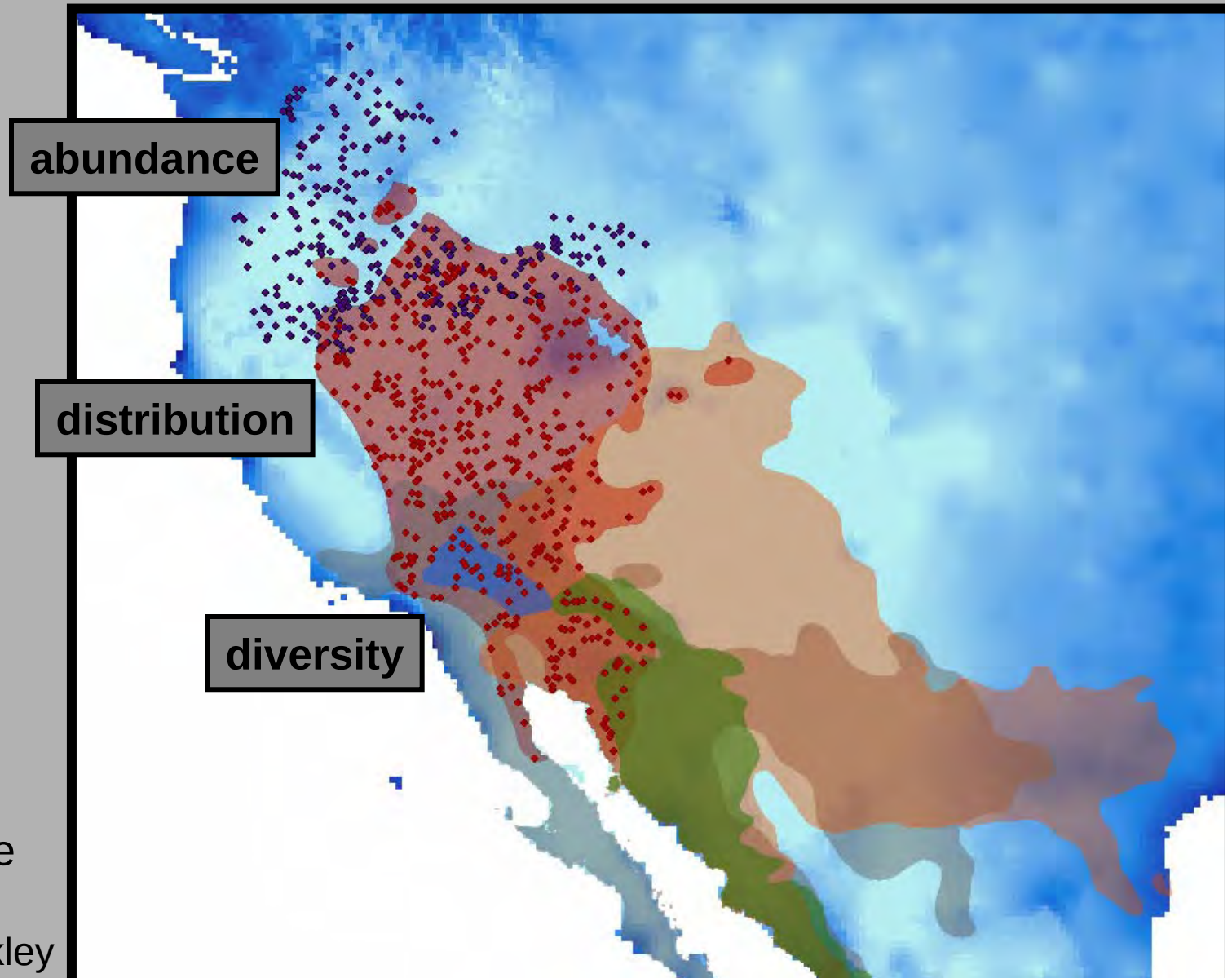


Spatial Analysis



Lauren Buckley
Santa Fe Institute

santafe.edu/~lbuckley

Space: the final frontier for ecological theory

- Kareiva 1994

Why space matters

An ecological example of spatial analysis

Georeferencing

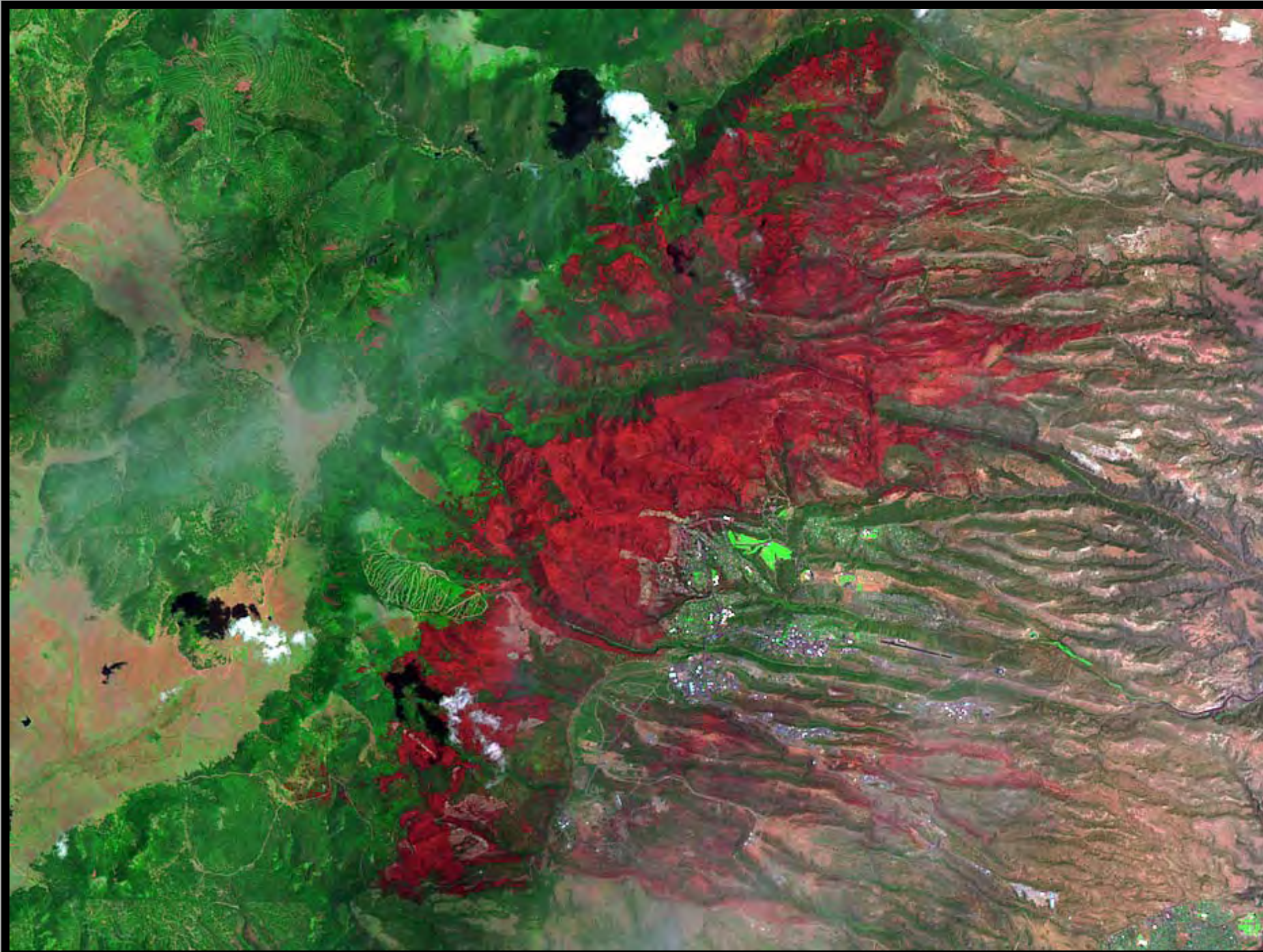
Spatial environmental data

Spatial ecological data

Data processing in GIS

Spatial statistics in R

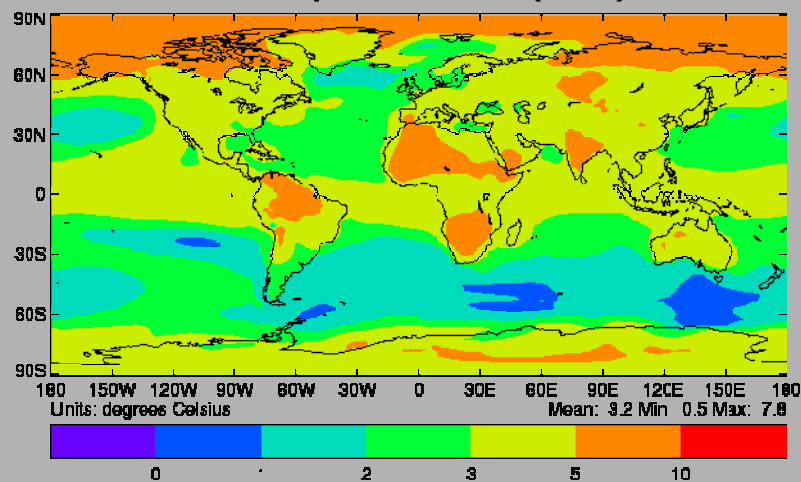




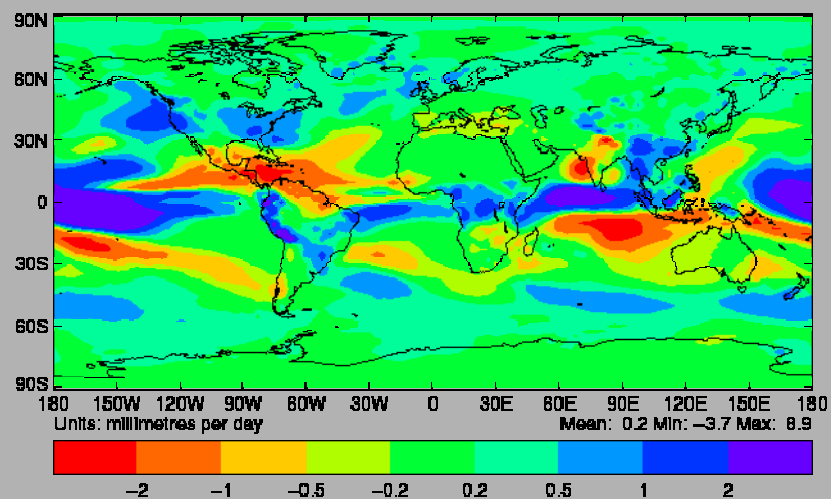




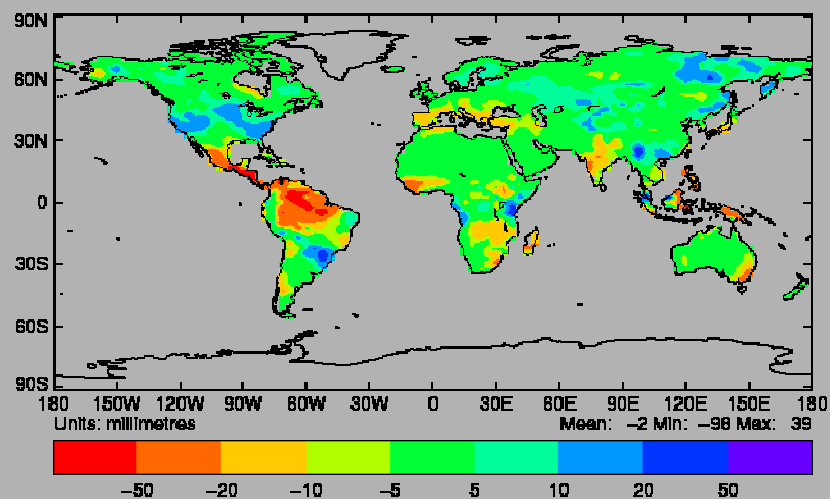
Temperature (°C)



Precipitation (mm day⁻¹)



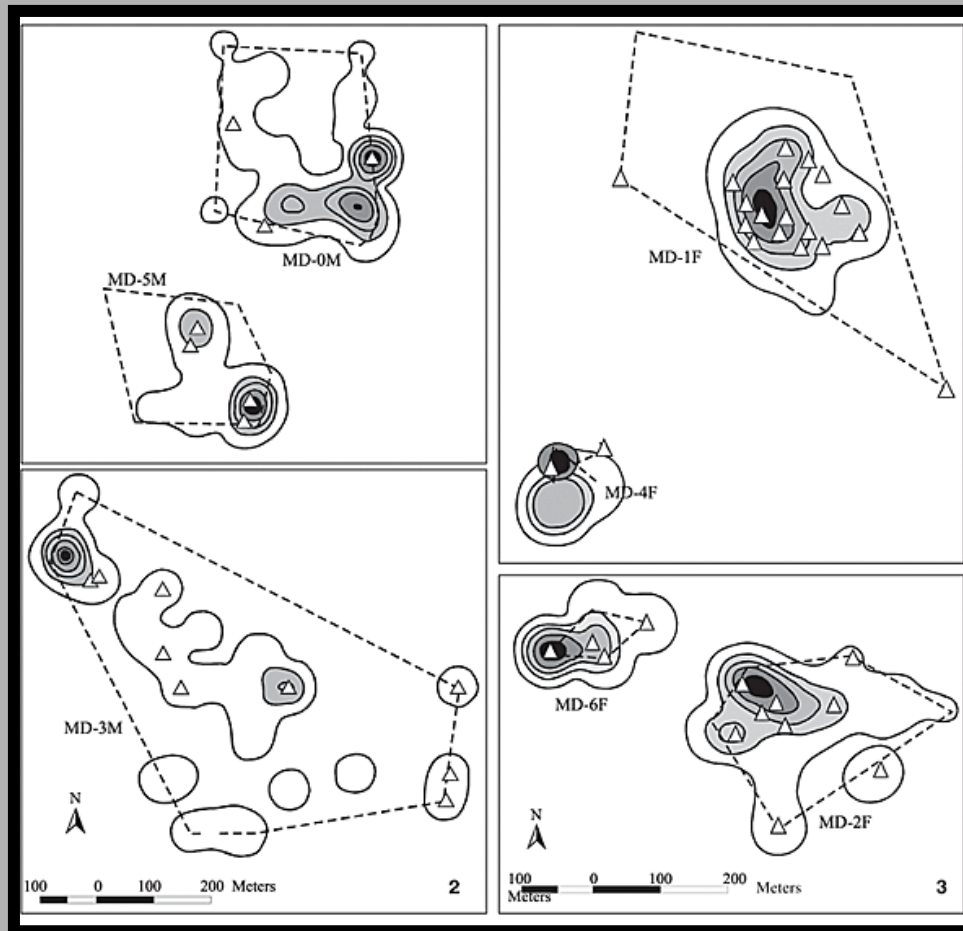
Soil moisture (mm)



1960-1990 to 2070-2100
(Hadley Center)

INDIVIDUALS:

- environmental suitability
- maximize energetic yield



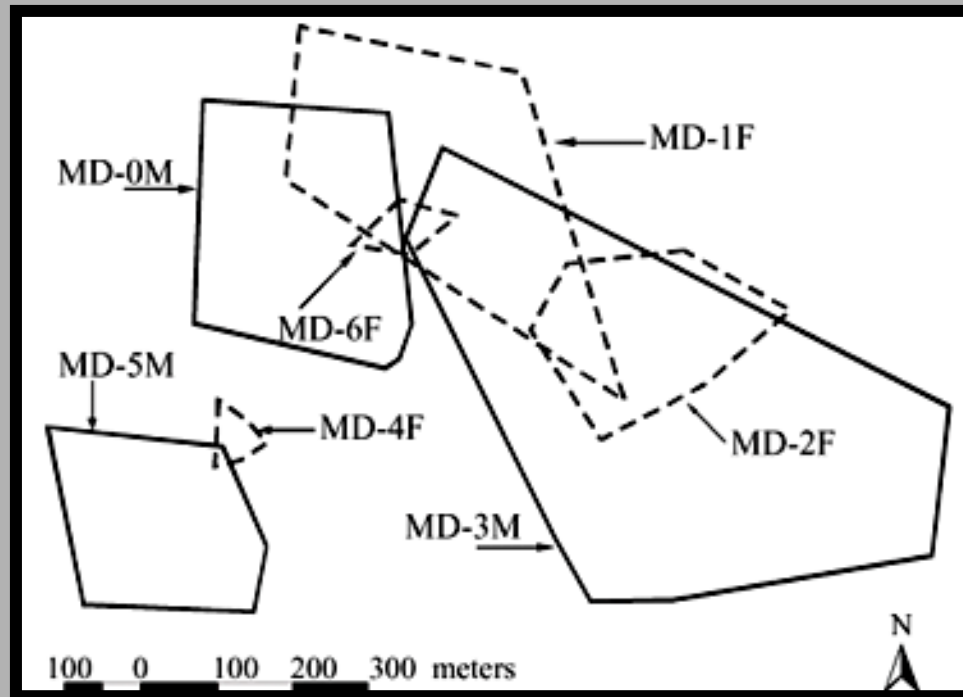
Opossums

△ Nests

(Morales and Chiarello 2005)

POPULATIONS:

- social interactions
- partition shared resources



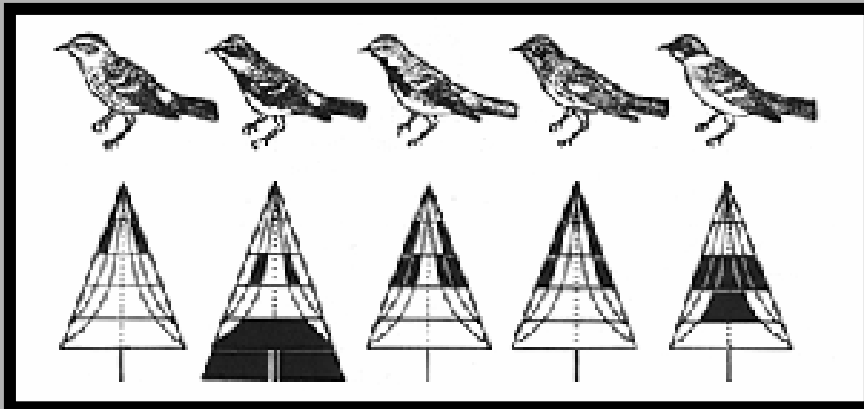
Opossums

- female
- male

(Morales and Chiarello 2005)

