Politecnico
di Torino

Department of Environment,
Land and Infrastructure
Engineering

CALIBRATING ECOMORPHODYNAMIC MODELLING WITH FIELD DATA FOR SHORT-TERM RIPARIAN SIMULATIONS

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RIPARIAN CORRIDORS

Aquatic-terrestrial transitional zone (ATTZ)

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ANTHROPOGENIC THREATS

RIVER RESTORATION

RESEARCH QUESTIONS

HP: eco-morphodynamic modelling can support river restoration

1. Which ecomorphodynamic models are available?
2. How do they include vegetation dynamics and how can we improve them?
3. How can we calibrate the model parameters based on real data?

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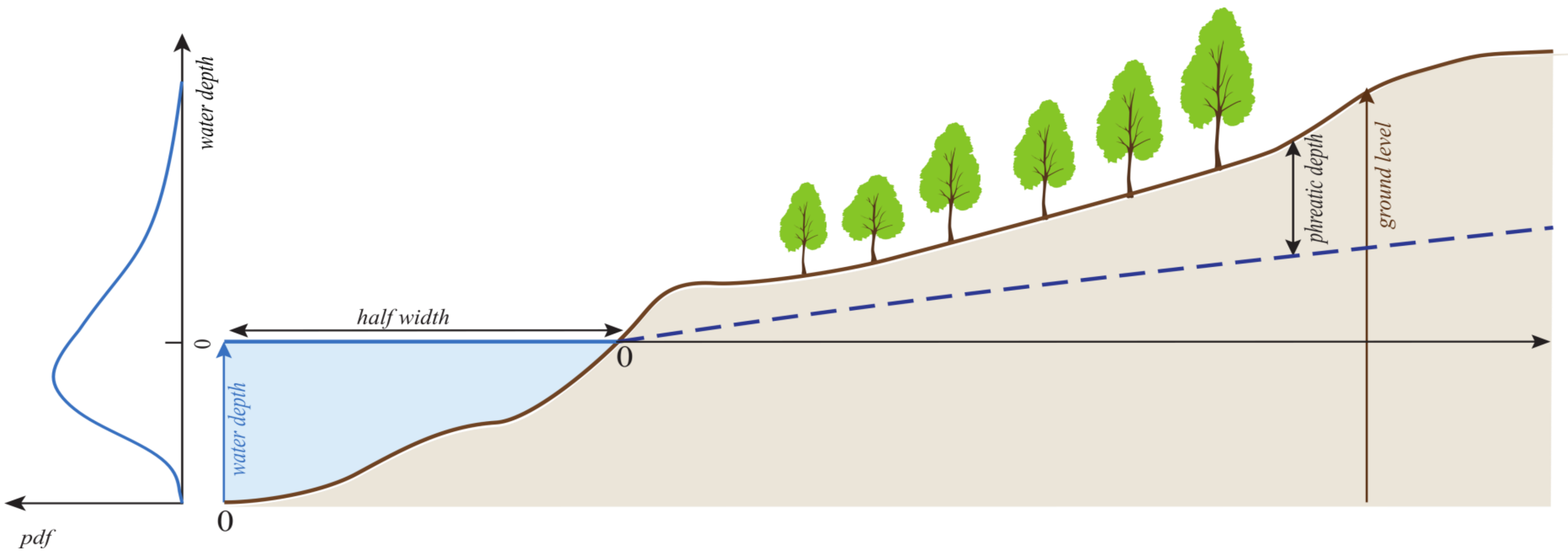
1. LITERATURE MODELS

Minimalistic models

Camporeale & Ridolfi (2006)



$$\frac{d\ biomass}{d\ time} = -\alpha * biomass$$

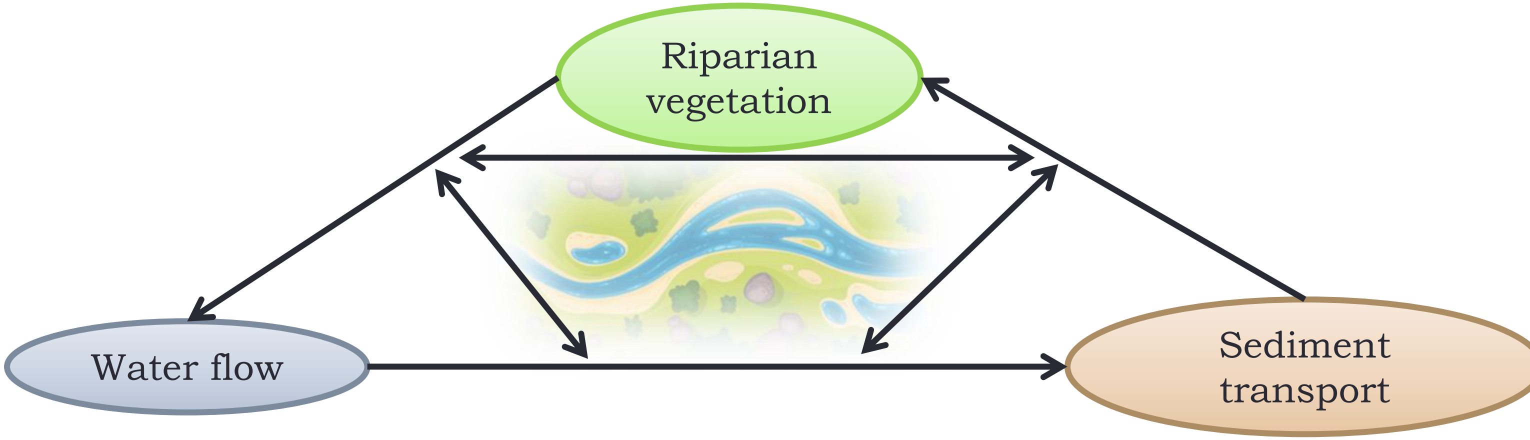
$$\frac{d\ biomass}{d\ time} = biomass\ (\beta - biomass)$$

$$p(\nu) = \frac{N}{\alpha} \nu^{\frac{\beta(1-\alpha\tau)-(\alpha+\beta)P_I}{\alpha\beta\tau}} (\beta - \nu)^{\frac{P_I}{\beta\tau}-1} (\alpha + \beta - \nu)$$

ν vegetation biomass
α decay factor
β carrying capacity
h water level

η topographic level
N normalization constant
τ integral scale of the process
Pi probability of inundation

1. LITERATURE MODELS



Model complexity

Number of included processses

- **Mechanicistic dynamic vegetation models**
- **Cellular automata**
- **Physically-based differential models**
- **Advanced numerical**

