

Modelling hydroecological processes in semi-arid riparian areas

The Riparian Vegetation Dynamic Model (RVDM)

Alicia García-Arias and Félix Francés

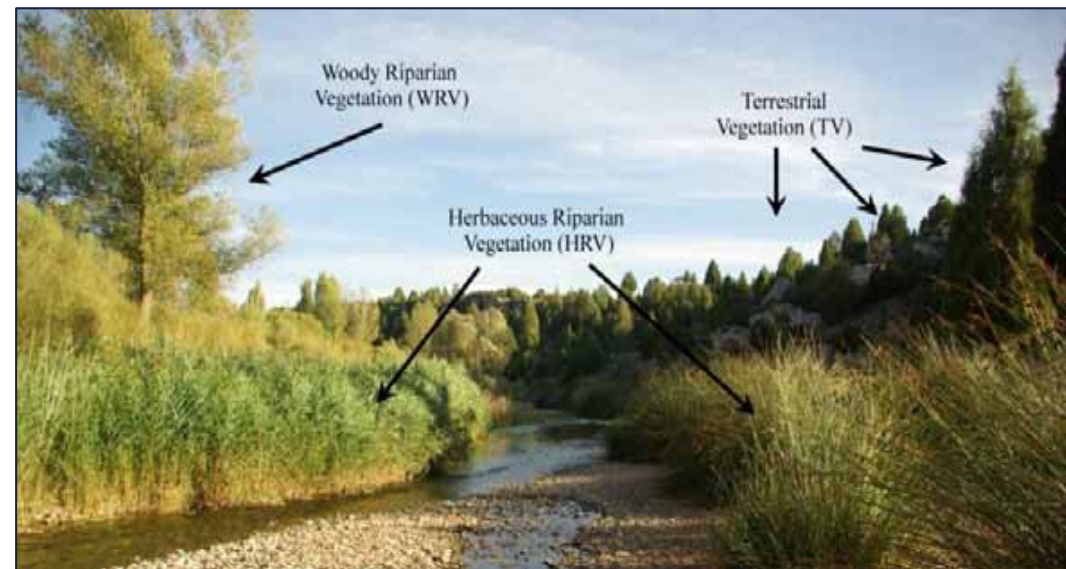
(algarar2@upv.es, ffrances@upv.es)

Research Group of Hydrological and Environmental Modelling (Iluvia.dihma.upv.es)

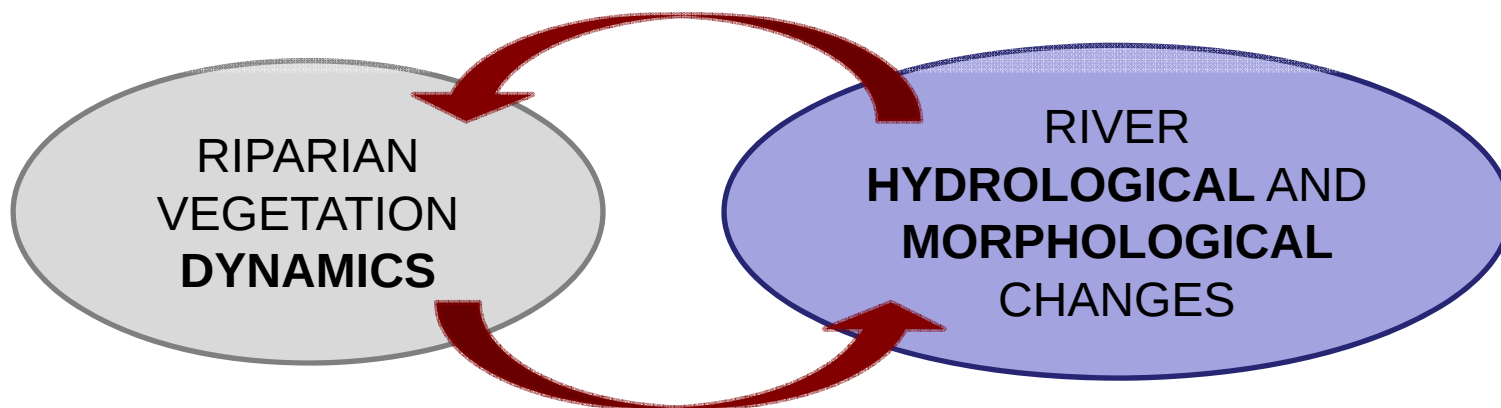
Research Institute of Water Engineering and Environment

Universitat Politècnica de València (Valencia, Spain)

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



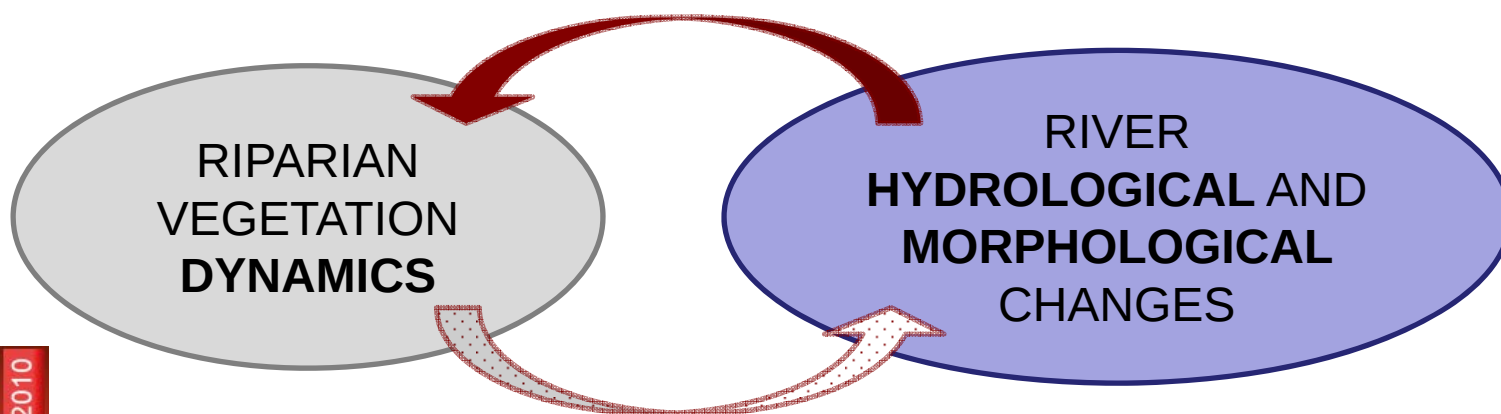
- Riparian ecosystems are important by their self and for their ecological services
- River hydrodynamics determines the riparian vegetation distribution ...
- ... and viceversa



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.

- 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

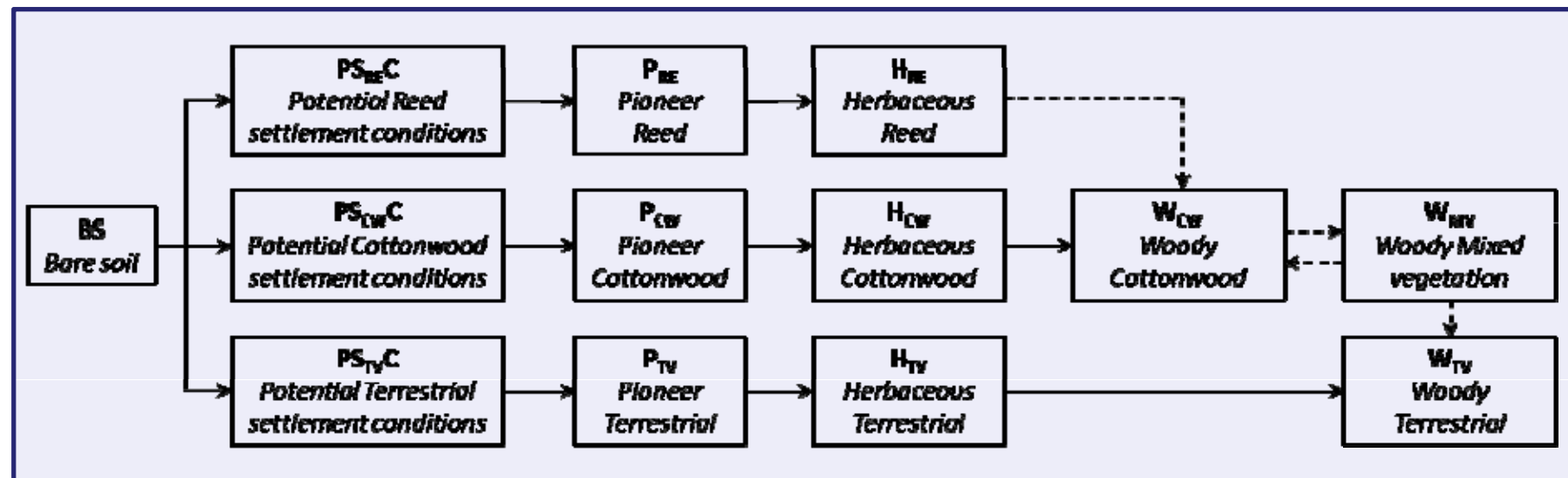


- To develop a flexible dynamic model of riparian vegetation, with focus on Mediterranean semi-arid conditions
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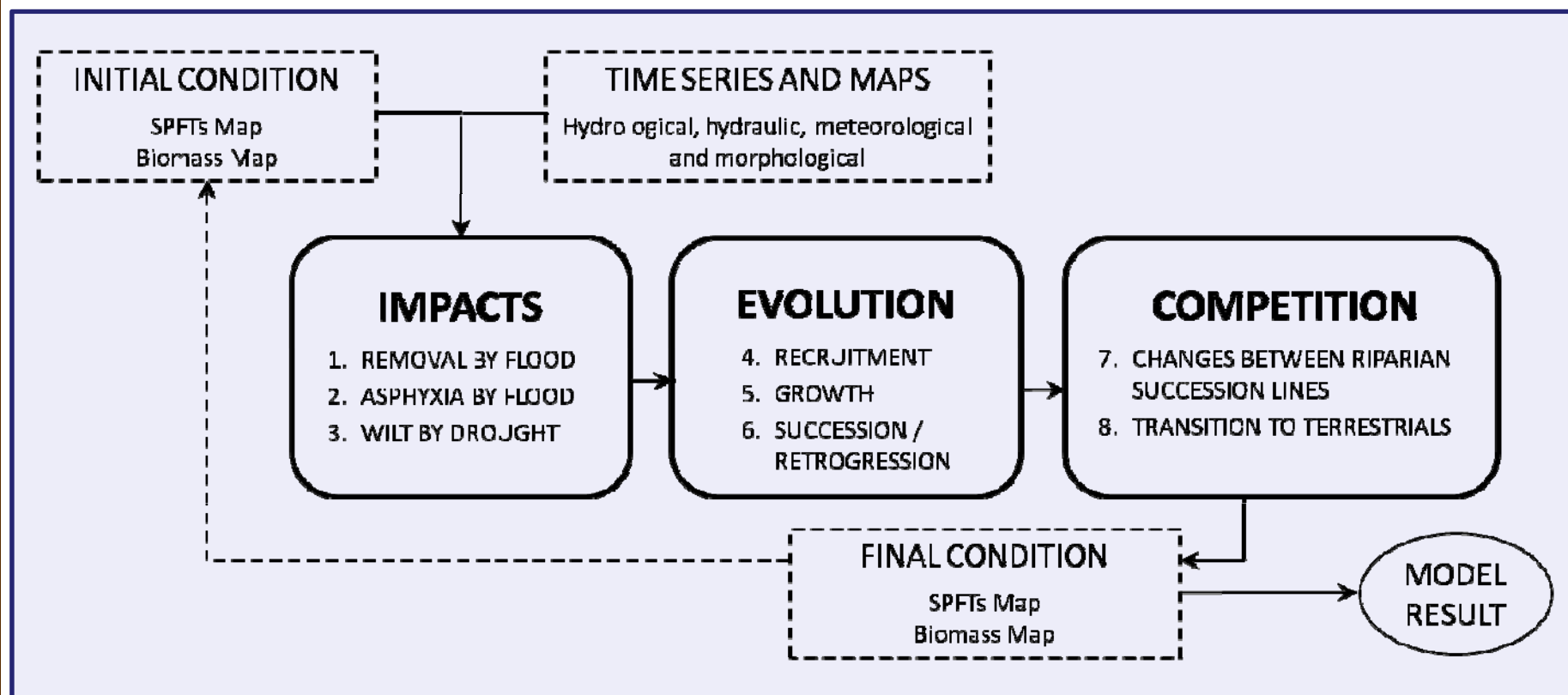
The Riparian Vegetation Dynamic Model (RVDM)

