Department of Civil, Environmental
and Mechanical Engineering

Vegetation responses to global changes

Field observations and modelling perspectives

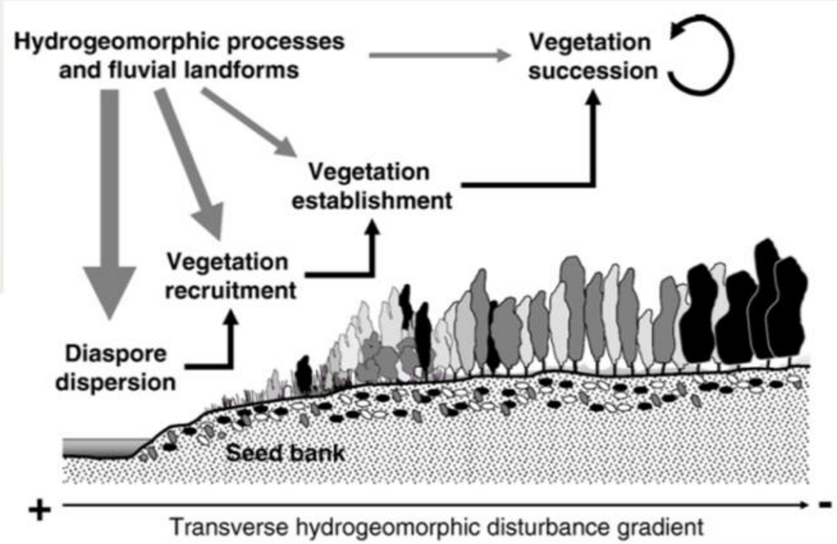
Walter Bertoldi

State of Science

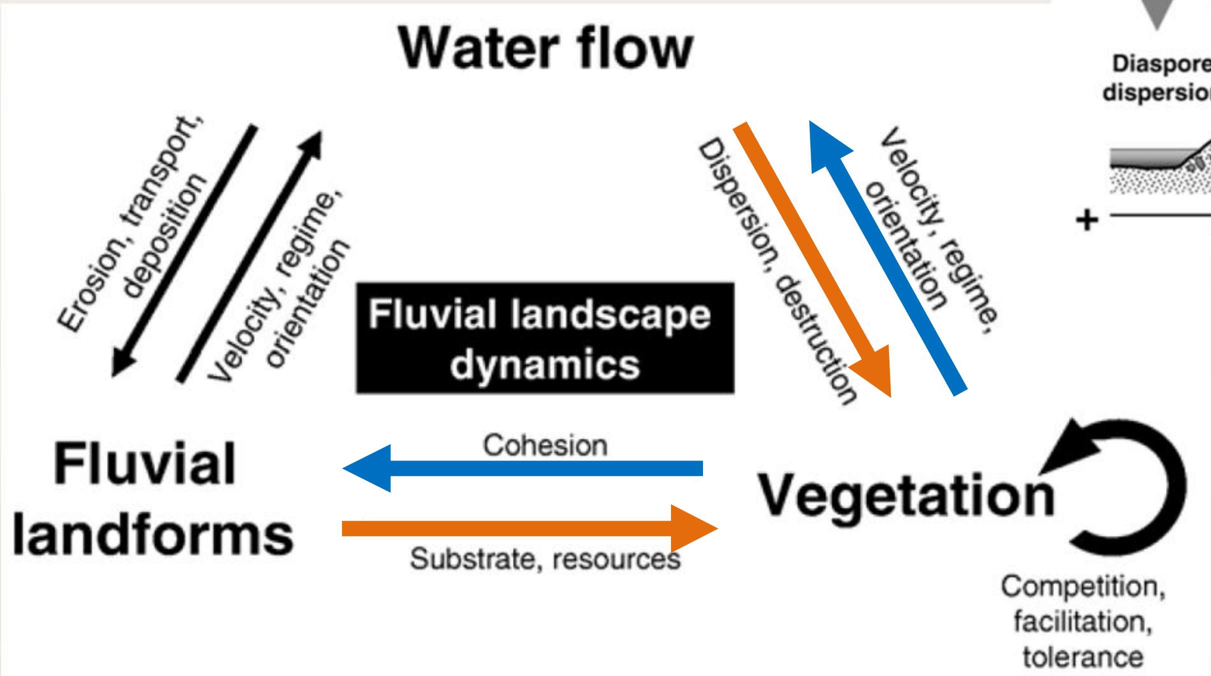
Plants as river system engineers

Angela Gurnell*
School of Geography, Queen Mary, University of London, London, UK

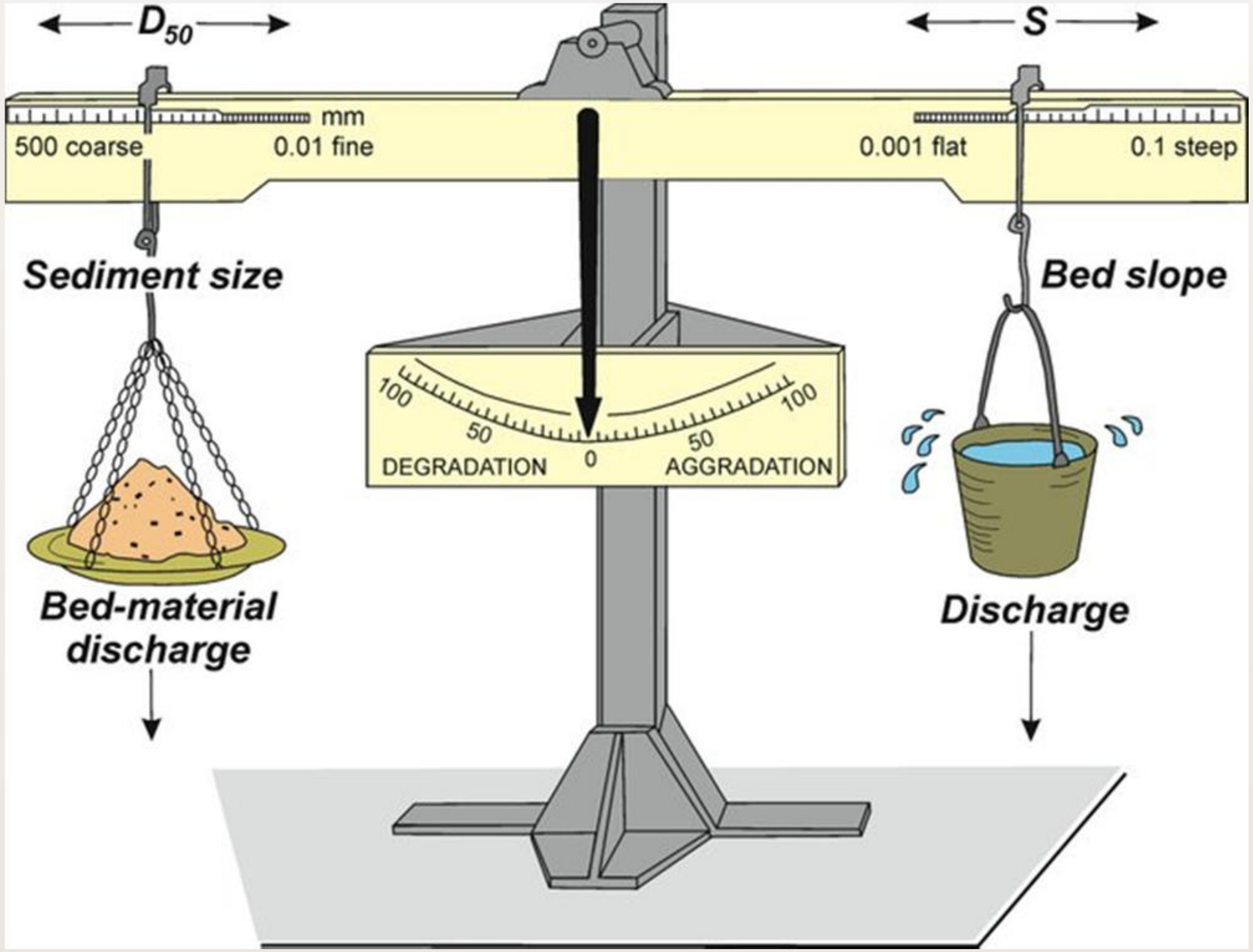
ESPL
Earth Surface Processes and Landforms



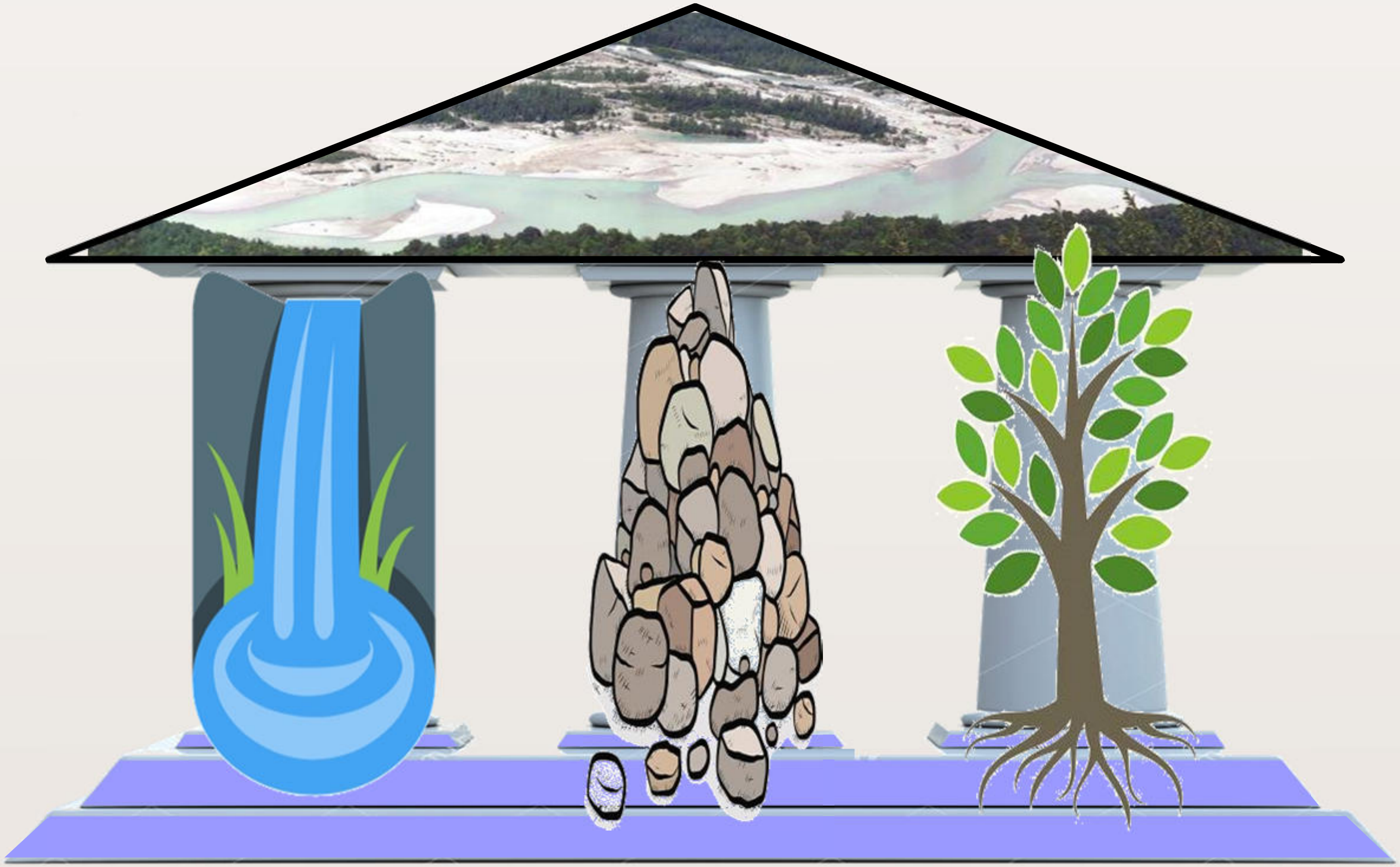
From Corenblit et al., 2007



FROM LANE'S BALANCE…



FROM LANE'S BALANCE TO A THREE PILLARS BUILDING



VEGETATION DYNAMICS

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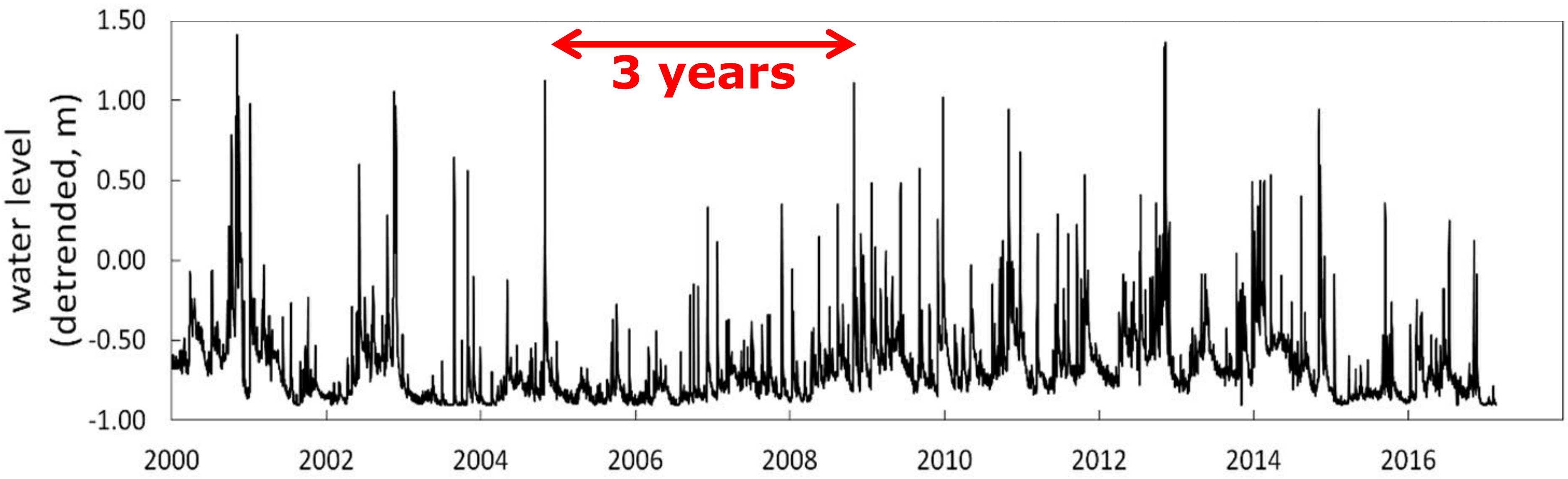
VEGETATION DYNAMICS

Gurnell, Bertoldi, Francis, Gurnell, Mardhiah

Understanding processes of island development on an island braided river over timescales from days to decades

Earth Surf. Process. Landforms 44, 624–640 (2019)



