University of Mississippi
Graduate Student Council
9th Annual Research Symposium
March 26, 2019

Ecological Drivers of Subterranean Termite Distributions

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&

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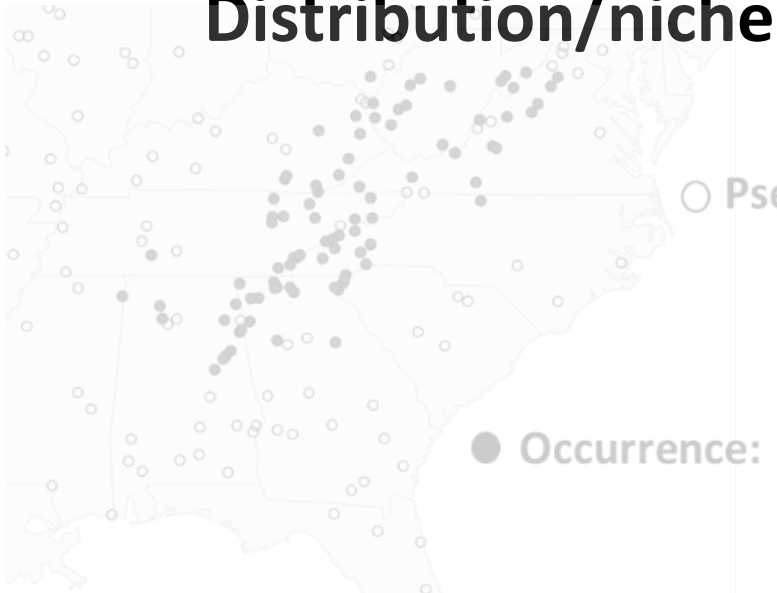
Distribution/niche modeling: occurrence data and environmental variables



○ Pseudoabsence: 100

● Occurrence: Rf = 91 Rm = 17 Rv = 30

Predictors: 4

Model Training and Testing

x5

Machine Learning Algorithms:

Random Forest

Artifical Neural Network

Generalized Boosted Regression Trees

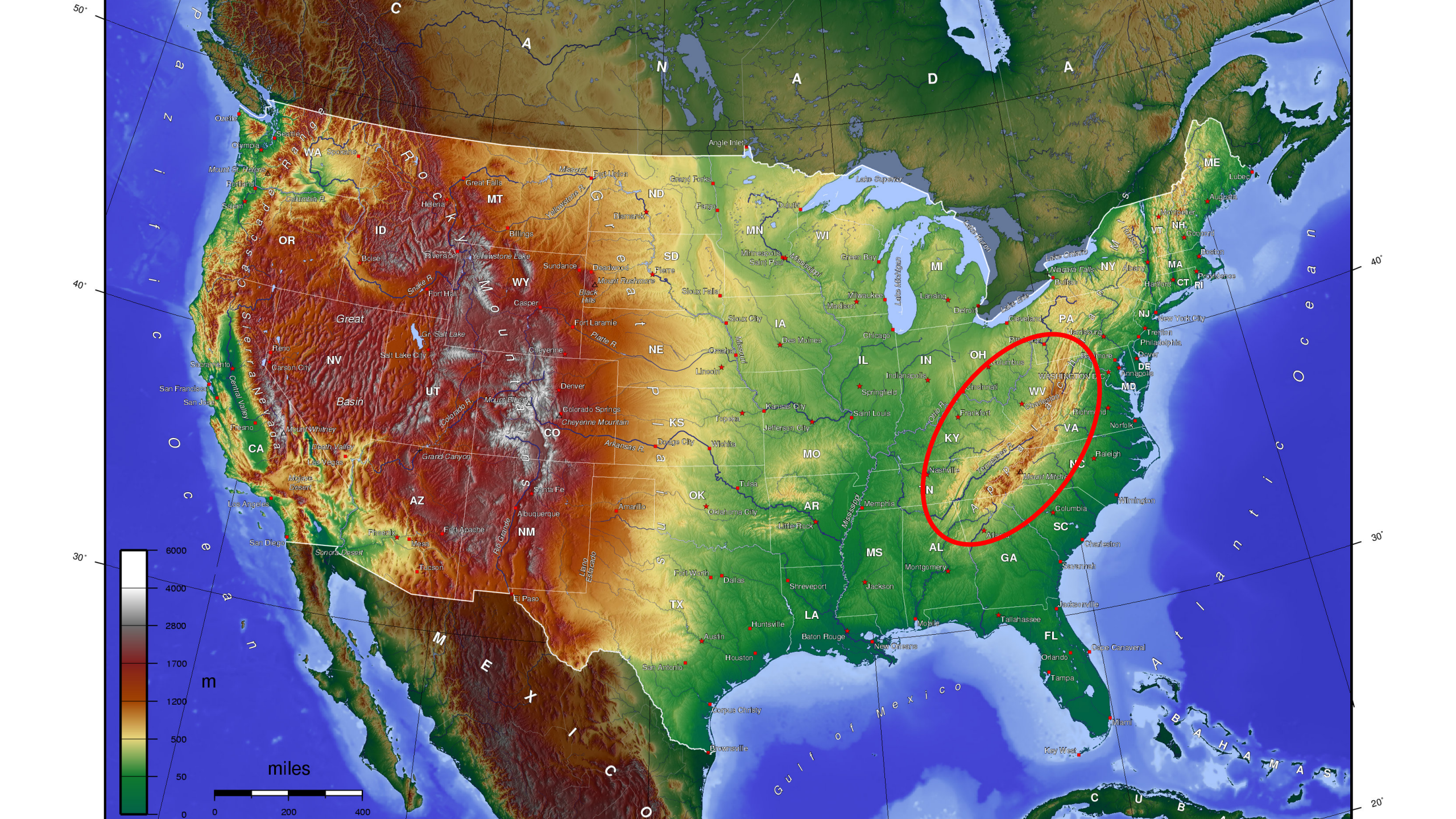
Maximum Entropy

x20

20 Sets of
100 Pseudoabsence Points

100
Runs

Consensus Projections:


Pacific Ocean
Atlantic Ocean
Gulf of Mexico
MEXICO
CUBA
BAHAMAS
CANADA
Rocky Mountains
Cascade Range
Sierra Nevada
Central Valley
Great Basin
Colorado Plateau
Appalachian Mts.
WA
OR
CA
ID
NV
MT
WY
UT
AZ
CO
NM
ND
SD
NE
KS
OK
TX
MN
IA
MO
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VA
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PA
NY
ME
VT
NH
MA
CT
RI
NJ
DE
MD
Seattle
Portland
Spokane
Boise
Billings
Great Falls
Helena
Salt Lake City
Denver
Albuquerque
Santa Fe
Phoenix
Tucson
El Paso
Las Vegas
Los Angeles
San Diego
San Francisco
Sacramento
San Jose
Reno
Carson City
Fresno
Mount Whitney
Death Valley
Mojave Desert
Sonora Desert
Grand Canyon
Yellowstone Lake
Mount Rushmore
Black Hills
Cheyenne Mountain
Mount Elbert
Fort Apache
Rio Grande
Colorado R.
Columbia R.
Snake R.
Yellowstone R.
Missouri
Platte R.
Arkansas R.
Ohio R.
Tennessee R.
Mississippi
Lake Superior
Lake Michigan
Lake Huron
Lake Erie
Lake Ontario
Niagara Falls
Angle Inlet
Fort Union
Grand Forks
Fargo
Bismarck
Duluth
Minneapolis
Saint Paul
Green Bay
Milwaukee
Madison
Chicago
Detroit
Lansing
Cleveland
Buffalo
Sioux Falls
Sioux City
Des Moines
Omaha
Lincoln
Fort Laramie
Cheyenne
Casper
Riverside
Deadwood
Pierre
Sundance
Fort Hall
Gr. Salt Lake
Indianapolis
Springfield
Kansas City
Saint Louis
Jefferson City
Topeka
Dodge City
Wichita
Oklahoma City
Tulsa
Amarillo
Memphis
Little Rock
Nashville
Frankfort
Columbus
Cincinnati
Charleston
Richmond
Norfolk
Raleigh
Mount Mitchell
Columbia
Charleston
Wilmington
Savannah
Jacksonville
Tallahassee
Orlando
Cape Canaveral
Tampa
Miami
Key West
Mobile
Montgomery
Jackson
Shreveport
Dallas
Fort Worth
Huntsville
Austin
Houston
Baton Rouge
New Orleans
San Antonio
Corpus Christy
Brownsville
Harrisburg
Philadelphia
New York City
Trenton
Baltimore
Annapolis
Dover
Albany
Boston
Providence
Hartford
Concord
Montpelier
Augusta
Lubec
Ozette
Olympia
Salem
Mount St. Helens
Llano Estacado
6000
4000
2800
1700
1200
500
50
0
m
miles
0
200
400
50°
40°
30°
20°

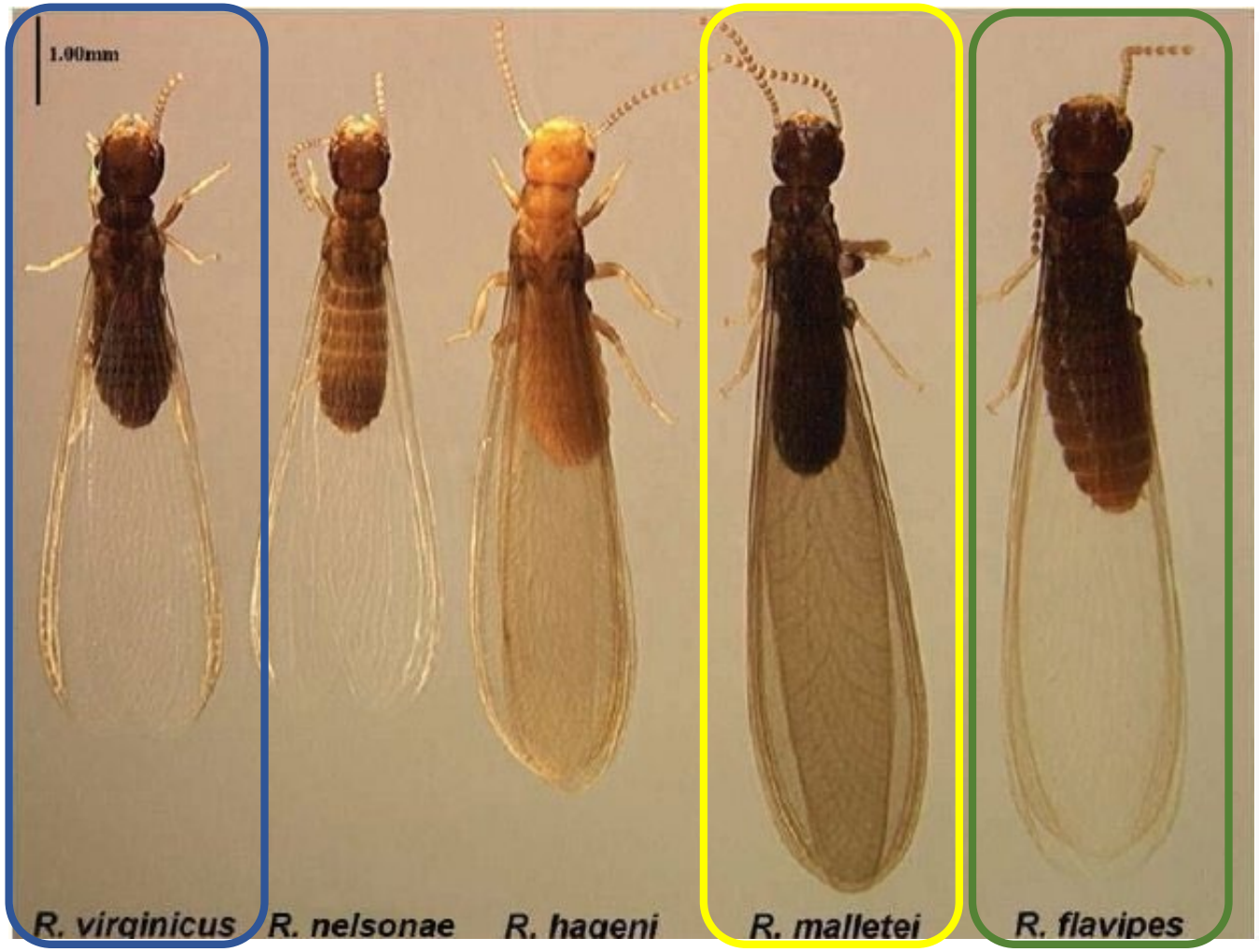
Why are some termite species ~~pests~~ more successful than others?

