Climate Envelope Model to Predict Effects of Warming and Drying Scenarios on Florida Ecosystems

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Data used to build the Florida Plant Species-Climatic Envelope Model

Range maps of 125 important tree, shrub species from:

E.L. Little, Jr. 1978. *Atlas of United States Trees, vol. 5: Florida*. U.S.D.A. Misc. Publ. 1361.

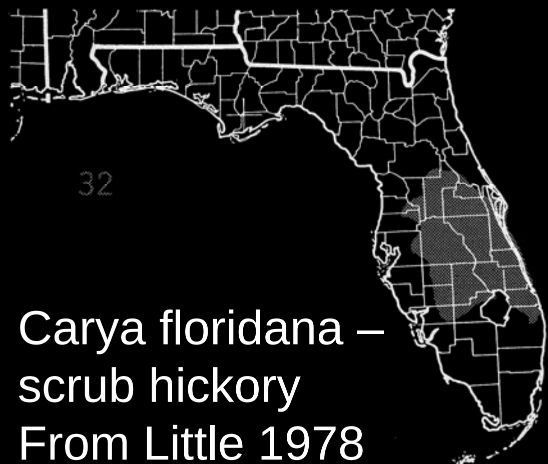
Extensive species lists for 36 areas (189 sites).

Climate data from (100+ stations, 1890-1990):

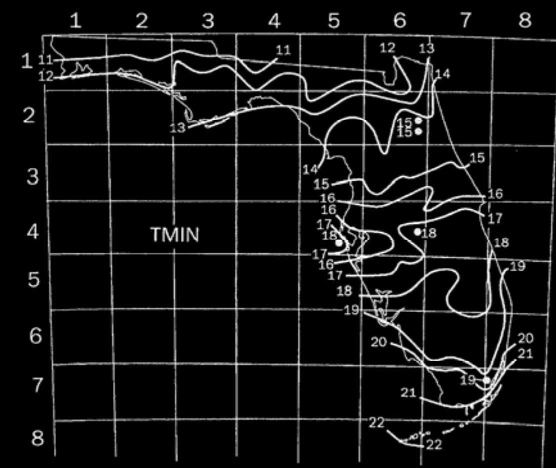
C.J. Willmott, et al. 1981. Public. in Climatology 34(2). Univ. Delaware.

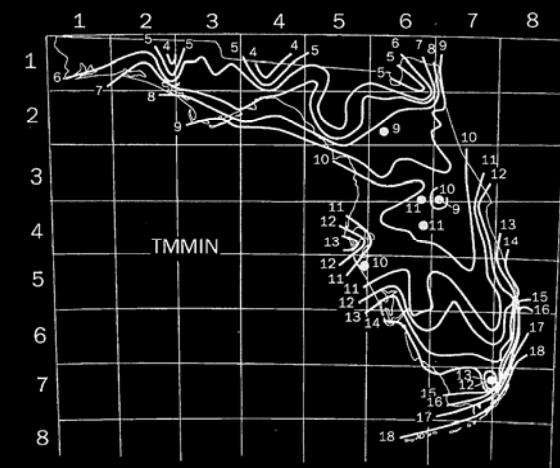
National Oceanic and Atmospheric Administration. 1982 and 1990 publications of Florida climate data.

Other sources.

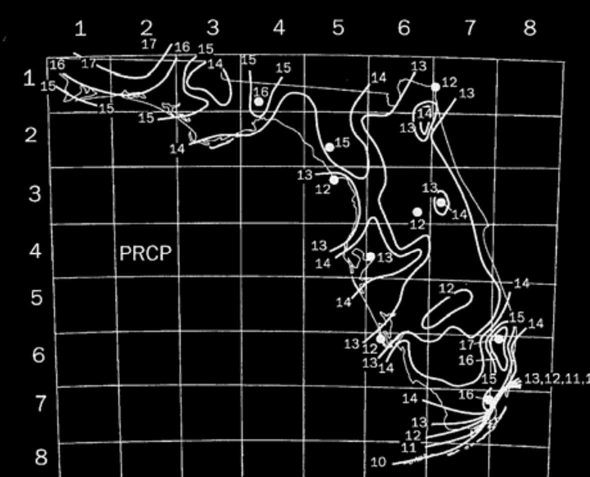


Carya floridana –
scrub hickory
From Little 1978





Magnolia grandiflora –
Southern magnolia
From Little 1978



Climatic variables used in the model

TMAX = mean temperature warmest month (C^O)

TMIN = mean temperature coldest month (C^O)

DTY = annual range of monthly mean temperature (=TMAX – TMIN, C^O)

TMMIN = mean minimum temperature, coldest month (C^O)

TABMIN = absolute minimum temperature (C^O)

PRCP = average annual precipitation (mm)

MI = annual moisture index (PRCP/average annual PET, where PET = mean annual temperature X 58.93; see Holdridge 1959, Box 1986)

PMIN = average precipitation driest month (mm)

THE FLORIDA PLANT SPECIES - CLIMATIC ENVELOPE MODEL

Winter and summer temperatures, overall moisture balance and dry-season precipitation have important direct and/or indirect effects on the natural distribution of many important native, woody plant species in Florida.

A climate-envelope is the climatic space corresponding to the geographical range of a species (community, type, etc.). The basic assumption is that a species will not grow at a place if the local value of any climatic variable exceeds that used to define its envelope.

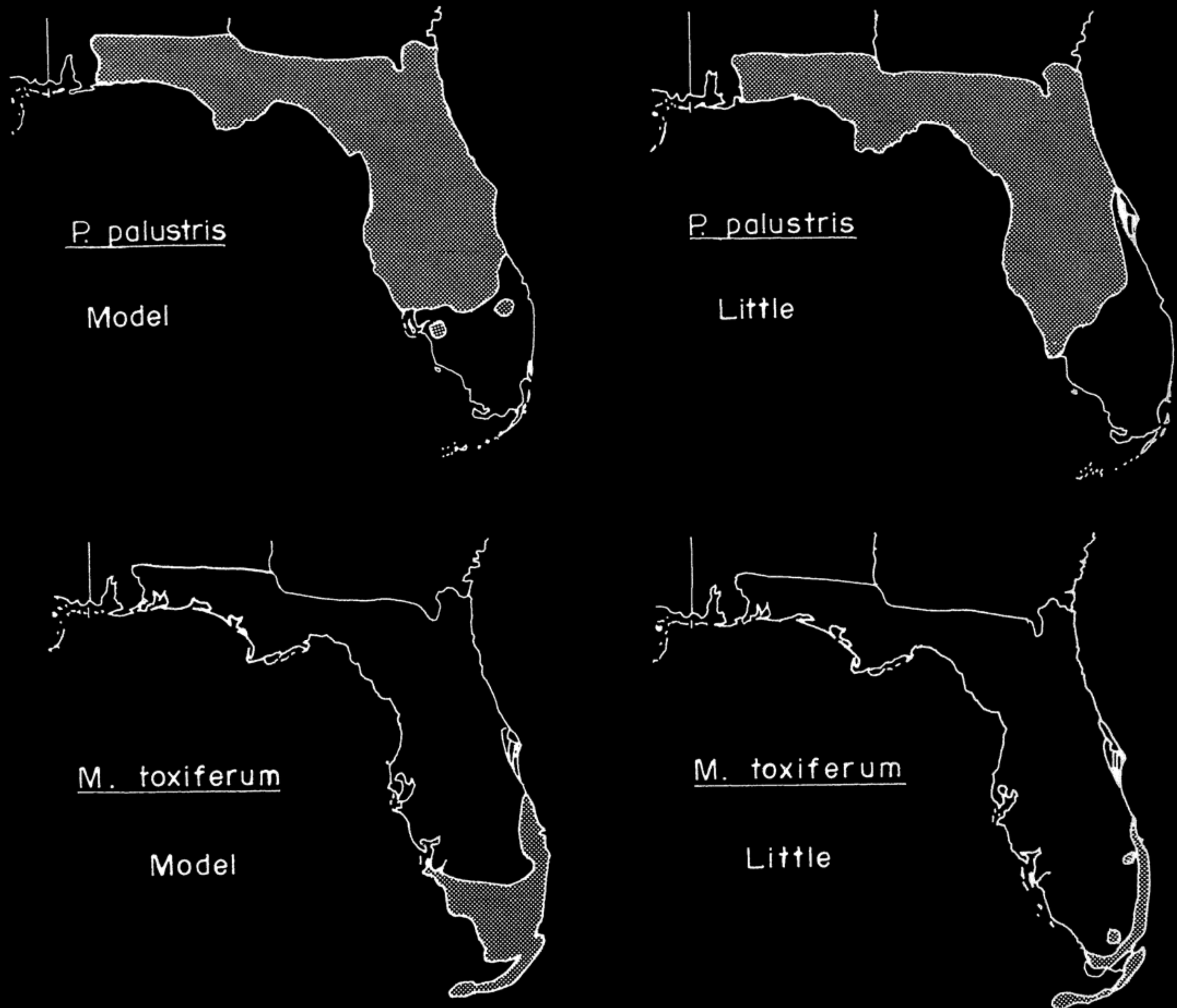
THE FLORIDA PLANT SPECIES - CLIMATIC MODEL

The model does not consider other important factors, such as substrate, topography, fire, competition, predation, CO_2 enrichment , vegetation inertia, disease, and migration rates.

The model is a deterministic and an equilibrium model.

Sites used in building and testing the Florida Plant Species-Climate Model

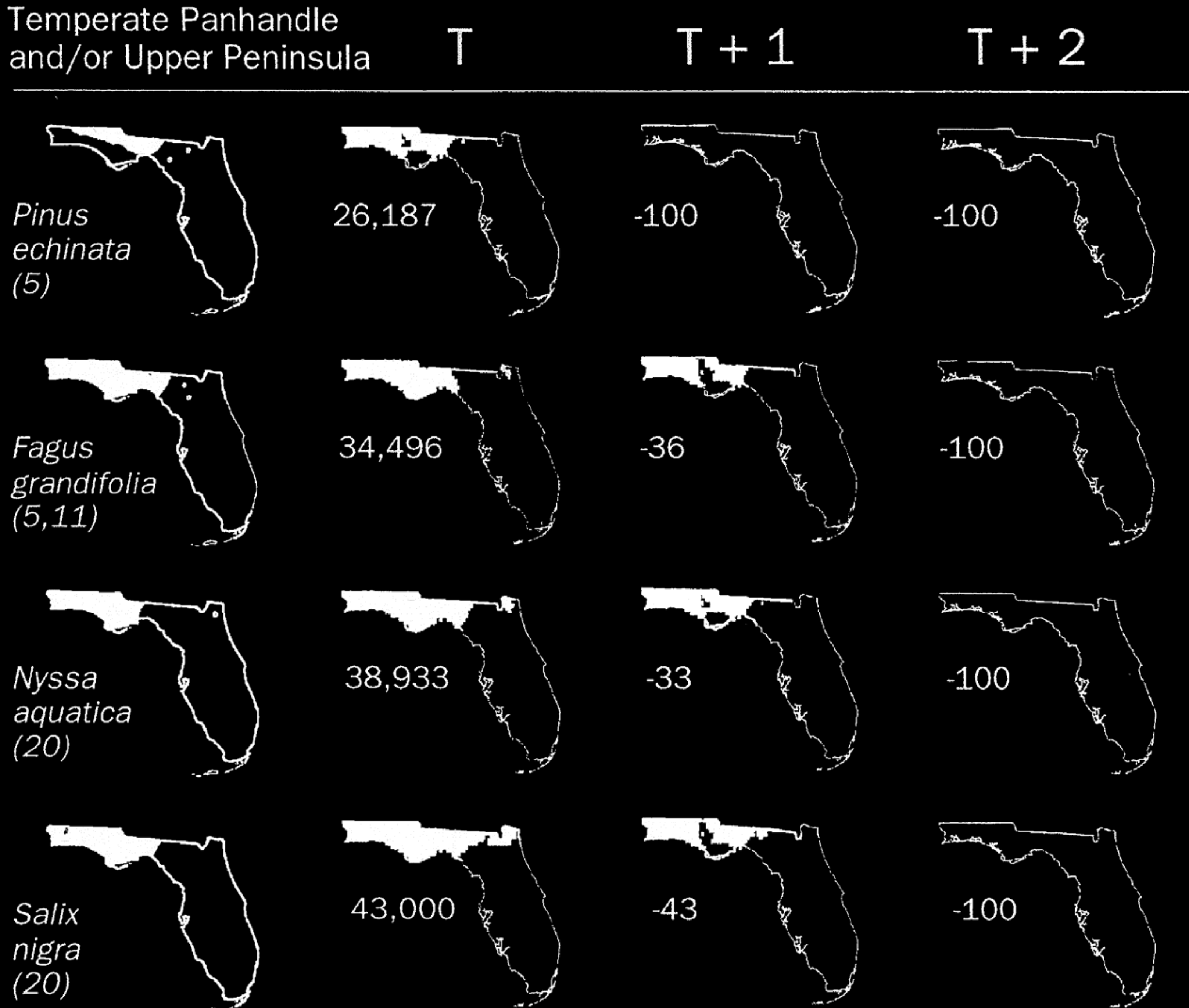
Comparison of model baseline maps with Little (1978) range maps

