Calibration of a stochastic model for riparian vegetation dynamics from LiDAR acquisitions

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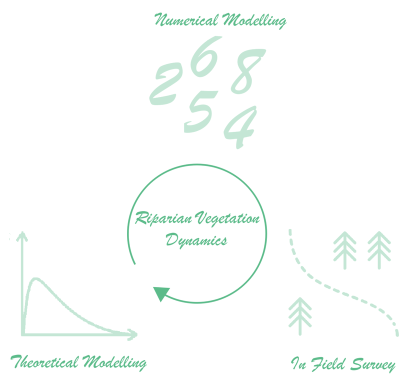
A) INTRODUCTION

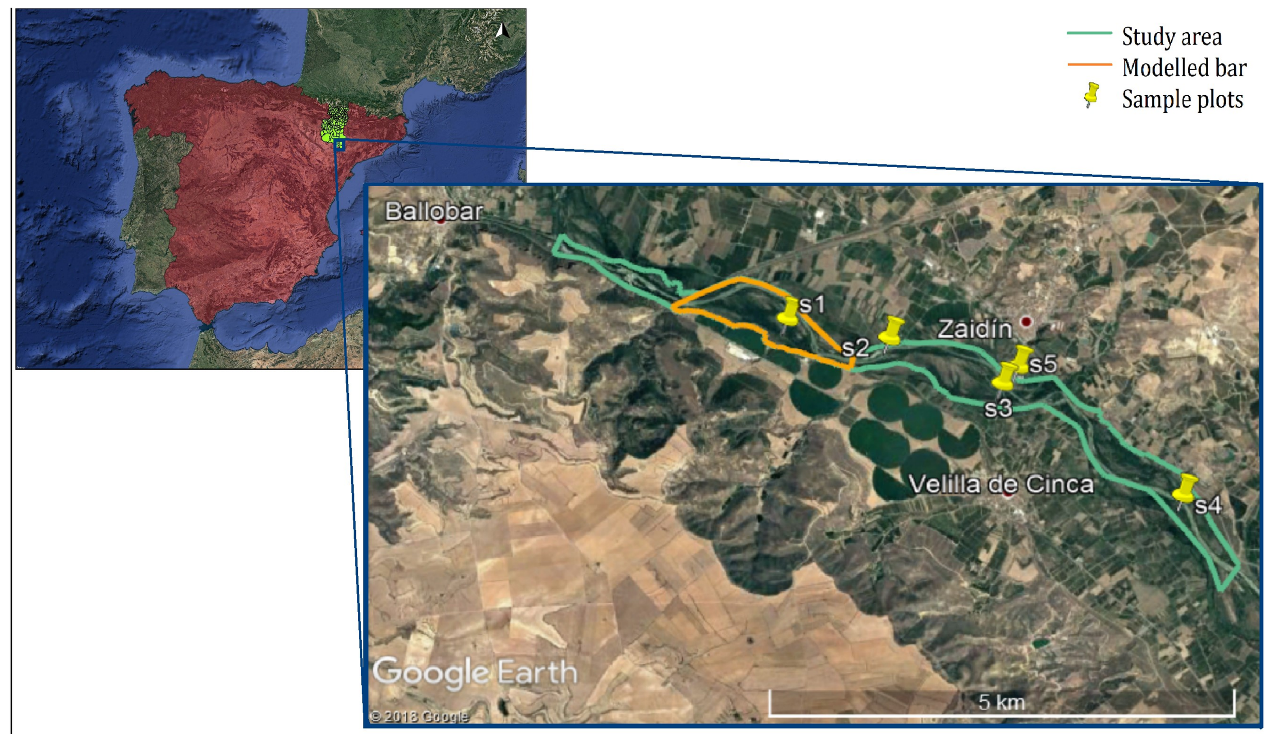
Various approaches have been proposed so far to model the response of vegetation to external forcings and understand its temporal and spatial evolution. As these approaches are usually adopted individually or in pairs (e.g numerical modelling based on field data), the aim of this work is to combine three activities to study riparian vegetation dynamics under different, though complementary, perspectives. The final goal consists of the calibration of a theoretical model through a field-based biomass estimation and numerically modelled hydraulic conditions.