Niche divergence and competitive exclusion

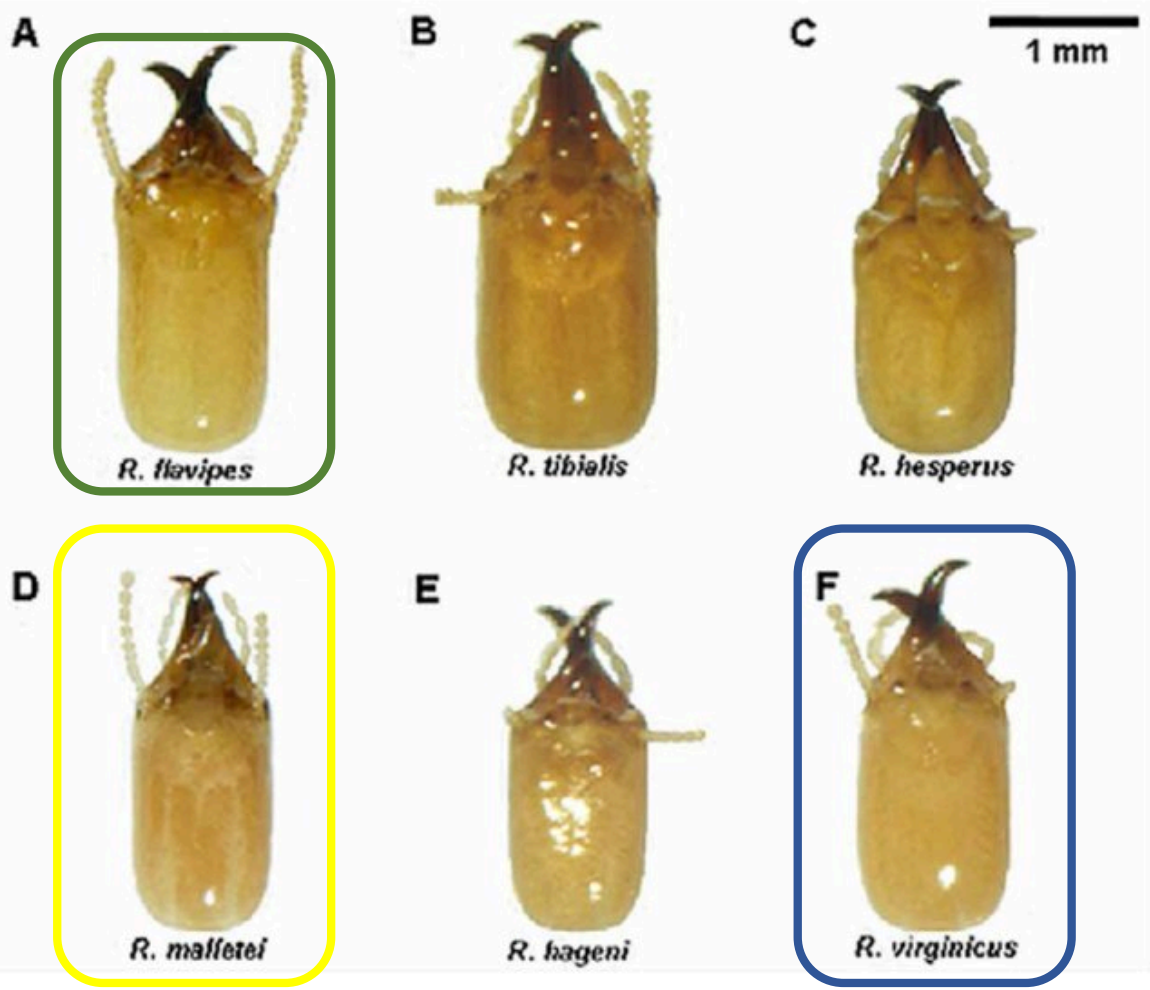
Is there niche divergence among species of subterranean termites?
Competition for resources: do species competitively exclude other species?

Geographic distribution and abundance

What environments do subterranean termites occur in?
What environmental conditions facilitate geographic and demographic expansions?

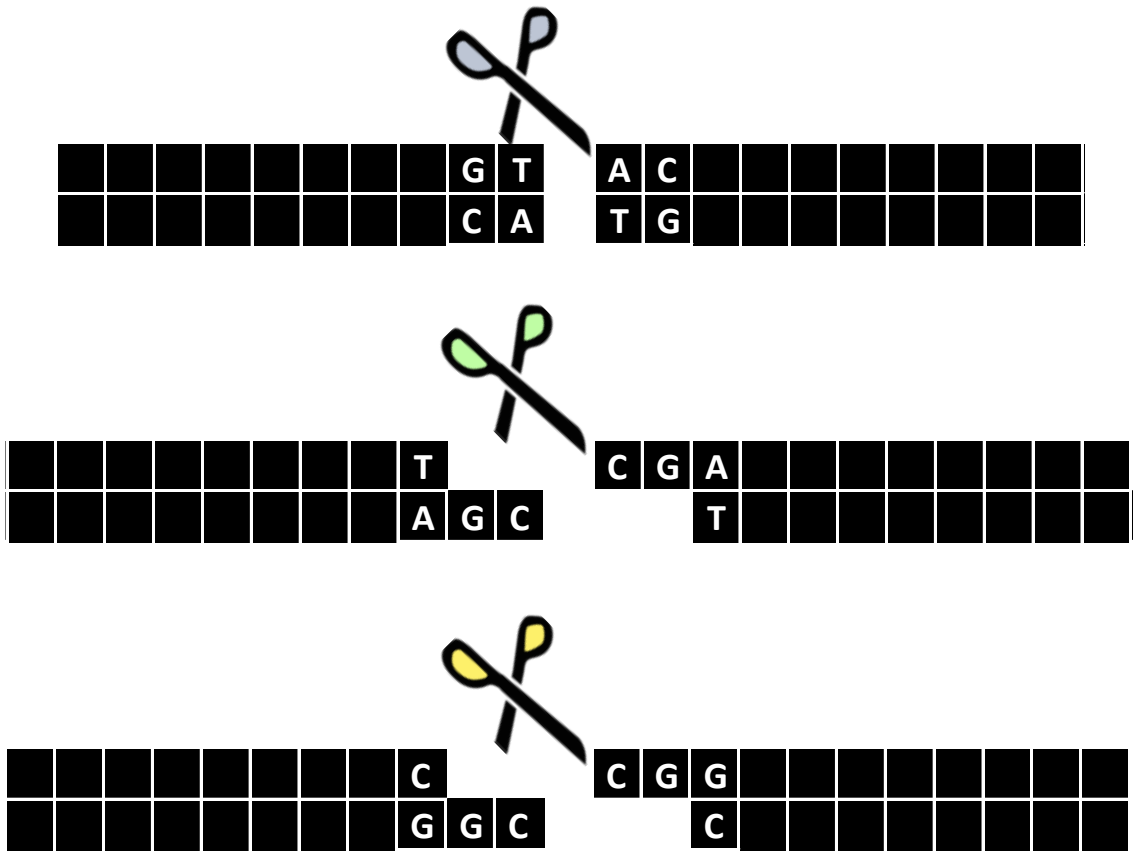


Lim SY, Forschler BT. Reticulitermes nelsonae, a New Species of Subterranean Termite (Rhinotermitidae) from the Southeastern United States. *Insects* 2012;3:62–90.



Austin JW, -G. Bagnères A, Szalanski AL, *et al.* Reticulitermes malletei (Isoptera: Rhinotermitidae): a valid Nearctic subterranean termite from Eastern North America. *Zootaxa* 2007;1554:1–26.

Restriction Digestion



Restriction Enzymes: RsaI TaqI MspI

Digestion of 376 bp fragment of mitochondrial DNA

Restriction Enzyme	Fragment Sizes (bp)	Species				
		R. flavipes	*R. hageni*	*R. malletei*	*R. nelsonae*	*R. virginicus*
Rsa I	175, 201	✓	×	×	✓	✓
	48, 127, 201	×	×	✓	✓	×
	86, 115, 175	✓	✓	×	×	×
Taq I	376	×	✓	✓	✓	✓
	153, 223	×	×	×	✓	×
	183, 193	✓	×	×	×	×
	67, 126, 183	✓	×	×	×	×
	30, 67, 126, 153	✓	×	×	×	×
Msp I	376	✓	×	×	✓	✓
	37, 339 *	✓	×	✓	×	×
	77, 299	×	✓	×	✓	×
	37, 40, 299	×	×	✓	×	×

Geographic Sampling

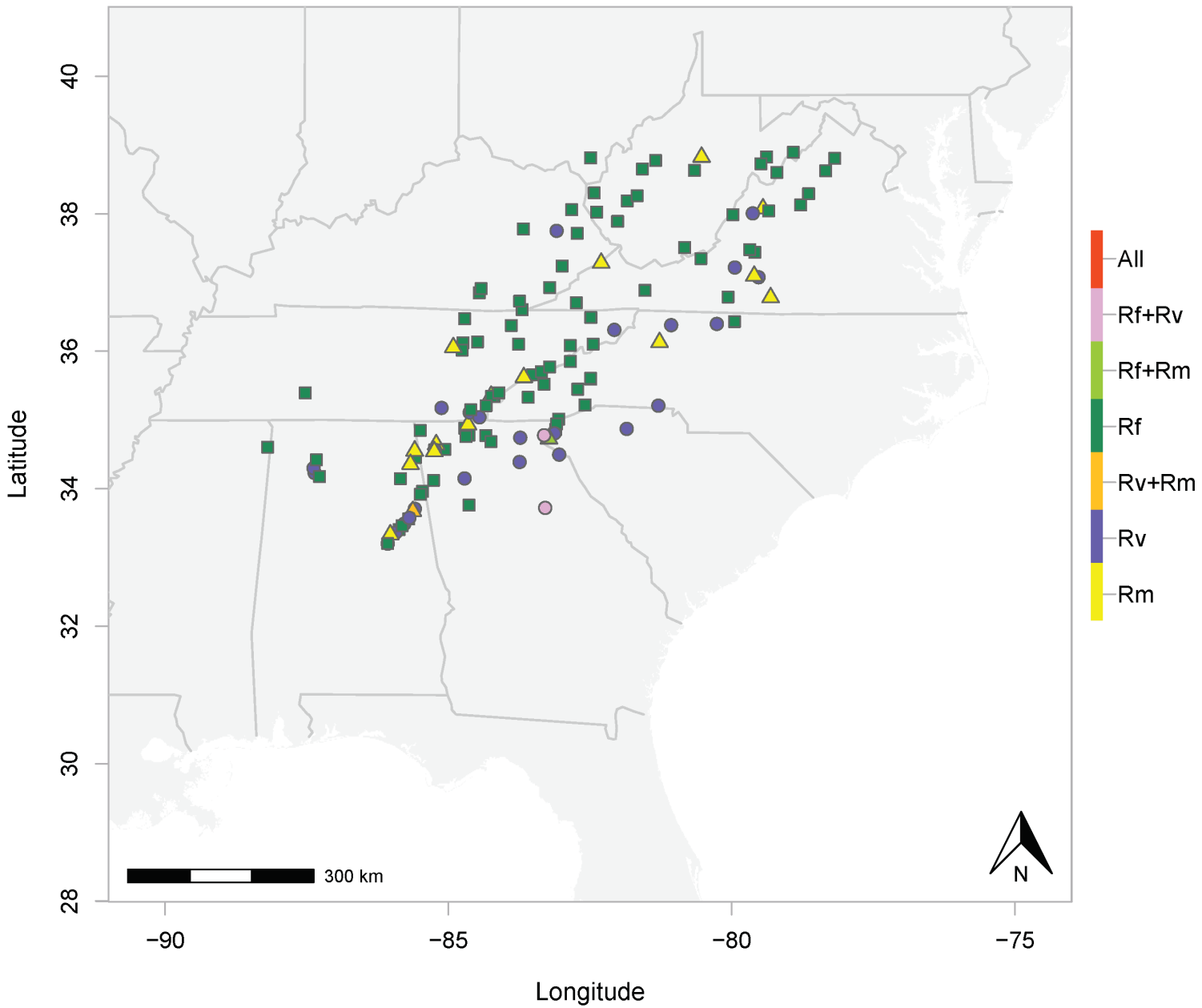
132 sampling sites:

