Winter climate thresholds for tidal wetland foundation species: salt marshes vs. mangrove forests in the southeastern U.S.

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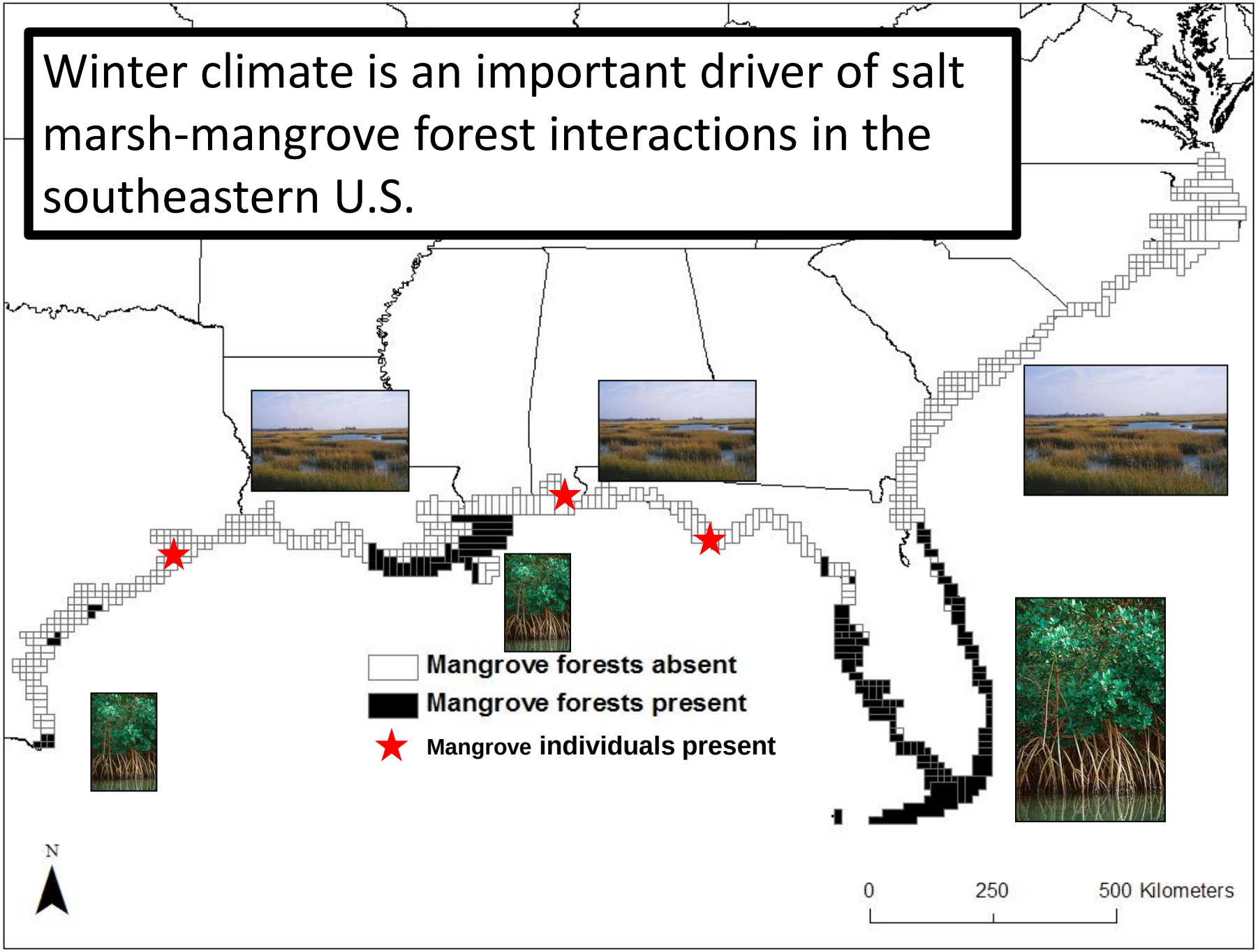
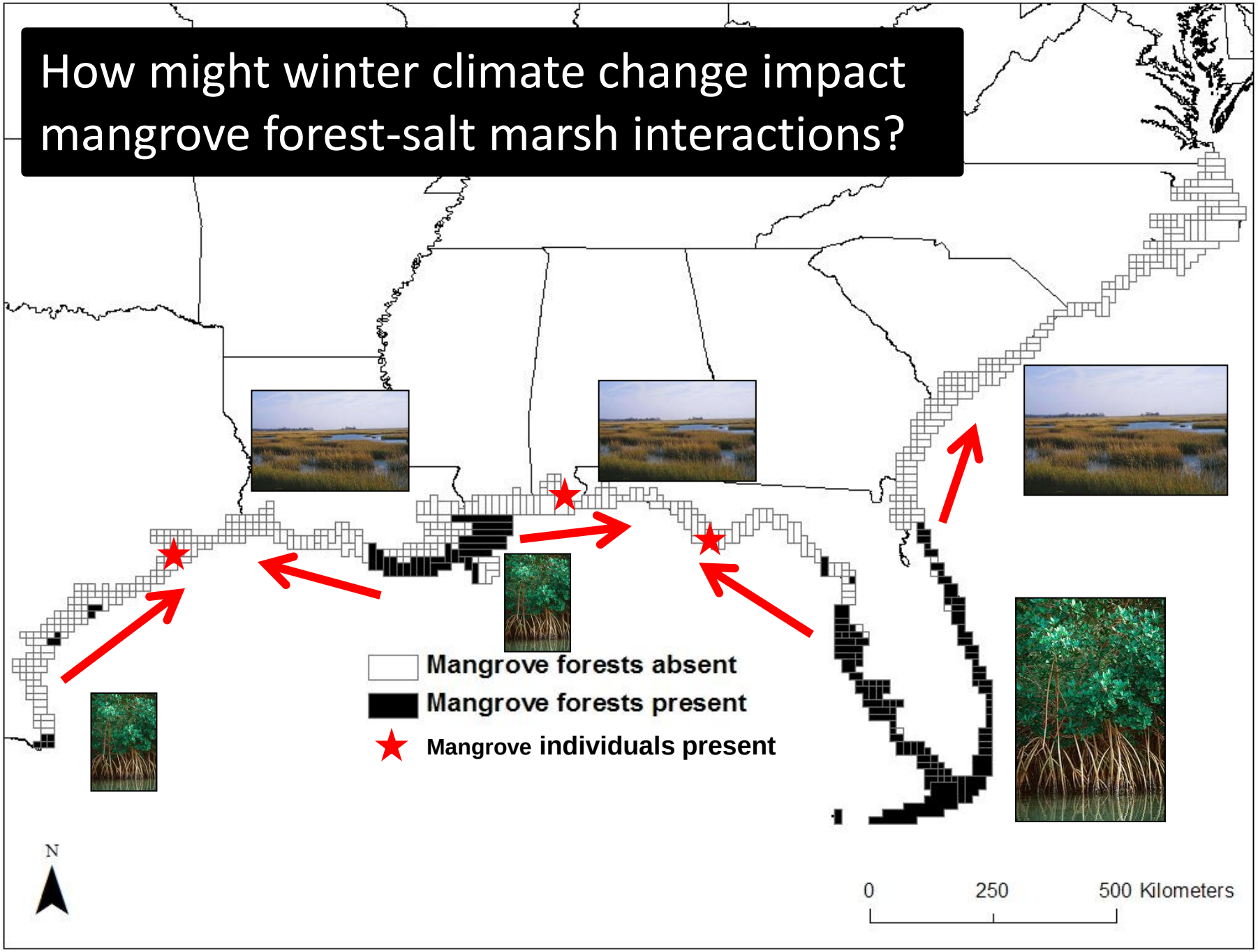
Winter climate is an important driver of salt marsh-mangrove forest interactions in the southeastern U.S.



How might winter climate change impact mangrove forest-salt marsh interactions?



Foundation species

"a single species that defines much of the structure of a community by creating locally stable conditions for other species, and by modulating and stabilizing fundamental ecosystem processes" Dayton (1972)

