Simulation of (tropical) forest stands using marked point processes

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Description of a forest stand

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List of trees (x_i, y_i, D_i, s_i)

- spatial coordinates (x, y)
- diameter D (height...)
- species s

Spatialized information is required, *e.g.*

- To run an individual-based space-dependent model of forest dynamics
  - ☞ initial state for management-oriented simulations
- To make simulation study of such a model
  - ☞ repetitions
- To make simulation study of distance-based estimators of wood biomass, etc.

… but is rarely available

- Permanent sample plots: few repetitions
- Inventory data (list of trees): diameter, species
- Aggregated data: mean diameter, species composition

Disaggregation

How to simulate a virtual forest stand given partial data?

$$\left.\begin{array}{r} (D_i, s_i) \\ N, f(D), f(s) \\ N, \bar{D}, f(s) \end{array}\right\} \longrightarrow (x_i, y_i, D_i, s_i)$$

➔ Fit a model (point process) to a reference forest stand with parameters that can be estimated from partial data

High species diversity

Hundreds of species/ha in tropical moist forest

About 40 species/ha in tropical dry forest

☺ Simplification: grey species (otherwise: see Goreaud, 2004; Loussier, 2003) ☺

➔ Marked point process (mark = diameter)

Fitting to a reference forest stand

- In terms of spatial pattern: intensity, second-order characteristics (pair correlation function, Ripley's K-function)
- In terms of diameter distribution
- Interaction between diameter and spatial pattern

Computing time constraint

Simulation of a virtual has to be fast

(compared to the time required by an individual-based space-dependent model to reach stationary state)

Spatial pattern

- homogeneity and isotropy is assumed
- intensity
- Ripley's K-function

Diameter distribution

- histogram of diameters
- variogram (as if it was a random field)

Interaction between diameter and spatial pattern

Schlather (2001); Parrott & Lange (2004):

1. mark variogram?
2. Cressie's mark covariance function?
3. Stoyan's mark covariance function?
4. Stoyan's mark correlation function (k_{mm})?

5. Isham's mark correlation function?

6. mark difference function?

7. mark expectation function?

Conditional K-function given $D \geq x$

$$\text{Or:} \quad \frac{\Pr[\|\mathbf{x} - \mathbf{x}'\| \leq r | D < D']}{\Pr[\|\mathbf{x} - \mathbf{x}'\| \leq r]}$$

Random field model

Ψ: marked process

Φ: unmarked process

Z: random field

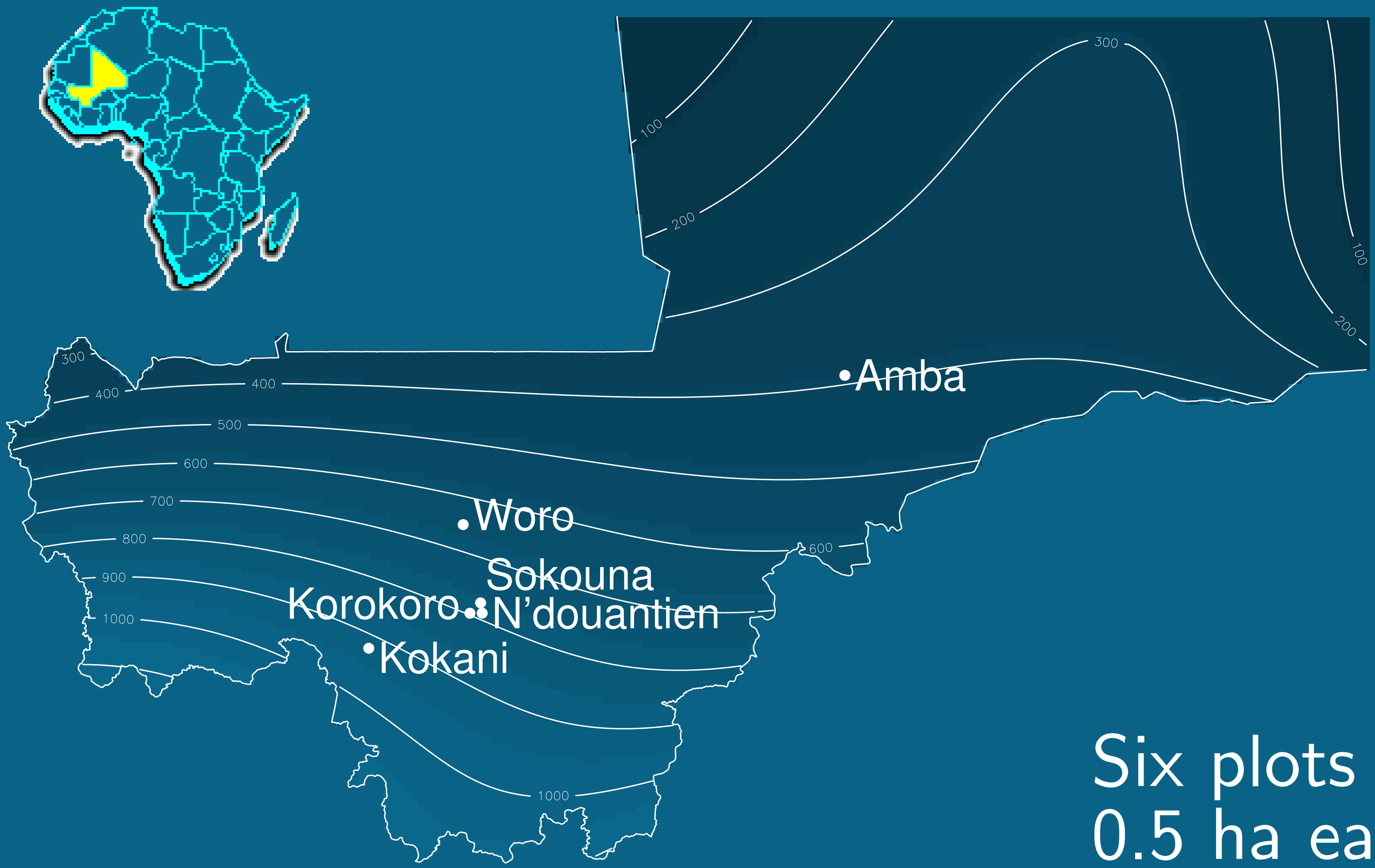
$$\Psi = \bigcup_{x \in \Phi} [x;\, Z(x)]$$

and Z independent of Φ.

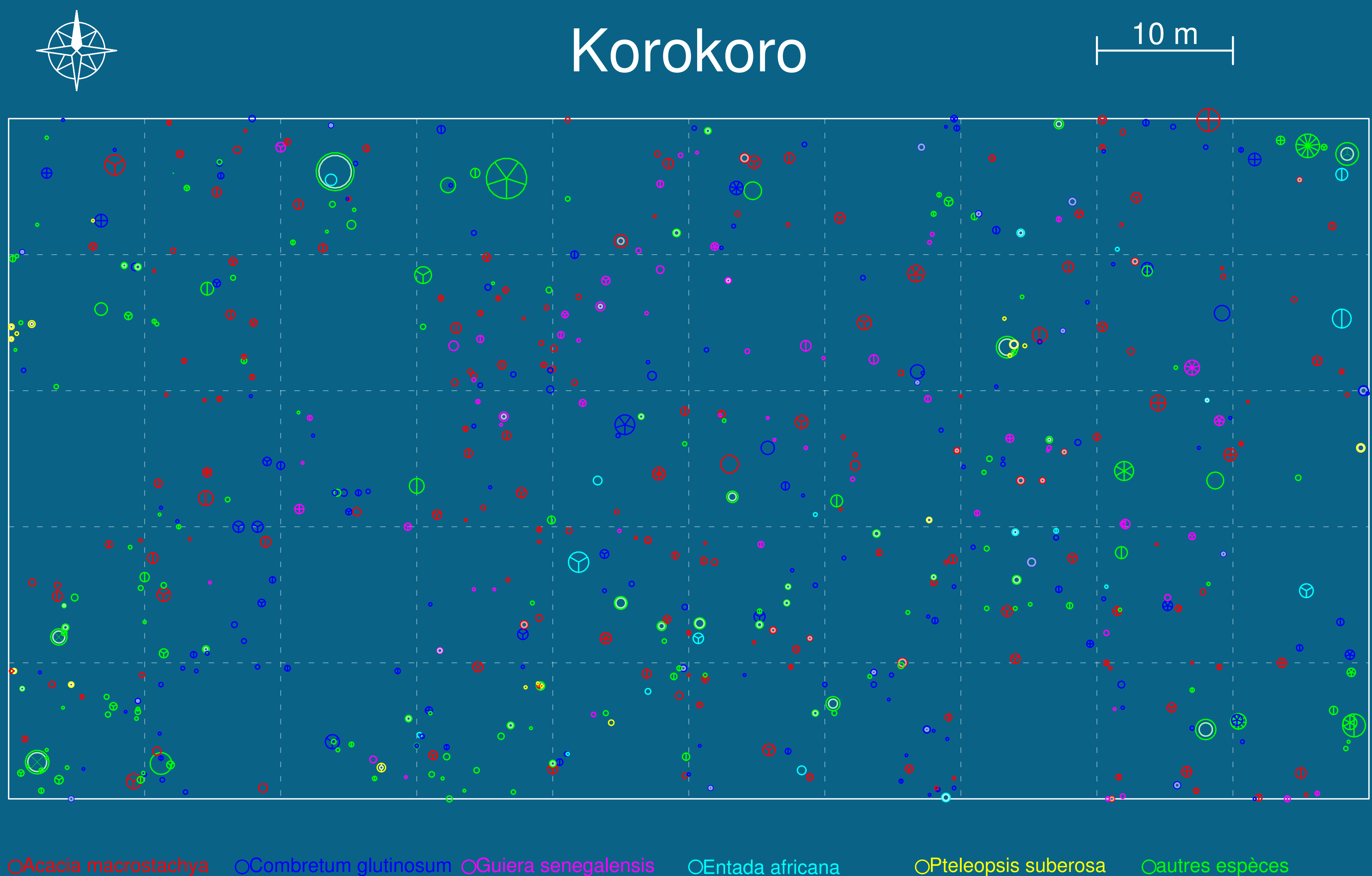
Schlather (2002); Schlather *et al.* (2004): test of dependence between marks and locations for Gaussian marks

