Community theory with stochastic demography

Modeling abundances and distributions in diverse communities based on individual biology: birth, death, dispersal

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Leipzig, Germany
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A stochastic community theory

Biology of individuals:

Community patterns:

A stochastic community theory

Biology of individuals:

Mortality
Reproduction
Growth
Dispersal
Speciation

⇒

Community patterns:

Competition
Diversity
Abundance
Spatial patterns
Species-area relationship
Extinction

A stochastic community theory

Biology of individuals:

Mortality
Reproduction
Growth
Dispersal
Speciation

Community patterns:

Competition
Diversity
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Spatial patterns
Species-area relationship
Extinction

Community properties of broad interest emerge from the model without any direct assumptions

(ie, no assumption about diversity required to produce diversity, etc.)

Importance of the neutral theory is not neutrality

Stochastic & individual-based community theory:

- stochastic individual demography
- species input (an open community)

The Voter Model

Stochastic Community Demography

1	2	1	2	1
1	1	1	4	1
1	3	1	1	2
4	1	1	3	1
1	1	2	1	1

Stochastic Community Demography

1	2	1	2	1
1	1	1	4	1
1	3	~~1~~	1	2
4	1	1	3	1
1	1	2	1	1

death

Stochastic Community Demography

1	2	1	2	1
1	1	1	4	1
1	3		1	2
4	1	1	3	1
1	1	2	1	1

birth

Stochastic Community Demography

1	2	1	2	1
1	1	1	4	1
1	3	4	1	2
4	1	1	3	1
1	1	2	1	1

dispersal

Stochastic Community Demography

1	2	1	2	1
1	1	1	4	1
1	3	6	1	2
4	1	1	3	1
1	1	2	1	1

Torus wrapping

Stochastic Community Demography

1	2	1	2	1
1	1	1	4	1
1	3	4	1	2
4	1	1	3	1
1	1	2	1	1

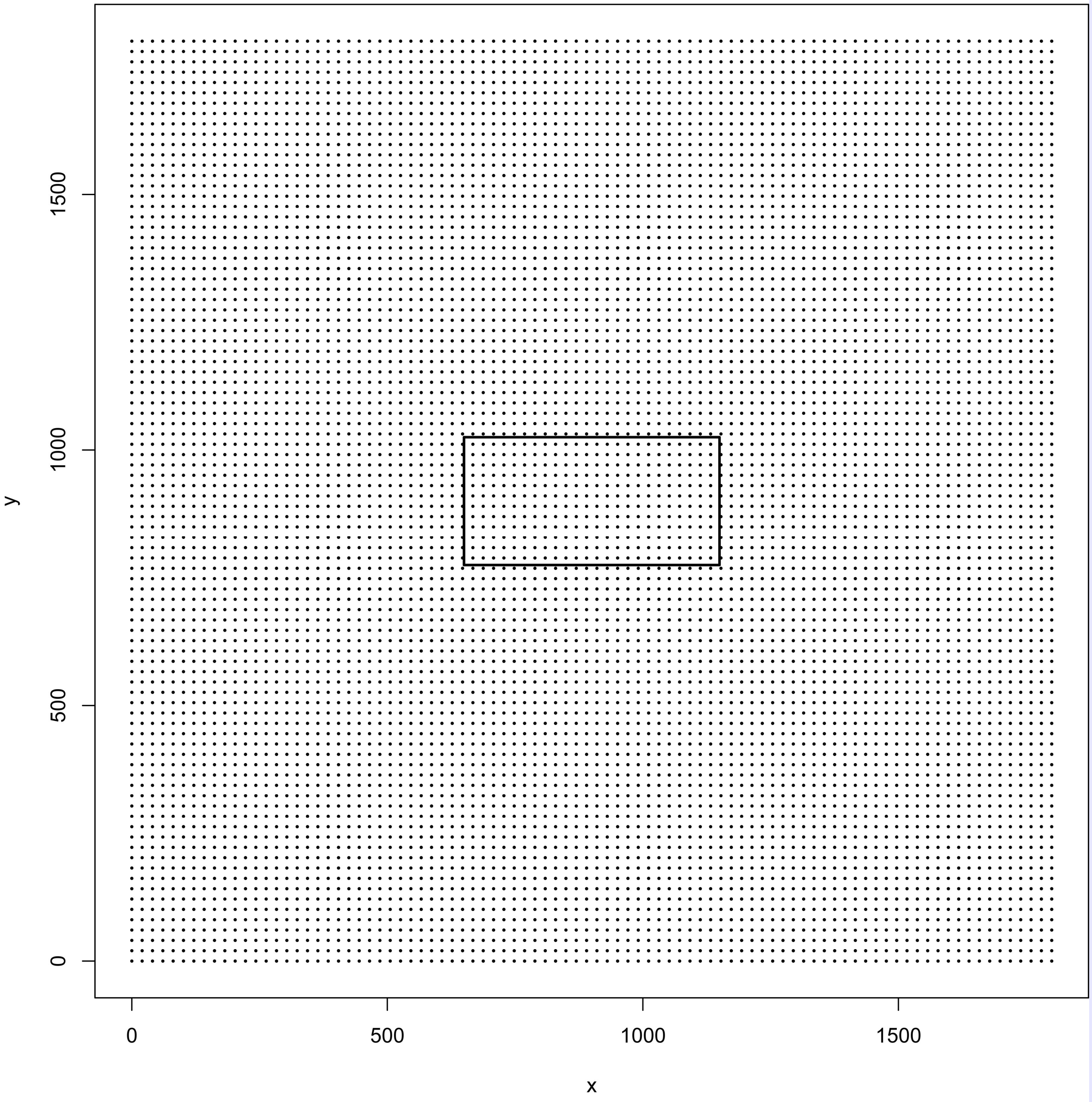
dispersal

Stochastic Community Demography

1	2	1	2	1
1	1	1	4	1
1	3	6	1	2
4	1	1	3	1
1	1	2	1	1

speciation
or
immigration

Fig. 6.1



Basic results

Stochastic model without speciation leads to a
a monodominant community (Gause's principal)

In 3D model, not so!

Diversity is maintained despite no niche differences,
as long as there is speciation

Background of the stochastic community model

Kimura, M., and Weiss, G.H. 1964. The stepping stone model of population genetic structure and the decrease of genetic correlation with distance. Genetics 49:561-576.

Caswell, H. 1976. Community structure: a neutral model analysis. Ecological Monographs, 46: 327-354.

Liggett, T.M. 1985. *Interacting particle systems*. Springer.

Dewdney, A.K. 2000. A dynamical model of communities and a new species-abundance distribution. Biological Bulletin, 198: 152-165.

Hubbell, S.P. 2001.*The Unified Neutral Theory of Biodiversity and Biogeography*. Princeton, NJ, Princeton University Press.

Leigh, E.G. 2007. Neutral theory: an historical perspective. Evolutionary Biology, doi:10.1111/j.1420-9101.2007.01410.x

A stochastic community theory

Three sets of predictions and data to test

1. The abundance distribution
2. Aggregation patterns (range size)
3. Niche segregation

Tabebuia guayacan

The data...

Global Forest Observatory Network (GFON)

~ 8,200 species
~ 3 million trees monitored globally

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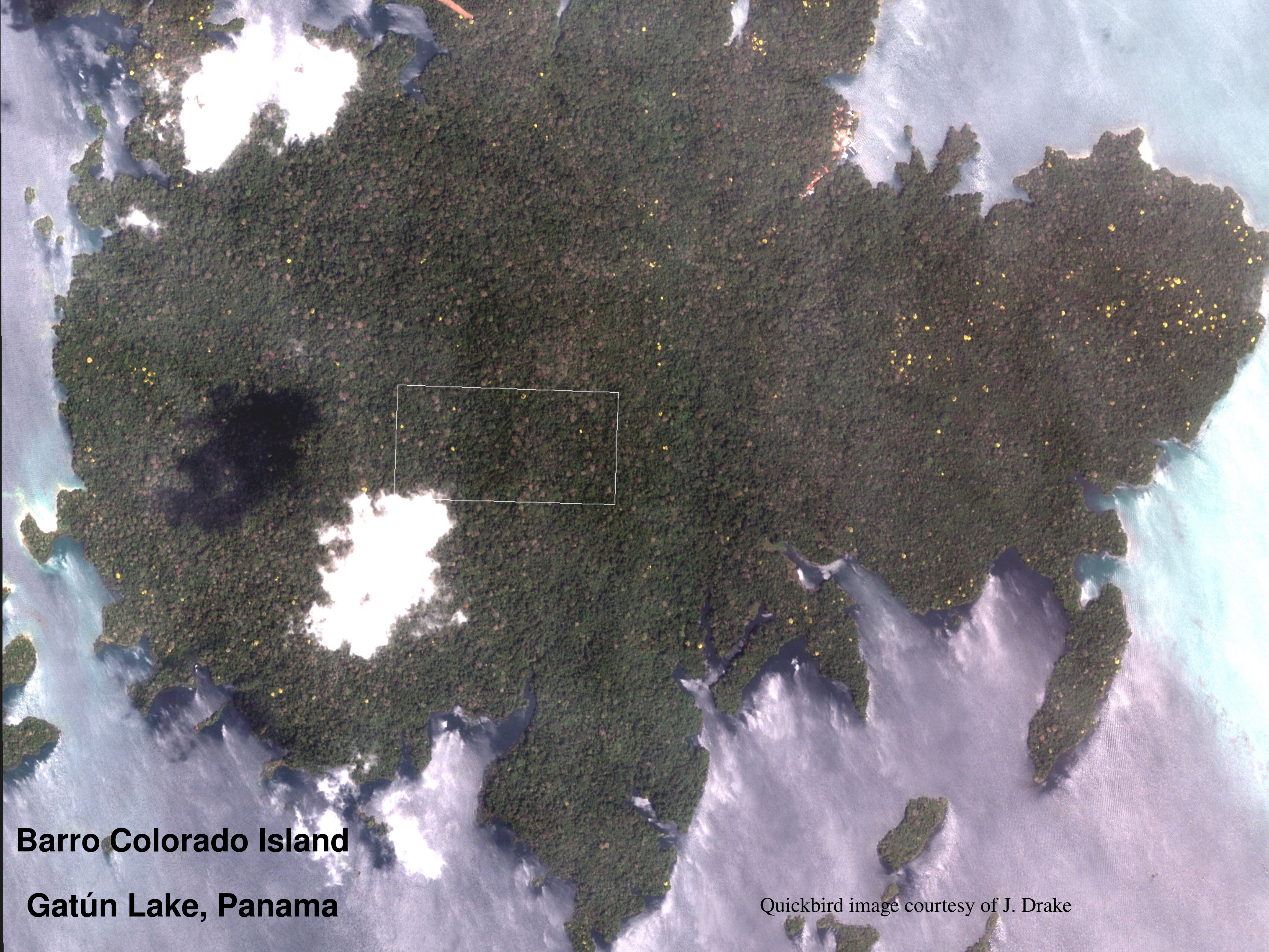