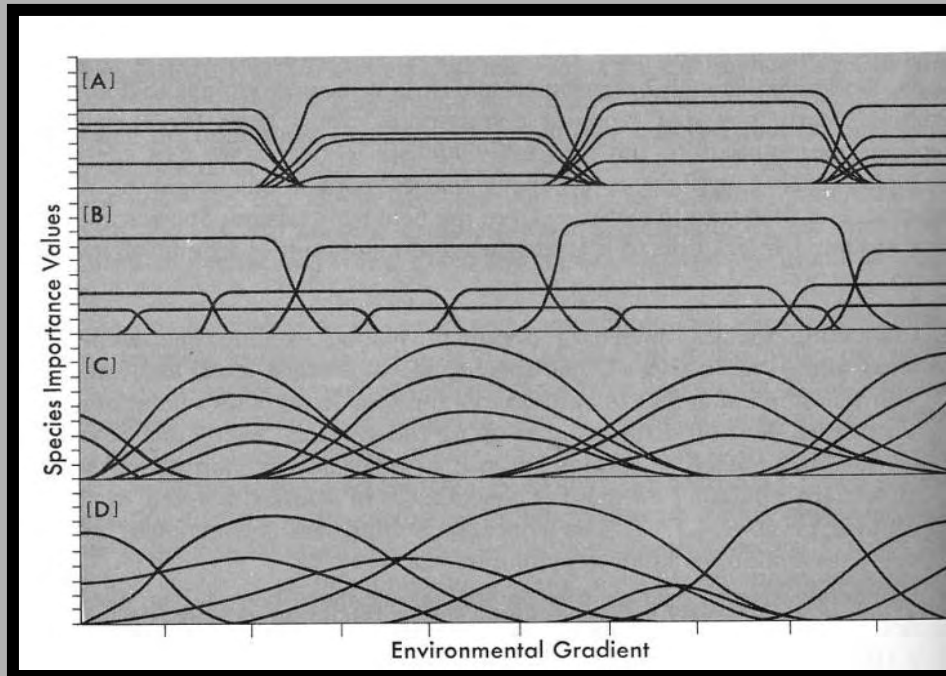
COMMUNITIES:

- species partition space
- species partition resources



Warblers

(MacArthur 1958)



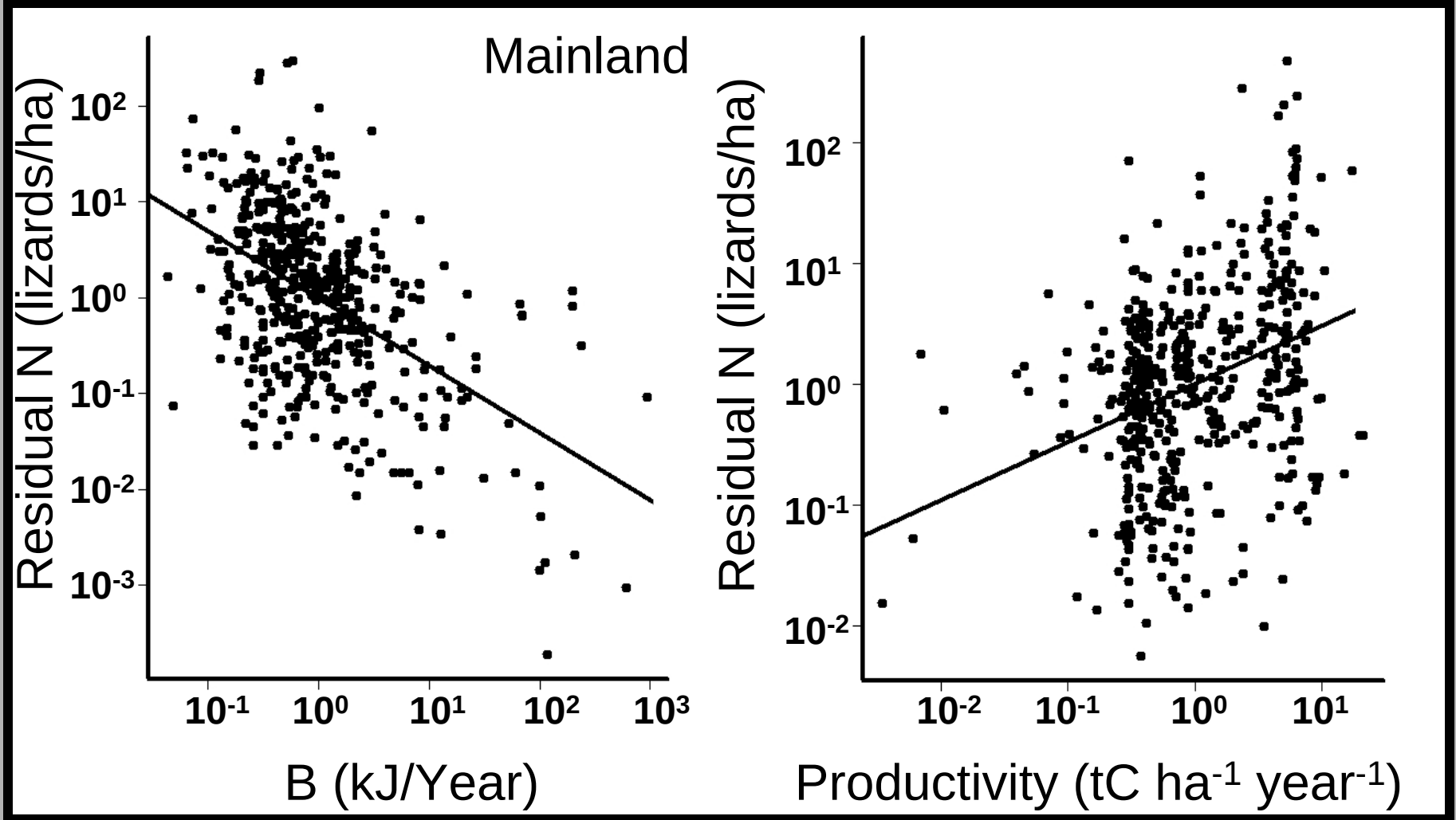
Plants

(Whittaker 1975)

Determinants of population density?

Buckley LB and Jetz W. 2007. Insularity and the determinants of lizard population density. *Ecology Letters* 10:481-489.

Environmental constraints

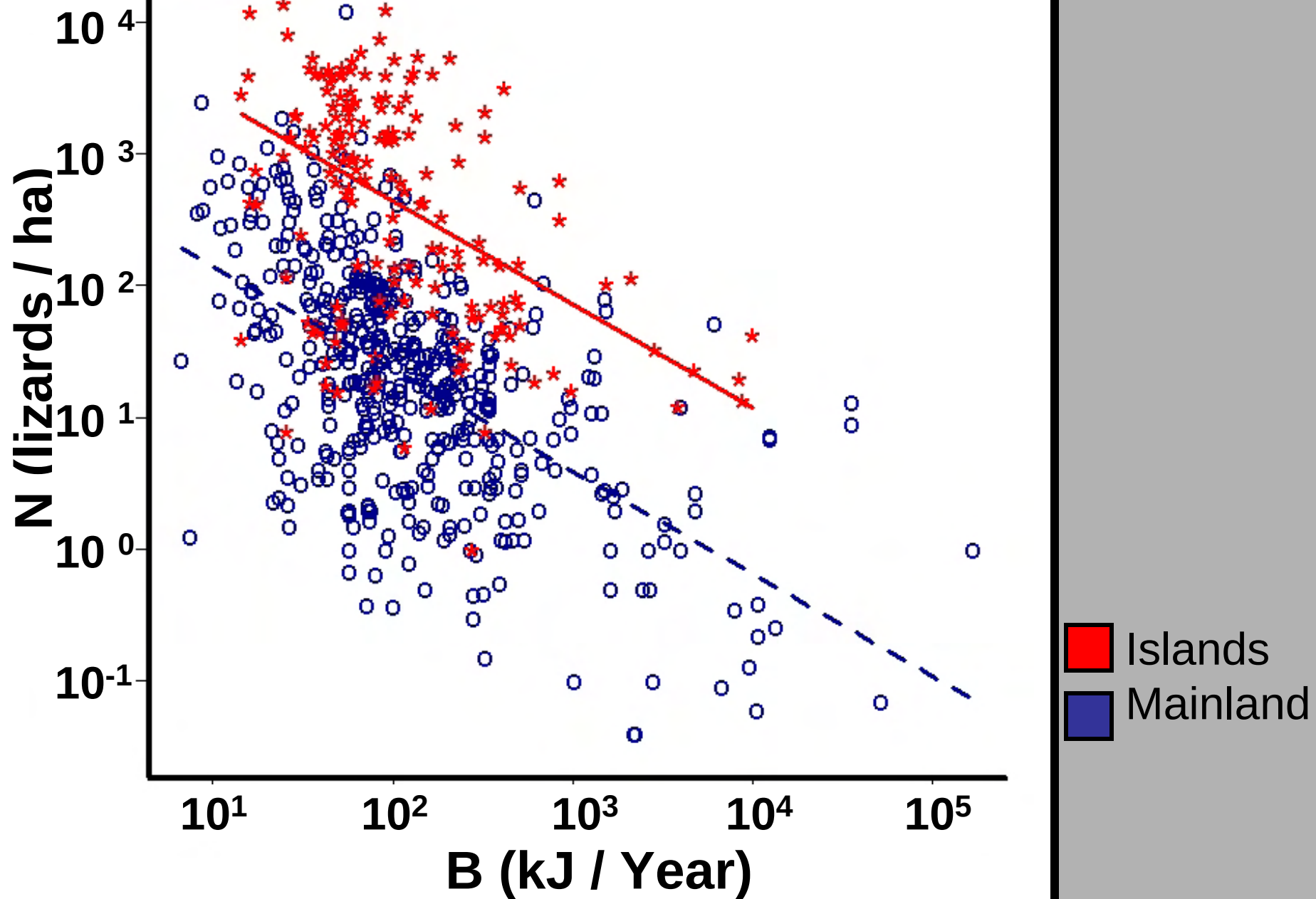


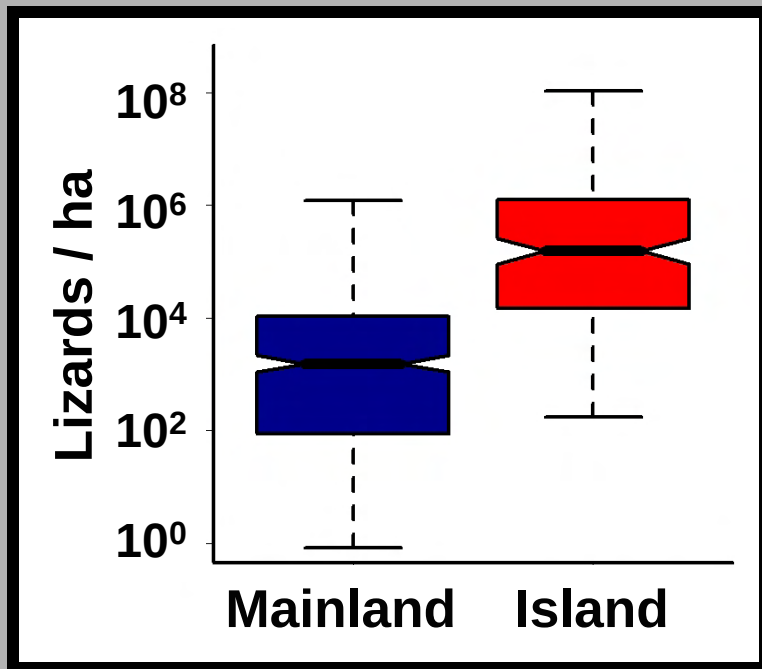
$$B \propto M^{3/4} e^{-E/kT} \text{ (Gillooly et al. 2001)}$$

M: body mass (g) T: temperature (K)

B: energy use / individual (kJ yr⁻¹)

Environmental constraints

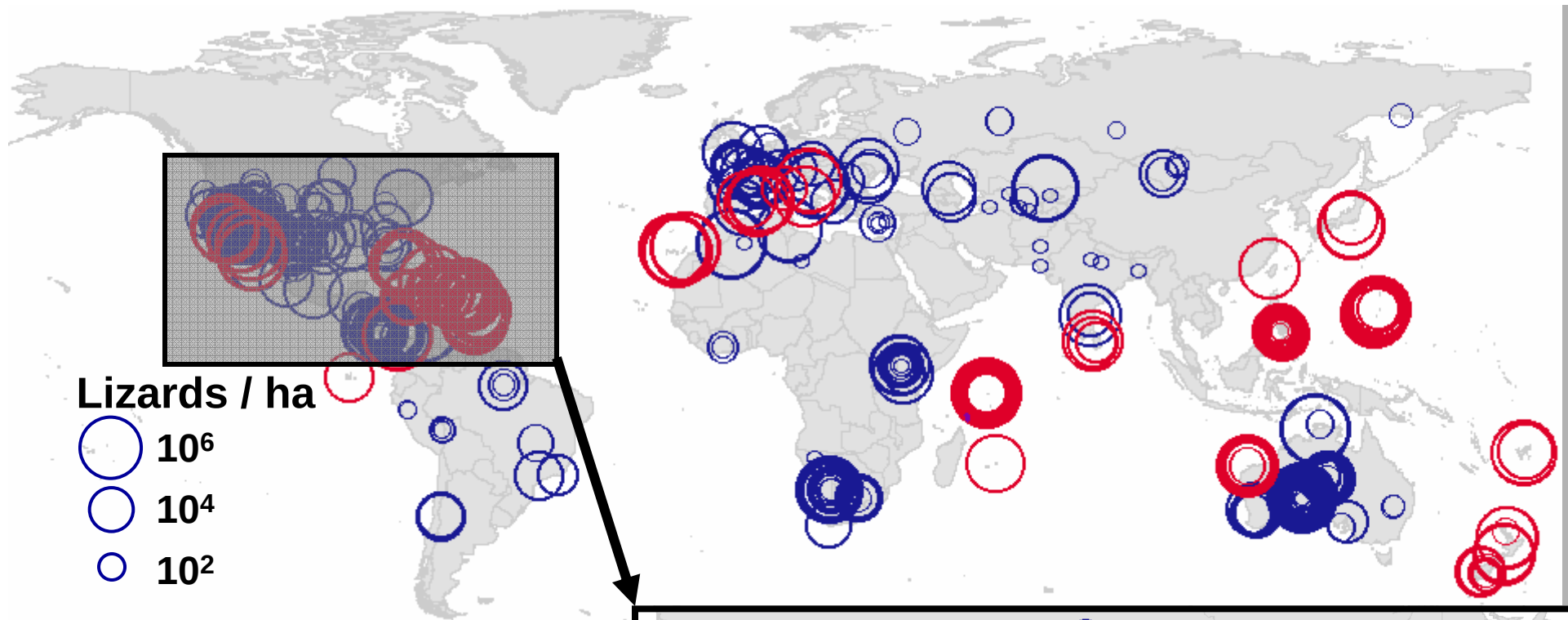




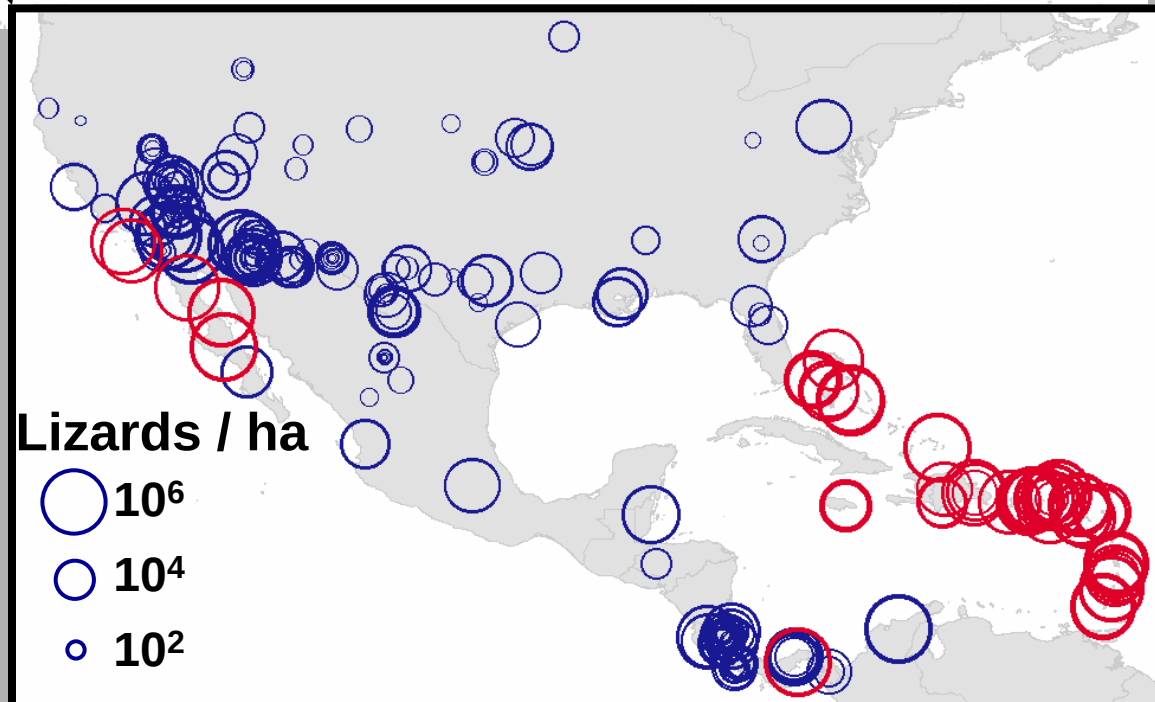
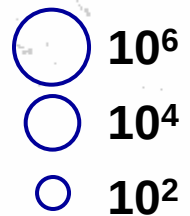
for 10g lizard

at 20°C and $0.60 \text{ tC ha}^{-1}\text{yr}^{-1}$ NPP

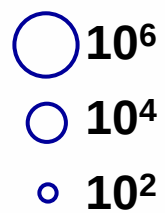
$$N_{\text{island}} \approx 10^{1.07 \pm 0.08} N_{\text{mainland}}$$



