TECHNISCHE UNIVERSITÄT DRESDEN

FOREST BIOMETRICS & SYSTEMS ANALYSIS

DRESDEN concept

Individual-based modeling to discover the ecological importance of tree networks

Uta Berger[1], Marie-Christin Wimmler[1], Cyril Piou[2], Etienne Delay[3], Alejandra Vovides[4]

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[4] University of Glasgow, UK

ESAUSSEE

LOUISVILLE 2019

tree networks
via root connections

indirect | direct

mycorrhiza | grafting
clonal growth

New Phytologist — Research

Architecture of the wood-wide web: *Rhizopogon* spp. genets link multiple Douglas-fir cohorts

Kevin J. Beiler[1,2], Daniel M. Durall[1], Suzanne W. Simard[2], Sheri A. Maxwell[3] and Annette M. Kretzer[4]
[1]Biology and Physical Geography Unit and SARAHS Centre, University of British Columbia Okanagan, Kelowna, BC V1V 1V7, Canada; [2]Department of Forest Sciences, University of British Columbia, Vancouver, BC V6T 1Z4, Canada; [3]Department of Biology, University of Western Ontario, London, ON N6A 5B8, Canada; [4]SUNY College of Environmental Science and Forestry, Faculty of Environmental and Forest Biology, One Forestry Drive, Syracuse, NY 13210-2788, USA

FOREST ECOLOGY

Belowground carbon trade among tall trees in a temperate forest

Tamir Klein,[1]*† Rolf T. W. Siegwolf,[2] Christian Körner[1]

tree networks
via root connections

<u>indirect</u>

mycorrhiza

<u>direct</u>

grafting
clonal growth

Old Tikjo
(Spruce) Sweden

Pando
(Aspen, USA)

- Exchange of resources
- Long living (9550 & 80,000 yrs)

tree networks
via root connections

indirect

mycorrhiza

direct

clonal growth
grafting

NATURAL ROOT GRAFTS

B. F. GRAHAM, JR.
Biology Department, Grinnell College, Grinnell, Iowa
and
F. H. BORMANN
School of Forestry, Yale University, New Haven, Connecticut

Already 150! species listed in 1966

Why should trees have natural root grafts? FREE

Simcha Lev-Yadun, Douglas Sprugel

Tree Physiology, Volume 31, Issue 6, June 2011, Pages 575–578, https://doi.org/10.1093/treephys/tpr061

Published: 01 June 2011 **Article history** ▾

- Support of resources
- Parasitism
- Better anchorage
- ..

1059

NRC Research Press

ARTICLE

Natural root grafting in *Picea mariana* to cope with spruce budworm outbreaks

Roberto L. Salomón, Emilie Tarroux, and Annie DesRochers

frontiers in PLANT SCIENCE

REVIEW ARTICLE
published: 17 December 2014
doi: 10.3389/fpls.2014.00727

Plant grafting: new mechanisms, evolutionary implications

Eliezer E. Goldschmidt*

The Robert H. Smith Institute of Plant Sciences and Genetics in Agriculture, Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, Rehovot, Israel

VOL. 178, NO. 1 THE AMERICAN NATURALIST JULY 2011

Facilitation within Species: A Possible Origin of Group-Selected Superorganisms

Eliot J. B. McIntire[1,*] and Alex Fajardo[2]

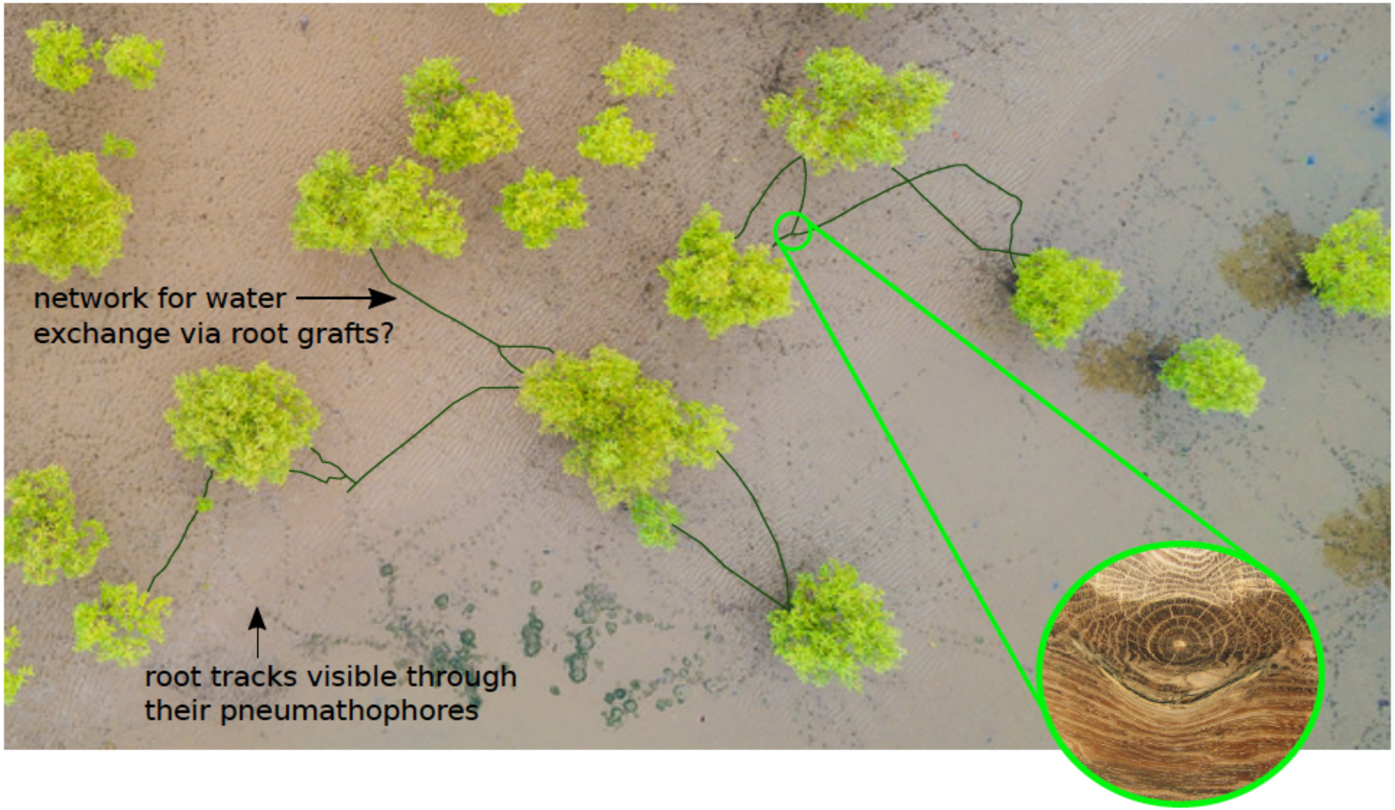
Question

Ecological importance of root grafting for individuals, and on stand level?

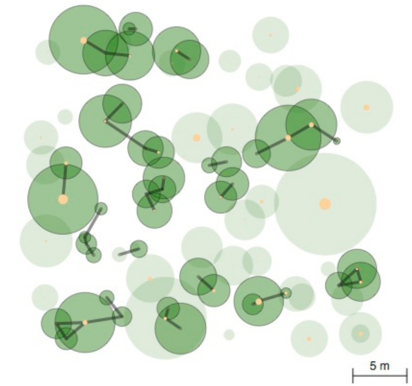
Challenges

- measurements of resource exchange only “bi-treeal”
- roots not (easily) accessible

