# Observations on State of the Art Modeling of Vegetation under Climate Change

# Summary of Previous Efforts

| Reference | Method | Domain | Species | Time | Grain | Models / scenarios |
|---|---|---|---|---|---|---|
| Iverson et al. 2008 | Machine learning (randomForest, bagging trees, single decision tree) to model spp. abundances using FIA data and env data | Eastern U.S. | 134 tree species | 2100 | 20 km | HadleyCM3, GFDL CM2.1, PCM<br><br>A1, B1, ave. across emissions scenarios |
| Potter et al. 2010 | 17 env factors reduced with PCA, correlated with FIA presence | North America | 200 tree species | 2050<br>2100 | 4 km | Hadley, PCM<br><br>A1, B1 |
| Coops and Waring 2011 | Id climate limitations to Douglas fir growth for 1950-75 with process-based model (3-PG), use decision tree and FIA data to predict presence. | Western U.S. | 15 tree species | 2011 - 2040<br>2041 - 2070<br>2071 - 2100 | 1 km | CGCM3 downscaled using CLIMATE-WNA<br><br>A2, B1 |
| McKenney et al. 2011 | BIOMAP generates statistical distributions for bioclimatic variables where species are. Locations that fall within some portion of the reference distribution are retained. | North America | 130 tree species | 2011-2040<br>2041-2070<br>2071-2100 | 10 km | CCCMA) v. CGCM2 v. GCM3.1<br>CSIRO v. CSIRO-Mk2.0 v. CSIRO-MK3.5<br>NCAR v. PCM v. CCSM3.0<br><br>A2 |
| Crookston et al. 2010 | For. Veg. Sim. model change in species composition and growth by (1) linking mortality and regen.to climate (2) linking site index to climate and modifying growth rates, and (3) changing growth rates due to climate-induced genetic responses. | Western U.S. | 74 tree species | 2030, 2060, 2090 (10 yr periods) | | CGCM3, GFDLCM21, HADCM3<br><br>A1B, A2, B1, B2 |
| Morin et al. | | | | | | |

# Summary of Climate Model and Scenario Predictions

**Scenarios**

**A1 - high emissions – which assume that the current emission trends continue for the next several decades without modification (ca 3x pre-industrial)**

**B1 - significant conservation and reduction of CO2 emissions (ca 2x pre-industrial)**

Average climate conditions in the eastern US: currently and for four future scenarios: Hadley A1fi, PCM B1, and average A1fi and B1 for Hadley, PCM, and GFDL

| Variable | Current | Hadley high | PCM low | Ave high | Ave low |
|---|---|---|---|---|---|
| PPT (mm) | 1027 | 1118 | 1082 | 1066 | 1083 |
| PPTMAYSEP (mm) | 499 | 498 | 536 | 485 | 515 |
| TJAN (C) | −0.9 | 4.7 | 0.9 | 3.5 | 1.5 |
| TJUL (C) | 24.0 | 32.4 | 26.1 | 31.4 | 27.4 |
| JULJANDIFF (C) | 25.0 | 27.6 | 25.2 | 27.9 | 25.9 |
| TMAYSEP (C) | 21.1 | 29.0 | 23.2 | 27.9 | 24.4 |
| TAVG (C) | 12.1 | 19.1 | 14.2 | 17.8 | 15.1 |

**Relatively warm - HadleyCM3 A1**
**Relatively cool – PCM B1**

**Iverson et al. 2008**

# Summary of Climate Model and Scenario Predictions

McKenney et al. 2011

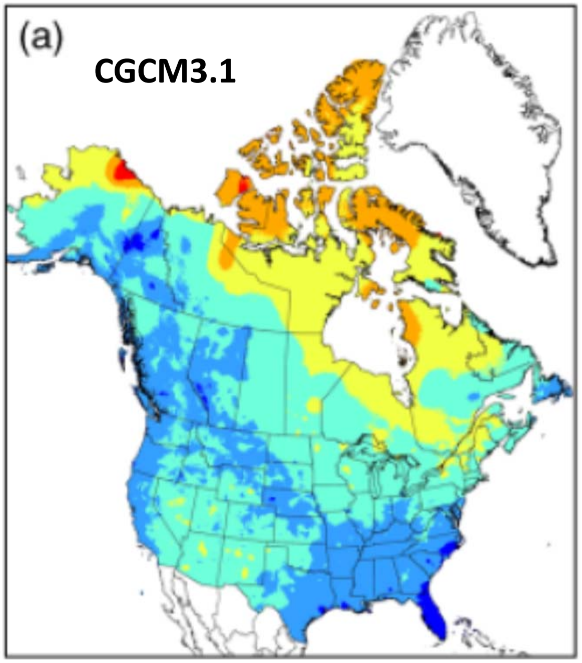
**Scenarios**

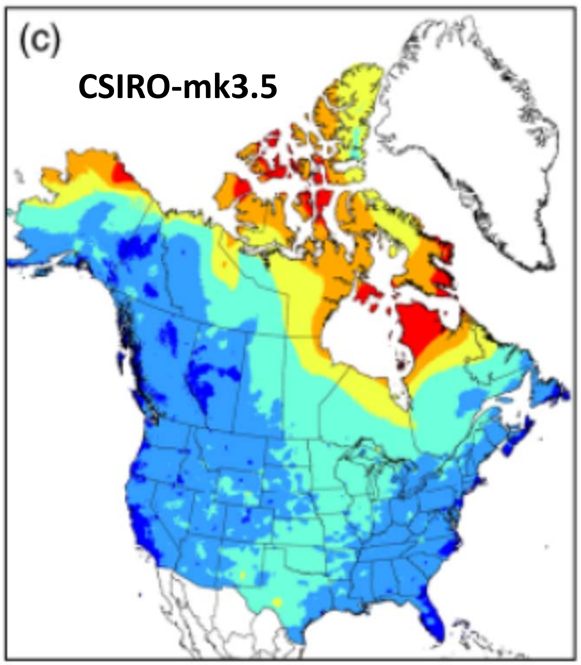
**A2 - assumes rapid population growth, a reduction in forested land, and increasing levels of pollution and GHG emissions**

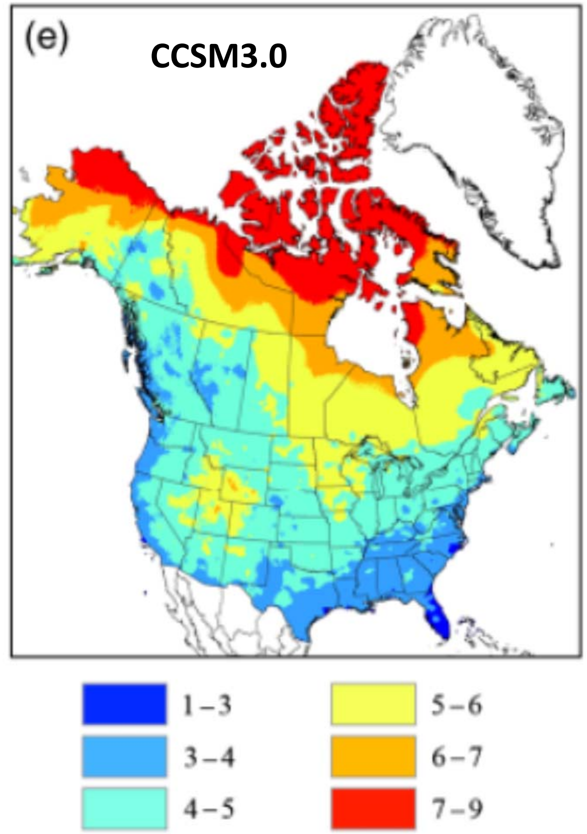
Table 1 Details on the AOGCM versions used in this study

| Developer | TAR-version | AR4-version | Major improvements between versions |
|---|---|---|---|
| Canadian Centre for Climate Modeling and Analysis (CCCMA), Canada | CGCM2 | CGCM3.1 | Horizontal resolution increased from 608 to 680 cells<br>More levels in the vertical<br>Improved land surface module, which includes 3 soil layers, a snow layer, and a canopy layer<br>Improved convection algorithm<br>More detailed solar radiative heating module<br>Improved water vapour transport algorithm |
| Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia | CSIRO-Mk2.0 | CSIRO-MK3.5 | Horizontal resolution increased from 528 to 2613 cells<br>More levels in the vertical<br>Improved land surface module, which includes 6 soil layers, 3 snow layers, and a land cover type<br>Improved convection algorithm<br>New prognostic cloud scheme; allows model to generate its own physically based cloud properties, based on cloud water and cloud ice<br>Improved water vapour transport using Semi-Lagrangian algorithm |
| National Center for Atmospheric Reaearch (NCAR), USA | PCM | CCSM3.0 | Horizontal resolution increased from 1118 to 4368 cells<br>More levels in the vertical<br>Greater detail in land–atmosphere flux components<br>New treatments of cloud processes<br>Improved aerosol radiative forcing<br>Improved ocean mixed layer processes<br>More realistic sea ice dynamics<br>Many others (see reference) |

