Point process models to account for interactions across different ranges in joint species distribution models

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I acknowledge the Traditional Owners of the land where I live and work, and pay my respects to their Elders past, present and emerging.

Poisson point processes in JSDMs

Poisson point processes in JSDMs

Key features and assumptions:

- PPMs model spatial locations
- Individuals located independently from one another
- Abundance driven by environmental covariates
- Straightforward calibration & interpretation of model parameters

However, the assumptions are often unrealistic!

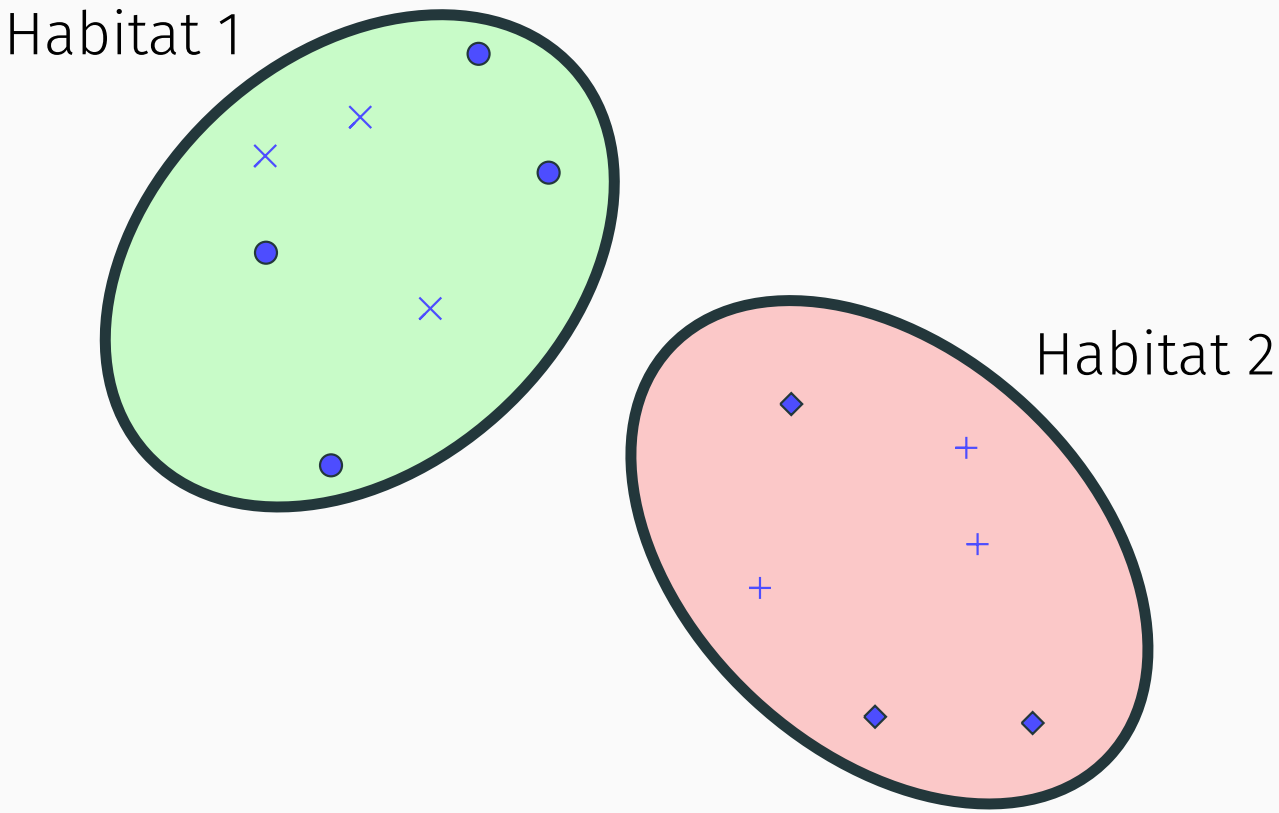
Conclusion

Even when accounting for environmental covariates, there is a need to model interactions between individuals.