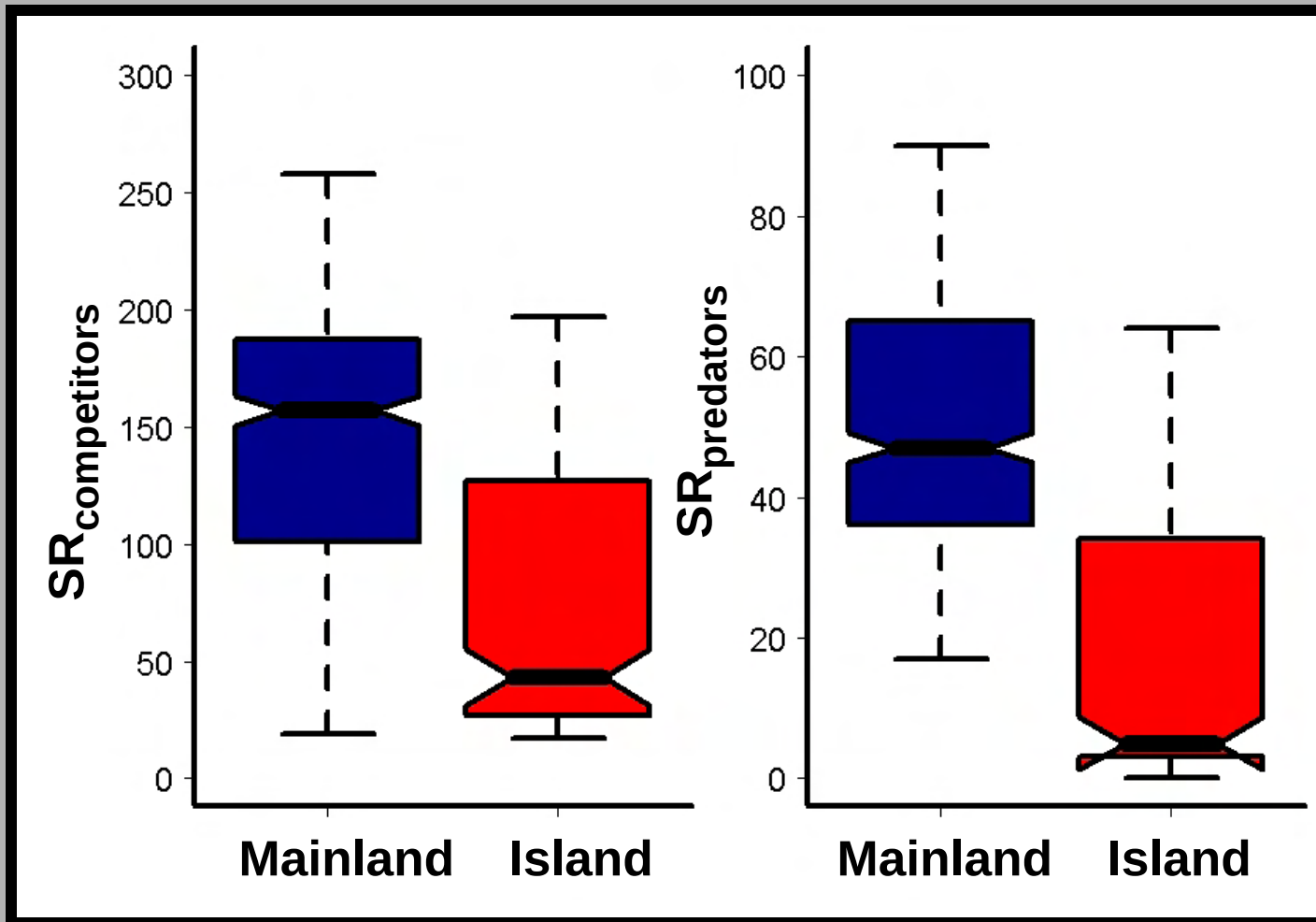
Lizards / ha



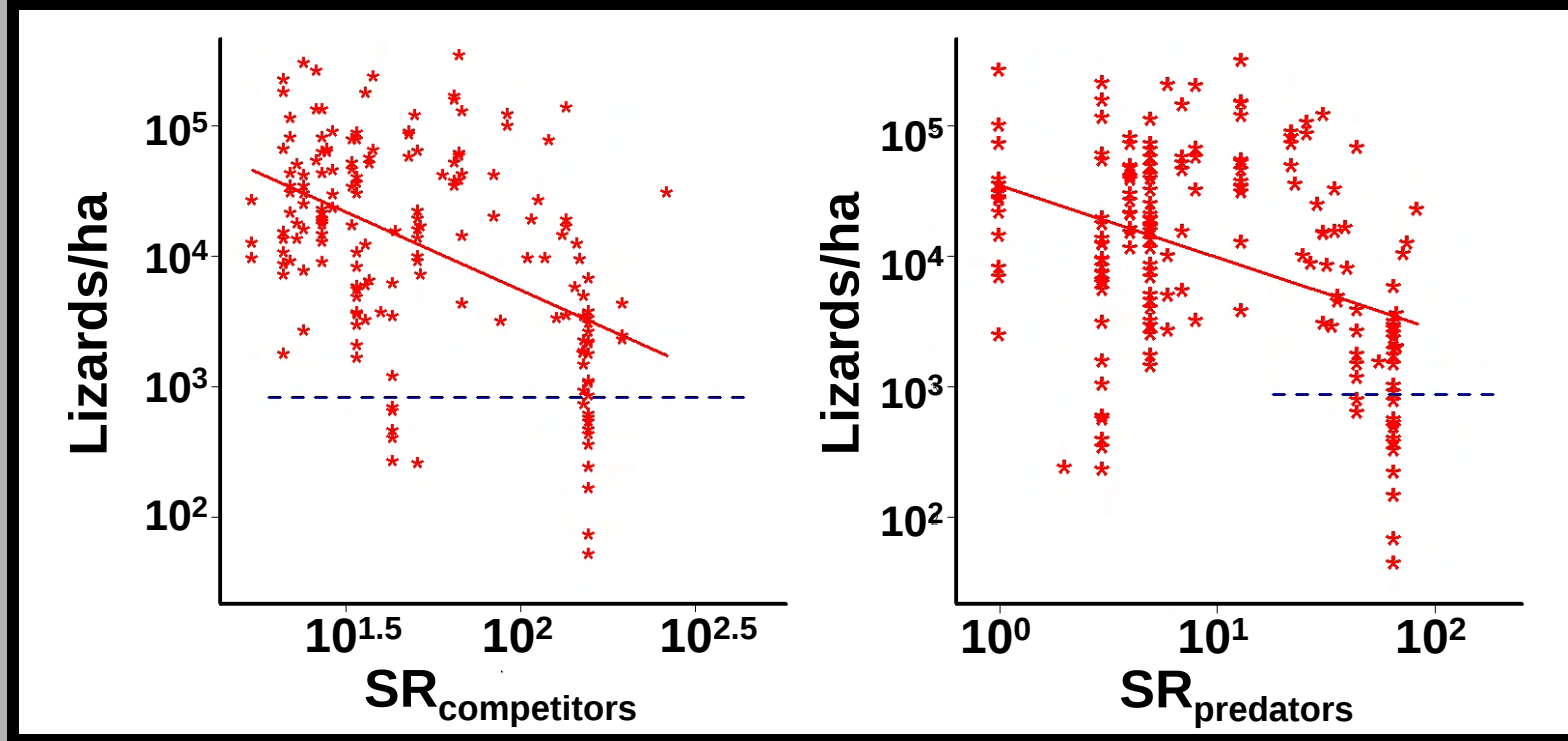
Lizards / ha



Ecological constraints



Ecological constraints



(controlled for rates of energy use and supply)

Effect of competition > predation

Effect of $SR_{\text{insectivorous birds}} > SR_{\text{lizards}}$



Required data

lizard population density data

spatial locations of populations

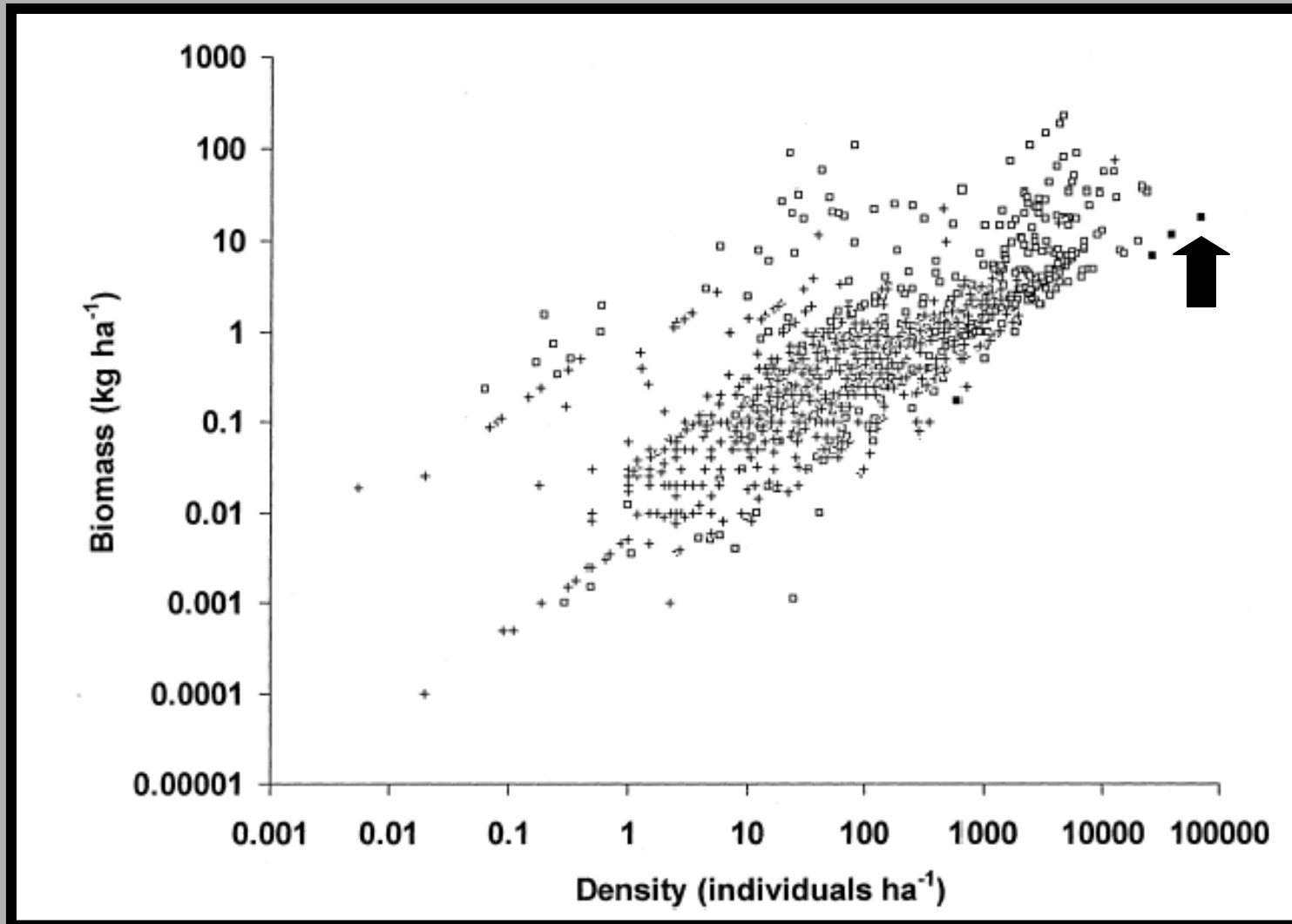
environmental data at location (temperature, productivity)

ecological constraints at location (competition, predation)

Lizard population density data

SHORT COMMUNICATION

The densest terrestrial vertebrate



Database

Microsoft Access

File Edit View Insert Format Records Tools Window Help

Type a question for help

IslandDensity1 (30: Database | Access 2000 file format)

Open Design New

Objects

Tables

Queries

Forms

Reports

Pages

Macros

Module

Name	Description	Modified	Created	Type
Create table in Design view				
Create table by using wizard				
Create table by entering data				
Locations		11/9/2005 6:35:28 PM	9/9/2005 8:52:32 AM	Table
DensitiesInitialRODDA		9/9/2005 9:04:23 AM	9/9/2005 9:04:22 AM	Table
References		9/9/2005 11:24:55 ...	9/9/2005 10:49:37 ...	Table
AdditionalAssemblageData		9/25/2005 2:38:47 PM	9/9/2005 4:48:01 PM	Table
DensityFilteredGIS		8/11/2006 1:32:53 PM	9/26/2005 12:01:4...	Table

DensitiesInitialRODDA: Table

ID	Species	Reference	Venue	IslMainl	SampMeth	NumPe
1	Acanthodactylus erythrurus	Seva et al. 1982	Europe, Spain, Alicante, 1976-80	m	total enumeratic	
2	Acanthodactylus scutellatus	Busack 1973	Africa, Tunisia, grazed plot, 1972	m	total enumeratic	
3	Acanthodactylus scutellatus	Busack 1975	Africa, Tunisia, Medenine, 1972	m	quadrats	
4	Acanthodactylus scutellatus	Busack 1973	Africa, Tunisia, ungrazed plot, 1972	m	total enumeratic	
5	Agama atra	Burrage 1974	Africa, S. Africa, Dekelders Cape, Coastal Cliffs, 1971-72	m	total enumeratic	
6	Agama atra	Burrage 1974	Africa, S. Africa, Dekelders Cape, Inland rock, 1971-72	m	total enumeratic	
7	Ailuronyx sechellensis	Brooke and Houston 1983	Indian Ocean, Seychelles, Cousin Isl., 1978-79	i	quadrats	
8	Ailuronyx sechellensis	Evans and Evans 1980	Indian Ocean, Seychelles, Praslin, Intermediate forest, 1976	i	quadrats	
9	Ameiva ameiva	Duellman 1987	S. America, Peru, Cuzco Amazonico, 1986	m	strip transect	
10	Ameiva ameiva	Duellman 1987	S. America, Peru, Cuzco Amazonico, camp clearing, 1986	m	strip transect	
11	Ameiva exsul	Rodda et al. 2001	Atlantic Ocean Isl, West Indies, Lesser Antilles, Brit. Virgin Isl., Guana Isl	i	total enumeratic	
12	Ameiva festiva	Scott 1976	C. America, Costa Rica, La Selva, 1970-1	m	quadrats	
13	Ameiva festiva	Lieberman 1986	C. America, Costa Rica, La Selva, Old Cacao, 1972-3	m	quadrats	
14	Ameiva festiva	Lieberman 1986	C. America, Costa Rica, La Selva, Primary Forest, 1972-3	m	quadrats	
15	Ameiva fuscata	Bullock and Evans 1990	W. Indies, Lesser Antilles, Dominica, Cabrits, dry scrub woodland, 1984	i	quadrats	
16	Ameiva fuscata	Bullock and Evans 1990	W. Indies, Lesser Antilles, Dominica, Canefield Est., cultivated, 1984	i	quadrats	
17	Ameiva fuscata	Bullock and Evans 1990	W. Indies, Lesser Antilles, Dominica, Canefield Est., dry scrub woodland,	i	quadrats	
18	Ameiva fuscata	Bullock and Evans 1990	W. Indies, Lesser Antilles, Dominica, Delices, litoral woodland, 1984	i	quadrats	
19	Ameiva fuscata	Bullock and Evans 1990	W. Indies, Lesser Antilles, Dominica, La Plaine, cultivated, 1984	i	quadrats	
20	Ameiva fuscata	Bullock and Evans 1990	W. Indies, Lesser Antilles, Dominica, Petit Coulibri, cultivated, 1984	i	quadrats	
21	Ameiva fuscata	Bullock and Evans 1990	W. Indies, Lesser Antilles, Dominica, Petit Coulibri, dry scrub woodland, 1	i	quadrats	
22	Ameiva fuscata	Bullock and Evans 1990	W. Indies, Lesser Antilles, Dominica, Portsmouth, cultivated, 1984	i	quadrats	
23	Ameiva fuscata	Bullock and Evans 1990	W. Indies, Lesser Antilles, Dominica, Turtle Point, cultivated, 1984	i	quadrats	
24	Ameiva plei	Censky 1996	W. Indies, Lesser Antilles, Anguilla, 1991	i	mark-recapture	
25	Ameiva plei	Censky 1996	W. Indies, Lesser Antilles, Dog, 1992	i	mark-recapture	
26	Ameiva polops	Meier et al. 1993	W. Indies, Lesser Antilles, US Virgin Islands, St. Croix, Green Cay, 1987	i	mark-recapture	
27	Ameiva quadrilineata	Hirth 1963	C. America, Costa Rica, Tortuguero, 1959-61	m	total enumeratic	
28	Anguis fragilis	Smith 1990 in Platenburg and	Europe, England, Dorset	i	mark-recapture?	
29	Anniella pulchra	Miller 1944	N. America, US, CA, Point Pinos, Second Islet, 1939-40	i	mark-recapture	
30	Anolis acutus	Ruibal and Philibosian 1974	W. Indies, Lesser Antilles, St. Croix, Sprat Hall	i	mark-recapture	
31	Anolis aeneus	Roughgarden et al. 1983; Rou	W. Indies, Lesser Antilles, Grenada, Beach Forest, 1976	i	mark-recapture	
32	Anolis aeneus	Roughgarden et al. 1983; Rou	W. Indies, Lesser Antilles, Grenada, Junction, 1976	i	mark-recapture	

Georeferencing

A screenshot of the BioGeomancer website's georeferencing form, viewed in a Mozilla Firefox browser window. The browser's address bar shows 'http://classic.biogeomancer.org/'. The page features the 'BioGeoMancer' logo and a 'Peabody Museum NATURAL HISTORY' logo. The main heading is 'Georeference a single locality'. Below this, there are four input fields for location data: 'Country' (United States), 'State or province' (New Mexico), 'Admin Level 2' (Santa Fe), and 'Locality' (Santa Fe Baldy). To the right of these fields, there is a note: 'e.g., county, shire, municipio. Leave blank if not known.' At the bottom, there is a 'Format results as:' section with radio buttons for 'html' (selected), 'map', and 'xml'. A 'Submit Query' button is located at the bottom center of the form.