B) OBJECTIVES

1. **Biomass estimation by LiDAR measurements:** the use of remote sensing techniques allows for the reduction of costly and time-spending in situ surveys. Thus, a procedure to obtain vegetation statistics by LiDAR measurement is defined and then coupled to an allometric formula that relates biomass to vegetation geometric features. LiDAR raw data are processed with GIS and FUSION/LDV software, while the required allometric relationship is determined by regressing field data.
2. **Numerical modelling of a vegetated bar:** the roughness increase due to vegetation is usually neglected in river modelling, yet it strongly influences the spatial distribution of inundation areas. To account for roughness heterogeneity, the trachytopes-definition functionality, offered by Delft3DFM, is implemented. The model is set with the LiDAR-derived DTM and the flow rate and grain size distribution field data. The water levels in the bar are obtained for a set of characteristic flow rates, leading to the evaluation of inundation probability.
3. **Calibration of an analytical stochastic model for riparian vegetation dynamics:** vegetation evolution is influenced by the topography and the randomness of hydrological fluctuations, acting as a dichotomous Markov noise. The response of vegetation to this forcing is determined by intrinsic biological features, as the growth and decay rate. However, the decay rate still needs to be calibrated. To this purpose, the model output (i.e. biomass distribution) is set as LiDAR-derived biomass, while the hydraulic modelling outcomes are processed to computed the probability of inundation and the integral scale of the stochastic process. The decay rate remains the only unknown variable and can be calibrated. The high-resolution of LiDAR data allows for the computation of the decay rate for various topographic bands.

C) STUDY AREA

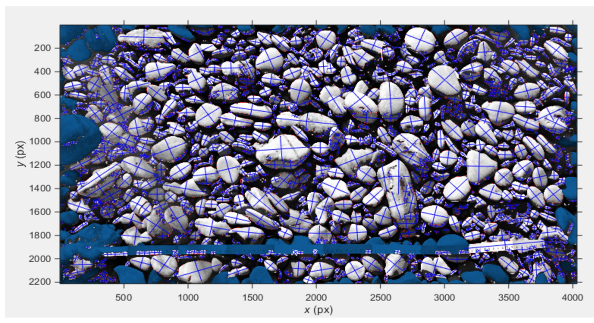


D) IN FIELD SURVEY

d1) Grain size distribution

Phase 1: Wolman Pebble Count

Phase 2: BaseGrain processing



Phase 3: d50, d90 computing

$$\Delta p_i = \frac{\Delta q_i d_{mi}^{0.8}}{\sum_{i=1}^{n} \Delta q_i d_{mi}^{0.8}}$$

(eq. 1)

Δp_i = (weight of fraction *i*)/(weight of total sample);

Δq_i = (number of pebbles in fraction *i*)/(total amount of pebbles);

d_{mi} = mean diameter of fraction *i*.