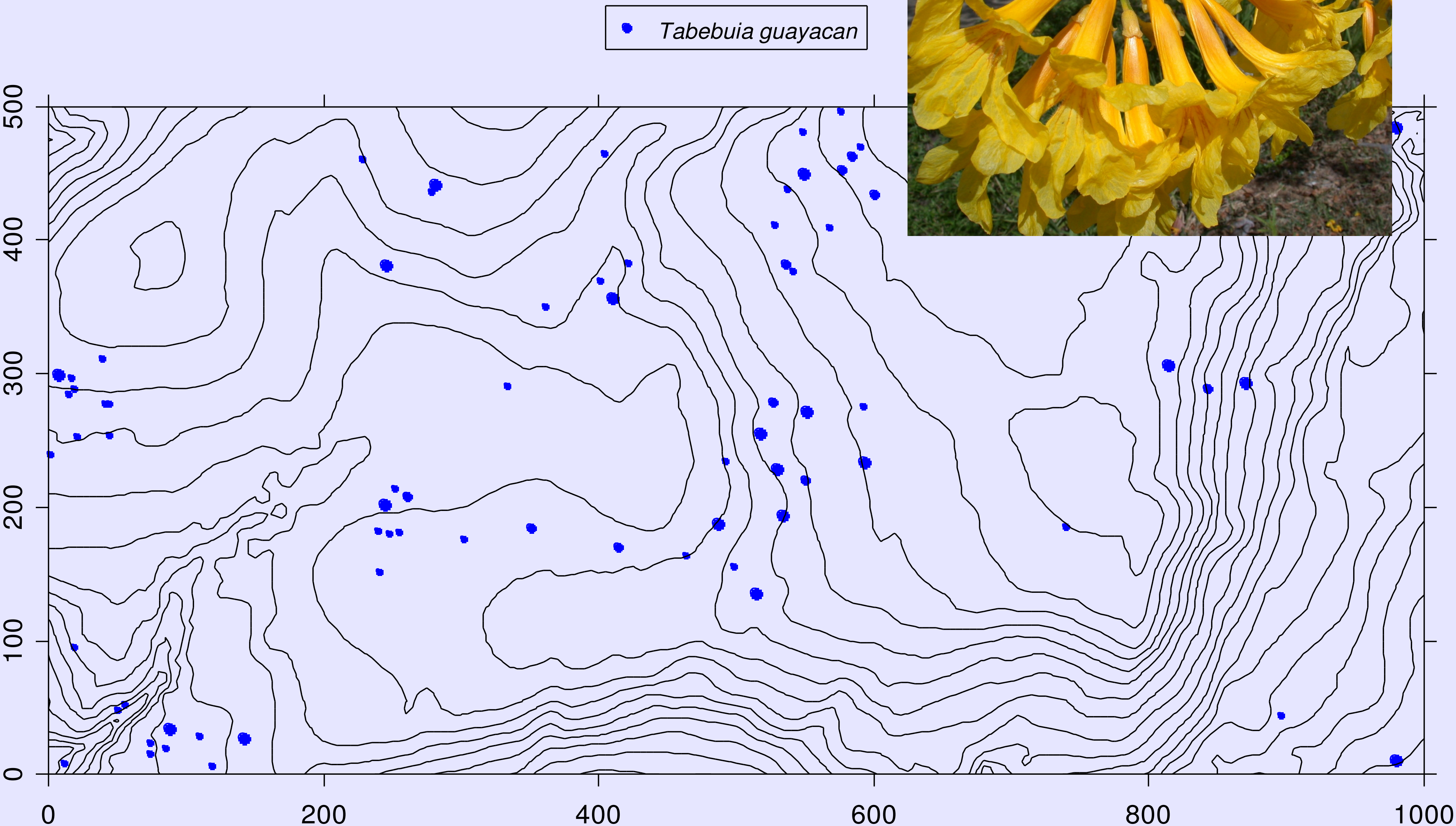
Quickbird image courtesy of J. Drake


460 100

Dipteryx oleifera

Barro Colorado 50 ha plot (Panama)

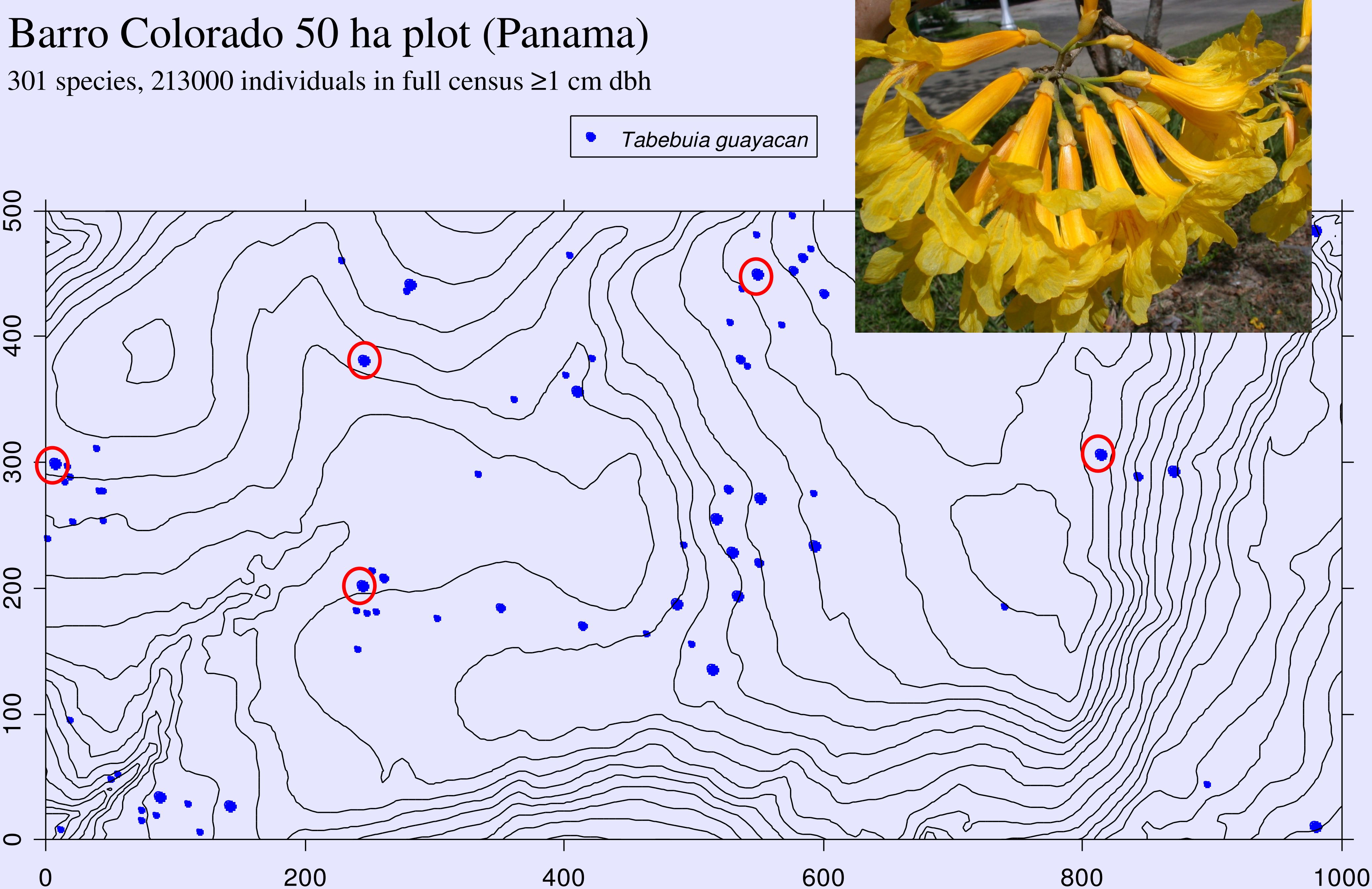
301 species, 213000 individuals in full census ≥1 cm dbh



S. Hubbell, R. Foster, R. Condit, R. Perez, S. Lao

Barro Colorado 50 ha plot (Panama)

301 species, 213000 individuals in full census ≥1 cm dbh



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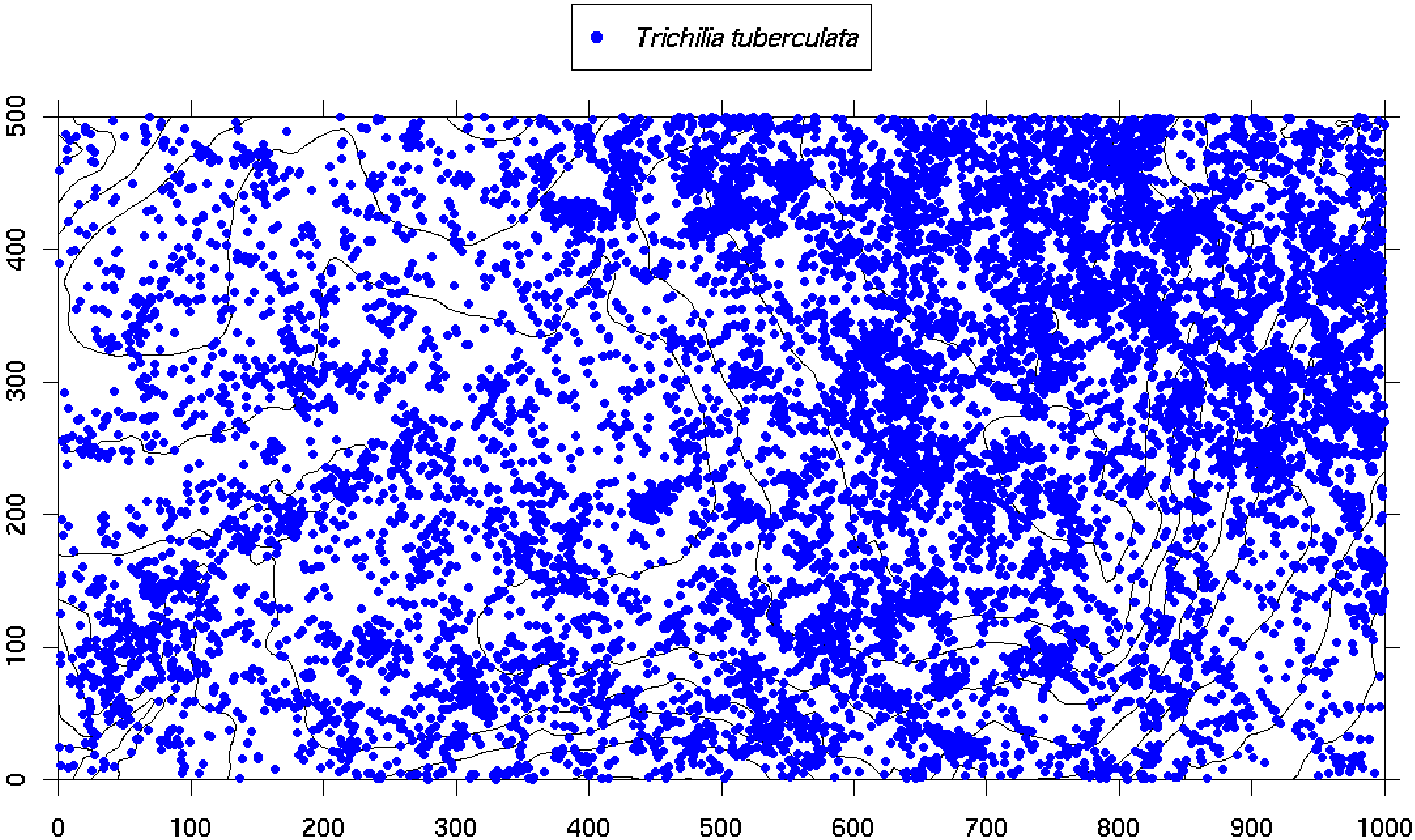
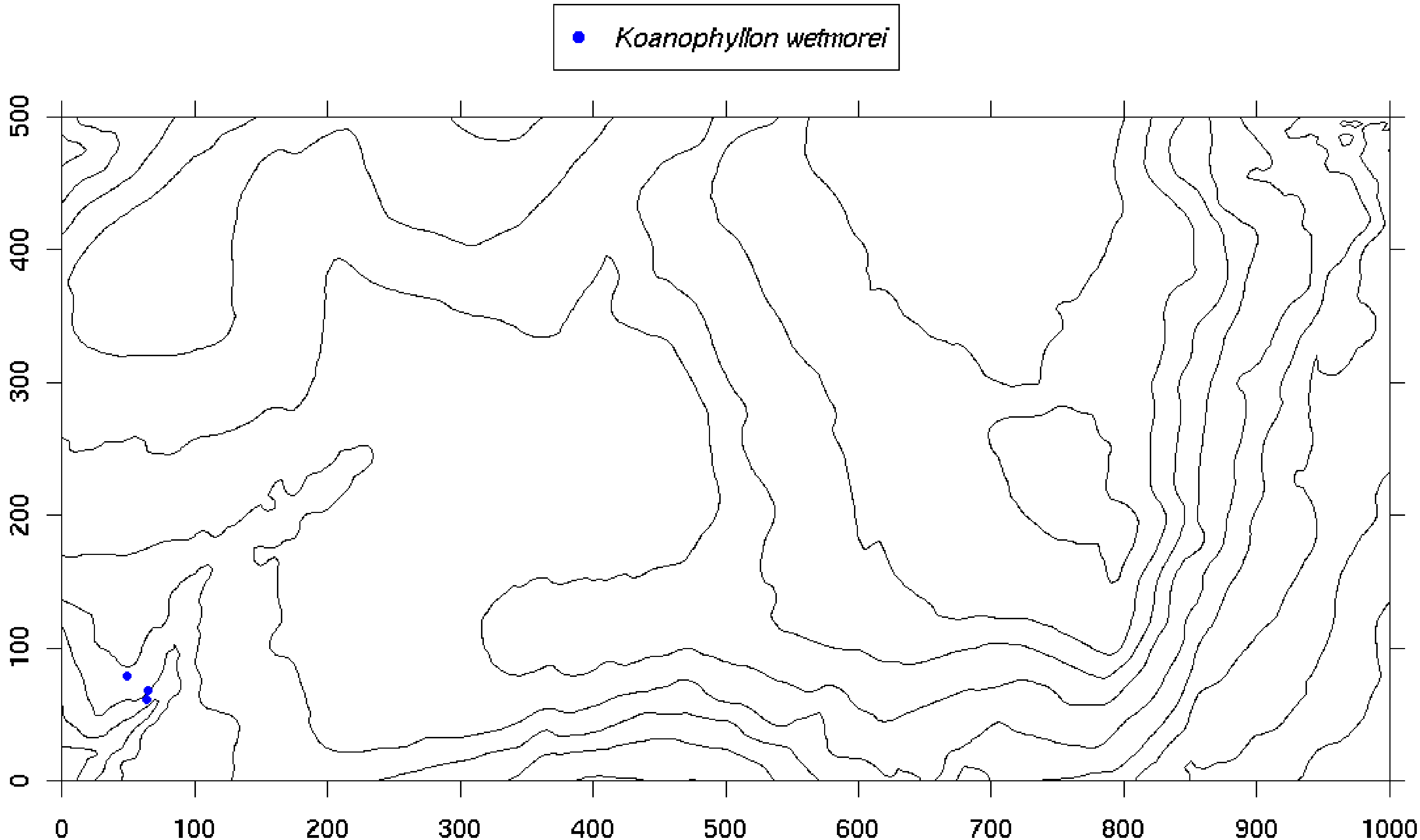
BCI species vary over ...



