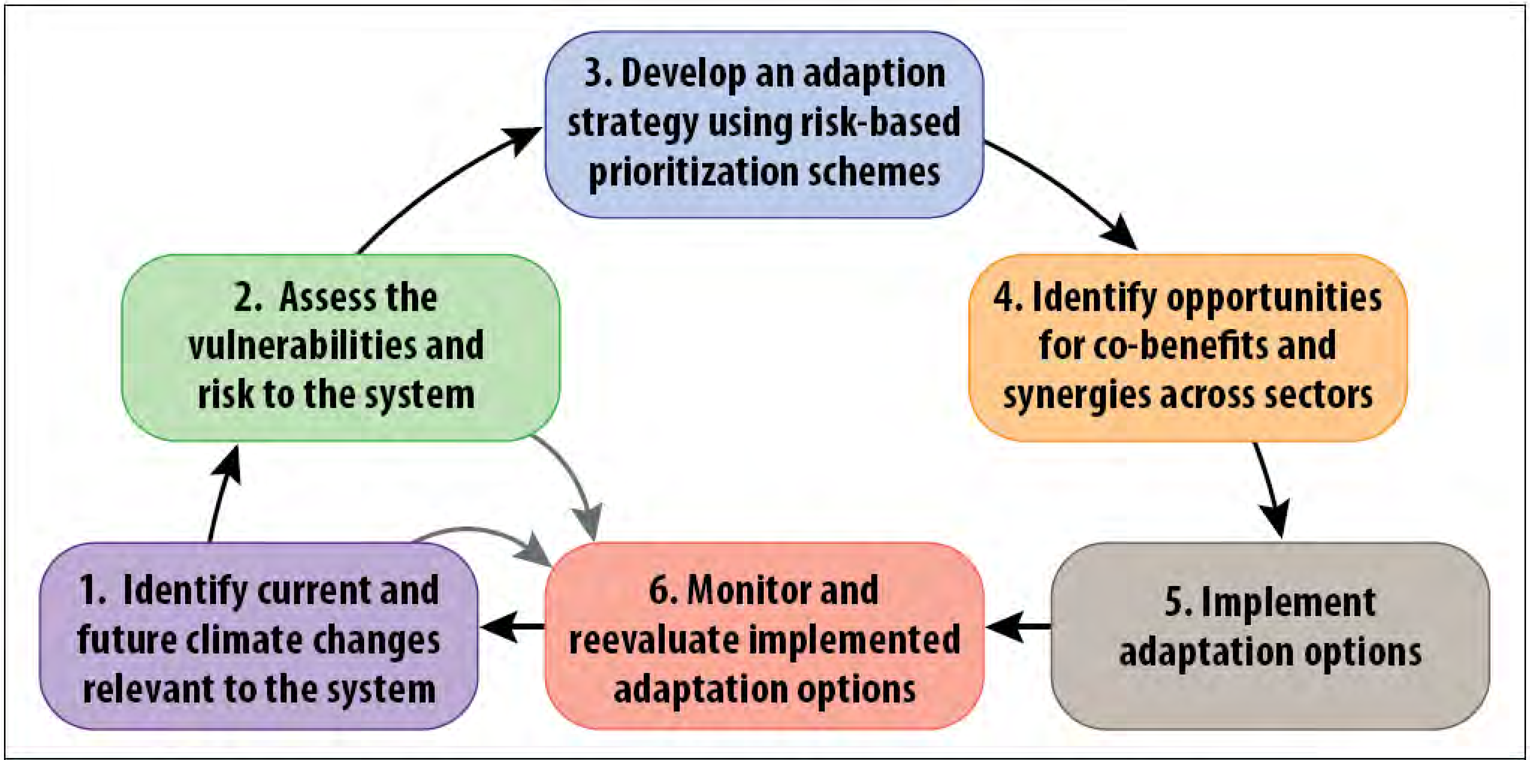



**Figure 1.** Adaptation planning is envisioned as a cyclical, iterative process incorporating these six steps.

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# Success?

- Success must include assessment of:
  - Effectiveness, Efficiency, Equity, Legitimacy
    - Recognize heterogeneity in capacity, benefits, objectives
    - Ensure actions do not adversely affect others (minimize negative downstream effects)
    - Be careful not to amplify conflicts
- Scale-specific criteria
  - International/National/State/County/Household
    - Implement and Evaluate at relevant scale
  - Cross-scale interactions will add complexity

# Monitoring

- Trailing edge of rare species
- Reproduction and regeneration should be monitored in protected areas to determine if facilitated migration of populations is necessary among protected areas or to extend species ranges.