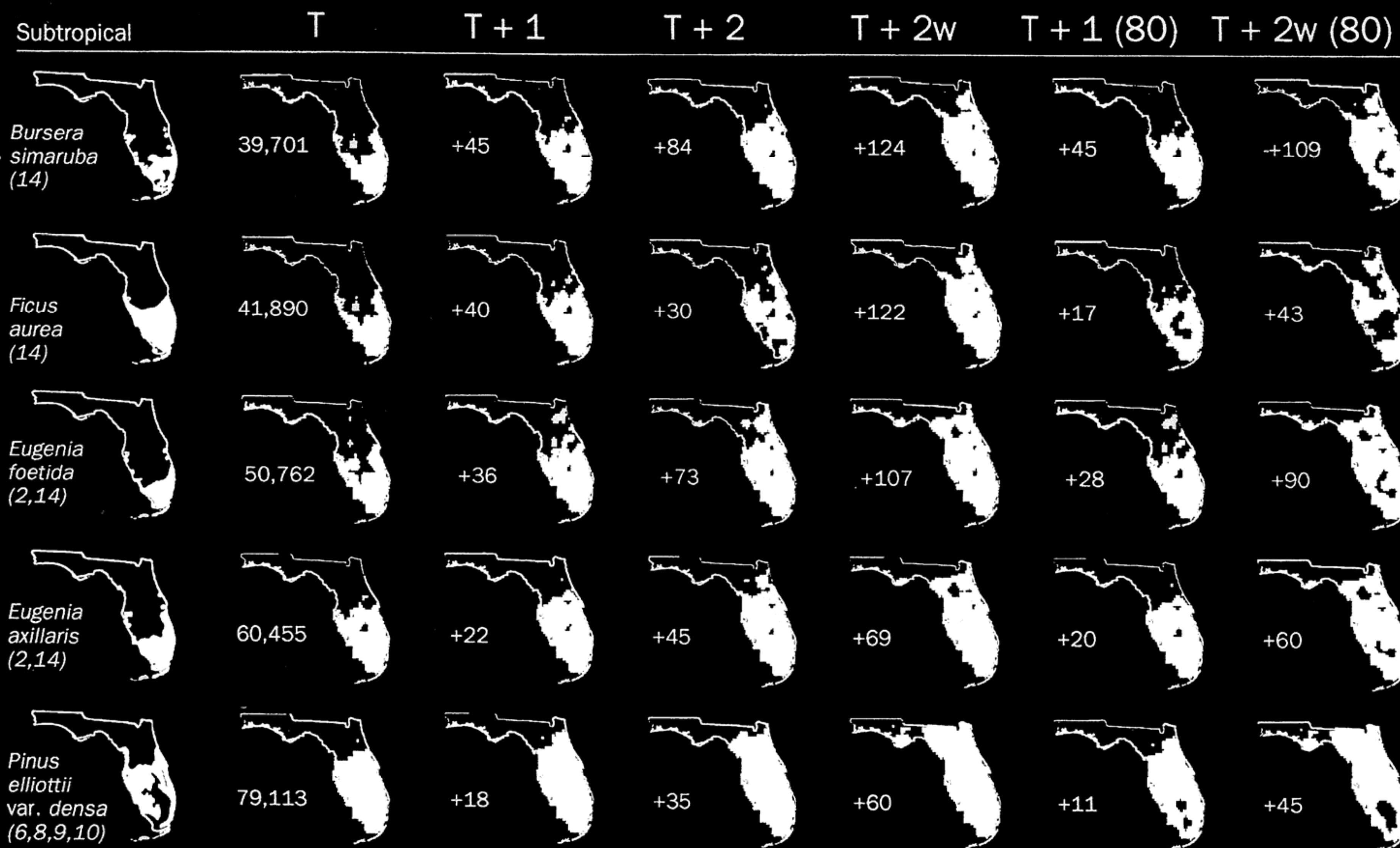


Climate Change Scenarios

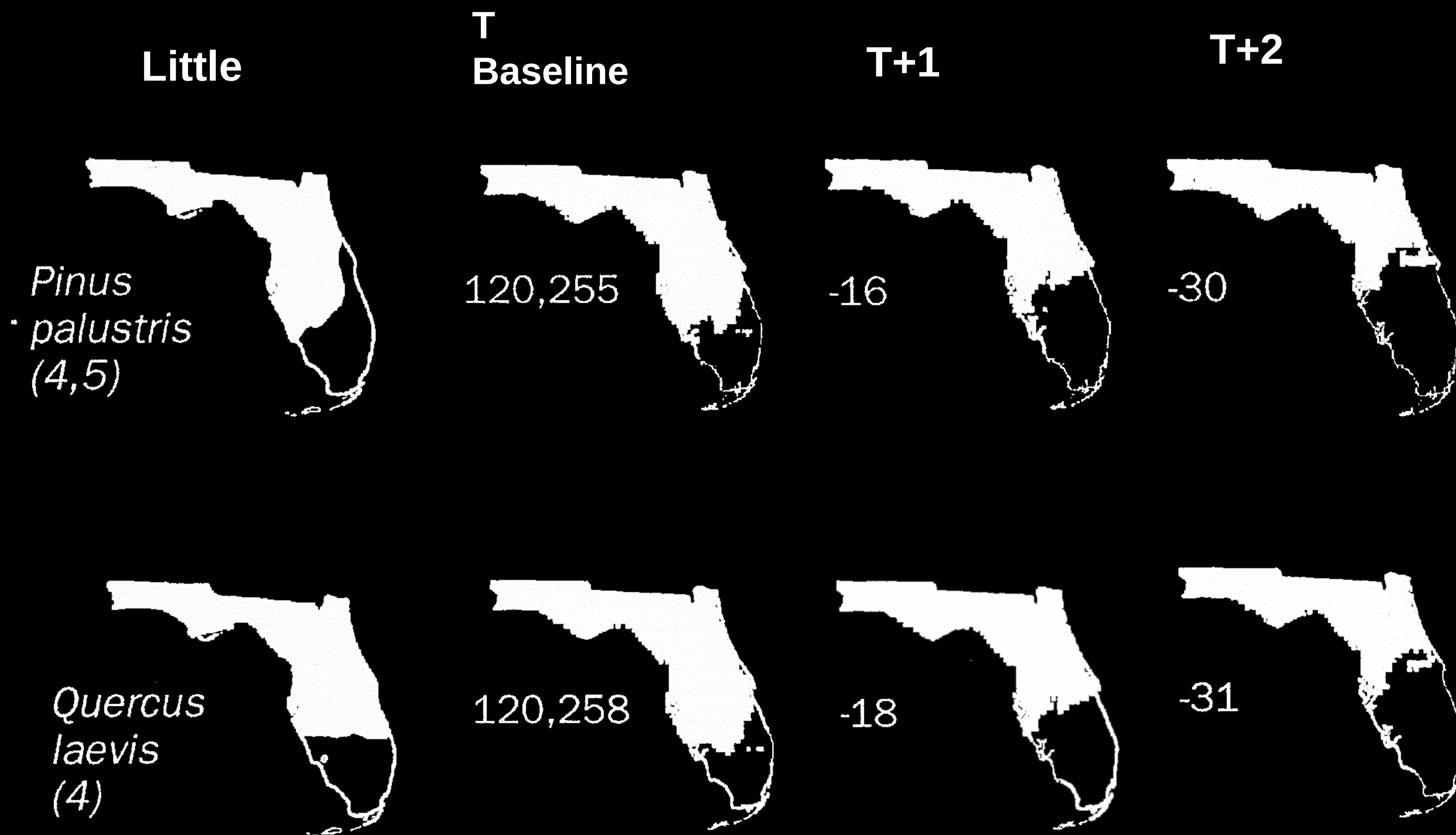
- **T** = Baseline; predicted from current monthly temperature and precipitation levels.
- **T+1, T+2** = 1C and 2C increases in mean annual temperature, equally to each month; baseline moisture balance held constant.
- **T+1w, T+2w** = 1C and 2C increases but with greater winter warming and less summer warming; baseline moisture balance constant.
- **T+1(80), T+2w(80)** = temperature as above; 20% decrease in annual precipitation.

Natural Range Type and Species
Scenario
Temperate Panhandle and/or Upper Peninsula
T
T + 1
T + 2
T + 1w
T + 2w
T + 1 (80)
T + 2w (80)
Fagus grandifolia
34,496
-36
-100
-98
-100
-100
-100
Quercus falcata
66,868
-26
-48
-40
-98
-49
-98
Warm Temperate
Pinus palustris
120,255
-16
-30
-24
-43
-71
-85
Quercus virginiana
152,915
0
-15
0
-13
-5
-30
Warm Temperate - Subtropical
Serenoa repens
152,915
0
0
0
0
0
-3
Subtropical
T
T + 1
T + 2
T + 1w
T + 2w
T + 1 (80)
T + 2w (80)
Bursera simaruba
39,701
+45
+84
+68
+124
+45
-+109
Pinus elliottii var. densa
79,113
+18
+35
+29
+60
+11
+45

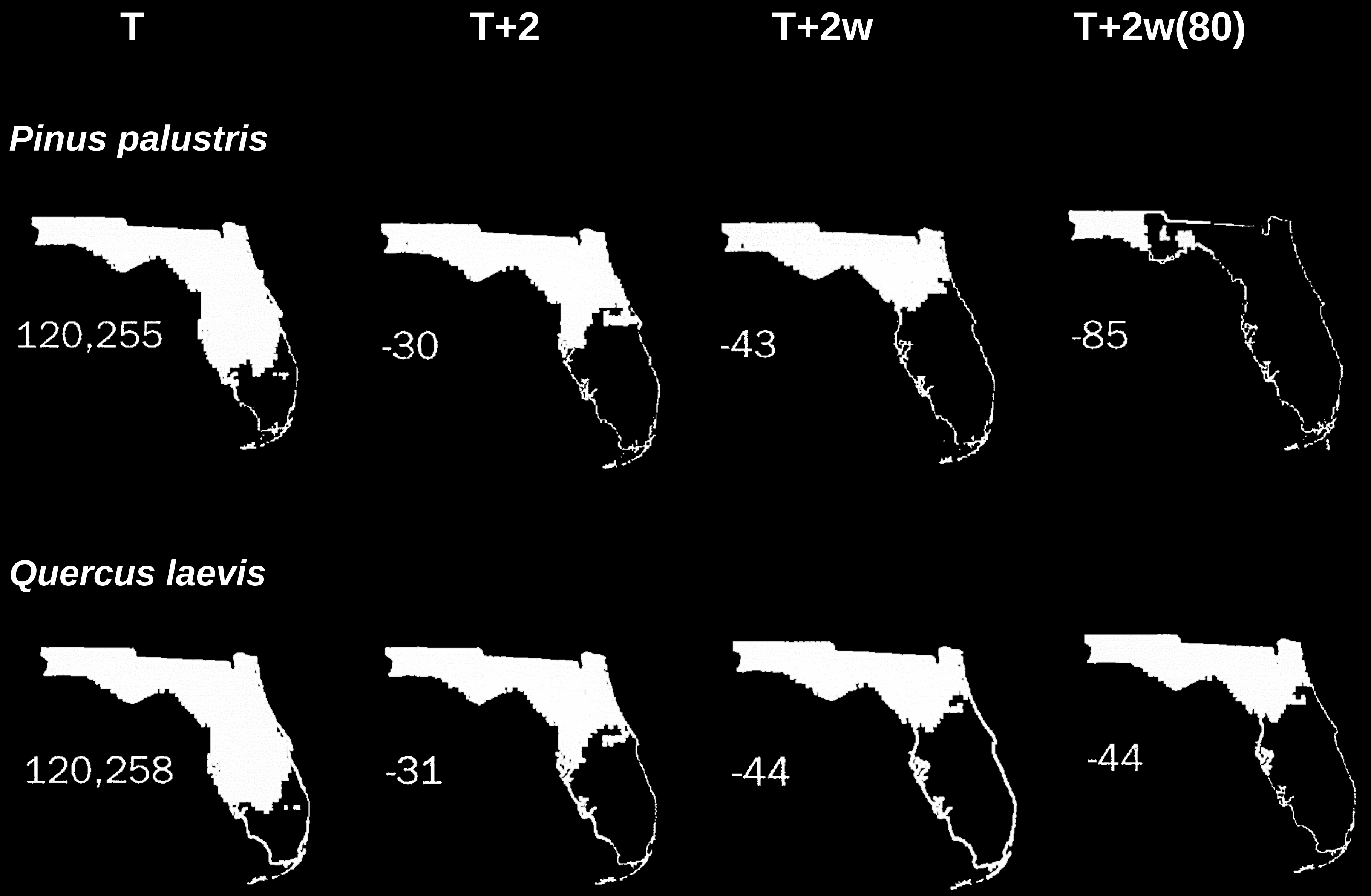

Temperate Panhandle and/or Upper Peninsula
T
T + 1
T + 2
Pinus echinata (5)
26,187
-100
-100
Fagus grandifolia (5,11)
34,496
-36
-100
Nyssa aquatica (20)
38,933
-33
-100
Salix nigra (20)
43,000
-43
-100



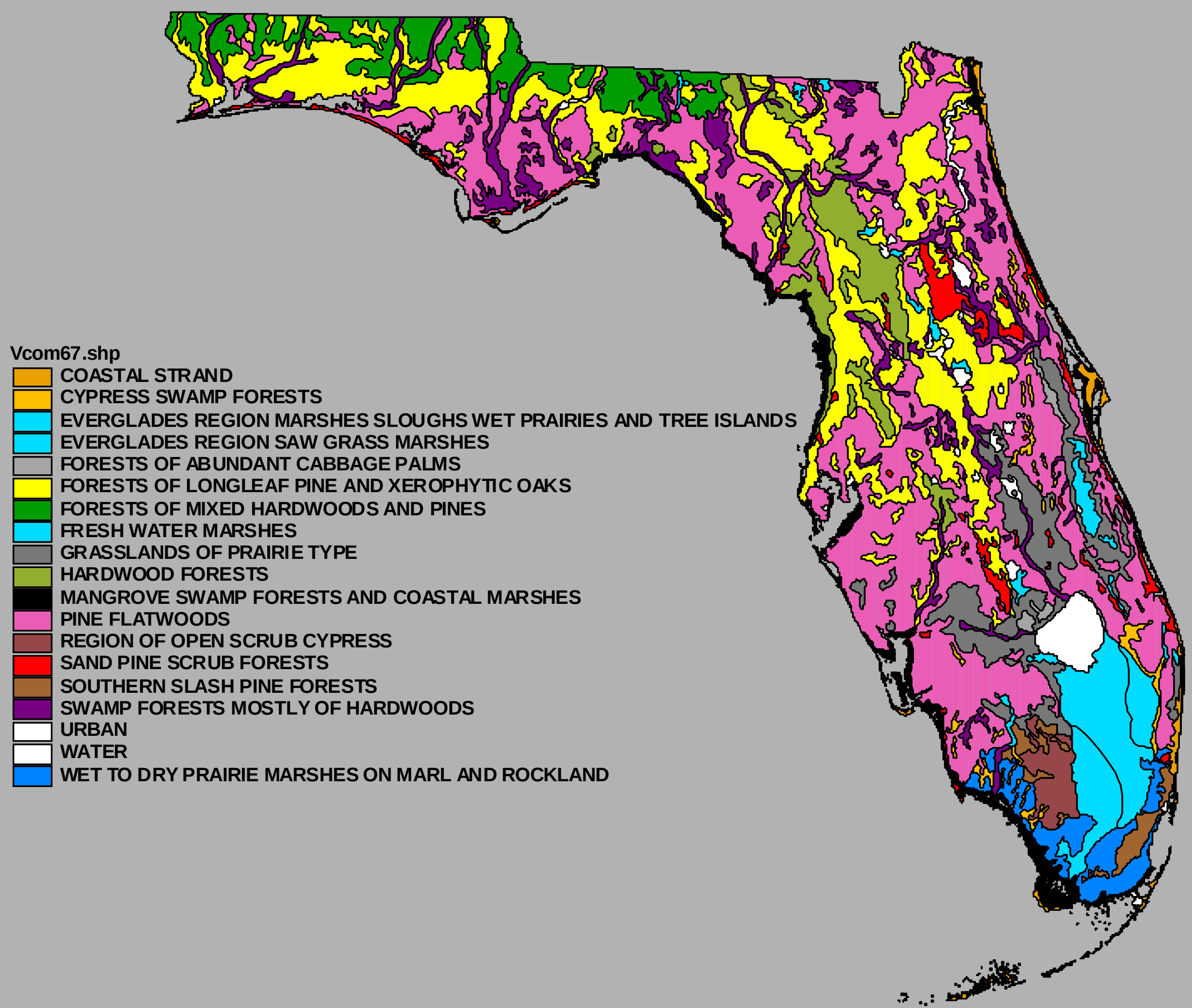
Subtropical
T
T + 1
T + 2
T + 2w
T + 1 (80)
T + 2w (80)
Bursera simaruba (14)
39,701
+45
+84
+124
+45
+109
Ficus aurea (14)
41,890
+40
+30
+122
+17
+43
Eugenia foetida (2,14)
50,762
+36
+73
+107
+28
+90
Eugenia axillaris (2,14)
60,455
+22
+45
+69
+20
+60
Pinus elliottii var. densa (6,8,9,10)
79,113
+18
+35
+60
+11
+45



Little
T
Baseline
T+1
T+2
Pinus
palustris
(4,5)
120,255
-16
-30
Quercus
laevis
(4)
120,258
-18
-31


T
T+2
T+2w
T+2w(80)
Pinus palustris
120,255
-30
-43
-85
Quercus laevis
120,258
-31
-44
-44

General Map of Natural Vegetation of Florida after J. H. Davis, 1967

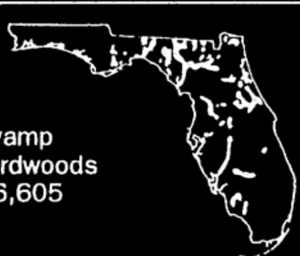
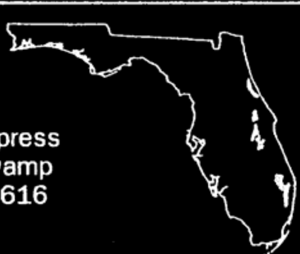


Longleaf Pine – Turkey Oak Hills (Sandhills)

Dominant Species	Scenario					
	T+1	T+1w	T+2	T+2w	T+1 (80)	T+2w (80)
Pinus palustris	0-20	0-20	0-20	21-40	61-80	61-80
Quercus incana	0-20	0-20	0-20	21-40	0-20	21-40
Quercus laevis	0-20	0-20	0-20	21-40	0-20	21-40

Mixed Pine Hardwood and Upland Pine Forests

Dominant Species	Scenario					
	T+1	T+1 w	T+2	T+2 w	T+1 (80)	T+2w (80)
Fagus grandifolia	0-20	81-100	81-100	81-100	81-100	81-100
Magnolia grandiflora	21-40	0-20	81-100	0-20	61-80	41-60
Pinus echinata	81-100	81-100	81-100	81-100	81-100	81-100
Pinus palustris	0-20	0-20	0-20	0-20	0-20	41-60
Pinus taeda	0-20	0-20	0-20	41-60	0-20	41-60
Quercus falcata	0-20	0-20	0-20	81-100	0-20	81-100