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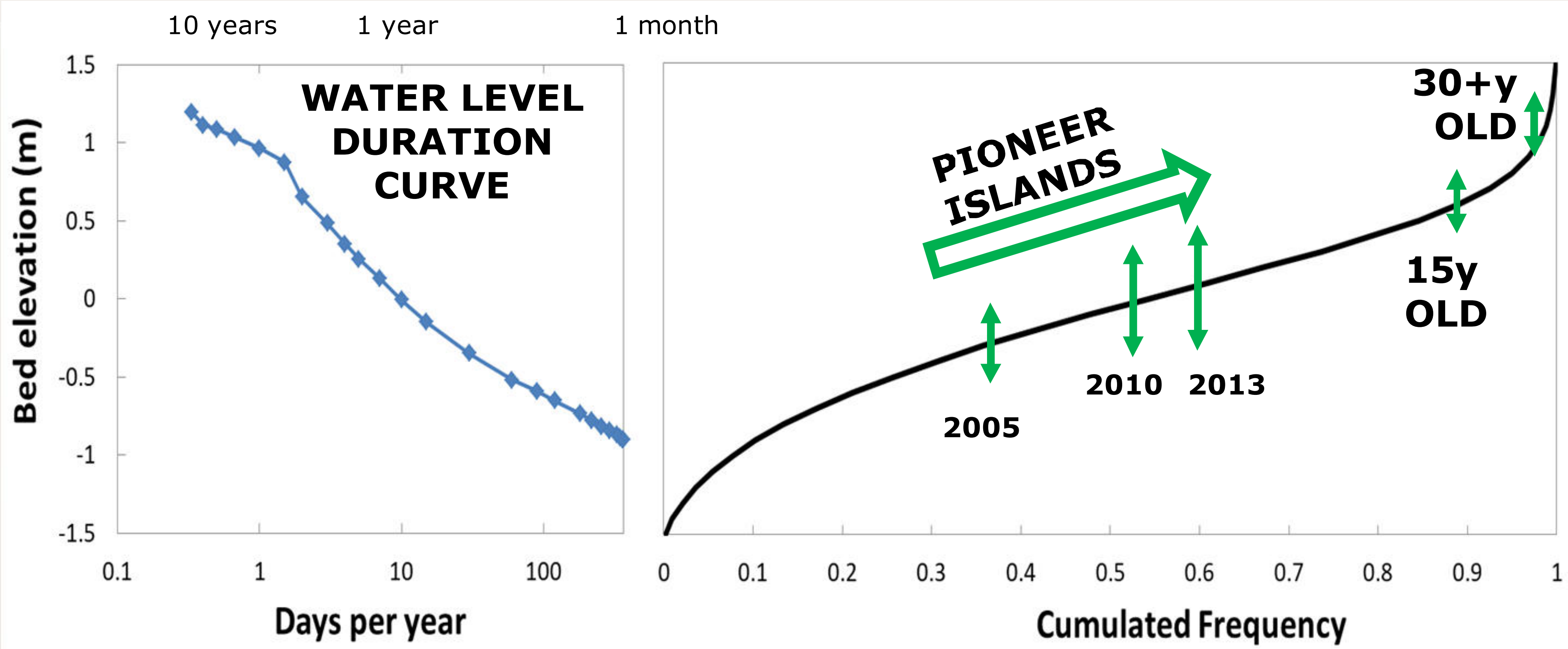

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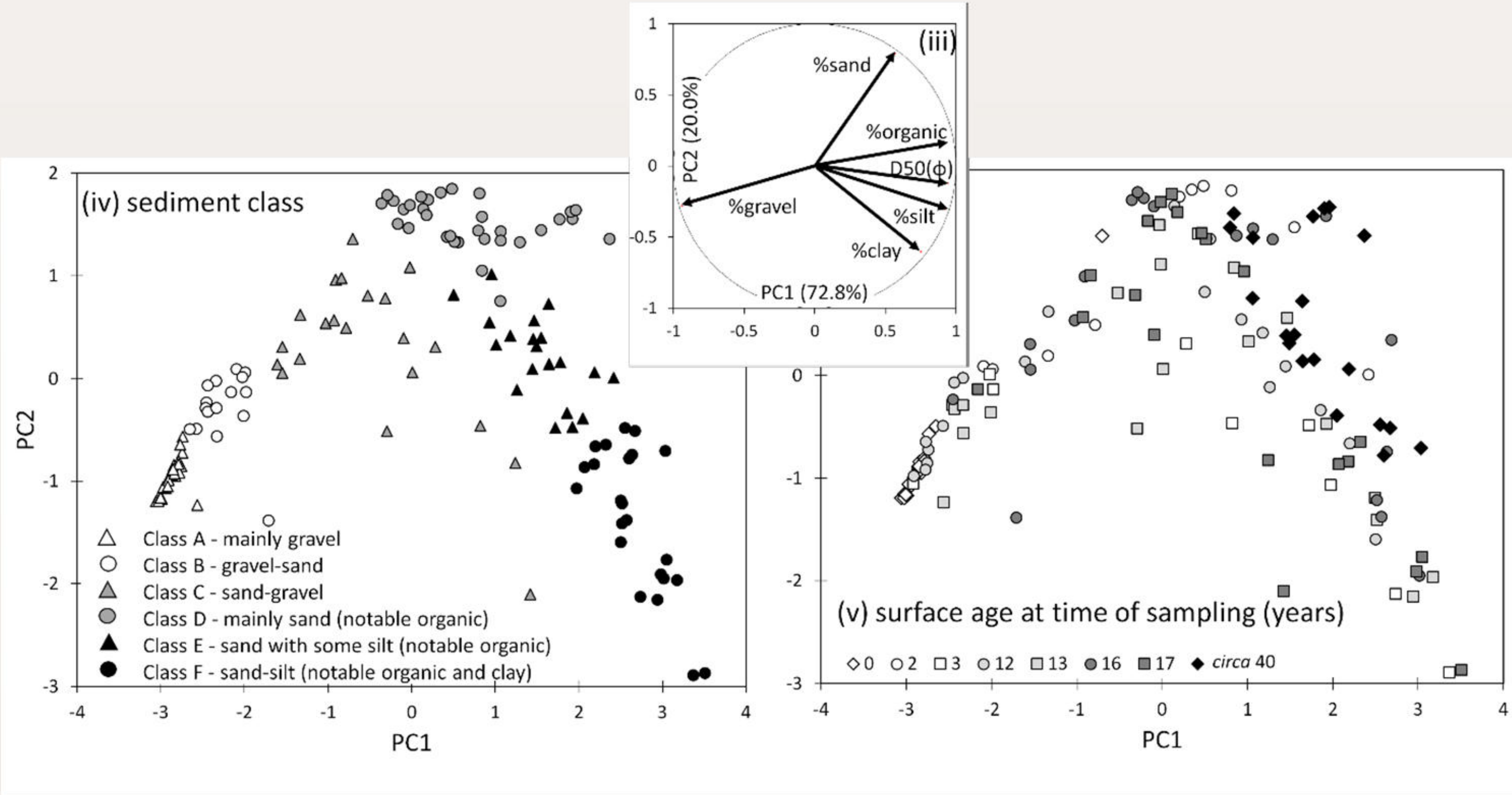
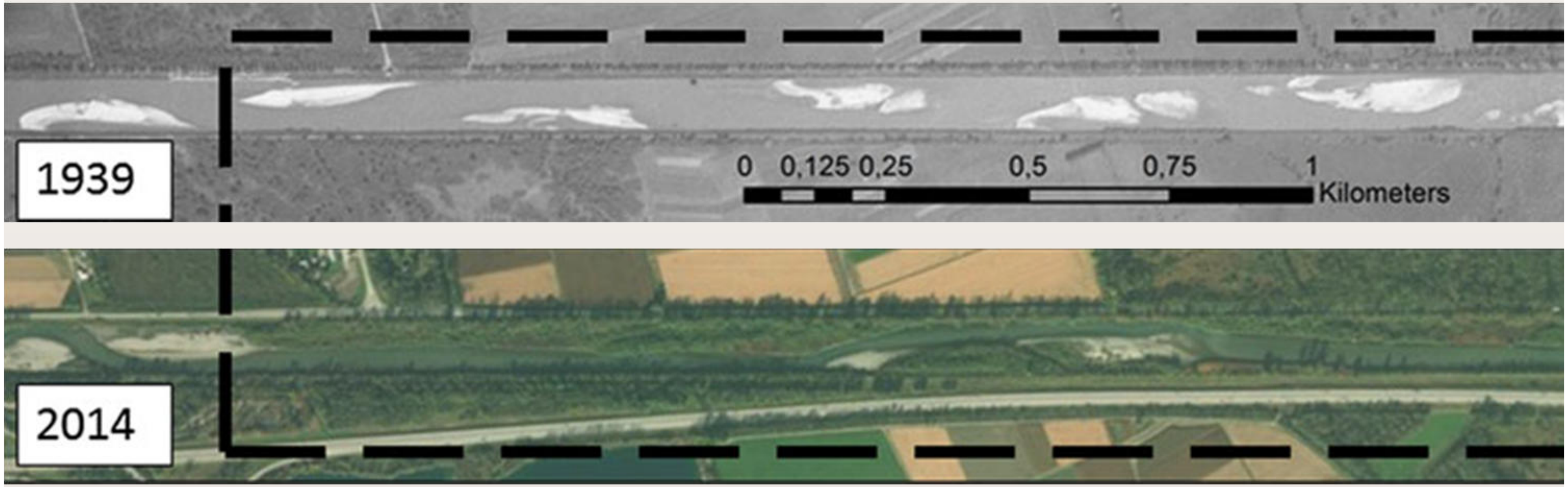


VEGETATION DYNAMICS

Serlet, Gurnell, Zolezzi, Wharton, Belleudy, Jourdain

Biomorphodynamics of alternate bars in a channelized, regulated river: An integrated historical and modelling analysis

Earth Surf. Process. Landforms 43, 1739–1756 (2018)



Isere River, France

VEGETATION DYNAMICS

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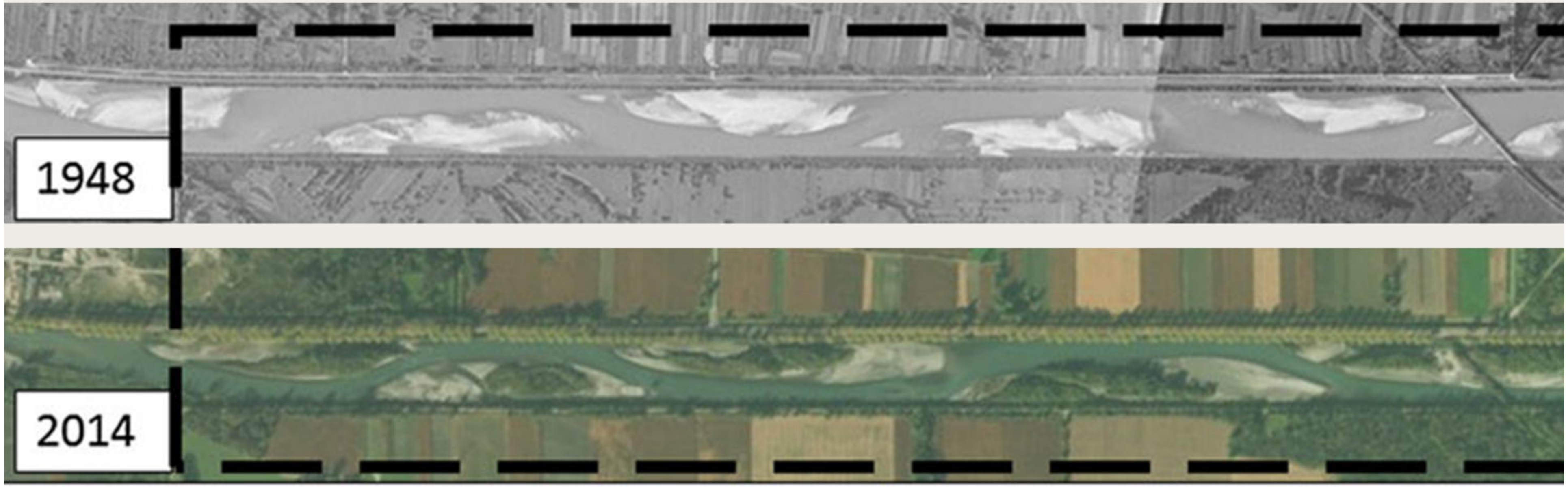


Isere River, France

VEGETATION DYNAMICS

Why is vegetation growing on the Isere?

And why not on the Rhine?

CAN WE MODEL THIS

?

WHAT ARE THE HYPOTHESIS?

IS IT USEFUL?

"…all models are wrong, but some are useful…"

George Box

*"An experiment need **NOT** be a scale model of a natural system. It need only include **enough** of the relevant dynamics."*

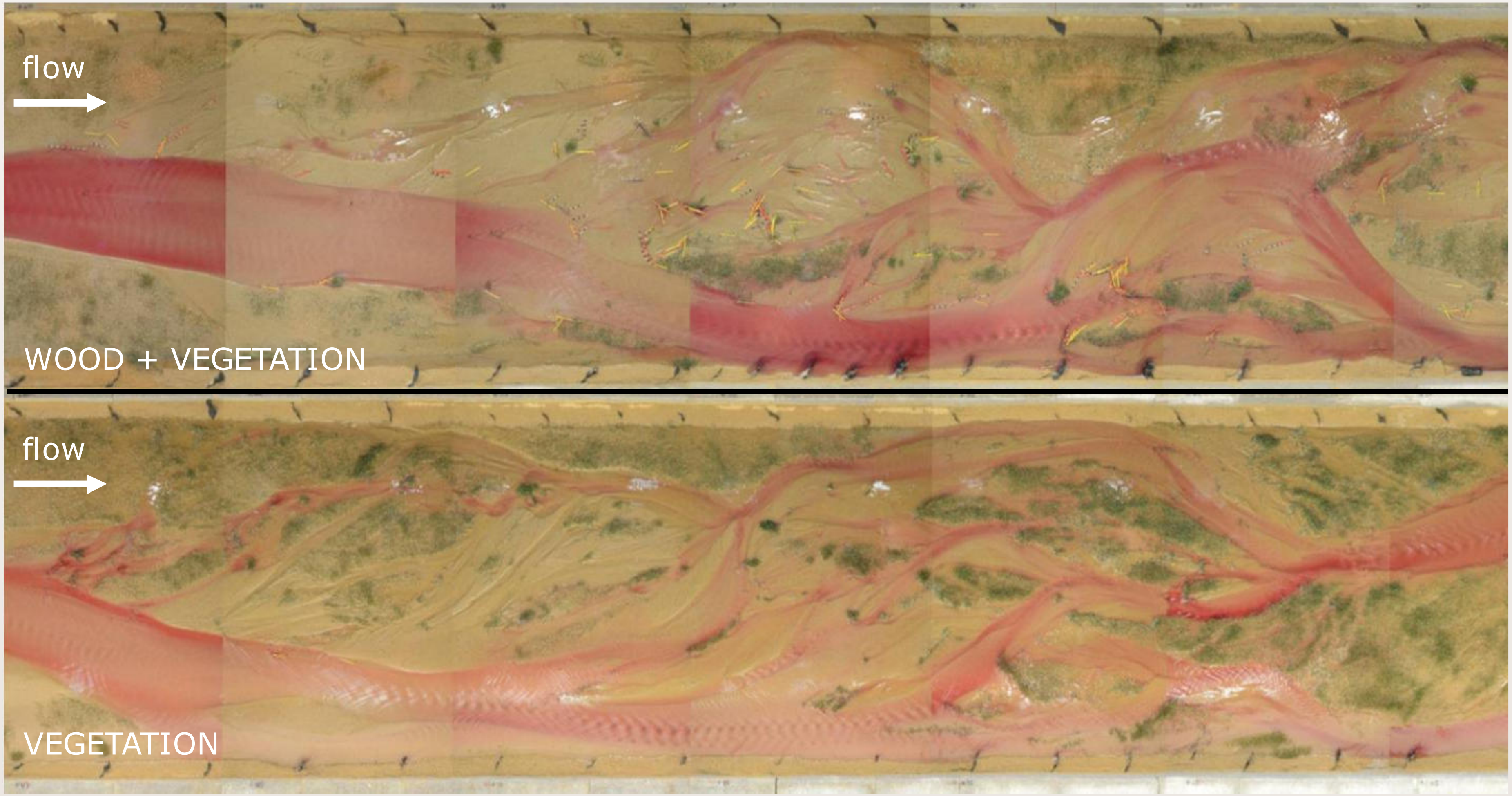
Paola, Straub, Mohrig, Reinhard (2009)
The "unreasonable effectiveness" of stratigraphic and geomorphic experiments.
Earth-Science Reviews 97, 1–43