BCI species vary over ... 4 orders of magnitude in abundance



Equilibrium species abundance distribution

The neutral stochastic model with speciation leads to a log-series abundance distribution

The log-series has a rare tail, with singletons always the most frequent category

The dominance of singletons is driven by speciation

Recent advances in theory

Volkov, I., et al. 2003. Neutral theory and relative species abundance in ecology. Nature 424: 1035-1037.

Volkov, I. et al. 2005. Density dependence explains tree species abundance and diversity in tropical forests. Nature 438: 658-661.

Etienne. R. 2005. A new sample formula for neutral biodiversity. Ecology Letters, 8: 253-260.

Zillio, T., and Condit, R. 2007. The impact of neutrality, niche differentiation and species input on diversity and abundance distributions. Oikos, doi: 10.1111/j.2007.0030-1299.15662.x

Summary I: Abundances in a stochastic community

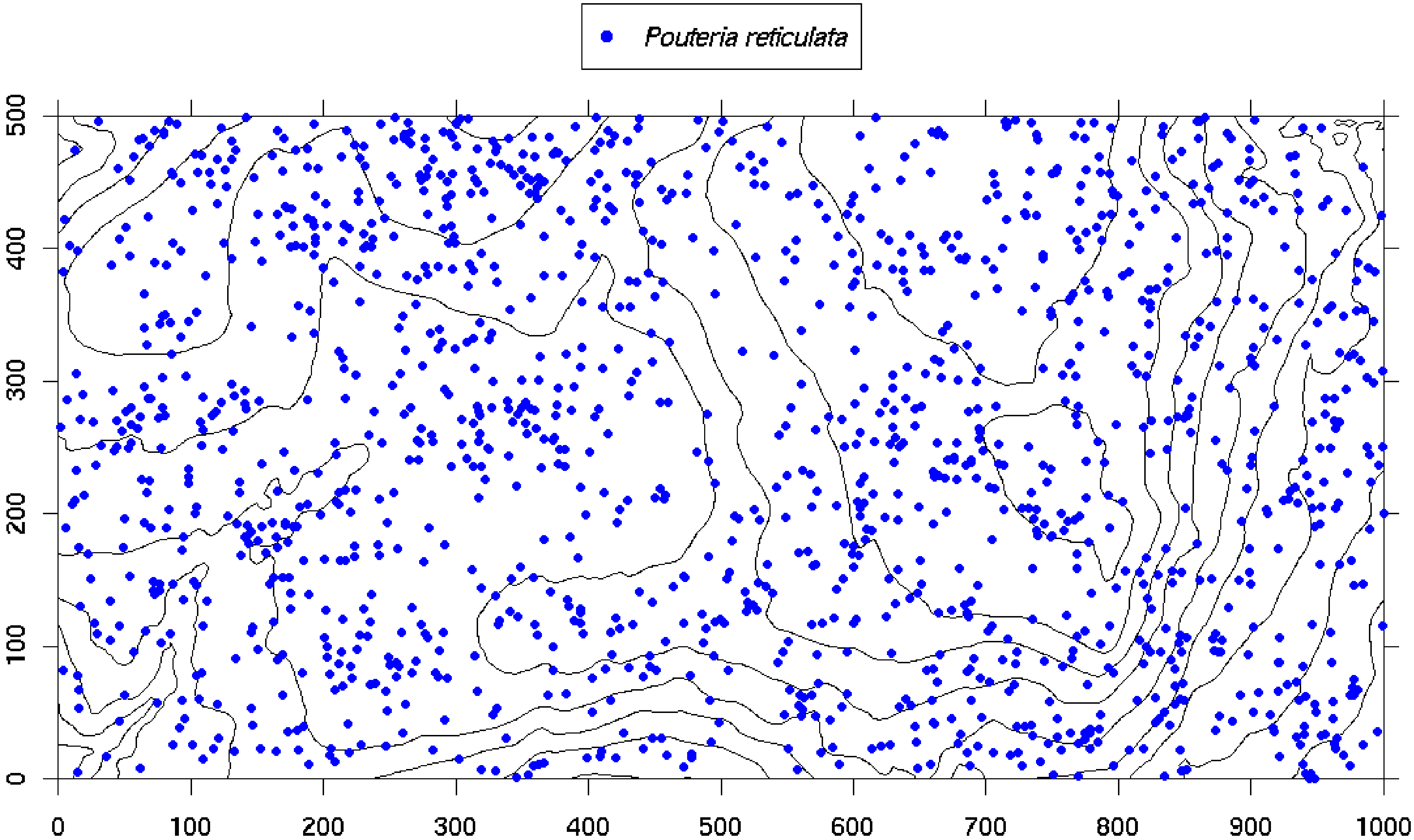
Neutral theory predicts abundance distribution correctly ...

... but it's not neutrality, it's species input & stochastic demography

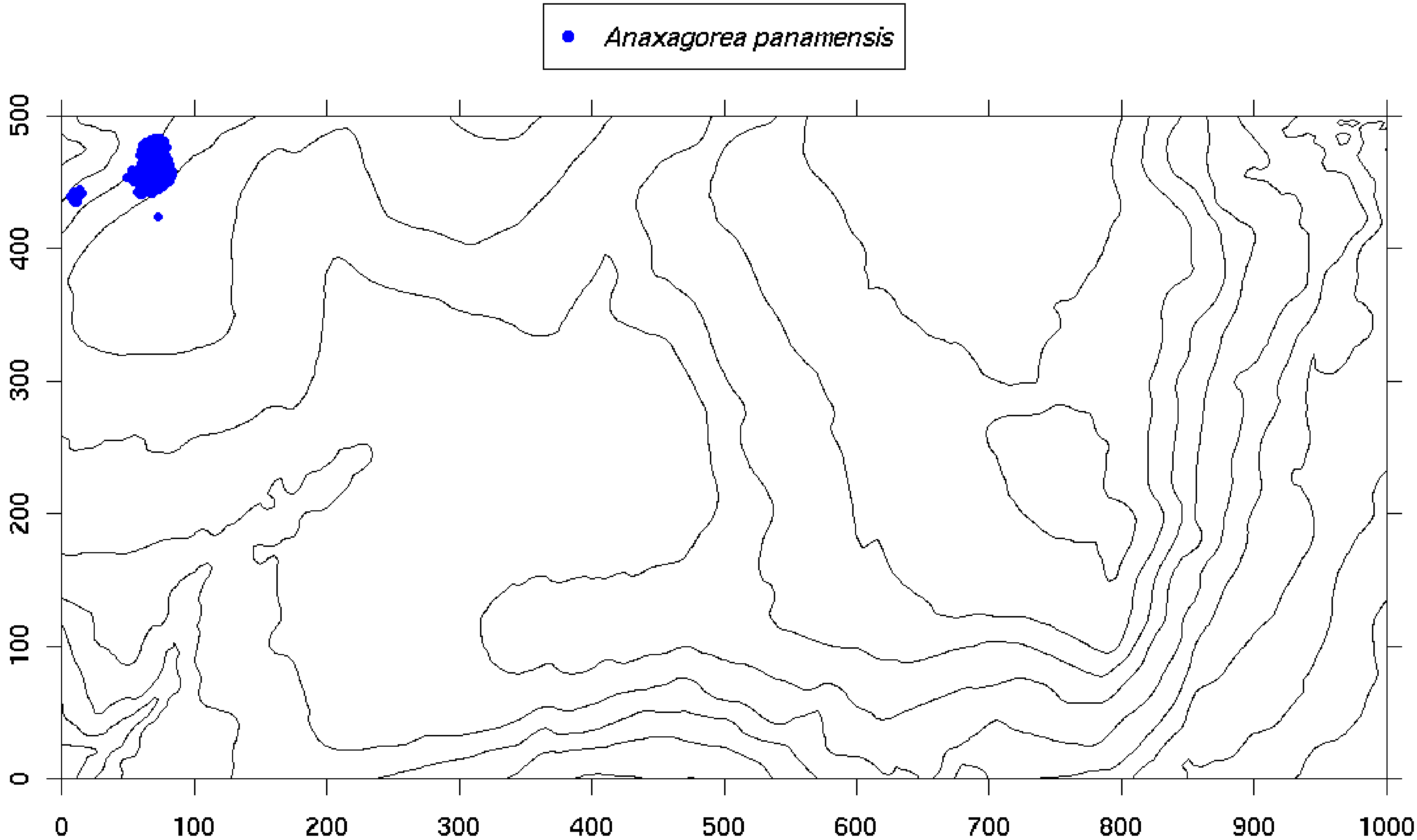
Nevertheless, species differences may sometimes be irrelevant in understanding abundances because of dominating influence of species turnover

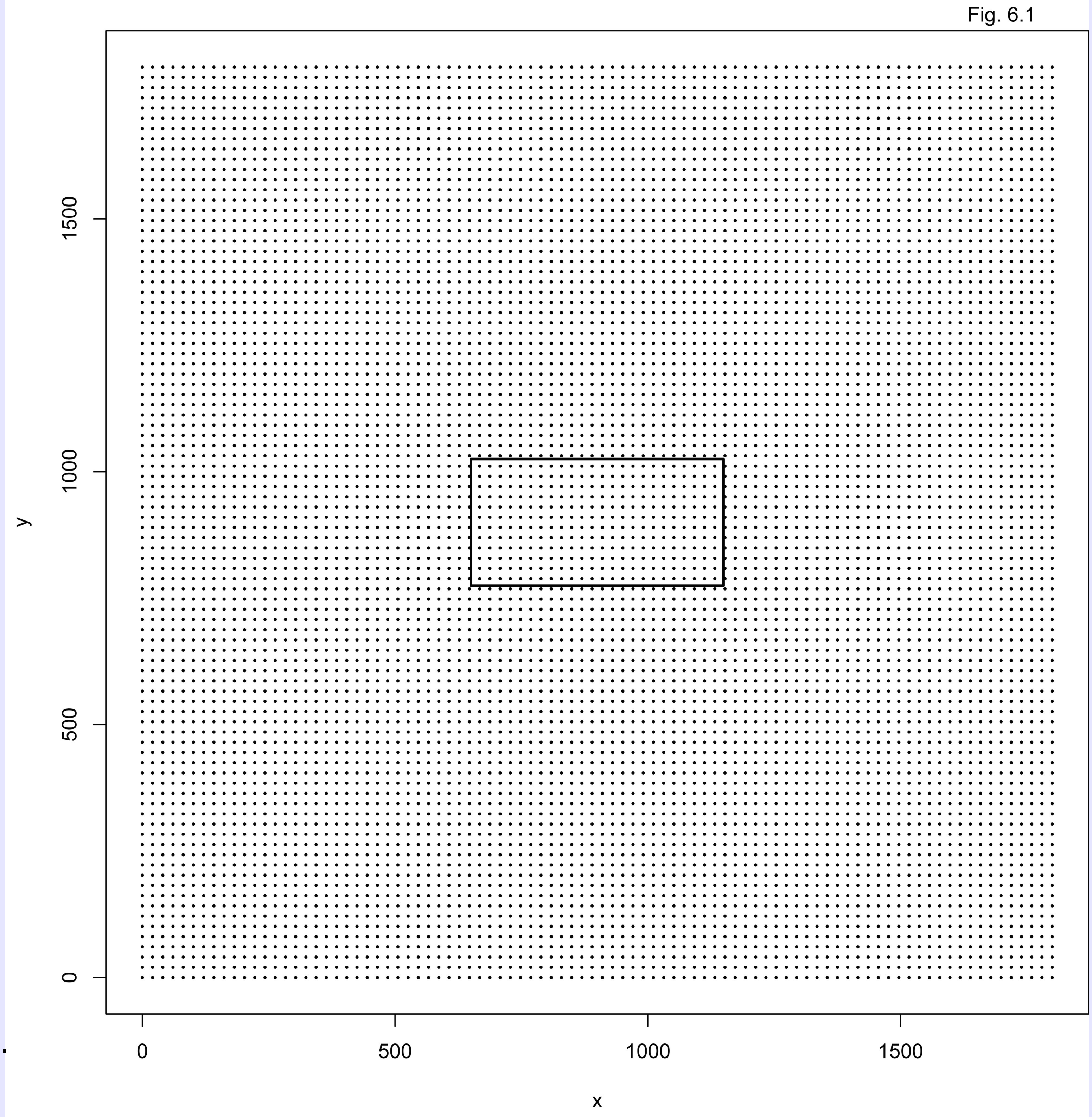
Spatial patchiness in the stochastic community