# Summary of Climate Model and Scenario Predictions



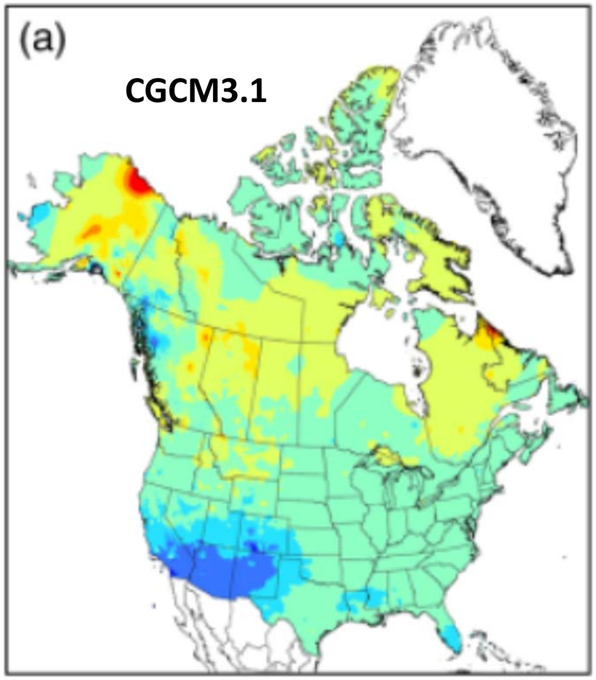



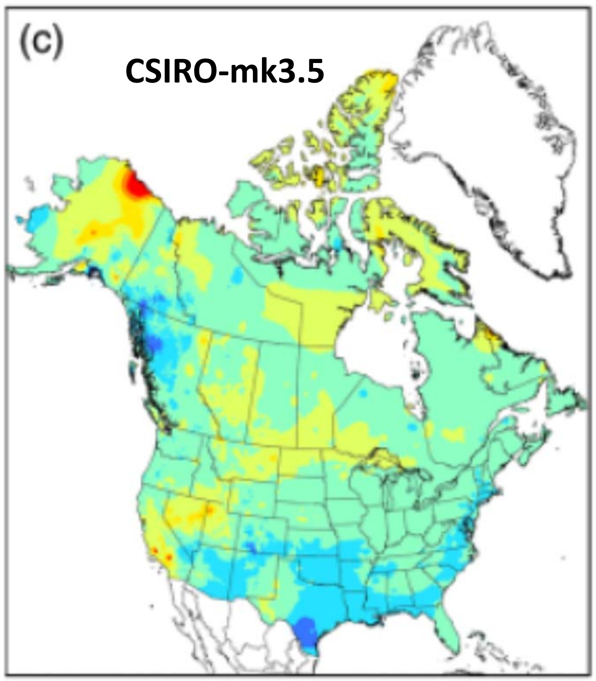



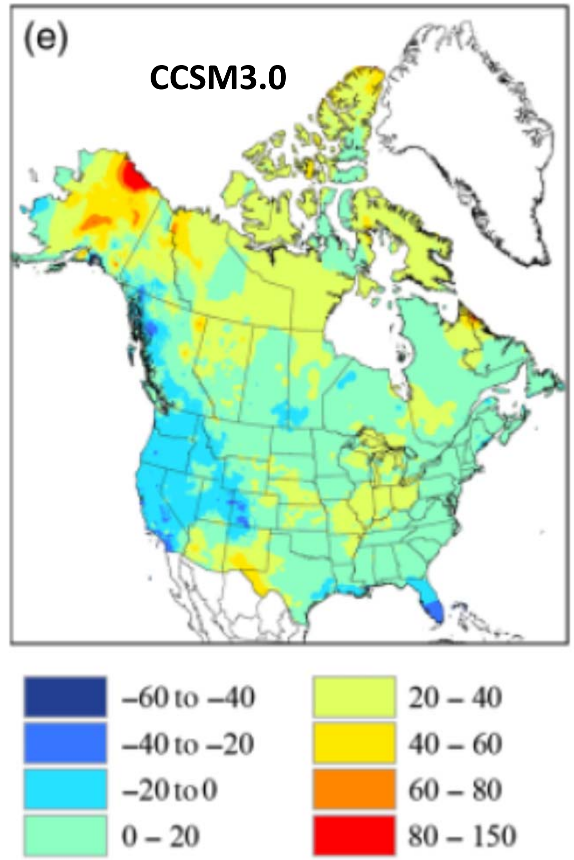

**Differences between current (1971–2000) and future (2071–2100) mean annual temperature ( deg C)**

**McKenney et al. 2011**

# Summary of Climate Model and Scenario Predictions




**Differences between current (1971–2000) and future (2071–2100) annual precipitation (expressed as a percentage of current values)**

**McKenney et al. 2011**

# Rationale for Approaches

**Plant species will respond in one of three ways to changes that push their current habitat out of their climatic tolerance limits (Davis et al. 2005):**

1) **adaptation**
2) **migration (range shift), or**
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# Predictors

Variables used to predict current and future tree species habitat

| | |
|---|---|
| Climate[a] | |
| TAVG | Mean annual temperature (°C) |
| TJAN | Mean January temperature (°C) |
| TJUL | Mean July temperature (°C) |
| TMAYSEP | Mean May–September temperature (°C) |
| PPT | Annual precipitation (mm) |
| PPTMAYSEP | Mean May–September precipitation (mm) |
| JULJANDIFF | Mean difference between July and January temperature (°C) |
| Elevation[b] | |
| ELV_CV | Elevation coefficient of variation |
| ELV_MAX | Maximum elevation (m) |
| ELV_MEAN | Average elevation (m) |
| ELV_MIN | Minimum elevation (m) |
| ELV_RANGE | Range of elevation (m) |
| Soil class[c] | |
| ALFISOL | Alfisol (%) |
| ARIDISOL | Aridisol (%) |
| ENTISOL | Entisol (%) |
| HISTOSOL | Histosol (%) |
| INCEPTSOL | Inceptisol (%) |
| MOLLISOL | Mollisol (%) |
| SPODOSOL | Spodosol (%) |
| ULTISOL | Ultisol (%) |
| VERTISOL | Vertisol (%) |
| Soil property[d] | |
| BD | Soil bulk density (g/cm$^3$) |
| CLAY | Percent clay (<0.002 mm size) |
| KFFACT | Soil erodibility factor, rock fragment free (susceptibility of soil erosion to water movement) |
| NO10 | Percent soil passing sieve no. 10 (coarse) |
| NO200 | Percent soil passing sieve no. 200 (fine) |
| OM | Organic matter content (% by weight) |
| ORD | Potential soil productivity (m$^3$ timber/ha) |
| PERM | Soil permeability rate (cm/h) |
| PH | Soil pH |
| ROCKDEP | Depth to bedrock (cm) |
| SLOPE | Soil slope (%) of a soil component |
| TAWC | Total available water capacity (cm, to 152 cm) |
| Land use and fragmentation[e] | |
| FRAG | Fragmentation index (Riitters et al. (2002)) |
| AGRICULT | Cropland (%) |
| FOREST | Forest land (%) |
| NONFOREST | Nonforest land (%) |
| WATER | Water (%) |