BioGeoMancer

[Home](#) | [Documentation](#) | [Batch forms](#) | [Partners](#)

Georeference a single locality

Country	United States
State or province	New Mexico
Admin Level 2	Santa Fe
Locality	Santa Fe Baldy

e.g., county, shire, municipio.
Leave blank if not known.

Format results as: ☒ html ☐ map ☐ xml

Georeferencing

BioGeoMancer results - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://georef.peabody.yale.edu/cgi-bin/bgm-0.2/sample-cgi-form biogeomancer

Getting Started Latest Headlines Northern New Mexic...

BioGeoMancer results

Your query:

Country: *United States*
Admin Lev 1: *New Mexico*
Admin Lev 2: *Santa Fe*
Locality: *Santa Fe Baldy*

Results Summary:

multiPointMatch:	MULTIPOINT(-105.75778 35.83222)
boundingBoxCentroidErrorRadius:	0.0
countryName:	United States
countryBoundingBox:	-180 -2. -15.5 90
queryAdm2:	Santa Fe
boundingBox:	BOX(-105.75778 35.83222, -105.75778 35.83222)
queryCountry:	United States
weightedCentroid:	POINT(-105.75778 35.83222)
boundingBoxCentroid:	POINT(-105.75778 35.83222)
matchedRecordCount:	1
queryId:	
queryAdm1:	New Mexico
boundingBoxCentroidErrorRadiusUnits:	km
queryString:	Santa Fe Baldy

Specimen data

GBIF Biodiversity Data Portal - Mozilla Firefox

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http://www.asia.gbif.net/portal/ecat_search.jsp?termsAccepted=true herpnet

Getting Started Latest Headlines Northern New Mexic...

HOME | GBIF | BROWSE TAXONOMY | SEARCH | DATA PROVIDERS | COUNTRIES | DATA USE

GBIF Prototype data portal
Global Biodiversity Information Facility

Search

Search for name: Country/Territory:

Selecting a country limits results to those taxa which specimen/observation records show have been identified from the country concerned.

☒ Search by scientific name (any rank) ☒ Find names starting with search string (minimum 3 characters)

☐ Search by common name in any language ☐ Find names containing search string (minimum 3 characters)

☐ Search by English name ☐ Find exact matches

[Contact info](#) | [Webmaster](#)

Specimen data

GBIF Biodiversity Data Portal - Mozilla Firefox

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http://www.asia.gbif.net/portal/ecat_browser.jsp?taxonKey=235052&countryKey=0&resourceKey=0 herpnet

Getting Started Latest Headlines Northern New Mexic...

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GBIF Prototype data portal
Global Biodiversity Information Facility

Species: *Sceloporus undulatus* (Bosc and Daudin in Sonnini and Latreille, 1801)

Eastern fence lizard / Fence lizard / Plateau lizard / Prairie lizard

Status of name

Status	Authority	Details	User feedback
Accepted name	Catalogue of Life: Integrated Taxonomic Information System	+	✉

Synonyms

Name	Synonym type	Authority	Details	User feedback
<i>Stellio undulatus</i> Bosc and Daudin in Sonnini and Latreille, 1801	Unambiguous synonym	Catalogue of Life: Integrated Taxonomic Information System	+	✉

Higher taxonomy

Rank	Name	Authority	Details	User feedback
Kingdom	Animalia			
Phylum	Chordata			
Class	Reptilia			
Order	Squamata			
Family	Phrynosomatidae	Catalogue of Life: Integrated Taxonomic Information System	+	✉
Genus	Sceloporus			

Subordinate taxa

Rank	Name	Authority	Details	User feedback
Subspecies	<i>Sceloporus undulatus consobrinus</i> Baird and Girard, 1853	Catalogue of Life: Integrated Taxonomic Information System	+	✉
Subspecies	<i>Sceloporus undulatus cowlesi</i> Lowe and Norris, 1956	Catalogue of Life: Integrated Taxonomic Information System	+	✉
Subspecies	<i>Sceloporus undulatus elongatus</i> Stejneger, 1890	Catalogue of Life: Integrated Taxonomic Information System	+	✉
Subspecies	<i>Sceloporus undulatus erythrocheilus</i> Maslin, 1956	Catalogue of Life: Integrated Taxonomic Information System	+	✉

Specimen data

GBIF Biodiversity Data Portal - Mozilla Firefox

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 http://www.asia.gbif.net/portal/ecat_browser.jsp?taxonKey=235052&countryKey=0&resourceKey=0  herpnet

Getting Started Latest Headlines Northern New Mexic...

Language	Name	Authority	Details	User feedback
English	Eastern fence lizard	Catalogue of Life: Integrated Taxonomic Information System		
English	Fence lizard	Catalogue of Life: Integrated Taxonomic Information System		
English	Plateau lizard	Catalogue of Life: Integrated Taxonomic Information System		
English	Prairie lizard	Catalogue of Life: Integrated Taxonomic Information System		
Spanish	Lagartija-escamosa de pradera			

Specimens/observations
Including records from: Mexico; United States

Service	Resource	All	Lat/Long
Berkeley Natural History Museums (bnhm.berkeley.edu)	University of California Museum of Paleontology DiGIR provider	9  	0
BYU BioAg DiGIR Provider (mlbean.byu.edu)	Reptile and Amphibian Collection	909  	0
California Academy of Sciences (CAS) (digir.calacademy.org)	CAS Herpetology Collection Catalog	644  	50  
Cornell University Museum of Vertebrates (CUMV) (digir.cumv.cornell.edu)	Amphibians and Reptiles Collection	187  	1  
Florida Mus Nat Hist (UF) (digir.flmnh.ufl.edu)	Herpetology specimens	999  	0
GBIF-Sweden Provider (www.gbif.se)	Herpetology (NRM)	4  	0
GBIF-Sweden Provider (www.gbif.se)	Zoology (Museum of Evolution - Uppsala)	8  	0
GBIF-Sweden Provider (www.gbif.se)	Reptiles and Amphibians of the Gothenburg Natural History Museum	1  	0
Illinois Natural History Survey (INHS) (www.inhs.uiuc.edu)	Herps Specimens	1096  	0
James R. Slater Museum (PSM) (nhmuseum.ups.edu)	Terrestrial vertebrates	26  	0
Los Angeles County Museum of Natural History (LACM)	Vertebrate specimens	802  	48  
MCZ-Harvard University Provider (digir.mcz.harvard.edu)	MCZ Herpetology Collection - Reptile Database	384  	0
Michigan State University Museum (MSUM) (manis.museum.msu.edu)	Vertebrate specimens	173  	0
Museum of Southwestern Biology - Amphibians and Reptiles (chrysemys.unm.edu)	Museum of Southwestern Biology, Division of Amphibians and Reptiles database	2991  	2280  
Museum of Vertebrate Zoology (MVZ) (128.32.146.144)	Terrestrial vertebrate specimens	553  	510  
NatureServe (services.natureserve.org)	NatureServe Network Species Occurrence Data	23  	0
NLBIF (145.18.162.60)	(Zoological Museum Amsterdam) Amphibia and Reptilia	5  	0
Paleobiology Database (paleodb.org)	Paleobiology Database	7  	7  
Royal Ontario Museum (digir.rom.on.ca)	Herp specimens	53  	0
San Diego Natural History Museum (209.242.146.121)	Herps specimens	1157  	0
Sternberg Museum of Natural History (secure.fhsu.edu)	Herp Collection	43  	43  

Specimen data

GBIF Biodiversity Data Portal - Mozilla Firefox

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http://www.asia.gbif.net/portal/digit_viewer.jsp?taxonKey=235052&countryKey=0&resourceKey=0&georeferencedOnly=true&showMap=true&star herpnet

Getting Started Latest Headlines Northern New Mexic...

Species: *Sceloporus undulatus* (Bosc and Daudin in Sonnini and Latreille, 1801)

Eastern fence lizard / Fence lizard / Plateau lizard / Prairie lizard

Specimens/observations



Mapping service provided by Belgian Biodiversity Information Facility

Dynamic map service from Canadian Biodiversity Information Facility

BeBIF
Belgian Biodiversity Information Facility

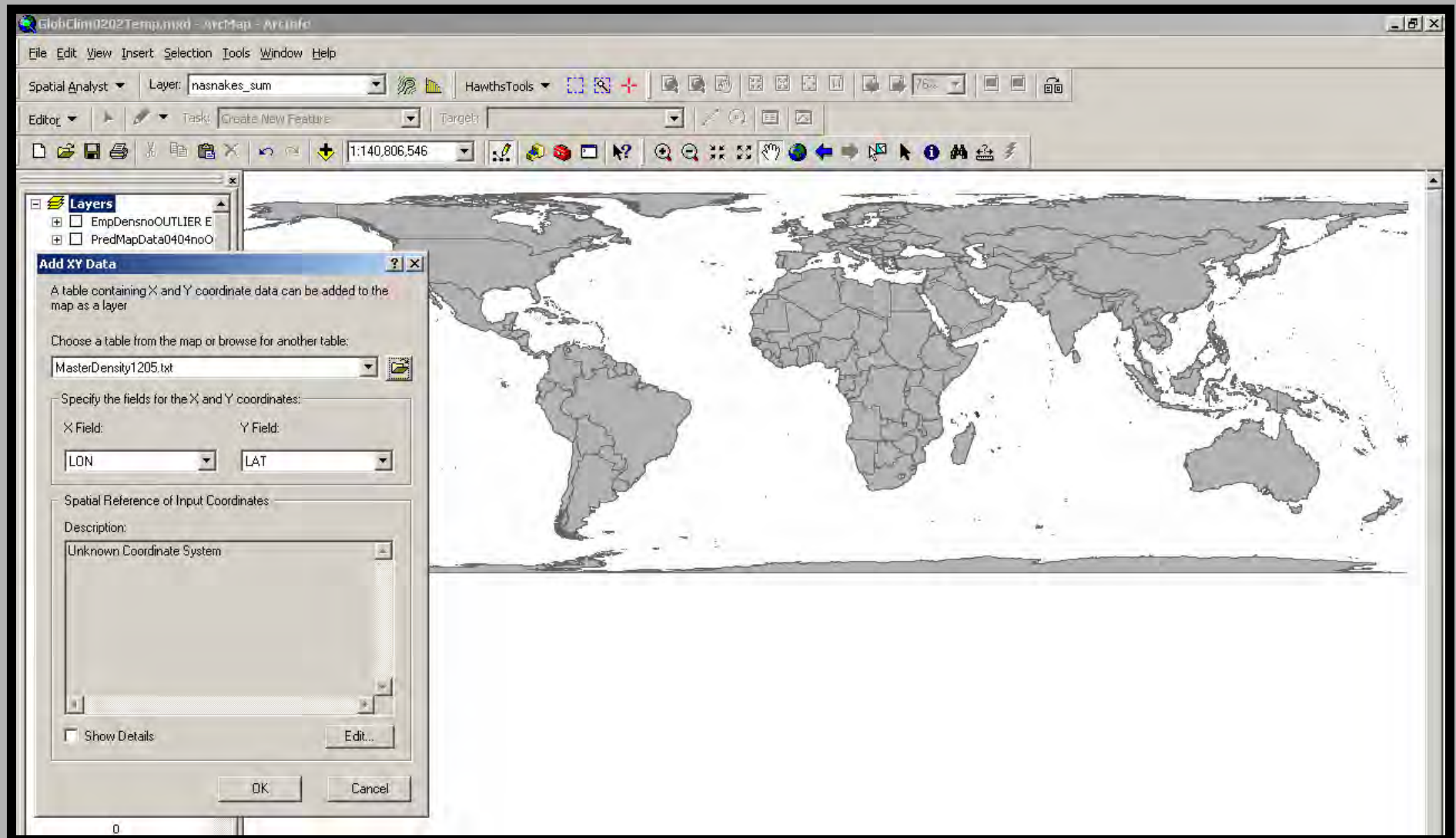
Canada

Specimen data

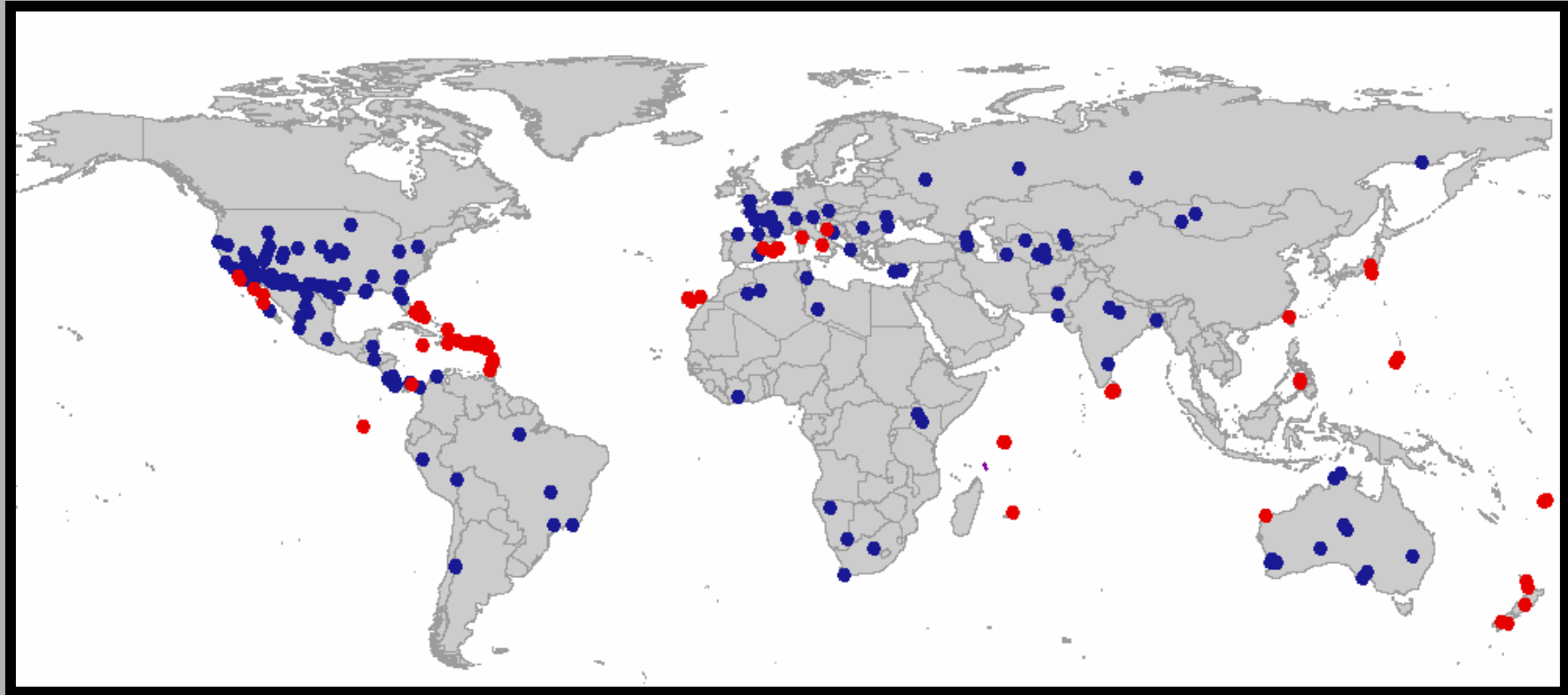
Record	Scientific name	Date	Country/Territory	Location	Latitude	Longitude	User feedback
17560	Sceloporus undulatus	-	USA	Lakehurst	40.014	-74.312	
17561	Sceloporus undulatus	Apr 8, 1945	USA	N. Lake Drummond of Great Dismal Swamp	36.6	-76.46	
17562	Sceloporus undulatus	Apr 22, 1944	USA	8mi N Lake Drummond: Dismal Swamp	36.71	-76.46	
17563	Sceloporus undulatus	Apr 22, 1944	USA	8mi N Lake Drummond: Dismal Swamp	36.71	-76.46	
17564	Sceloporus undulatus	Apr 22, 1944	USA	8mi N Lake Drummond: Dismal Swamp	36.71	-76.46	
17565	Sceloporus undulatus	Apr 22, 1944	USA	8mi N Lake Drummond: Dismal Swamp	36.71	-76.46	
17566	Sceloporus undulatus	Apr 22, 1944	USA	8mi N Lake Drummond: Dismal Swamp	36.71	-76.46	
17573	Sceloporus undulatus	Sep 2, 1954	USA	3mi W Thomasville	30.859	-84.022	
17575	Sceloporus undulatus	Aug 22, 1954	USA	8mi S.W. Ranger	32.38	-98.77	
17576	Sceloporus undulatus	Aug 22, 1954	USA	8mi S.W. Ranger	32.38	-98.77	
17577	Sceloporus undulatus	Aug 22, 1954	USA	8mi S.W. Ranger	32.38	-98.77	
51228	Sceloporus undulatus	Mar 29, 1967	USA	Pipe Springs	34.698	-94.645	
74245	Sceloporus undulatus	Apr 22, 1945	USA	1.5 mi. W Deep Creek	36.75	-76.36	
74246	Sceloporus undulatus	Apr 22, 1945	USA	1.5 mi. W Deep Creek	36.75	-76.36	
97444	Sceloporus undulatus	Aug 2, 1948	USA	2 mi. W. Dunning	41.828	-100.142	
97445	Sceloporus undulatus	Jun 26, 1951	USA	10 mi. W. Tryon	41.554	-101.147	
97446	Sceloporus undulatus	May 3, 1955	USA	near Tom's River	39.954	-74.198	
97447	Sceloporus undulatus	May 3, 1955	USA	near Tom's River	39.954	-74.198	
97448	Sceloporus undulatus	May 3, 1955	USA	near Tom's River	39.954	-74.198	
97449	Sceloporus undulatus	Jul 15, 1954	USA	near Tom's River	39.954	-74.198	
97496	Sceloporus undulatus	Apr 8, 1950	USA	2 mi. S. Okay	35.824	-95.33	
97497	Sceloporus undulatus	Apr 8, 1950	USA	2 mi. S. Okay	35.824	-95.33	
97499	Sceloporus undulatus	Jul 17, 1972	USA	Rest stop, 31.2 mi. W. Cornudas	31.84	-105.972	
136580	Sceloporus undulatus	-	USA	Caddo Lake State Park	32.69	-94.17	
136581	Sceloporus undulatus	-	USA	Caddo Lake State Park	32.69	-94.17	
136582	Sceloporus undulatus	-	USA	Caddo Lake State Park	32.69	-94.17	
136583	Sceloporus undulatus	-	USA	Caddo Lake State Park	32.69	-94.17	
136584	Sceloporus undulatus	-	USA	Caddo Lake State Park	32.69	-94.17	
136585	Sceloporus undulatus	-	USA	Caddo Lake State Park	32.69	-94.17	
136586	Sceloporus undulatus	-	USA	Caddo Lake State Park	32.69	-94.17	