122 sites: 1 rotting log each
10 sites: 2-4 rotting logs each

Reticulitermes flavipes **= Rf (91)**

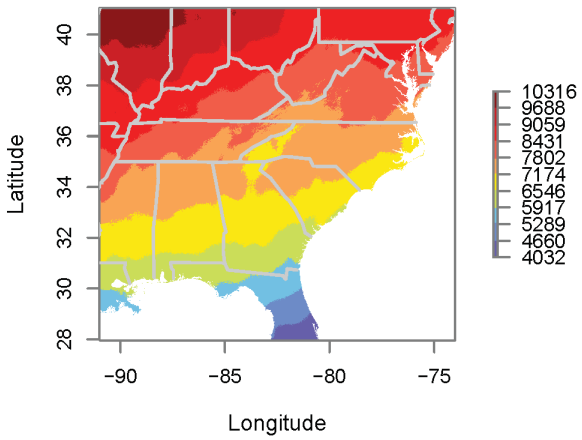
Reticulitermes malletei **= Rm (17)**

Reticulitermes virginicus **= Rv (30)**

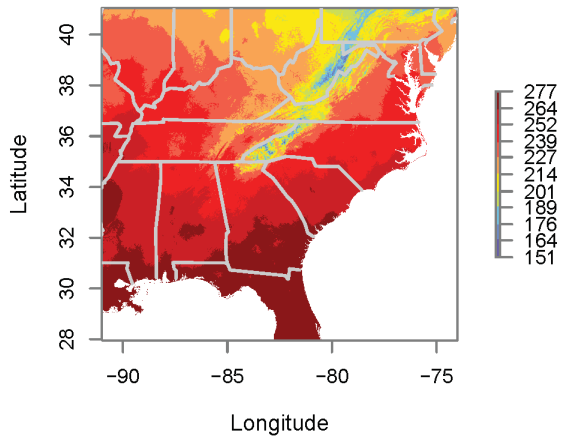


Bioclimatic (biologically-relevant climatic) variables

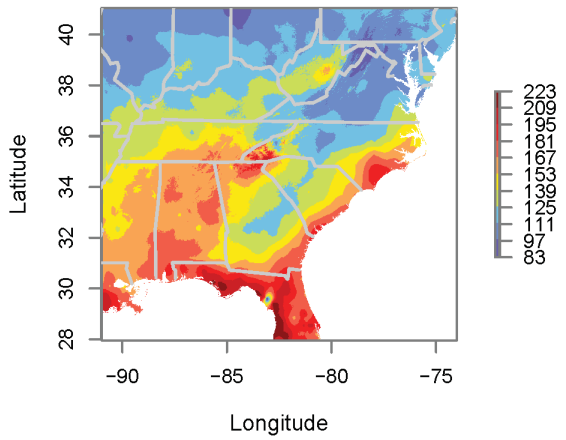
bio4: Temp. Seasonality



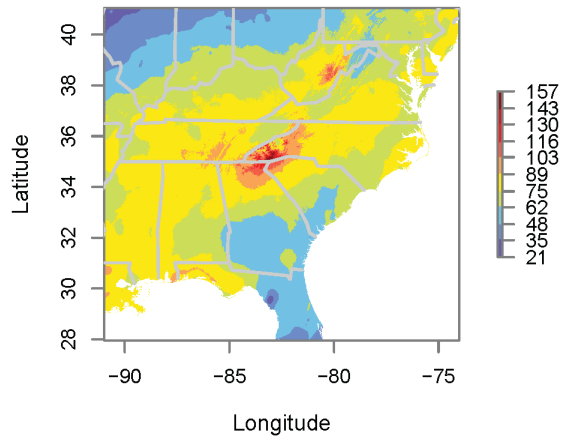
bio10: Mean Temp. of Warmest Qrtr.



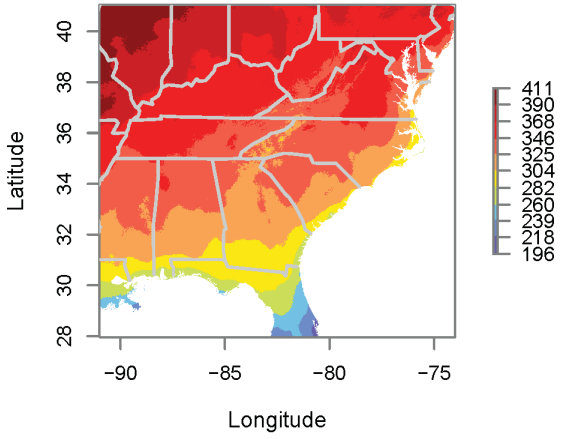
bio13: Precip. of Wettest Mo.



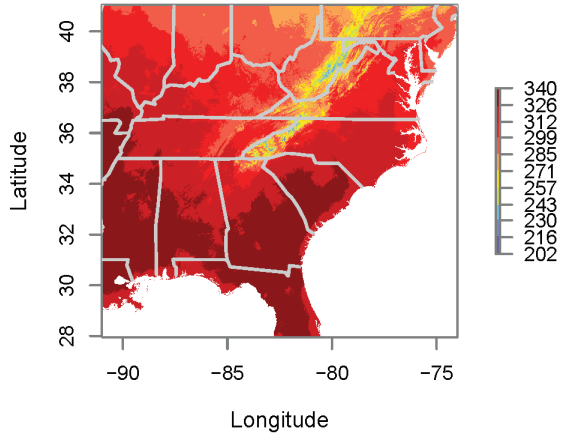
bio14: Precip. of Driest Mo.



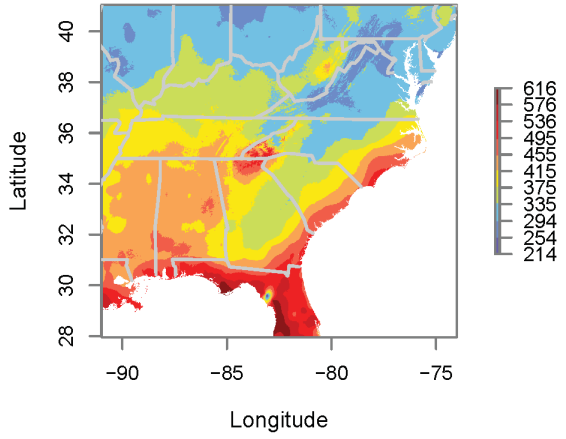
bio7: Temp. Annual Range



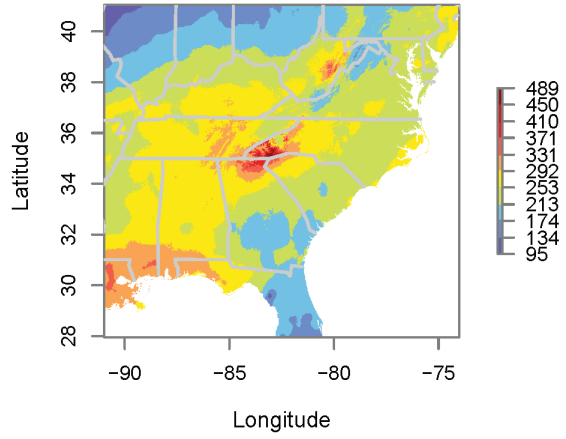
bio5: Max. Temp. of Warmest Mo.



bio16: Precip. of Wettest Qrtr.



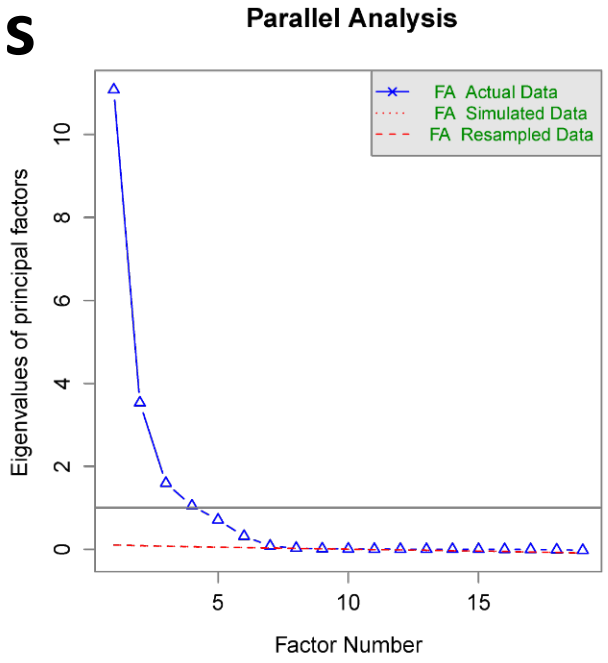
bio17: Precip. of Driest Qrtr.