**Strongest predictors:**

**Temperature**
**PPTMAY-SEPT**
**SLOPE**
**PPT**
**ORD (soil prod)**
**Soil texture**

**Iverson et al. 2008**

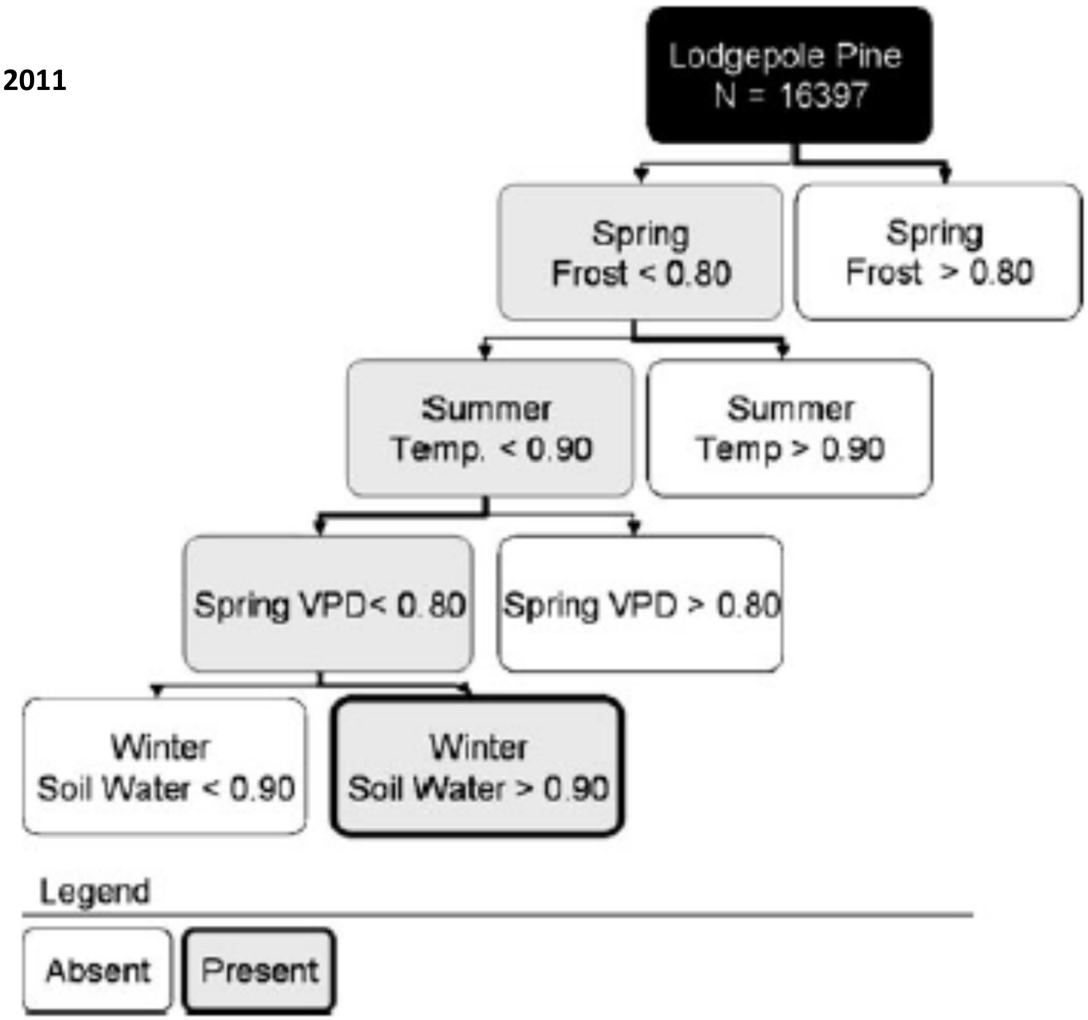
**Table 1.—Spatial environmental variables included in the Multivariate Spatio-Temporal Clustering (MSTC) analysis.**

| Category | Spatial environmental variable |
|---|---|
| Soil | |
| | Plant-available water capacity |
| | Bulk density of soil |
| | Kjeldahl soil nitrogen |
| | Organic matter in soil |
| Temperature | |
| | In the coldest quarter |
| | In the warmest quarter |
| | Diurnal temperature difference |
| | Biotemperature |
| | Solar insolation |
| Precipitation | |
| | In the driest quarter |
| | In the wettest quarter |
| | In the warmest quarter |
| | In the coldest quarter |
| | Ratio of precipitation to evapotranspiration |
| Topography | |
| | Compound topographic index (convexness or concavity) |
| Growing season | |
| | Length in integer months |

**Potter et al. 2010**

# Predictors

Coops and Waring 2011




**Decision tree developed to predict presence and absence of lodgepole pine, based on the maximum effect of the four seasonal climate modifiers**

# Rationale for Approaches

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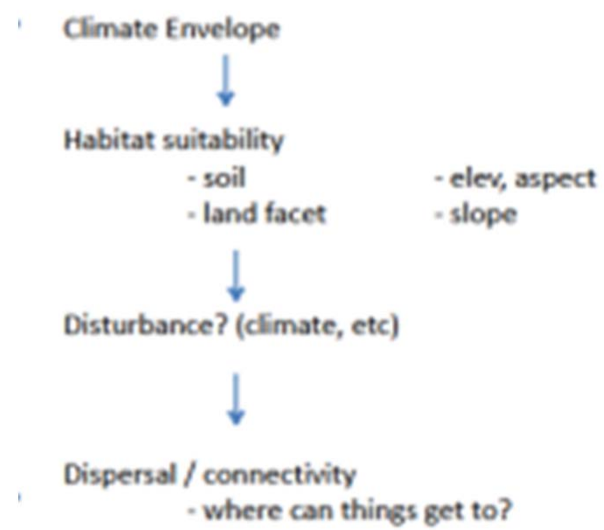
**Where will suitable habitat be located under climate change?**

- **climate/habitat suitability modeling**

**Can the population get to the newly suitable habitats?**

- **Dispersal ability of species**
- **Geographic Resistance**
  - ❖ **Distance from current to new habitat**
  - ❖ **Topography**
  - ❖ **Land facets**
  - ❖ **Vegetation fragmentation**
  - ❖ **Land use**



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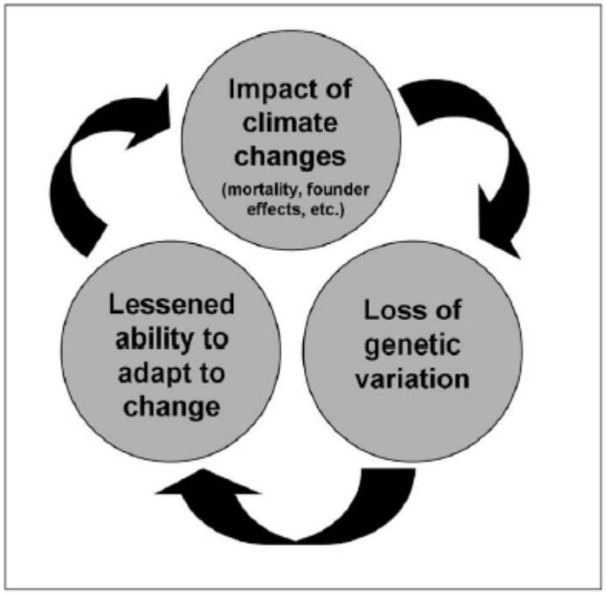


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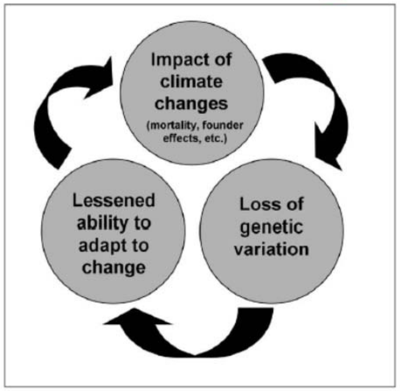


**Table 2.—Factors, both intrinsic and extrinsic to a species or population of forest trees, that increase its risk of extinction, extirpation, or genetic degradation.**

| Intrinsic factors | Extrinsic factors |
|---|---|
| Limited range | Extensive fragmentation |
| Small/disjunct populations | Pest/pathogen infestation |
| Limited to high elevations | Large shift of range with climate change |
| Long lifespan | Exploitation |
| Long time to reproduction | Exposure to atmospheric deposition |
| Low fecundity | Geographic dispersal barriers[a] |
| Physical habitat specialization | Anthropogenic dispersal barriers[a] |
| Limited seed/pollen dispersal | Exposure to sea-level rise[a,b] |
| Low species-wide genetic variation | |
| Late successional species | |
| Dependence on specific disturbance regime[a] | |
| Reliance on interspecific interactions[a] | |
| Sensitivity to temperature and precipitation change[a] | |
| Lack of phenological flexibility[a] | |

[a] From Young et al. (2009).
[b] Not applicable to the Appalachian Mountains.