Barro Colorado plot



Barro Colorado plot

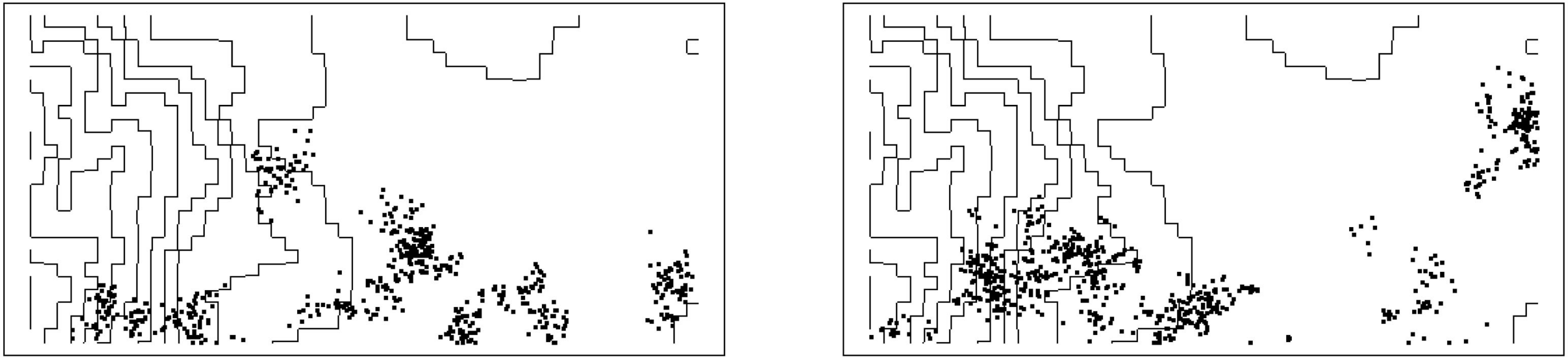




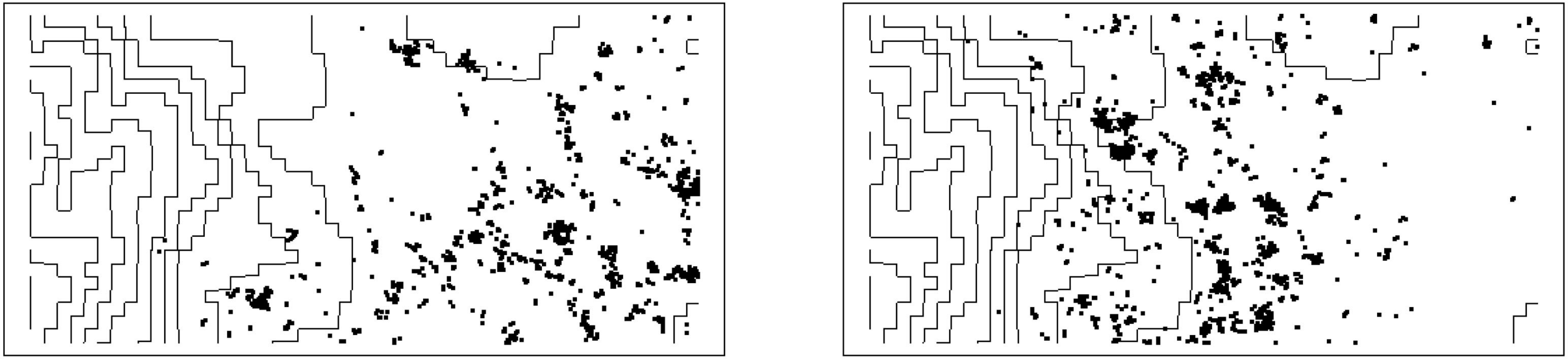
simulations...

Rare long-distance dispersal and range

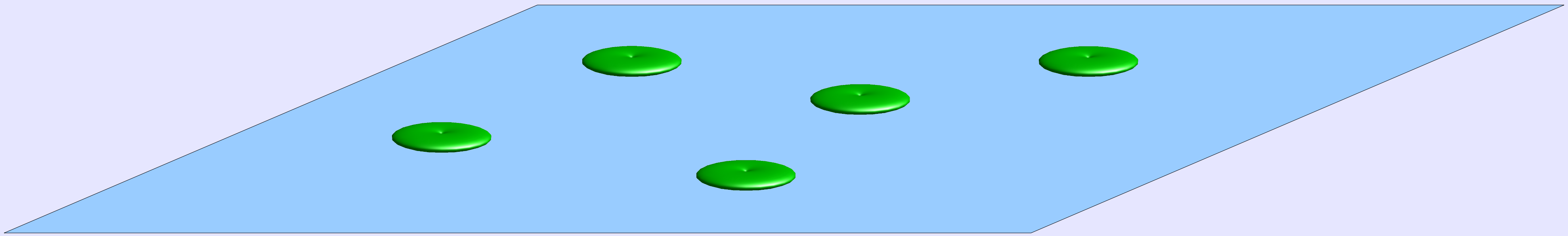
10-m dispersal (plus 1 in 1000 100-m dispersal)



6-m dispersal (plus 1 in 10 100-m dispersal)