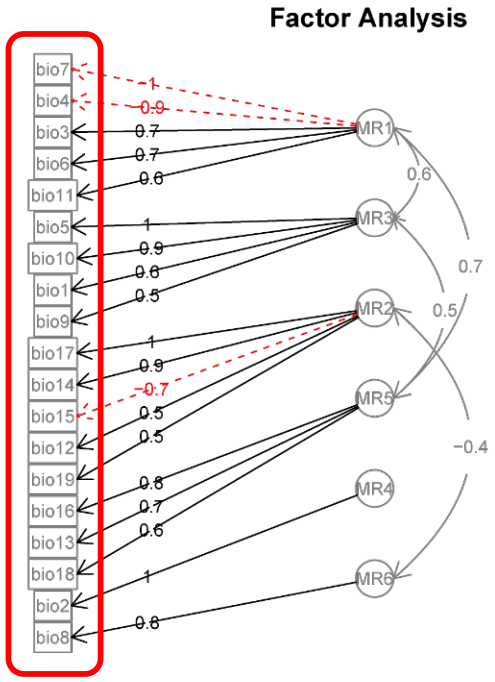


Factor analysis

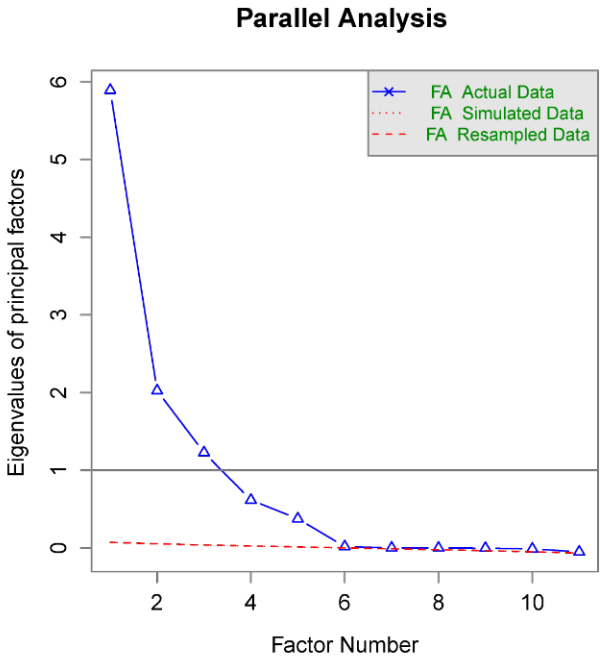
From 19 bioclimatic variables

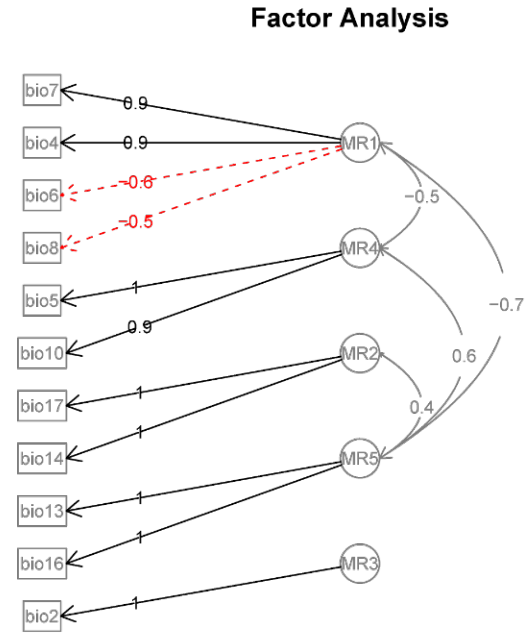
Iteration 1



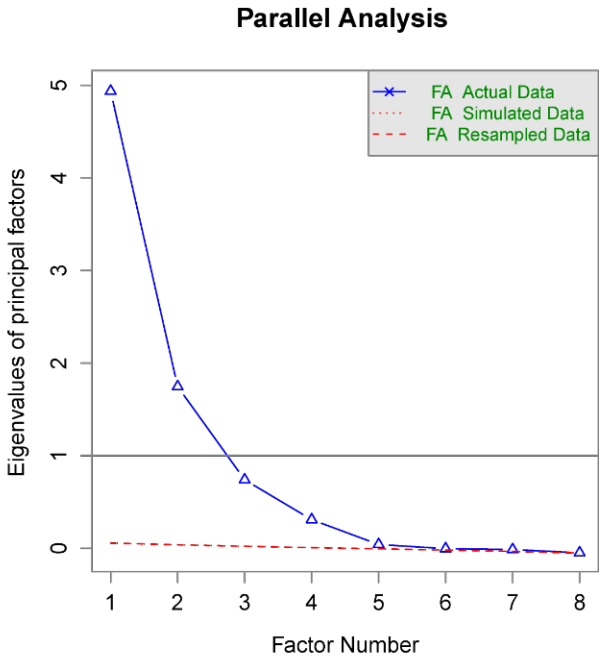


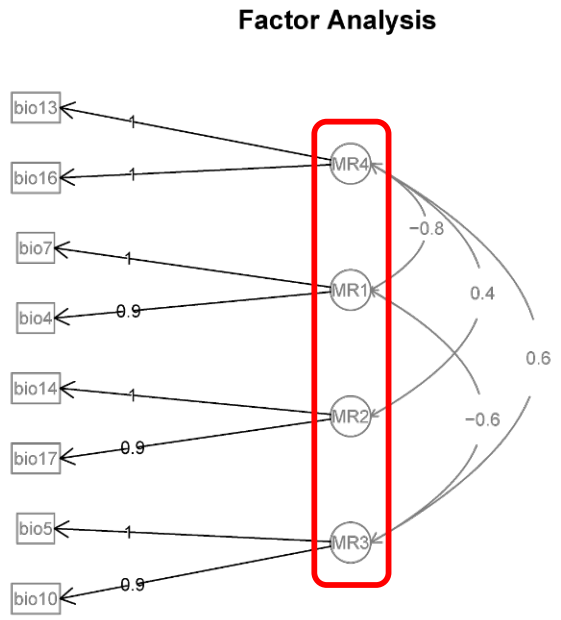
Iteration 2





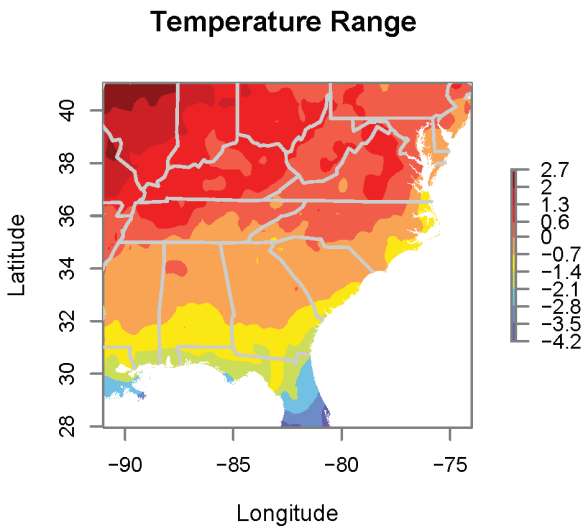
Iteration 3

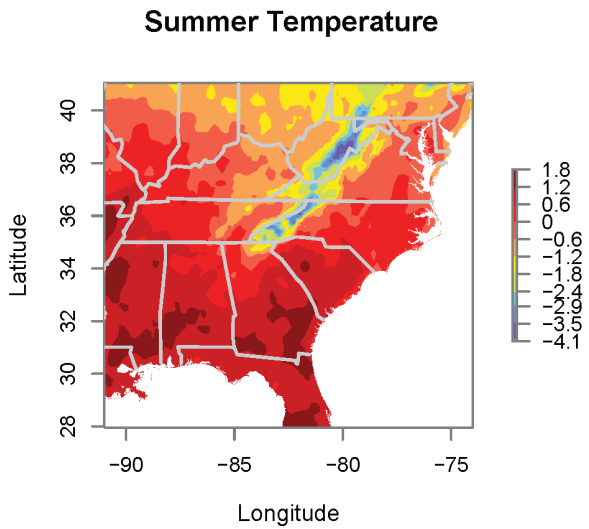


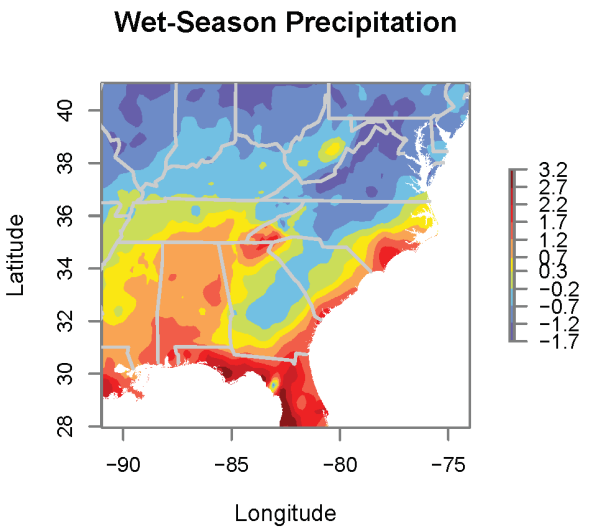


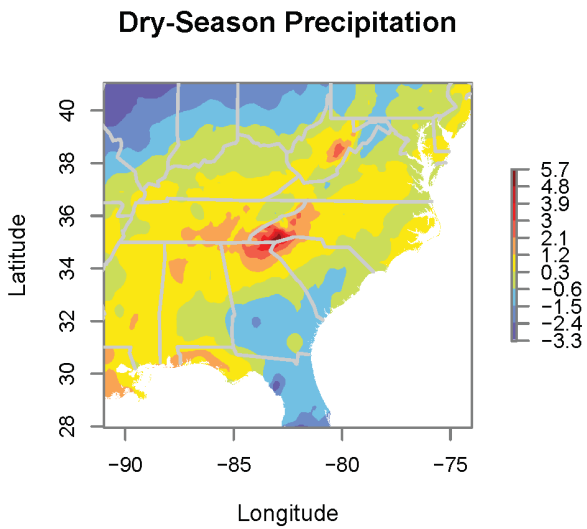
To 4 climatic factors

Environmental/climatic factors

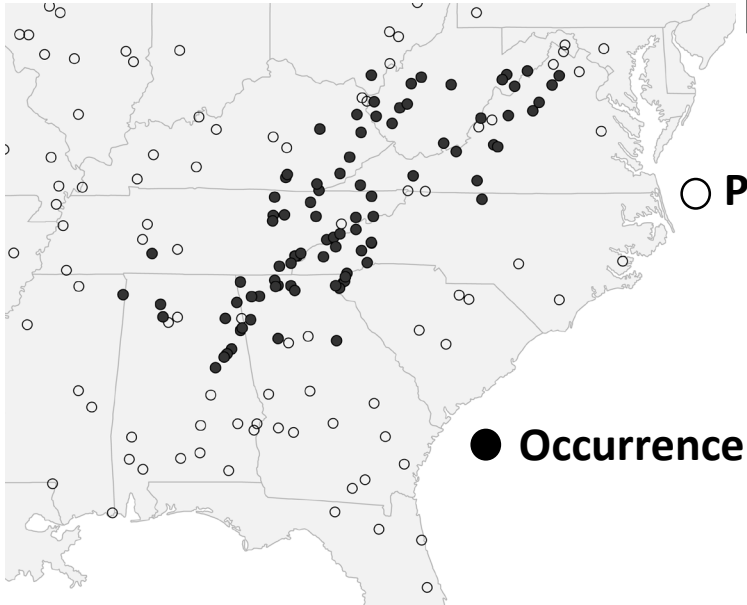






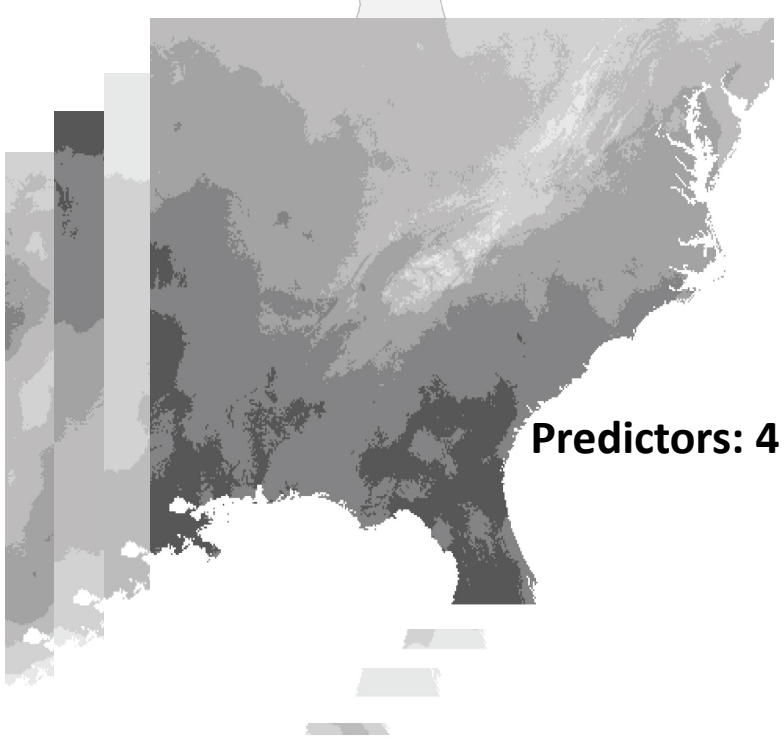


Predicting distribution/niche: occurrence data and environmental factors



○ Pseudoabsence: 100

● Occurrence: Rf = 91
Rm = 17
Rv = 30



Predictors: 4

Model Training and Testing

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Random Forest
Artifical Neural Network
Generalized Boosted Regression Trees
Maximum Entropy