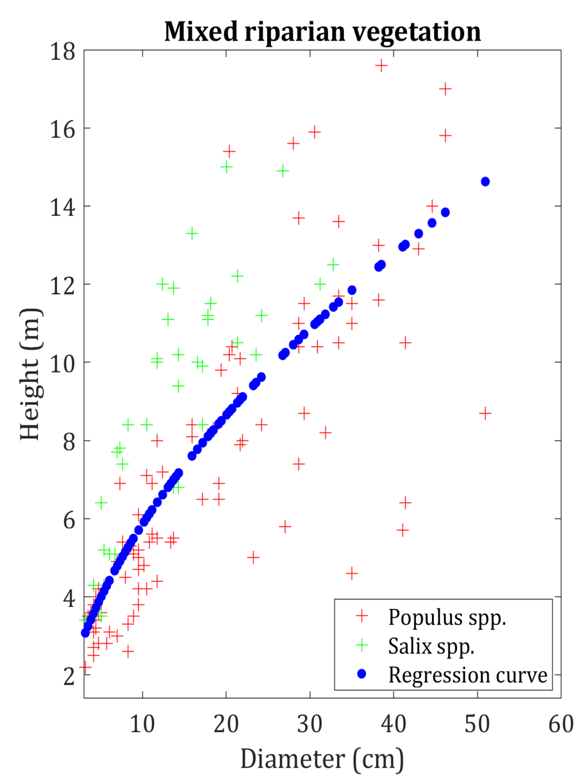
d2) Allometric relationships

Phase 1: Tree measurements

—> Height : laser rangefinder

—> DBH: diameter at 1.40 m

Phase 2: Allometric regression



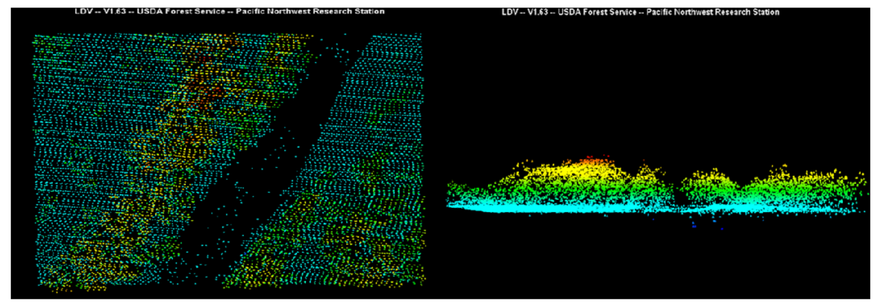
$h = 1.6047 d^{0.5623}$

(eq. 2)