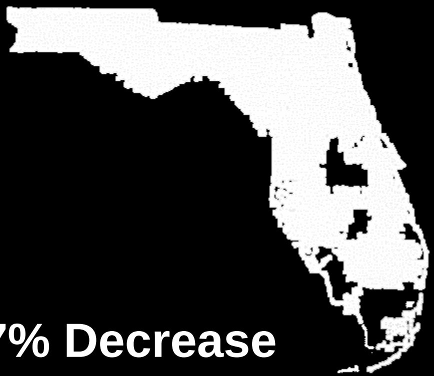
	Dominant Species	Scenario					
		T+1	T+1 w	T+2	T+2 w	T+1 (80)	T+2w (80)
 Bottomland Hardwoods 8,118	*Carya aquatica*	0-20	0-20	0-20	0-20	21-40	41-60
	Quercus laurifolia	0-20	0-20	0-20	0-20	21-40	41-60
	Quercus michauxii	0-20	0-20	0-20	41-60	61-80	81-100
	Salix nigra	0-20	81-100	81-100	81-100	81-100	81-100
 Swamp Hardwoods 16,605	*Acer rubrum*	0-20	0-20	0-20	21-40	0-20	41-60
	Nyssa sylvatica	0-20	0-20	0-20	21-40	81-100	81-100
	Taxodium distichum	0-20	0-20	0-20	0-20	61-80	81-100
 Cypress Swamp 3,616	*Nyssa sylvatica*	0-20	21-40	21-40	61-80	61-80	61-80
	Salix caroliniana	0-20	0-20	41-60	41-60	0-20	41-60
	Taxodium distichum	0-20	0-20	0-20	41-60	61-80	81-100

Warm Temperate
Taxodium distichum – Bald cypress

T
Baseline from model

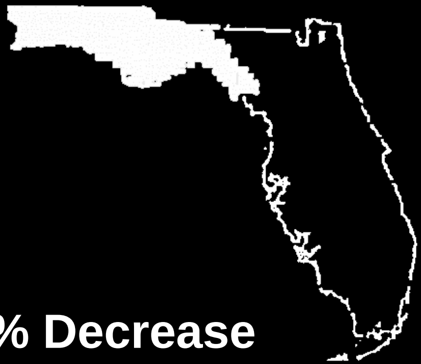
152,562 km^2
(58,905 mi^2)

T+2
+2C proportioned annually
Moisture index constant



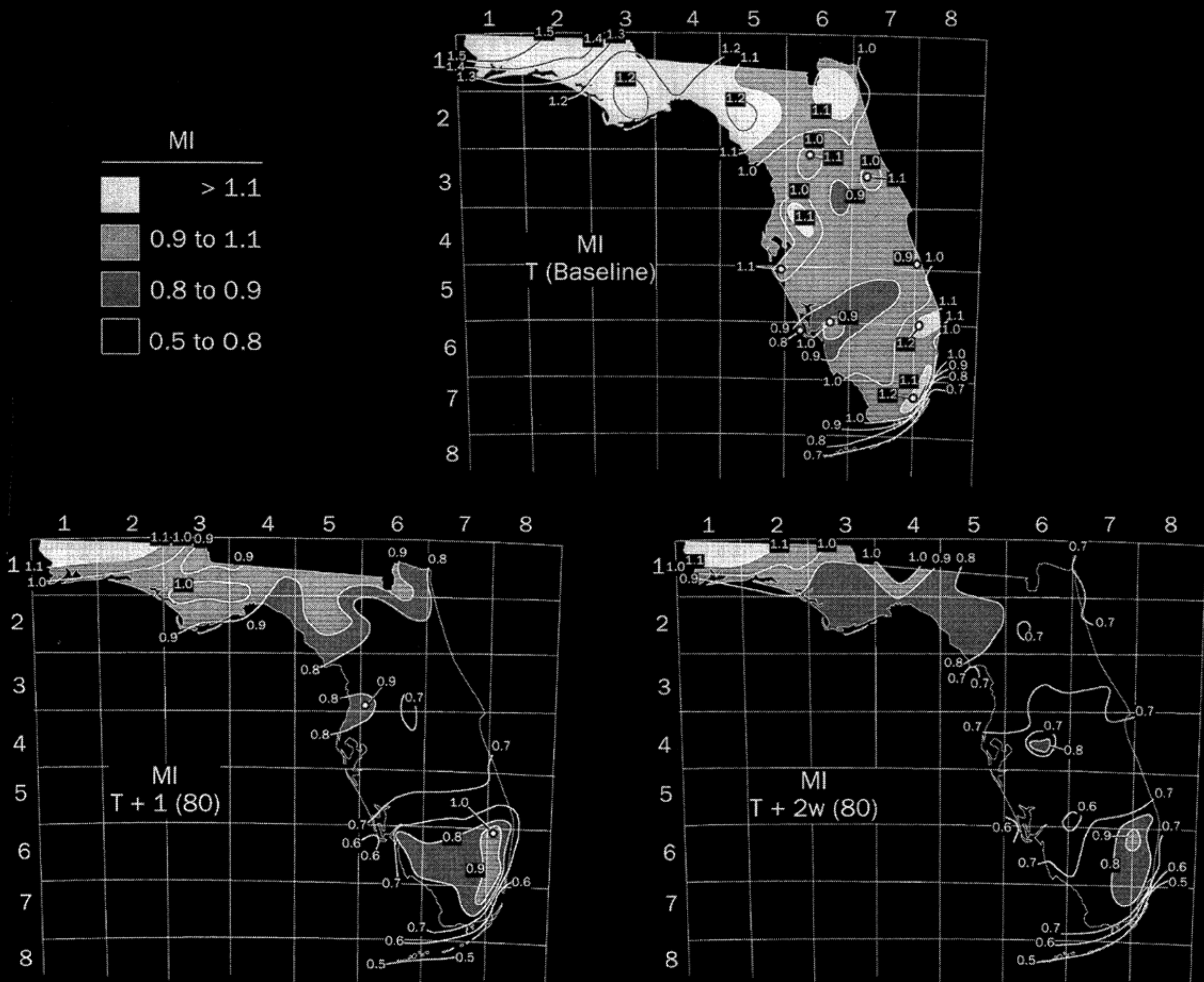
17% Decrease

T+2w(80)
+2C greater in winter
80% annual precipitation

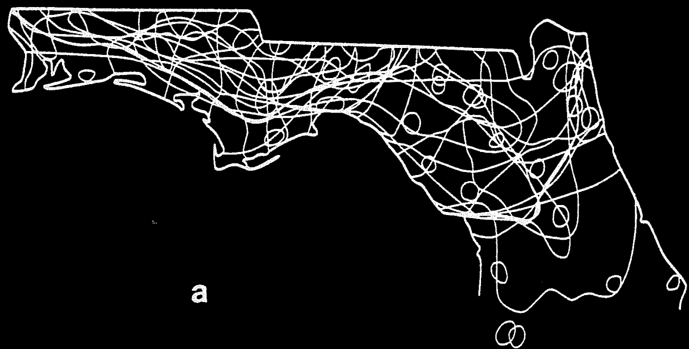


76% Decrease

Holdridge moisture index (MI) for three scenarios.

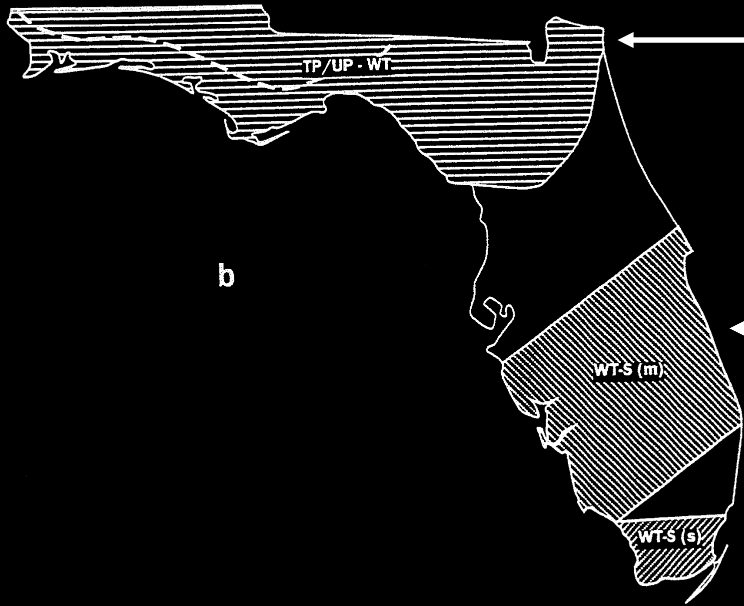


Boundaries and Transition Zones
Natural Range Types – 112 Species



a

Southern range boundaries – Temperate Panhandle/Upper Peninsula Species



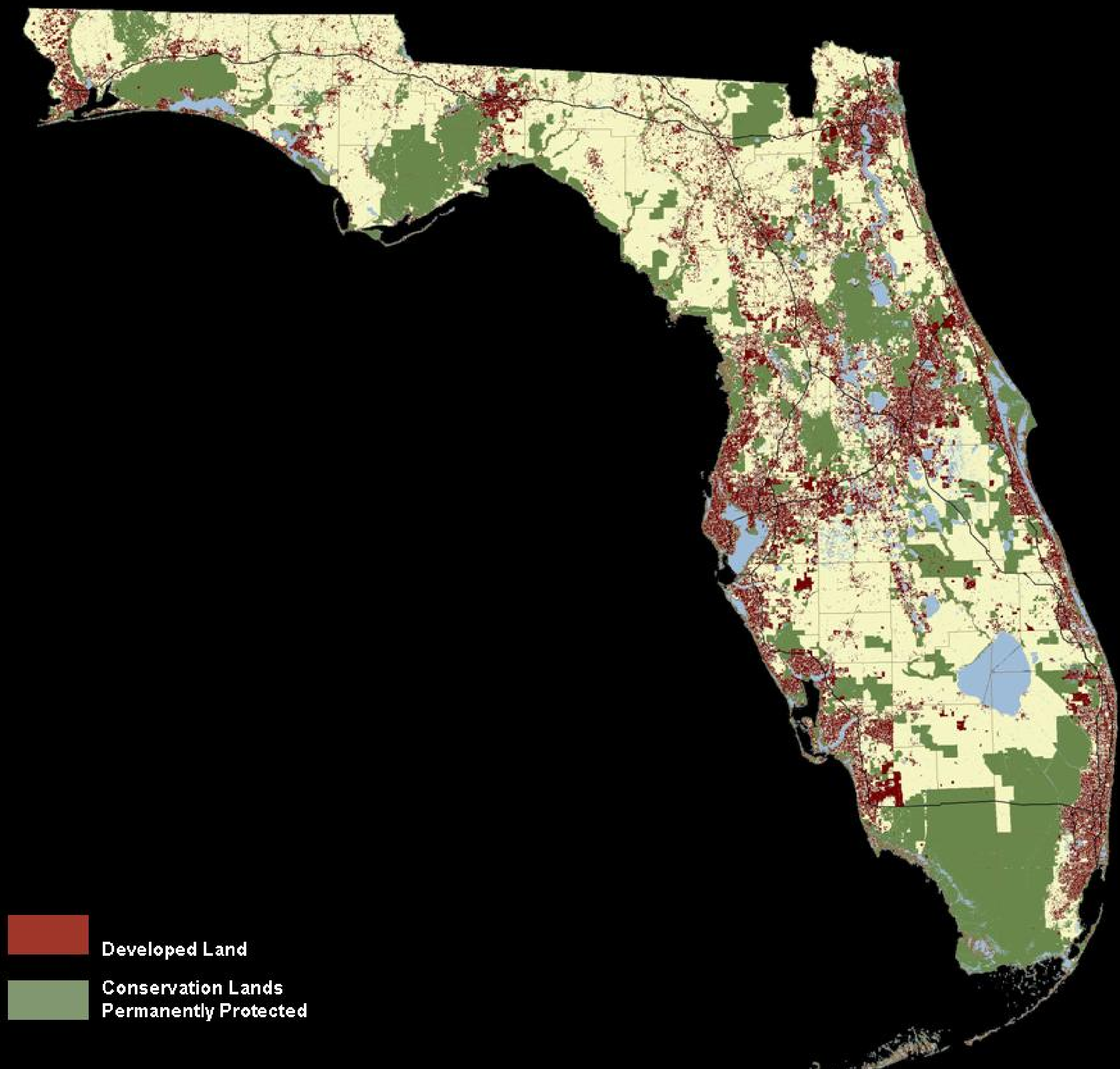
b

Temperate Panhandle/Upper Peninsula – Warm Temperate Species Transition Zone

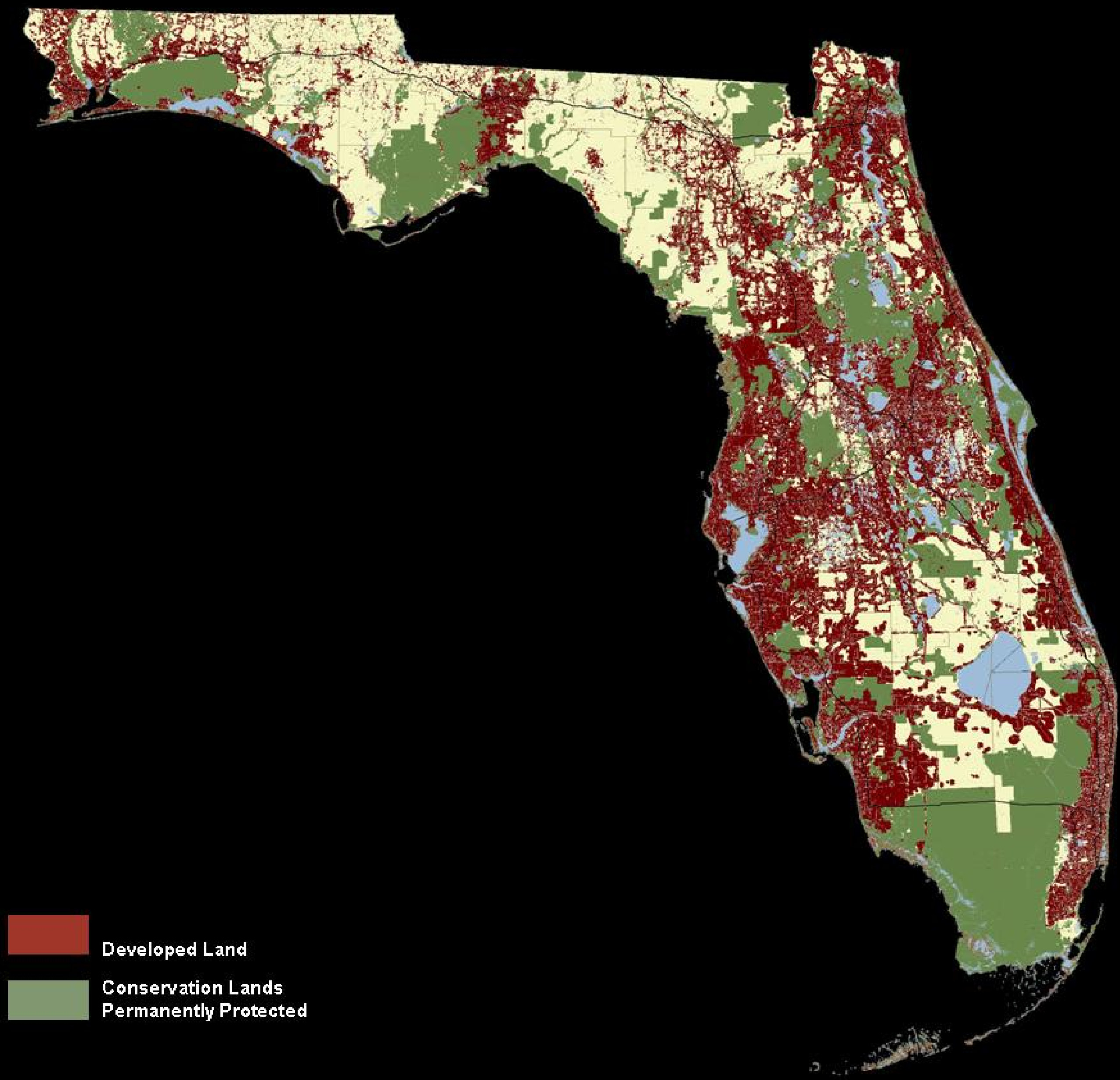
Major Warm Temperate – Subtropical Species Transition Zone

Secondary Warm Temperate – Subtropical Species Transition Zone

Existing Developed Lands and Permanent Conservation Lands



2060 Developed Lands and Permanent Conservation Lands



Florida 2060: A Research Project of 1000 Friends of Florida

Convergence of Models and Hypotheses?

