Modelling hydroecological processes in semi-arid riparian areas

The Riparian Vegetation Dynamic Model (RVDM)

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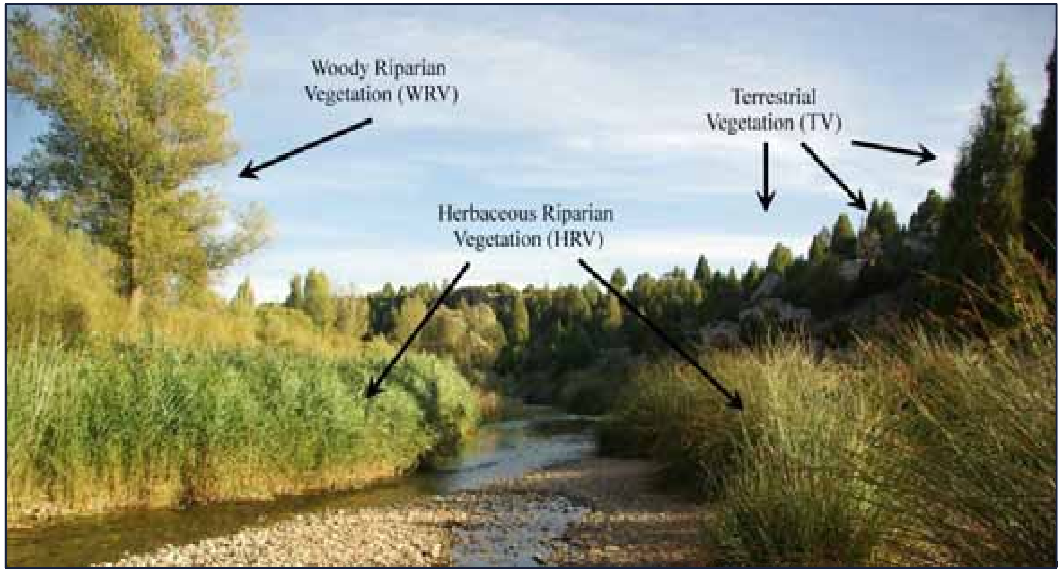
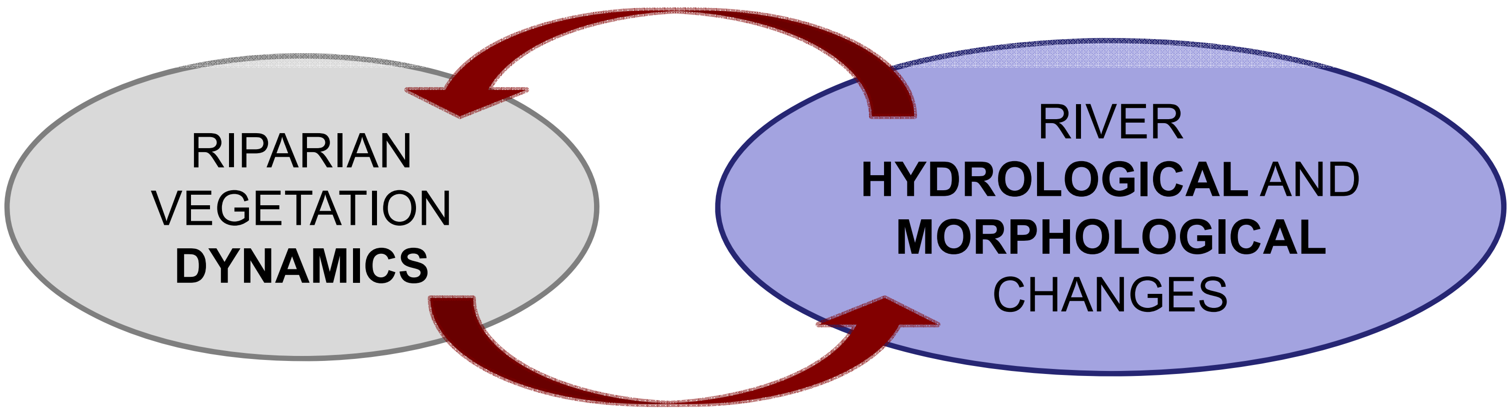
OUTLINE

- Introduction
- The RVDM model description
- Model implementation in a case study
- Exploitation and discussion



INTRODUCTION

- Riparian ecosystems are important by their self and for their ecological services
- River hydrodynamics determines the riparian vegetation distribution …
- … and viceversa



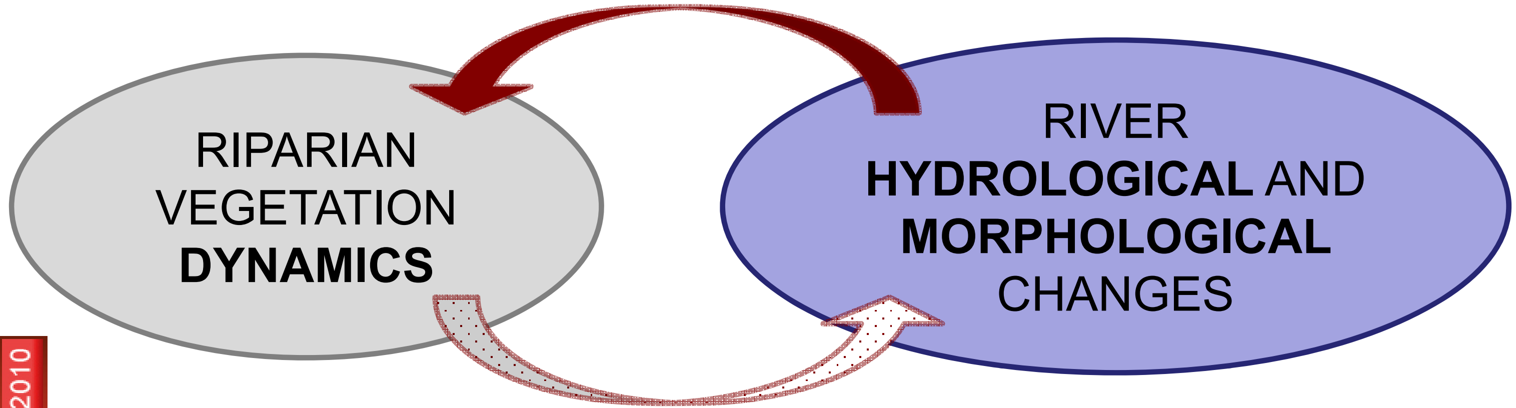
INTRODUCTION

Different **recent** modelling approaches available:

- Hooke *et al*., 2005
- Camporeale and Ridolfi, 2006
- Perona *et al*., 2009
- Benjankar *et al*., 2011→ CASiMiR-veg (humid climates)
- Maddock III *et al*., 2012
- García-Arias *et al*., 2013 → **CASiMiR-veg** (semi-arid climates)
- Ye et al., 2013
- García-Arias *et al*., 2014 → **RibAV** (semi-arid climates)
- Etc.

SCIENTIFIC OBJECTIVE:

- To develop a flexible dynamic model of riparian vegetation, with focus on Mediterranean semi-arid conditions
- Merging and **improving** of two models:
  - **CASiMiR-veg**, humid climate, retrogression by flood destruction
  - **RibAv**, semi-arid, retrogression by water stress



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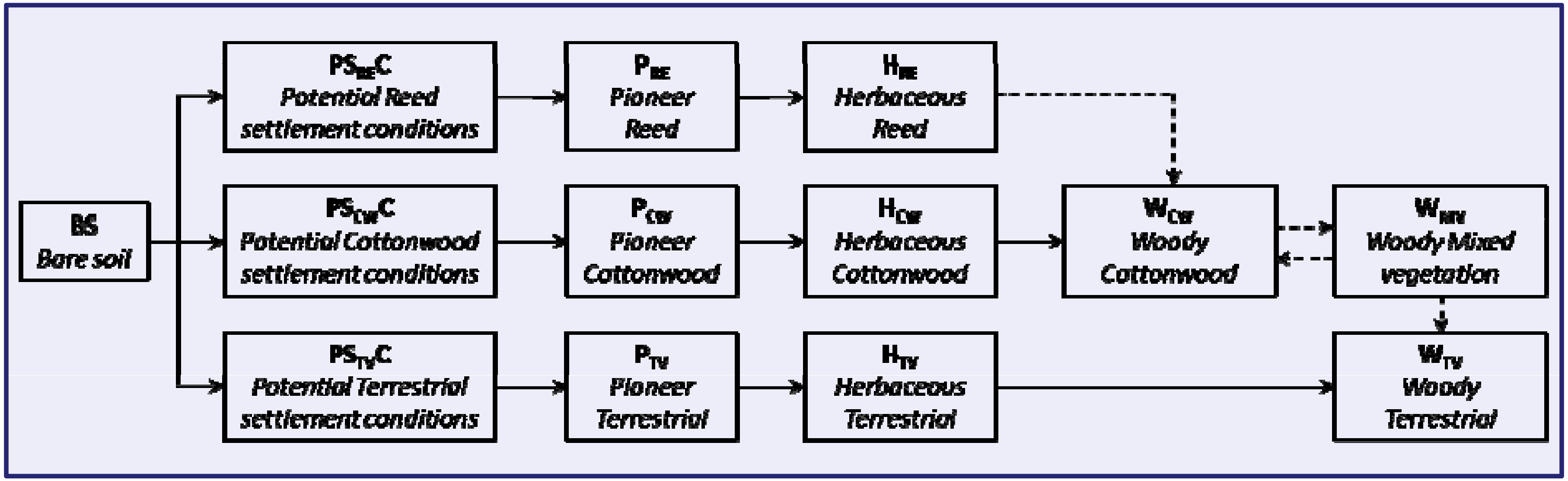
The Riparian Vegetation Dynamic Model (RVDM)

THE RVDM MODEL DESCRIPTION

- **Modular structure**
- Temporal resolution → **daily** time step
- Distributed in small cells → **0.5 - 2 metres**
  (height influence)
- Vegetation state variables:
  - **Successional Plant Functional Types (SPFTs)**
  - Biomass estimations

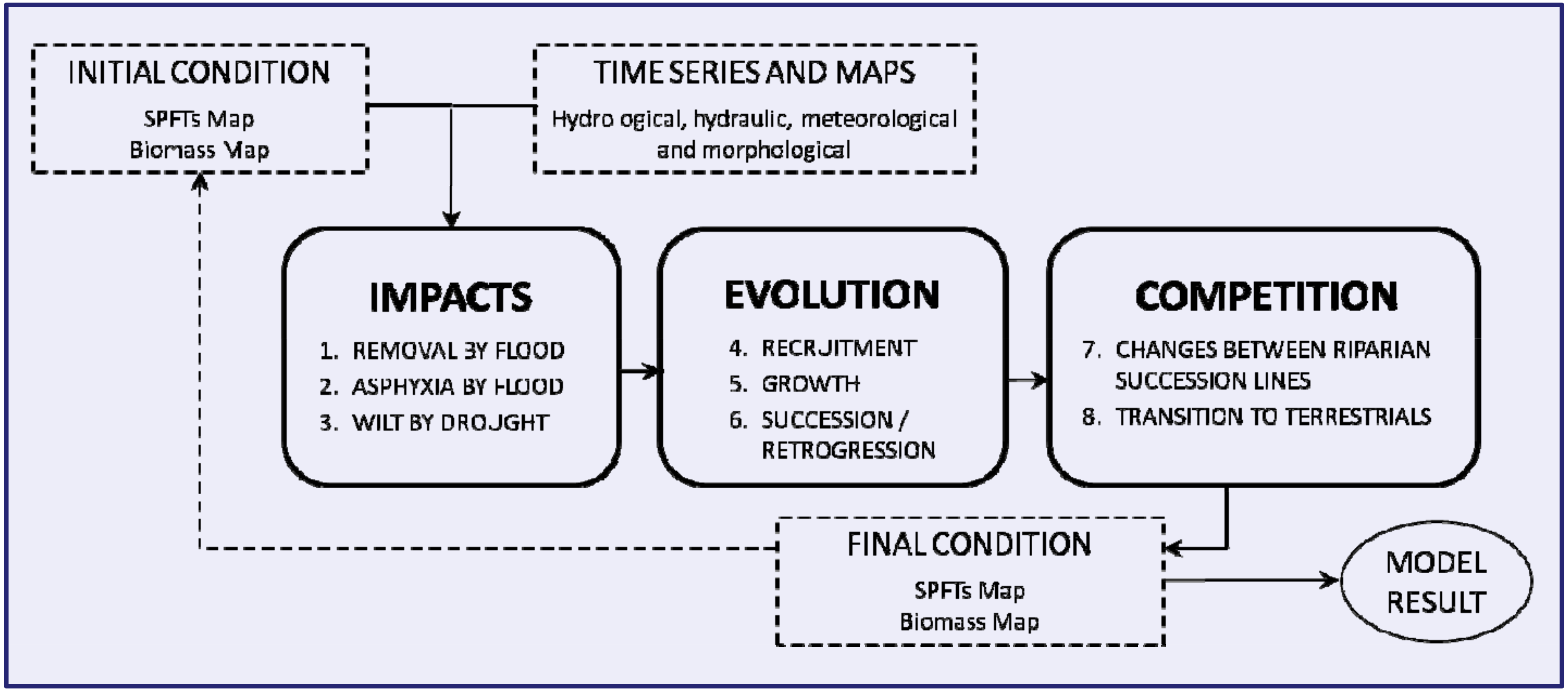
SUCCESSIONAL PLANT FUNCTIONAL TYPES (SPFTs)