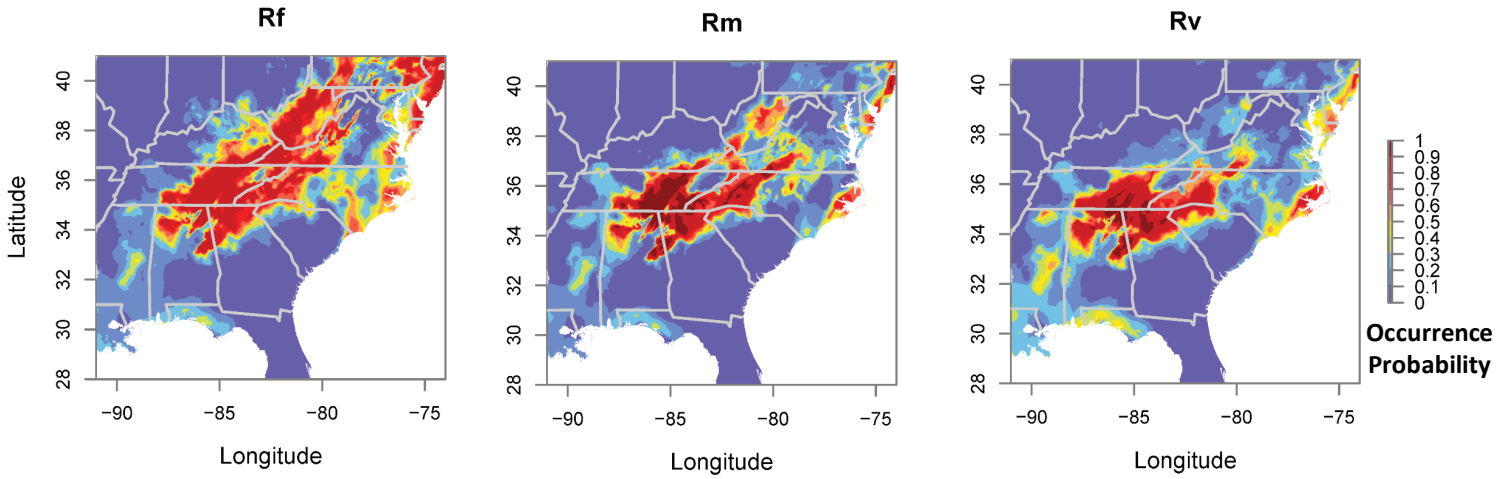
x5

x20

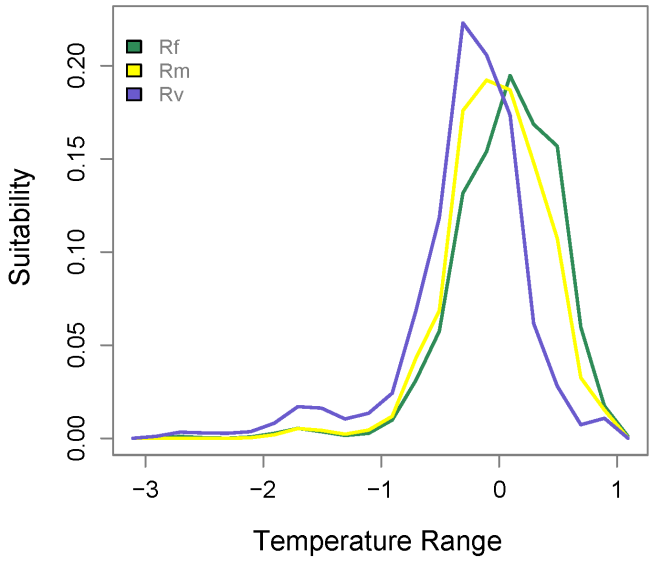
20 Sets of
100 Pseudoabsence Points

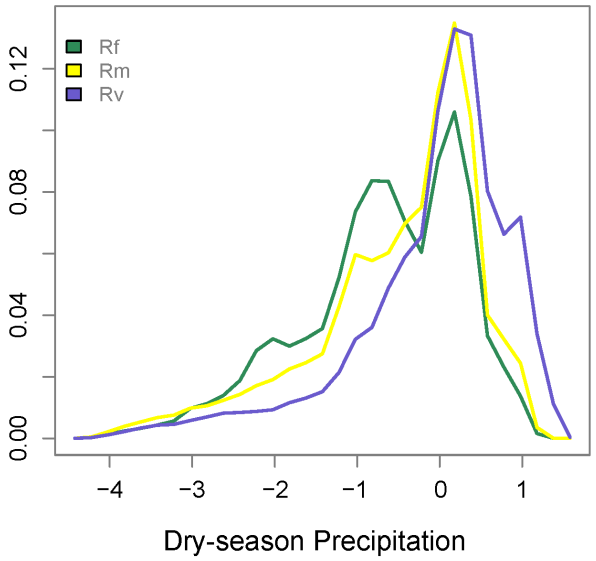
100
Runs

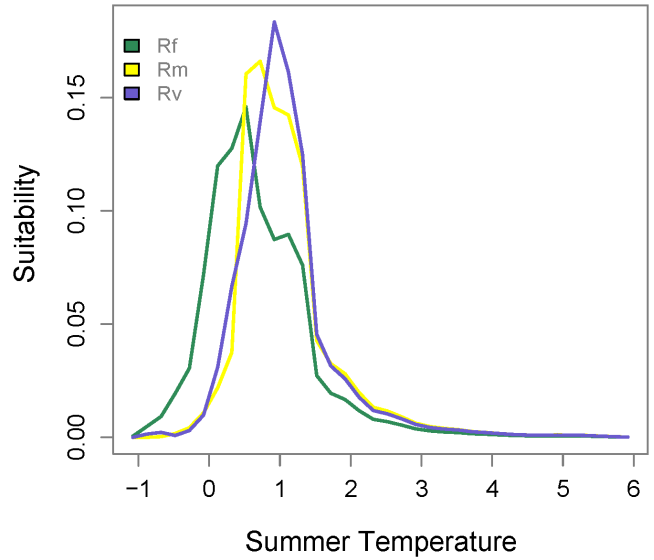
Consensus Projections:

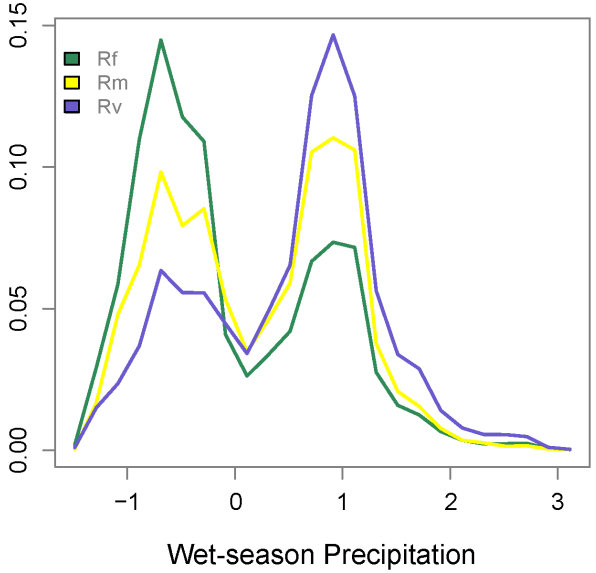


Predicted niche occupancy









Niche overlap:
two different statistics: D and I

	Rf	Rm	Rv
Rf	-	D = 0.744 $p = 0.280$	**D = 0.582** **$p < 0.001$**
Rm	I = 0.935 $p = 0.239$	-	D = 0.788 $p = 0.630$
Rv	**I = 0.843** **$p < 0.001$**	I = 0.961 $p = 0.750$	-

Niche identity test:
p value < 0.05 = niche divergence

Niche overlap (for each environmental factor):
two different statistics: D and I

		TR	DP	ST	WP
D	Rf/Rm	0.889	0.872	0.693	0.820
	Rf/Rv	0.683	0.707	0.680	0.680
	Rm/Rv	0.791	0.809	0.894	0.848
I	Rf/Rm	0.991	0.990	0.919	0.982
	Rf/Rv	0.917	0.928	0.926	0.942
	Rm/Rv	0.952	0.961	0.990	0.984

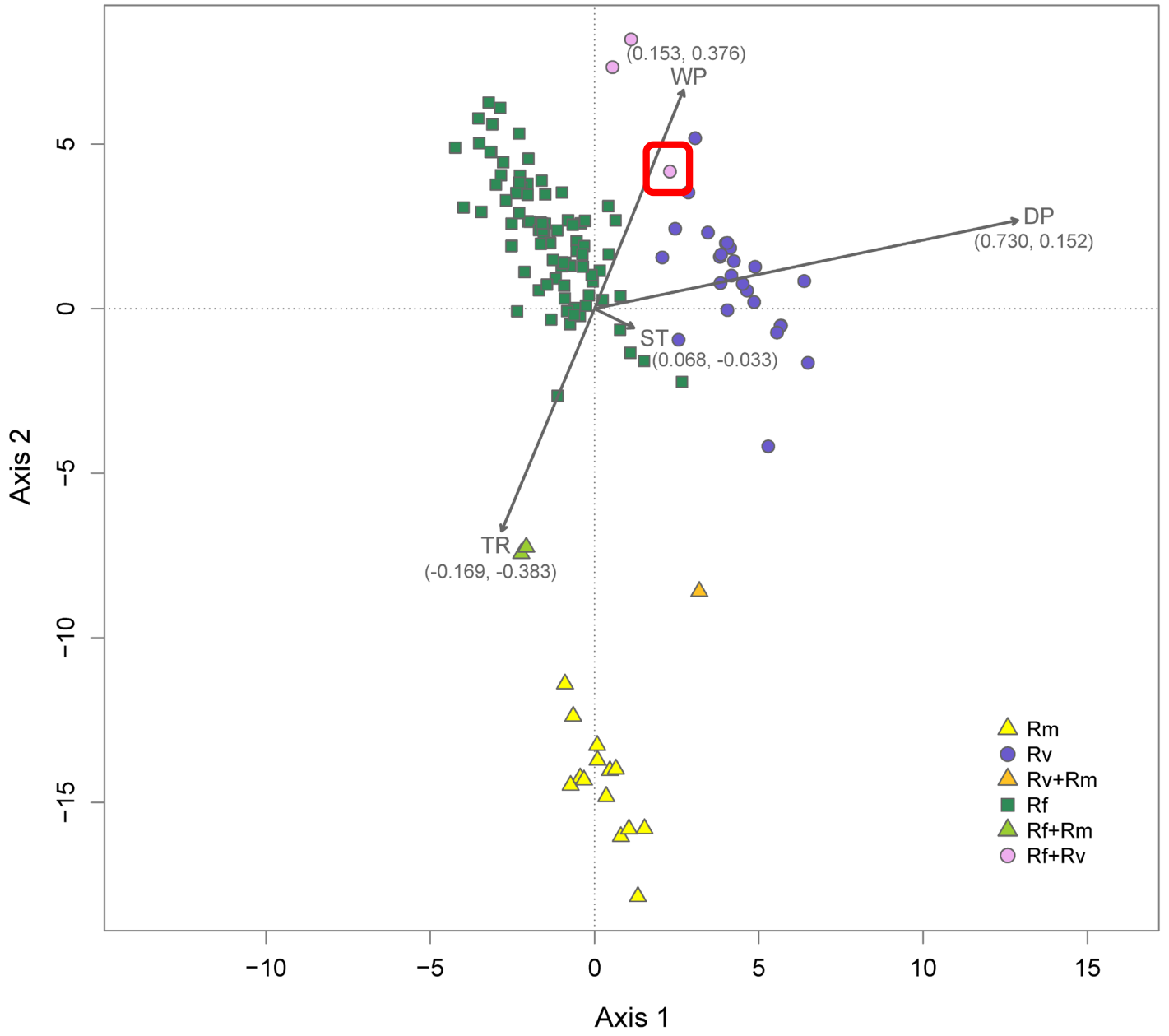
Site	Longitude	Latitude	Alt. (m)	Rf	Rm	Rv	# of Logs
1	-84.63805	34.77972	764	1	0	0	1
2	-85.06536	34.57297	450	1	0	0	1
3	-85.21630	34.64336	386	0	1	0	1
4	-85.24268	34.56515	408	1	0	0	1
5	-85.24043	34.56416	427	0	0	1	1
6	-79.38618	38.82374	528	2	0	0	2
7	-79.38506	38.82585	548	1	0	0	1
8	-79.48494	38.72694	936	1	0	0	1
9	-85.25067	34.54107	341	0	2	0	2
10	-86.07185	33.20099	301	0	0	2	2
11	-85.80658	33.47105	621	1	0	1	2
12	-85.77732	33.49199	413	0	0	1	1
13	-85.69289	33.57288	340	0	0	1	1
14	-85.59404	33.70745	360	0	0	1	1
15	-85.62832	33.67281	427	0	1	1	2
16	-85.87318	33.40451	460	2	0	0	2
17	-85.93159	33.36097	440	0	0	1	1
18	-86.02572	33.33344	313	0	1	0	1
19	-87.36352	34.23058	273	0	0	1	1
20	-85.70074	33.56059	425	1	0	0	1
21	-87.38140	34.29811	279	0	0	1	1
22	-87.33273	34.41979	321	1	0	0	1
23	-87.27680	34.17659	248	1	0	0	1
24	-85.58357	34.45540	395	1	0	0	1
25	-85.59611	34.55167	526	0	1	0	1
26	-85.67106	34.35716	392	0	1	0	1
27	-85.45730	33.96340	300	1	0	0	1
28	-85.84679	34.14676	188	1	0	0	1
29	-85.26428	34.12260	232	1	0	0	1
30	-85.81731	33.46215	485	1	0	0	1
31	-84.71650	34.15014	272	0	0	1	1
32	-83.10755	34.86200	536	2	0	0	2
33	-83.05563	35.01376	887	1	0	0	1
34	-83.08929	34.94523	744	1	0	0	1
35	-83.12841	34.80557	481	0	0	1	1
36	-83.22783	34.72782	394	2	1	0	3
37	-83.31242	34.77755	469	1	0	1	1
38	-83.29258	33.72088	132	2	0	2	4
39	-86.07201	33.20150	291	1	0	0	1
40	-84.71137	34.87866	354	1	0	0	1
41	-84.65486	34.93135	485	0	1	0	1
42	-84.33880	34.77507	730	1	0	0	1
43	-84.25093	34.68311	810	1	0	0	1
44	-83.73265	34.74192	766	0	0	1	1
45	-83.51849	35.65682	780	1	0	0	1
46	-83.35717	35.70232	653	1	0	0	1
47	-83.31077	35.52117	666	1	0	0	1
48	-83.21343	35.77140	575	1	0	0	1
49	-83.66993	35.61933	593	0	1	0	1
50	-84.69140	34.75931	804	1	0	0	1
51	-85.49764	33.91858	257	1	0	0	1
52	-84.62477	35.10896	530	0	0	1	1
53	-82.07211	36.31100	648	0	0	1	1
54	-80.54509	37.34757	1121	1	0	0	1
55	-78.78368	38.12902	814	1	0	0	1
56	-78.64308	38.29123	761	1	0	0	1
57	-78.18149	38.80508	755	1	0	0	1
58	-78.34060	38.62592	1032	1	0	0	1
59	-79.44785	38.07403	669	0	1	0	1
60	-79.34980	38.04052	784	1	0	0	1
61	-87.52677	35.39384	304	1	0	0	1
62	-84.74478	36.12452	378	1	0	0	1
63	-84.48829	36.13606	496	1	0	0	1
64	-85.49971	34.84695	315	1	0	0	1
65	-88.19299	34.60502	177	1	0	0	1
66	-84.24760	35.34883	327	1	1	0	2
67	-84.19383	35.34534	425	1	0	0	1
68	-83.59187	35.32969	593	1	0	0	1
69	-82.48742	35.59535	722	1	0	0	1
70	-82.74536	36.70494	460	1	0	0	1
71	-79.59341	37.44090	692	1	0	0	1
72	-79.94446	37.21840	473	0	0	1	1
73	-79.97707	37.98723	508	1	0	0	1
74	-79.20190	38.60225	591	1	0	0	1
75	-79.62846	38.00583	440	0	0	1	1
76	-78.91022	38.89373	589	1	0	0	1
77	-82.49056	38.81387	277	1	0	0	1
78	-84.75872	36.01773	572	1	0	0	1
79	-84.91430	36.05598	588	0	1	0	1
80	-84.71430	36.47398	479	1	0	0	1
81	-79.68214	37.47978	759	1	0	0	1
82	-84.45749	36.84983	412	1	0	0	1
83	-84.42480	36.91024	336	1	0	0	1
84	-83.76402	36.10415	399	1	0	0	1
85	-83.89043	36.37519	490	1	0	0	1
86	-83.69725	36.60349	352	1	0	0	1
87	-83.74413	36.72807	390	1	0	0	1
88	-83.21425	36.92808	767	1	0	0	1
89	-82.48692	36.49101	427	1	0	0	1
90	-82.30345	37.28378	549	0	1	0	1
91	-82.99386	37.24096	318	1	0	0	1
92	-81.53171	36.88458	731	1	0	0	1
93	-85.69242	33.57481	344	0	0	1	1
94	-84.63633	33.76154	295	1	0	0	1
95	-82.49127	35.60575	770	1	0	0	1
96	-82.71758	35.44758	1205	1	0	0	1
97	-82.58961	35.21877	809	1	0	0	1
98	-84.24123	35.34314	413	1	0	0	1
99	-84.11201	35.39665	553	1	0	0	1
100	-84.33586	35.20793	513	1	0	0	1
101	-84.45322	35.03918	614	0	0	1	1
102	-84.60815	35.14822	588	1	0	0	1
103	-80.06615	36.78941	386	1	0	0	1
104	-85.12241	35.17524	231	0	0	1	1
105	-83.74414	34.38905	356	0	0	1	1
106	-82.84724	35.85284	656	1	0	0	1
107	-82.84973	36.08371	408	1	0	0	1
108	-82.44664	36.10384	522	1	0	0	1
109	-81.27322	36.12973	373	0	1	0	1
110	-80.26266	36.39726	511	0	0	1	1
111	-81.06851	36.37937	412	0	0	1	1
112	-81.29543	35.20810	271	0	0	1	1
113	-81.85325	34.87066	191	0	0	1	1
114	-83.04584	34.49625	200	0	0	1	1
115	-83.67732	37.77913	256	1	0	0	1
116	-83.09057	37.75175	292	0	0	1	1
117	-82.72829	37.71582	213	1	0	0	1
118	-82.82529	38.05997	209	1	0	0	1
119	-82.42619	38.30313	186	1	0	0	1
120	-79.95090	36.43191	256	1	0	0	1
121	-82.38316	38.02512	402	1	0	0	1
122	-82.01469	37.88885	260	1	0	0	1
123	-81.84275	38.18754	201	1	0	0	1
124	-81.66953	38.26121	267	1	0	0	1
125	-81.57557	38.65200	241	1	0	0	1
126	-81.34470	38.77533	240	1	0	0	1
127	-80.65887	38.63269	394	1	0	0	1
128	-80.53176	38.82579	284	0	1	0	1
129	-80.83122	37.50894	550	1	0	0	1
130	-79.31298	36.78146	228	0	1	0	1
131	-79.52662	37.07664	309	0	0	1	1
132	-79.60274	37.09430	282	0	1	0	1