Predict northward movement of species with warming
- contraction of southern boundaries of temperate species
- expansion of northern boundaries of subtropical species
- no changes for some species?

Natural movement of species may be slow, less than 200 km/century at most, perhaps more in the range of 20-50 km/century.

Movement of species will be complicated or prevented by
- Fragmentation due to development
- Competition from non-native invasive exotics
- Competition from native invasive species (weeds)
- Diseases and insects, both native and exotic
- Filtration and inertia of existing stands
- Ecotypic/genetic variation
- Fire
- Soil variation

Predict changes in plant community composition, structure and function.

Predict losses of biodiversity and resulting ecological and economic impacts.

Recommendations - Management

Increase and develop long-term commit to management of protected areas

- Long-term planning.
- Adequate resources.
- Increase prescribed burning efforts.
- Increase invasive exotic identification and control efforts.
- Implement procedures to prevent importation and introduction of new invasive exotics.
- Assure that adequate refugia are present.
- Address issue of protecting genetic diversity.

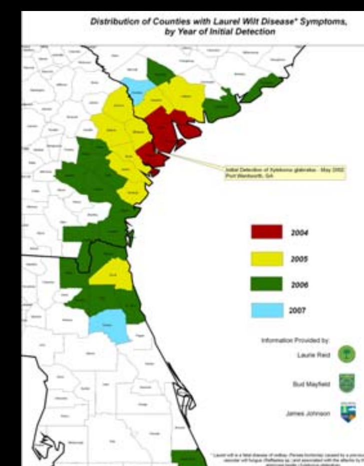
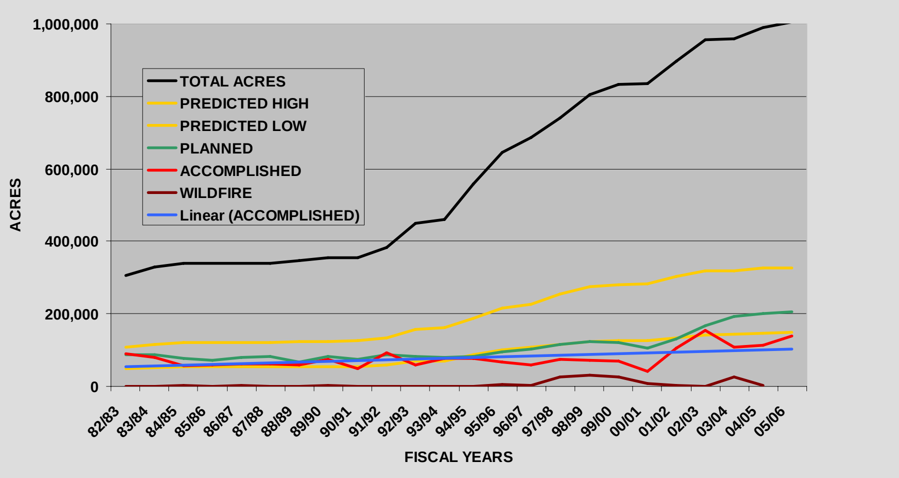


Figure 1. Florida State Forest fire history, 1982-2005, by Fiscal Year, showing total state forest acreage, predicted high and low plan acreage, and actual planned, accomplished and wildfire acreage.



Recommendations – Acquisition and agreements

Continue "protection" of both large and small areas for conservation, and of interlocking habitat corridors.
Protection occurs through

- **Fee simple acquisition for conservation purposes by public and private entities**
- **Conservation easement acquisition through agreements**

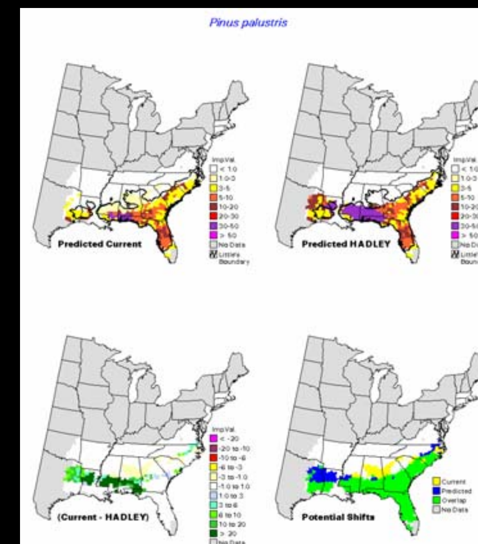
Pay particular attention to potential "transitional" areas, gaps, and potential refugia.

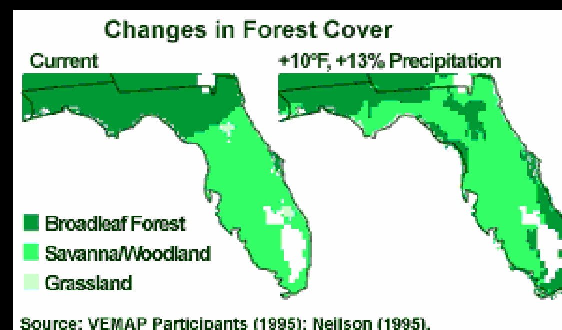
Fund existing programs – Florida Forever, Rural and Family Lands Protection Programs, Forest Legacy

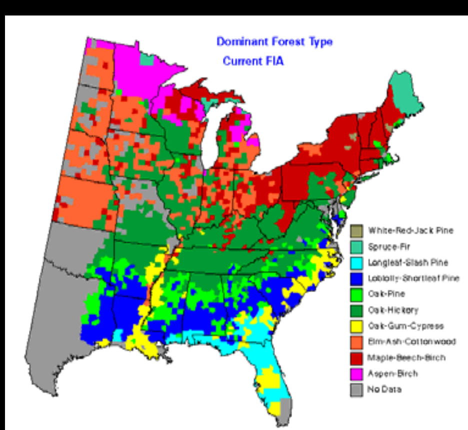
Recommendation – Modeling, especially Florida-specific models

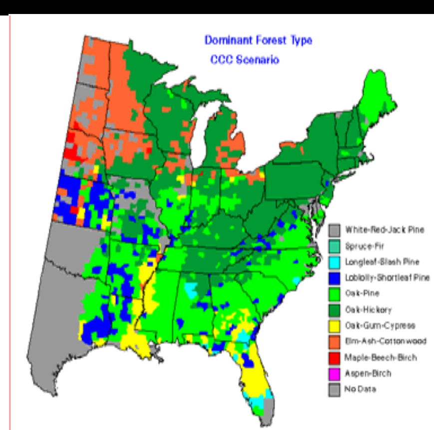
Continue all types of modeling efforts of species movements, historical and predictive, based on

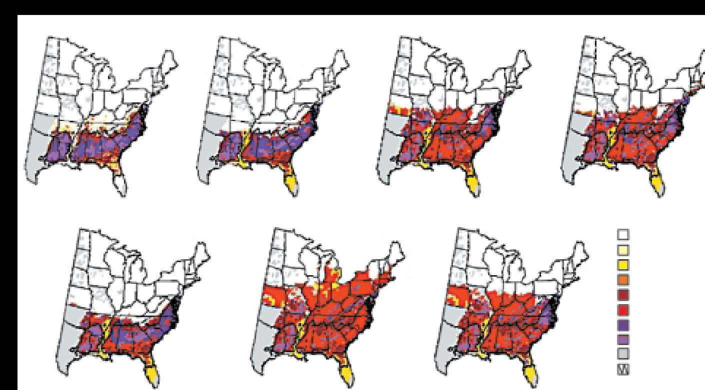
- **Genetics**
- **Pollen record**
- **Species biological processes, e.g.,**
    - **Physiology**
    - **Reproduction**
    - **Dispersal**
    - **Recruitment**
    - **Growth**
    - **Mortality**
- **Climate**
- **Insects and diseases**











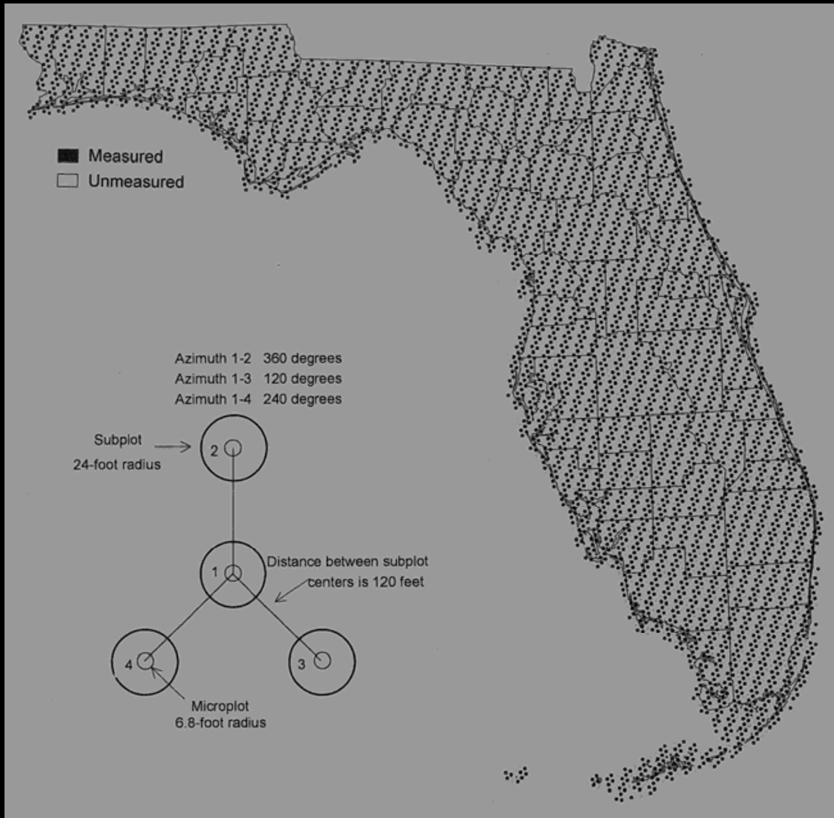
Recommendation - Monitoring

Strengthen, focus on and commit to existing programs:

- Forest Inventory and Analysis
- Listed species
- Insects and diseases
- Invasive exotics
- Economically important species
- Focus on potential transition areas

Needed programs

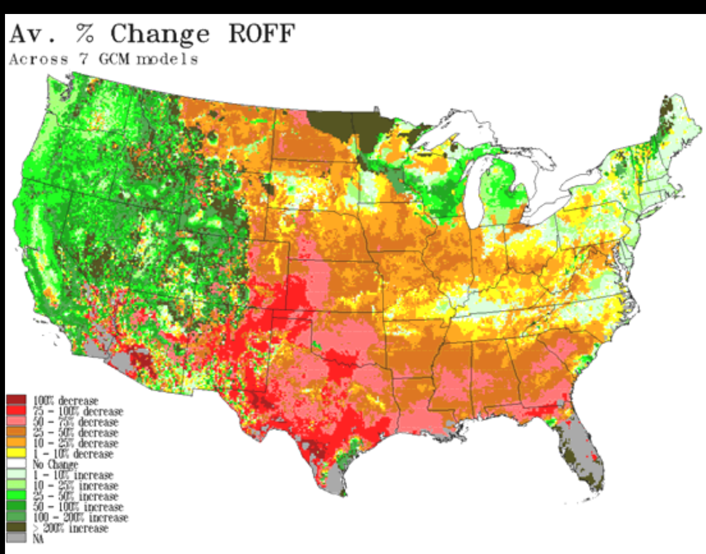
- Prescribed fire
- Restoration

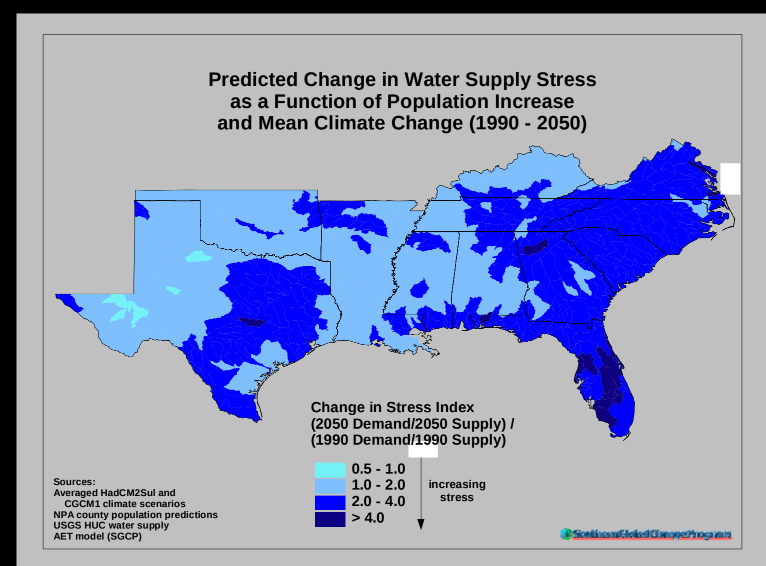


Recommendations?

Determine whether assistance with northward and inland migration and establishment of native subtropical species appropriate.

Curtailment of land drainage with provision of supplemental irrigation in key areas.





Florida Plant Species Climate Model

1993. E.O. Box, D.W. Crumpacker and E.D. Hardin. **A climatic model for the location of plant species in Florida, U.S.A.** Journal of Biogeography 20:629-644.

1999. E.O. Box, D.W. Crumpacker and E.D. Hardin. **Predicted effects of climatic change on distribution of ecologically important native tree and shrub species in Florida.** Climate Change 41:213-248.

2001. D.W. Crumpacker, E.O. Box and E.D. Hardin. **Potential breakup of Florida plant communities as a result of climatic warming.** Florida Scientist 64(1):29-43.

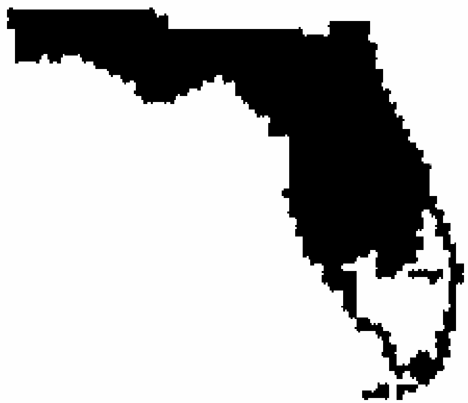
2001. D.W. Crumpacker, E.O. Box and E.D. Hardin. **Temperate-subtropical transition areas for native woody plant species in Florida, U.S.A.: Present locations, predicted changes under climatic warming, and implications for conservation.** Natural Areas Journal 21(2):136-148.

2001. D.W. Crumpacker, E.O. Box and E.D. Hardin. **Implications of climatic warming for conservation of native trees and shrubs in Florida.** Conservation Biology 15(4):1008-1020.

2002. D.W. Crumpacker, E.O. Box and E.D. Hardin. **Use of plant climatic envelopes to design a monitoring system for early biotic effects of climatic warming.** Florida Scientist 65(3):159-184.