Plant ecology

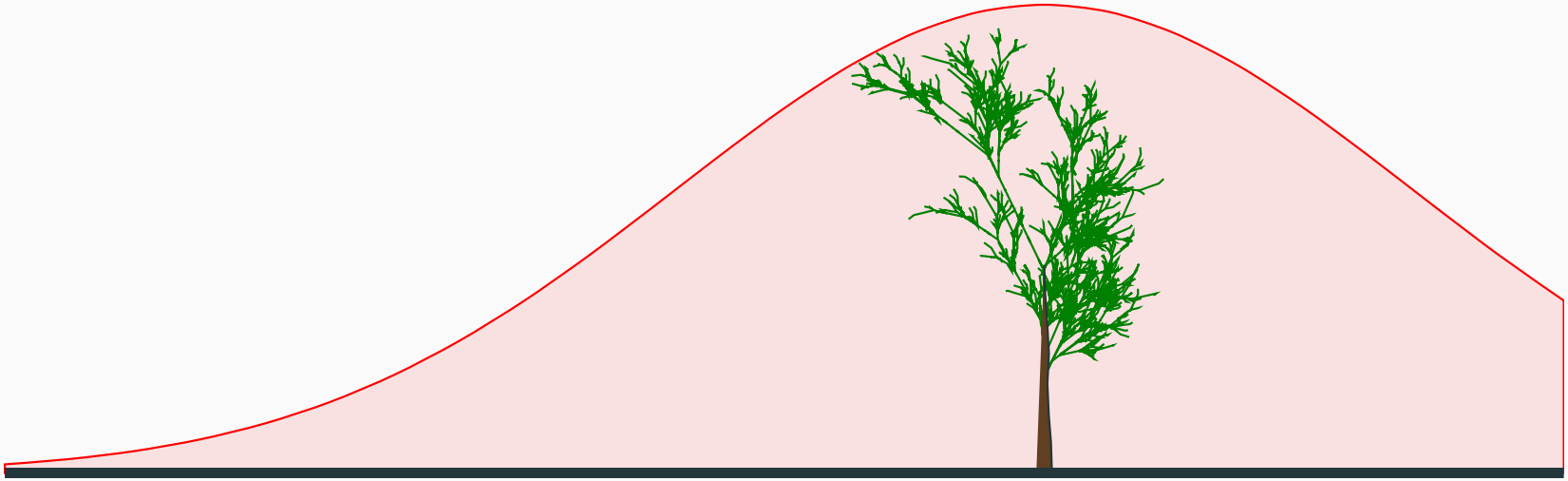
Plant ecology (1)

Habitat filtering



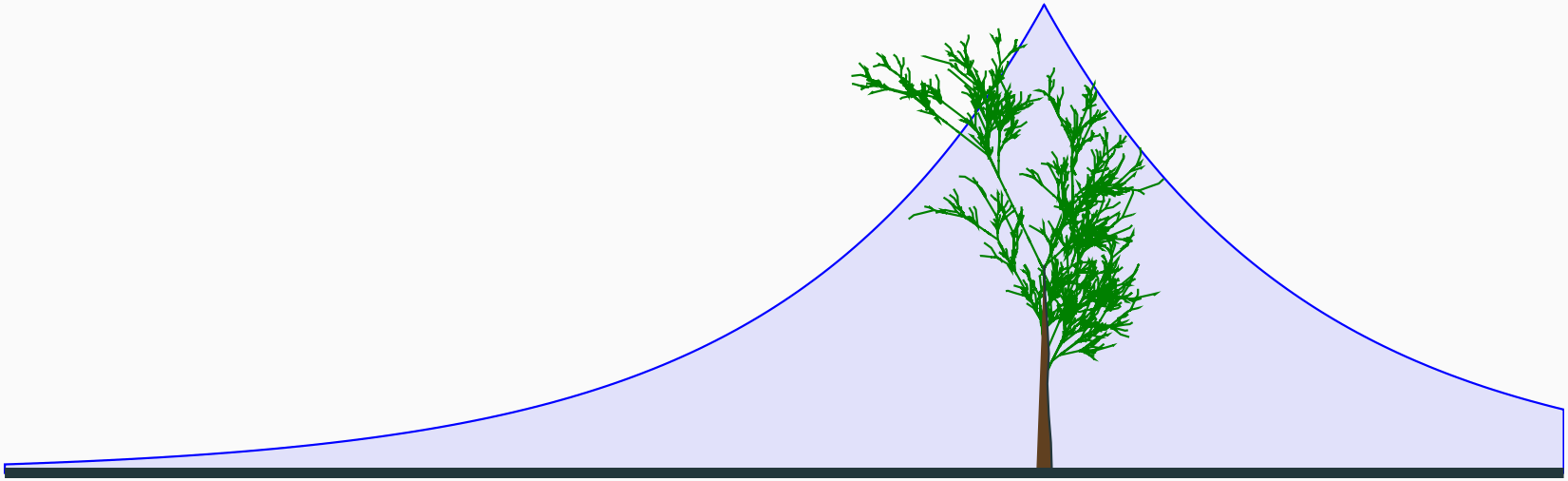
Plant ecology (2)