- **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

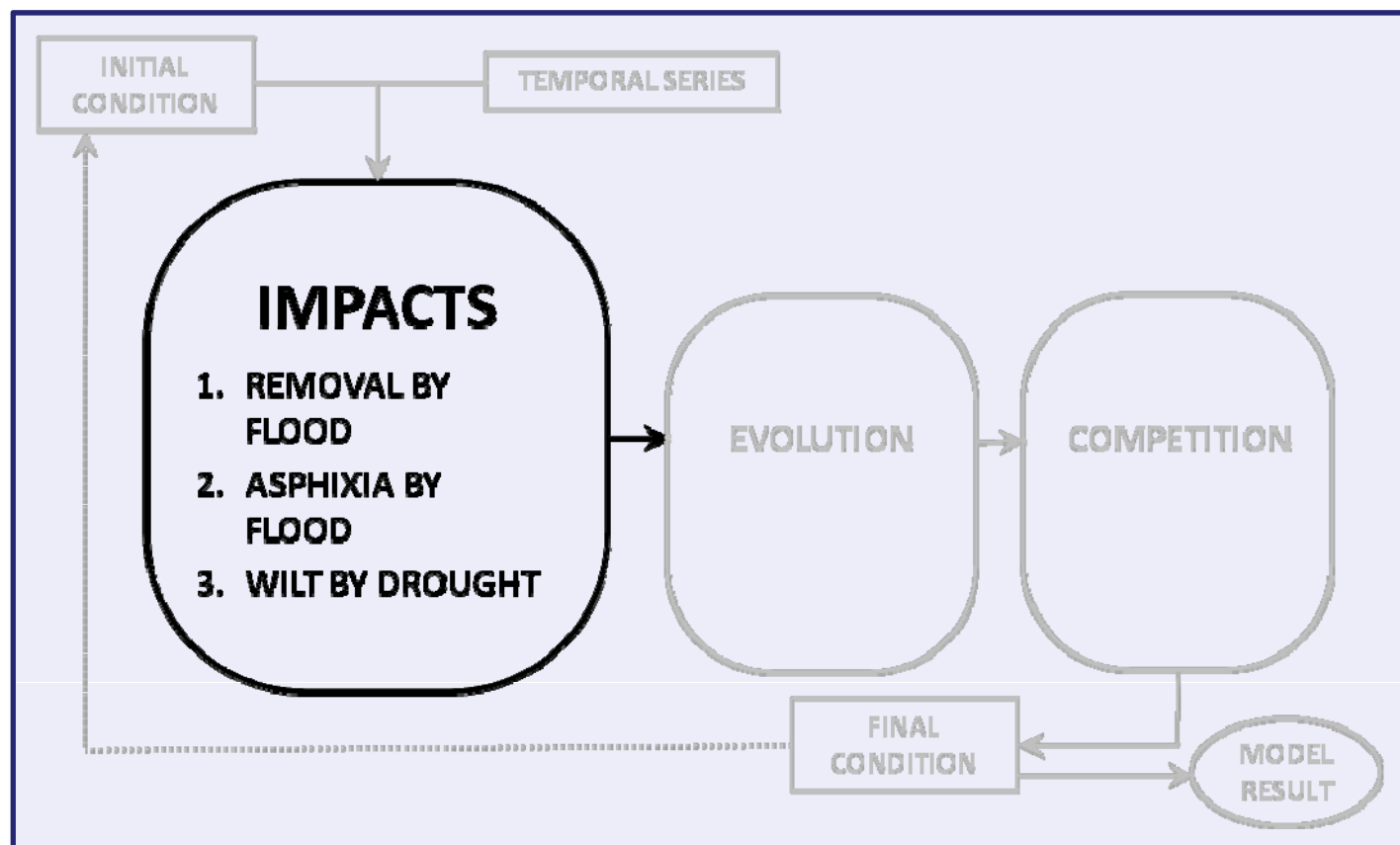
- **SPFT → Main state variable of RVDM**
 - 2 Riparian succession lines: **Reed (RE)** and **Cottonwood (CW)**
 - 1 Terrestrial (TV) → zonal vegetation



RVDM → Modular structure

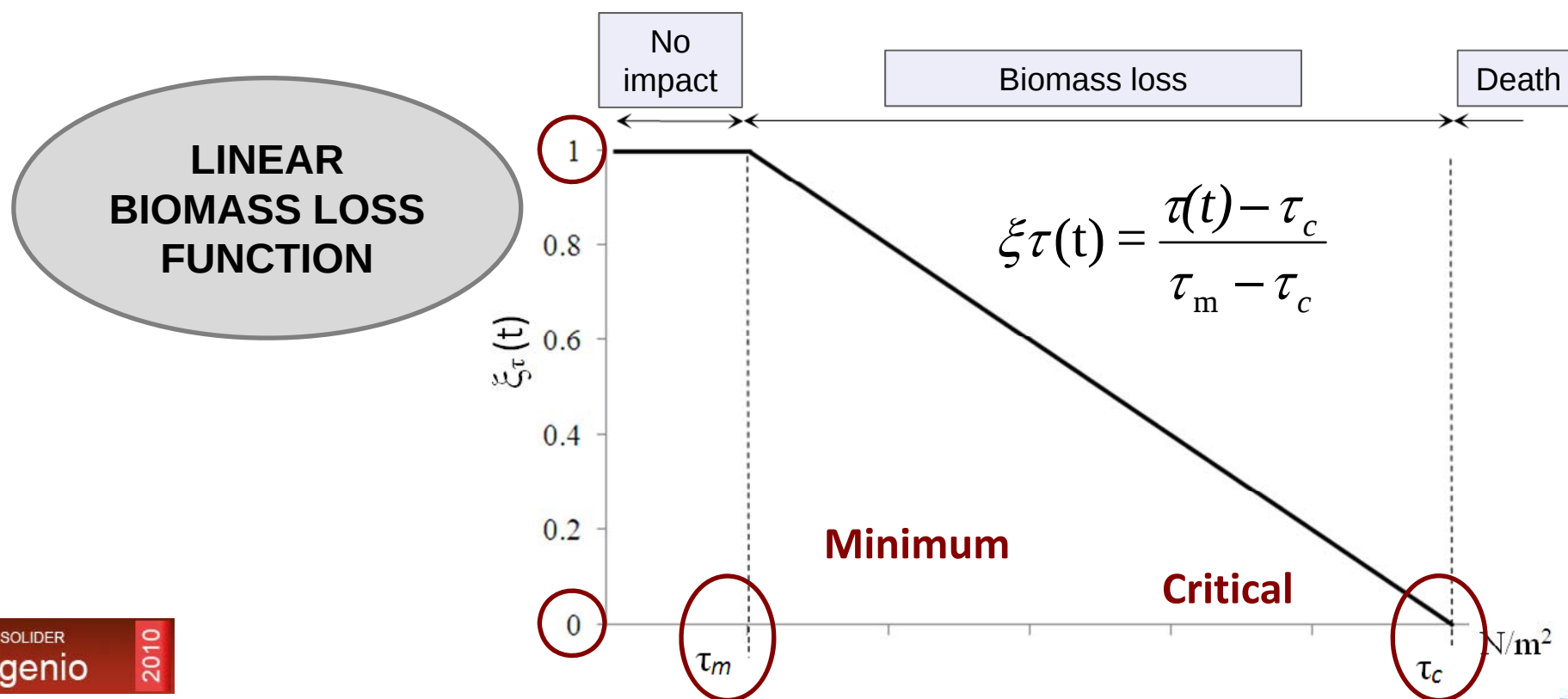


- **MODULE 1.- IMPACTS** → effect of the hydrological extremes over the vegetation