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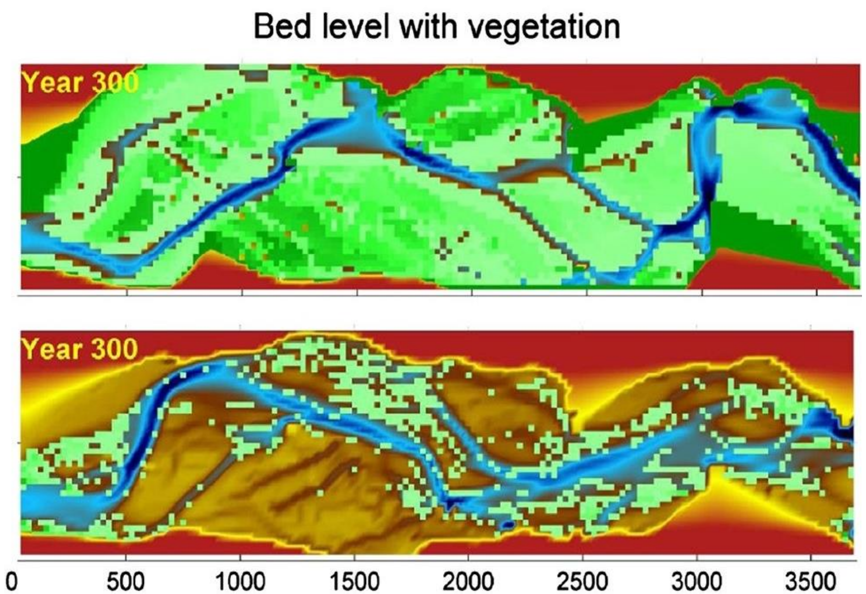
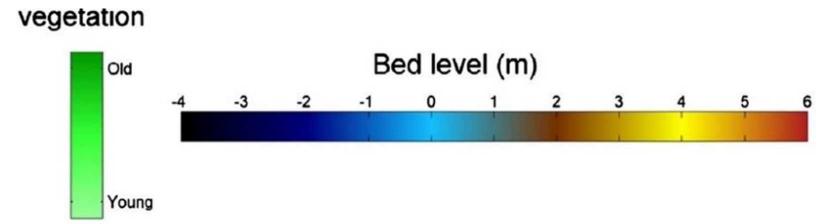
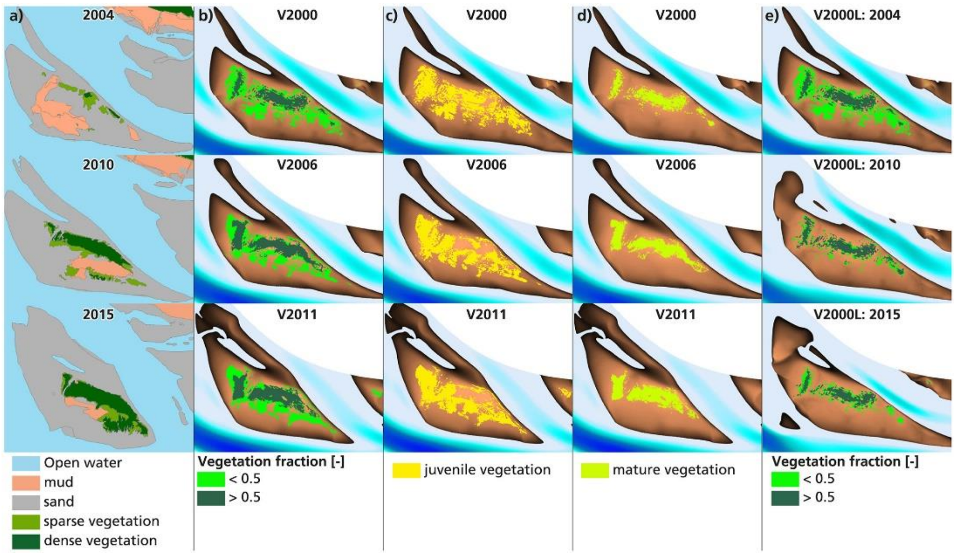
Advanced numerical



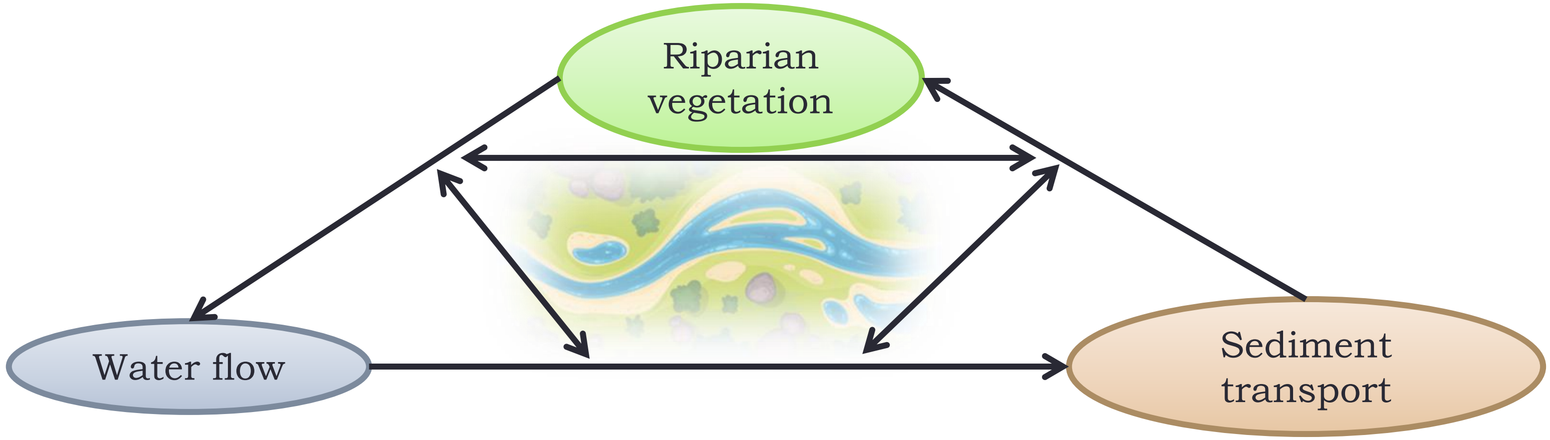


van Oorschot et al. (2016)

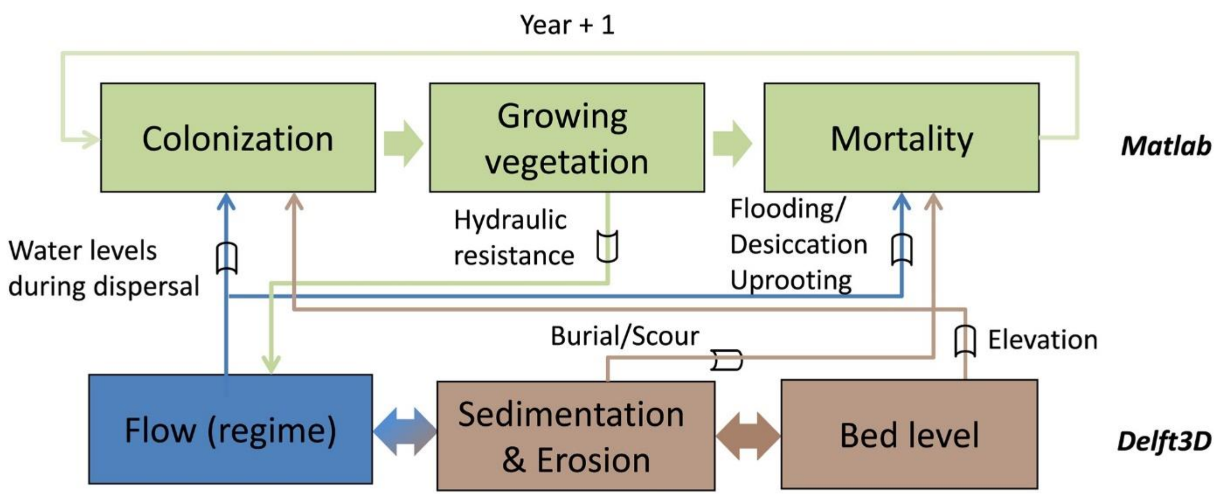
Brückner et al. (2019)



2.a HOW DO THEY INCLUDE VEGETATION DYNAMICS?



<u>OUR METHOD</u>: approach by van Oorschot et al. (2016) through the modification of the Matlab code by Bruckner et al. (2019)



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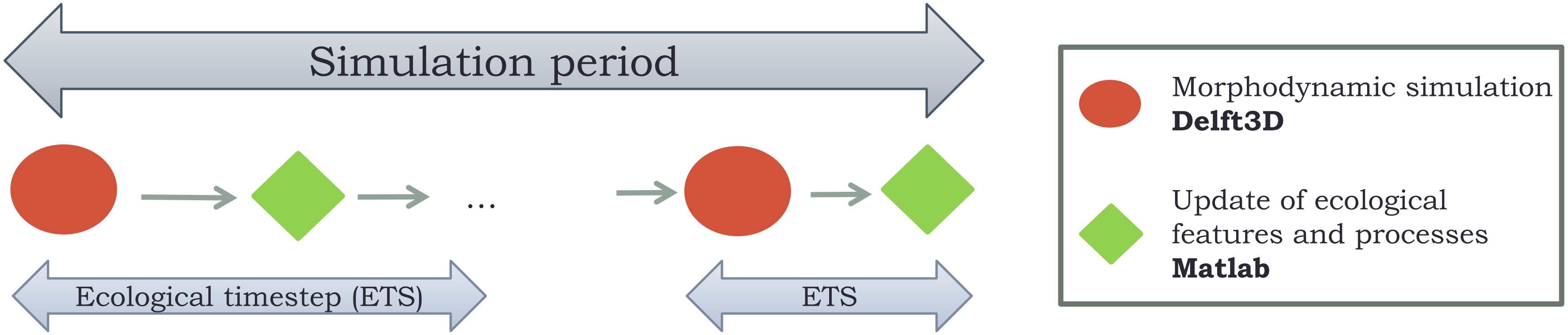