Dispersal limitation



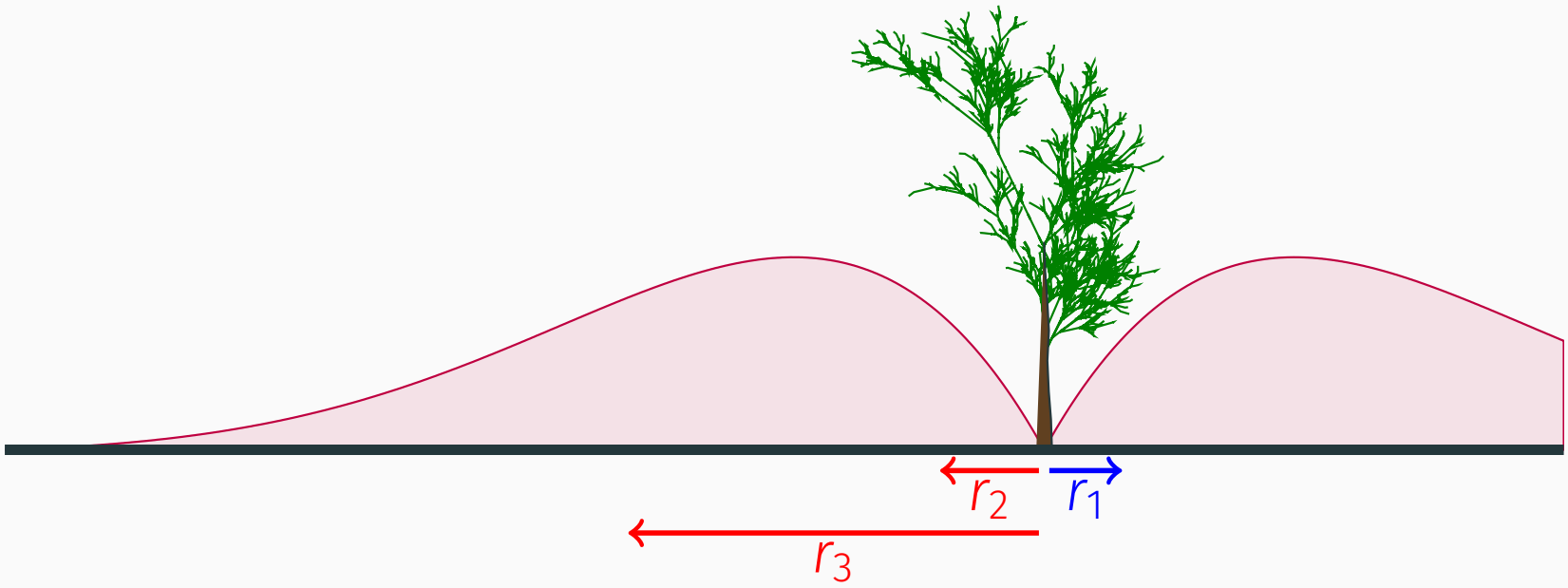
Plant ecology (3)