**Potter et al. 2010**

# Modeling Approaches

**Bioclimate Envelope Models**

- **Iverson et al. 2008**
- **Potter et al. 2010**
- **McKenney et al. 2011**

**Simulation Models**

- **Demographic Models**
  - ❖ **Forest Vegetation Simulator (Crookston et al. 2010)**
  - ❖ **FIRE-BGC V2 (Keene et al. )**

**Hybrid Models**

- **3PG / Climate envelope (Coops and Waring 2010)**

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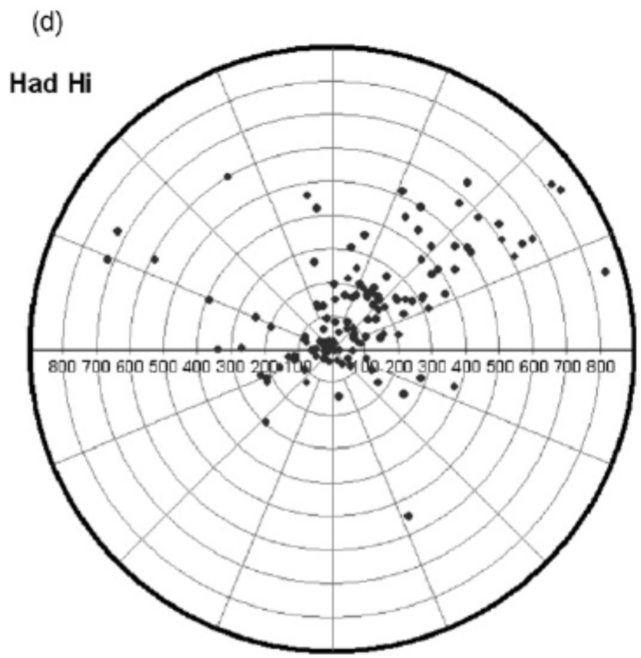
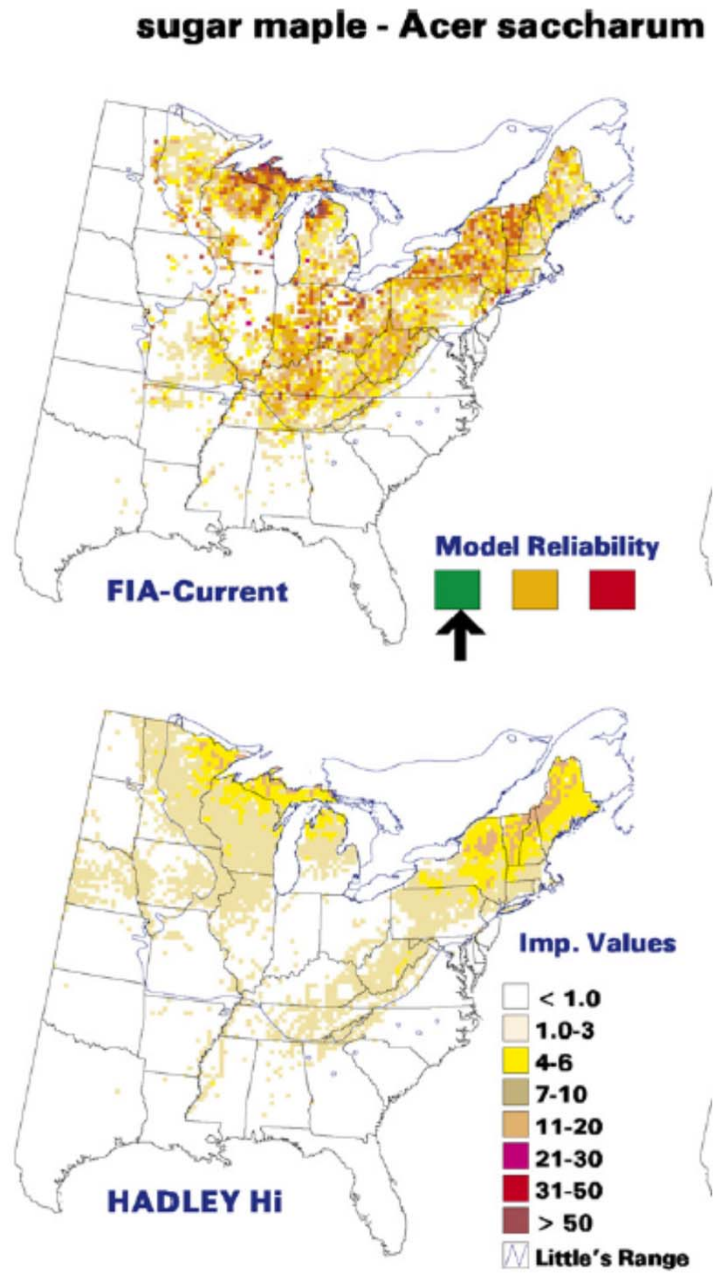
**“In this approach, we cannot include changes in land use and land cover likely to occur in the next 100 years, or disturbances such as pests, pathogens, natural disasters, and other human activities. Coupling these outputs with process-based ecosystem dynamics models which include disturbance would be a productive line of research.” Iverson et al. 2008**

# Results: Iverson et al. 2008

- 55% of species  increase in habitat by >=2%
- 14% of species decrease in habitat by >=2%
- Considering importance value leads to more declines: 66 species increase, 54 decrease, 14 no change.
- Species severely diminished: black spruce, mountain maple, butternut, paper birch, quaking aspen, balsam poplar, balsam fir, northern white cedar, black maple, red spruce , white spruce.

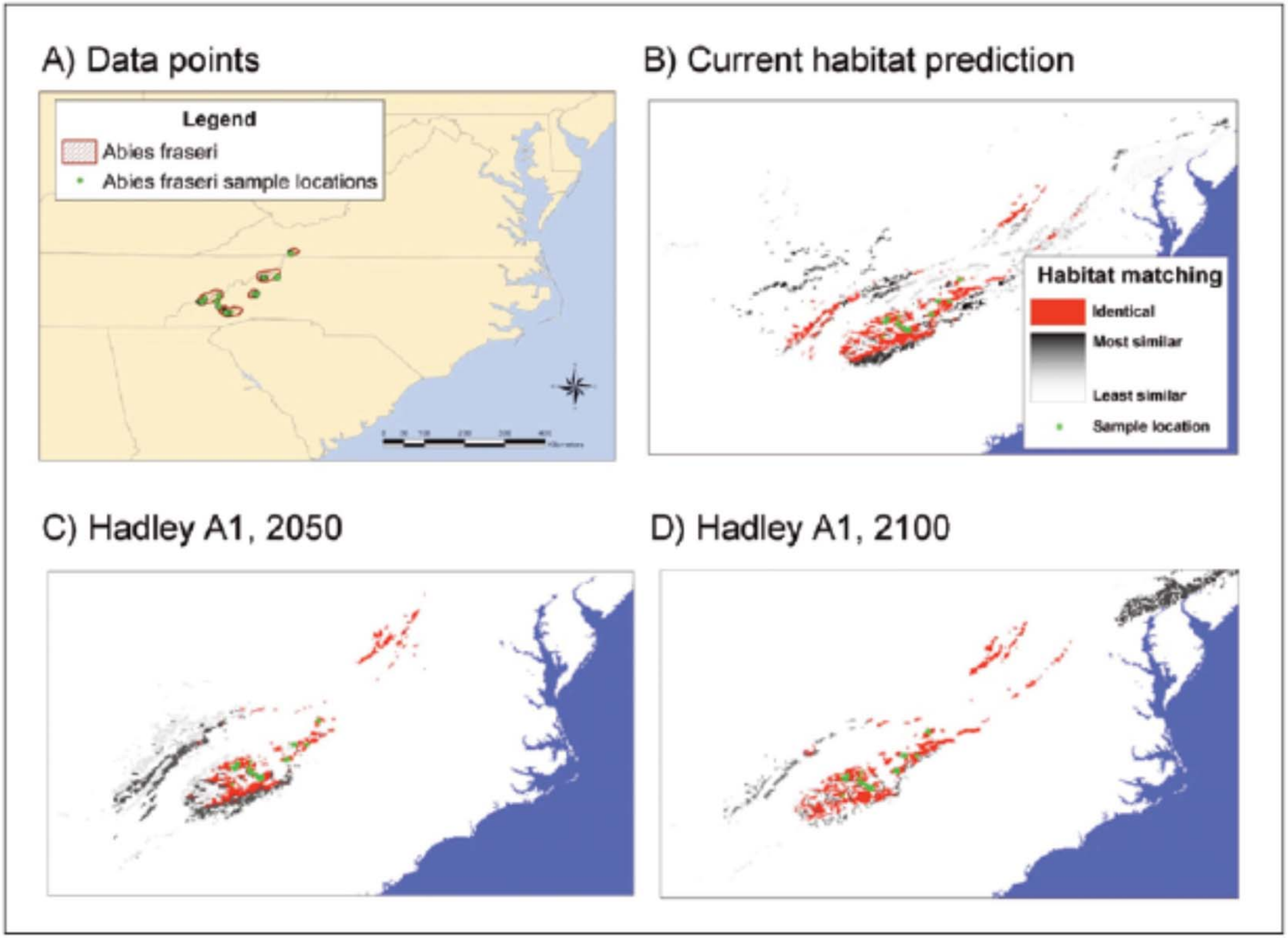



Potential changes in distance and direction of mean centers of suitable habitat
(26 species > 400 km)