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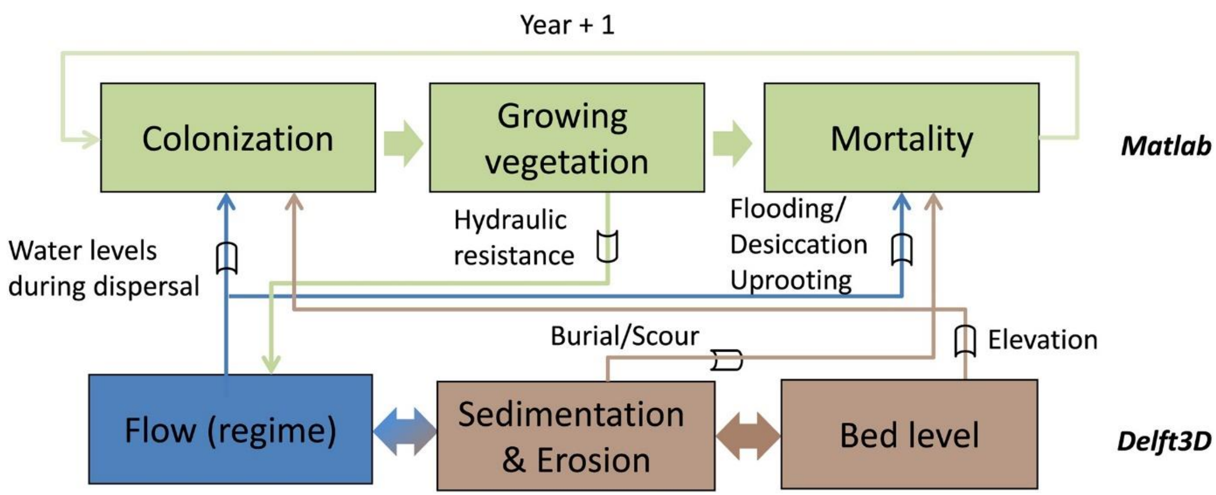

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2.b HOW CAN WE IMPROVE THEM?

ORIGINAL WORKS:

Ideal or quasi-real river reach

Arbitrary vegetation as initial condition

Literature values for vegetation parameters

OUR APPROACH:

Real river segment

Real initial vegetation features

Calibration of some vegetation parameters

VEGETATION PARAMETERS

1. Tree **height**
2. Tree **diameter**
3. Maximum **root lenght**
4. Cell **vegetation cover**
5. **Biomass**

Adding biomass budget

VEGETATION PROCESSES

1. Plant **growth**
   - Above-ground: March-September
   - Below-ground: March-September
2. Plant **decay**: January-December
3. Sexual **colonization**: June-July

Calibrating the parameters based on real data (LiDAR)

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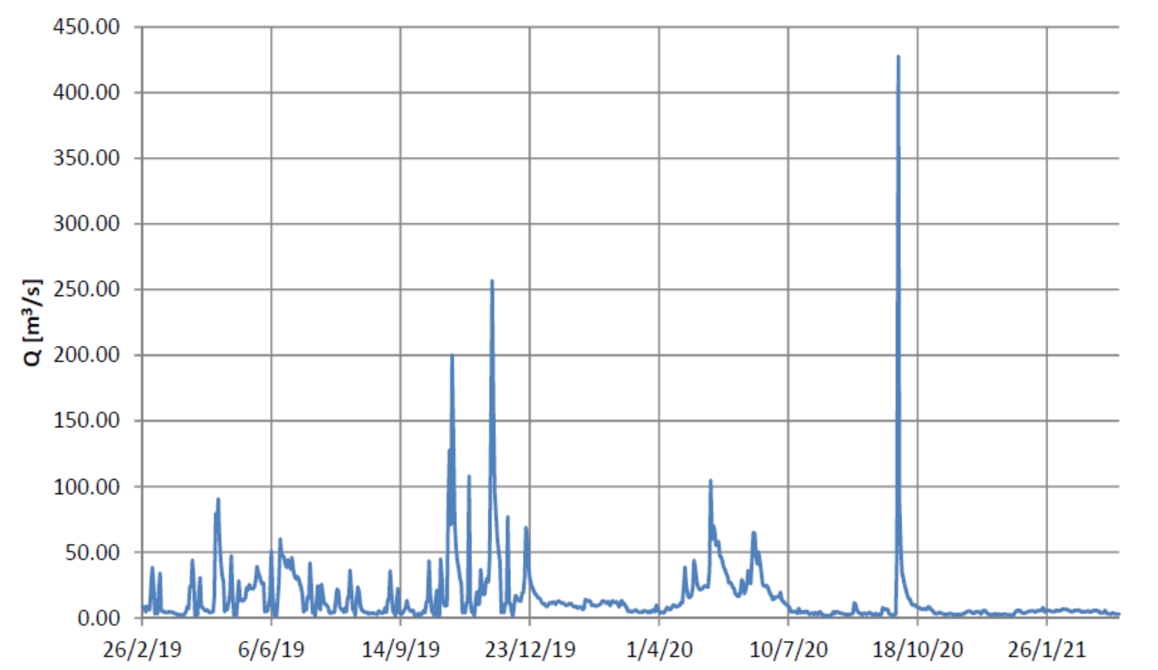
3. HOW CAN WE CALIBRATE THE MODEL PARAMETERS?

STUDY SITE

HYDROLOGY

1. **Mean daily flow rate**: $\bar{Q} = 21\ m^3/s$
2. Threshold to activate **sediment transport**: $Q_{morfo} = 40\ m^3/s$
3. Daily **time series** for the modelled period:



GRAIN SIZE

d_{50}=77.74 mm from filed measurements

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3. HOW CAN WE CALIBRATE THE MODEL PARAMETERS?

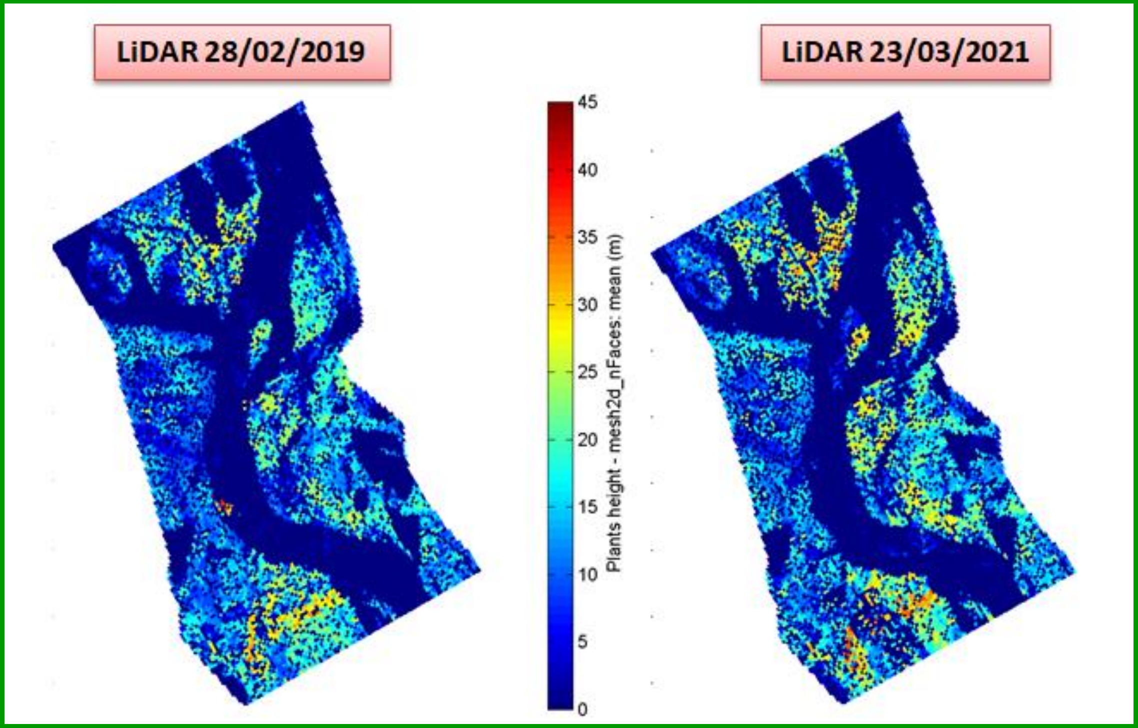
TOPOGRAPHY and VEGETATION

DTM from Airborne Laser Scanner (ALS) acquisitions (28/02/2019 ed il 23/03/2021).