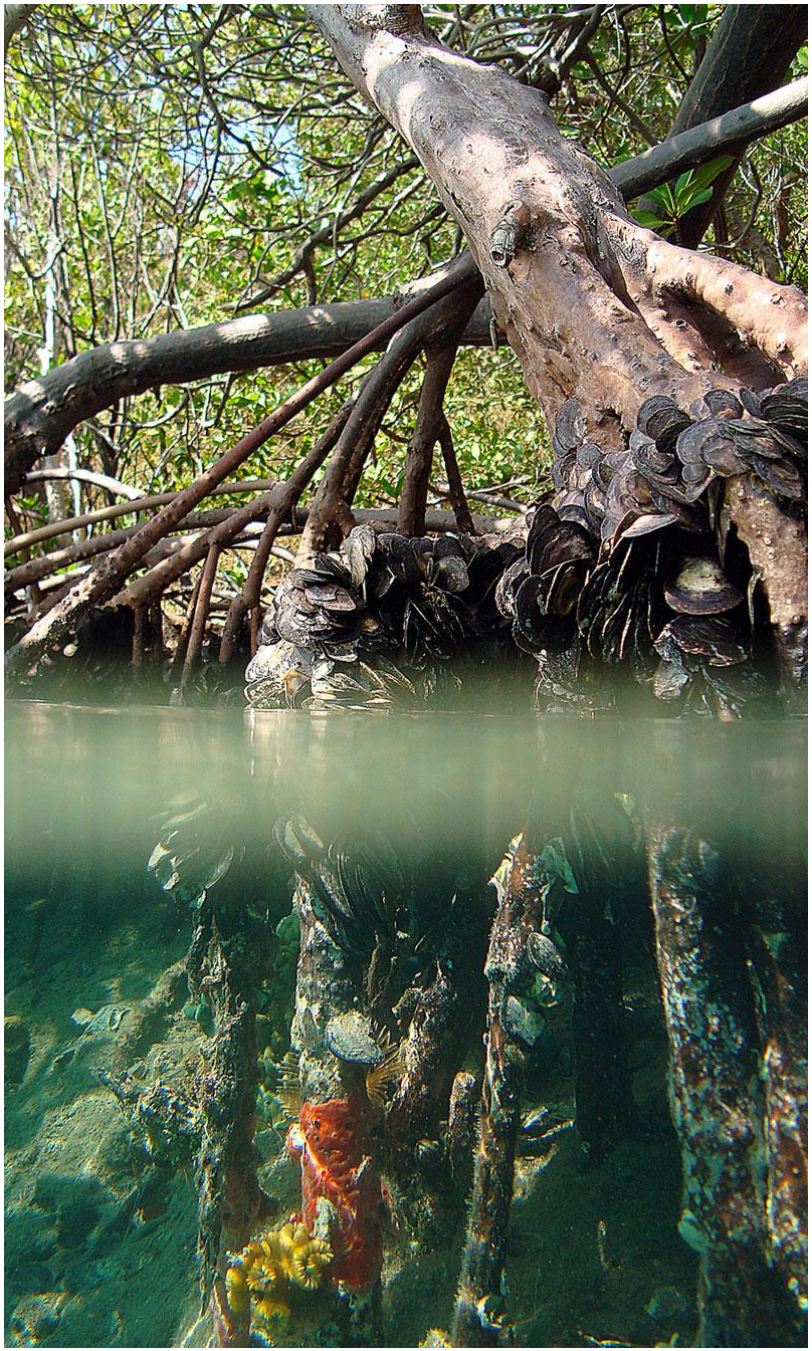


Photo: nps.gov- Rogers

Photo: nps.gov-Pringle

Why investigate the impact of winter climate change upon tidal saline wetland foundation species?

- Salt marshes and mangrove forests provide many important ecosystem goods and services

- Due to high abiotic stress, low compositional diversity = ↑ potential for landscape-scale structural change (regime shift; grass-to-tree conversions)

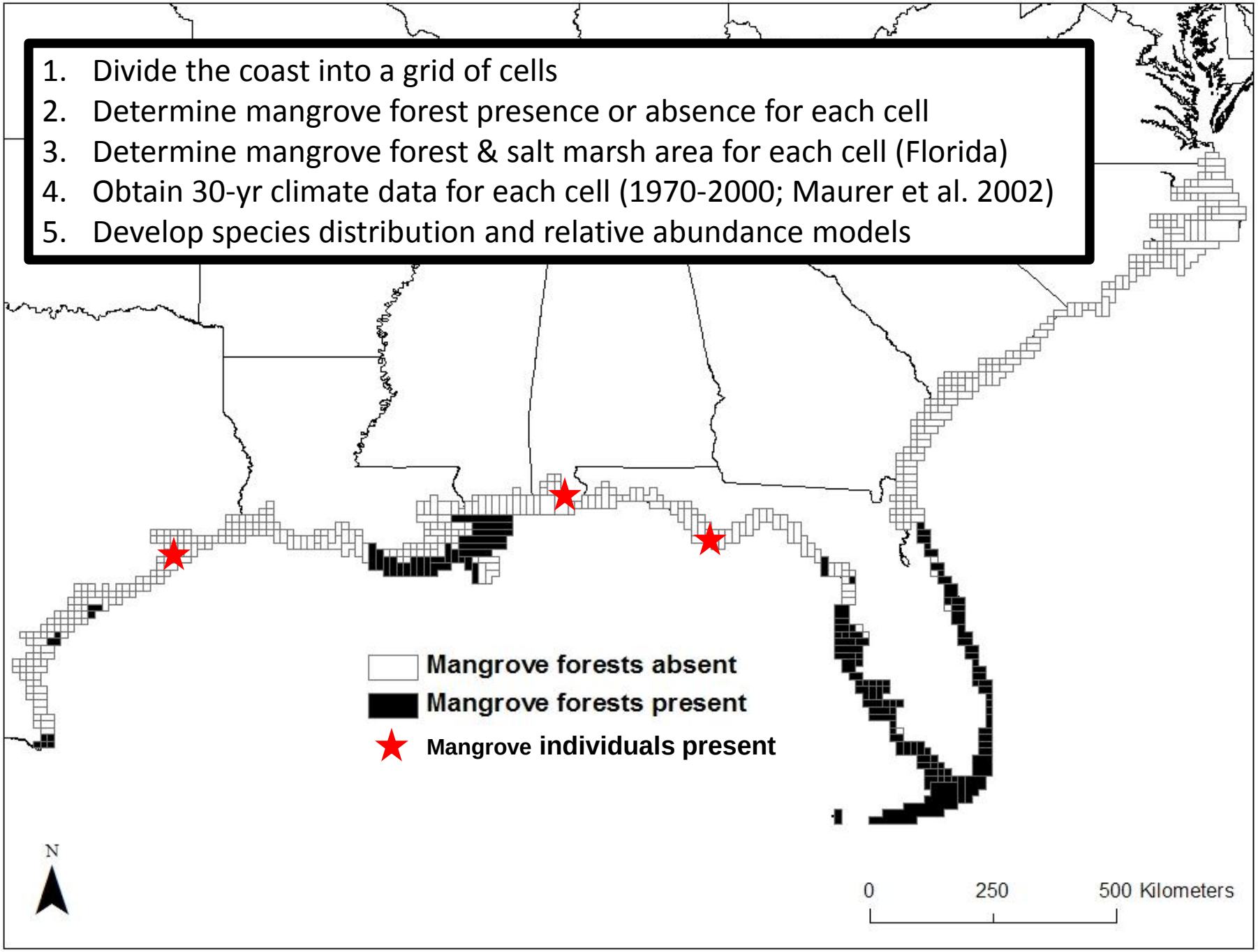
- Long-distance water dispersal via currents and storms (species distribution = climate niche)

Reference to winter climate thresholds for mangrove forests

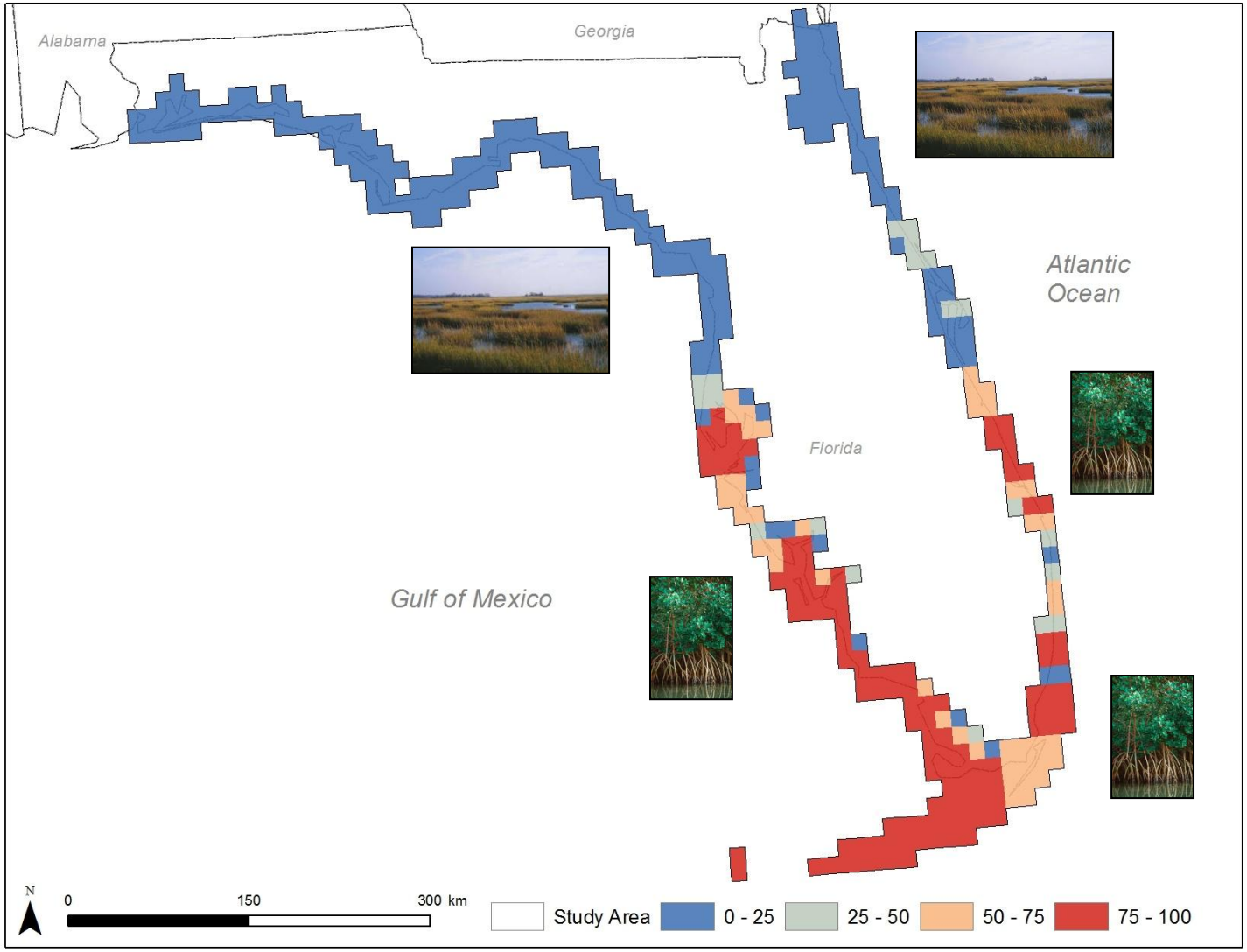
- **Sea surface temperatures**
  - 24°C annual isotherm (Tomlinson 1986)
  - 20°C winter isotherm (Duke 1998)
- **Monthly mean air temperatures**
  - Greater than 20°C and where seasonal range is less than 10°C [Chapman (1977), Walsh (1974), Duke (1998)]
  - 16°C (Twilley 1999)
  - 15-20°C (Clough (1992)
- **Minimum temperatures**
  - Below -4°C for mortality (Davis 1940)
  - Freezes that affect the citrus industry appear to coincide with freezes that affect mangroves (Stevens 2006)