- **SPFT → Main state variable of RVDM**
  - 2 Riparian succession lines: **Reed (RE)** and **Cottonwood (CW)**
  - 1 **Terrestrial (TV)** → zonal vegetation



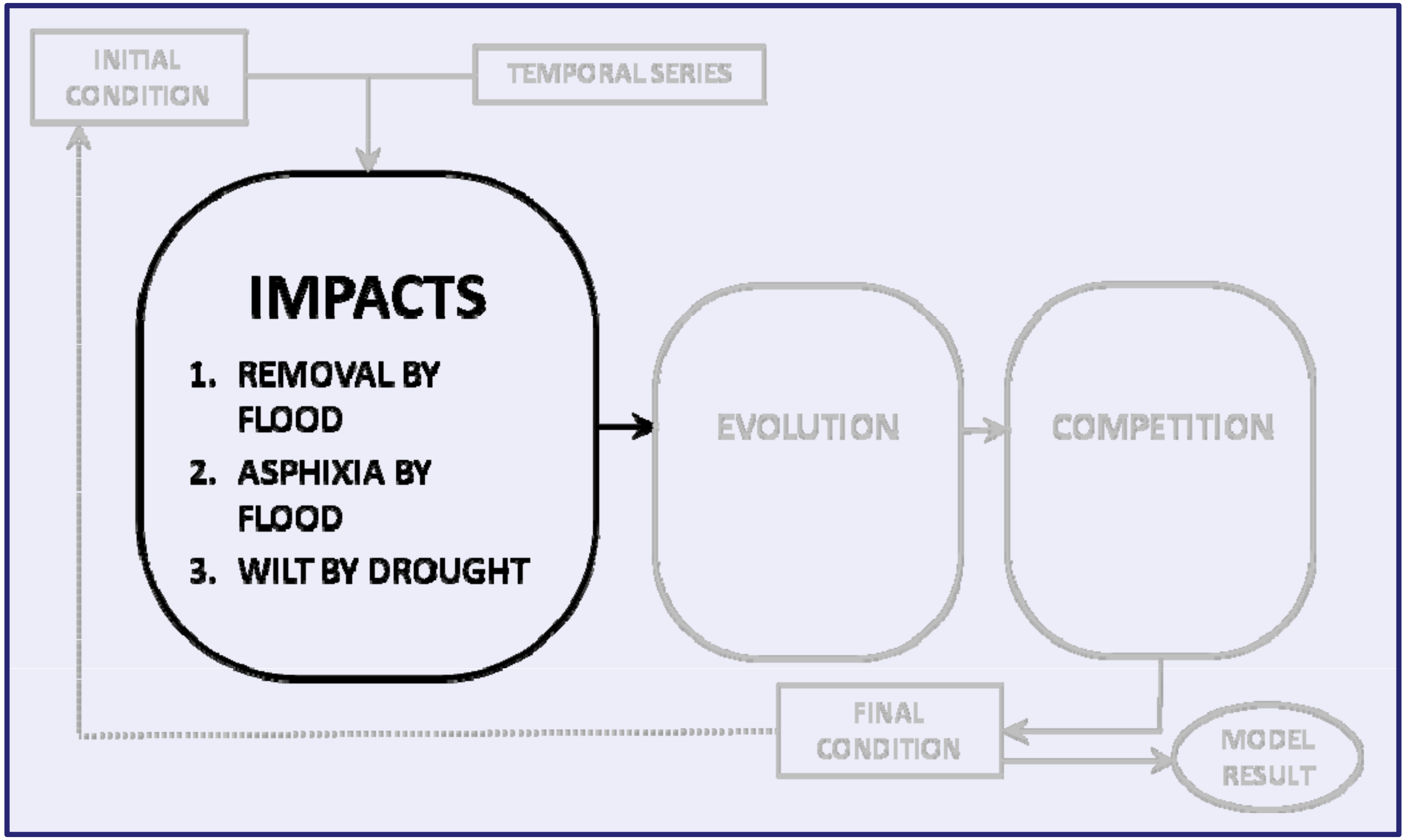
THE RVDM MODEL DESCRIPTION

- RVDM → **Modular structure**



THE RVDM MODEL DESCRIPTION

- **MODULE 1.- IMPACTS** → effect of the hydrological extremes over the vegetation

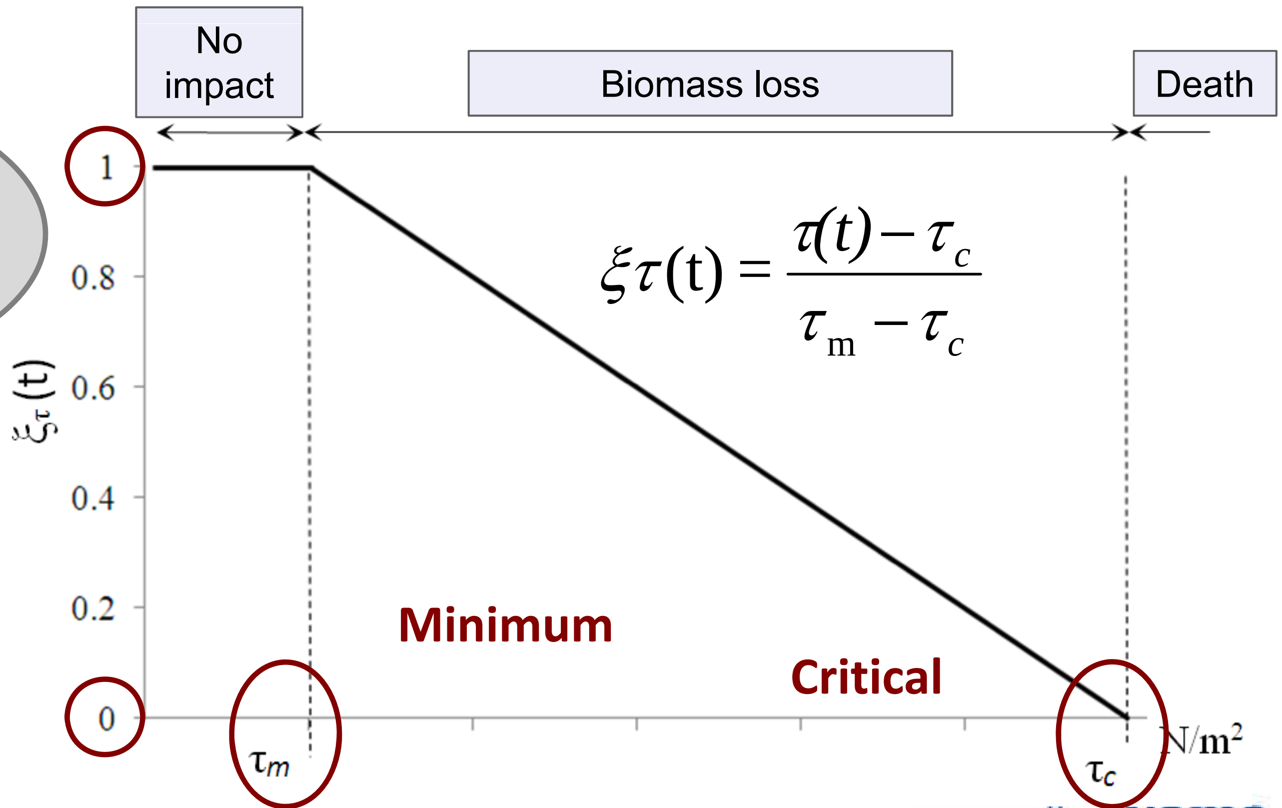


THE RVDM MODEL DESCRIPTION

- **MODULE 1.- IMPACTS** → effect of the hydrological extremes over the vegetation
  - **Biomass remain → B(t) = B(t-1) · ξ(t)**
  - Parameters: **minimum** and **critical** values to mark out the impact
    - No impact
    - Limited growth
    - Biomass loss
    - **Plant death => retrogression to bare soil**
  - **Biomass loss function, ξ(t) → linear**

- **MODULE 1.- IMPACTS** → effect of the hydrological extremes over the vegetation
  - Effects of the **removal** → f(water shear stress)

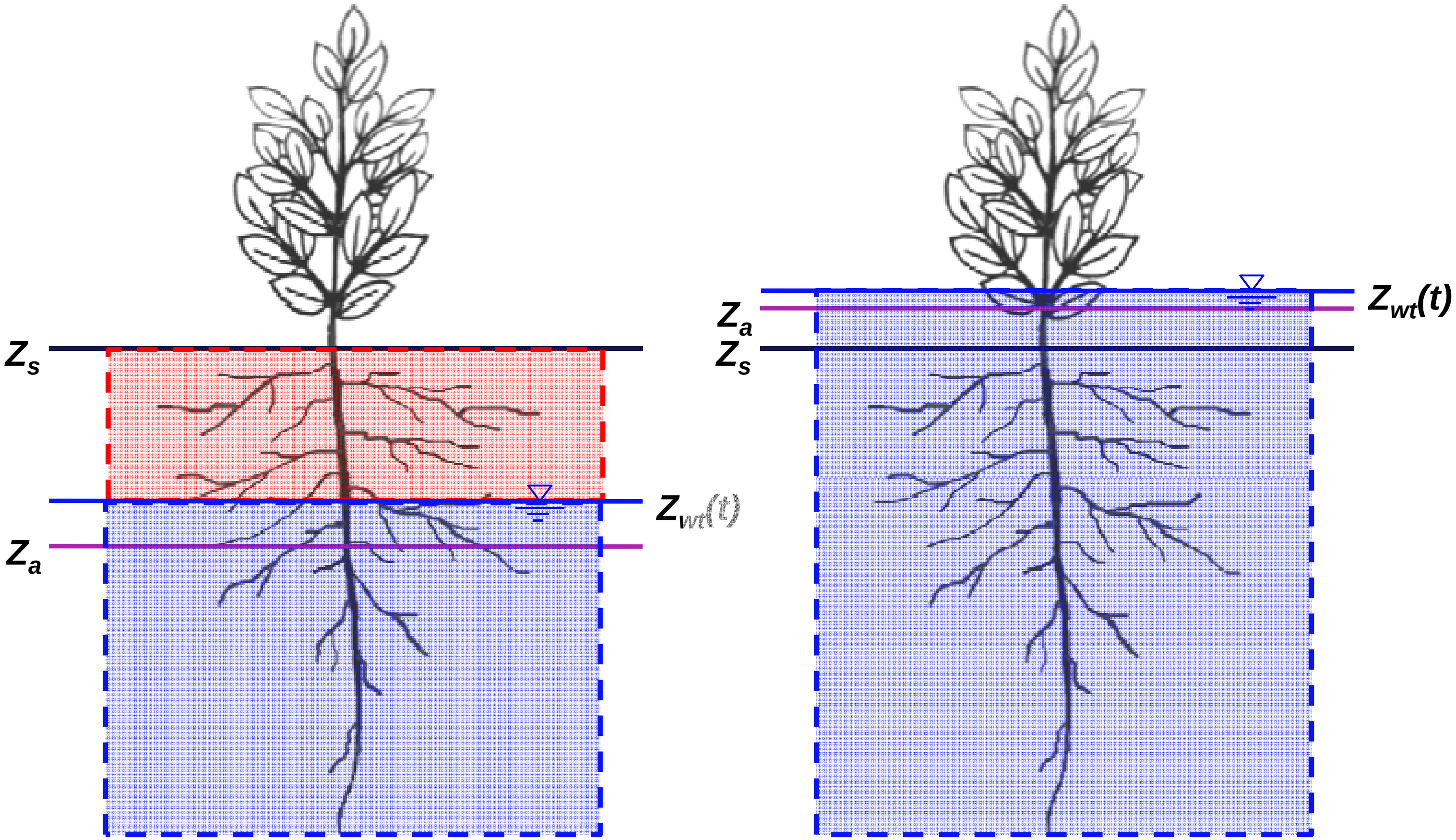
LINEAR BIOMASS LOSS FUNCTION



$$\xi\tau(t) = \frac{\tau(t) - \tau_c}{\tau_m - \tau_c}$$

THE RVDM MODEL DESCRIPTION

- **ASPHYXIA BY FLOOD** → number of days that $Z_{wt} > Z_a$
  - Z_a > or < Z_s? → **SPFTs parameter**