Bathymetry from field measurements.

Tree height applying the individual tree detection method by Latella et al. (2021) to ALS data.

Allometric relationships from field measurements.



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3. HOW CAN WE CALIBRATE THE MODEL PARAMETERS?

Morphodynamic modelling → Additional roughness → Baptist et al. (2007)

$$C = \frac{1}{\sqrt{\frac{1}{C_b^2} + \frac{c_d n h_v}{2g}}} + \frac{\sqrt{g}}{\kappa} \ln \frac{h}{h_v}$$

C resulting Chezy factor
C_b bare soil Chezy factor
C_d vegetation drag coefficient

N stem density*diameter
h water depth
h_v vegetation height

Delft3D-FM → ***Trachytope*** module → Input files created according to LiDAR data and Latella et al. (2021) method

3. HOW CAN WE CALIBRATE THE MODEL PARAMETERS?

VEGETATION GROWTH

DIAMETER

REFERENCE WORK
Logarithmic growth
Literature values

OUR APPROACH
Logistic law
Botkin et al. (1972)

$$\frac{d\vartheta}{dt^*} = \frac{G(\vartheta D_m^*)^{q-1}\left[(\vartheta^3 - 2\vartheta^2 + 1)H_m^* - (\vartheta - 1)^2\,\vartheta H_0^*\right]}{2[H_0^* + \vartheta(2\vartheta - 3)(H_0^* - H_m^*)]H_m^*}$$

$$\vartheta = \frac{D^*}{D_m^*}$$

D^* diameter (m)
H^* height (m)
H_0 reference height = 1.37 m
$_m$ = maximum

Statistical calibration based on LiDAR data

$$G = 7.06$$

$$q = 2$$

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3. HOW CAN WE CALIBRATE THE MODEL PARAMETERS?

VEGETATION GROWTH

HEIGHT

REFERENCE WORK
Logarithmic growth
Literature values

OUR APPROACH
Field-regressed allometric relationships

$$H = A * D^B$$

H height (m)
D diameter (m)
A,B parameters

$A = 1.6950$ $B = 0.6252$

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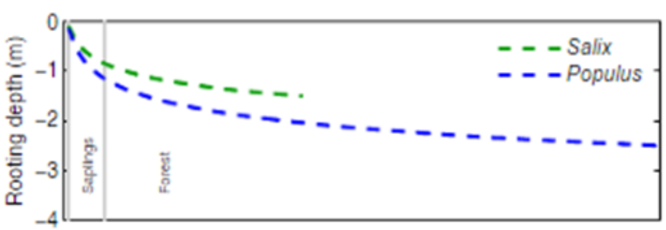
3. HOW CAN WE CALIBRATE THE MODEL PARAMETERS?

VEGETATION GROWTH

ROOT LENGTH

REFERENCE WORK
Logarithmic growth
Literature values



van Oorschot et al. (2016)

OUR APPROACH

1^ attempt: as the reference work (van Oorschot et al., 2016)

$$G = F_v \log(a)$$

G root length (m)
Fv growth factor (-)
a age (yr)

SPECIE	F_v
Pioppo	1.15
Salice	0.85

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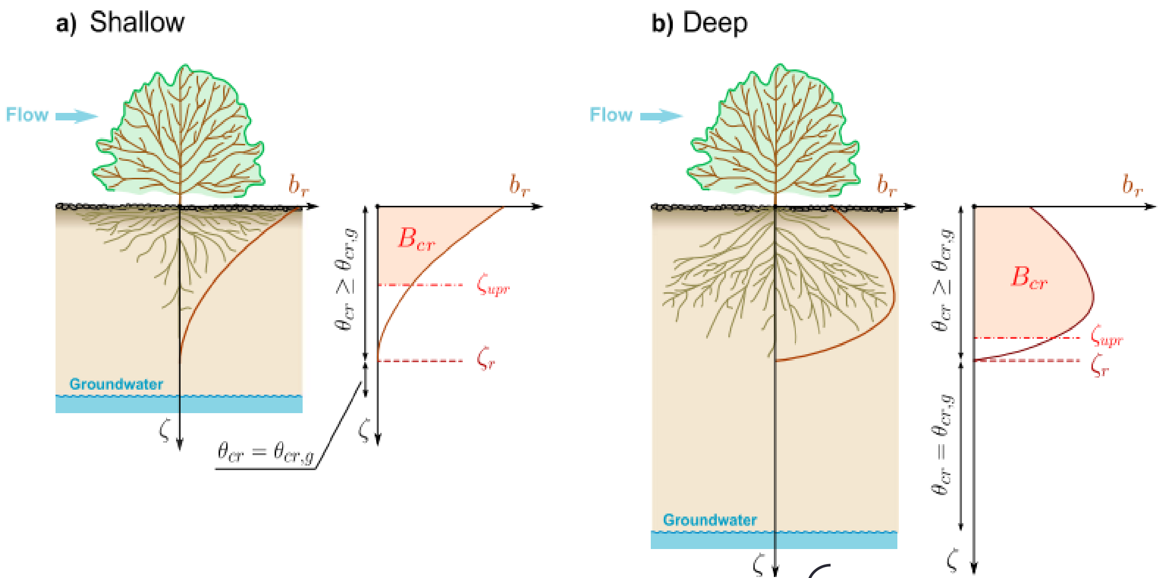
3. HOW CAN WE CALIBRATE THE MODEL PARAMETERS?

VEGETATION GROWTH

ROOT LENGTH

OUR APPROACH

2^ attempt: stochastic root model (Tron et al., 2014)



Dimensionless root biomass

$$B_r(z) = \int_0^z b_r(z)dz = F(\mu, \sigma, \tau)$$

- μ mean water depth (m)
- σ standard deviation water depth (m)
- τ integral scale of water depths (d)

Time-evolution of the root length ζ_r

$$\frac{d\zeta_r}{dt} = \sigma_r(\zeta_{r,max} - \zeta_r)$$

Scour condition

$$B_r(\zeta_{upr}) \geq B_{cr} = 0.8\, B_r(\zeta_r)$$

3. HOW CAN WE CALIBRATE THE MODEL PARAMETERS?

VEGETATION GROWTH

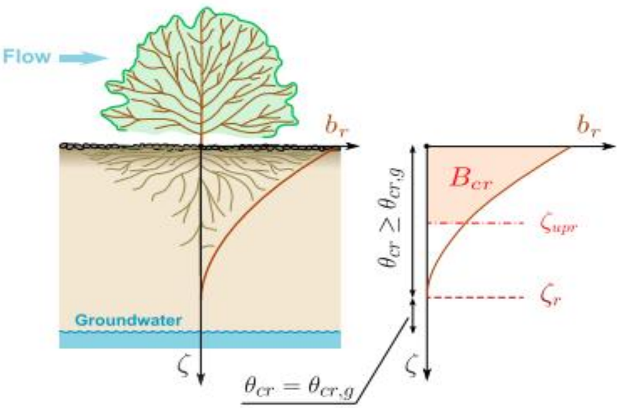
ROOT LENGTH

OUR APPROACH

Stochastic root model → CALIBRATION BASED ON SIMULATED WATER LEVELS

Dimensionless root biomass

$$B_r(z) = \int_0^z b_r(z)\,dz = F(\mu, \sigma, \tau)$$

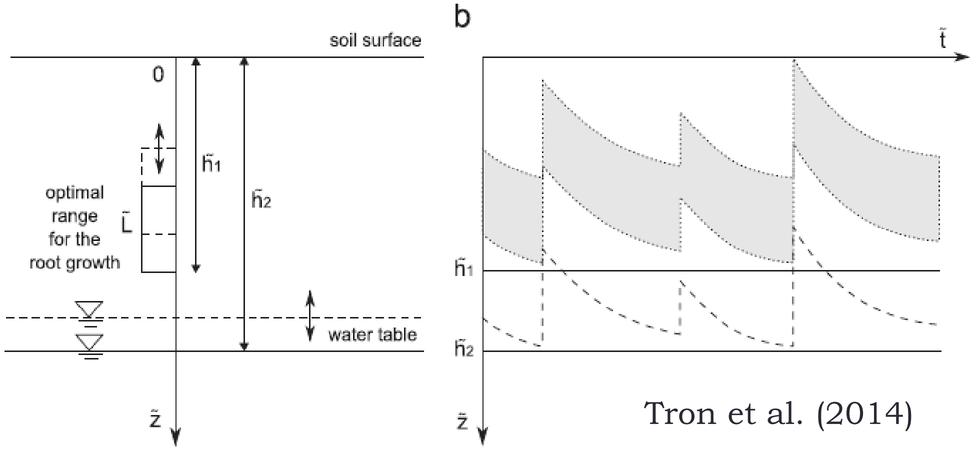


Vertical density distibution of the dimensionless root biomass

$$b_r(z) = \frac{2\sigma(z)k(z)}{\sigma(z) + \sigma(z)k(z) + 1 - k(z)}$$

Probability of being within the zone of optimal root growth…

…based on the statistical analysis of water levels



Tron et al. (2014)

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3. HOW CAN WE CALIBRATE THE MODEL PARAMETERS?