Models are useful when they help **understand processes and controls** that are difficult to explore in real rivers

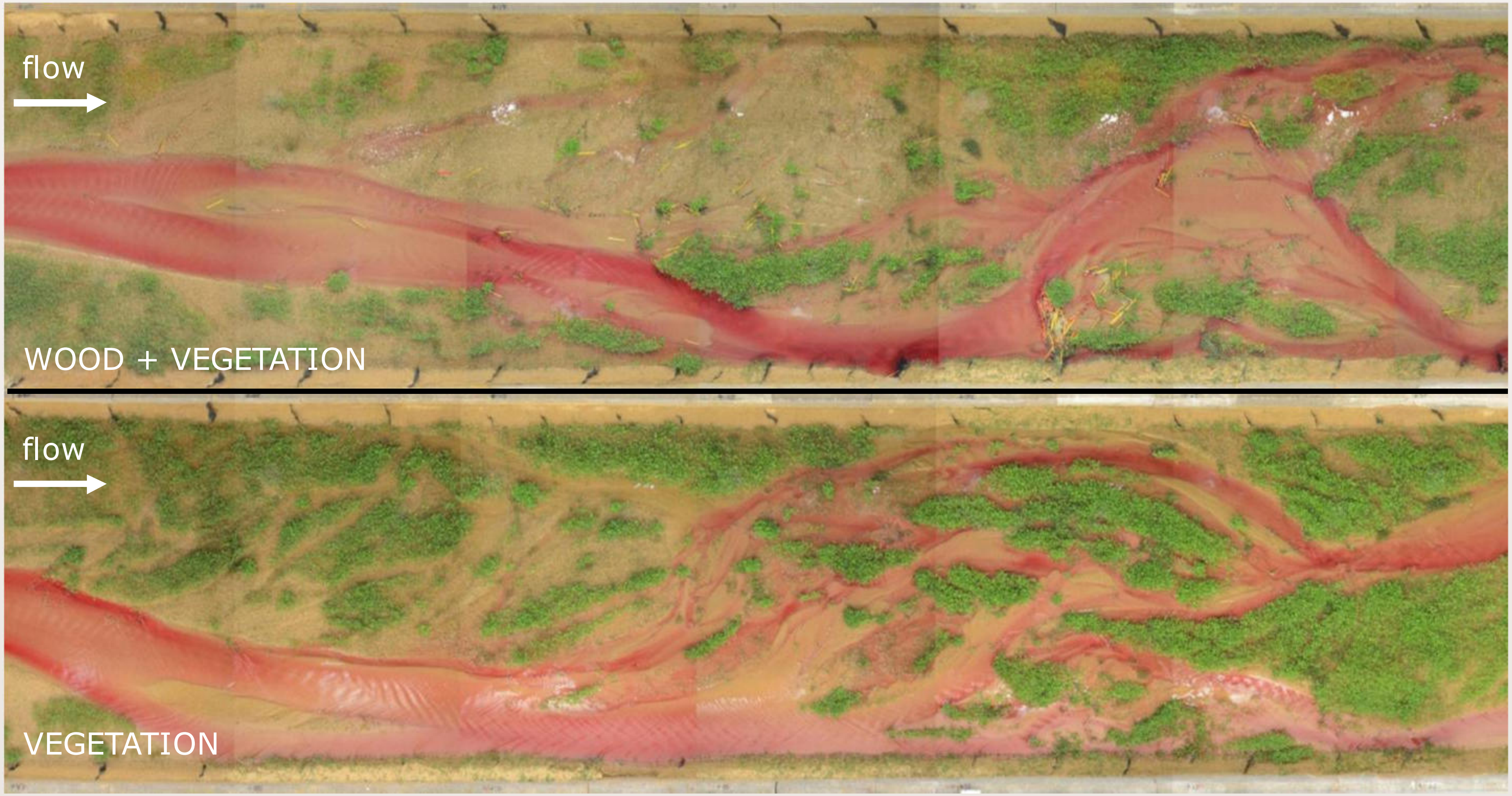
Bertoldi, Welber, Gurnell, Mao, Comiti, Tal
Physical modelling of the combined effect of vegetation and wood on river morphology
Geomorphology 246, 178–187 (2015)

wood and vegetation are modelled differently

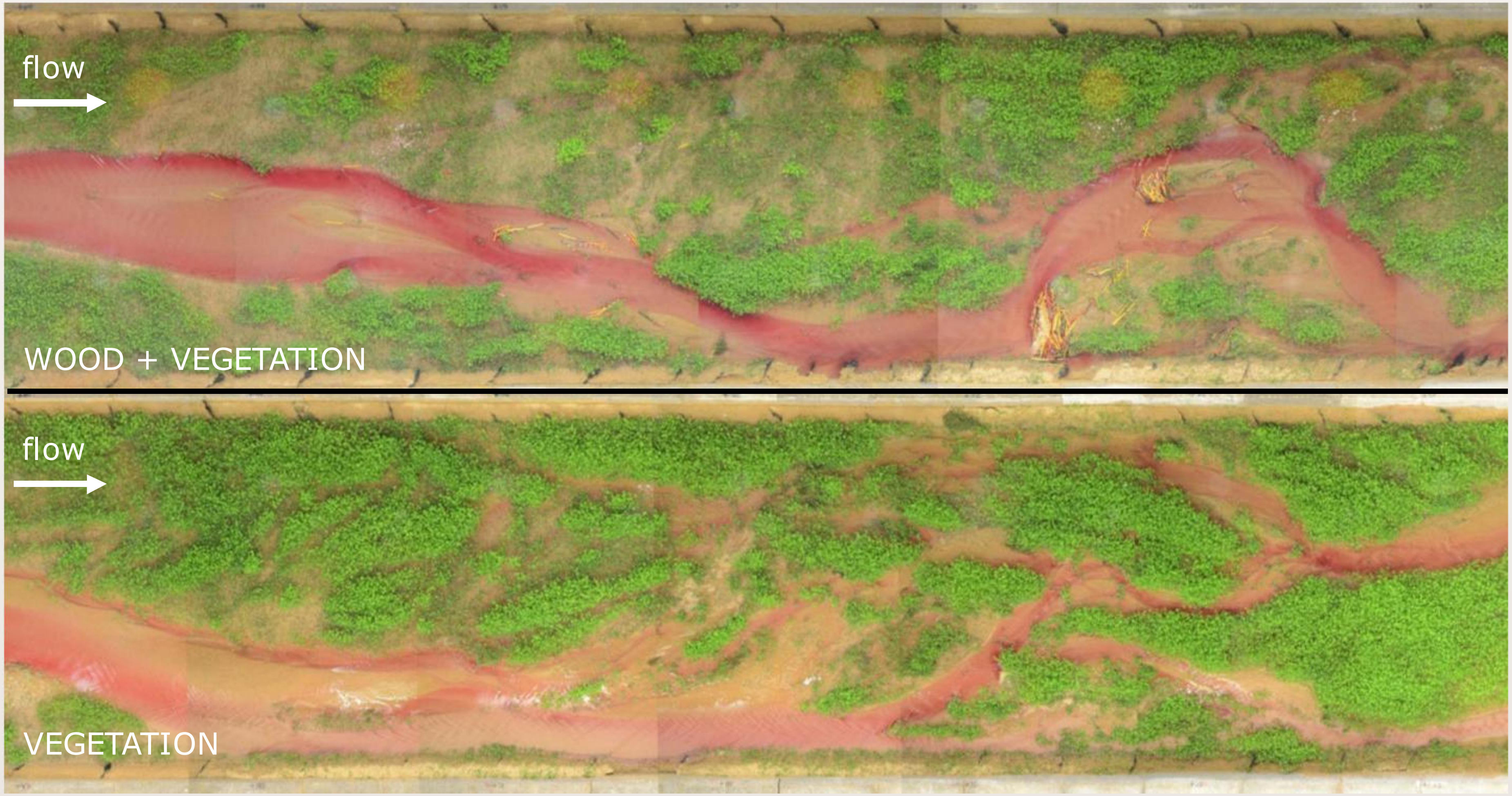

Tagliamento River



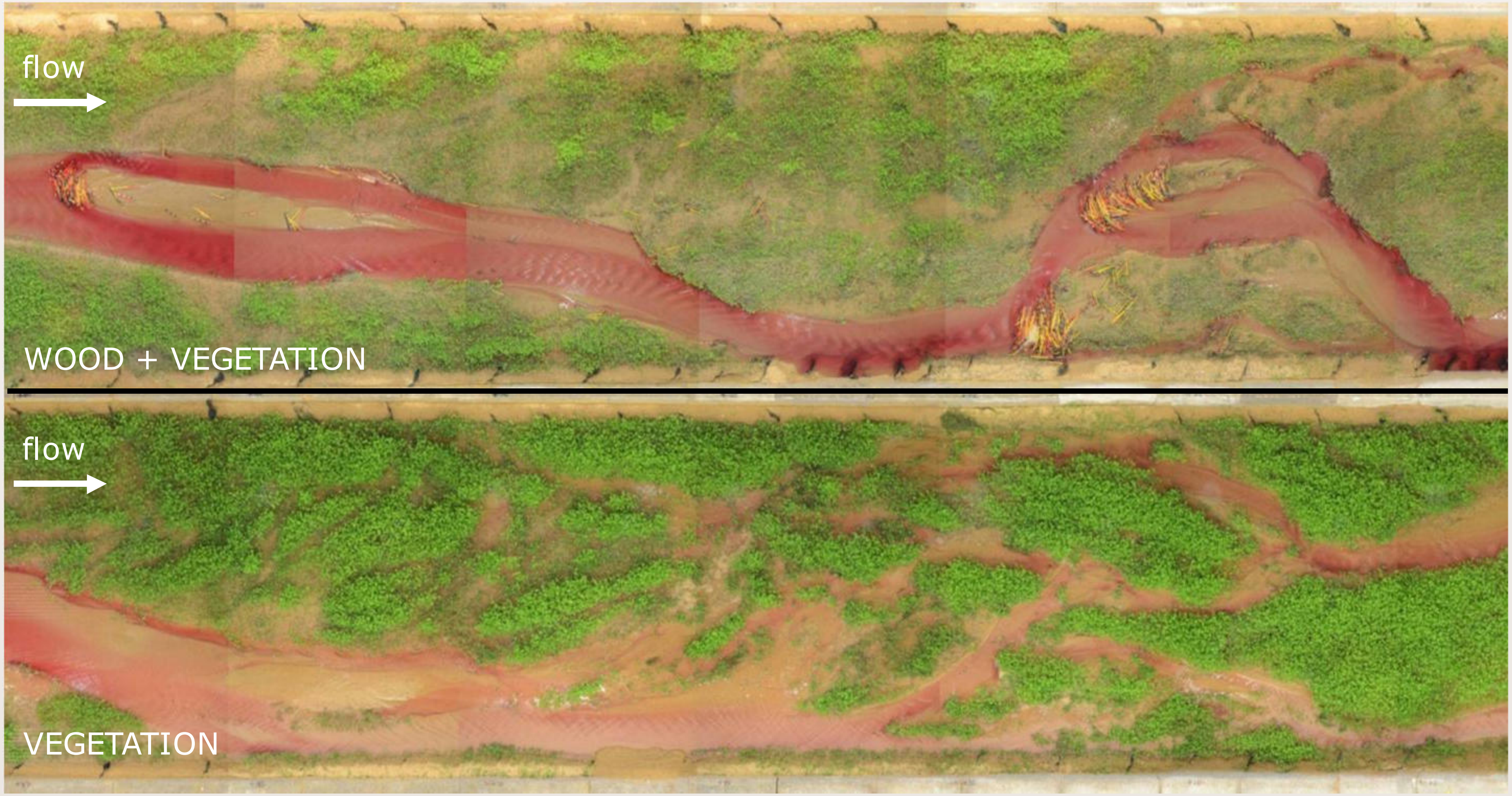
WEEK 1



WEEK 2



WEEK3



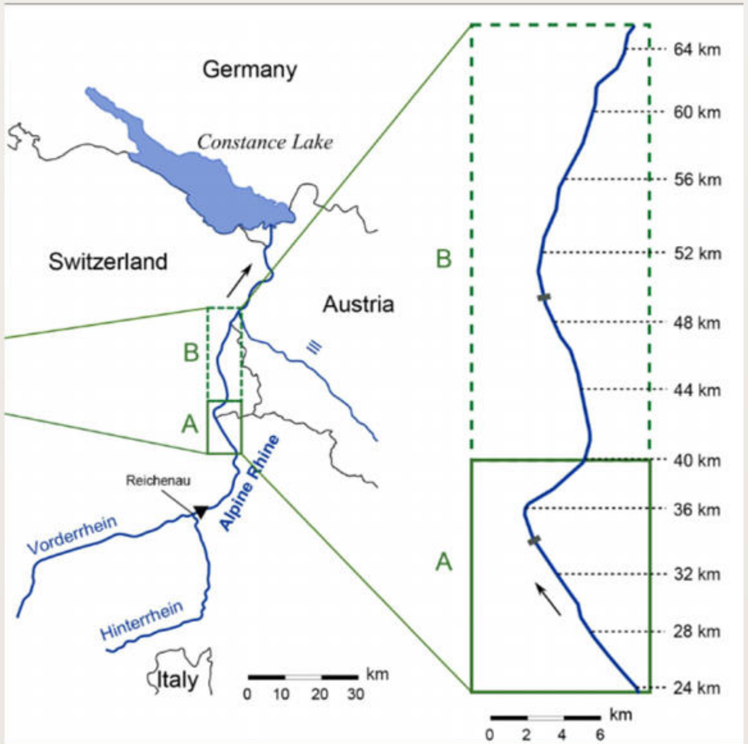
WEEK 4

RIVER BARS AND VEGETATION
THE CASE OF THE ALPINE RHINE RIVER

Caponi, Koch, Bertoldi, Vetsch, Siviglia

When does vegetation establish on gravel bars?
Observation and modeling in the Alpine Rhine River