Diameter has exponential distribution

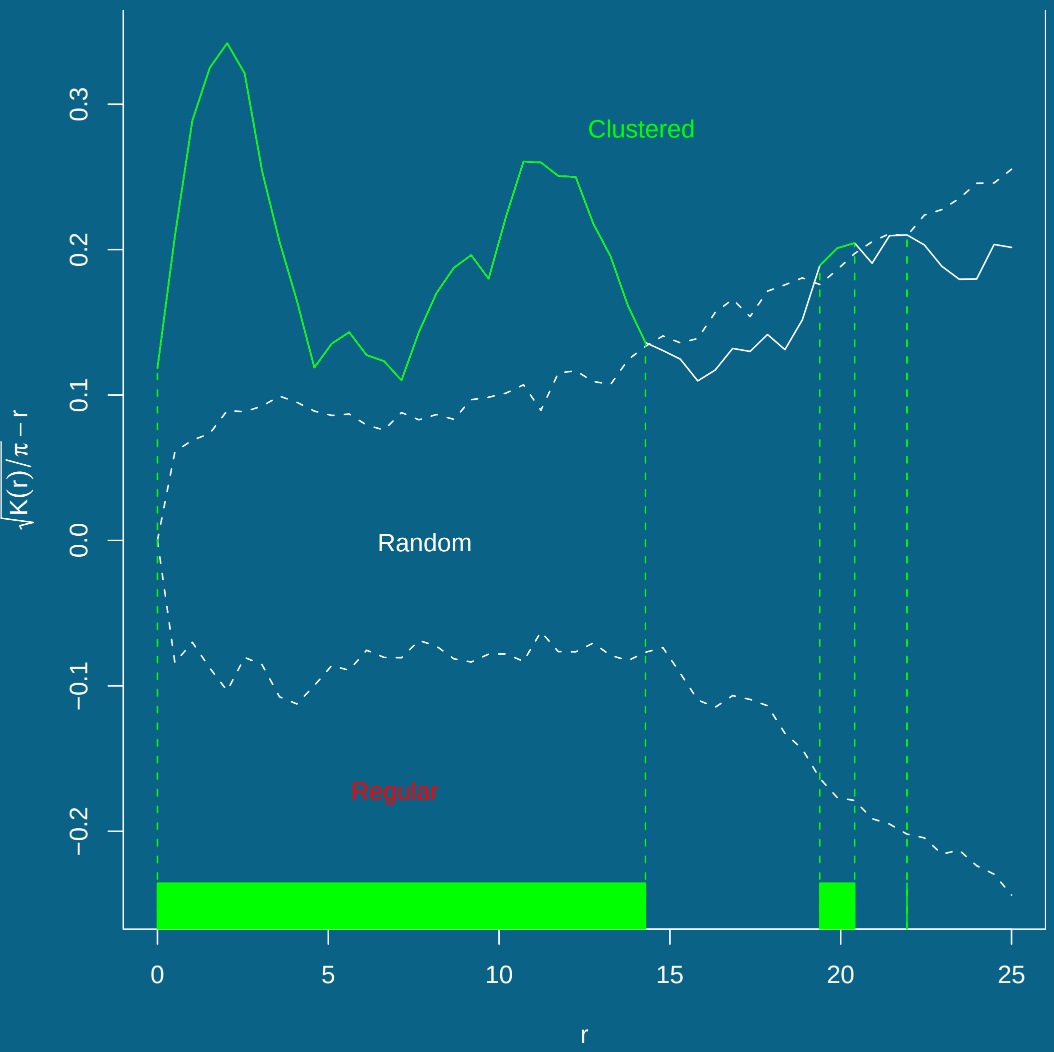
First case study: Mali savannas



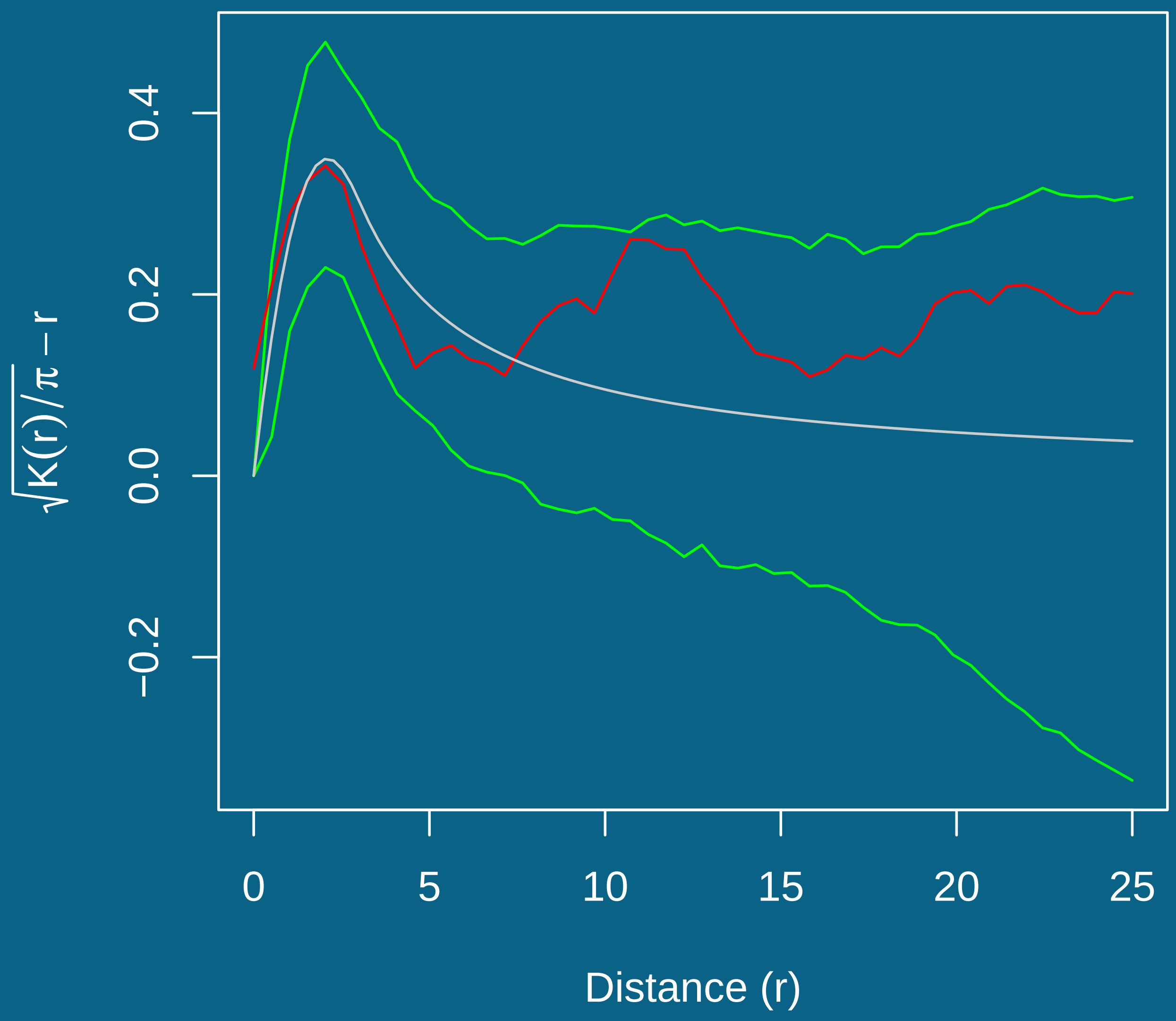
Six plots
0.5 ha each


Korokoro
10 m
Acacia macrostachya
Combretum glutinosum
Guiera senegalensis
Entada africana
Pteleopsis suberosa
autres espèces