Pinus palustris – longleaf pine

Baseline from model



120,255 km^2

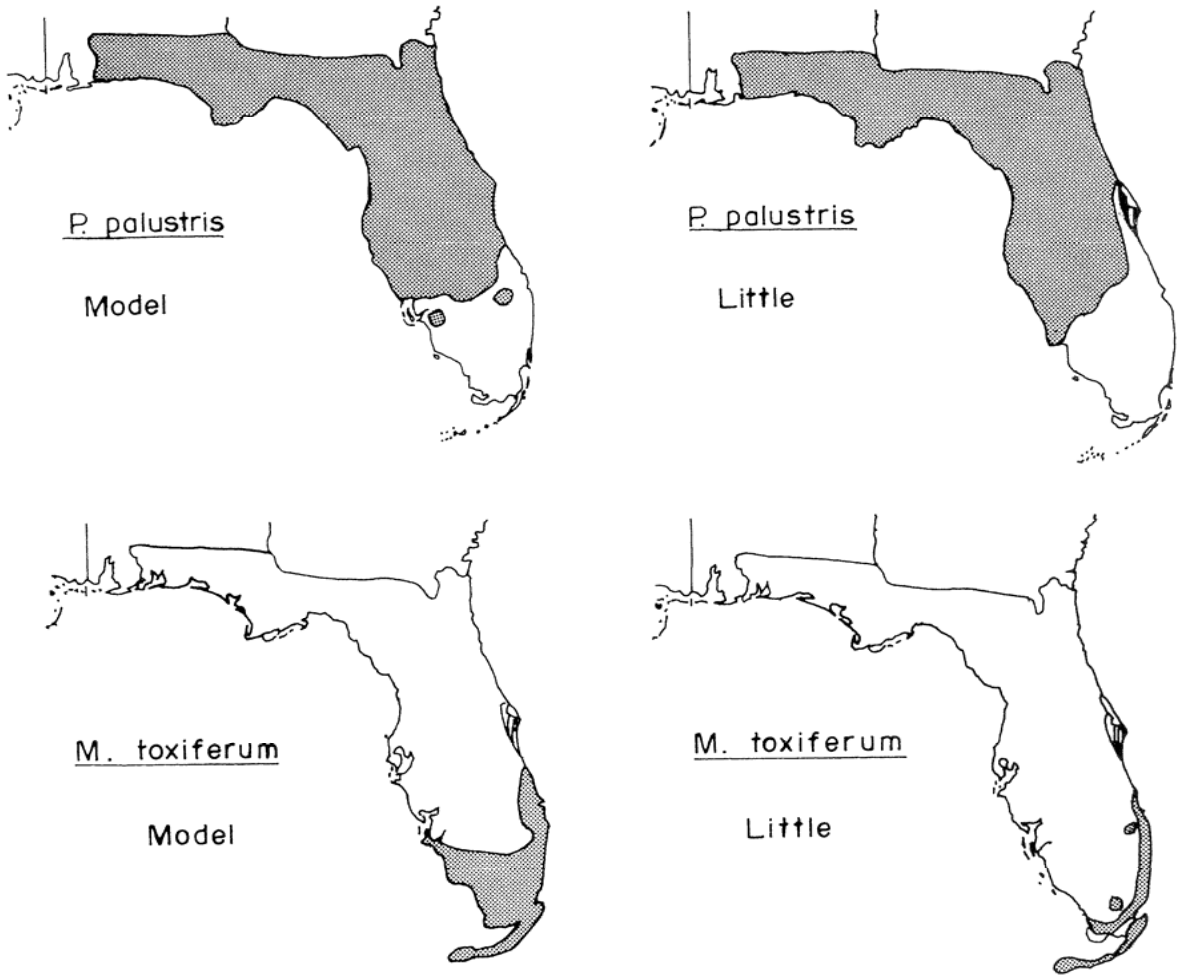
46,431 mi^2

+2C proportioned annually
Moisture index constant

30% decrease

+2C greater in winter
80% annual precipitation

85% decrease

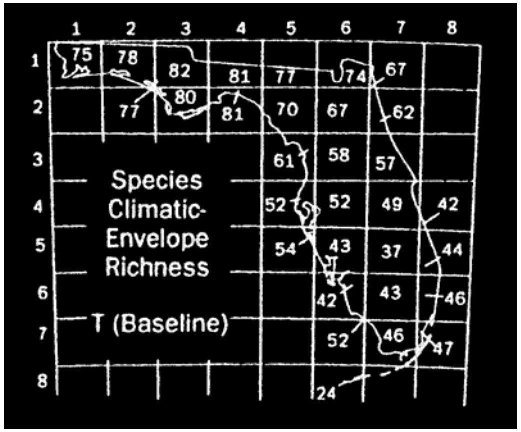

P. palustris
Model
P. palustris
Little
M. toxiferum
Model
M. toxiferum
Little

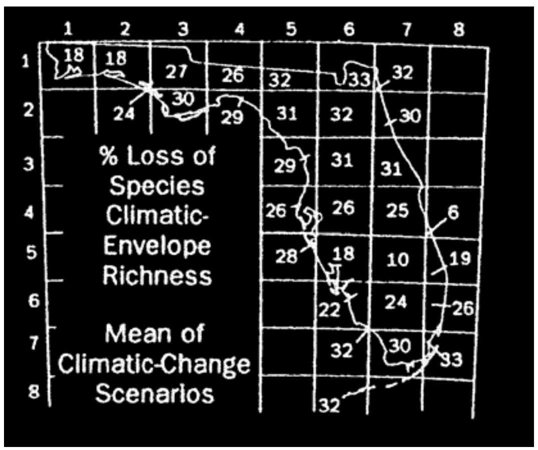
Florida Plant Species Climate Model

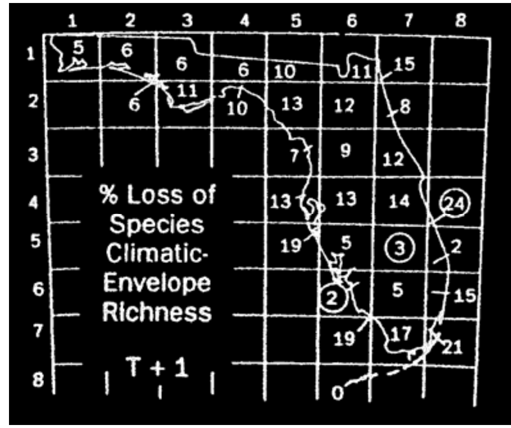
Coauthors:

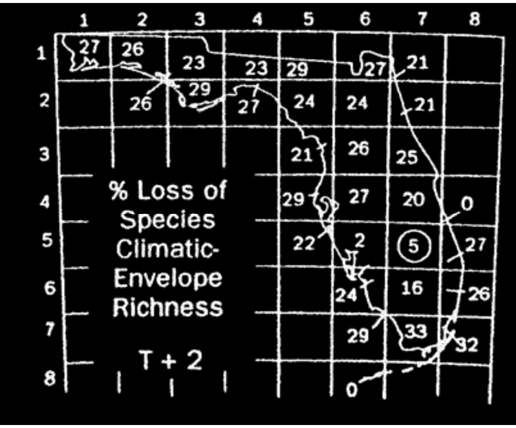
Elgene Box, Department of Geography and Institute of Ecology, University of Georgia

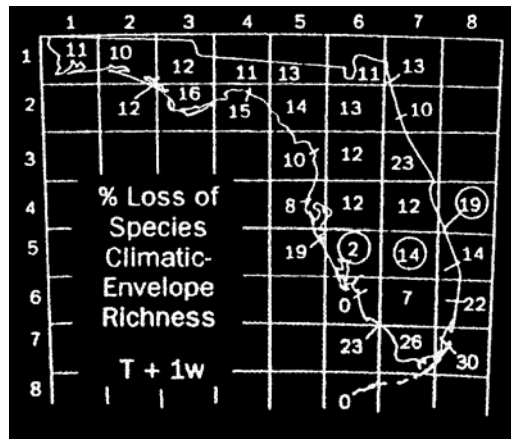
David Wilson Crumpacker, Department of Environmental, Population and Organismic Biology, University of Colorado

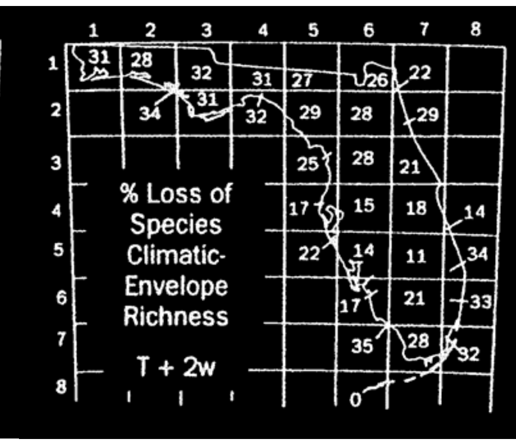

Species
Climatic-
Envelope
Richness
T (Baseline)
75 78 82 81 77 74 67
77 80 81 70 67 62
61 58 57
52 52 49 42
54 43 37 44
42 43 46
52 46 47
24

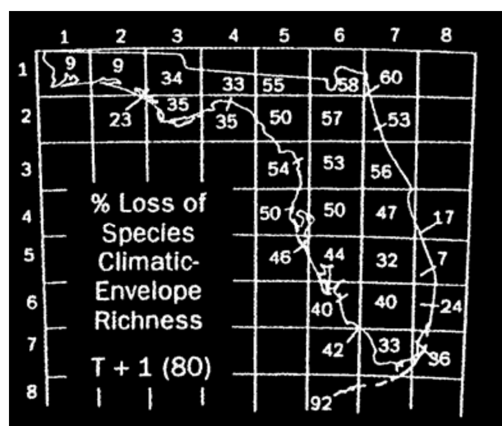

% Loss of
Species
Climatic-
Envelope
Richness
Mean of
Climatic-Change
Scenarios
18 18 27 26 32 33 32
24 30 29 31 32 30
29 31 31
26 26 25 6
28 18 10 19
22 24 26
32 30 33
32

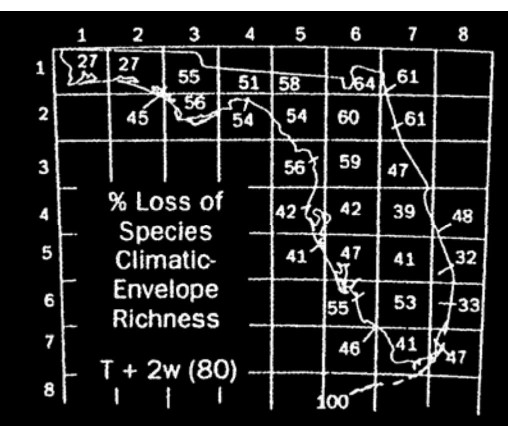

% Loss of
Species
Climatic-
Envelope
Richness
T + 1
5 6 6 6 10 11 15
6 11 10 13 12 8
7 9 12
13 13 14 24
19 5 3 2
2 5 15
19 17 21
0

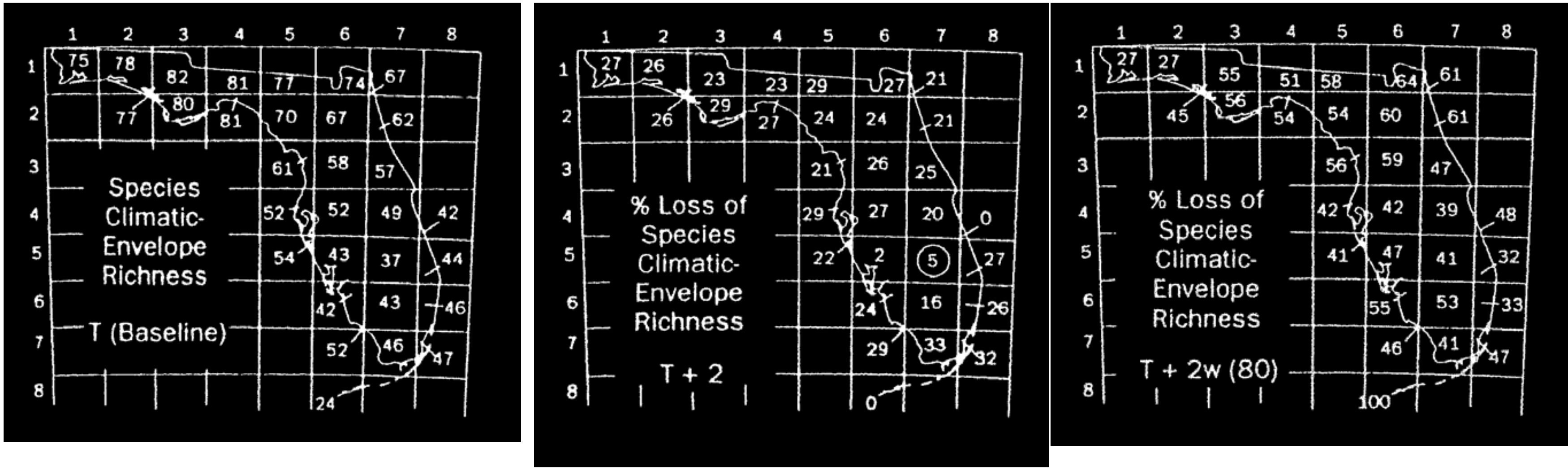

% Loss of
Species
Climatic-
Envelope
Richness
T + 2
27 26 23 23 29 27 21
26 29 27 24 24 21
21 26 25
29 27 20 0
22 2 5 27
24 16 26
29 33 32
0


% Loss of
Species
Climatic-
Envelope
Richness
T + 1w
11 10 12 11 13 11 13
12 16 15 14 13 10
10 12 23
8 12 12 19
19 2 14 14
0 7 22
23 26 30
0


% Loss of
Species
Climatic-
Envelope
Richness
T + 2w
31 28 32 31 27 26 22
34 31 32 29 28 29
25 28 21
17 15 18 14
22 14 11 34
17 21 33
35 28 32
0


% Loss of
Species
Climatic-
Envelope
Richness
T + 1 (80)
9 9 34 33 55 58 60
23 35 35 50 57 53
54 53 56
50 50 47 17
46 44 32 7
40 40 24
42 33 36
92


% Loss of
Species
Climatic-
Envelope
Richness
T + 2w (80)
27 27 55 51 58 64 61
45 56 54 54 60 61
56 59 47
42 42 39 48
41 47 41 32
55 53 33
46 41 47
100


Species Climatic-Envelope Richness
T (Baseline)
% Loss of Species Climatic-Envelope Richness
T + 2
% Loss of Species Climatic-Envelope Richness
T + 2w (80)

Climatic variables used in the model

TMAX	=	mean temperature of the warmest month (°C).
TMIN	=	mean temperature of the coldest month (°C).
DTY	=	annual range of monthly mean temperature (= TMAX – TMIN, °C).
TMMIN	=	mean minimum temperature of the coldest month (°C).
TABMIN	=	absolute minimum temperature (°C).
PRCP	=	average annual precipitation (mm).
MI	=	annual moisture index (PRCP ÷ average annual potential evapotranspiration or PET), based on the Holdridge estimate of PET which is obtained as TMEAN (mean annual temperature) × 58.93; see Holdridge, 1959; and Box, 1986).
PMIN	=	average precipitation of the driest month (mm).

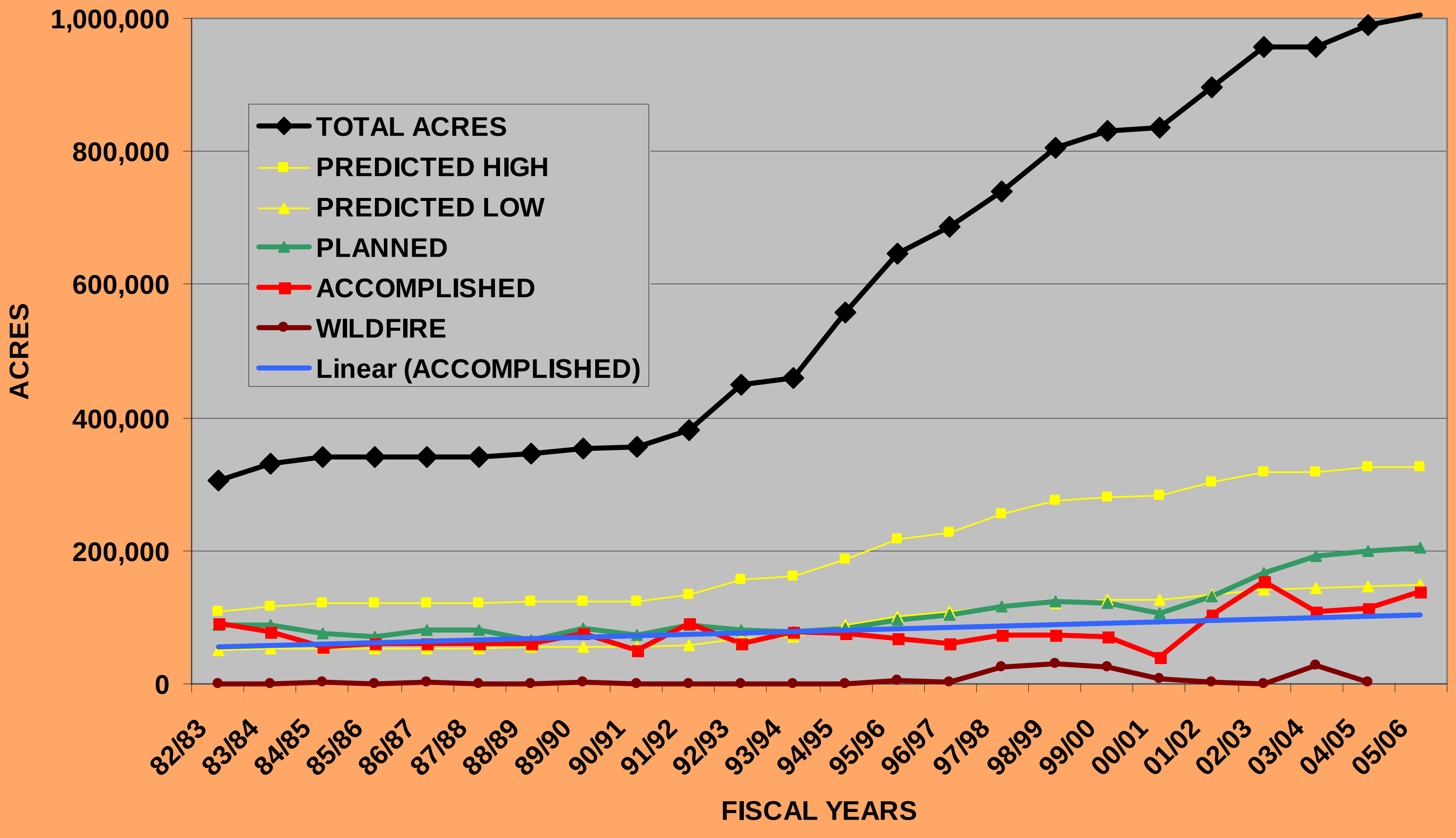
Potential mitigations:

1. Completion of an interlocking system of conservation areas in the major temperate-subtropical transition zone of the south central peninsula.
   Recommit to management.