Research Objectives

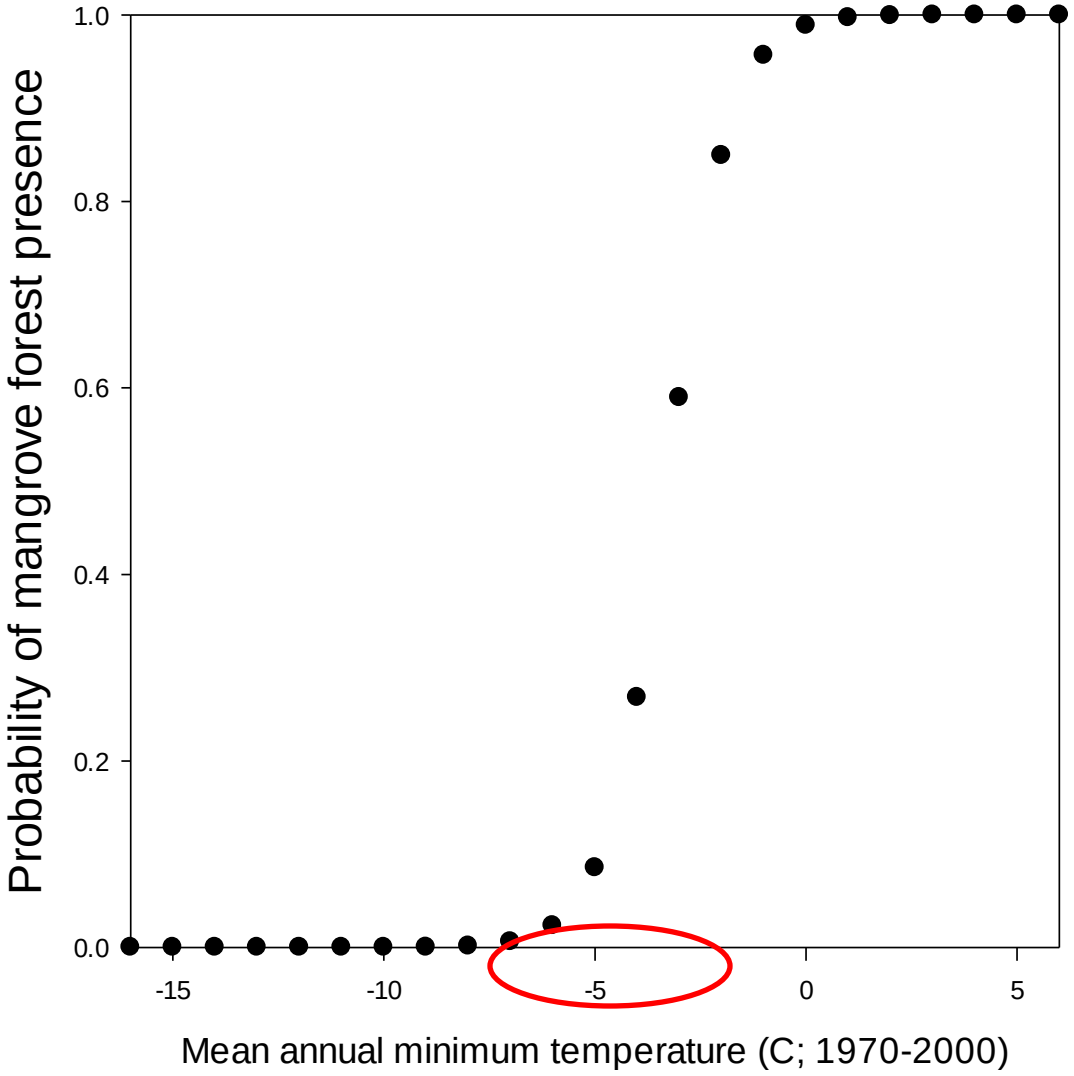
- Develop winter climate-based mangrove forest species distribution and relative abundance models
- Identify winter climate thresholds for mangrove-salt marsh interactions
- Evaluate salt marsh vulnerability to mangrove forest range expansion
- Evaluate the implications of alternative future winter climate scenarios for mangroves & salt marshes


1. Divide the coast into a grid of cells
2. Determine mangrove forest presence or absence for each cell
3. Determine mangrove forest & salt marsh area for each cell (Florida)
4. Obtain 30-yr climate data for each cell (1970-2000; Maurer et al. 2002)
5. Develop species distribution and relative abundance models
Mangrove forests absent
Mangrove forests present
Mangrove individuals present
N
0
250
500 Kilometers

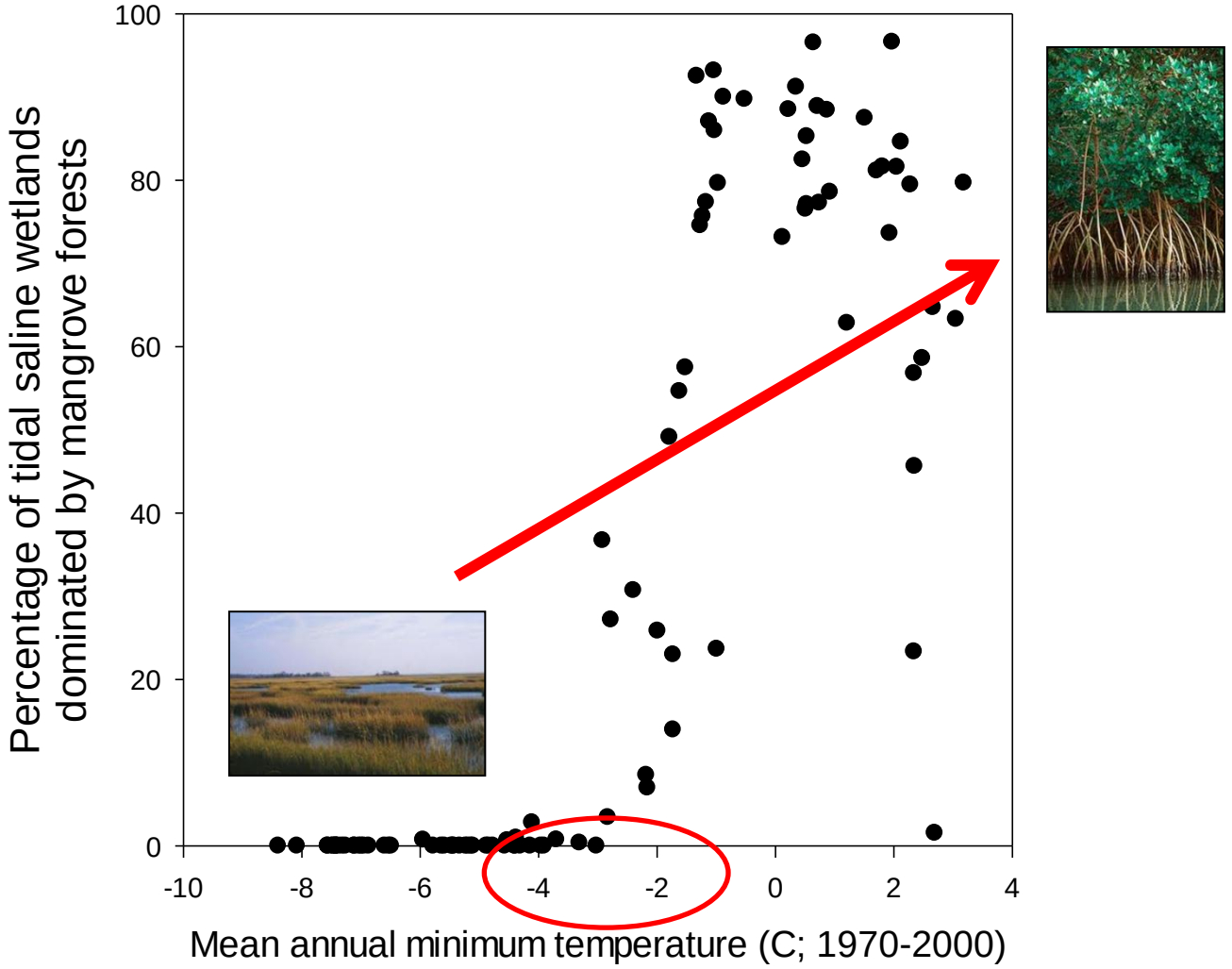
Percentage of tidal saline wetlands dominated by mangrove forests



The relationship between winter severity and mangrove forest presence



The relationship between winter severity and mangrove forest dominance



Thresholds; species distribution and relative abundance models for 8 winter severity variables