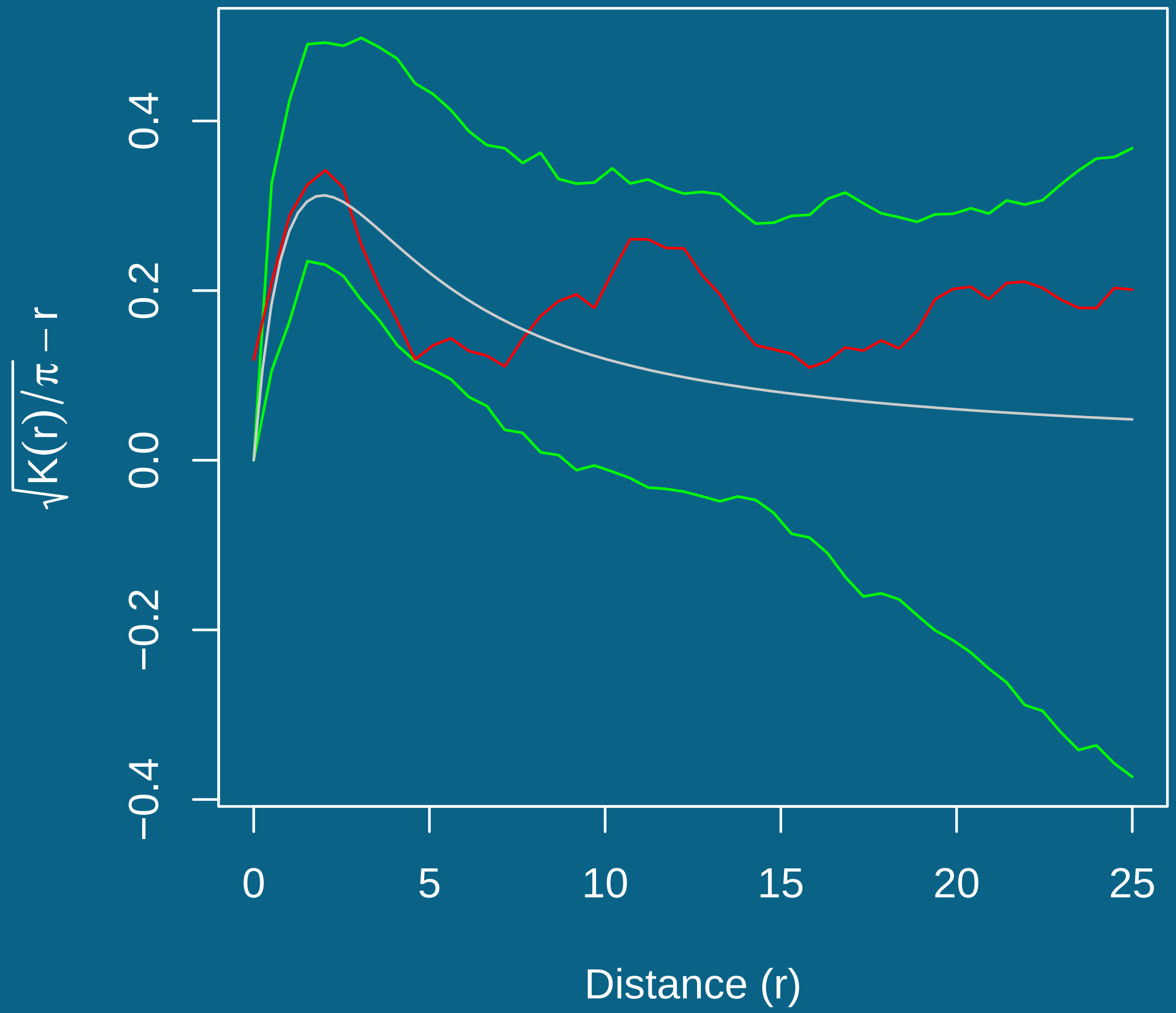
Korokoro, K-function (all trees)