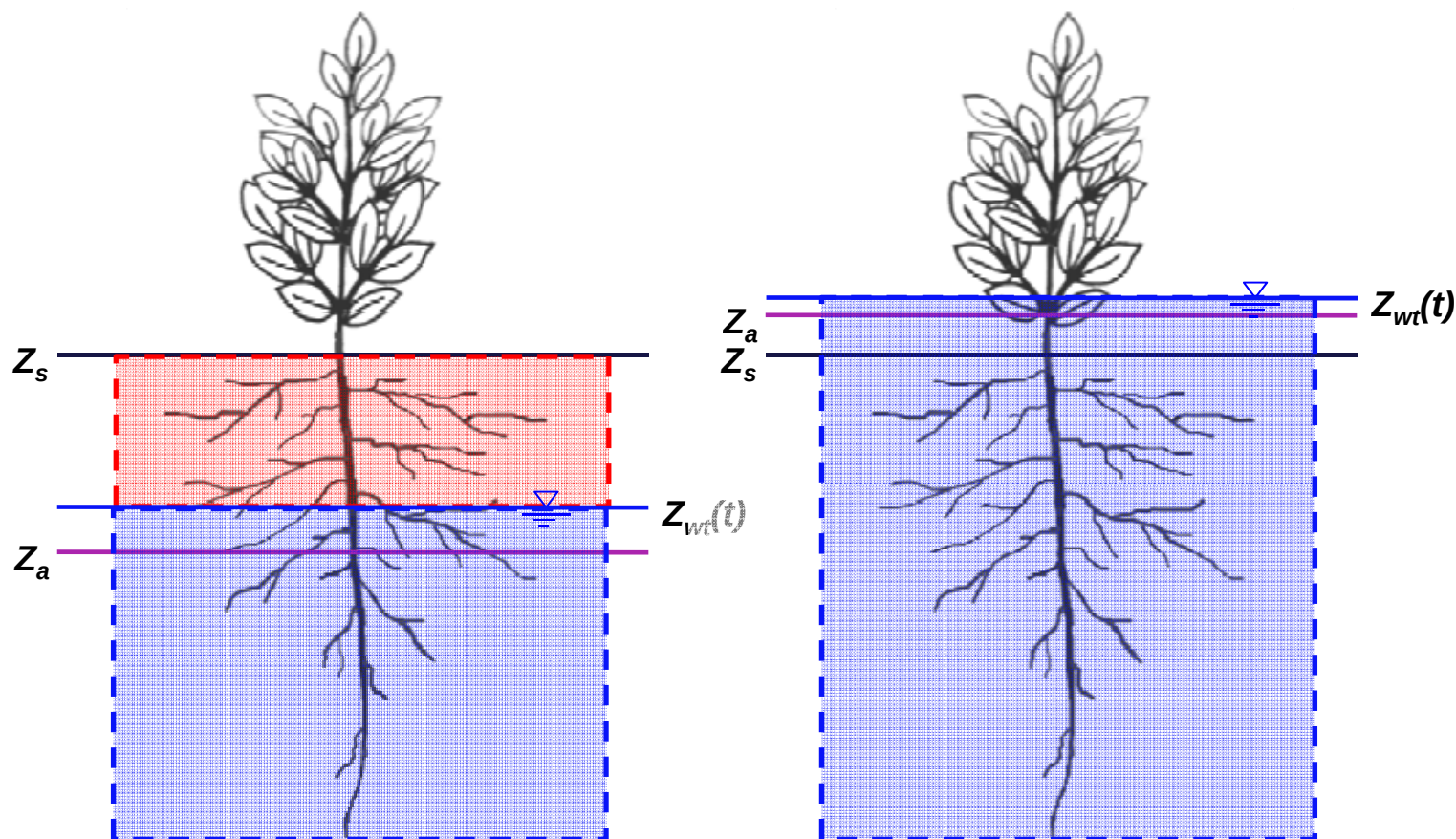


- **MODULE 1.- IMPACTS** → effect of the hydrological extremes over the vegetation
 - **Biomass remain** → $B(t) = B(t-1) \cdot \xi(t)$
 - Parameters: **minimum** and **critical** values to mark out the impact
 - No impact
 - Limited growth
 - Biomass loss
 - **Plant death => retrogression to bare soil**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

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



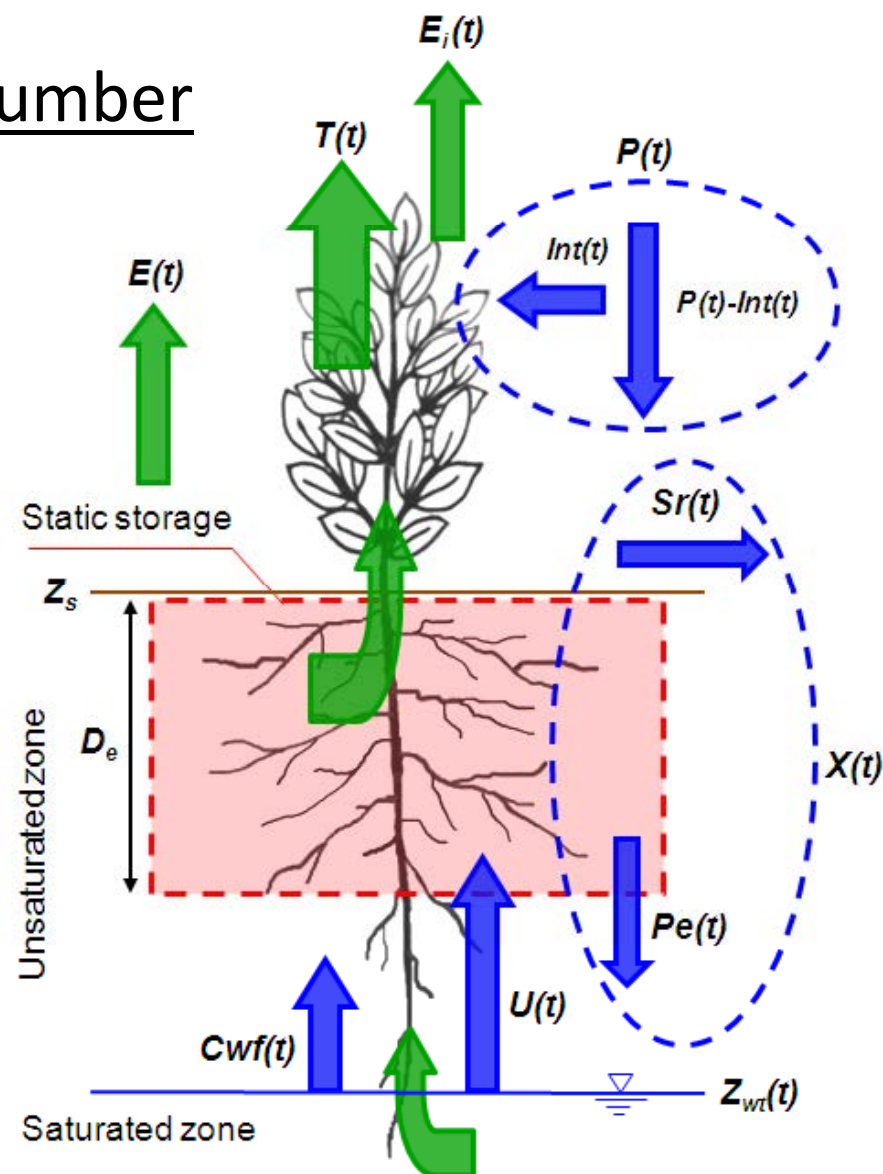
- ASPHYXIA BY FLOOD → number of days that $Z_{wt} > Z_a$
- $Z_a > \text{or} < Z_s$? → SPFTs parameter



- ## => Hydrological submodel

WATER FLUXES →

Green arrows
represent the
actual ET



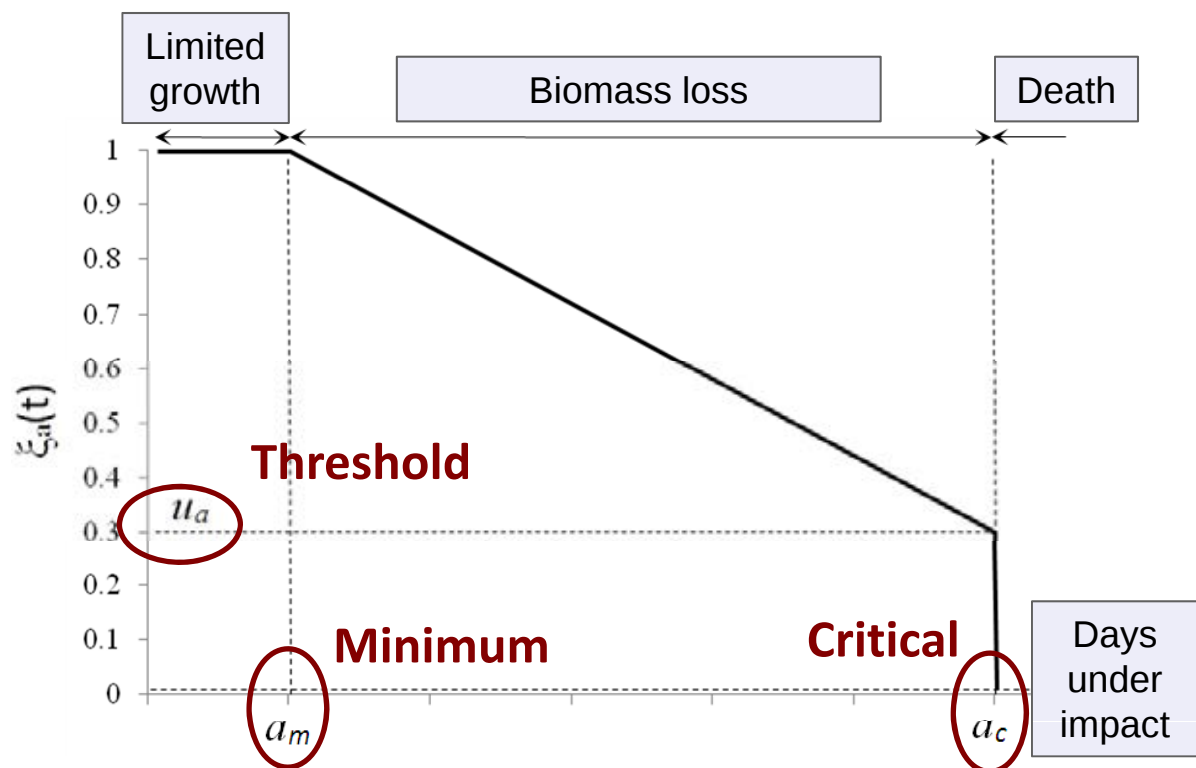
MODULE 1.- IMPACTS → effect of the hydrological extremes over the vegetation

- Effects of **asphyxia** → $f(Z_{wt})$
- Effects of **wilt** → $f(T)$

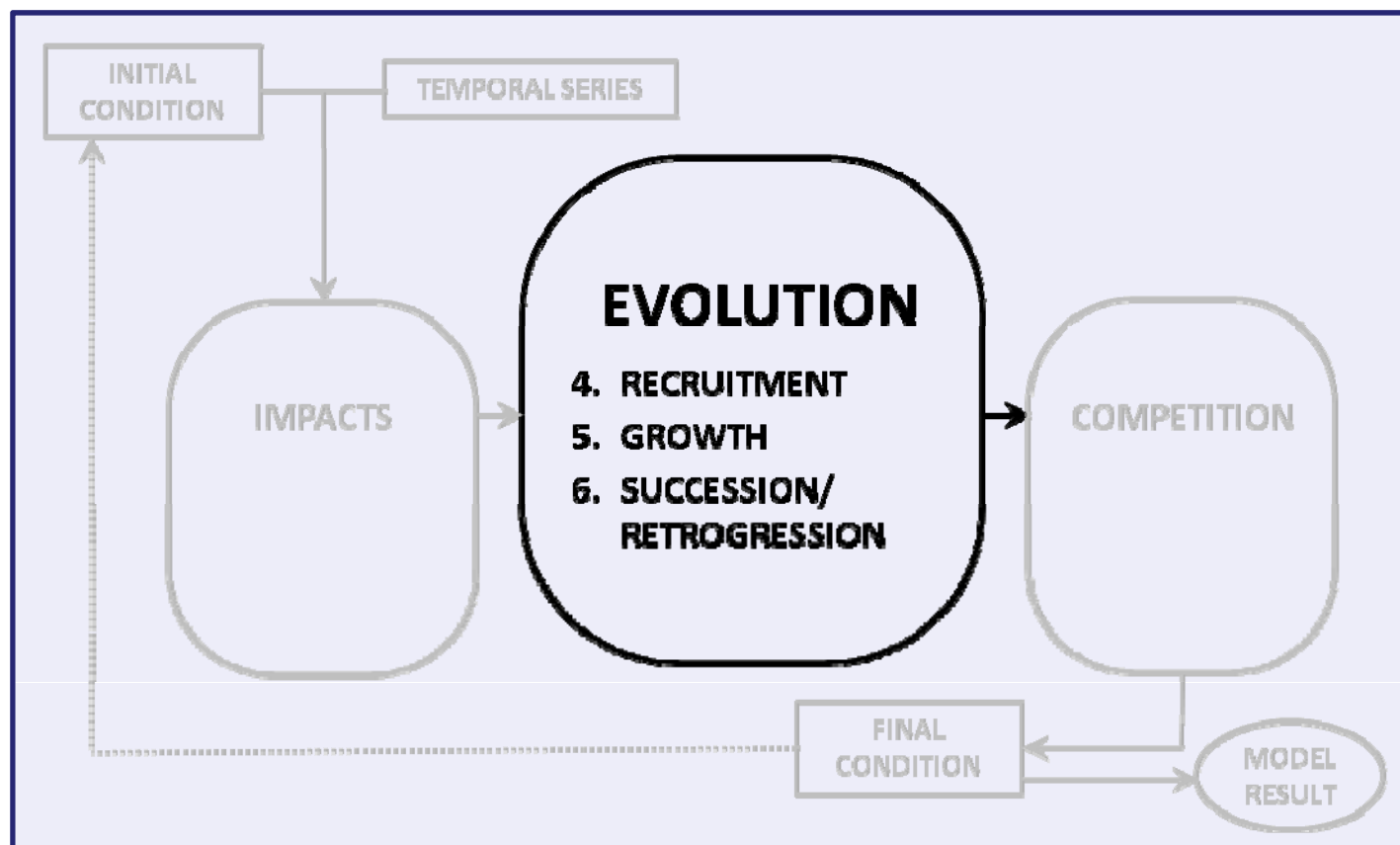
LINEAR BIOMASS LOSS FUNCTIONS

ASPHYXIA and WILT:

- Same function
- Different parameters values
- W_m , W_c and U_w



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



MODULE 2.- EVOLUTION → a) RECRUITMENT

- Presence of available seeds: $BS \rightarrow PSC$
- Germination of the seeds: $PSC \rightarrow P$
- Establishment of the seedlings: $P \rightarrow H$

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

- 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-TV} or P_{CW-TV}

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

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

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

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

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

WATER
AVAILABILITY

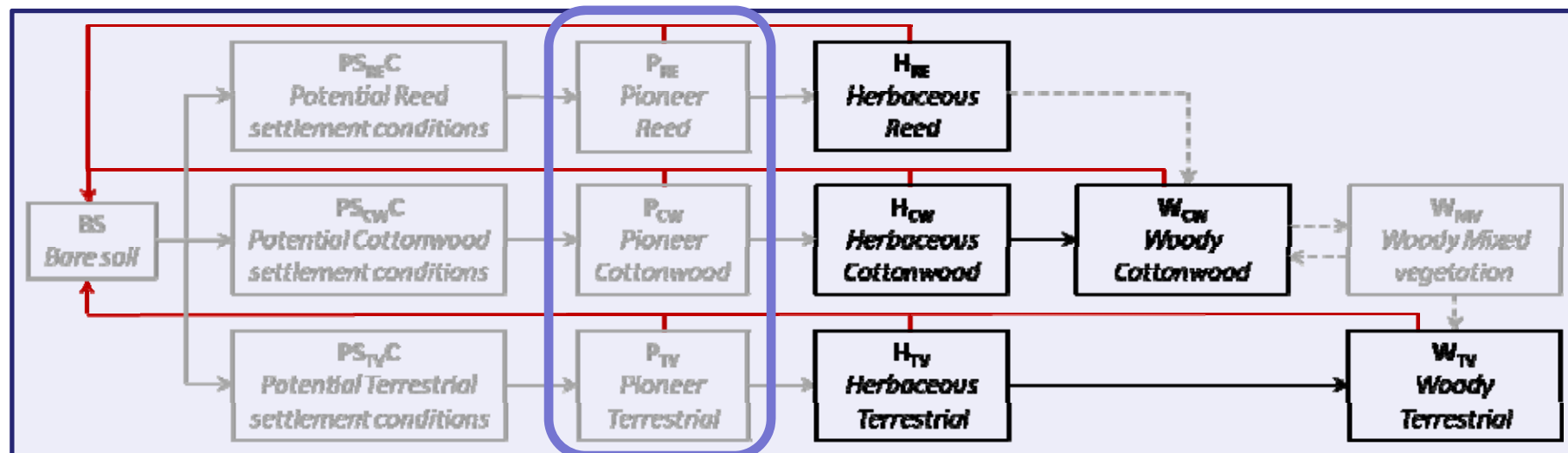
Logistic component

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

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**

MODULE 2.- EVOLUTION → c) SUCCESSION/RETROGRESSION



THRESHOLDS

SUCCESSION

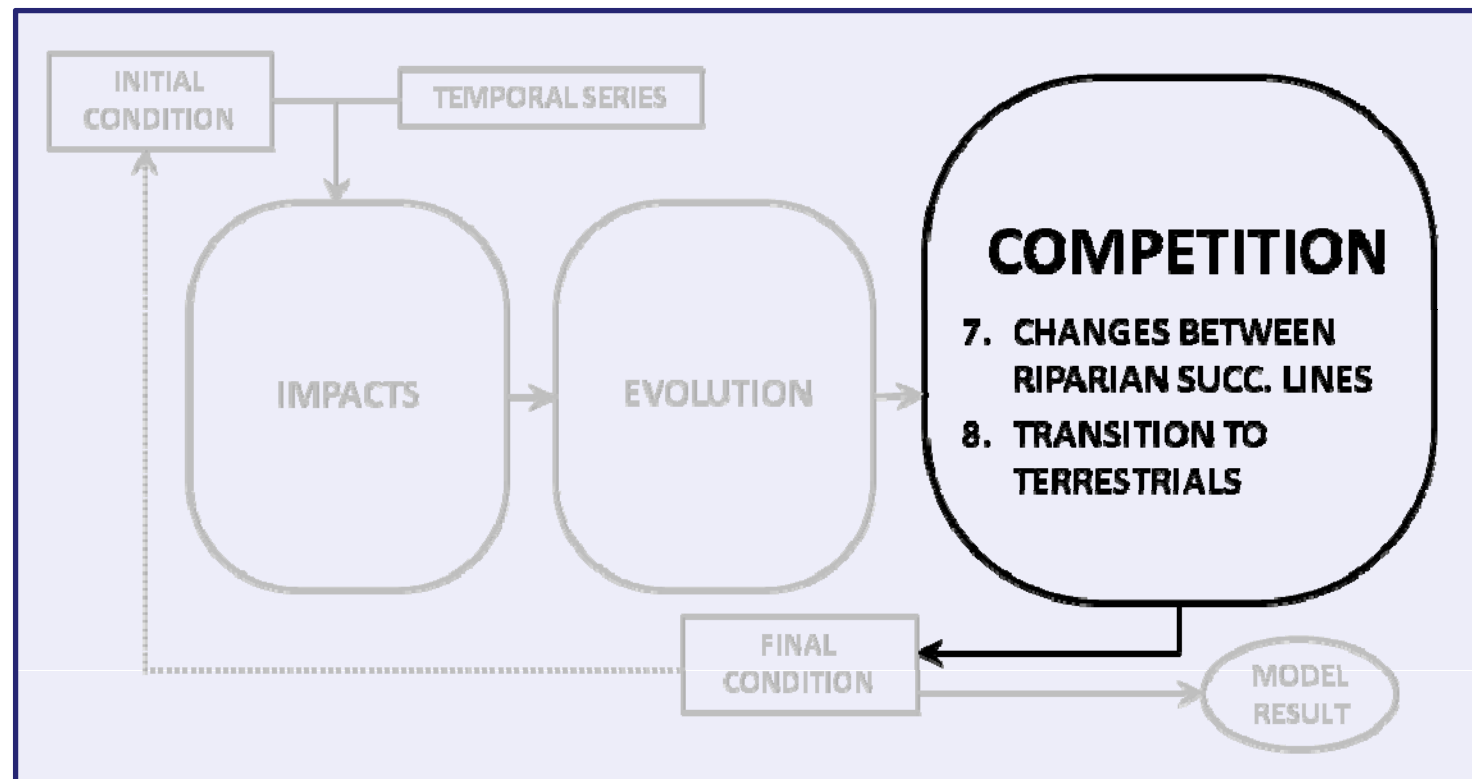
B_{min} minimum biomass
 Age_s minimum num. days

RETROGRESSION

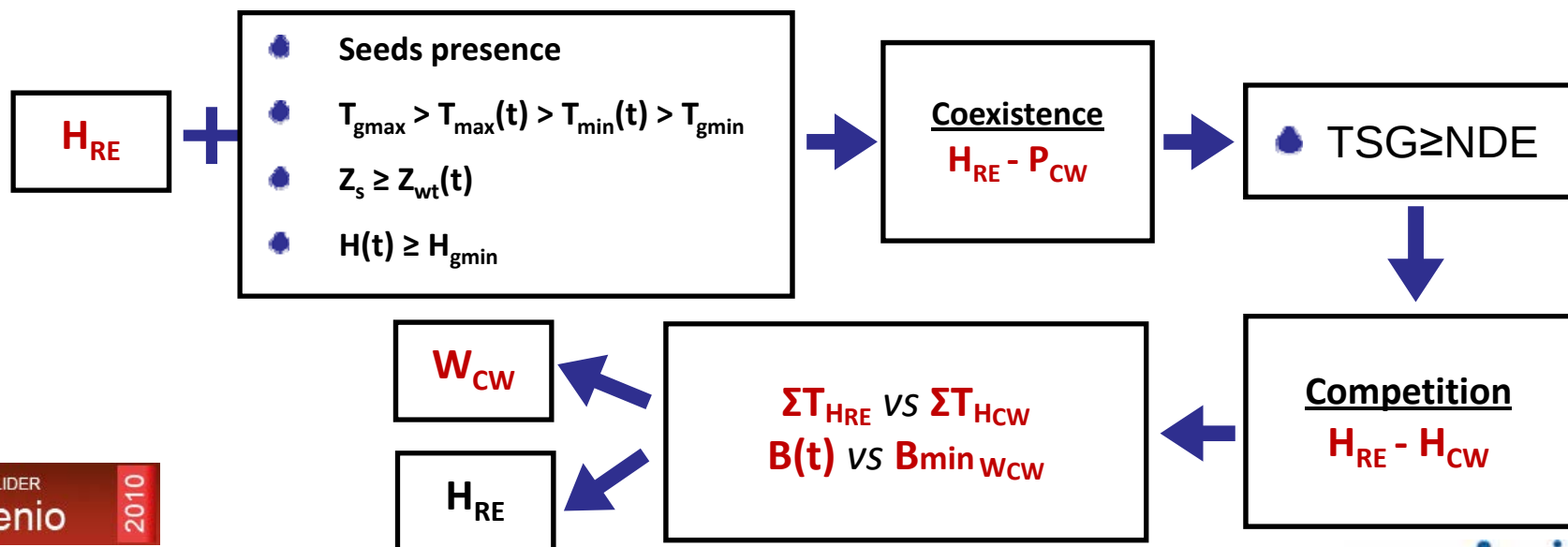
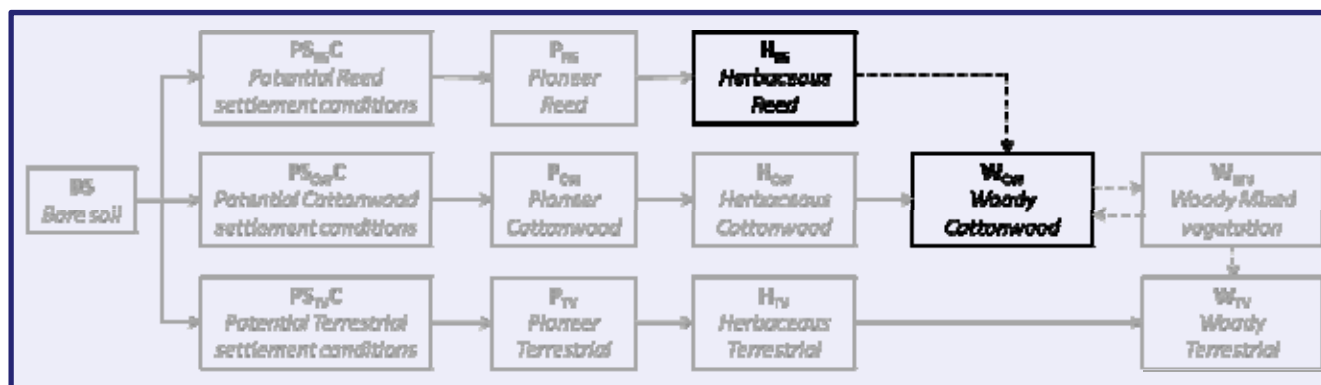
Age_{max} maximum num. days