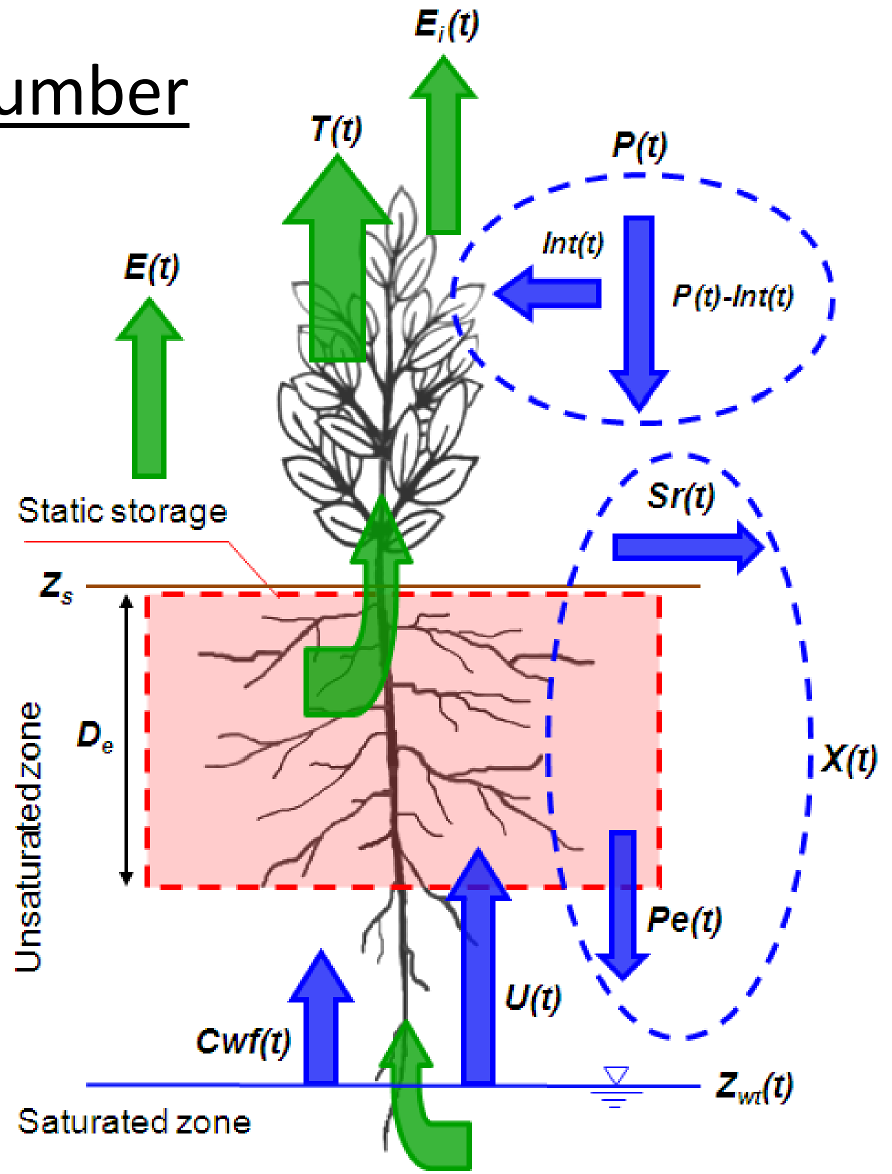
THE RVDM MODEL DESCRIPTION

- **WILT BY DROUGHT** → number of days that **T(t)=0**

=> Hydrological submodel

WATER FLUXES →

Green arrows represent the **actual ET**



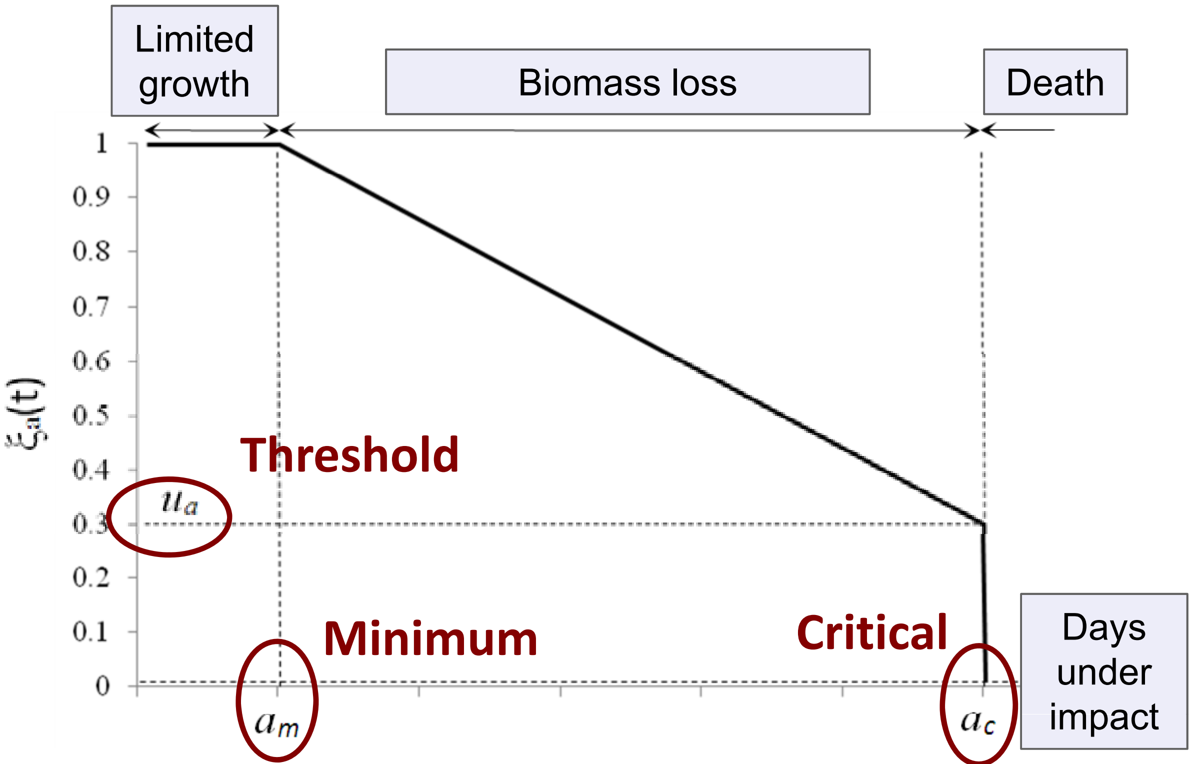
THE RVDM MODEL DESCRIPTION

- **MODULE 1.- IMPACTS** → effect of the hydrological extremes over the vegetation
  - Effects of **asphyxia** → f(Z_{wt})
  - Effects of **wilt** → f(T)

LINEAR BIOMASS LOSS FUNCTIONS

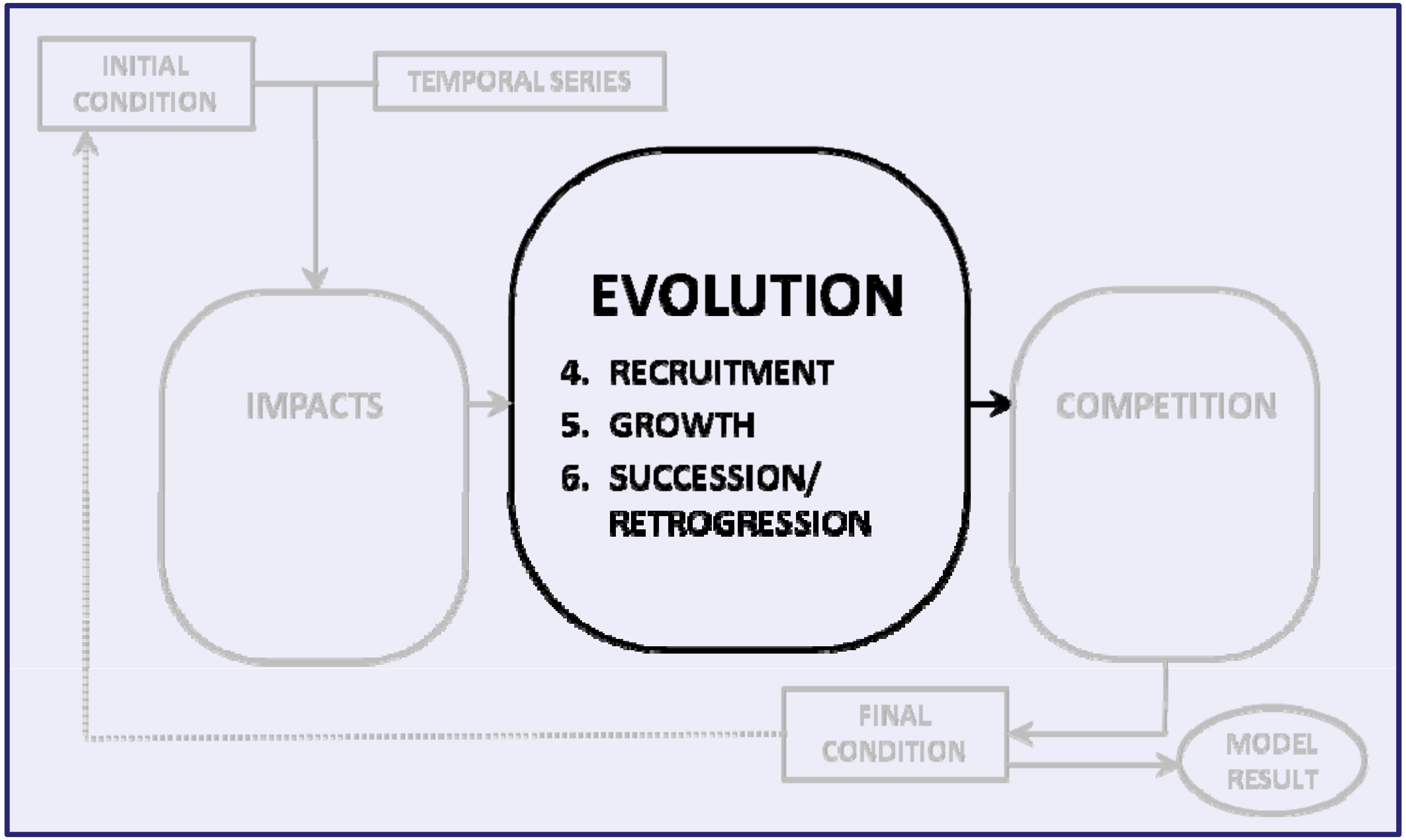
ASPHYXIA and <u>WILT</u>:

- Same function
- Different parameters values
- **Wm**, **Wc** and **Uw**



THE RVDM MODEL DESCRIPTION

- **MODULE 2.- EVOLUTION** → colonization and development of the vegetation



THE RVDM MODEL DESCRIPTION

MODULE 2.- EVOLUTION → a) RECRUITMENT

- **Presence** of available seeds: **BS → PSC**
- **Germination** of the seeds: **PSC → P**
- **Establishment** of the seedlings: **P → H**

PRESENCE of available seeds → controlled by **seasonal timing** and **floods occurrence** (time and magnitud)

- Autumn-winter floods are destructive
- Seeds dispersal
  - **REED** → **requires spring flood**

GERMINATION of seeds → requirements of **temperature**, **oxygen, moisture** and **light**

- **Temperature** → $T_{gmax} > T_{max}(t) > T_{min}(t) > T_{gmin}$
- **Oxygen** → $Z_s \geq Z_{wt}(t)$
- **Moisture** → $H(t) \geq H_{gmin}$
- **Light** → PAR threshold $P_{RE\text{-}TV}$ or $P_{CW\text{-}TV}$

ESTABLISHMENT of seedlings → controlled by pioneer's **transpiration** , the **number of days necessary for establishment (NDE)** and the **time since germination (TSG)**

- **TSG ≥ NDE** → There are possible cases: $\Sigma T(t)_{RE}$ *vs* $\Sigma T(t)_{TV}$ *vs* $\Sigma T(t)_{CW}$
- **P → H** then **Successful RECRUITMENT**

THE RVDM MODEL DESCRIPTION

- MODULE 2.- EVOLUTION → **b) GROWTH**
- Leaf biomass dynamic based on **Light Use Efficiency**

$$\frac{dB}{dt} = \left(LUE \cdot ET_{idx}(t) \cdot APAR(t) - \mathrm{Re}(t)\right) \cdot \varphi_l(t-1) - k_a \cdot B(t-1)$$

$$ET_{idx}(t) = \frac{T(t)}{cv\, ET_0(t) - E_i(t)}$$

← WATER AVAILABILITY

Logistic component

$$\varphi_l(t) = 1 - \frac{LAI(t)}{LAI_{\max}}$$

Particular cases where biomass does not grow

- If **$\tau(t) \geq \tau_m$**, → B(t) from **1a.REMOVAL BY FLOOD**
- If **$Z_{wt} \geq Z_a$** → B(t) from **1b.ASPHYXIA BY FLOOD**
- If **T(t) = 0** → B(t) from **1c.WILT BY DROUGHT**