2. Scientifically-assessed and publicly-supported use of land and water protection methods that allow as much management flexibility as possible
   - control non-native species invasions,
   - assistance with northward and inland migration,
   - establishment of native subtropical species, and
   - curtailment of land drainage with
   - provision of supplemental irrigation in key areas.

3. Purchase of less expensive options to buy future linkage areas that are presently in need of ecological restoration.
   Recommit to managemnet

Figure 1. Florida State Forest fire history, 1982-2005, by Fiscal Year, showing total state forest acreage, predicted high and low plan acreage, and actual planned, accomplished and wildfire acreage.



Potential biases that may result in underestimation of species and community loss:

1. Warming impacts on temperate species due to loss of climatic fitness that is not accompanied by climatic-envelope loss (no part of a species' envelope is removed until the climatic fitness of that part reaches zero).
2. Interspecific competition from invasive exotics and native species.
3. Temperature-sensitive ecotypes along a north-south gradient within a species' climatic envelope.
4. Greater warming-induced CO_2 enrichment of fast-growing, aggressive, native and non-native C_3 species.

Potential biases that may result in overestimation of species and community loss:

1. A warming induced, generalized CO_2 enrichment response of C_3 temperate woody species.
2. Buffering of dominant woody floodplain species from negative warming and drying impacts.
3. Reduction of community breakup as a result of replacement of *Pinus elliotii* var. *elliottii* by *Pinus elliottii* var. *densa*.

Temperate Panhandle/Upper Peninsula
Fagus grandifolia – American beech

Little, 1978

T
Baseline from model

34,496 km²
(13,319 mi²)

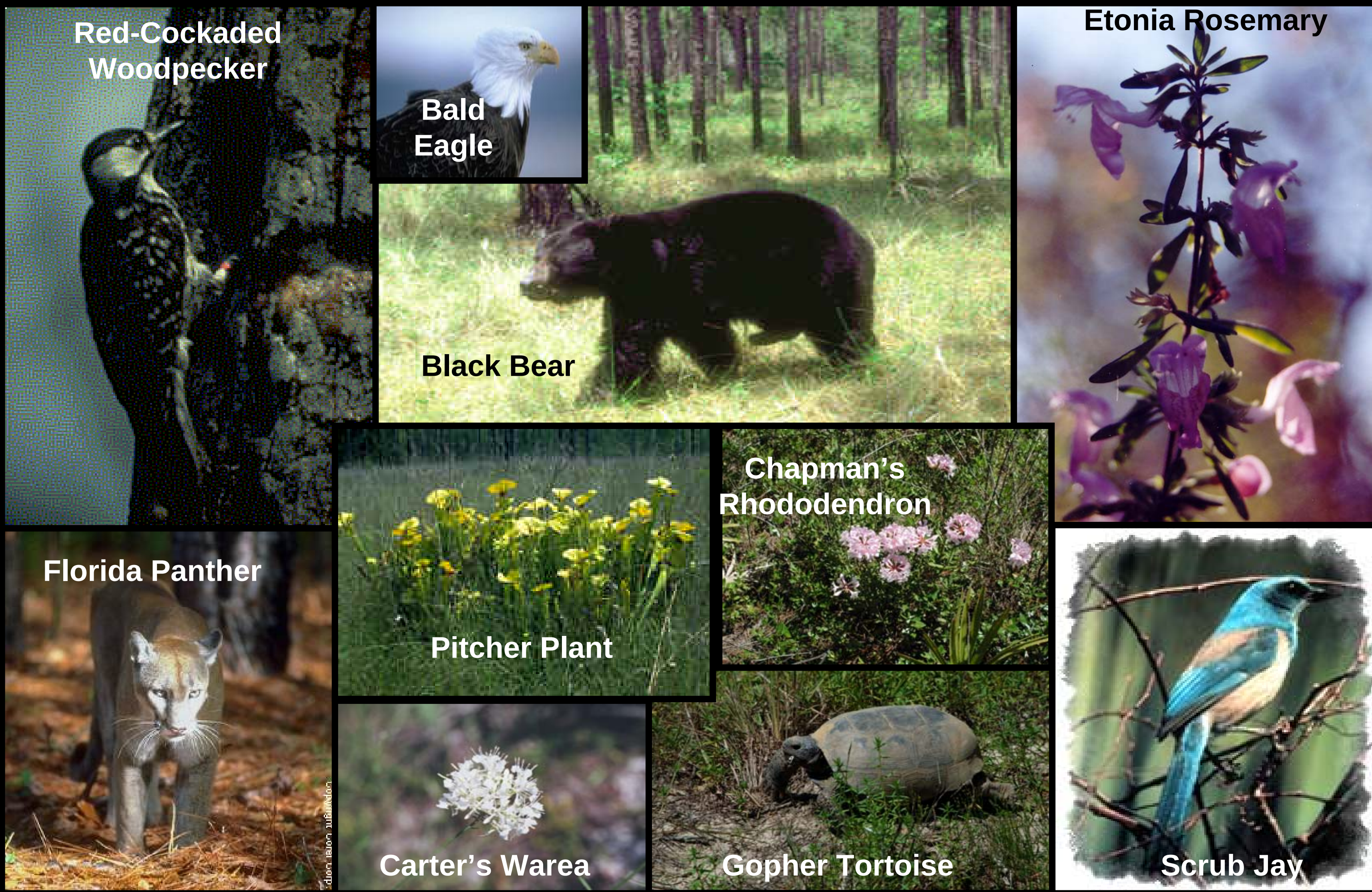
T+2
+2C proportioned annually, Moisture index constant

100% decrease

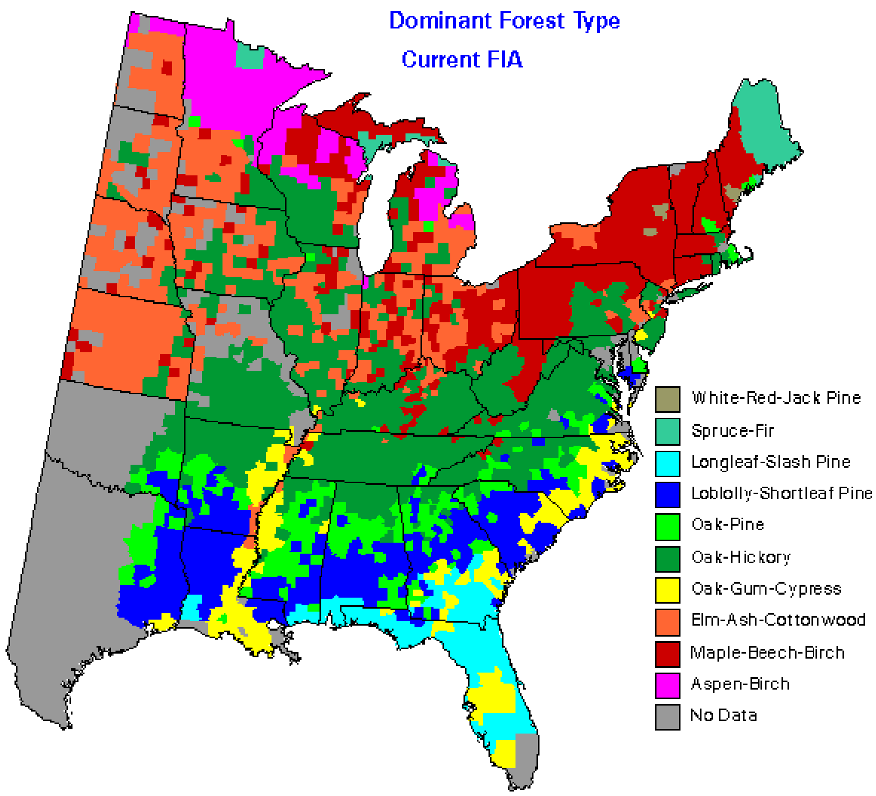
T+2w(80)
+2C greater in winter 80% annual precipitation