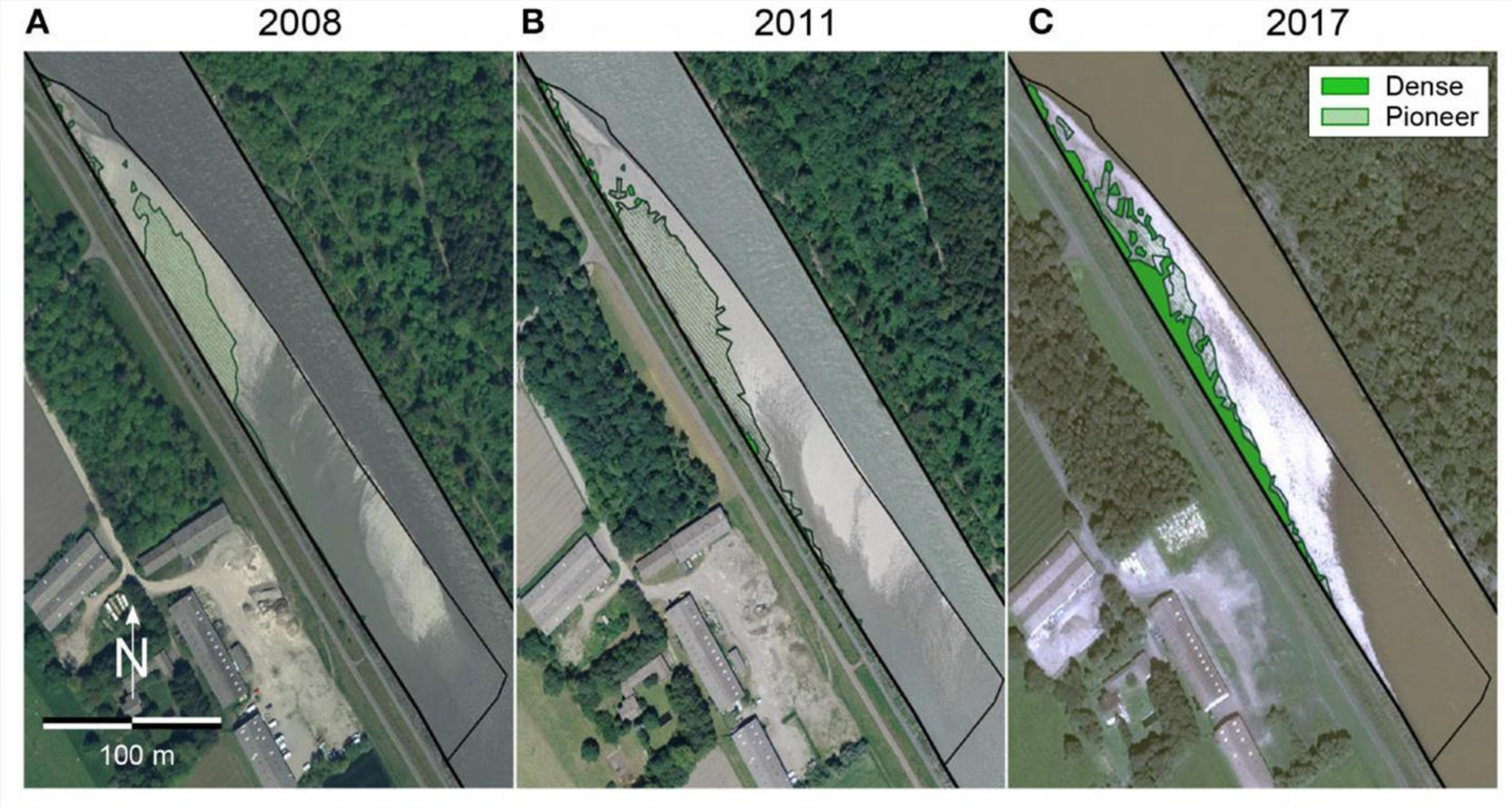
Frontiers in Environmental Science 7, 1–18 (2019)



Alternate bar morphology

- Reach A: steady bars,
- Reach B: migrating bars

RIVER BARS AND VEGETATION
THE CASE OF THE ALPINE RHINE RIVER



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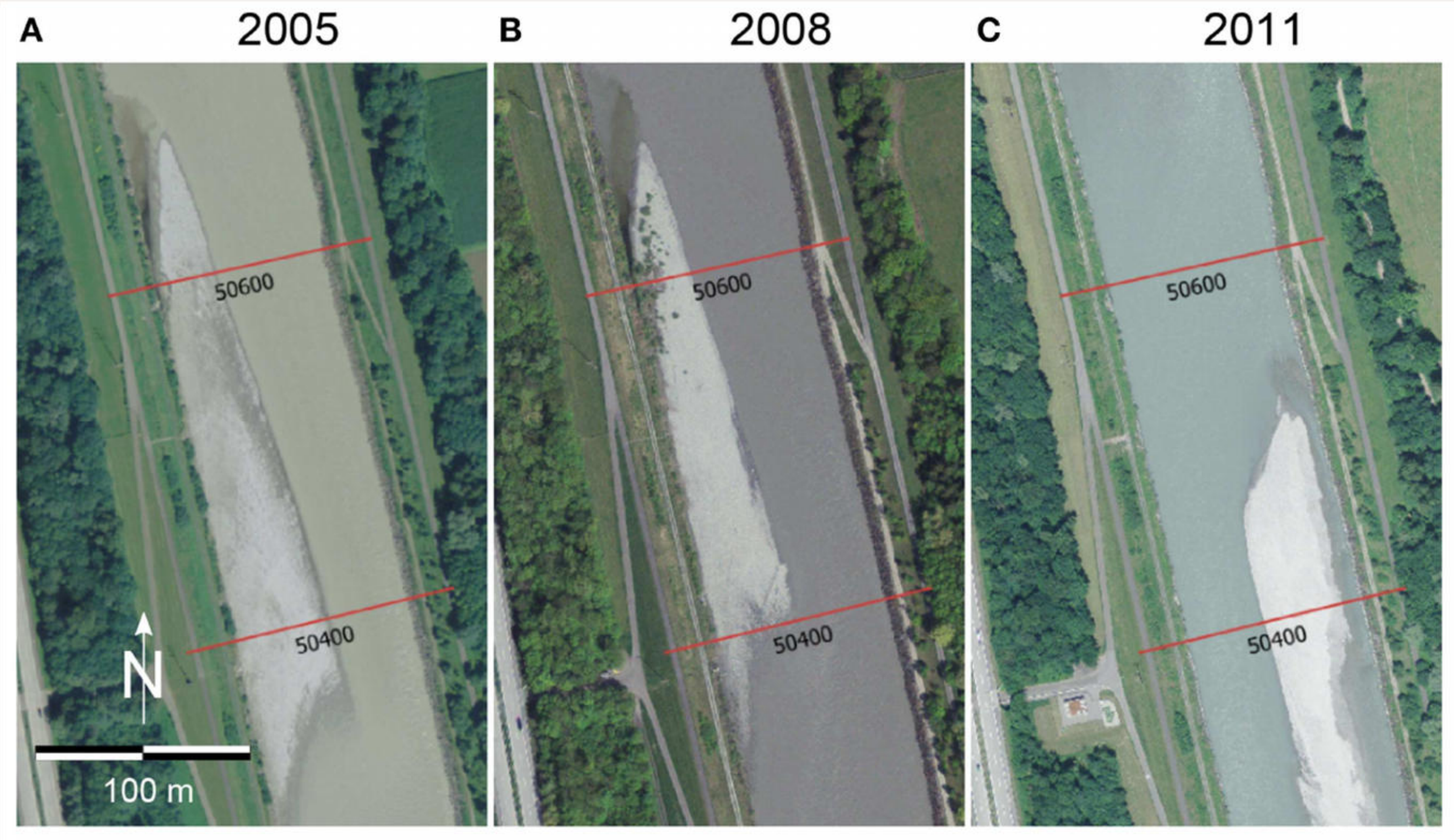

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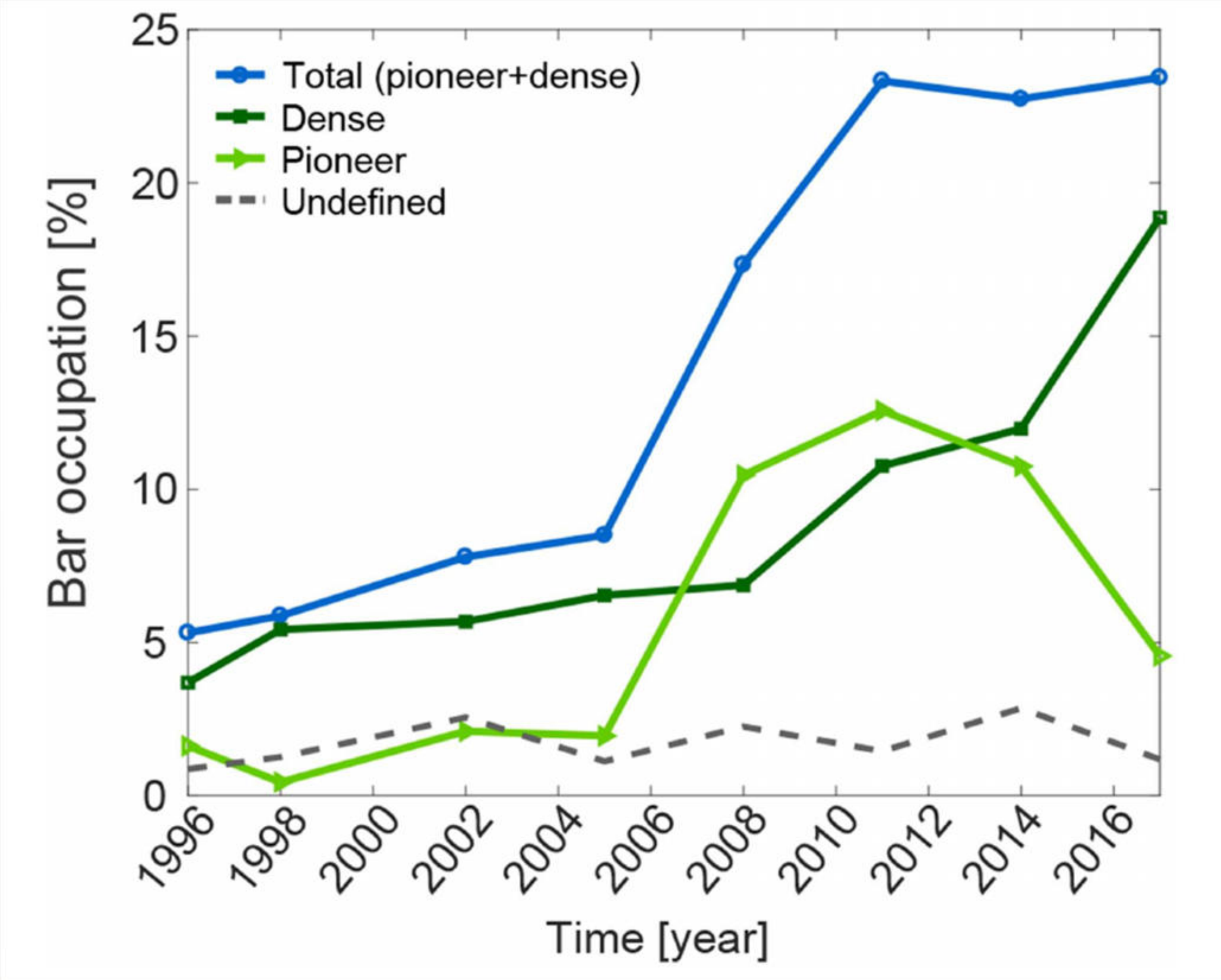


RIVER BARS AND VEGETATION
THE CASE OF THE ALPINE RHINE RIVER

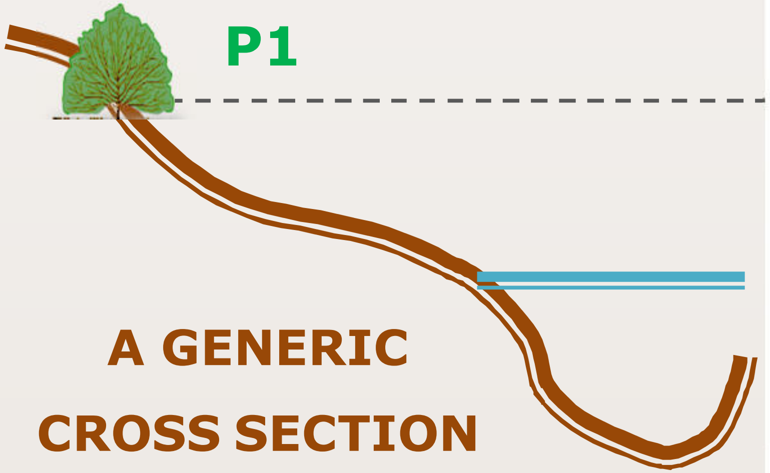
We modelled this referring to the framework of the **WINDOWS OF OPPORTUNITY** (after Balke et al., 2011)

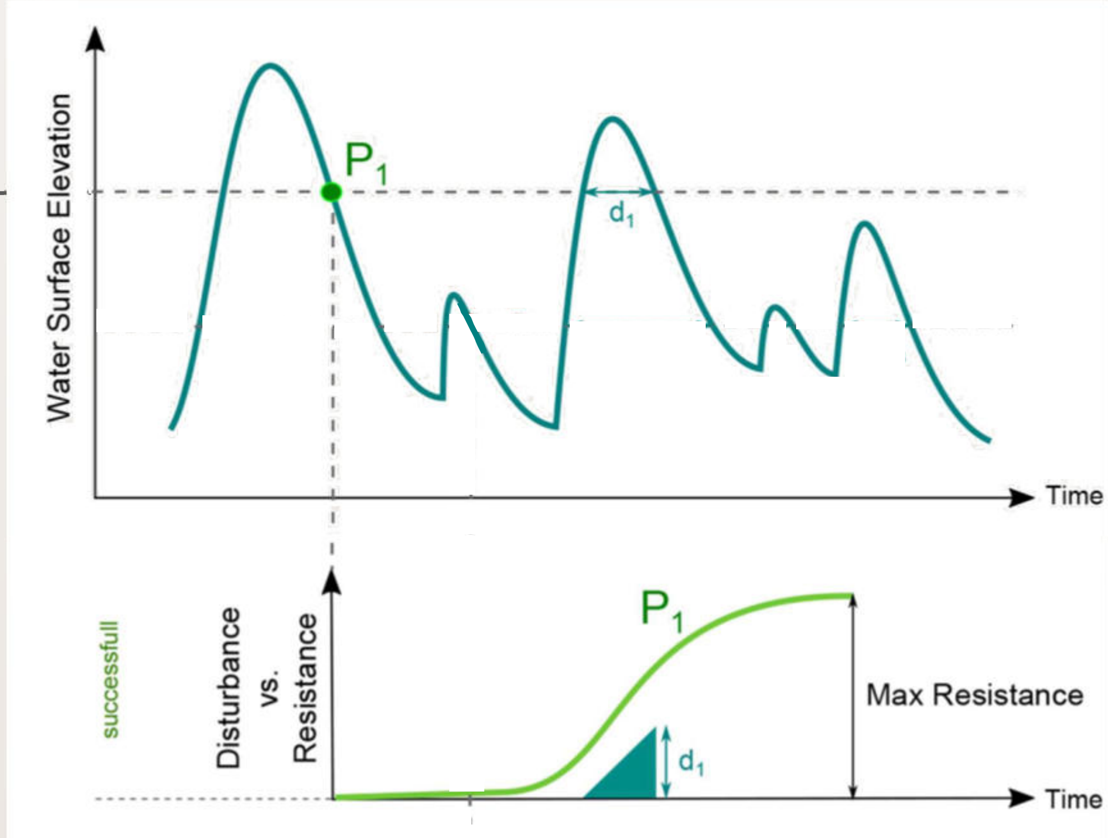
→ plants need **sufficient time** to establish and develop enough resistance to uprooting

→ time series of flow level can be transformed into **disturbance/resistance series**

Balke, Bouma, Horstman, Webb, Erftemeijer and Herman (2011)
Windows of opportunity: thresholds to mangrove seedling establishment on tidal flats.
Mar. Ecol. Prog. Ser. 440, 1–9.