COLONIZATION

REFERENCE WORK	OUR APPROACH
Seed dispersal and settling according to land submersion and water regression during the reproduction time span	Added condition for effective colonization
Potential colonization →	**Effective colonization**
Deposition Max water level > evapo-transpiration threshold germination Min water level < evapo-transpiration threshold	Guilloy-Froget et al. (2002) condition *Less than 7 consecutive days without water in the 30 days following seed deposition*

3. HOW CAN WE CALIBRATE THE MODEL PARAMETERS?

DECAY

TOTAL PLANT REMOVAL
(van Oorschot et al. 2016)

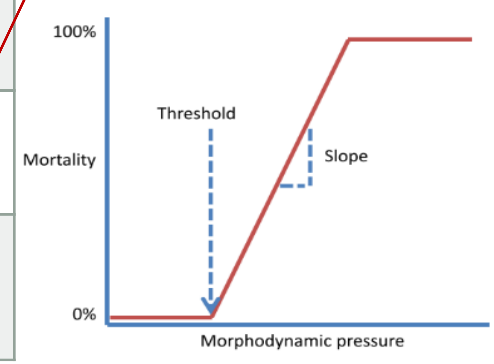
Cause	Model condition
Burial	$H_{burial}>H_{plant}$
Scour	$Z_{scour}>$ root length
Senescence	Age >= Max age

PARTIAL VEGETATION COVER REMOVAL (DOSE-EFFECT RELATIONSHIPS)
(Van Oorschot et al. 2016)

Cause	Model parameter
Flooding	Flooded days
Dessication	Dry days
Uprooting	Velocità di flusso

We set it as
0.8*root biomass
(as Caponi et al., 2020)

Calibrated according to model results



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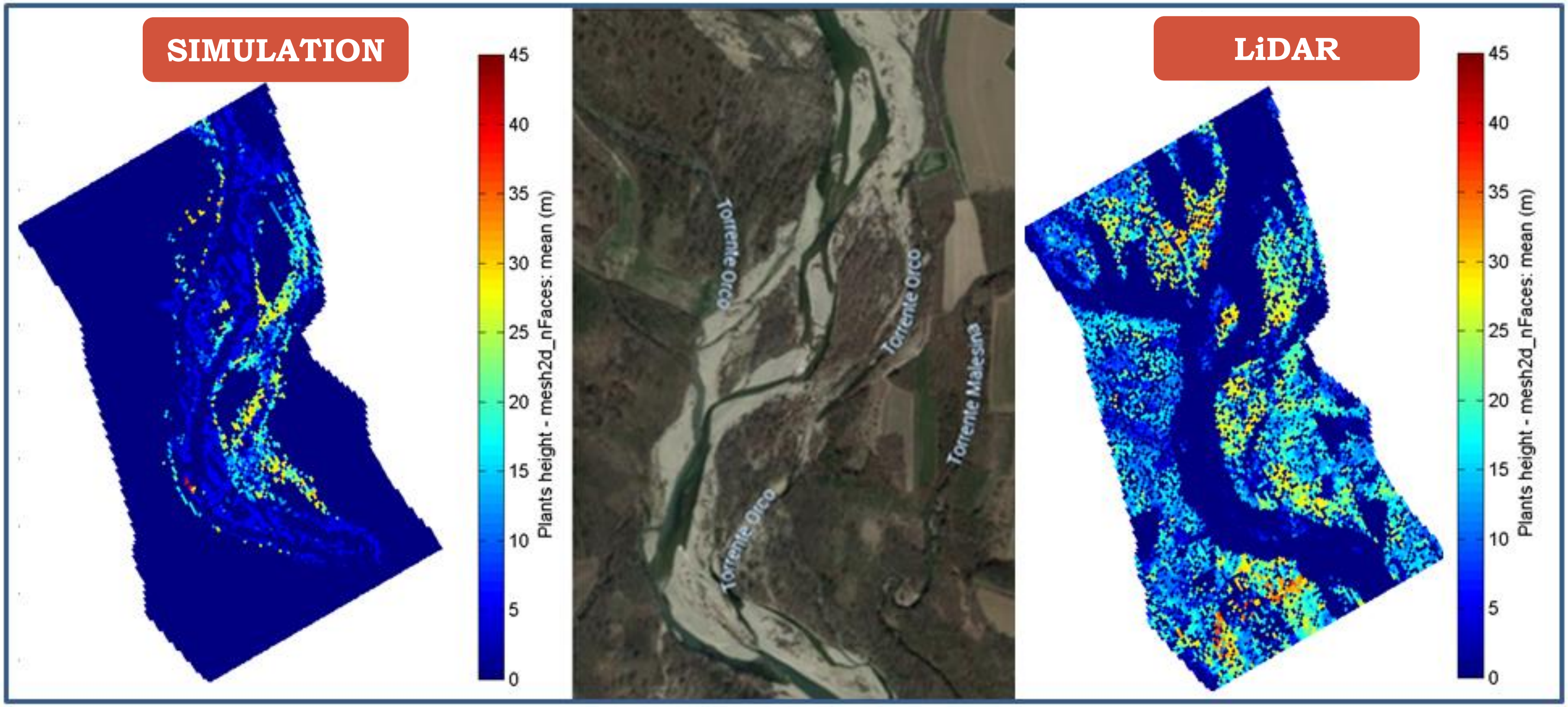
CALIBRATION RESULTS



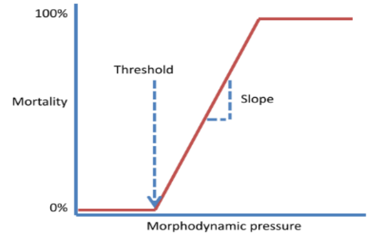
Excessive mortality induced by dessication