Only one rotting log with more than one species!

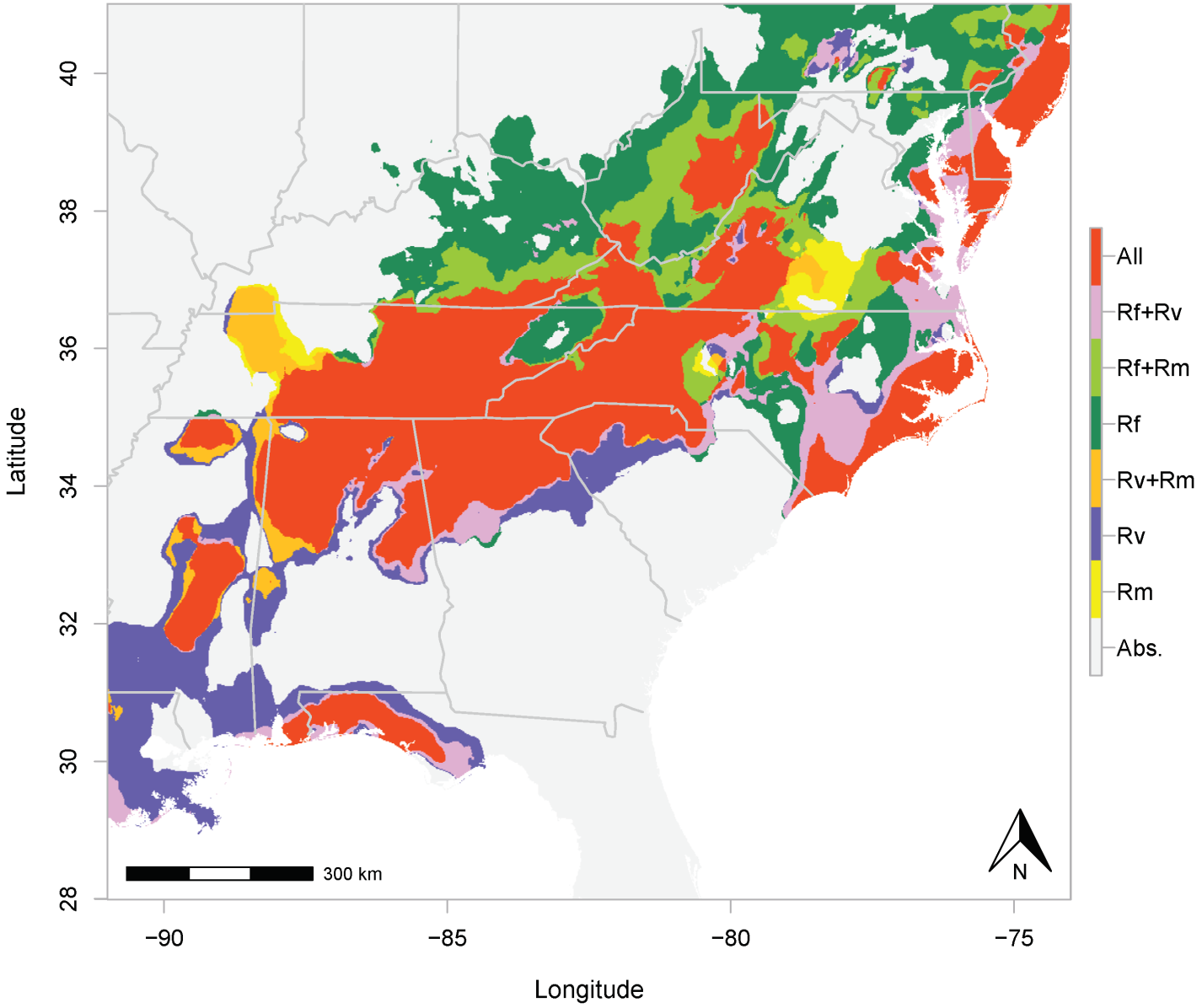
Competitive exclusion?

Geography and environment: where do termites species co-occur?

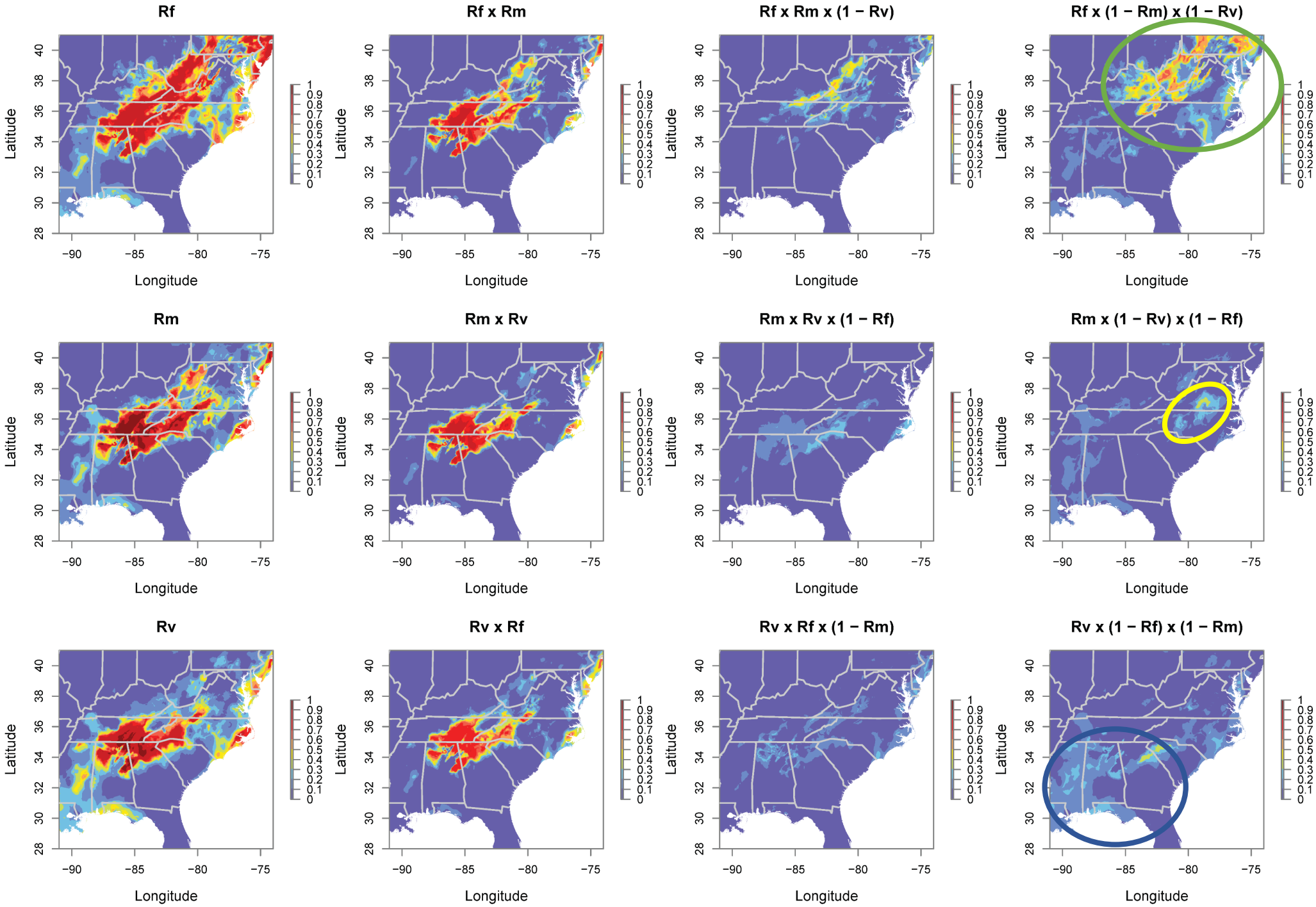
Distance-based redundancy analysis:
Fixed effect: *Environment*
Random effect: *Geography*