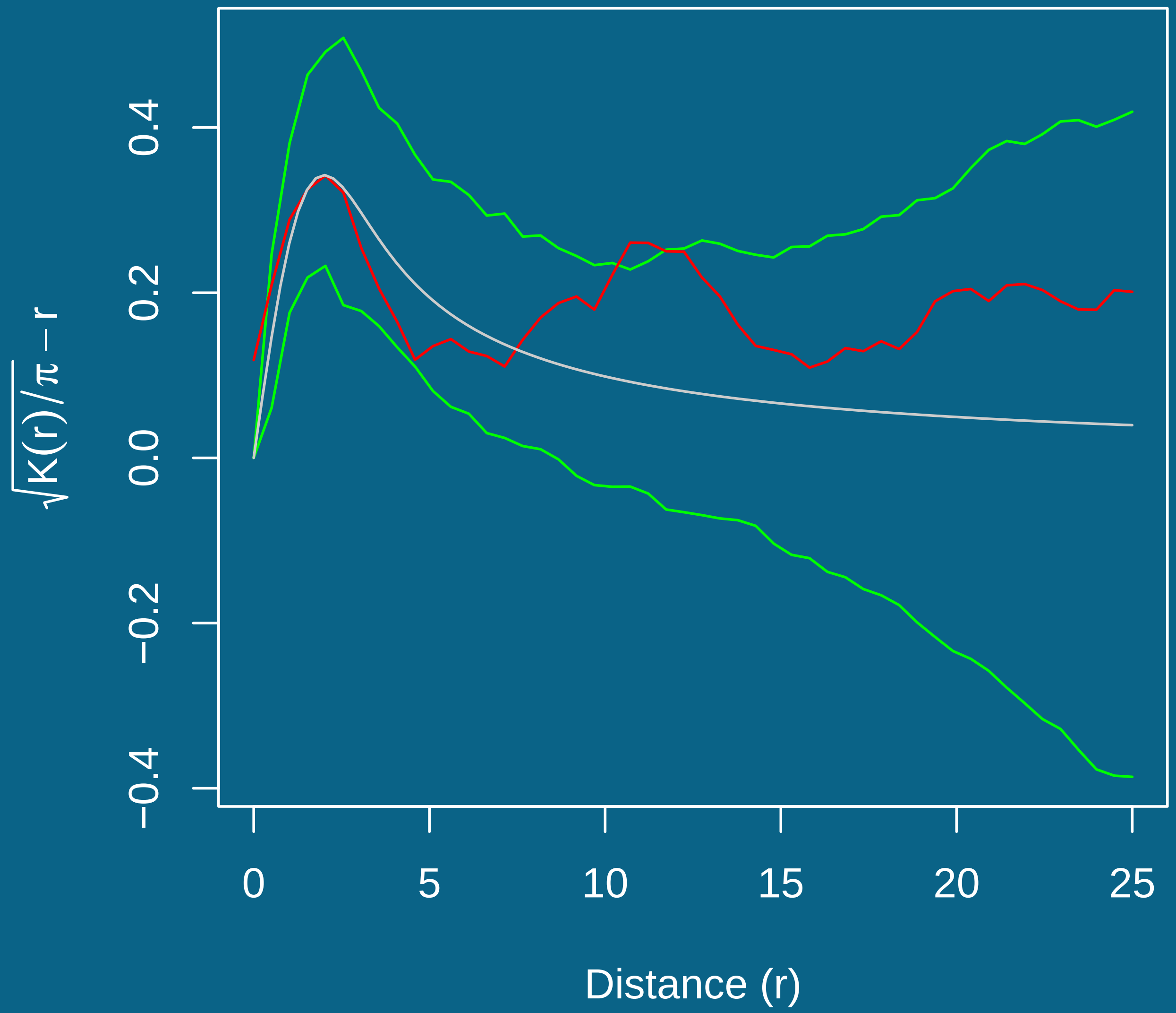
Korokoro, Matérn process



Korokoro, log Gaussian Cox process

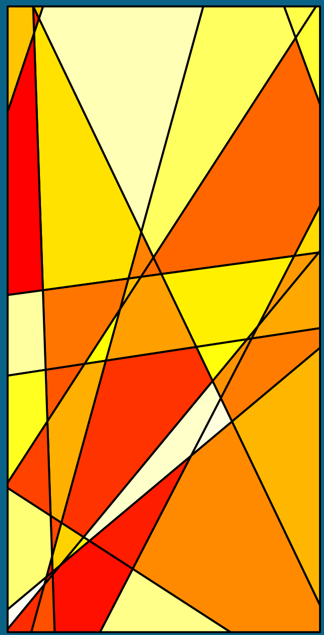


Korokoro, Poisson-gamma process

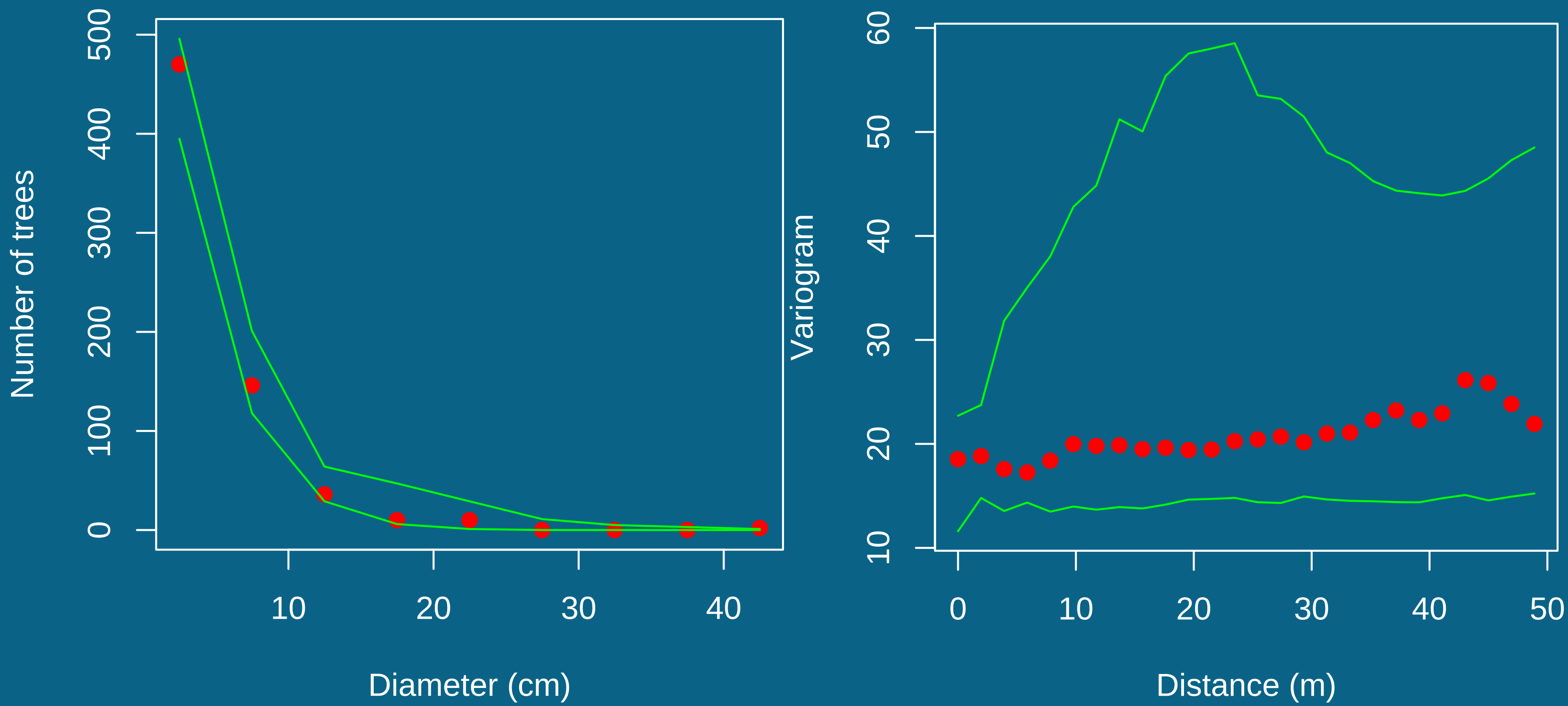


Diameter: exponential random field with exponential covariance function