● Affects to each succession line independently

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



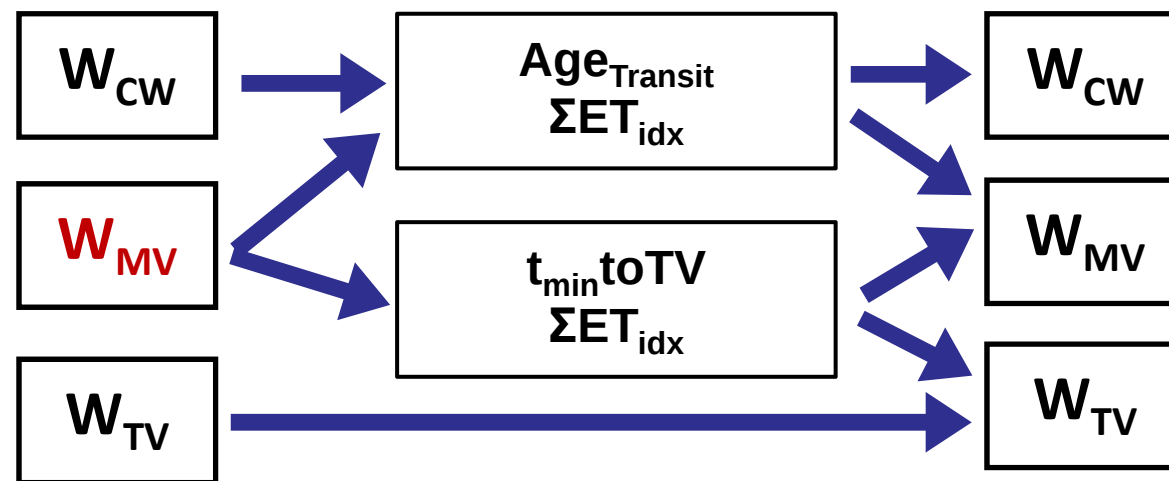
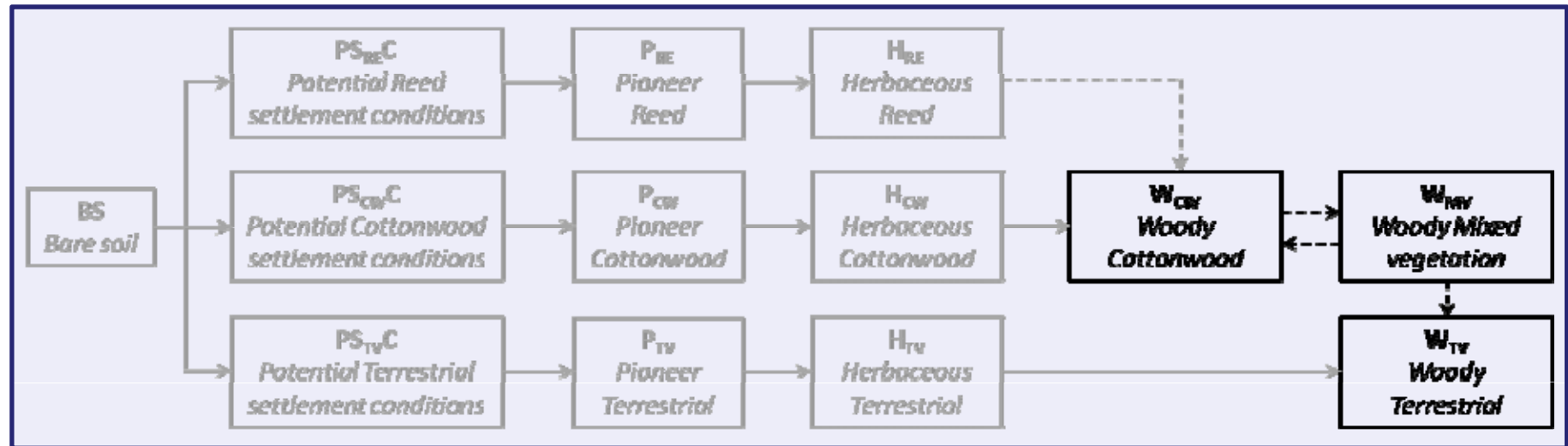
MODULE 3.- COMPETITION → a) CHANGES BETWEEN RIPARIAN SUCCESSION LINES



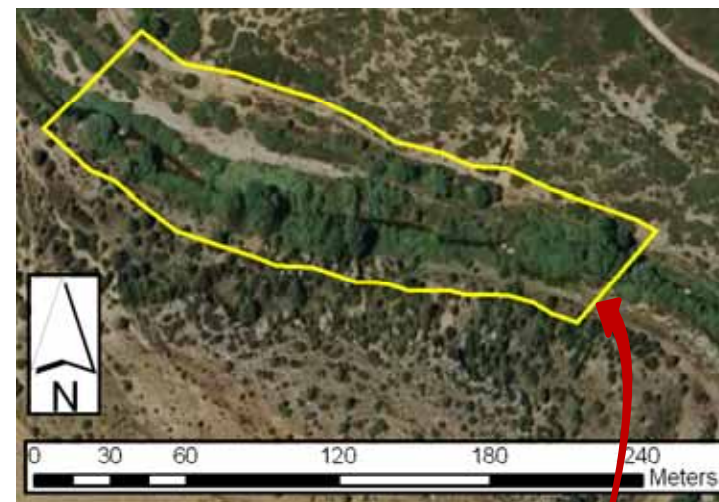
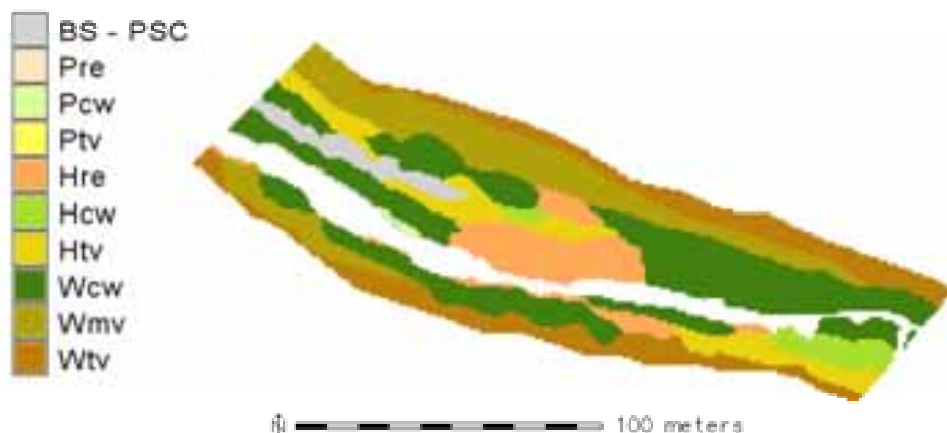


THE RVDM MODEL DESCRIPTION

MODULE 3.- COMPETITION → b) TRANSITION TO TERRESTRIALS



Terde reach (Mijares River, Spain)



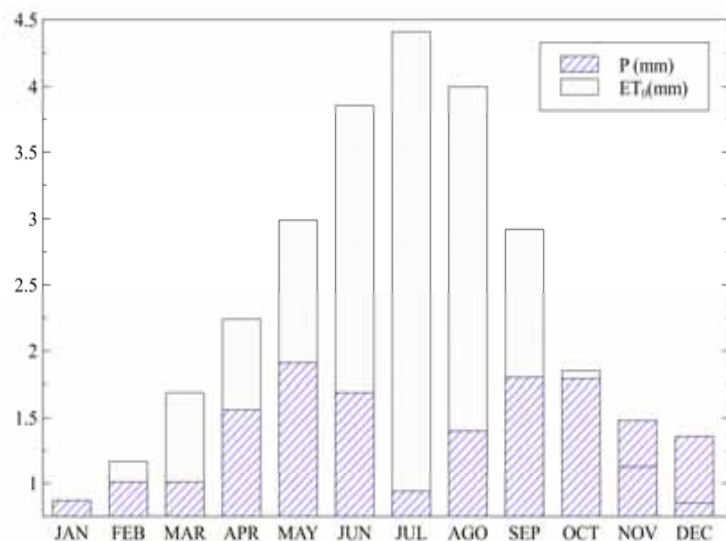
- Altitude: 850 m.a.s.l.
- Length: 228.5 m
- Basin area: 665 km²
- Average Q_d : 0.855 m³/s
- Near natural conditions:
Willows and poplars are dominant