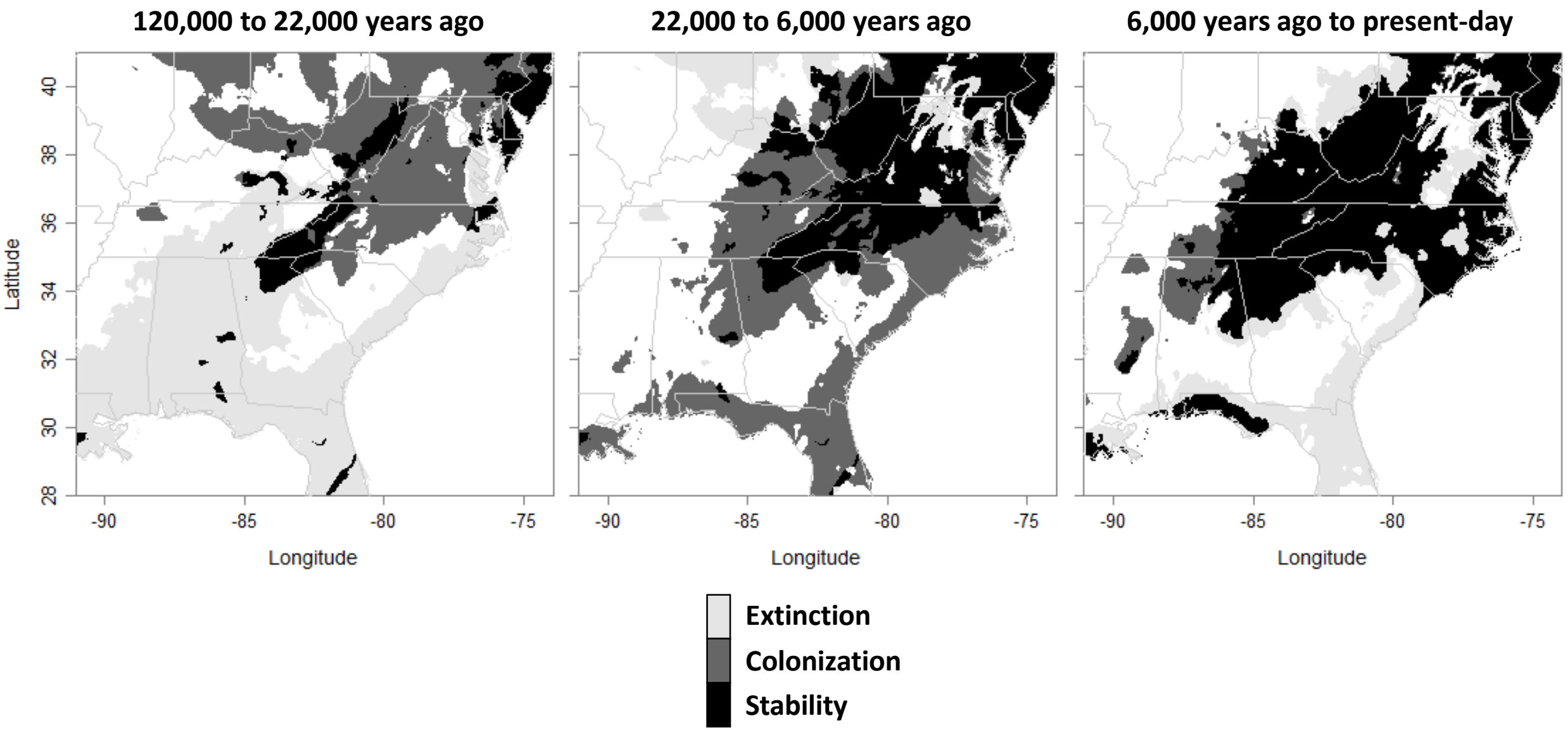
Co-occurrence of subterranean termite species



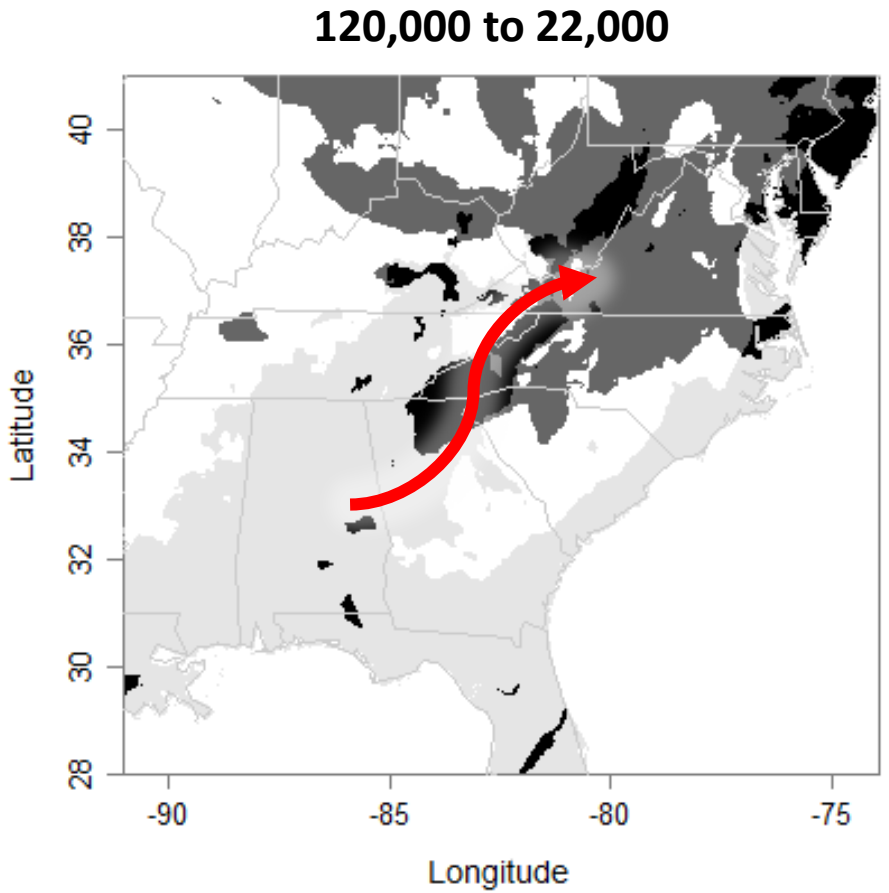
Competitive exclusion?

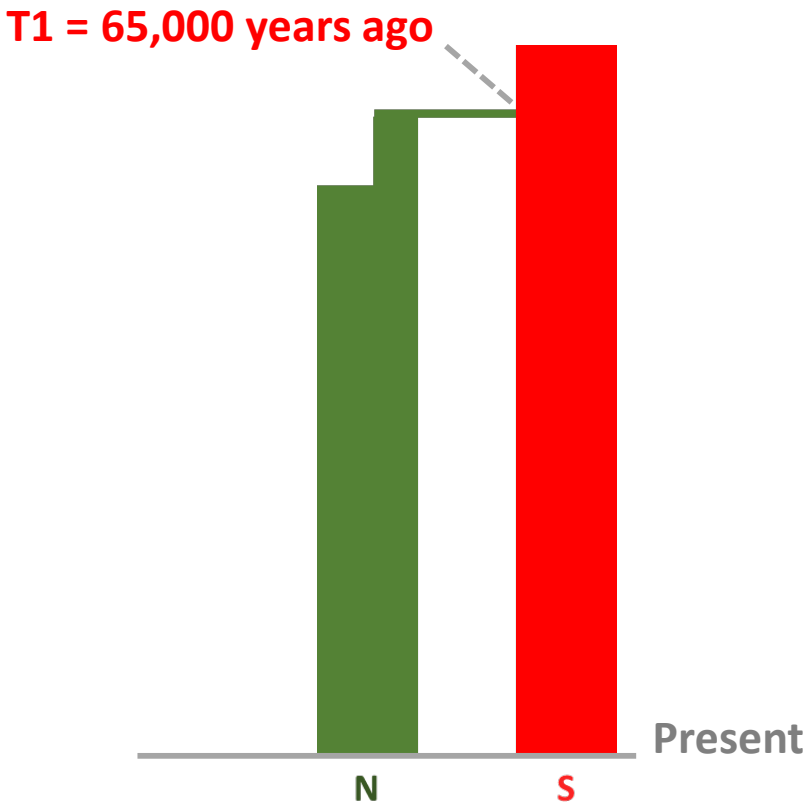


How/when did Rf spread northward?