Except mangroves:



cross section of a functional root graft

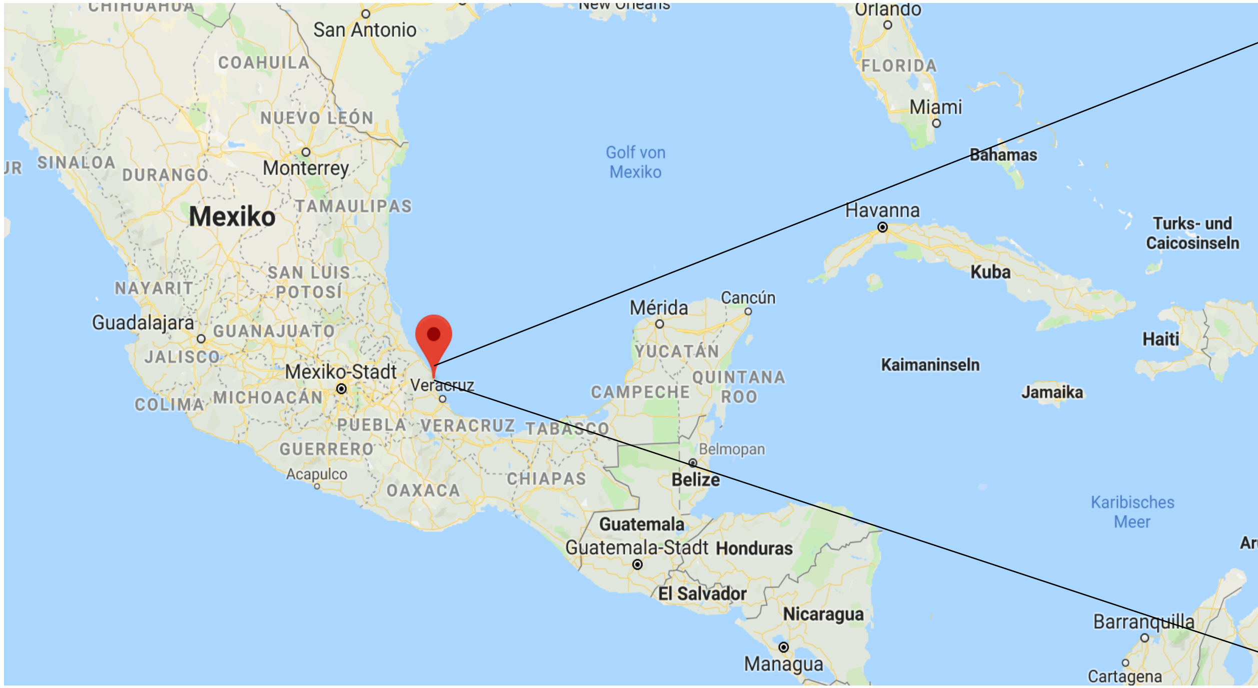


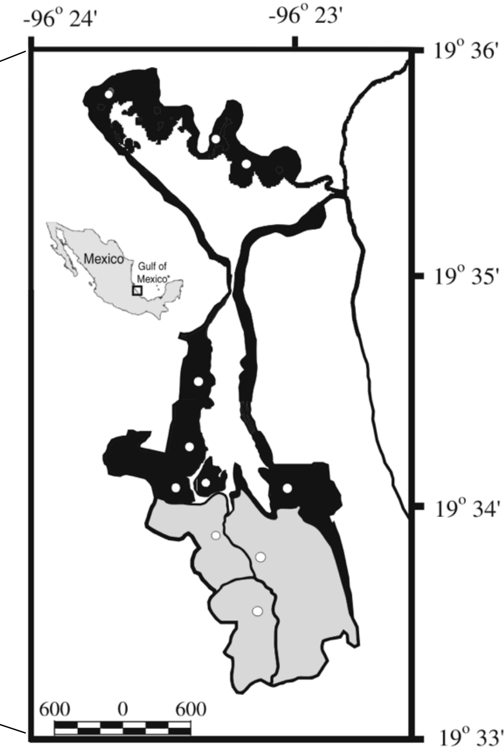
- **Root grafting** (*Avicennia germinans*)

Possible explanation of root grafting

- Randomness
- Water sharing

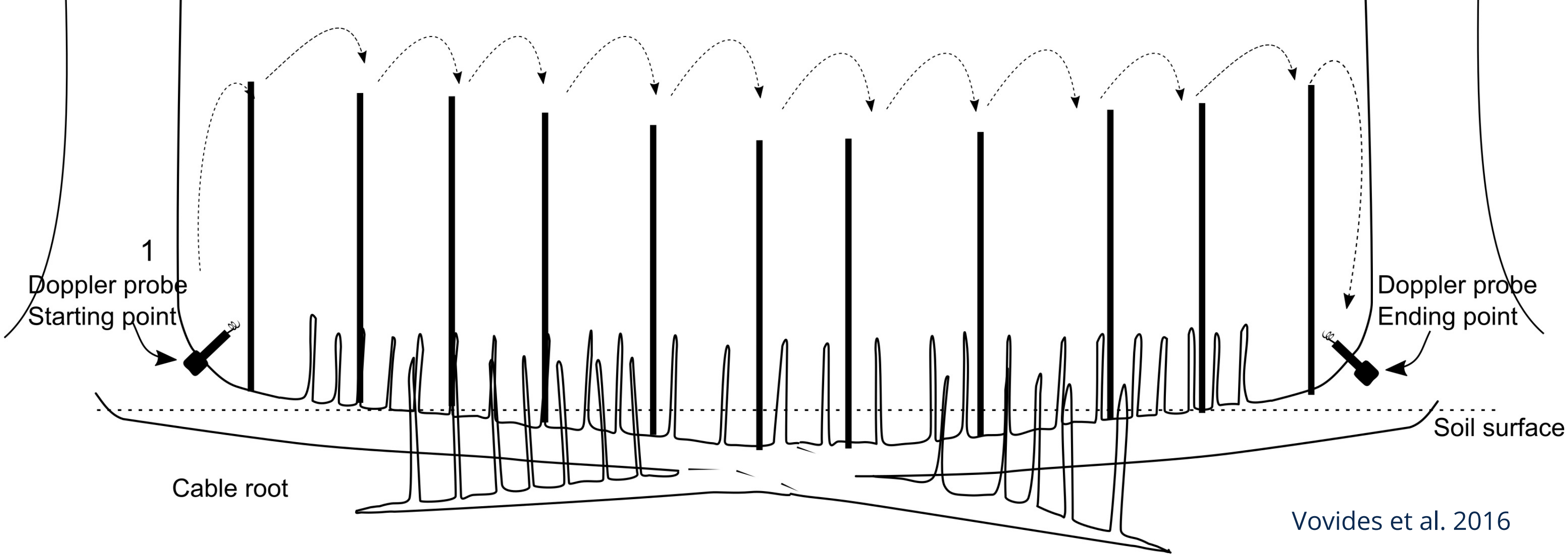
Study site – La Mancha Lagoon, Veracruz, Mexico