Distribution models

Relative abundance models

Variable	Mangrove forest presence					Mangrove forest abundance			
	AIC	a	b	a Wald χ^2	b Wald χ^2	R^2	a	b	c
Mean annual minimum temperature	181.1	4.46	1.37	34	58	‡0.85***	75***	0.18**	-1.75***
Minimum temperature	190.5	8.99	0.91	41	54	‡0.82***	74***	0.50**	-6.97***
Mean annual maximum number of consecutive days with minimum temperature < 0°C	197.0	4.73	-2.14	49	72	‡0.85***	75***	-0.07*	1.51***
Mean annual minimum monthly mean temperature	200.5	-13.42	1.04	80	67	‡0.84***	74***	0.26**	14.76***
Mean annual maximum number of consecutive days with minimum temperature < -6.7°C	208.3	2.45	-9.14	37	75	†0.79***	70***	10.04***	NA
Mean annual number of days with minimum temperature < 0°C	225.4	2.23	-0.45	38	71	‡0.85***	75***	-0.11**	2.25***
Maximum number of consecutive days with minimum temperature < 0°C	228.4	6.53	-1.26	41	55	†0.63***	167***	0.37***	NA
Maximum number of consecutive days with minimum temperature < -6.7°C	247.0	2.52	-1.38	34	83	†0.78***	71***	1.23***	NA

Thresholds for predicting mangrove forest presence

Variable	Presence	Dominance
Mean annual minimum temperature	-3.0 (0.63)	-1.7 (0.84)
Minimum temperature	-8.9 (0.64)	-7.0 (0.81)
Mean annual maximum number of consecutive days with minimum temperature < 0°C	2.2 (0.60)	1.5 (0.85)
Mean annual minimum monthly mean temperature	13.6 (0.64)	14.9 (0.83)
Mean annual maximum number of consecutive days with minimum temperature < -6.7°C	0.2 (0.60)	0.0 (0.76)
Mean annual number of days with minimum temperature < 0°C	3.7 (0.59)	2.2 (0.85)
Maximum number of consecutive days with minimum temperature < 0°C	4.5 (0.48)	4.5 (0.80)
Maximum number of consecutive days with minimum temperature < -6.7°C	1.5 (0.57)	0.5 (0.76)

Thresholds for predicting mangrove forest dominance

Winter climate thresholds

- **Minimum temperature (30 yr)**
  - Mangrove forest presence: -8.9°C
  - Mangrove forest dominance: -7.0 °C
  - Threshold for many citrus species: between -4.5°C and -9°C (Wiltbank and Oswalt 1987)

- **Mean annual minimum temperature (30 yr)**
  - Mangrove forest presence: -3.0 °C
  - Mangrove forest dominance: -1.7 °C

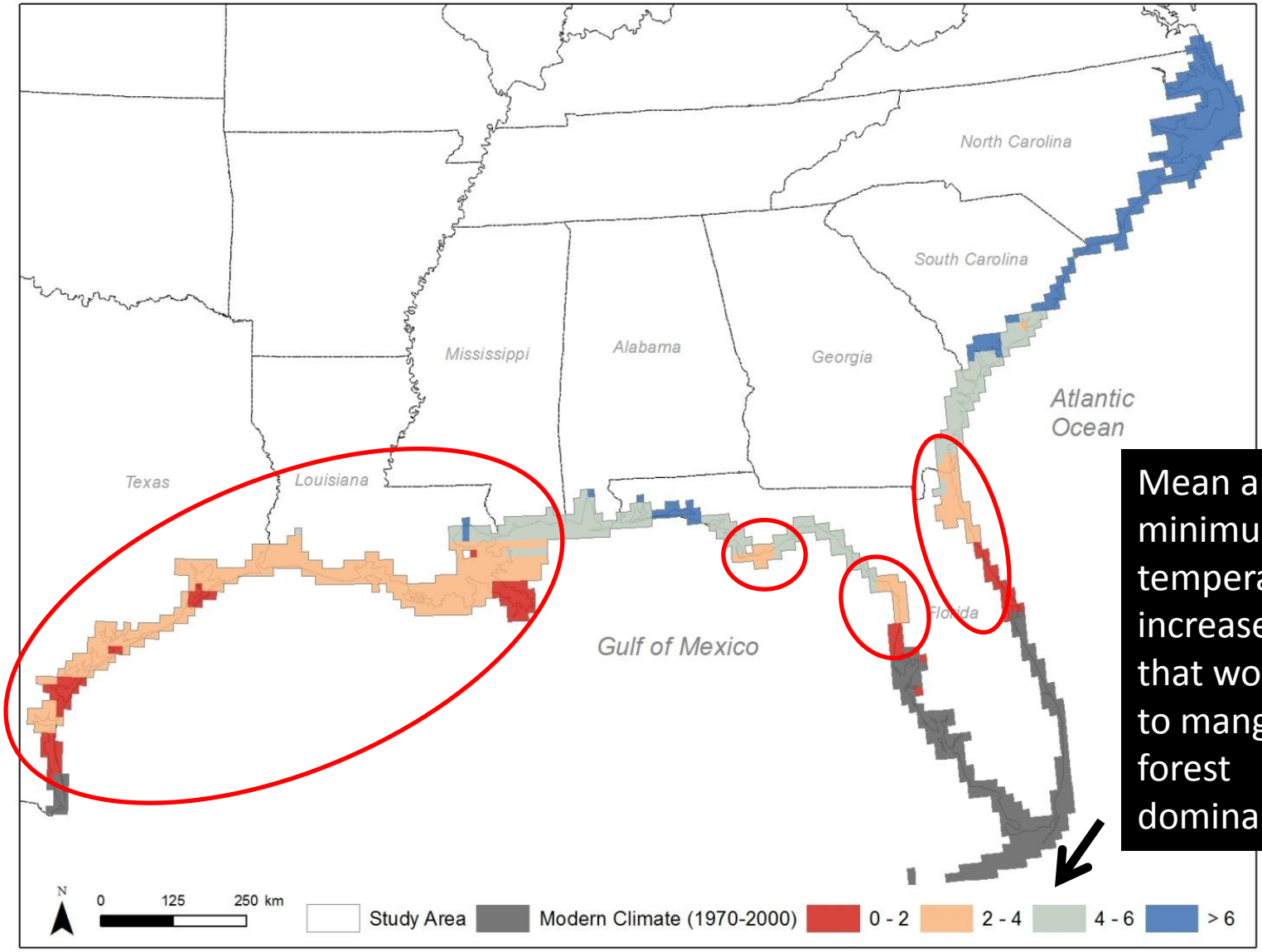
Alternative future climate scenarios

Two approaches:

1. Warming scenarios (0-8°C)

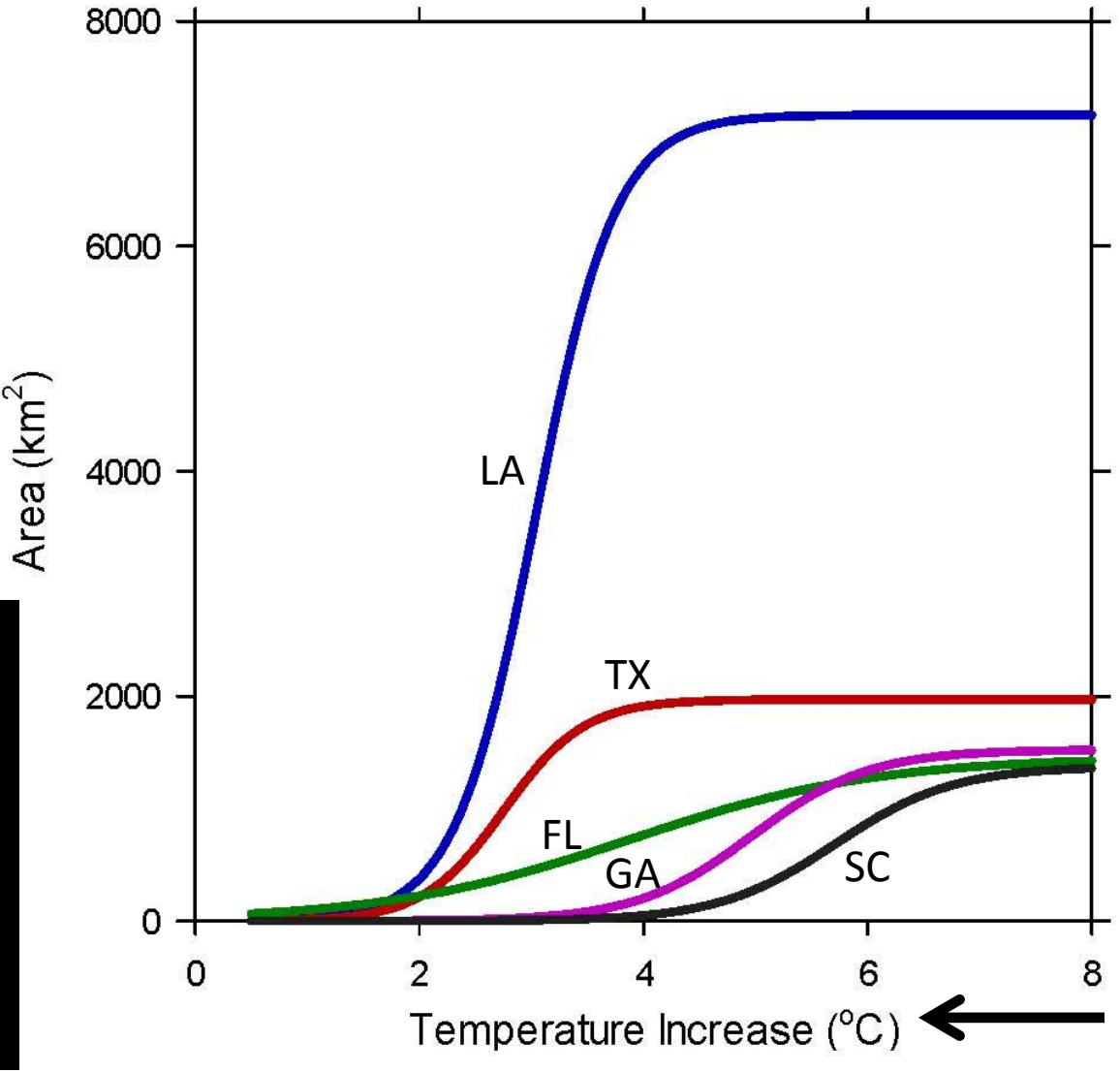
2. Future climate projections (2070-2100)