Competition for resources



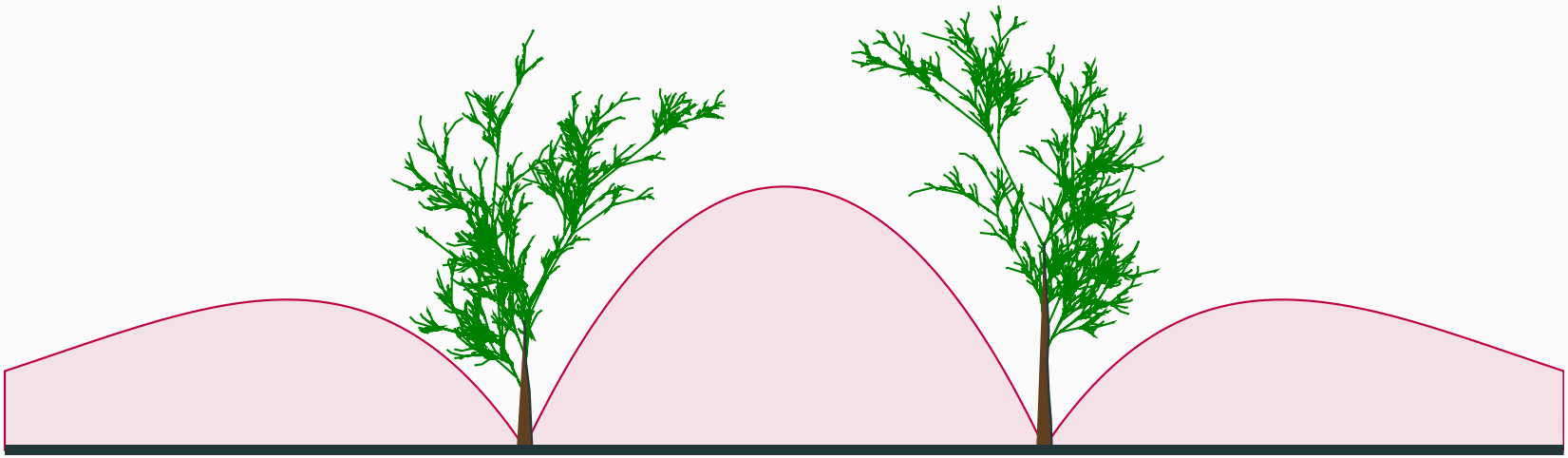
Plant ecology (4)

Sum of effects



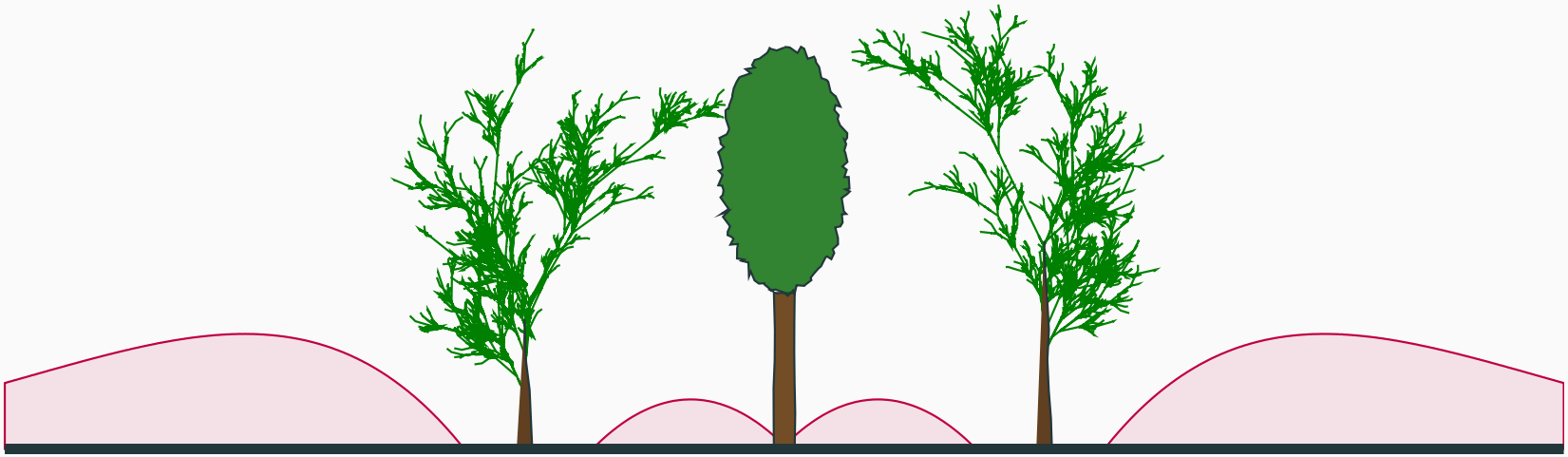
Plant ecology (4)