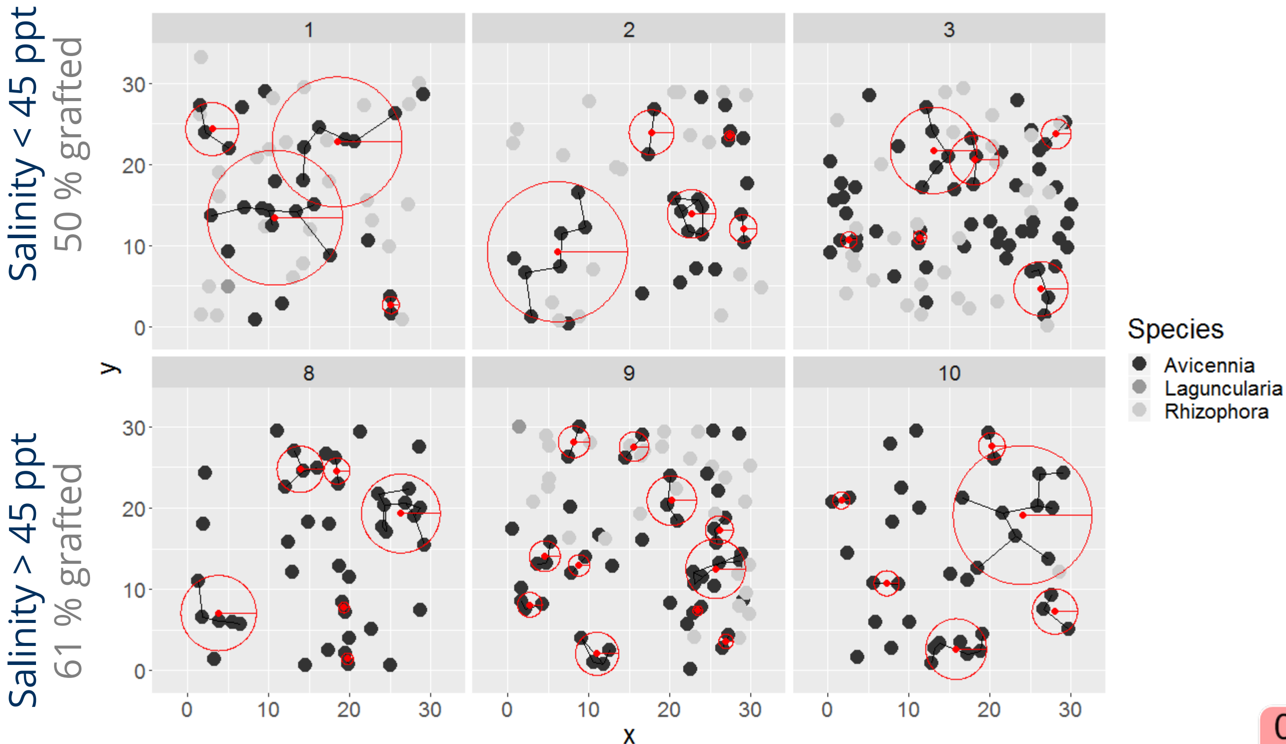
Vovides et al. 2014

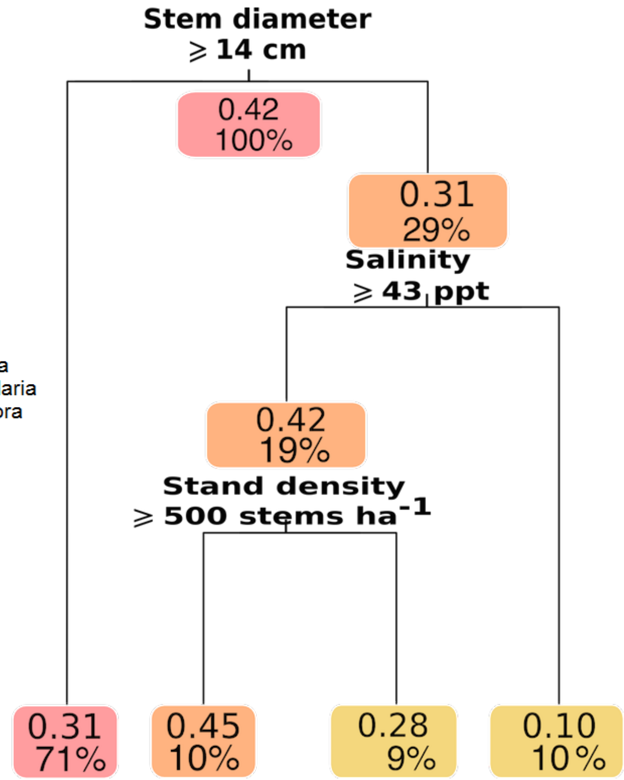
Network detection via echosounder



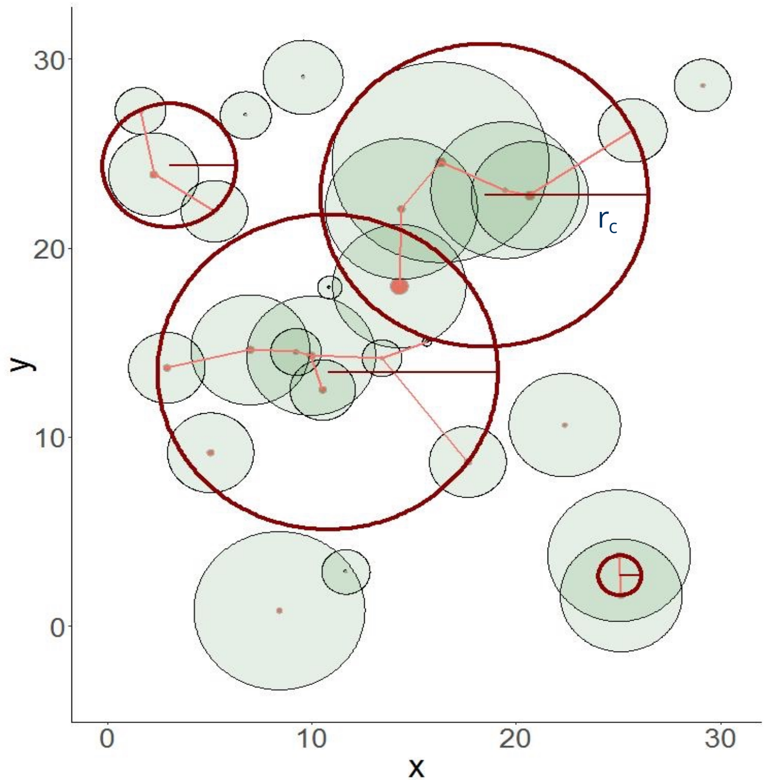
Vovides et al. 2016

La Mancha *A. germinans* networks





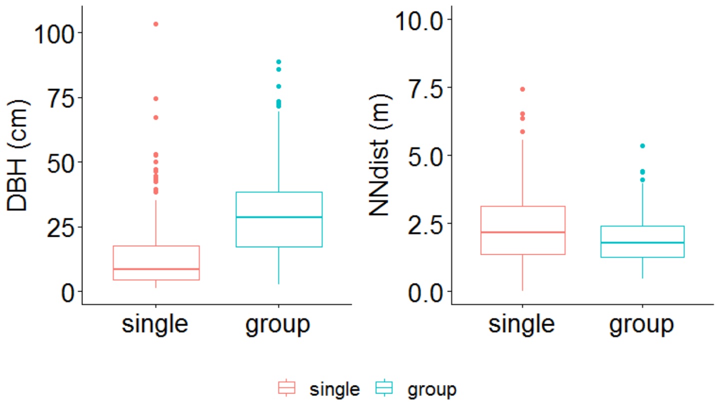
Root graft data represented as network

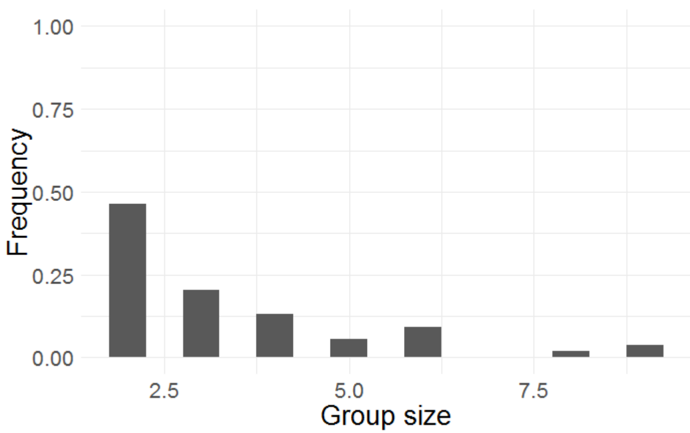


Network >> Sampling plot
Node >> Tree
Edge >> Link between root grafted trees
Component >> Group of linked trees
All networks are **undirected & unweighted**

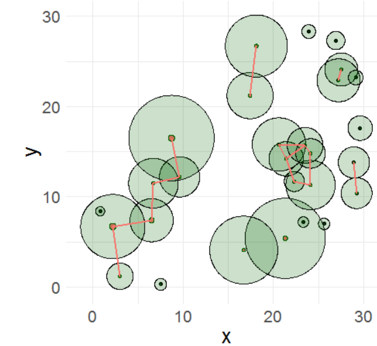
# Nodes	27
# Links	15
# Groups	4
Edge density	0.043
Connectance	0.563
Mean distance	1.78
Mean diameter	3.25
% RG trees	66.7 %
# RG trees · ha^{-1}	200
# Groups · ha^{-1}	44.4