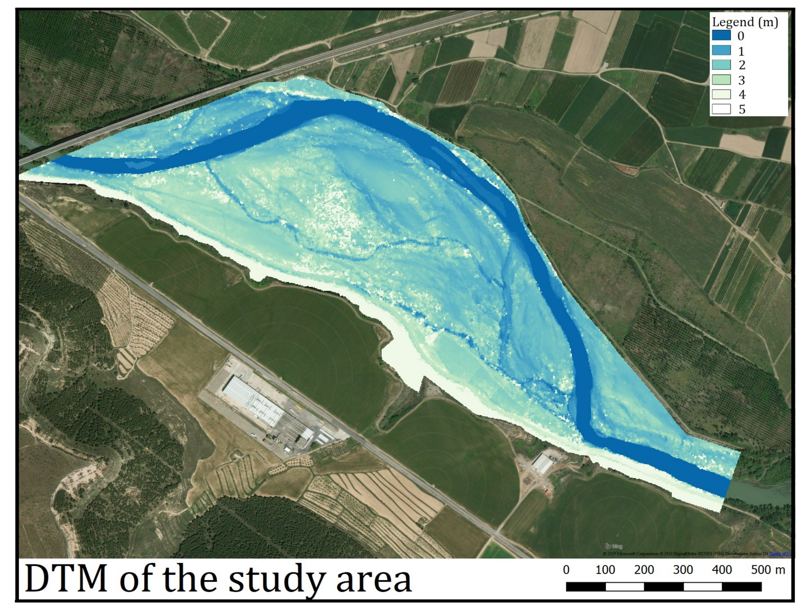
E) BIOMASS ESTIMATION

Phase 1: LiDAR raw data processing with FUSION/LDV

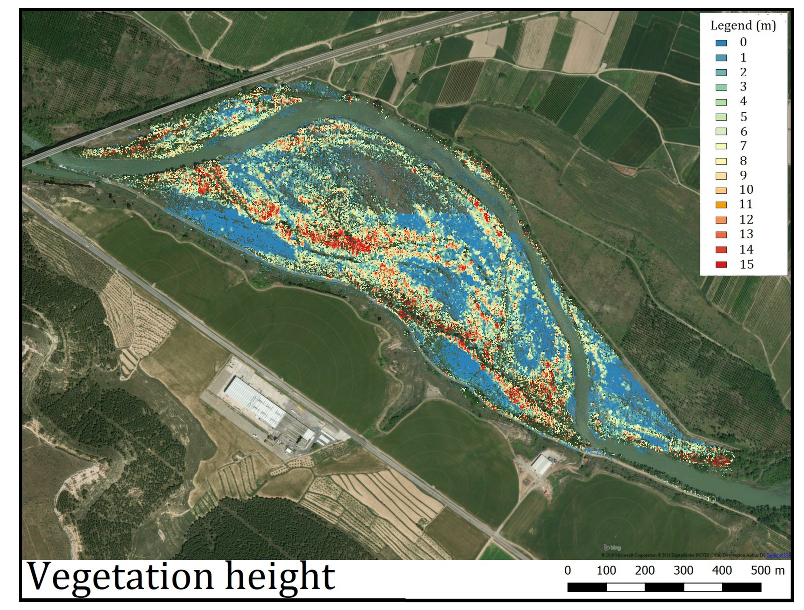
Input



Output1



Output2

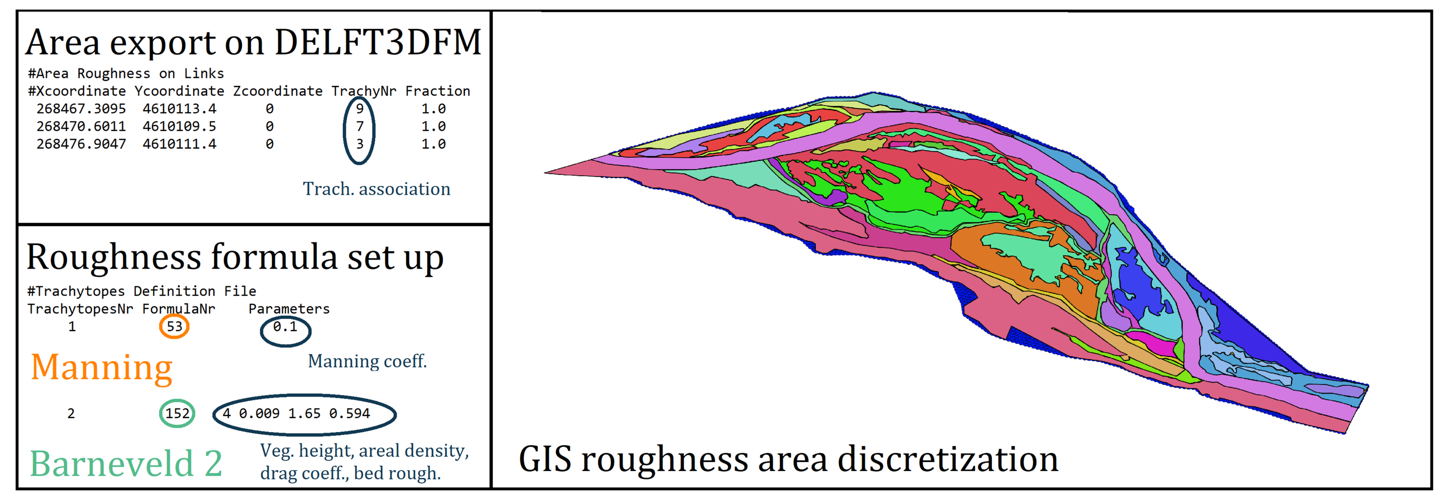


Phase 2: Biomass computation in 3 steps:

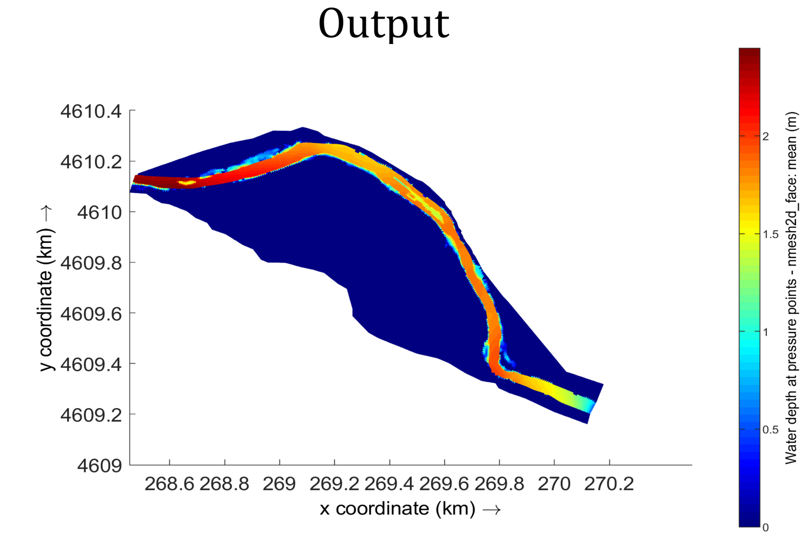
1. D_{veg} by allometric relationship (eq. 2)
2. Tree biomass by cylindric analogy
3. Areal biomass by defining an areal density