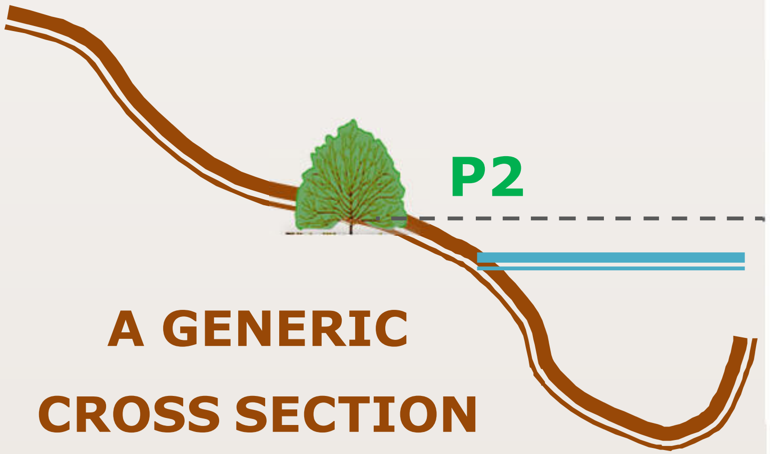
RIVER BARS AND VEGETATION
THE CASE OF THE ALPINE RHINE RIVER





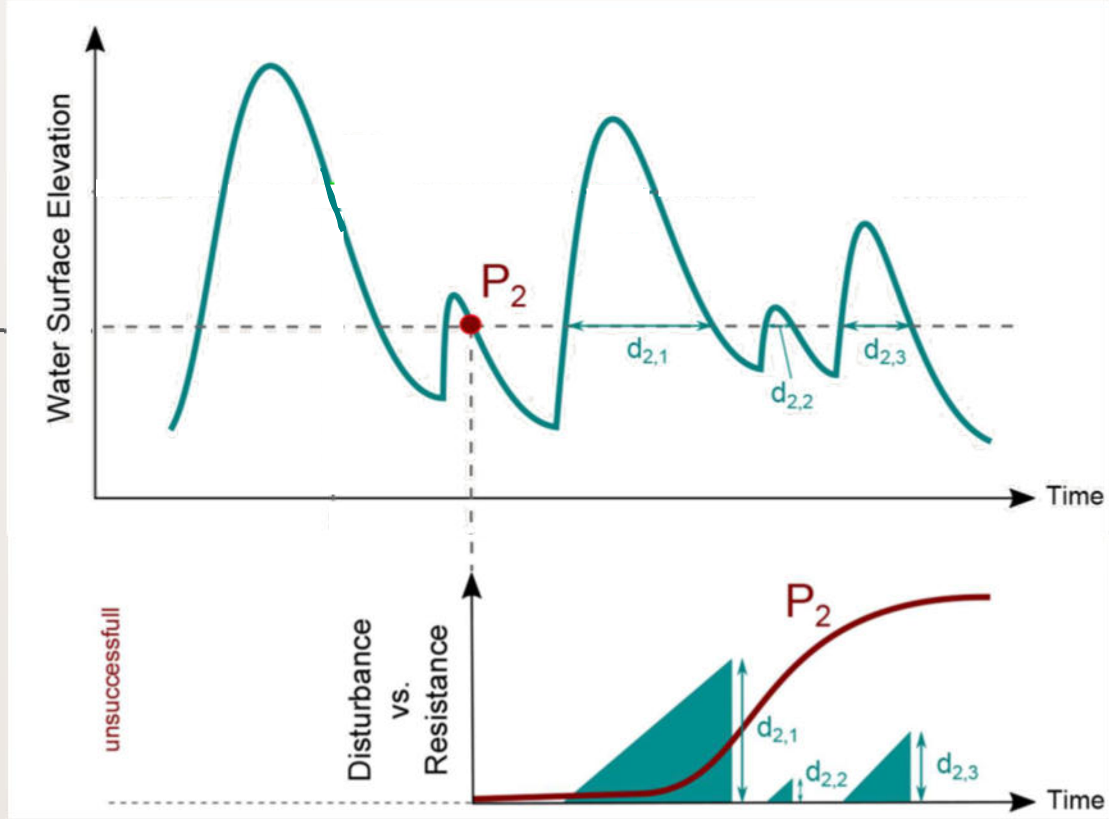
SUCCESFULL

RIVER BARS AND VEGETATION
THE CASE OF THE ALPINE RHINE RIVER



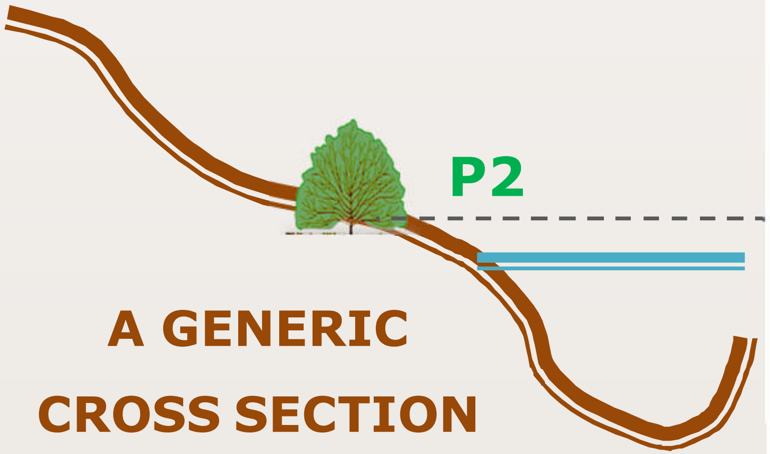
A GENERIC

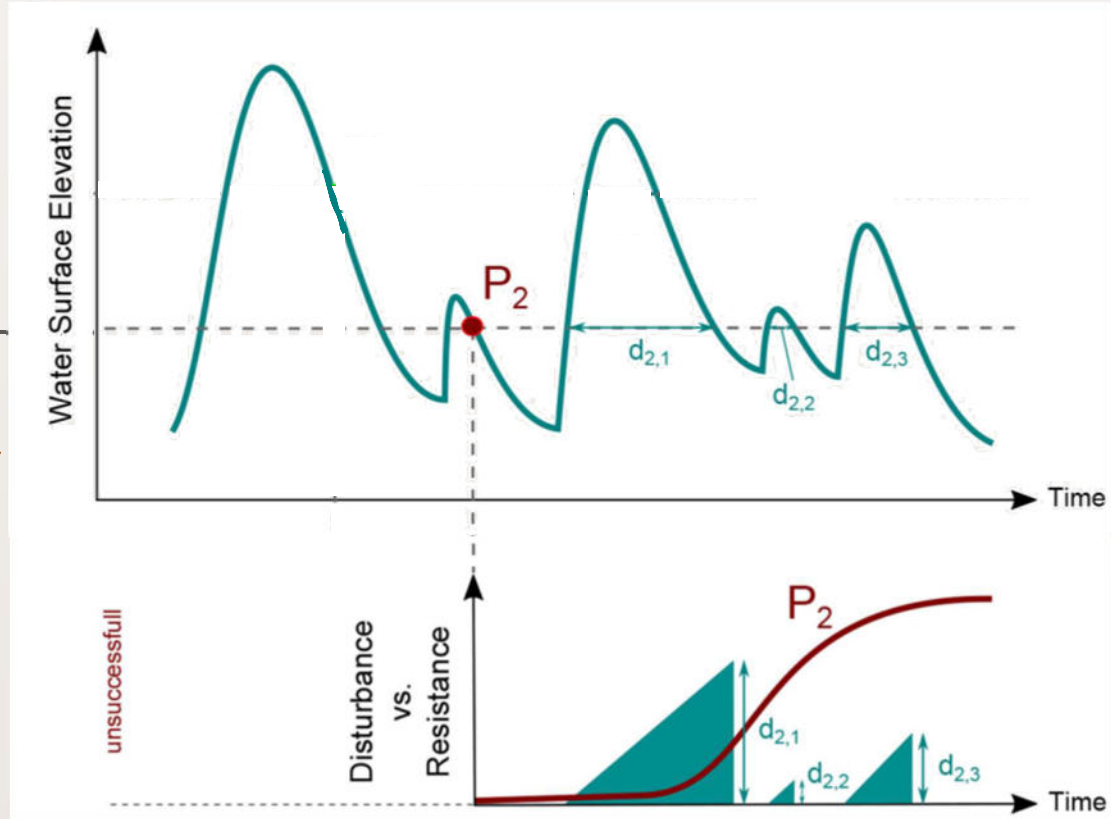
CROSS SECTION



UNSUCCESFULL

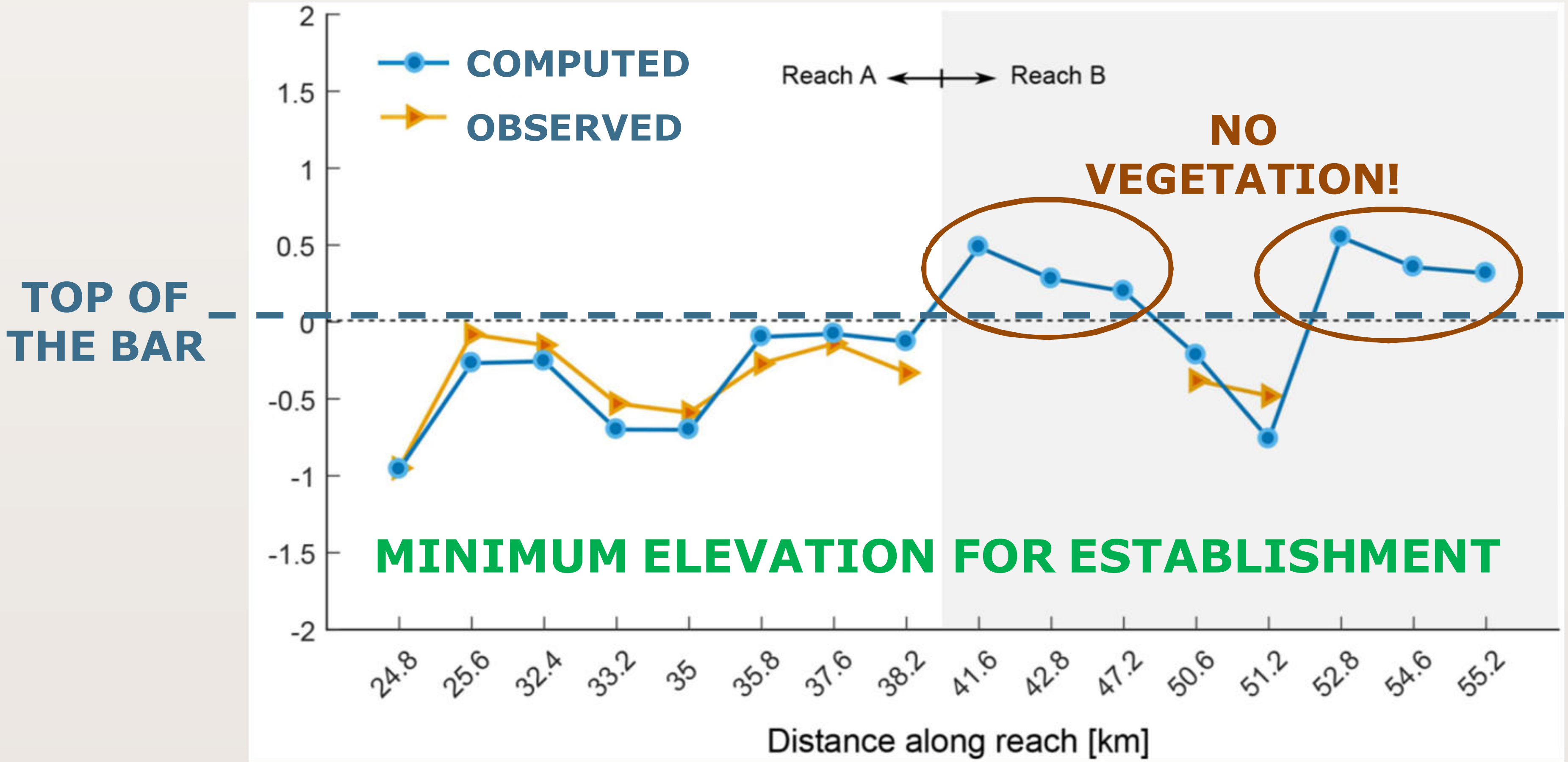
RIVER BARS AND VEGETATION
THE CASE OF THE ALPINE RHINE RIVER





→ MINIMUM ELEVATION FOR ESTABLISHMENT

RIVER BARS AND VEGETATION
THE CASE OF THE ALPINE RHINE RIVER



RIVER BARS AND VEGETATION
THE CASE OF THE ALPINE RHINE RIVER

The model allowed us to estimate that vegetation in this case needs a **Windows of Opportunity of at least 85 days** from sprouting to the first disturb

But is submersion enough to cause vegetation mortality?