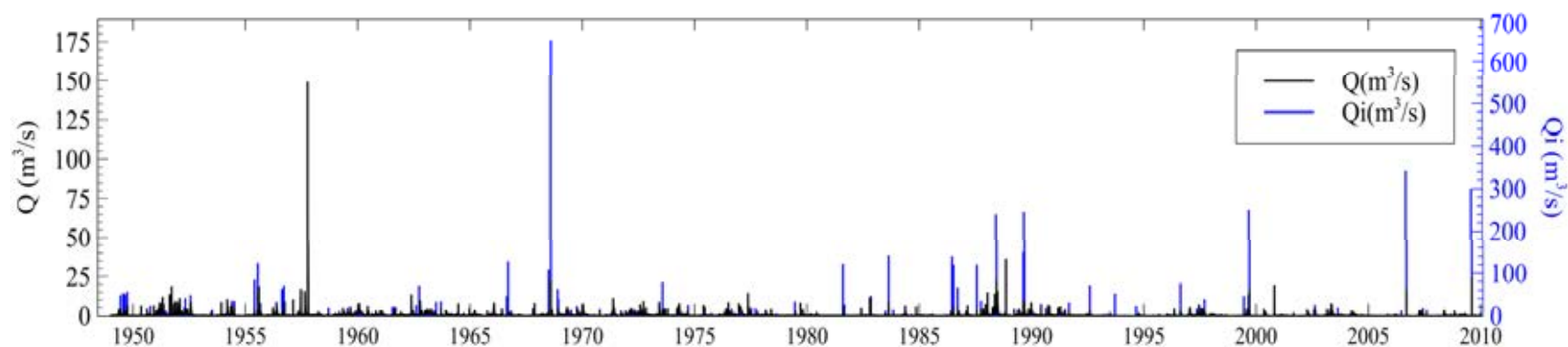
MODEL INPUTS DEFINITION

Hidro-meteorological data



Time period: **P= 506 mm/year**
1949 - 2009 **ET₀ = 843 mm/year**

Typical Mediterranean and
semiarid environment



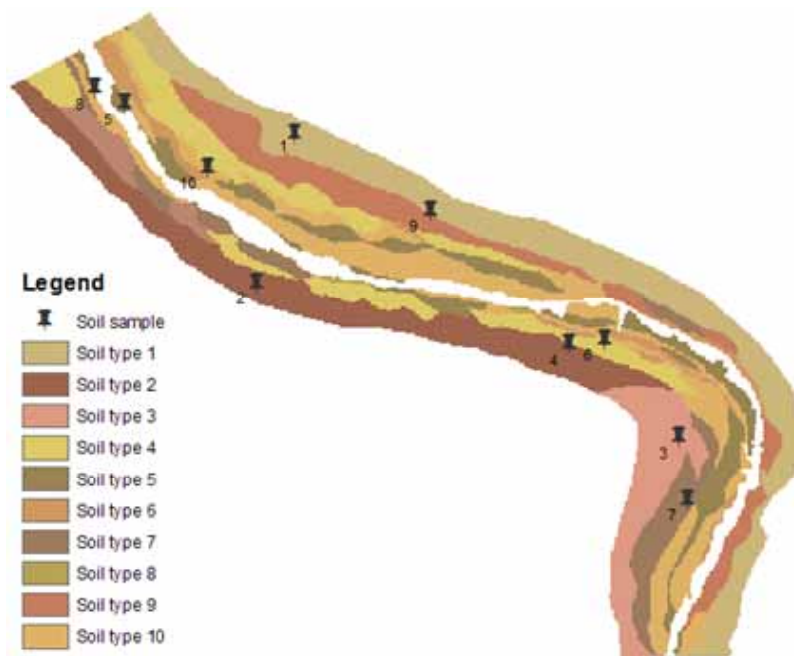
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2010



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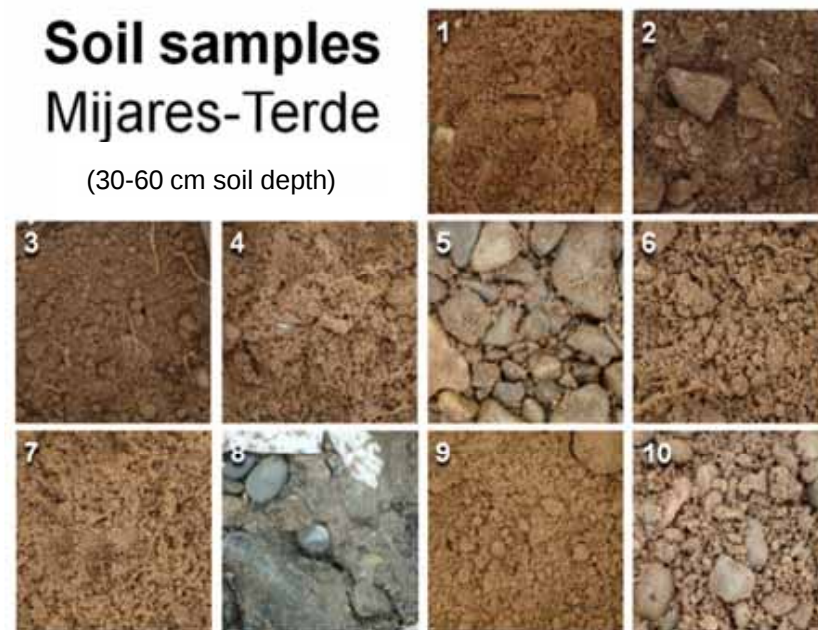


- The substrate is varied: fine gravel, gravel, cobbles, scattered boulders



Soil samples Mijares-Terde

(30-60 cm soil depth)

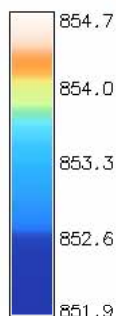
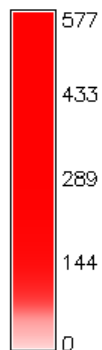
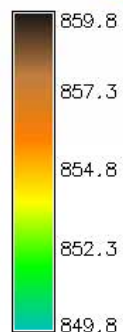
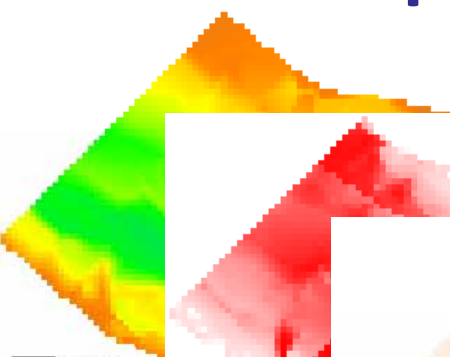


Soil types parameters

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

DEM (m.a.s.l.)

 τ (N/m²) Z_{wt} (m.a.s.l.)