# Adapting to the Impacts of Climate Change

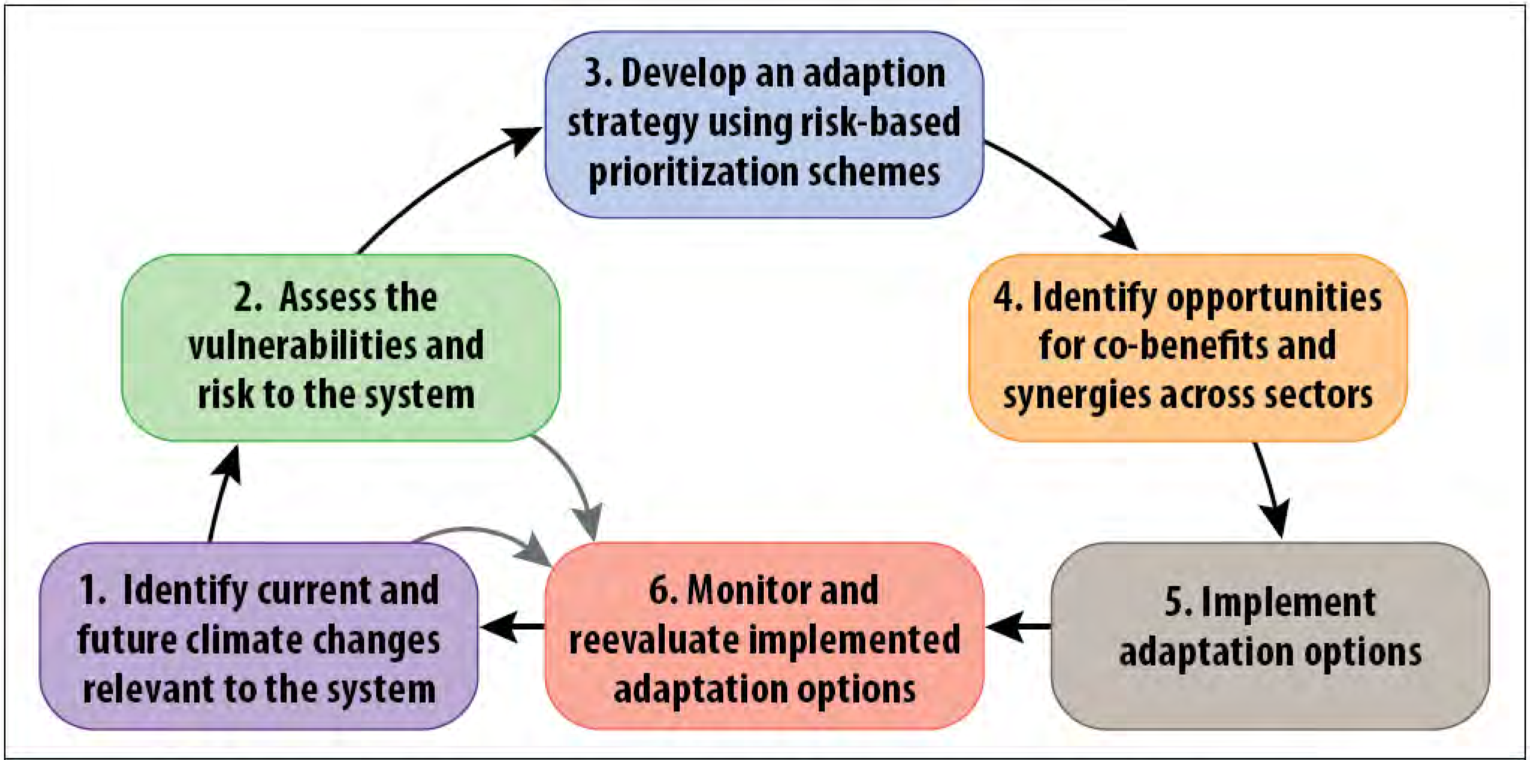


**Figure 1.** Adaptation planning is envisioned as a cyclical, iterative process incorporating these six steps.

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