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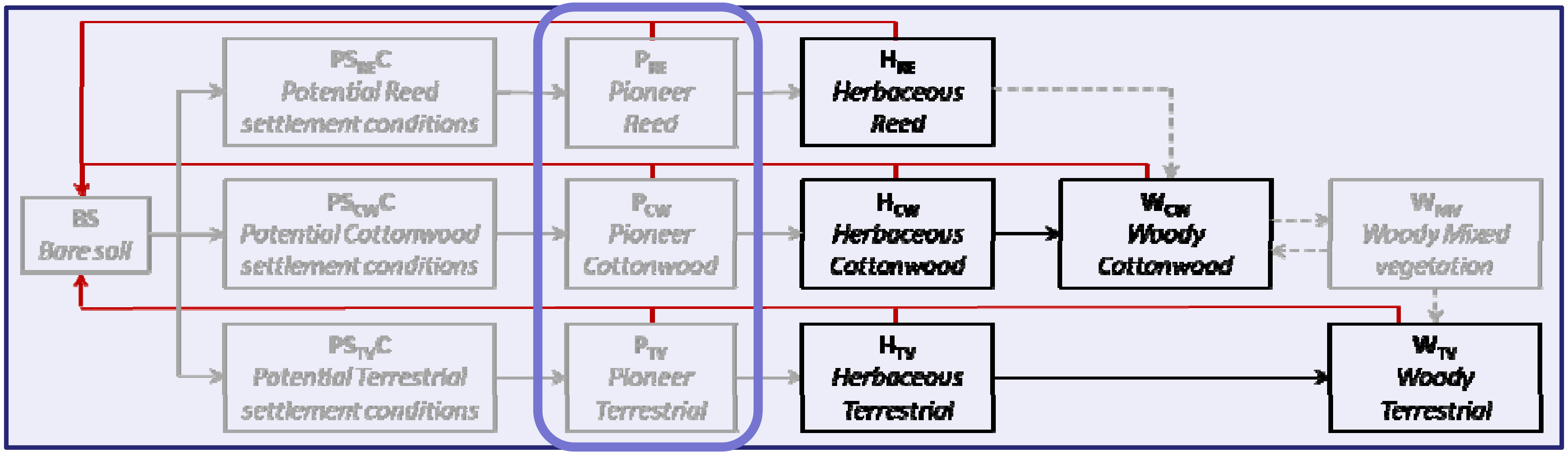
THE RVDM MODEL DESCRIPTION

- MODULE 2.- EVOLUTION → **c)SUCCESSION/RETROGRESSION**



THRESHOLDS

SUCCESSION

B_{min} minimum biomass

Age_s minimum num. days

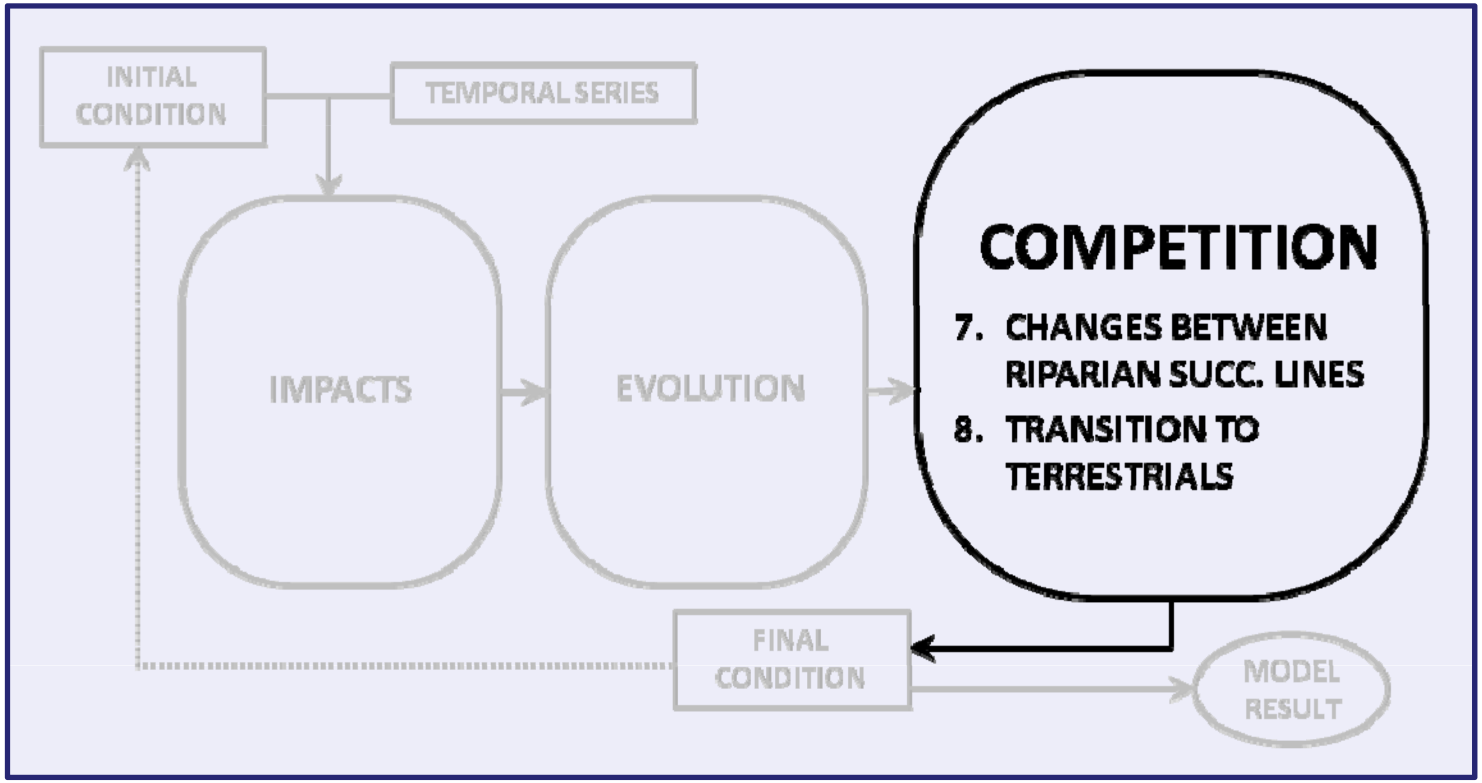
RETROGRESSION

Age_{max} maximum num. days

- Affects to each succession line independently

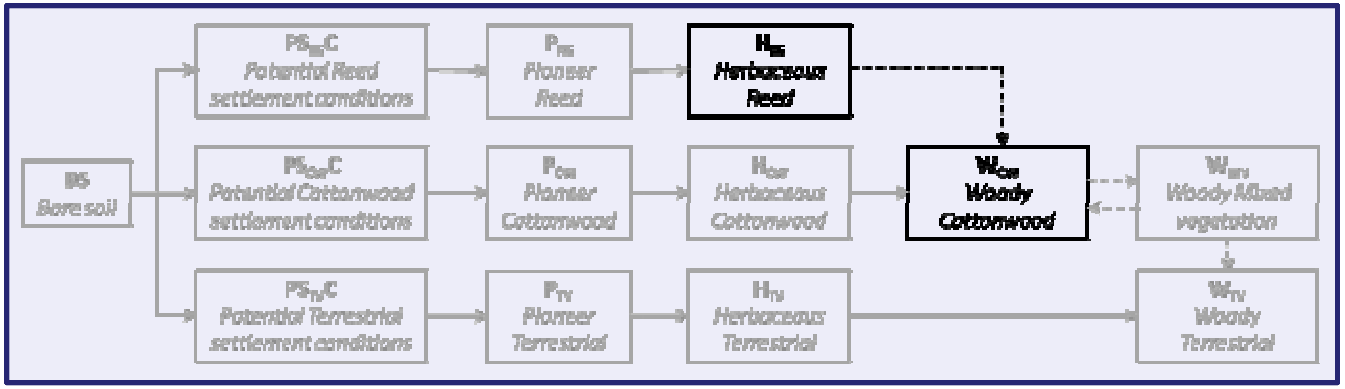
THE RVDM MODEL DESCRIPTION

- **MODULE 3.- COMPETITION** → changes between successional lines and transitional areas



THE RVDM MODEL DESCRIPTION

MODULE 3.- COMPETITION → **a) CHANGES BETWEEN RIPARIAN SUCCESSION LINES**



H_{RE} +

- **Seeds presence**
- $T_{gmax} > T_{max}(t) > T_{min}(t) > T_{gmin}$
- $Z_s \geq Z_{wt}(t)$
- $H(t) \geq H_{gmin}$

→ **Coexistence** $H_{RE} - P_{CW}$

→ TSG≥NDE

→ **Competition** $H_{RE} - H_{CW}$

→ ΣT_{HRE} *vs* ΣT_{HCW}
$B(t)$ *vs* $Bmin_{WCW}$

→ W_{CW}

→ H_{RE}

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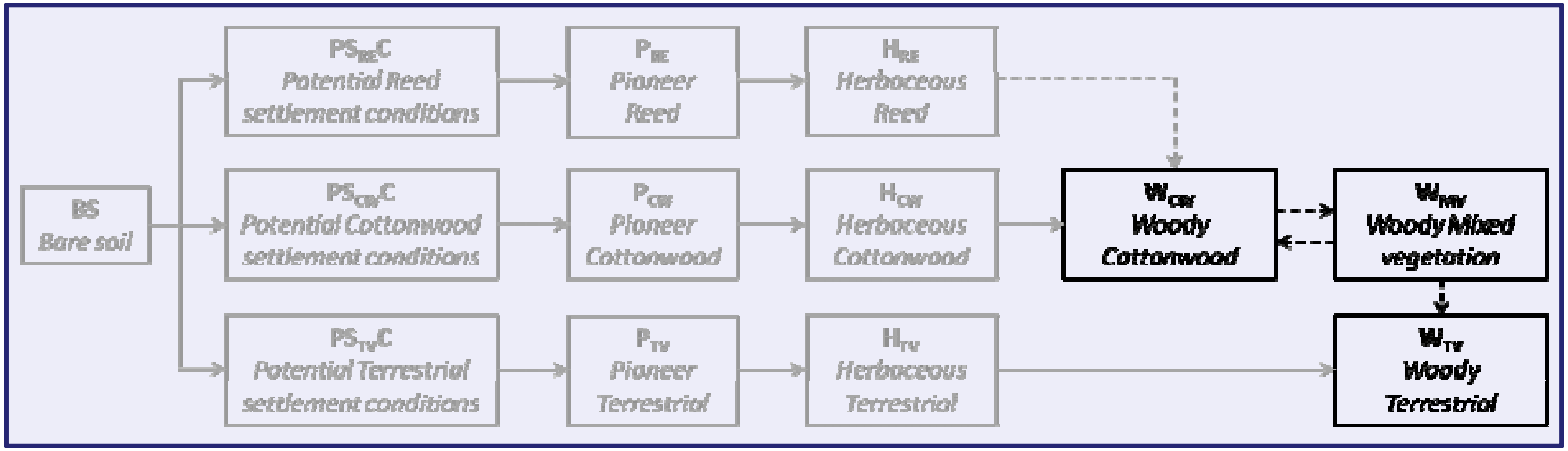
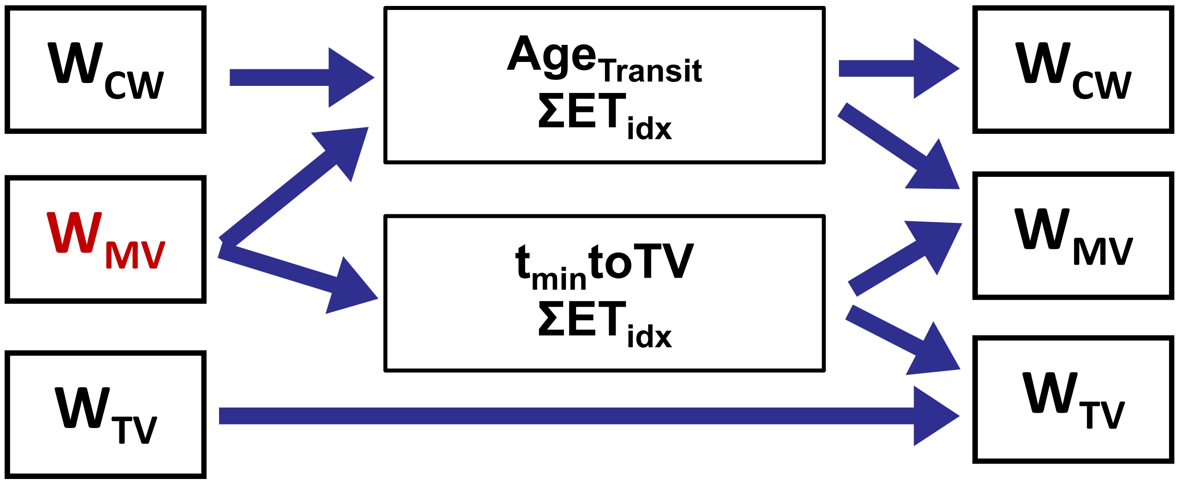
THE RVDM MODEL DESCRIPTION