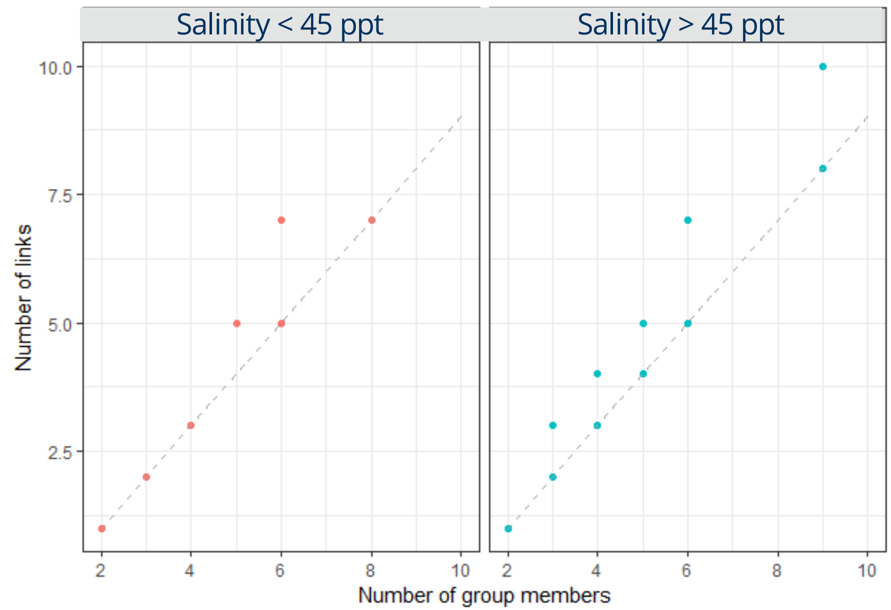
Network data from **La Mancha**





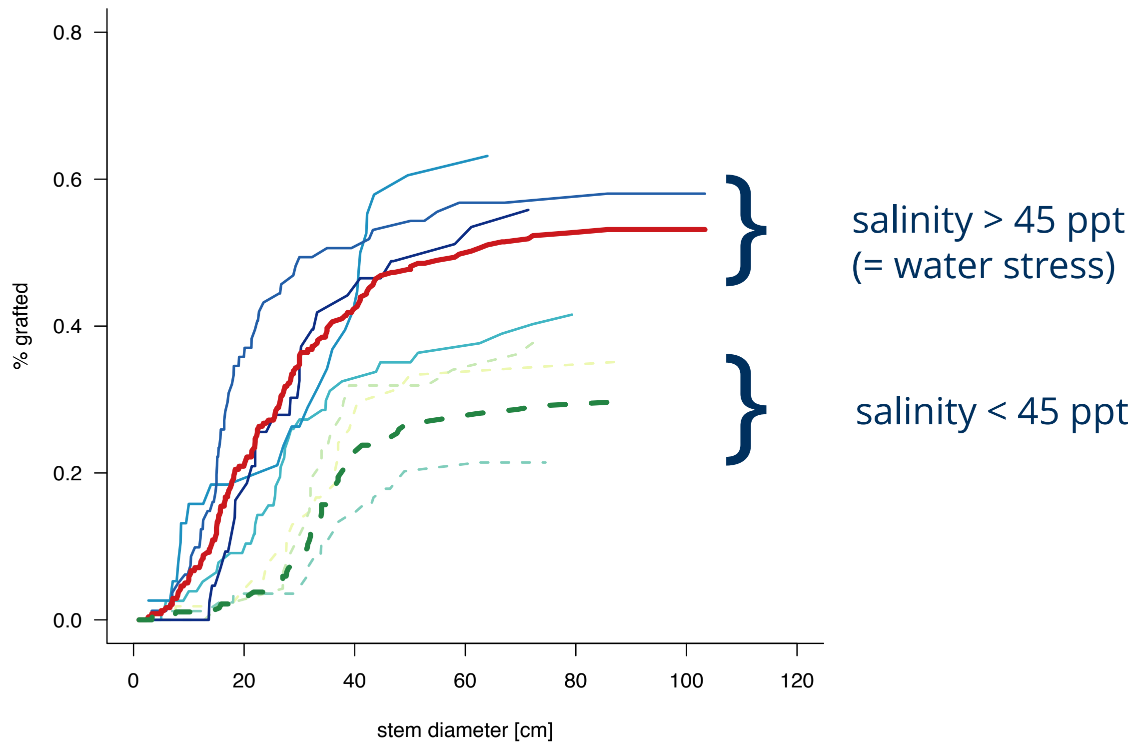
- 75% of grafted trees linked to closest neighbour
- linear structure





Further patterns observed in La Mancha ..

- spatial distribution
- #grafts ~ density
- #grafts = f(salinity, tree size …)
- ..



NULL model

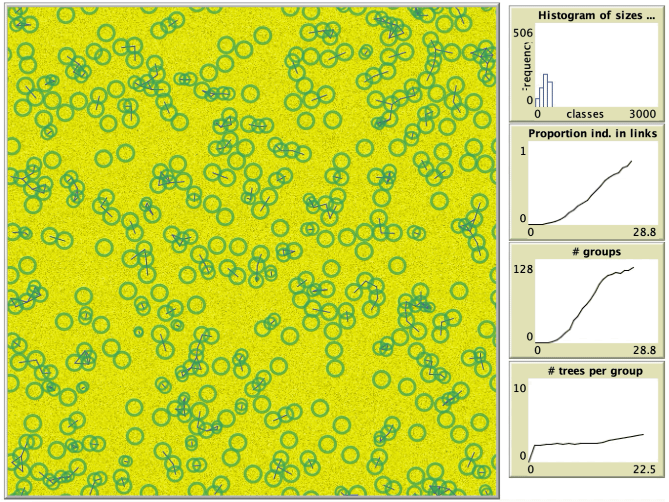
Input: La Mancha data
- (x, y)

Random grafting
- each tree to one of its nearest neighbour
- Random selection
- Probability according to field observations

Networks of
La Mancha

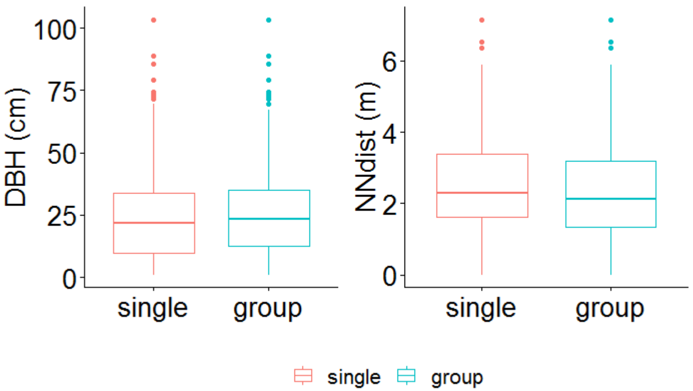
randomness or process?

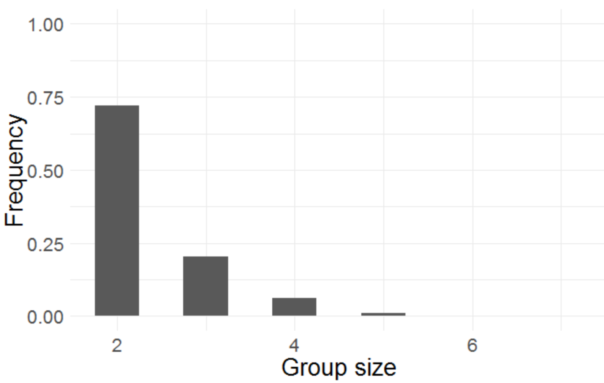
AZOI forest model

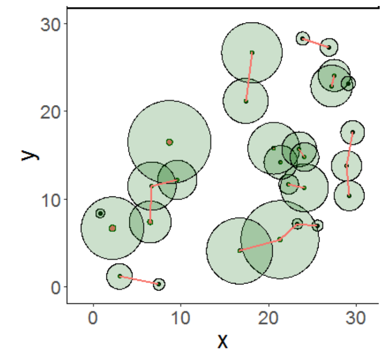


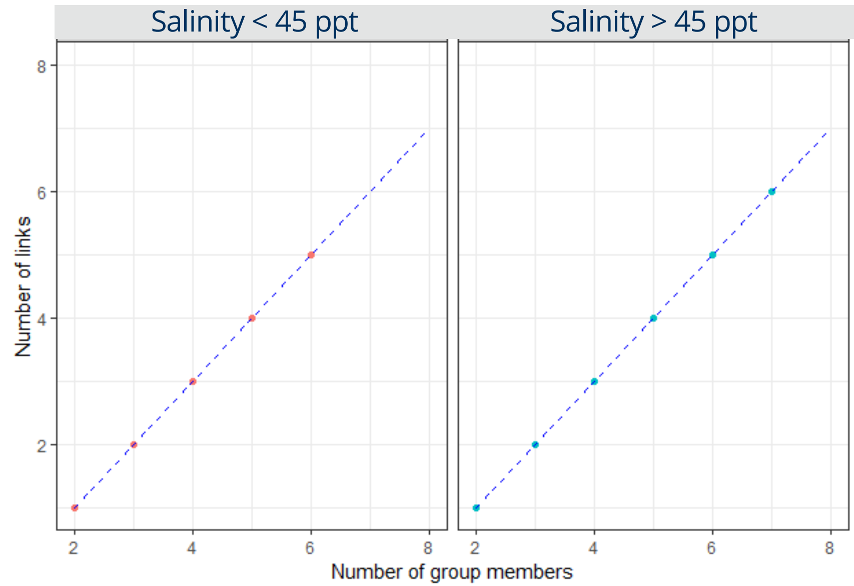
Life processes of trees considered
1. Recruitment
2. Growth
3. Competition
4. Mortality
5. Grafting & Exchange of resources