Salt marsh vulnerability to winter climate change-induced mangrove forest range expansion



Mean annual minimum temperature increase (°C) that would lead to mangrove forest dominance

Salt marsh vulnerability to winter climate change-induced mangrove forest range expansion



Amount of salt marsh area within each state that would become vulnerable to mangrove forest replacement

Mean annual minimum temperature increase (°C) that would lead to mangrove forest dominance

Alternative future climate scenarios

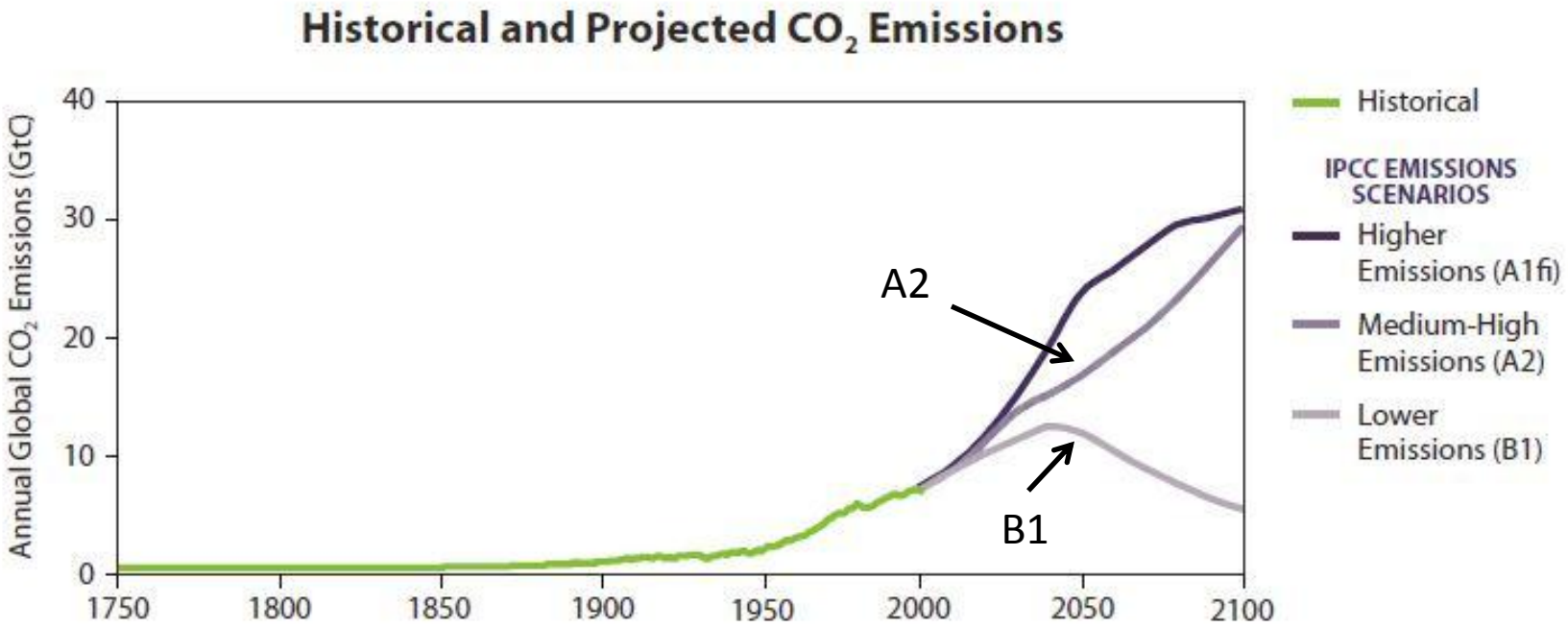
Two approaches:

~~1. Warming scenarios (0-8°C)~~

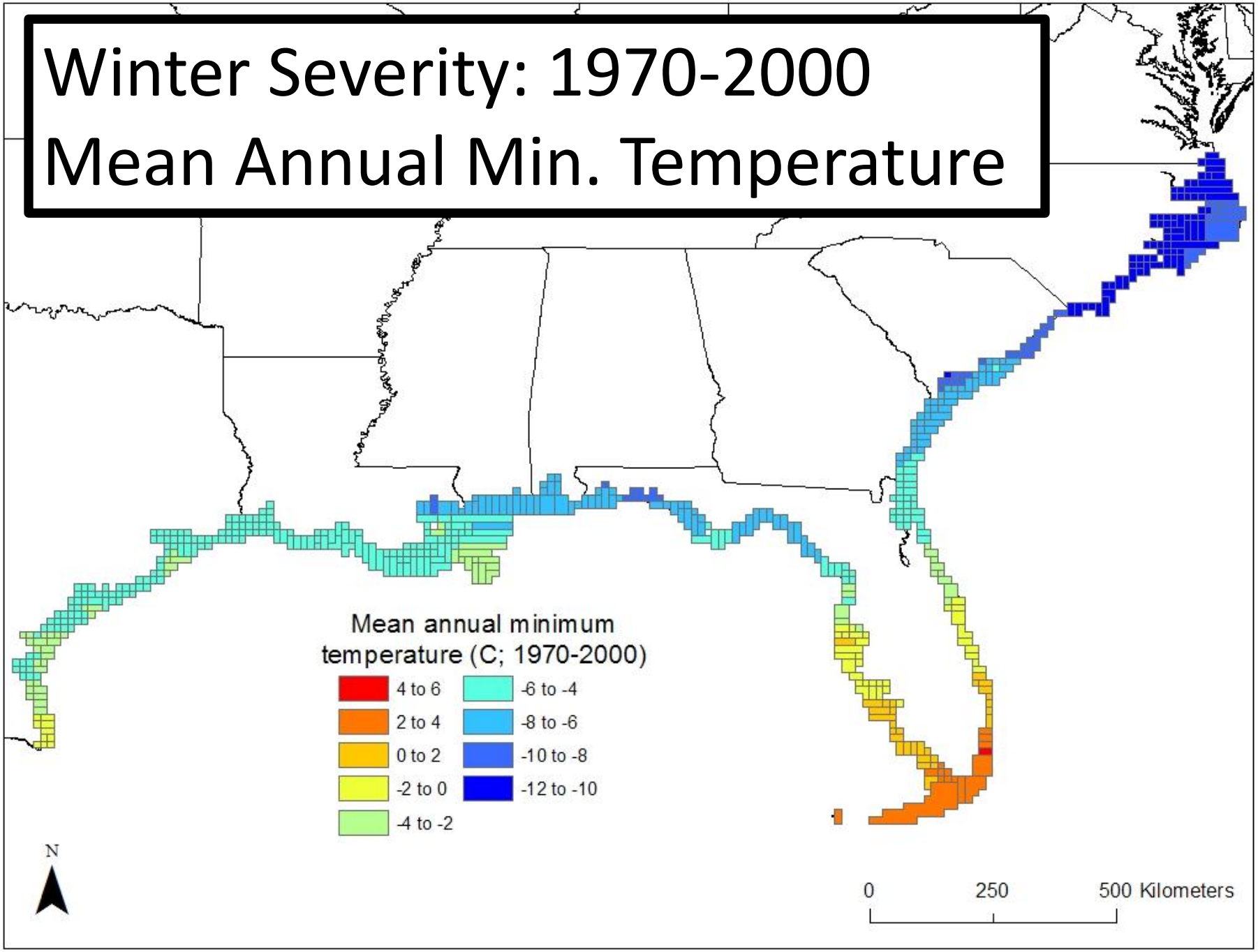
2. Future climate projections (2070-2100)