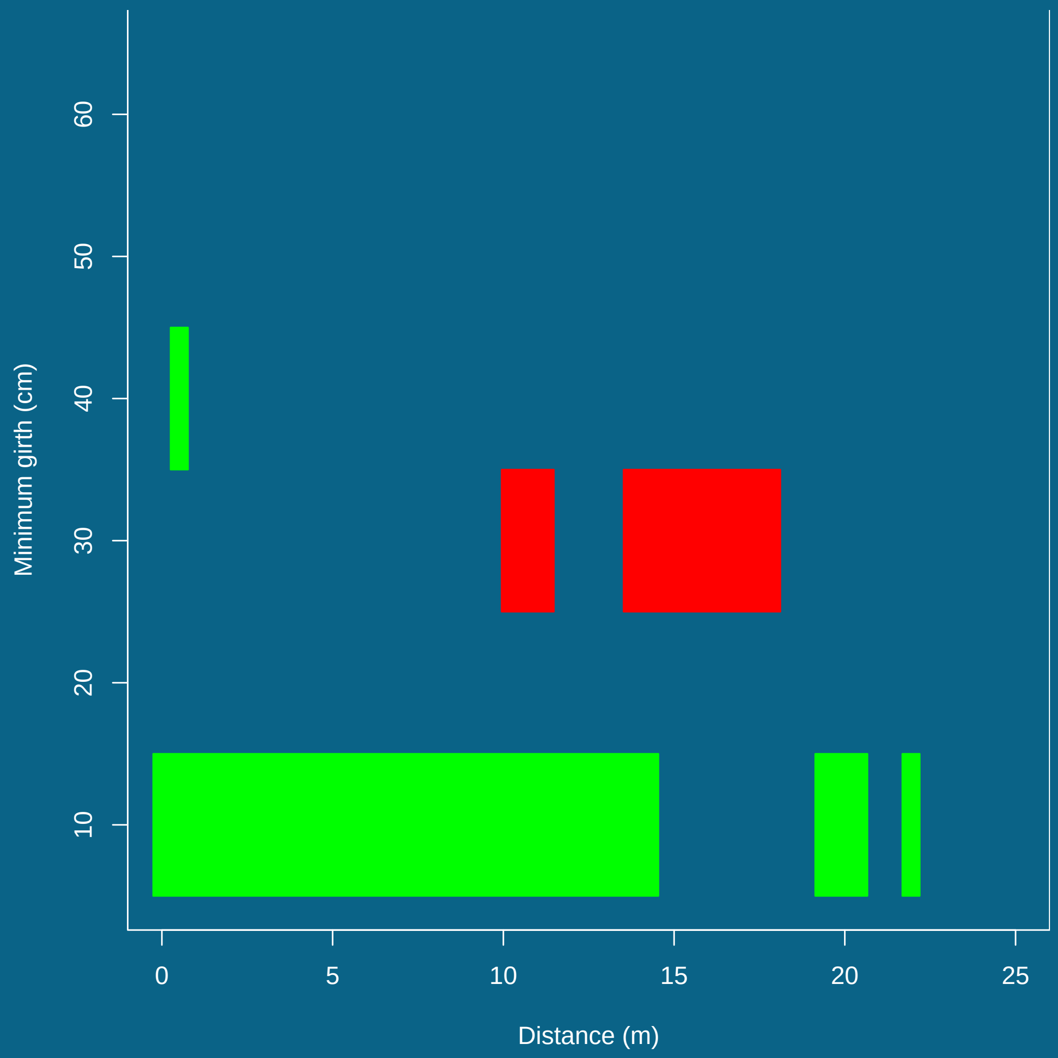
Simulation using tessellation method (Schlather, 1999):



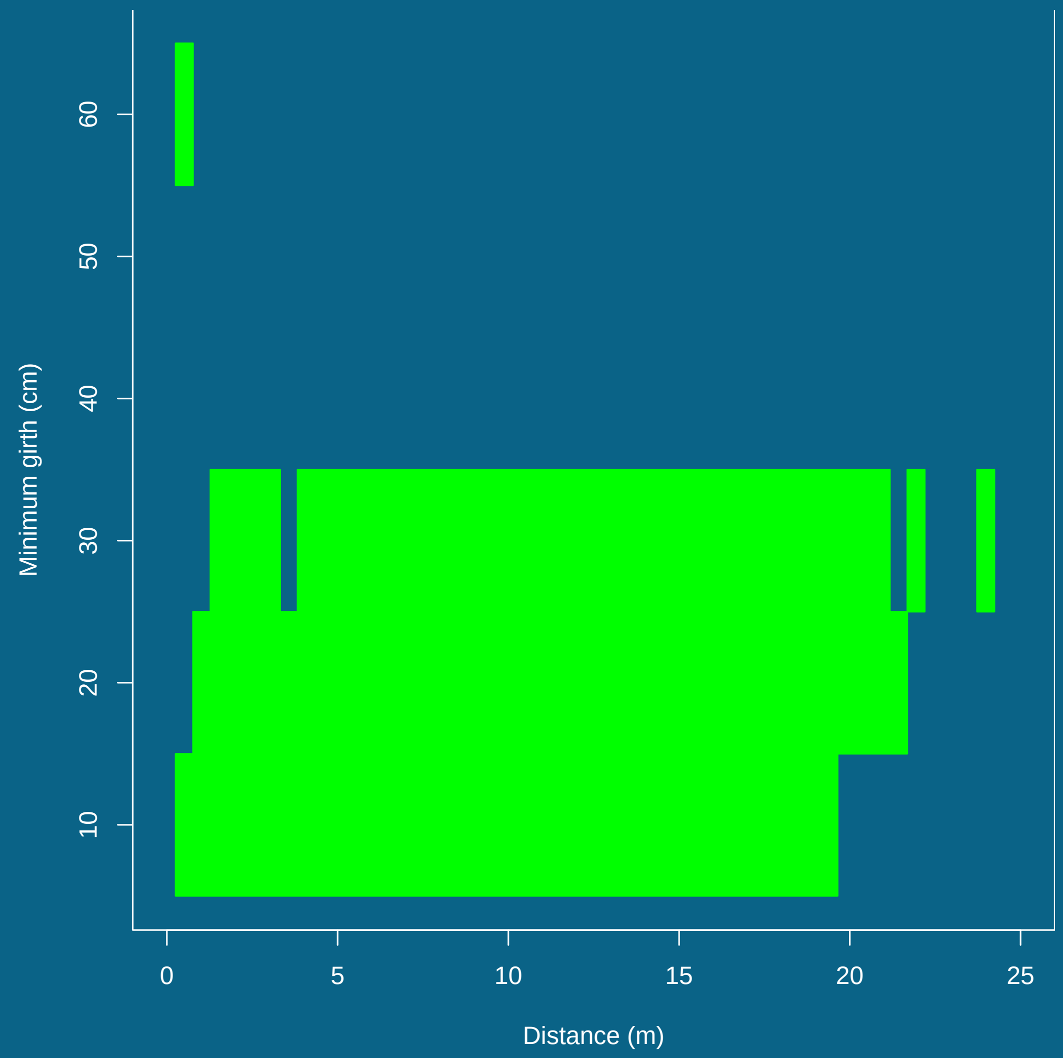
Korokoro, diameter distribution & variogram



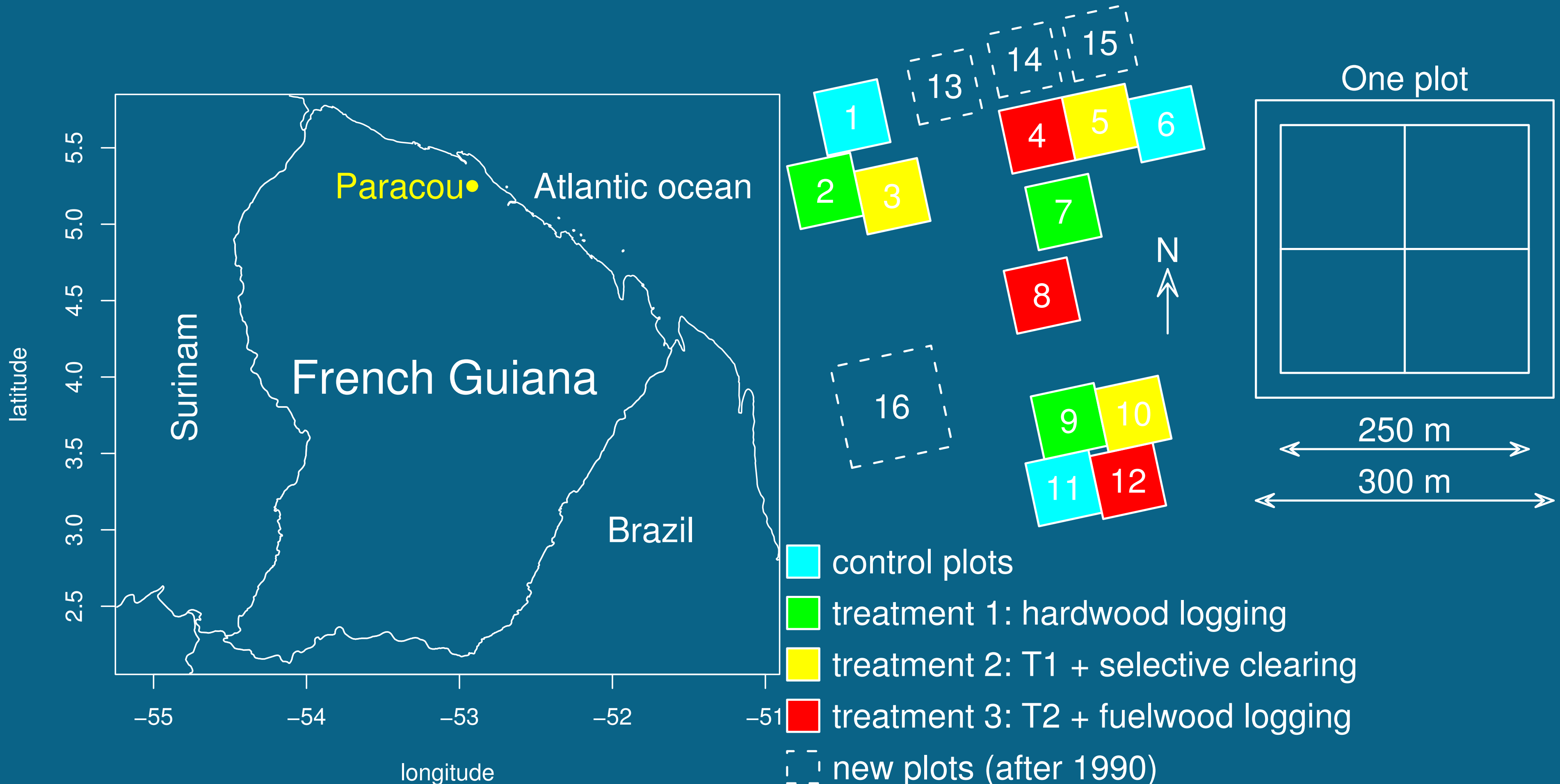
Korokoro: interaction diameter/positions