Null model

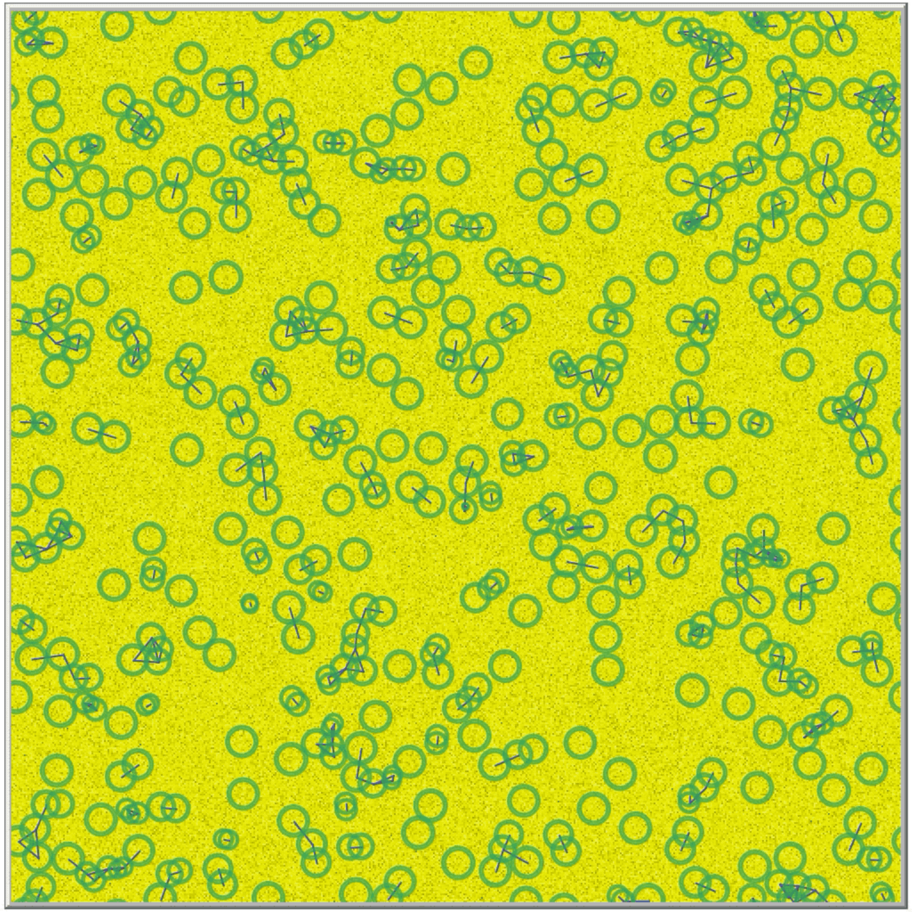

DBH (cm)
100
75
50
25
0
single
group
NNdist (m)
6
4
2
0
single
group
single
group

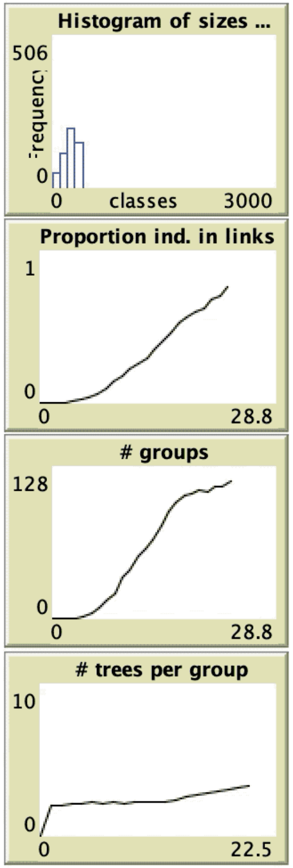

Frequency
1.00
0.75
0.50
0.25
0.00
2
4
6
Group size


y
30
20
10
0
0
10
20
30
x


Salinity < 45 ppt
Salinity > 45 ppt
Number of links
8
6
4
2
2
4
6
8
2
4
6
8
Number of group members

AZOI model description

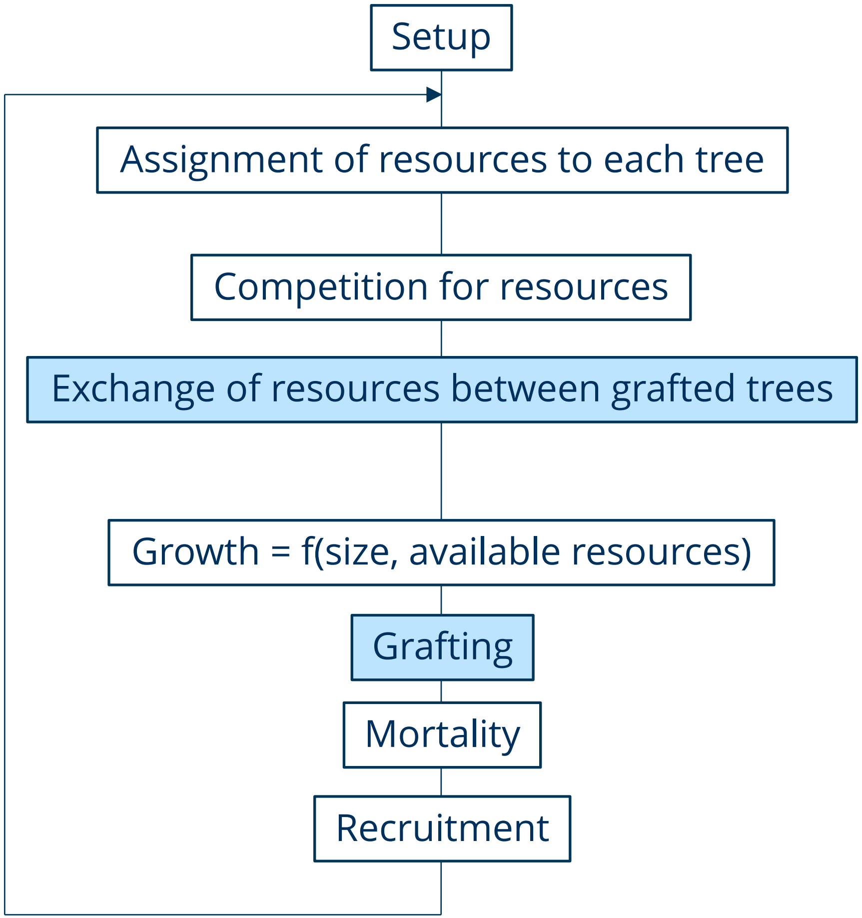


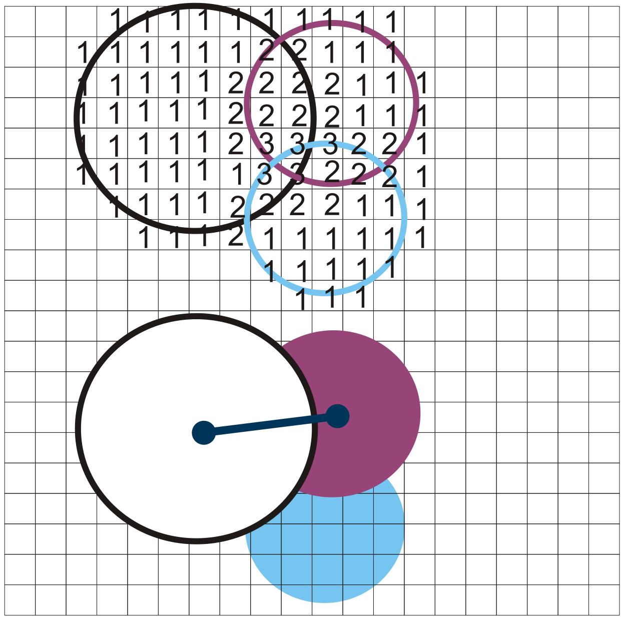


Entity	State Variables	Description
Plants	B_{max}	Maximum biomass
	B	Current biomass
	x,y	coordinates of stem position
	P_{netw}	Probability to graft with neighbour
	radius	Radius of the Zone Of Influence (size)
Patches	r	resource availability
	owners	IDs of trees claiming this patch