Excessive colonization of areas close to active channels

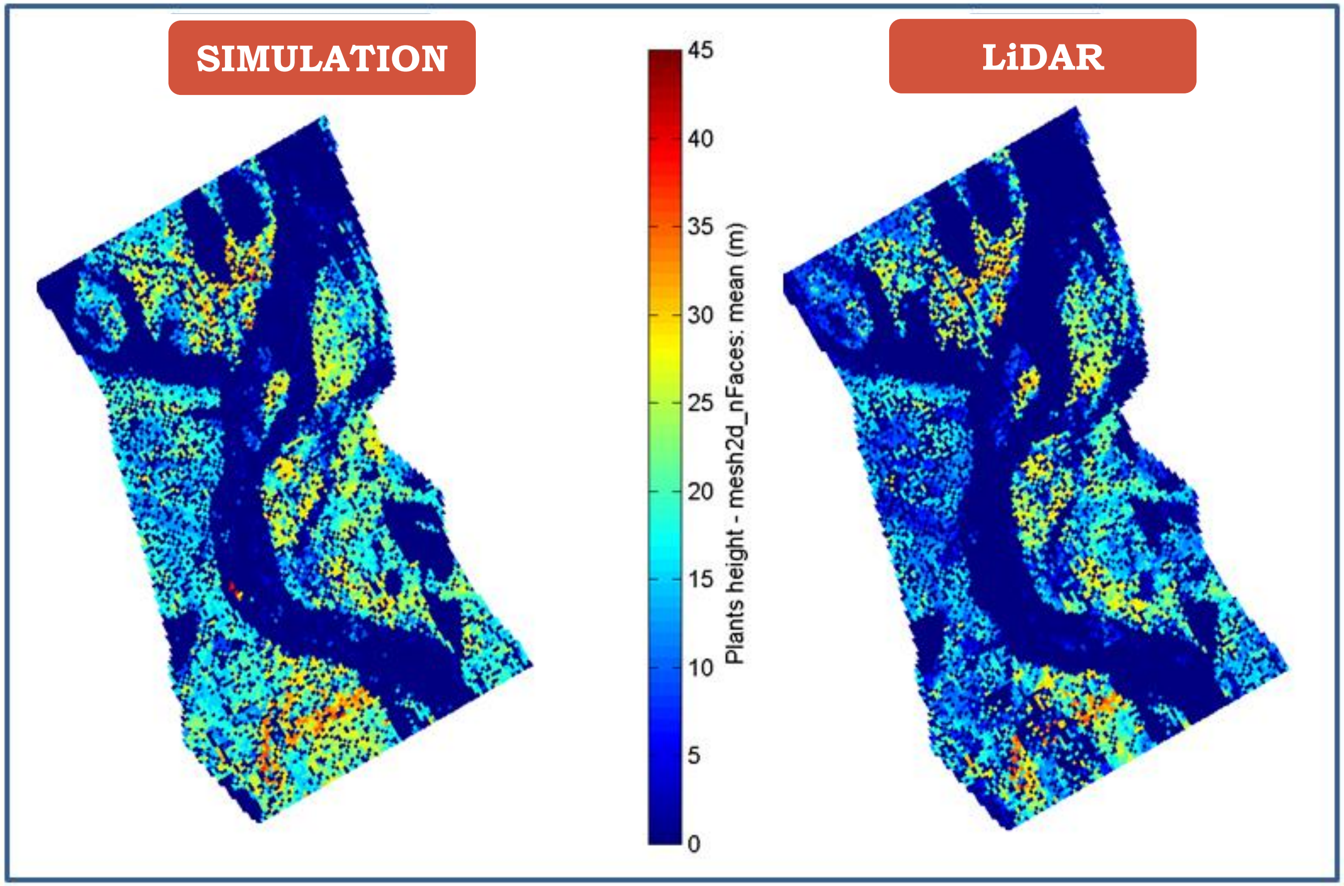
→ Dose-effect law CALIBRATION REQUIRED

CALIBRATION RESULTS

Reduced slope of dose-effect dessication law: from 0.75 to 0.015

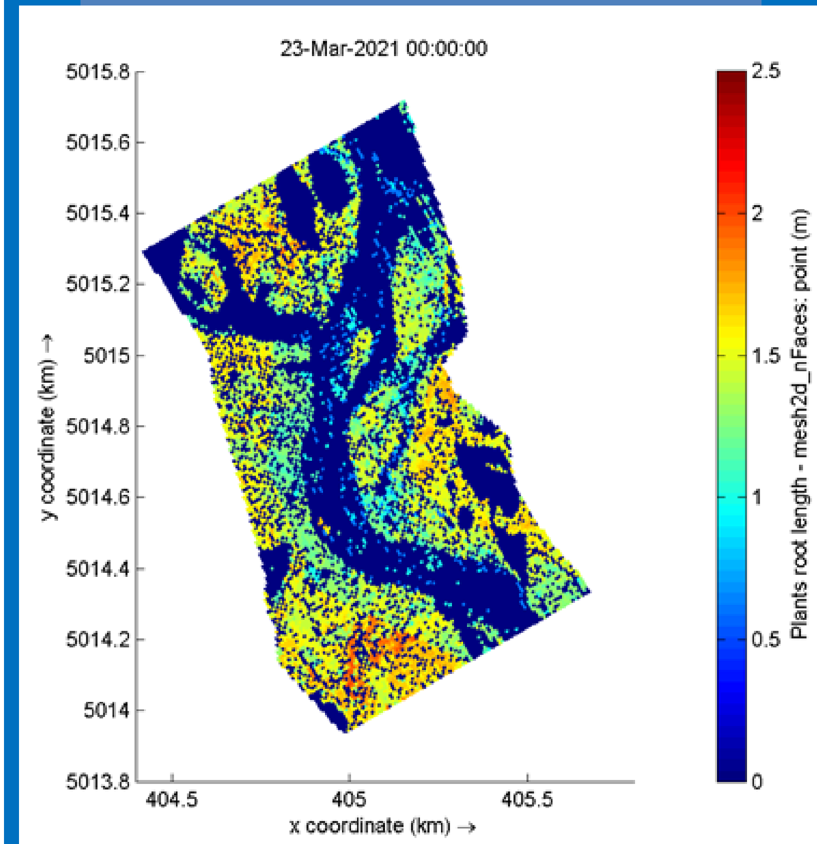


Addition of Guilloy-Froget et al. (2002) condition considering a reference threshold of 0.1 m