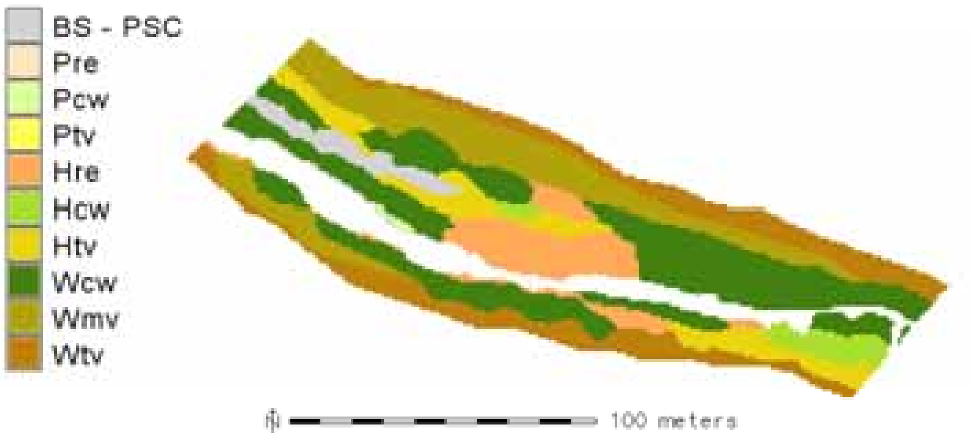
MODULE 3.- COMPETITION → **b) TRANSITION TO TERRESTRIALS**

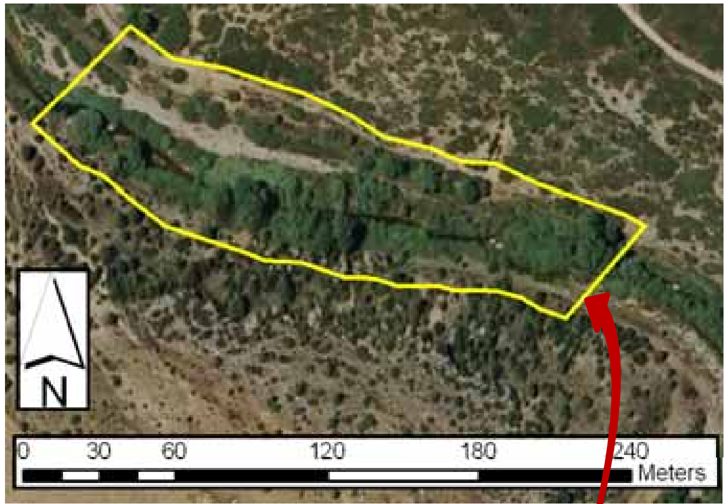


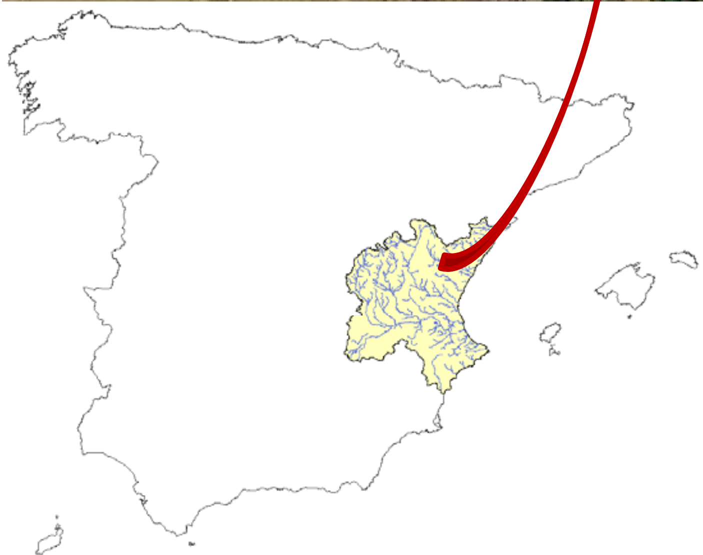


STUDY SITE DESCRIPTION

Terde reach (Mijares River, Spain)







- Altitude: 850 m.a.s.l.
- Length: 228.5 m
- Basin area: 665 km^2
- Average Q_d: 0.855 m^3/s
- Near natural conditions:
  Willows and poplars are dominant

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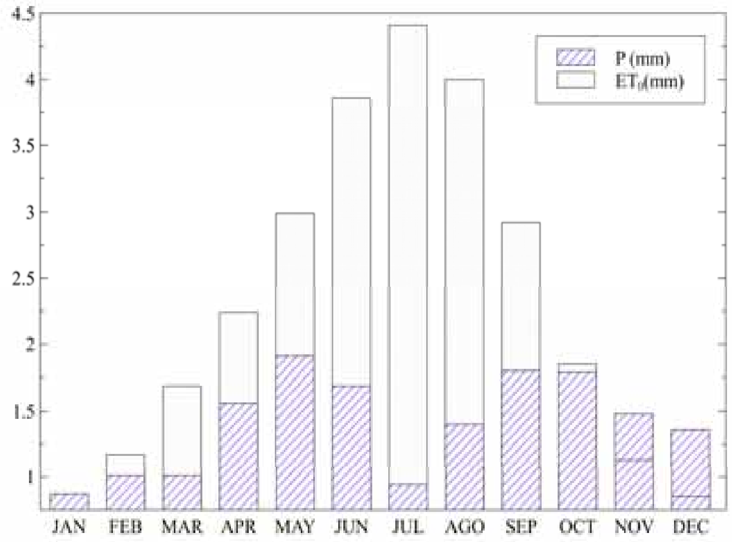
MODEL INPUTS DEFINITION

Hidro-meteorological data

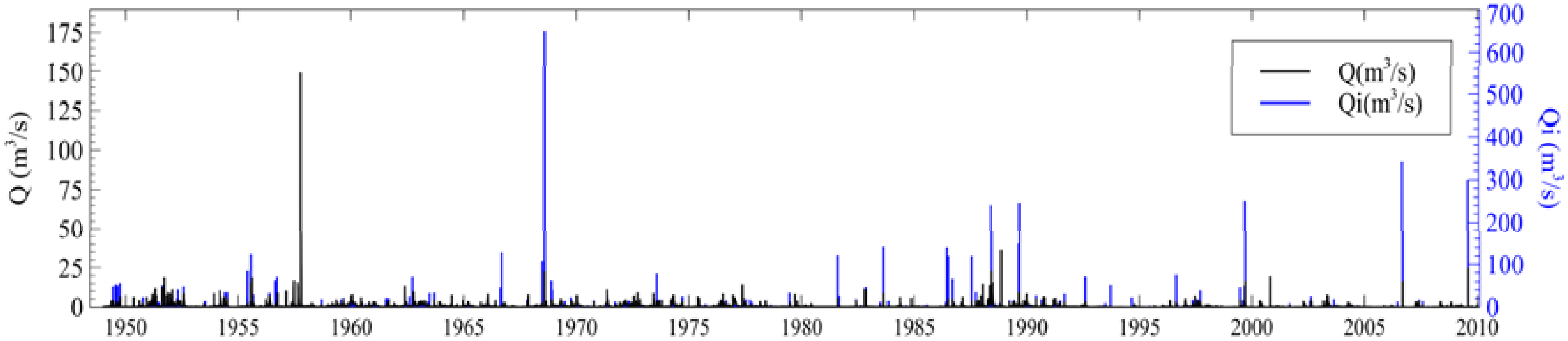


Time period:
1949 - 2009

P= 506 mm/year

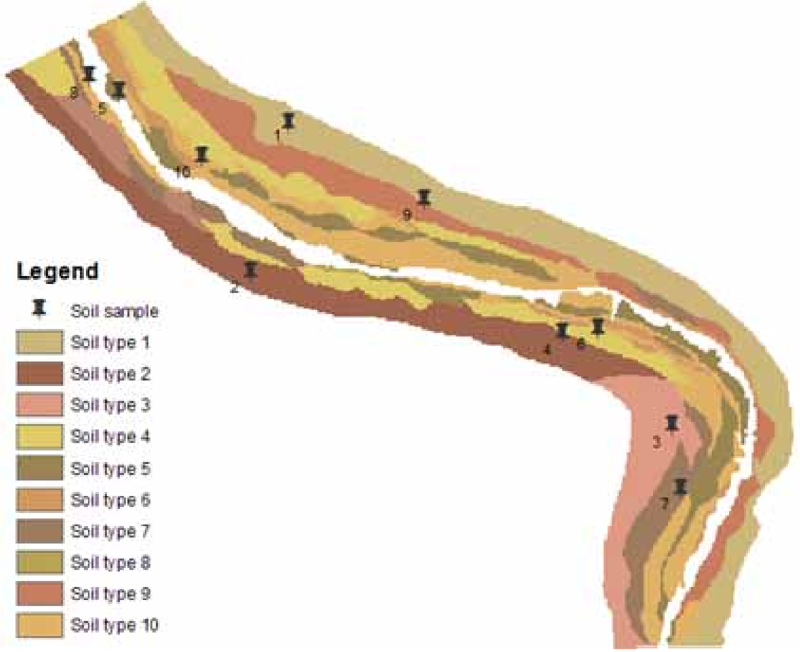
ET_0 = 843 mm/year

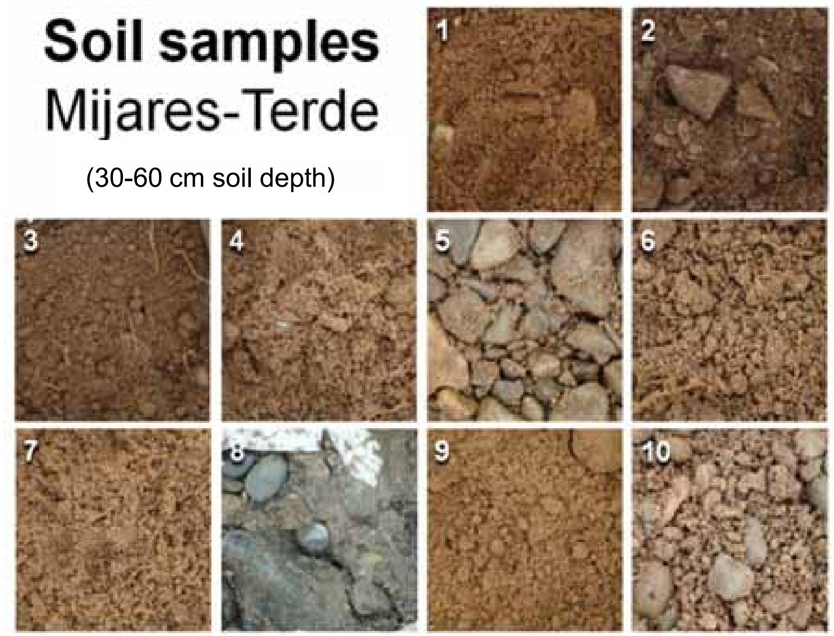
Typical Mediterranean and **semiarid environment**