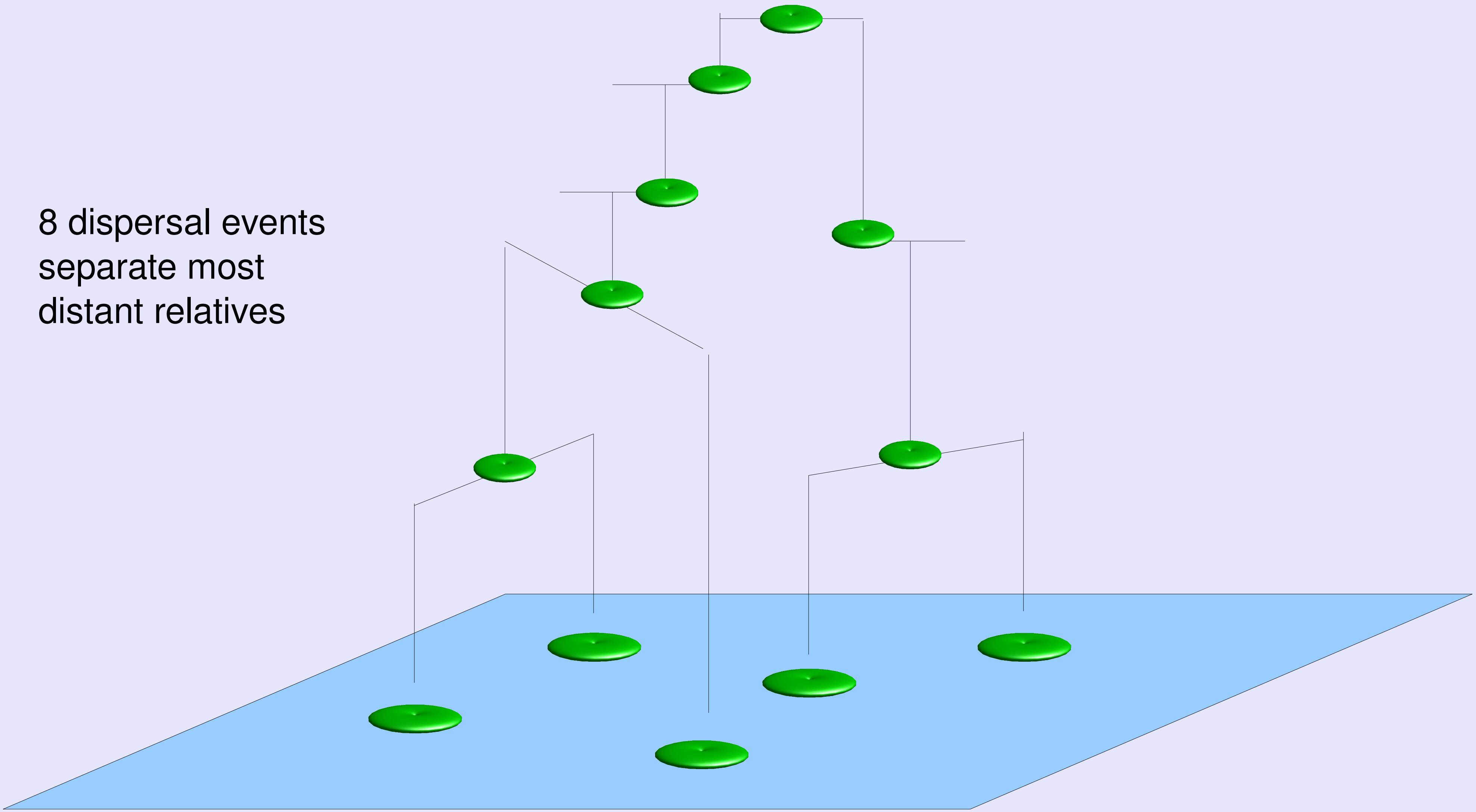


dispersal & range

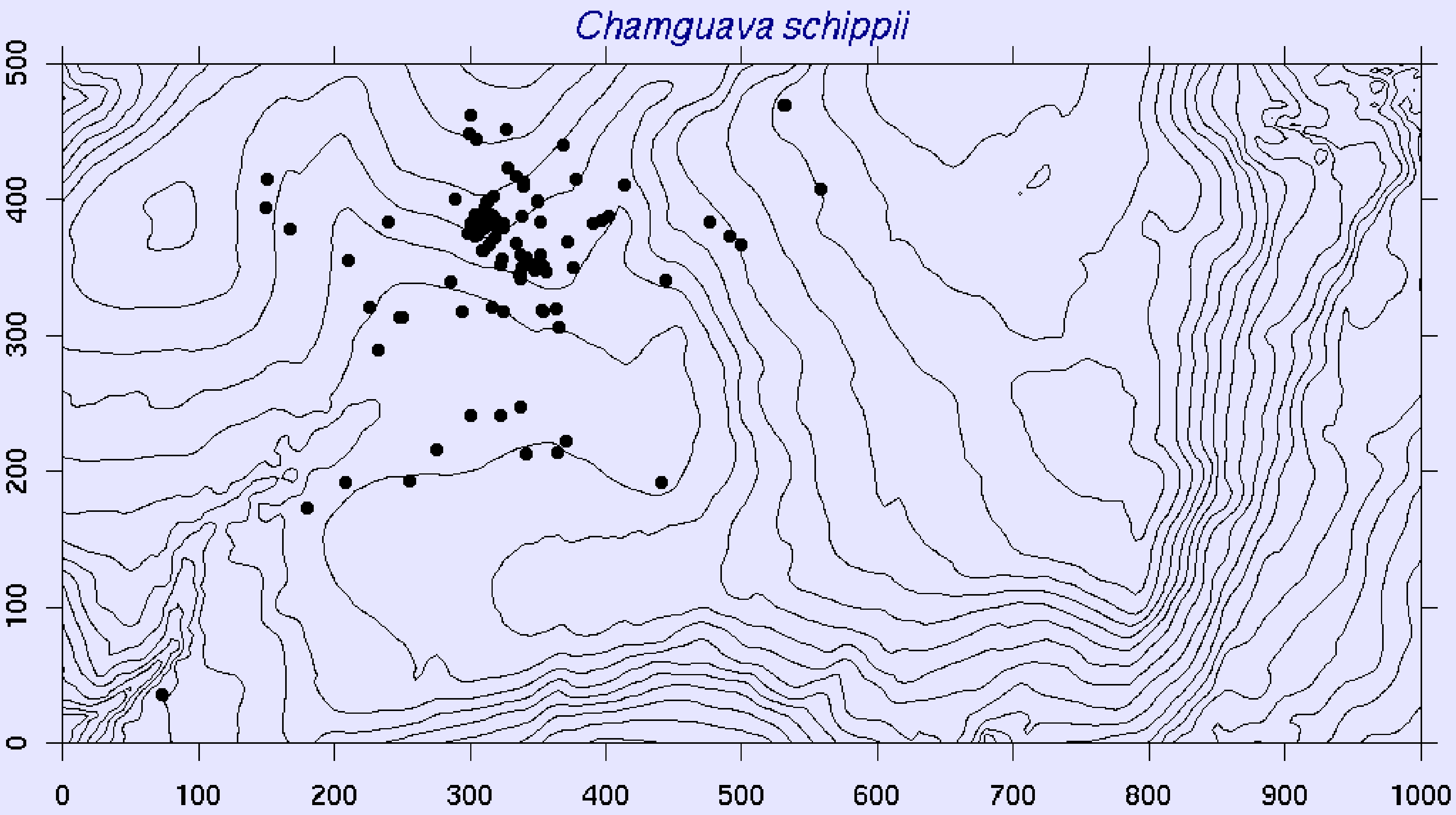


Pedigree + dispersal = range

8 dispersal events
separate most
distant relatives



Barro Colorado plot: dispersal of 1-cm recruits



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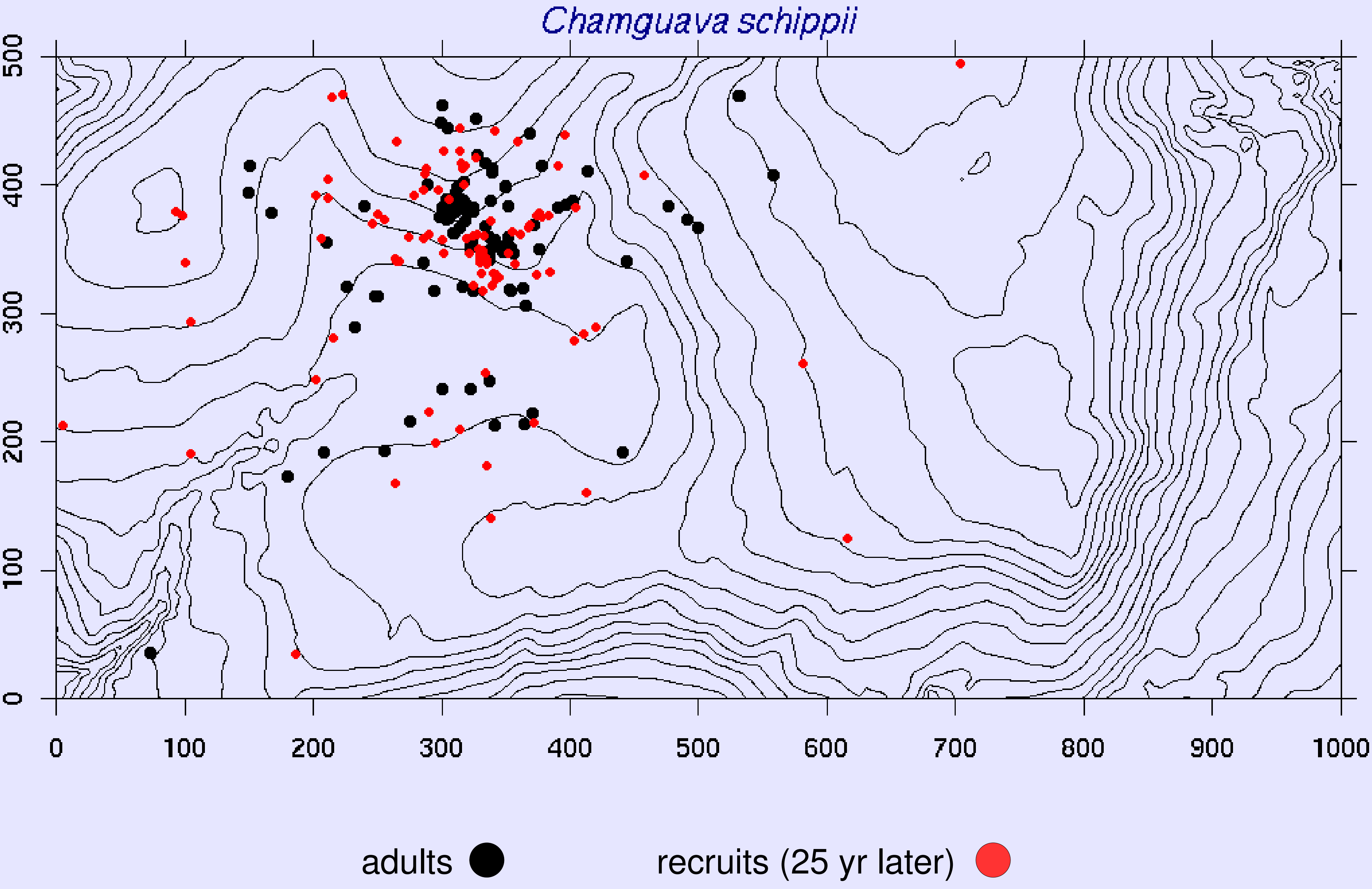

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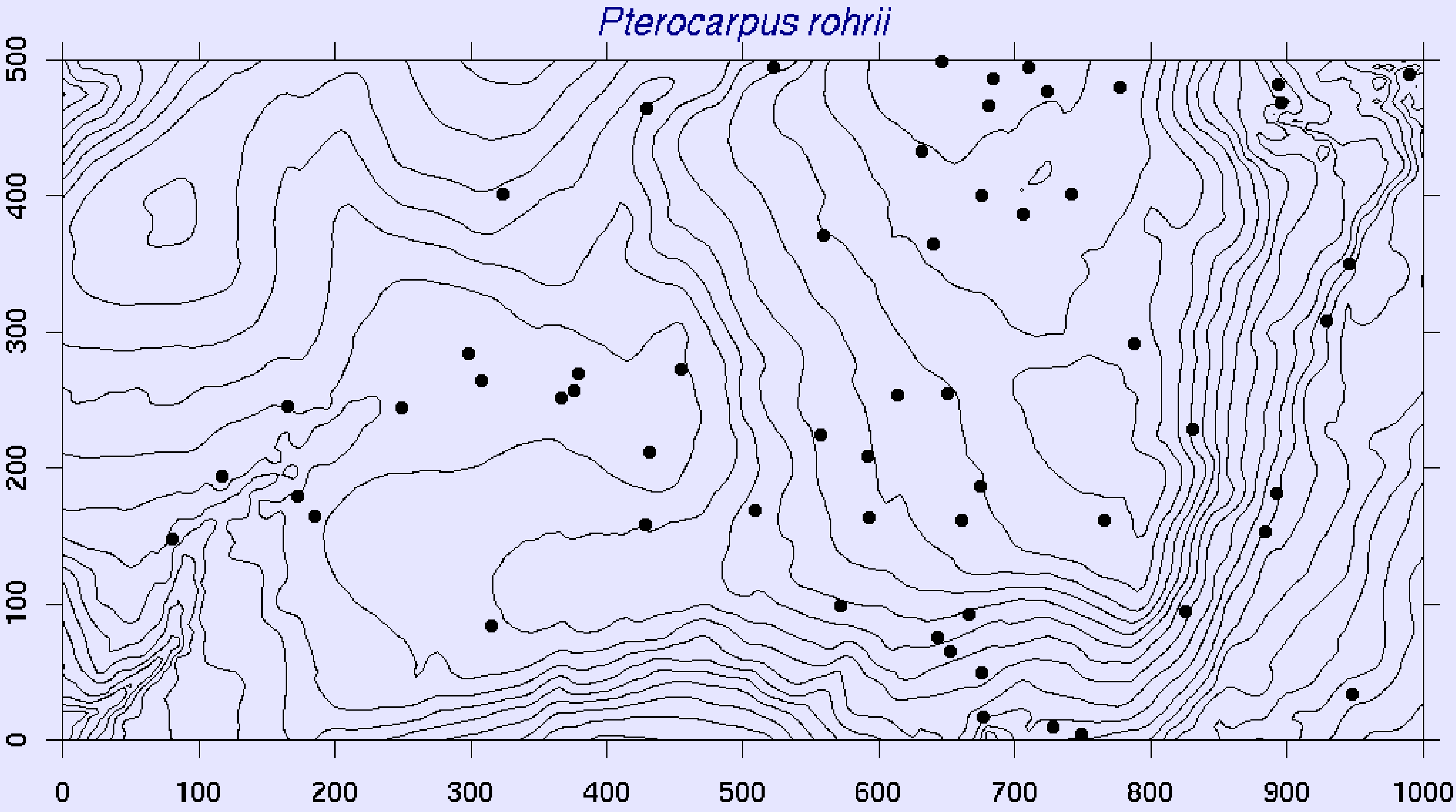

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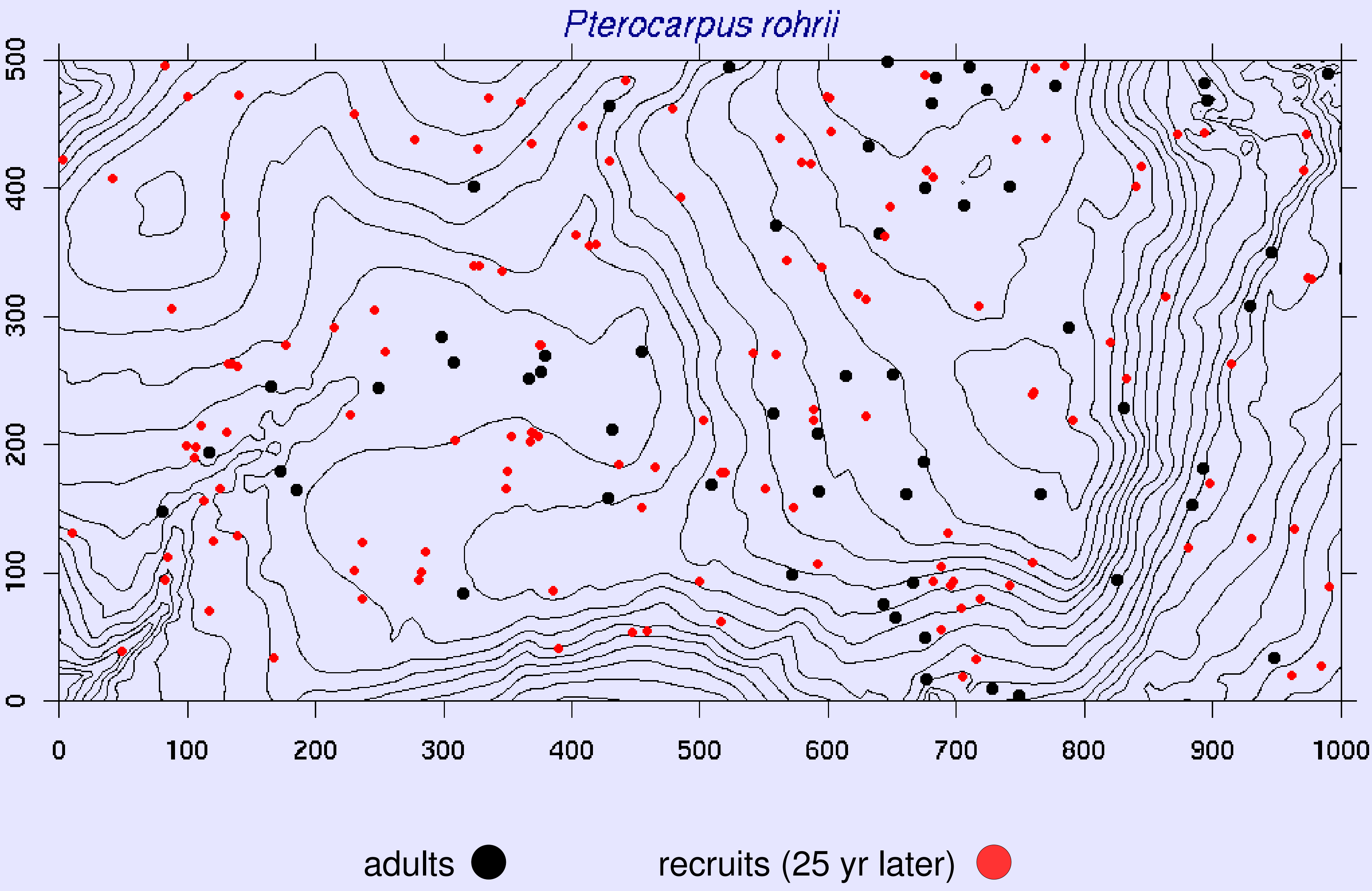