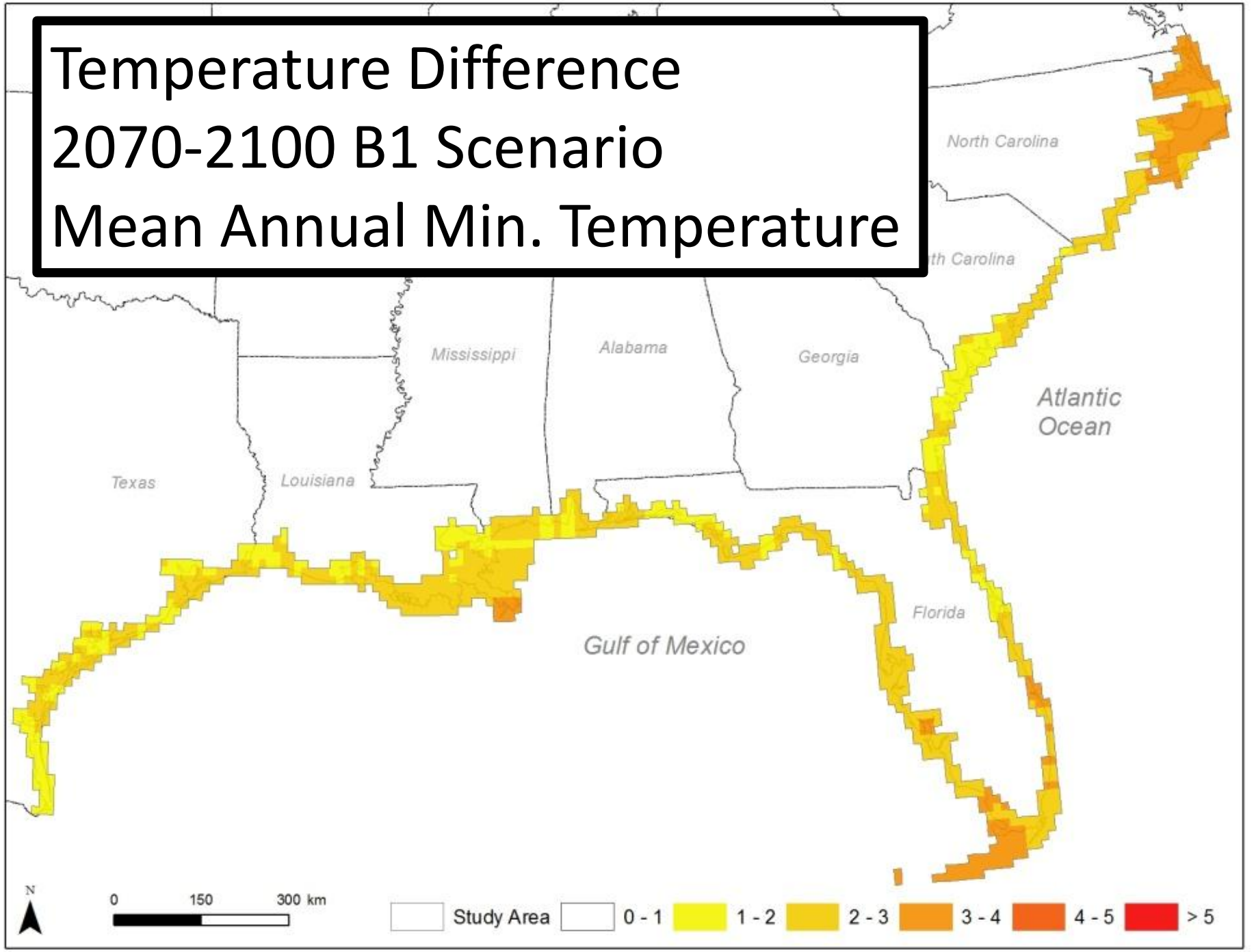
Future climate projections (2070-2100)

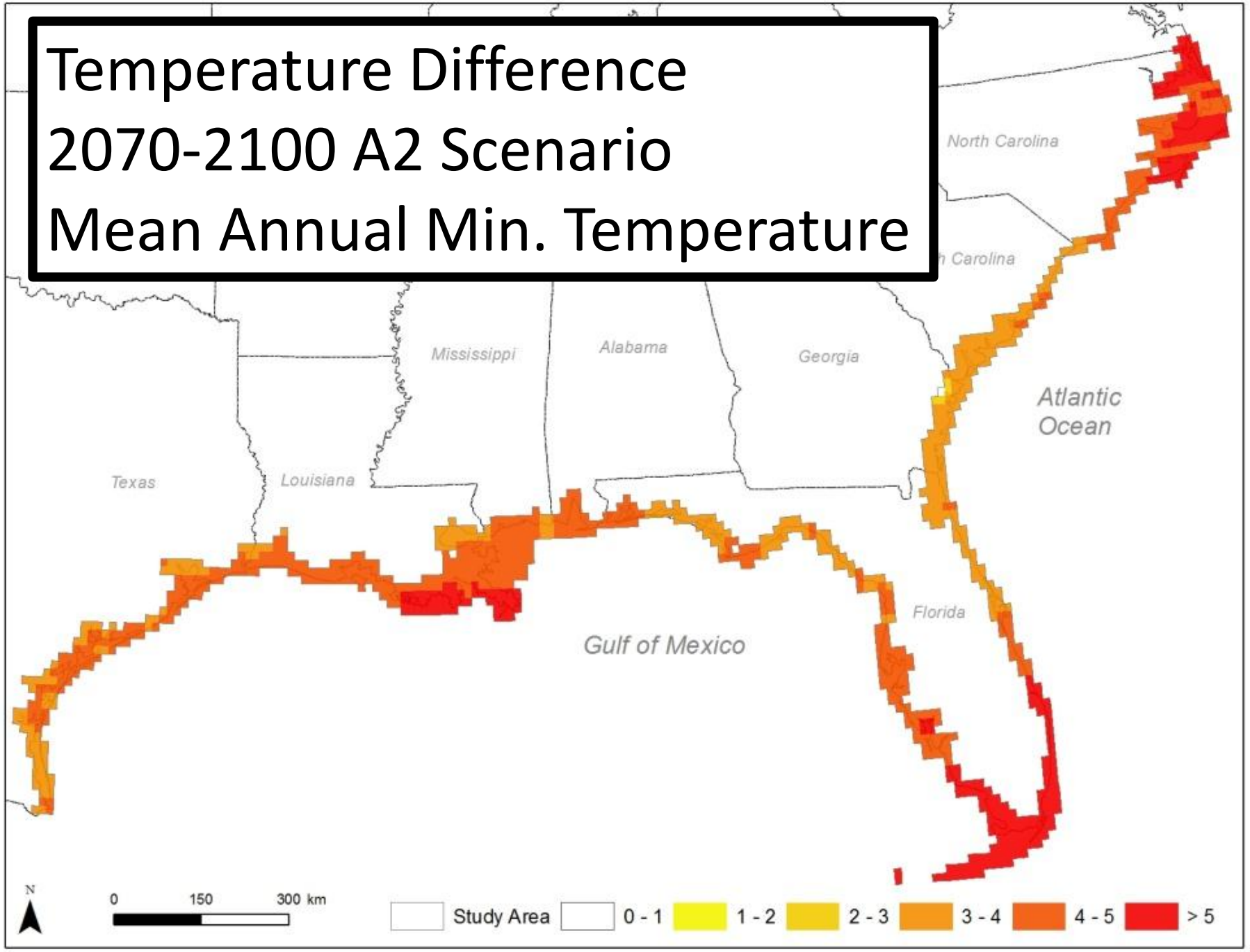
- Statistically-downscaled climate projections [Stoner, Hayhoe, and Yang (*in review*)]
- Two emission scenarios:
  - A2 (ensemble approach- 8 global climate models)
  - B1 (ensemble approach- 8 global climate models)



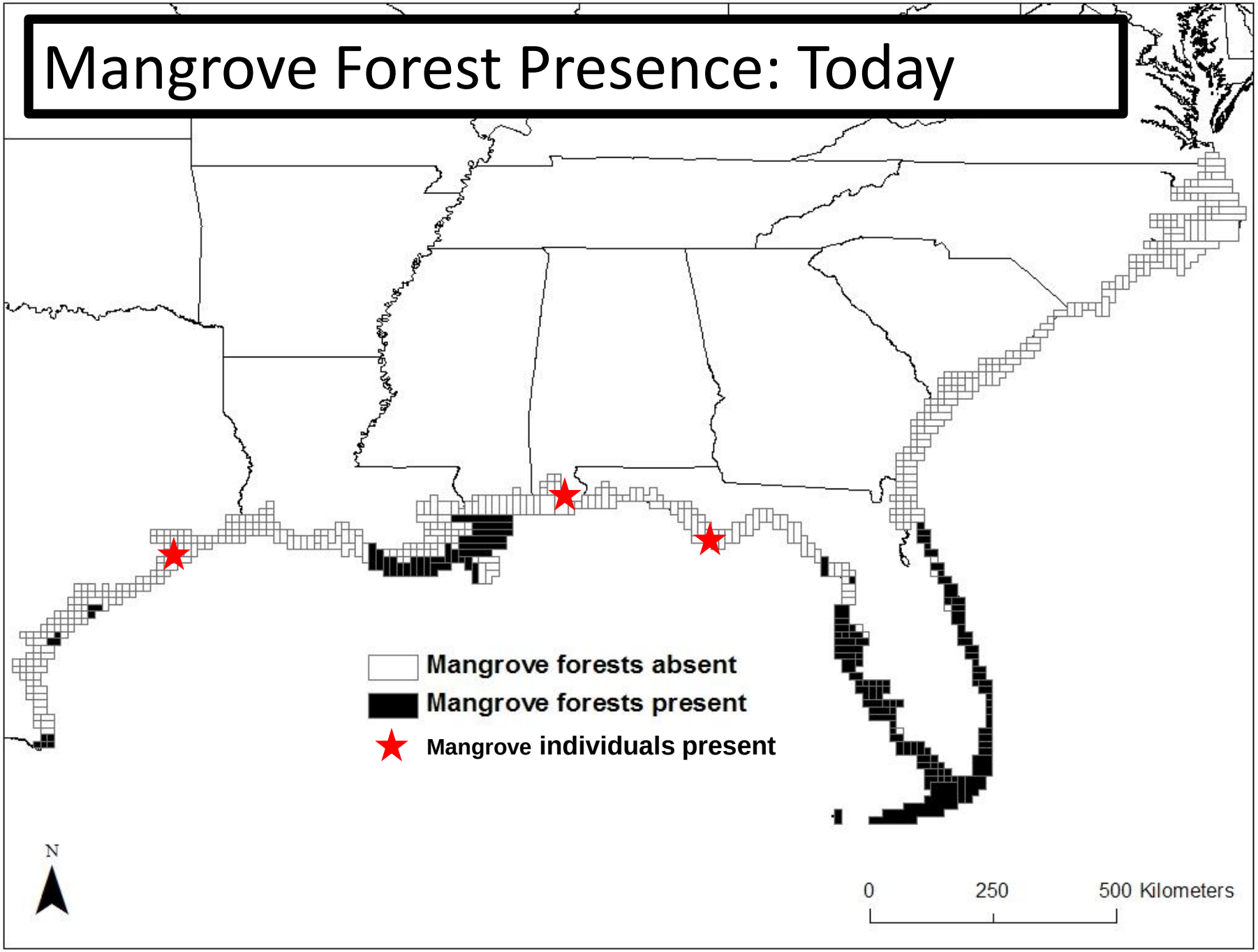
Winter Severity: 1970-2000
Mean Annual Min. Temperature