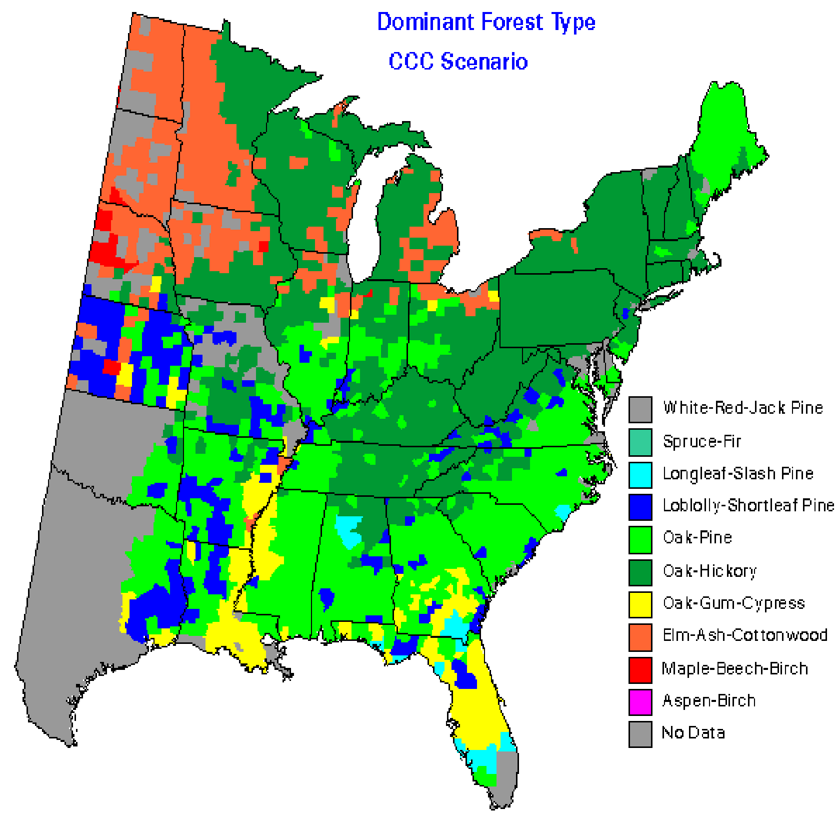
100% decrease

Forestland Species

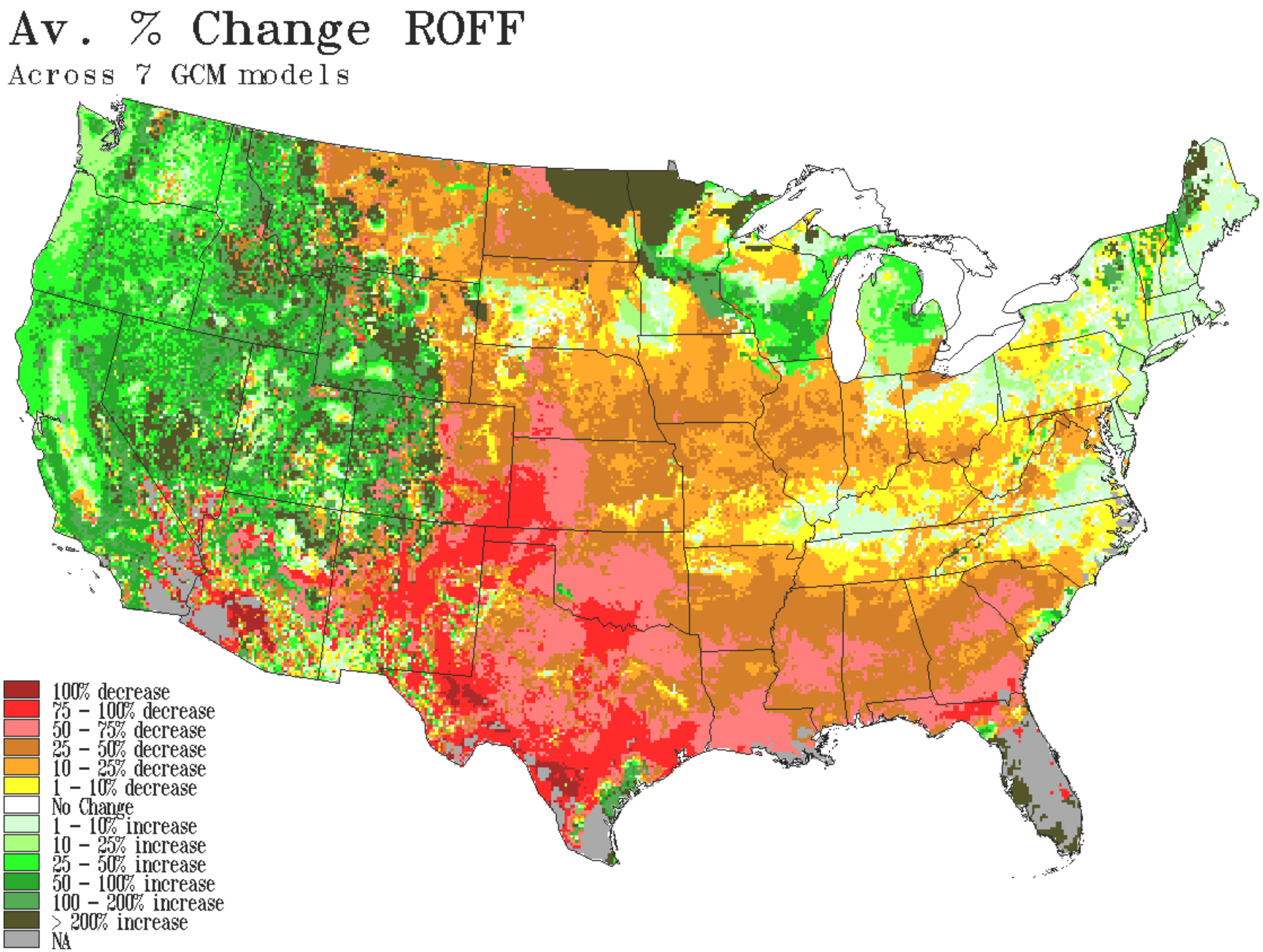


Ecosystem Changes: Tree Species Migration



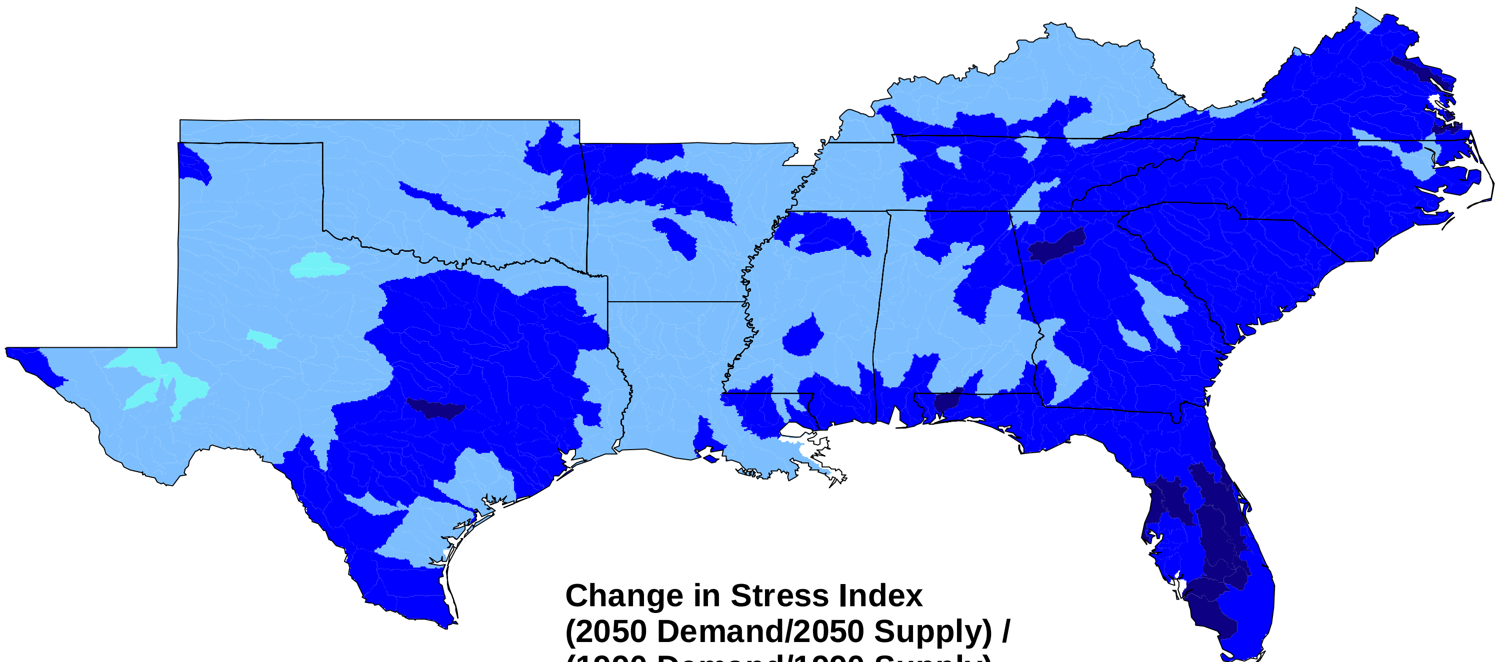


Water Cycle: Potential Effects of Climate Change on US Forests



Water Cycle: Potential Effects of Climate Change on US Forests

Predicted Change in Water Supply Stress as a Function of Population Increase and Mean Climate Change (1990 - 2050)



Change in Stress Index (2050 Demand/2050 Supply) / (1990 Demand/1990 Supply)

- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- > 4.0

increasing stress

Sources:
Averaged HadCM2Sul and CGCM1 climate scenarios
NPA county population predictions
USGS HUC water supply
AET model (SGCP)

Southern Global Change Program

TABLE I

Climatic-space of climatic envelopes for two species in the Florida Plant Species – Climatic Model

	TMAX	TMIN	DTY	TMMIN	TABMIN	PRCP	MI	PMIN
Bursera simaruba								
Maximum	32.0	28.0	15.0	26.0	28.0	[a]	3.00	60
Minimum	22.0	16.7	0.0	10.0	–6.0	800	0.65	0
Fagus grandifolia								
Maximum	29.0	13.0	50.0	16.0	13.0	[a]	[a]	[a]
Minimum	17.0	–20.0	8.0	0.0	–30.0	500	1.13	30

The region of potential occurrence of a species is described by the climatic space of its climatic envelope, defined by limiting maximum and minimum values for the following eight climatic variables:

[a] Refers to unspecified and presumably unimportant (unattainable) limiting values. The limits for PRCP and DTY are currently set wide enough that they do not directly influence model predictions in Florida under current or foreseeable conditions.

Warm Temperate
Pinus palustris – longleaf pine

T
Baseline from model

120,255 km²

(46,431 mi²)

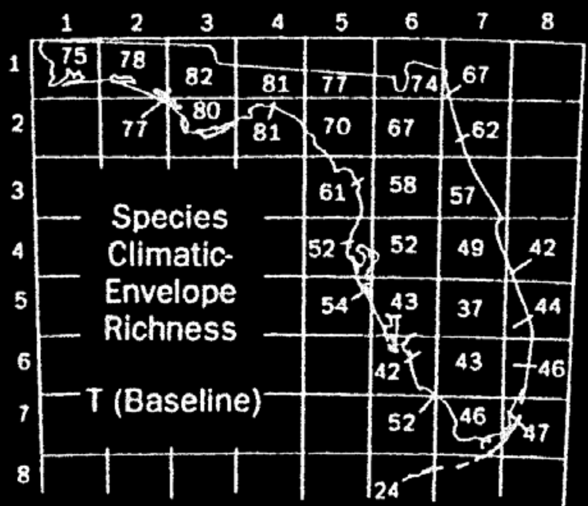
T+2
+2C proportioned annually
Moisture index constant

30% decrease

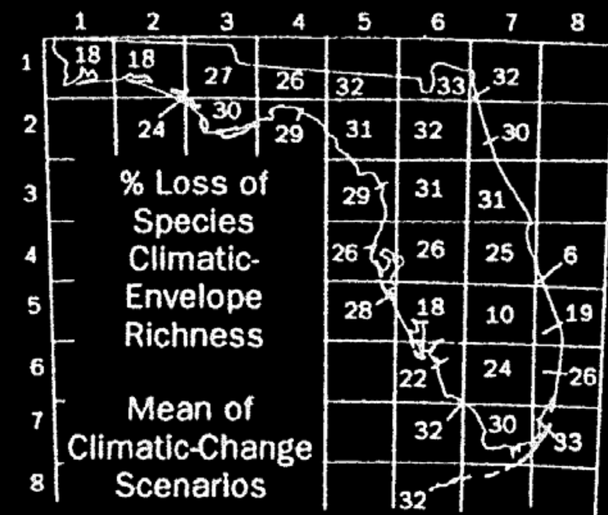
T+2w(80)
+2C greater in winter
80% annual precipitation

85% decrease

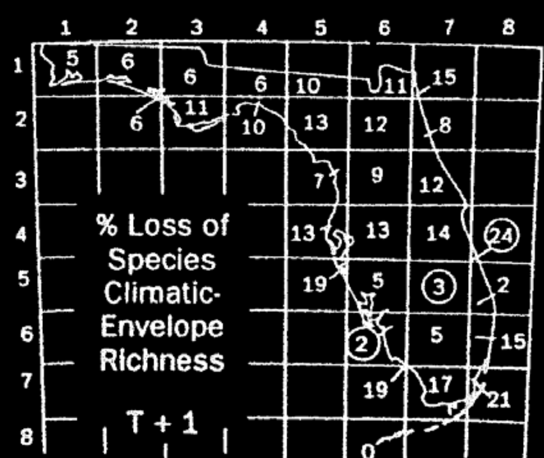
Species Climatic Envelope Richness Loss



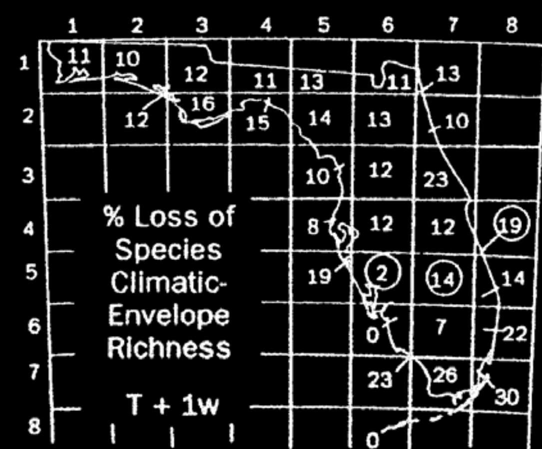
Baseline



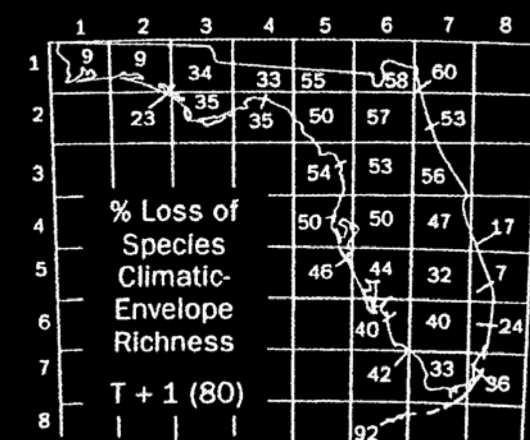
Mean of change scenarios



T + 1



T + 1 w



T + 1 (80)

Subtropical
Bursera simaruba – gumbo limbo

T
Baseline from model

39,701 km²
(15,329 mi²)

T+2
+2C proportioned annually
Moisture index constant

84% increase

T+2w(80)
+2C greater in winter
80% annual precipitation

109% increase

Warm Temperate/Subtropical
Serenoa repens – saw palmetto

T
Baseline from model

152,915 km²
(59,041 mi²)

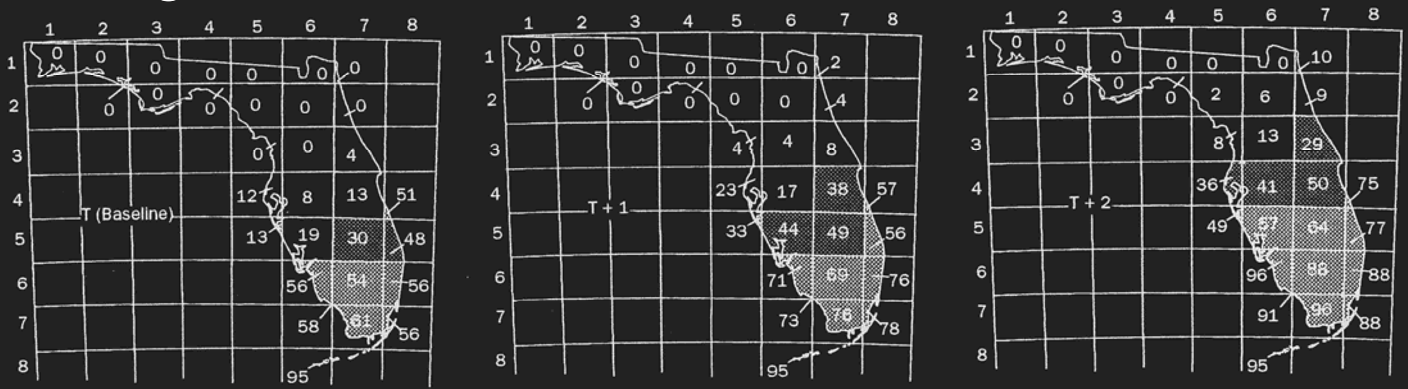
T+2
+2C proportioned annually
Moisture index constant

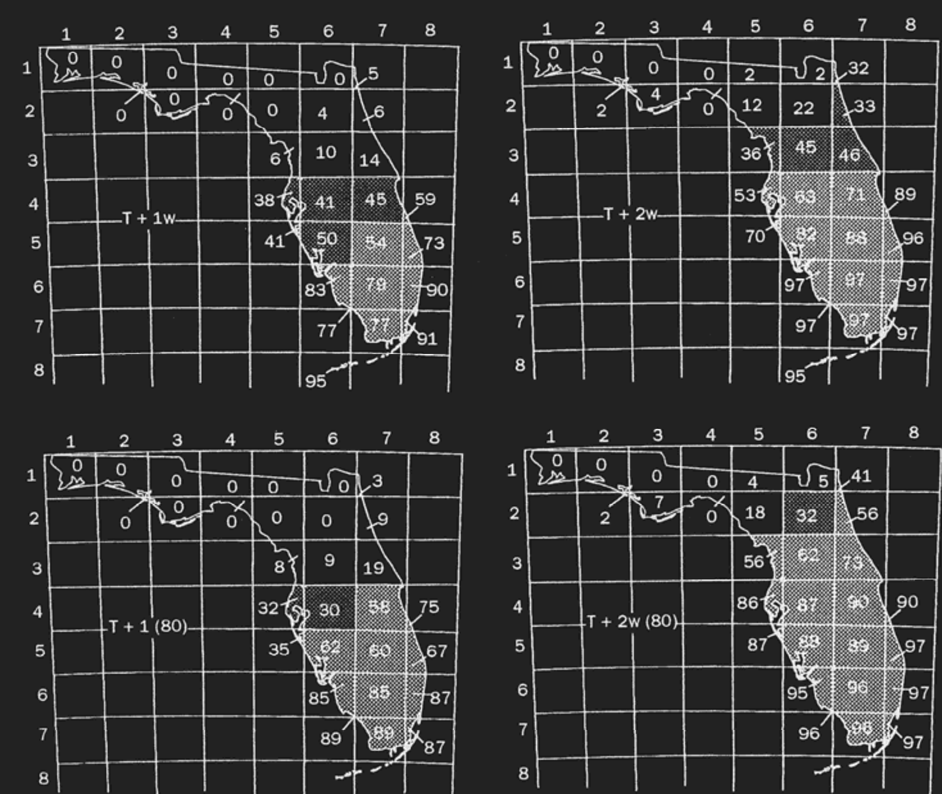
No change

T+2w(80)
+2C greater in winter
80% annual precipitation

3% decrease

Transition Zones – Presence of >50% of a species' range in 100 km x 100 km grid cell





No shading - <25% Subtropical Species

Light shading – 25-50% Subtropical Species

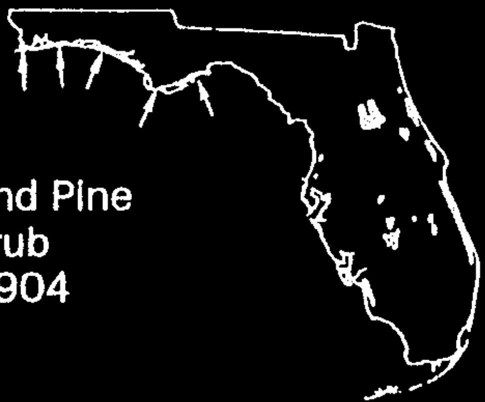
Heavy shading > 50% Subtropical Species

Predicted effects of climate-change scenarios on climatic-envelope areas of four major range types of ecologically important, woody species in Florida.

Range type	# sp	T+1	T+1w	T+2	T+2w	T+1(80)	T+2w(80)	Mean
Temperate Panhandle	7	-41	-69	-76	-95	-81	-97	-76
Warm Temperate	12	-15	-16	-30	-38	-50	-65	-36
Warm Temp./ Subtropical	2	+6	+8	+8	+8	+6	+4	+7
Subtropical	7	+42	+75	+75	+145	+36	+122	+82

Values in table are percent change in area from that of the baseline scenario.