Records: [Previous](#) | [Next](#) | [1-30](#) | [31-60](#) | [61-90](#) | [91-120](#) ... [2911-2939](#)

XY data in GIS



Density data

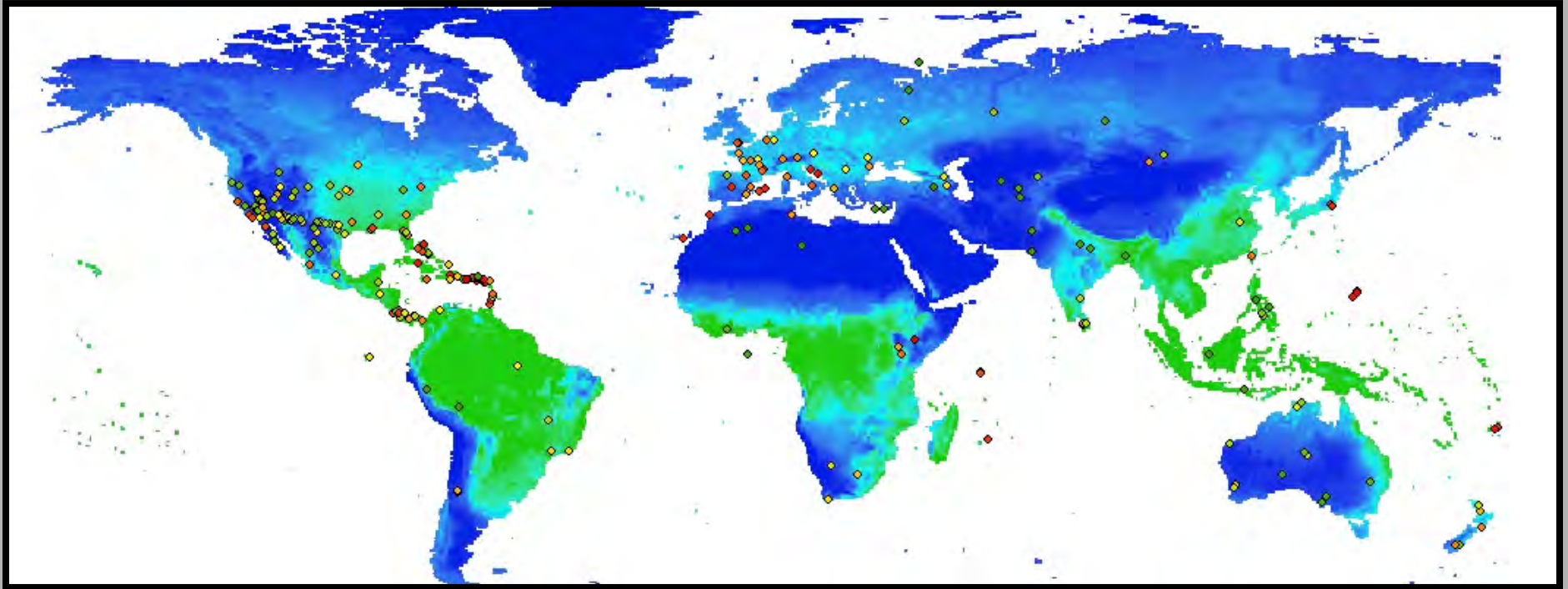


Lizard density (lizards/ha)

● Mainland (n=470)

● Island (n=173)

Environmental constraints on density?

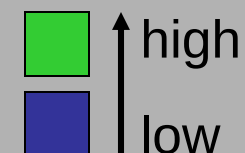
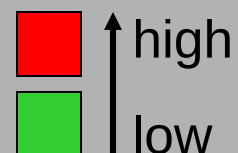


Reptile density

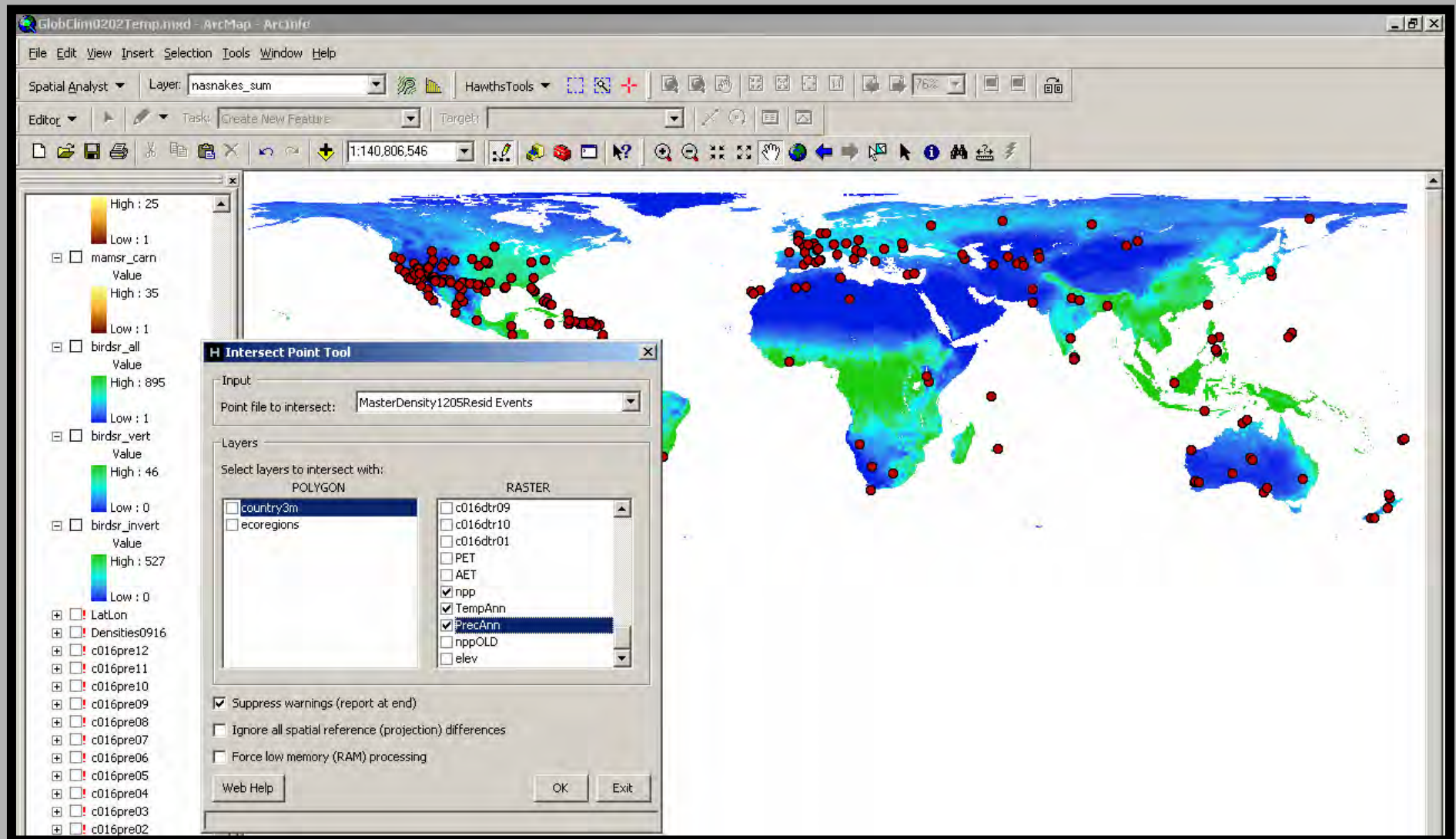
(lizards/ha)

Annual NPP

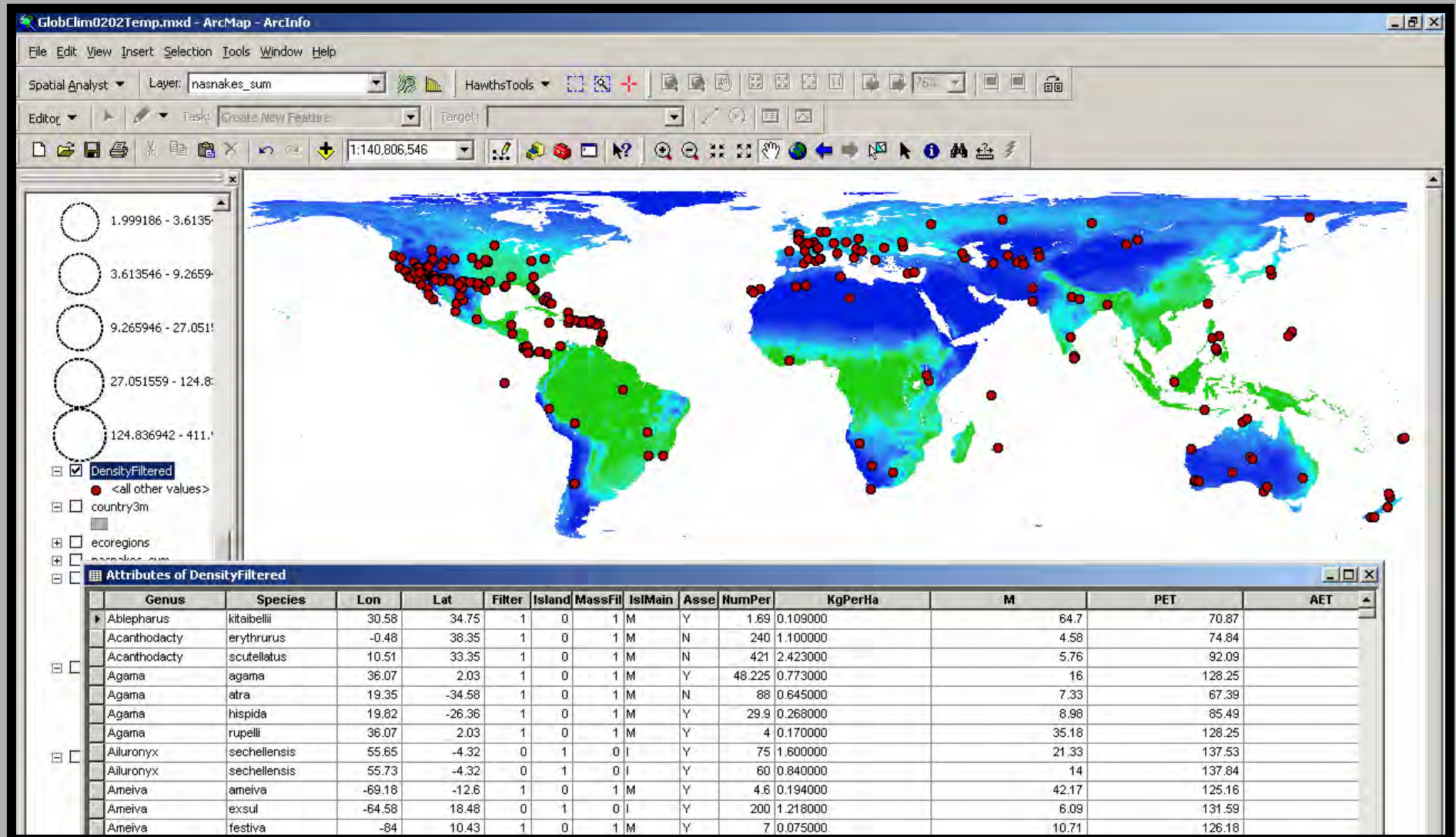
(DOLY model)



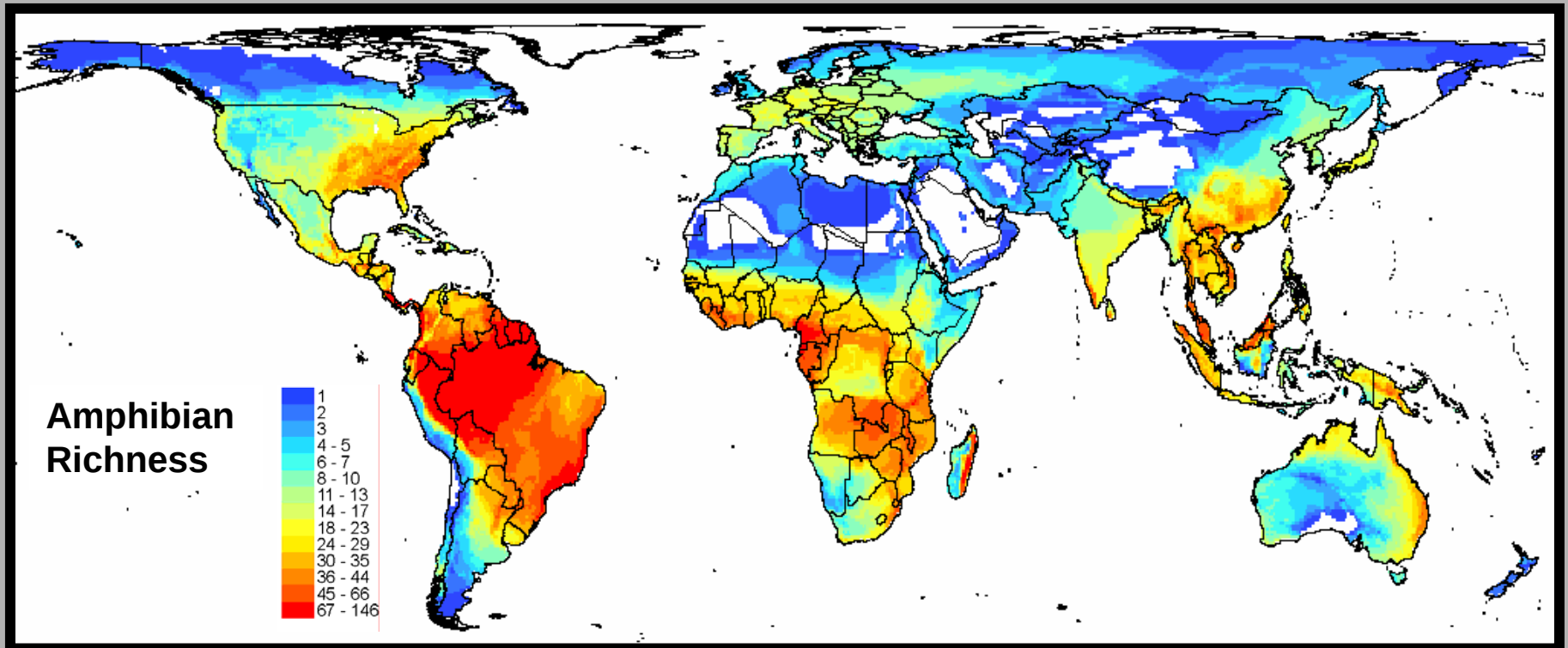
Environmental constraints



Environmental constraints



Ecological constraint on density? Competition and predation?



Ecological constraints

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http://www.natureserve.org/explorer/

Getting Started Latest Headlines Northern New Mexic...



NatureServe EXPLORER



Highlights

October 2006 Data Refresh!
NatureServe Explorer data has been updated.

 [Support NatureServe Explorer Through the CFC](#)

[Impact Rankings of Invasive Non-Native Plants](#)

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An Online Encyclopedia of Life



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- scientific and common names
- conservation status
- distribution maps
- images for thousands of species
- life histories, conservation needs, and more

Ecological constraints

Species - *Sceloporus undulatus* - Mozilla Firefox

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http://www.natureserve.org/explorer/servlet/NatureServe?sourceTemplate=tabular_report.wmt&loadTemplate=species_RptComprehensive.wmt&st NatureServe

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Sceloporus undulatus - (Bosc & Daudin, in Sonnini and Latreille, 1801)
Fence/prairie/plateau Lizard
Unique Identifier: ELEMENT_GLOBAL.2.101699
Element Code: ARACF14130
Informal Taxonomy: Animals, Vertebrates - Reptiles - Lizards

[Google](#)
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Kingdom	Phylum	Class	Order	Family	Genus
Animalia	Craniata	Reptilia	Squamata	Phrynosomatidae	Sceloporus

Genus Size: D - Medium to large genus (21+ species)

☐ Check this box to expand all report sections:

Concept Reference [Expand](#) ?

Conservation Status [Expand](#) ?