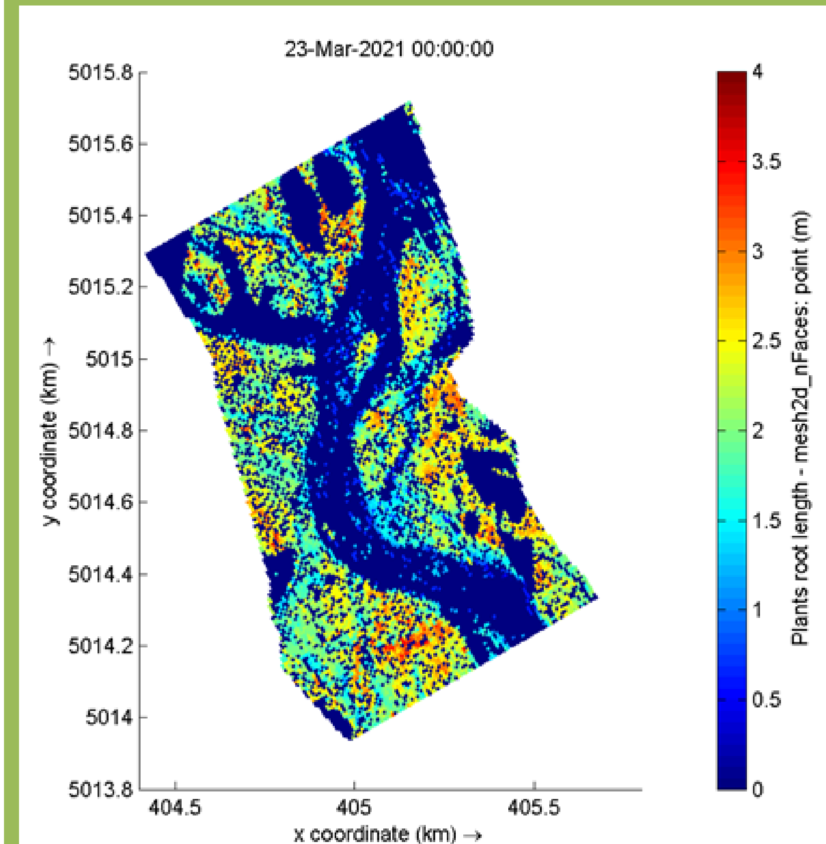


CALIBRATION RESULTS

LOGARITHMIC ROOT MODEL



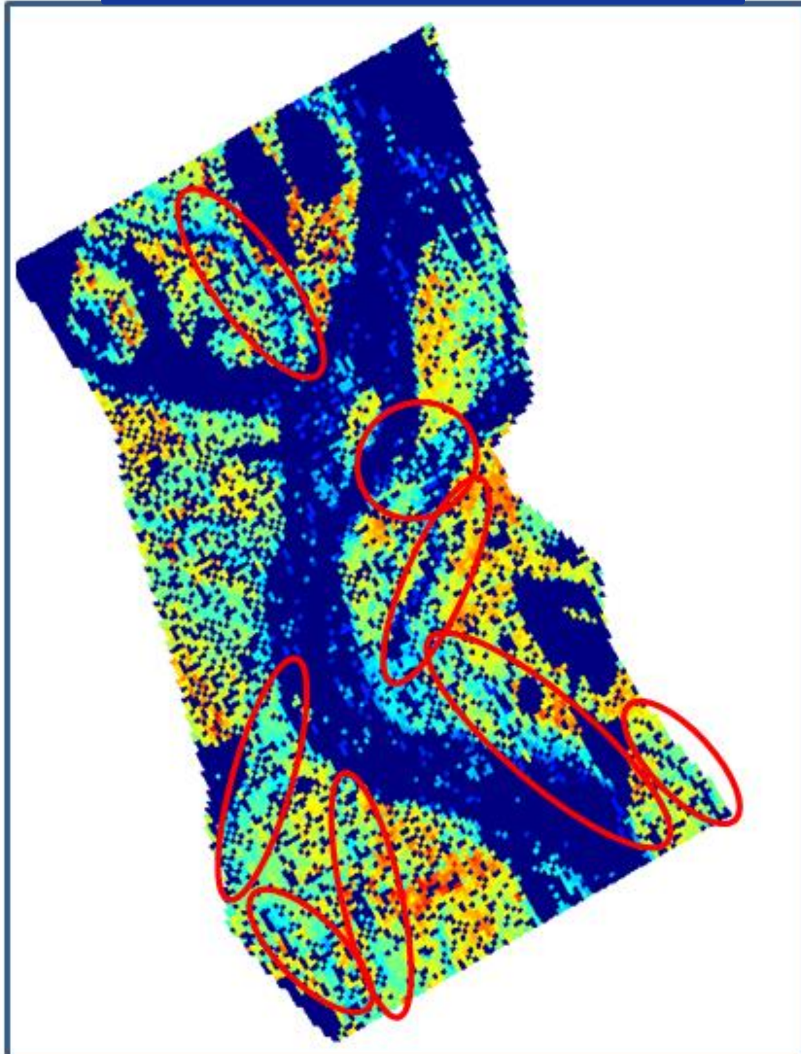
STOCHASTIC ROOT MODEL



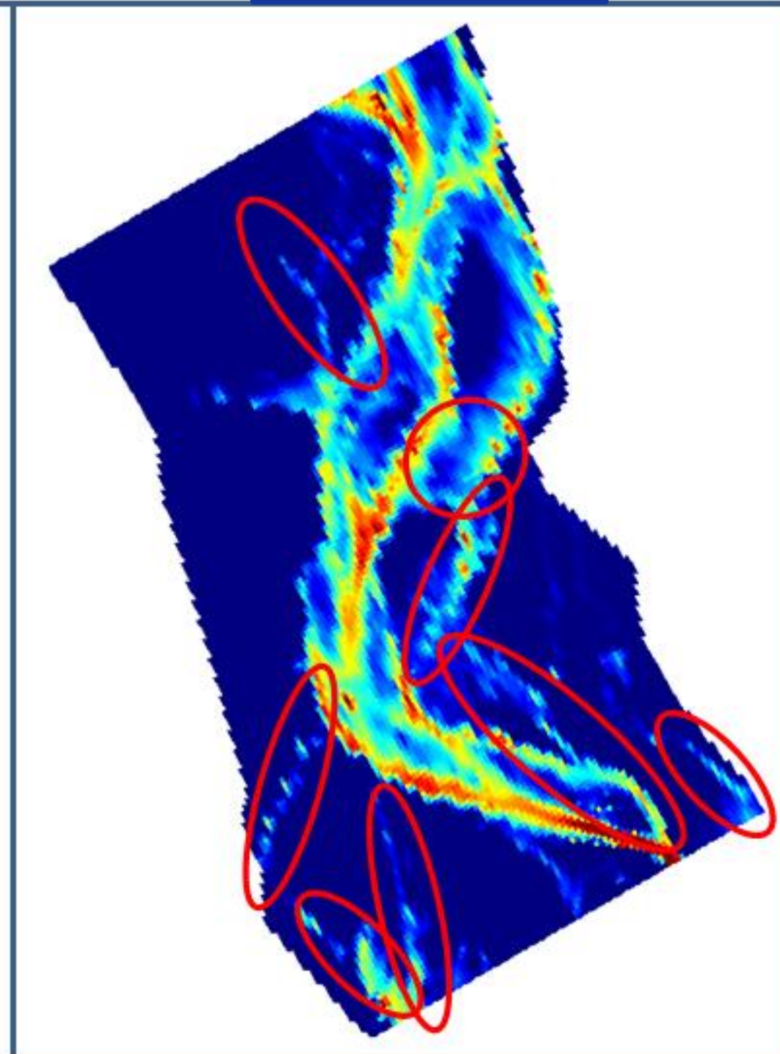
Higher root length variability → different below-ground biomass

CALIBRATION RESULTS

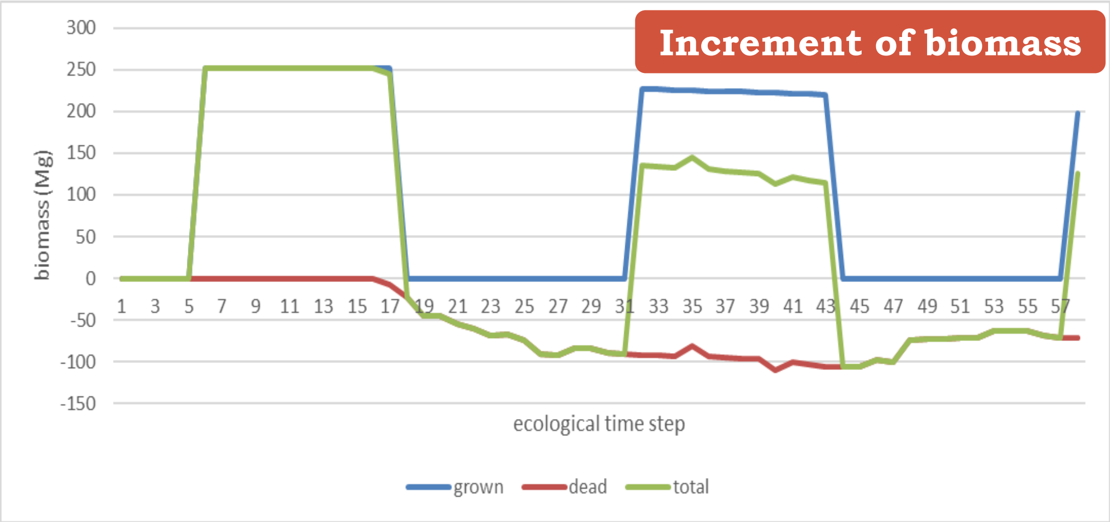
Root length

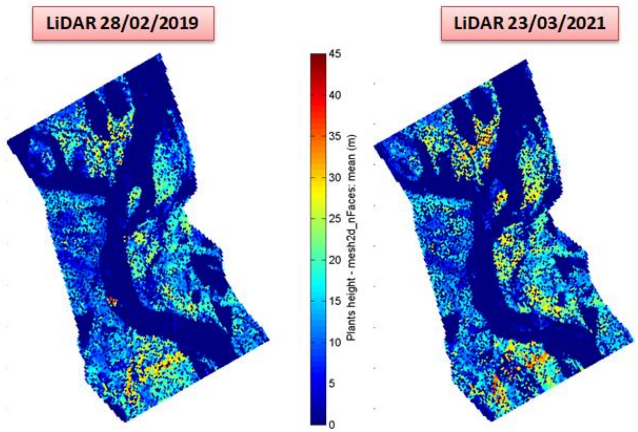


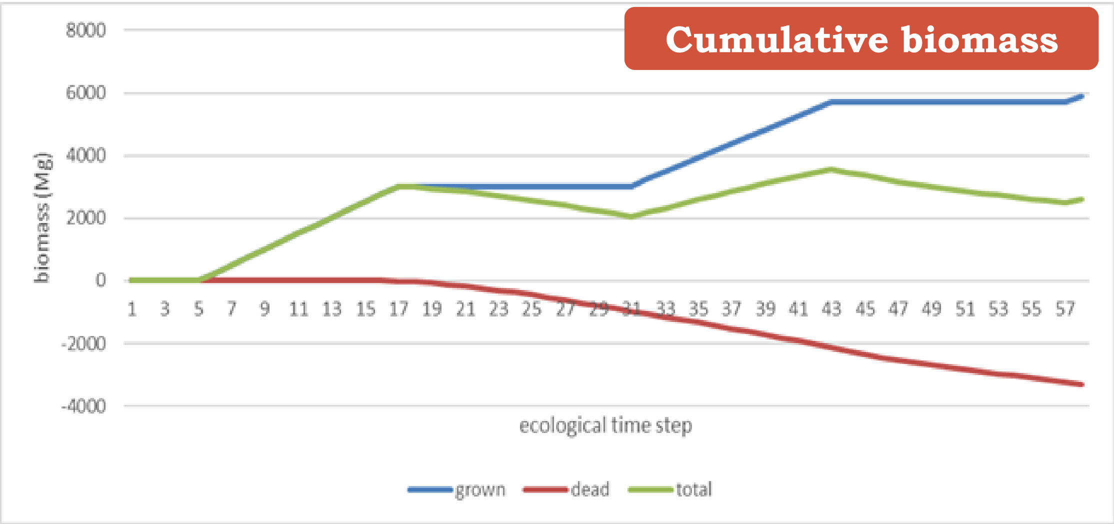
Water depth



BIOMASS BUDGET







CONCLUSIONS

CURRENT MODEL	FUTURE WORKS
Sexual reproduction during a short time period	**Asexual** reproduction is one of the key features of pioneer riparian species (Gurnell, 2016)
Death when all the plant is **buried**	**Adventitious roots** prevent death from burial
Uprooting according to dose-effect relationship	«Uprooting» embraces **several mechanisms**