Scales

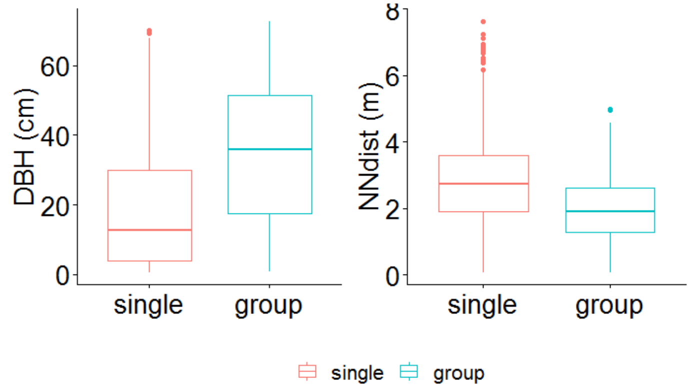
Space: 100 m x 100 m = 1 ha
Time step: 1 year
$Time_{max}$: 1000 years

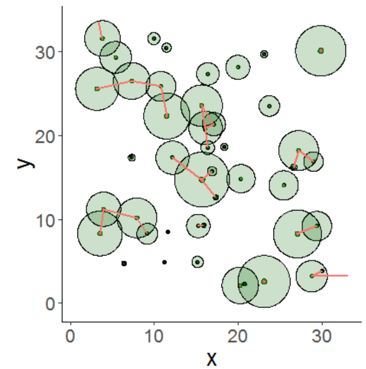


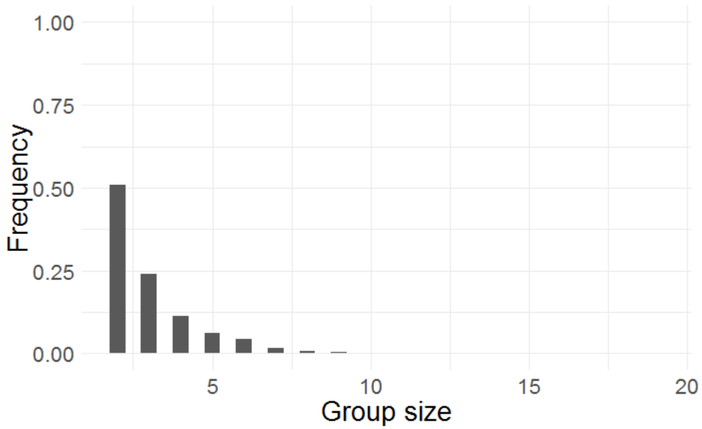


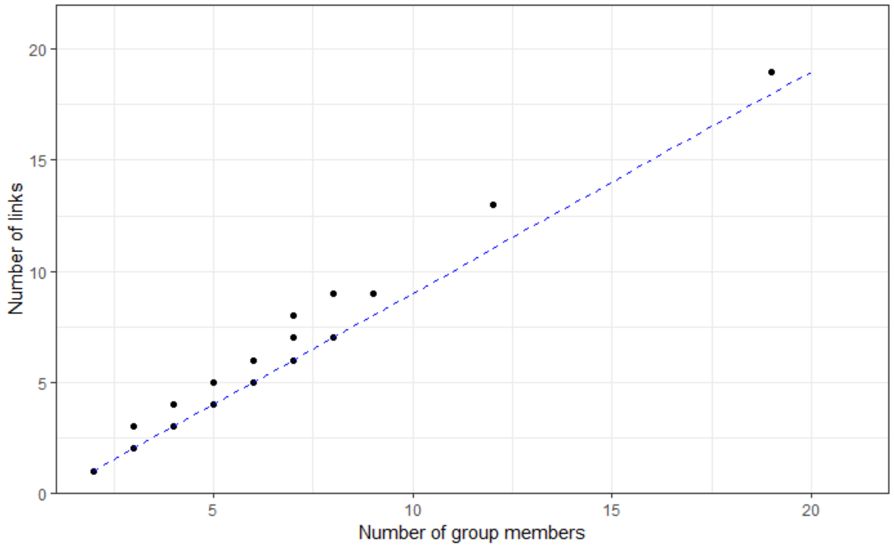
Zone of Influence (ZOI, Weiner et al. 2001!)