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

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

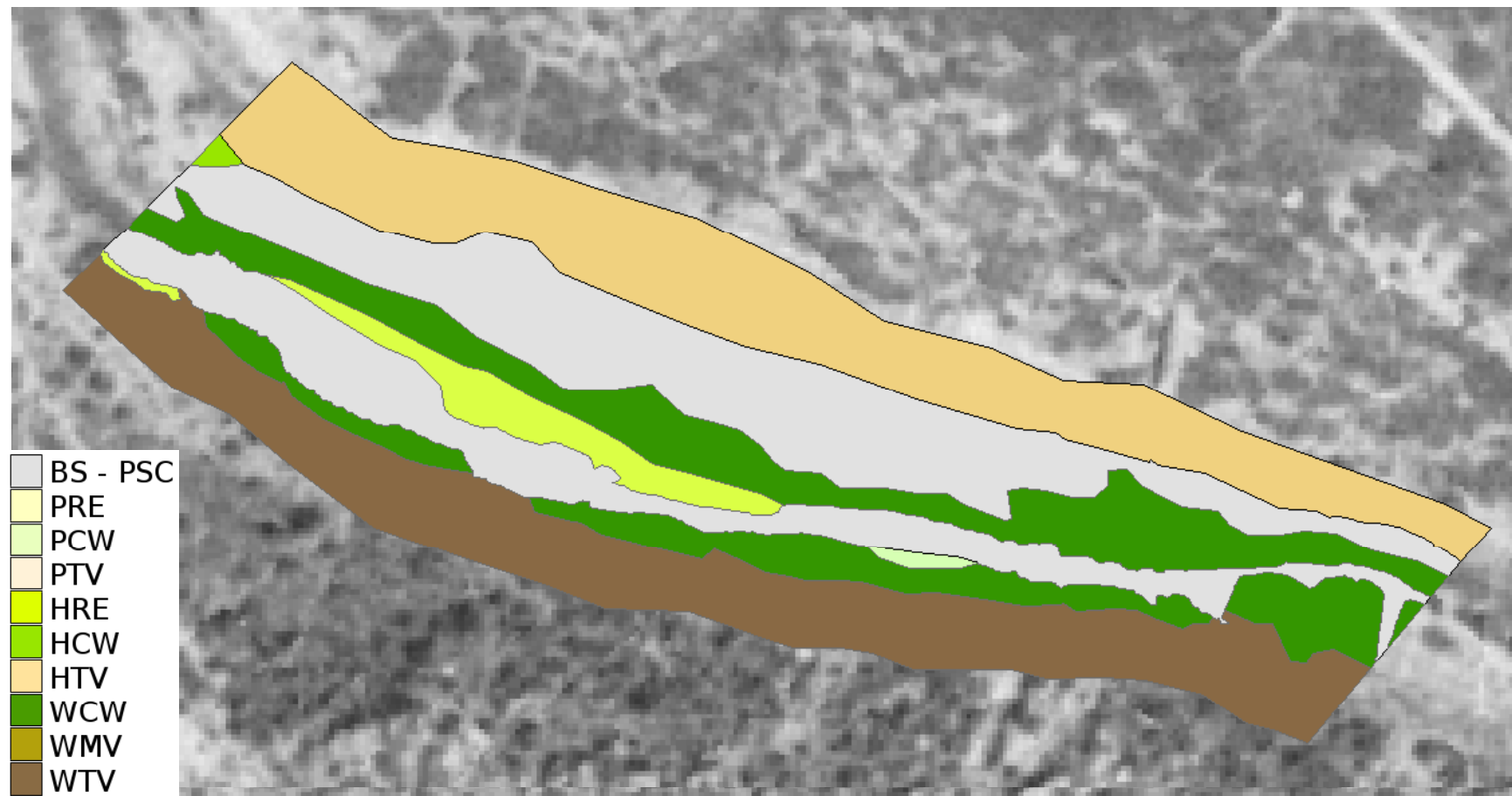
SPFTs MAPS – YEAR 2000





MODEL INPUTS DEFINITION

SPFTs MAPS – YEAR 1985



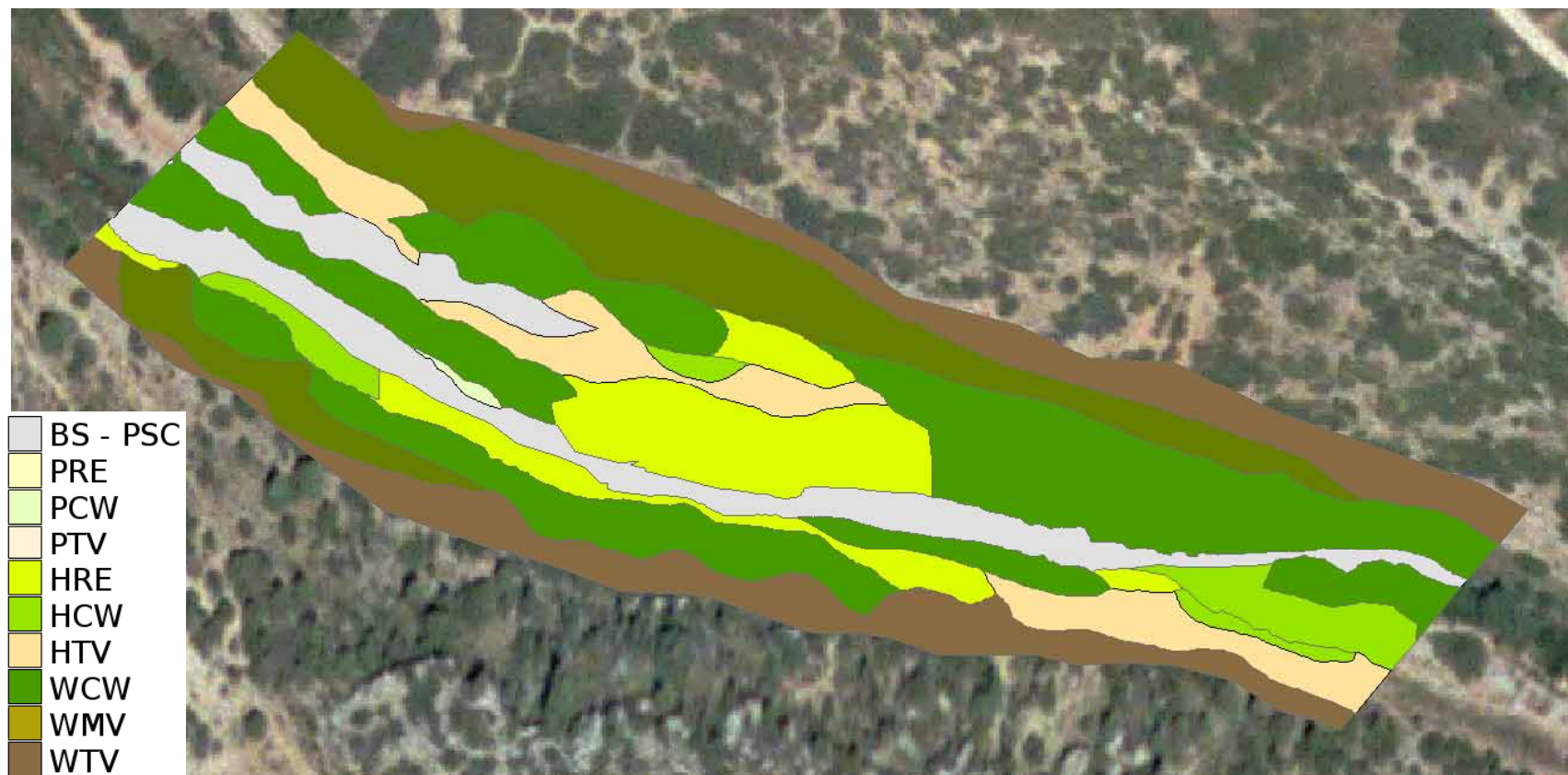
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SPFTs MAPS – YEAR 2006



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

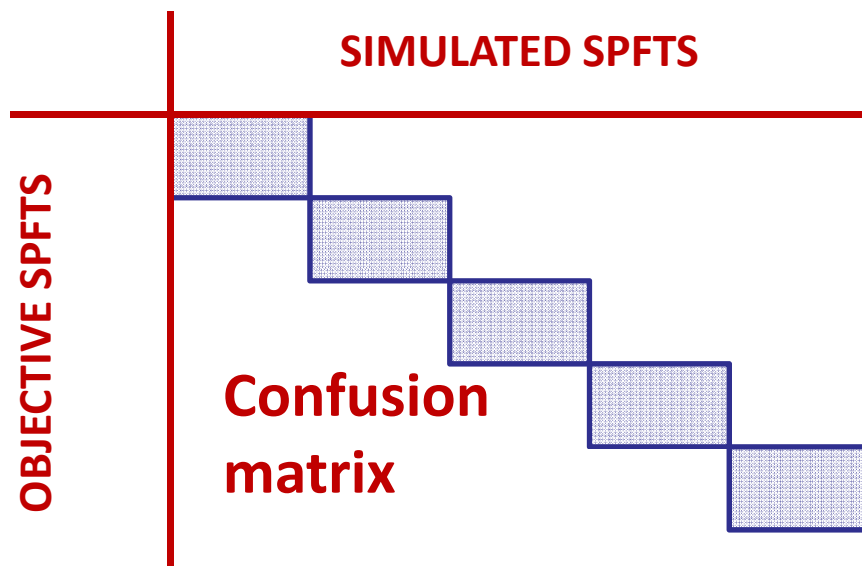
1985 – 2000

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:

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

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

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



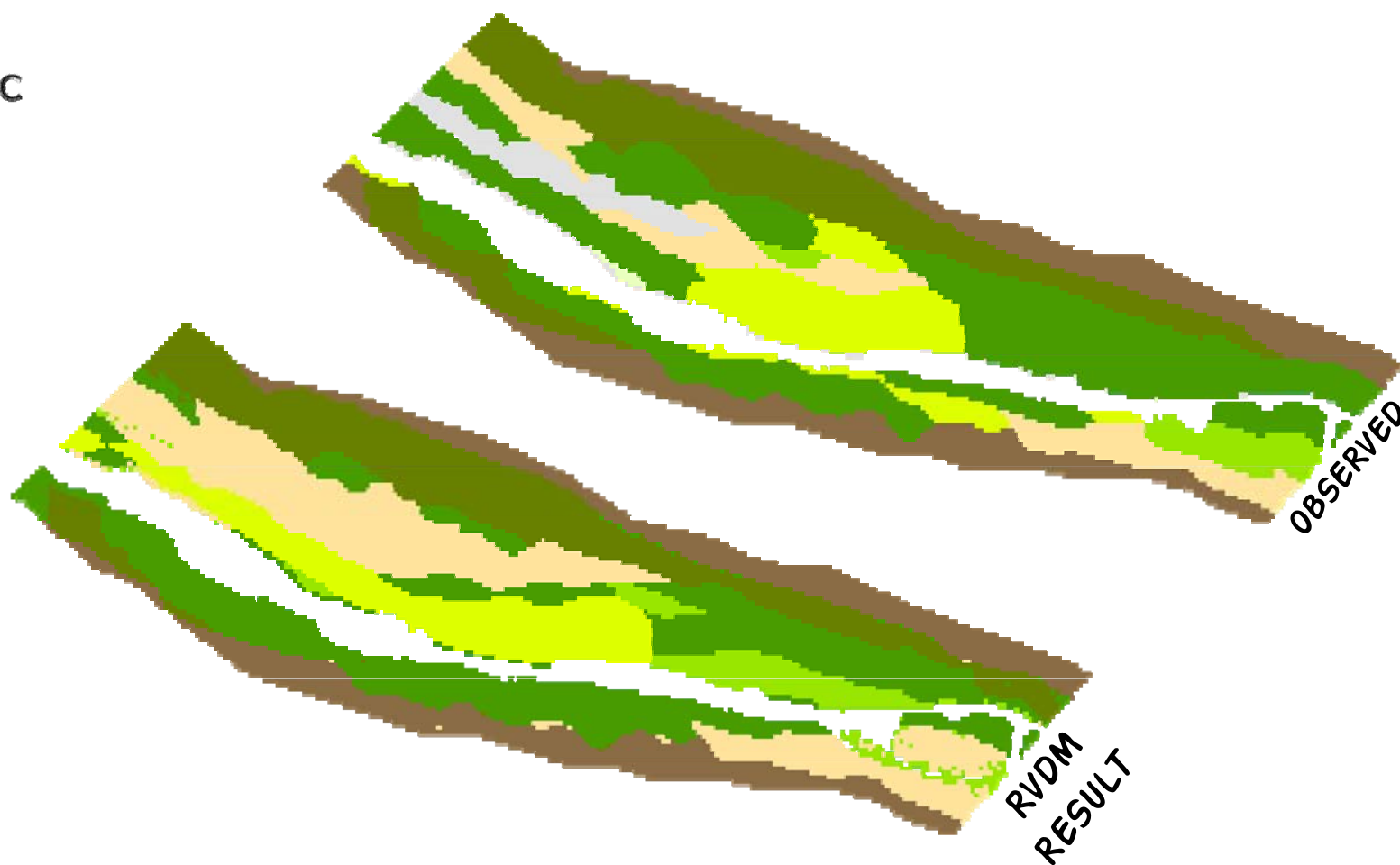
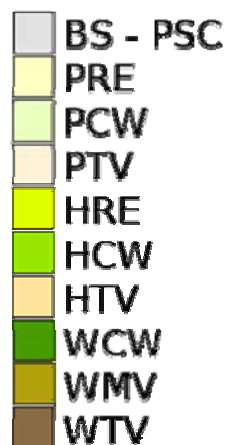
RESULTS