# Results: Potter et al. 2010

**Predictions are sometime surprising!**



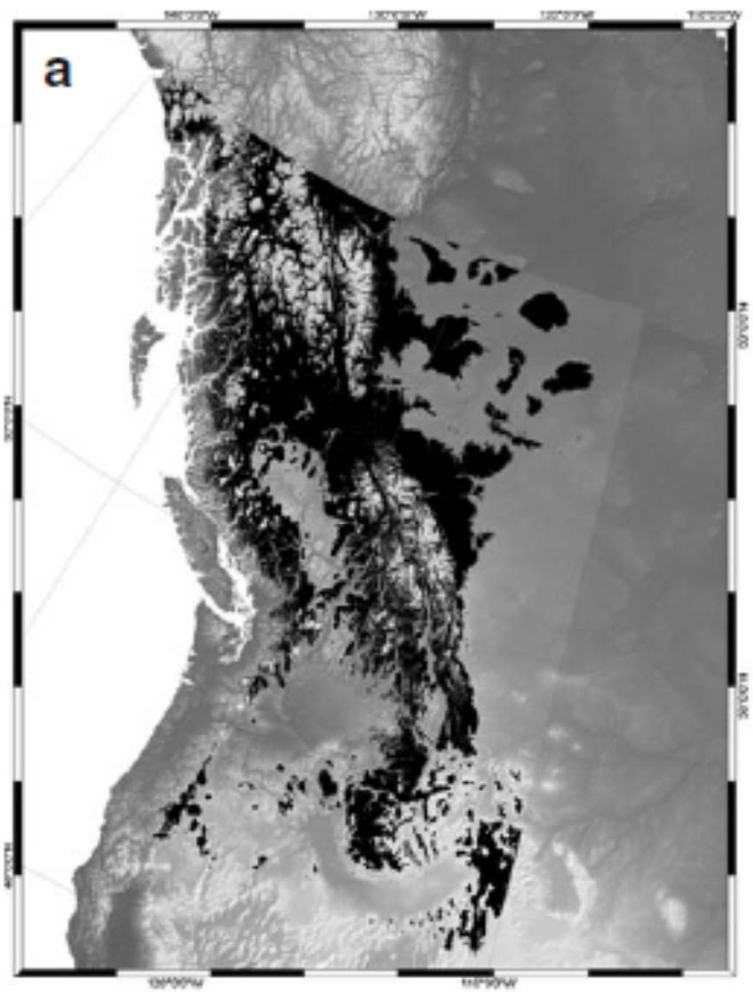

**Fraser Fir**

# Results: Coops and Waring 2011

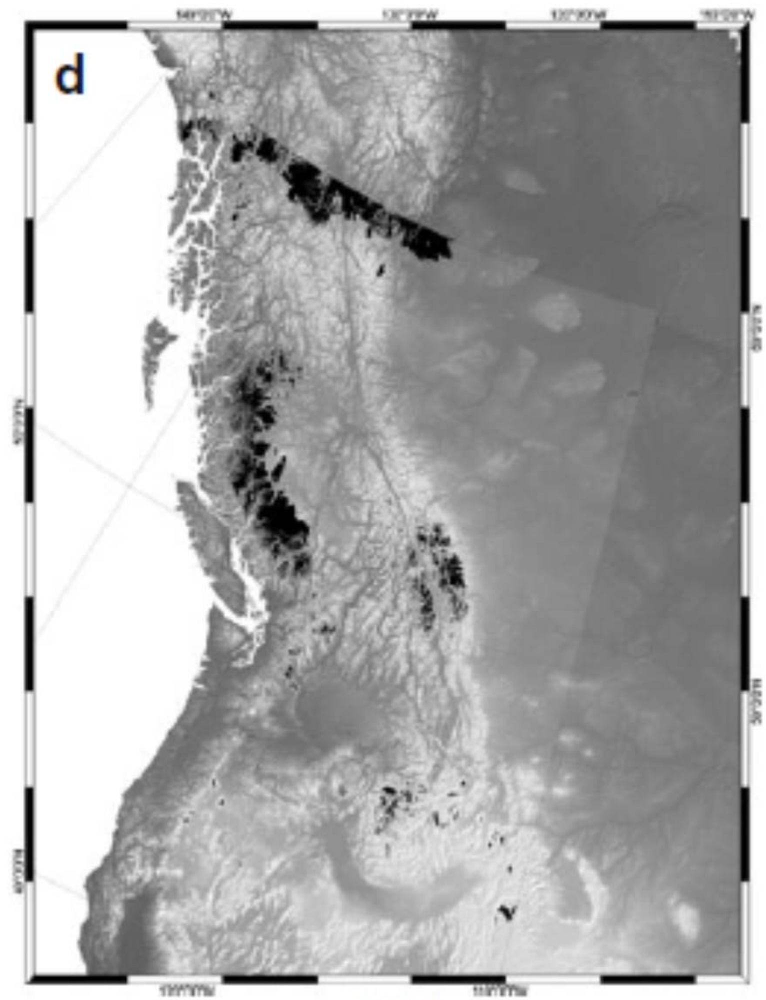
## Lodgepole pine

**Sites with significant spring frost, summer temperatures averaging <15◦C and soils that fully recharged from snowmelt were most likely to support lodgepole pine.**