MODEL INPUTS DEFINITION

- The substrate is varied: fine gravel, gravel, cobbles, scattered boulders

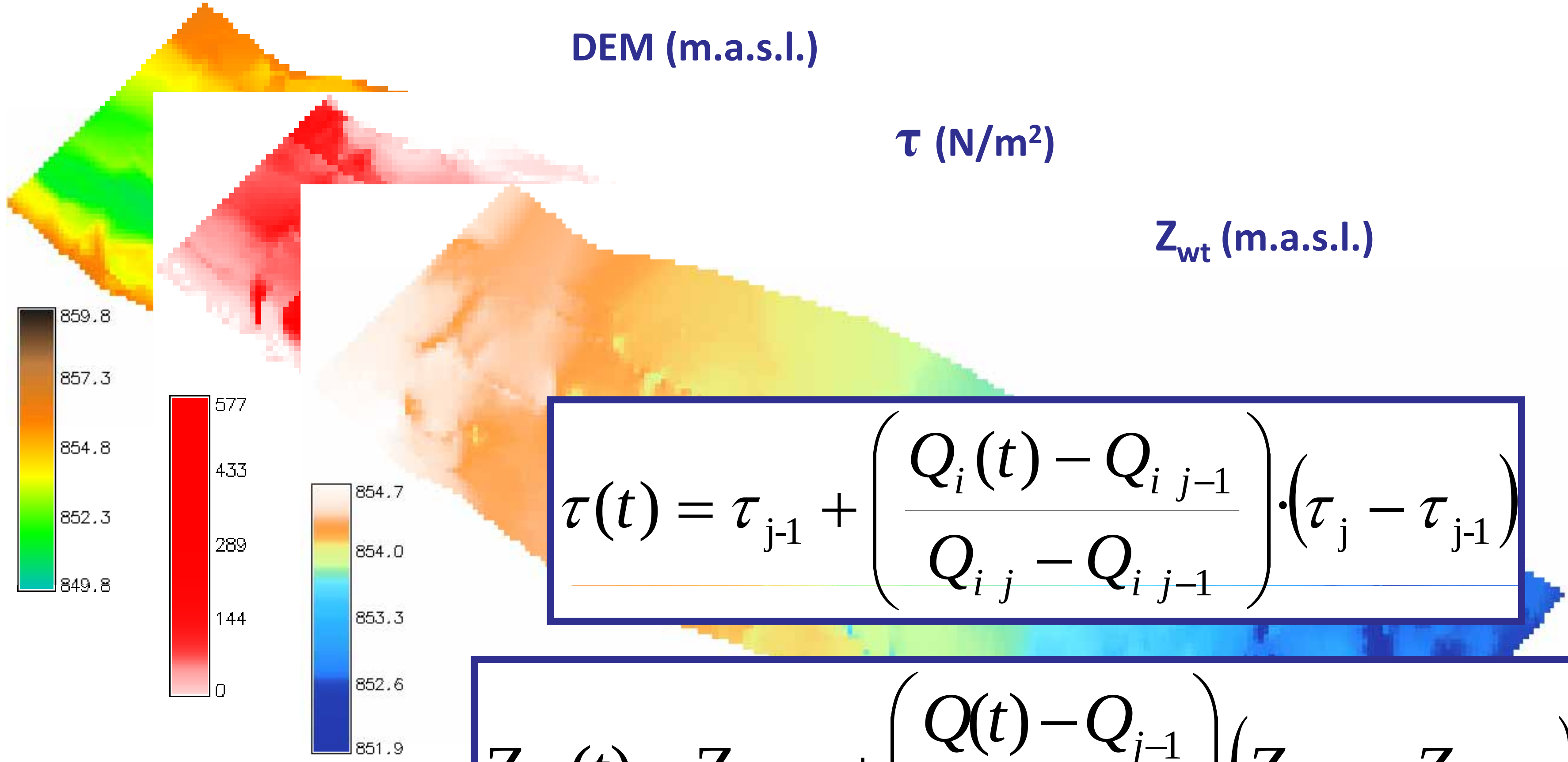




Soil types parameters

Field Capacity Moisture [ ] (Typical value, moisture to 33 Kpa)
Porosity [ ]
Soil Saturated Hydraulic Conductivity [mm/hr]
Bubble pressure [Kpa]
Porosity index

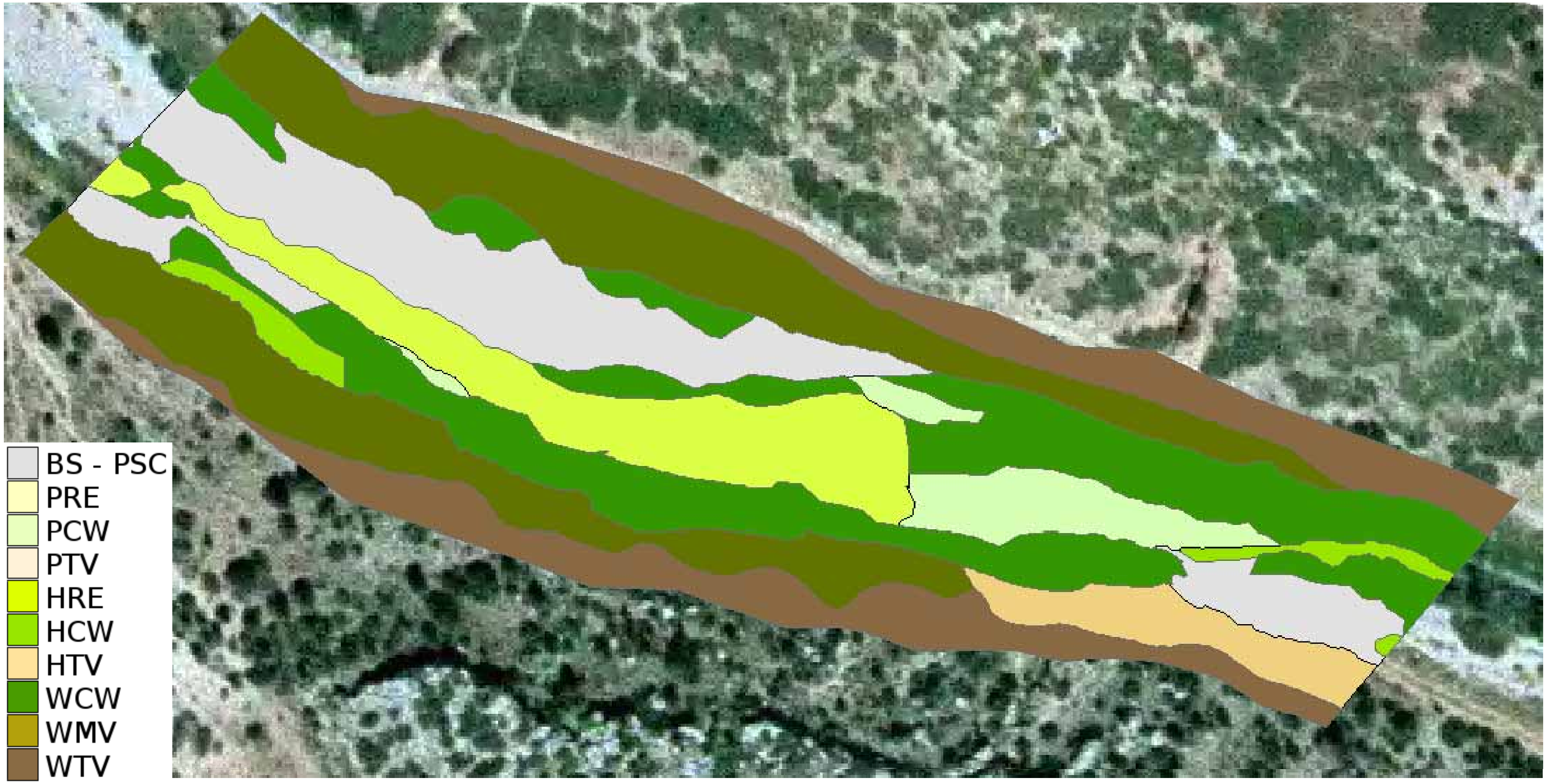
Topographic and hydraulic maps



$$\tau(t) = \tau_{j\text{-}1} + \left(\frac{Q_i(t) - Q_{i\ j-1}}{Q_{i\ j} - Q_{i\ j-1}} \right) \cdot \left(\tau_j - \tau_{j\text{-}1} \right)$$

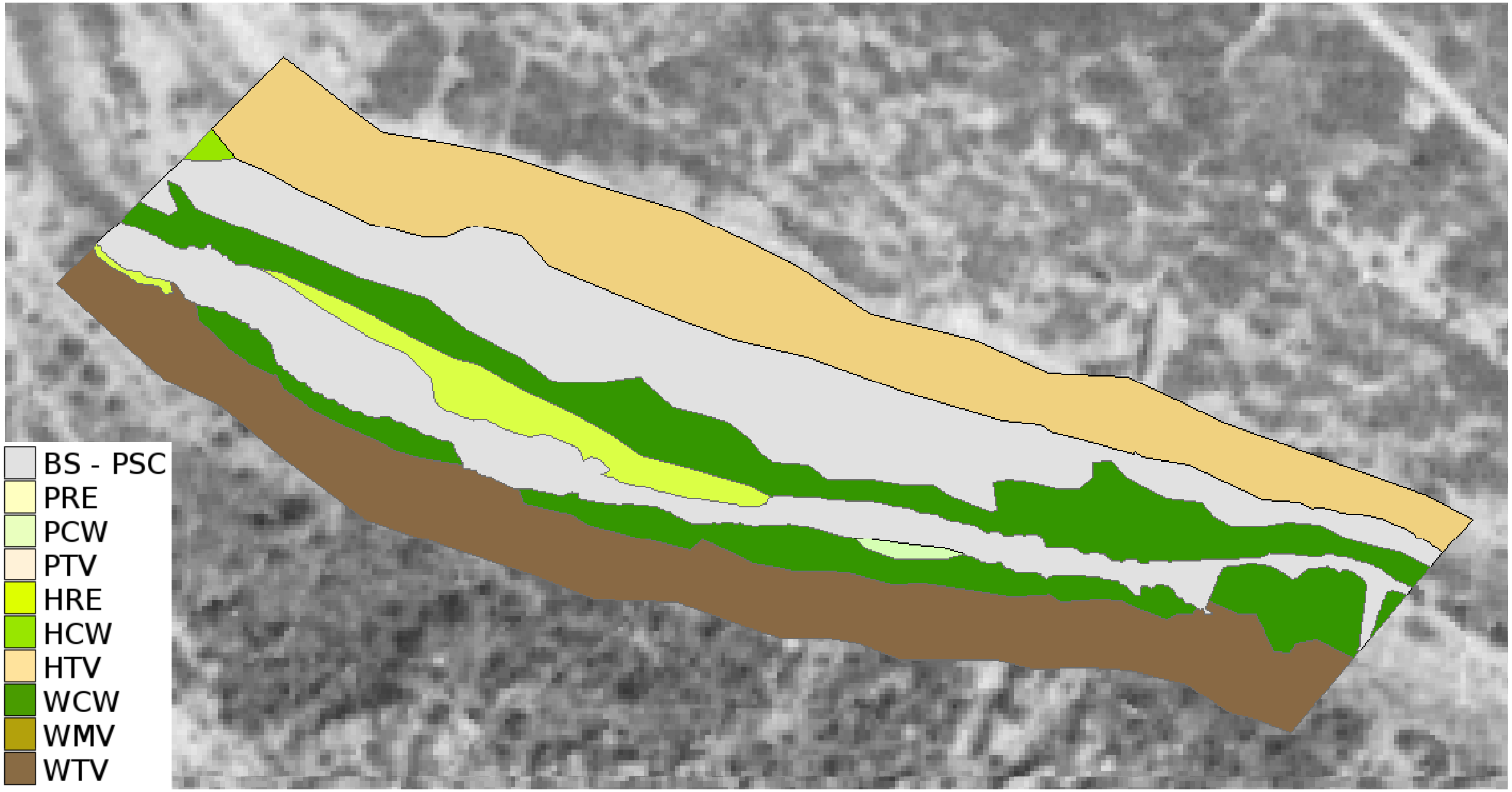
$$Z_{wt}(t) = Z_{wt\ j\text{-}1} + \left(\frac{Q(t) - Q_{j-1}}{Q_j - Q_{j-1}} \right) \cdot \left(Z_{wt\ j} - Z_{wt\ j-1} \right)$$