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

MODEL PERFORMANCE : CALIBRATION 2000 – 2006

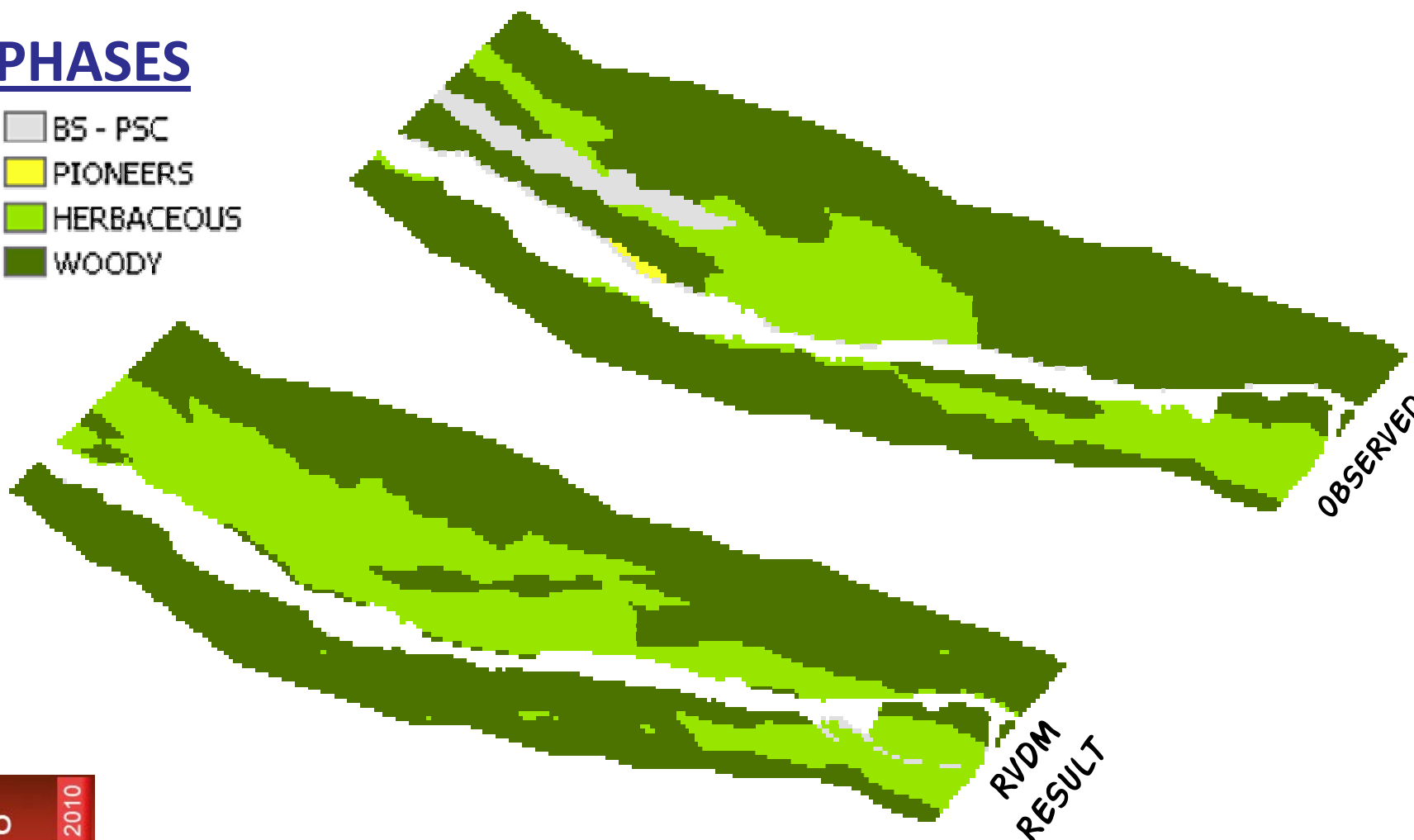
SPFTs



MODEL PERFORMANCE : CALIBRATION 2000 – 2006

PHASES

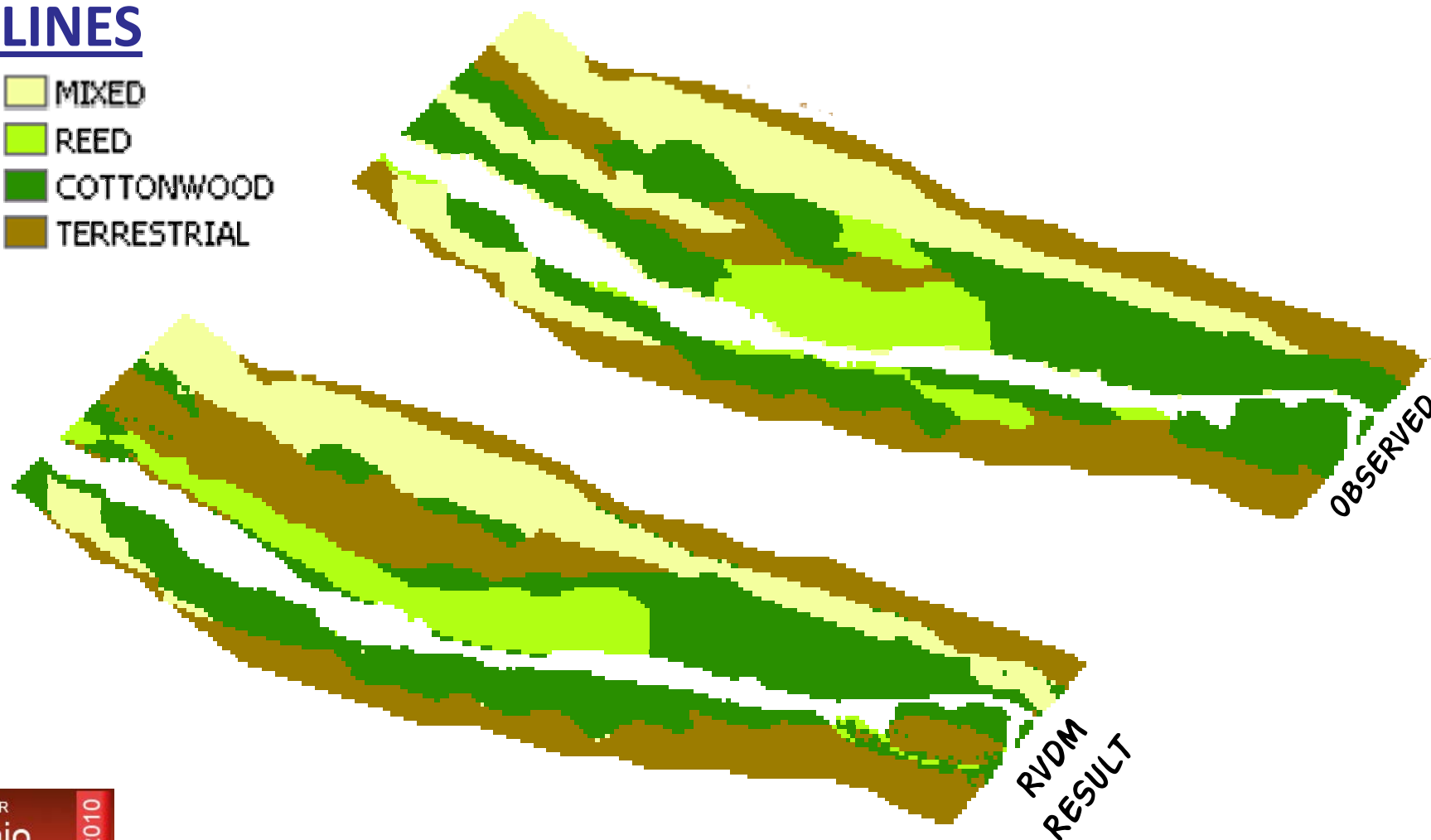
-  BS - PSC
-  PIONEERS
-  HERBACEOUS
-  WOODY



MODEL PERFORMANCE : CALIBRATION 2000 – 2006

LINES

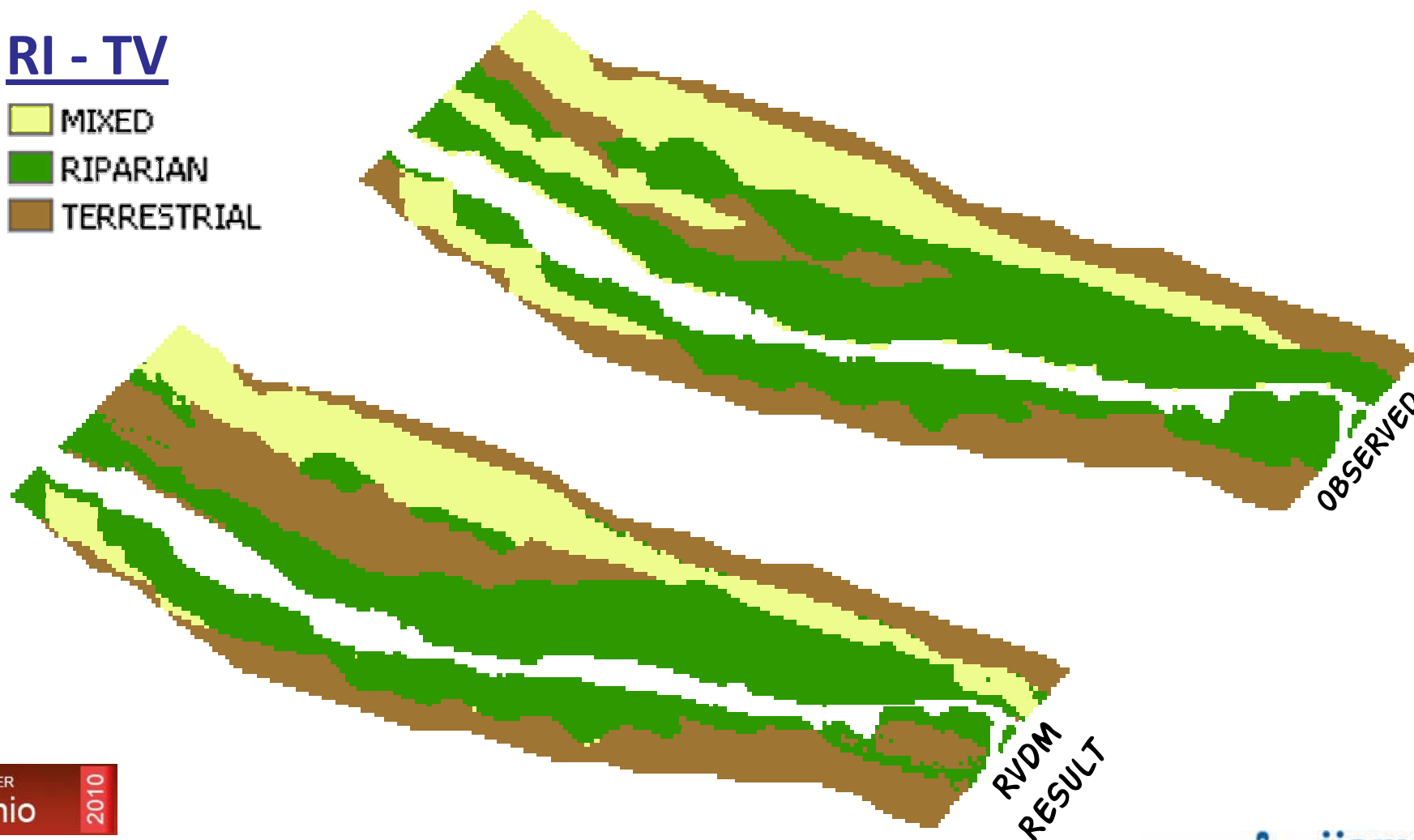
- MIXED
- REED
- COTTONWOOD
- TERRESTRIAL



MODEL PERFORMANCE : CALIBRATION 2000 – 2006

RI - TV

- MIXED
- RIPARIAN
- TERRESTRIAL



- 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

- 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

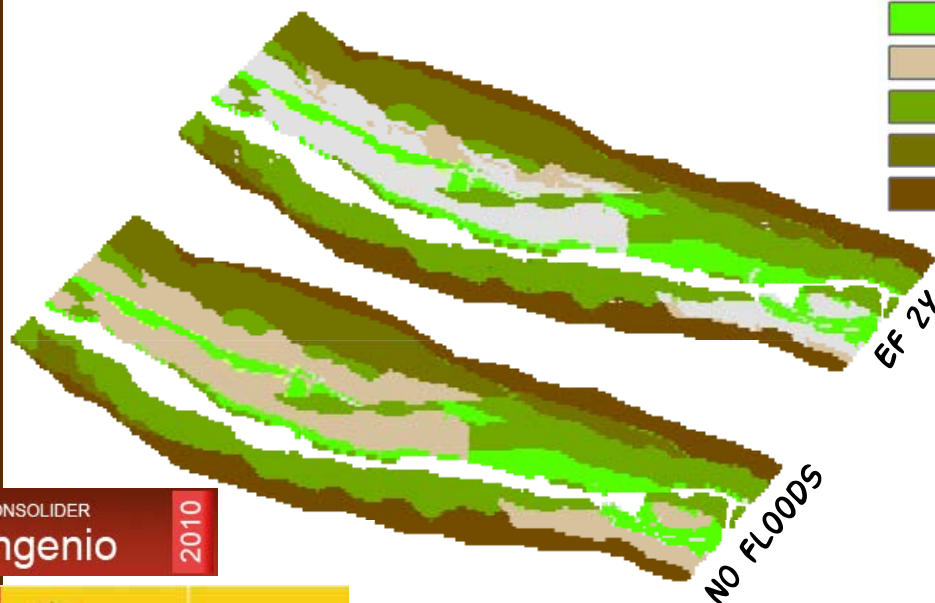
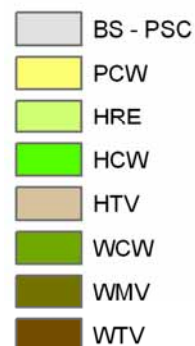
- Hydrological regime change
- Floods magnitude reduction
- Floods frequency reduction
- WTE stabilization



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

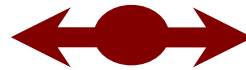
SPFTs



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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