Proportion of recruits dispersing various distances from their parents

species	< 30 m	> 100 m
Chamguava schippii	**0.383**	**0.224**
Prioria copaifera	**0.287**	**0.242**
Cecropia obtusifolia	**0.186**	**0.237**
Eugenia coloradoensis	**0.256**	**0.591**
Talisia princeps	**0.045**	**0.494**
Inga marginata	**0.132**	**0.645**
Chrysophyllum argenteum	**0.041**	**0.712**
Pterocarpus rohrii	**0.034**	**0.770**
Hampea appendiculata	**0.089**	**0.714**
Calophyllum longifolium	**0.006**	**0.842**
Inga acuminata	**0.023**	**0.848**
Nectandra lineata	**0.027**	**0.861**

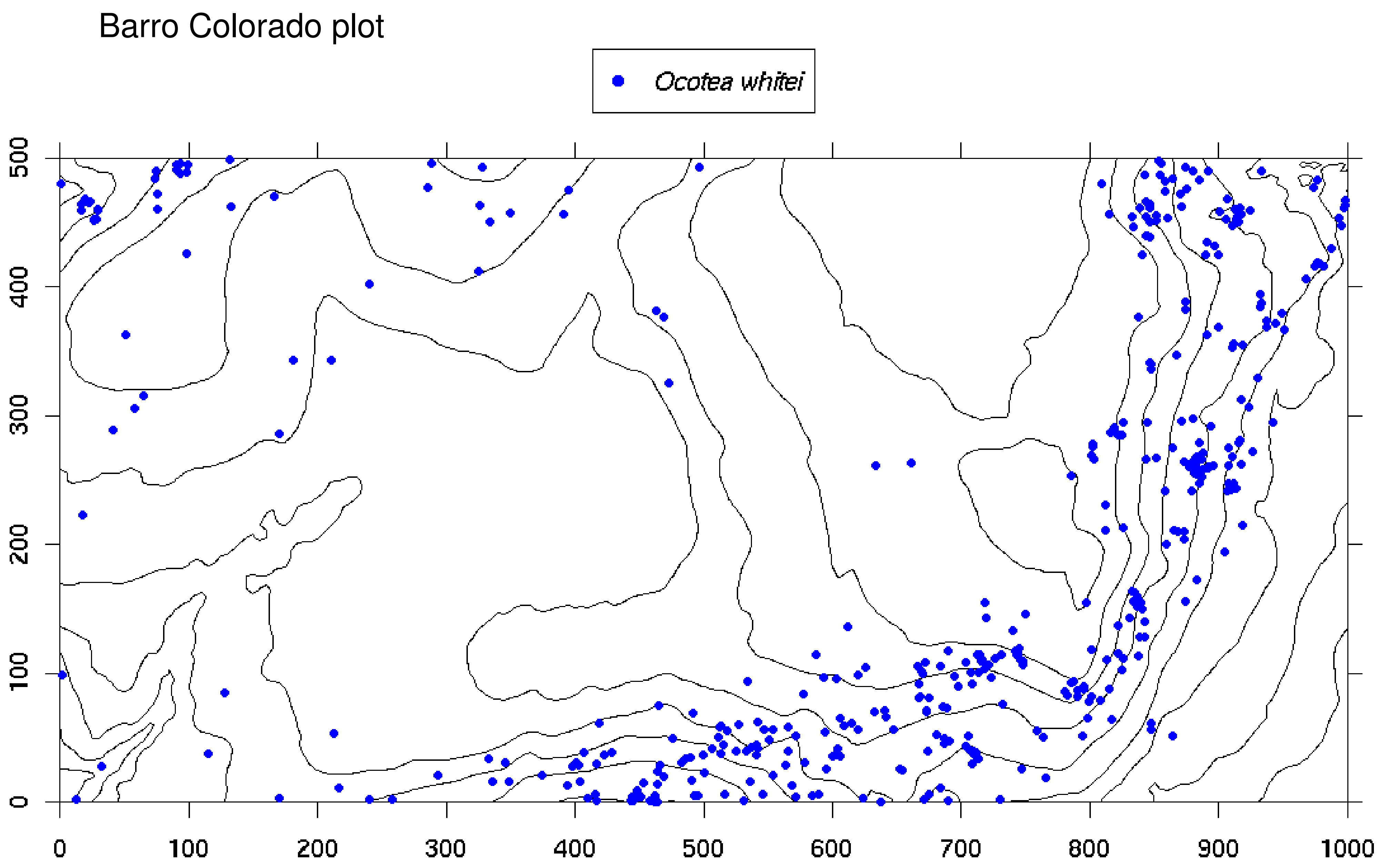
Summary II: Spatial patchiness in a stochastic community

Poor dispersal creates very patchy distribution ...
... the degree of patchiness is simply related to dispersal distance

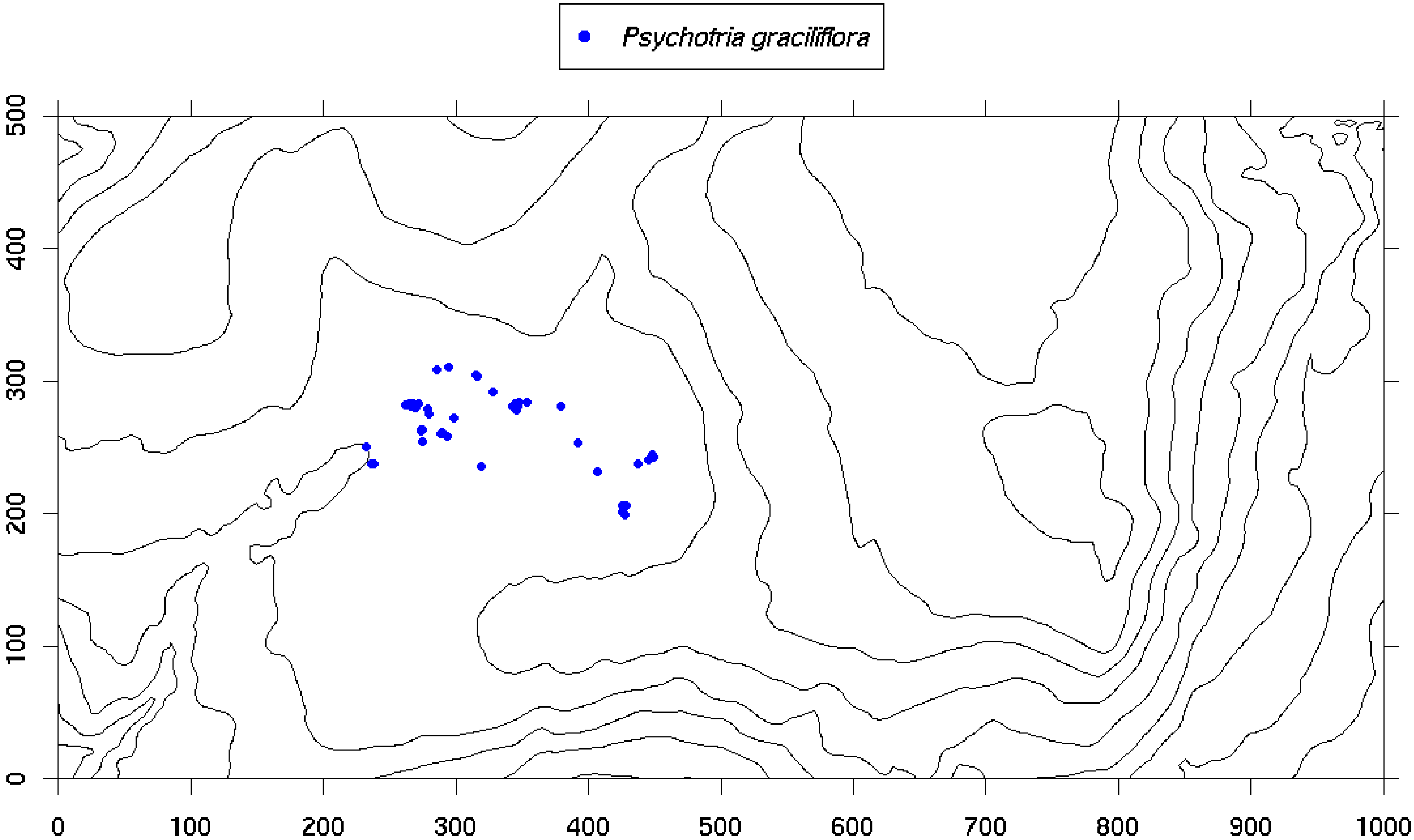
Most tree species are widely distributed across 50 hectares ...
... and match simulations with ~ 200 m or better dispersal distances

Independent data on dispersal distances also suggest that most species dispersal well at the scale of 50 hectares

Niche segregation and spatial patterns

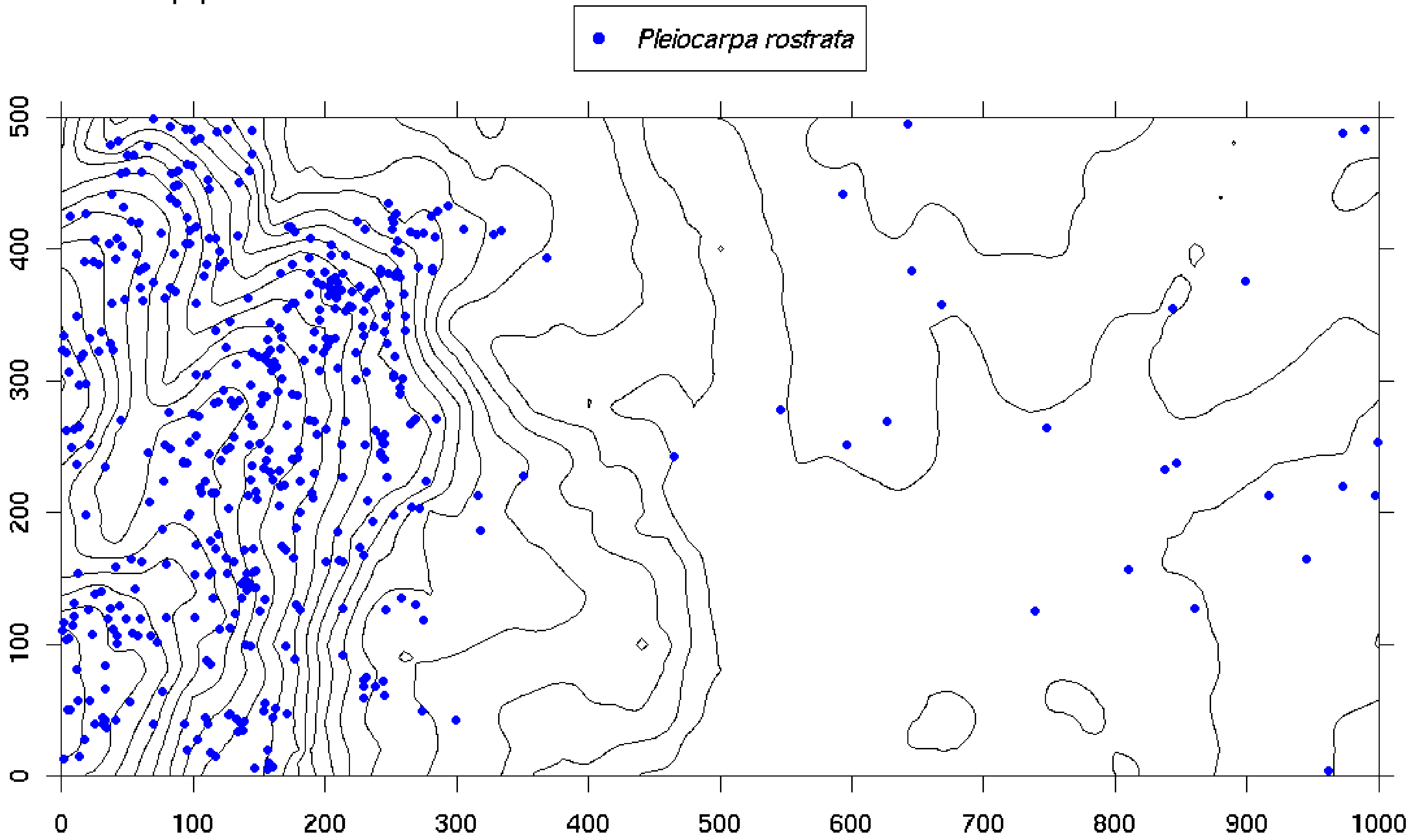

Barro Colorado plot
Ocotea whitei
0
100
200
300
400
500
600
700
800
900
1000
0
100
200
300
400
500