Bertoldi, Siviglia, Tettamanti, Toffolon, Vetsch, Francalanci

Modeling vegetation controls on fluvial morphological trajectories

Geophysical Research Letters 41, 7167–7175 (2014)

BASEMENT

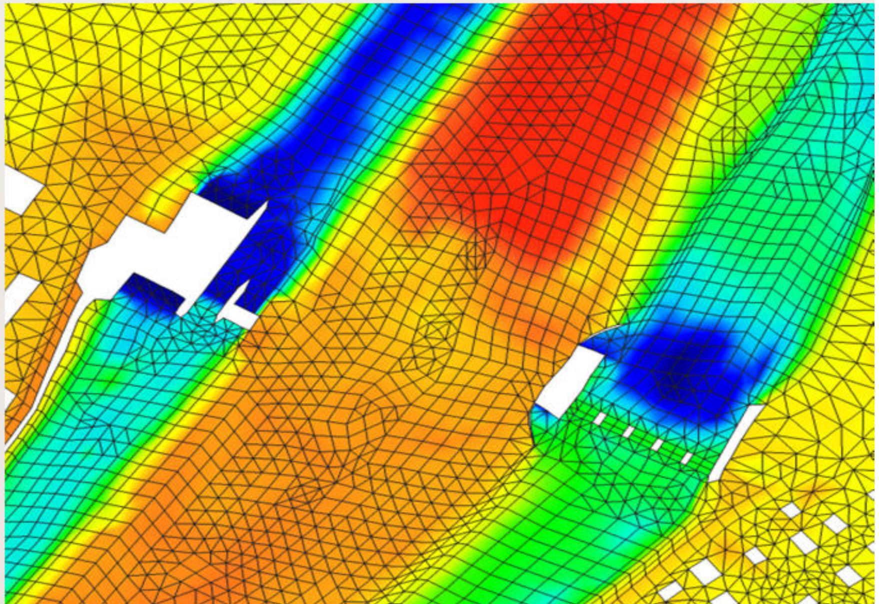
BASIC SIMULATION ENVIRONMENT
FOR COMPUTATION OF ENVIRONMENTAL FLOW
AND NATURAL HAZARD SIMULATION

Hydrodynamics

- depth-averaged equations for fluid flow
- finite volume discretization using Riemann solvers
- unstructured grid (2D)

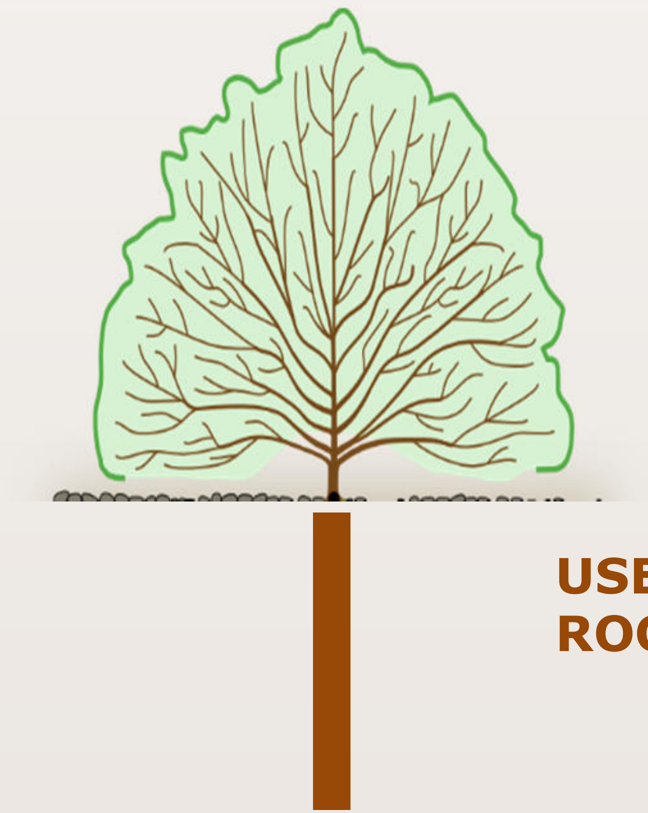
Morphodynamics

- Exner equation
- Uniform sediments
- Bedload



MODELLING FRAMEWORK

Vegetation is described only by its total **BIOMASS**



BIOMASS → **Flow resistance**

Shear stress

Sediment cohesion

USER IMPOSED ROOTS LENGTH → **Vegetation removal**

MODELLING FRAMEWORK

Vegetation **GROWTH** is described by a **LOGISTIC FUNCTION** and is **spatially distributed** as a function of

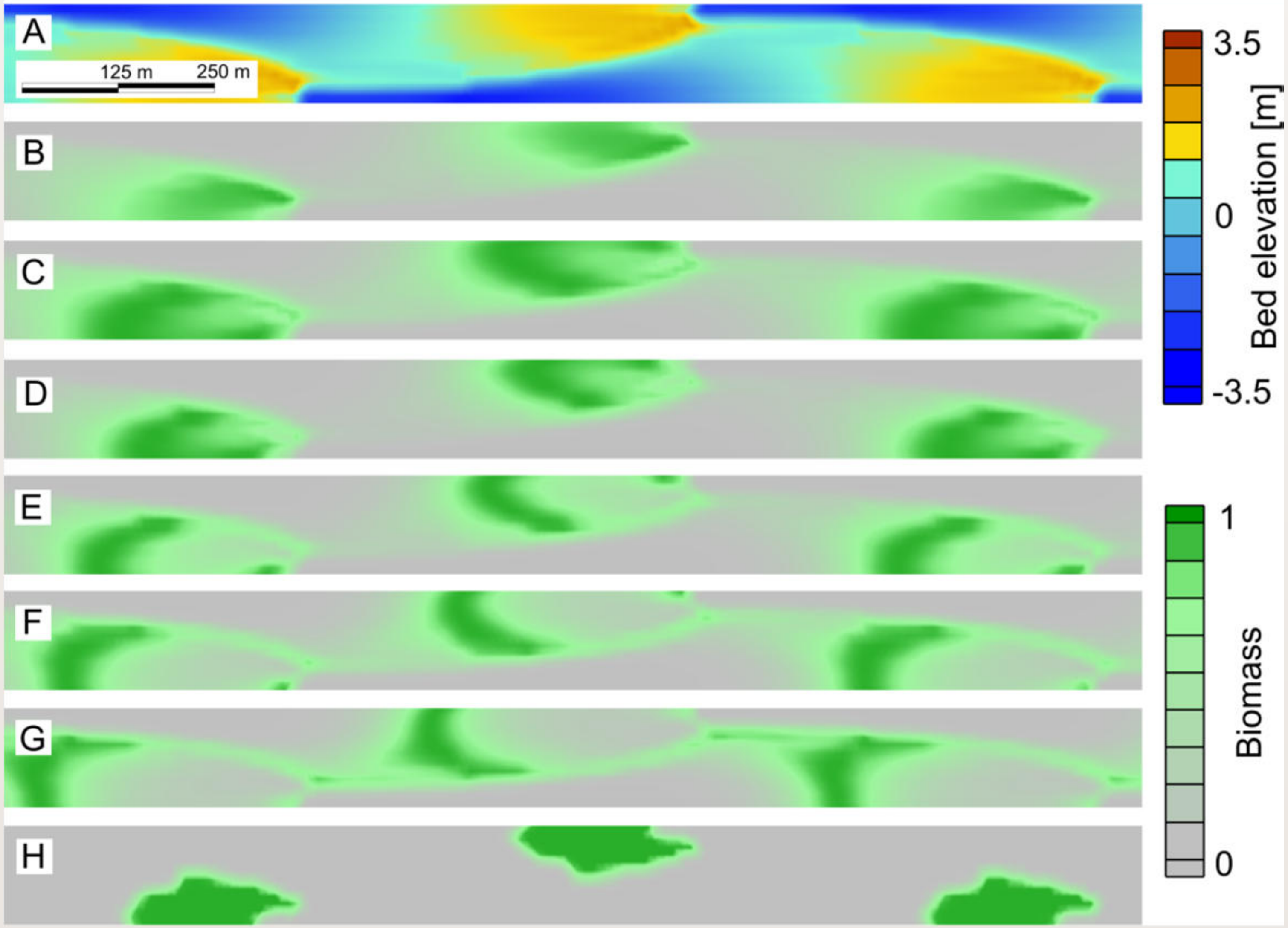
- **Vegetation type**
- **Ground water level**

→ It may grow better
near the channel
or on bar top
or …

VEGETATION IS SPATIALLY DISTRIBUTED

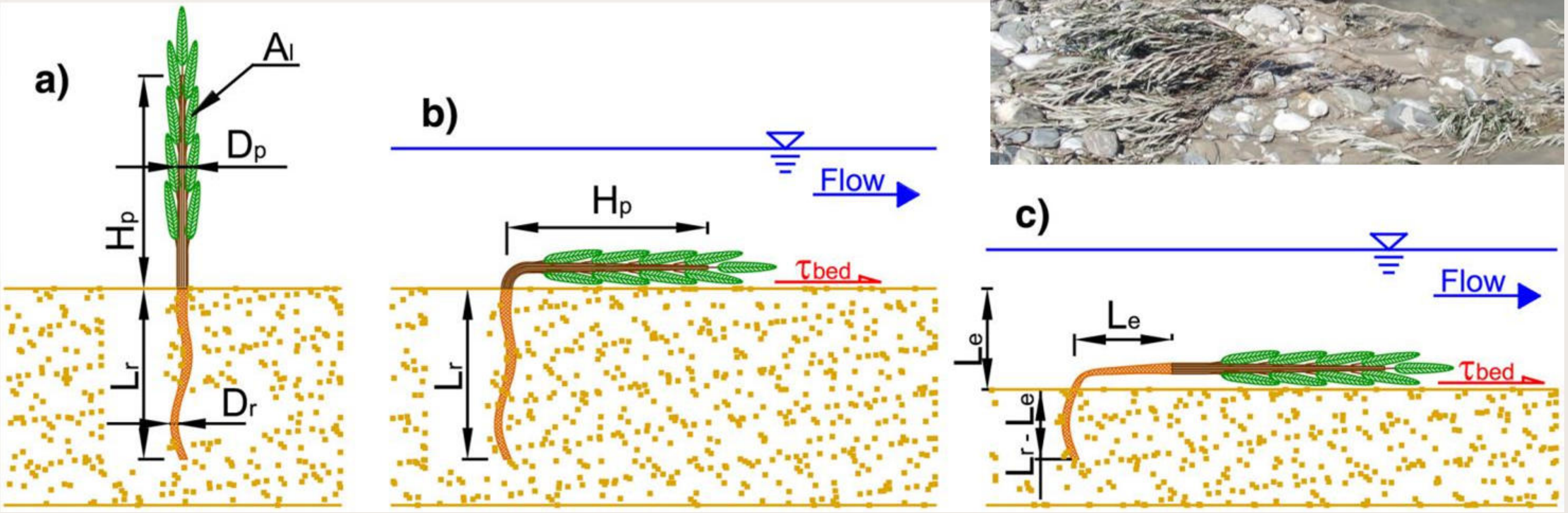
DIFFERENT SPECIES

CONSTANT DISTRIBUTION



VEGETATION UPROOTING

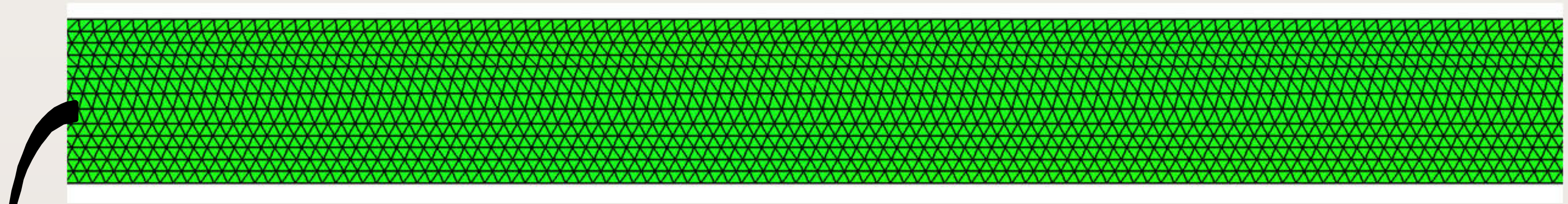
UPROOTING → RIVERBED EROSION



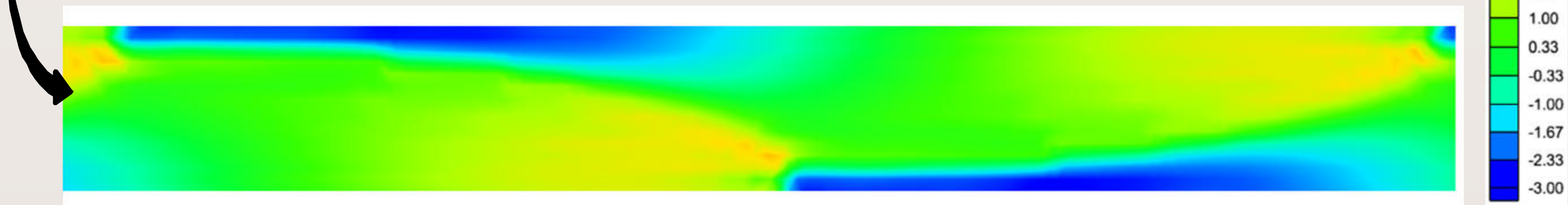
Calvani, Francalanci, Solari 2019.
A physical model for the uprooting of flexible vegetation on river bars.
Journal of Geophysical Research: Earth Surface 124(4): 1018– 1034.