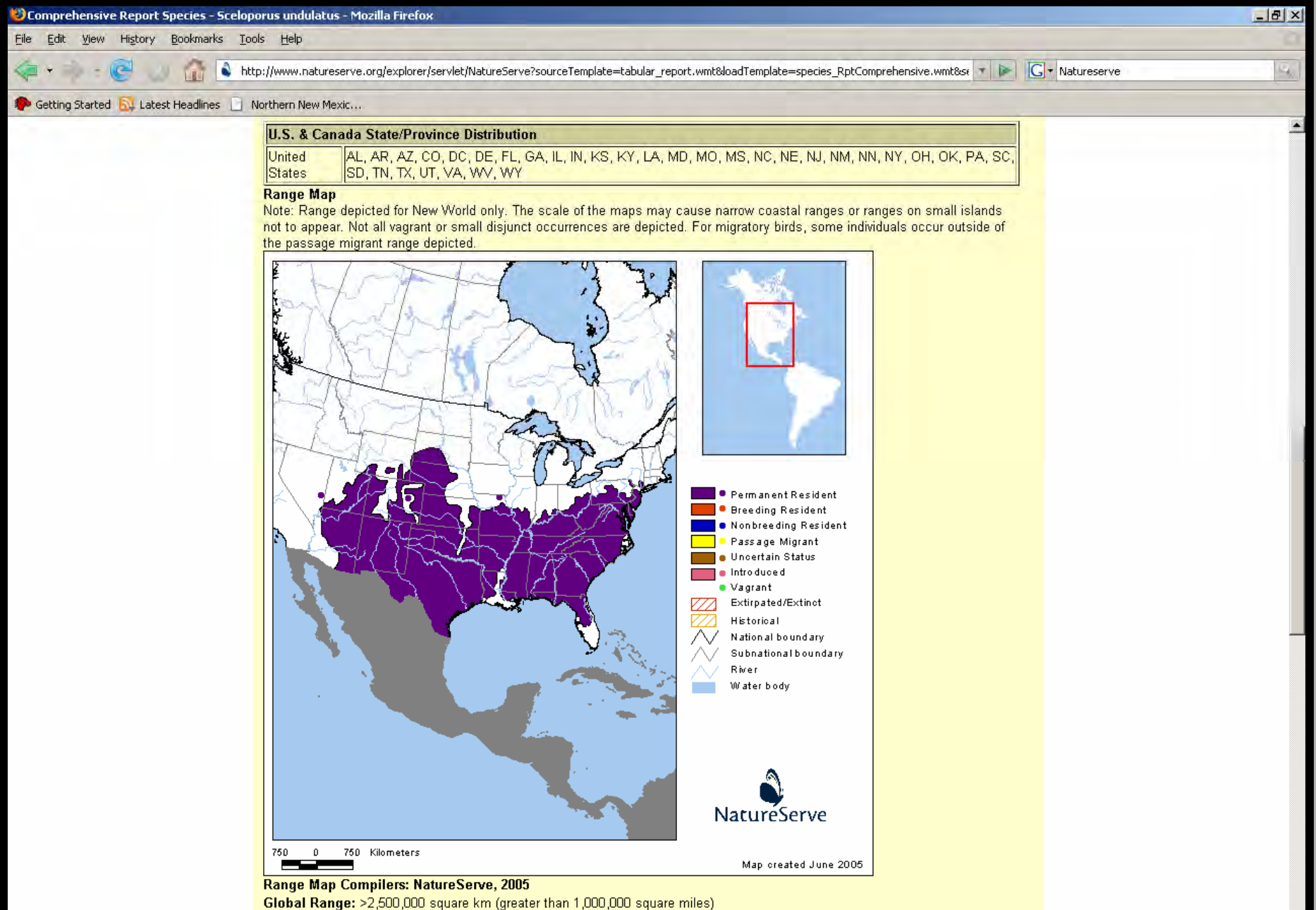
Distribution [Expand](#) ?

Ecology & Life History [Collapse](#) ?

Reproduction Comments: Clutch size (mean 6-11) and frequency (up to 2-3 clutches/year in most areas) and oviposition dates vary greatly throughout range. Sexually mature in 1st or 2nd year, depending on location.

Ecology Comments
Average density ranges from a few per ha to about 50 per ha in different areas (Tinkle and Dunham 1986). In Mississippi, spring density ranged up to 72/ha (Parker 1994). In late summer, juvenile density may reach several hundred/ha in some areas, but

Ecological constraints



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Phrynosoma hernandesi - (Girard, 1858)

Short-horned Lizard

Other Common Names: Greater Short-horned Lizard, Mountain Short-horned Lizard

Other Related Names: *Phrynosoma douglasii brevirostre*

Unique Identifier: ELEMENT_GLOBAL.2.106178

Element Code: ARACF12080

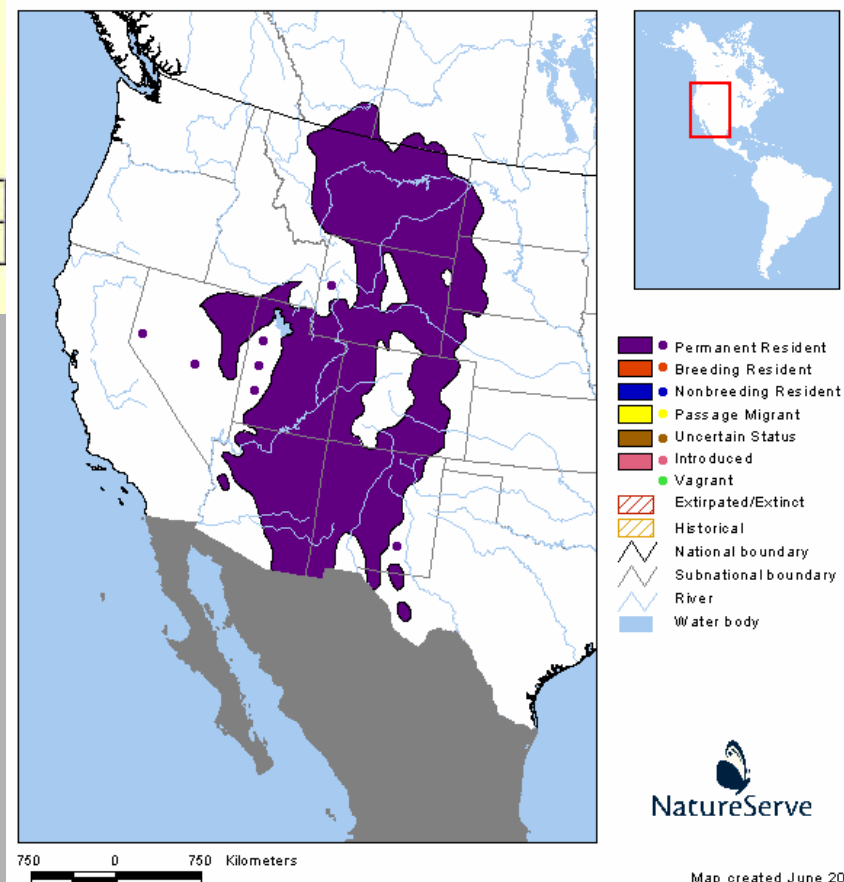
Informal Taxonomy: Animals, Vertebrates - Reptiles - Lizards

Kingdom	Phylum	Class	Order
Animalia	Craniata	Reptilia	Squamata

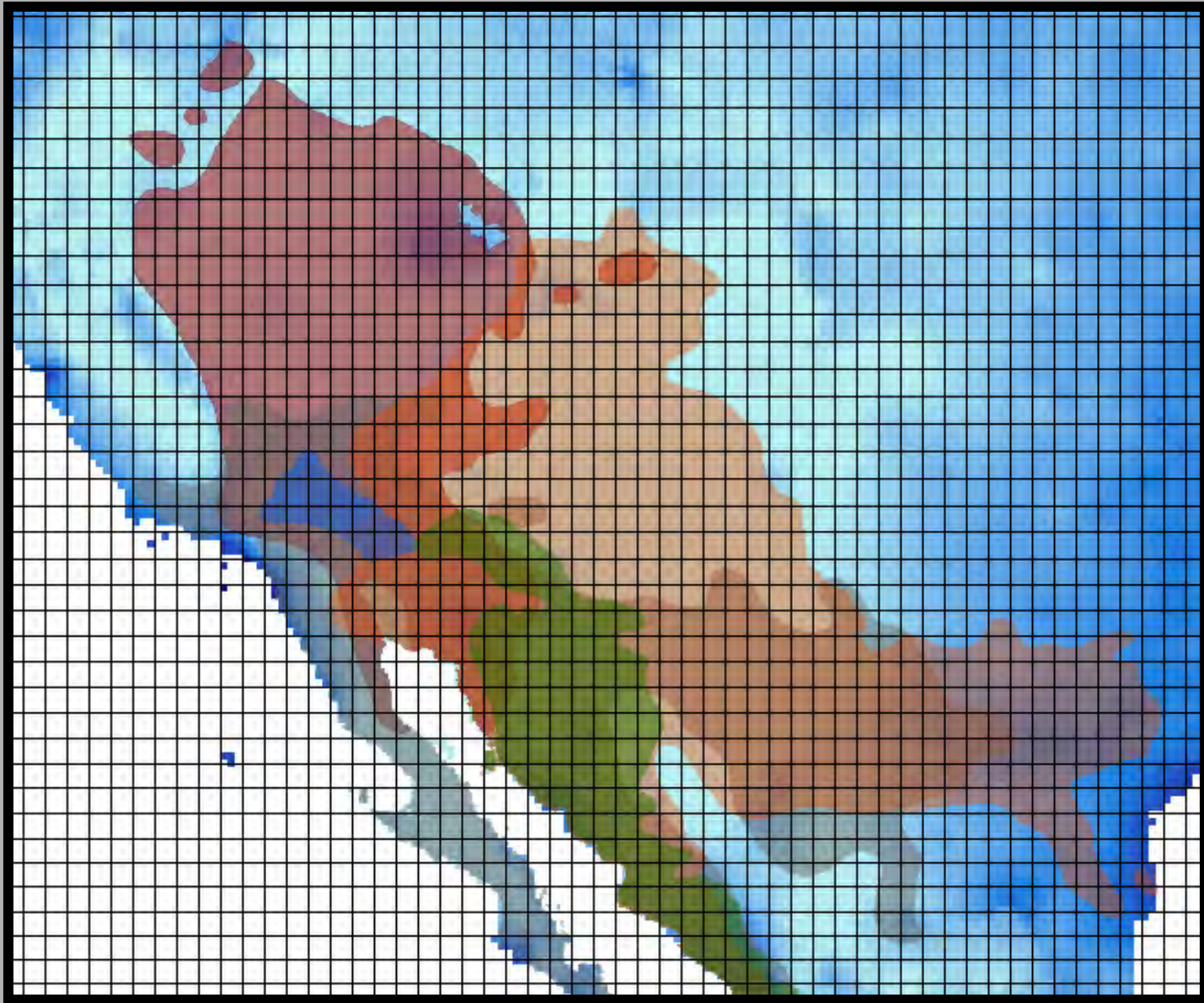
Genus Size: C - Small genus (6-20 species)

Google

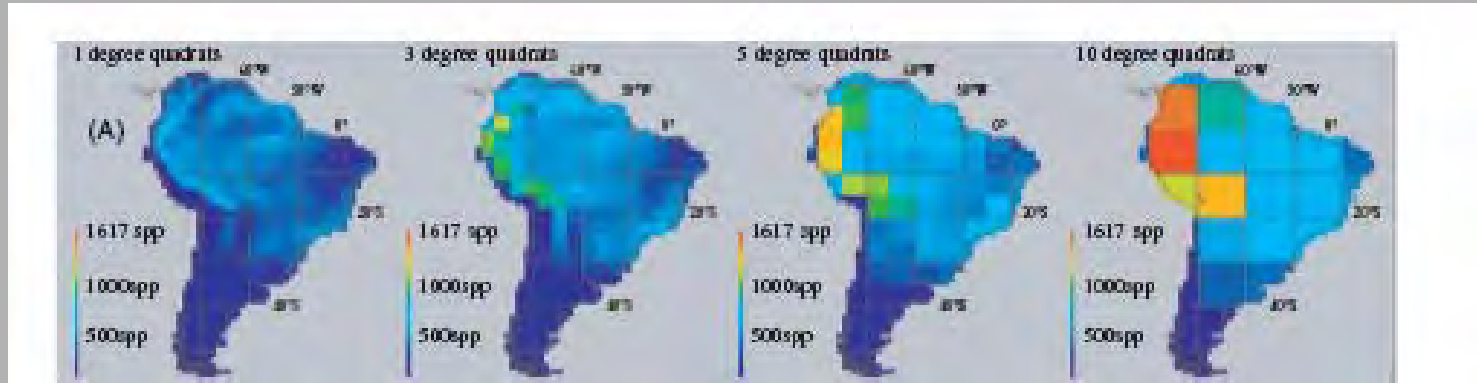
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Ecological constraints



0.5° grid cell



← high SPATIAL RESOLUTION low

South American Birds

Species richness

low

high

(Rahbek 2005)

Ecological constraints

Competitors

Insectivorous birds

Lizards

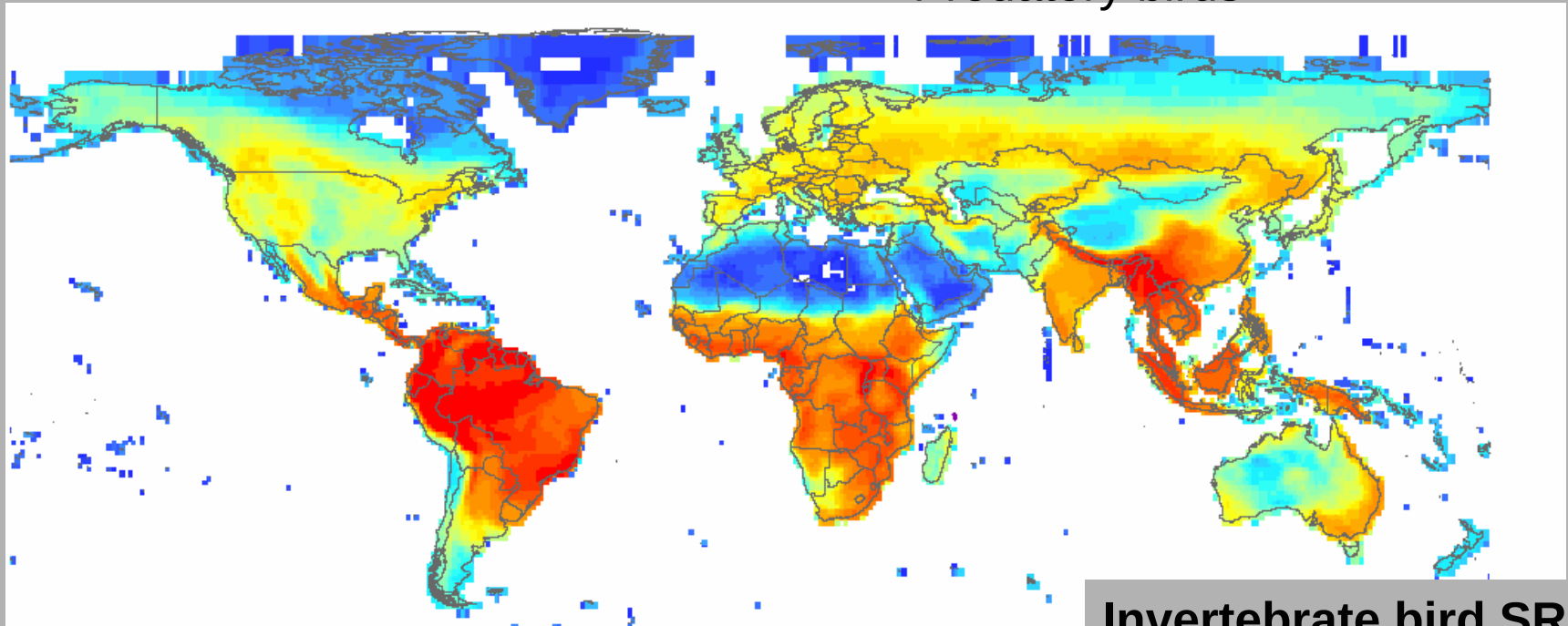
Insectivorous mammals

Predators

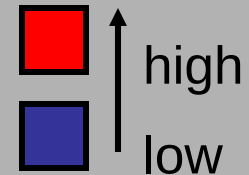
Carnivorous mammals

Snakes

Predatory birds

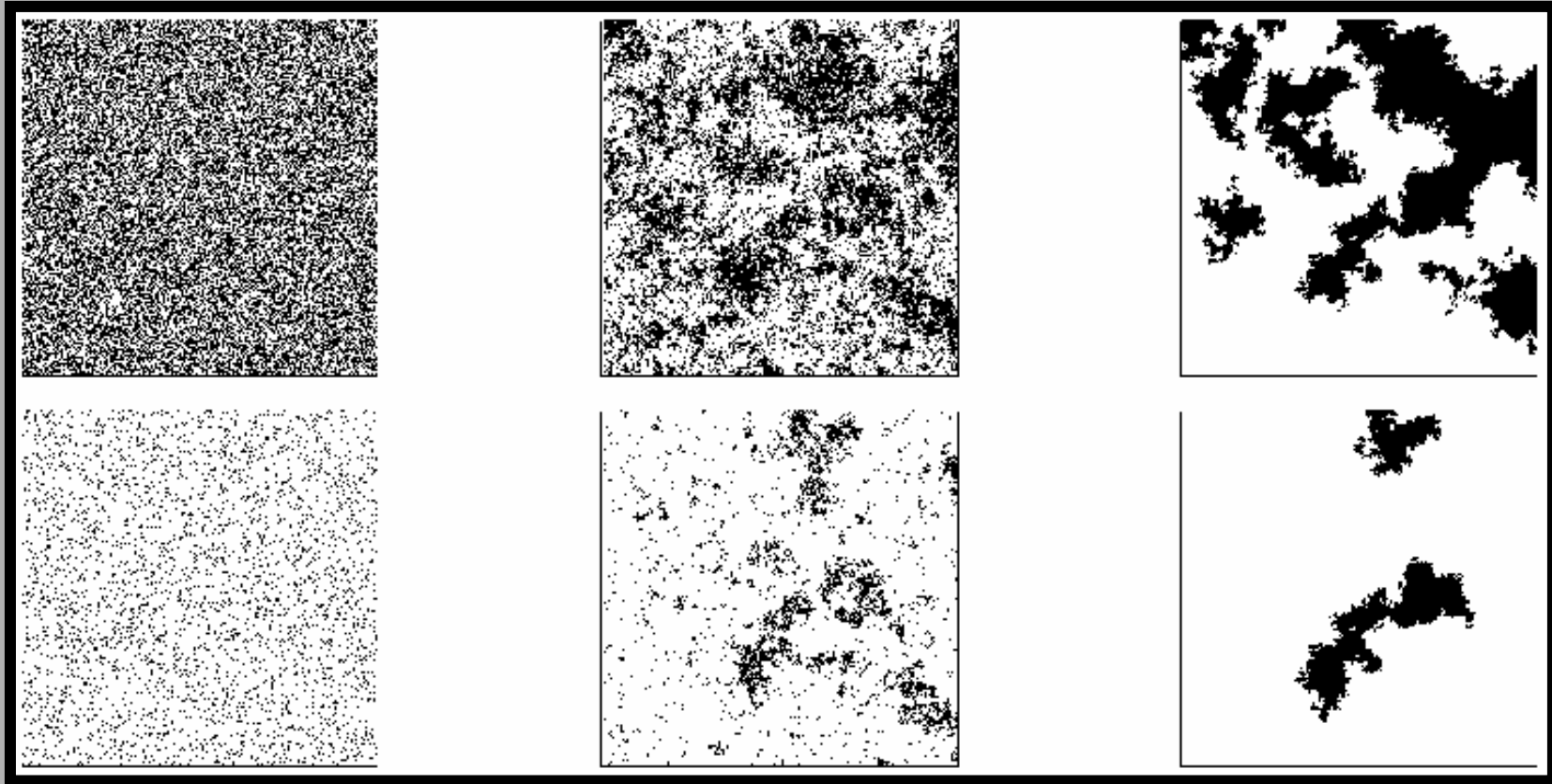


Invertebrate bird SR



Spatial autocorrelation

correlation of a variable with itself through space



Moran's I

$$I = \frac{N \sum_i \sum_j W_{i,j} (X_i - \bar{X})(X_j - \bar{X})}{(\sum_i \sum_j W_{i,j}) \sum_i (X_i - \bar{X})^2}$$