Random field model (Matérn process)

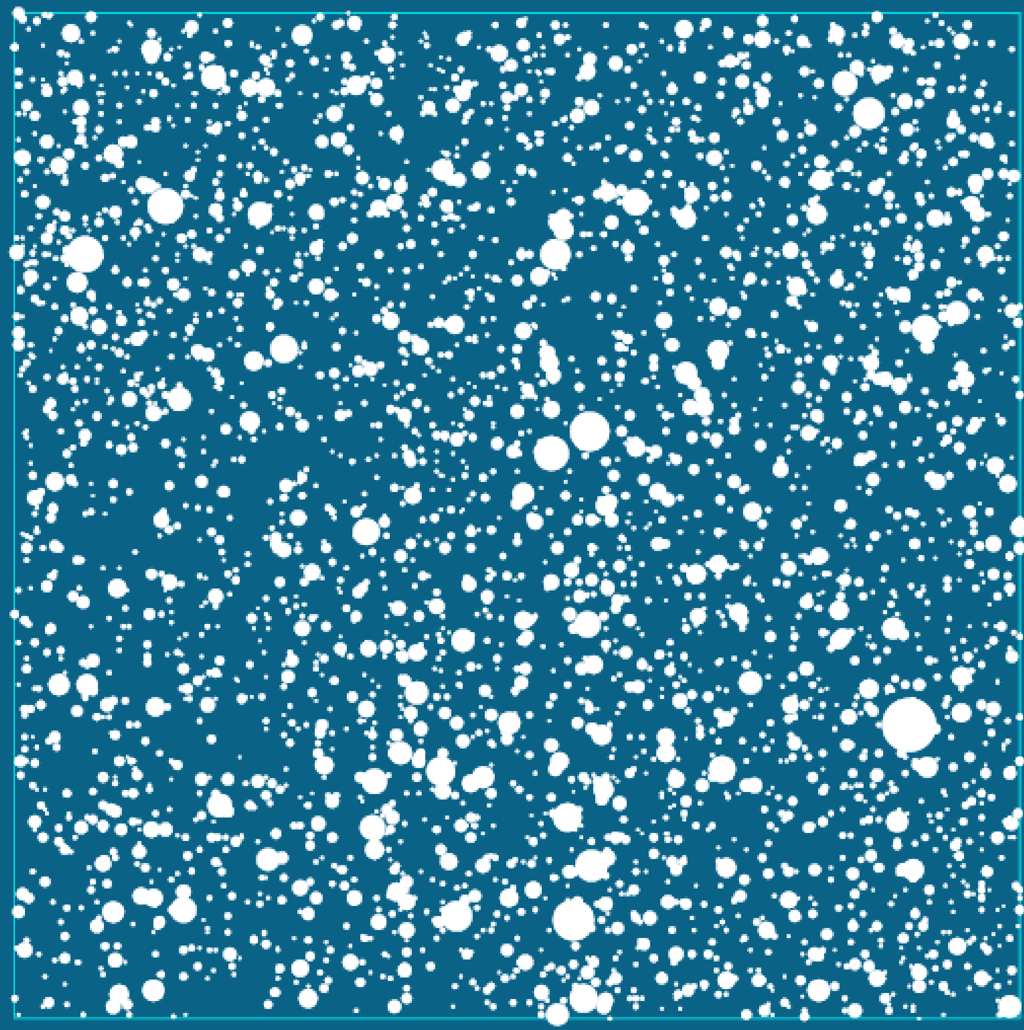


Second case study: Paracou

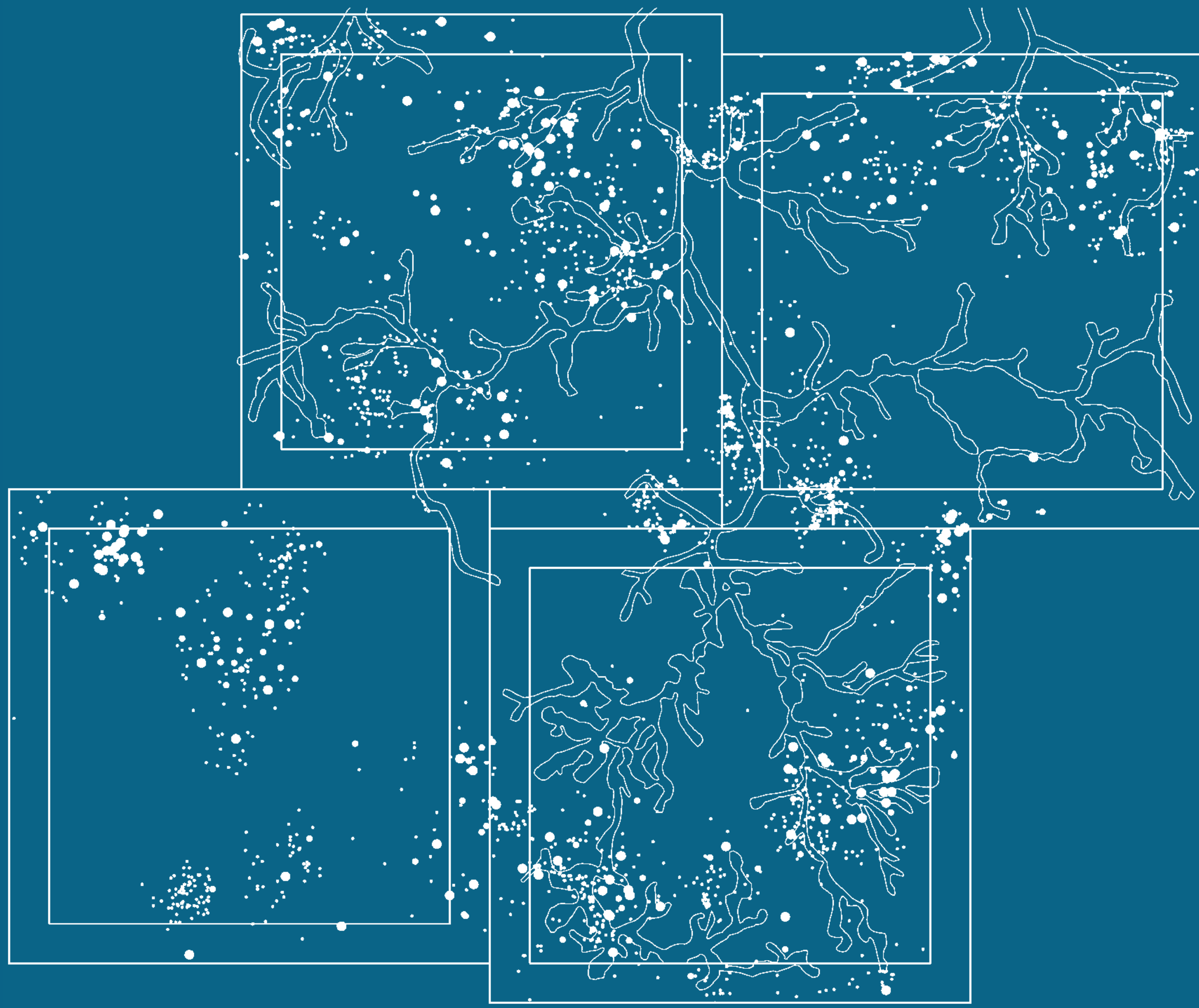


Since 1984, 120 ha, over 46,000 trees monitored

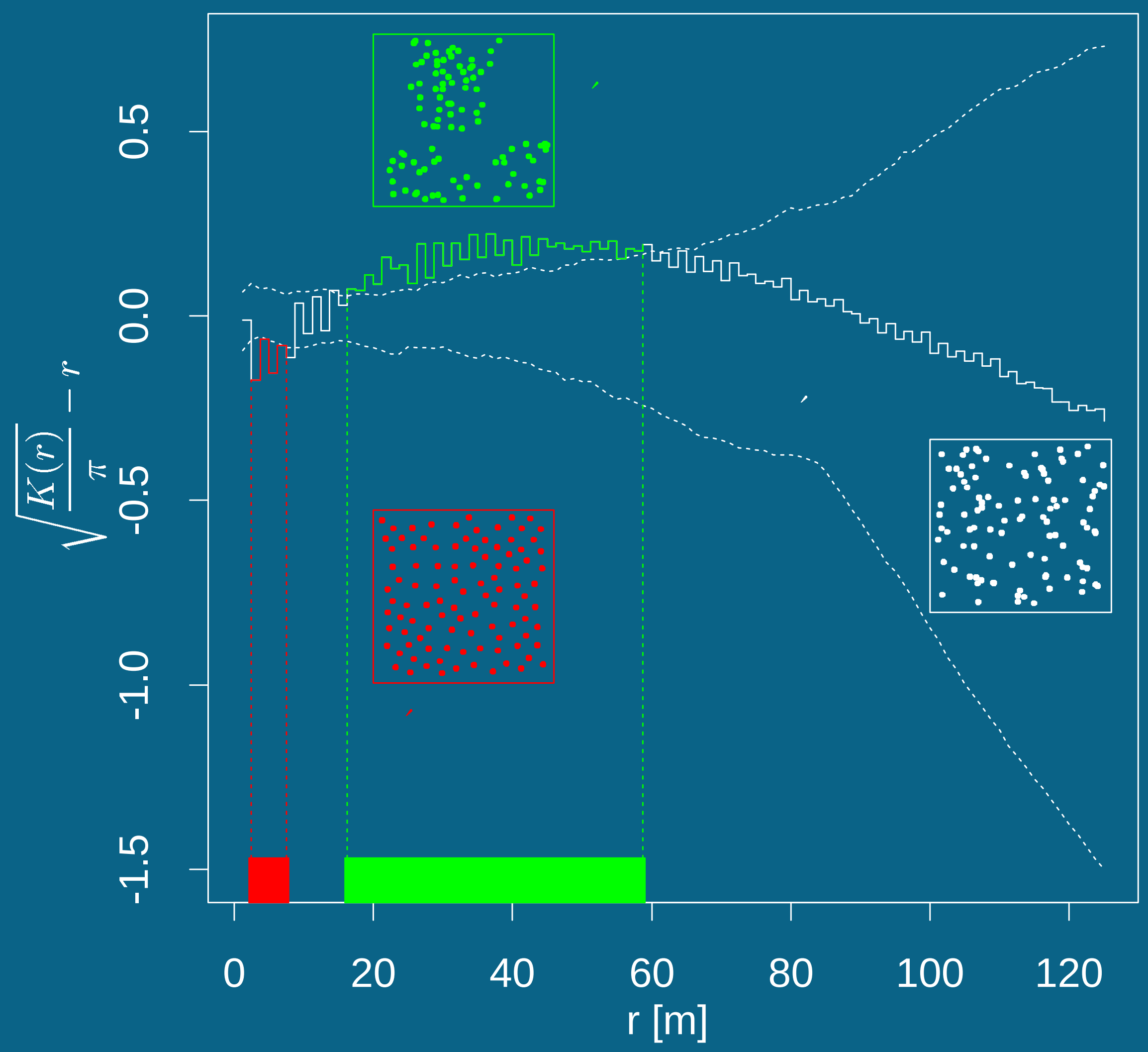
Plot 1 in 1984 ($D \geq 10$ cm)