CONCLUSIONS

ACHIEVED GOALS

Biomass and carbon budget

Multitemporal remote sensing data to inform ecological laws → saving time related to field surveys

Integrating field data, remote sensing and modelling → a comprehensive and multi-disciplinary approach

BROADER IMPACTS

Short- and long- term forecast of ecosystem functioning and riparian biogeography

Indicating most suitable areas where to intervene with restoration activities

References

Baptist, M. J., Babovic, V., Rodríguez Uthurburu, J., Keijzer, M., Uittenbogaard, R. E., Mynett, A., & Verwey, A. (2007). On inducing equations for vegetation resistance. Journal of Hydraulic Research, 45(4), 435-450.

Botkin, D. B., Janak, J. F., & Wallis, J. R. (1972). Some ecological consequences of a computer model of forest growth. *The Journal of ecology*, 849-872.

Brückner, M. Z., Schwarz, C., van Dijk, W. M., van Oorschot, M., Douma, H., & Kleinhans, M. G. (2019). Salt marsh establishment and eco-engineering effects in dynamic estuaries determined by species growth and mortality. *Journal of Geophysical Research: Earth Surface*, *124*(12), 2962-2986.

Camporeale, C., & Ridolfi, L. (2006). Riparian vegetation distribution induced by river flow variability: A stochastic approach. *Water resources research*, *42*(10).

Caponi, F., Vetsch, D. F., & Siviglia, A. (2020). A model study of the combined effect of above and below ground plant traits on the ecomorphodynamics of gravel bars. *Scientific reports*, *10*(1), 1-14.

Guilloy-Froget, H., Muller, E., Barsoum, N., & Hughes, F. M. M. (2002). Dispersal, germination, and survival of Populus nigra L.(Salicaceae) in changing hydrologic conditions. *Wetlands*, *22*(3), 478-488.Which ecomorphodynamic models are available?

Latella, M., Sola, F., & Camporeale, C. (2021). A density-based algorithm for the detection of individual trees from LiDAR data. Remote Sensing, 13(2), 322.

Oorschot, M. V., Kleinhans, M., Geerling, G., & Middelkoop, H. (2016). Distinct patterns of interaction between vegetation and morphodynamics. *Earth Surface Processes and Landforms*, *41*(6), 791-808.

Tron, S., Laio, F., & Ridolfi, L. (2014). Effect of water table fluctuations on phreatophytic root distribution. *Journal of theoretical biology*, *360*, 102-108.

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Thanks for your attention!

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3. HOW CAN WE CALIBRATE THE MODEL PARAMETERS?

VEGETATION GROWTH

BIOMASS

REFERENCE WORK
Not computed

OUR APPROACH

$$dB = \frac{\pi D^2}{4} dH \, \rho \, \frac{F \, A \, 4}{\pi D^2}$$

dB biomass increment
D diameter (m)
H height (m)
ρ biomass density (kg/m3)
F cell vegetation cover (-)
A cell area (m^2)

Total dimensionless biomass

$$\frac{dB}{dt} = \frac{dB_{canopy}}{dt} + \frac{dB_{root}}{dt} = \lambda_{canopy}\frac{dB}{dt} + \lambda_{root}\frac{dB}{dt}$$

$$\lambda_{canopy} + \lambda_{root} = 1$$

$$\lambda_{canopy} = \lambda_{root} = 0.5$$

USED TO SET THE INITIAL ROOT CONFIGURATION

Above-ground initial biomass dB_{canopy} + Inizial age dt → Below-ground initial biomass dB_{root} → Initial shoot length ζ_r

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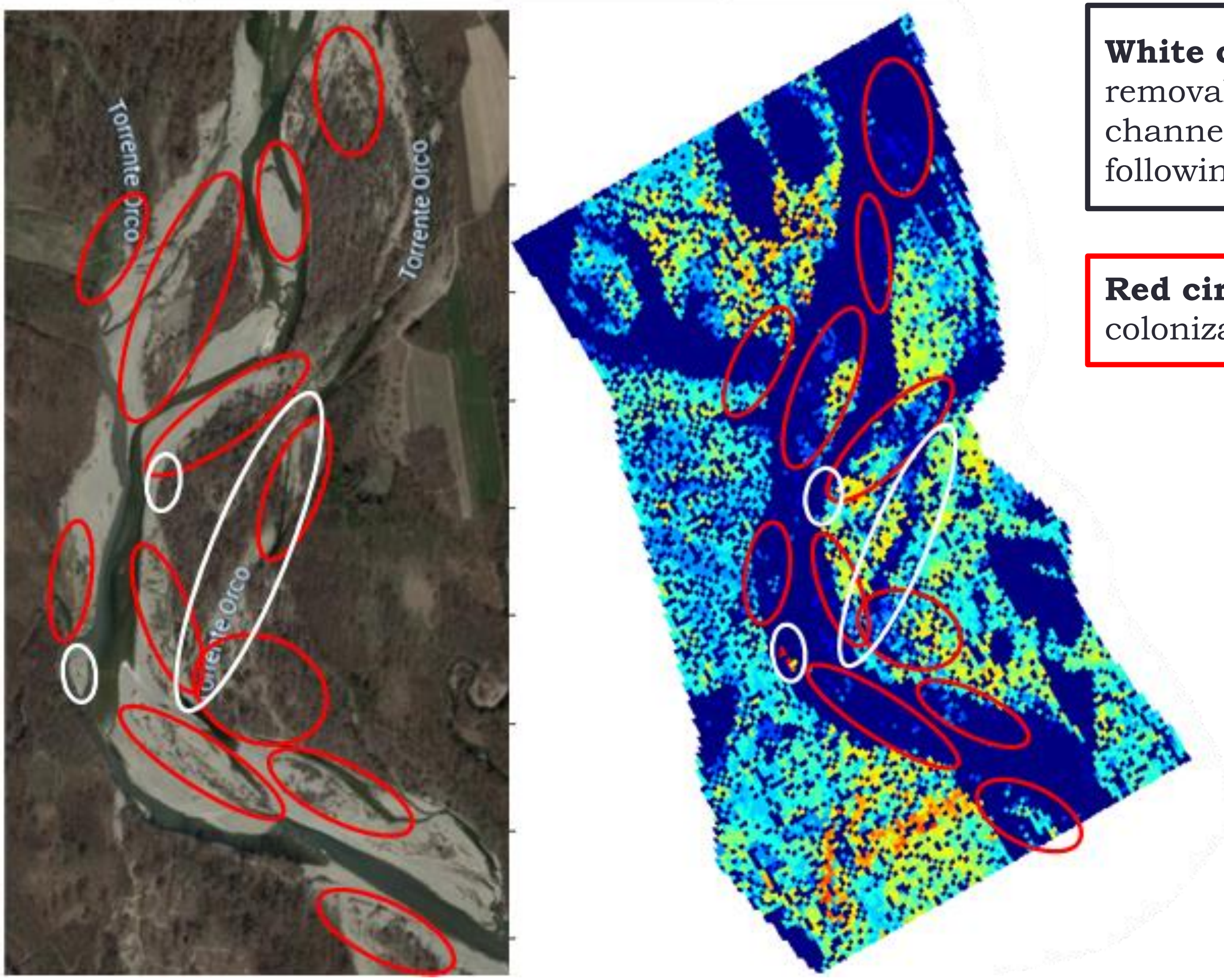
CALIBRATION RESULTS



White circles: plant removal due to secondary channel re-activation and following re-colonization.

Red circles: new colonization sites.