Compares the value of the variable at any one location with the value at all other locations

Where N is the number of cases

X_i variable value at location i

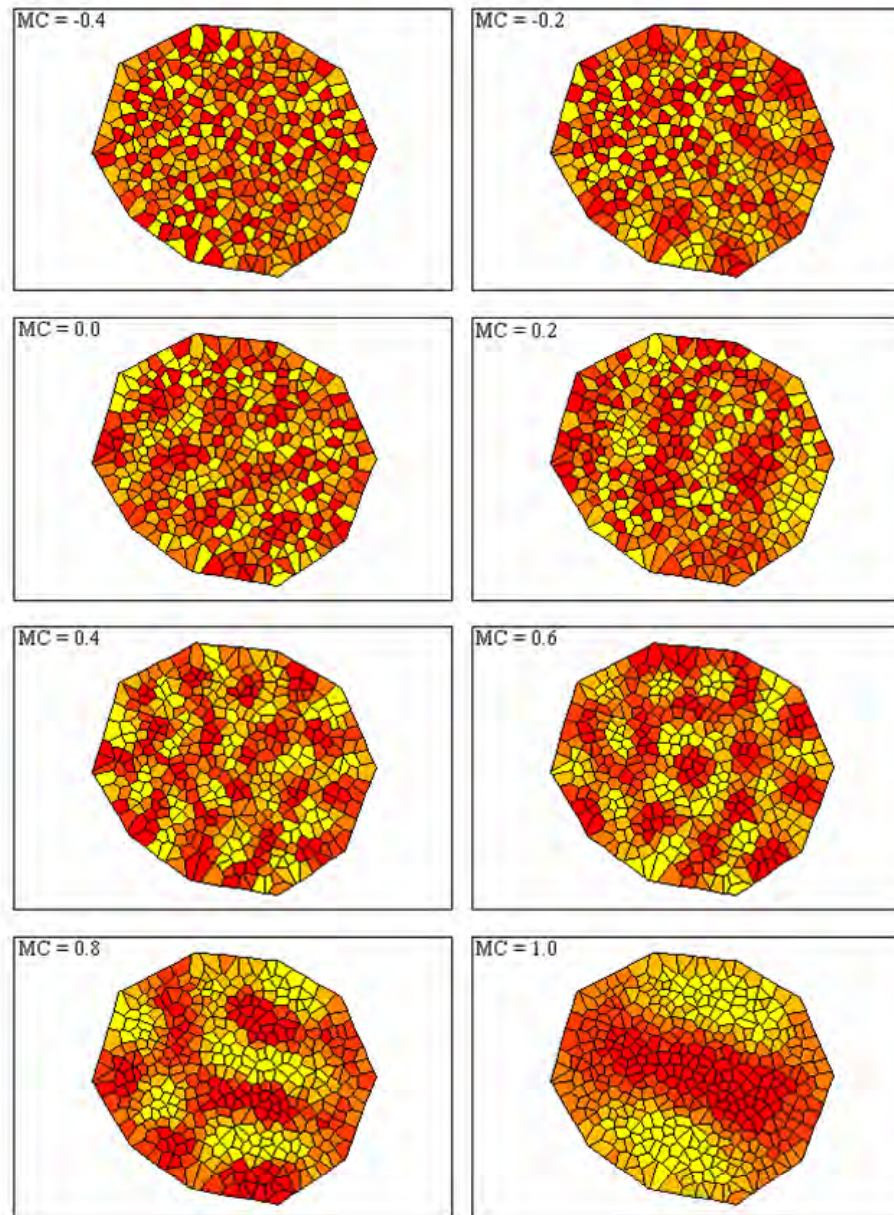
X_j variable value at location j

$\bar{X}$ variable mean

W_{ij} distance-based weight applied to the comparison between locations i and j

Moran's I

dispersed



clustered

Moran's I Significance

$$Z(I) = \frac{I - E(I)}{S_{E(I)}}$$

$$S_{E(I)} = \text{SQRT}\left[\frac{N^2 \sum_{ij} w_{ij}^2 + 3(\sum_{ij} w_{ij})^2 - N \sum_i (\sum_j w_{ij})^2}{(N^2 - 1)(\sum_{ij} w_{ij})^2}\right]$$

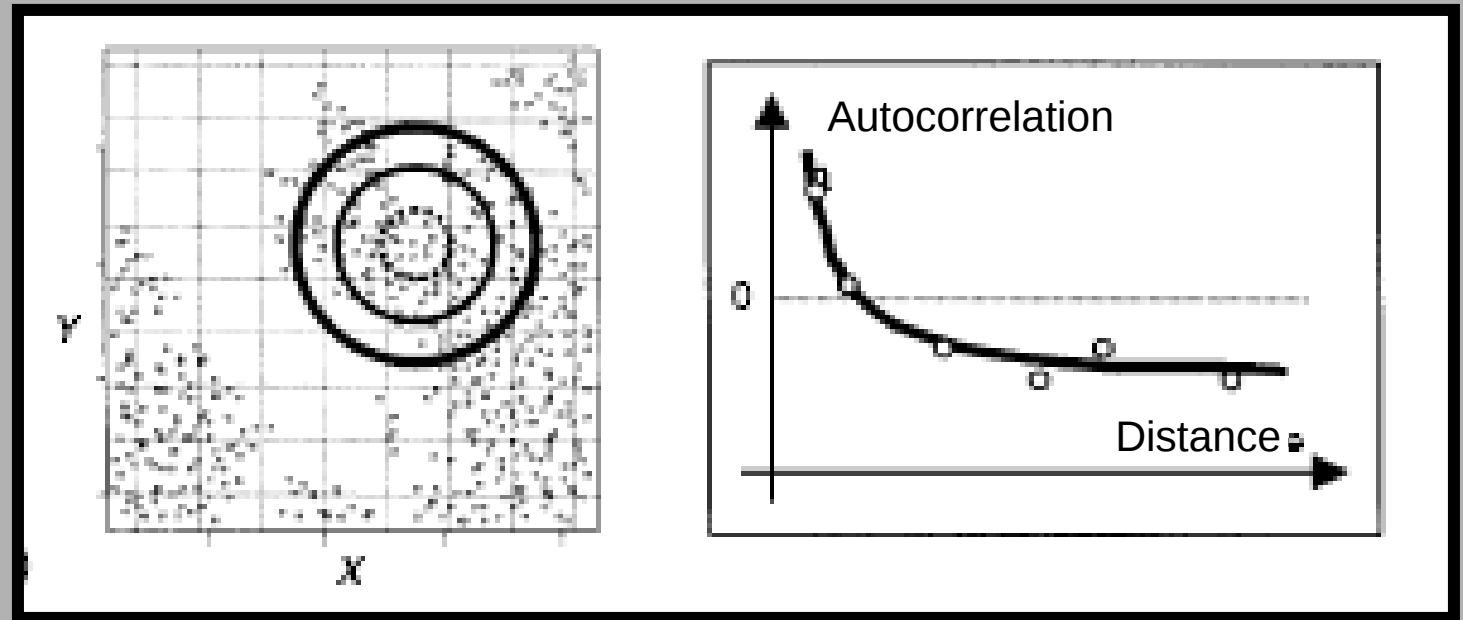
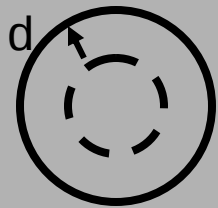
Compare empirical distribution to theoretical distribution by dividing by an estimate of the theoretical standard deviation

Correlogram

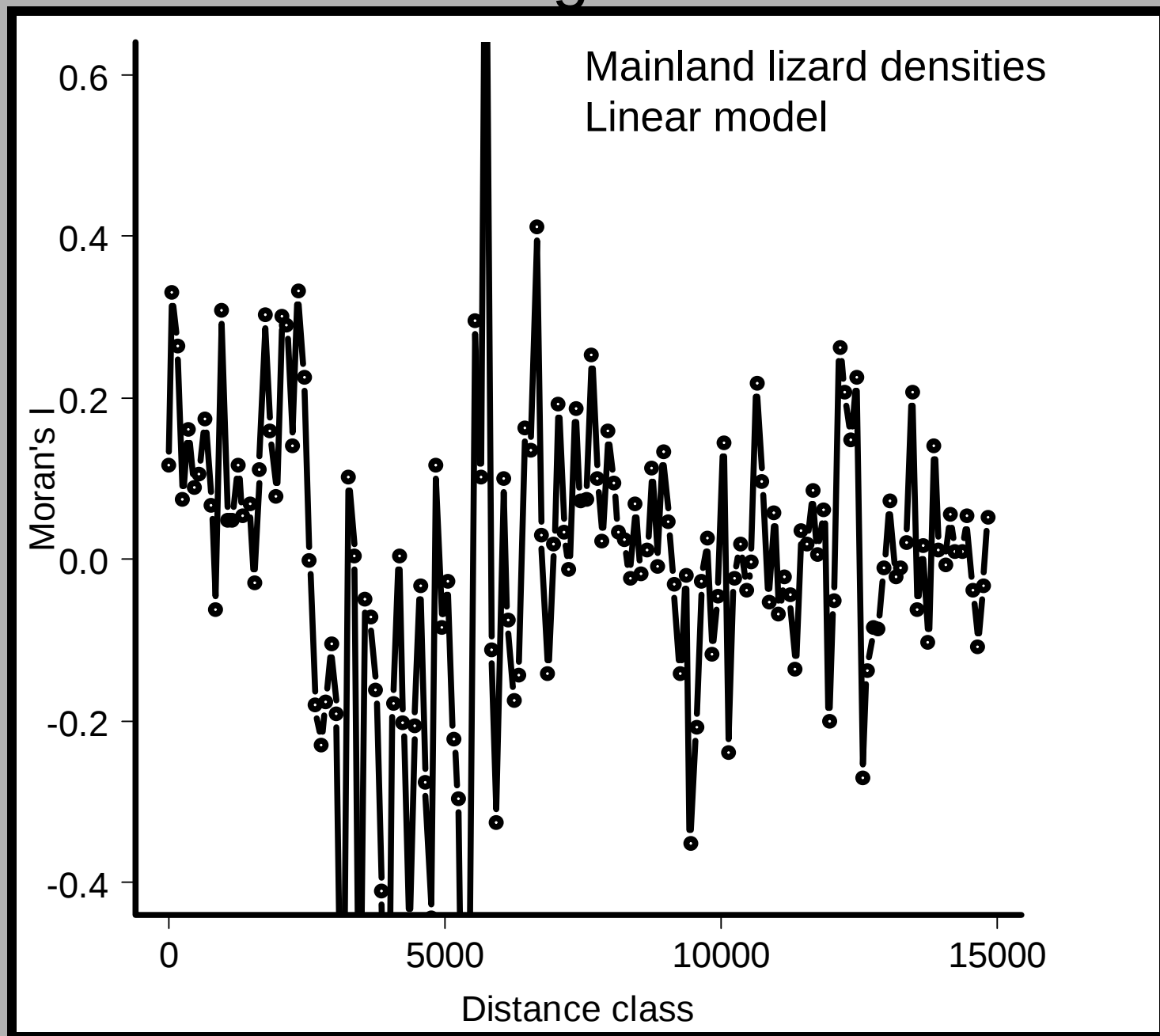
Spatial range of pattern
e.g. Patch size



Moran's I
Distance class



Correlogram



Spatially autoregressive models

maximum likelihood linear model

$$\mathbf{y} = \boldsymbol{\beta}\mathbf{x} + \mathbf{e}$$

Lagged-response model

spatial-autocorrelation in response variable

$$\mathbf{y} = \rho\mathbf{W}\mathbf{y} + \boldsymbol{\beta}\mathbf{x} + \mathbf{e}$$

ρ : autoregression parameter

$\mathbf{W}$: spatial weights matrix

$\boldsymbol{\beta}$: slopes for original predictor matrix $\mathbf{x}$

Lagged-mixed model

spatial-autocorrelation in response and predictor variable

$$\mathbf{y} = \rho\mathbf{W}\mathbf{y} + \boldsymbol{\beta}\mathbf{x} + \boldsymbol{\gamma}\mathbf{W}\mathbf{x} + \mathbf{e}$$

+ regression coefficients ($\boldsymbol{\gamma}$) of the spatially lagged predictors ($\mathbf{W}\mathbf{x}$)

Spatially autoregressive models

maximum likelihood linear model

$$\mathbf{y} = \boldsymbol{\beta}\mathbf{x} + \mathbf{e}$$

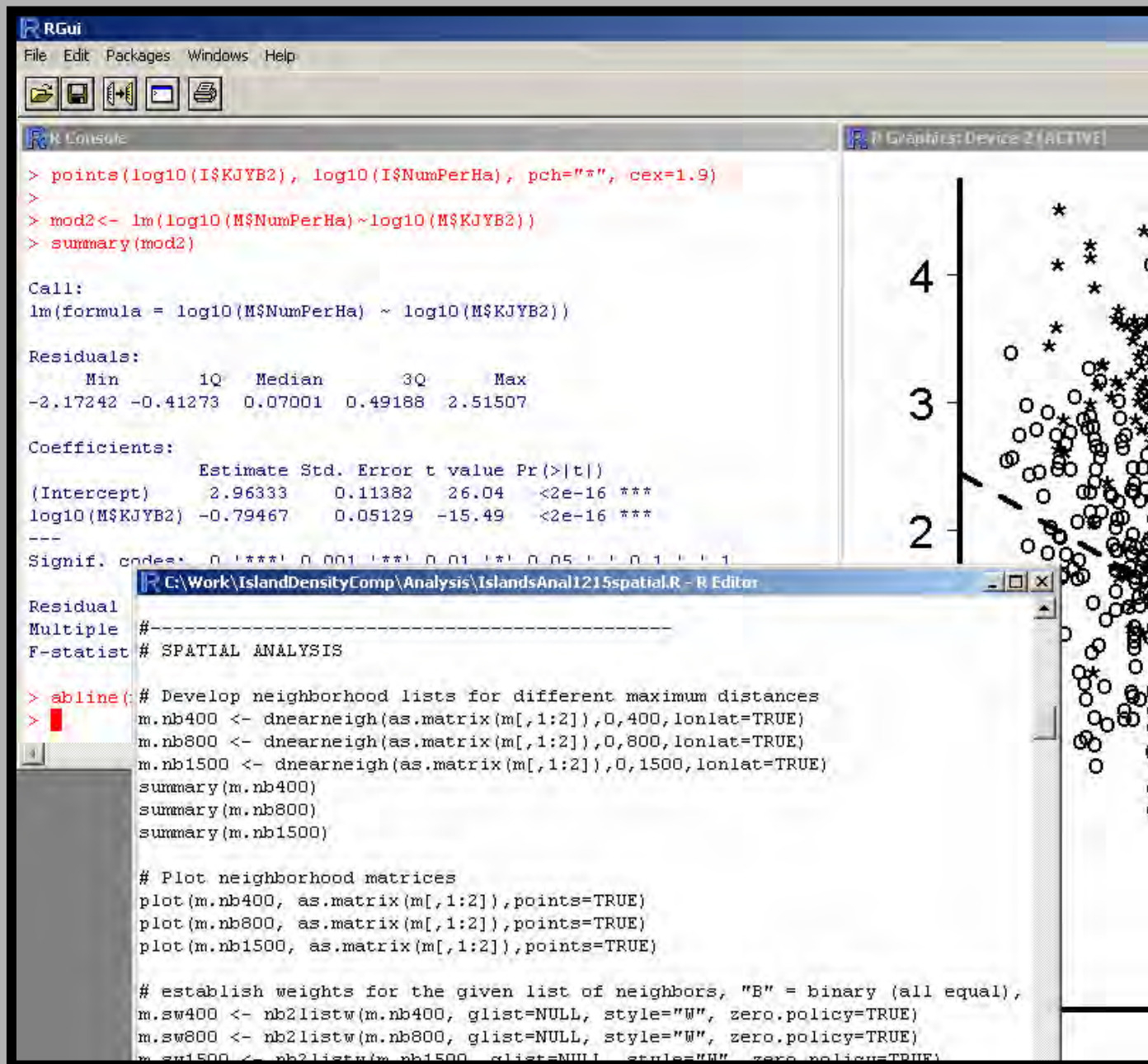
Spatial error model

spatial-autocorrelation only in the error term

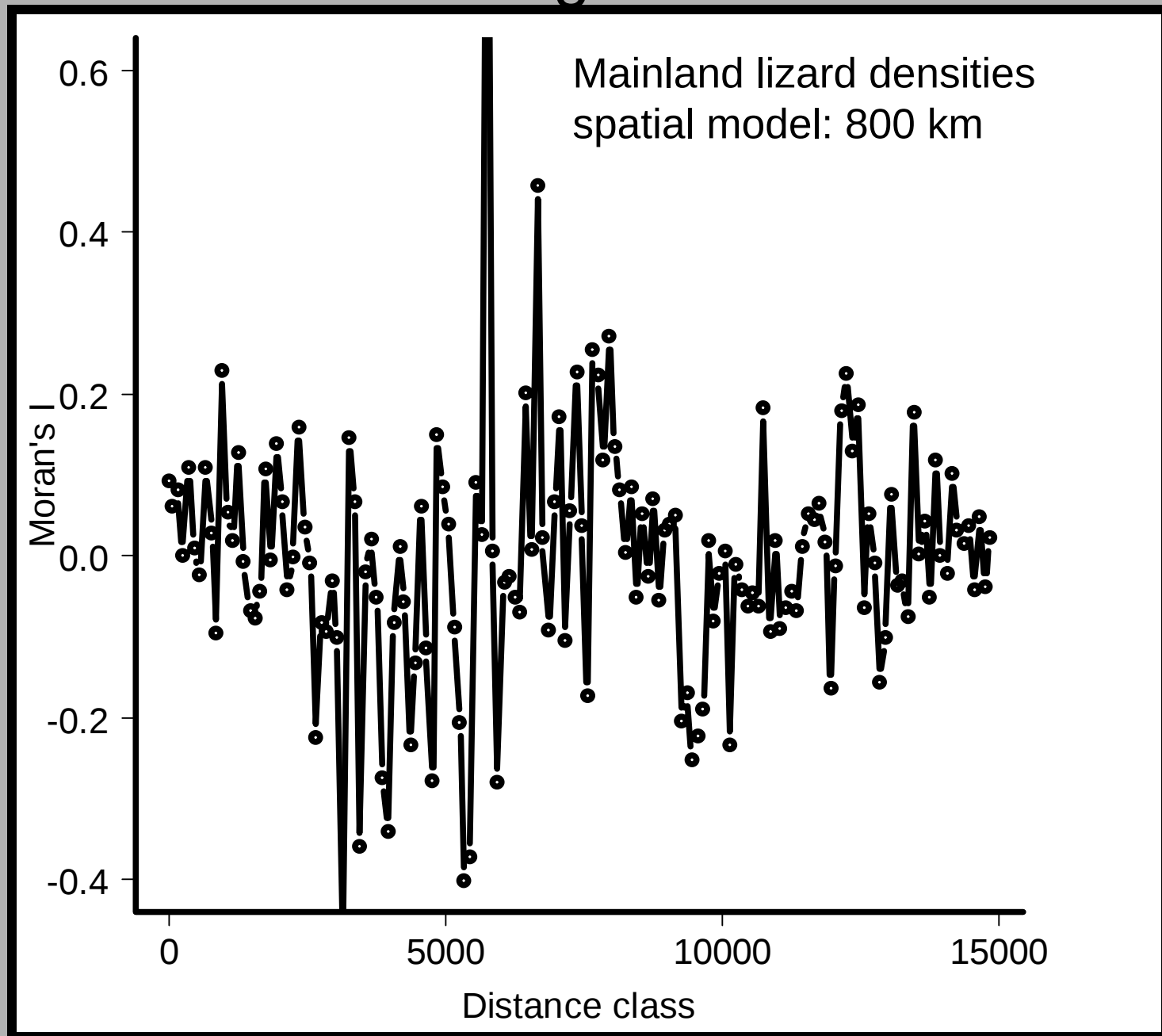
$$\mathbf{y} = \boldsymbol{\beta}\mathbf{x} + \lambda\mathbf{W}\mathbf{u} + \mathbf{e}$$