Effect of another individual



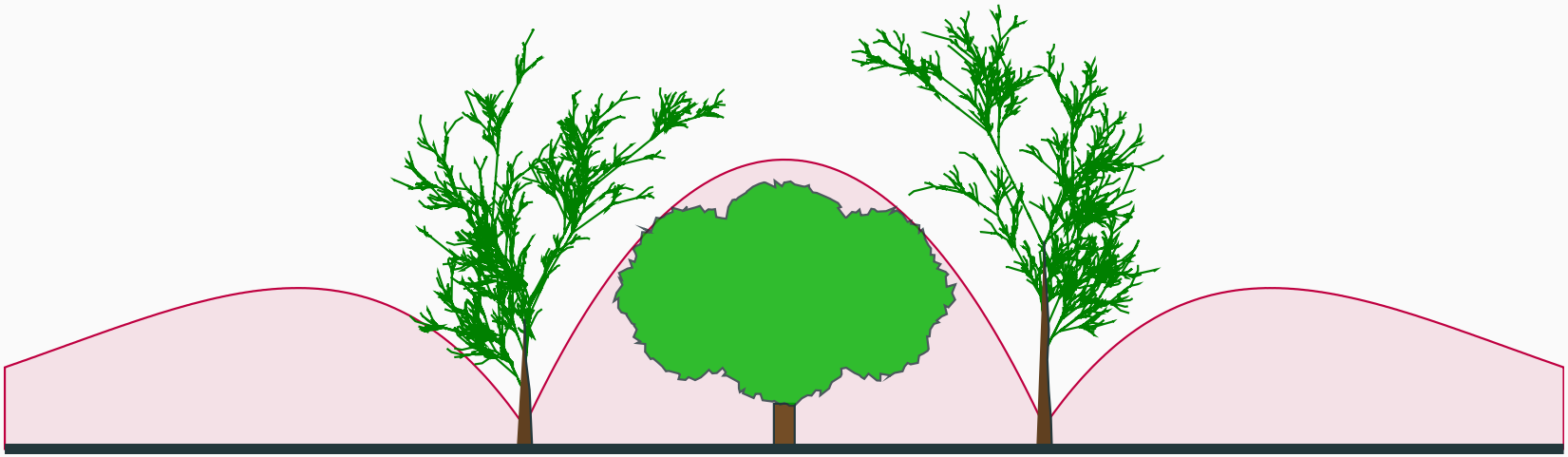
Plant ecology (5)

Competition with other species



Plant ecology (6)

Facilitation



Plant ecology (7)

Conclusion

We model positive and negative interactions between individuals, over different ranges, with intensity proportional to their distances from one another, alongside environmental covariates.

Note

Although motivated by plant ecology, our model can be used in other settings, and on other scales.