SPFTs MAPS – YEAR 2000



MODEL INPUTS DEFINITION

SPFTs MAPS – YEAR 1985



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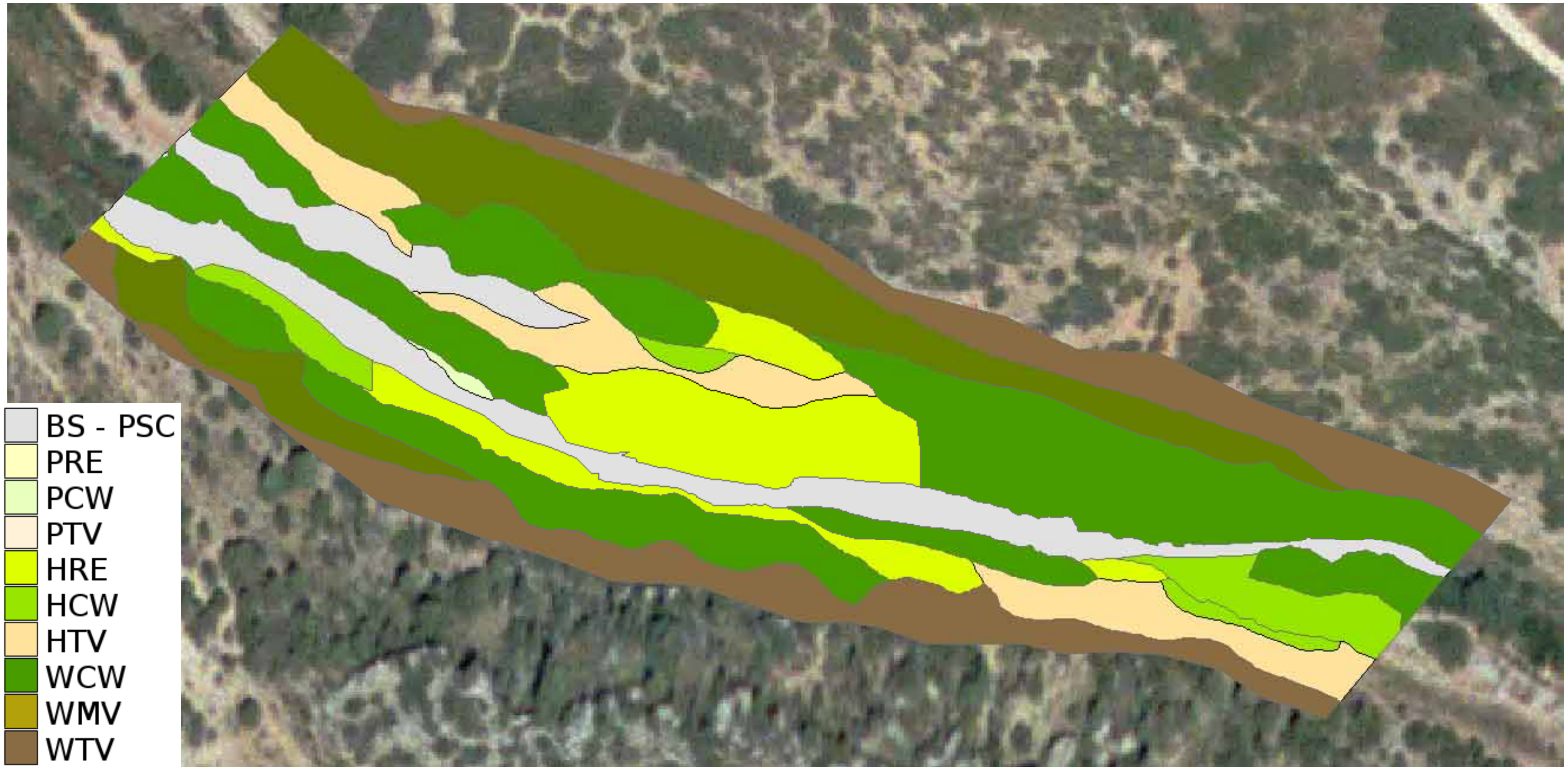
SPFTs MAPS – YEAR 2006



SPFTs MAPS – YEAR 2009

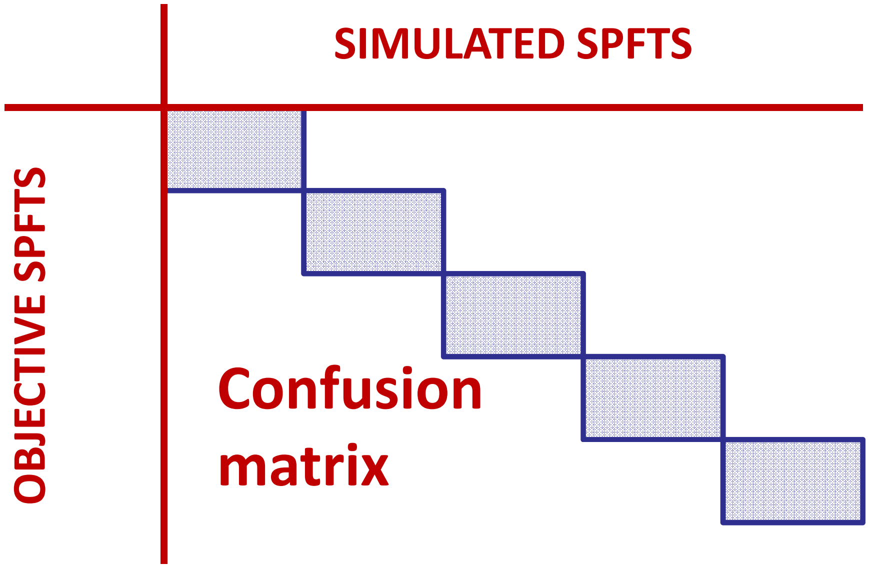
CAL/VAL TIME PERIODS

- **CALIBRATION:**
  - **Initial condition:**
    - SPFTs map → **Jul-2000**
    - Biomass map → internal rules
  - **Final objective condition:**
    - SPFTs map → **Aug-2006**
- **VALIDATION:**
  - **Initial conditions:**
    - SPFTs maps → **Jul-1985** and **Jul-2000**
    - Biomass maps → internal rules (1985,2000)
  - **Final objective conditions:**
    - SPFTs maps → **Jul-2000, Aug-2006 and Dec-2009**

Calibration
2000 – 2006

Validation
1985 – 2000
1985 – 2006
1985 – 2009
2000 – 2009

MODEL PERFORMANCE EVALUATION



Correctly classified instances:

$$CCI = \frac{1}{N}\sum_{i=1}^{n} x_{ii}$$

Kappa coefficient of agreement:

$$k = \frac{f_0 - f_e}{1 - f_e}$$

$$f_0 = CCI = \sum_{i=1}^{n} x_{ii}$$

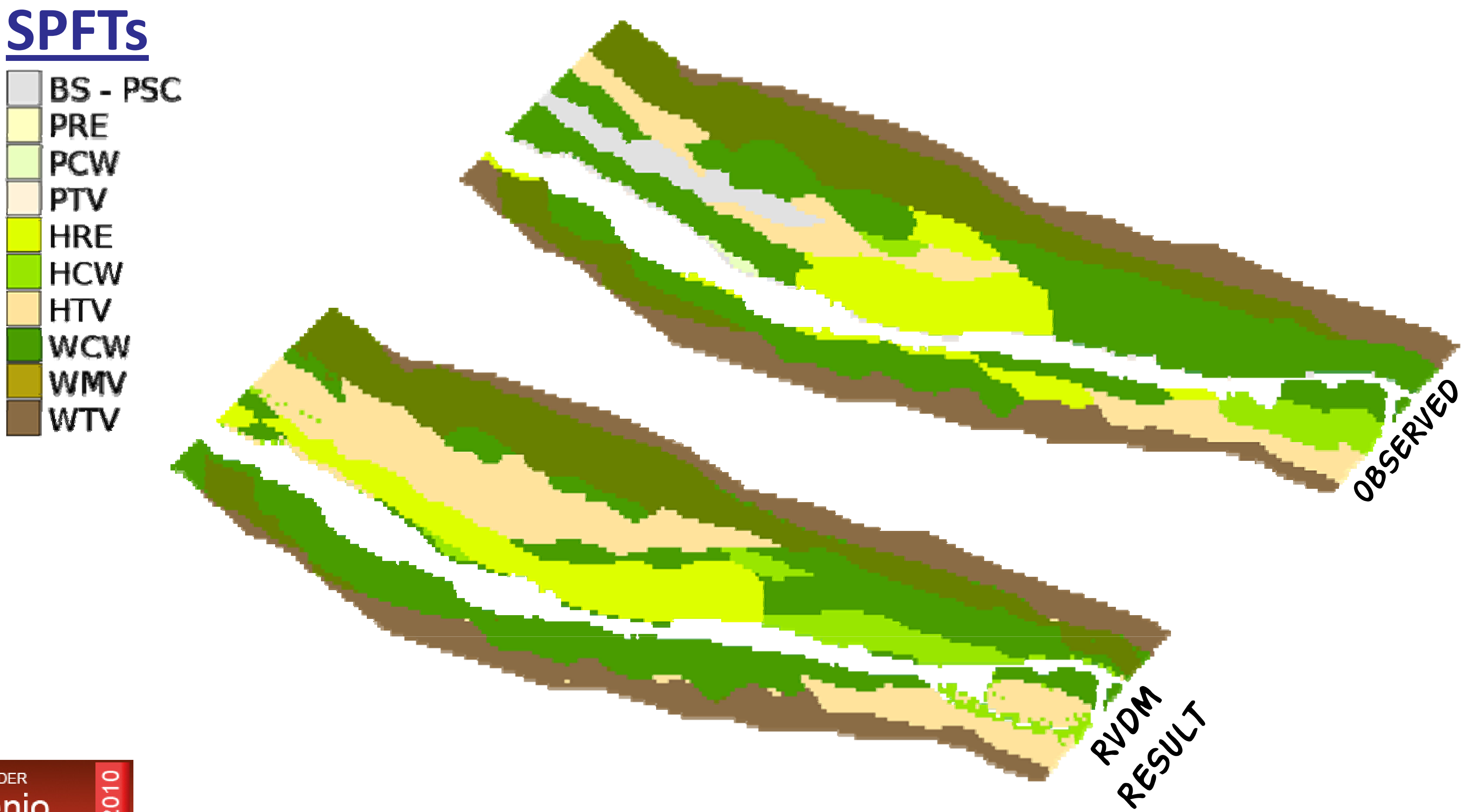
$$f_e = \frac{1}{N}\sum_{i=1}^{n} r_i c_i$$

MODEL PERFORMANCE

	TIME PERIOD	OBJECTIVE FUNCTION	STATE VARIABLE			
			SPFTs	PHASES	LINES	RI – TV
CAL	2000 – 2006	CCI	0.679	0.761	0.726	0.805
		KAPPA	0.602	0.474	0.617	0.588
VALIDATION	2000 – 2009	CCI	0.497	0.656	0.551	0.618
		KAPPA	0.382	0.248	0.356	0.367
	1985 – 2000	CCI	0.407	0.789	0.452	0.454
		KAPPA	0.313	0.605	0.279	0.339
	1985 – 2006	CCI	0.473	0.759	0.525	0.565
		KAPPA	0.349	0.472	0.311	0.339
	1985 – 2009	CCI	0.380	0.654	0.439	0.508
		KAPPA	0.273	0.248	0.191	0.247