Barro Colorado plot




Africa
ASIA
Morocco
Tunisia
Mediterranean Sea
Algeria
Libya
Egypt
Nile R.
Red Sea
Mauritania
Mali
Niger
Chad
Sudan
Eritrea
Djibouti
Arabian Sea
Burkina Faso
Guinea
Benin
Ghana
Nigeria
Ethiopia
Liberia
C.A.R.
Cameroon
Togo
Somalia
Eq. Guinea
Democratic Rep. of the Congo
Uganda
Sao Tome & Principe
Gabon
Kenya
INDIAN OCEAN
Rep. of the Congo
Rwanda
Burundi
Cabinda (Angola)
Tanzania
Seychelles
Malawi
Comoros
Angola
Zambia
Mozambique
Mauritius
Korup
Namibia
Zimbabwe
Madagascar
Botswana
Réunion (France)
800 Miles
800 Kilometers
Swaziland
South Africa
Lesotho
20° W
0°
20° E
40° E
60° E

Korup plot



Pleiocarpa rostrata
0
100
200
300
400
500
0
100
200
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500
600
700
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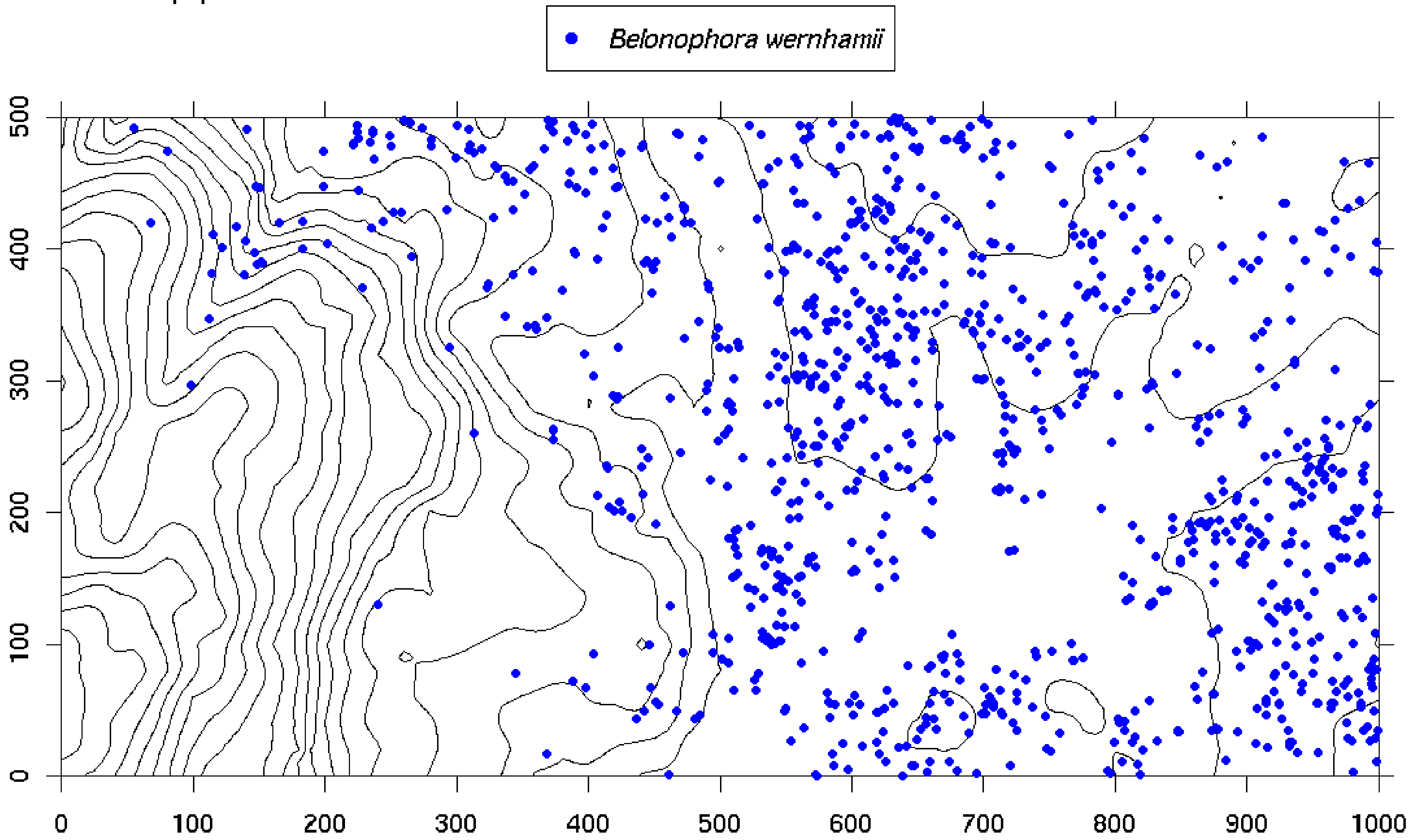
900
1000

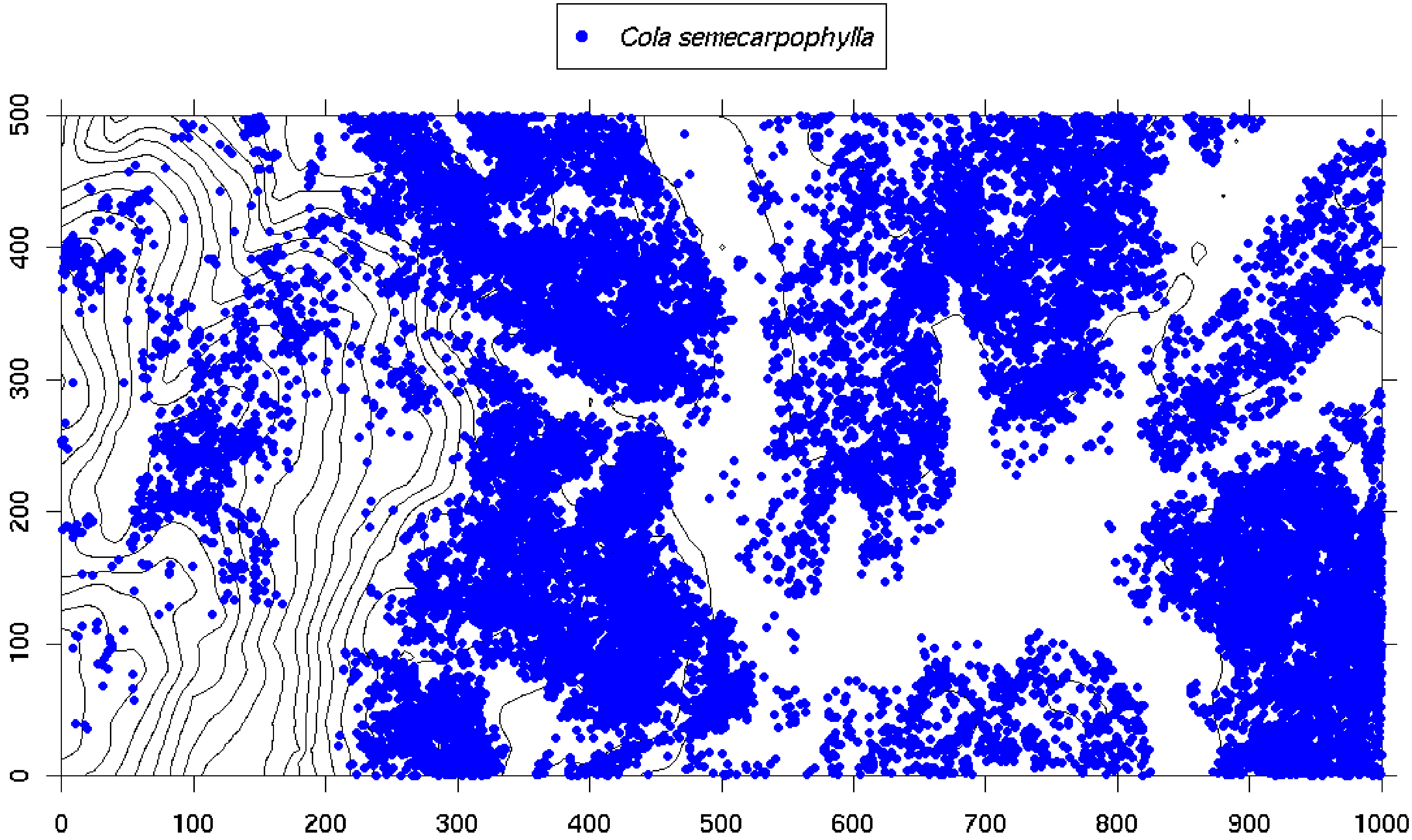
Korup plot



Belonophora wernhamii
0
100
200
300
400
500
600
700
800
900
1000
0
100
200
300
400
500

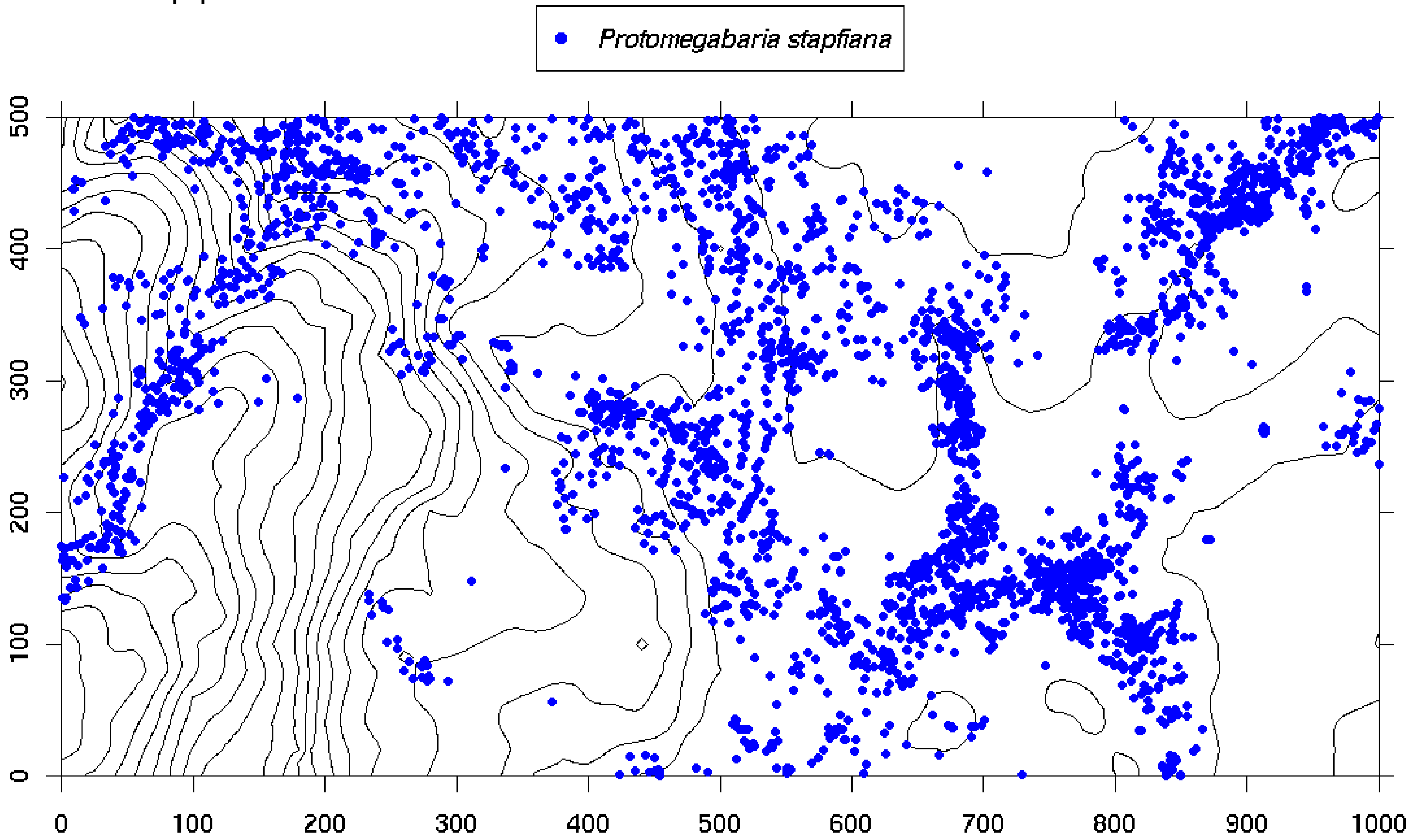
Korup 50 ha plot (Cameroon)