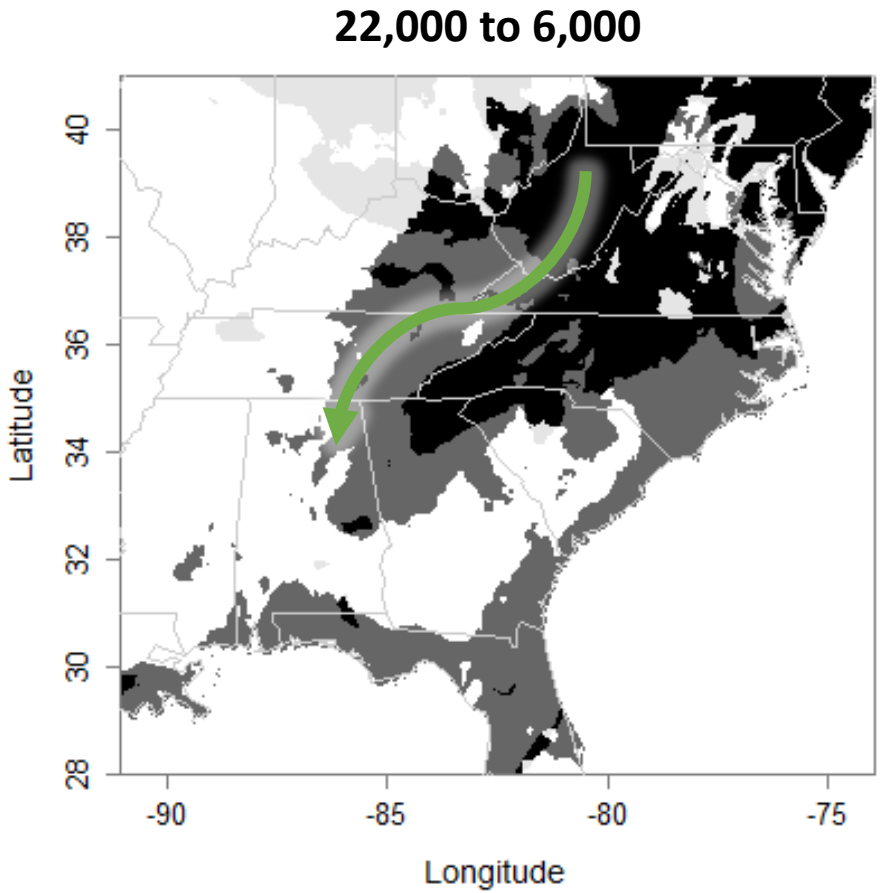


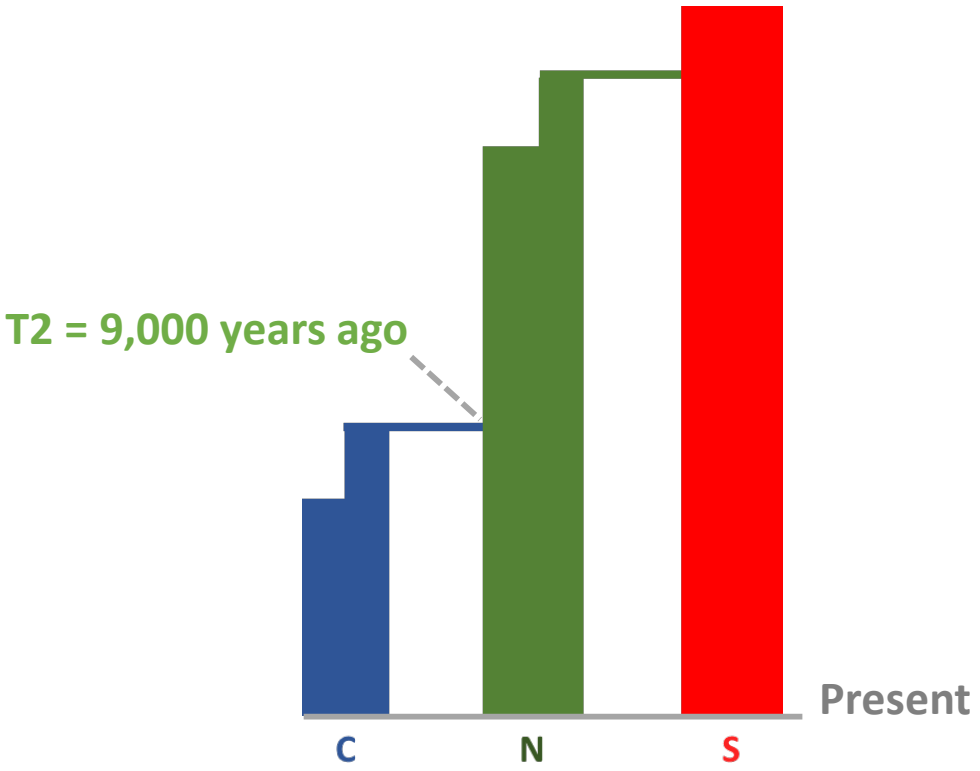
Distributional Shift: South-to-North



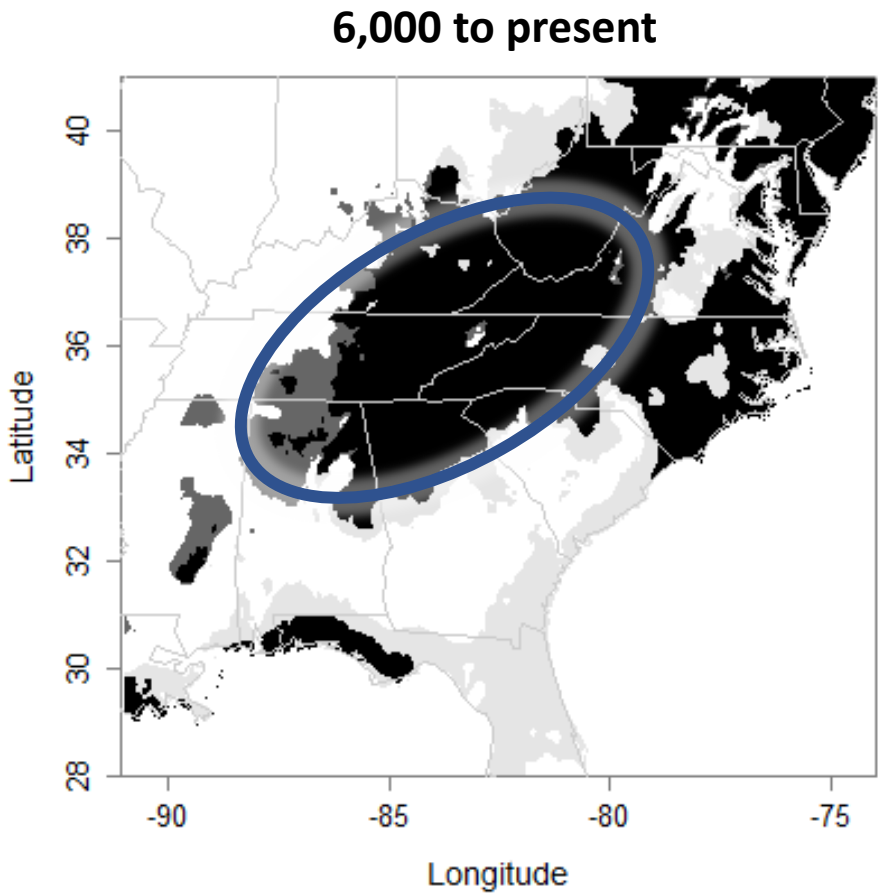


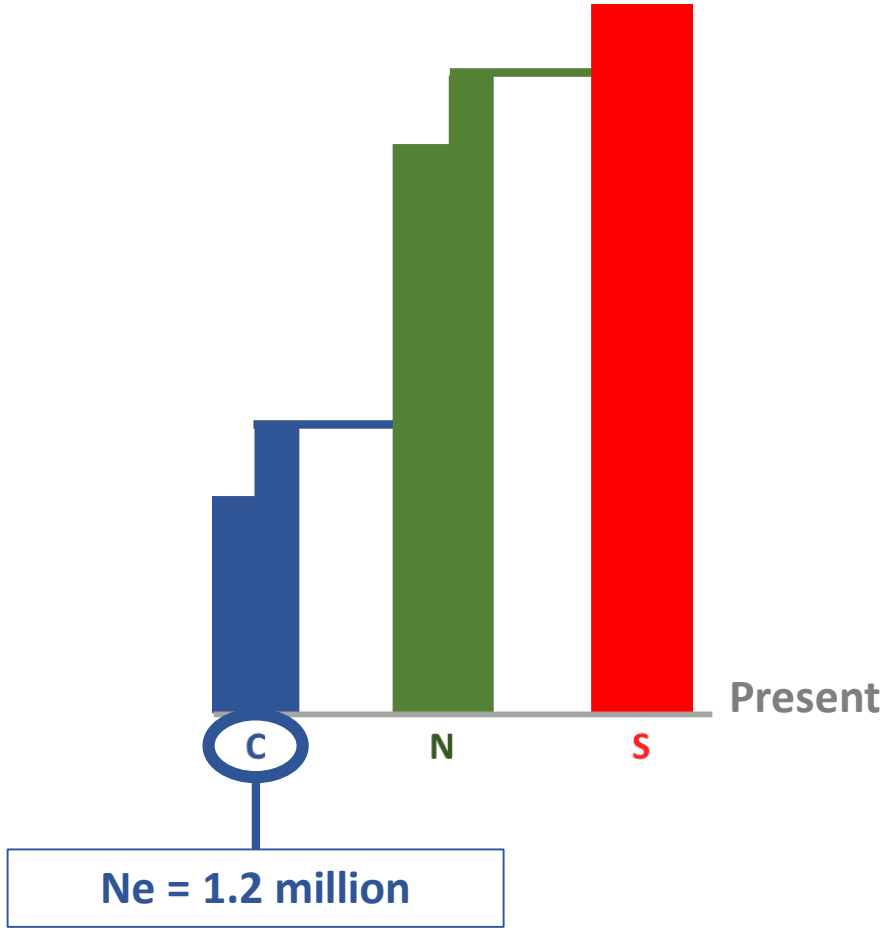
Distributional Shift: North-to-Center





Central Expansion





Why is *R. flavipes* ~~a pest~~ more successful?

Niche divergence and competitive exclusion

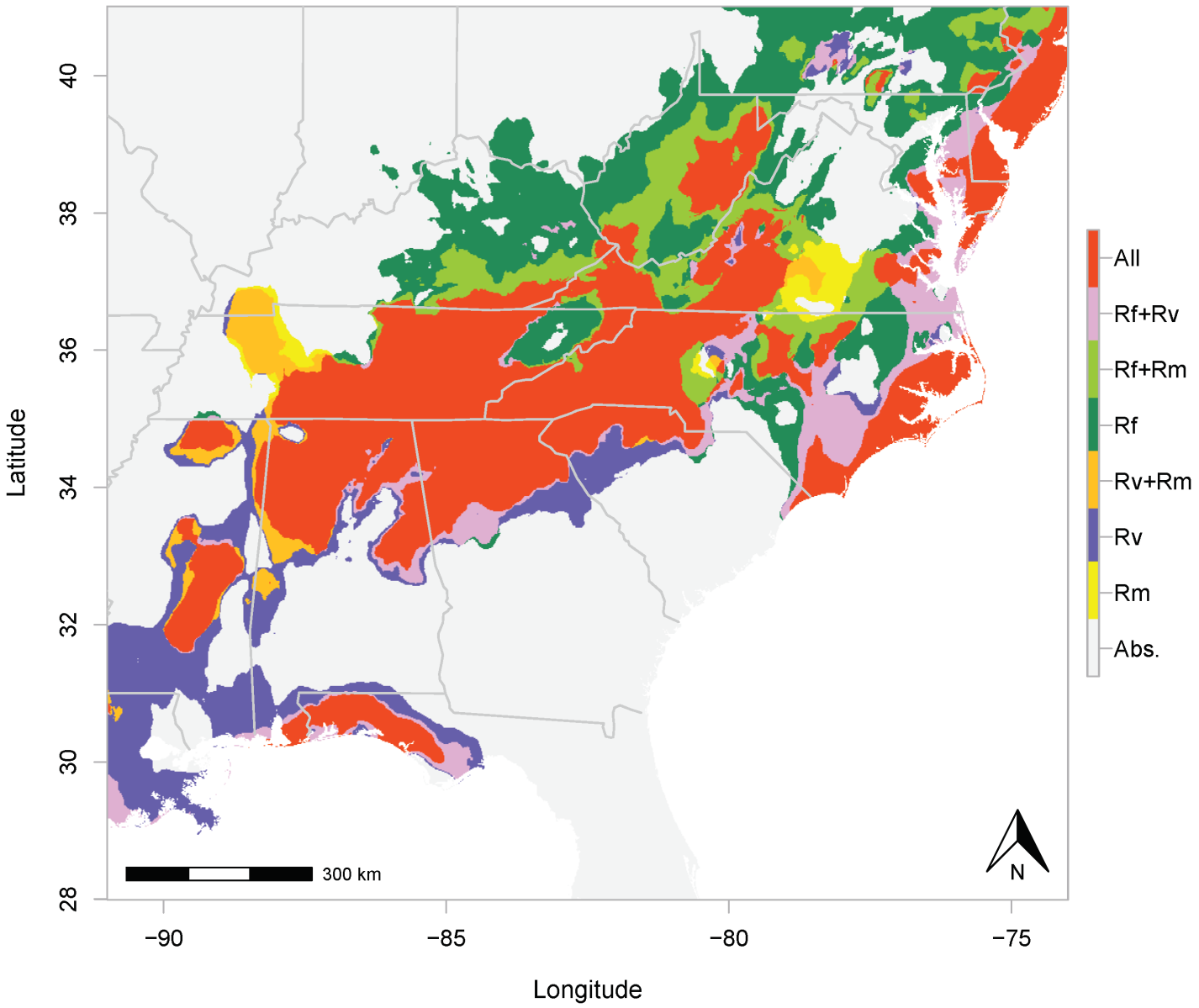
- Significant niche divergence between *R. flavipes* and *R. virginicus*
- Competitive exclusion: *R. flavipes* occurs to the exclusion of other two species in the north

Geographic distribution and abundance

- All three *Reticulitermes* species co-occur in mid-latitudes of the southern Appalachians (high dry-season precipitation)
- Broad distribution: *R. flavipes* occurs farther north (low dry- and wet-season precipitation) than other two species
- Northward distributional shift followed by geographic/demographic expansion

Acknowledgements

- Family/Field Assistants
  - Estelle Blair
  - Lucy Blair
  - Baxter & Nala
- Garrick Lab
  - Stephanie Burgess
  - Zanethia Choice Barnett
  - Lee Ann Passarella
  - Megan Stubbs
  - Rita Walsh
  - Haley Williams
- Committee
  - Dr. Erik Hom
  - Dr. Brice Noonan
  - Dr. Rebecca Symula
  - Dr. Louis Zachos (Dept. of Geol. & Geol. Eng.)
  - Dr. Rodney Dyer (VCU)


Latitude
40
38
36
34
32
30
28
−90
−85
−80
−75
Longitude
300 km
N
All
Rf+Rv
Rf+Rm
Rf
Rv+Rm
Rv
Rm
Abs.