spatial structure ($\lambda\mathbf{W}$) in the spatially dependent error term ($\mathbf{u}$)

R spdep package



Correlogram



Spatial analysis

Space matters

Spatial analysis techniques

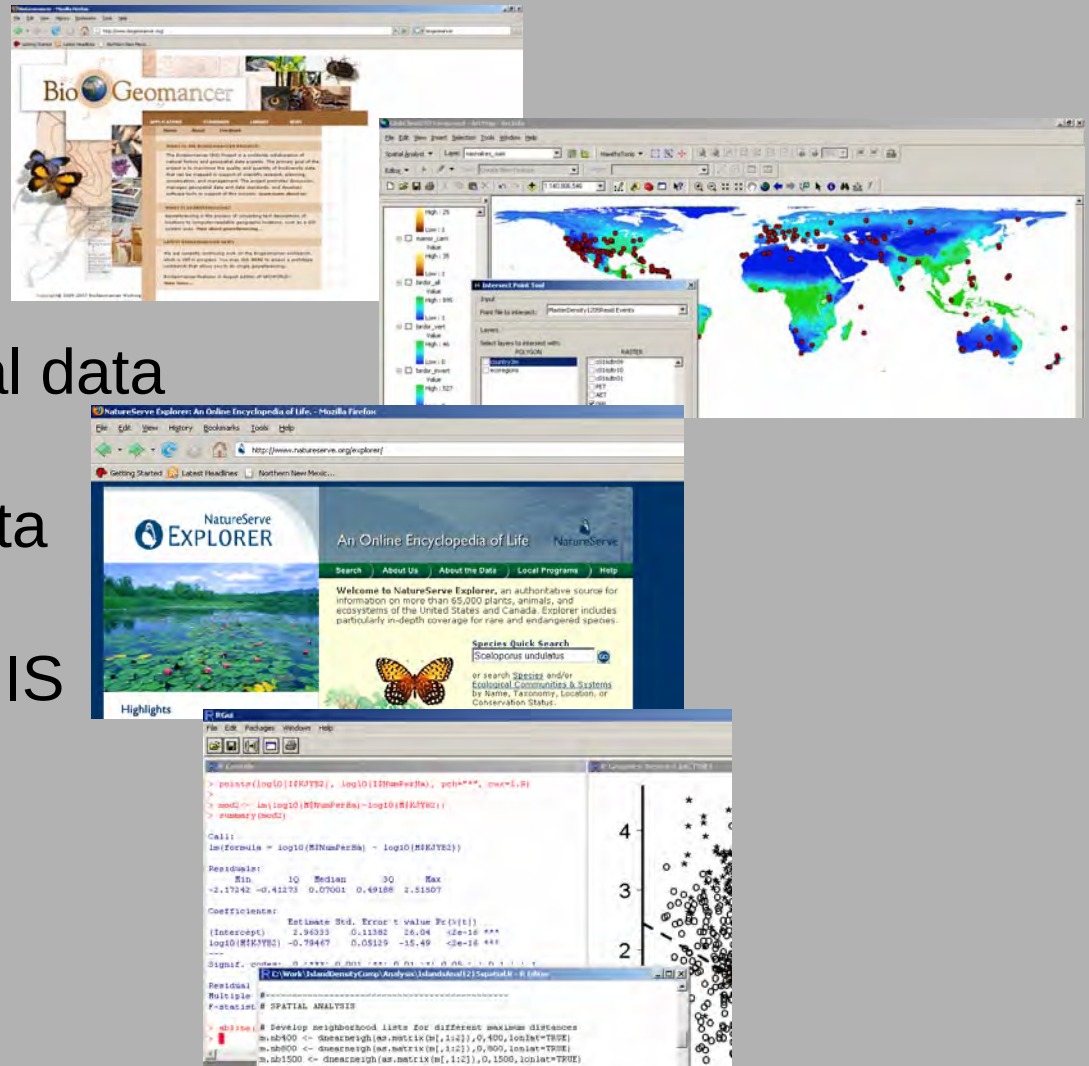
Georeferencing

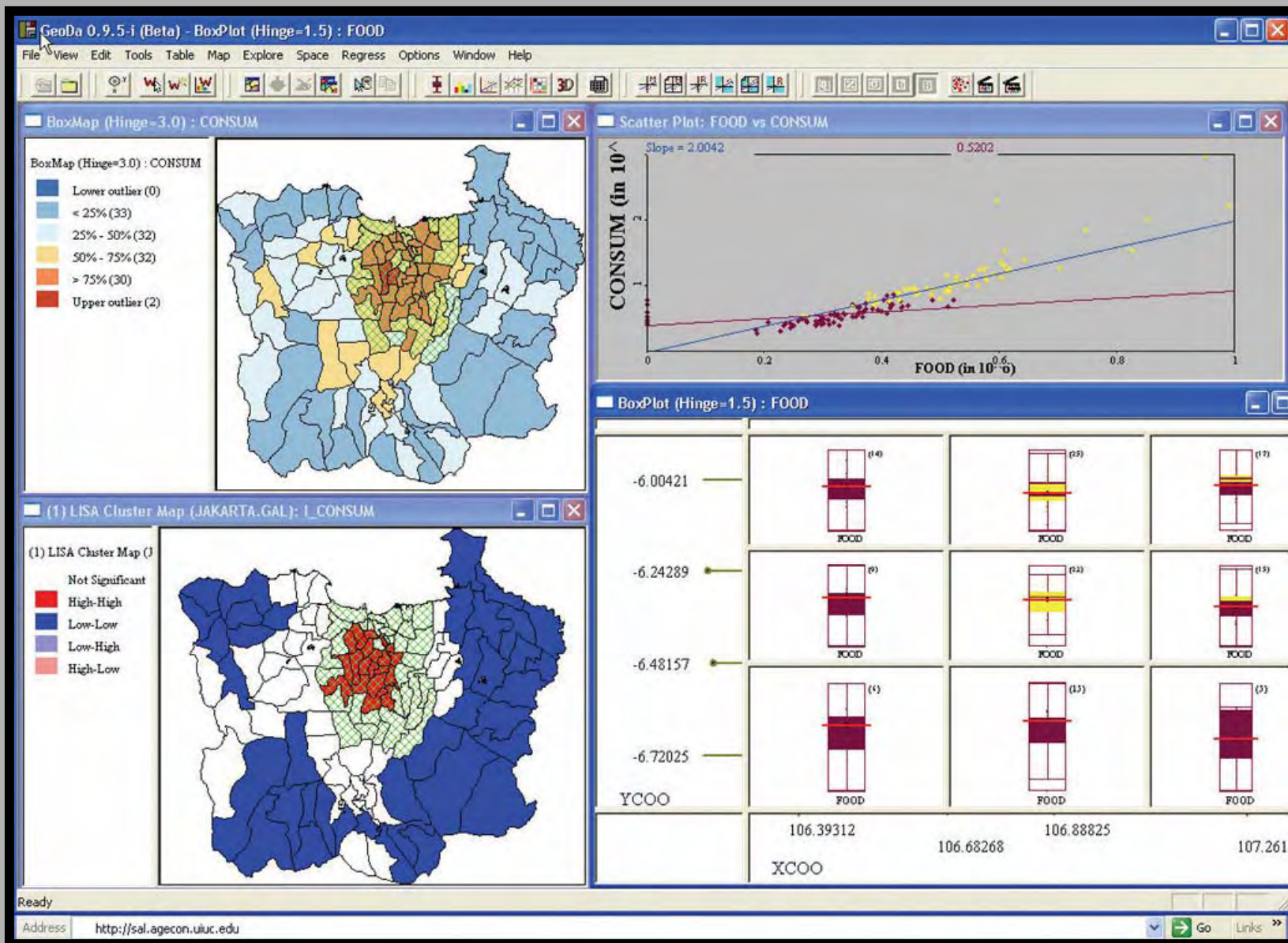
Spatial environmental data

Spatial ecological data

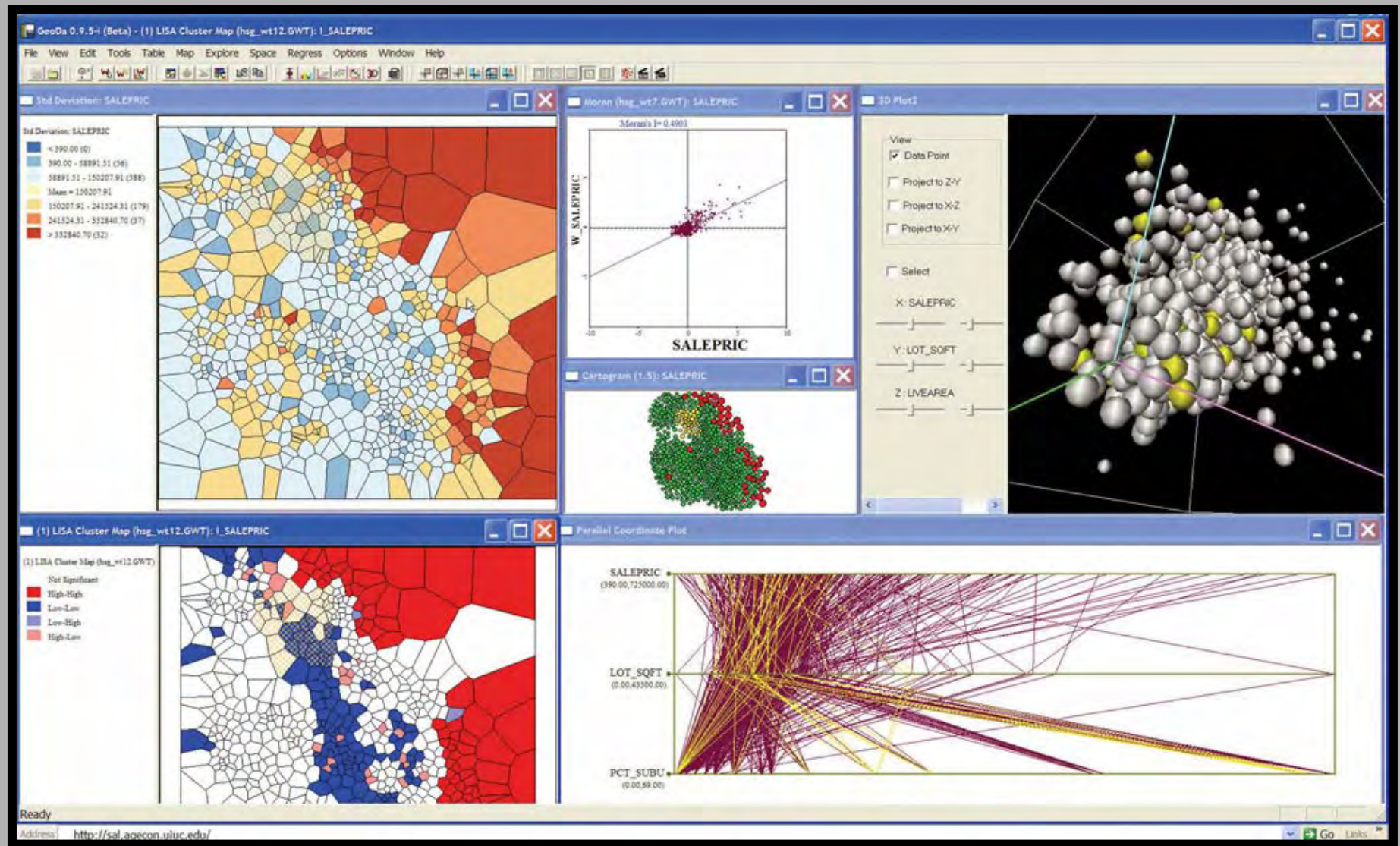
Data processing in GIS

Spatial statistics in R

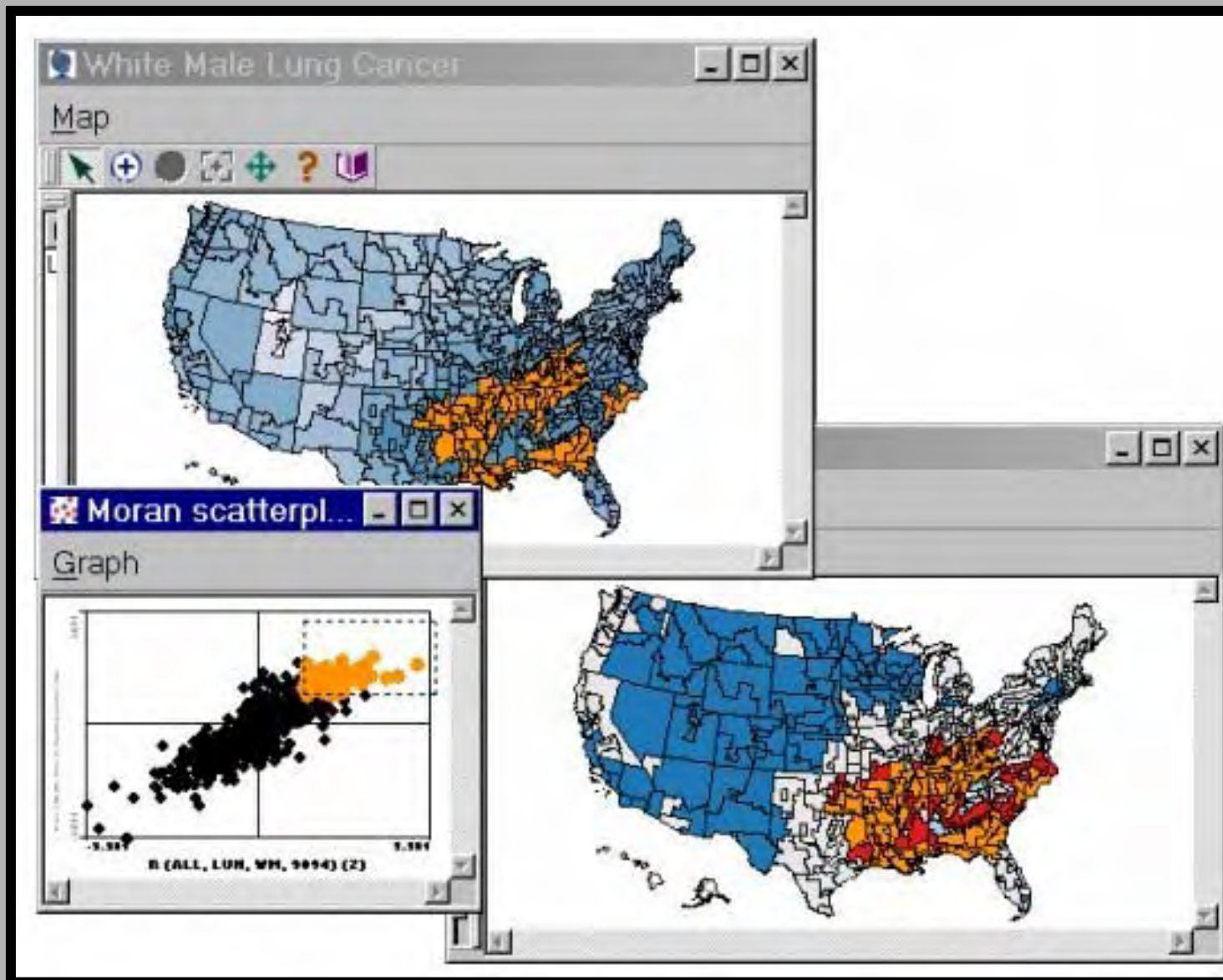




Neighborhood consumption in Jakarta, Indonesia
(Image: Anselin)



Seattle housing prices
(Image: Anselin)



Lung cancer
(Image: Anselin)