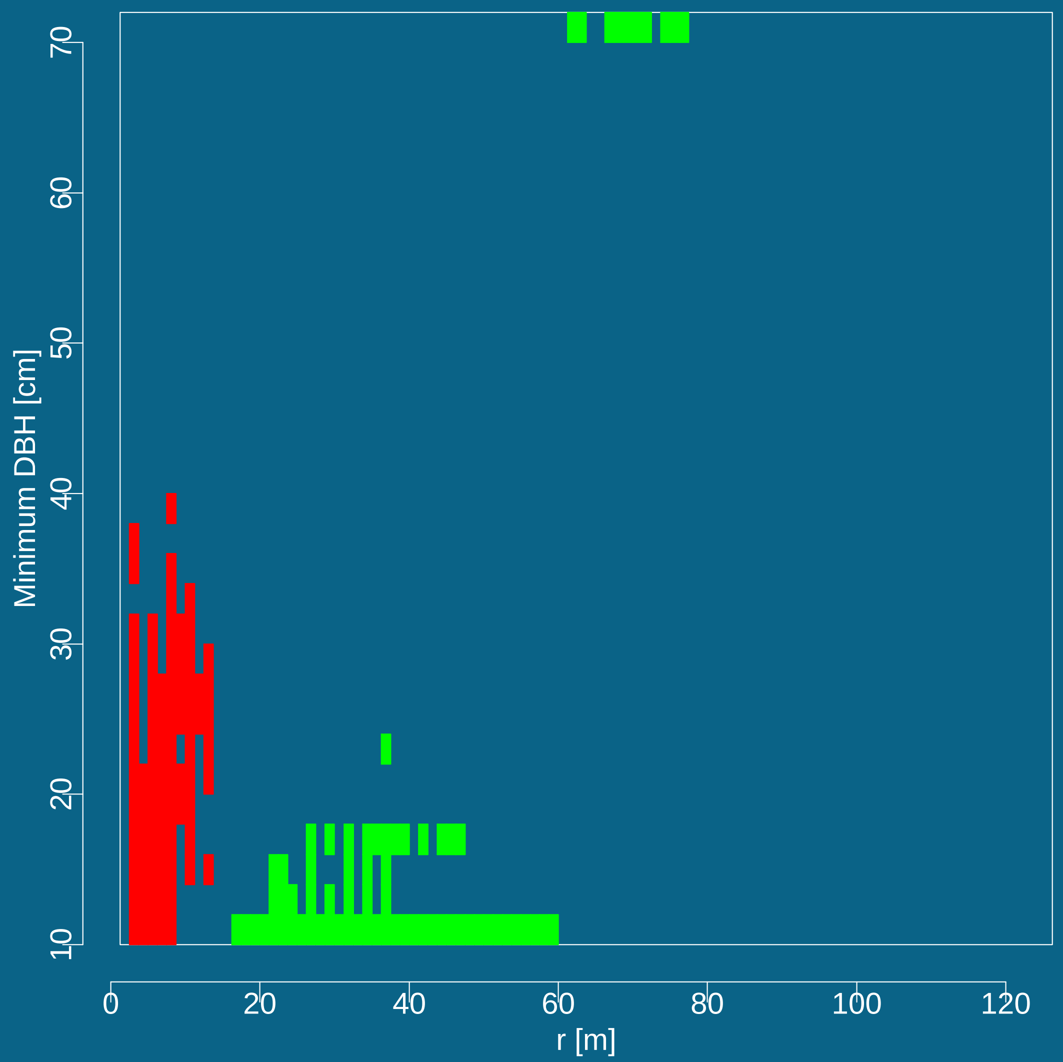
Angelique in South block in 1999



K-function, plot 1 in 1984, $D \geq 10$ cm

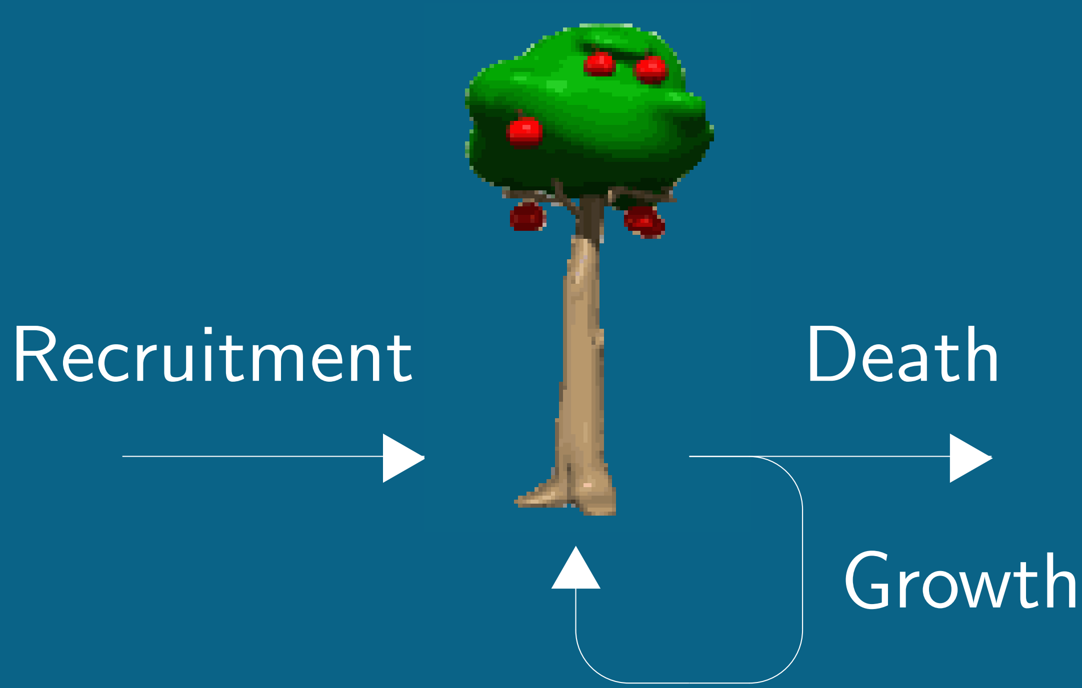


K-function, plot 1 in 1984, $D \geq x$

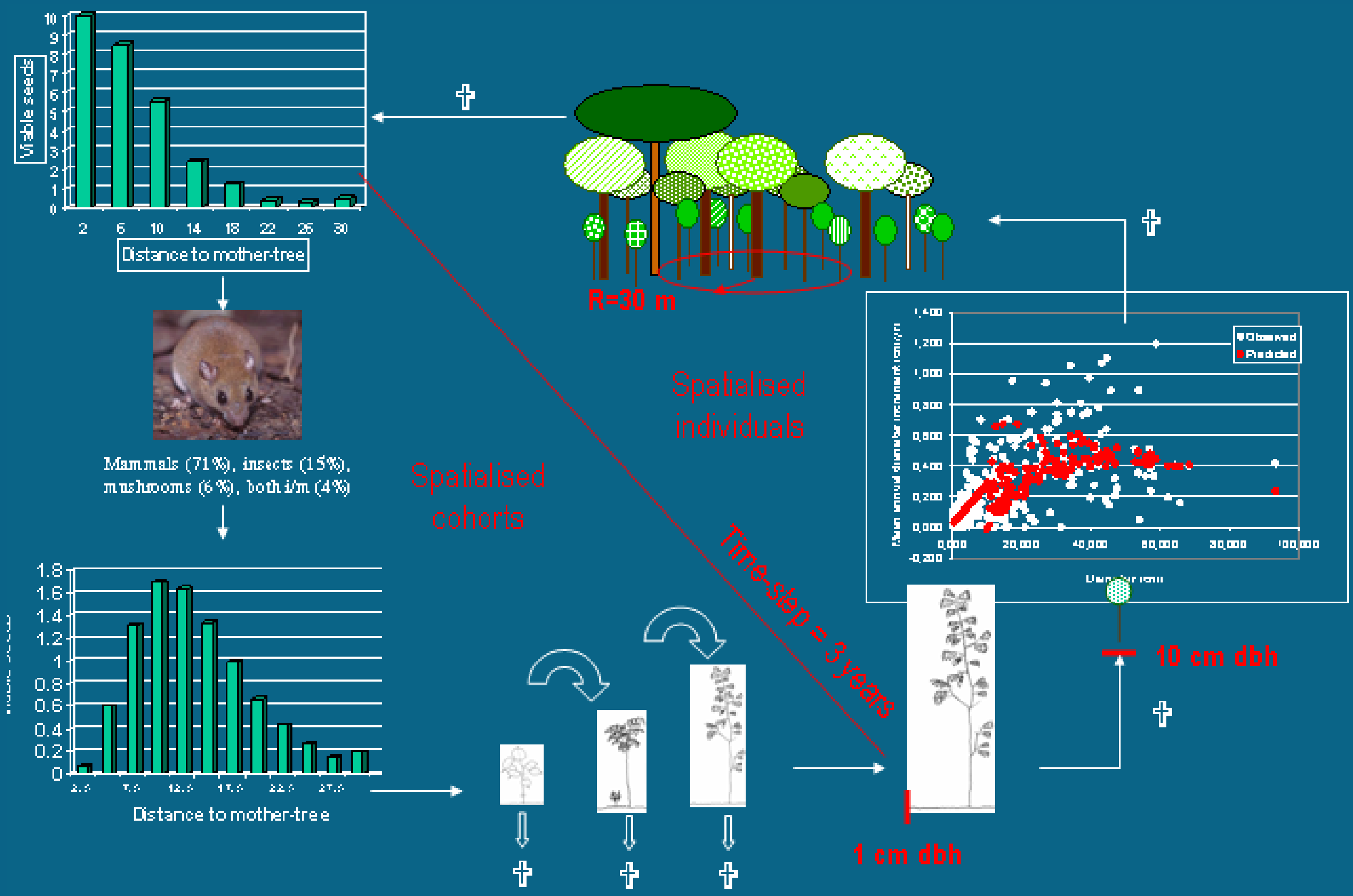


Individual-based space-dependent models as space-time marked point processes

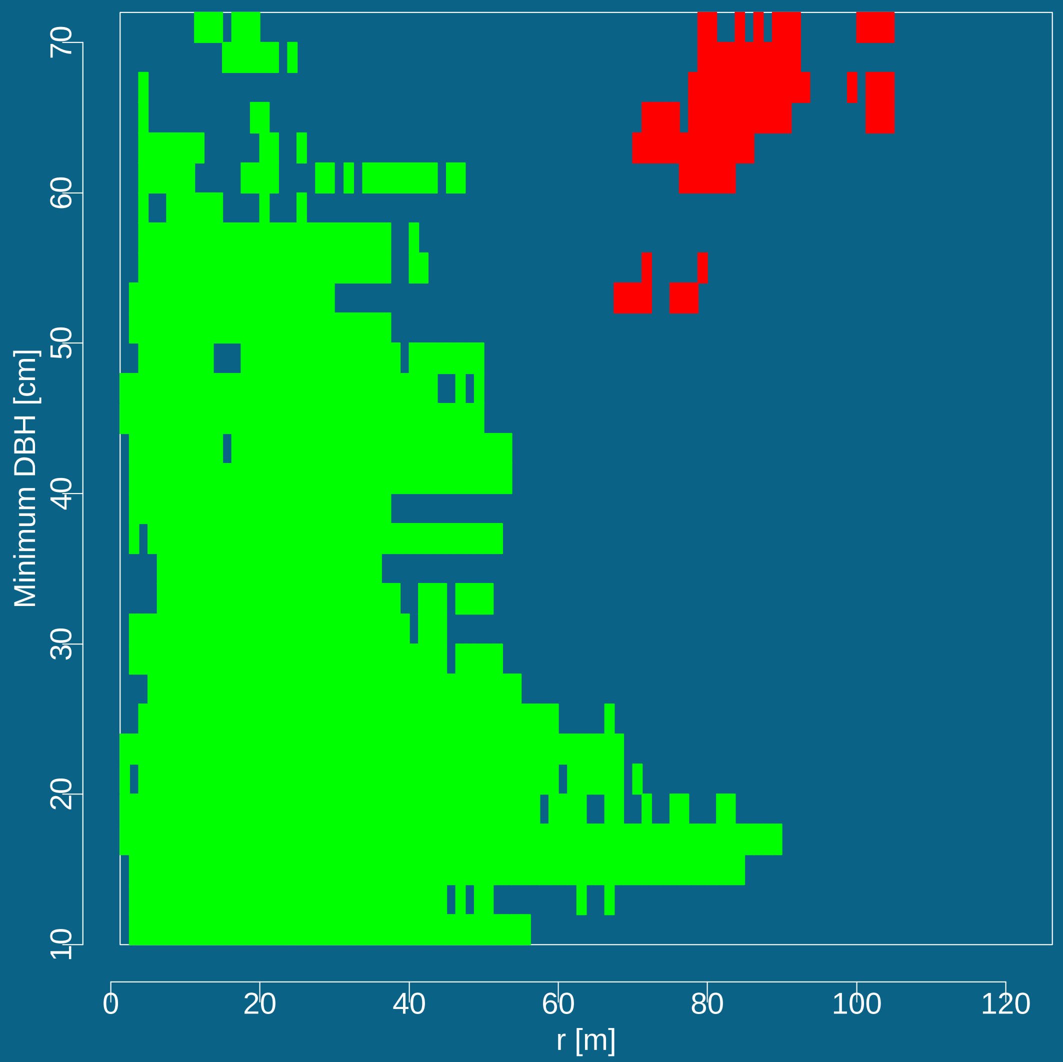
Rathbun & Cressie (1994), Stoyan & Penttinen (2000):



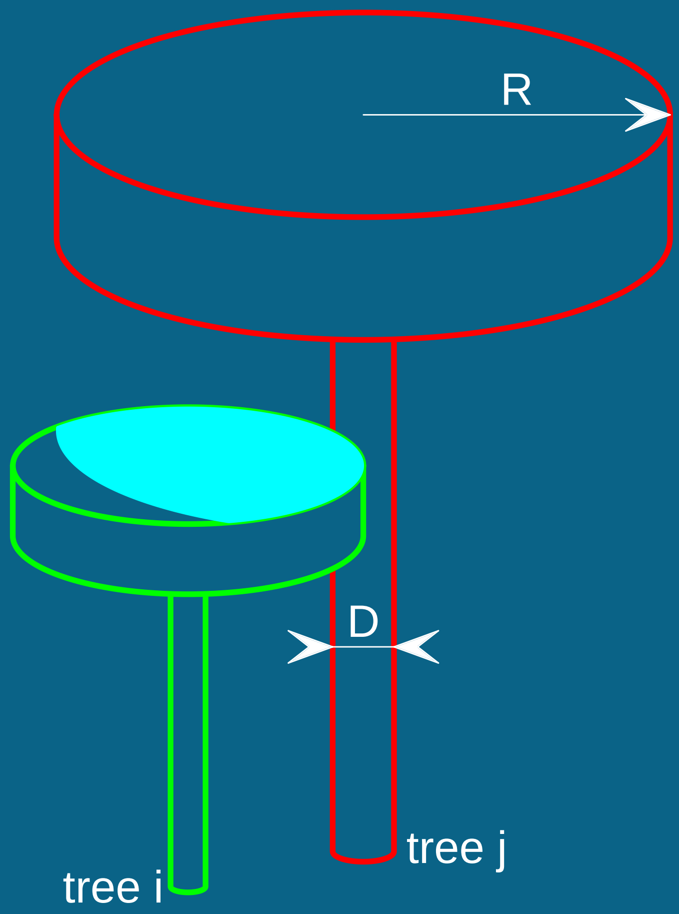
SELVA model


Viable seeds
Distance to mother-tree
Mammals (71%), insects (15%), mushrooms (6%), both i/m (4%)
Distance to mother-tree
Spatialised cohorts
Spatialised individuals
R=30 m
Time-step = 3 years
Observed
Predicted
1 cm dbh
10 cm dbh