494 species,329000 individuals in full census ≥1 cm dbh



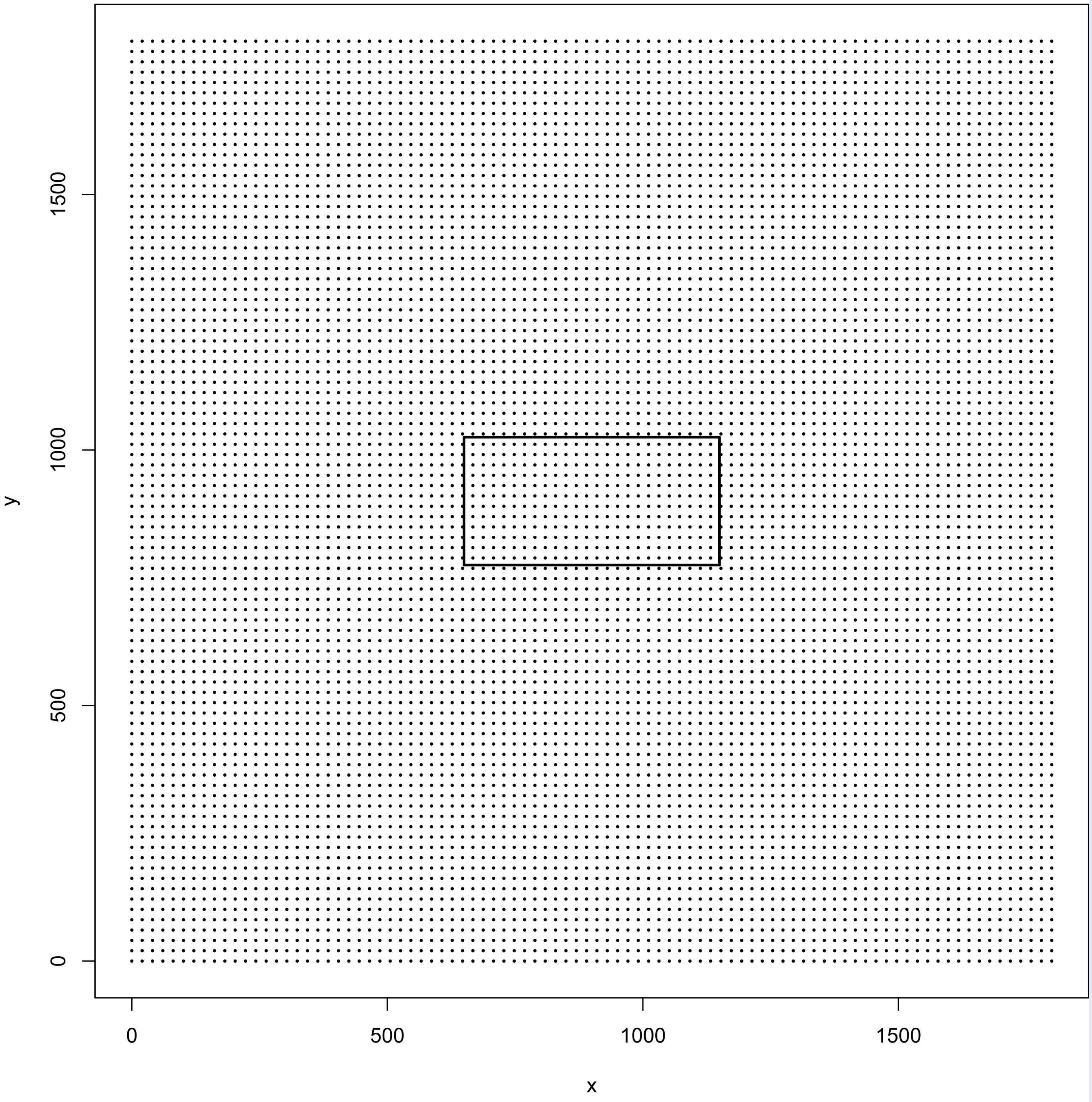
D. Thomas, D. Kenfack, G. Chuyong, R. Condit

Korup plot

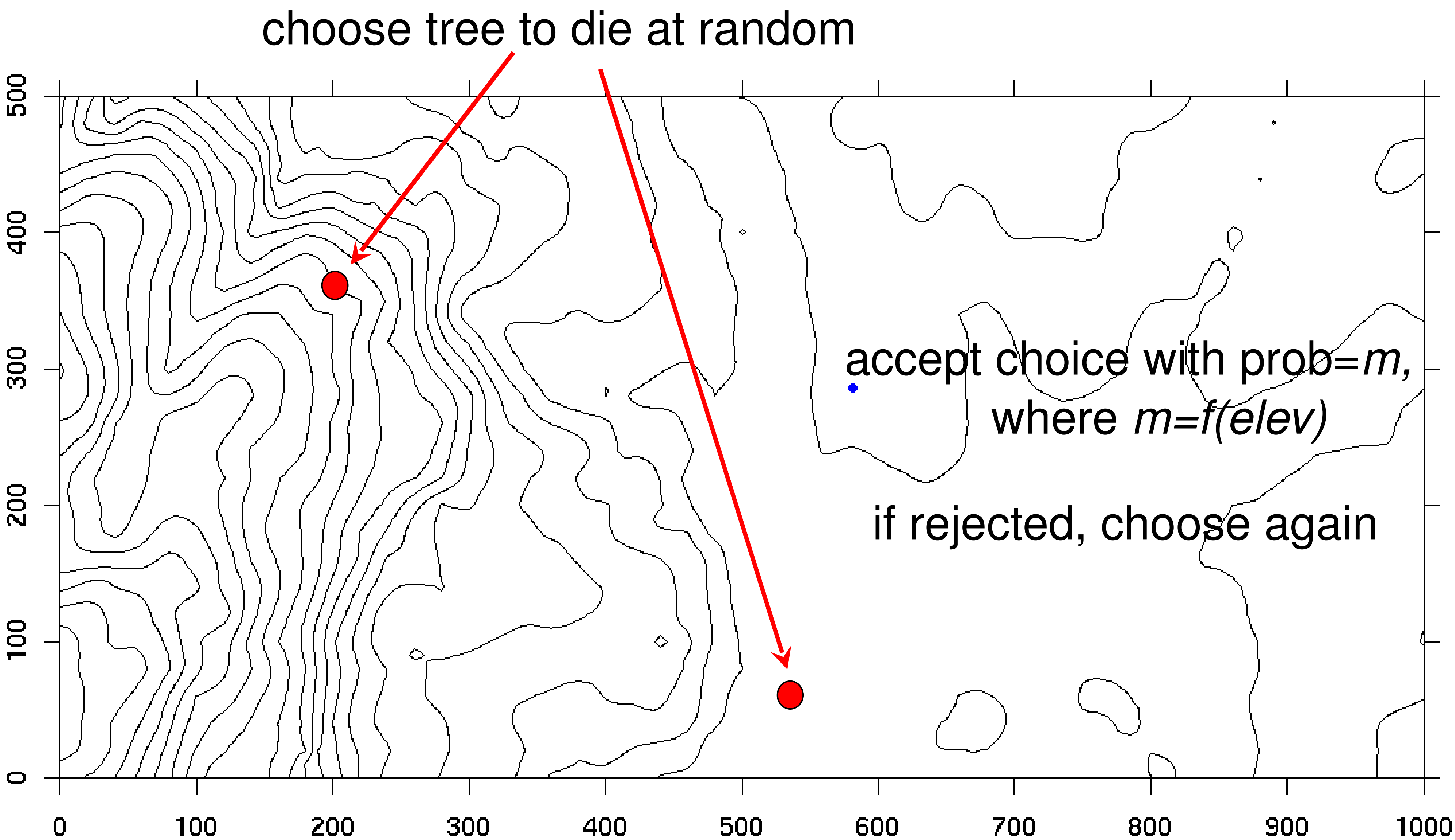


Protomegabaria stapfiana
0
100
200
300
400
500
600
700
800
900
1000

Fig. 6.1

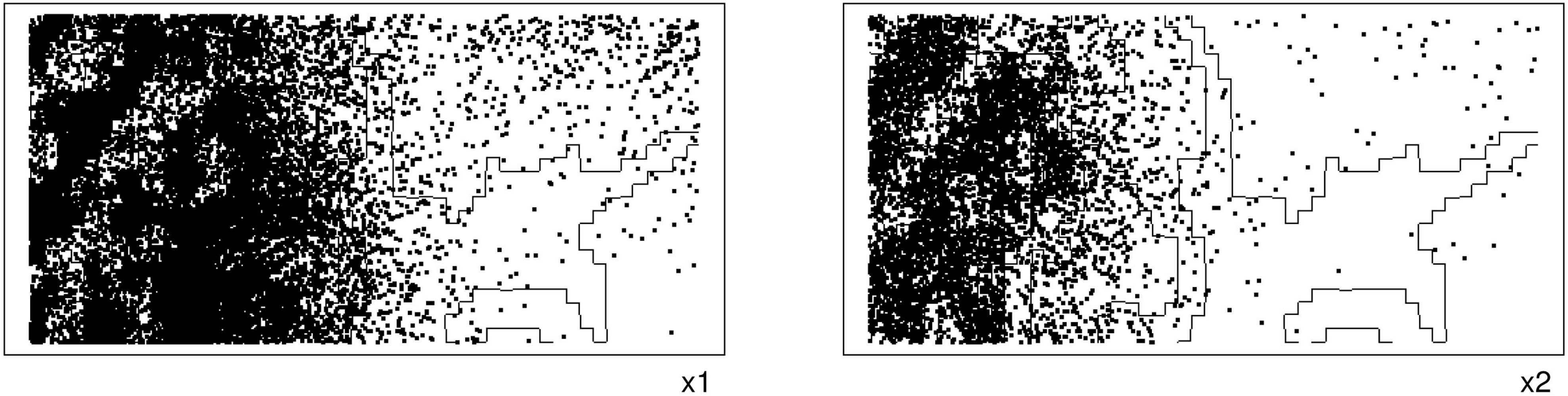


Incorporating niche differences into the stochastic model

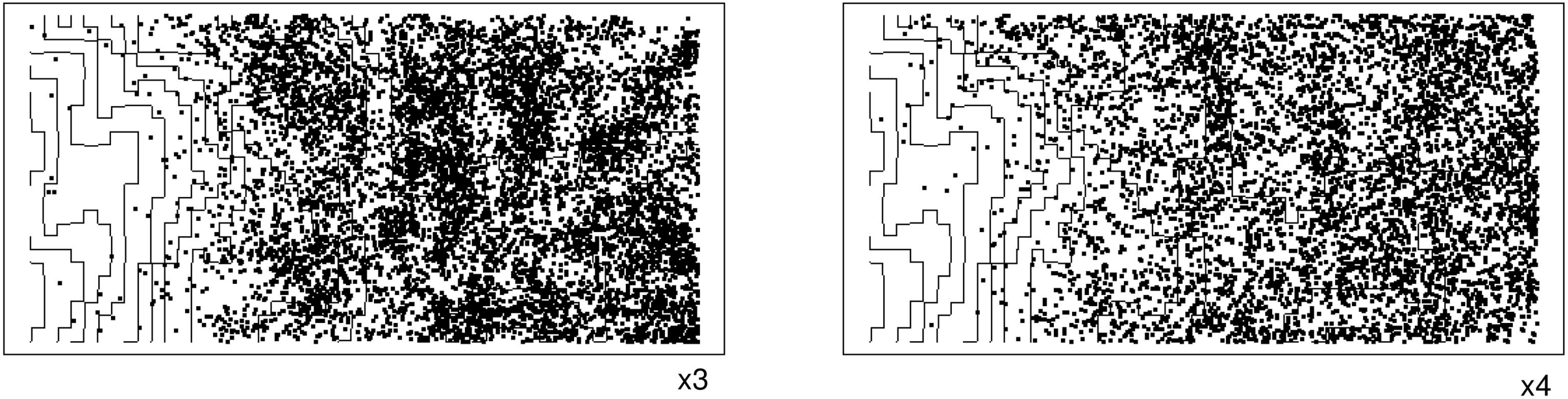


Simulated species distributions with niche differences

Community has 140 species, one with 17484 individuals ... 45 singletons



44 unique niche responses, 10 most abundant species all have one of these 4



more simulations....

Summary III: Spatial niches in a stochastic community

With species input, many species with the same habitat requirements co-occur

Poor dispersal can prevent species from reaching suitable habitat

Good dispersal sends species into unsuitable habitat

An unnamed *Cola* species