F) VEGETATED BAR NUMERICAL MODELLING

Input



Output



E) STOCHASTIC MODEL CALIBRATION

Theoretical model (Camporeale & Ridolfi, 2006)

—> Basic equations for vegetation dynamics:

$$\frac{dv}{dt} = -\alpha v^n, \quad h \geq \eta,$$

$$\frac{dv}{dt} = v^m(\beta - v)^p, \quad h < \eta,$$

$$\alpha = \frac{\langle \alpha_1 \rangle}{\alpha_2} = \frac{K\langle h - \eta \rangle}{\alpha_2} = k\langle h - \eta \rangle$$

ν = dimensionless biomass

h = water level

η = topographic level

β = veg. carrying capacity

α_2 = rate of veg. growth

K = rate of veg. decay

To be calibrated

—> Merged in a stochastic differential equation:

$$\frac{dv}{dt} = f(v) + \xi(t) g(v)$$

where:

$$f(v) = \frac{\Delta_I v^m (\beta - v)^p + \alpha \Delta_E v^n}{\Delta_I - \Delta_E}$$

$$g(v) = \frac{\alpha v^n + (\beta - v)^p v^m}{\Delta_E - \Delta_I}$$

ξ(t) = dichotomoic Markov process to switch between inundation (Δ_I) and exposure (Δ_E)

m,n,p = veg.-dependent coeff.

Results

—> Model output for a set topographic height:

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

From LiDAR-based biomass estimation

From vegetated bar numerical modelling

p(ν)= dimensionless biomass pdf

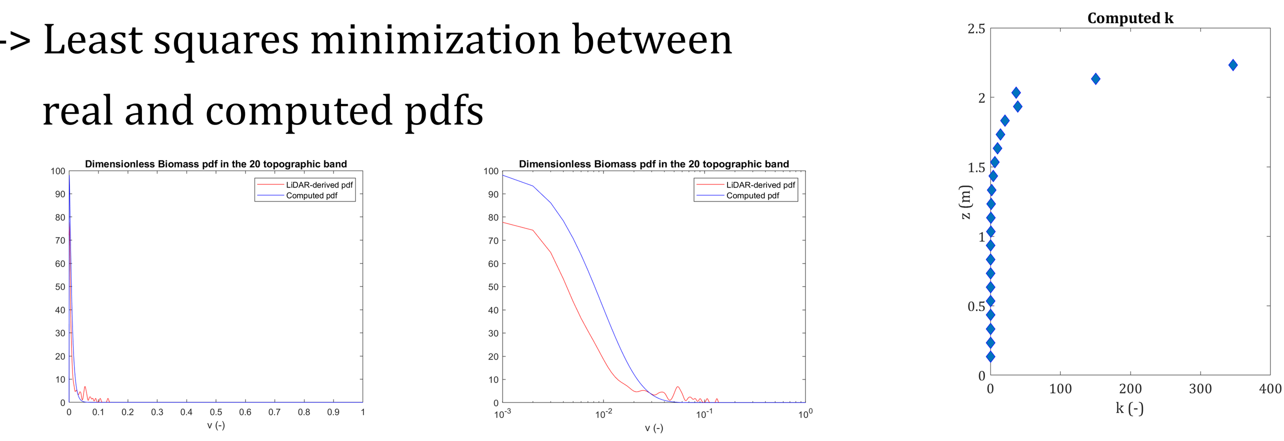
P_I = inundation probability

τ = stochastic process integral scale

β = function of phreatic surface depth

α/k= (h-η)

—> Least squares minimization between real and computed pdfs



G) FUTURE WORKS

The calibrated stochastic model will be used for forecasting the evolution of vegetation under different hydrological regimes. Examples may be decreasing flow rates due to river damming and regime variation linked to climate change.

References

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Photography encouraged