**CGCM2**

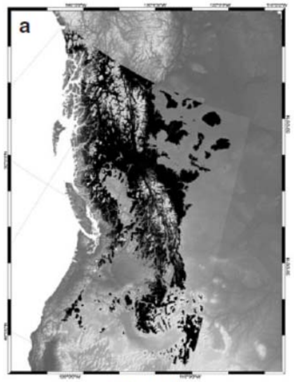



Current



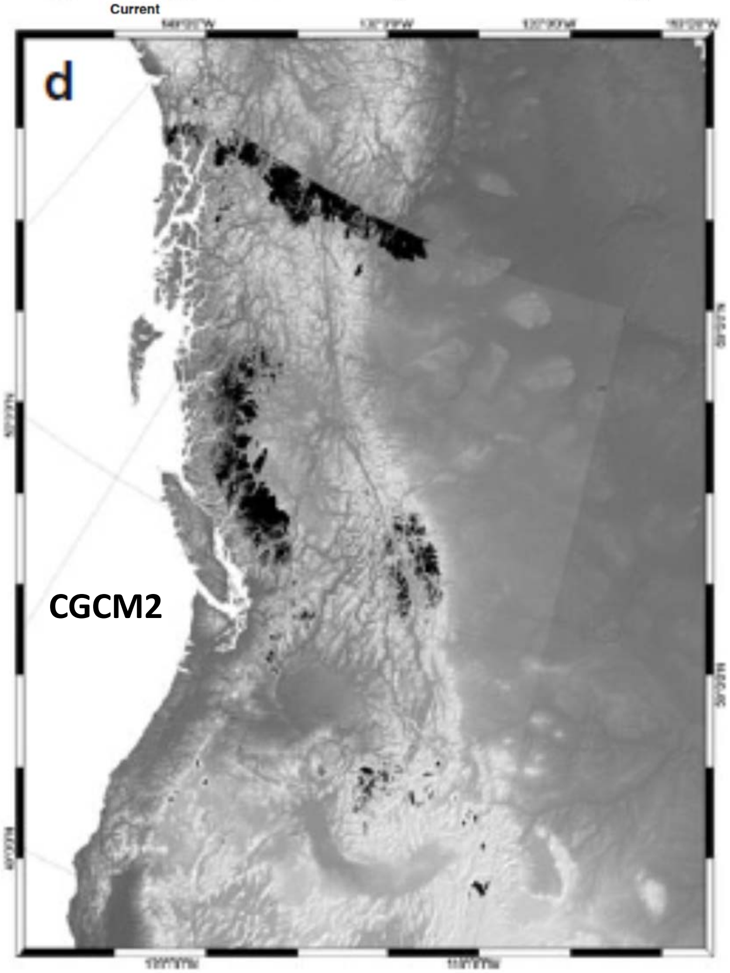

2080

# Results: Lodgepole Pine



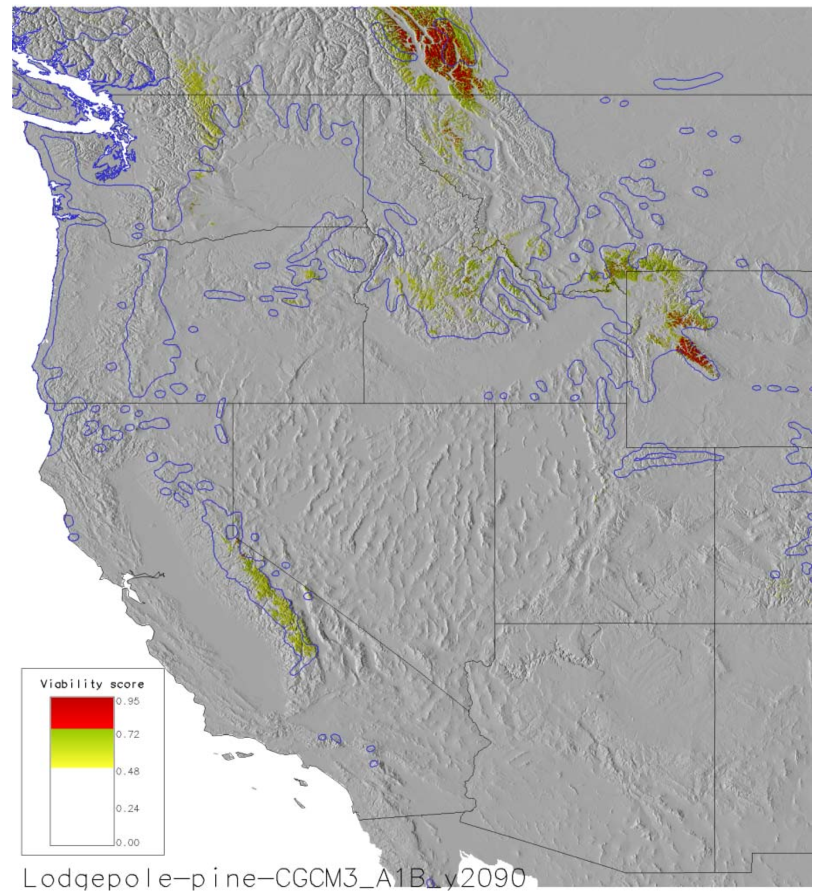

Current

**Coops and Waring 2011**




2080

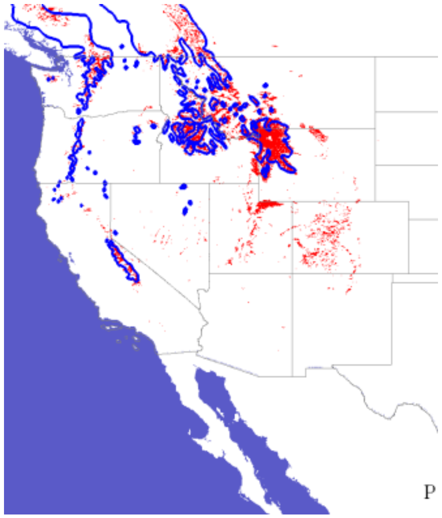
**Cookson et al.**




**CGCM3, A1B** **2090**

# Results: Whitebark pine

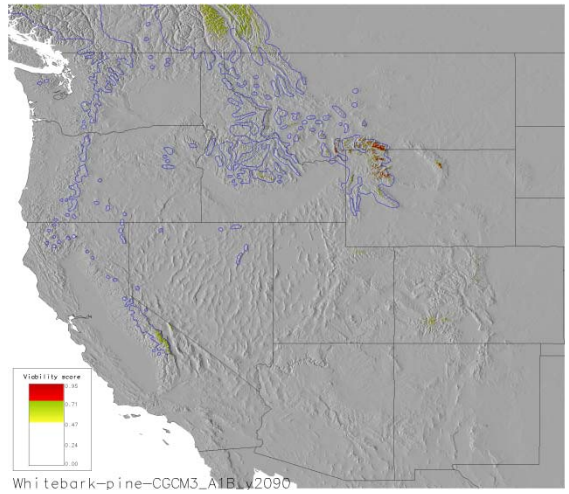
**Hargroves et al.**



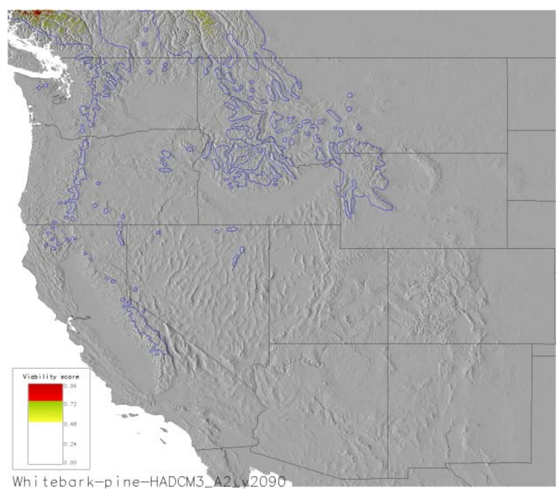

**PCM, Scenario A1, 2100**

**Hadley, Scenario A1, 2100**

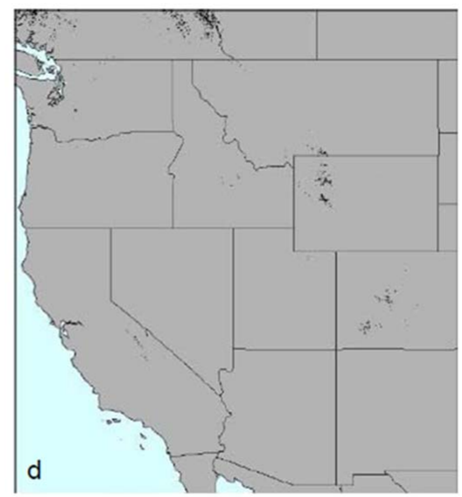
**Cookson et al.**




**CGCM3, A1B, 2090**



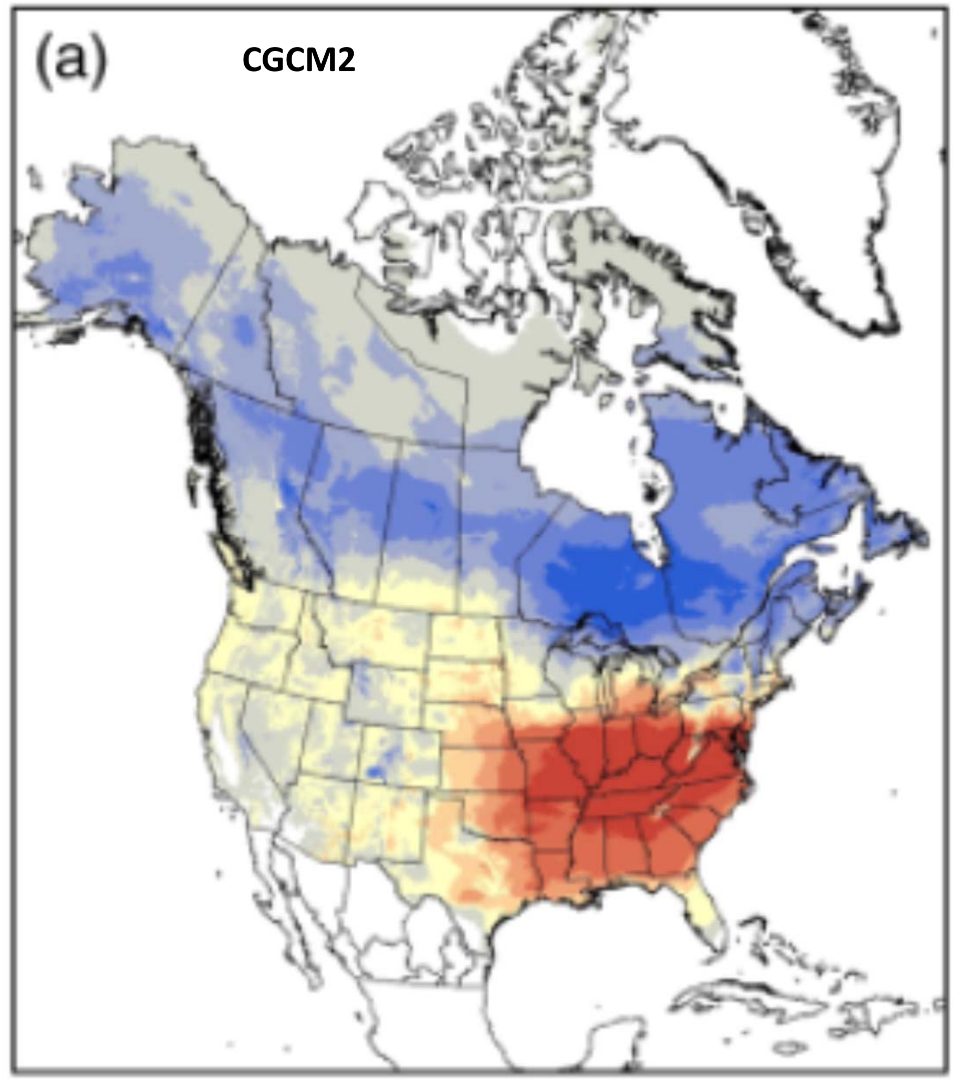

**Hadley CM3, A2,2090**




**Hadley + CCMA-GCM/2, 2090**

**Warell et al. 2007**

# Results: McKinney et al. 2011

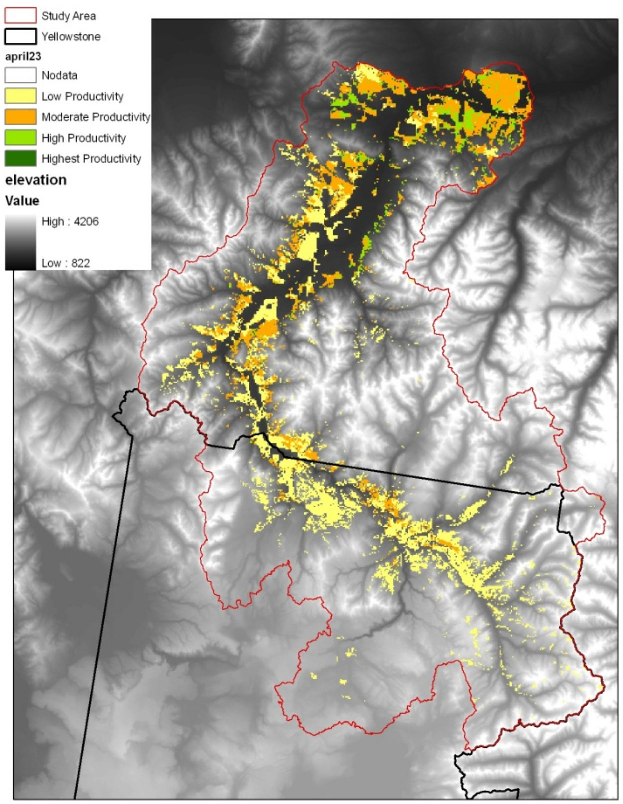

**Differences between current (1971–2000) and future (2071–2100) tree climate envelope richness (i.e., number of tree species).**

# Conclusions

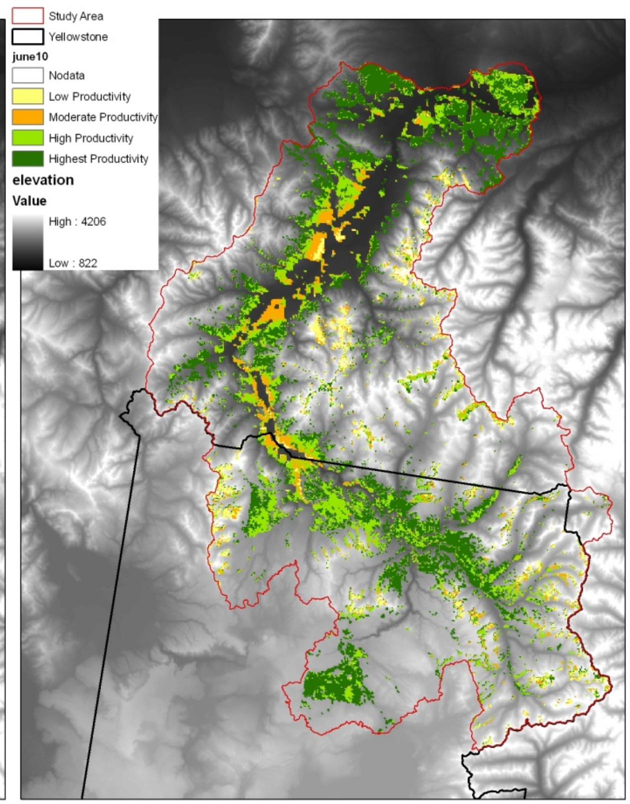
- **Rather than duplicate existing efforts, we should synthesize their results in ways that are relevant to our collaborators??? Or not?**