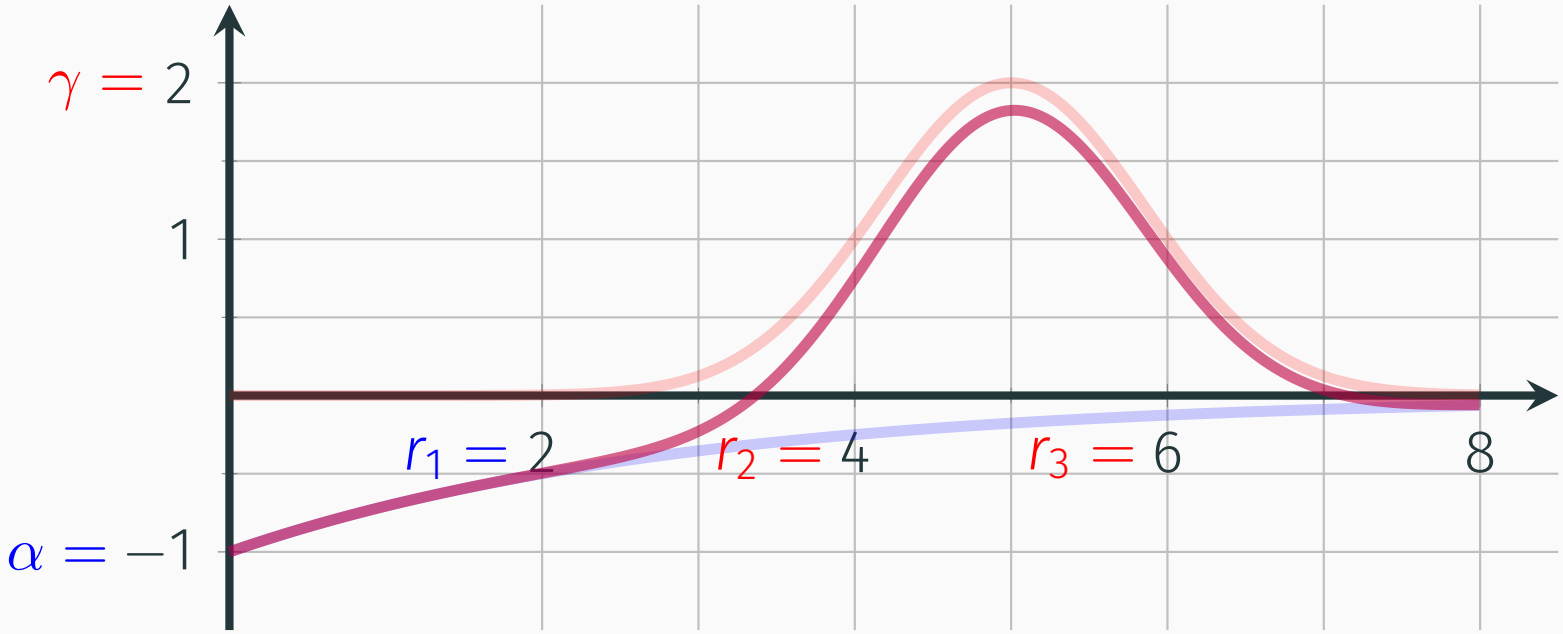
Model

Model

Model

Saturated pairwise interaction Gibbs point process

Potentials



- α: short-range interaction coefficient
- r_1: short-range interaction range
- γ: medium-range interaction coefficient
- r_2: medium-range interaction range
- r_3: long-range interaction range

Model likelihood

- ω: locations
- ω_i: locations of species i
- φ_{r_1}: short-range potential
- ψ_{r_2,r_3}: medium-range potential

$$p(\omega) = C \exp\Bigg[\overbrace{\sum_{i=1}^{p}\left(\beta_{i,0} + \sum_{k=1}^{n}\beta_{i,k}\sum_{x\in\omega_i} X_k(x)\right)}^{\text{inhomogeneous Poisson term}} + \sum_{i_1,i_2=1}^{p}\alpha_{i_1,i_2}\sum_{x\in\omega_{i_1}}\overbrace{\max_{\substack{\eta\subset\omega_{i_2}\\ \text{s.t. } |\eta|\leq N}}\sum_{y\in\eta}\varphi_{r_1}(\|x-y\|)}^{\text{short-range effect of } \omega_{i_2} \text{ on } x} + \sum_{i_1,i_2=1}^{p}\gamma_{i_1,i_2}\sum_{x\in\omega_{i_1}}\underbrace{\max_{\substack{\eta\subset\omega_{i_2}\\ \text{s.t. } |\eta|\leq N}}\sum_{y\in\eta}\psi_{r_2,r_3}(\|x-y\|)}_{\text{medium-range effect of } \omega_{i_2} \text{ on } x}\Bigg]$$

Summary of model parameters

- α: magnitude of the short-range interactions (occurring at less than r_1)
- γ: magnitude of the medium-range interactions (occurring between r_2 and r_3)
- β: environmental response
- **Note:** intra/inter-species versions of all parameters