MODEL SIMULATIONS

Computational mesh + River bed elevation[m]

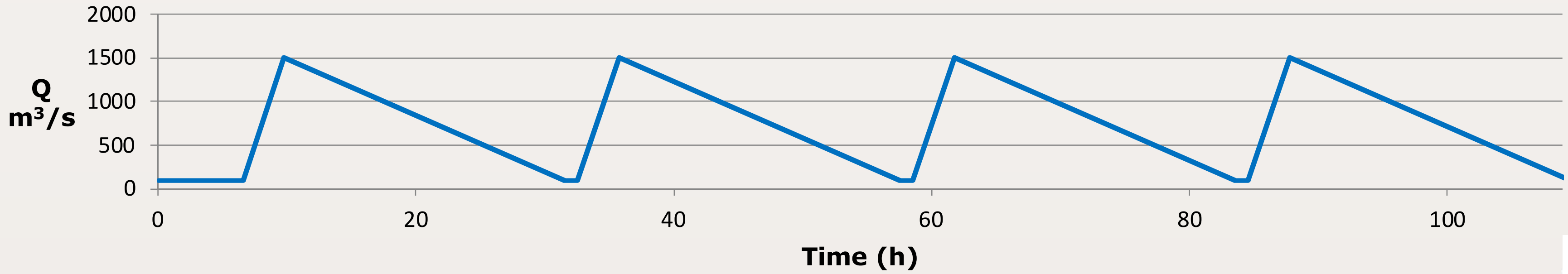


River bed elevation: Initial configuration for all simulations

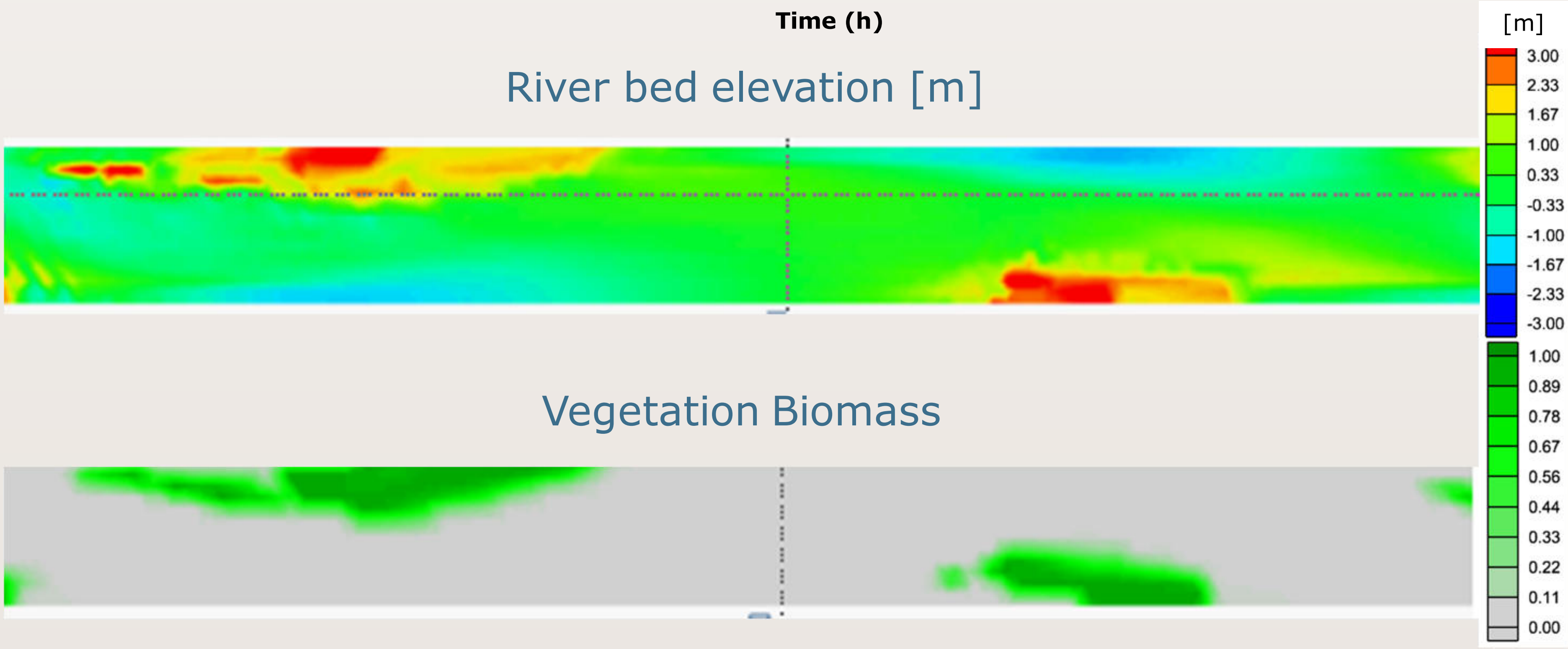


MODEL SIMULATIONS

Hydrograph

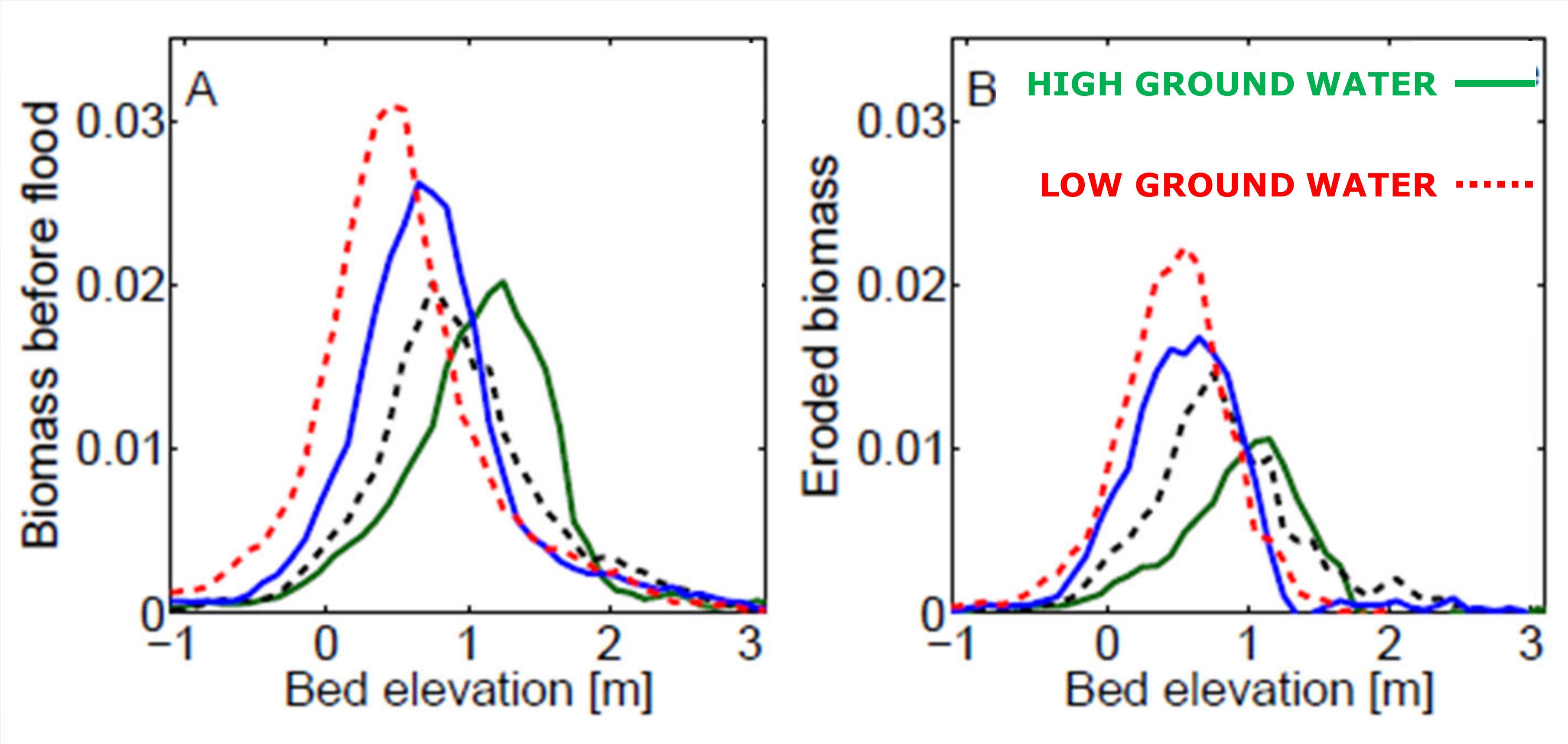


River bed elevation [m]



Vegetation Biomass

THE EFFECT OF GROUND WATER LEVEL



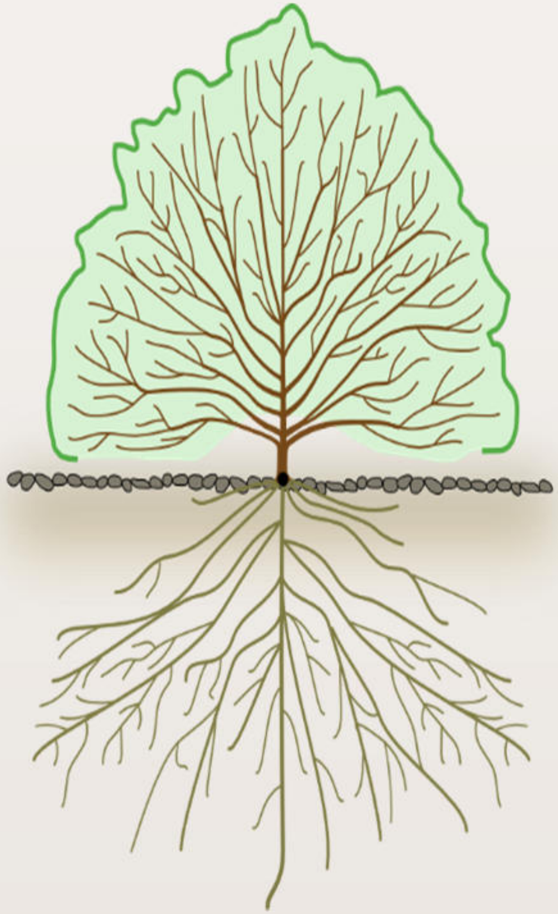
WHAT WE FOUND

→ Relevance of the **uprooting** mechanism

→ Possibility to reproduce the effect of **groundwater** alterations

→ Relevance of **flood sequence** and interval between floods (not only magnitude)

MODELLING ROOTS DYNAMICS

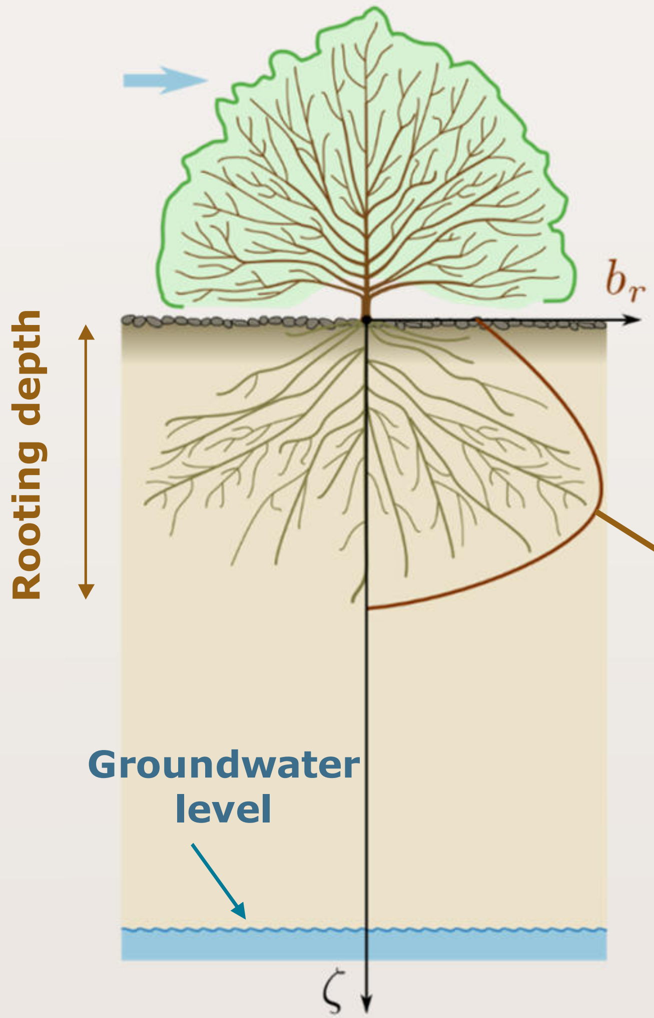


ABOVE-GROUND BIOMASS ⇨ **Flow resistance**, **Shear stress**

BELOW-GROUND BIOMASS ⇨ **Sediment cohesion**, **Vegetation removal**

This work is part of ***Francesco Caponi****'s PhD thesis*
Laboratory of Hydraulics, Hydrology and Glaciology, ETH Zurich

MODELLING ROOTS DYNAMICS



Above-ground and below-ground biomass are allocated through allometric relationships

Vertical root density distribution as in *Tron et al., 2014* as a function of groundwater oscillations