- **This should include synthesis of projected climate change and response of tree species and ecological system types.**
- **We can add value to these by additional analyses of change in habitat area, role of disturbance, dispersal ability, landscape resistance under land use change.**
- **We can also do finer resolution modeling for select species/types of high interest to collaborators (e.g., WBP).**

# Patch Dynamics of Grassland Phenology - Nate

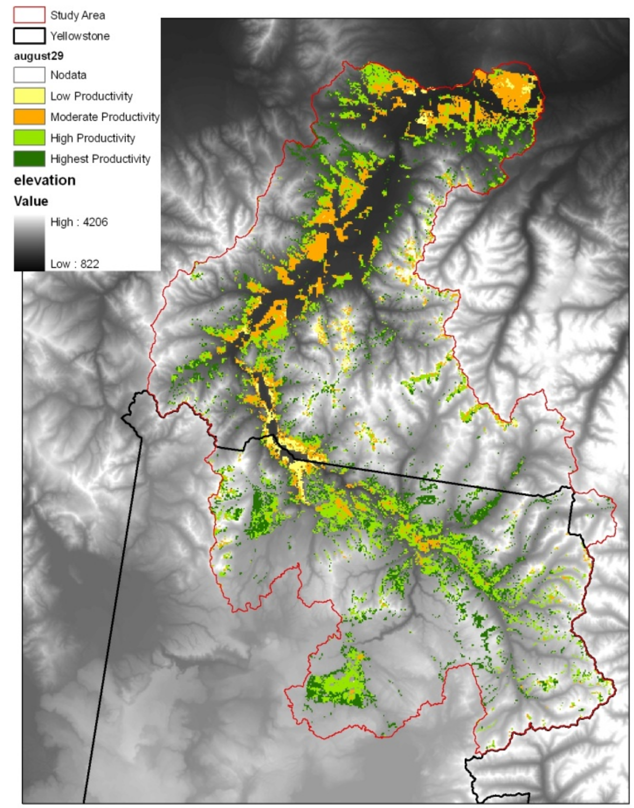
- **Spatial dynamics of "green flush"**
- **Climate predictors of phenology**
- **Land use modification of phenology**




April 23, 2010

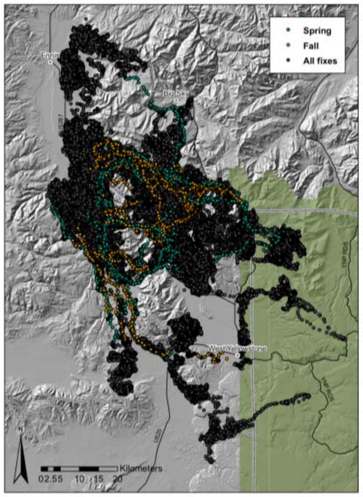



June 10, 2010




August 29, 2010

# Evaluating alternative approaches to identifying wildlife corridors - Meredith



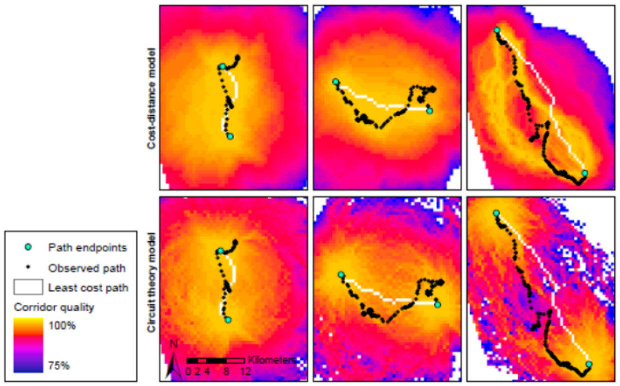




Figure 9. Best (a) cost-distance model and (b) circuit theory model outputs for spring migration of sample individuals. Outputs are from the model variant excluding climate-related covariates.