simulation results AZOI model

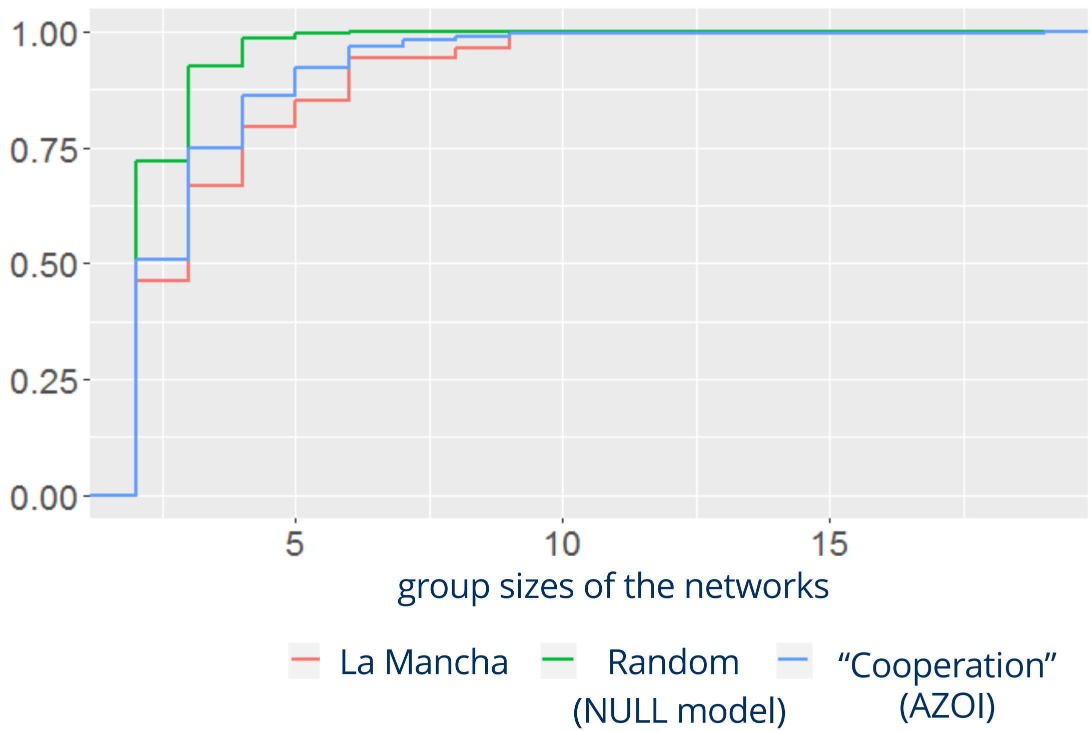




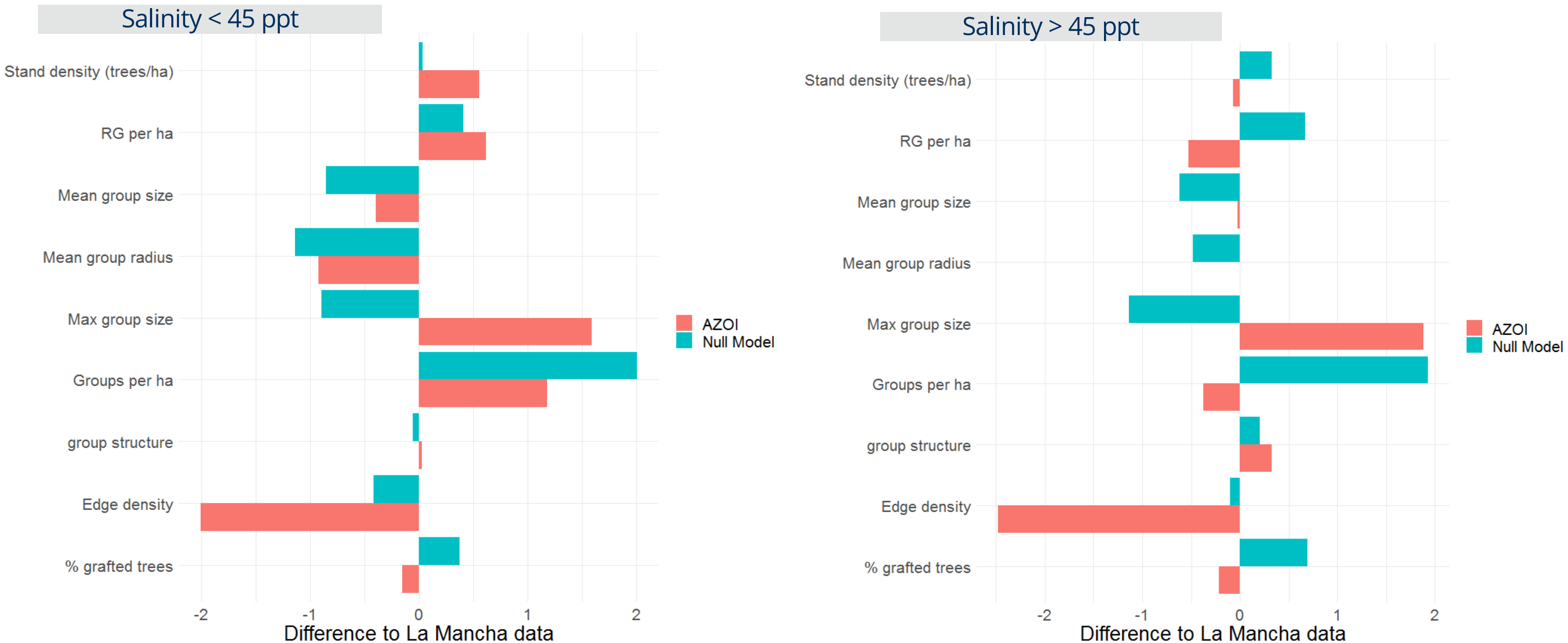




Direct comparison of La Mancha data with both models

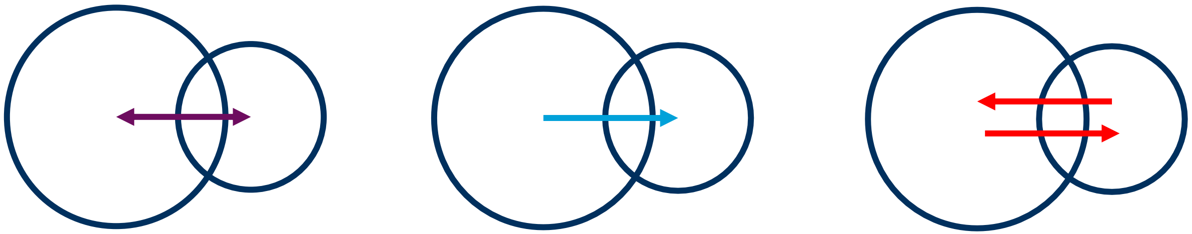


Direct comparison of La Mancha data with both models



AZOI model: 3 different submodels to exchange of resources:

submodel	explanation
random	Resources flow between grafted trees in random direction.
big2small	Resources flow from bigger to smaller tree.
fast2slow	Resources flow from faster growing tree to the slower growing.



Sub-model	% grafted trees	Grafts per ha	Groups per ha	Mean group size	Max group size	Mean group radius	linearity	Edge density
big2small	56.8	286.7	91.9	3.1	11.8	2.0	1.06	0.003
fast2slow	57.65	291.1	92.2	3.2	11.1	2.0	1.06	0.003
random	53.15	268.1	88.3	3.0	10.1	2.0	1.05	0.003
LM, <= 45 ppt	55.8	203.7	55.6	3.8	6.3	3.7	1.04	0.031
LM, > 45 ppt	61.7	352.8	108.4	3.5	7.2	2.4	1.04	0.020

No conclusion yet …

OpenMOLE the model exploration software

DOC TUTORIALS COMMUNITY DEMO DOWNLOAD

Direct sampling for parameter optimization:

411600

EMBED YOUR MODEL

1. Scala
2. Java
3. NetLogo
4. Python
5. R
6. Scilab
7. Linux Executable

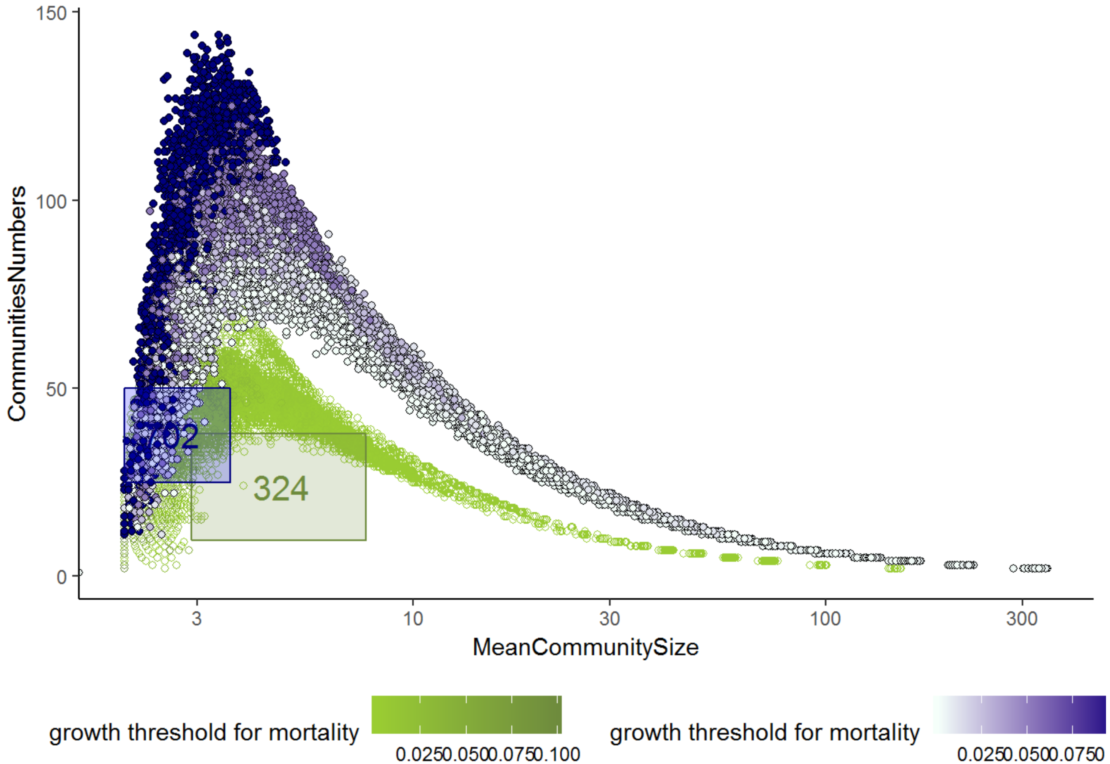
EXPLORE YOUR MODEL

1. Samplings
   a. Elementary Samplings
   b. Samplings for High Dimension Spaces
   c. Uniform Sampling
   d. Sampling Over Files
   e. Spatial Sampling
   f. Custom Sampling
   g. Advanced Operations on Samplings
2. Calibration
3. Stastistical Sensitivity Analysis
4. Profile
5. Pattern Space Exploration
6. Origin Space Exploration

Model version 1

Competition = F; Cooperation = F

MeanPnetw, SDPnetw, grperCrit, MortNoCompet



Data points within the target (mean +- 2*sd)