Real dataset

Swamp Savannah river dataset

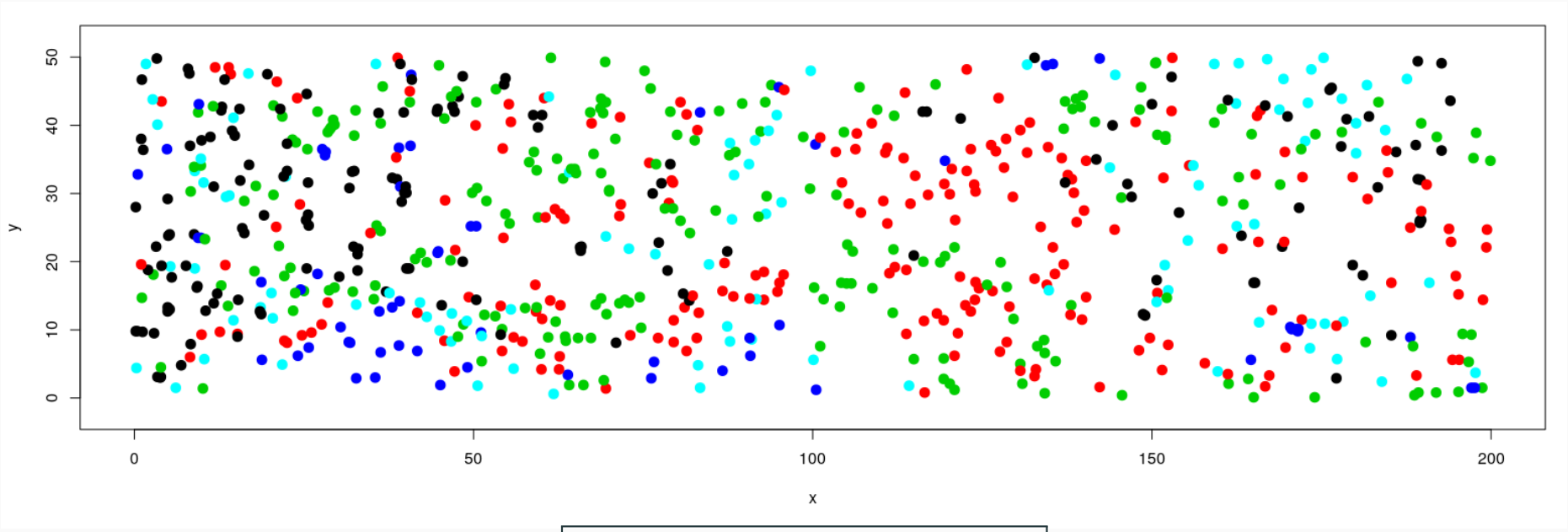
Locations of 156 Carolina ashes, 215 Water tupelos, 205 Swamp tupelos, 98 Bald cypresses and 60 stems of 8 additional species, in a $200\mathrm{m} \times 50\mathrm{m}$ plot in the Savannah River Site, South Carolina.

`ecespa::swamp`.

Studied in Dixon (2002).

Wikimedia Commons, Xerantheum / CC BY

Swamp Savannah river plot



- Carolina ash
- Swamp tupelo
- Water tupelo
- Other species
- Bald cypress

Swamp Savannah river results (1)

Short-range interactions ($\leq 5\mathrm{m}$):

$$\alpha = \begin{pmatrix} \mathbf{1.34} & -0.01 & \mathbf{-0.21} & \mathbf{-0.34} & 0.03 \\ -0.01 & \mathbf{0.56} & \mathbf{-0.33} & -0.16 & \mathbf{-0.36} \\ \mathbf{-0.21} & \mathbf{-0.33} & \mathbf{1.13} & -0.14 & \mathbf{-0.22} \\ \mathbf{-0.34} & -0.16 & -0.14 & \mathbf{1.09} & -0.05 \\ 0.03 & \mathbf{-0.36} & \mathbf{-0.22} & -0.05 & -0.27 \end{pmatrix}$$

Bold: CI does not contain 0

(1) Carolina ash
(2) Swamp tupelo
(3) Water tupelo
(4) Other species
(5) Bald cypress

Swamp Savannah river results (2)