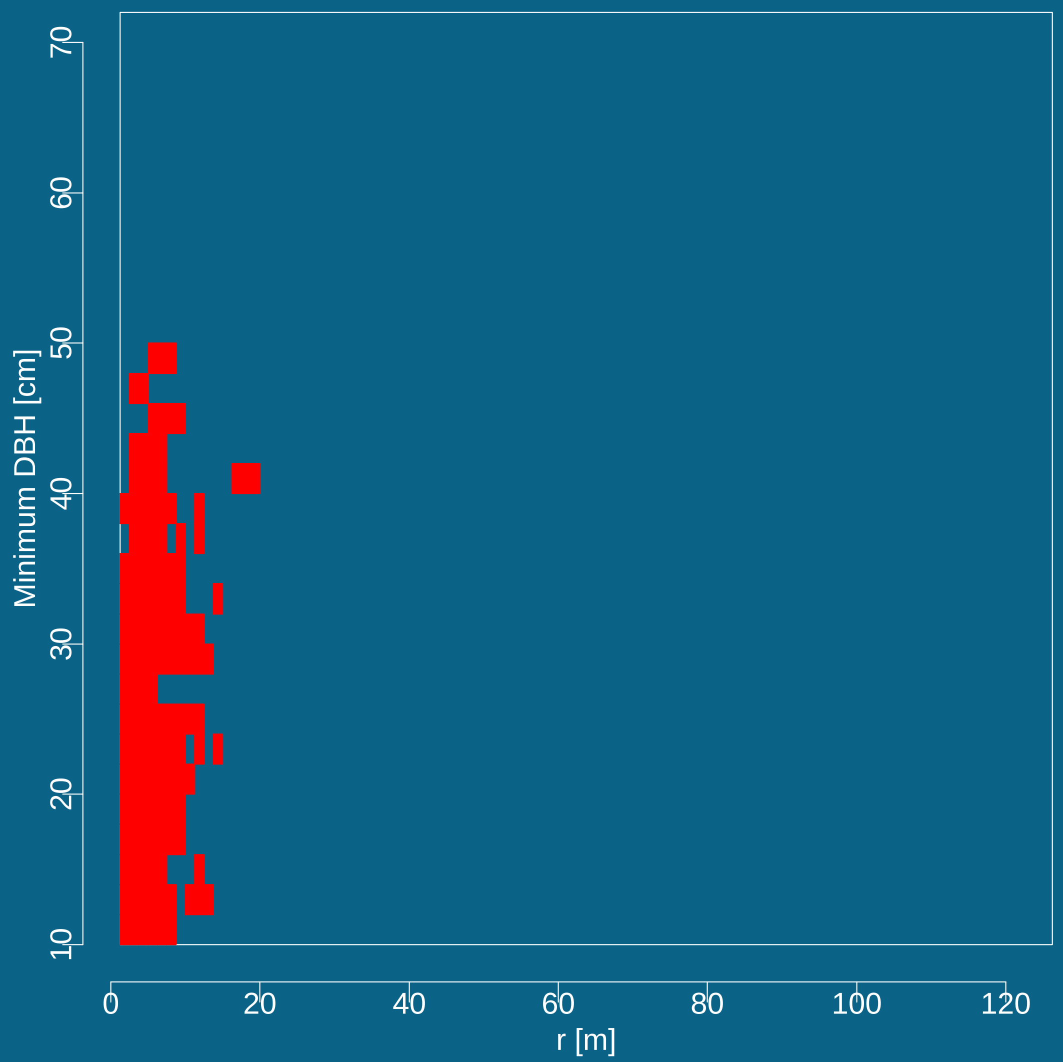
SELVA model, K-function



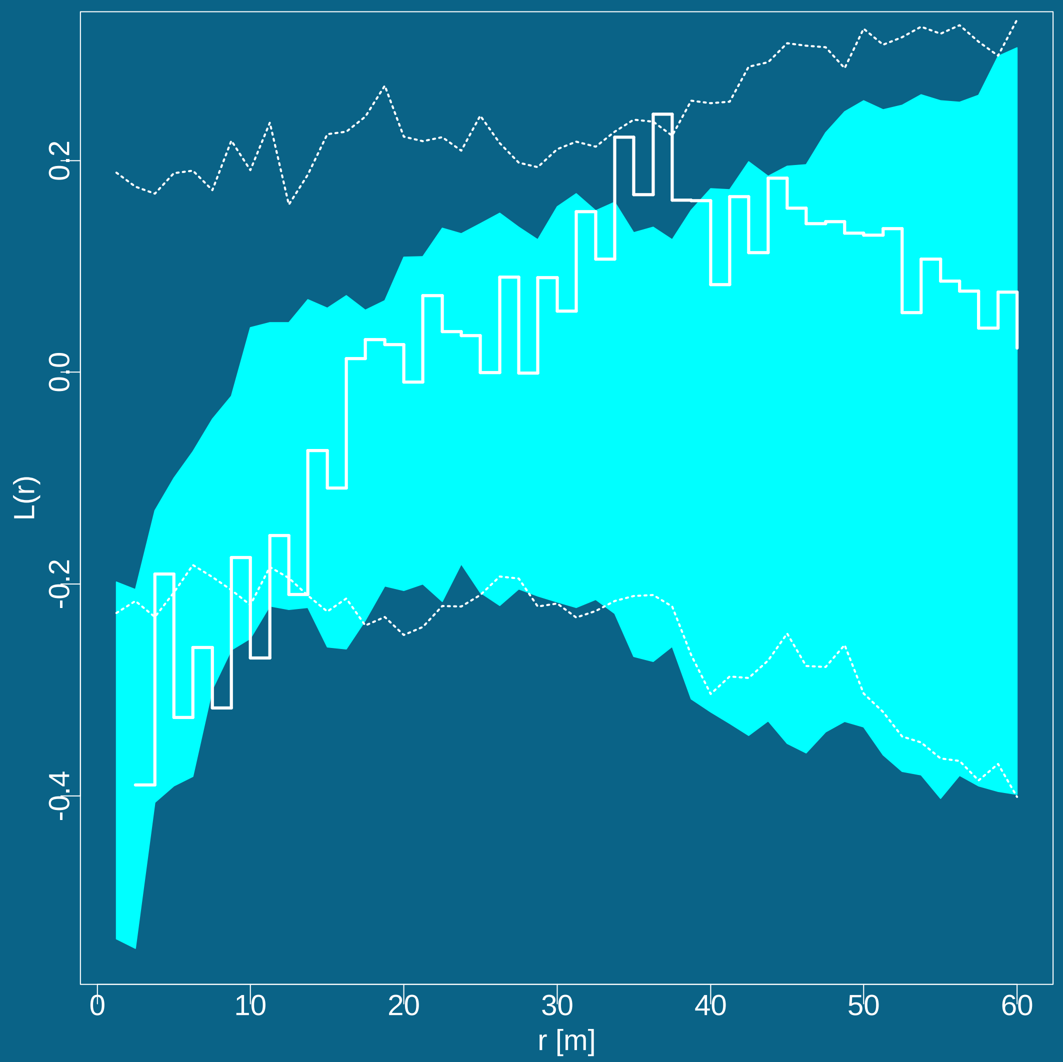
Another model with short-range interactions



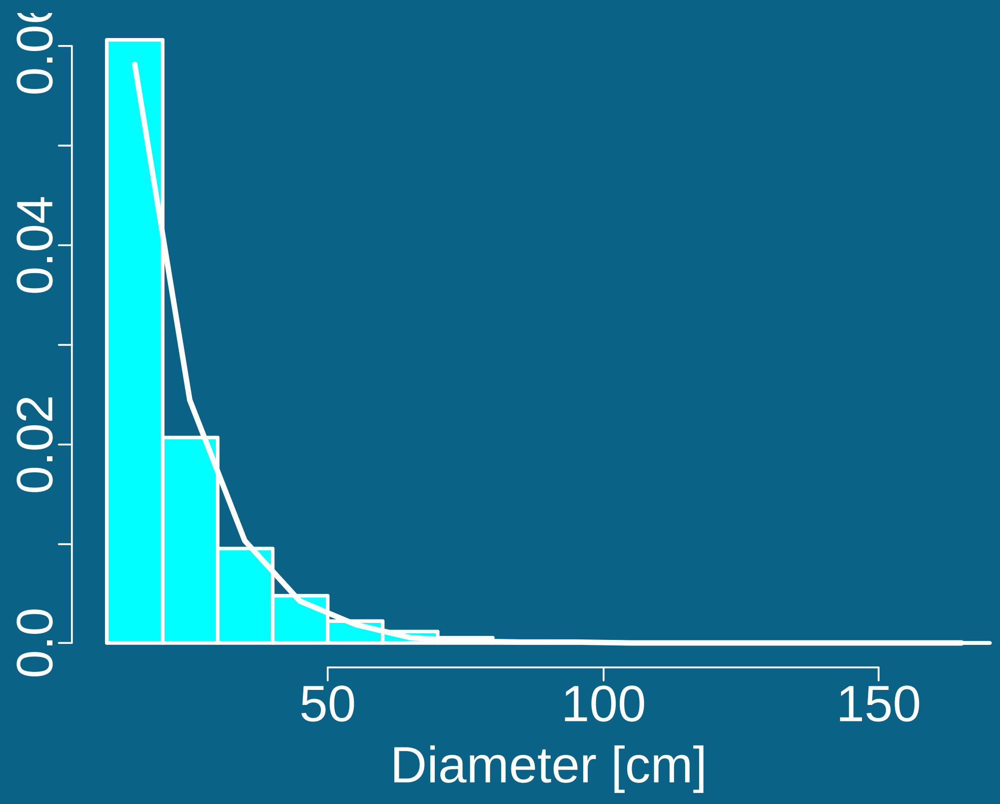
Stationary state, K-function



Stationary state, K-function, $D \geq 22$ cm



Stationary state, diameter distribution



Observed pattern might be reproduced by a model with

- clustered recruitment
- short-range competition

... but simulation time very long ☹

References

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[4] S. L. Rathbun and N. Cressie. A space-time survival point process for a longleaf pine forest in southern Georgia. *Journal of the American Statistical Association*, 89(428):1164–1174., 1994.

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[7] M. Schlather. Characterization of point processes with Gaussian marks independent of locations. *Mathematische Nachrichten*, 239-240(1):204–214, 2002.

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