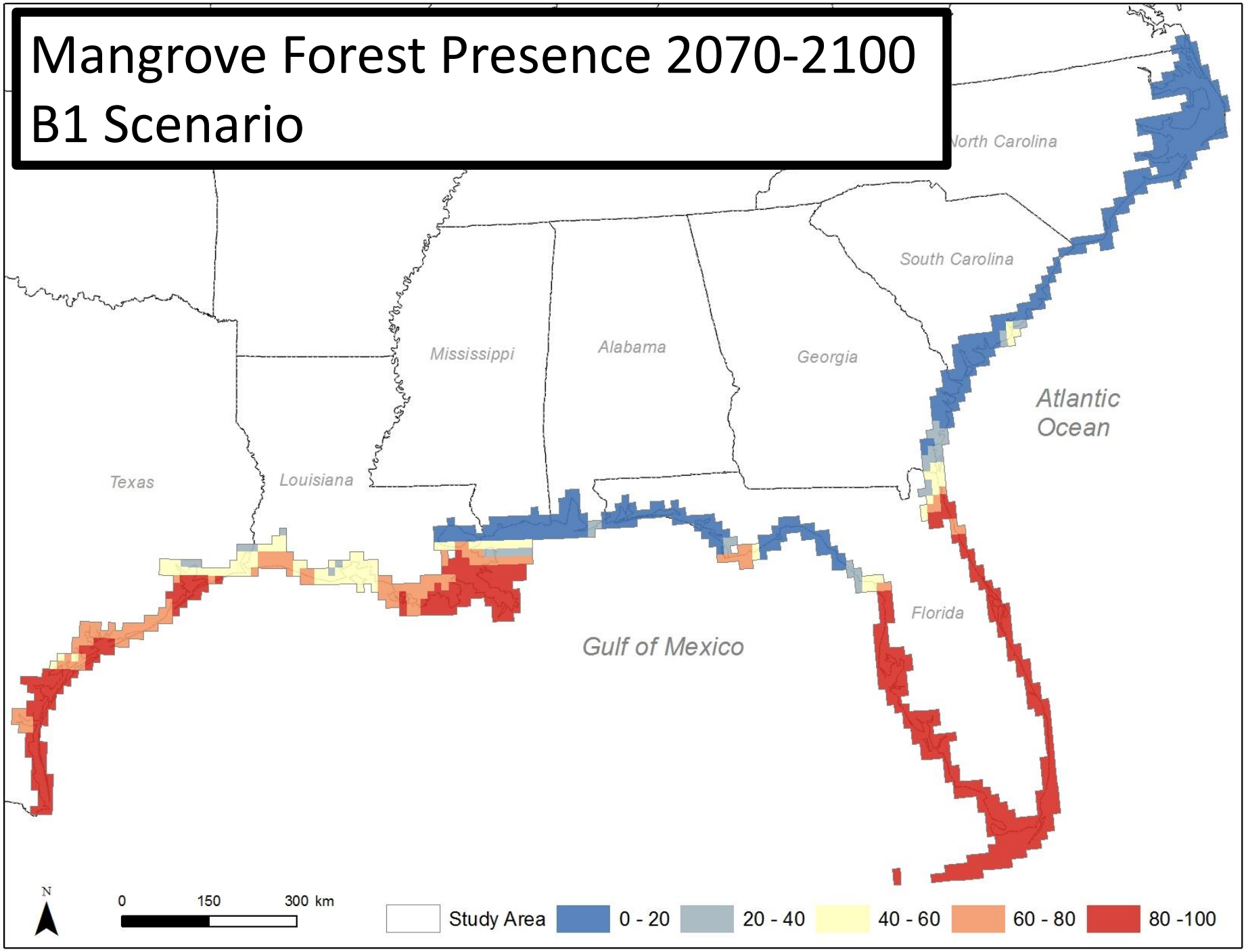

Temperature Difference
2070-2100 B1 Scenario
Mean Annual Min. Temperature
North Carolina
th Carolina
Mississippi
Alabama
Georgia
Atlantic
Ocean
Texas
Louisiana
Florida
Gulf of Mexico
N
0
150
300 km
Study Area
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5

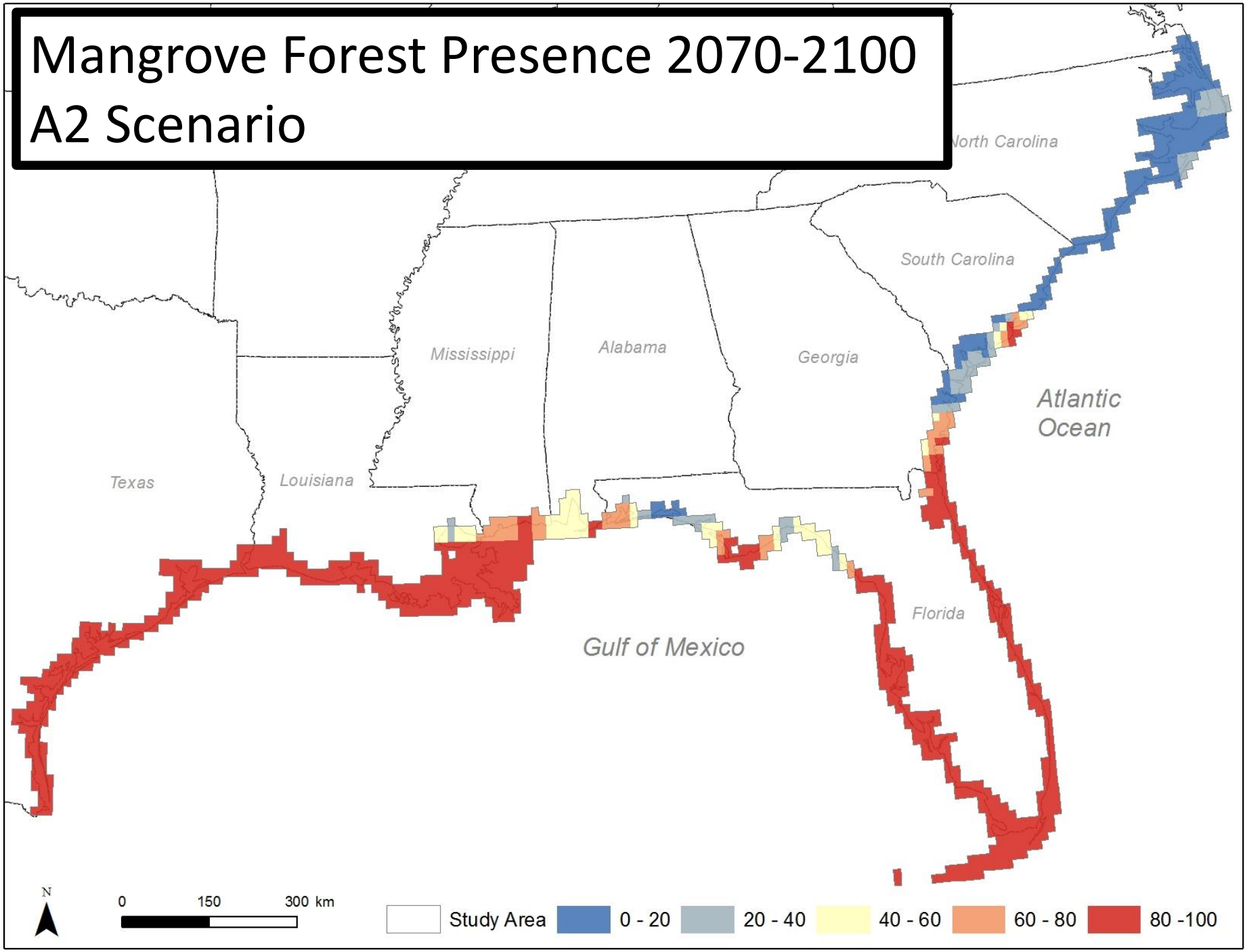

Temperature Difference
2070-2100 A2 Scenario
Mean Annual Min. Temperature
North Carolina
Mississippi
Alabama
Georgia
Atlantic Ocean
Texas
Louisiana
Florida
Gulf of Mexico
N
0
150
300 km
Study Area
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5