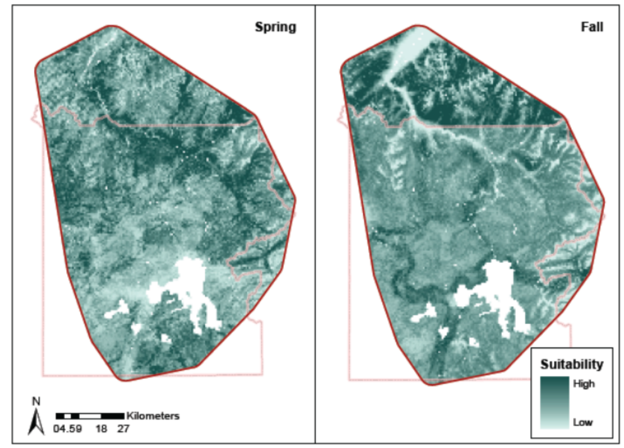
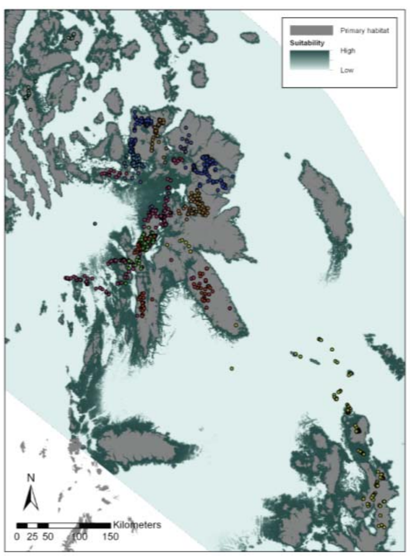
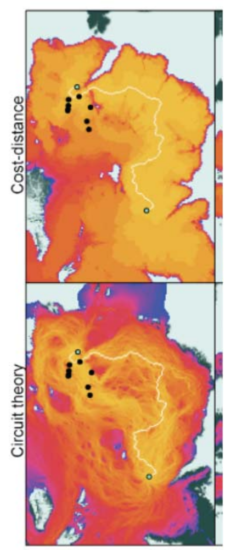



Figure 13. Application of best habitat suitability models from Madison Valley study area to Northern Range study area in (a) spring and (b) fall.

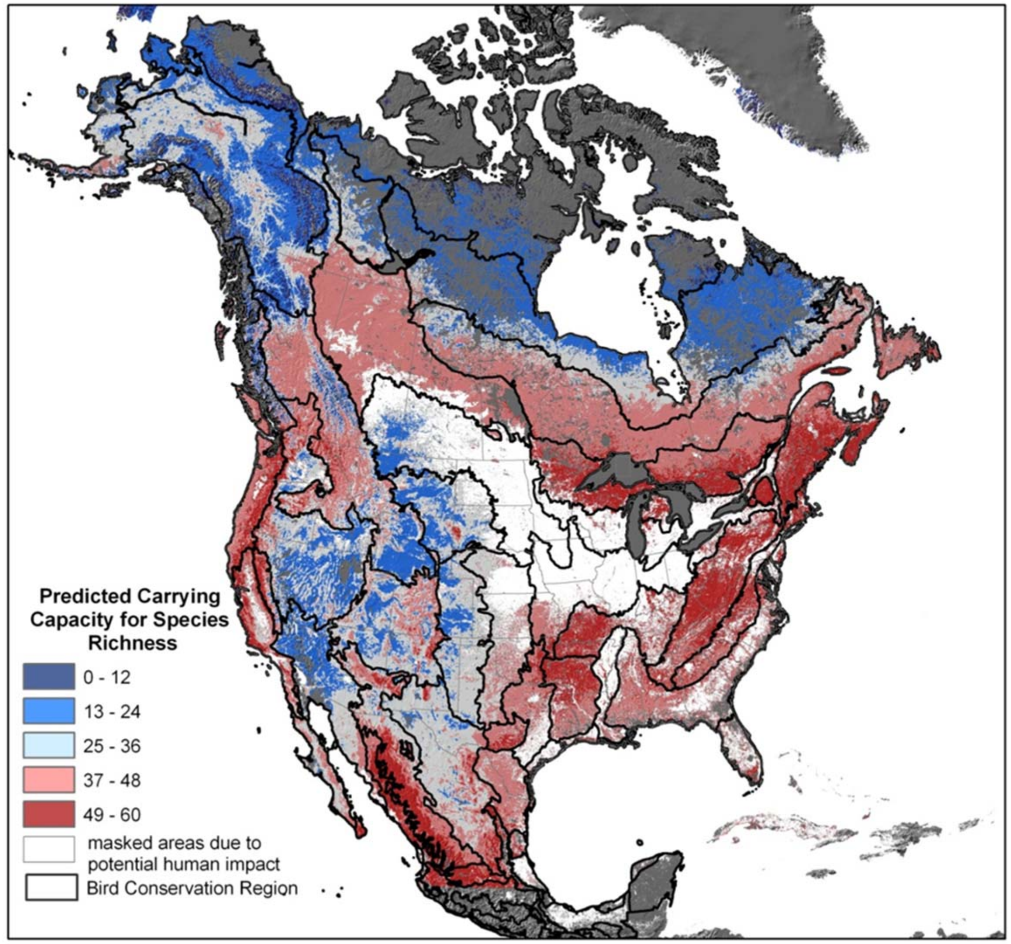



Next Step:

Nate phenology + Meredith elk connectivity + climate change

# Carrying Capacity for Species Richness for Landbirds



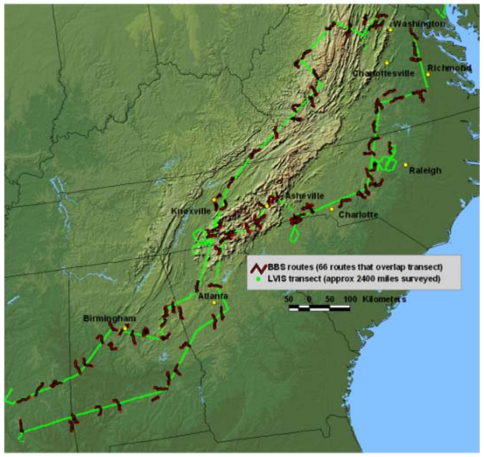

$S_K = 27.042\ aGPP - 0.004\ aGPP^2 - 19.425\ \%SCV + 0.005\ PET$

Hansen et al. in press. Global Ecology and Biogeography

%SCV: Interannual variation in GPP

PET: Potential evapotranspiration

# GPP, Canopy Structure, Land Use: Bird abundance and Diversity




**Methods and Datasets**

***Geographic Location*** → Southeast US

***Three Analysis units*** → (1) (BBS sample locations) , (2) Segments (5 sample average) , (3) Routes

***Stratify with:*** → Disturbance History and Land Use

***Response variable*** → Breeding Bird Survey Species Richness and Diversity
(allspecies; GUILDS: cowbird acceptors; insectivores; vertivores; forest interior; cavity, ground and open-cup nesters; sensitive)

***Predictor variables***

- LVIS
  - Canopy cover
  - Canopy cover by height class
- Landcover
  - Percent Ag
  - Percent developed
  - Percent Canopy
  - Variety of cover types
- MODIS
  - GPP
  - VCF forest
- Soil fertility
- Other biophysical
  - Temperature
  - Precipiation
  - Elevation
  - NDVI

***Statistical Analysis***