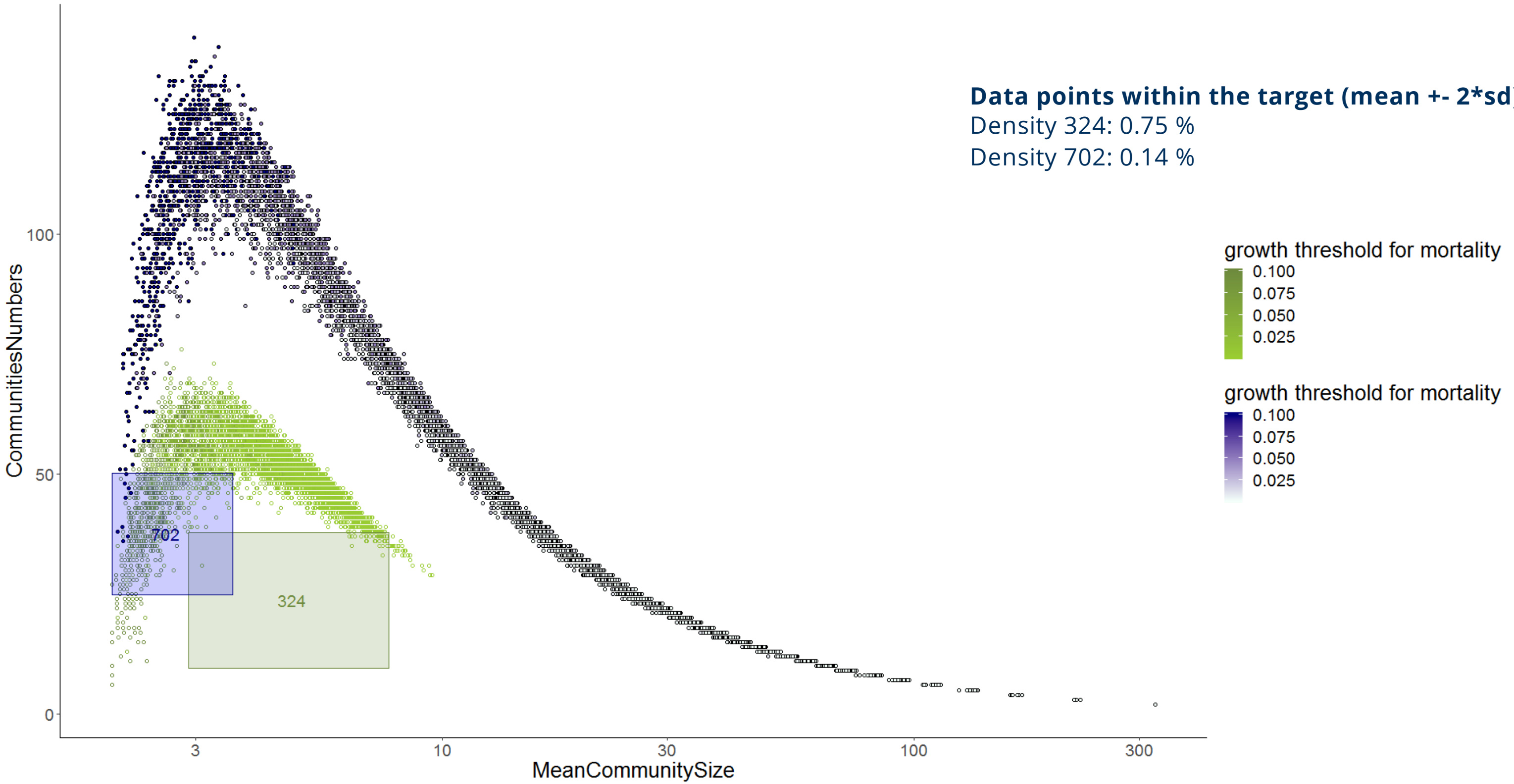
Density 324: 4.93 %

Density 702: 5.93 %

Model version 3

Competition = T; Cooperation = T; Random Benefits = On

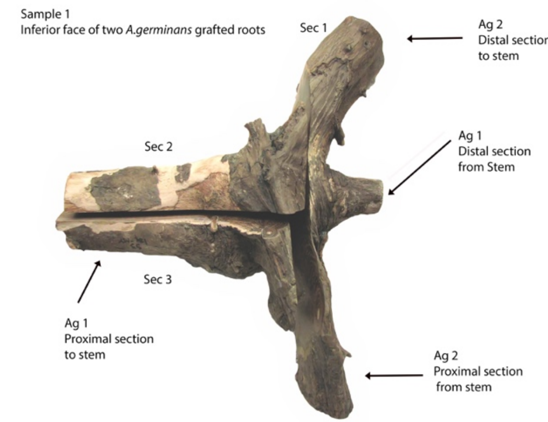
MeanPnetw, SDPnetw, grperCrit, Mn, cost



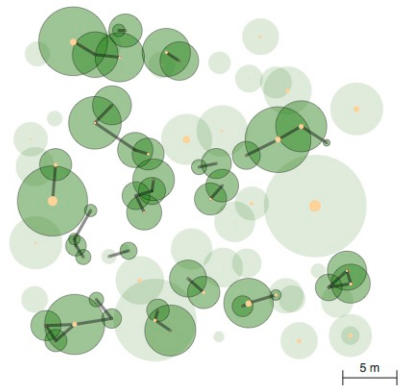
Data points within the target (mean +- 2*sd)
Density 324: 0.75 %
Density 702: 0.14 %

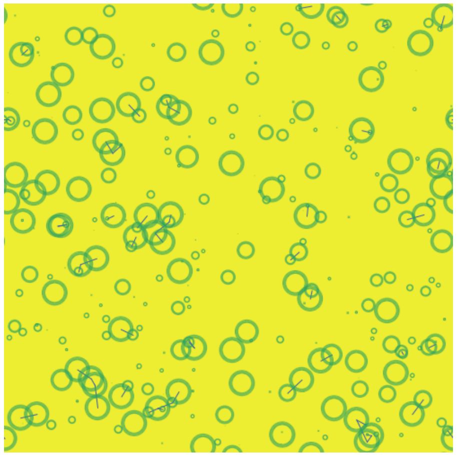
Feeding back into empirical studies:

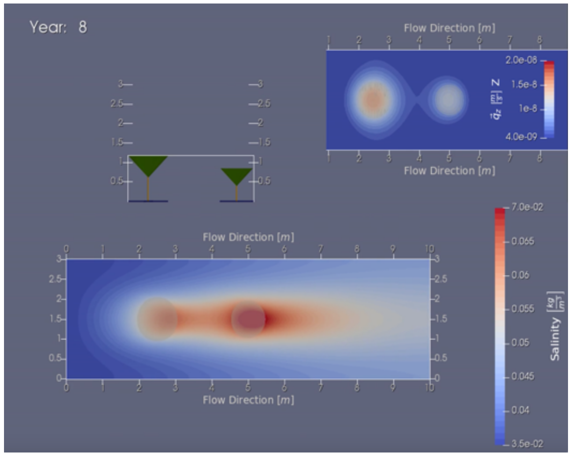
funded by Volkswagen Foundation Germany

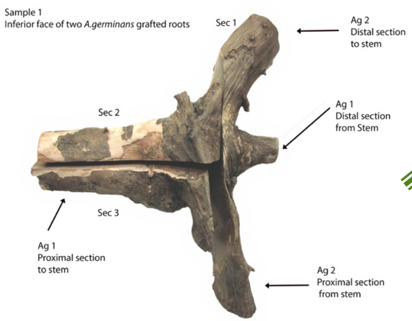


https://mangroverootnetworks.info/


5 m




Year: 8
Flow Direction [m]
Flow Direction [m]
Flow Direction [m]
Flow Direction [m]
Salinity


Sample 1
Inferior face of two A.germinans grafted roots
Sec 1
Ag 2
Distal section
to stem
Sec 2
Ag 1
Distal section
from Stem
Sec 3
Ag 1
Proximal section
to stem
Ag 2
Proximal section
from stem

Conclusion

Specific

- Positive effect of root grafting for single trees known but not its ecological importance for stands
- Our empirical studies specify networks but not the mechanisms of resource exchange
- Simulation models used to test whether networks are just random
- Agent-based model used
  - to develop hypotheses about the direction of resource exchange
  - to derive sap-flow measurements in the field

In general

- Case study shows (first) **cycle of field studies – simulation experiments – field studies**
- The use of the established **ZOI** approach reduces modelling effort and enables focus on one mechanism (resource exchange _ networking): **build on existing theory == develop new theory**
- ZOI will not be sufficient: first principles do not only produce but require mechanistic understanding

Acknowledgments


Ale Vovides


Marie-Christin Wimmler


Etienne Delay


Cyril Piou