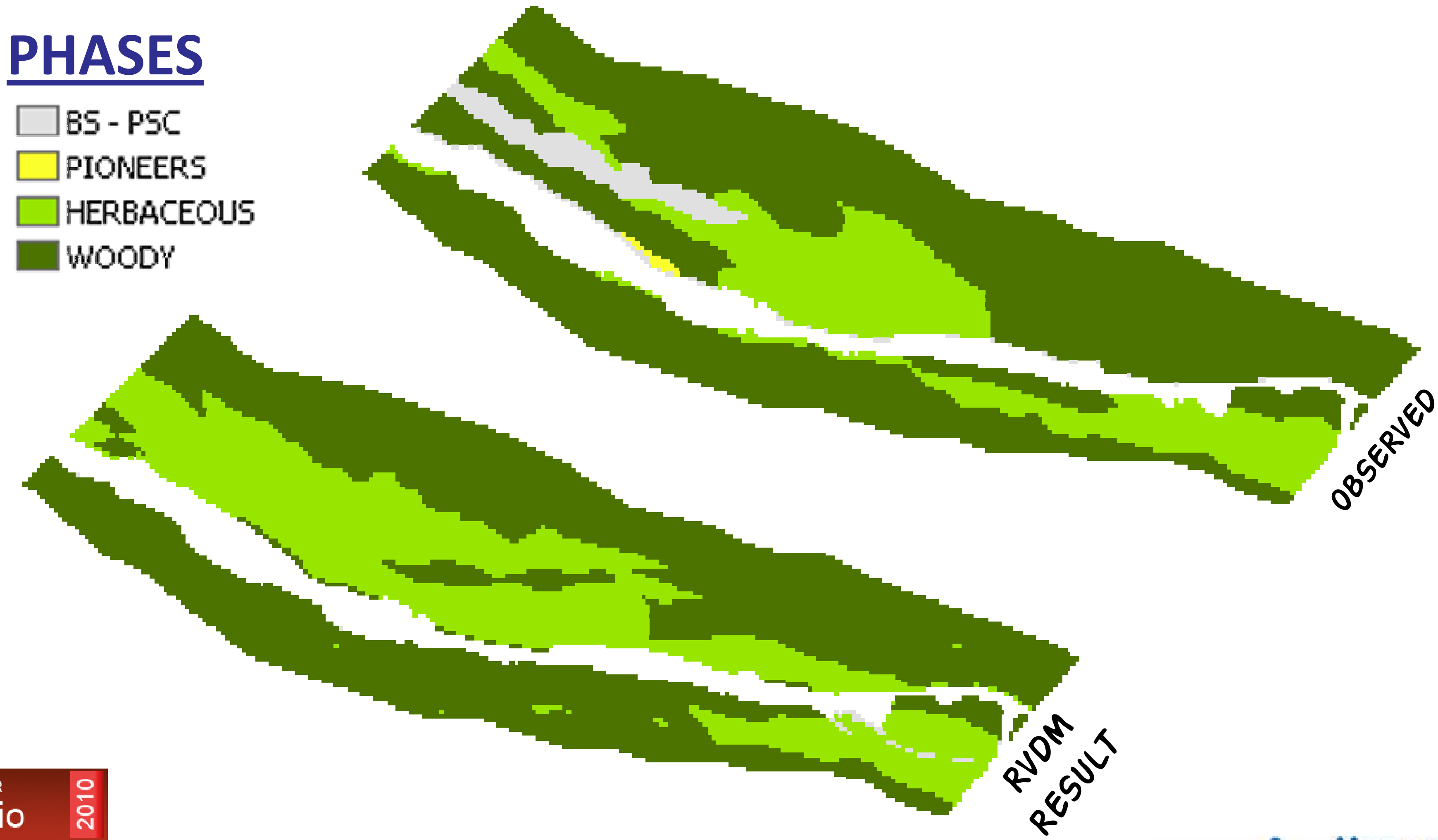
RESULTS

MODEL PERFORMANCE : CALIBRATION 2000 – 2006



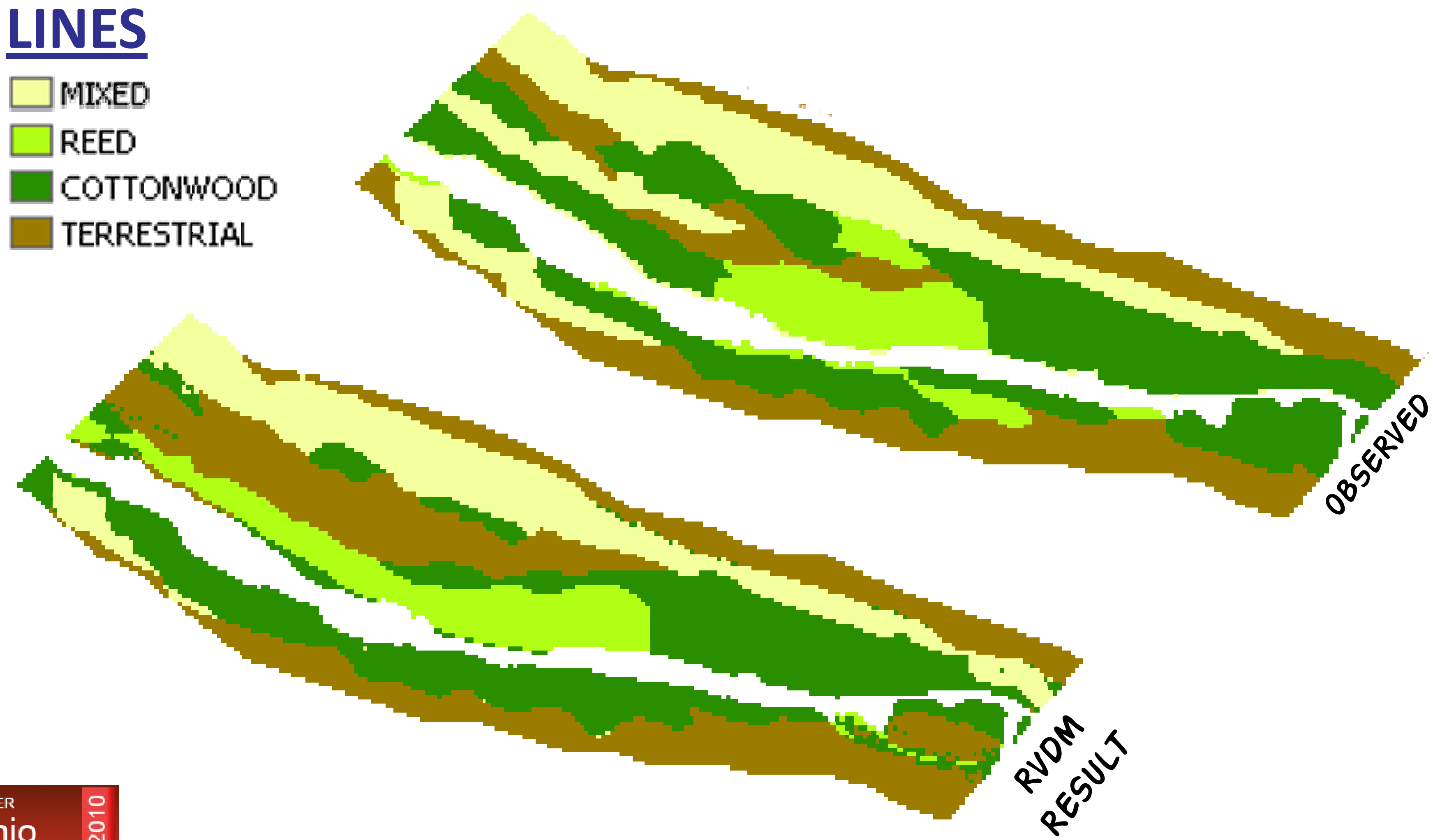
RESULTS

MODEL PERFORMANCE : CALIBRATION 2000 – 2006



RESULTS

MODEL PERFORMANCE : CALIBRATION 2000 – 2006



RESULTS

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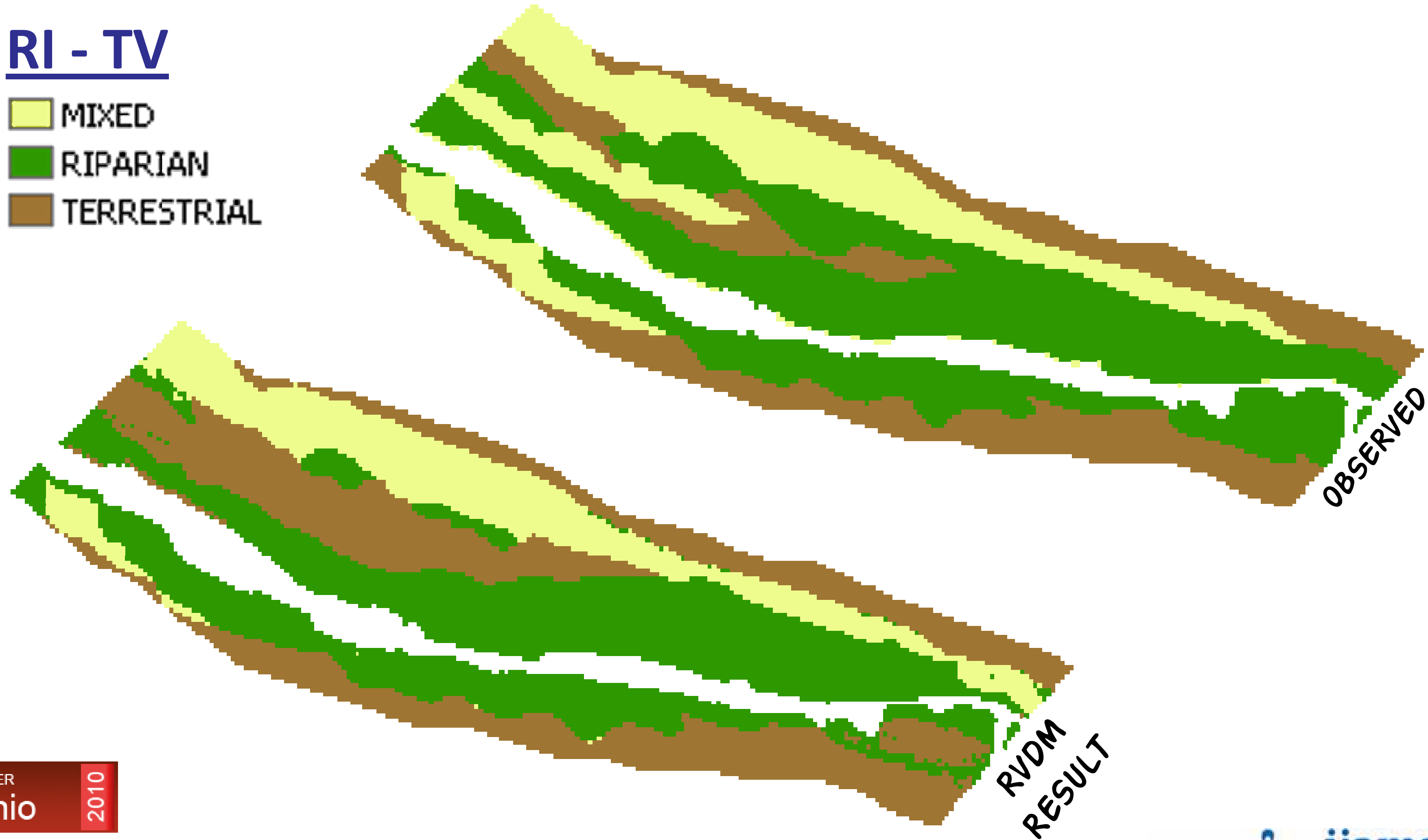


DISCUSSION

- Natural variability of the river hydro-morphological conditions → temporal and spatial variability of vegetation → model with a high spatial and temporal resolution

- RVDM integrates and improves the strengths of previous models
  - Physical and ecological processes are efficiently represented
  - Morphological changes can be included off-line
  - Satisfactory performance once the influent parameters are calibrated
  - Good quality of the validation results → robust model

DISCUSSION

- The model implementation is not difficult → data requirements are limited and accessible in general
  - But, a standardized method to obtain vegetation maps from aerial photographs is desirable

- Model exploitation: necessary to have a tool capable to predict the riparian vegetation response to its driving forces, as far as these drivers can change in the future:
  - Analyze global change impacts
  - Meet environmental objectives
  - Compare restoration initiatives

Riparian Vegetation under upstream dams

Drivers of change

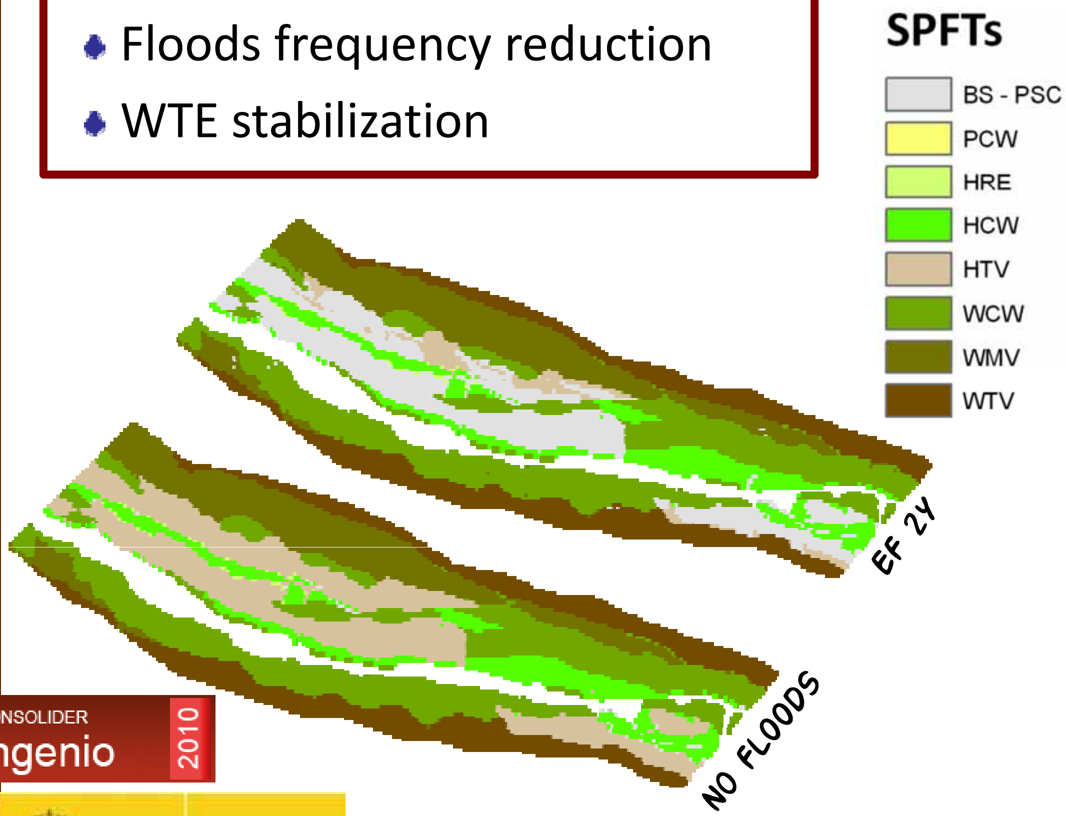
- Hydrological regime change
- Floods magnitude reduction
- Floods frequency reduction
- WTE stabilization

Impacts and Vulnerability

- Increase of terrestrial vegetation presence
- Riparian areas reduction (presence and biomass)
- Aging of the ecosystem
- Reduction on plant diversity

⇒ Changes on the shadowing capabilities of the canopy

⇒ Worsening of the ecological status of the river



Riparian Vegetation under Climate Change

Drivers of change

- Temperature increase
- Precipitation regimes change
- Flow reduction
- Changes in extreme events

Impacts and Vulnerability

- Riparian areas reduction
- Increase of areas with bare soil
- Increase of terrestrial vegetation presence
- Earlier successional phases unfavoured

⇒ Reduction on ET capabilities

⇒ Gradual changes in riparian ecosystems

Thank you for your attention

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