Mangrove Forest Presence: Today

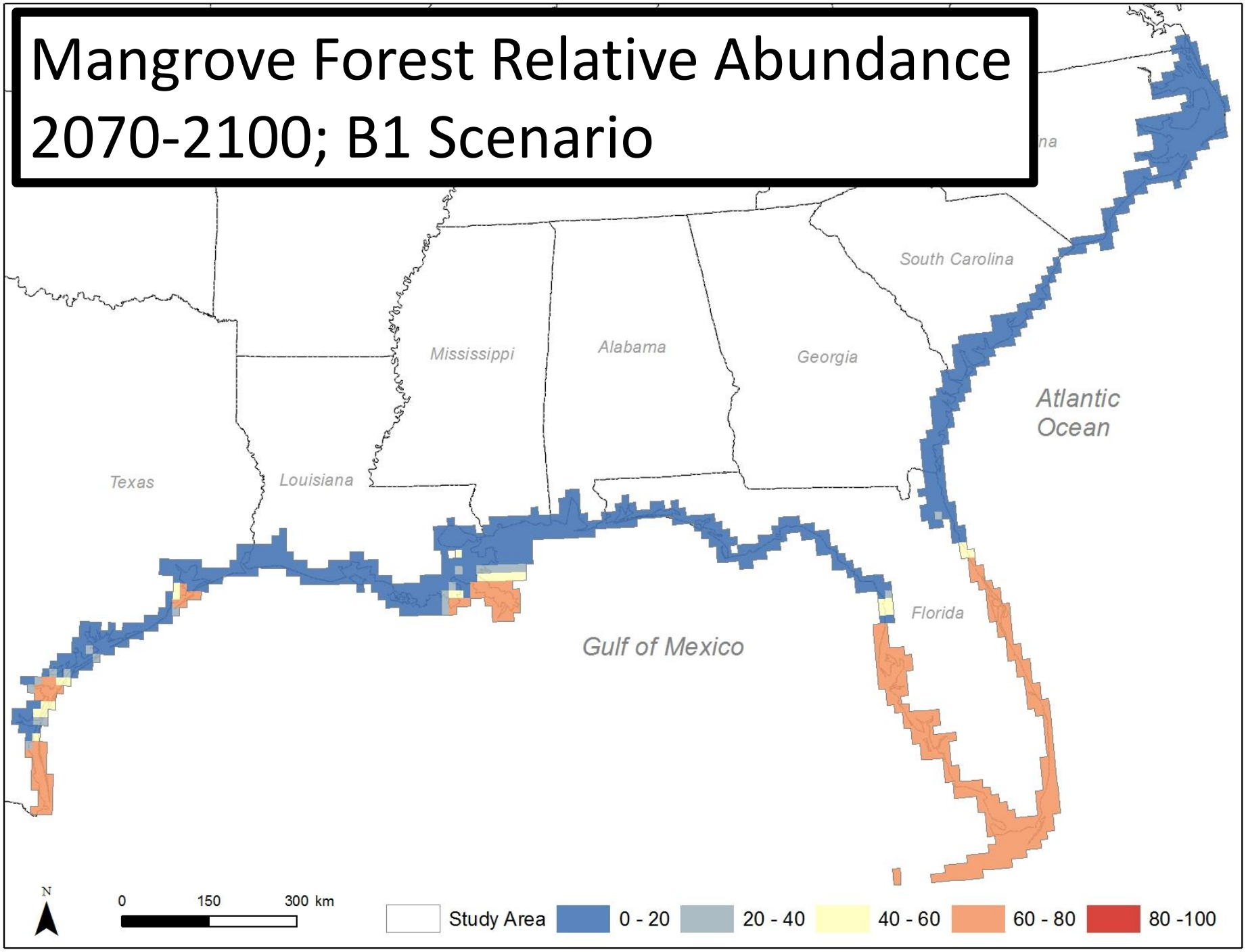


Mangrove Forest Presence 2070-2100
B1 Scenario

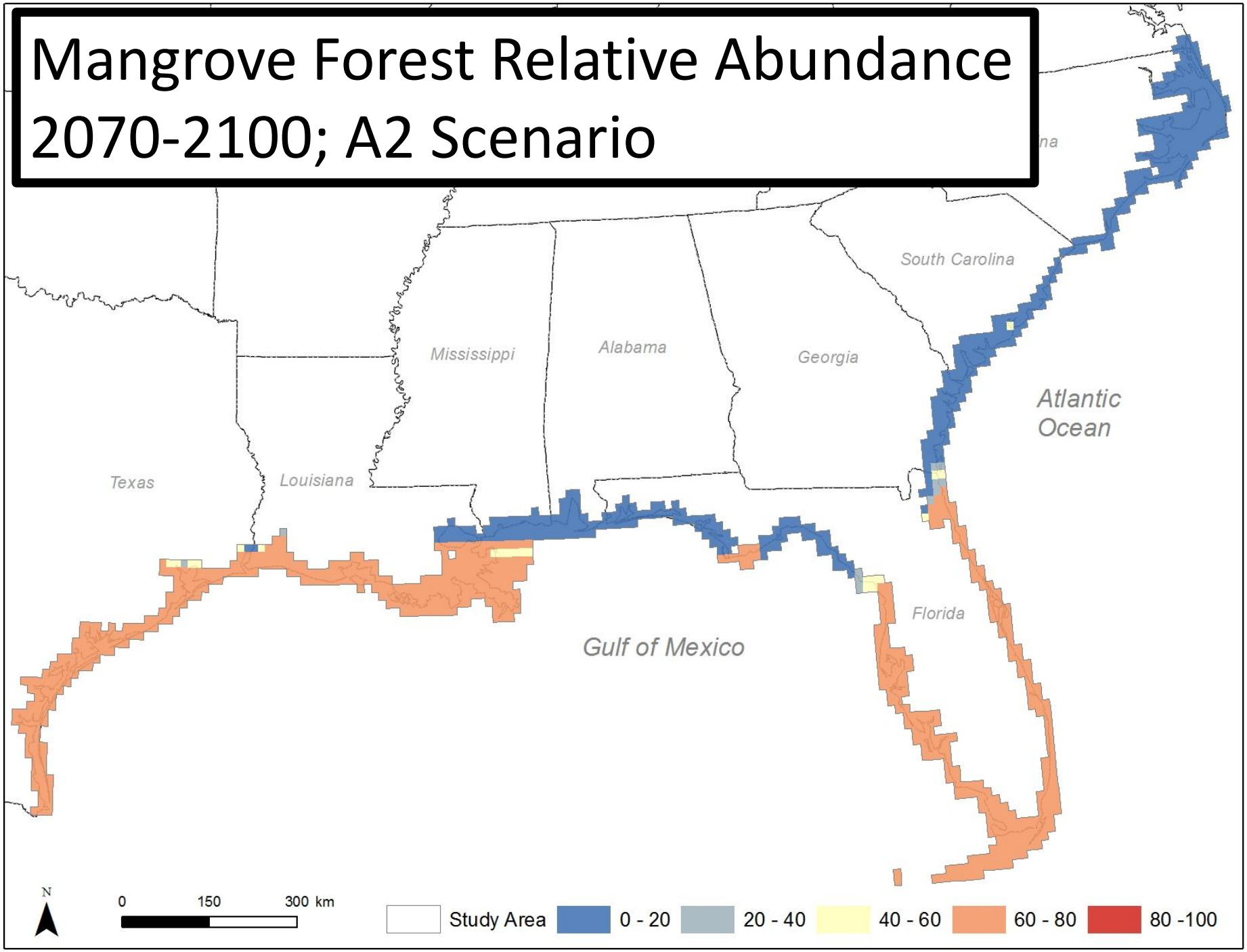



Mangrove Forest Presence 2070-2100
A2 Scenario
North Carolina
South Carolina
Georgia
Alabama
Mississippi
Louisiana
Texas
Florida
Atlantic Ocean
Gulf of Mexico
N
0
150
300 km
Study Area
0 - 20
20 - 40
40 - 60
60 - 80
80 -100

Mangrove Forest Relative Abundance 2070-2100; B1 Scenario



Mangrove Forest Relative Abundance 2070-2100; A2 Scenario



Summary

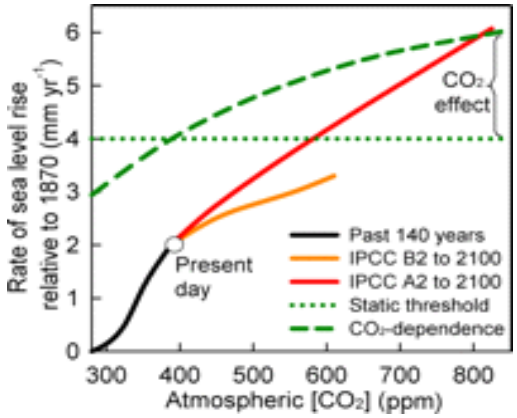
- Winter climate is an important driver of ecosystem change in tidal saline wetlands in the southeastern U.S.
- We developed simple winter climate-based mangrove forest species distribution and relative abundance models
- We identified winter climate thresholds
- Salt marsh vulnerability to winter climate change-induced mangrove forest range expansion is high (especially in Louisiana, Texas, and Florida)
- Need for research that investigates the ecological implications of mangrove forest expansion

What are the ecological implications?

- **Fisheries** (nursery and breeding habitat; food web linkages)
- **Avian habitat** (land bird migration; colonial nesting wading birds; marsh birds)
- **Biogeochemistry** (C, N, sediment , water quality)
- **Stability and resilience** (sea level rise; drought)
- **Coastal protection** (storms; erosion)

Interactions with other aspects of climate change?

Sea level rise



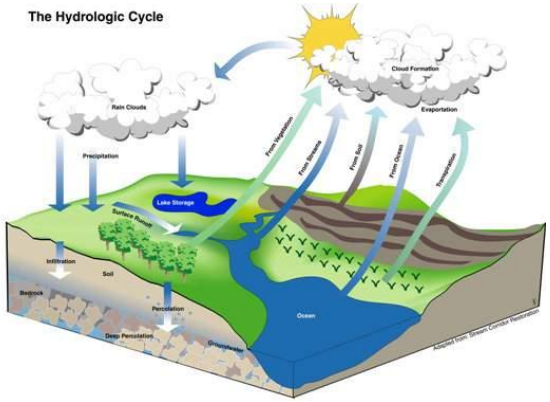
Langley et al. 2009

Saltwater intrusion

Elevated CO_2

Source: Megonigal, SERC

Precipitation



Temperature change

Acknowledgments

- **Collaborators:** Nicholas Enwright, Mary Ellison, Richard Day, Tom Doyle
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