Medium-range interactions ($20\mathrm{m} \sim 25\mathrm{m}$):

$$\gamma = \begin{pmatrix} 0.22 & \mathbf{-0.21} & 0.15 & 0.09 & \mathbf{-0.20} \\ \mathbf{-0.21} & 0.36 & \mathbf{-0.28} & 0.05 & 0.02 \\ 0.15 & \mathbf{-0.28} & -0.06 & -0.07 & -0.11 \\ 0.09 & 0.05 & -0.07 & -0.22 & -0.15 \\ \mathbf{-0.20} & 0.02 & -0.11 & -0.15 & -0.08 \end{pmatrix}$$

(1) Carolina ash
(2) Swamp tupelo
(3) Water tupelo
(4) Other species
(5) Bald cypress

Bold: CI does not contain 0

Swamp Savannah river results (3)

Intercept and environmental response to horizontal covariate

$$\beta = \begin{pmatrix} -5.02 & \mathbf{-4.87 \cdot 10^{-3}} \\ -3.40 & -1.99 \cdot 10^{-3} \\ -3.55 & -2.75 \cdot 10^{-3} \\ -4.09 & -4.81 \cdot 10^{-3} \\ -1.69 & -4.35 \cdot 10^{-3} \end{pmatrix}$$

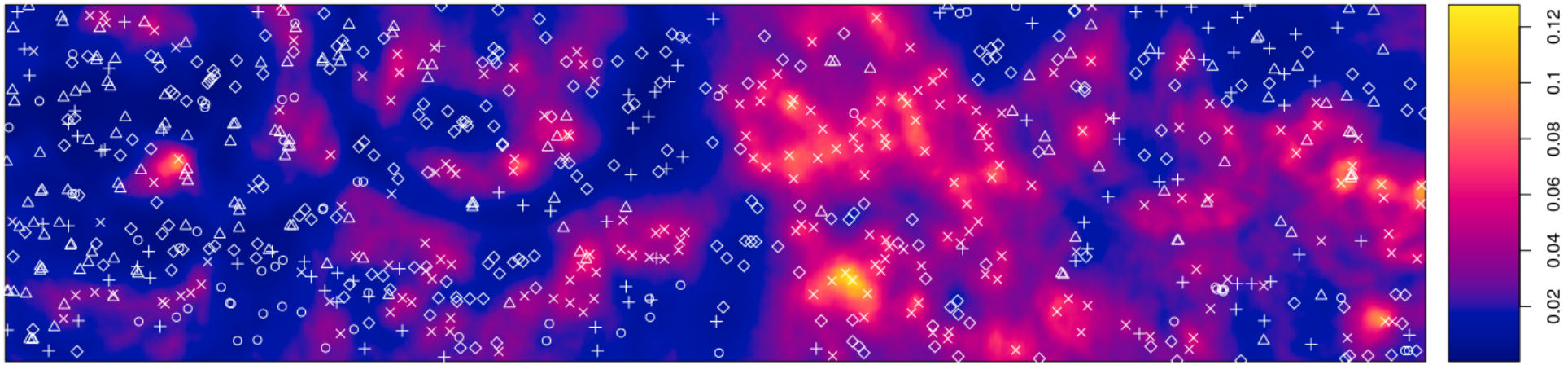
intercept slope

(1) Carolina ash
(2) Swamp tupelo
(3) Water tupelo
(4) Other species
(5) Bald cypress

Bold: CI does not contain 0

Swamp Savannah river conditional intensity

Probability of finding Swamp Tupelo individual



△ Carolina ash

× Swamp tupelo

◇ Water tupelo

○ Other species

\+ Bald cypress

R package

R package

- Simulation, fitting and analysis functions in **ppjsdm**:

  github.com/iflint1/ppjsdm

- Example usage on various datasets from plant ecology in **ppjsdm_on_datasets**:

  github.com/iflint1/ppjsdm_on_datasets

- All the figures and results presented here can be generated from

  gist.github.com/iflint1/
  e8fd3d4c29bdd9ad2538e7d992c40a49

Conclusion

Conclusion

When should you use the model?

- Spatial locations
- Inter and intra species interactions
- Multi-species environments

References

- Dixon, P. (2002), “Nearest-neighbor contingency table analysis of spatial segregation for several species”. Écoscience 9: pp. 142–151.

Thank you for listening!