Sand Pine Scrub

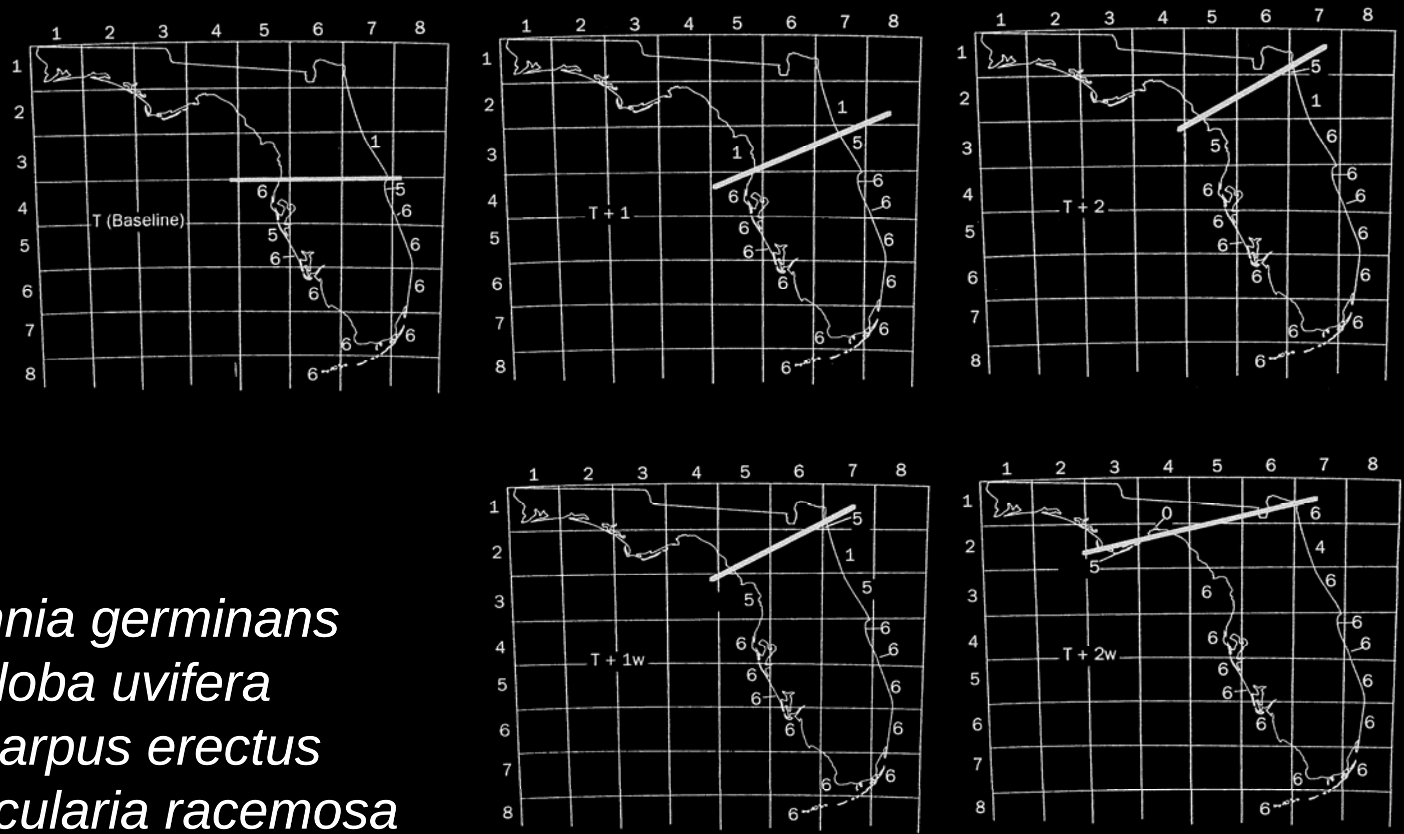


Sand Pine
Scrub
5,904

Scenario

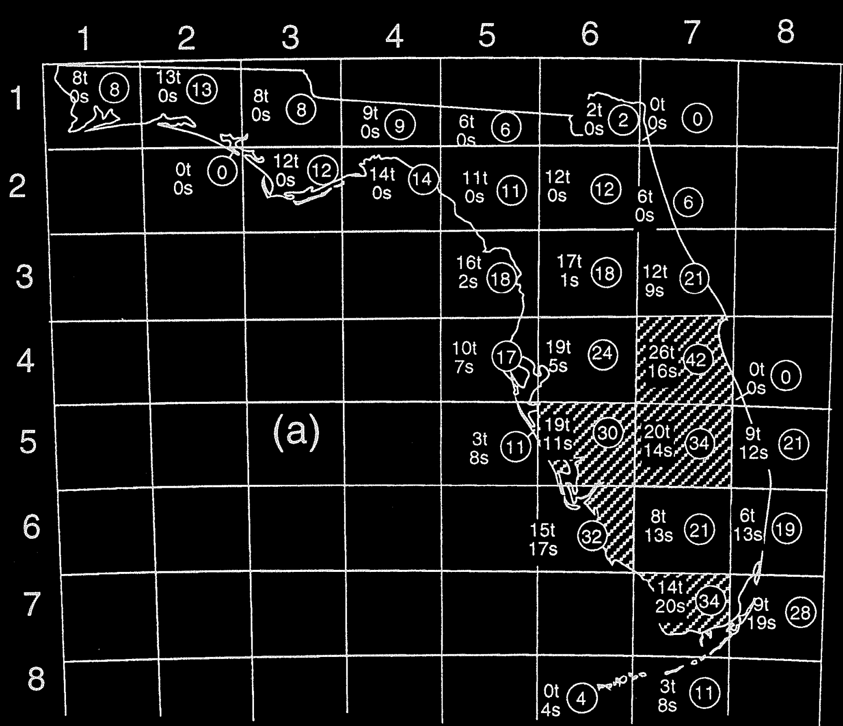
Dominant Species	T+1	T+1w	T+2	T+2w	T+1 (80)	T+2w (80)
Pinus clausa	0-20	0-20	21-40	41-60	61-80	61-80
Quercus chapmanii	0-20	0-20	0-20	41-60	0-20	41-60
Quercus geminata	0-20	0-20	21-40	41-60	41-60	61-80
Quercus myrtifolia	0-20	0-20	21-40	41-60	0-20	41-60

Predicted northern boundary of six subtropical coastal species, any part of range in grid cell.

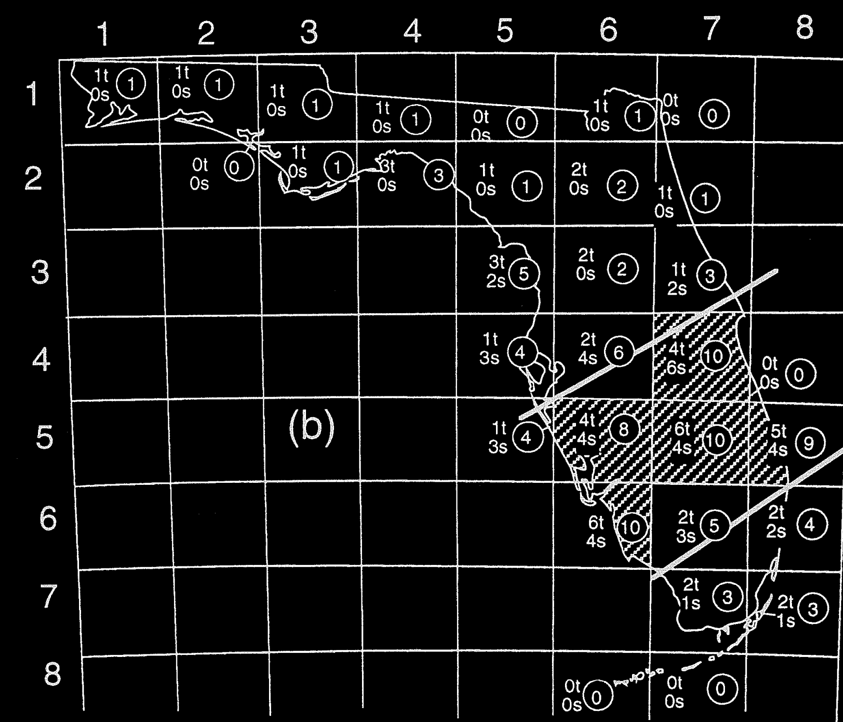


Avicennia germinans
Coccoloba uvifera
Conocarpus erectus
Laguncularia racemosa
Rhizophora mangle
Suriana maritima

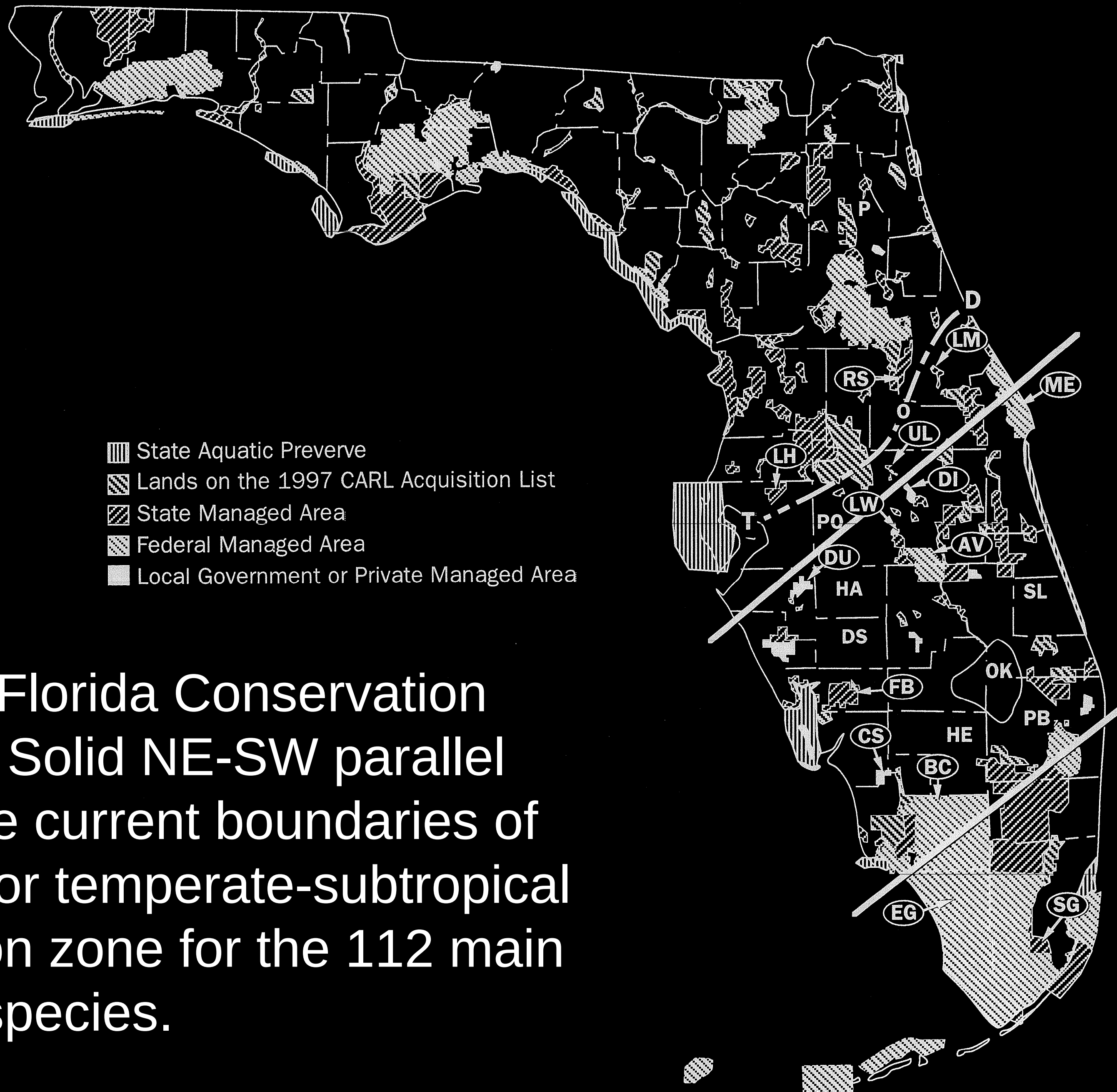
Transition Zones – Presence of any part of a species' range in 100 km x 100 km grid cell (excluding subtropical coastal species).



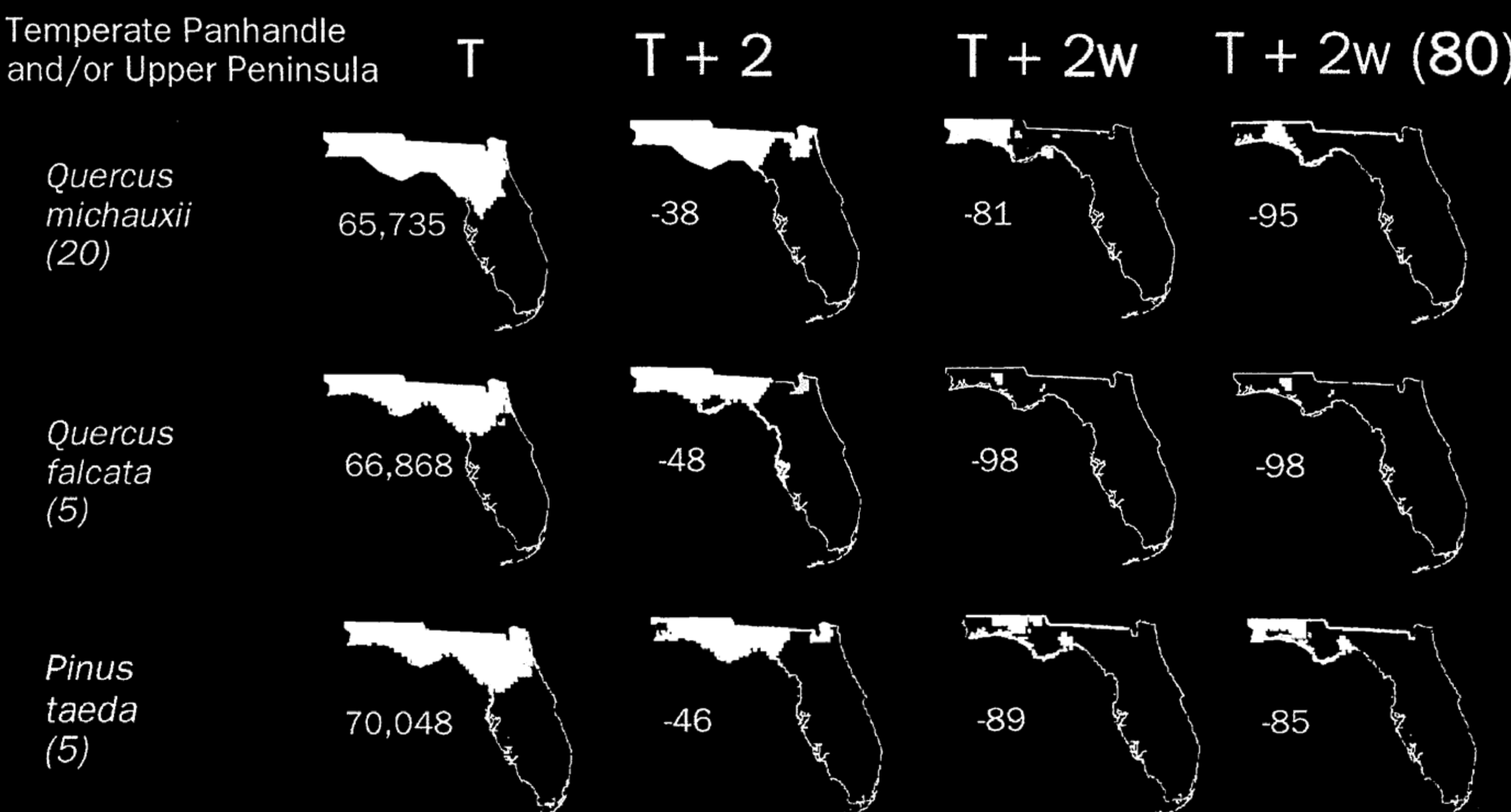
Overlap of >30 of 112 Main Model Species



Overlap of >10 of 26 "Ecologically Important" Species



Map of Florida Conservation Lands. Solid NE-SW parallel lines are current boundaries of the major temperate-subtropical transition zone for the 112 main model species.



Temperate Panhandle
and/or Upper Peninsula
T
T + 2
T + 2w
T + 2w (80)
Quercus michauxii (20)
65,735
-38
-81
-95
Quercus falcata (5)
66,868
-48
-98
-98
Pinus taeda (5)
70,048
-46
-89
-85

North Florida Flatwoods

Dominant Species	Scenario					
	T+1	T+1 w	T+2	T+2 w	T+1 (80)	T+2w (80)
Pinus elliottii var. *elliottii*	0-20	0-20	0-20	21-40	41-60	81-100
Pinus palustris	0-20	0-20	0-20	0-20	41-60	81-100
Pinus serotina	0-20	0-20	0-20	21-40	61-80	81-100

T
Baseline from model

T+2
+2C proportioned annually
Moisture index constant

T+2w(80)
+2C greater in winter
80% annual precipitation

Pinus elliottii var. *elliotti* – North Florida slash pine

95,669 km^2
36,938 mi^2

28% decrease

81% decrease

Pinus elliottii var. *densa* – South Florida slash pine

79,113 km^2
30,546 mi^2

35% increase

45% increase