*This work is part of **Francesco Caponi**’s PhD thesis*
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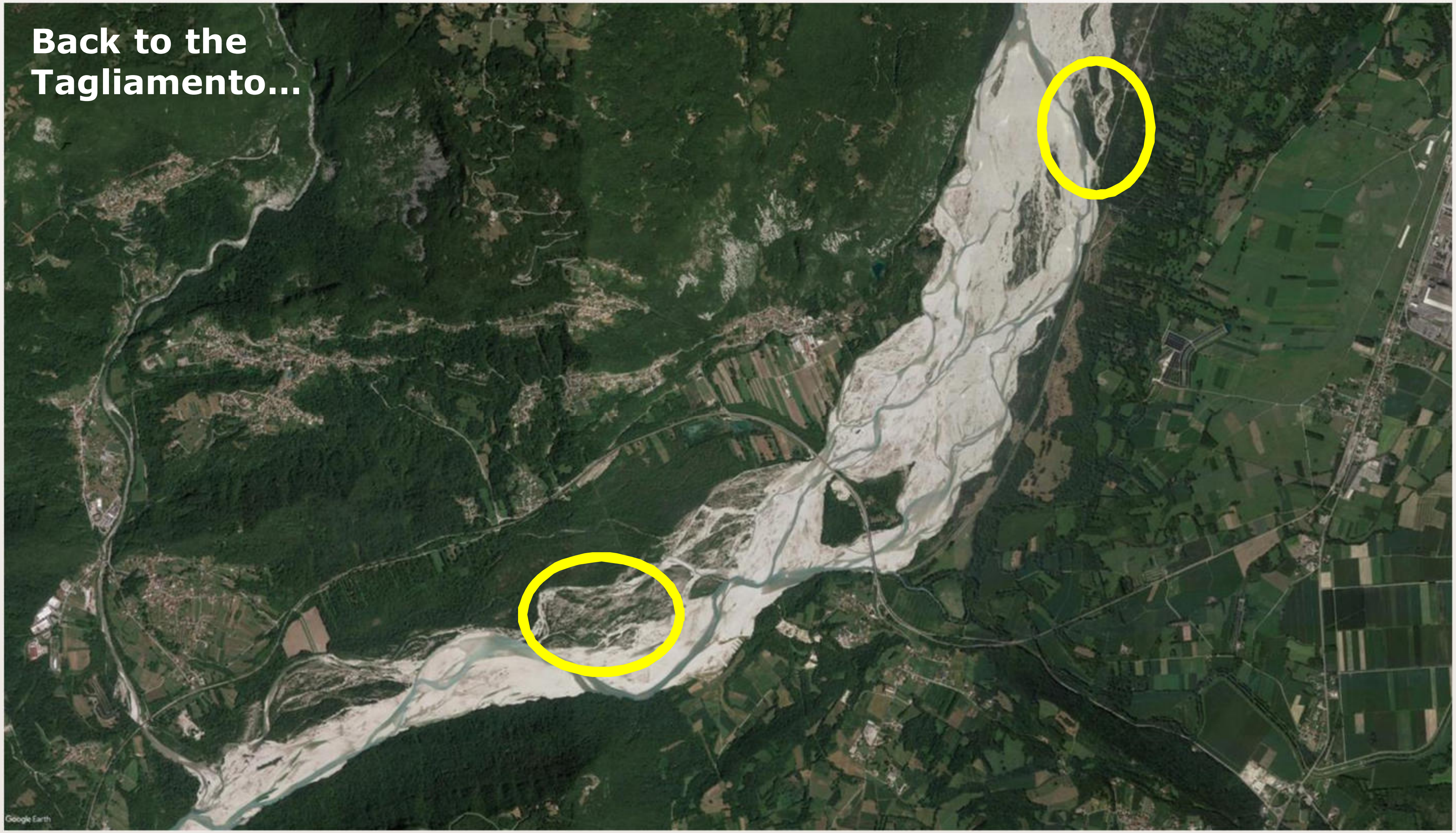
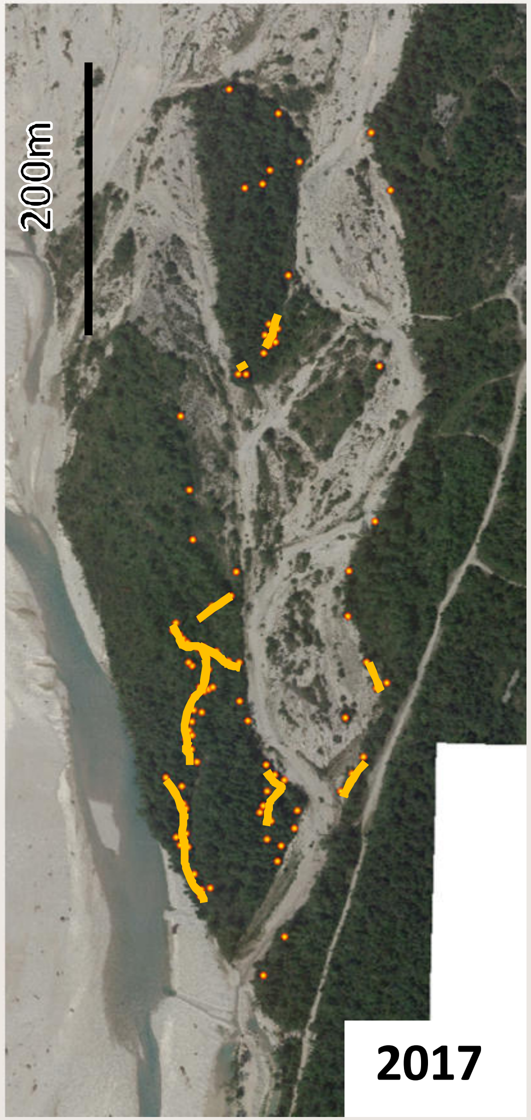
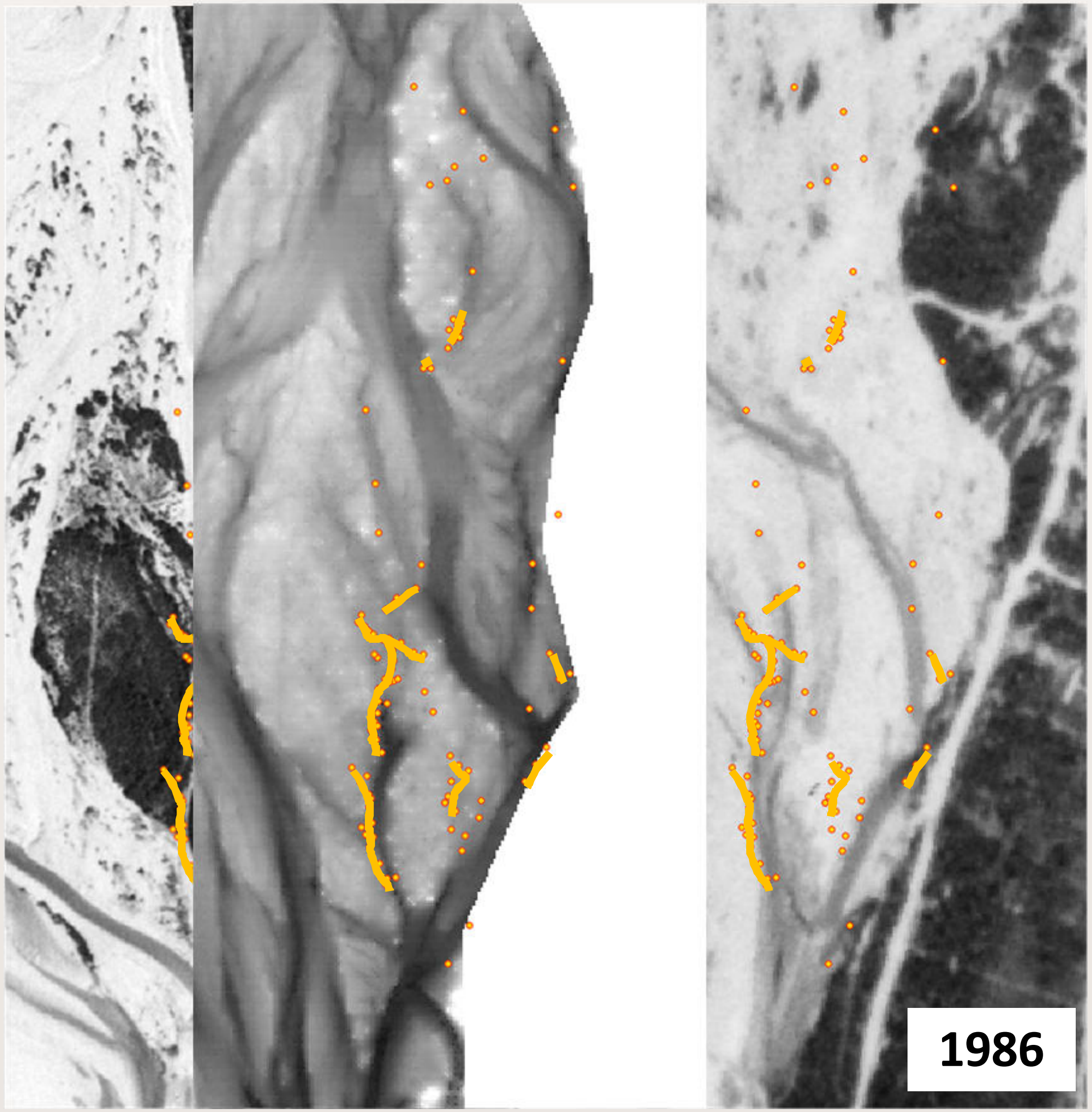
THE ROLE OF DIFFERENT TREE SPECIES

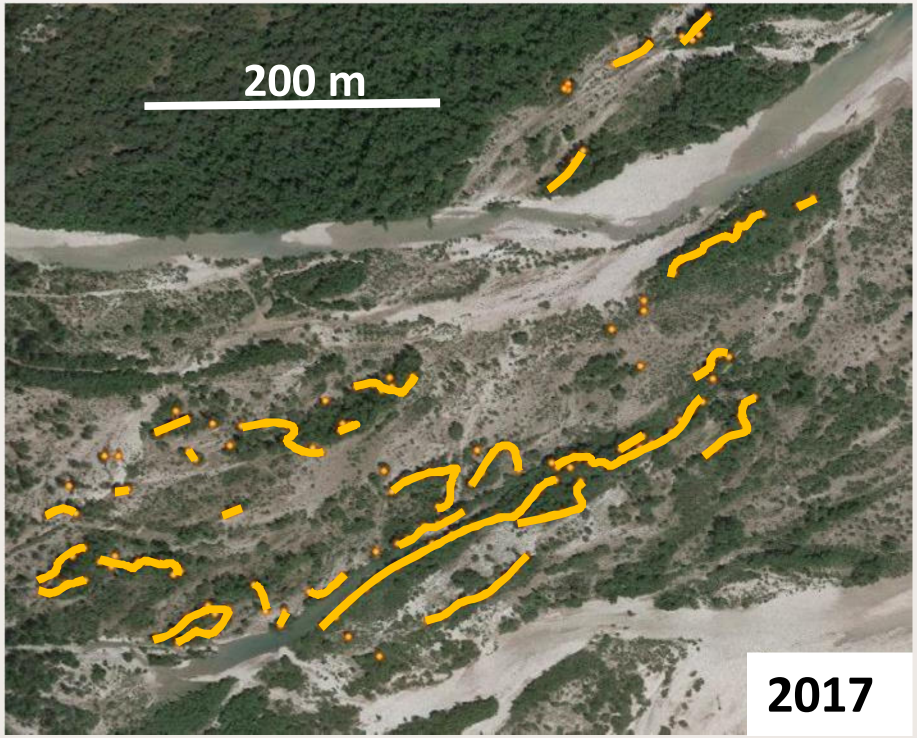


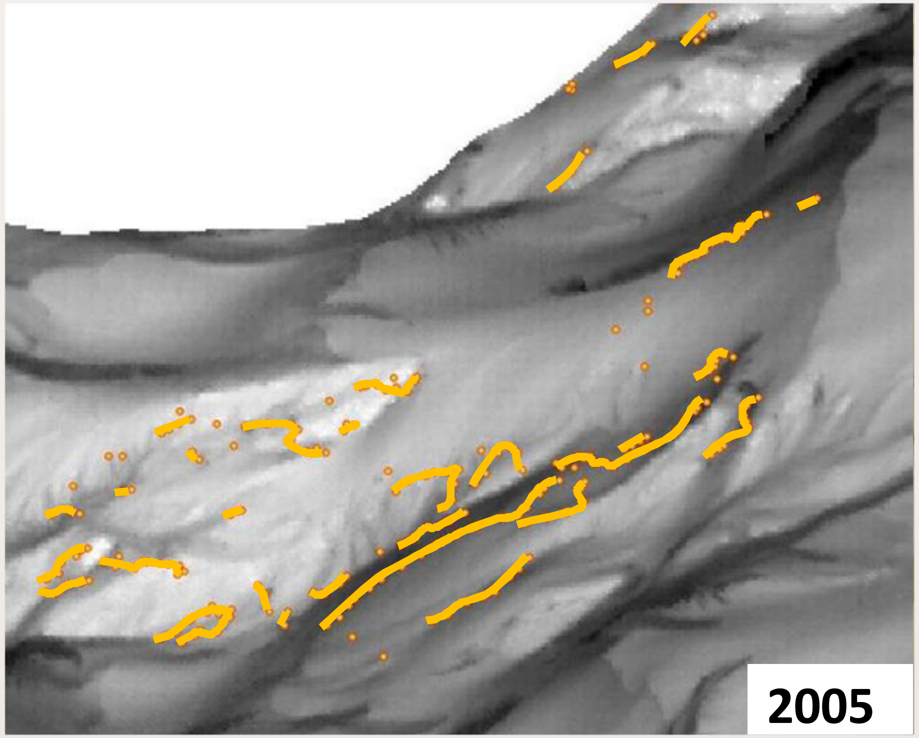
ALNUS vs. POPULUS





ALNUS vs. POPULUS



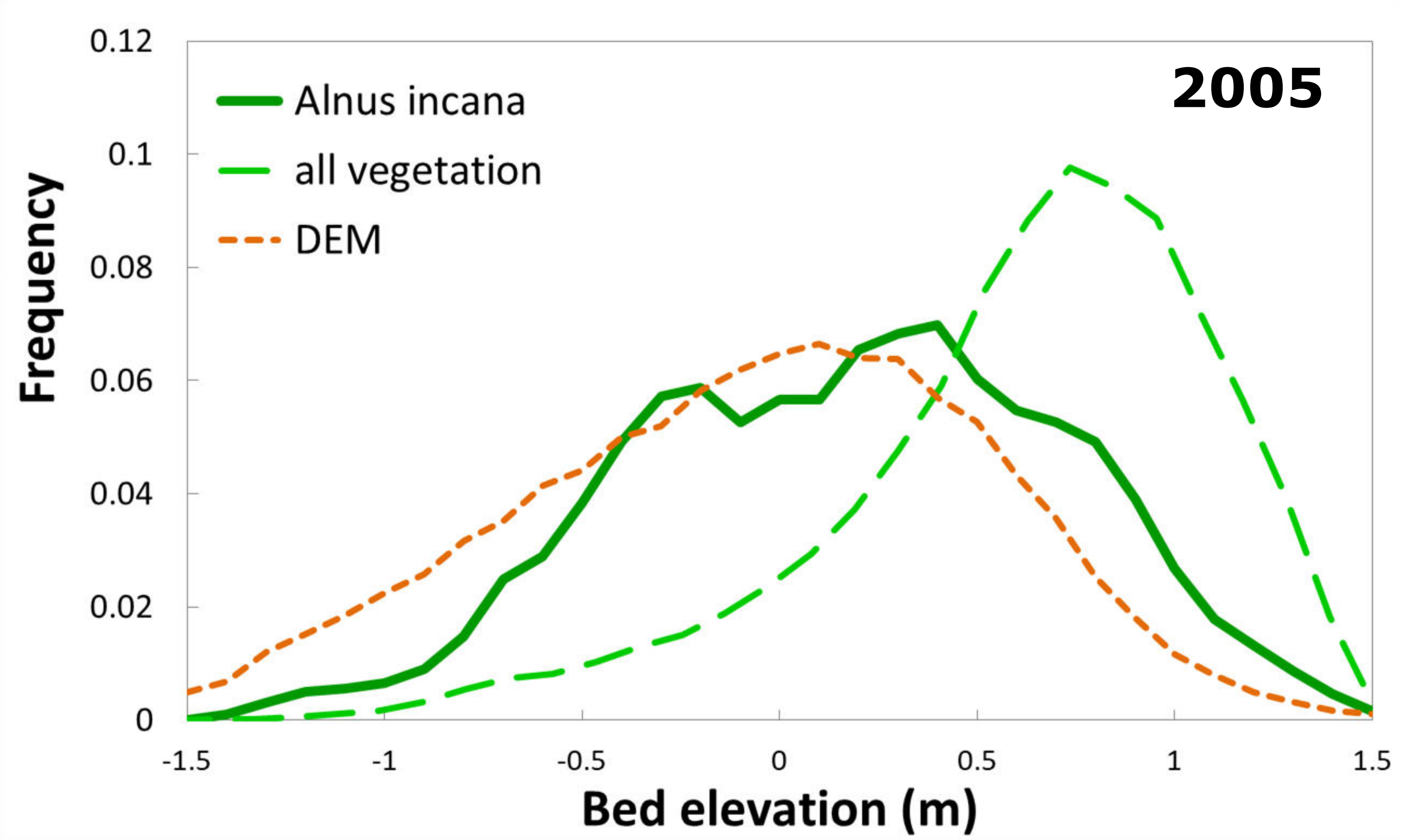


Alnus incana

→ **Specific environmental conditions**

→ **Specific role as an ecosystem engineer**

ALNUS vs. POPULUS



WHAT NEXT?

- We need **more observations** and data to feed models (spatial and temporal variability)
- **Roots** are the most relevant part!
- Models need to be used to **explore scenarios** and understand major controls (not to reproduce specific cases)

UNIVERSITY OF TRENTO

Department of Civil, Environmental and Mechanical Engineering

THANKS FOR YOUR ATTENTION!